A. GULF OF MAINE ATLANTIC COD (*GADUS MORHUA*) STOCK ASSESSMENT FOR 2012, UPDATED THROUGH 2011

Executive Summary

TOR 1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data and take into account the recommendations and subsequent work from the March 2012 MRIP workshop. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.

Since 1964, catch of Gulf of Maine Atlantic cod has ranged from 3,242 mt to 22,272 mt. Recent catches over the past five years have ranged from approximately 5,500 mt to 8,400 mt. Catch estimates prior to 1981 do not include commercial discards or estimates of recreational removals. Given the smaller mesh sizes and lower minimum retention sizes that existed pre-1977, commercial discards could have been substantial, particularly given the presence of several strong year classes in the 1970s. Since 1982, commercial landings have been the largest source of fishery removals, comprising 40-90% of the total catch. Commercial discards constituted a large proportion of the catch between 1998 and 2003 when trip limits ranged from 30-500 lb/day (13.6 – 226.8 kg/day). Since 2006 commercial discards have accounted for <10% of the total catch and <3% of the catch since 2010. Major uncertainties in the commercial catch include the mis-allocation of commercial landings stemming from industry mis-reporting of statistical area and uncertainty in the discard estimation method. The uncertainty with respect to mis-reporting is estimated to be small (5%). In recent years precision of the estimated discards has been high with coefficients of variation (CV) <20%. Beginning with the SAW 53 assessment, the Gulf of Maine cod assessment has included hindcasted commercial discard back to 1982; however, the uncertainty on these estimates is unknown.

A notable contraction of both the commercial trawl and gillnet fleets has been observed since the mid-1990's. Generally, the fishery has become highly concentrated in the western Gulf of Maine, exhibiting similar trends as those observed in the resource as a whole as evidenced from fishery-independent surveys. Between 2006 and 2010, there was an intense aggregation of the commercial fishery within a small geographic area of approximately 260 km^2 (<0.5% of the total Gulf of Maine surface area). By 2010, this area (known as ten minute square '427044') was responsible for >45% of the total commercial landings. There are several likely causes for this concentration in the fishery including concentration of the cod resource as well as regulatory changes. These factors are described in more depth under TOR2.

There is a large recreational fishery in the Gulf of Maine that, over the last decade, has accounted for approximately 20-31% of the total catch. Previous assessments have used data collected under the Marine Recreational Fisheries Statistical Survey (MRFSS). Beginning with this current assessment, MRFSS data have been re-estimated using revised methodologies consistent with the new Marine Recreational Information Program (MRIP) which has replaced the MRFSS program. The revised MRIP recreational catch estimates are approximately 25% lower than the MRFSS estimates pre-2003 and range from 4% higher to 50% lower between 2004 and 2011.

With increases in the recreational minimum retention size, the discard component has become an increasingly important component of recreational catch with discards more than two times greater than the recreational landings in terms of numbers of fish between 2006 and 2011. This assessment includes revised estimates of the survival of discarded fish, with only 30% of recreationally released fish estimated to die. The true percentage of recreational discards suffering mortality remains a key source of uncertainty in the estimate of recreational removals. The uncertainty associated with the estimates of total recreational catch is on the order of 10-25% in terms of percent standard error (PSE). An additional source of uncertainty is the age composition of recreational discards prior to 2005. Beginning with the SAW 53 assessment, the recreational discard length frequency distributions were hindcasted to 1981 in an effort to incorporate recreational discards into an age-based assessment.

As noted previously, the current assessment incorporates revised estimates of the mortality of fish discarded in both the commercial and recreational fishery. The previous assessment of this stock (SAW 53, NEFSC 2012) assumed 100% mortality of all discarded fish. The revised estimates are a product of a Discard Mortality Working Group (DMWG) convened in July 2012 to evaluate the available scientific information on the survival of cod on a gear-by-gear basis. The working group consisted of scientific experts with experience in field estimation of discard survival and stock assessments as well as both recreational and commercial fishermen and other industry representative. The revised mortality estimates developed by the DMWG ranged from 20-80% depending on gear type. The impacts of the revised mortality rates on the total estimates of fishery removals are most pronounced in the recreational fishery where 30% of discarded cod are estimated to die. In the commercial fishery, where discards are dominated by otter trawl and sink gillnet gear, the revised discards mortality estimates had a much smaller impact since 75% and 80% of the fish discarded by otter trawl and sink gillnet gear are estimated to die.

TOR 2. Present the survey data and calibration information being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Consider model-based (e.g. GLM) as well as design-based analyses of the survey data in developing trends in relative abundance. Investigate the utility of commercial or recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.

The Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys began in 1968 and 1963 respectively, providing a long time series of fishery independent indices. Age-specific indices for Gulf of Maine cod began in 1970. All previous Gulf of Maine cod assessments have used only the offshore survey strata. The aggregate indices of abundance (numbers) and biomass have generally declined since time series highs in the 1960/1970s. Current indices are at, or near, all time lows. The number of stations and strata where cod have been observed in the Gulf of Maine has generally decreased over time as the resource has become increasingly concentrated in the western Gulf of Maine. It appears that two related, but separate, processes may be underway with respect to the concentration of the resource. Over the longer term, there has been a loss of cod from the eastern and central Gulf of Maine with an apparent concentration of cod in the western area. In addition to this, since 2006 there has been a further aggregation of cod within the western Gulf of Maine into highly localized areas which are hypothesized to be driven by prey availability. While it is difficult to prove definitely that these processes are responsible for the observed distribution changes, the evidence is suggestive.

The impacts of including the inshore survey strata in the NEFSC survey indices were examined by the 55th Stock Assessment Workshop Working Group (SAW 55 WG). The overall trends in both the aggregate and age specific indices of older fish was not markedly different with the inclusion of the inshore strata, and more importantly, there was inconsistent sampling of the inshore survey strata throughout the time series which impedes the construction of consistent and stable survey indices. For this reason, and because the inshore areas that were sampled by the NEFSC survey are largely covered by the Massachusetts Department of Marine Fisheries (MADMF) bottom trawl survey, the SAW 55 WG concluded that the status quo should be maintained with the inshore strata excluded from NEFSC indices. The NEFSC survey vessel was replaced in spring 2009 resulting in changes to the survey protocol. Calibration experiments to estimate differences in catchability between the two survey series were conducted and peer-reviewed. Length based calibration models were used to express the 2009-2012 NEFSC indices in units equivalent to the longer time series. Preliminary attempts to estimate length-based survey calibration factors internally within a Statistical Catch at Age (SCAA) assessment model were conducted and reviewed by the SAW 55 WG and found to be very similar to the externally estimated calibration factors used in previous assessment. While the SAW 55 WG generally supported the internally estimated approach as a longer-term research recommendation, given the high level of agreement between the internally and externally estimated calibration coefficients the SAW 55 WG supported continued use of the existing calibration coefficients.

The SAW 55 WG also considered model-based estimates of the NEFSC survey indices as opposed to the design-based estimators that have been employed in past assessments. The model-based estimates were based on a generalized linear model (GLM) that attempted to standardize for multiple factors including stratum, time of day and depth. Overall there was a high degree of agreement between the GLM-based estimates and the design-based estimates; however, the variability about the GLM-based estimates was considerably higher than the design-based estimates. The SAW 55 WG was concerned about the incorporation of GLM-based smoothed indices into the assessment model, which then effectively applies an additional smooth as it fits the survey index. Given the similarity of the indices, the increased variability in the GLM-based indices, and concerns over the use of smoothed series in assessment models, the SAW 55 WG concluded that the existing design-based indices be used as inputs to the assessment model.

The MADMF bottom trawl survey began in 1978, with two surveys (spring and fall) conducted annually. Age-specific indices are available beginning in 1982. The MADMF fall survey catches very few older fish and there is poor cohort tracking within the survey. For this reason, the MADMF fall survey is not used in the Gulf of Maine cod assessment. MADMF spring biomass index is currently at a time series lows and the abundance (numbers) index is the third lowest observed. Similar to what has been observed in the NEFSC survey, the number of stations and stratum in which cod have been observed has declined over time.

The SAW 55 WG spent considerable time evaluating catch per unit effort indices and their utility as indices of abundance within the Gulf of Maine cod stock assessment. A number of analyses were undertaken to describe Gulf of Maine cod distributional changes, which particularly since 2006, appear to have been driven by fine-scale spatial processes of prey (primarily sand lance). A number of surveys indicate that the Stellwagen Bank area appears to be a foraging ‘hot spot’ for cod feeding on sand lance. Additionally, the VTR, observer and VMS information from the commercial fishery indicates that fishing effort since the mid-2000s has become concentrated in this area. Over the longer term, there have been a number of regulatory changes (e.g. seasonal closures, trip limits, etc) which call into question the utility of commercial LPUE as an index of GOM cod biomass. Based on these concerns, the SAW 55 WG recommended that the commercial LPUE index not be used in the SAW 55 assessment model. This recommendation is consistent with the findings of the recent NEFSC sponsored LPUE workshop. Given concerns comparable to those of the commercial fishery, the SAW 55 WG recommended that the recreational LPUE index also not be included in the GOM cod assessment model. It should be noted that sensitivity runs were conducted which incorporated LPUE indices and these model results are similar to those of the base model (described in Appendix A.6).

The SAW 55 WG also evaluated data from the Maine – New Hampshire (ME/NH) inshore groundfish survey which began in the fall of 2000. Because of lack of age-specific information and the short time series of the survey, the survey was not included in the assessment models. Progress has been made on the implementation and analysis of the data collected since the start of the survey; specifically, spring and fall 2005 and spring 2011 ageing has been completed and spring 2006 is in progress (S. Sherman, ME DMR, pers. comm.). The SAW 55 WG recommended that the complete ageing of the entire time series of collected otoliths be considered a high priority.

TOR 3. Summarize the findings of recent workshops on stock structure of cod of the Northeastern US and Atlantic Canada. Summarize the findings of recent workshops on stock structure of cod of the Northeastern US and Atlantic Canada.

A work plan on the topic of Atlantic cod stock structure in the Northeast United States/Scotian Shelf region was recommended by the New England Fishery Management Council's Scientific and Statistical Committee (SSC). The work plan laid out a three-phase process for re-evaluating, and possibly revising, the spatial basis for assessment and management of Atlantic cod. The first phase was to review data (genetic, life history, tagging, etc.) in order to evaluate the “null hypothesis” of the status quo management units.

The NEFSC sponsored a public workshop on cod stock structure, held June 12-14, 2012, facilitated by the Gulf of Maine Research Institute to address Phase I. Invited participants from the fishing and scientific communities presented on a range of topics with opportunities for discussion. The full workshop report is available at http://www.gmri.org/mini/index.asp?ID=52&p=149.

Many of the workshop participants felt that there was compelling evidence that the current management units need to be revised. The Workshop did not reach any conclusions on what the most appropriate management units might be. This will require further data analysis and modeling in order to complete Phase I of the SSC recommended process. The workshop report also identifies gaps in the data and analyses and recommended action to address them.

The Workshop did not explicitly address and propose the next steps in the process. The Steering Committee recommended that an inclusive, but focused, Working Group meeting be held involving a small group of Canadian and US scientists to consider the results of the Workshop. This Working Group should be provided the short-term data and analyses identified as missing by the Workshop. Using that information, as well as the conclusions from the Workshop, the Working Group should determine the most appropriate representations of biological stock structure to complete Phase I of the process. The results from this Working Group meeting should be evaluated through an independent peer-review process.

Since the phased review process of cod stock structure that was recommended by the SSC has not been completed, no changes to stock structure were incorporated into this assessment.

TOR 4. Investigate the evidence for natural mortality rates which are time- and/or age-specific. If appropriate, integrate these into the stock assessment (TOR 5).

Previous assessments of Gulf of Maine cod have assumed a constant, age-invariant rate of instantaneous natural mortality (*M*) of 0.2. The SAW 55 WG evaluated the sufficiency of this assumption through life history analyses of natural mortality. From the meta-analysis of life history-based estimates, the evidence available with respect to Gulf of Maine cod life history parameters suggests that an assumption of $M = 0.2$ is reasonable. It should be noted that maximum age as high as 16 has been observed in the commercial fishery as recently as 2009 which suggests comparable natural mortalities relative to earlier in the time series. Also, examinations of maturity-at-age and condition factor over time show no evidence of strong trends both of which can relate to changes in natural mortality.

The method of Lorenzen (1996) was used to provide an aged-based estimate of *M*. This method, which is based upon the relationship between body weight and *M* across a wide range of species, was used in SAW 54 to provide age-based estimates of *M* for Southern New England – Mid Atlantic Bight yellowtail flounder. The peer review panel of SAW 54 (O'Boyle et al. 2012) considered that applying an inter-species relationship to infer within-species dynamics was an over-interpretation of the method. While *M* no doubt may be age-specific, the pattern estimated from the Lorenzen method may not be appropriate.

Two working papers considered the predator field of cod in the Gulf of Maine area (Link 2012, Waring 2012). Link (2012) noted that directed piscivory of cod by other fish was not common, with fewer than 200 cod observed in over 550,000 stomachs examined. Similarly, the evidence for cannibalism is weak with only 20 cod found in over 20,000 stomachs. Studies to date suggest that *M* due to fish predation is likely low and is focused on juvenile and smaller size groups (Smith and Link 2010). Waring (2012) considered marine mammals as a potential source of elevated *M* in the Gulf of Maine area. Four species of seals (Harbor, Grey, Harp and Hooded) are found in New England with Harbor and Grey seals being the most numerous. The Harbor seal population, which was about 38,000 individuals in 2001, has been growing at an annual rate 6.6%. The Grey seal herd has increased from tens of animals in the early 1980s to thousands of animals in the late 2000s. Firm estimates on the size of the current herds are not available. Notwithstanding this, the food habit research suggests that cod mortality due to seals is low. Additionally, while seals are known to prey on cod, they are generalist feeders and the importance of cod in the diet of Gulf of Maine grey seals is unknown. There is limited information that suggests that cod represent only a minor component of harbor seal diet along the Maine coast (Wood 2001).

An analysis of tagging data collected during 2003 – 2006 to jointly estimate natural and fishing mortality was undertaken during GARM III (Miller and Tallack 2007). This analysis was updated for SAW 55 (Miller 2012). Contrary to the earlier work, this analysis was not length-based. Estimates of *M* ranged 0.4 – 0.7 for the Gulf of Maine. It also provided evidence of significant cod movements between GOM and GB and area 4X on the order of 4.1 to 29.7%. While *M* was relatively high compared to current estimates, *F* was comparatively low, prompting discussion on whether or not it was representative of the fishery due to local effects. The results were sensitive to the assumptions on the return rate of high-reward tags. High-reward return rates on the order of 50% were associated with Gulf of Maine cod *M* estimates of 0.3, with *M* increasing as the high-reward tag rate increased. Model preference (based on log-likelihood function) was for assumptions of near-100% on reporting rates of the high-reward tags. Estimates of fishing mortality, *F*, were inversely related to the *M* response with *F* declining with higher assumptions of high-reward tags reporting rates. Across the full range of high-reward tag reporting rates total mortality (*Z*) was estimated at approximately 1.0.

Concerns were raised with the tagging conducted in the Cape Cod area, which represented over 50% of the date in the database. The tagging had been conducted employing a wide range of expertise with mostly small cod tagged. This in combination with the warm water in the area may have resulted in higher tag induced mortality than assumed in the model. There were additional concerns with the assumed tag reporting rate (100%) for high reward tags. There is evidence to suggest differential reporting rates among some sectors of the commercial fishery, most notably the reporting rate by gillnet vessels was five times lower than that of trawl vessels (Tallack 2006). It is unknown if these same reporting trends also apply to the high-reward tags. There was also discussion on the age groups of cod represented by the study. GOM cod of 50 cm are approximately 2.5 – 3 years old, implying that the estimates of *M* are for ages 2.5 – 3 plus with it weighted towards the younger ages.

The SAW 55 WG discussed how best to use these estimates of *M*. It was hesitant to conclude that *M* was in the range of 0.6 – 0.7 and to recommend that these estimates be directly included in the assessment models. Rather, the tagging analysis is another form of modeling that should be considered. The SAW 55 WG discussed the availability of historical tagging to which the current estimates could be compared. It was reported that tagging work conducted in the Gulf of Maine area during the 1970s and 1980s suggested *M* estimates in the range of 0.2 – 0.3 whereas tagging in the 1990s was suggestive of *M* similar to the more recent results. These observations are based upon unpublished work that could not be corroborated at the meeting. Much of the historical work (e.g. Hunt et al. 1999) had been focused on cod movements and did not provide estimates of natural, fishing or total mortality. Further, concerns were raised that there was no obvious mechanism (e.g. predation) that could explain a recent increase in *M*. While counter arguments were raised that no mechanism has been identified for the current *M* estimate of 0.2, it should be noted that this estimate is supported by life history parameters. The SAW 55 WG recommended profiling natural mortality across both the historical and more recent periods of the assessment to inform the discussion as to whether or not there has been a long-term change in *M*. The SAW 55 WG agreed that an option with an *M* change should be considered as an alternate to a base assessment model which would assume no change in *M* (i.e. $M = 0.2$).

TOR 5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Consider feasibility of survey catchability estimates, the starting year for the assessment, estimation of the stock recruitment curve, inclusion of multiple fleets, and whether to use domed or flat selectivity-at–age for the NEFSC surveys. Provide a summary of steps in the model building process. Include a historical retrospective analysis to allow a

comparison with previous assessment results. Review the performance of historical projections with respect to stock size, catch recruitment and fishing mortality.

There were several changes to the input data and the impacts of these changes on the existing SAW 53 model have been documented in this report. The primary changes to the data inputs were the revised recreational catch estimates, updated assumptions about the mortality of discarded fish and minor updates to the MADMF spring survey indices-at-age. The data updates resulted in only a -54 mt difference in the 2010 estimate of spawning stock biomass (< 1% difference). The data updates did result in moderate differences in the terminal estimate of fishing mortality due to the revisions to recreational catch and discard mortality assumptions. The combined effect of these revisions adjusted the SAW 53 estimate of 2010 age 5 fishing mortality downward from 1.14 to 0.67. Revising the discard mortality assumption increased the retrospective patterning associated with spawning stock biomass, fishing mortality and age 1 recruitment. This increase in the retrospective pattern may suggest that the revised discard mortality estimates underestimate the true mortality.

In addition to the data updates, there have been changes to the model formulation of the ASAP model. The most notable change is the move from two to three fishery selectivity blocks and the assumption of flat-topped selectivity in the fishery compared to the SAW 53 model which allowed fishery selectivity to be freely estimated. There was also a minor change in the functional form used to estimate selectivity for the MADMF spring survey. Whereas the SAW 53 model used a double logistic function to fit age 1-9 indices, the approach used in the revised ASAP model utilizes a non-parametric approach with the selectivity at ages 1-6 estimated independently.

The SAW 55 WG selected four different models for review by the SARC 55 Panel. Between the four models, there were two issues in terms of the science that arose in the SAW 55 WG that resulted in significant differences in interpretation of the Gulf of Maine cod assessment, different assessment results, and consequently led to lack of consensus. The first issue involved the use of data prior to 1982 in conducting the assessment and in determining the stock recruitment relationship based on an assessment using this data. The second issue involved whether or not natural mortality was changing in the Gulf of Maine system. Two SCAA models were put forward which evaluated the performance of models using pre-1982 with internal stock recruit relationship to assumptions of a) constant natural mortality; and, b) natural mortality ramping (linearly) from a constant 0.2 in the years pre-1989 to a constant natural mortality of 0.4 from 2003 onward. Similarly, two ASAP models were put forward which used only data from 1982 onward but explored the two natural mortality scenarios.

With respect to the first issue, the SARC 55 Panel expressed a number of concerns regarding the use of pre-1982 data and the fitting of a stock-recruit function, but ultimately the Panel discounted the results and eliminated the SCAA approach from further consideration. Given all of the information provided to the Panel, there remained considerable uncertainty in the estimates of M. The evidence for and against constant and ramped natural mortality was equivocal. As with the Working Group, the Panel was unable to reach a decision on which natural mortality values or time varying scenarios best characterized this system. The SARC 55 Panel recognized that one of the motivations for examining how, or if, changes in natural mortality had occurred was driven by an effort to reduce the retrospective pattern present in the $M = 0.2$ model. However, the Panel concluded that "*…finding that including a changing M provides a better fit, is generally not sufficient to justify using such a model modification without other ecologically directed information to back it up*" (SARC 55 Panel Summary

Report, 2012). Noting the lack of conclusive evidence to support a change in *M* they determined that it was unclear as to whether a change in natural mortality was influencing the retrospective pattern or some other factor. For example, a Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp *M* approach could be partially aliasing unaccounted fishing mortality.

Given that there was no clear way forward for providing a single model for guiding management advice, the SARC 55 Panel put forward (accepted) both the ASAP $M = 0.2$ and *M*-ramp models. The consequences associated with using or disregarding either approach are outlined under TOR 8.

The assessment results for the two ASAP models accepted by the SARC Panel are as follows:

$M = 0.2$ ASAP model

The ASAP $M = 0.2$ (SAW55_3BLOCK_BASE) assessment model indicates that total SSB has ranged from 6,268 mt to 22,036 mt during the assessment time period, with current SSB in 2011 estimated at 9,903 mt (90% posterior probability 7,644 – 13,503 mt). The base model estimates SSB in 2010 at 11,141 mt which is 6% lower than the SAW 53 estimate of 11,868 mt. Total January 1 biomass in 2011 is estimated at 14,728 mt (90% posterior probability 11,890 – 19,149 mt) and F's at the end of the time series are estimated between 0.75 and 1.00 with the 2011 fully recruited, $F_{full} = 0.86$ (90% posterior probability 0.53 – 1.05).

Recruitment over the past decade has been poor despite modest increases in SSB. Age-1 recruitment has not exceeded 10 million fish in the last two decades and has been below 7 hundred thousand fish over the last decade. The five highest recruitment events in the time series were spawned during a six year period from 1982 to 1987 where the SSB was near the highest observed in the time series, averaging over 14,000 mt annually. The current population structure is comprised primarily of fish that have not yet fully recruited to the fishery (fish age 1-3), with >80% of the population age 4 and younger.

Retrospective analysis for the 2004-2011 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB. The 5-year Mohn's rho value for SSB and F were 0.40 and -0.27 respectively. While the retrospective pattern is larger than that observed in the SAW53 model, the directionality in the terminal year has shifted such that spawning stock biomass tended to be underestimated and fishing mortality overestimate. It appeared that the retrospective pattern was transient with a one year peel showing no bias. Both the SAW 55 WG and SARC 55 Panel agreed that no adjusmtment be made for retrospective pattern given that the retrospective pattern is small, it may be transient in nature and that SAW 53 made no retrospective adjustment.

M-ramp ASAP model

The ASAP *M*-ramp (SAW55_3BLOCK_BASE_M_SPLIT) assessment model indicates that total SSB has ranged from 7,930 mt to 21,531 mt during the assessment time period, with current SSB in 2011 estimated at 10,221 mt (90% posterior probability 7,943 – 13,676 mt). Total January 1 biomass in 2011 is estimated at 16,312 mt (90% posterior probability 13,173 – 20,771 mt) and F's at the end of the time series are estimated between 0.60 and 0.90 with the 2011 fully recruited, $F_{full} = 0.90$ (90% posterior probability 0.57 – 1.09).

Recruitment over the past decade has been poor to moderate despite modest increases in SSB. Age-1 recruitment has been below ten thousand fish since 2008. The current population structure is comprised primarily of fish that have not yet fully recruited to the fishery (fish age 1-3), with >80% of the population age 4 and younger.

Retrospective analysis for the 2004-2011 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB. The 5-year Mohn's rho value for SSB and F were -0.01 and 0.06 respectively. The retrospective error is considerably reduced relative to the $M = 0.2$ (SAW55_3BLOCK_BASE) model. Both the SAW 55 WG and SARC 55 Panel agreed that no retrospective adjustment should be conducted for the purposes of stock status determination or short-term projections.

TOR 6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY}, and MSY) and provide estimates of their uncertainty. Consider alternative parametric models of the stock recruitment relationship. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and any "new" (i.e., updated, redefined, or alternative) BRPs.

The existing MSY reference points based on a spawning potential ratio (SPR) of 40% were established at SAW 53 (NEFSC 2012). The overfishing definition is $F_{MSYproxy} = F_{40\%} = 0.20$. A stock is considered to be overfished if spawning biomass is less than half of SSB_{MSY}. The existing overfished definition is ½ $SSB_{40\%} = 0.5 \cdot 61{,}218$ mt = 30,609 mt. New reference points are warranted given the changes in fishery selectivity and fishery weights-at-age due to the revisions in recreational catch estimates and discard mortality assumptions. Additionally the *M*-ramp assumption has considerable impacts on recruitment estimates which will impact the estimation of SSB_{MSY} and MSY.

Analytic model-based reference points are not estimable because of insufficient contrast in the ASAP base model time series of estimated SSB and recruitment (1982-2011). As no standard stock-recruitment relationship could be found, the use of proxy reference points for this stock was necessary. A yield per recruit (YPR) analysis was performed using a 3-year average of weights-at-age (2009-2011) which was consistent with the approach used in SAW 53 and supported by recent observed trends. The remaining YPR inputs were time invariant (maturity-at-age) or were constant in the most recent time block of the assessment model (selectivity, natural mortality). The SARC 55 Panel concluded that for long-term projections (i.e., the establishment of reference points) natural mortality should be assumed equal to 0.2, because the longer-term historical evidence seems to indicate that M=0.2 is more plausible than the more recent 0.4 assumed under the *M*-ramp model. Given the SARC 55 Panel's conclusions regarding natural mortality, there are only minor differences in the selectivity vectors between the $M = 0.2$ and *M*-ramp YPR inputs; all other inputs are identical. YPR inputs are summarized in Table A.93 for both the M= 0.2 and *M*-ramp models.

The basis for the existing reference points was derived at GARM III (NEFSC 2008), and is based on $F_{40\%}$. The SARC 55 Panel recommended to maintain the $F_{40\%}$ basis for reference points for both the $M = 0.2$ and *M*-ramp models but noted that "We *do not suggest that F_{40}% is necessarily the best proxy to use, rather there has yet to be compelling reasons to abandon* *it*" (SARC 55 Panel Summary Report, 2012).

To arrive at estimates for SSB_{MSY} and a corresponding MSY, long term projections were run sampling from the empirical distribution of recruitment estimates from the preferred ASAP model. The recruitment vector included years 1982-2009; recruitment in 2010 and 2011 were not included due to their greater variance. The projection model samples from a cumulative density function derived from estimated age-1 recruitment. However, the revised model adjusts projected recruitment when SSB falls below some specified spawning biomass threshold based on a linear function that declines to zero at zero spawning stock biomass. Consistent with the SAW 53 assessment, the 'hinge' was set at the lowest observed SSB in the time series. For the $M = 0.2$ scenario, this was 6,300 mt and 7,900 mt for the M-ramp scenario. To approximate the distribution of the SSB and MSY distributions, the long term projections were made from 1000 estimates of numbers at age in 2011, which were estimated by performing MCMC simulation of the ASAP models (described above under TOR 5). The 2011 age 1 estimates were based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009. All projections were conducted with the AGEPRO software (Age Structured Projection Model v4.1).

For the ASAP, 1982 start, $M = 0.2$ scenario, the resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy} = F_{40\%}$ (0.18) are SSB_{MSY} = 54,743 mt (40,207 – 73,354 mt) and MSY = 9,399 mt (6,806 – 13,153 mt).

For the ASAP, 1982 start, *M*-ramp scenario, the resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy} = F_{40\%}$ (0.18) are SSB_{MSY} = 80,200 mt (64,081 – 99,972 mt) and MSY = 13,786 mt (10,900 – 17,329 mt).

TOR 7. Evaluate stock status with respect to the existing model (from the most recent accepted peer reviewed assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.

a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.

The updated SAW 53 model (SAW55_BASE) estimates 2011 SSB at 11,874 mt. This is less than the existing overfished threshold of 30,609 mt; therefore, the stock is overfished. The updated estimate of fully recruited fishing mortality (F_{full}) in 2011 is 0.59. This is greater than the overfishing limit of 0.20, and therefore, overfishing is occurring.

b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs (from Cod TOR-6).

For the ASAP, 1982 start, $M = 0.2$ scenario, the revised reference points are $F_{MSYproxy} = F_{40\%} = 0.18$ and SSB_{MSY} = 54,743 mt (0.5 x SSB_{MSY} = 27,372 mt). The model estimates 2011 SSB at 9,903 mt. This is less than the overfished threshold of 27,372 mt; therefore, the stock is overfished. The estimate of 2011 fully recruited fishing mortality (F_{full}) is 0.86. This is greater than the overfishing limit of 0.18, and therefore, overfishing is occurring.

For the ASAP, 1982 start, *M*-ramp scenario, the revised reference points are $F_{MSYproxy} = F_{40\%} = 0.18$ and SSB_{MSY} = 80,200 mt (0.5 x SSB_{MSY} = 40,100 mt). The model estimates 2011 SSB at 10,221 mt. This is less than the overfished threshold of 40,100 mt; therefore, the stock is overfished. The estimate of 2011 fully recruited fishing mortality (F_{full}) is 0.90. This is greater than the overfishing limit of 0.18, and therefore, overfishing is occurring.

Under both the $M = 0.2$ and *M*-ramp scenarios the stock is assessed to be overfished and overfishing is occurring. It is notable that this stock has experienced a long history of overfishing relative to current reference points.

TOR 8. Develop and apply analytical approaches to conduct single and multi-year stock projections to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. **Provide numerical annual projections (3-5 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).**

Short term projections of future stock status were conducted based on the current assessment results without accounting for retrospective bias. This rationale was identical to that of stock status determination. Numbers-at-age in 2012 were derived from 1000 different vectors of numbers-at-age produced from the MCMC chain with 2011 age 1 estimates based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009. Biological inputs were identical to those used for reference point determination. Short term projections have used an assumed catch in 2012 of 3,767 mt. This estimate is based on the current commercial and recreational catches as well as the expected catch over the remainder of the year which has been extrapolated using the harvest trajectories from the past two years (NEFMC PDT, T. Nies pers. comm.).

Recruitment was sampled from a cumulative density function (CDF) of estimated age 1 recruitment from 1982 to 2009. The same AGEPRO model used for reference point determination was used to conduct short-term projections (i.e., model adjusts projected recruitment based on a linear function that declines to zero at zero SSB when SSB falls below some 'hinge' SSB-level corresponding to the lowest SSB observed in the time series). For the $M = 0.2$ scenario, the 'hinge' SSB value was set at 6,300 mt and 7,900 mt for the *M*-ramp scenario. All projections were run under the assumption of 75% F_{MSY} ($0.18 \cdot 0.75 = 0.135$).

A consequence analysis was conducted to evaluate the sensitivity of management advice to the assumptions about *M* (i.e. $M = 0.2$ or *M*-ramp). For the *M*-ramp scenario the projections were provided assuming that: a) *M* remained at 0.4; or, b) that *M* returns to 0.2 in the projection period.

Under 75% F_{MSY} exploitation, the stock is projected to rebuild under the $M = 0.2$ and

M-ramp (*M* = 0.2) scenarios by 2022. The stock cannot rebuild under the *M*-ramp (*M* = 0.4) scenario since the reference points are based on an assumption of *M* returning to 0.2 in the long-term. It is important to note that the SARC Panel was not willing to conclude that *M* would remain at 0.4 in perpetuity and so did not provide reference points for the *M*-ramp model under a long-term assumption of *M* = 0.4. A full discussion of the three scenarios evaluated is provided under TOR 8b.

b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

The risks associated with management actions taken during 2013 – 2015 were examined by undertaking stock projections under the competing assumptions for the state of nature. For example, if the true state of nature is that natural mortality has remained unchanged at 0.2 and that stock productivity is best reflected by the 1982 – present dataset (SPR, *M* = 0.2 model), then the consequences of management actions by setting projected catch according to 75% F_{MSY} based on the two alternative states of nature were examined (*M*-ramp scenario with *M* = 0.2 in short-term and *M*-ramp scenario with *M* = 0.4 in the short term). In all cases, the 2012 catch was provided by the NEFMC Groundfish Plan Development Team. Projections were only conducted until 2015. There may be longer term consequences which might be revealed through a more extensive analysis. This is beyond the current terms of reference.

The three states of nature considered were:

- *M* = 0.2: stock dynamics and assessment based on 1982 – present dataset with *M* remaining at 0.2 for the projection period.
- *M*-ramp: stock dynamics and assessment based on 1982 – present dataset with *M* returning to 0.2 in the projection period.
- *M*-ramp: stock dynamics and assessment based on 1982 – present dataset with *M* remaining at 0.4 for the projection period.

When management actions are correctly based upon a particular state of nature, a modest (5,300 – 13,000 mt) increase in SSB is projected between 2013 and 2015 for all three scenarios explored. The *M*-ramp (*M* = 0.2) scenario has the greatest rebuilding potential whereas the M-ramp (*M* = 0.4) has the lowest rebuilding potential. Fully recruited fishing mortality declines from 0.86 (*M* = 0.2) or 0.90 (*M*-ramp) to 0.14 (all scenarios). Catch declines from 6,830 mt in 2011 to 1,313 - 2,582 mt in 2015 depending on the scenario with the *M*-ramp (*M* = 0.4) scenario resulting in the lowest yield and the *M*-ramp (*M* = 0.2) having the highest yield. The *M* = 0.2 scenario is an intermediate case. If the management actions are correctly based upon the 'true' state of nature all scenarios indicate that the stock will be in an overfished state as of 2013.

The SARC 55 Panel concluded that the *M* = 0.2 projections and the *M*-ramp projections with *M* remaining at 0.4 in the short-term were equally realistic. Like the SAW 55 WG, the SARC 55 Panel could not decide which option was more plausible. The Panel concluded that if *M* is currently 0.2 [0.4] then it seemed more reasonable to assume that in the short-term *M* would remain at 0.2 [0.4]. Note that for long-term projections that Review Panel decided that *M* should be 0.2 under all scenarios, because the longer-term historical evidence seems to indicate that *M*=0.2 is more plausible.

The consequences of mis-specifying natural mortality (e.g., *M* = 0.2 is true state of nature and manage under *M*-ramp, *M* = 0.4) will not impact status determination in 2013; under all consequence analyses considered the stock will be in an overfished state in 2013. Considering only the *M* = 0.2 and *M*-ramp (*M* = 0.4) scenarios, the consequence of mis-specifying natural mortality will result in at most 717 mt of an over-/under-harvest of fishery yield in 2015. While the magnitude is small in terms of historical catch, this amounts to 55% of over- harvest (*M*-ramp is true state of nature and manage under *M* = 0.2) or a 35% under-harvest (*M* = 0.2 is true state of nature and manage under *M*-ramp, *M* = 0.4). Assuming an *M*-ramp (*M* = 0.4) when *M* is actually equal to 0.2 results in a lower than 'planned' fishing mortality and catch and higher than 'planned' SSB. When *M* is assumed to be 0.2 but an *M*-ramp (*M* = 0.4) is correct, fishing mortality and thus catch would be considerably higher than 'planned' with the result that in 2013 the stock would be experiencing overfishing.

c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

The Gulf of Maine cod stock is currently undergoing processes that have not been incorporated into the analytical formulations. Nevertheless, they should be considered when setting the ABC.

Since the mid-1990s, as observed in the NEFSC bottom trawl surveys and consistent with the trends in the fishery, the distribution of cod has become increasingly concentrated in the western part of the Gulf, with a gradual loss of cod from the coastal and central Gulf. Since the mid-2000s, the stock has become particularly concentrated in a small region of the western Gulf, an area which appears to be a forage 'hotspot' due to the presence of sand lance, a prey of cod. This biases CPUE as an indicator of the abundance of the stock as a whole.

There is uncertainty associated with natural mortality rates. Natural mortality of cod may be increasing through consumption by other fishes and marine mammals as these populations increase; however, evidence of this is lacking in the food habits data and among life history parameters. On the other hand, tagging studies suggest natural mortality levels higher than 0.2 during 2003 – 2006 time period. The tagging studies, combined with the reduced assessment model retrospective patterns were the basis of the *M*-ramp model. However, the states of nature as reflected in the natural mortality rates included in the models are uncertain. For example, a Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp *M* approach could be partially aliasing unaccounted fishing mortality.

It may be that at low population sizes, cod experience mortality from a number of unidentified sources. High mortality, both fishing and natural will lead to a truncated age structure, implying that spawning success is increasing dependent upon younger individuals. Murawski et al. (2001) suggest that reproduction by older females is more successful than by young females. There are a number of other factors that are known to negatively influence cod spawning success at low population sizes (Rowe et al., 2004).

If weak recruitment and low reproductive rates of Gulf of Maine cod continue, productivity and rebuilding of the stock will be less than projected. Over the last five years recruitment estimates have declined to a low level in both the $M = 0.2$ and M-ramp assessment models. Recent survey indices of recruitment indicate continued poor recruitment. Additionally, the NEFSC 2011 fall and 2012 spring survey abundance indices were the 4th lowest and the lowest in their respective time series. The MADMF 2012 spring survey biomass index was the lowest in its times series. The 2012 spring survey observations were not incorporated into the assessment formulations, implying that projections may be optimistic.

The current assessment provides a range of views of current stock status, all of which indicate that the resource is in an overfished state and has experienced a long history of overfishing. Concerns for stock status may also be apparent in the fishery. Cumulative commercial and recreational catches to date in 2012 are projected to be less than 60% of the total allocated quota (based on projected catch provided by NEFMC PDT, T. Nies pers. comm.). While this is suggestive of an overall difficulty on the part of the commercial fishery to locate Gulf of Maine cod it is not definitive given other possible explanations such as sector quota restrictions on other co-occurring species. However, observations from the recreational fishery which is not subject to the same catch share system as the commercial fishery has also reported difficulty locating Gulf of Maine cod.

TOR 9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

The SAW 55 WG reviewed the status of previous research recommendations and proposed new ones to address issues raised during the three SAW 55 WG meetings. There was a single research recommendation carried forward from GARM III which has been addressed in this report. Of the nine research recommendations brought forward from SAW 53, six have been either partially or fully addressed. The remaining research recommendations from SAW 53 include estimation of cod bycatch in both the nearshore and offshore lobster fishery, ageing of the backlog of otoliths collected from the Maine – New Hampshire inshore groundfish survey and the re-evaluation of Atlantic cod stock structure in the northeast region. There is currently work in progress to address all three of these research recommendations, but progress was not sufficient to inform this assessment.

The SAW 55 WG proposed eight new research recommendations which primarily focus on improving estimates of natural mortality and the survival of post-capture fish as well as advances in assessment methods. All new research recommendations proposed by the SAW 55 WG have been assigned relative priorities (high, medium, low) as appropriate. Many of these recommendations were felt to be common to both the Gulf of Maine and Georges Bank Atlantic cod stocks and are labeled as ‘general’. The SARC 55 Panel also contributed seven additional research recommendations which are included in this section.

SAW 55 Terms of Reference for Gulf of Maine Atlantic cod (*Gadus morhua*)

1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data and take into account the recommendations and subsequent work from the March 2012 MRIP workshop. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.

2. Present the survey data and calibration information being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Consider model-based (e.g. GLM) as well as design-based analyses of the survey data in developing trends in relative abundance. Investigate the utility of commercial or recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.

3. Summarize the findings of recent workshops on stock structure of cod of the Northeastern US and Atlantic Canada.

4. Investigate the evidence for natural mortality rates which are time- and/or age-specific. If appropriate, integrate these into the stock assessment (TOR 5).

5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Consider feasibility of survey catchability estimates, the starting year for the assessment, estimation of the stock recruitment curve, inclusion of multiple fleets, and whether to use domed or flat selectivity-at–age for the NEFSC surveys. Provide a summary of steps in the model building process. Include a historical retrospective analysis to allow a comparison with previous assessment results. Review the performance of historical projections with respect to stock size, catch recruitment and fishing mortality.

6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} , and MSY) and provide estimates of their uncertainty. Consider alternative parametric models of the stock recruitment relationship. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and any "new" (i.e., updated, redefined, or alternative) BRPs.

7. Evaluate stock status with respect to the existing model (from the most recent accepted peer reviewed assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.
   a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
   b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs (from Cod TOR-6).

8. Develop and apply analytical approaches to conduct single and multi-year stock projections to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. Provide numerical annual projections (3-5 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).
b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.
c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

Introduction

The 55th Stock Assessment Workshop Working Group (SAW 55 WG) prepared the assessment. The working group held three meetings during 27 August – 2 November 2012. The meeting dates and locations are listed below. Working group participation varied by meeting. A complete list of working group participants can be found in Appendix A.1.

- SAW 55 Data Working Group Meeting
    - August 27-31, 2012
    - Northeast Fisheries Science Center (NEFSC), Woods Hole, MA
- SAW 55 Models Working Group Meeting
    - October 15-19, 2012
    - Northeast Fisheries Science Center (NEFSC), Woods Hole, MA
- SAW 55 Models and Biological Reference Points Working Group Meeting
    - October 30-November 2, 2012
    - Northeast Fisheries Science Center (NEFSC), Woods Hole, MA

Assessment history

The initial analytical assessment of the Gulf of Maine stock was conducted using a virtual population analysis (VPA) model by Serchuk and Wigley (1986) and presented at the 7th Northeast Fisheries Science Center (NEFSC) Stock Assessment Workshop (SAW) in 1988 (NEFSC 1989). Subsequently, the stock was reviewed again at SAW 12, 15, 19, and 24 (NEFSC 1991, 1993, 1995, 1997, 1998; Mayo 1995, 1998, Mayo et al. 1993, 1998, 2002). Additionally, interim assessments were reviewed outside of the SAW framework by the Northern Demersal Working Group in July 1999 (NEFSC 2000) and again in August 2000 (NEFSC 2001a).

Amendment 4 (1991) to the MultispecIes Fisheries Management Plan implemented $F_{20\%}$ as an overfishing mortality threshold for Gulf of Maine cod. Estimates of $F_{20\%}$ and F_{max} are shown below (**note $F_{20\%}$ was not reported in the SAW 7 documents*):

Stock assessment workshop	Year	$F_{20\%}$	F_{max}	Model type	Notes
SAW 7	1988		0.27	VPA	Commercial landings only
SAW 12	1991	0.40	0.27	VPA	Commercial landings only
SAW 15	1993	0.36	0.25	VPA	Commercial landings only
SAW 19	1995	0.35	0.27	VPA	Commercial landings only
SAW 24	1997	0.37	0.29	VPA	Commercial landings only
SAW 27	1998	0.39	0.29	VPA	Commercial landings only

The 1996 re-authorization of Magnuson-Stevens Conservation and Management Act required the redefinition of overfishing and overfished with respect to the rate of fishing mortality associated with producing maximum sustainable yield. SAW 27 provided estimates of F_{MSY} and B_{MSY} based on the ASPIC surplus production model with survey catchability coefficients conditioned on biomass estimates from the SAW 27 VPA. These estimates were mean age 1^+ B_{MSY} =33,000 mt (total biomass) and age 1^+ total biomass weighted F_{MSY}=0.31. This method was used in the Report of the Overfishing Definition Review Panel (Applegate et al. 1998) and the corresponding reference points were adopted in Amendment 9 to the multispecies

FMP. The biomass threshold was set at ¼ B_{MSY} (8,300 t).

In the last eleven years, the Gulf of Maine cod stock has undergone five peer-reviewed assessments: SAW 33 (NEFSC 2001), the Groundfish Assessment Review Meeting (GARM, NEFSC 2002), GARM II (NEFSC 2005), GARM III (NEFSC 2008) and SAW 53 (NEFSC 2012a). Summaries of these assessments and the resulting stock status are provided in Tables A.1 and A.2. All of these assessments, with the exception of SAW 53 were conducted using the ADAPT VPA model. All assessments began the assessment time series in 1982 which corresponds to the availability of age data from the commercial fishery. The data inputs from SAW 33 through GARM II were nearly identical, with GARM I and II representing updates to the SAW 33 model inputs. Commercial discards were accounted for by increasing the total landings by 500 mt increments; the size of the increase was determined based on the estimated discards. This method assumes that the discarded fraction of the catch is of the same size composition as the landed catch. In the existence of trip limits, this assumption may be appropriate, but when discarding is occurring primarily as a result of minimum retention sizes, such a method may incorrectly characterize the age composition of the catch. The SAW 53 assessment included direct estimates of commercial discards since 1989 as well as including hindcasted estimates for the years 1982-1988. Recreational landings were included in these assessments prior to SAW 53, but recreational discards were not. Beginning with the SAW 53, estimates of recreational discards were included in the fishery removals. Additionally, prior to SAW 53 catch and stock weights-at-age were estimated solely from the landed fraction of the catch. When discards due to minimum sizes restrictions contribute a sizeable fraction of overall removals, this method has the potential to overestimate stock biomass. The weights-at-age used as inputs to SAW 53 provided a more realistic characterization of fish weights relative to the approach taken in previous assessments.

SAW 33 included catch through 2000 and survey indices through 2001 (spring only). SAW 33 re-evaluated reference points using an age based production model with a Beverton-Holt stock recruit relationship (NEFSC 2001b). Reference points were estimated as total stock age 1^+ total biomass B_{MSY}=90,300 mt, SSB_{MSY}=78,000 mt, and F_{MSY}=0.23. The SAW 33 assessment concluded that Gulf of Maine cod were not over fished, but overfishing was occurring. It is noteworthy that the stock status determination applied at SAW 33 was different than the current basis. For SAW 33 the overfished definition was based on ¼ B_{MSY} criteria (Applegate et al. 1998) unlike the ½ SSB_{MSY} that was later adopted by the Working Group on Re-estimation of Biological Reference Points for New England Groundfish (NEFSC 2002b). The 2001 total stock biomass was estimated at 24,000 mt (18,000 mt SSB); just over 25% of B_{MSY}. Fishing mortality (F) was estimated at 0.73 which was over three times higher than F_{MSY}.

The Working Group on Re-evaluation of Biological Reference points for New England Groundfish (NEFSC 2002a) further revised Gulf of Maine cod reference points; SSB_{MSY} was revised to 82,800 mt based on change in the period used to derive mean stock weights. F remained unchanged. Amendment 13 (2004) to the Multispecies FMP adopted the Working Group's revised reference points (SSB_{MSY}=82,800 mt, F_{MSY}=0.23). The biomass threshold was revised to ½ SSB_{MSY} (41,400 t). GARM I updated the data inputs by one year (through 2001) using the same VPA formulation as SAW 33. Spawning stock biomass in 2001 was estimated at 22,040 mt, approximately 25% of SSB_{MSY}. F was estimated at 0.47, two times greater than F_{MSY}. As of 2002 Gulf of Maine cod were overfished and overfishing was occurring. GARM II was a three year update (through 2004) to the GARM I assessment. Biological reference points remained unchanged from GARM I. Spawning stock biomass had declined to 18,800 mt in 2004 and F had increased to 0.63. The stock complex was still overfished and overfishing was occurring. The GARM II assessment exhibited a retrospective pattern in both F and SSB, with a tendency for F to be underestimated and SSB to be overestimated in the most recent three years.

The 2008 GARM III assessment represented a benchmark assessment update. Major changes from the previous assessments include a more thorough consideration of commercial discards and updates to the biological reference points. Unlike previous assessments where landings-at-age were increased in fixed amounts, the GARM III method applied an estimated discard ratio to the landings-at-age. While this method better characterizes the true trends in discards, it still makes the assumption that the age composition of the discards is identical to the landed fraction. It should be noted that the ratio increase in landings-at-age was only applied from 1999 to 2007. Prior to 1999, commercial discards were not accounted for. As in previous assessments, catch and stock weights-at-age were estimated solely from the landed fraction of the catch and recreational discards were not included in the catch estimates. Biological reference points were based on the non-parametric yield and SSB per recruit analysis with $F_{40\%}$ used as a proxy for F_{MSY}. The reference points were estimated as follows: $F_{MSY} = 0.237$ and $SSB_{MSY} = 58,248$ mt. Terminal year estimates of F were 0.46 and SSB was estimated to have increased to 33,877 mt. The stock was perceived to no longer be overfished, but overfishing was still occurring. The large increase in SSB was contingent on the relative strength of the 2003, and to a greater degree, the 2005 year classes. The 2005 year class was estimated at 23.9 million fish (age 1) which represented the second largest observed year class in the assessment time period. The 2005 year class was only age 2 in 2007 and had yet to enter the fishery; the 2007 estimates of partial recruitment indicated that the vulnerability of this year class to the fishery was at less than 1%. The entire strength of the 2005 year class was primarily derived from the NEFSC spring and MADMF fall survey indices.

The SAW 53 assessment was also a benchmark assessment. For SAW 53 a new assessment model (ASAP) was developed that incorporated updated estimates of the length-weight equation, maturity at age, and weights at age. Additional changes from the GARM III assessment include the inclusion of direct estimates of commercial discards and the inclusion of recreational discards as mentioned previously. Given the major changes in data that have occurred in the most recent update, the SAW 53 assessment is not entirely comparable with previous assessments. Much of the scale differences between the SAW 53 assessment and previous assessments were the result of changes to the underlying data (e.g., weights-at-age) and not as a result of the assessment or choice of model. Biological reference points were based on the non-parametric yield and SSB per recruit analysis with $F_{40\%}$ used as a proxy for F_{MSY}. The reference points were estimated as follows: $F_{MSY} = 0.20$ and $SSB_{MSY} = 61,218$ mt. Terminal year estimates of F were 1.14 and SSB was estimated at 11,868 mt. The stock was perceived to be overfished, and overfishing was occurring. The major change in estimated biomass from the GARM III assessment resulted primarily from the revised estimates of weights at age, and more importantly, from revised estimates of the strength of the 2003 and 2005 year class. With three years of additional survey and fishery data it appears that the GARM III overestimated the strength of these two year classes and subsequently the spawning stock biomass in 2007. The overestimation by the GARM III assessment was partly the result of too much confidence put on highly uncertain survey observations near the end of the time series. The ASAP model developed for SAW 53 allows direct incorporation of survey and fishery precision estimates and is more robust to uncertain data inputs.

Fisheries Management

Gulf of Maine Atlantic cod have been managed under two different management authorities in recent history. Prior to 1977 the 5Y component (statistical areas 511-515) of the stock was managed under an international treaty through the International Commission for the Northwest Atlantic Fisheries (ICNAF). Fisheries management was primarily controlled through annual total allowable catches (TACs) and minimum mesh sizes (Serchuk et al. 1994). The TACs remained constant at 10,000 mt between 1973 and 1975 followed by reductions to 8,000 mt in 1976 and then to 5,000 mt in 1977. The Magnuson Fishery Conservation and Management Act (MFMCA) was passed in 1977 and subsequently the management authority of the Gulf of Maine cod stock, as well as all other New England groundfish stocks, shifted to the New England Fishery Management Council (NEFMC).

The use of TACs continued under the NEFMC authority through 1982, with TACs dispersed among quarters and vessel tonnage classes. The early quota period was accompanied by poor catch monitoring and reported black markets for quota managed species and may have contributed to increased uncertainty over catches. The system adopted in the mid-80's had numerous exceptions and special programs to mesh and minimum size requirements that make it difficult to draw conclusions about how regulations influenced fishery selectivity. In 1982, the "Interim" Groundfish Fisheries Management Plan (FMP) was implemented which replaced the quota system (TAC) with input controls such as mesh sizes and minimum retention sizes (Table A. 3). The "Interim" FMP was replaced by the initial Groundfish FMP in 1985 which largely carried forward the existing measures from the interim FMP. Amendment 4 to the FMP required the use of a Nordmore grate in the northern shrimp fishery as well as placing a prohibition on the retention of groundfish bycatch. Beginning with Amendment 5 (1994), there was a concerted attempt to reduce fishing effort through a days-at-sea (DAS) reduction schedule. Additionally, Amendment 5 brought about mandatory vessel reporting in the way of the Vessel Trip Reports (VTRs). Effort controls were increased under Amendment 7 through further acceleration of the DAS reduction schedule, and the addition of seasonal and year round closures in the Gulf of Maine. Between 1997 and 1999 trips limits on Gulf of Maine cod were reduced from 1000 lbs/day to 30 lbs/day. Amendment 13, implemented in May 2004, placed additional restrictions on DAS usage while allowing for the use of regular B DAS to target healthy stocks. Additionally, Amendment 13 implemented mandatory electronic reporting for all primary federally permitted seafood dealers. In 2006, Framework 42 established reference point thresholds for the 18 groundfish stocks reviewed at GARM II as well as formalized rebuilding plans for all overfished stocks ($< ½ SSB_{MSY}$), such as Gulf of Maine cod. Through 2010 a series of additional framework actions and interim rules placed additional restrictions on DAS usage and seasonal closures on the recreational fishery.

The effort controls first adopted in 1994 were frequently changed, making it difficult to isolate the effects of individual regulations. The use of often-changing trip limits led to increased discard rates and may have contributed to high-grading. Seasonal (rolling) and year-round closures may have limited fishery access to larger spawning fish, and strict DAS limits focused effort on easily caught nearshore cod and led to the increased use of sink gillnet gear.

In 2010, the groundfish fishery experienced a major management change with the passage of Amendment 16. Amendment 16, with the introduction of annual catch limits (ACLs), represented a return to the use of hard TACs. Additionally, 17 new groundfish sectors were approved and those vessels not members of a groundfish sector were subject to additional cuts in DAS and restrictive trip limits. Vessels fishing under the sector management were exempt from DAS restrictions and instead, each sector was given a share of the total commercial groundfish sub-ACL. How the catch was divided up amongst sector vessels or how catch was allocated throughout the year was left to the sole discretion of the sector. One of the requirements of Amendment 16 was an increase in the overall level of observer coverage. This was accomplished using observers trained through the existing Northeast Fisheries Observer Program (NEFOP) as well as a new class of observers termed At-Sea Monitors (ASMs). The data collection protocols for ASMs were restricted to catch estimation and the collection of limited biological information (e.g., lengths). The recent shift to a catch share system in 2010 appears to have dramatically reduced discards but it is too soon to fully understand the overall impacts of the sector management system.

Since the passage of Amendment 16, two framework modifications have been made to the FMP with direct impacts on the management of Gulf of Maine cod. Framework 45 implemented in May 2011 created the Whaleback closure area in the western Gulf of Maine designed to protect spawning aggregations of cod that occur in this area. This is a seasonal closure area extending from April 1 to June 30 and applies to both the recreational and commercial fisheries. Framework 47 was implemented in May 2012 and reduced the minimum retention size in the recreational fishery to 19 inches as well as reducing the recreational bag limit to 9 fish per angler. It should be noted that Framework 47 took effect outside of the time frame being used for the current assessment which only considers data through December 31st 2011.

Biology

Stock structure

Atlantic cod (*Gadus morhua*) is a demersal gadoid species whose range in United States (US) waters extends from Cape Hatteras north to the Canadian border. Globally, Atlantic cod occur on both sides of the North Atlantic Ocean, extending southward in the eastern Atlantic to the Bay of Biscay. Within the United States Exclusive Economic Zone (EEZ) there are two recognized stocks of cod: Gulf of Maine and Georges Bank. The existing Gulf of Maine of Maine stock complex extends from the northern tip of Cape Cod east to the US/Canadian border and north to the coast of Maine (Fig. A.1).

Recent reviews of historical and contemporary tagging studies (O'Brien et al. 2005, Tallack 2007, Loehrke and Cadrin 2007) suggest that there is movement of fish between the Gulf of Maine and Georges Bank stocks with the degree of mixing < 30% (Hunt et al. 1999, Tallack 2009, Miller 2012). The SAW 55 WG reviewed some preliminary analyses evaluating possible impacts of stock mixing on assessment results (Chen and Cao 2012). Overall, the results indicated that the lack of consideration of inter-stock mixing had little impact on the GOM cod assessment results. The importance of the quality of the catch information was highlighted. The WG expressed several concerns and possible areas of improvement in the analysis. While the study is a work in progress with many assumptions and issues to be resolved, it highlighted the value of undertaking modeling to explore complex spatial processes influencing cod in the Gulf of Maine.

Several meta-analyses of the life history parameters of Atlantic cod in the region have been conducted over the last four decades that generally support the current stock boundaries. These investigations have highlighted differences in both the growth and maturity rates between the Gulf of Maine and Georges Bank stocks (Pentilla and Gifford 1976, Begg et al. 1999). These differences are highlighted in the current assessment as well in addition to differences that have been noted in the trends of condition factor between stocks. There are recognized localized metapopulations within the Gulf of Maine (e.g., Ames 2004, Kovach et al. 2010, Siceloff and Howell 2012), between which, the degree of mixing is unknown. Additionally, there is recent work showing possible genetic connections between the Gulf of Maine and Nantucket Shoals (current considered part of the Georges Bank stock; Kovach et al. 2010). Investigations into the relative importance of these connections as well as a re-investigation of all stock structure information are under way and summarized under TOR 3. The existing stock structure boundaries constitute the best available science for the current assessment.

Length-weight relationship

The SAW 53 assessment used seasonal survey-based length-weight (LW) equations as the basis for converting catch weights to numbers-at-age (Equations 1-3, Fig. A.2). Since 1992, the NEFSC bottom trawl surveys have used digital scales to record individual fish lengths. Using these data, updated survey-based length weight equations were compared to the existing length weight equation. Both seasonal (spring/fall) and annual updates were evaluated. The use of a time-invariant LW equation is only appropriate if the LW relationship has remained stable over time. Information presented in the SAW 53 assessment report (NEFSC 2012a) showed the temporal stability of LW relationships over time. Additionally, seasonal condition factors have remained relatively stable over time (Fig. A.3), providing additional support to the use of a time-invariant LW equation.

(1) $W = 0.000004714L^{3.1741}$ (Spring)
(2) $W = 0.000006178L^{3.1322}$ (Fall)
(3) $W = 0.000005132L^{3.1625}$ (Annual)

There are divergent opinions as to whether it is more appropriate to use a landings-based length-weight equation versus a survey-based length-weight equation to convert catch weights to numbers-at-age. Advocates for a landings-based derivation argue that since the fishery may catch larger (heavier) fish at length, there is the possibility that a survey-based length weight equation may be biased low, particularly at greater lengths. A survey-based approach may be preferred when a large portion of the catch s comprised of discards (or some other fraction not sampled such as recreational landings) or when the catch weights-at-age are also used to estimate stock weights due to sparse sampling of older ages in the surveys (missing or highly variable estimates of weights-at-age). In the case of Gulf of Maine Atlantic cod, the arguments for a survey-based LW relationship are valid (large fraction of catches not from commercial landings and use of catch weights to estimate stock weights). Currently in the Northeast Region, fishery surveys are the only source of individual length-weight sampling.

The suitability of applying a survey-based LW equation to commercial landings was evaluated by applying the seasonal LW relationships in equations 1 and 2 to the observed length frequency distributions of commercial biological samples collected between 1982 and 2011. The estimated weights were then compared to the recorded sample weight and the distributions of differences were examined for the presence of bias. Examinations across years showed no evidence of strong temporal trends and across all market categories the interquartile ranges of the differences overlapped the equality line in the majority of years for both the 'scrod' and 'market' landings market categories (Fig. A.4). There was some indication that the estimated weights were greater than the recorded weights for the 'large' market category which could suggest that the survey LW relationships estimate heavier fish at length relative to the true relationship within the commercial landings. Interestingly, using the arguments made against the use of survey-based LW presented above, this is opposite of the expectation.

Since cod are typically landed in gutted form, a more likely explanation for the discrepancies noted in the 'large' market category is that the current conversion factor for converting gutted cod to its live weight equivalent is incorrectly specified. There has been an ongoing data collection effort by the NEFSC's Cooperative Research Program to collecting information to support a re-evaluation of the established conversion factors for a variety of groundfish species. Preliminary analyses of the data collected to date suggest that a more appropriate conversion factor should be 1.20 compared to the established 1.17 that has been used to date (Table A.4). While the differences are quite small, applying the preliminary 1.20 estimate to the above analysis resolves much of the apparent bias in the large market category (Fig. A.5). The preliminary work is suggestive that a revisions may be needed to the gutted-live weight conversion factor; however the work is still preliminary and additional data are needed before the work can be finalized. It should be stressed that the small changes in the conversion factor that are suggested by the preliminary work will have negligible impact on the assessment results.

Growth and maturity

Atlantic cod in the Gulf of Maine and Georges Bank reach a maximum size around 130 cm (≈ 25 kg). Cod in the Gulf of Maine tend to grow slower than on Georges Bank (Fig. A.6 - 7). Generally, the differences in growth parameters lend support to the treatment of Gulf of Maine and Georges Bank as separate stocks. These results are consistent with that of previous research on the topic (Penttila and Gifford 1976, Begg et al. 1999). The Gulf of Maine cod von Bertalanffy growth parameters were re-estimated using NEFSC survey data from 1970 to 2012 (Equation 4). A summary of the number of ages included in the analysis are presented in Table A.5. Given the sparseness of the sampling of older ages, the L_∞ may be poorly estimated.

$$(4) \qquad L = 150.93 \cdot (1 - e^{-0.11(t-0.13)}) \text{ (Annual)}$$

To examine whether there have been large scale changes in the growth rates over time as well as evidence of cohort-specific growth rates associated with year class strength, von Bertlanffy growth curves were fit to the 1960-2005 year classes. Since K and L_∞ tend to be correlated and given the limited observations when fitting growth curves on a cohort basis, L_∞ was fixed at the time series estimate of 150.93 cm. Plots of K by cohort show oscillations about the mean cohort *K* value of 0.12 with *K* values of the most recent cohorts tending to fall below the mean (Fig. A.8). Comparison of cohort *K* values to age 1 estimated recruitment from the SAW 53 assessment shows no discernible relationship between *K* and cohort strength (Fig. A.9), suggesting a lack of density dependent growth within the range of recruitment events that have been observed.

Examination of monthly trends in the mean length of Gulf of Maine cod landed in the commercial fishery suggests that the majority of somatic growth occurs between March and December, with little growth occurring January through February (Fig. A.10). Examination of mean survey weights-at-age suggests that fish size-at-age has oscillated about the long-term mean with no strong increasing or decreasing trends (Fig.'s A.11-12).

A logistic regression method (O'Brien et al. 1993) was used to fit maturity-at-age from the NEFSC spring survey data from 1970 to 2012. The number of maturity samples taken per year ranges from 23 to 229 (Table A.6). The SAW 55 WG examined the trends in annual age-at-50% maturity (A_{50}; Fig. A.13), and determined that the estimated A_{50} (age at which 50% of fish are mature) varied about the time series average, but without any persistent trends. Based on the lack of persistent trends, the SAW 55 WG supported the use of a time-invariant maturity ogive to characterize the maturity schedule of GOM cod (Fig. A.14).The input to the stock assessment model is based on the female maturity ogive presented in Table A.7. The time series $A_{50\%}$ for male cod was 2.85 and 2.66 for females. The approach is identical to that used for the SAW 53 assessment and the estimated values are similar, with the only changes resulting from incorporation of an additional year of survey data.

The SAW 55 WG also evaluated trends in length-based maturity (Fig. A. 15). Similar to the age-based maturity examinations, the annual L_{50} estimates lacked persistent trends, though they were generally more variable than the patterns present in the A_{50}. The WG discussed possible reasons for this and concluded that this was likely due to the high variability in the length distributions observed in any given year (Fig. A.16). The time series average L_{50} was estimated at 40.8 cm for females and 42.9 cm for males. Length-based maturity ogives are presented in Figure A.17.

In relation to spawning time, genetic and growth research presented to the WG (Kovach et al. 2010, Dean et al. 2012) indicated that cod in the western Gulf of Maine are comprised of northern spring (May/June) and southern winter (December/January) spawning components, with homing of each group to their respective and distinct spawning grounds. However, there was no information available to evaluate the relative contribution of each of the spawning components. This raised the issue as to what date to use for peak spawning. The previous assumed peak was April 1st. The WG recommended that rather than defining the assessment spawning period as a 'peak' spawning date it was more appropriate to base the date used for the estimation of SSB on the mid-point between the spawning periods, which is approximately 1st April (SAW 55 WG 2012a).

Response to the Terms of Reference

TOR A.1. Estimate catch from all sources including landings and discards

Overview

In the recent period (1982 to present) total catch has ranged from 21.0 thousand metric tons (mt) to 3.1 thousand mt (Table A.8, Fig. A18). Commercial landings are the predominant source of fishery removals averaging 75% of the total catch between 1982 and 2011. The current levels of commercial landings are on similar scales with historical (pre-1982) estimates (Table A.9 and Fig. A.19). There is an indication that a higher level of commercial landing were supported pre-1932, however these landings were estimated from a proration of combined Georges Bank and Gulf of Maine landings and have a higher degree of uncertainty than the landings estimates beginning in 1932 (Serchuk and Wigley 1992). Some research has suggested that landings of Gulf of Maine cod during the mid-1800's could have been as high as 60,000 mt (Alexander et al. 2009, Fig. A.19). Georges Bank landings have typically exceeded Gulf of Maine landings throughout much of the time series, though Gulf of Maine landings have generally exceeded those of Georges Bank over the last decade (Fig. A.20).

Prior to 1999, landings were the primary component of the total catch, constituting 63-93% of the total catch. Since 1999, landings have made up only about 46-73% of the total catch (Table A.8, Fig. A.18). There are three primary reasons for this shift: (1) significant restrictions on commercial landings leading to (2) an increase in commercial discards, and (3) increased contribution from the recreational fishery.

Beginning in 1999, commercial discards became a significant component of the catch, accounting for greater than 30% of the overall catch (Fig. A.18). Notable increases in commercial discards were primarily the result of restrictive trip limits between 1998 and 2000 (Table A.3). Trip limits were gradually relaxed from 2000 through 2004 resulting in an overall decrease in the contribution of commercial discards to the overall catch.

Recreational landings peaked in 1987, but generally, recreational landings prior to 1999 constituted approximately 13% of the overall catch, whereas they accounted for, on average, about 25% from 1999 through 2011. Recreational discards became an increasingly important component of the overall Gulf of Maine cod catch as the minimum retention size of cod was progressively increased from 15 in. in 1982 to the current size limit of 24 in., which has been in effect since 2006. The recreational minimum size was decreased to 19 in. in 2012, but that is beyond the time series used in the current assessment.

Commercial landings

In 1982, the United Nations Convention on the Law of the Sea (UNCLOS) defined a countries exclusive economic zone (EEZ) as a zone extending up to 200 nautical miles from a nation's coast. The EEZ defines the region where each country has sovereign rights to marine resources including fisheries. The geographic proximity of the US and Canada in the Gulf of Maine and Georges Bank Regions resulted in an overlap of each nation's EEZ. Given the importance of these areas with respect to resource extraction (among other reasons), the US and Canada both submitted cases to the International Court of Justice at The Hague, Netherlands seeking clarification. The Court issued a final ruling on October 12, 1984 formally delineating the US and Canadian EEZ. Hereafter, this demarcation line became informally known as the "Hague Line".

Within the Gulf of Maine, the US EEZ splits statistical areas 464, 465 and 467 (Fig. A.1). Prior to Hague line implementation, landings of cod in US ports from these statistical areas could have been either from the Gulf of Maine or Scotian Shelf stocks. Current management of Gulf of Maine cod includes catch from these areas against the fisheries ACLs. Previous assessments have not included these catches. While landings from these statistical areas have been low since 1985, accounting for less than two percent of the total Gulf of Maine landings (Fig. A.21), these landings are included in the current assessment to maintain consistency with the existing ACL monitoring programs. Based on the recommendations of the SAW 53 and 55 WGs, no attempt was made to adjust landings prior to 1985.

Since 1964, when modern catch statistics began, commercial landings of Gulf of Maine cod have ranged from 1.4 thousand mt to nearly 18 thousand mt (Tables A.8 and A.9). Landings statistics for area 5 (Gulf of Maine and part of Georges Bank stocks) exist back to 1893 (e.g., Mayo et al. 2009, Fig. A.19) and there are isolated estimates of commercial landings in the mid-1800's (Alexander et al. 2009). The methods used to apportion landings to individual stock complex prior to 1964 are not well documented and generally, these stock landings are considered less certain. Estimates of historical Gulf of Maine cod landings are of similar magnitude as landings between 1964 and 2010, though there was a period of sustained high landings above 8,000 mt prior to 1930. Total species landings are derived from the weighout reports of commercial seafood dealers and these data are generally considered a census of total landings. While un-reported landings are possible, no estimates exist to evaluate their magnitude. A secondary data source is required to apportion dealer landings to statistical area (stock) and assign basic information on fishing effort (e.g., gear, mesh, tow duration). Prior to 1994, the partitioning of stocks from total cod landings was accomplished, in part, through a port-interview process conducted by port agents working for the National Marine Fisheries Service (NMFS). The percent of Gulf of Maine cod landings attributed to interviewed trips was generally less than 40% (Fig. A.22). When trips were not interviewed, the port-agent would attribute area and fishing effort characteristics to the landings using their knowledge of the fishery and or information obtained during the interview process about vessels operating in the vicinity of the interviewed captain.

With the requirement of vessel-reported VTRs starting in 1994, the port interview process stopped and the area and effort information was inferred directly from the VTRs. Currently, a standardized procedure is used to assign area and effort from VTRs to dealer-reported landings from 1994 onward (Wigley et al. 2008). The product from this process is stored the NEFSC allocation (AA) database tables. Landings are matched to VTRs in a hierarchal manner, with landings matched at the top tier (level A, direct matching) having a higher confidence in the area and fishing effort attribution than those matched at the lower tiers. The matching rates have improved over time with approximately 80% of Gulf of Maine cod landings being matched at the highest level since 2004 (Figs. A.22 and 23). Interestingly, there is a seasonal component to the matching success, with generally poor matching success around the month of May (Fig. A.24). This phenomenon has not been fully explained, but does coincide with the start of the groundfish fishing year and annual renewal of vessel permits during which reporting compliance checks have historically been conducted. The overall precision associated with the allocation process, in terms of a CV is estimated at less than 0.1 (Table A.10).

An additional area of uncertainty with stock landings stems from the mis-reporting and/or under reporting of statistical areas on VTRs. Federal regulations require that a separate VTR logbook sheet be filled out for each statistical area or gear/mesh fished. Vessels fishing in multiple statistical areas frequently under-report the number of statistical areas fished (Palmer and Wigley 2007, 2009 and 2012). Following the SAW 53 assessment of Gulf of Maine cod there was also public concern that vessels were fishing in the vicinity of Stellwagen Bank in the western Gulf of Maine, but hauling back their catches across the Gulf of Maine/Georges Bank stock boundary and reporting the catch as Georges Bank cod. Based on comparisons of VTR reports with the observer and vessel monitoring system (VMS) data, the impacts of this misreporting on Gulf of Maine landings estimates are estimated to be small. Since 2006, the magnitude of this error is ≤ 2% (Table A.11). While VTR mis-reporting remains problematic, it is not likely to be a large source of error with respect to the quantification of Gulf of Maine cod landings.

For some species, there may be a component of the catch that does not get reported by seafood dealers. In the case of Gulf of Maine cod, fish retained by the crew for home consumption are the most significant component of commercial landings that would not be reported by seafood dealers. Estimates of home consumption can be derived from VTRs, but these estimates are likely underestimates of total home consumption landings due to incomplete reporting. From 1994 to 2011, home consumption landings are estimated at ≤ 0.3% of total commercial landings (Table A.12). Even if these represent underestimates, it is unlikely that home consumption landings represent a significant source of fishery removals. Because of the low magnitude, home consumption estimates are not included in estimates of commercial landings.

The commercial fishery is primarily conducted by vessels fishing trawl and gillnet gear with gillnet gear having become progressively more important over time (Fig. A.25). Current landings by trawl and gillnet gear are about equal and account for nearly 95% of the total landings. Landings by longline and handline (jig) are minor. There is a seasonal component to fleet activity in the Gulf of Maine with gillnet landings decreasing during the spring months (March through June) when parts of the western Gulf of Maine are inaccessible due to rolling closures. Larger trawl vessels which have the capacity to fish further off shore, to the east of the rolling closures, dominate the landings during the spring months (Fig. A.26).

The ports of Gloucester and Portland have historically been the primary offload ports of Gulf of Maine cod (Fig. A.27). Portland landings have declined over the last twenty years and Gloucester now accounts for over 60% of total commercial landings. The rolling closures in the western Gulf of Maine affects port landing patterns in a manner similar to their impact on the gear trends. Landings in Gloucester drop off during the months of April and May when the nearshore waters in the western Gulf of Maine are closed to groundfishing (Fig. A.28). During these months, cod are primarily landed in ports along the Maine coast. The rolling closures cycle clockwise around the western Gulf of Maine, and by June, when the rolling closures are off the coast of Maine, Gloucester again becomes the dominant port for Gulf of Maine cod landings.

The patterns for landings by statistical area are similar to the port trends. Over the last twenty years, landings have become increasingly concentrated in statistical area 514 (Fig. A.29), which is the statistical area in closest proximity to Gloucester. Landings from statistical areas to the north and east have declined. Currently, statistical area 514 accounts for >70% of total stock landings. The rolling closures have had impacted the statistical area landing patterns in manner much like the port and gear trends (Fig. A.30).

The waters of the northeast U.S. are divided into ten minutes squares which are rectangular areas ten minutes of latitude by ten minutes of longitude. Each ten minute square covers approximately 260 km^2, representing approximately 0.5% of the total 52,462 km^2 surface area of the Gulf of Maine cod management area. Annual Lorenz curves were estimated for both the commercial trawl and gillnet fishery based on the cumulative catch by ten minute square (following methods outlined in Wigley 1996). From the Lorenz curve an annual Gini index, or concentration index, can be estimated using Equation (5).

$$G = A/(A+B) \tag{5}$$

Where G is the Gini index, A is the area between 1:1 equality line and B is the area under the Lorenz curve.

Annual Gini indices were developed for both the commercial trawl and gillnet fishery based on the cumulative catch by ten minute square. The gillnet Gini index was relatively flat between 1994 and 2002 but then increased steadily through 2010, with a slight decline in 2011. Comparatively, the trawl Gini index has increased steadily over the VTR time series, though the index has been relatively flat since 2008 (Fig. A.31). The concentration in the commercial fleet is characterized by a directional shift in the catch-weighted center (centroid) of fishing activity to the southwest. The current center of fish of fishing activity is located in the western Gulf of Maine in the vicinity of 42.6° N x 70.3° W (Fig. A.32).

There has been a decline of approximately 40% in the number of ten minute squares contributing to the annual Gulf of Maine cod landings (Fig. A.33). However because approximately 60% of the landings prior to 1994 were not from interviewed trips and the spatial information from non-interviewed trips is only precise to the quarter degree square level, the true decline is likely greater. Comparison of ten minute square landings patterns from the mid 1990’s to the late 2000’s showed two noticeable patterns: (1) cod were being caught in fewer ten minute squares, particularly along coastal Maine, and (2) in the 1990’s landings were evenly distributed across the Gulf of Maine, where as in the late 2000’s landings were dominated by only a few ten minute squares in the western Gulf of Maine (Fig. A.34). The increases in the contribution of landings from a relatively small area of the Gulf of Maine are consistent with the concentration indicated by the Gini indices.

The top five most important ten minute squares throughout the VTR time series (1994-2011) were identified based on their average annual contribution to the total Gulf of Maine cod landings. The use of these ten minute squares over time in terms of total annual landings was investigated to determine if particular regions within the Gulf of Maine appeared to exhibit unique properties in terms of cod removals. These trends can be thought of in terms of a utilization index for small areas (i.e., does the fishery tend to differentially utilize certain areas and are there persistent trends?).

The top five ten minute squares with respect to annual contribution to Gulf of Maine cod landings are all located to the west of the Western Gulf of Maine Closure Area (Fig. A.35). Three of these ten minute squares (427034, 427044, 427054) correspond with Stellwagen Bank, a prominent bathymetric feature in the western Gulf of Maine. These five ten minute squares account for 10 to 65% of the total Gulf of Maine cod commercial landings in any year, with the contribution generally increasing over time (Fig. A.36). Examination of the annual trends of each of the ten minute squares shows that one ten minute square, 427044, is the predominant ten minute square, accounting for > 45% of the total commercial landings in 2010. In terms of total landings contribution, the 427044 square is unlike any other region in the Gulf of Maine. The second most important ten minute square only contributed 10% to the total landings in a given year (427034) and interestingly is located directly to the west of 427044.

As previously mentioned, a shortcoming of VTR data is that they are self reported and the catch amounts and location are subject mis-reporting. To verify that the apparent trends were not byproducts of VTR misreporting, utilization indices were created using observer and VMS data (using methods outlined in Palmer and Wigley 2009). The utilization trends for ten minute square 427044 estimated from VMS and observer data exhibit similar trends to those from the VTR data for both the trawl and gillnet fleet (Fig. A.37). The observer data indicates slightly more utilization of the area during the 2000 period relative to the VTR data. Caution should be taken to not over interpret the earlier trends in the observer data due to the low number of observer trips in the early part of the time series. Overall, three sources provide evidence of a large increase in the utilization of ten minute square 427044 beginning around 2006 and persisting through 2010. The three data sources provide slightly different perceptions about when the increase began, but all three data sources suggest that by 2011, the level of utilization had dropped off.

The increased utilization of 427044 occurred not only in terms of fraction of annual landings, but also in terms of the number of trips and vessels. Between 1994 and 2010 there was an increase in the number of vessels and fishing trips into this ten minute square while outside of 427044 there was an overall decline in the number of vessels and trips landing Gulf of Maine cod (Fig. A.38). One hypothesis for the utilization trends of 427044 is increased sand lance abundance on Stellwagen Bank from 2006 through 2010 (Richardson et al. 2012).

Landings of Gulf of Maine cod have been dominated by ton class 2 (5-50 tons) and 3 (51-150 tons) vessels. Prior to 1994 ton class 4 (151-500 tons) contributed between 10-25% of the total commercial landings (Fig. A.39). Partly as results of the trip limits that were introduced in the late 1990's it became unprofitable for the larger vessels to target cod, and over the past decade Gulf of Maine cod has been predominately targeted by the smaller ton class 2 day boat vessels. With the implementation of groundfish sectors in May 2010 and the removal of trip limits there has been an increase in the relative landings by ton class 3 and 4 vessels, but they have not returned to the same levels observed in the 1980s through early 1990s. The rolling closures affect the seasonal patterns of ton class landings similar to the patterns observed for gear type and area (Fig. A.40).

Commercial landings of Gulf of Maine cod are classified by four primary market categories: scrod, market, large and unclassified. Other market categories exist such as snapper, whale and steaker, but these are considered variants of the scrod (snapper) and large (whale and steaker) market categories. Market sized fish typically dominate annual landings with scrod sized fish having become less common over time, possibly in response to increasing minimum retention sizes (Fig. A.41). Over the past six years, market cod have accounted for approximately 70% of the total landings (Fig. A.42).

The temporal landing patterns of Gulf of Maine cod has been relatively consistent over the past six years with the exception of 2010 (Fig. A.43). From 2006 through 2009, the fishery was most active from May through March, with very little landings occurring during the months of March and April. Presumably, the low landings during these months were the result of a combination of limited availability of DAS and rolling closures. However, a large increase was observed in April 2010, likely in response to the major changes brought about by Amendment 16. It is possible that vessels that were entering sectors in May 2010 sought to fully utilize any remaining DAS as its currency would be useless under a sector-based system. Seasonal landing patterns in 2011 were similar to those observed from 2006-2009.

Commercial landings: biosampling

Biological sampling (length and age) of Gulf of Maine cod prior to 1982 was poor to non-existent (Table A.13). The sufficiency of biological sampling has always limited age-based assessments of Gulf of Maine cod to the period from 1982 onward. Prior to 1982 it was not uncommon for sampling to be absent across entire market categories, or even for an entire year. From 1982 to 1995 sampling was relatively constant at around approximately 30 to 60 samples per year. When sampling dropped off, it was typically sampling of the smaller (scrod) and larger (large) market categories that suffered. Beginning in 1996 there was a notable increase in overall sampling. The years 1998 to 2000 were exceptions to this trend and were marked by years of low landings, including the lowest level of commercial landings (i.e., 1,407 mt in 1999).

Since 1982 length sampling of the commercial landings has varied from 28.1 to 517.9 mt per 100 lengths (Table A.14). Sampling intensities less than 200 mt per 100 lengths has traditionally been considered an unofficial NAFO/ICNAF standard. Sampling intensity has generally increased over time and has exceeded the standard since 1996. Prior to 1982 length sampling was poor with sampling intensities exceeding 1000 mt per 100 lengths sampled. The sampling density (number of lengths per sample) has ranged from 3 to 345 lengths per sample with an average of 79 lengths per sample (Table A.13). In the earlier periods, while sampling intensity was lower than the current period, the density was generally higher. Part of the trend in declining sampling densities has come about from a relaxation of the requirement to collect the full number of desired lengths per sample. In the past, samplers would frequently not sample unless they could collect a full sample (typically 100 lengths, but has varied by market category over time). Given that age sampling is conducted at the same time as length sampling (but lower density), it is not surprising that the sampling of age structures (otoliths) has followed similar trends as lengths. From 1995 onward the metric tons per 100 ages have been less than 1000 mt with sampling in the last five years on the order of 100 mt per 100 ages (Table A.15).

Prior to SAW 53, Gulf of Maine cod assessments have estimated numbers-at-age by aggregating lengths into 3 cm bins. A complete update of the catch-at-age was conducted for SAW 53 and in doing so, an attempt was made to use 1 cm intervals. This required a greater degree of age imputation to manually fill in gaps in the age length key (ALK). The majority of market/time blocks required no imputation and for those that did, generally the percentage of landings requiring imputation was less than 5% (Table A.16). ALK imputation was primarily restricted to the older ages; given the small numbers of the population in these ages combined with the plus group handling of older ages, the impacts of this imputation are likely negligible.

When estimating the number of fish landed-at-age, every attempt was made to maintain the market category/quarter sampling design. However, when the availability of lengths for a particular market/quarter block was low, either a semiannual or annual time block was used. A criterion of 100 lengths per block was applied to the commercial landings for use as an objective basis to decide when it was appropriate to bin across quarters. In situations where an annual time block was required, the annual LW relationship (Equation 3) was used to convert landings to numbers-at-age. Otherwise, the appropriate seasonal LW equation was applied (Equations 1 and 3). A summary of the amount of binning that was required is presented in Table A.14. Total numbers-at-age are presented in Table A.17. The bootstrapped generated CVs on the landings-at-age estimates are shown in Table A.18. CVs are generally less than 30% for those ages that make up the majority of the landings (Ages 3-6). Prior to 1984, the calculation of bootstrap CVs were not possible due to the inability to identify individual sampling events. There is considerable uncertainty in the estimates of landings-at-age among some of the older ages, particularly beyond age 9 where the average CV begins to exceed 40%. Overall, younger ages have become less prevalent in the commercial landings with increases in the minimum retention size (Fig. A.44). Older fish were less common in the landings back in the late 1990's, likely due to a truncated population age structure. Estimates of weights-at-age from landings in the commercial fishery are presented in Table A.19.

Commercial discards

Gulf of Maine Atlantic cod are primarily discarded in the commercial fishery for three reasons: (1) fish are below the minimum retention size (too small), (2) fish are of poor quality, and (3) high grading of smaller or poor quality fish in situations where a limited amount of fish can be landed (e.g., under trip limits). Discarding of smaller/poor quality fish became increasingly important from 1999 onward when the trip limits became more restrictive. However, the primary reported reason for fish discards has been because the fish were too small (Fig. A.45). With increases to the commercial minimum retention sizes in 2002, discarding due to undersized fish accounts for approximately 70% of total fish discards. This finding is in contrast to the conclusions of the GARM III assessment that "*...presumed that cod of all sizes and ages are discarded without prejudice.*" The GARM III conclusion was based on an examination of the years 1998 to 2000 when trip limits were most restrictive; however, this conclusion does not hold for other periods. This distinction is important to consider when determining how best to estimate the discards-at-age. Given that the majority of discards are of fish that are below minimum retention size, the method used in GARM III to account for discards in the catch-at-age was is not appropriate for the full time series and would lead to an underestimation in the fishing mortality on younger fish and an overestimation in older fish.

Direct sampling of the commercial fishery for discards has been conducted by fisheries observers since 1989. Of the Gulf of Maine cod that were observed to have been discarded by fishery observers, the following gear types account for greater than 99% of the total observed discards: benthic longline, small mesh (<5.5") otter trawl, large mesh (≥ 5.5") otter trawl, shrimp trawl, and large mesh (5.5"-7.99") and extra large mesh (≥ 8.0") sink gillnet gear (Table A.20).

While handline gear does not constitute a large fraction of observed discards, this is partly because this gear type is not frequently observed owing to the small size of these vessels and regulatory exemptions from observer coverage for some handline permit categories. Regardless, it is known that discarding by this gear does occur and it is accounted for in the in-season groundfish monitoring programs. The SAW 53 assessment attempted to estimate discards for this gear type, but the SAW 53 WG concluded that the proportion of observed trips for handline was too low and the imprecision of the discard estimates was too high to give confidence in the derived estimates (Table A.21). This decision was supported by the SAW 55 WG.

The in-season groundfish catch monitoring program makes a distinction between otter trawl gear types, specifically between standard otter trawls and the two modified otter trawl gear types, the Ruhle trawl and the haddock separator trawl. An examination of dealer data and observer data was conducted to determine if the data would support such a distinction when estimating discards for the stock assessment. The data indicate that there are more trips observed that use these modified gear types than report the gear types on the VTR (Table

A.22). This suggests that these gear types are not being accurately reported in the VTR data and no distinction can be made between the modified gear types and the standard otter trawl. However, given that the use of these gear types did not begin until 2009 and the frequency of use is low, this should have negligible impacts on discard estimates.

The total number of observed trawl, gillnet and longline trips ranged from a low of 62 in 1997 to a current high of 2,850 trips (Table A.23). The large increase in the number of observed trips in 2010 was due to the additional contribution of ASMs that were required for the groundfish fishery under Amendment 16. ASM coverage averaged approximately 25% of total groundfish trips whereas regular observer coverage (NEFOP) averaged about 7% (M. Palmer, NEFSC, unpublished data). A comparison of the estimated discard rates between ASM and NEFOP observers (Wigley et al. 2012) showed no statistical difference for the majority of gears and quarters examined. Generally, the Gulf of Maine cod ASM discard rates were statistically indistinguishable from the NEFOP discard rates as evidenced by the fact that the 95% confidence intervals of the difference between estimates include zero (Figs. A.46 and A.47). A comparison of the length frequency distributions showed only small differences in the longline and extra-large mesh gillnet distributions with the large mesh otter trawl and gillnet being nearly identical (Figs. A.48 and A.49). As in the SAW 53 assessment, no distinction has been made between data collected by ASM and NEFOP observers with respect to discard estimation.

The SAW 53 assessment evaluated several different temporal stratification schemes with respect to their impact on total discards and relative precision. Quarterly, semi-annual and annual stratifications were explored. All achieved nearly identical results with respect to total discards, with the annual stratification having slightly lower CVs, though generally all CVs were below the informal target of 30%. Given the lack of sensitivity to choice of temporal stratification, a decision was made to use a semi-annual stratification owing to its ease of use from an operational perspective when estimating discards-at-age. The current assessment has retained this approach.

Final estimates of discards ranged from under 100 mt in 1998 to a high of 2,198 mt in 1990 (Table A.24). While there are exceptions, large-mesh otter trawl is the major source of cod discards. Shrimp trawl discards were an important component of cod discards in the early years, but the required use of a Nordmore grate for the Gulf of Maine shrimp fishery beginning in 1992 was highly effective at reducing cod discards. The resulting CVs on the discard estimates are variable on a gear-specific basis. At the aggregate level, CVs of total discards are typically less than 30% and below 20% over the last four years (Table A.25). As a means of evaluating the accuracy of the discard estimation procedure, a check was conducted to attempt to estimate total landings using the same methodology used to estimate discards. Instead of estimating a d_{cod}/k_{all} ratio, a k_{cod}/k_{all} ratio is estimated. When compared to the total cod landings, the results show close agreement with respect to scale and trends lending support to the accuracy of the discard estimation procedure (Fig. A.50).

Discard mortality

The SAW53 assessment assumed 100% mortality of all discarded fish. A working group was convened in July 2012 to evaluate the available scientific information on the survival of cod on a gear-by-gear basis (summarized in Palmer 2012a). The working group consisted of scientific experts with experience in field estimation of discard survival and stock assessments as well as both recreational and commercial fishermen and other industry representative. Using a modified Delphi approach the WG developed revised mortality estimates of cod (NEFSC 2012b). The revised estimates ranged from 20-80% depending on gear (Table A.26, Fig. A.51) which are generally consistent with the literature reviewed in Palmer (2012a). However, an accurate quantification of true discard mortality is difficult. Sole reliance on the results of the available literature is likely to bias the discard estimates low both because of the largely unaccounted impacts of long-term post-release mortality as well as unobserved escapement mortality. The discards incorporated into stock assessments only account for the observed discards brought on deck. There is some additional and un-quantified mortality associated with fish that escape the capture process. While this fraction is likely small, it is an additional component that if not considered will result in negatively biased estimates of discard mortality (ICES 2005). Additional research is needed to better quantify both the true mortality of fish discarded at sea as well as quantify the magnitude of unobserved mortality in the Gulf of Maine cod fisheries.

Given that the otter trawl and gillnet gear are the dominant gear types with respect to commercial Gulf of Maine cod discards, the revised mortality estimates had only a moderate impact on the total estimates of commercial discards (Fig. A.52).

Commercial discards: biosampling

Observers collect length and age information from the discarded fraction of the catch (as well as on the retained catch); however, only length samples are currently available. ALKs were created using both commercial landings and NEFSC survey ALK corresponding to the appropriate season (spring/fall). Length sampling extends back to 1989 and has generally been quite good with sampling intensities for most years less than 100 mt of discards per 100 lengths (Table A.27). The length distributions by gear are shown in Figure A.53 on an aggregate basis and by year in Figure A.54. Increases in the minimum fish size as well as the impacts of trip limits leading to the discarding of larger sized fish are evident in the time series plots. Generally, shrimp trawl captures the smallest fish with the sink gillnet gear having a much broader distribution of lengths including a large proportion of lengths in excess of the minimum size. The reasoning for the expanded length distribution in the gillnet fishery is largely due to the prevalence of poor quality discards in this fishery (e.g., damage due to seals, dogfish or sand fleas that occurs during the gear soak).

When estimating discards at length, attempts were made to maintain the separate semi-annual estimates so that the most appropriate seasonal LW equation could be applied. For some years and gear types this was not possible owing to limited sampling. A criterion of 50 lengths per block was applied to the commercial landings to provide an objective basis to decide when it was appropriate to bin across semesters and or gear types. Binning across gear types was only done between the two gillnet gears owing to the similarities of their length frequency distributions.

Commercial discard hindcasting: pre-1989

Direct observations of discards by fishery observers only exist from 1989 to present. The model formulations used in past assessments have started in 1982 owing to the availability of information on the age composition of commercial landings. Prior to the SAW 53 assessment, no attempt was made to hindcast discards back to 1982. The SAW 53 assessment applied a survey filter method described in Palmer et al. (2008) and previously applied to groundfish stocks in the Northeast Region (e.g., Mayo et al. 1992, O'Brien and Esteves 2001) to extend discard estimates back to 1982. Discards were only hindcasted for the three primary discard gear types during this period: large mesh otter trawl, shrimp trawl and large mesh sink gillnet. This same approach has been used in the current assessment.

The survey filter method requires information on survey numbers at length (N_i), estimates of gear selectivity at length (m_i), a scaling factor (q) and an estimate of total fishery effort (f). Assuming these are available, discard-at-length can be estimated using the following equations:

If:

(6.a) $C_i/f = q \bullet (N_i \bullet m_i)$, then
(6.b) $C_i = (q \bullet f) \bullet (N_i \bullet m_i)$ as above.

If :

(6.c) $K_i = C_i \bullet s_i$, and
(6.d) $D_i = C_i \bullet (1\text{-}s_i)$, then
(6.e) $D_i = (q \bullet f) \bullet (N_i \bullet m_i) \bullet (1\text{-}s_i)$, and
(6.f) $D_i /f = q \bullet [N_i \bullet m_i \bullet (1\text{-}s_i)]$

where:
C_i is the catch retained by a given commercial mesh at length i,
N_i is the abundance of fish in the survey at length i,
m_i is the proportion of the available population retained by a given mesh at length i,
s_i is the proportion of the retained catch kept at length i,
K_i is the kept portion of the catch at length i, and
D_i is the discarded portion of the catch at length i.
f is some estimate of total fishing effort.

If it is assumed that the fish discarded pre-1989 were all less than the minimum size, the above equation can be simplified by setting s_i to 0. This assumption is likely valid for large mesh otter trawl and shrimp trawl, but may not hold for large mesh sink gillnet gear (Fig. A.55). The impacts of this assumption on the estimation of proportion at age is evaluated later. Using a set of years when management was similar to the hindcast years, gear selectivity at length (m_i), and the appropriate scaling factor (q) can be estimated and the accuracy of the overall method can be evaluated. The years 1989 to 1993 were used for method development and evaluation of trawl and gillnet gear and the years 1989 to 1991 for shrimp trawl due to major changes in the shrimp trawl discard patterns that occurred in 1992 (i.e., Nordmore grate).

Using Pope's (1975) 'alternate tow' approach, the ratios of observed proportion-at-length discarded from the fishery to the proportion-at-length present in the survey are generated (e.g., Fig. A.56). Equation 7 (Wileman et al. 1996) is then fit to the aggregate ratios (across all years) to generate selectivity ogives (Fig. A.57). The fits to the shrimp trawl were poor, and given the small size distribution of cod discarded in the shrimp trawl fishery, an assumption was made that the selectivity of the shrimp trawl was identical to that of the NEFSC bottom trawl survey. The mesh sizes of the shrimp fishery during this period (1.75"/4.45 cm) were not all together dissimilar from those of the survey gear (11.5 cm codend with a 1.27 cm liner). Comparison of the proportions at length between the survey-filter method and the direct observations recorded by observers shows reasonably close agreement in the length distributions across years for large mesh otter trawl and shrimp trawl gears (Figs. A.58 and A.59). There was less agreement among the length frequency distributions for sink gillnet gear, with only two of the five years showing close agreement (Fig. A.60). Conversion of the number-at-length to numbers-at-age using a combined spring and fall NEFSC survey ALK showed even closer agreement between the survey-filter approach and the direct estimates (Fig. A.61 – A.63). This suggests that while the assumptions of the survey filter method may not accurately reflect the length distribution of gillnet discards, the overall impacts on the age distribution are mitigated.

(7) $$r(l) = \left[\frac{\exp\,(a+bl)}{1+\exp\,(a+bl)}\right]$$

By regressing the ratio of observed discards-at-length to the total fishing effort (K_{all} was used similar to the contemporary discard estimates) on the ratio of selectivity-adjusted survey numbers-at-length, the gear-specific scaling factor (q) can be estimated as the slope of the regression line (Equation 6.f, Fig. A.64). In performing these regressions, it was noted that the relationship of the two ratios was different in 1990 relative to other years. It's possible that this reflects some effects of the 1987 year class moving into the fishery; the 1987 year class was the largest year class observed during the SAW 53 assessment time series (NEFSC 2012a).

Total discards estimated using the survey filter approach reflected the relative trends and scales from the direct estimates (Table A.28). The large mesh gillnet estimates were underestimated relative to the direct estimates, possibly due to the assumption of smaller fish in the survey filter method. In 1990 the survey filter underestimated across all gear types, possibly due to poor fit of q in that year as described above.

The SAW 53 WG considered an alternative metric to the survey-filter hindcast: use of an average of the d_{cod}/k_{all} ratio from years 1989-1993 and raise it by the annual K_{all} in years 1982-1988. The SAW 53 WG discussed whether the average d_{cod}/k_{all} ratio could be biased from including the 1990 value in the estimate, which may have been much higher owing to the anomalously large 1987 year class. As an intermediate approach, the WG recommended a third calculation of hindcasted discards using the average d_{cod}/k_{all} ratio for years 1989 to 1993, *excluding 1990* (Fig. A.65). The SAW 53 WG discussed the appropriateness of hindcasting, and whether assuming that discards are zero is better than making assumptions to derive estimated amounts. Ultimately, the SAW 53 WG concluded that the true discards are likely between zero and the d_{cod}/k_{all} ratio estimates that included the 1990 value (which provides a likely upper bound). The final approach applied the average d_{cod}/k_{all} ratio for years 1989 to 1993, *excluding 1990* as the basis for the amount of hindcasted annual discards with the proportion at age determined using the survey filter method. These estimates have been retained in the current assessment. Commercial discards-at-age and weights-at-age are presented in Tables A.29 and A.30 respectively. Figure A.66 shows the impact of the revised discard mortality estimates on estimates of total discards in terms of numbers. Bubble plots of commercial discards-at-age over time are shown in Fig. A.67.

Recreational landings

There is a large recreational fishery for cod in the Gulf of Maine that, over the last decade, has accounted for approximately 20-31% of the total catch. Previous assessments have used data collected under the Marine Recreational Fisheries Statistical Survey (MRFSS). Beginning with this current assessment MRFSS data have been re-estimated using revised methodologies consistent with the new Marine Recreational Information Program (MRIP) which has replaced the MRFSS program (NMFS 2012). Since the existing data were collected under the MRFSS program, they will be referred to as MRFSS data. The conversion of MRFSS data to MRIP estimates is described later. The MRFSS data collection program began in 1979, though estimates of recreationally caught cod are not available until 1981. Recreational catch data are divided into three components: directly observed landings (A), unobserved landings (B1), and unobserved discards (B2). Recreational catch is partitioned into Gulf of Maine and Georges Bank stocks using annual site register lists; catches attributed to intercept/interview sites in Maine and New Hampshire as well as Massachusetts landings from Essex, Suffolk, and Plymouth counties are allocated to the Gulf of Maine stock. Landings from Barnstable County (Massachusetts) are split such that intercept sites bordering Cape Cod Bay are allocated to the Gulf of Maine stock and those on the east and south side of Cape Cod are allocated to the Georges Bank stock.

While MRFSS/MRIP is the source for official recreational catch estimates, VTRs provide a useful source for understanding some of the finer spatial and temporal trends that cannot be easily determined from the MRFSS data. They also help inform the validity of the MRFSS sampling scheme and treatment of data. VTR data are only available for the federally permitted party (head boats) and charter modes. Early in the time series party vessels were the predominate source of VTR-reported recreational catch, though charter boat landings have increased over the last five years (Fig. A.68). VTR data do not cover the private recreational fleet or party/charter vessels operating only within state waters. Federally permitted recreational vessels only represent from 14 to 69% of the total recreational harvest in a given year (Table A.31), thus VTR-based estimates will underestimate the total recreational landings (Fig. A.69). The MRFSS program did not sample the New England region in Wave 1 (January/February); however, VTR data suggest that historically, very low recreational activity occurs in these months (Table A.32). Since May 1, 2006 the recreational fishery has been prohibited from possessing cod in the Gulf of Maine between November 1st and March 31st. This prohibition was extended to April 15th in 2009. MRFSS-based estimates of total catch by sampling wave show highly variable temporal patterns, but are generally consistent with VTR data, with waves 2-5 having the highest proportion of total annual catch (Table A.33). Based on the VTRs, there are virtually no landings of Gulf of Maine cod in ports south of Massachusetts (Table A.34). This finding supports the existing allocation scheme based on the site register lists that is used to assign MRFSS recreational catch to the Gulf of Maine and Georges Bank stock components.

Unlike the commercial trawl fishery the recreational fishery has always been relatively concentrated with Gini indices ranging from 0.81-0.92 (Fig. A.70). There have been no large scale changes in the center of recreational effort over time (Fig. A.71). The majority of VTR-reported recreational landings come almost exclusively from statistical areas 513 – 515 (Table A.35), with most recreational activity located to the west of 70° W (Fig. A.72). The recreational fleet does not to utilize 427044 to the same extent as the commercial fleet (Fig. A.73). While the charter boat fleet does have two notable periods of high utilization of this area (1998-2000 and 2007-2010) the relative use is much less than that of the commercial fleet (Fig. A.74).

The MRFSS data collection program is a numbers-based survey and conversion of MRFSS estimates to removals in terms of total biomass can be accomplished in several ways. Total weight estimates typically provided by the MRFSS program convert numbers to weight using the average sampling weights by state and semester. In the earlier time periods, sampling was poor such that average MRFSS weights did not exist for all cells. This can lead to an underestimation of removals in terms of average weight (Method 1). Imputing the missing cells using the averages from other cells within the same year addresses the issue of missing cells (Method 2). The quality of the MRFSS weight sampling is unknown, though it is generally perceived that the quality of the length information is more reliable. Length sampling of recreational landings has improved over time, though the sampling intensity is not as good as that of the commercial fishery (Table A.36). An alternative method is to use the annual length frequency distributions (Figs. A.75 and A.76) to generate numbers at length and then apply the annual LW equation to estimate total removals in terms of weight (Method 3). Because the majority of recreational catch occurs mid-way between the spring and fall NEFSC surveys, it was not appropriate to partition out catch into spring and fall components. Methods 2 and 3 achieve similar results in terms of total landings, Method 1 tends to underestimate total removals early in the time series when sampling was sparse (NEFSC 2012a). Consistent with SAW 53, method 3 has been used to report out total recreational catch in terms of biomass, though these estimates are not used in the stock assessment model.

The numbers-based estimates of recreational landings were converted to numbers-at-age using ALKs borrowed from the NEFSC survey which include age information collected from the inshore strata. The inclusion of the inshore strata provided a better spatial overlap with the recreational fishery compared to the use of just the offshore strata (Fig. A.72). Recreational landings-at-age show similar trends with respect to the impacts of increasing minimum retention sizes (Fig. A.77). Like the commercial landings, older ages are absent from the recreational landings throughout much of the 1990s.

Recreational discards

With increases in the minimum recreational retention sizes, the contribution of recreational discards to total recreational catch has been increasing over time (Fig. A.18). Prior to the SAW 53 assessment, recreational discards were reported, but they were not included in the catch-at-age used in the assessment models. The primary reason for the exclusion was that historically, there had been no length sampling of recreational discards, and thus no information to convert the total recreational discard estimates (B2 catch) to estimates of discards-at-age. The largest fraction of discards is attributed to the party/charter mode in areas that are greater than 3 miles from shore and the private/rental mode, which has seen an increasing trend in the fraction taken more than 3 miles from shore (Table A.37). Beginning in 2005 direct sampling of cod discards from party boats began in the Gulf of Maine (i9 sampling; Table A.38). Sampling intensities have averaged approximately 200 mt of discards per 100 lengths sampled which is slightly higher relative to the length sampling of recreational landings during the same period.

Because of the increasing importance of recreational discards over time, the SAW 53 assessment attempted a hindcast of recreational discards using the available length frequency information and a variant of the survey filter method used to hindcast commercial discards.

Unlike commercial discards, estimates on the magnitude of recreational discards in terms of total numbers were already available from the MRFSS data. The survey filter method was needed only to construct the length frequency distribution of the recreational discard catch back in time. Similar to commercial discards, the assumption was made that all discarding was done due to minimum retention sizes. This assumption appears to be valid for the recreational fishery, with almost no discarding of legal-sized fish occurring in the 2005 – 2010 period (Fig. A.78). Using the alternate-tow approach used for commercial discards, a gear selectivity ogive was constructed (Fig. A.79). Comparing the survey-filter length frequency distributions to the observed length frequency distributions showed close agreement (Fig. A.80). Applying the survey filter method back to 1981 (start of the length sampling of recreational landings) yielded the length distributions shown in Fig. A.81. The same NEFSC survey ALKs applied to the recreational landing was used for the recreational discards resulting in the discard-at-age patterns shown in Figure A.82. As with commercial discards, the SAW 53 assessment assumed 100% mortality of all recreationally discarded fish. The revised estimate of 30% mortality was applied the recreational discards for the current assessment.

Conversion of MRFSS data using MRIP methodologies

In 2012 NMFS released revised estimate of recreational catch extending back to 2004. The revised estimates were based on the application of the MRIP sampling design to the existing MRFSS data. For Gulf of Maine cod, the revised MRIP estimates ranged from 48.4-98.1% of the MRFSS landings estimates and 52.5-101% of the MRFSS discard estimates (Table A.39). A working group convened in March 2012 recommended applying a ratio estimator to MRFSS data collected pre-2004 to convert the old data into scales consistent with the revised MRIP estimates. The WG concluded that the ratio estimator be based on the "ratio of means" (across all comparison years included) rather than based on the "mean of ratios" for individual years (NMFS 2012). Consistent with the recommendations of the WG, that approach has been employed in the current assessment yielding a ratio estimator of 0.742 for AB1 catch and 0.756 for B2 catch (Table A.39).

Total recreational catch has been re-estimated since SAW 53 due to minor updates to the MRFSS data and to accommodate the MRIP re-estimation. The minor updates to the MRFSS data resulted in differences generally < 1%, but some larger differences were present in the more recent year, most notably in the estimates of B2 catch (Table A.40). Conversion of the MRFSS estimates to MRIP-based estimates resulted in differences ranging from 1-50% for AB1 catch and -4-44% for B2 catch (Table A.41).

A summary of recreational catch from 1981 to 2010 is presented in Table A.42. Recreational catch has ranged between 0.3 and 4.1 thousand mt. Because of the method used to apportion MRFSS/MRIP cod estimates to stock areas, there are no direct estimates of precision available for recreational catches; however, the published estimates of percent standard error (PSE) provide some gauge as to the relative precision of the recreational catch estimates (Table A.43). Overall the general precision of these estimates is about equal to the commercial discards. Total cumulative recreational landings-at-age and landing weights-at-age are presented in Tables A.44 and A.45. Recreational discards-at-age and discard weights-at-age are presented in Table A.46 and A.47.

Total catch-at-age and mean weight-at-age

Estimates of total catch-at-age were determined by summing the numbers-at-age across all of the catch components: commercial landings, commercial discards, recreational landings and recreational discards (Table A.48). The age structure of fishery catch was truncated in the early 1990s relative to that observed in the 1980s. The truncation persisted through 2000 with age 9 and older fish beginning to reappear in the fishery in greater numbers beginning in 2001. These older age classes persisted through 2007 but have become less common in the fishery catches over the most recent four years. Mean catch weights-at-age were estimated by using a numbers weighted average of the individual catch component's mean weights-at-age (Table A.49). There is evidence of declines in the mean weights-at-age for fish older than age 5 over the last decade (Fig. A.83).

Estimation of January 1/spawning stock weights

Sampling of older age fish in the trawl surveys has historically been low, and use of survey-based weights-at-age to estimate January 1 and spawning stock weights for use as model inputs would require extensive imputation. For this reason, catch weights-at-age were used to estimate January 1 and spawning stock weights. Prior to estimation of stock/spawning stock weights, minor imputation of the catch weights at-age were required to fill in gaps in the older age classes (primarily in the age 9+ group). An examination of possible approaches (e.g., moving averages or time series averages) showed that imputation using a 5-year centered moving average would be most appropriate.

January 1 and spawning stock weights were estimated from catch weights using a method described in Rivard (1980, 1982). March 1 is the assumed spawning event in the base model. Given that there is little somatic growth between January 1 and the assumed start of the major spawning period (April 1; Fig. A.10), spawning stock weights were set equal to January 1 weights-at-age. The Rivard method adjusts the catch mean weights-at-age, which are generally presumed to represent mid-year weights, back to January 1. Mean weights at the beginning of the year for a given age class are calculated as the geometric mean of the weight in the same year and of the same cohort in the previous year. No adjustments are made for the plus group calculation. Calculations for the initial and final years and ages are described in Rivard (1980, 1982). January 1/spawning stock weights are shown in Table A.50.

Brooks et al. (2012) evaluated the sufficiency of applying Rivard-adjusted catch weights as a proxy for January 1/spawning stock weights. The analyses found the Rivard-adjusted age-specific catch weights to have similar trends and scale compared to NEFSC spring survey weights but had far less variability than survey weights and were not subject to the large number of missing ages and years of observation.

TOR A.2. Present the survey data and calibration information being used in the assessment; investigate the utility of commercial or recreational LPUE as a measure of relative abundance

There are three primary fishery independent surveys that operate bi-annually in the Gulf of Maine: the NEFSC bottom trawl survey, Massachusetts Department of Marine Fisheries (MADMF) bottom trawl survey and the Maine-New Hampshire (ME/NH) inshore groundfish survey. All three surveys operate in both the spring and fall with the seasonal timing differing slightly between surveys. The NEFSC survey occurs the earliest of the three spring surveys with MADMF and ME/NH having similar timing (Fig. A.84). Conversely, the MADMF survey occurs first in the fall with the NEFSC and ME/NH survey having similar timing.

NEFSC bottom trawl survey

The NEFSC spring and fall bottom trawl surveys began in 1968 and 1963 respectively, providing the longest regional time series of fishery independent information. All previous Gulf of Maine cod assessments used only the offshore survey strata (Fig. A.85). The current approach to generating NEFSC indices ignores the inshore strata (Figs. A.86 and A.87) because a) historically they are not consistently sampled (Figs. A.88 and A.89); and b) the Massachusetts Department of Marine Fisheries (MADMF) survey covers the inshore areas and this survey has traditionally been included in the Gulf of Maine cod assessments. The impacts of including the inshore survey strata in the NEFSC survey indices were examined by both the SAW 53 and SAW 55 WGs. The overall trend in the aggregate abundance (numbers) and biomass indices were similar between the offshore-only indices and the combined inshore-offshore indices (Fig. A.90). There were several years in which the spring survey indices were noticeably higher due to inclusion of the inshore survey strata, but the general trends were similar suggesting that inclusion of the inshore variability increased the between year variability of the survey. The observed increases were primarily due to increases in age 0-2 fish with minimal impact on the age-specific indices of older age classes (Figs. A.91 and A.92). Due to the inconsistent sampling and minimal impact on the index trends, the SAW 55 WG supported the conclusions of the SAW 53 WG to exclude the inshore survey strata from the NEFSC Gulf of Maine cod survey index.

A frequent criticism of the NEFSC bottom trawl survey is that it does not cover the same areas where the commercial and recreational fisheries catch cod, and thus ‘misses’ much of the cod that exists in the Gulf of Maine. A comparison of the NEFSC spring and fall survey catches to commercial (total observed cod catches by ten minute square) and recreational activity (total number of trips catching cod by ten minute square) show close agreement between the location of survey and fishery catches (Fig. A.93).

The NEFSC bottom trawl survey has utilized three different vessels and three different door configurations throughout the time series of the survey (Table A.51). In an effort to maintain a consistent survey time series, survey indices are converted to ‘Albatross IV/Polyvalent door’ equivalents using several different conversion factors (Table A.52). The largest change in the survey time series occurred in 2009 when the *RV* Albatross IV was decommissioned and replaced by the *FSV* Henry B. Bigelow. This resulted in changes not only to the vessel and doors, but also to the overall trawl gear as well as the survey protocols (summarized in Table A.53). Calibration experiments to estimate survey differences were conducted in the spring and fall of 2008 (Brown 2009). The results of those experiments were peer reviewed by a panel of external (non-NMFS) experts and summarized in Miller et al. (2010). These results provide annual calibration coefficients both in terms of abundance (numbers) and biomass (weight). Further work by Brooks et al. (2010) developed length-specific abundance calibration coefficients for Atlantic cod. This method uses a segmented regression model where a constant conversion factor is applied to fish ≤ 20 cm and ≥ 54 cm, and a constantly decreasing linear regression is fit to fish between 20 and 54 cm (Fig. A.94). A comparison of the converted and unconverted spring and fall survey indices is presented in Figure A.95. It should be noted that while considerable focus has been placed on the Albatross/Bigelow calibration, the effects of door calibration are generally larger than those of the *Albatross/Bigelow* calibration. Attempts to estimate *Albatross/Bigelow* calibration coefficients directly within an assessment model yielded similar coefficients as those estimated by Brooks et al. (2010), thus leading the SAW 55 WG to support the continued use of the existing *Albatross/Bigelow* calibrations coefficients (see Appendix A.5 for a description of the estimation of *Albatross/Bigelow* calibration coefficients within a statistical catch-at-age model).

During the SAW 53 fishing industry meeting (August 16, 2011 in Gloucester, MA), industry expressed concern with the 24-hour operation of the survey. There was a sense that there were differences in the relative catchability of cod between daytime and nighttime hours. These observations are supported in the scientific literature (e.g., Beamish 1966), though the nature of off bottom movements is highly variable. An analysis was pursued as to whether there were appreciable differences in survey catchability between daytime and nighttime tows. The results showed that generally catchability was slightly higher in the daytime tows. However, the trends between day and night tows were similar, and in most years the day/night survey indices fell within the 80% CI of the aggregate index (Fig. A.96). Because of the similarity in the trends it is appropriate to use both day and night tows to calculate indices for the assessment. Splitting by day and night would result in reduced tows and lost strata (Table A.54), which would increase the likelihood that survey indices could be influenced by a single large tow in any year.

Aggregate survey indices over time are presented in Table A.55 and the corresponding CVs are presented in Table A.56. It is worth noting that some of the highest survey indices are associated with relatively high CVs/confidence intervals. This is an important consideration in determining how to interpret survey indices; i.e., do increases in survey indices represent true increases in the relative size of the resource, or are the indices being driven by a few influential tows that are not indicative of the resource abundance/biomass? Generally, survey indices were higher in the earlier time periods, reaching lows in the mid-1990s. During the early to mid-2000s there was a slight increase in survey indices relative to the mid-1990, but subsequently survey indices have declined and are at, or near, time series lows (Figs. A.97 and A.98). There is reasonably good agreement between the intra-season survey indices (spring numbers vs. biomass) and inter-season indices (e.g., spring biomass vs. fall biomass), but poor agreement between inter-season and inter-index comparisons (e.g., spring biomass vs. fall numbers; Fig. A.99).

Indices-at-age for both the spring and fall surveys are presented in Tables A.57-A.60 and Figures A.100 and A.101. It should be noted that age information for the spring and fall survey does not begin until 1970. Similar to the trends observed in the commercial and recreational fisheries, there were few older fish present in the survey catch-at-age throughout most of the 1990s. Within the spring survey there is strong cohort tracking out to age 6 (Fig. A.102) and out to age 9 in the fall survey (Fig. A.103).

Plots of the spring and fall survey catches (number/tow) show a general decline in the overall abundance and spatial extent of the resource from the 1970s through the 1990s (Fig. A.104). There is an increase in the 2000-2010 period, but the increase appears to be restricted to the western Gulf of Maine. Moderate survey catches occurred along the coast of Maine in the 1970s, but these have not been observed in the past twenty years. To further address the aspect of spatial aggregation, a time series of Gini indices were calculated following the techniques outlined in Wigley (1996). These results support the patterns shown in distribution plots and suggest an overall concentration of the resource over the last twenty years (Fig. A.105). The number of stations and strata where cod have been observed in the Gulf of Maine has generally decreased over time as the resource has become increasingly concentrated in the western Gulf of Maine (Figs. A.106 and A.107). Not surprisingly, the largest declines have been observed in those strata (01380-01400) off the coast of eastern Maine. These patterns are similar to the spatial aggregation that has occurred in the commercial fishery.

NEFSC model-based survey indices

The SAW 55 WG considered a generalized linear model (GLM) of the survey data, in which the factors considered included cruise (proxy for year), stratum, temperature, depth and time of day (Terceiro 2012). This model highlighted the highly contagious and over dispersed nature of the data, which called for use of a negative binomial distribution (one of many explored) in the fitting of the model. The best fit to the data was achieved with a model using cruise, stratum and time of day as factors. Overall, the temporal trends estimated by the model were similar to those of the design-based estimators described above.
The WG considered that use of the GLM estimates in the assessment model would result in an underestimation of the variability in the survey indices as the GLM is effectively acting as a smoothing function of each time series. The WG therefore recommended that the design-based survey indices be used in the assessment models. However, it noted that the CVs from the GLM could be compared to those generated during the stage two iterative re-weighting process as the latter incorporate both observation and process error, similar to what the GLM produces.

MADMF bottom trawl survey

The MADMF has conducted research bottom trawl surveys during the spring and fall since 1978, though age information is not available until 1982. A complete description of the MADMF trawl survey is provided in King et al. (2010). The survey strata included in the MADMF survey primarily includes the nearshore habitat within Massachusetts state waters in the southwestern Gulf of Maine (Fig. A.108). Because the MADMF surveys are conducted in relatively shallow waters and are limited in their spatial extent, they do not provide an index of the total stock resource, but may provide some information on the younger age classes inhabiting the nearshore environment (i.e., a recruitment index). Additionally, given the limited spatial extent, the MADMF survey may be more susceptible to resource availability due to timing of onshore/offshore seasonal movements (i.e., process error).

The abundance indices of these surveys exhibit the same overall trends as the NEFSC surveys, with the spring index currently at an all-time low (Table A.61 and Fig. A.109). The corresponding CVs for the aggregate indices are presented in Table A.62. Fall abundance indices are near time series lows, but the biomass index is currently above average (Fig. A.110). There is moderate agreement between the intra-season survey indices (spring numbers vs. biomass), but poor agreement among other index comparisons (Fig. A.111). Similar to what has been observed in the NEFSC survey, the number of stations and stratum in which cod have been observed has declined since highs early in the time series (Figs. A.112 and A.113).

In constructing the proportions at age in Massachusetts inshore survey, it was noted that a

number of length groups in the ALK were missing age information. While there was a modest (20 days) difference in the timing of the MADMF and the NEFSC spring survey, an attempt was made to augment the ALK of the inshore survey using aging data collected during the sampling of the inshore strata of the NEFSC survey consistent with the approach used for the SAW 53 assessment (NEFSC 2012a). The number of otoliths sampled in both surveys was about the same. After analysis conducted during the SAW 55 WG meeting, it was agreed that such augmentation was not necessary, with the ALK before and after this treatment being very similar. It was therefore recommended that the aging data in the Massachusetts inshore survey not be augmented with the NEFSC ageing data. MADMF indices at-age are presented in Tables A.63-66 and Figs. A.114 and 115.
The SAW 55 WG considered diagnostics of the Massachusetts spring and fall surveys, specifically how well the abundance of year-classes was being tracked by each survey. In general, year-class tracking in the spring survey was reasonable between ages 1-6 (Fig. A.116) but only reasonable between ages 0-1 in the fall survey (Fig. A.117). The WG discussed reasons why this might be the case, including seasonal movements of cod between the inshore and offshore. Based upon this analysis, the WG recommended that the MADMF spring, but not fall, survey time series be used in the SAW 55 assessment model of GOM cod consistent with the SAW 53 assessment.

ME/NH inshore groundfish trawl survey

The ME/NH inshore groundfish trawl survey has not been included in previous assessments, though previous assessment reviews have encouraged a thorough examination of the information available from this survey (e.g., NEFSC 2002b, NEFSC 2012a). The ME/NH survey began in fall 2000 and has been conducted in the spring and fall annually in the nearshore waters of the Gulf of Maine (Fig. A.118; Sherman et al. 2005). The ten year time series of abundance and biomass indices do not exhibit strong interannual fluctuations (Fig. A.118). Overall, there is moderate agreement between seasonal abundance and biomass indices, but poor agreement between spring and fall similar to the patterns observed in the MADMF survey (Fig. A.120). The SAW 55 WG discussed the possibility that seasonal north/south movements of cod along the Maine coast may be partly responsible for the lack of cohesion between the spring and fall survey, though no definitive information was available to evaluate these hypotheses. Similar to the NEFSC and MADMF surveys there has been a general decline in the percent of positive tows over the last decade in both the spring and fall surveys (Fig. A.121), though the fall survey has exhibited small increases the number of positive tows over the last three years.

The spatial distribution of catches seems consistent with the patterns observed in the NEFSC surveys with the highest catches occurring in the southwestern Gulf of Maine off the coasts of New Hampshire (Fig. A.122). There are some indications of high catches along the eastern Maine coast and could be indicative of spawning aggregations. The length frequency distributions suggests that the survey captures primarily age 0 through 2 fish (<40 cm; Fig. A.123). The size frequencies seem to suggest that ME/NH captures the same age classes observed in MADMF survey.

The biggest impediment to inclusion of this survey is the absence of age information. Progress has been made on the implementation and analysis of the data collected since the start of the survey; specifically, spring and fall 2005 and spring 2011 ageing has been completed and spring 2006 is in progress (S. Sherman, ME DMR, pers. comm.). The WG recommended that the complete ageing of the entire time series of collected otoliths be considered a high priority. The WG concluded that while this survey may be valuable in the longer term, it is both too short and lacking the aging data to be used in the SAW 55 assessment.

Following up on the research recommendations of the SAW 53 WG, the SAW 55 WG evaluated available reproductive information to determine whether any of the fish sampled in this survey were mature and whether there was evidence to suggest the presence of spawning aggregations along the Maine coast. Since 2004 over 100 maturity samples have been taken annually in the ME/NH survey (Table A.67). Trends in the length-at-50% (L_{50}) maturity were evaluated which did not indicate large shifts over the short times series (Fig. A.124), but did show that the fish captured in the ME/NH tend to mature at a smaller size relative to those captured in the NEFSC survey. The L_{50} for cod captured in the ME/NH survey was 31.8 cm and 32.5 cm for females and males respectively (Fig. A.125) compared to 40.8 and 42.9 cm in the NEFSC spring survey. The cause of the discrepancy in the maturity schedule is not known, but similar patterns have been observed in other species such as winter flounder (S. Sherman, ME DMR, pers. comm.). Plots of fish greater than 25 cm show the possibly of spawning aggregations at both the southern and northern extents of the survey (Fig. A.126). Examination of maturity samples by region indicate a higher proportion of mature fish in the northern regions (Table A.68). It’s not clear whether these patterns are confounded by north/south differences in the maturity schedule (i.e., fish at the southern extents mature at a larger size).

Inter-survey comparisons

Comparisons of inter-survey indices show moderate levels of agreement between NEFSC and MADMF surveys within seasons, but generally poor agreement across seasons (Figs. A.127 and A.128). Neither the NEFSC and MADMF surveys showed good agreement with the ME/NH survey, but this may be partly related to the short time series of ME/NH survey and general lack of contrast.

Catch per unit effort (CPUE) indices

Trends in commercial landings per unit effort (LPUE) had been used in Gulf of Maine cod stock assessments prior to SAW 53. The 1982-1993 age composition of the landings corresponding to the effort of an otter trawl sub-fleet (summarized in Mayo et al. 1994) had been used to calculate LPUE-at-age indices for ages 2 through 6 (Mayo et al. 2009). The index was never extended beyond 1994 due to major changes occurring in the Gulf of Maine groundfish fishery (Table A.3) including regulatory measure to reduce fishing effort, closed areas, changes in mesh size and trip limits in addition to a switch in the fisheries-dependent data collection system from a landings interview/intercept program to a self reported logbook program. All of these issues affect the comparability of LPUEs estimated from 1994 onward with the earlier time series. Additionally, these same issues would make standardization of a contemporary catch per unit effort (CPUE) index difficult. The SAW 53 WG examined model sensitivity runs to assess the utility of including the Mayo et al. (2009) LPUE index. Model results were insensitive to the index and the SAW 53 WG concluded to remove the index from the SAW 53 assessment.

The apparent disconnect between the increasing catch per unit effort (CPUE) reported by groundfish fishermen and the comparatively limited rebuilding suggested in SAW 53 assessment (NEFSC 2012a) received notable attention following the release of the final assessment results. To address the criticism the NEFSC convened a CPUE WG in August 2012 to review and evaluate the information available on both commercial and recreational catch per unit effort (NEFSC 2012c). The CPUE WG concluded that ideally, LPUE indices should be formally considered and vetted as inputs into the assessment model. If a LPUE index is determined to be a poor index of fish abundance, while it may not be formally included as a model input, the index should be described in the assessment report and explanations put forward describing why the information in the LPUE index may be inconsistent with other assessment tuning indices.

The SAW 55 WG considered a number of analyses in an attempt to develop representative indices of GOM cod fishable biomass based on commercial and recreational LPUE. One analysis updated the LPUE index used by Mayo et al. (1994) through 2011 (Palmer 2012b). This index used year, depth, tonnage class, quarter and statistical unit area as factors in a GLM assuming lognormal error (Fig. A.129, Table A.69). Trends produced by the analysis tracked spawning biomass (SSB) as estimated during the SAW 53 relatively well up until 2006 after which time LPUE increased much faster than SSB. The reasons for this divergence were discussed at length by the WG. A hypothesis considered by the WG is that sand lance abundance, which is a forage species of cod, became abundant in a small region of the western GOM (near Stellwagen Bank) between 2006 and 2010 (Richardson et al. 2012). It was theorized that this resulted in the aggregation of cod in the area and thus elevated commercial catch rates. The incidence of occurrence of sand lance in cod stomachs collected during the spring and fall NEFSC BTS surveys has increased since 2006. These surveys indicate that the Stellwagen Bank area appears to be a forage 'hot spot' for cod feeding on sand lance. The VTR, observer and VMS information from the commercial fishery indicates that fishing effort since the mid-2000s has become highly concentrated in this area as documented previously in this report (Palmer 2012b). A large abundance of cod in a region easily exploitable by the day boat fleet was likely responsible for the increase in CPUE reported by the fishing industry between 2006 and 2010. Interestingly, the two large NEFSC spring survey tows that were identified to have contributed to the large increase in estimated biomass in the GARM III assessment (NEFSC 2012a) both occurred on Stellwagen Bank - one in 2007 and the other in 2008. The same processes that led to the overestimation of biomass in the GARM III assessment were also responsible for the increases in CPUE reported by the fishing industry.

The SAW 55 WG discussed at length the processes that may be influencing the cod distribution in the Gulf of Maine. It appears that two related but separate processes may be underway. Over the longer term, there has been a loss of cod from the central and coastal areas of the Gulf with an apparent concentration of cod in the western area. Additionally, since 2006, there has been further aggregation of cod within the western Gulf into forage hot spots, hypothesized to be driven by sand lance. While it is difficult to prove definitely that these processes are responsible for the observed distribution changes, the evidence is suggestive. Notwithstanding the causes of the observed patterns, cod appear now to be aggregated in a small area of the Gulf, which suggests that the catchability (relationship between LPUE and biomass) has changed over the LPUE time series and has likely increased more recently. Over the longer term, there have a number of regulatory changes (e.g. seasonal closures, trip limits, etc) which call into question the utility of commercial LPUE as an index of GOM cod biomass. Similar issues with commercial catch rate indices have been observed elsewhere (e.g. Harley et al., 2001). Based on these concerns, the WG recommended that the commercial LPUE index not be used in the SAW 55 assessment model. This recommendation is consistent with the findings of the recent NEFSC-sponsored LPUE workshop.

An LPUE index was also developed for the recreational fishery (Wood 2012). A GLM using year, month, area, permit and fishing category as factors was applied to the 1994 – 2011 recreational landings data (Fig. A.129, Table A.70). A number of error structures were explored with a lognormal model ultimately chosen. Contrary to the commercial fishery, recreational fishing has consistently occurred within a restricted region of the western Gulf. As with the commercial fishery, recreational fishing has been impacted by a series of regulations (e.g. seasonal closures, bag limits, etc). The analysis only included landings and was not able to include the release information which has become an increasing component of the catch. Further, the GLM analysis was only able to include party-charter boats. Overall, given concerns comparable to those of the commercial fishery, the WG recommended that the recreational LPUE index not be included in the GOM cod assessment model.

TOR A.3. Summarize the findings of recent workshops on stock structure of cod

A work plan on the topic of Atlantic cod stock structure in the Northeast United States/Scotian Shelf region was recommended by the New England Fishery Management Council's Scientific and Statistical Committee (SSC). The work plan laid out a three-phase process for re-evaluating, and possibly revising, the spatial basis for assessment and management of Atlantic cod. The first phase was to review data (genetic, life history, tagging, etc.) in order to evaluate the “null hypothesis” of the status quo management units.

The NEFSC sponsored a public workshop on cod stock structure, held June 12-14, 2012, facilitated by the Gulf of Maine Research Institute to address Phase I. Invited participants from the fishing and scientific communities presented on a range of topics with opportunities for discussion. The full workshop report is available at http://www.gmri.org/mini/index.asp?ID=52&p=149.

Many of the workshop participants felt that there was compelling evidence that the current management units need to be revised. The Workshop did not reach any conclusions on what the most appropriate management units might be. This will require further data analysis and modeling in order to complete Phase I of the SSC recommended process. The workshop report also identifies gaps in the data and analyses and recommended actions to address them.

The Workshop did not explicitly address and propose the next steps in the process. The Steering Committee recommended that an inclusive but focused Working Group meeting be held involving a small group of Canadian and US scientists to consider the results of the Workshop. This Working Group should be provided the short-term data and analyses identified as missing by the Workshop. Using that information, as well as the conclusions from the Workshop, the Working Group should determine the most appropriate representations of biological stock structure to complete Phase I of the process. The results from this Working Group meeting should be evaluated through an independent peer-review process.

Since the phased review process of cod stock structure that was recommended by the SSC has not been completed, no changes to stock structure were incorporated into this assessment.

TOR A.4. Investigate the evidence for natural mortality rates

Previous assessments of Gulf of Maine cod have assumed a constant, age-invariant rate of instantaneous natural mortality (*M*) of 0.2 (NEFSC 2012a, NEFSC 2008, Mayo et al. 2009). The SAW 55 WG evaluated the sufficiency of this assumption through life history analyses of natural mortality. Hoenig (1983) demonstrated that natural mortality can be estimated as a function of the maximum observed age (t_{max}) in a population (*ibid*; Equation 8). Depending on whether the maximum age observed from the surveys ($t_{max} = 17$) or the maximum age observed in the fishery ($t_{max} = 16$) is used, this approach yields estimates of $M = 0.25$ or 0.26. This approach was further refined by Hewitt and Hoenig (2005; Equation 9), and through the revised approach yields similar results of $M = 0.24$ or 0.26. Because the Gulf of Maine cod stock has been heavily exploited for most of its recent history (post-1970; Figure A.19), and age samples are only available from the 1970s, *M* values in the range of 0.246 to 0.281 estimated from maximum age likely overestimate the true *M*.

An alternative approach relies on the gonadosomatic index (GSI) which used the ratio of gonad weight to somatic weight (Gunderson 1997). The general premise it that *M* is positively correlated with reproductive effort (*ibid*; Equation 10), more specifically, female reproductive effort. Estimates of GSI were not readily available for Gulf of Maine cod; however using a GSI value of 0.117 reported for the adjacent Georges Bank cod (McIntyre and Hutchings 2003) yields and *M* estimate of 0.209. Pauly (1980) first showed that *M* is proportional to the von Bertalanffy growth parameter, *K*. Using a variant of the relationship (Jensen 1996; Equation 11) and an estimate of g=1.598 (Gunderson et al. 2003) provides estimates of $M = 0.165$ or 0.201 depending on whether the *K* value is taken from the growth parameters estimated from the fall or spring surveys respectively. The lack of observed change in condition, as evidenced by a constant LW equation, does not support a hypothesis for a shift in life history parameters.

(8)	$ln(Z) = a + b*ln(t_{max})$
(9)	$M = 4.22/t_{max}$
(10)	$M=1.79*GSI$
(11)	$M=gK$

where:

Z is total mortality,
$a = 1.46$,
$b = -1.01$,
t_{max} is the maximum observed age in a population,
M is natural mortality,
GSI is the gonadosomatic index,
$g = 1.598$ (after Gunderson et al. 2003),
K is the von Bertalanffy growth parameter

From this, the meta-analysis of life history-based estimates the evidence available with respect to Gulf of Maine cod life history parameters suggests that an assumption of $M = 0.2$ is reasonable. It should be noted that maximum age as high as 16 has been observed in the commercial fishery as recent as 2009 which suggests comparable natural mortalities relative

to earlier in the time series (Table A.19). Also examinations of maturity-at-age and condition factor over time show no evidence of strong trends both of which can related to changes in natural mortality.

The method of Lorenzen (1996) was used to provide an aged-based estimate of *M* (Fig. A.130, Table A.71). This method, which is based upon the relationship between body weight and *M* across a wide range of species, was used in SAW 54 to provide age-based estimates of *M* for Southern New England – Mid Atlantic Bight yellowtail flounder (Equation 12). The peer review panel of SAW 54 (O'Boyle et al. 2012) concluded that the application of an inter-species relationship to infer within-species dynamics was an over-interpretation of the method. While *M* no doubt may be age-specific, the pattern estimated from the Lorenzen method may not be appropriate. Recent work performed by Deroba and Shueller (*https://afs.confex.com/afs/2012/webprogram/Paper10183.html*) indicated that using constant or age varying mortality would have similar impacts on the assessment. The SAW 55 WG thus concluded that the parsimonious approach is for the SAW 55 assessment models to use a single *M* for all ages.

$$M_w = M_u W^b \quad (12)$$

where:

M_w = natural mortality associated with fish of weight, W,
Mu = natural mortality at unit weight, (3.69, consistent with Lorenzen ocean ecosystem constant)
W = weight (g),
b = allometric scaling factor (-0.305, consistent with Lorenzen ocean ecosystem constant)

Two working papers considered the predator field of cod in the Gulf of Maine area (Link 2012, Waring 2012). Link (2012) noted that directed piscivory of cod by other fish was not common, with well less than 200 cod in over 550,000 stomachs observed. Similarly, the evidence for cannibalism is weak with only 20 cod found in over 20,000 stomachs. Studies to date suggest that *M* due to fish predation is likely low and is focused on juvenile and smaller size groups (Smith and Link 2010). Waring (2012) considered marine mammals as a potential source of elevated *M* in the Gulf of Maine area. Four species of seals (Harbor, Grey, Harp and Hooded) are found in New England with Harbor and Grey seals being the most numerous. The Harbor seal population, which was about 38,000 individuals in 2001, has been growing at an annual rate 6.6%. The Grey seal herd has increased from tens of animals in the early 1980s to thousands of animals in the late 2000s. Firm estimates on the size of the current herds are not available. Notwithstanding this, the food habit research suggests that cod mortality due to seals is low. Additionally, while seals are known to prey on cod, they are generalist feeders and the importance of cod in the diet of Gulf of Maine grey seals is unknown. There is limited information that suggests that cod represent only a minor component of harbor seal diet along the Maine coast (Wood 2001).

An analysis of tagging data collected during 2003 – 2006 to jointly estimate natural and fishing mortality was undertaken during GARM III (Miller and Tallack 2007). This analysis was updated for SAW 55 (Miller 2012). Contrary to the earlier work, this analysis was not length-based. Estimates of *M* ranged from 0.4 to 0.7 for the Gulf of Maine with Gulf of Maine *M* estimates tending to be lower than Georges Bank estimates. It also provided evidence of significant cod movements between GOM and GB and area 4X on the order of 4.1 to 29.7%. While *M* was relatively high compared to current estimates, *F* was comparatively low, prompting discussion on whether or not it was representative of the

fishery due to local effects. The results were highly sensitive to the assumed return rate of high-reward tags. High-reward return rates on the order of 50% were associated with Gulf of Maine cod *M* estimates of 0.3, with *M* increasing as the high-reward tag rate increased. Model preference (based on log-likelihood function) was for assumptions of near-100% on reporting rates of the high-reward tags. Estimates of fishing mortality, *F*, were inversely related to the *M* response with *F* declining with higher assumptions of high-reward tags reporting rates. Across all ranges total mortality (*Z*) was estimated at approximately 1.0.

Concerns were raised with the tagging conducted in the Cape Cod area, which represented over 50% of the data in the database. The tagging had been conducted employing a wide range of expertise with mostly small cod tagged. This in combination with the warm water in the area may have resulted in higher tag induced mortality than assumed in the model. There were additional concerns with the assumed tag reporting rate (100%) for high reward tags. There is evidence to suggest differential reporting rates among some sectors of the commercial fishery, most notably the reporting rate by gillnet vessels was five times lower than that of trawl vessels (Tallack 2006). It is unknown if these same reporting trends also apply to the high-reward tags. There was also discussion on the age groups of cod represented by the study. GOM cod of 50 cm of about 2.5 – 3 years old, implying that the estimates of *M* are for ages 2.5 – 3 plus with it weighted towards the younger ages.

The SAW 55 WG discussed how best to use these estimates of *M*. It was hesitant to conclude that *M* was in the range of 0.6 – 0.7 and to recommend that these estimates be directly included in the assessment models. Rather, the tagging analysis is another form of modeling that should be considered. The WG discussed the availability of historical tagging to which the current estimates could be compared. It was reported that tagging work conducted in the Gulf of Maine area during the 1970s and 1980s suggested *M* estimates in the order of 0.2 – 0.3 whereas tagging in the 1990s was suggestive of *M* similar to the more recent results. These observations are based upon unpublished work that could not be corroborated at the meeting. Much of the historical work (e.g. Hunt et al. 1999) had been focused on cod movements and did not provide estimates of natural, fishing or total mortality. Further, concerns were raised that there was no obvious mechanism (e.g. predation) that could explain a recent increase in *M*, although it was countered that no mechanism has been identified for the current *M* estimate of 0.2, though this estimate is supported by life history parameters. The SAW 55 WG recommended profiling natural mortality across both the historical and more recent periods of the assessment to inform the discussion as to whether or not there has been a long-term change in *M*. The WG agreed that an option (*M*-ramp) with an *M* change should be considered as an alternate to a base model which would assume no change in *M* (i.e. *M* = 0.2).

Catch-curve analyses

Catch curves were constructed for the aggregate fishery catches (commercial and recreational landings and discards; Fig. A.131) and for the NEFSC spring (Fig. A.132) and fall surveys (Fig. A.133) based on the methods of Robson and Chapman (1961). Catch curves were conducted on a cohort basis rather than an annual basis which removed the confounding effects of differential year class strength on the interpretation of catch curve results. Linear regressions were fit to the log transformed catches of ages 4-8. While ages 4-8 may not precisely match the fully recruited age classes in both the catch and the survey it offers a compromise between full selection and having sufficient ages to fit a reliable regression (i.e., few fish beyond age 8 are regularly observed across the survey time series). The slope of the regressions provides an indication of cohort *Z* which is useful when interpreting the implied total mortality of both tagging models (e.g., Miller 2012) and assessment models. The analyses suggest time series *Z* estimates on the order of 1.0 with the survey estimates being considerably more variable than the catch-based analyses (Fig. A.134). The catch-based *Z* estimates indicate total mortality around 1.0 beginning with the 1979 cohort and increasing above 1.5 with the 1988 and 1989 cohorts before dropping to time series lows near 0.6 with the 1994-1996 cohorts. Current *Z* estimates are estimated at approximately 1.0 for the 2004 cohort which is consistent with the total mortality suggested by the Miller (2012) tagging analysis.

Catch curves can also be useful for making general inferences on the selectivity of both fisheries and surveys. While selectivities can be estimated from the fitting of stock assessment models, it is useful to have model-independent estimates of selectivity that can be used to validate model-based estimates and/or provide some *apriori* understanding of selectivity. A method described in Restrepo et al. (2007) uses the residuals from the log-transformed linear catch curve analysis to infer relative selectivity-at-age. Selectivities are estimated using the ratio of observed to predicted catch proportions and then rescaling the residuals from each curve so that the maximum positive residual equals 1. This analysis was conducted on the catch curves from the total catch and NEFSC spring and fall surveys. The distribution of selectivities-at-age from all cohorts was examined to evaluate the time series distributions of selectivity at age. While this approach masks any changes that may be occurring in the selectivity across time, it is useful for gaining a general understanding of catch and survey selectivities and evaluating whether there is strong evidence for the presence of domed-selectivity (i.e., lower selectivity at older ages). Examination of the residual patterns from total catch (Fig. A.135) and the NEFSC spring (Fig. A.136) and fall surveys (Fig. A.137) do not provide evidence for domed selectivity. The selectivity distributions on the younger ages are consistent with the model-based selectivity from the SAW 53 assessment (NEFSC 2012a) with age at 50% ($A_{50\%}$) selectivity roughly between ages 3 to 3.5 for the total catch, ages 3 to 4 for the NEFSC spring survey and ages 2 to 3 for the NEFSC fall survey.

Additionally, a comparison of proportion of fish age 5 and older caught in the NEFSC surveys relative to the fishery shows a higher ratio of old fish caught by the NEFSC surveys (Tables A.72 and A.73). This in itself does not confirm the presence of flat top survey selectivity in the survey, but does indicate that the surveys may have higher selectivity on the older ages relative to the fishery.

There have been discussions during previous assessment meetings and working group meetings that adult cod may be unavailable to the NEFSC surveys due to the presence of fixed gear (primarily lobster pots) in the inshore areas. However, the ME/NH survey actively works with the lobster industry to have gear removed in advance of the survey and as noted before, this survey is not capturing large cod (Fig. A.123). Decreased selectivity in the fishery may be plausible, particularly if large cod are exploiting closed areas unavailable to the fishery (either permanent or seasonal). However, the SAW 53 WG examined the Massachusetts cod industry-based survey (Hoffman et al. 2006) which sampled in closed areas. The length frequencies from this survey did not indicate the presence of larger cod in the rolling closure areas relative to those captured in the fishery or surveys. Additionally, an analysis of cod tagging data conducted by Hart and Miller (2008) concluded that there was no evidence that larger/older Atlantic cod are subjected to lower fishing mortality in the Gulf of Maine than smaller cod.

TOR A.5. Estimate annual fishing mortality, recruitment and stock biomass

Summary of the SAW 53 assessment model

The SAW 53 Gulf of Maine cod assessment applied the statistical catch-at-age model, ASAP (Age Structured Assessment Program v2.0.20, Legault and Restrepo 1998, Legault 2008), which can be obtained from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). This represented a change from previous stock assessments which historically had been assessed using VPA models. The reasons for selecting the ASAP model included the ability to explore alternative model formulations to counter/lend support to VPA results, additional flexibility to explore starting condition assumptions (e.g., extending the time series beyond 1982), ability to estimate a stock-recruit relationship internal to the model, and the ability to explicitly handle data uncertainty, particularly given the lessons learned from the update of the VPA model with respect to uncertainty in the survey data.

ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption is partially relaxed by allowing for fleet-specific computations and by allowing the selectivity-at-age to change in blocks of years. Weights are input for different components of the objective function which allows for configurations ranging from relatively simple age-structured production models to fully parameterized statistical catch-at-age models. The objective function is the sum of the negative log-likelihood of the fit to various model components. Catch-at-age and survey age composition are modeled assuming a multinomial distribution, while most other model components are assumed to have lognormal error. Specifically, lognormal error is assumed for: total catch in weight by fleet, survey indices, stock recruit relationship, and annual deviations in fishing mortality. Recruitment deviations are also assumed to follow a lognormal distribution, with annual deviations estimated as a bounded vector to force them to sum to zero (this centers the predictions on the expected stock recruit relationship). For more technical details, the reader is referred to the technical manual (Legault 2012a).

The SAW 53 assessment covered the years 1982 to 2010. The choice of the 1982 start year (as opposed to early start years) was chosen because this is the period which as the highest data density. Data are available on the quantity and size composition of the landings and discards, both commercial and recreational. Several survey indices are available (NEFSC and MADMF), each with aggregate indices of abundance and biomass, along with data on age/size composition. Biological information such as growth, maturity and length / weight relationships are also available. Extending the time series before 1982 results in not only loss of information quality, but also introduces additional uncertainty into the assessment. Prior to 1982 there was no information on commercial discards and there was no information on recreational catch prior to 1981. Extending the assessment back in time requires tenuous assumptions about unrecorded historical catches. Any hindcasting of both unrecorded catches and assumptions on the selectivity of the fishery back in time are confounded by the extensive regulatory changes back in time (Table A.3). Alternative start years were examined in the SAW 53 assessment and had negligible impact on the terminal year assessment result (NEFSC 2012a).

An age 9^+ group was utilized in the assessment due to the difficulties encountered when attempting to estimate older ages in the population. Additionally there was evidence of truncation in the population age structure over the most recent three years and the difficulties in precisely estimating fishery selectivities of the older ages in preliminary developmental ASAP runs. The mid-point of the spawning period was assumed to be April 1 (25% through fishing year). Recruitment is modeled as deviations from the geometric mean (steepness fixed at 1.0). During the SAW 53 assessment, unsuccessful attempts were made to fit a Beverton-Holt function internally within the model because of insufficient contrast in the ASAP base model time series of estimated SSB and recruitment (1982-2010).

The model included two different fishery selectivity blocks with the first extending from 1982 to 1990 and the second from 1991 to 2010. The choice of selectivity blocks was informed on known periods of major change in the fishery with respect to mesh size, minimum retention size and changes in the regulatory reporting system. Different split years ranging from 1989 to 1994 were explored that encompassed these major changes. Sensitivity runs indicated that the 1990/1991 split had the lowest objective function and offered improved fit to the age composition in the way of reduced residual patterning. For the fishery, selectivity-at-age is freely estimated within each block for 8 out of 9 ages, with one age class fixed at full selectivity in each block. In block 1, age 5 was assumed to be fully selected, while in block 2 age 6 was assumed to be fully selected. This decision was informed on the basis of smaller mesh sizes and minimum retention sizes during the years included in block 1.

Each of the two NEFSC surveys included a single time invariant selectivity vector with selectivity-at-age being freely estimated from ages 1 to 5 and fixed at age 6 and older. The choice of the flat-topped selectivity pattern for the NEFSC survey indices was informed in part by the VPA results from SAW 53 results, which suggested increasing catchability with age, and the likelihood calculated in ASAP for domed versus flat-topped scenarios. Additionally, comparison of proportion of fish age 5 and older caught in the NEFSC surveys relative to the fishery shows a higher ratio of old fish caught by the NEFSC surveys (NEFSC 2012a). This in itself does not confirm the presence of flat top survey selectivity, but does support a conclusion of higher selectivity-at-age in the survey relative to the fishery. The MADMF spring survey was fit using a double logistic function to account for the sharp declines in selectivity-at-age observed in the VPA results. The descending slope of the double logisitic function experienced boundary problems in preliminary runs and was subsequently fixed at 10 in the base model.

The effective sample size (ESS) estimated for both the fishery and survey catch-at-age data (which are treated as multinomial) was compared to the input effective sample size in an iterative fashion until the effective sample size specified more or less matched the mean model estimated value, or until no further improvement in trying to match the estimated value could be made. Additionally, following Francis (2011), minor adjustment in the effective sample sizes were informed by the overall fit between the predicted and observed mean age of the catch. The final ESS for the fishery was set to 75, the two NEFSC surveys set to 30 and the MADMF spring set to 15. The CVs on the surveys were initially set equal to the bootstrapped CVs presented in Tables A.47 and A.52). The bootstrapped CVs characterize the sampling error, but additional process error may be present in the survey indices that are not reflected in the bootstrapped CVs. Subsequent examination of the model fits to the survey indices resulted in adjustments to the survey CVs by adding the following constants to each of the survey CV vectors to account for additional process error: 0.2 (NEFSC spring), 0.1 (NEFSC fall), 0.3 (MADMF spring). It should be noted that these minor adjustments offered slight improvements to the statistical fit of the SAW 53 model but had little impact on the model results (NEFSC 2012a).

An annual CV of 0.05 was assumed for the fishery catch. This was a trade-off in forcing an exact fit to the catch (as in a VPA-like formulation) versus accounting for some of the uncertainty in catch owing to the uncertainty in stock allocation, discard estimation and hindcasting procedure. Commercial landings in the assessment time period are assumed to be very precise. There is a limited amount of error introduced in the allocation procedure and through VTR misreporting, but generally, these uncertainties are low. CVs on commercial discards are in the range of 0.11 – 0.38 and recreational catch PSEs are in the vicinity of 20%. Given the overall uncertainties, the assumption of a constant catch CV=0.05 was not unreasonable. Model sensitivities to alternate CV assumptions were also explored during SAW 53, but overall, the model results are robust to alternate estimates of catch precision.

Update of the SAW 53 assessment model using revised data inputs

The general approach used to build the bridge from the SAW 53 ASAP model to an updated SAW 55 model was as follows (run numbers correspond to the run summaries presented in Tables A.74 and A.75):

- **Run 1:** Base model from SAW 53 (**SAW53_BASE**).
- **Run 2:** Update the recreational catch to account for changes from MRFSS to MRIP methodology. Requires updates to the total catch-at-age and catch weights-at-age matrices (**SAW55_B1**).
- **Run 3:** Update commercial and recreational discards to account for the revised assumptions of discard mortality. Requires updates to the total catch-at-age and catch weights-at-age matrices (**SAW55_B2**).
- **Run 4:** Update the stock weights-at-age matrix to account for the revisions in recreational catch numbers resulting from the changes from MRFSS to MRIP methodology (**SAW55_B3**).
- **Run 5:** Update the maturity ogive to account for the minor changes in maturity resulting from the inclusion of an additional year of maturity observations (**SAW55_B4**).
- **Run 6:** Update the MADMF spring survey to account for changes in the indices-at-age resulting from the use of only the MADMF ALK. Also, update the timing of the survey from April to May to account for a misspecification in the SAW 53 model (**SAW55_B5**).
- **Run 7:** Add 2011 data (**SAW55_B6**)
- **Run 8:** Update ASAP software to version 3.0.8 (Legault 2012a). ***This model represents the new SAW 55 reference model*** (**SAW55_BASE**).
- **Run 9:** Run SAW55_BASE under the assumption of 100% discard mortality to evaluate the impacts of the alternate discard mortality assumption on the SAW 55 reference model (**SAW55_BASE_100MORT**).

The results from the bridge building exercise are presented in Table A.75.

Overall, the impacts of the data updates were minimal on the 1982-2010 model formulation with a total 54 mt difference in the 2010 spawning stock biomass between the SAW55_B5 and SAW53_BASE models (Fig. A.138). There were moderate differences in the terminal estimate of age 5 fishing mortality driven by the effects of the revisions to recreational catch and discard mortality assumptions (Fig. A.139). Both of these revisions revised the SAW 53 estimate of 2010 age 5 fishing mortality downward from 1.14 to 0.67. The lower assumed catches attributed to revisions to the recreational catch and discard mortality assumptions resulted in minor negative re-scaling of age 1recruitment estimates (Fig. A.140). Adding an additional year of data to the assessment model (2011) resulted in a 7% increase in 2010 spawning stock biomass and 7% decrease in 2010 age 5 fishing mortality relative to the SAW 53 results. The ASAP software change had no impact on the assessment model results. There were small changes in the estimated fishery and survey selectivities associated with the data updates (Table A.76). The selectivities were primarily affected by the changes in the discard mortality assumptions which shifted the selectivity curves to the right.

Compared to the impacts of the data update process on the assessment results, there was a larger impact on the observed retrospective patterns by discard mortality estimates. The SAW 53 assessment assumed 100% mortality of all discarded fish. Discard mortality has been revised in the SAW 55 assessment based on the recommendations of the Discard Mortality WG (NEFSC 2012b, Table A.26). Revising the discard mortality assumption increased the retrospective patterning associated with spawning stock biomass, age 5 fishing mortality and age 1 recruitment (Fig. A.141). To confirm that the discard mortality assumptions had a similar effect on the revised SAW55_BASE model, a variant of the SAW55 reference model was run using an assumption of 100% discard mortality (SAW55_BASE_100MORT). Introducing 100% discard mortality back into the SAW 55 model reduced the retrospective patterns to levels below those observed in the SAW 53 assessment (Figs. A.141 and A.142). Based on the minor retrospective patterns observed in the SAW 53 model, the SARC 53 Panel recommended that stock status determination should not be based on retrospective adjusted estimates of SSB and F (NEFSC 2012a). There are a number of potential sources of retrospective patterns, including missing catch (Legault 2009) which would be the expected effect if the true discard mortality was closer to the 100% assumption used in SAW 53 as opposed the revised estimates that are being used in SAW 55. While it is difficult to identify the exact cause of a retrospective pattern, the change in discard mortality assumptions from SAW 53 to SAW 55 does introduce additional retrospective patterning which negatively impacts the reliability of the model. Given the previously noted concerns with the revised discard mortality assumptions, further work is needed to revisit these assumptions and conduct field studies to better quantify discard mortality.

One interesting aspect of the SAW 55 retrospective pattern is that while the magnitude of the previous retrospective biases has increased, the additional year of data has caused the sign of the retrospective bias to switch such that the 2011 model underestimates spawning stock biomass relative to the 2010 model and fishing mortality is overestimated. These retrospective patterns will be further discussed as they relate to the final ASAP model(s).

Further refinement of the SAW 55 reference model

In developing the final ASAP model for SAW 55, over one hundred different model configurations were explored. The nature of the sensitivity runs fell into two different categories: 1) determining whether an alternate model formulation offered improved fit to the data; and 2) evaluating the sensitivity of the model with respect to a range of assumptions. These investigations explored the model's sensitivity to the following:

<u>Model fit explorations</u>

- Survey calibration coefficients
- Use of survey numbers vs. biomass indices
- Survey catchability
- Multiple fleet definitions
- Inclusion of catch-per-unit-effort indices
- Plus group assumption (age 9^+ vs. 11^+)
- Survey selectivity assumptions (dome vs. flat topped)

<u>Evaluating the sensitivity of the model with respect to a range of assumptions</u>

- Inclusion/exclusion of survey indices
- Assessment starting points (e.g., 1964, 1970 vs. 1982)
- Catch precision assumptions
- Stock structure considerations

With a few exceptions, the distributions of the results from these sensitivity runs were similar to the SAW 55 reference case (SAW55_BASE) indicating that the model results are robust to a wide range of alternate assumptions and configurations (Fig. A.143).The major sensitivities runs that were explored are described in detail in Appendix A.6. Only the primary sensitivity runs that describe the transition from the SAW55_BASE model to the final SAW 55 model(s) are described with the main body of this report.

Placement of selectivity blocks in a two-block model

The SAW 53 model included two fishery selectivity blocks with a split between 1990/1991. Examination of residual patterns in the fits to catch-at-age from the SAW55_BASE model indicated problems with the model fits to the catch-at-age both in the early (pre-1990) and late (post-2004) time periods (Fig. A.144). Alternate model configurations were explored within the two-block model that attempted to reduce the residual patterning by adjusting the years in which the split occurs between the selectivity blocks from 1986/1987 to 1992/1993 in two year increments. There was a ten point improvement in the objective function associated with the 1986/1987 and 1988/1989 splits (Table A.77). Both of these earlier splits reduced the residual patterning in the fits to the catch-at-age in the earlier period but offered no improvement in the residual patterns occurring post-2004. With the earlier selectivity block splits, there was minor degradation in the precision of the selectivity-at-age estimates (Table A.77). The CVs on ages 1-3 increased from 17 to 44% and 24% for age 9^+. While the percent change in the selectivity CVs was large, the CVs were still relatively small for ages 1-3. The increase in CVs is likely a result of having fewer observations within the earlier time blocks with which to estimate selectivity. Overall this is a small tradeoff given the overall improvement in objective function and improved fits to the catch-at-age. Additionally, while this analysis was instructive in informing placement for the first selectivity block (between 1987 and 1989) it does not address the residual patterning in the latter part of the time series which is perhaps better addressed in a three-block model. An exploration of three-block models will be conducted later in this report.

Fitting of the MADMF spring survey selectivity-at-age

An area of concern with the SAW 53 assessment model were boundary solutions on the selectivity parameter estimates for the MADMF spring survey. The survey selectivity is estimated using a double logistic function; in the SAW 53 assessment the ascending slope parameter was fixed at 10.0 to avoid boundary problems with this parameter, but other boundary problems existed for the $A_{50\%}$ and $A_{50\%}$ descending parameters (Table A.76). These problems persist in the SAW55_BASE model. In an effort to address these concerns, attempts were made to fit the MADMF spring survey using a non-parametric approach with each age having an independent selectivity parameter. Informed by the double logistic fit, selectivity at age 1 was fixed at 1.0 and selectivity at all other ages was freely estimated. The first modeling approach (SAW55_BASE_FIXED_MADMF_AGE1_9) fitted all ages 1-9. The estimated selectivity curve was similar to that double logistic fit of the SAW55_BASE model (Figure A.145). There was a high degree of imprecision with the selectivity estimates beyond age 6. This is consistent with the finding that the year-class tracking in the spring survey was reasonable between ages 1-6 (Fig. A.116). Based on these results a second attempt was made to restrict the model to fitting only ages 1-6 in the MADMF spring survey (SAW55_BASE_FIXED_MADMF_AGE1_6). The estimated selectivity curve from the age 1-6 fit is nearly identical in to the age 1-9 fit between ages 1 and 6 both with respect to the estimated selectivity at age and CVs. Additionally, there is no perceptible change in the residual patterns observed in the survey fits to age (Fig. A.146). Fitting the model to only MADMF spring survey ages 1-6 resulted in improved fits to the catch at age compositions (Table A.78). These investigations indicate that further Gulf of Maine Atlantic cod assessment models should restrict the ages used when fitting the MADMF spring survey to ages 1-6.

Development of a three selectivity block model

Based on the results of the two-block examinations as well as the fits to the MADMF spring survey, attempts were made to fit a three-block model with the MADMF spring survey fit non-parametrically to ages 1-6. The two-block model examinations showed support for a split between the first and second survey blocks somewhere between 1987/1988 and 1988/1989. Additionally, the catch-at-age residuals suggested that a third selectivity block between 2004/2005 may address some of the observed residual patterning. There were no major regulatory changes in specifically in 2004 or 2005 that would give *a priori* expectation for a change in selectivity at this precise cut-off; however, there was a major change in the reporting system used for commercial landings with a switch from a paper weighout system to mandatory electronic self-reporting for all federally permitted dealers. Additionally, in 2006 there were increases in the recreational minimum retention size, seasonal recreational closures and the implementation of 2:1 DAS accounting in the commercial fishery (Table A.3).

Several different attempts were made to fit a three-block model including:

- **SAW55_3BLOCK**: a simple implementation of the SAW55_BASE non-parametric selectivity with the addition of a third-selectivity block starting in 2005.
- **SAW55_3BLOCK_DL**: Identical blocking to that used in the SAW55_3BLOCK model, but a utilizing a double logistic function to estimate fishery selectivity.

- **SAW55_3BLOCK_SL**: Identical blocking to that used in the SAW55_3BLOCK model, but a utilizing a single logistic function to estimate fishery selectivity (flat-topped).

The SAW55_3BLOCK model offered improved model fit relative to the two-block SAW55_BASE in the way of improved objective function while having minimal impact on the assessment results (Table A.79). The SAW55_3BLOCK model resolved the residual patterns that were evident late in the time series in the previous two-block explorations (Fig. A.147). One of the problems with the two-block model were some of the boundary problems observed in fitting the fleet selectivities as well as the high CVs on the selectivity estimates on older ages. These same problems existed in the SAW55_3BLOCK model; specifically, boundaries were hit at age 4 and age 8 in the first selectivity block and age 5 in the second selectivity block and CVs exceeded 0.3 in all ages ≥ 8 when boundary problems were not encountered (Table A.80). Fitting the fleet selectivity using a double logistic function attempted to address these issues but proved problematic due to the difficulty in estimated the downward portion of the double logistic function. The $A_{50\%}$ and downward slope parameter estimates either hit boundary solutions or had excessively high CVs (Table A.80, Fig. A.148). The problems encountered in both the parametric and double logistic selectivity fits suggest general problems with estimating the downward component of the dome-shaped selectivity. Overall, there did not appear to be sufficient information within the data with which to estimate dome-shaped selectivity for the fleet. Given these results, an attempt was made to estimate fleet selectivity used a single logistic fit. The SAW55_3BLOCK_SL estimated similar selectivities for the younger ages and the parameter estimates were all well estimated with CVs < 0.1 (Table A.80). There were minor differences in the catch-at-age residuals between the SAW55_3BLOCK and SAW55_3BLOCK_SL models (Fig. A.147). Additionally, the SAW55_3BLOCK model did not offer an improved model fit relative to the single logistic formulation (10 objective point difference and 18 parameter difference). The SAW55_3BLOCK_SL model resolved the diagnostic problems present in the SAW55_3BLOCK model and offered a more parsimonious model formulation with negligible difference in the assessment results (no change in 2011 F, <1% change in 2011 SSB).

While there was some evidence of higher selectivity at older ages relative to the fishery (Tables A.72 and A.73), the examination of the catch curve residuals (Figs. A.135) did not provide compelling evidence for a dome-shaped fleet selectivity. The use of single logistic form to estimate fleet selectivity does not negate that there may be minor doming of the fleet selectivity, but the weight of evidence combined with the model fit diagnostics indicate that the evidence is weak and the assumption of a dome has a negligible influence on the assessment results. Additionally, a working paper considered by the SAW 55 WG, Legault (2012b), examined the effects of different error assumptions on model estimated selectivities and concluded that *"[t]his argues for greater reliance on external information for the existence of domes. Or as a corollary, more forcing of flat tops in the selectivity functions unless strong external evidence is available to support the presence of domed selectivity."*

The next steps in the formulation of the final three block model were to incorporate an earlier split between the first and second blocks and incorporate the fitting of the age 1-6 MADMF spring survey indices at age using a non-parametric approach. Based on the observed lack of improvement in the objective function seen between the 1986/1987 and 1988/1989 split models a 1988/1989 split was applied to ensure that there were sufficient data within the first block with which to precisely estimate selectivity. The move from the 1990/1991 split

(SAW55_3BLOCK_BASE_SL) to the 1988/1989 split addressed the residual patterning observed in the catch-at-age during the early part of the time series (Fig. A.147) as well as offering a 12 point improvement in the objective function.

The penultimate step in the development of a three-block model was the modification in fitting the MADMF spring survey selectivity (SAW55_3BLOCK_SL_MADMF_1_6). Changing the MADMF spring survey selectivity from a double logistic to a non-parametric selectivity-at-age fit to ages 1-6 had only minor impacts on the assessment results (1.5% decrease in SSB, and 3% increase in age 5 F and no perceptible changes in fishery selectivity patterns; Fig. A.148). More importantly, this change addressed the diagnostics issues with the fitting of the MADMF spring survey that were previously mentioned. Examination of the root mean square error (RMSE) fits to the aggregate survey indices did not provide any indication that the further adjustments were needed to the survey CVs. All SAW 55 model explorations incorporated the same CV adjustments used in the SAW53_BASE model to account for additional process error: 0.2 (NEFSC spring), 0.1 (NEFSC fall), 0.3 (MADMF spring).

The final steps in the development of the three-block model were to a) modify the penalty function applied to the recruitment deviations and b) to adjust the input effective sample sizes (ESS). In all previous models there was a penalty function, lambda, applied to the recruitment deviations. Since the existing model does not fit a stock recruit relationship the SAW 55 WG consensus was that the model should place less constraint on recruitment estimates. Through an iterative approach a final agreed approach set the lambda value at 0.2 with CVs set at 0.5. This approach addressed the WG concerns and provided some constraints at the end of the time series where there is little information to inform recent recruitment. The ESS adjustments were based on the application of ESS multipliers consistent with Method 1.8 of Francis (2011). The multipliers are computed such that the stage 2 input effective sample sizes are equal to the current input effective sample sizes times the multiplier. Thus, a value of 1 leaves the input sample size unchanged, while values greater than 1 increase the input sample size and values less than 1 decrease the input sample size. Francis (2011) recommends only applying these multipliers once after all other model formulations have been determined. The new input ESS values are the result of applying these stage 2 multipliers to the original input ESS (rounded to the nearest integer). The ESS adjustments applied following this approach are as follows (multipliers are in brackets):

- Fleet catch: 75 · (1.064) = 80
- NEFSC spring survey: 30 · (0.516) = 15
- NEFSC fall survey: 30 · (0.494) = 15
- MADMF spring survey: 15 · (0.588) = 9

The net effect of these was moderate with respect to the terminal estimates of spawning stock biomass and age 5 fishing mortality (Table A.79). The 2011 SSB estimate decreased by 16% and the age 5 F increased by 22%. The final base model is referred to as the SAW55_3BLOCK_BASE.

Natural mortality

As noted earlier, the SAW 55 WG spent considerable time discussing natural mortality (SAW 55 WG 2012a, 2012b, 2012c). There was conflicting evidence for both the scale and trends in natural mortality with the tagging information providing the only evidence for changes in *M*.

Meta-analyses that were considered as well as food habits information provided no compelling evidence for changes in *M* over time. To address the conflicts in information, the WG recommended profiling the models over a wide range of *M* values. The profiles were conducted for three separate time blocks: 1982 – 2002, 2003 – 2011 and 1982 – 2011. The first two time blocks correspond to the period before/during the contemporary tagging study analyzed in Miller (2012). Profiling was conducted on the SAW55_3BLOCK_BASE model across a wide range of *M* values. Profiling over the entire 1982-2011 time series showed support for *M* between 0.3 and 0.5. When profiling was conducted on the restricted time blocks an *M* of between 0.1 and 0.2 was preferred for the 1982-2002 period whereas profiling conducted on 2003-2011 period suggested an *M* between 0.1 and 0.6 (Fig. A.149). These profiles were consistent with the tagging evidence for *M* being greater than 0.2 in the 2000s and a change in *M* over the longer term. Interestingly, when profiling was conducted over the full 1982-2011 time period on a variation of the base model under an assumption of 100% discard mortality there was model preference for *M* in the range of 0.2 to 0.4. Discard mortality assumptions have implications for model-based inferences of natural mortality.

It should be noted that ASAP profiling exercises conducted using modified time blocks (1982-2004, 2005-2011) which showed clear support for an *M* between 0.1 and 0.2 in the early time period and an *M* between 0.4-0.6 in the later time period. These profile results are not shown because they are not entirely consistent with the tagging period examined (2003-2006). However, they do illustrate that the assessment model-based evidence for a higher *M* in the more recent time period is sensitive to the time blocks examined. This highlights the low discriminatory power of the models to estimate *M*. Despite the low-discriminatory power of the models, the SAW 55 WG did agree to explore an *M*-ramp model with *M* during the 1982 – 88 period set equal to 0.2, during 2003 – 2011 at 0.4, with a linear ramping up of *M* during 1989 – 2002 between 0.2 and 0.4 (Fig. A.150).

Sensitivity runs of the final three-block model

The SAW55_3BLOCK_BASE model presented above constitutes the preferred ASAP model for the SAW 55 Gulf of Maine Atlantic cod assessment. The SAW 55 WG explored several sensitivities of this model with respect to different assumptions of discard mortality (revised discard mortality vs. 100% discard mortality), natural mortality (*M* = 0.2 vs. *M*-ramp) and fishery selectivity (flat-topped vs. dome). A factorial comparison of the various sensitivity assumptions was conducted to fully evaluate model sensitivity. The examined models are displayed in Table A.81 and the sensitivities are described below. Plots of the model estimated fishery selectivities are provided in Figs. A.151 (flat-topped) and A.152 (domed). The time series of spawning stock biomass, age 5 fishing mortality and age 1 recruitment are provided in Fig. A.153 (flat-topped) A.154 (domed). Retrospective plots are provided in Figs. A.155 (flat-topped) and A.156 (domed). Model diagnostics are provided in Tables A.82 (flat-topped) and A.83 (domed).

While the SAW 55 WG had previously agreed to move forward with the use of the alternate discard mortality rates, concern were raised due to the degradation of model performance when the alternate discard mortalities were incorporated into both the SAW53_BASE and SAW 55_BASE models, specifically the increase in retrospective patterning (Figs. A.141-142). The incorporation of the 100% discard mortality has only small effects on the fishery selectivity estimates, primarily in the way of causing a slight shift towards smaller fish in all selectivity blocks (Figs. A.151-152). The 100% discard mortality assumption causes a slight positive re-scaling of both age 1 recruitment and spawning stock biomass with minimal effects on the 2011 estimates. It does however result in an increase in the fishing mortality estimates in 2010 and 2011 under all scenarios (Tables A.82-83, Figs. A.153-154). As observed in previous models, there was a reduction in the SSB and F retrospective patterning on the order of 30-40% (Tables A.82-83) when 100% discard mortality was used compared to the alternate discard mortality rates. The WG noted that assuming 100% mortality of discards (as done by SAW 53) moderately improved model fits and reduced the retrospective pattern and was more consistent with tagging studies in which carefully handled cod can experience high (e.g. 50%) mortality within two days of being released (Miller 2012). Notwithstanding this, the WG agreed to use the estimates from the Discard Mortality WG (NEFSC 2012b) for status determination and projections but to show the impact of the 100% discard mortality estimates on the 2011 spawning stock biomass (SSB) and fishing mortality (F) estimates without bringing these through to reference points and projections.

Earlier formulations of the SAW55 ASAP model indicated no statistical basis to choose a dome over a flat-top and stock trends were the same. It was noted that during GARM III, the principle was adopted that a flat-top should be assumed unless there was evidence for a dome (NEFSC 2008). Tagging analyses considered at that time indicated that flat-top relationships were to be expected (Hart and Miller 2008). The WG discussed other processes which could explain a dome or a flat top (e.g. gear mix) but there were no specific explanations for a dome. In response, it was noted that the SCAA models favored domes although over-parameterization could be an issue (Legault 2012b). The SCAA models were rerun with the flat-top selectivities from the ASAP models to see how this assumption is influencing the difference between the two formulations. These runs confirmed that use of a flat-topped fishery selectivity was not consequential to the difference and thus the WG agreed that further formulations would use flat top fishery selectivity relationships. It should be stressed that for the fishery selectivity curves that were estimated for the Gulf of Maine cod in this assessment, the choice of a flat-topped or domed shape has negligible impact on the assessment results (Fig. A.157).

The influence of the *M*-ramp (M_SPLIT) had almost no impact on fishery selectivity estimates, but resulted in positive re-scaling of age 1 recruitment and spawning stock biomass and negative re-scaling of fishing mortality from about 1991 onward. Interestingly, there were only small impacts on the 2011 terminal estimates (Tables A.82-83, Figs. A.153-154). Under an assumption of *M* ramping to 0.4 in the later period of the time series, the removals attributed to natural mortality exceed fishery removals from 1998 to 2010 (Fig. 158). There was considerable improvement in the retrospective patterns both in the flat-topped (Fig. A.155) and domed (A.156) ASAP formulations. There was an 8 point improvement in the objective function under both the flat-topped and domed assumptions (Table A.82-83). Support for an *M*-ramp rests primarily on its ability to reduce the retrospective pattern, although the retrospective patterning in the Gulf of Maine stock is not as severe as that of the Georges Bank cod stock assessment. It should be noted that the Miller (2012) tagging analysis supported a much higher *M* (0.6) than used in the *M*-ramp model (0.4). A sensitivity run of the ASAP *M*-ramp model (flat-topped) was conducted using an *M* of 0.6 during the recent period. Compared to the model using an *M* ramped up to 0.6, the fit with *M* ramped up to 0.4 improved fit by 22 log-likelihood points. These analyses indicated that while estimation of current spawning stock biomass (SSB) was generally comparable between models with different *M* options, the bigger issue is the impact of these options on reference point and thus stock status determination. The WG agreed to pursue two *M* options ($M = 0.2$ and *M*-ramp) with respect to their potential impact on reference points and short-term projections (SAW 55 WG 2012c). **The SAW55_3BLOCK_BASE (*M* = 0.2) and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) ASAP models were forwarded to the SARC 55 Panel for consideration.**

Recommendations of the SAW 55 WG

The SAW 55 WG could not reach consensus on which model should serve as the basis of current stock status determination and management advice, but noted that "*…lack of consensus should not be interpreted as implying equal support for the models…*" Consequently, both the *M* = 0.2 and *M*-ramp ASAP models were put forward for consideration by the SARC 55 Panel along with the list of support for and against both modeling approaches which is outlined below:

<u>*M* = 0.2 approach</u>

The features that lend support to the assumption that *M* has remained constant throughout the time series are those features which do not support the *M* ramp assumption, which is discussed below. The main feature against the assumption of constant *M* is the presence of a retrospective pattern. However, there is some evidence to suggest that this may be transitory and becoming less of an issue (SAW 55 WG, 2012c). It was for this reason that no adjustment for the retrospective pattern has been made to any of the models.

<u>*M*-ramp approach</u>

One of the main features supporting the assumption of a recent change in natural mortality is that it employs an *M* = 0.4 which is generally consistent with the results of the 2003 – 2006 GMRI tagging data and associated analyses (if one assumes a 50% reporting rate of high reward tags). The tagging analysis indicated that *M* could be as high as 0.6. Tag reporting rates would have to be very low in order to be consistent with an *M* of 0.2.

Another line of support for this assumption is the model fits. The value of the objective function for the *M*-ramp model was lower (by 8-10 log-likelihood points depending on the specific formulation) than that of the *M* = 0.2 model. Further, compared to the *M* = 0.2 model, assuming that *M* had changed more recently reduces the retrospective pattern.

The final observation supporting a recently elevated *M* in Gulf of Maine Cod is evidence of increasing *M* in the adjacent NAFO Div. 4X Cod stock, based on both tagging analyses and assessment model fits.

A number of features don't lend support to a recently increasing *M*. There is no evidence for increased predation, either by fish or pinnipeds, in the diet compositional data collected by the NEFSC. Regarding the GMRI tagging analyses, if reporting rates of high reward tags were less than 50%, natural mortality would be less than 0.4. It is unfortunate that there are little or no historical tagging studies to which the results of the GMRI study could be compared. Besides using different assumptions, these earlier studies did not formally incorporate parameters to estimate movement. For these reasons, the tagging studies which suggested higher (than 0.2) *M* in 4X may not apply to Gulf of Maine Cod (SAW 55 WG 2012a).

Regarding model fits, the likelihood profile of *M* for the 2003 – 2011 period was relatively flat, with estimates between 0.1 and 0.6 potentially possible. Exploratory runs indicated that *M* profiling was sensitive to which years to include in the recent period of high *M*. A change of two years would result in a more informative profile (favoring higher *M*).

The final lines of evidence against a recently elevated *M* relate to the life history information. Compared to adjacent stocks, there have been little or no long-term changes in maturity at age, fish condition and growth. Meta-analyses of life history parameters suggest an *M* of 0.2 with no trend over time. For example, fish as old as age 16 have been observed in the population within the past five years, seemingly inconsistent with a two-fold increase in natural mortality.

Diagnostics and results of the M = 0.2 ASAP model (SAW55_3BLOCK_BASE)

Model fits to the fishery catches were good, with no strong patterning of residuals over time and generally good agreement between modeled and observed catches (Fig. A.159). An ESS of 80 on the fishery catch-at-age appeared reasonable (Fig. A.160) though the application of the Francis (2011) stage 2 multipliers results in slightly lower ESS than would have been achieved using the iterative mean approach used in SAW 53 (NEFSC 2012a). The input ESS did achieve reasonable fits to the observed catch-at-age (Fig. A.161.a-c) with no large residual runs or obvious year class effects apparent in the residual patterning (Fig. A.162). The Francis approach focuses on the model fits to the observed mean catch-at-age which are generally good (Fig. A.163). Overall, the fits to the mean age in the SAW55_3BLOCK_BASE model are improved over those from SAW 53 (0.96 vs. the SAW 53 values of 1.28). Fishery selectivities were flat-topped as described in depth in previous sections (Fig. A.164). The trends in selectivity, with decreasing selectivity on the younger ages through time is consistent with management measures that have gradually increased mesh sizes and minimum retention sizes. The fishery selectivity parameters are well estimated with CVs ≤ 0.10 on all parameters (Table A.84).

Fits to the NEFSC spring survey index exhibited no strong residual patterning (Fig. A.165). It is notable that the ASAP model did not fit the 2007 and 2008 index values well, with the model fits being influenced by the high CVs in these years. These two index values were the subject of considerable discussions during SAW 53 and are partly responsible for the large discrepancies between the GARM III and SAW 53 assessment results (NEFSC 2012a). The input ESS value of 15 was generally supported by the modeled estimates (Fig. A.166), though as noted with the fishery ESS values, they appear to be lower than those that would have resulted from the iterative mean approach used in SAW 53. There is a decent fit of observed to predicted age compositions (Fig. A.167). There was no strong residual patterning to the index age composition fits, although there are some small transient year class effects in the early to mid-1990s. Fits to the mean age were comparable to the fishery mean ages (Fig. A.168, RMSE=1.02) lending additional support to the input ESS.

Models fits to the NEFSC fall survey were generally better than the spring fits, with stronger coherence between the observed index and modeled estimate and less residual patterning

(Fig. A.169). ESS values of 15 are generally lower than the modeled estimates; additionally there is some suggestion of decreased ESS more recently in the time series (Fig. A.170). The fit to the age composition was generally good, with very little patterning to the survey indices age composition residuals (Fig. A.171). There does appear to be a small increase in the residuals in the more recent years which is likely related to the trends observed in the model estimated ESS. The overall fit to the mean catch-at-age is reasonable, though there is some indication of reduced fit in the most recent period (Fig. A.172) as suggested by the comparison of the input ESS to the modeled ESS values and the residual patterns in the fits to the indices-at-age.

Similar to the fits to the NEFSC surveys, the fit to the MADMF spring survey is reasonably good with the model tracking the observed index values moderately well, with no strong residual patterning (Fig. A.173). The input ESS appears generally reasonable (Fig. A.174). The MADMF spring age compositions were not fit as well as the NEFSC surveys, with the magnitude of residuals being somewhat larger for this survey relative to the others, particularly at the younger ages (Fig. A.175). However, no long runs of residuals (either positive or negative) are observed and there are no indications of year class effects. Estimated mean ages were fairly close to the observed mean ages, with a RMSE of 1.06 (Fig. A.176).

The NEFSC fall survey exhibits higher selectivity at younger ages relative to the spring survey (Table A.84, Fig. A.177). Survey catchabilities (*q*) are presented in Figure A.178. The *q* CVs were less than 20%. The NEFSC spring survey q=0.92 which would appear to suggest that the NEFSC spring is close to 100% efficient. Considering the calibration coefficients applied to the Bigelow survey years, this would suggest greater than 100% efficiency over the last two years. This is not necessarily a valid assumption and caution needs to be taken when interpreting the area-swept converted values of *q*. A full exploration of the survey *q* estimates is provided in Appendix A.6 along with model independent estimates of total stock biomass which support the general scale of biomass estimated by the BASE model. Long-term retrospective analyses were conducted to evaluate the patterns of survey catchability changes over time (NEFSC spring and fall and MADMF spring). While the NEFSC spring (Fig. A.179) survey *q* exhibited a sharp increase during the 1990s, *q* has remained relatively stable for the NEFSC fall (Fig. A.180) and MADMF spring (Fig. A.181) surveys. The WG discussed potential causes for this pattern, though no concrete hypotheses were put forward. One hypothesis concerned the intense aggregation of cod that was observed in the vicinity of Stellwagen Bank between 2006 and 2010; however a *q* retrospective on just the 1982-2002 time series suggests that the shift in *q* was independent of this process (Fig. A.182).

The SAW55_3BLOCK_BASE assessment model indicates that total SSB has ranged from 6,268 mt to 22,036 mt during the assessment time period, with current SSB in 2011 estimated at 9,903 mt (Table A.85, Fig. A.183). The base model estimates SSB in 2010 at 11,141 mt which is 6% lower than the SAW 53 estimate of 11,868 mt. Total January 1 biomass in 2011 is estimated at 14,728 mt (Table A.85, Fig. A.184) and F's at the end of the time series are estimated between 0.75 and 0.98 (Fig. A.183) with the 2011 fully recruited, F_{full} = 0.86 (Table A.86). Fishing mortalities-at-age are presented in Table A.87. The low fishing mortality on ages 1 through 3 is notable given that the maturity $A_{50\%}$ is between ages 2 and 3. The current fishery selectivity allows one to two spawning events, on average prior to entering the fishery. These patterns partly explain the persistence of the population in the presence of the high Fs over the past decade. The coefficients of variation on SSB and F have generally been less than 0.1 except at the end of the time series where CVs increased to at or near 0.2 (Fig. A.185).

Recruitment over the past decade has been poor despite modest increases in SSB (Fig. A.186 and A.187). Age-1 recruitment has not exceeded 10 million fish in the last two decades and has been below 7 hundred thousand fish over the last decade (Table A.88). While there is an absence of a well defined stock-recruit relationship there is some indication of a relationship (Fig. A.188). The five highest recruitment events in the time series were spawned during a six year period from 1982 to 1987 where the SSB was near the highest observed in the time series, averaging over 14,000 mt annually. The current population structure is comprised primarily of fish that have not yet fully recruited to the fishery (fish age 1-3), with >80% of the population age 4 and younger (Table A.88 and Fig. A.189).

MCMC simulation was performed to obtain posterior distributions of the SSB, total B, F_{full} and $F_{5\text{-}7}$ time series. Two MCMC chains of initial length of ten thousand were simulated with every thousandth value saved. The trace of each chain's saved draws suggests good mixing (Fig. A.190 and A.191). The lagged autocorrelations showed decreasing correlation with increased lag with correlations ≤ 0.1 beyond lag 1 (Fig. A.192 and A.193). From the MCMC distributions, 90% posterior probability intervals (PI) were calculated to provide a measure of uncertainty for the model point estimates. Time series plots of the SSB and F_{full} 90% PIs as well as plots of the posterior probability distributions for SSB_{2011} and $F_{full(2011)}$ are shown in Figures A.194 through A.197. ASAP point estimates and the 90% PIs are reported in Table A.91.

Retrospective analyses for the 2004-2011 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB (Fig. A.155). The 5-year Mohn's rho value for SSB and F were 0.40 and -0.27 respectively (Table A.82). While the retrospective pattern is larger than that observed in the SAW53_BASE model, the directionality in the terminal year has shifted such that spawning stock biomass tended to be underestimated and fishing mortality overestimate. The SAW 55 WG discussed criteria to judge when to adjust for a retrospective pattern (SAW 55 WG 2012c). It was mentioned that there are no firm guidelines on when to (or not) adjust for a retrospective pattern. There was however SAW 55 WG agreement to always adjust for a consistent retrospective pattern and to do this on the numbers at age.

The ASAP model presented retrospective patterns based upon five year peels. It appeared that the retrospective pattern was transient with a one year peel showing little bias. The SAW 55 WG could not agree on general criteria to adjust for the retrospective pattern, noting that this is a broader issue than the Gulf of Maine cod assessment. The group agreed that further formulations should not adjust for the retrospective pattern given that the retrospective pattern is small, it may be transient in nature and that SAW 53 made no retrospective adjustment. This decision was supported by the SARC 55 Panel (i.e., no retrospective adjustment should be conducted for the purposes of stock status determination or short-term projections).

Diagnostics and results of the M-ramp ASAP model (SAW55_3BLOCK_BASE_M_SPLIT)

Model fits to the fishery catches were good, with no strong patterning of residuals over time and generally good agreement between modeled and observed catches (Fig. A.198). An ESS of 80 on the fishery catch-at-age appeared reasonable (Fig. A.199) though the application of the Francis (2011) stage 2 multipliers results in slightly lower ESS than would have been achieved using the iterative mean approach used in SAW 53 (NEFSC 2012a). The input ESS did achieve reasonable fits to the observed catch-at-age (Fig. A.200.a-c) with no large residual runs or obvious year class effects apparent in the residual patterning (Fig. A.201). As noted previously, the Francis approach focuses on the model fits to the observed mean catch-at-age which were generally good (Fig. A.202). As with the $M = 0.2$ model, fishery selectivities were flat-topped as described in depth in previous sections (Fig. A.203). Similar to the $M = 0.2$ model, selectivity on the younger ages decreased over time blocks consistent with management measures that have gradually increased mesh sizes and minimum retention sizes. The fishery selectivity parameters are well estimated with CVs ≤ 0.10 on all parameters (Table A.84).

Fits to the NEFSC spring survey index exhibited no strong residual patterning (Fig. A.204). It is notable that the ASAP model did not fit the 2007 and 2008 index values well, with the model fits being influenced by the high CVs in these years. The input ESS value of 15 were generally supported by the modeled estimates (Fig. A.205), though as noted with the fishery ESS values, they appear to be lower than those that would have resulted from the iterative mean approached used in SAW 53. There is a decent fit of observed to predicted age compositions (Fig. A.206). There was no strong residual patterning to the index age composition fits, although there are some small transient year class effects in the early to mid-1990s. Fits to the mean age were comparable to the fishery mean ages (Fig. A.207, RMSE=1.02) lending additional support to the input ESS.

Models fits to the NEFSC fall survey were generally better than the spring fits, with stronger coherence between the observed index and modeled estimate and less residual patterning (Fig. A.208). ESS values of 15 are generally lower than the modeled estimates; additionally there is some suggestion of decreased ESS more recently in the time series (Fig. A.209). The fit to the age composition was generally good, with very little patterning to the survey indices age composition residuals (Fig. A.210). There's a a small increase in the residuals in the more recent years which is likely related to the trends observed in the model estimated ESS. The overall fit to the mean catch-at-age is reasonable, though there is some indication of reduced fit in the most recent period (Fig. A.211) as suggested by the comparison of the input ESS to the modeled ESS values and the residual patterns in the fits to the indices-at-age.

Similar to the fits to the NEFSC surveys, the fit to the MADMF spring survey is reasonably good with the model tracking the observed index values moderately well, with no strong residual patterning (Fig. A.212). The input ESS appears generally reasonable (Fig. A.213). The MADMF spring age compositions were not fit as well as the NEFSC surveys, with the magnitude of residuals being somewhat larger for this survey relative to the others, particularly at the younger ages (Fig. A.214). However, no long runs of residuals (either positive or negative) are observed and there are no indications of year class effects. Estimated mean ages were fairly close to the observed mean ages, with a RMSE of 1.06 (Fig. A.215).

The NEFSC fall survey exhibits higher selectivity at younger ages relative to the spring survey (Table A.84, Fig. A.216). Survey catchabilities (q) are presented in Figure A.217. The q CVs were less than 20%.

The SAW55_3BLOCK_BASE_M_SPLIT assessment model indicates that total SSB has ranged from 7,930 mt to 21,531 mt during the assessment time period, with current SSB in 2011 estimated at 10,221 mt (Table A.85, Fig. A.218). Total January 1 biomass in 2011 is estimated at 16,312 mt (Table A.85, Fig. A.219) and F's at the end of the time series are estimated between 0.60 and 0.90 (Fig. A.218) with the 2011 fully recruited, $F_{full} = 0.90$ (Table A.86). Fishing mortalities-at-age are presented in Table A.89. The low fishing mortality on ages 1 through 3 is notable given that the maturity $A_{50\%}$ is between ages 2 and 3. The current fishery selectivity allows one to two spawning events on average prior to entering the fishery. These patterns partly explain the persistence of the population in the presence of the high Fs over the past decade. The coefficients of variation on SSB and F have generally been less 0.1 except at the end of the time series where CVs increased to at or near 0.2 (Fig. A.220).

Recruitment over the past decade has been poor to moderate despite modest increases in SSB (Fig. A.221). There is no well defined stock-recruit with very little relationship between age 1 recruitment and spawning stock biomass (Fig. A.222). Age-1 recruitment has been below ten thousand fish since 2008 (Table A.90 and Fig. A.223). The current population structure is comprised primarily of fish that have not yet fully recruited to the fishery (fish age 1-3), with >80% of the population age 4 and younger (Table A.90 and Fig. A.224).

Identical to the $M = 0.2$ model, MCMC simulation was performed to obtain posterior distributions of the SSB, total B, F_{full} and $F_{5\text{-}7}$ time series. Two MCMC chains of initial length of ten thousand were simulated with every thousandth value saved. The trace of each chain's saved draws suggests good mixing (Fig. A.225 and A.226). The lagged autocorrelations showed decreasing correlation with increased lag with correlations ≤ 0.1 beyond lag 1 (Fig. A.227 and A.228). From the MCMC distributions, 90% PIs were calculated to provide a measure of uncertainty for the model point estimates. Time series plots of the SSB and F_{full} 90% PIs as well as plots of the posterior probability distributions for SSB_{2011} and $F_{full(2011)}$ are shown in Figures A.229 through A.232. ASAP point estimates and the 90% PIs are reported in Table A.91.

Retrospective analysis for the 2004-2011 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB (Fig. A.155). The 5-year Mohn's rho value for SSB and F were -0.01 and 0.06 respectively (Table A.82). This retrospective is considerably reduced relative to the SAW55_3BLOCK_BASE ($M = 0.2$) model. Both the SAW 55 WG and SARC 55 Panel agreed that no retrospective adjustment should be conducted for the purposes of stock status determination or short-term projections.

Conclusions of the SARC 55 Panel

The SARC 55 Panel recognized that one of the motivations for examining how, or if, changes in natural mortality had occurred was driven by an effort to reduce the retrospective pattern present in the $M = 0.2$ model. Given all of the information provided to the Panel, there remained considerable uncertainty in the estimates of M. The evidence for and against constant and ramped natural mortality was equivocal. As with the Working Group, the Panel was unable to reach a decision on which natural mortality values or time varying scenarios best characterized this system.

With respect to the improved diagnostics of the M-ramp model, the Panel concluded that "*…finding that including a changing M provides a better fit, is generally not sufficient to justify using such a model modification without other ecologically directed information to* *back it up"* (SARC 55 2012). Noting the lack of conclusive evidence to support a change in *M* they determined that it was unclear as to whether a change in natural mortality was influencing the retrospective pattern or some other factor. For example, a Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp M approach could be partially aliasing unaccounted fishing mortality.

Given that there was no clear way forward for providing a single model for guiding management advice, the SARC 55 Panel put forward (accepted) both the ASAP *M* = 0.2 and *M*-ramp models. The consequences associated with using or disregarding either approach are outlined under TOR 8.

Other models considered by the SARC 55 Panel, but not accepted:

Historical (1932) ASAP model with Beverton-Holt stock recruit relationship

While the SAW55_3BLOCK_BASE (*M* = 0.2) and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) models constituted the accepted models, the SAW 55 WG felt it was worthwhile to develop candidate ASAP models that both a) utilized the historical information back to 1932; and b) fit a Beverton-Holt (BH) stock recruit (SR) function internally within the model. In this respect they provided a more similar comparison to the SCAA candidate models (though a BH model was also developed for the SCAA model). The current version of ASAP does not allow the fitting of a Ricker SR relationship. Extending the assessment back in time is necessary to establish sufficient contrast in the SR relationship such that a SR function can be estimated. Such an approach, by necessity, requires that the assessment incorporate data of lower informational quality, but also data with higher uncertainty. **It is important to note that the ASAP BH models were not presented to the SARC 55 Panel as preferred ASAP models, rather they were prepared to provide ASAP equivalents to the SCAA models (described in next section). The SARC 55 Panel did not accept the SCAA modeling approach for the reasons outlined in the next section. Many of the SARC 55 Panel's objections to the SCAA modeling approach would also apply to the ASAP BH models (e.g., incorporation of highly uncertain historical data, influence of uncertain recruitment on steepness parameters, volatility of MSY reference points to SR functional form).**

To adjust historical catches to account for un-recorded commercial discards and recreational catch the average ratio of these catches to the commercial landings between 1982 and 1988 (0.32) was applied as an adjustment factor. While the constant ratio approach was the best that could be developed by the SAW 55 WG, it is based on several critical assumptions, namely that the commercial discards were constantly proportional to commercial landings prior to 1982. This assumption may not be valid, particularly when historical landings of non-targeted fisheries such as the northern shrimp fishery are considered. There is evidence that landings, and presumably effort, of northern shrimp were greater back during the late 1960s to mid-1970s (Fig. A.233). This fishery was responsible for large amounts of Gulf of Maine cod discards, particularly during the mid-1980s (Fig. A.24) prior to implementation of the Nordmore grate. Given the fisheries tendency to catch small cod (Fig. A.53), the discard patterns of this fishery would be subject not only to relative effort, but also the year-class strength of Gulf of Maine cod. These observations suggest that the discards of Gulf of Maine cod could have been much greater relative to landings during the late-1960s to mid-1970s. While no better direct estimates are available for the historical catches, these types of issues should be considered when determining the reliability of historical catch estimates used in stock assessments. Given the high uncertainty in the historical catches, the SAW 55 WG agreed to apply a CV of 0.4 between 1932 and 1963 and 0.2 between 1964 and 1982. Time series averages of catch weights and stock weights were used for the period prior to 1982. The assumptions used for historical catches were identical between ASAP and SCAA runs.

For the ASAP 1932 BH runs, both M = 0.2 and M-ramp models were developed. In each model initial guesses for numbers-at-age, fishing mortality and steepness were set. The model was free to estimate fishing mortality and steepness with no imposed penalty function/prior, though the initial numbers at age were fixed. Preliminary investigations of the ASAP 1932 Beverton-Holt model explored alternate starting points, with model convergence and results robust to these alternate starting points. The final model applied an initial F = 0.2 in 1932. A summary of model diagnostics are presented in Table A.92. An interesting finding from the 1932 BH runs is that there is no model preference for the M-ramp, in fact imposing the M-ramp on the 1932 BH model results in a loss of 17 objective points, though most of these differences were due to differences in the recruitment deviations. Additionally, unlike the 1982 ASAP model, the retrospective pattern is worse under the M-ramp assumption (Fig. A.234). Since the support for the M-ramp in the 1982 ASAP formulation rested in part on its ability to reduce the retrospective pattern, these results call into question the justification for an M-ramp model.

The spawning stock biomass, fishing mortality and age 1 recruitment estimate time series were nearly identical to their 1982 equivalents for the years in which overlap occurred (1982-2011; Fig. A.235). The imposed M-ramp did affect the historical time series due to the effects on the estimated SR relationship (Fig. A.236). Steepness was estimated at 0.90 in the M = 0.2 model and 0.82 in the M-ramp model. Overall, the corresponding reference points appeared well-estimated with CVs < 0.15 (Table A.92). Profiling over various values of steepness shows that for the M = 0.2 run, there is equal evidence for a steepness between about 0.85 and 0.95 (Fig. A.237) between which there is no considerable change with respect to reference points or 2011 estimates of SSB or F (Fig. A.238). Consequently, across the range of likely steepness values, there is little impact on stock status determination (Fig. A.239). The converse is not true for the M-ramp model where there is equal evidence for steepness between 0.7 and 0.9 with large implications on the estimate of F_{MSY} (ranges from approximately 0.5 to 1.1). While B_{MSY} and the 2011 SSB estimate were not highly sensitive to the steepness estimate, given that the 2011 SSB estimate (8,442 mt) was close to the B_{MSY} estimate of 7,713 mt, steepness values in the range of 0.7 and 0.9 can lead to very different perceptions about stock status (Fig. A.239).

These results are important to consider in both in the context of current stock biomass and fishing mortality and in the justification of an M-ramp. The 2011 estimates of the 1932 BH ASAP models were both below those of the 1982 models, but both generally exhibited the same time series trends and scale. The implementation of an M-ramp into the 1932 BH model degraded the model performance, particularly with respect to the retrospective patterns which was a justification for its consideration in the 1982 model.

SCAA model

Statistical catch-at-age (SCAA) assessment models were also considered by the SAW 55 WG, the details of which are provided in Appendices A.2-A.5. The primary differences between the ASAP and SCAA model formulations are the choice of starting points with the SCAA model starting in 1932 and the fitting of an internal Ricker stock-recruit relationship. The treatment of the historical input data in the SCAA model was identical to that described in the ASAP 1932 BH models detailed in Appendix A.6. There were other minor differences between the models but the WG concluded that each model series estimated similar spawning stock biomass across the range of the time series (Fig. A.240), but did note that the terminal 2011 estimates exhibited differences in scale with the SCAA model tending to estimate high biomass at the end of the time series. The WG discussed the source(s) of this difference and identified it as the weightings given to recent stock – recruitment data, with the SCAA model applying greater shrinkage to the SR relationship in the more recent years.

Both a constant $M = 0.2$ and an M-ramp model SCAA were developed and brought forward for consideration by the SARC 55 Panel. **A full description of the comparison of the ASAP and SCAA modeling approaches put forward by the SAW 55 WG is provided in Appendix A.7.** Ultimately, the SARC 55 Panel did not accept the SCAA approach. Below is the justification provided by the SARC 55 Panel (SARC 55 2012):

"While using information in the earlier part of the time series to help define a stock-recruitment relationship is laudable, it can be tricky. A number of concerns were raised and discussed regarding the use of the pre-1982 data (which was not of the same detail and quality as the post-1982 series) and the results from fitting the stock-recruitment curves to these data. Any one concern, by itself, might not have been enough to preclude the use of these methods in the assessment, but together these concerns led the Review Panel to discount the results and consequently the approach was eliminated from further consideration. These concerns can be examined from the point of view of the two parametric stock recruitment models (Ricker and Beverton-Holt) and then from the point of view of the data. These concerns are outlined below:

- *The FMSY reference point derived from the Ricker model based on the longer data series was sometimes higher than total mortality derived from surveys suggesting that FMSY estimated in this way is higher than would make sense as the stock decreased at these mortality levels. The Review Panel acknowledges that the criterion for determining survey total mortality integrates selectivity as well, but believes the above argument still holds.*

- *Although the Ricker model fit the longer data series better than other models (neither the Ricker or Beverton-Holt could be reasonably fit without including some other information, as that derived from the longer data series or some other external piece of prior information), the fit was clearly influenced by low recruitments in earlier years associated with high spawning stock biomass (SSB). The Review Panel could not decide if this was a period with low recruitment productivity driven by external forces or if it was a low recruitment period because of high SSB. If the low productivity had been estimated at two or more periods of high SSB then the Review Panel would have had put more consideration into the Ricker model. There was also no evidence of density dependent effects on recruitment rate such as cannibalism.*

- *The Beverton-Holt stock-recruitment model was similarly rejected because these low recruitment points also inflated the steepness parameter to values beyond what seemed reasonable.*

- *Including the earlier catch series was necessary to fit a stock recruit relationship, however, because of the above arguments and concerns about the quality and the less detailed information available in earlier part of the data series, the Review Panel concluded that these relationships were too unreliable to provide MSY reference points for characterizing assessment advice and so all model formulations (either ASAP and SCAA) that included a stock recruitment relationship were not considered further.*

- *Regarding the low recruitment values of the 1960s, it looked like there were other avenues that could be pursued to help validate whether or not they should be included in determining stock recruitment model fits and associated reference point calculations. For example, examining evidence of ecosystem drivers would help determine if these recruitments were more likely to be evidence of density dependence or alternatively an environmental regime shift or a change in predation by other species. A general concern about the quality of the data in the earlier part of the series provides further motivation for examining the credibility of these influential points.*

- *As no standard stock-recruitment relationship could be found, the use of proxy reference points for this stock was supported.*

- *One other important related issue should be noted when using the Ricker or the Beverton-Holt relationships for data like these. The two models result in very different SSB_{MSY} and F_{MSY} reference points although the resulting recruitment levels at these points may be close to indistinguishable. Basing overfishing thresholds on such a volatile criterion may not be the best approach for establishing stable and sustainable management actions for stocks with this type of recruitment history."*

Historical assessment retrospective

A comparison between the results of the current SAW 55 assessment (both M = 0.2 and M-ramp model) and the five previous assessment (SAW 33, GARM I, GARM II, GARM III, and SAW 53) is provided in Figure A.241. This historical "retrospective" examination of past model performance illustrates the general tendency of updated models to achieve higher estimates of F and lower estimates of SSB, total biomass and overall stock size over the last decade. These patterns are in addition to the intra-model retrospective patterns that are present in the existing ASAP model as well as past VPA models. Given the major changes in data that have occurred in both the SAW 55 as well as the SAW 53 benchmark assessments, the current assessment is not entirely comparable with previous assessments. Much of the scale differences between the current assessment and previous assessments are driven by changes to the underlying data (e.g., recreational catch estimates, discard mortality assumptions, weights-at-age) and not as a result of the assessment or choice of model.

TOR A.6. State the existing stock status definitions for "overfished" and "overfishing"; update or redefine biological reference points.

The existing MSY reference points based on a spawning potential ratio (SPR) of 40% were established at SAW 53 (NEFSC 2012). The overfishing definition is $F_{MSYproxy} = F_{40\%} = 0.20$. A stock is considered to be overfished if spawning biomass is less than half of SSB_{MSY}. The existing overfished definition is ½ $SSB_{40\%} = 0.5 \cdot 61{,}218$ mt = 30,609 mt. New reference points are warranted given the changes in fishery selectivity and fishery weights-at-age due to the revisions in recreational catch estimates and discard mortality assumptions. Additionally the *M*-ramp assumption has considerable impacts on recruitment estimates which will impact the estimation of SSB_{MSY} and MSY.

As noted under TOR 5, the ASAP model has the capability to estimate a Beverton-Holt stock recruit function within the model; however, model runs attempting to fit a Beverton-Holt function were unsuccessful when 1982 is used as a starting year. Analytic model-based reference points are not estimable because of insufficient contrast in the ASAP base model time series of estimated SSB and recruitment (1982-2011). *As no standard stock-recruitment relationship could be found, the use of proxy reference points for this stock was necessary*. A yield per recruit (YPR) analysis was performed using a 3-year average of weights-at-age (2009-2011) which was consistent with the approach used in SAW 53 and supported by recent observed trends. The remaining YPR inputs were time invariant (maturity-at-age) or were constant in the most recent time block of the assessment model (selectivity, natural mortality). The SARC 55 Panel concluded that for long-term projections (i.e., the establishment of reference points) natural mortality should be assumed equal to 0.2, because the longer-term historical evidence seems to indicate that M=0.2 is more plausible than the more recent 0.4 assumed under the *M*-ramp model. Given the SARC 55 Panel's conclusions regarding natural mortality, there are only minor differences in the selectivity vectors between the $M = 0.2$ and *M*-ramp YPR inputs; all other inputs are identical. YPR inputs are summarized in Table A.93 for both the M= 0.2 and *M*-ramp models.

The basis for the existing reference points was derived at GARM III (NEFSC 2008), and is based on $F_{40\%}$. This decision was based on an assumed natural mortality of $M = 0.2$. The decision to use $F_{40\%}$ as a proxy was endorsed by the independent reviewers at GARM III meeting, stating that *"If recruitment and spawning stock biomass derived from the assessment are not informative about a relationship, the panel recommended use of $F_{40\%MSP}$ as a proxy for FMSY (NEFSC 2002) and SSB_{MSY} proxy computed using a stochastic projection approach, also referred to as the "nonparametric approach"* (NEFSC 2008, p979). Additional analyses by the SAW 55 WG evaluated various proxies for F_{MSY} by comparing estimated SSB and recruitment ratios (SSB/R) with expected spawning biomass per recruit (SPR) over a range of fishing mortalities (F=20% to F80% in 5% increments) to investigate the potential for replacement under equilibrium assumptions (i.e. constant harvest rate and biology over the lifespan). The SAW WG considered an analysis of replacement lines under recent productivity (approximately last 10 years) and concluded that for the $M = 0.2$ option, $F_{40\%}$ (0.18) was still appropriate (Fig. A.242). It should be noted that subsequent to the SAW/SARC 55, work was presented at SAW 56 WG that invalidates the replacement line approach for determining an appropriate spawning potential ratio and suggested that $F_{40\%}$ be maintained for fish with typical groundfish life histories (Legault and Brooks 2013). The

SARC 55 Panel recommended to maintain the $F_{40\%}$ basis for reference points for both the *M* = 0.2 and *M*-ramp models but noted that "*…F40% is necessarily the best proxy to use, rather there has yet to be compelling reasons to abandon it*" (SARC 55 Panel Summary Report, 2012).

To arrive at estimates for SSB_{MSY} and a corresponding MSY, long term projections were run sampling from the empirical distribution of recruitment estimates from the preferred ASAP model. The recruitment vector included years 1982-2009; recruitment in 2010 and 2011 were not included due to their greater variance. The projection model samples from a cumulative density function derived from estimated age-1 recruitment. However, the revised model adjusts projected recruitment when SSB falls below some specified spawning biomass threshold based on a linear function that declines to zero at zero spawning stock biomass. Consistent with the SAW 53 assessment, the 'hinge' was set at the lowest observed SSB in the time series. For the *M* = 0.2 scenario, this was 6,300 mt and 7,900 mt for the M-ramp scenario. To approximate the distribution of the SSB and MSY distributions, the long term projections were made from 1000 estimates of numbers at age in 2011, which were estimated by performing MCMC simulation of the ASAP models (described above under TOR 5). The 2011 age 1 estimates were based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009. All projections were conducted with the AGEPRO software (Age Structured Projection Model v4.1).

For the ASAP, 1982 start, *M* = 0.2 scenario, the resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy} = F_{40\%}$ (0.18) are SSB_{MSY} = 54,743 mt (40,207 – 73,354 mt) and MSY = 9,399 mt (6,806 – 13,153 mt).

For the ASAP, 1982 start, *M*-ramp scenario, the resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy} = F_{40\%}$ (0.18) are SSB_{MSY} = 80,200 mt (64,081 – 99,972 mt) and MSY = 13,786 mt (10,900 – 17,329 mt).

A detailed summary of these reference points is also provided in Table A.94.

TOR A.7. Evaluate stock status with respect to the existing model

TOR A.7.a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.

The updated SAW 53 model (SAW55_BASE) estimates 2011 SSB at 11,874 mt. This is less than the existing overfished threshold of 30,609 mt; therefore, the stock is overfished. The updated estimate of fully recruited fishing mortality (F_{full}) in 2011 is 0.59. This is greater than the overfishing limit of 0.20, and therefore, overfishing is occurring.

TOR A.7.b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs (from Cod TOR-6).

For the ASAP, 1982 start, *M* = 0.2 scenario, the revised reference points are $F_{MSYproxy} = F_{40\%}$ = 0.18 and SSB_{MSY} = 54,743 mt (0.5 x SSB_{MSY} = 27,372 mt). The model estimates 2011 SSB at 9,903 mt. This is less than the overfished threshold of 27,372 mt; therefore, the stock is overfished. The estimate of 2011 fully recruited fishing mortality (F_{full}) is 0.86. This is greater than the overfishing limit of 0.18, and therefore, overfishing is occurring.

For the ASAP, 1982 start, *M*-ramp scenario, the revised reference points are $F_{MSYproxy} = F_{40\%} = 0.18$ and SSB_{MSY} = 80,200 mt (0.5 x SSB_{MSY} = 40,100 mt). The model estimates 2011 SSB at 10,221 mt. This is less than the overfished threshold of 40,100 mt; therefore, the stock is overfished. The estimate of 2011 fully recruited fishing mortality (F_{full}) is 0.90. This is greater than the overfishing limit of 0.18, and therefore, overfishing is occurring.

Under both the $M = 0.2$ and *M*-ramp scenarios the stock is assessed to be overfished and overfishing is occurring. It is notable that this stock has experienced a long history of overfishing relative to current reference points (Fig. A.243).

TOR A.8. Develop and apply analytical approaches to conduct single and multi-year stock projections

TOR A.8.a. Provide numerical annual projections

Short term projections of future stock status were conducted based on the current assessment results without accounting for retrospective bias. This rationale was identical to that of stock status determination. Numbers-at-age in 2012 were derived from 1000 different vectors of numbers-at-age produced from the MCMC chain with 2011 age 1 estimates based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009. Biological inputs were identical to those used for reference point determination. Short term projections have used an assumed catch in 2012 of 3,767 mt. This estimate is based on the current commercial and recreational catches as well as the expected catch over the remainder of the year which has been extrapolated using the harvest trajectories from the past two years (NEFMC PDT, T. Nies pers. comm.).

Recruitment was sampled from a cumulative density function (CDF) of estimated age 1 recruitment from 1982 to 2009. The same AGEPRO model used for reference point determination was used to conduct short-term projections (i.e., model adjusts projected recruitment based on a linear function that declines to zero at zero SSB when SSB falls below some 'hinge' SSB-level corresponding to the lowest SSB observed in the time series). For the $M = 0.2$ scenario, the 'hinge' SSB value was set at 6,300 mt and 7,900 mt for the *M*-ramp scenario. All projections were run under the assumption of 75% F_{MSY} ($0.18 \cdot 0.75 = 0.135$).

A consequence analysis was conducted to evaluate the sensitivity of management advice to the assumptions about *M* (i.e. $M = 0.2$ or *M*-ramp). For the *M*-ramp scenario the projections were provided assuming that: a) *M* remained at 0.4; or, b) that *M* returns to 0.2 in the projection period.

Projection results are summarized in terms of median SSB and fishery catch (yield) under all three scenarios outlined above in Table A.95. Under 75% F_{MSY} exploitation, the stock is projected to rebuild under the $M = 0.2$ and *M*-ramp ($M = 0.2$) scenarios by 2022. The stock cannot rebuild under the *M*-ramp ($M = 0.4$) scenario since the reference points are based on an assumption of *M* returning to 0.2 in the long-term. It is important to note that the SARC 55 Panel was not willing to conclude that *M* would remain at 0.4 in perpetuity and so did not provide reference points for the *M*-ramp model under a long-term assumption of $M = 0.4$. A full discussion of the three scenarios evaluated is provided under TOR 8b.

TOR A.8.b. Comment on which projections seem most realistic assumptions

Consequence Analysis

The risks associated with management actions taken during 2013 – 2015 were examined by undertaking stock projections under the competing assumptions for the state of nature. For example, if the true state of nature is that natural mortality has remained unchanged at 0.2 and that stock productivity is best reflected by the 1982 – present dataset (SPR, $M = 0.2$ model), then the consequences of management actions by setting projected catch according to 75% F_{MSY} based on the two alternative states of nature were examined (M-ramp scenario with $M = 0.2$ in short-term and M-ramp scenario with $M = 0.4$ in the short term). In all cases, the 2012 catch was provided by the NEFMC Groundfish Plan Development Team. Projections were only conducted until 2015. There may be longer term consequences which might be revealed through a more extensive analysis. This is beyond the current terms of reference.

The column headers in Table A.96 and Figure A.244 represent the 'true' states of nature considered, these being:

- $M = 0.2$: stock dynamics and assessment based on 1982 – present dataset with M remaining at 0.2 for the projection period.
- M-ramp: stock dynamics and assessment based on 1982 – present dataset with M returning to 0.2 in the projection period.
- M-ramp: stock dynamics and assessment based on 1982 – present dataset with M remaining at 0.4 for the projection period.

The row headers in Table A.96 indicate the basis of the management action during the projected period (2013 – 2015). For example, the row header 'ASAP, 1982 start, M = 0.2' indicates that catch was projected assuming that the stock conditions and reference points were as per these dynamics. All projections were conducted at 75% F_{MSY}, based on the assumed state of nature and thus which establishes the catch in each cell. This is the 'planned' catch. The cells of the table indicate the SSB and fully recruited fishing mortality (F_{full}) which are a consequence of applying the catch based on the assumed state of nature to the SSB of the 'true' state of nature. The diagonal rows represent the situation in which the management actions based upon the assumed state of nature are in fact correct.

The consequence analysis is summarized in Figure A.244. As with Table A.96, the column headers indicate one of the 'true' states of nature. The row headers indicate whether or not catch, SSB or F_{full} is being displayed along the row. The content of each cell summarizes the consequences (reflected by the medians of the distributions in question) of assuming one state of nature when another is true. The black line in each cell indicates the catch, SSB and F_{full} for the 'true' state of nature. The coloured lines (for the projected period only) indicate the catch, SSB and F_{full} which result when the 75% F_{MSY} estimated catch is incorrectly based upon an alternate state of nature. The dashed lines in each figure are the B_{MSY}, F_{MSY} and MSY for the 'true' states of nature.

When management actions are correctly based upon a particular state of nature (the diagonals of Table A.96), a modest increase in SSB is projected between 2013 and 2015 for all three scenarios explored. The M-ramp ($M = 0.2$) scenario has the greatest rebuilding potential whereas the M-ramp (*M* = 0.4) has the lowest rebuilding potential. Fully recruited fishing mortality declines from 0.86 (*M* = 0.2) or 0.90 (*M*-ramp) to 0.14 (all scenarios). Catch declines from 6,830 mt in 2011 to 1,313 - 2,582 mt in 2015 depending on the scenario with the *M*-ramp (*M* = 0.4) scenario resulting in the lowest yield and the *M*-ramp (*M* = 0.2) having the highest yield. The *M* = 0.2 scenario is an intermediate case. If the management actions are correctly based upon the 'true' state of nature all scenarios indicate that the stock will be in an overfished state as of 2013 (Table A.96).

The SARC 55 Panel concluded that the *M* = 0.2 projections and the *M*-ramp projections with *M* remaining at 0.4 in the short-term were equally realistic. Like the SAW 55 WG, the SARC 55 Panel could not decide which option was more plausible. The Panel concluded that if *M* is currently 0.2 [0.4] then it seemed more reasonable to assume that in the short-term *M* would remain at 0.2 [0.4]. Note that for long-term projections that Review Panel decided that *M* should be 0.2 under all scenarios, because the longer-term historical evidence seems to indicate that *M*=0.2 is more plausible.

The consequences of mis-specifying natural mortality (e.g., *M* = 0.2 is true state of nature and manage under *M*-ramp, *M* = 0.4) will not impact status determination in 2013; under all consequence analyses considered the stock will be in an overfished state in 2013. Considering only the *M* = 0.2 and *M*-ramp (*M* = 0.4) scenarios, the consequence of mis-specifying natural mortality will result in at most 717 mt of an over-/under-harvest of fishery yield in 2015. While the magnitude is small in terms of historical catch, this amounts to 55% of over-harvest (*M*-ramp is true state of nature and manage under *M* = 0.2) or a 35% under-harvest (*M* = 0.2 is true state of nature and manage under *M*-ramp, *M* = 0.4). Assuming an *M*-ramp (*M* = 0.4) when *M* is actually equal to 0.2 results in a lower than 'planned' fishing mortality and catch and higher than 'planned' SSB. When *M* is assumed to be 0.2 but an *M*-ramp (*M* = 0.4) is correct, fishing mortality and thus catch would be considerably higher than 'planned' with the result that in 2013 the stock would be experiencing overfishing (Table A.97).

TOR A.8.c. Describe this stock's vulnerability

The Gulf of Maine cod stock is currently undergoing processes that have not been incorporated into the analytical formulations. Nevertheless, they should be considered when setting the ABC.

Since the mid-1990s, as observed in the NEFSC bottom trawl surveys and consistent with the trends in the fishery, the distribution of cod has become increasingly concentrated in the western part of the Gulf, with a gradual loss of cod from the coastal and central Gulf. Since the mid-2000s, the stock has become particularly concentrated in a small region of the western Gulf, an area which appears to be a forage 'hotspot' due to the presence of sand lance, a prey of cod. This biases CPUE as an indicator of the abundance of the stock as a whole.

There is uncertainty associated with natural mortality rates. Natural mortality of cod may be increasing through consumption by other fishes and marine mammals as these populations increase; however, evidence of this is lacking in the food habits data and among life history parameters. On the other hand, tagging studies suggest natural mortality levels higher than 0.2 during 2003 – 2006 time period. The tagging studies, combined with the reduced assessment model retrospective patterns were the basis of the *M*-ramp model. However, the states of nature as reflected in the natural mortality rates included in the models are uncertain. For example, a Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp *M* approach could be partially aliasing unaccounted fishing mortality.

It may be that at low population sizes, cod experience mortality from a number of unidentified sources. High mortality, both fishing and natural will lead to a truncated age structure, implying that spawning success is increasingly dependent upon younger individuals. Murawski et al. (2001) suggest that reproduction by older females is more successful than by young females. There are a number of other factors that are known to negatively influence cod spawning success at low population sizes (Rowe et al., 2004).

If weak recruitment and low reproductive rates of Gulf of Maine cod continue, productivity and rebuilding of the stock will be less than projected. Over the last five years recruitment estimates have declined to a low level in both the $M = 0.2$ and *M*-ramp assessment models. Recent survey indices of recruitment indicate continued poor recruitment. Additionally, the NEFSC 2011 fall and 2012 spring survey abundance indices were the 4th lowest and the lowest in their respective time series. The MADMF 2012 spring survey biomass index was the lowest in its times series. The 2012 spring survey observations were not incorporated into the assessment formulations, implying that projections may be optimistic.

The current assessment provides a range of views of current stock status, all of which indicate that the resource is in an overfished state and has experienced a long history of overfishing. Concerns for stock status may also be apparent in the fishery. Cumulative commercial and recreational catches to date in 2012 are projected to be less than 60% of the total allocated quota (based on projected catch provided by NEFMC PDT, T. Nies pers. comm.). While this is suggestive of an overall difficulty on the part of industry to locate Gulf of Maine cod it is not definitive given other possible explanations such as sector quota restrictions on other co-occurring species. However, observations from the recreational fishery which is not subject to the same catch share system as the commercial fishery has also reported difficulty locating Gulf of Maine cod.

TOR A.9. Review, evaluate and report on the status of the SARC and Working Group research recommendations

The SAW 55 WG reviewed the status of previous research recommendations and proposed new ones to address issues raised during the three WG meetings. For all new research recommendations proposed by the SAW 55 WG, the WG has indicated relative priorities (high, medium, low) as appropriate. Many of these recommendations were felt to be common to both the Gulf of Maine and Georges Bank Atlantic cod stocks. These are indicated as 'General' below. The SARC 55 Panel also contributed several additional research recommendations which are included in this section.

GARM III

- The Panel recommended that historical data be used to hindcast recruitments as far back in time as possible for use in the estimation of reference points and projections.

- *Analyses to explore the use of the historical information were undertaken by the WG with the sensitivity of reference points examined.*

SAW 53

- Examine historical and contemporary estimates of cod catch in the lobster fishery. Preliminary discussions with Maine DMR suggest that the lobster bycatch may be relatively small proportional to other fishery removals.
  - *There is ongoing work through a collaboration between the University of Maine and the Maine Department of Marine Resources to estimate Atlantic cod bycatch in the Maine lobster fishery. Work is still in progress and no information was available for evaluation during SAW 55 (Y. Chen, University of Maine Orono, pers. comm.).*
  - *Observer coverage of both nearshore and offshore lobster vessels has been allocated by the Northeast Fishery Observer Program for period April 2012 – March 2013 with the specific objective of obtaining information on fishery bycatch.*
  - *The WG recommended that this research recommendation be carried forward.*

- The SAW 53 data WG had recommended that consideration be given to inclusion of the inshore strata data when switching to the *FRV* Bigelow survey time series. Sampling in these strata during both spring and fall surveys has been inconsistent or non-existent, dependent upon the stratum.
  - *The analysis presented to the SAW 55 WG indicated that inclusion of these inshore strata had minimal influence on the trends in both survey indices. It was thus recommended that these inshore strata be excluded from the SAW 55 analyses.*
  - *When it is judged that the Bigelow time series is long enough to include as a separate series, reconsideration needs to be given to adding these strata back into the survey index since there has been consistent sampling of these survey strata since the change in survey vessels in 2009.*

- Further pursue the incorporation of the Maine/New Hampshire Inshore Trawl (MENH) Survey in future assessments. The unavailability of age information and short time series have precluded this survey from being used in past assessments. While age structures are currently collected from this survey, they have not been aged.
  - *Progress has been made on the implementation and analysis of the data collected since the start of the ME/NH survey in 2000/2001; specifically, spring and fall 2005 and spring 2011 ageing has been completed and spring 2006 is in progress (S. Sherman, ME DMR, pers. comm.). Continued progress towards ageing the entire time series of collected otoliths should be considered a high priority.*

- The SARC 53 Data Working Group suggested exploration of the maturity information collected by the ME/NH survey to examine agreement with the NEFSC maturity ogives.

- *Maine DMR (S. Sherman, ME DMR, pers. comm.) provided the maturity info for the ME/NH inshore groundfish survey. These data were analyzed and presented at the SAW 55 data meeting and summarized in this report.*

- Examine the reproductive information collected from the ME/NH survey for the early years (e.g., where Downeast Maine stations were sampled to evaluate whether any of the fish were mature and if it could possibly suggest the presence of a spawning aggregation.
    - *ME DMR (S. Sherman ME DMR pers. comm.) provided maps of cod ≥ 25 cm broken down in to two time blocks (2001- 2006, 2007-2011). Additionally, maturity data were examined in terms of proportion mature by region. These data were presented at the SAW 55 data meeting and summarized in this report.*

- Examine the impacts of excluding the Commercial LPUE index from the assessment. The Commercial LPUE index exists for the year 1982 – 1993 and is no longer updated. Regulations implemented since 1994 (e.g., trip limits, area closures) limit the utility of a LPUE index that extends beyond these years. Initial modeling to explore this recommendation indicated no impact to the updated VPA and negligible impact to the ASAP base model if the Commercial LPUE index is excluded. The NDMBRPWG therefore decided to drop the Commercial LPUE index from this, and all future assessments of Gulf of Maine cod.
    - *This recommendation was included in TOR 2 of SAW 55. A number of surveys indicate that the Stellwagen Bank area appears to be a forage 'hot spot' for cod feeding on sand lance. As well, the VTR, observer and VMS information from the commercial fishery indicates that fishing effort since the mid-2000s has become concentrated in this area. Over the longer term, there have a number of regulatory changes (e.g. seasonal closures, trip limits, etc) which call into question the utility of commercial LPUE as an index of GOM cod biomass. Based on these concerns, the WG recommended that the commercial LPUE index not be used in the SAW 55 assessment model. This recommendation is consistent with the findings of the recent NEFSC sponsored LPUE workshop. Given concerns comparable to those of the commercial fishery, the WG recommended that the recreational LPUE index also not be included in the GOM cod assessment model.*

- Stock definition should be re-assessed. The SARC 53 panel recommended that efforts be undertaken to reassess the stock definition for Gulf of Maine Atlantic cod. Cod is a very population-rich species, and matching the scale of the assessment to the spatial scale of the population dynamics is important to achieve reliable, accurate assessments. Several lines of evidence support this recommendation: 1) the assessment under review presents compelling evidence of a change in the distribution of cod within the current stock area. The SARC 53 panel was not able to determine whether this is solely a demographic response, but comments made during the SARC indicate that it may also relate to a reduction in the diversity of spawning times and locations; 2) there is compelling historical and contemporary evidence from natural history information and tagging studies of movements across stock boundaries that compromises the integrity of existing stock definitions, and 3) There is a wealth of historical and more recent genetic information of local stock structure and local adaption in cod and in fish populations general at finer spatial scales than previously admitted.

  - *As indicated under TOR 3, a separate process has been initiated to address this recommendation. The SAW 55 WG reported on the findings of a recent workshop on stock structure which was an element of this initiative.*

- The level, schedule and variability of natural mortality should be evaluated. Currently, the level of fishing mortality, F, estimated in Gulf of Maine Atlantic cod is substantially higher than the estimated rate of natural mortality, *M*. However, as managers begin to regulate harvests more effectively, F will decline and approach *M*. Under such circumstances the accuracy of the assumed *M* becomes more important. Accordingly, the SARC 53 panel recommended that efforts be increased to evaluate size-specific, age-specific and inter-annual variation in *M* be expanded.
  - *This was considered and reported on under TOR 4 of SAW 55. The SAW 55 WG considered analyses which provide evidence for M greater (up to 0.6) than the currently assumed value of 0.2 during 2003 – 2006. These and other analyses were the basis of the WG's decision to consider an M change model option.*

- Study of the behavior of fishers in response to changes in the distribution of the stock and to changes in management. There was clear evidence presented in the assessment and at SARC 53 of changes in the distribution of cod within the stock area. The SARC 53 panel recommended that research and analyses be conducted to: 1) understand and characterize changes in the distribution of the stock, 2) understand and characterize changes in the distribution of fishing effort and to evaluate the impacts of such changes on the pattern and biological characteristics of removals from the stock and 3) evaluate the potential for changes in the distribution of effort to be associated with changes in the distribution of vulnerability of different components of the stock to fishing mortality.
  - *As reported under TOR 2, a number of analyses were undertaken to describe GOM cod distributional changes, which particularly since 2006, appear to have been driven by prey (sand lance) spatial processes. The associated changes in commercial and recreational effort distribution, as well as regulatory changes over the longer term, imply that LPUE is no longer a representative index of abundance and led to the WG's decision to exclude these time series from the base models.*

SAW 55 WG (new recommendations)

- The tagging analysis of Miller (2012, WP 31) provided evidence of natural mortality greater than 0.4 during the 2003 – 2006 period. Historical tagging data were reported to exist, but there was no comparable analysis to which this could be compared. It would be useful to reconsider historical tagging data using modern analytical methods similar to that in Miller (2012) to allow comparisons of the estimates of natural and fishing mortality. (High)

- Improved estimates of discard mortality/survival (i.e. post capture mortality) are needed, particularly in the recreational fishery. Studies which incorporate electronic tags and acoustic arrays would allow confirmation of the currently used estimates. (Low)

- Studies to provide information on the natural mortality of cod and inferred temporal trends are needed. Specifically, predator population estimates (i.e. pinnepeds) specific to Gulf of Maine/Georges Bank and focused stomach collection and analyses of fish and other predators would assist in evaluating whether or not natural mortality may have changed. (High)

- The SAW 55 WG noted that there may be advantages to inclusion of the tagging analysis formally within the stock assessment model. This would allow consideration of the factors affecting tagging estimates of F and M, including age/size based processes. This would be a longer-term project given the complexity of integrating the two analyses. (High, General)

- The SAW 55 WG discussed at length the appropriateness of the methods used to weight the proportions at age data within the ASAP and SCAA models. The current ASAP error assumption (multinomial) assumes that the standardized variance on the proportions at age is constant. Analyses were presented to the WG that indicated that the variance on the proportions at age was not constant and that in order to properly account for this in the model fitting process, it was necessary to employ an age-dependent weighting, as the adjusted log-normal does. While use of the multinomial would not produce biased estimates, it would likely result in the variance being over-estimated. Further, the AIC criterion would not be valid in model selection, although it was countered that the ASAP uses a penalized likelihood. This issue could not be fully resolved by the WG and further work is required to explore the appropriate weighting of the proportions at age data. (Medium, General)

- The SAW 55 WG considered an approach that incorporated the *Bigelow/Albatross* calibration coefficients within an SCAA assessment model. This allowed re-estimation of the coefficients as data on year-classes was updated. While the effect in this assessment was small, the approach may have merit and consideration should be given for the incorporation into the ASAP software. (Medium, General)

- Explore the utility of applying a random errors approach to the internal fitting of stock – recruitment relationships. This would require extensive software changes to ASAP code. (Medium, General)

- Simulations (conditioned on data) of the internal estimation of stock - recruitment functions be used to explore potential bias in the fitting of these relationships. (Medium, General)

SARC 55 Panel (new recommendations)

- Provide analysis on changes in the location and quality of preferred environment and habitats for cod and potential implications on *M* (adult and juvenile) and spawning potential.

- Telemetry tagging may provide a more direct way to measure natural mortality, particularly if there are local cod populations with high site fidelity.

- Consider other assessment models that include 'smoothing' approaches (e.g. penalized random walks) to deal with changes in fishery selectivity and natural mortality.

- Consider accounting for residual patterns and retrospective patterns using process errors. A rationale for this is that process errors can be projected into the future to potentially better account for the model/process uncertainty (indicated by residual and retrospective patterns) in projections and MSY reference points. The current approach of retrospective correcting for process error does not seem sufficient particularly in long-term projections for rebuilding analyses and reference point calculations. Uncertainty in calibrations to standardize survey time series for changes in vessels and fishing gear (i.e. doors) was not accounted for in the stock size indices. This may be a useful area for future research, although hopefully the time-series will soon be long enough that direct calibration will not be required.

- A GLM approach could be used to combine NEFSC and MADMF survey indices into two more complete indices for the Spring and Fall. The NEFSC surveys have better coverage in offshore strata, and the MADMF surveys had better coverage in inshore strata. Combining surveys would result in better coverage of the whole stock and hopefully better stock size indices.

- As part of the model building exercise, consider summarizing the information about mortality rates and trends in stock size using a survey-only assessment model such as SURBA. This could replace catch-curve estimation of Z's. It can also be used to explore conflict (or lack thereof) between surveys and catches.

- When stock-recruit data are uncertain but the time-series is long, consider constraining R_{max} to be some reasonable value (e.g. maximum of historic assessment values) and derive MSY reference points using the constrained stock-recruit curve. There are nonparametric approaches that could be used to address sensitivity of MSY reference points to simple parametric assumptions about stock-recruitment relationships

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Tables

Table A.1. Summary of model inputs and formulations used to assess the Gulf of Maine Atlantic cod stock over the last eleven years. *Notes: [1]1999-2000 commercial landings raised to account for commercial discards, [2]1999-2001 commercial landings raised to account for commercial discards, [3]Not known with certainty that MADMF time series included the spring 2002 survey, [4]1999-2004 commercial landings were raised to account for commercial discards.*

Year	Meeting	Model	Starting year	Catch data series				Survey series			Plus group
				Commercial landings	Commercial discards	Recreational landings	Recreational discards	NEFSC	MADMF	Commercial LPUE	
2001	SAW 33	VPA	1982	1982-2000[1]		1982-2000		1982-2000	1982-2000	1982-1993	7+
2002	GARM I	VPA	1982	1982-2001[2]		1982-2001		1982-2002	1982-2002[3]	1982-1993	7+
2005	GARM II	VPA	1982	1982-2004[4]		1982-2004		1982-2005	1982-2005	1982-1993	7+
2008	GARM III	VPA	1982	1982-2007	1999-2007	1982-2007		1982-2008	1982-2008	1982-1993	11+
2011	SARC 53	ASAP	1982	1982-2010	1982-2010	1982-2010	1982-2010	1982-2010	1982-2010		9+

Table A.2. Summary of the results of the Gulf of Maine Atlantic cod assessments over the last eleven years and the resulting stock status determinations based on the existing biological reference points at the time of the assessment. *Notes: [1]SR (BH) = Beverton-Holt stock recruitment; [2]Stock status was determined using a different basis in 2001 (total biomass, 25% of BMSY; Applegate et al. 1998); [3]YPR = Yield per recruit, based on 5-year averages of weights-at-age, maturity-at-age and selectivity-at-age, F_{MSY}=$F_{40\%}$. [4]YPR = Yield per recruit, based on 3-year averages of weights-at-age, F_{MSY}=$F_{40\%}$.*

Year	Meeting	SSB (mt)$_{terminal}$	$F_{terminal}$	F note	Reference point basis	SSBmsy (mt)	Fmsy	MSY (mt)	Stock status
2001	SAW 33	13,100 (B=24,400)	0.73	F_{avg4-5}	SR (BH)[1]	8,000 (B_{MSY}=90,300 mt)	0.230	N/A	Not overfished, overfishing is occuring[2]
2002	GARM I	22,040	0.47	F_{avg4-5}	SR (BH)[1]	82,830	0.225	16,600	Overfished, overfishing is occuring
2005	GARM II	18,800	0.63	F_{avg4-5}	SR (BH)[1]	82,830	0.225	16,600	Overfished, overfishing is occuring
2008	GARM III	33,877	0.46	F_{avg5-7}	YPR[3]	58,248	0.237	10,014	Not overfished, overfishing is occuring
2011	SARC 53	11,868	1.14	F_{mult}	YPR[4]	61,218	0.200	10,392	Overfished, overfishing is occuring

Table A.3. Summary of major regulatory actions that have affected the Gulf of Maine Atlantic cod fishery since 1973. For a more detailed summary of recent regulatory actions see Nies (2011).

Date	Regulatory action	Cod end minimum mesh size (in)	Minimum fish size (in)		Commercial trip limits	Recreational trip limits	Closures	Differential DAS Counting
			Commercial	Recreational				
01/01/73		4.5	?	?				
01/01/77	Groundfish FMP	5.125	16	16				
01/01/82			17	15				
01/01/83		5.5						
01/01/89			19	19				
04/01/92	Shrimp trawl fishery: Nordmore grate regulation, groundfish bycatch prohibited							
05/01/94	Amendment 5	6.0						DAS monitory w/ reduction schedule, mandatory reporting
05/01/96	Amendment 7			20				Accelerated DAS reduction
05/01/97	Framework 20			21	1000 lbs day for first 4 days, then 1500 lbs/day; no overall cap but RA had authority to reduce limit			
05/01/98	Framework 25				700 lbs/day; no overall cap but RA had authority to reduce limit		WGOM (Jeffreys Ledge, Stellwagen Bank)	
06/25/98					400 lbs/day; no overall cap but RA had authority to reduce limit			
02/01/99	Framework 26						Additional month-block closures for February to April	
05/01/99	Framework 27	6.5 square/6.0 diamond			200 lbs/day; no overall cap			
05/28/99					30 lbs/day			
08/03/99	Interim rule				100 lbs/day, 500 lbs max per trip; modifications to running clock			
01/05/00	Framework 31				400 lbs/day, 4000 lb/trip		Additional month-block closures for February	
06/01/00	Framework 33	6.5 square/6.5 diamond						
11/01/00							One month closure of Cashes Ledge	
05/01/02	Interim rule		22	23	500 lb/day, 4000 lb/trip	10 cod/person	Additional month-block closures for May - June 2003; Cashes Ledge Closed year round	20% reduction in DAS
06/01/02	Revised interim rule		19					
08/01/02	Emergency rule		22			5 - 10 cod/person (seasonal)		
05/01/04	Amendment 13				800 lb/day, 4000 lb/trip		WGOM, Cashes Ledge and rolling closures continued	Further reduction in DAS
05/01/06	Emergency rule				600 lb/day, 4000 lb/trip			
11/22/06	FW 42			24	800 lb/day, 4000 lb/trip	Possession prohibited November to March 31st		DAS counted 2:1 in inshore GOM
05/01/09	Interim rule					Possession prohibited November to April 15		
05/01/10	Amendment 16				None for sector vessels, varies in-season for common pool, handgear A and B vessels (50 lb/trip - 800 lb/day, 4000 lb/trip)	10 cod/person, Possession prohibited November to April 15	Some changes to rolling closures for sector vessels	DAS counted in 24 -hour blocks; no differential DAS counting except as AMs
05/01/11	Framework 45						Whaleback closure April 1 - June 30 (commercial and recreational)	
05/01/12	Framework 47			19		9 cod/person, Possession prohibited November to April 15		

Table A.4. Preliminary estimates of updated Atlantic cod gutted-to-live weight conversion factors summarized by quarter, sex and maturity stage. Raw data were provided by the Northeast Fisheries Science Center's Cooperative Research Program (C. Sarro pers. comm.).

Class variable		N	Mean	Standard Deviation	Coefficient of Variation	Median	5th Percentile	95th Percentile
All		422	1.200	0.091	0.076	1.190	1.077	1.381
Quarter	1	123	1.170	0.076	0.065	1.154	1.077	1.308
	2	179	1.191	0.099	0.083	1.172	1.070	1.381
	3	120	1.244	0.077	0.062	1.235	1.144	1.387
	4	0						
Sex	Male	98	1.172	0.085	0.073	1.157	1.070	1.323
	Female	84	1.214	0.110	0.091	1.189	1.077	1.415
Maturity	Immature	5	1.125	0.086	0.076	1.125	1.050	1.263
	Developing	35	1.209	0.072	0.059	1.200	1.107	1.333
	Ripe	19	1.241	0.098	0.079	1.222	1.103	1.488
	Ripe and running	11	1.193	0.068	0.057	1.174	1.111	1.333
	Spent	7	1.119	0.033	0.030	1.133	1.077	1.160
	Resting	85	1.154	0.063	0.054	1.143	1.077	1.267
	Unknown	1	1.222			1.222	1.222	1.222

Table A.5. Summary of the number of Atlantic cod otiliths sampled from Northeast Fisheries Science Center (NEFSC) bottom trawl surveys from 1970 to 2012 by stock and age. Otiliths that have not been aged are not included in this summary.

Age	Georges Bank	Gulf of Maine
0	372	188
1	2353	1378
2	4112	2544
3	3919	2832
4	2813	2462
5	1556	1420
6	781	782
7	369	378
8	190	171
9	79	116
10	54	59
11	28	33
12	14	30
13	4	16
14	6	18
15	3	3
16	1	3
17		1
18	1	

Table A.6. Number of Atlantic cod maturity samples taken from the Northeast Fisheries Science Center (NEFSC) spring survey from 1970 to 2012 by year.

Year	Unknown	Male	Female	Total
1970	6	41	51	98
1971		23	40	63
1972	2	31	50	83
1974	1	35	66	102
1975	4	42	75	121
1976	3	75	71	149
1977		70	88	158
1978		37	64	101
1979	13	96	119	228
1980		35	56	91
1981	5	112	106	223
1982	4	74	91	169
1983	2	77	66	145
1984	1	40	65	106
1985		47	81	128
1986	1	44	56	101
1987	2	77	46	125
1988	32	64	59	155
1989	3	68	74	145
1990	1	56	57	114
1991	1	62	70	133
1992	1	51	61	113
1993		45	63	108
1994	1	61	45	107
1995		39	36	75
1996		58	60	118
1997		60	63	123
1998		73	55	128
1999	5	80	71	156
2000	9	78	70	157
2001	1	46	79	126
2002	3	121	135	259
2003		156	121	277
2004	2	23	40	65
2005		52	52	104
2006	7	63	59	129
2007		85	127	212
2008	1	60	79	140
2009	6	148	229	383
2010		118	130	248
2011		46	58	104
2012	8	152	177	337

Table A.7. Gulf of Maine Atlantic cod female maturity ogive. The time series average incorporated data collected the Northeast Fisheries Science Center (NEFSC) spring survey between 1970 and 2012.

Age (years)	Proportion Mature	Lower 95% CI	Upper 95% CI
0	0.03	0.02	0.03
1	0.09	0.08	0.11
2	0.29	0.26	0.31
3	0.61	0.59	0.64
4	0.86	0.84	0.88
5	0.96	0.95	0.97
6	0.99	0.99	0.99
7	1.00	1.00	1.00
8	1.00	1.00	1.00
9	1.00	1.00	1.00
10	1.00	1.00	1.00
11	1.00	1.00	1.00

Table A.8. Estimates of Gulf of Maine of Atlantic cod catch (mt) by fleet (commercial, recreational) and disposition (landed, discarded) from 1982 to 2011.

Year	Recreational discards (mt)	Recreational landings (mt)	Commercial discards (mt)	Commercial landings (mt)	Total catch (mt)
1982	8.1	2816.7	805.4	13465.9	17096.2
1983	17.6	1772.8	829.1	13867.4	16486.8
1984	16.6	1266.8	858.9	10725.3	12867.6
1985	16.9	2765.9	962.9	10645.3	14390.9
1986	10.1	1928.4	964.2	9669.6	12572.4
1987	48.0	3547.2	884.0	7526.2	12005.4
1988	13.5	1688.5	682.9	7948.2	10333.2
1989	76.1	1957.2	786.9	10550.7	13370.8
1990	66.7	2246.7	1560.6	15439.7	19313.7
1991	68.0	2287.2	663.9	17959.0	20978.1
1992	35.5	623.6	668.6	11019.4	12347.0
1993	101.9	1011.9	479.8	8366.7	9960.4
1994	100.6	721.7	207.5	8030.2	9060.1
1995	96.2	627.2	235.4	6606.8	7565.6
1996	81.0	498.6	157.2	7019.8	7756.7
1997	58.8	236.3	87.1	5432.1	5814.3
1998	72.2	353.1	78.5	4074.3	4578.1
1999	71.7	577.2	1021.9	1407.4	3078.1
2000	137.6	967.1	946.1	3771.8	5822.7
2001	227.5	1967.6	1545.4	4314.4	8054.9
2002	286.9	1254.8	1329.1	3638.3	6509.1
2003	282.4	1607.7	741.0	3865.6	6496.7
2004	201.4	1150.9	631.1	3782.3	5765.7
2005	267.3	1346.9	269.5	3557.6	5441.3
2006	194.0	702.3	342.3	3029.4	4268.0
2007	316.9	1042.2	178.4	3989.8	5527.3
2008	315.4	1267.2	349.2	5443.5	7375.2
2009	292.4	1357.1	752.3	5952.9	8354.7
2010	384.5	1758.2	170.8	5356.4	7669.9
2011	334.2	1799.1	98.8	4597.9	6830.0

Table A.9. Historical estimates of Gulf of Maine of Atlantic cod catch (mt) by fleet (commercial, recreational) and disposition (landed, discarded) from 1932 to 1981. *Estimates of both United States (US) and foreign fleet commercial landings are shown. No estimates of recreational catch are available prior to 1981 and no estimates of commercial discards are available pre-1982.*

Year	US recreational discards (mt)	US recreational catch (mt)	US commercial discards (mt)	US commercial landings (mt)	Foreign landings (mt)	Total catch (mt)
1932				5,858.0		5,858.0
1933				7,025.0		7,025.0
1934				11,619.0		11,619.0
1935				9,679.0		9,679.0
1936				7,442.0		7,442.0
1937				7,432.0		7,432.0
1938				7,547.0		7,547.0
1939				5,504.0		5,504.0
1940				5,836.0		5,836.0
1941				6,124.0		6,124.0
1942				6,679.0		6,679.0
1943				9,397.0		9,397.0
1944				10,516.0		10,516.0
1945				14,532.0		14,532.0
1946				9,248.0		9,248.0
1947				6,916.0		6,916.0
1948				7,462.0		7,462.0
1949				7,033.0		7,033.0
1950				5,062.0		5,062.0
1951				3,567.0		3,567.0
1952				3,011.0		3,011.0
1953				3,121.0		3,121.0
1954				3,411.0		3,411.0
1955				3,171.0		3,171.0
1956				2,693.0		2,693.0
1957				2,562.0		2,562.0
1958				4,670.0		4,670.0
1959				3,795.0		3,795.0
1960				3,448.0		3,448.0
1961				3,216.0		3,216.0
1962				2,989.0		2,989.0
1963				2,595.0		2,595.0
1964				3,217.4	25.0	3,242.4
1965				3,611.5	148.0	3,759.5
1966				3,841.1	384.0	4,225.1
1967				5,526.6	297.0	5,823.6
1968				6,076.0	61.0	6,137.0
1969				7,828.4	327.0	8,155.4
1970				7,511.7	449.0	7,960.7
1971				7,192.5	282.0	7,474.5
1972				6,786.1	141.0	6,927.1
1973				6,061.1	77.0	6,138.1
1974				7,425.4	125.0	7,550.4
1975				8,676.1	112.0	8,788.1
1976				9,877.7	16.0	9,893.7
1977				11,992.8		11,992.8
1978				11,890.1		11,890.1
1979				10,972.3		10,972.3
1980				12,514.9		12,514.9
1981	18.8	4,111.5		12,381.6		16,512.0

Table A.10. Coefficients of variation (CV) associated with the landings allocation procedure (AA tables, Wigley et al. 2008) for Gulf of Maine Atlantic cod commercial landings.

Year	CV
1994	0.003
1995	0.012
1996	0.003
1997	0.003
1998	0.003
1999	0.007
2000	0.003
2001	0.002
2002	0.003
2003	0.002
2004	0.003
2005	0.002
2006	0.002
2007	0.001
2008	0.001
2009	0.001
2010	0.003
2011	0.002

Table A.11. Relative differences between VTR and VMS-based allocation of Gulf of Maine Atlantic cod by stock and year (from Palmer and Wigley 2012).

Year	Stock	
	GBK	GOM
2004	0.7	-1.9
2005	2.2	-5.0
2006	0.2	-0.2
2007	0.8	-0.8
2008	0.6	-0.4
2009	1.0	-0.6
2010	2.0	-1.0
2011	2.0	-1.0

Table A.12. Estimates of total United States landings of Gulf of Maine Atlantic cod associated with 'non-dealer' transactions from 1994 to 2011. These estimates are obtained from information reported on Vessel Trip Reports (VTRs).

Year	Home consumption (mt)	Bait (mt)	LUMF (mt)	Total non-dealer transacations (mt)	Total commercial landings (mt)	Percentage of total dealer landings (%)
1994	0.9			0.9	8030.2	0.0
1995	3.5	0.1		3.5	6606.8	0.1
1996	8.3	0.1		8.4	7019.8	0.1
1997	3.2			3.2	5432.1	0.1
1998	3.3	0.0		3.3	4074.3	0.1
1999	4.0	0.0		4.1	1407.4	0.3
2000	5.3	0.0		5.4	3771.8	0.1
2001	6.7	0.2		6.9	4314.4	0.2
2002	6.6			6.6	3638.3	0.2
2003	6.3			6.3	3865.6	0.2
2004	4.0			4.0	3782.3	0.1
2005	3.1	0.0		3.1	3557.6	0.1
2006	2.4			2.4	3029.4	0.1
2007	1.6	0.1		1.7	3989.8	0.0
2008	2.0			2.0	5443.5	0.0
2009	1.2	0.0		1.2	5952.9	0.0
2010	3.5	0.0	0.5	4.0	5356.4	0.1
2011	0.7	0.1	0.5	1.3	4597.9	0.0

Table A.13. Total number of Gulf of Maine Atlantic cod biological samples taken from commercial landings by market category and year between 1969 and 2011.

Year	Scrod (0814) Quarter 1	Scrod (0814) Quarter 2	Scrod (0814) Quarter 3	Scrod (0814) Quarter 4	Market (0813) Quarter 1	Market (0813) Quarter 2	Market (0813) Quarter 3	Market (0813) Quarter 4	Large (0811) Quarter 1	Large (0811) Quarter 2	Large (0811) Quarter 3	Large (0811) Quarter 4	Total	Total lengths (excludes unclassified)	Sampling intensity (lengths/sample)
1969															
1970					1								1	100	100.0
1971															
1972															
1973															
1974	1							1					2	203	101.5
1975		1		1									2	248	124.0
1976															
1977	1	1	3	3		1	2	1		1	1		14	2,525	180.4
1978	3	2	1		2	2	2	1			1		14	2,256	161.1
1979	1		1	2		1	2	1					8	755	94.4
1980	3	1	1										5	364	72.8
1981	1	1	1	3			1	3			1		11	1,189	108.1
1982	2	3	3	2	2	2	3	1		2	1	2	23	3,848	167.3
1983	3	3	3	3	3	3	3	1	1	2	2	2	29	5,241	180.7
1984	7	5	6	7	4	3	5	6	1	6	3	2	55	3,925	71.4
1985	5	6	7	5	9	6	7	4	7	5	3	6	70	5,284	75.5
1986	5	5	6	3	5	6	8	3	1	5	4	3	54	4,069	75.4
1987	5	4	3	4	4	5	3	5	4	2	3	1	43	3,188	74.1
1988	4	2	4	4	1	5	3	5	1	2	2		33	2,619	79.4
1989	3	3	4	3	4	2	5	4	2	1	1	1	33	2,718	82.4
1990	3	7	3	5	4	7	4	3		2	1		39	2,981	76.4
1991	2	10	4	4	5	11	12	3		3	3	1	58	4,676	80.6
1992	2	8	6	3	6	7	7	3	3	1	1	4	51	4,086	80.1
1993	3	3	3	1	1	2	4	1	1	1	2	1	23	1,686	73.3
1994		2	2	4	1	6	3	5		2	3	2	30	2,658	88.6
1995	4	3	2	4	2	8	2	2		3		1	31	2,557	82.5
1996	5	4	7	9	6	9	11	11	1	2	3	3	71	6,486	91.4
1997	7	13	3	10	12	11	10	9	2	8	2	2	89	7,559	84.9
1998	4	7		3	9	9	9	5	1		2	1	50	4,536	90.7
1999	6				3	1	1		2				13	1,073	82.5
2000	13	6	5	7	16	14	5	9				1	76	5,921	77.9
2001	4	4	4	7	4	10	8	16	2	15	18	20	112	7,117	63.5
2002	3	2		1	16	3	6	5	50	8	16	19	129	5,263	40.8
2003	5	1	17	8	14	8	25	19	50	34	34	33	248	11,479	46.3
2004	17	11	6	22	18	23	15	15	37	20	11	27	222	11,210	50.5
2005	23	29	33	16	14	15	22	19	21	41	72	64	369	10,163	27.5
2006	15	8	8	3	17	21	18	12	48	49	62	63	324	10,770	33.2
2007	10	6	11	8	7	14	18	17	43	73	102	60	371	10,623	28.6
2008	13	7	5	7	12	15	13	11	58	72	73	71	357	10,922	30.6
2009	9		2	14	10	17	20	37	61	97	114	135	516	14,871	28.8
2010	4	2		9	30	22	42	21	79	52	77	33	371	17,451	47.0
2011	6	7	3	13	23	33	32	36	23	71	49	41	337	18,682	55.4

Table A.14. Total numbers of Gulf of Maine Atlantic cod lengths sampled from commercial landings by market category and year between 1969 and 2011. Sampling intensity is expressed as metric tons landings per 100 lengths sampled (*200 metric tons per 100 lengths is an unofficial NAFO/ICNAF standard*). Cells shaded in grey indicate where lengths were aggregated semi-annually. Cells shaded orange indicate where lengths were aggregated annually. Aggregation occurred when length sampling was insufficient; a general criterion of 100 lengths/block was used to determine sufficiency.

Year	Scrod (0814)				Market (0813)				Large (0811)				Unclassified (0815)				Total lengths	Landings (mt)	Metric tons/100 lengths
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4			
1969																114	114	7,828	6867.0
1970					100								287				387	7,512	1941.0
1971																	0	7,193	
1972																	0	6,786	
1973																	0	6,061	
1974	102							101									203	7,425	3657.8
1975		186		62													248	8,676	3498.4
1976														101		56	157	9,878	6291.5
1977	101	66	402	1012		277	371	64		80	152						2,525	11,993	475.0
1978	407	455	65		370	304	500	100			55						2,256	11,890	527.0
1979	56		58	116		100	237	188									755	10,972	1453.3
1980	213	100	51										212				576	12,515	2172.7
1981	52	57	81	236			82	471			210						1,189	12,382	1041.3
1982	401	488	484	308	418	309	665	345		208	64	158	97	102	122		4,169	13,466	323.0
1983	712	626	578	253	396	1021	583	200	56	205	514	97		53			5,294	13,867	261.9
1984	344	271	342	378	396	264	443	551	75	552	204	105	94				4,019	10,725	266.9
1985	263	352	449	241	837	565	677	351	542	341	263	403					5,284	10,645	201.5
1986	229	264	319	160	520	608	834	329	75	279	269	183					4,069	9,670	237.6
1987	281	232	165	271	344	490	351	399	157	150	258	90					3,188	7,526	236.1
1988	298	99	215	249	59	539	291	481	59	194	135						2,619	7,948	303.5
1989	154	170	201	174	401	204	506	***409***	195	102	104	98					2,718	10,551	388.2
1990	156	362	165	260	409	715	370	300		136	108						2,981	15,440	517.9
1991	100	533	192	215	514	1034	***1137***	275		302	273	101					4,676	17,959	384.1
1992	***118***	443	320	180	633	725	592	263	297	142	75	298					4,086	11,019	269.7
1993	159	173	174	55	97	173	393	106	65	87	141	63		67			1,753	8,367	477.3
1994		102	107	181	97	576	324	567		184	322	198					2,658	8,030	302.1
1995	211	196	107	249	170	807	215	224		280		98					2,557	6,607	258.4
1996	278	275	491	691	596	961	1165	1178	68	200	303	280					6,486	7,020	108.2
1997	520	848	188	751	1235	1071	991	880	190	539	201	145					7,559	5,432	71.9
1998	295	383		101	911	951	1103	436	99		175	82					4,536	4,074	89.8
1999	385				311	108	58		***211***								1,073	1,407	131.2
2000	694	304	294	426	1588	1167	409	924				115					5,921	3,772	63.7
2001	189	215	216	404	428	984	697	1548	172	474	892	898					7,117	4,314	60.6
2002	106	80		39	1365	260	411	395	1192	397	524	494					5,263	3,638	69.1
2003	254	66	214	73	1121	705	1762	1402	1179	1432	1583	1688					11,479	3,866	33.7
2004	361	299	233	73	1384	1887	1288	994	2049	***1419***	283	940	25				11,235	3,782	33.7
2005	73	193	324	506	919	1095	1384	1362	790	709	1330	1478		61	180		10,404	3,558	34.2
2006	494	167	294	125	1291	1412	1075	753	***1552***	871	1348	1388					10,770	3,029	28.1
2007	291	174	315	293	584	1188	1521	1488	654	811	1887	1417			66		10,689	3,990	37.3
2008	536	251	203	85	969	1403	1196	927	712	1314	1753	1573					10,922	5,443	49.8
2009	407		62	141	800	1601	***1791***	2601	954	***1656***	2304	2554					14,871	5,953	40.0
2010	150	53		199	2679	1762	2788	1741	1428	2106	2561	1984					17,451	5,356	30.7
2011	287	320	144	577	2005	2848	2674	3260	1141	2250	1884	1292					18,682	4,598	24.6

Table A.15. Total numbers of Gulf of Maine Atlantic cod ages sampled from commercial landings by quarter between 1977 and 2011.

Year	Quarter 1	2	3	4	Total	Landings (mt)	Metric tons/100 ages
1977	20	114	229	205	568	11992.8	2111.4
1978	124	124	115	20	383	11890.1	3104.5
1979	10	20	48	52	130	10972.3	8440.2
1980	35	27	15		77	12514.9	16253.1
1981	12	15	67	170	264	12381.6	4690.0
1982	194	237	251	183	865	13465.9	1556.7
1983	277	513	400	158	1348	13867.4	1028.7
1984	245	350	296	337	1228	10725.3	873.4
1985	446	377	397	323	1543	10645.3	689.9
1986	243	360	398	173	1174	9669.6	823.6
1987	252	229	226	228	935	7526.2	804.9
1988	131	223	187	196	737	7948.2	1078.5
1989	206	129	203	165	703	10550.7	1500.8
1990	140	302	171	150	763	15439.7	2023.6
1991	126	447	385	152	1110	17959.0	1617.9
1992	220	298	264	178	960	11019.4	1147.9
1993	72	130	186	49	437	8366.7	1914.6
1994	21	195	149	308	673	8030.2	1193.2
1995	144	311	101	126	682	6606.8	968.7
1996	190	315	426	449	1380	7019.8	508.7
1997	395	632	331	285	1643	5432.1	330.6
1998	192	325	276	199	992	4074.3	410.7
1999	227	27	11		265	1407.4	531.1
2000	639	481	205	396	1721	3771.8	219.2
2001	280	574	674	950	2478	4314.4	174.1
2002	1320	301	437	347	2405	3638.3	151.3
2003	1046	1111	1948	1525	5630	3865.6	68.7
2004	1880	1011	425	228	3544	3782.3	106.7
2005	494	644	1117	1287	3542	3557.6	100.4
2006	1109	806	1225	1197	4337	3029.4	69.9
2007	719	1020	1138	1030	3907	3989.8	102.1
2008	858	1225	1213	1173	4469	5443.5	121.8
2009	947	1407	1684	2222	6260	5952.9	95.1
2010	1335	1235	1856	1103	5529	5356.4	96.9
2011	735	1867	1555	1412	5569	4597.9	82.6

Table A.16. Percent of Gulf of Maine Atlantic cod length observations missing corresponding age information by market category and quarter. Cells shaded in grey indicate where lengths were aggregated semi-annually. Cells where the imputation percentage exceeded 5% are highlighted in bold italics. Cells where no imputation was required are null.

Year	Scrod (0814)				Market (0813)				Large (0811)			
	Quarter				Quarter				Quarter			
	1	2	3	4	1	2	3	4	1	2	3	4
1982	0.5	0.4	3.3	0.3					***22.6***		***12.2***	
1983		0.2							1.1		0.2	
1984			0.3	0.3							0.5	1.0
1985									0.4		1.1	0.2
1986									0.8			3.8
1987									0.6		0.6	
1988	1.3							0.8			2.2	
1989								***18.8***		***19.6***	2.5	
1990												
1991	***44.0***		4.7	0.9	2.5		4.3		4.3		***11.4***	***33.7***
1992	1.7								***5.4***	***12.0***	***10.2***	
1993			0.4		***8.1***		0.5	***12.3***	2.6		***9.3***	
1994			0.9				0.3		***19.6***		***7.5***	1.0
1995	***21.3***				1.2				0.7		***28.6***	
1996	3.6				0.2						1.0	***5.0***
1997		0.7		0.3	0.5				***14.7***	0.4		2.1
1998		***5.7***							4.8			
1999									2.8			
2000	0.1								2.6			
2001									1.7	0.6	0.2	0.1
2002									0.3	1.0		
2003			1.0						0.4	0.1	0.1	0.1
2004		0.7							0.1		1.1	0.7
2005									0.4	0.1	0.3	0.1
2006									0.2	0.9	0.3	0.5
2007									0.6	0.1	0.7	0.4
2008										0.1	0.2	
2009			0.5				0.2			0.2		
2010											0.0	0.1
2011												

Table A.17. Total Gulf of Maine Atlantic cod commercial landings-at-age (numbers) from 1982 to 2011.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1982		27,609	1,335,509	1,634,173	1,116,072	619,571	51,241	69,146	59,375	43,415	32,683	6,285	898				
1983			833,083	2,413,843	1,067,910	627,331	407,393	44,212	57,669	25,845	12,747	3,800	3,515	1,719	2,599		
1984		2,782	425,538	1,227,232	1,504,575	396,710	195,918	96,402	9,105	16,794	14,229	11,957	2,335	3,863	1,235		
1985			387,614	1,440,985	1,002,193	615,000	123,315	73,198	32,430	3,962	10,619	2,438	4,573	1,583	470		
1986			85,363	2,187,322	818,717	239,742	161,736	38,700	27,497	19,813	4,745	1,497	3,940	2,434	306		
1987		442	193,735	627,766	1,116,907	267,706	64,579	45,981	5,481	8,410	9,270	182	607		2,129		
1988			167,468	1,356,369	907,960	400,942	58,792	21,864	20,247	3,257	2,438	1,213			606		
1989			322,130	1,486,592	1,354,890	451,857	70,570	58,876	7,931	2,238	9,000	3,945		1,127	1,127		
1990			210,618	3,403,626	2,227,578	452,797	151,887	25,246	24,675	7,680	16,034	11,764	2,353	3,597			
1991			198,915	609,915	4,543,525	904,421	138,556	42,961	25,983	7,877	4,698	2,571					
1992			302,552	527,720	432,280	1,969,905	213,021	77,420	5,837	4,488	1,042						
1993			25,866	1,543,228	729,548	92,745	464,198	37,780	11,264								
1994			29,014	1,055,313	1,170,244	240,940	63,586	69,917	28,114	6,108	384	1,008					
1995			183,724	938,703	1,056,404	207,195	28,494	6,521	17,992	580	2,228						
1996			55,763	507,349	1,763,068	375,559	35,144	3,903	413	845							
1997			77,455	434,378	435,036	800,750	67,415	5,368	2,080	393	636						
1998			87,919	391,916	544,744	139,369	187,088	27,507	4,853	1,495	762						
1999			2,858	179,688	191,438	66,127	23,995	22,398	7,504	1,035							
2000			102,341	258,469	501,545	124,105	66,295	9,007	6,465								
2001			43,737	471,763	326,442	206,475	65,902	38,490	5,509	8,803	1,006						
2002			1,439	111,287	433,957	170,415	102,971	41,667	12,019	3,750	4,055	434	80		40		
2003			8,113	47,543	198,476	380,859	120,697	52,001	19,769	9,173	4,250	2,812	472				
2004			492	142,749	130,172	220,142	170,502	52,305	26,442	13,941	6,789	1,414	620				
2005			1,217	37,890	423,154	64,419	178,040	83,220	21,459	12,366	5,056	3,125	1,817	500			
2006			777	115,306	181,958	300,653	21,412	62,692	29,111	10,477	5,994	2,537	1,242	953	180		
2007			5,209	95,694	629,852	99,105	178,429	5,952	15,582	7,698	3,753	1,468	1,323	1,174	126	345	
2008			4,142	283,069	465,757	600,316	53,944	82,494	2,490	6,652	3,224	986	473	367	234	104	21
2009			2,700	283,610	718,934	333,800	199,827	16,653	20,518	857	2,311	1,072	952	224	127	61	49
2010			1,683	121,449	578,192	463,641	114,076	59,845	8,069	2,947	446	476	162	112	17	28	
2011			534	97,964	296,737	396,070	256,786	26,149	29,090	4,906	1,177	196	538	68	178		

Table A.18. Coefficients of variation (CV) associated with the estimates of Gulf of Maine Atlantic cod commercial landings numbers-at-age from 1982 to 2011. CVs greater than 0.3 are shaded grey.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15	Age 16
1984	0.7443	0.12	0.04	0.02	0.04	0.06	0.06	0.17	0.16	0.22	0.20	0.39	0.29	0.69		
1985		0.08	0.06	0.04	0.03	0.05	0.05	0.10	0.25	0.14	0.27	0.35	0.48	0.76		
1986		0.18	0.05	0.04	0.06	0.08	0.14	0.13	0.20	0.44	0.56	0.37	0.65	0.89		
1987	1.3501	0.19	0.07	0.04	0.07	0.09	0.15	0.29	0.28	0.43	0.90	0.44		0.68		
1988		0.29	0.06	0.05	0.06	0.09	0.15	0.24	0.48	0.81	0.81			1.32		
1989		0.38	0.08	0.09	0.07	0.14	0.24	0.33	0.56	0.23	0.34		0.68	0.69		
1990		0.26	0.07	0.08	0.13	0.24	0.47	0.36	0.41	0.26	0.28	0.67	0.70			
1991		0.23	0.15	0.04	0.11	0.12	0.23	0.31	0.27	1.02	0.64					
1992		0.18	0.20	0.13	0.06	0.11	0.18	0.62	0.56	0.88						
1993		0.89	0.09	0.18	0.29	0.11	0.34	0.41								
1994		0.49	0.10	0.07	0.27	0.25	0.21	0.22	0.64	1.02	0.89					
1995		0.25	0.12	0.09	0.10	0.35	0.23	0.21	1.05	0.61						
1996		0.27	0.10	0.04	0.14	0.20	0.28	0.95	0.69							
1997		0.20	0.09	0.07	0.06	0.14	0.32	0.27	0.62	0.60						
1998		0.16	0.11	0.07	0.15	0.15	0.27	0.37	0.49	0.99						
1999			0.19	0.12	0.31	0.36	0.23	0.17	0.58							
2000		0.14	0.08	0.06	0.12	0.23	0.49	0.55								
2001		0.24	0.06	0.07	0.08	0.11	0.14	0.30	0.28	0.59						
2002		1.11	0.22	0.05	0.09	0.07	0.11	0.15	0.29	0.26	0.48	1.21		1.38		
2003		0.35	0.17	0.05	0.03	0.06	0.07	0.10	0.17	0.19	0.23	0.46				
2004		1.38	0.11	0.07	0.07	0.06	0.09	0.13	0.21	0.23	0.49	0.75				
2005		0.66	0.15	0.05	0.08	0.09	0.08	0.12	0.12	0.15	0.21	0.26	0.42			
2006		1.02	0.17	0.06	0.04	0.14	0.09	0.09	0.14	0.11	0.17	0.22	0.27	0.56		
2007		0.49	0.13	0.04	0.08	0.10	0.27	0.19	0.12	0.15	0.25	0.23	0.27	0.69	0.46	
2008		0.72	0.10	0.05	0.05	0.13	0.08	0.39	0.16	0.17	0.29	0.38	0.44	0.56	0.80	1.43
2009		0.52	0.10	0.05	0.09	0.07	0.18	0.12	0.25	0.17	0.26	0.26	0.40	0.59	0.90	1.01
2010		0.50	0.12	0.04	0.04	0.08	0.10	0.13	0.16	0.38	0.34	0.66	0.67	1.38	1.42	
2011		0.28	0.04	0.02	0.01	0.01	0.02	0.02	0.07	0.14	0.34	0.26	0.72	0.45		
Average	1.05	0.43	0.11	0.06	0.10	0.13	0.19	0.27	0.35	0.43	0.42	0.46	0.50	0.82	0.90	1.22

Table A.19. Mean weights-at-age (kg) of commercially landed Gulf of Maine Atlantic cod from 1982 to 2011.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15	Age 16
1982		0.831	1.177	1.669	2.790	5.006	7.097	9.580	9.945	12.789	19.365	16.480	22.443				
1983			1.172	1.621	2.428	3.812	6.058	5.982	10.480	11.548	11.138	18.890	12.669	24.552	22.224		
1984		0.569	1.179	1.656	2.679	3.568	5.563	8.541	10.290	13.711	14.485	14.318	15.430	17.886	19.285		
1985			1.312	1.740	2.820	4.528	5.610	8.436	11.238	12.479	14.280	13.394	16.112	16.739	22.012		
1986			1.392	1.819	2.905	4.691	6.272	7.994	9.826	13.592	13.496	15.888	15.808	20.232	16.834		
1987		0.998	1.369	1.719	3.252	4.805	6.912	9.318	10.769	14.810	16.101	13.418	8.066		22.379		
1988			1.293	1.943	2.448	5.282	5.315	6.374	9.951	10.434	17.787	9.857			21.886		
1989			1.314	1.763	3.055	4.242	5.943	9.379	13.425	16.500	20.410	22.606		27.911	27.896		
1990			1.247	1.660	2.238	4.380	7.816	11.229	12.270	15.999	16.344	22.690	23.134	22.138			
1991			1.489	1.834	2.412	4.031	7.164	9.689	12.261	15.093	6.203	24.937					
1992			1.608	1.941	2.899	3.070	5.699	10.984	10.766	13.418	19.072						
1993			1.356	1.930	2.350	4.595	5.802	9.649	13.673								
1994			1.434	1.955	3.186	3.349	6.350	7.787	12.422	10.012	22.008	22.643					
1995			1.588	1.774	2.838	5.187	7.054	11.466	13.223	19.756	23.143						
1996			1.746	2.258	2.337	3.532	7.523	11.759	14.795	16.331							
1997			1.846	2.291	3.093	3.162	4.829	9.027	12.177	15.625	17.749						
1998			1.396	2.020	2.726	4.025	4.376	7.235	12.111	17.500	15.060						
1999			1.545	1.741	2.539	3.390	5.049	7.563	10.220	12.279							
2000			1.736	2.608	3.635	4.678	6.158	5.600	8.939								
2001			1.937	2.556	3.400	5.036	6.544	7.684	9.213	8.945	17.660						
2002			1.326	2.706	3.378	4.269	6.300	7.072	8.965	10.167	10.786	15.353	17.249		18.746		
2003			1.871	2.475	3.279	4.321	5.544	7.584	8.892	10.909	12.121	13.709	14.362				
2004			1.648	2.689	3.686	4.261	5.976	7.590	9.902	12.654	14.059	11.423	22.553				
2005			1.926	2.274	3.118	4.584	4.793	6.447	8.066	11.054	13.942	14.901	15.362	19.605			
2006			2.671	2.540	3.437	3.877	4.905	5.673	7.605	9.709	12.724	16.000	15.761	20.480	20.326		
2007			2.090	2.616	3.317	4.053	5.014	6.518	7.182	10.140	12.199	13.344	14.213	17.126	21.784	21.757	
2008			1.848	2.768	3.145	3.811	4.777	6.036	6.106	8.583	11.258	13.800	16.189	19.251	19.918	18.735	25.984
2009			1.939	2.766	3.532	3.972	4.775	6.007	8.367	11.208	10.805	12.934	15.971	15.803	22.452	22.459	22.812
2010			2.228	2.731	3.528	4.268	4.874	5.550	8.478	10.152	11.016	13.209	12.519	16.891	20.103	16.834	
2011			1.746	2.724	3.389	4.094	4.988	5.934	6.076	11.750	12.190	17.376	17.827	23.845	19.502		
Average		0.799	1.614	2.160	2.995	4.196	5.836	7.990	10.254	12.755	14.823	16.056	16.216	20.189	21.096	19.946	24.398

Table A.20. Fractions of the total Gulf of Maine Atlantic cod observed to have been discarded by the commercial fishery from 1989 to 2011, broken down by gear type. Gears contributing greater than 5% of the total observed discards in any year are shaded grey.

Year	Total observed discards (mt)	Fraction of total observed discards								
				Otter trawl (mt)			Sink Gillnet (mt)			
		Longline	Handline	Small mesh (< 5.5")	Large mesh (>= 5.5")	Shrimp trawl	Small mesh (< 5.5")	Large mesh (5.5 - 7.99")	Extra large mesh (>= 8.0")	Other
1989	4.1	0.00	0.00	0.03	**0.37**	**0.37**	0.00	**0.23**	0.00	0.00
1990	5.7	0.00	0.00	0.00	**0.37**	**0.34**	0.00	**0.29**	0.00	0.00
1991	11.3	0.00	0.00	0.00	**0.23**	**0.14**	0.00	**0.63**	0.00	0.00
1992	9.7	0.01	0.00	0.00	**0.35**	**0.06**	0.00	**0.58**	0.00	0.00
1993	4.6	0.01	0.00	0.00	**0.21**	0.02	0.00	**0.76**	0.00	0.00
1994	1.0	0.00	0.00	0.00	**0.24**	**0.10**	0.00	**0.62**	0.04	0.01
1995	2.0	0.00	0.00	**0.10**	**0.50**	0.02	0.00	**0.33**	**0.06**	0.00
1996	1.1	0.00	0.01	**0.10**	**0.12**	0.01	0.00	**0.65**	**0.11**	0.01
1997	0.4	0.00	0.00	**0.06**	**0.21**	0.02	0.00	**0.62**	**0.07**	0.03
1998	0.9	0.00	0.00	0.00	0.01	0.00	0.00	**0.96**	0.02	0.01
1999	11.3	0.00	0.00	0.02	**0.07**	0.00	0.00	**0.91**	0.00	0.00
2000	11.3	0.00	0.00	0.00	**0.68**	0.00	0.00	**0.31**	0.01	0.00
2001	14.5	0.00	0.00	0.00	**0.66**	0.00	0.00	**0.32**	0.01	0.00
2002	21.3	0.00	0.00	0.04	**0.65**	0.00	0.00	**0.28**	0.03	0.00
2003	36.5	0.02	0.00	0.04	**0.63**	0.00	0.00	**0.24**	**0.06**	0.00
2004	34.0	0.00	0.00	0.02	**0.34**	0.00	0.00	**0.43**	**0.21**	0.00
2005	28.1	**0.16**	0.00	**0.07**	**0.36**	0.00	0.00	**0.31**	**0.09**	0.00
2006	14.3	**0.17**	0.00	0.04	**0.61**	0.00	0.00	**0.16**	0.02	0.00
2007	13.2	**0.14**	0.00	0.01	**0.67**	0.00	0.00	**0.14**	0.03	0.00
2008	33.3	**0.06**	0.00	0.01	**0.86**	0.00	0.00	**0.05**	0.02	0.00
2009	80.9	0.02	0.00	0.00	**0.86**	0.00	0.00	**0.10**	0.01	0.00
2010	33.8	0.03	0.00	0.01	**0.61**	0.00	0.00	**0.26**	**0.07**	0.01
2011	39.4	**0.12**	0.04	0.01	**0.59**	0.00	0.00	**0.21**	0.02	0.00

Table A.21. Preliminary estimates of Gulf of Maine Atlantic cod commercial handline discards from SAW 53 (NEFSC 2012).

Year	Trips	Handline (mt)	CV
1989			
1990			
1991			
1992	2	0.0	
1993			
1994	2		
1995	1		
1996	2		
1997			
1998			
1999	1		
2000			
2001			
2002			
2003	1		
2004	3	0.0	
2005	4	34.4	0.69
2006	2	0.0	
2007	5	6.9	0.62
2008			
2009	3	75.9	0.49
2010	10	44.1	0.98
2011	30		

Table A.22. Number of Ruhle and haddock separator trawl trips recorded in the commercial dealer data and in the at-sea observer data from the Gulf of Maine. Fractional trips in the dealer data are a function of the stock allocation process used to partition dealer-reported landings to stock area.

Year	NEGEAR	Number of dealer trips	Number of observed trips
2009	054	6.0	
2009	057		2
2010	054	0.3	
2010	057	12.1	17
2011	054	1.0	
2011	057	5.9	31

Table A.23. Total number of Gulf of Maine trips (statistical areas 464, 465, 467, 511-515) observed from 1989 to 2011, summarized by gear type. *The 2010-11 numbers include trips observed by both at-sea monitors and observers.*

Year	Longline	Otter trawl		Shrimp trawl	Sink Gillnet		Total
		Small mesh (< 5.5")	Large mesh (>= 5.5")		Large mesh (5.5" - 7.99")	Extra large mesh (>= 8.0")	
1989		23	44	40	84		191
1990		8	26	31	120		185
1991	2	29	53	52	801		937
1992	9	15	45	82	896		1047
1993	2	6	17	81	560		666
1994			9	77	82	7	175
1995		30	29	73	62	14	208
1996		40	19	35	39	10	143
1997		3	7	16	31	5	62
1998			7		78	6	91
1999		11	25		70	8	114
2000			122		70	19	211
2001		4	136	3	39	21	203
2002		34	199		62	25	320
2003	14	19	278	15	254	95	675
2004	8	68	321	12	587	340	1336
2005	58	69	534	17	505	251	1434
2006	36	24	209	20	109	35	433
2007	36	16	234	14	92	46	438
2008	20	12	260	19	130	49	490
2009	35	22	428	12	271	30	798
2010	52	30	685	15	1080	379	2241
2011	80	25	1098	1	1382	264	2850

Table A.24. Estimates of total Gulf of Maine Atlantic cod commercial discards (mt) by gear from 1982 to 2011 by gear. Estimates from 1989 to 2011 were estimated using an approach consistent with the Standardized Bycatch Report Methodology (Wigley et al., 2007). Estimates from 1982 to 1988 were hindcasted using an approach documented in this report. *Gear-specific estimates do not account for survival of discarded fish.*

Year	Longline	Otter trawl		Shrimp trawl	Sink Gillnet		Total	Total w/ discard survival
		Small mesh (< 5.5")	Large mesh (>= 5.5")		Large mesh (5.5" - 7.99")	Extra large mesh (>= 8.0")		
1982			882.9	144.0	108.3		1135.2	805.4
1983			904.5	160.1	104.9		1169.4	829.1
1984			861.4	228.6	120.0		1209.9	858.9
1985			943.4	311.2	105.9		1360.5	962.9
1986			853.5	380.6	125.5		1359.5	964.2
1987			774.1	345.9	125.1		1245.0	884.0
1988			612.0	216.7	128.5		957.2	682.9
1989		6.1	677.3	256.4	161.2		1101.1	786.9
1990		0.9	1567.6	410.7	219.0		2198.2	1560.6
1991	0.3	0.8	621.1	205.2	106.0		933.5	663.9
1992	8.0	0.0	778.7	48.9	108.2		943.8	668.6
1993	281.7	0.0	370.8	6.3	153.6		812.4	479.8
1994			163.8	7.5	105.1	4.3	280.8	207.5
1995		8.3	152.5	4.0	129.7	20.3	314.9	235.4
1996		3.3	25.1	3.0	145.2	23.7	200.4	157.2
1997		16.6	27.9	4.7	59.1	6.8	115.0	87.1
1998			11.6		82.4	5.5	99.5	78.5
1999		11.6	826.5		536.0	8.1	1382.1	1021.9
2000			789.0		473.8	18.5	1281.3	946.1
2001		0.2	873.0	0.0	1113.5	54.2	2040.9	1545.4
2002		16.4	868.6		828.6	58.4	1772.0	1329.1
2003	66.4	22.0	553.8	2.6	321.8	71.0	1037.6	741.0
2004	7.9	2.9	532.4	0.9	231.8	84.6	860.6	631.1
2005	123.9	3.8	166.0	1.1	109.5	26.7	431.0	269.5
2006	47.7	2.6	337.7	0.3	94.3	15.8	498.4	342.3
2007	67.3	2.0	102.6	0.9	83.6	19.3	275.7	178.4
2008	58.4	6.1	343.1	0.2	84.8	21.8	514.5	349.2
2009	19.1	2.1	719.9	0.1	263.2	37.4	1041.8	752.3
2010	11.6	6.3	159.6	0.3	52.6	10.6	241.1	170.8
2011	31.9	4.6	77.9	0.0	34.5	3.7	152.6	98.8

Table A.25. Coefficients of variation (CV) for the Gulf of Maine Atlantic cod commercial discard (mt) estimates from 1989 to 2011 by gear; CVs greater than 0.3 are shaded in grey. *CVs are not available for hindcasted discards (pre-1989).*

Year	Longline	Otter trawl		Shrimp trawl	Sink Gillnet		Total
		Small mesh (< 5.5")	Large mesh (>= 5.5")		Large mesh (5.5" - 7.99")	Extra large mesh (>= 8.0")	
1989		**0.67**	**0.34**	0.25	0.29		0.22
1990		**0.79**	**0.37**	**0.42**	0.23		0.28
1991	**0.40**	**0.60**	**0.37**	**0.32**	0.10		0.26
1992	**0.64**	**3.72**	**0.33**	0.24	0.07		0.27
1993	0.20		**0.44**	0.13	0.09		0.22
1994			**0.63**	0.15	**0.32**	**0.75**	**0.38**
1995		0.24	**0.59**	0.24	0.26	**0.45**	**0.31**
1996		**2.84**	**0.91**	**0.34**	0.30	0.28	0.25
1997		0.25	**0.44**	**0.41**	**0.42**	**0.85**	0.25
1998			**0.55**		0.28	**0.95**	0.25
1999		**0.62**	**0.56**		**0.37**	**0.51**	**0.36**
2000			0.28		0.27	**0.31**	0.20
2001		**1.84**	0.27		**0.52**	**0.58**	**0.31**
2002		**0.55**	**0.34**		0.24	**0.59**	0.20
2003	**0.30**	**0.72**	0.29	**0.42**	0.14	0.28	0.16
2004	**0.48**	**0.44**	**0.34**	**0.37**	0.13	0.12	0.22
2005	0.24	0.27	0.19	**0.38**	0.13	0.12	0.11
2006	0.29	0.27	**0.39**	**0.44**	**0.38**	**0.32**	0.28
2007	0.17	**0.43**	0.22	**0.70**	0.29	**0.31**	0.13
2008	**0.42**	**0.37**	0.21	**0.55**	0.18	**0.49**	0.16
2009	0.17	0.28	0.14	**0.64**	0.19	**0.49**	0.11
2010	**0.33**	0.28	0.19	**0.90**	0.11	0.17	0.13
2011	0.18	**0.41**	0.09		0.04	0.07	0.06

Table A.26. Median, 25th and 75th percentiles of the discard % death estimates by gear type developed by the Discard Mortality Working Group (expressed as percent dead; NEFSC 2012b). Median estimates were used to adjust discard estimates in the current assessment.

Percentile	Commercial handline	Longline	Otter trawl	Recreational hook and line	Sink gillnet
Median (50th percentile)	20	33	75	30	80
25th percentile	13	26	70	20	68
75th percentile	25	39	80	35	86

Table A.27. Length sampling of Gulf of Maine Atlantic cod commercial discards from 1989 to 2011 by gear type and semester. Sampling intensity is expressed as metric tons landings per 100 lengths sampled (*200 metric tons per 100 lengths is an unofficial NAFO/ICNAF standard*). Colors denote specific gear/mesh sizes; in all years except 2003-2005, 2007/08 and 2010/11 the length frequency distributions from large mesh gillnet were applied to extra large mesh gillnet due to insufficient sampling. A general criterion of 50 lengths/block was used to determine sufficiency.

Year	Longline		Otter trawl - small mesh		Otter trawl - large mesh		Shrimp trawl		Gillnet - large mesh		Gillnet - extra large mesh		Total	Total discards (mt)	mt/100 lengths
	Semi 1	Semi 2	Semi 1	Semi 2	Semi 1	Semi 2	Semi 1	Semi 2	Semi 1	Semi 2	Semi 1	Semi 2			
1989			125	14	542	1053	2011	77		104			3926	1101.1	28.0
1990			**		587	818	607	31	138	3			2184	2198.2	100.6
1991	*		**		706	124	397		65	30			1322	933.5	70.6
1992	*		**		924	924	401	10	78	130			2467	943.8	38.3
1993	48		**		68	866	591		90	223			1886	812.4	43.1
1994			**		194		563	40	274	112		7	1190	280.8	23.6
1995				69	225	473	377	3	60	147	20	3	1377	314.9	22.9
1996			52	19	15	73	44	21	109	31	16	20	400	200.4	50.1
1997			7***		104	1	17*****		34	11	1	2	153	115.0	75.2
1998			***		5****				43	40	9	3	95	99.5	104.8
1999				6***		220			130	1156		14	1520	1382.1	90.9
2000			***		248	85			125	157	6	6	627	1281.3	204.3
2001			***		61	647			223	144	3	4	1082	2040.9	188.6
2002				192	104	1162			412	845	1	39	2755	1772.0	64.3
2003	718		173	131	1109	234	192		603	1352	38	205	4755	1037.6	21.8
2004	197		103	519	385	771	76		1165	1524	27	536	5303	860.6	16.2
2005	2283	147	180	183	986	2939	70		190	663	47	104	7792	431.0	5.5
2006	880	3	43	9	1899	339	96		44	59	6	15	3393	498.4	14.7
2007	817	327	1	62	1172	1103	12******		91	310	53	164	4100	275.7	6.7
2008	958			18	2316	1639	42******		142	73	72	26	5244	514.5	9.8
2009	552	187		22	2219	1744	2******		502	112	7	15	5360	1041.8	19.4
2010	239	57	4	51	716	2672	5******		289	903	30	94	5055	241.1	4.8
2011	1322	107		27	2522	3612			792	694	33	41	9150	152.6	1.7

*Borrowed from 1993 LF

**Used 1989-1995 aggregate LF

***Used 1996-2002 aggregate LF

****Borrowed from 1997 LF

*****Used 1996-1997 aggregate LF

******Used 2007 - 2010 aggregate LF

Table A.28. Comparison of the survey-filter discard estimates to direct observer-based discard estimates for large mesh otter trawl, shrimp trawl and large mesh gillnet between 1989 and 1993 for Gulf of Maine Atlantic cod.

Year	Otter trawl, large mesh (>= 5.5")		Shrimp trawl		Sink gillnet, large mesh (5.5" - 7.99")	
	Discard estimate (mt)	Survey-filter estimate (mt)	Discard estimate (mt)	Survey-filter estimate (mt)	Discard estimate (mt)	Survey-filter estimate (mt)
1989	677.3	499.8	256.4	215.6	161.2	70.9
1990	1567.6	722.0	410.7	273.2	219.0	80.5
1991	621.1	917.3	205.2	243.8	106.0	71.4
1992	778.7	769.4			108.2	62.4
1993	370.8	572.6			153.6	73.1

Table A.29. Total Gulf of Maine Atlantic cod commercial discards-at-age (numbers) from 1982 to 2011. *These estimates include gear-specific assumptions of discard survival.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1982	581	347,720	1,156,034	224,521	50,895	0	0	0	0	0	0	0	0	0	0	0	0
1983	13,645	562,544	1,281,940	158,839	5,416	0	0	0	0	0	0	0	0	0	0	0	0
1984	18,275	347,694	1,445,433	219,644	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	67,101	459,681	1,162,717	516,585	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	17,767	731,053	1,522,658	208,195	48,007	0	0	0	0	0	0	0	0	0	0	0	0
1987	100,702	252,248	1,375,956	406,263	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	3,446	405,259	1,149,396	275,330	23,306	0	0	0	0	0	0	0	0	0	0	0	0
1989	43	157,339	733,450	415,475	51,442	5,129	1,380	502	109	0	0	0	0	0	0		
1990	0	61,442	539,508	1,619,321	185,562	1,188	216	0	0	0	0	0	0	0	0		
1991	3,251	115,661	244,750	156,398	273,359	23,658	945	211	0	494	22	0					
1992	23,803	364,755	481,485	278,021	32,164	91,688	2,805	119	14	0	0						
1993	26,570	100,225	345,799	212,563	62,392	47	682	187	0	0	0	0	0				
1994	11,734	119,195	93,081	140,124	14,606	816	234	270	0	0	0	0					
1995	11,572	75,059	57,584	104,772	42,720	3,914	413	0	0	0	0						
1996	22,067	31,719	22,411	24,451	38,147	6,928	657	102	78	542	0						
1997	1,472	66,116	33,817	27,941	5,256	13,811	766	120	0	0	0						
1998	699	2,565	36,073	20,996	13,651	1,615	1,536	82	0	0	0						
1999	63	58,620	35,442	77,449	78,134	64,863	19,741	22,472	3,779	32	0	0	0	0			
2000	0	10,977	192,879	122,257	137,216	26,040	8,080	1,471	315								
2001	0	584	166,381	181,295	117,448	89,585	23,098	9,463	1,433	1,304	0						
2002	0	10,379	26,625	95,299	150,797	58,039	36,422	15,103	9,627	3,784	3,221	270	220	0	0		
2003	22,873	30,227	60,078	48,552	131,760	95,818	18,452	5,589	1,985	819	315	204	15				
2004	187	130,674	71,594	234,041	42,241	41,615	19,027	4,267	1,900	569	231	88	11				
2005	1,487	19,746	72,822	27,925	88,613	2,854	7,378	2,689	588	435	156	176	80	43			
2006	204	10,521	29,696	159,504	38,366	53,974	2,405	2,150	1,902	93	34	5	0	1	0		
2007	407	10,720	49,447	57,421	49,909	4,291	2,782	49	53	6	0	2	0	0	0	0	
2008	305	7,598	58,021	104,763	59,668	40,918	1,629	1,361	75	17	27	26	0	0	0	0	0
2009	81	5,791	52,840	167,603	143,740	56,239	26,856	734	1,259	13	33	7	0	8	0	0	0
2010	213	4,607	23,503	52,319	27,322	15,926	3,289	989	20	2	0	0	0	0	0	0	0
2011	27	1,612	13,351	31,934	28,579	6,662	1,533	153	29	87	0	0	0	0	0	0	0

Table A.30. Mean weights-at-age (kg) of commercially discarded Gulf of Maine Atlantic cod from 1982 to 2011.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1982	0.000	0.315	0.500	0.608	0.648												
1983	0.024	0.218	0.509	0.649	0.752												
1984	0.001	0.225	0.485	0.610													
1985	0.039	0.194	0.541	0.589													
1986	0.005	0.274	0.439	0.621	0.573												
1987	0.004	0.143	0.492	0.559													
1988	0.003	0.121	0.442	0.554	0.615												
1989	0.046	0.224	0.490	0.751	1.751	4.112	5.534	9.336	6.408								
1990		0.195	0.645	0.703	0.846	4.340	4.564										
1991	0.014	0.238	0.859	0.917	0.993	1.401	6.746	8.389		18.191	3.705						
1992	0.023	0.053	0.680	0.773	1.082	1.154	1.614	5.239	2.425								
1993	0.021	0.073	0.684	0.944	0.926	1.953	4.309	7.342									
1994	0.022	0.049	0.629	0.827	1.798	3.872	12.083	9.439									
1995	0.027	0.093	0.809	0.925	1.637	4.928	4.682										
1996	0.033	0.067	0.676	1.126	1.840	3.752	6.768	11.559	12.656	17.406							
1997	0.017	0.058	0.590	0.928	1.984	1.785	4.381	8.657									
1998	0.007	0.200	0.603	1.093	1.686	3.316	3.287	3.285									
1999	0.052	0.201	0.595	1.940	3.353	4.626	6.586	6.605	9.634	12.279							
2000		0.292	0.962	1.843	3.041	3.882	4.881	4.279	6.121								
2001		0.316	0.669	2.023	3.777	4.898	5.908	6.594	7.159	8.790							
2002		0.203	0.923	1.415	2.987	4.222	6.258	7.030	9.453	12.322	10.912	10.519	14.222				
2003	0.038	0.133	0.804	1.364	1.672	2.772	4.085	6.911	9.868	8.622	11.658	10.100	12.774				
2004	0.025	0.106	0.455	1.128	1.879	2.800	4.834	6.755	8.763	11.588	11.820	10.579	11.694				
2005	0.027	0.109	0.564	1.170	1.400	3.246	3.573	5.707	7.370	10.673	15.830	16.405	17.950	23.098			
2006	0.069	0.276	0.665	1.066	1.494	1.604	1.871	3.857	2.822	7.902	8.238	13.434		13.434			
2007	0.024	0.227	0.658	1.063	1.394	1.710	2.171	4.447	5.197	6.529		7.736					
2008	0.078	0.203	0.770	1.273	1.572	1.741	3.047	6.283	6.021	5.514	10.341	10.660					
2009	0.026	0.356	0.913	1.515	2.010	2.109	2.402	3.970	3.288	8.250	8.733	7.259		10.510			
2010	0.023	0.251	1.047	1.251	1.743	1.912	1.962	2.184	4.322	8.210							
2011	0.122	0.361	0.875	1.181	1.303	1.473	1.592	1.669	2.623	16.409							

Table A.31. Proportion of recreationally harvested (type A, and B1 catch) Gulf of Maine Atlantic cod by mode and area as estimated by the Marine Recreational Information Program from 1981 to 2011. **The summary only includes catch from Maine, New Hampshire and Massachusetts. The 'Shore' category includes man-made and beach catch. Due to the proration step that is required to split Massachusetts landed fish between the Gulf of Maine and Georges Bank, these estimates are not directly translatable to the aggregate estimates of Gulf of Maine recreational catch; they are provided for informational purposes only.*

	Shore (beach/bank/structure)		Party/charter			Private/rental		
Year	Inland	Ocean ≤ 3 miles	Inland	Ocean ≤ 3 miles	Ocean ≥ 3 miles	Inland	Ocean ≤ 3 miles	Ocean ≥ 3 miles
1981	0.00	0.00	0.04	0.06	0.54	0.03	0.28	0.05
1982	0.00	0.00	0.00	0.02	0.46	0.10	0.32	0.09
1983	0.00	0.01	0.01	0.02	0.35	0.01	0.40	0.20
1984	0.01	0.00	0.01	0.05	0.36	0.03	0.28	0.26
1985	0.01	0.00	0.00	0.07	0.27	0.13	0.26	0.27
1986	0.00	0.05	0.00	0.08	0.59	0.05	0.12	0.10
1987	0.00	0.00	0.00	0.19	0.53	0.01	0.14	0.14
1988	0.00	0.02	0.01	0.03	0.36	0.03	0.09	0.47
1989	0.00	0.00	0.05	0.05	0.37	0.22	0.08	0.22
1990	0.00	0.01	0.01	0.05	0.53	0.02	0.10	0.27
1991	0.00	0.00	0.00	0.00	0.34	0.05	0.10	0.51
1992	0.00	0.03	0.00	0.00	0.39	0.02	0.09	0.47
1993	0.00	0.00	0.00	0.01	0.66	0.03	0.10	0.19
1994	0.00	0.00	0.00	0.02	0.37	0.17	0.16	0.28
1995	0.00	0.00	0.00	0.04	0.69	0.04	0.05	0.17
1996	0.00	0.00	0.02	0.03	0.56	0.01	0.05	0.34
1997	0.00	0.00	0.01	0.09	0.65	0.02	0.04	0.17
1998	0.00	0.00	0.00	0.05	0.57	0.02	0.09	0.28
1999	0.00	0.00	0.00	0.03	0.51	0.00	0.11	0.34
2000	0.00	0.00	0.01	0.01	0.51	0.04	0.16	0.28
2001	0.00	0.00	0.02	0.01	0.24	0.12	0.20	0.41
2002	0.00	0.00	0.00	0.00	0.17	0.03	0.23	0.57
2003	0.00	0.00	0.00	0.00	0.26	0.00	0.11	0.63
2004	0.00	0.00	0.00	0.00	0.29	0.18	0.09	0.43
2005	0.00	0.00	0.00	0.00	0.39	0.03	0.14	0.43
2006	0.00	0.00	0.00	0.00	0.56	0.02	0.08	0.34
2007	0.00	0.00	0.00	0.02	0.42	0.17	0.02	0.37
2008	0.00	0.00	0.00	0.00	0.32	0.07	0.02	0.58
2009	0.00	0.00	0.02	0.00	0.47	0.04	0.01	0.47
2010	0.00	0.00	0.01	0.00	0.27	0.02	0.02	0.69
2011	0.00	0.00	0.22	0.03	0.31	0.04	0.02	0.37
Average	0.00	0.00	0.01	0.03	0.43	0.06	0.13	0.34

Table A.32. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by month from 1994 to 2011. Recreational vessels are prohibited from possessing Gulf of Maine Atlantic cod in the months shaded grey. Since May 1, 2006 recreational possession was prohibited from November 1st to March 31st. In 2009 the prohibition period was extended to November 1st to April 15th.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1994	0.00	0.00	0.00	0.01	0.02	0.17	0.15	0.22	0.13	0.16	0.03	0.11
1995	0.02	0.02	0.02	0.10	0.16	0.16	0.12	0.16	0.10	0.05	0.06	0.01
1996	0.00	0.00	0.02	0.14	0.22	0.18	0.14	0.15	0.09	0.05	0.00	0.00
1997	0.00	0.00	0.01	0.14	0.23	0.16	0.15	0.15	0.10	0.05	0.01	0.00
1998	0.00	0.00	0.01	0.15	0.21	0.19	0.17	0.12	0.10	0.04	0.01	0.00
1999	0.00	0.00	0.02	0.20	0.24	0.14	0.13	0.12	0.09	0.05	0.01	0.00
2000	0.00	0.01	0.03	0.18	0.22	0.15	0.13	0.12	0.11	0.05	0.01	0.00
2001	0.01	0.03	0.06	0.15	0.18	0.16	0.16	0.12	0.09	0.04	0.01	0.00
2002	0.01	0.02	0.05	0.25	0.19	0.14	0.14	0.10	0.07	0.02	0.01	0.00
2003	0.00	0.00	0.02	0.12	0.24	0.16	0.15	0.15	0.09	0.04	0.01	0.01
2004	0.00	0.01	0.01	0.14	0.27	0.17	0.13	0.12	0.09	0.04	0.02	0.00
2005	0.00	0.00	0.03	0.15	0.17	0.21	0.13	0.14	0.10	0.03	0.03	0.00
2006	0.01	0.02	0.09	0.19	0.18	0.18	0.13	0.09	0.08	0.03	0.00	0.00
2007	0.00	0.00	0.00	0.16	0.23	0.17	0.14	0.12	0.12	0.05	0.00	0.00
2008	0.00	0.00	0.00	0.20	0.26	0.17	0.13	0.11	0.08	0.06	0.00	0.00
2009	0.00	0.00	0.00	0.17	0.30	0.17	0.10	0.09	0.11	0.06	0.00	0.00
2010	0.00	0.00	0.00	0.14	0.25	0.23	0.12	0.13	0.08	0.04	0.00	0.00
2011	0.00	0.00	0.00	0.13	0.27	0.24	0.15	0.11	0.08	0.03	0.00	0.00
Average	0.00	0.01	0.02	0.15	0.21	0.18	0.14	0.13	0.09	0.05	0.01	0.01

Table A.33. Proportion of recreationally caught (type A, B1 and B2) Gulf of Maine Atlantic cod by sampling wave as estimated by the Marine Recreational Information Program between 1981 and 2011.

Year	Wave				
	2	3	4	5	6
1981	0.16	0.63	0.11	0.10	0.00
1982	0.33	0.29	0.22	0.16	0.01
1983	0.11	0.29	0.26	0.32	0.02
1984	0.08	0.40	0.39	0.12	0.01
1985	0.19	0.53	0.16	0.09	0.02
1986	0.22	0.13	0.21	0.26	0.18
1987	0.41	0.26	0.11	0.12	0.11
1988	0.04	0.41	0.12	0.41	0.02
1989	0.04	0.35	0.25	0.29	0.06
1990	0.11	0.46	0.15	0.25	0.03
1991	0.14	0.49	0.06	0.20	0.10
1992	0.26	0.24	0.19	0.29	0.03
1993	0.17	0.39	0.17	0.20	0.07
1994	0.05	0.31	0.20	0.14	0.31
1995	0.18	0.23	0.08	0.41	0.10
1996	0.12	0.32	0.19	0.21	0.15
1997	0.31	0.28	0.18	0.07	0.16
1998	0.30	0.26	0.23	0.06	0.16
1999	0.33	0.22	0.16	0.23	0.06
2000	0.22	0.37	0.16	0.20	0.04
2001	0.12	0.31	0.22	0.23	0.12
2002	0.17	0.28	0.19	0.17	0.19
2003	0.19	0.40	0.18	0.15	0.09
2004	0.06	0.39	0.13	0.27	0.14
2005	0.21	0.36	0.25	0.12	0.07
2006	0.20	0.32	0.31	0.15	0.03
2007	0.22	0.30	0.25	0.12	0.10
2008	0.07	0.54	0.27	0.12	0.00
2009	0.11	0.57	0.16	0.12	0.03
2010	0.13	0.45	0.20	0.22	0.00
2011	0.04	0.69	0.17	0.08	0.02
Average	0.17	0.37	0.19	0.19	0.08

Table A.34. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by state from 1994 to 2011.

Year	CT	FL	MA	ME	NH	NJ	NK	NY	RI	VA
1994	0.00	0.00	0.59	0.32	0.08	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.72	0.18	0.10	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.69	0.21	0.10	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.63	0.25	0.12	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.59	0.27	0.14	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.67	0.19	0.14	0.00	0.00	0.01	0.00	0.00
2000	0.00	0.00	0.67	0.17	0.16	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.71	0.13	0.16	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.64	0.11	0.24	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.66	0.14	0.19	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.60	0.12	0.26	0.00	0.00	0.00	0.01	0.00
2005	0.00	0.00	0.56	0.10	0.33	0.00	0.00	0.00	0.01	0.00
2006	0.00	0.00	0.55	0.13	0.32	0.00	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.48	0.17	0.34	0.00	0.00	0.01	0.00	0.00
2008	0.00	0.00	0.52	0.15	0.34	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.50	0.17	0.33	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.54	0.11	0.34	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.02	0.62	0.07	0.30	0.00	0.00	0.00	0.00	0.00
Average	0.00	0.00	0.61	0.17	0.22	0.00	0.00	0.00	0.00	0.00

Table A.35. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by statistical area from 1994 to 2011.

Year	464	465	510	511	512	513	514	515
1994	0.00	0.00	0.00	0.00	0.02	0.29	0.43	0.26
1995	0.00	0.00	0.00	0.00	0.00	0.36	0.51	0.12
1996	0.00	0.00	0.00	0.00	0.00	0.38	0.59	0.03
1997	0.00	0.00	0.00	0.00	0.00	0.48	0.51	0.01
1998	0.00	0.00	0.00	0.00	0.00	0.49	0.50	0.01
1999	0.00	0.00	0.00	0.00	0.01	0.39	0.58	0.02
2000	0.00	0.00	0.00	0.00	0.00	0.34	0.61	0.05
2001	0.00	0.00	0.00	0.00	0.00	0.31	0.66	0.03
2002	0.00	0.00	0.00	0.00	0.00	0.37	0.60	0.03
2003	0.00	0.00	0.00	0.00	0.00	0.36	0.54	0.10
2004	0.00	0.00	0.00	0.00	0.00	0.33	0.62	0.04
2005	0.00	0.00	0.00	0.00	0.00	0.39	0.57	0.04
2006	0.00	0.00	0.00	0.00	0.00	0.42	0.54	0.05
2007	0.00	0.00	0.00	0.00	0.01	0.45	0.52	0.01
2008	0.00	0.00	0.00	0.00	0.00	0.44	0.54	0.02
2009	0.00	0.00	0.00	0.00	0.00	0.42	0.58	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.45	0.50	0.06
2011	0.00	0.00	0.00	0.00	0.00	0.31	0.66	0.03
Average	0.00	0.00	0.00	0.00	0.00	0.39	0.56	0.05

Table A.36. Length sampling intensity of recreationally harvested (type A, and B1) Gulf of Maine Atlantic cod by semester and year as estimated by the Marine Recreational Information Program from 1981 to 2011. Sampling intensity is expressed as metric tons of landings per 100 lengths sampled (*200 metric tons per 100 lengths is an unofficial NAFO/ICNAF standard*).

Year	Semester		Total	A,B1 estimated numbers (000s)	AB1 Landings (mt)	Lengths per 1000 fish	mt per 100 lengths
	1	2					
1981	355	366	721	2011.2	4111.5	0.4	570.3
1982	320	276	596	1368.7	2816.7	0.4	472.6
1983	609	560	1169	937.1	1772.8	1.2	151.7
1984	394	391	785	678.9	1266.8	1.2	161.4
1985	272	155	427	1212.5	2765.9	0.4	647.7
1986	77	90	167	734.0	1928.4	0.2	1154.8
1987	167	367	534	1504.5	3547.2	0.4	664.3
1988	325	213	538	943.2	1688.5	0.6	313.9
1989	208	352	560	893.2	1957.2	0.6	349.5
1990	160	210	370	930.9	2246.7	0.4	607.2
1991	377	83	460	1023.1	2287.2	0.4	497.2
1992	710	268	978	238.4	623.6	4.1	63.8
1993	136	200	336	568.3	1011.9	0.6	301.2
1994	333	485	818	392.9	721.7	2.1	88.2
1995	663	434	1097	378.6	627.2	2.9	57.2
1996	585	515	1100	260.0	498.6	4.2	45.3
1997	190	392	582	105.0	236.3	5.5	40.6
1998	447	215	662	144.2	353.1	4.6	53.3
1999	111	117	228	184.7	577.2	1.2	253.1
2000	70	77	147	388.5	967.1	0.4	657.9
2001	124	121	245	755.6	1967.6	0.3	803.1
2002	181	196	377	409.1	1254.8	0.9	332.8
2003	361	322	683	454.9	1607.7	1.5	235.4
2004	422	473	895	379.4	1150.9	2.4	128.6
2005	391	382	773	446.9	1346.9	1.7	174.2
2006	681	155	836	188.7	702.3	4.4	84.0
2007	479	220	699	303.5	1042.2	2.3	149.1
2008	590	231	821	382.6	1267.2	2.1	154.3
2009	852	488	1340	386.9	1357.1	3.5	101.3
2010	621	508	1129	503.9	1758.2	2.2	155.7
2011	711	496	1207	516.0	1799.1	2.3	149.1

Table A.37. Percentage of recreationally discarded (type B2) Gulf of Maine Atlantic cod by mode and area as estimated by the Marine Recreational Information Program from 1981 to 2011. **The summary only includes catch from Maine, New Hampshire and Massachusetts. The 'Shore' category includes man-made and beach catch. Due to the proration step that is required to split Massachusetts landed fish between the Gulf of Maine and Georges Bank, these estimates are not directly translatable to the aggregate estimates of Gulf of Maine recreational catch; they are provided for informational purposes only.*

	Shore (beach/bank/structure)		Party/charter			Private/rental		
Year	Inland	Ocean ≤ 3 miles	Inland	Ocean ≤ 3 miles	Ocean ≥ 3 miles	Inland	Ocean ≤ 3 miles	Ocean ≥ 3 miles
1981	0.00	0.00	0.00	0.00	0.16	0.11	0.63	0.10
1982	0.00	0.00	0.00	0.00	0.44	0.01	0.26	0.29
1983	0.00	0.04	0.00	0.00	0.15	0.10	0.54	0.17
1984	0.01	0.00	0.00	0.03	0.26	0.00	0.45	0.25
1985	0.01	0.00	0.00	0.23	0.35	0.02	0.03	0.36
1986	0.00	0.00	0.01	0.16	0.36	0.06	0.19	0.21
1987	0.00	0.00	0.00	0.29	0.47	0.02	0.08	0.14
1988	0.00	0.00	0.02	0.04	0.49	0.01	0.12	0.31
1989	0.00	0.00	0.04	0.06	0.37	0.14	0.08	0.30
1990	0.00	0.00	0.02	0.06	0.44	0.02	0.08	0.38
1991	0.00	0.00	0.00	0.00	0.35	0.04	0.09	0.51
1992	0.00	0.03	0.00	0.00	0.34	0.05	0.07	0.50
1993	0.00	0.00	0.00	0.01	0.65	0.04	0.14	0.16
1994	0.00	0.00	0.00	0.01	0.37	0.22	0.13	0.27
1995	0.00	0.00	0.00	0.05	0.68	0.04	0.06	0.17
1996	0.00	0.00	0.01	0.03	0.56	0.02	0.06	0.34
1997	0.00	0.00	0.03	0.10	0.56	0.04	0.06	0.22
1998	0.00	0.00	0.00	0.06	0.52	0.02	0.12	0.28
1999	0.00	0.00	0.00	0.03	0.44	0.01	0.11	0.42
2000	0.00	0.00	0.01	0.01	0.48	0.03	0.18	0.29
2001	0.00	0.00	0.03	0.01	0.21	0.13	0.22	0.39
2002	0.00	0.00	0.00	0.00	0.14	0.03	0.25	0.58
2003	0.00	0.00	0.00	0.00	0.23	0.00	0.12	0.65
2004	0.00	0.00	0.00	0.00	0.29	0.20	0.10	0.41
2005	0.00	0.00	0.00	0.00	0.39	0.04	0.13	0.44
2006	0.00	0.00	0.00	0.00	0.55	0.03	0.07	0.36
2007	0.00	0.00	0.00	0.00	0.41	0.14	0.02	0.44
2008	0.00	0.00	0.00	0.00	0.34	0.09	0.02	0.55
2009	0.00	0.00	0.01	0.00	0.46	0.05	0.00	0.47
2010	0.00	0.00	0.01	0.00	0.25	0.02	0.02	0.71
2011	0.00	0.00	0.23	0.03	0.28	0.04	0.02	0.41
Average	0.00	0.00	0.01	0.04	0.39	0.06	0.14	0.36

Table A.38. Length sampling intensity of recreationally discarded (type B2) Gulf of Maine Atlantic cod by semester and year as estimated by the Marine Recreational Information Program from 2005 to 2011. Length samples of recreationally discarded (i9 samples) Atlantic cod were unavailable prior to 2005. Sampling intensity is expressed as metric tons landings per 100 lengths sampled (*200 metric tons per 100 lengths is an unofficial NAFO/ICNAF standard*).

Year	Semester		Total	B2 releases (000s)	B2 releases (mt)	Lengths per thousand fish	Metric tons per 100 lengths
	1	2					
2005	577	624	1201	1038.1	891.0	1.2	208.1
2006	952	599	1551	708.4	646.7	2.2	162.9
2007	728	846	1574	964.4	1056.2	1.6	216.2
2008	1258	709	1967	952.1	1051.2	2.1	156.4
2009	765	889	1654	826.0	974.8	2.0	216.2
2010	715	1024	1739	1049.4	1281.6	1.7	243.2
2011	493	937	1430	892.4	1114.1	1.6	290.1

Table A.39. Annual ratios of Marine Recreational Fisheries Statistical Survey (MRFSS) and Marine Recreational Information Program (MRIP) catch estimates and aggregate time series ratios (ratio of means).

Year	MRIP		MRFSS		Ratio	
	Landings, AB1 (numbers)	Releases, B2 (numbers)	Landings, AB1 (numbers)	Releases B2, (numbers)	Landings, AB1	Releases, B2
2004	379,444	736,820	536,147	885,537	0.708	0.832
2005	446,894	1,038,133	590,390	1,356,379	0.757	0.765
2006	188,699	708,360	227,980	763,402	0.828	0.928
2007	303,540	964,427	309,786	1,180,096	0.980	0.817
2008	382,555	952,120	477,913	1,281,510	0.800	0.743
2009	386,913	826,019	478,765	1,130,115	0.808	0.731
2010	503,887	1,049,409	1,041,480	2,000,702	0.484	0.525
2011	516,049	892,438	526,101	882,038	0.981	1.012
Sum	3,107,981	7,167,726	4,188,561	9,479,780	0.742	0.756

Table A.40. Relative difference between SAW 53 recreational catch estimates (numbers) and the unadjusted updated Marine Recreational Fisheries Statistical Survey (MRFSS) estimates. Positive numbers indicate SAW 53 estimates were larger (e.g., 0.50 implies the updated estimates are 50% lower than the SAW 53 estimates).

Relative difference between SARC 53 numbers and adjusted MRFSS numbers				
Year	**Type A**	**Type B**	**Type AB1 (harvest)**	**Type B2 (releases)**
1981	-0.04	0.00	-0.02	0.00
1982	0.01	0.00	0.00	0.00
1983	-0.01	0.00	0.00	0.00
1984	-0.01	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00
1986	0.01	0.00	0.00	0.00
1987	0.01	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	-0.04	0.00	-0.01	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	-0.01	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	-0.19	0.06	-0.01	0.01
2005	0.03	-0.01	0.00	-0.08
2006	-0.01	0.00	0.00	-0.12
2007	-0.03	0.00	-0.01	-0.15
2008	-0.02	0.00	0.00	-0.10
2009	-0.01	0.00	0.00	-0.07
2010	-0.11	-0.03	-0.04	-0.07

Table A.41. Relative difference between SAW 53 recreational catch estimates (numbers) and the updated Marine Recreational Information Program (MRIP) estimates. Positive numbers indicate SAW 53 estimates were larger (e.g., 0.50 implies the updated estimates are 50% lower than the SAW 53 estimates).

Year	Type AB1 (harvest)	Type B2 (releases)
1981	0.24	0.24
1982	0.26	0.24
1983	0.25	0.24
1984	0.25	0.24
1985	0.26	0.24
1986	0.26	0.24
1987	0.26	0.24
1988	0.26	0.24
1989	0.26	0.24
1990	0.26	0.24
1991	0.26	0.24
1992	0.26	0.24
1993	0.26	0.24
1994	0.26	0.24
1995	0.26	0.24
1996	0.26	0.24
1997	0.25	0.24
1998	0.26	0.24
1999	0.26	0.24
2000	0.26	0.24
2001	0.26	0.24
2002	0.26	0.24
2003	0.26	0.24
2004	0.29	0.18
2005	0.24	0.18
2006	0.17	-0.04
2007	0.01	0.06
2008	0.20	0.18
2009	0.19	0.22
2010	0.50	0.44

Table A.42. Estimates of Gulf of Maine Atlantic cod recreational catch in numbers (000's) and weight (mt). Recreational releases are shown using both the 100% discard mortality (grey) and Discard WG revised 30% mortality assumptions.

Year	Numbers (000s)				Mass (mt)				
	Harvest (AB1)	Released (B2) w/ 100% discard mortality	Released (B2) w/ 30% discard mortality	Total catch w/ 30% discard mortality	Harvest (AB1)	Released (B2) w/ 100% discard mortality	Released (B2) w/ 30% discard mortality	Total catch w/ 30% discard mortality	Released:harvest ratio
1981	2011.2	145.1	43.5	2054.7	4111.5	62.8	18.8	4130.4	0.07
1982	1368.7	71.6	21.5	1390.2	2816.7	27.2	8.1	2824.9	0.05
1983	937.1	174.2	52.2	989.4	1772.8	58.6	17.6	1790.4	0.19
1984	678.9	148.7	44.6	723.6	1266.8	55.3	16.6	1283.4	0.22
1985	1212.5	150.9	45.3	1257.8	2765.9	56.2	16.9	2782.7	0.12
1986	734.0	91.9	27.6	761.6	1928.4	33.7	10.1	1938.5	0.13
1987	1504.5	428.5	128.6	1633.1	3547.2	160.0	48.0	3595.2	0.28
1988	943.2	133.3	40.0	983.2	1688.5	45.2	13.5	1702.1	0.14
1989	893.2	432.6	129.8	1023.0	1957.2	253.6	76.1	2033.2	0.48
1990	930.9	357.6	107.3	1038.2	2246.7	222.4	66.7	2313.4	0.38
1991	1023.1	310.3	93.1	1116.1	2287.2	226.7	68.0	2355.3	0.30
1992	238.4	180.8	54.2	292.7	623.6	118.2	35.5	659.0	0.76
1993	568.3	568.0	170.4	738.7	1011.9	339.8	101.9	1113.9	1.00
1994	392.9	543.6	163.1	556.0	721.7	335.3	100.6	822.3	1.38
1995	378.6	516.2	154.8	533.5	627.2	320.5	96.2	723.4	1.36
1996	260.0	340.8	102.2	362.3	498.6	270.1	81.0	579.7	1.31
1997	105.0	227.0	68.1	173.1	236.3	195.9	58.8	295.1	2.16
1998	144.2	289.6	86.9	231.1	353.1	240.8	72.2	425.3	2.01
1999	184.7	359.7	107.9	292.6	577.2	238.8	71.7	648.8	1.95
2000	388.5	696.2	208.8	597.4	967.1	458.7	137.6	1104.7	1.79
2001	755.6	992.0	297.6	1053.2	1967.6	758.3	227.5	2195.0	1.31
2002	409.1	823.5	247.1	656.1	1254.8	956.2	286.9	1541.7	2.01
2003	454.9	837.8	251.3	706.3	1607.7	941.4	282.4	1890.1	1.84
2004	379.4	736.8	221.0	600.5	1150.9	671.2	201.4	1352.2	1.94
2005	446.9	1038.1	311.4	758.3	1346.9	891.0	267.3	1614.2	2.32
2006	188.7	708.4	212.5	401.2	702.3	646.7	194.0	896.3	3.75
2007	303.5	964.4	289.3	592.9	1042.2	1056.2	316.9	1359.1	3.18
2008	382.6	952.1	285.6	668.2	1267.2	1051.2	315.4	1582.6	2.49
2009	386.9	826.0	247.8	634.7	1357.1	974.8	292.4	1649.6	2.13
2010	503.9	1049.4	314.8	818.7	1758.2	1281.6	384.5	2142.6	2.08
2011	516.0	892.4	267.7	783.8	1799.1	1114.1	334.2	2133.3	1.73

Table A.43. Percent standard error (PSE) of Gulf of Maine Atlantic cod recreational catch estimates (A, B1 and B2) by state by the Marine Recreational Information Program between 1981 and 2011. **Note: due to the proration step that is required to split Massachusetts landed fish between the Gulf of Maine and Georges Bank, these estimates of PSE are not directly translatable to the aggregate estimates of Gulf of Maine recreational catch. The PSEs are provided for informational purposes only.*

Year	Maine	New Hampshire	Massachusetts
1981	35.7	24.6	23.4
1982	22.0	47.1	39.1
1983	20.6	18.5	13.6
1984	16.7	14.7	13.9
1985	24.2	26.3	23.3
1986	18.4	24.0	22.6
1987	40.4	36.1	14.3
1988	75.4	25.6	10.6
1989	21.1	19.6	14.6
1990	29.8	24.9	11.2
1991	33.9	36.5	9.5
1992	43.3	31.1	13.5
1993	33.6	30.2	13.1
1994	32.2	31.3	9.2
1995	34.9	16.3	11.2
1996	38.6	20.2	13.2
1997	36.3	23.8	17.6
1998	47.0	17.9	17.4
1999	43.7	14.7	17.7
2000	21.9	12.6	14.5
2001	26.1	10.6	8.0
2002	20.3	11.9	9.1
2003	28.1	11.7	9.5
2004	40.5	15.5	19.7
2005	21.5	14.8	15.1
2006	16.6	10.9	13.9
2007	32.7	14.4	16.8
2008	23.0	14.9	17.7
2009	17.1	13.6	18.0
2010	20.0	12.1	17.6
2011	27.6	18.9	12.0
Average	30.4	20.8	15.5

Table A.44. Total Gulf of Maine Atlantic cod recreational landings-at-age (numbers) from 1982 to 2011.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1981		159,922	623,992	622,091	426,564	69,951	42,612	7,392	29,365		25,105		4,184				
1982	765	67,908	420,464	427,446	263,437	129,184	14,639	24,905	13,178	3,904	574		2,296				
1983		14,924	315,694	339,632	128,267	76,679	45,287	5,810	4,873	1,777	1,390	802	2,004				
1984		11,741	224,928	226,199	139,013	40,743	23,707	9,247	390	420	350	627		432	1,153		
1985		35,163	368,684	438,416	149,622	123,096	38,047	33,994	15,929	2,206	5,509	316	1,005	532			
1986		21,723	120,551	351,802	124,583	39,540	40,989	9,316	10,691	6,281	3,579	865	3,202	865			
1987		16,878	348,751	517,856	457,592	77,647	24,836	35,051	8,978	8,452	6,339	1,878	282				
1988		3,134	197,888	449,655	225,659	46,787	8,638	3,696	6,000			1,753					
1989		3,619	116,660	436,314	242,898	64,122	15,197	10,911	1,329	2,127							
1990		2,812	40,204	449,749	295,754	87,368	36,966	4,457	11,742	1,887							
1991		3,614	35,323	152,702	701,569	106,170	11,169	12,368			143						
1992		2,101	21,451	43,626	35,194	123,077	10,143	2,642	193								
1993		1,913	42,807	343,796	133,450	10,536	32,237	3,594									
1994		475	13,965	243,207	103,423	24,535	2,404	3,971	600	370							
1995		25	35,494	187,086	144,820	9,965	1,024		192								
1996			11,977	64,661	162,532	19,752	850	34		236							
1997		78	5,075	31,836	21,300	42,823	3,631	35	192								
1998	218		9,310	52,886	52,992	11,547	15,851	1,107	315								
1999		552	5,301	53,525	61,018	39,039	9,650	14,515	1,105								
2000			52,606	130,285	163,854	25,350	10,670	2,007	3,741								
2001			42,329	386,498	214,243	84,322	17,177	9,279	1,320	464							
2002			310	57,771	233,715	73,361	23,839	9,622	6,047	785	1,454		2,170				
2003			4,884	37,189	149,359	188,046	41,113	18,104	7,470	5,073	1,170	1,724	817				
2004			97	98,544	72,720	129,126	58,696	11,806	4,675	1,764	1,182	224	609				
2005			3,181	47,690	280,723	19,902	57,931	23,160	6,401	4,575	1,601	830	649	251			
2006			167	29,903	47,416	78,493	5,155	14,283	7,461	2,864	1,753	636	344	184	41		
2007			1,762	35,777	186,312	25,702	42,350	1,937	3,598	2,781	1,394	737	392	595	96	109	
2008			3,945	93,103	123,240	101,819	27,956	26,590	1,476	2,097	2,330						
2009			1,529	74,035	162,755	66,702	66,208	3,325	8,426	210	1,685	931	914	192			
2010			10,155	93,506	204,897	141,754	37,562	9,467	3,124	1,413	223		1,785				
2011			3,419	88,254	176,415	150,699	77,558	8,261	9,161	1,523	394	143	95	107	21		

Table A.45. Mean weights-at-age (kg) of recreationally landed Gulf of Maine Atlantic cod from 1982 to 2011.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1981		0.341	0.995	1.524	2.915	4.715	5.645	5.863	8.359		12.339		18.100				
1982	0.022	0.372	0.848	1.401	2.209	5.362	6.955	9.732	8.990	11.008	11.547		21.416				
1983		0.378	0.791	1.398	2.401	3.772	6.032	6.745	8.393	9.627	15.175	19.306	19.182				
1984		0.372	0.775	1.365	2.668	4.005	5.349	6.559	6.583	8.955	11.743	13.474		17.780	27.103		
1985		0.346	0.752	1.281	2.810	5.310	6.771	8.645	11.257	11.854	12.252	8.049	9.297	8.332			
1986		0.375	0.668	1.589	2.770	5.308	7.418	8.584	11.185	11.839	14.266	14.560	22.376	14.560			
1987		0.243	0.900	1.472	2.696	4.196	8.162	10.978	11.301	12.673	13.141	13.835	8.332				
1988		0.170	0.787	1.528	2.188	4.550	4.414	5.123	10.614			10.175					
1989		0.539	0.989	1.500	2.700	4.579	6.191	8.715	7.616	17.137							
1990		0.132	0.916	1.439	2.261	4.965	7.351	8.502	10.658	13.166							
1991		0.180	1.088	1.499	2.025	3.388	6.933	13.033			3.838						
1992		0.106	1.360	1.715	2.541	2.923	4.437	9.324	2.516								
1993		0.184	0.805	1.566	1.827	2.890	3.791	11.707									
1994		0.136	1.169	1.514	2.262	2.270	5.374	5.751	18.165	2.156							
1995		0.509	1.432	1.514	1.769	3.381	2.479		4.244								
1996			1.483	1.809	1.863	2.502	9.632	8.622		13.434							
1997		0.307	1.626	1.924	2.389	2.396	2.964	6.038	11.932								
1998	0.010		1.600	2.071	2.435	3.491	3.179	4.591	12.220								
1999		0.290	1.296	1.943	2.951	3.687	5.490	5.561	7.637								
2000			1.561	1.961	2.718	3.199	5.103	5.023	10.277								
2001			1.709	2.199	2.659	3.732	5.019	6.259	10.560	5.813							
2002			1.275	2.135	2.581	3.048	5.265	6.429	7.919	8.984	10.569		21.420				
2003			1.954	2.237	2.525	3.225	4.822	8.064	9.802	11.167	11.115	15.401	21.534				
2004			1.545	2.045	2.612	2.829	3.911	5.747	9.387	12.100	13.609	13.256	20.155				
2005			1.510	1.968	2.374	3.566	3.904	6.089	7.852	9.766	13.574	14.627	16.347	17.544			
2006			2.321	2.270	2.969	3.301	4.683	5.470	8.339	10.105	12.466	15.021	15.090	18.390	17.774		
2007			2.226	2.503	2.965	3.535	4.418	5.147	7.863	11.709	12.713	14.426	14.231	16.520	15.964	19.820	
2008			1.922	2.746	2.910	3.415	2.747	5.124	10.004	12.290	18.942						
2009			2.197	2.506	3.066	3.518	4.444	6.371	8.034	9.777	10.005	12.269	18.736	19.782			
2010			2.563	2.728	3.151	3.771	4.115	7.441	9.409	9.584	9.850		15.000				
2011			1.798	2.474	3.032	3.707	4.577	5.274	5.624	12.022	16.019	18.353	14.407	19.306	13.835		

Table A.46. Total Gulf of Maine Atlantic cod recreational discards-at-age (numbers) from 1982 to 2011. *These estimates include assumptions of 30% discard survival.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1981		13,575	24,578	5,363													
1982		5,612	14,535	1,052	278												
1983		20,028	31,320	901													
1984		8,107	33,657	2,856													
1985		10,816	25,312	9,151													
1986		7,925	18,474	492	675												
1987		12,226	99,875	16,449													
1988		6,688	28,038	5,279													
1989		5,478	74,963	46,707	2,626												
1990		1,273	22,214	75,071	8,729												
1991		2,352	20,600	23,716	42,819	3,603											
1992		3,446	24,659	18,197	2,446	5,287	198										
1993		3,791	97,835	49,454	19,319												
1994		4,326	65,863	86,959	5,930												
1995		3,848	42,660	91,272	16,491	579											
1996		5,817	21,418	31,232	40,139	3,642											
1997		2,950	21,137	25,402	6,176	11,777	660										
1998		3,376	37,760	26,503	17,554	289	1,398										
1999		14,776	47,252	37,178	6,006	2,315	313	84									
2000		13,781	137,217	45,526	11,069	1,145	112										
2001			141,504	124,214	26,316	5,148	423										
2002		6,452	13,217	110,592	94,169	21,982	244		394								
2003		14,672	52,512	34,528	102,484	41,375	5,760										
2004		18,746	33,734	134,010	14,587	16,564	3,407										
2005		3,799	102,844	46,076	153,325	2,048	3,247	79	9	14							
2006	27	8,728	28,442	121,853	22,392	28,622	1,369	530	542	5							
2007	23	1,451	52,053	110,524	110,351	8,306	6,602	9	11								
2008	110	4,558	64,400	117,489	58,727	37,397	2,826	131									
2009	18	4,860	44,423	97,205	67,844	21,111	11,863	184	303								
2010		3,552	48,239	127,212	78,138	46,935	9,364	1,382									
2011	626	7,071	43,222	104,012	87,852	20,425	4,033	363	128								

Table A.47. Mean weights-at-age (kg) of recreationally discarded Gulf of Maine Atlantic cod from 1982 to 2011.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
1981		0.367	0.456	0.492													
1982		0.307	0.400	0.450	0.509												
1983		0.260	0.386	0.326													
1984		0.288	0.387	0.436													
1985		0.272	0.395	0.426													
1986		0.319	0.380	0.429	0.499												
1987		0.221	0.393	0.371													
1988		0.185	0.357	0.438													
1989		0.395	0.524	0.692	0.867												
1990		0.231	0.528	0.637	0.786												
1991		0.234	0.536	0.776	0.819	0.818											
1992		0.217	0.590	0.724	0.837	0.902	0.868										
1993		0.252	0.487	0.769	0.794												
1994		0.283	0.470	0.740	0.683												
1995		0.302	0.520	0.635	0.870	0.931											
1996		0.277	0.655	0.827	0.902	0.918											
1997		0.196	0.685	0.915	1.095	1.092	1.294										
1998		0.203	0.630	1.007	1.072	1.211	1.365										
1999		0.301	0.535	0.869	1.078	1.157	1.097	1.456									
2000		0.275	0.574	0.911	1.109	1.003	1.211										
2001			0.581	0.886	1.098	1.105	1.290										
2002		0.156	0.468	1.035	1.406	1.444	1.371		1.937								
2003		0.345	0.544	1.223	1.327	1.507	1.422										
2004		0.142	0.523	0.963	1.429	1.528	1.721										
2005		0.213	0.509	1.012	1.050	1.034	1.316	1.940	2.516	1.734							
2006	0.086	0.304	0.565	0.869	1.216	1.346	1.263	1.773	1.656	2.851							
2007	0.048	0.167	0.642	1.062	1.289	1.603	1.548	2.768	3.977								
2008	0.105	0.320	0.817	1.119	1.296	1.285	1.744	5.263									
2009	0.057	0.315	0.803	1.194	1.338	1.381	1.544	2.142	1.739								
2010		0.282	0.952	1.059	1.448	1.528	1.449	3.196									
2011	0.084	0.322	0.873	1.341	1.328	1.497	1.631	1.834	2.221								

Table A.48. Total catch-at-age (numbers, 000s of fish) of Gulf of Maine Atlantic cod from 1982 to 2011 with an age 9^+ group. **Only ages 1 through the 9^+group are used as assessment model inputs.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	1.3	448.8	2926.5	2287.2	1430.7	748.8	65.9	94.1	72.6	90.1
1983	13.6	597.5	2462.0	2913.2	1201.6	704.0	452.7	50.0	62.5	56.2
1984	18.3	370.3	2129.6	1675.9	1643.6	437.5	219.6	105.6	9.5	53.4
1985	67.1	505.7	1944.3	2405.1	1151.8	738.1	161.4	107.2	48.4	33.2
1986	17.8	760.7	1747.0	2747.8	992.0	279.3	202.7	48.0	38.2	47.5
1987	100.7	281.8	2018.3	1568.3	1574.5	345.4	89.4	81.0	14.5	37.5
1988	3.4	415.1	1542.8	2086.6	1156.9	447.7	67.4	25.6	26.2	9.3
1989	0.0	166.4	1247.2	2385.1	1651.9	521.1	87.1	70.3	9.4	19.6
1990	0.0	65.5	812.5	5547.8	2717.6	541.4	189.1	29.7	36.4	43.3
1991	3.3	121.6	499.6	942.7	5561.3	1037.9	150.7	55.5	26.0	15.8
1992	23.8	370.3	830.1	867.6	502.1	2190.0	226.2	80.2	6.0	5.5
1993	26.6	105.9	512.3	2149.0	944.7	103.3	497.1	41.6	11.3	0.0
1994	11.7	124.0	201.9	1525.6	1294.2	266.3	66.2	74.2	28.7	7.9
1995	11.6	78.9	319.5	1321.8	1260.4	221.7	29.9	6.5	18.2	2.8
1996	22.1	37.5	111.6	627.7	2003.9	405.9	36.7	4.0	0.5	1.6
1997	1.5	69.1	137.5	519.6	467.8	869.2	72.5	5.5	2.3	1.0
1998	0.9	5.9	171.1	492.3	628.9	152.8	205.9	28.7	5.2	2.3
1999	0.1	73.9	90.9	347.8	336.6	172.3	53.7	59.5	12.4	1.1
2000	0.0	24.8	485.0	556.5	813.7	176.6	85.2	12.5	10.5	0.0
2001	0.0	0.6	394.0	1163.8	684.4	385.5	106.6	57.2	8.3	11.6
2002	0.0	16.8	41.6	374.9	912.6	323.8	163.5	66.4	28.1	20.3
2003	22.9	44.9	125.6	167.8	582.1	706.1	186.0	75.7	29.2	26.8
2004	0.2	149.4	105.9	609.3	259.7	407.4	251.6	68.4	33.0	27.4
2005	1.5	23.5	180.1	159.6	945.8	89.2	246.6	109.1	28.5	31.7
2006	0.2	19.2	59.1	426.6	290.1	461.7	30.3	79.7	39.0	27.3
2007	0.4	12.2	108.5	299.4	976.4	137.4	230.2	7.9	19.2	22.0
2008	0.4	12.2	130.5	598.4	707.4	780.5	86.4	110.6	4.0	16.6
2009	0.1	10.7	101.5	622.5	1093.3	477.9	304.8	20.9	30.5	9.6
2010	0.2	8.2	83.6	394.5	888.5	668.3	164.3	71.7	11.2	7.6
2011	0.7	8.7	60.5	322.2	589.6	573.9	339.9	34.9	38.4	9.4

Table A.49. Mean weights-at-age (kg) of the total catch Gulf of Maine Atlantic cod from 1982 to 2011 an age 9^+ group. Mean catch weights-at-age in the 9^+ group were estimated using a numbers weighted approach. Cells shaded grey were imputed using a 5-year centered moving average, cells shaded red were imputed using a time series average. **Only ages 1 through the 9^+group are used as assessment model inputs.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	0.012	0.356	0.858	1.514	2.606	5.067	7.065	9.620	9.771	15.664
1983	0.024	0.224	0.768	1.542	2.418	3.808	6.055	6.071	10.317	13.325
1984	0.001	0.234	0.653	1.478	2.678	3.609	5.540	8.368	10.138	14.828
1985	0.039	0.206	0.733	1.404	2.819	4.658	5.884	8.502	11.244	13.676
1986	0.005	0.277	0.501	1.698	2.774	4.778	6.504	8.109	10.206	14.646
1987	0.004	0.154	0.642	1.323	3.090	4.668	7.259	10.036	11.099	14.582
1988	0.003	0.122	0.577	1.666	2.360	5.205	5.200	6.193	10.103	12.993
1989	0.046	0.236	0.752	1.518	2.959	4.282	5.980	9.276	12.519	20.913
1990	0.021	0.193	0.811	1.349	2.141	4.474	7.721	10.820	11.750	18.718
1991	0.014	0.236	1.113	1.601	2.281	3.894	7.144	10.429	12.261	14.031
1992	0.023	0.055	1.033	1.530	2.747	2.976	5.587	10.921	10.483	14.483
1993	0.021	0.081	0.690	1.748	2.150	4.420	5.670	9.817	13.673	15.701
1994	0.022	0.058	0.730	1.712	3.085	3.251	6.335	7.684	12.542	11.846
1995	0.027	0.103	1.288	1.591	2.649	5.090	6.865	11.466	13.128	22.443
1996	0.033	0.100	1.293	2.096	2.260	3.462	7.558	11.728	14.455	16.269
1997	0.017	0.064	1.351	2.128	3.022	3.074	4.699	9.000	12.156	16.938
1998	0.008	0.202	1.071	1.931	2.633	3.972	4.255	7.122	12.118	16.676
1999	0.052	0.222	0.635	1.723	2.777	3.892	5.670	6.704	9.811	12.279
2000	0.030	0.282	1.081	2.150	3.316	4.325	5.898	5.352	9.331	12.680
2001	0.045	0.316	0.890	2.176	3.144	4.666	6.140	7.273	9.072	9.559
2002	0.032	0.185	0.795	1.797	2.906	3.792	6.132	6.969	8.808	12.205
2003	0.038	0.202	0.809	1.843	2.378	3.654	5.112	7.649	9.191	12.058
2004	0.025	0.111	0.483	1.606	2.965	3.547	5.350	7.220	9.764	13.303
2005	0.027	0.126	0.558	1.625	2.401	4.233	4.502	6.349	8.002	12.549
2006	0.071	0.289	0.648	1.493	2.932	3.357	4.463	5.562	7.430	12.146
2007	0.025	0.220	0.744	1.731	2.922	3.735	4.771	6.167	7.302	12.394
2008	0.085	0.247	0.862	2.179	2.818	3.530	3.988	5.819	7.528	12.044
2009	0.032	0.337	0.911	2.153	3.126	3.575	4.368	5.959	8.000	12.887
2010	0.023	0.264	1.200	1.995	3.203	3.914	4.447	5.708	8.730	11.612
2011	0.086	0.329	0.933	2.056	2.874	3.870	4.839	5.717	5.953	12.984

Table A.50. Mean January 1/spawning stock weights-at-age (kg) of Gulf of Maine Atlantic cod from 1982 to 2011 an age 9^+ group. Weights were estimated from catch weights using Rivard (1980, 1982) approach. Cells shaded grey were imputed using a 5-year centered moving average, cells shaded red were imputed using a time series average. **Only ages 1 through the 9^+group are used as assessment model inputs.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	0.002	0.241	0.594	1.165	2.127	4.635	7.622	9.289	9.695	15.664
1983	0.008	0.050	0.501	1.114	1.894	3.136	5.539	6.549	9.962	13.325
1984	0.000	0.075	0.372	1.019	2.021	2.952	4.593	7.118	7.845	14.828
1985	0.015	0.014	0.403	0.910	2.013	3.532	4.608	6.863	9.700	13.676
1986	0.001	0.104	0.316	1.077	1.917	3.670	5.504	6.908	9.315	14.646
1987	0.001	0.028	0.406	0.777	2.273	3.574	5.889	8.079	9.487	14.582
1988	0.000	0.022	0.293	0.980	1.709	4.010	4.927	6.705	10.069	12.993
1989	0.022	0.027	0.292	0.887	2.179	3.172	5.578	6.945	8.799	20.913
1990	0.006	0.095	0.431	0.937	1.742	3.627	5.750	8.043	10.440	18.718
1991	0.007	0.071	0.450	1.083	1.689	2.846	5.654	8.972	11.518	14.060
1992	0.012	0.028	0.476	1.215	2.026	2.564	4.629	8.832	10.453	14.483
1993	0.012	0.046	0.191	1.254	1.702	3.449	4.083	7.388	12.219	15.708
1994	0.010	0.038	0.236	1.003	2.244	2.571	5.294	6.601	11.095	11.846
1995	0.012	0.051	0.275	0.946	2.021	3.934	4.722	8.526	10.045	22.443
1996	0.022	0.060	0.356	1.462	1.784	2.971	6.185	8.967	12.844	16.357
1997	0.005	0.049	0.391	1.466	2.407	2.571	3.973	8.245	11.940	16.938
1998	0.002	0.059	0.256	1.445	2.245	3.423	3.558	5.739	10.442	16.676
1999	0.022	0.044	0.343	1.196	2.237	3.139	4.752	5.301	8.351	12.279
2000	0.009	0.120	0.461	1.063	2.257	3.422	4.773	5.508	7.882	12.661
2001	0.023	0.097	0.456	1.305	2.420	3.851	5.091	6.513	6.912	9.538
2002	0.012	0.089	0.465	1.050	2.249	3.247	5.296	6.514	7.924	12.152
2003	0.022	0.089	0.346	1.053	1.742	2.977	4.118	6.837	8.011	12.023
2004	0.011	0.066	0.351	0.971	2.110	2.620	4.199	5.908	8.627	13.288
2005	0.008	0.060	0.248	0.821	1.654	3.338	3.841	5.758	7.593	12.546
2006	0.043	0.089	0.295	0.808	1.890	2.467	4.076	4.912	6.744	12.137
2007	0.009	0.124	0.450	0.925	1.771	3.005	3.723	5.020	6.329	12.394
2008	0.046	0.085	0.420	1.117	1.888	2.892	3.630	5.147	6.803	12.040
2009	0.014	0.171	0.480	1.248	2.283	2.908	3.658	4.735	6.735	12.878
2010	0.006	0.100	0.589	1.168	2.328	3.198	3.685	4.778	7.153	11.612
2011	0.084	0.087	0.492	1.353	1.972	3.262	4.114	4.788	5.751	12.995

Table A.51. Summary of vessels and trawl doors used in the Northeast Fisheries Science Center (NEFSC) spring and fall surveys from 1963 to 2012. All survey indices are standardized to Albatross IV, Polyvalent door equivalents. **Note, the spring survey did not begin until 1968, 2012 fall survey data are not available at time of this report.*

Year	Spring	Autumn	Door
1963		Albatross IV	BMV
1964		Albatross IV	BMV
1965		Albatross IV	BMV
1966		Albatross IV	BMV
1967		Albatross IV	BMV
1968	Albatross IV	Albatross IV	BMV
1969	Albatross IV	Albatross IV	BMV
1970	Albatross IV	Albatross IV	BMV
1971	Albatross IV	Albatross IV	BMV
1972	Albatross IV	Albatross IV	BMV
1973	Albatross IV	Albatross IV	BMV
1974	Albatross IV	Albatross IV	BMV
1975	Albatross IV	Albatross IV	BMV
1976	Albatross IV	Albatross IV	BMV
1977	Albatross IV	Delaware II	BMV
1978	Albatross IV	Delaware II	BMV
1979	Albatross IV/Delaware II	Albatross IV/Delaware II	BMV
1980	Albatross IV/Delaware II	Delaware II	BMV
1981	Delaware II	Albatross IV/Delaware II	BMV
1982	Delaware II	Albatross IV	BMV
1983	Albatross IV	Albatross IV	BMV
1984	Albatross IV	Albatross IV	BMV
1985	Albatross IV	Albatross IV	Polyvalent
1986	Albatross IV	Albatross IV	Polyvalent
1987	Albatross IV/Delaware II	Albatross IV	Polyvalent
1988	Albatross IV	Albatross IV/Delaware II	Polyvalent
1989	Delaware II	Delaware II	Polyvalent
1990	Delaware II	Delaware II	Polyvalent
1991	Delaware II	Delaware II	Polyvalent
1992	Albatross IV	Albatross IV	Polyvalent
1993	Albatross IV	Delaware II	Polyvalent
1994	Delaware II	Albatross IV	Polyvalent
1995	Albatross IV	Albatross IV	Polyvalent
1996	Albatross IV	Albatross IV	Polyvalent
1997	Albatross IV	Albatross IV	Polyvalent
1998	Albatross IV	Albatross IV	Polyvalent
1999	Albatross IV	Albatross IV	Polyvalent
2000	Albatross IV	Albatross IV	Polyvalent
2001	Albatross IV	Albatross IV	Polyvalent
2002	Albatross IV	Albatross IV	Polyvalent
2003	Delaware II	Albatross IV	Polyvalent
2004	Albatross IV	Albatross IV	Polyvalent
2005	Albatross IV	Albatross IV	Polyvalent
2006	Albatross IV	Albatross IV	Polyvalent
2007	Albatross IV	Albatross IV	Polyvalent
2008	Albatross IV	Albatross IV	Polyvalent
2009	Henry B. Bigelow	Henry B. Bigelow	PolyIce oval
2010	Henry B. Bigelow	Henry B. Bigelow	PolyIce oval
2011	Henry B. Bigelow	Henry B. Bigelow	PolyIce oval
2012	Henry B. Bigelow		PolyIce oval

Table A.52. Summary of survey calibration coefficients for converting survey index values to Albatross IV, Polyvalent door equivalent units.

Calibration type	Index	Length (cm)	Calibration coefficient	Lower 95% CI	Upper 95% CI	Source
Deleware II to Albatross IV	Biomass (weight)	*NA*	0.670	0.530	0.870	Forrester et al., 1997
	Abundance (numbers)	*NA*	0.790	0.690	0.940	
BMV door to Polyvalent door	Biomass (weight)	*NA*	1.620	1.370	1.940	
	Abundance (numbers)	*NA*	1.560	1.330	1.880	
Bigelow to Albatross IV	Biomass (weight)	*NA*	1.580	0.906	1.643	Miller et al. 2010
	Abundance (numbers)	≤ 20	5.724	4.166	7.864	Brooks et al. 2010
		21	5.600	4.094	7.661	
		22	5.477	4.022	7.458	
		23	5.353	3.950	7.256	
		24	5.230	3.877	7.054	
		25	5.106	3.805	6.852	
		26	4.983	3.733	6.651	
		27	4.859	3.660	6.451	
		28	4.736	3.588	6.251	
		29	4.612	3.515	6.052	
		30	4.489	3.442	5.854	
		31	4.365	3.369	5.657	
		32	4.242	3.295	5.460	
		33	4.118	3.221	5.265	
		34	3.995	3.147	5.071	
		35	3.871	3.072	4.879	
		36	3.748	2.996	4.688	
		37	3.624	2.919	4.499	
		38	3.501	2.841	4.313	
		39	3.377	2.762	4.130	
		40	3.254	2.680	3.950	
		41	3.130	2.596	3.774	
		42	3.007	2.509	3.604	
		43	2.883	2.417	3.440	
		44	2.760	2.320	3.284	
		45	2.636	2.216	3.136	
		46	2.513	2.105	2.999	
		47	2.389	1.986	2.874	
		48	2.266	1.860	2.760	
		49	2.142	1.726	2.659	
		50	2.019	1.586	2.569	
		51	1.895	1.442	2.491	
		52	1.772	1.295	2.423	
		53	1.648	1.147	2.368	
		≥ 54	1.602	1.092	2.350	

Table A.53. Summary of the differences in survey protocol from the FSV Albatross IV survey (2008 and earlier) and FSV Henry B. Bigelow (2009 - present). Adapted from Brooks et al. (2010).

Measure	**FSV Henry B Bigelow**	**FSV Albatross IV**
Tow speed	3.0 knots SOG	3.8 knots SOG
Tow duration	20min	30 mins
Headrope height	3.5-4m	1-2m
Ground gear	Rockhopper Sweep	Roller Sweep
(cookies, rock hoppers, etc.)	Total Length-25.5m	Total Length-24.5m
	Center- 8.9m length, 16” rockhoppers.	Center-5m length, 16” rollers.
	Wings- 8.2m each	Wings- 9.75m each, 4” cookies.
	14” rockhoppers	
Mesh	Poly webbing	Nylon webbing
	Forward Portion of trawl (jibs, upper and lower wing ends, 1st&2nd side panels, 1st bottom belly)12cm,4mm	Body of trawl= 12.7cm
	Square aft to codend:6cm, 2.5mm	Codend- 11.5cm
	Codend: 12cm, 4mm dbl.	Liner (codend and aft portion of top belly)- 1.27cm knotless
	Codend Liner: 2.54cm, knotless	
Net design	4 Seam, 3 Bridle	Yankee 36 (recent years)
Door type	550 kg PolyIce oval	450 kg polyvalent
Other comments	Wing End to Door distance= 36.5m	Wing End to Door Distance= 9m

Table A.54. Summary of the sampling of Northeast Fisheries Science Center (NEFSC) Gulf of Maine offshore survey strata broken down by survey (spring/fall) and time of day (day/night) between 1963 and spring 2011. The day/night classification is based on sunrise/sunset (zenith angle of 90°50'). *Note that the spring survey did not begin until 1968.*

Year	Strata sampled				Tows sampled			
	Spring		Fall		Spring		Fall	
	Day	Night	Day	Night	Day	Night	Day	Night
1963			8	9			22	35
1964			10	9			15	32
1965			10	9			25	23
1966			9	9			22	21
1967			8	10			19	30
1968	8	10	9	10	27	23	19	31
1969	9	9	9	10	25	26	18	33
1970	6	9	10	10	17	35	21	32
1971	10	9	10	10	28	29	20	35
1972	10	9	8	9	28	27	24	31
1973	10	9	8	10	23	25	20	34
1974	10	8	9	9	29	18	28	29
1975	8	7	8	9	25	27	27	38
1976	8	9	7	10	30	34	17	38
1977	10	10	8	10	37	30	26	45
1978	10	10	10	9	37	29	54	66
1979	9	9	10	10	44	28	56	73
1980	10	8	10	10	26	24	23	28
1981	10	9	10	10	34	18	27	26
1982	9	9	10	10	32	21	21	33
1983	10	7	8	9	34	19	19	29
1984	9	10	7	9	31	19	20	31
1985	9	9	9	10	27	20	17	33
1986	9	10	7	9	25	27	19	34
1987	8	7	9	9	28	19	23	28
1988	10	9	8	9	35	19	23	29
1989	8	10	8	8	27	24	20	31
1990	9	10	8	10	23	29	23	29
1991	10	9	9	10	29	21	20	33
1992	10	9	9	10	29	23	21	30
1993	9	9	9	9	27	23	24	27
1994	10	9	8	10	35	18	18	32
1995	10	9	9	10	27	26	20	37
1996	10	9	10	9	27	25	25	27
1997	10	10	8	10	30	23	24	28
1998	10	10	9	10	39	36	33	34
1999	9	10	9	10	29	23	33	37
2000	9	9	9	10	30	22	21	31
2001	10	9	9	9	33	19	27	27
2002	10	10	10	10	29	26	27	22
2003	7	9	10	9	23	29	19	32
2004	10	8	8	9	32	18	21	27
2005	10	6	9	9	32	19	21	30
2006	10	10	8	9	33	26	25	33
2007	10	10	9	9	27	23	23	30
2008	10	9	10	10	30	21	21	32
2009	10	9	9	8	39	31	22	31
2010	8	10	9	9	34	30	22	29
2011	8	9			28	25		

Table A.55. Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl survey indices for Gulf of Maine Atlantic cod from 1963 to 2012. **Note: the spring survey did not begin until 1968, 2012 fall survey data not available at time of this report.*

Year	Abundance (numbers/tow)		Biomass (kg/tow)	
	Spring	Fall	Spring	Fall
1963		5.914		17.950
1964		4.015		22.799
1965		4.500		12.089
1966		3.720		12.838
1967		2.602		9.313
1968	5.329	4.374	17.480	19.437
1969	3.215	2.758	13.100	15.154
1970	2.191	4.905	11.089	16.442
1971	1.429	4.361	7.004	16.529
1972	2.057	9.301	8.031	12.988
1973	7.525	4.452	18.807	8.764
1974	2.902	4.328	7.419	8.959
1975	2.512	6.143	6.039	8.619
1976	2.782	2.148	7.556	6.740
1977	3.872	3.073	8.541	10.199
1978	2.050	5.773	7.697	12.899
1979	3.644	3.142	7.555	13.927
1980	2.155	7.035	6.232	14.202
1981	4.832	2.349	10.650	7.533
1982	3.763	7.769	8.616	15.919
1983	3.912	2.786	10.962	8.416
1984	3.667	2.449	6.143	8.735
1985	2.517	2.821	7.645	8.264
1986	1.957	1.950	3.476	4.715
1987	1.083	2.996	1.976	3.394
1988	3.127	5.903	3.603	6.616
1989	2.112	4.553	2.424	4.535
1990	2.362	2.986	3.077	4.912
1991	2.393	1.252	2.891	2.782
1992	2.435	1.434	8.627	2.448
1993	2.507	1.232	5.875	1.003
1994	1.271	2.130	2.428	2.737
1995	1.930	2.008	2.432	3.665
1996	2.465	1.327	5.427	2.352
1997	2.192	0.872	5.616	1.872
1998	1.710	0.843	4.180	1.501
1999	2.301	1.807	5.090	3.505
2000	3.083	2.604	3.211	4.652
2001	2.147	1.980	6.215	7.324
2002	3.724	5.328	10.934	24.659
2003	3.677	2.529	9.495	5.988
2004	0.981	3.533	2.412	4.906
2005	1.765	1.338	2.701	2.897
2006	1.363	3.594	2.702	4.229
2007	12.393	1.992	15.811	2.714
2008	7.990	3.460	10.823	5.307
2009	3.599	3.447	7.161	5.845
2010	1.296	0.948	3.336	2.572
2011	0.894	0.990	2.133	2.647
2012	0.893		1.645	
Avg	2.978	3.342	6.806	8.337
Min	0.893	0.843	1.645	1.003
Max	12.393	9.301	18.807	24.659

Table A.56. Coefficients of variation (CV) for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl survey indices for Gulf of Maine cod from 1963 to 2012. **Note: the spring survey did not begin until 1968, 2012 fall survey data not available at time of this report.*

Year	Abundance (numbers/tow)		Biomass (kg/tow)	
	Spring	Fall	Spring	Fall
1963		0.250		0.391
1964		0.412		0.496
1965		0.274		0.273
1966		0.217		0.227
1967		0.223		0.219
1968	0.127	0.181	0.153	0.198
1969	0.328	0.152	0.329	0.217
1970	0.214	0.318	0.237	0.248
1971	0.190	0.205	0.211	0.307
1972	0.208	0.535	0.233	0.199
1973	0.328	0.151	0.415	0.267
1974	0.188	0.260	0.199	0.201
1975	0.222	0.226	0.249	0.153
1976	0.181	0.197	0.166	0.214
1977	0.269	0.124	0.208	0.126
1978	0.191	0.188	0.207	0.151
1979	0.234	0.112	0.176	0.128
1980	0.171	0.261	0.182	0.153
1981	0.194	0.224	0.205	0.233
1982	0.219	0.636	0.223	0.670
1983	0.263	0.170	0.225	0.188
1984	0.443	0.220	0.324	0.334
1985	0.202	0.176	0.223	0.354
1986	0.314	0.230	0.197	0.228
1987	0.257	0.308	0.314	0.234
1988	0.211	0.349	0.281	0.232
1989	0.184	0.223	0.207	0.181
1990	0.249	0.190	0.280	0.204
1991	0.251	0.267	0.240	0.246
1992	0.317	0.213	0.374	0.243
1993	0.223	0.259	0.347	0.263
1994	0.223	0.309	0.216	0.292
1995	0.273	0.301	0.257	0.325
1996	0.240	0.254	0.275	0.249
1997	0.168	0.299	0.192	0.307
1998	0.344	0.346	0.324	0.287
1999	0.242	0.181	0.320	0.193
2000	0.221	0.306	0.155	0.332
2001	0.311	0.271	0.327	0.279
2002	0.203	0.578	0.215	0.686
2003	0.223	0.307	0.368	0.251
2004	0.256	0.327	0.293	0.214
2005	0.241	0.065	0.248	0.228
2006	0.203	0.301	0.249	0.188
2007	0.665	0.368	0.540	0.277
2008	0.716	0.389	0.609	0.285
2009	0.531	0.535	0.491	0.429
2010	0.243	0.233	0.264	0.304
2011	0.279	0.304	0.201	0.336
2012	0.187		0.209	
Avg	0.265	0.274	0.270	0.270
Min	0.127	0.065	0.153	0.126
Max	0.716	0.636	0.609	0.686

Table A.57. Northeast Fisheries Science Center (NEFSC) spring survey abundance indices-at-age (numbers/tow) from 1970 to 2012 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16	Age17
1970	0.000	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.045	0.076	0.133	0.059	0.000	0.018	0.000	0.000	0.000
1971	0.000	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.142	0.050	0.013	0.000	0.000	0.000	0.000	0.000	0.000
1972	0.053	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.300	0.027	0.017	0.026	0.000	0.017	0.000	0.000	0.000
1973	0.000	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.276	0.186	0.072	0.113	0.112	0.088	0.000	0.000	0.000
1974	0.164	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.038	0.089	0.043	0.037	0.000	0.016	0.000	0.035	0.000
1975	0.012	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.025	0.028	0.026	0.062	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.000	0.036	0.000	0.054	0.027	0.000	0.000	0.000	0.000
1977	0.000	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.000	0.006
1978	0.000	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.108	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.044	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.013	0.031	0.020	0.000	0.000	0.000	0.000	0.000	0.000
1980	0.070	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.105	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1981	0.000	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.014	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.040	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.013	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.071	0.033	0.017	0.045	0.000	0.016	0.000	0.000	0.000
1984	0.000	0.151	1.309	0.987	0.853	0.229	0.047	0.090	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.000	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000
1988	0.029	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.025	0.609	0.712	0.630	0.069	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.009	0.233	1.325	0.669	0.076	0.032	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.028	0.077	0.233	1.750	0.247	0.041	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.000	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.000	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.027	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.000	0.057	0.022	0.586	1.355	0.385	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.159	0.139	0.390	0.271	0.874	0.244	0.115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.018	0.228	0.359	0.513	0.143	0.408	0.021	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000
2000	0.026	1.173	0.737	0.438	0.485	0.099	0.092	0.011	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.000	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.082	0.030	0.011	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.029	0.739	0.081	0.623	0.011	0.138	0.128	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.028	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.100	3.422	3.077	4.446	0.437	0.796	0.075	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.079	1.165	3.930	1.582	1.099	0.053	0.082	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.000	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.010	0.005	0.000	0.010	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.005	0.024	0.140	0.383	0.189	0.086	0.033	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	0.000	0.069	0.105	0.224	0.243	0.159	0.051	0.036	0.004	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.58. Northeast Fisheries Science Center (NEFSC) spring survey biomass indices-at-age (weight/tow) from 1970 to 2012 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970. **Note, biomass indices are not used in the current assessment.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16	Age17
1970	0.000	0.007	0.037	0.034	0.154	0.715	2.274	3.140	0.626	0.390	0.605	1.840	0.950	0.000	0.318	0.000	0.000	0.000
1971	0.000	0.014	0.055	0.133	0.623	0.384	0.343	1.786	1.767	1.073	0.656	0.170	0.000	0.000	0.000	0.000	0.000	0.000
1972	0.000	0.014	0.054	0.827	0.522	0.738	0.284	0.516	0.914	3.161	0.256	0.208	0.268	0.000	0.270	0.000	0.000	0.000
1973	0.000	0.002	0.769	0.892	1.780	1.434	0.652	0.765	1.156	2.874	2.127	0.914	1.627	1.837	1.979	0.000	0.000	0.000
1974	0.002	0.011	0.015	1.056	0.478	1.310	0.655	0.000	0.470	0.176	1.213	0.402	0.527	0.000	0.289	0.000	0.815	0.000
1975	0.000	0.003	0.180	0.098	2.161	0.954	0.512	0.000	0.052	0.250	0.566	0.166	1.097	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.005	0.061	0.794	0.253	2.727	0.728	0.608	0.438	0.000	0.451	0.000	0.958	0.532	0.000	0.000	0.000	0.000
1977	0.000	0.008	0.086	0.359	2.132	0.321	3.710	0.000	1.134	0.000	0.000	0.000	0.000	0.000	0.666	0.000	0.000	0.126
1978	0.000	0.009	0.039	0.338	0.695	2.398	0.480	1.738	0.134	1.613	0.000	0.253	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.000	0.033	0.568	0.254	0.926	0.918	2.248	0.721	0.741	0.184	0.464	0.498	0.000	0.000	0.000	0.000	0.000	0.000
1980	0.000	0.002	0.175	0.563	0.263	1.019	0.875	1.880	0.000	1.072	0.383	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1981	0.000	0.137	0.285	0.937	3.306	1.289	1.869	0.605	1.220	1.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.038	0.456	0.672	1.901	3.511	0.339	1.085	0.000	0.439	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.057	0.448	1.536	1.138	1.718	1.672	0.682	0.000	1.134	0.526	0.306	1.283	0.000	0.462	0.000	0.000	0.000
1984	0.000	0.011	0.752	1.412	2.176	1.133	0.204	0.455	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.000	0.001	0.101	0.898	1.658	3.035	0.518	0.663	0.342	0.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.046	0.125	1.199	0.644	0.268	0.358	0.474	0.000	0.000	0.000	0.000	0.362	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.002	0.164	0.139	0.574	0.230	0.000	0.432	0.061	0.000	0.000	0.000	0.000	0.000	0.373	0.000	0.000	0.000
1988	0.000	0.036	0.162	0.821	0.489	1.035	0.548	0.177	0.191	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.001	0.111	0.518	1.151	0.182	0.461	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.001	0.057	1.042	1.357	0.263	0.210	0.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.002	0.015	0.204	2.083	0.376	0.104	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.000	0.003	0.112	0.225	0.713	5.715	1.204	0.494	0.000	0.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.012	0.164	1.100	0.714	0.321	2.341	0.589	0.258	0.000	0.377	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.001	0.061	0.348	0.467	0.210	0.150	0.804	0.060	0.098	0.229	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.004	0.045	0.794	0.411	0.415	0.135	0.000	0.032	0.000	0.597	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.000	0.004	0.007	1.054	2.802	1.269	0.291	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.010	0.062	0.553	0.719	2.581	0.914	0.777	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.001	0.102	0.427	1.043	0.461	1.849	0.136	0.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.015	0.115	0.722	0.683	0.953	0.768	1.482	0.000	0.000	0.000	0.000	0.000	0.353	0.000	0.000	0.000	0.000
2000	0.000	0.093	0.322	0.454	1.204	0.409	0.489	0.052	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.000	0.003	0.168	0.756	1.395	1.452	0.581	0.876	0.793	0.000	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.024	0.014	0.642	4.305	1.963	2.061	1.113	0.753	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.009	0.163	0.048	1.141	2.852	1.544	1.964	0.535	0.920	0.282	0.038	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.006	0.016	0.196	0.294	0.763	0.936	0.043	0.043	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.001	0.156	0.084	1.084	0.030	0.549	0.716	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.000	0.013	0.062	0.343	0.091	0.611	0.142	0.686	0.602	0.000	0.153	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.009	1.329	2.694	7.333	1.337	2.581	0.308	0.221	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.004	0.466	4.137	2.619	2.734	0.299	0.565	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.000	0.002	0.146	1.513	2.346	1.560	1.260	0.065	0.222	0.000	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.005	0.099	0.403	0.551	0.881	0.522	0.318	0.171	0.103	0.113	0.000	0.171	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.000	0.011	0.164	0.657	0.510	0.302	0.193	0.295	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	0.000	0.006	0.054	0.291	0.500	0.391	0.166	0.180	0.041	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.59. Northeast Fisheries Science Center (NEFSC) fall survey abundance indices-at-age (numbers/tow) from 1970 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16	Age17
1970	0.743	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.090	0.037	0.037	0.073	0.000	0.000	0.000	0.000	0.000
1971	1.334	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.193	0.031	0.040	0.081	0.000	0.000	0.000	0.000	0.000
1972	0.031	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.351	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000
1973	0.638	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.182	0.122	0.000	0.000	0.016	0.000	0.000	0.000	0.000
1974	0.265	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.066	0.000	0.120	0.000	0.000	0.069	0.000	0.000	0.000
1975	0.006	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.000	0.000	0.006	0.012	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.000	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.021	0.061	0.000	0.022	0.026	0.000	0.000	0.000	0.000
1978	0.241	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.082	0.000	0.019	0.000	0.028	0.000	0.000	0.000	0.000
1979	0.000	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.000	0.053	0.000	0.000	0.000	0.005	0.013	0.000	0.000
1980	0.027	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.012	0.000	0.049	0.000	0.014	0.000	0.000	0.022	0.000
1981	0.010	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.835	3.264	2.476	0.971	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.000	0.018	0.028	0.037	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.016	0.000	0.000	0.045	0.035	0.000	0.000	0.000	0.000
1985	0.218	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.394	0.404	0.626	0.368	0.073	0.041	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.128	0.570	1.388	0.586	0.198	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.000	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.011	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.145	2.468	1.458	0.283	0.138	0.053	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.057	0.218	1.788	0.611	0.255	0.048	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.009	0.144	0.151	0.230	0.621	0.075	0.000	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.059	0.289	0.448	0.144	0.041	0.327	0.126	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.031	0.210	0.575	0.361	0.017	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.032	0.184	0.909	0.816	0.093	0.051	0.000	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.008	0.068	0.308	1.226	0.304	0.082	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.029	0.122	0.379	0.231	0.516	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.297	0.091	0.165	0.168	0.151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.050	0.085	0.342	0.110	0.185	0.041	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.025	0.432	0.375	0.590	0.244	0.122	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.008	0.540	0.981	0.399	0.492	0.140	0.010	0.000	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.018	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.269	0.104	0.333	2.683	1.070	0.750	0.077	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.542	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.011	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000
2004	1.369	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.010	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.034	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.064	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.011	0.136	0.863	0.395	0.496	0.023	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.165	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.010	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.020	0.660	2.096	0.314	0.277	0.045	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.008	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
2011	0.036	0.060	0.091	0.210	0.304	0.175	0.078	0.005	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.60. Northeast Fisheries Science Center (NEFSC) fall survey biomass indices-at-age (weight/tow) from 1970 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970. **Note, biomass indices are not used in the current assessment.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16	Age17
1970	0.005	0.187	0.152	0.732	1.291	1.467	2.626	5.792	1.125	0.780	0.493	0.443	1.349	0.000	0.000	0.000	0.000	0.000
1971	0.333	0.050	0.269	0.321	1.769	2.138	2.743	1.519	2.520	2.357	0.644	0.337	1.531	0.000	0.000	0.000	0.000	0.000
1972	0.000	0.769	0.832	3.572	0.647	0.264	0.813	0.208	1.480	4.078	0.000	0.000	0.000	0.000	0.323	0.000	0.000	0.000
1973	0.006	0.036	0.984	0.374	2.282	0.919	0.322	0.178	0.235	2.076	1.128	0.000	0.000	0.224	0.000	0.000	0.000	0.000
1974	0.000	0.086	0.133	2.515	0.344	1.778	0.000	0.419	0.456	0.814	0.000	1.602	0.000	0.000	0.812	0.000	0.000	0.000
1975	0.000	0.056	1.328	0.144	5.392	0.695	0.587	0.169	0.000	0.000	0.000	0.095	0.154	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.073	0.182	0.678	0.154	3.230	0.328	0.963	0.000	0.000	1.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.000	0.009	0.237	0.565	2.121	0.506	3.589	0.188	0.929	0.298	1.031	0.000	0.300	0.427	0.000	0.000	0.000	0.000
1978	0.004	0.285	0.264	1.559	1.500	4.493	0.408	2.047	0.143	1.260	0.000	0.361	0.000	0.577	0.000	0.000	0.000	0.000
1979	0.000	0.140	0.542	0.347	2.328	1.744	5.123	0.573	1.607	0.000	1.042	0.000	0.000	0.000	0.122	0.360	0.000	0.000
1980	0.001	0.427	1.836	3.159	1.589	1.580	2.409	1.228	0.338	0.216	0.000	0.702	0.000	0.291	0.000	0.000	0.427	0.000
1981	0.000	0.135	0.440	0.993	2.249	0.516	0.656	0.676	1.225	0.000	0.644	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.412	4.594	6.161	3.224	1.528	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.072	0.979	1.310	0.957	1.222	2.154	0.000	0.000	0.000	0.266	0.648	0.809	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.147	0.422	1.345	1.419	1.287	1.465	0.705	0.000	0.302	0.000	0.000	0.907	0.737	0.000	0.000	0.000	0.000
1985	0.003	0.093	0.967	1.568	0.780	1.842	0.663	0.000	0.691	1.657	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.137	0.284	1.563	1.229	0.576	0.332	0.000	0.000	0.595	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.001	0.086	0.900	0.881	0.714	0.813	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.331	1.586	1.982	1.172	0.877	0.000	0.388	0.000	0.117	0.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.040	1.011	1.715	0.771	0.676	0.204	0.000	0.119	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.013	0.094	1.718	1.565	1.234	0.238	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.025	0.108	0.392	1.592	0.404	0.000	0.260	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.001	0.062	0.400	0.178	0.109	1.100	0.599	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.001	0.026	0.295	0.553	0.061	0.000	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.001	0.053	0.482	1.226	0.324	0.331	0.000	0.320	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.001	0.009	0.270	1.958	0.793	0.586	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.001	0.035	0.274	0.508	1.246	0.289	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.045	0.082	0.291	0.772	0.681	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.001	0.016	0.258	0.206	0.607	0.185	0.227	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.001	0.131	0.380	1.239	0.941	0.671	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.119	0.849	0.774	1.821	0.497	0.098	0.000	0.495	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.001	0.000	0.129	1.310	1.301	2.228	1.124	0.981	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.038	0.101	0.730	10.977	5.659	5.789	0.642	0.723	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.014	0.172	0.122	0.497	1.402	2.361	0.443	0.538	0.000	0.174	0.000	0.266	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.002	0.083	0.108	0.978	0.878	1.125	0.666	0.485	0.192	0.191	0.198	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.001	0.017	0.171	0.124	0.985	0.134	0.312	0.542	0.231	0.380	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.001	0.257	0.288	1.031	0.432	1.021	0.221	0.269	0.510	0.000	0.000	0.199	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.001	0.023	0.455	0.402	1.310	0.098	0.426	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.014	0.206	1.246	2.105	0.469	0.754	0.000	0.000	0.000	0.134	0.379	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.001	0.366	2.461	1.057	1.246	0.480	0.234	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.032	0.155	0.515	1.125	0.440	0.106	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.154	0.000	0.000	0.000
2011	0.001	0.017	0.086	0.372	0.706	0.802	0.385	0.054	0.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.61. Massachusetts Department of Marine Fisheries (MADMF) spring and fall survey indices from 1978 to 2012 for Gulf of Maine Atlantic cod. **Note: 2012 fall survey data not available at time of this report.*

Year	Abundance (numbers/tow)		Biomass (kg/tow)	
	Spring	Fall	Spring	Fall
1978	47.887	156.060	11.058	1.515
1979	96.559	8.924	14.276	1.052
1980	65.979	12.531	14.509	1.286
1981	69.406	9.291	18.689	3.638
1982	25.842	6.125	12.161	0.659
1983	54.850	1.676	18.746	0.092
1984	10.330	10.548	7.240	0.133
1985	8.455	2.871	4.765	0.070
1986	24.089	2.750	7.841	0.249
1987	17.206	313.148	7.865	0.348
1988	22.242	8.872	7.703	0.366
1989	52.244	4.150	17.346	0.218
1990	32.409	12.708	15.879	0.758
1991	13.699	7.483	8.730	0.480
1992	16.924	27.496	8.766	0.272
1993	92.659	51.500	5.861	1.353
1994	16.358	49.019	4.334	1.998
1995	23.364	4.678	3.993	0.807
1996	12.961	7.007	3.152	0.083
1997	17.887	1.456	2.500	0.014
1998	27.570	4.335	3.250	0.360
1999	161.058	8.005	8.997	0.308
2000	50.771	0.679	20.604	0.272
2001	41.844	49.555	26.445	0.757
2002	24.338	3.299	11.158	3.995
2003	1120.371	122.284	10.984	1.850
2004	131.589	57.620	8.147	5.580
2005	193.262	40.350	10.402	0.207
2006	1077.030	7.505	9.177	1.939
2007	61.576	7.918	8.430	0.077
2008	482.100	7.549	12.229	2.379
2009	480.516	5.042	4.489	0.807
2010	8.075	2.022	5.645	1.400
2011	59.064	2.610	4.519	1.355
2012	11.465		2.276	
Avg	132.914	29.914	9.776	1.079
Min	8.075	0.679	2.276	0.014
Max	1120.371	313.148	26.445	5.580

Table A.62. Coefficients of variation (CV) for the Massachusetts Department of Marine Fisheries (MADMF) spring and fall bottom trawl survey indices of Gulf of Maine Atlantic cod between 1978 and 2012. **Note: 2012 fall survey data not available at time of this report.*

Year	Abundance (numbers/tow)		Biomass (kg/tow)	
	Spring	Fall	Spring	Fall
1978	0.147	0.322	0.138	0.555
1979	0.278	0.260	0.219	0.377
1980	0.124	0.266	0.128	0.345
1981	0.207	0.422	0.265	0.453
1982	0.221	0.321	0.175	0.690
1983	0.166	0.338	0.153	0.569
1984	0.289	0.189	0.259	0.444
1985	0.206	0.308	0.194	0.396
1986	0.552	0.304	0.354	0.864
1987	0.221	0.173	0.271	0.186
1988	0.206	0.240	0.237	0.436
1989	0.268	0.064	0.342	0.456
1990	0.288	0.262	0.341	0.413
1991	0.219	0.263	0.122	0.543
1992	0.287	0.076	0.321	0.340
1993	0.340	0.245	0.270	0.237
1994	0.227	0.513	0.241	0.787
1995	0.262	0.316	0.225	0.690
1996	0.218	0.365	0.305	0.426
1997	0.240	0.243	0.250	0.456
1998	0.261	0.260	0.468	0.486
1999	0.369	0.552	0.261	0.452
2000	0.391	0.379	0.459	0.387
2001	0.435	0.474	0.536	0.545
2002	0.096	0.596	0.390	0.812
2003	0.507	0.478	0.219	0.466
2004	0.459	0.299	0.278	0.399
2005	0.223	0.415	0.197	0.412
2006	0.337	0.398	0.181	0.460
2007	0.274	0.275	0.251	0.665
2008	0.204	0.417	0.215	0.443
2009	0.352	0.416	0.187	0.431
2010	0.234	0.449	0.456	0.471
2011	0.534	0.328	0.424	0.246
2012	0.274		0.401	
Avg	0.283	0.330	0.278	0.481
Min	0.096	0.064	0.122	0.186
Max	0.552	0.596	0.536	0.864

Table A.63. Massachusetts Department of Marine Fisheries (MADMF) spring survey abundance indices-at-age (numbers/tow) from 1982 to 2012 for Gulf of Maine Atlantic cod. Age data are not available prior to 1982.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1982	1.668	13.218	6.649	2.921	1.024	0.216	0.049	0.046	0.050	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.718	30.253	17.570	4.710	0.347	1.121	0.075	0.023	0.033	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.257	1.898	5.090	2.101	0.751	0.147	0.086	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	1.569	1.670	2.695	2.024	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	1.075	18.031	3.376	0.903	0.582	0.100	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.725	8.622	5.376	2.045	0.168	0.147	0.053	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000
1988	1.895	10.409	6.750	1.927	1.211	0.016	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.298	21.463	22.947	6.868	0.513	0.108	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	4.930	4.972	5.938	14.182	2.149	0.155	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.355	5.331	2.295	1.801	3.669	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	1.506	4.379	5.699	3.444	0.484	1.301	0.066	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	80.090	2.842	6.100	2.509	0.879	0.166	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	4.627	5.406	3.883	1.703	0.608	0.131	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	11.998	5.985	2.420	2.408	0.525	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	8.843	0.777	0.497	0.955	1.590	0.299	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	12.431	2.910	1.035	0.920	0.190	0.383	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	23.481	1.487	0.924	0.779	0.637	0.034	0.211	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	143.000	11.832	2.407	2.275	0.735	0.630	0.036	0.127	0.017	0.000	0.000	0.000	0.000	0.000	0.000
2000	2.151	35.360	6.995	2.371	2.316	0.784	0.663	0.059	0.073	0.000	0.000	0.000	0.000	0.000	0.000
2001	25.987	0.084	4.998	4.710	3.448	1.961	0.323	0.227	0.106	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.924	19.340	0.220	1.379	1.145	0.561	0.318	0.111	0.253	0.025	0.049	0.000	0.012	0.000	0.000
2003	1094.105	17.109	5.496	0.439	1.938	0.937	0.221	0.074	0.014	0.025	0.000	0.014	0.000	0.000	0.000
2004	116.135	8.927	1.882	2.627	0.361	1.083	0.455	0.076	0.029	0.000	0.014	0.000	0.000	0.000	0.000
2005	179.479	5.524	4.141	0.795	1.955	0.263	0.663	0.243	0.094	0.105	0.000	0.000	0.000	0.000	0.000
2006	1053.701	9.992	7.139	3.930	0.525	1.532	0.109	0.057	0.000	0.017	0.028	0.000	0.000	0.000	0.000
2007	49.323	3.776	3.078	2.303	2.163	0.343	0.519	0.025	0.046	0.000	0.000	0.000	0.000	0.000	0.000
2008	456.954	7.275	10.336	3.242	2.287	1.695	0.155	0.155	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	466.098	8.907	2.350	1.654	1.045	0.348	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	1.165	2.415	1.393	1.423	0.819	0.678	0.129	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.000
2011	55.378	0.326	1.001	0.621	0.933	0.558	0.139	0.086	0.021	0.000	0.000	0.000	0.000	0.000	0.000
2012	6.239	3.368	0.671	0.446	0.304	0.415	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.64. Massachusetts Department of Marine Fisheries (MADMF) spring survey biomass indices-at-age (weight/tow) from 1981 to 2012 for Gulf of Maine Atlantic cod. Age data are not available prior to 1982. **Note: biomass indices are not used in the current assessment.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1982	0.001	1.539	3.012	3.230	2.081	1.212	0.248	0.315	0.523	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.001	2.497	6.811	4.805	0.567	2.669	0.787	0.105	0.506	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.197	2.112	2.722	1.414	0.546	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.016	0.213	1.393	2.022	1.120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.001	3.062	1.528	1.437	1.320	0.364	0.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.001	0.491	3.030	1.618	0.539	0.583	0.535	0.000	0.000	1.069	0.000	0.000	0.000	0.000	0.000
1988	0.002	0.311	2.263	2.343	2.472	0.101	0.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.001	1.543	7.795	6.497	0.851	0.402	0.257	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.005	0.262	2.430	9.278	2.831	0.513	0.560	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.607	0.759	2.013	4.702	0.648	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.001	0.215	2.545	2.594	0.683	2.232	0.363	0.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.090	0.104	2.162	1.918	0.908	0.470	0.208	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.001	0.425	1.083	1.434	1.024	0.366	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.010	0.288	0.955	1.948	0.722	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.003	0.063	0.212	0.770	1.607	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.008	0.212	0.575	0.851	0.324	0.509	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.017	0.093	0.360	0.846	1.119	0.086	0.688	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.073	1.114	1.166	2.580	1.521	1.831	0.123	0.524	0.066	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.002	3.323	3.263	3.238	4.704	2.196	2.893	0.326	0.659	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.018	0.004	2.350	7.397	8.089	5.370	1.655	0.832	0.731	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.001	0.750	0.051	1.303	2.230	1.690	1.650	0.660	1.879	0.184	0.511	0.000	0.250	0.000	0.000
2003	0.342	1.137	1.190	0.213	3.650	2.904	0.718	0.402	0.094	0.187	0.000	0.148	0.000	0.000	0.000
2004	0.050	0.345	0.720	2.127	0.635	2.321	1.241	0.288	0.238	0.000	0.182	0.000	0.000	0.000	0.000
2005	0.081	0.192	0.734	0.804	3.244	0.821	2.195	1.270	0.554	0.507	0.000	0.000	0.000	0.000	0.000
2006	0.997	0.484	0.824	2.232	0.596	3.138	0.210	0.271	0.000	0.149	0.275	0.000	0.000	0.000	0.000
2007	0.026	0.212	0.530	1.553	3.057	0.795	2.002	0.096	0.159	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.283	0.468	2.859	2.421	3.146	1.716	0.531	0.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.221	0.429	0.468	1.443	1.091	0.472	0.365	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.144	0.320	0.921	1.339	1.684	0.689	0.000	0.000	0.000	0.548	0.000	0.000	0.000	0.000
2011	0.021	0.015	0.291	0.540	1.361	1.393	0.442	0.309	0.147	0.000	0.000	0.000	0.000	0.000	0.000
2012	0.003	0.299	0.341	0.461	0.396	0.745	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.65. Massachusetts Department of Marine Fisheries (MADMF) fall survey abundance indices-at-age (numbers/tow) from 1981 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1982. **Note: this survey index is not used in the current assessment.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1982	4.571	1.023	0.476	0.004	0.026	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	1.339	0.257	0.021	0.030	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1984	10.286	0.148	0.081	0.017	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	2.536	0.301	0.010	0.010	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	1.883	0.464	0.375	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	312.047	1.075	0.000	0.019	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	5.490	3.136	0.225	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	3.940	0.038	0.114	0.030	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	7.735	4.233	0.525	0.150	0.038	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	5.043	1.950	0.398	0.013	0.066	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	26.408	0.980	0.071	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	49.188	1.735	0.397	0.148	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	40.006	4.943	3.622	0.415	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	2.933	1.080	0.333	0.312	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	6.921	0.049	0.012	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	1.429	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	3.273	0.619	0.293	0.071	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	5.793	2.066	0.123	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.046	0.423	0.176	0.021	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	49.115	0.090	0.123	0.149	0.051	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.913	1.103	0.069	0.223	0.317	0.349	0.197	0.094	0.034	0.000	0.000	0.000	0.000	0.000	0.000
2003	119.856	0.557	1.404	0.120	0.176	0.094	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	40.235	14.123	0.589	1.534	0.258	0.659	0.198	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	39.090	0.779	0.439	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.870	3.825	2.066	0.542	0.063	0.096	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	7.593	0.167	0.107	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.810	2.974	2.539	0.865	0.099	0.262	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	2.808	0.938	0.586	0.590	0.069	0.017	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.209	0.401	0.354	0.801	0.181	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	0.953	0.546	0.396	0.306	0.327	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.66. Massachusetts Department of Marine Fisheries (MADMF) fall survey biomass indices-at-age (weight/tow) from 1981 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1982. **Note: this survey index is not used in the current assessment.*

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1982	0.026	0.212	0.293	0.009	0.044	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.002	0.027	0.005	0.029	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.010	0.024	0.038	0.014	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.004	0.025	0.007	0.007	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.003	0.063	0.101	0.000	0.082	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.237	0.085	0.000	0.019	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.013	0.245	0.092	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.004	0.008	0.100	0.032	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.008	0.332	0.153	0.093	0.067	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.008	0.220	0.118	0.007	0.080	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.050	0.104	0.027	0.000	0.000	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.744	0.149	0.177	0.234	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.032	0.651	0.990	0.285	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.009	0.301	0.205	0.270	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.050	0.007	0.002	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.009	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.029	0.075	0.113	0.065	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.091	0.115	0.058	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.001	0.096	0.127	0.037	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.032	0.003	0.060	0.241	0.228	0.193	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.002	0.079	0.022	0.273	0.766	1.000	0.922	0.557	0.373	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.217	0.067	0.407	0.077	0.347	0.393	0.342	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.093	0.710	0.162	1.179	0.369	2.082	0.879	0.107	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.020	0.037	0.117	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.005	0.300	0.517	0.469	0.067	0.309	0.272	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.009	0.023	0.024	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.011	0.248	0.834	0.651	0.182	0.454	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.030	0.128	0.137	0.341	0.085	0.026	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.003	0.074	0.145	0.586	0.456	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	0.005	0.051	0.166	0.654	0.386	0.094	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.67. Summary of maturity samples (individual fish) taken by the Maine – New Hampshire inshore groundfish survey by region and year.

Total maturity samples by region						
	Region					
Year	1	2	3	4	5	Total
2001	12		2		19	33
2002	50	8			2	60
2003	6	1	1	1	1	10
2004	35	17	2	3	49	106
2005	114	34	32	15	69	264
2006	148	36	7	12	24	227
2007	189	14	5	6	80	294
2008	117	30	8	3	47	205
2009	127	9	7	8	58	209
2010	167	20	6		40	233
2011	44	30	23	14	60	171

Table A.68. Proportion of mature fish observed by the Maine – New Hampshire inshore groundfish survey by region and year.

Proportion mature by region						
	Region					
Year	**1**	**2**	**3**	**4**	**5**	**Total**
2001	0.83		1.00		1.00	0.94
2002	0.90	1.00			1.00	0.92
2003	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.86	0.88	1.00	0.67	0.90	0.88
2005	0.91	0.85	0.94	1.00	1.00	0.94
2006	0.95	0.94	0.86	0.92	0.83	0.93
2007	0.87	0.86	1.00	1.00	1.00	0.91
2008	0.89	0.93	1.00	1.00	1.00	0.93
2009	0.70	0.89	1.00	0.88	1.00	0.81
2010	0.82	0.95	1.00		1.00	0.87
2011	0.73	0.97	1.00	1.00	1.00	0.92
Average	0.86	0.93	0.98	0.93	0.98	0.91

Table A.69. Gulf of Maine Atlantic cod commercial otter trawl landings per unit effort index (LPUE) from 1982 to 2011 (from Palmer 2012b).

Year	Estimate	CV	Lower 95% CI	Upper 95% CI
1982	1.000			
1983	0.990	0.04	0.911	1.075
1984	0.684	0.04	0.628	0.745
1985	0.594	0.04	0.546	0.645
1986	0.468	0.04	0.432	0.508
1987	0.316	0.04	0.291	0.344
1988	0.321	0.04	0.295	0.348
1989	0.494	0.05	0.451	0.541
1990	0.712	0.05	0.652	0.778
1991	0.721	0.04	0.661	0.787
1992	0.375	0.04	0.344	0.408
1993	0.324	0.04	0.297	0.353
1994	0.142	0.04	0.131	0.154
1995	0.163	0.04	0.151	0.175
1996	0.222	0.04	0.207	0.240
1997	0.257	0.04	0.238	0.278
1998	0.268	0.04	0.248	0.288
1999	0.127	0.04	0.118	0.138
2000	0.372	0.04	0.345	0.400
2001	0.601	0.04	0.558	0.647
2002	0.580	0.04	0.538	0.625
2003	0.558	0.04	0.518	0.602
2004	0.493	0.04	0.456	0.533
2005	0.504	0.04	0.466	0.545
2006	0.709	0.04	0.655	0.768
2007	0.879	0.04	0.811	0.953
2008	1.477	0.04	1.365	1.600
2009	1.621	0.04	1.495	1.758
2010	1.986	0.05	1.818	2.170
2011	1.475	0.04	1.362	1.598

Table A.70. Gulf of Maine Atlantic cod recreational VTR landings per unit effort index (LPUE) from 1994 to 2011 (from Wood 2012).

Year	LPUE index	CV	Lower 95% CI	er 95% CI
1994	1.00			
1995	0.930	0.05	0.84	1.03
1996	0.821	0.05	0.74	0.91
1997	0.580	0.05	0.53	0.64
1998	0.541	0.05	0.49	0.60
1999	0.625	0.05	0.57	0.69
2000	0.747	0.05	0.68	0.82
2001	0.843	0.05	0.77	0.93
2002	0.568	0.05	0.52	0.62
2003	0.567	0.05	0.52	0.62
2004	0.497	0.05	0.45	0.55
2005	0.430	0.05	0.39	0.47
2006	0.256	0.05	0.23	0.28
2007	0.264	0.05	0.24	0.29
2008	0.309	0.05	0.28	0.34
2009	0.394	0.05	0.36	0.43
2010	0.520	0.05	0.47	0.57
2011	0.436	0.05	0.40	0.48

Table A.71. Example of Lorenzen-based age varying estimates of natural mortality (*M*) based on the average weight-at-age of Gulf of Maine Atlantic cod. Age-specific *M* estimates were re-scaled based on an assumption of age-invariant constant *M = 0.2*.

Age	Average weight (kg)	Standard deviation (kg)	Natural mortality (M)	Cumulative survival	Rescaled natural mortality (M_{adj})	Rescaled cumulative survival
1	0.116	0.062	0.86		0.48	
2	0.387	0.099	0.60	0.42	0.33	0.62
3	1.068	0.172	0.44	0.23	0.25	0.44
4	2.000	0.222	0.36	0.15	0.20	0.35
5	3.186	0.506	0.32	0.10	0.18	0.28
6	4.723	0.972	0.28	0.08	0.16	0.24
7	6.705	1.420	0.25	0.06	0.14	0.20
8	9.029	1.826	0.23	0.04	0.13	0.18
9	11.441	2.091	0.21	0.04	0.12	0.15
10	13.770	2.601	0.20	0.03	0.11	0.14
11	18.404	3.490	0.18	0.02	0.10	0.12

Table A.72. Ratio of NEFSC spring survey proportions-at-age to fishery proportion-at-age. Cells shaded blue indicate where the survey proportion-at-age was greater than observed in the fishery. Cells shaded grey indicate where no information was available from either the survey of the fishery and no comparison could be made. Cells shaded white indicate where the fishery proportion-at-age was greater relative to the survey.

Year	Age5	Age6	Age7	Age8	Age9+
1982	1.1	1.2	1.4	No survey	0.5
1983	0.8	0.9	1.9	No survey	5.2
1984	1.2	0.5	1.9	No survey	No survey
1985	1.1	0.7	1.2	0.6	0.9
1986	0.9	0.8	2.7	No survey	1.3
1987	0.7	No survey	2.8	2.6	1.3
1988	0.7	2.2	2.1	1.2	3.3
1989	0.7	4.0	No survey	No survey	No survey
1990	0.9	1.1	4.0	No survey	No survey
1991	1.0	1.1	1.4	No survey	No survey
1992	0.9	1.4	1.4	No survey	3.1
1993	0.8	0.9	1.4	2.1	No fishery
1994	0.4	1.1	2.6	0.4	7.6
1995	0.8	1.4	No survey	0.8	12.8
1996	1.0	1.7	No survey	No survey	No survey
1997	0.8	2.6	16.1	No survey	No survey
1998	0.6	1.3	0.5	2.6	No survey
1999	0.7	1.0	1.9	No survey	4.4
2000	0.7	1.4	1.1	2.7	No fishery
2001	0.9	0.6	1.7	6.6	1.0
2002	0.9	1.0	1.4	1.0	0.4
2003	0.8	1.1	2.3	1.4	2.3
2004	0.9	1.5	0.3	0.6	0.6
2005	0.2	1.0	2.0	0.9	No survey
2006	0.6	1.1	2.3	2.6	0.8
2007	1.0	1.1	2.9	0.7	No survey
2008	1.1	0.5	0.6	No survey	No survey
2009	1.0	1.1	0.3	0.6	0.3
2010	0.7	1.5	1.3	3.1	7.2
2011	1.0	0.7	2.7	2.6	No survey
Cells ≥ 1	5.0	20.0	23.0	11.0	10.0
Total	31.0	30.0	28.0	19.0	18.0
Fraction ≥ 1	0.16	0.67	0.82	0.58	0.56

Table A.73. Ratio of NEFSC fall survey proportions-at-age to fishery proportion-at-age. Cells shaded blue indicate where the survey proportion-at-age was greater than observed in the fishery. Cells shaded grey indicate where no information was available from either the survey of the fishery and no comparison could be made. Cells shaded white indicate where the fishery proportion-at-age was greater relative to the survey.

Year	Age5	Age6	Age7	Age8	Age9+
1982	1.4	No survey	No survey	No survey	No survey
1983	0.9	1.2	No survey	No survey	3.5
1984	0.7	1.3	0.9	No survey	2.7
1985	0.9	1.0	No survey	1.9	5.5
1986	1.0	0.8	No survey	No survey	3.7
1987	1.6	No survey	No survey	No survey	No survey
1988	0.9	No survey	4.7	No survey	6.6
1989	0.9	2.1	No survey	3.4	No survey
1990	1.3	0.7	0.9	No survey	No survey
1991	1.0	No survey	5.3	No survey	No survey
1992	0.8	3.1	No survey	No survey	No survey
1993	No survey	1.3	No survey	No survey	No fishery
1994	0.9	No survey	2.8	No survey	No survey
1995	1.1	1.1	No survey	No survey	No survey
1996	1.1	No survey	No survey	No survey	No survey
1997	1.1	No survey	No survey	No survey	No survey
1998	1.5	0.8	No survey	No survey	No survey
1999	1.5	0.7	No survey	No survey	No survey
2000	1.2	0.2	No survey	5.0	No fishery
2001	0.9	1.1	1.5	No survey	1.9
2002	1.0	1.4	0.4	0.5	No survey
2003	1.1	0.6	1.4	No survey	1.4
2004	1.0	0.9	1.3	1.1	1.2
2005	0.5	0.8	1.6	1.7	1.4
2006	0.9	1.8	1.0	1.4	0.7
2007	0.8	1.3	No survey	No survey	No survey
2008	1.0	No survey	No survey	No survey	11.0
2009	1.0	1.2	No survey	No survey	No survey
2010	0.9	1.0	1.3	No survey	5.7
2011	1.1	0.8	0.5	2.8	No survey
Cells ≥ 1	14.0	12.0	8.0	7.0	11.0
Total	30.0	23.0	14.0	9.0	13.0
Fraction ≥ 1	0.47	0.52	0.57	0.78	0.85

Table A.74. Summary of the Gulf of Maine Atlantic cod ASAP model formulation used to build a ‘bridge’ from the SAW 53 ASAP base model (SAW53_BASE) to the 2011 update of the same model (SAW55_BASE).

<table>
<tr><th rowspan="2">Step</th><th rowspan="2">Model</th><th rowspan="2">Description</th><th rowspan="2">Type</th><th rowspan="2">Software version</th><th rowspan="2">Years</th><th rowspan="2">Catch</th><th rowspan="2">Selectivity blocks</th><th rowspan="2">Time of spawning</th><th rowspan="2">Stock recruit</th><th rowspan="2">Survey selectivity</th><th colspan="2">NEFSC</th><th>MADMF</th></tr>
<tr><th>Spring</th><th>Fall</th><th>Spring</th></tr>
<tr><td>1</td><td>SAW53_BASE</td><td>Base model from SAW53</td><td rowspan="9">ASAP</td><td rowspan="7">v2.0.21</td><td rowspan="6">1982-2010</td><td>Single fleet</td><td rowspan="6">1982-1990, 1991-2010</td><td rowspan="9">April 1 (0.25)</td><td rowspan="9">Mean</td><td rowspan="9">NEFSC, flat topped (6+), MADMF double logistic</td><td colspan="3" rowspan="9">Ages 1-9</td></tr>
<tr><td>2</td><td>SAW55_B1</td><td>Update recreational catch and catch WAA (MRIP adjustments)</td><td>Single fleet; update recreational catch and catch WAA to account for MRIP adjustments</td></tr>
<tr><td>3</td><td>SAW55_B2</td><td>Update commercial and recreational discards to account for discard mortality, update catch WAA</td><td>Single fleet; update commercial and recreational discards and catch WAA to account for differential discard mortality</td></tr>
<tr><td>4</td><td>SAW55_B3</td><td>Update stock WAA</td><td rowspan="6">Single fleet</td></tr>
<tr><td>5</td><td>SAW55_B4</td><td>Update maturity ogive</td></tr>
<tr><td>6</td><td>SAW55_B5</td><td>Update MADMF spring survey index and timing (April-->May)</td></tr>
<tr><td>7</td><td>SAW55_B6</td><td>Add 2011 data</td><td rowspan="3">1982-2011</td><td rowspan="3">1982-1990, 1991-2011</td></tr>
<tr><td>8</td><td>SAW55_BASE</td><td>Update software</td><td rowspan="2">v3.0.8</td></tr>
<tr><td>9</td><td>SAW55_BASE_100MORT</td><td>100% discard mortality</td></tr>
</table>

Table A.75. Summary Gulf of Maine Atlantic cod model results from the 'bridge building' exercise performed to update the SAW 53 ASAP base model (SAW53_BASE) to the 2011 update of the same model (SAW55_BASE). Differences in model formulations are summarized in Table A.74.

Model		SAW53_BASE	SAW55_B1	SAW55_B2	SAW55_B3	SAW55_B4	SAW55_B5	SAW55_B6	SAW55_BASE	SAW55_BASE_100MORT
Model description		Base model from SAW53	Update recreational catch and catch WAA (MRIP adjustments)	Update commercial and recreational discards to account for discard mortality, update catch WAA	Update stock WAA	Update maturity ogive	Update MADMF spring survey	Add 2011 data	Update software	100% discard mortality
Number of parameters		99	99	99	99	99	99	101	101	101
Objective function		2467	2486	2471	2471	2471	2466	2554	2554	2570
Components of objective function	Recruit devs	286	285	282	282	282	282	293	293	296
	Suvey age comps	831	830	831	831	831	825	860	860	859
	Catch age comps	378	399	383	383	383	384	395	395	412
	Index fit	764	766	771	771	771	771	794	794	790
	Catch fit	208	206	204	204	204	204	211	211	213
RMSE	Fleet 1	0.24	0.25	0.29	0.29	0.29	0.29	0.29	0.29	0.25
	Index 1	1.05	1.07	1.12	1.12	1.12	1.12	1.14	1.14	1.09
	Index 2	0.91	0.94	0.97	0.97	0.97	0.97	0.97	0.97	0.94
	Index 3	1.07	1.09	1.15	1.15	1.15	1.15	1.13	1.13	1.07
	Recruit devs	1.28	1.04	1.08	1.08	1.08	1.08	1.42	1.42	1.04
SSB_{1982} (mt)		23,675	22,697	23,153	23,153	23,240	23,243	23,320	23,320	22,847
SSB_{2010} (mt)		11,868	11,172	11,515	11,515	11,877	11,814	12,746	12,746	12,984
SSB_{2011} (mt)								11,874	11,874	11,403
$F_{mult, 2010}$		1.14	0.85	0.67	0.67	0.67	0.67	0.62	0.62	0.74
$F_{mult, 2011}$		1.14						0.59	0.59	0.75
Mohn's rho (5 year peel)	SSB	0.22	0.25	0.47	0.47	0.47	0.46	0.33	0.33	0.14
	F_{mult}	-0.22	-0.24	-0.35	-0.35	-0.35	-0.35	-0.25	-0.25	-0.14
	Age 1 N	0.15	0.18	0.30	0.30	0.30	0.28	0.37	0.37	0.23

Table A.76. Summary Gulf of Maine Atlantic cod model estimated fishery and survey selectivity parameters results from the ‘bridge building’ exercise performed to update the SAW 53 ASAP base model (SAW53_BASE) to the 2011 update of the same model (SAW55_BASE). Differences in model formulations are summarized in Table A.74.

Model		SAW53_BASE		SAW55_B1		SAW55_B2		SAW55_B3		SAW55_B4		SAW55_B5		SAW55_B6		SAW55_BASE		SAW55_BASE_100MORT	
Description		Base model from SAW53		Update recreational catch and catch WAA (MRIP adjustments)		Update commercial and recreational discards to account for discard mortality, update catch WAA		Update stock WAA		Update maturity ogive		Update MADMF spring survey		Add 2011 data		Update software		100% discard mortality	
		Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV
	1	0.05	0.17	0.05	0.16	0.04	0.18	0.04	0.18	0.04	0.18	0.04	0.18	0.04	0.18	0.04	0.18	0.05	0.16
	2	0.28	0.10	0.29	0.10	0.25	0.10	0.25	0.10	0.25	0.10	0.25	0.10	0.25	0.10	0.25	0.10	0.29	0.10
	3	0.58	0.10	0.58	0.10	0.57	0.09	0.57	0.09	0.57	0.09	0.57	0.09	0.57	0.09	0.57	0.09	0.58	0.10
	4	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Fleet block 1	5	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	6	0.77	0.26	0.76	0.26	0.77	0.25	0.77	0.25	0.77	0.25	0.78	0.25	0.78	0.25	0.78	0.25	0.77	0.26
	7	0.99	0.39	0.99	0.39	1.00	0.38	1.00	0.38	1.00	0.38	1.00	0.14	1.00	0.15	1.00	0.15	1.00	0.39
	8	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
	9	0.31	0.47	0.31	0.47	0.33	0.46	0.33	0.46	0.33	0.46	0.33	0.45	0.33	0.45	0.33	0.45	0.31	0.47
	1	0.02	0.17	0.02	0.16	0.02	0.18	0.02	0.18	0.02	0.18	0.02	0.18	0.02	0.18	0.02	0.18	0.02	0.16
	2	0.11	0.10	0.10	0.10	0.07	0.11	0.07	0.11	0.07	0.11	0.07	0.11	0.07	0.11	0.07	0.11	0.10	0.10
	3	0.40	0.08	0.38	0.08	0.33	0.08	0.33	0.08	0.33	0.08	0.33	0.08	0.32	0.08	0.32	0.08	0.38	0.08
	4	0.84	0.08	0.84	0.08	0.82	0.07	0.82	0.07	0.82	0.07	0.82	0.07	0.79	0.07	0.79	0.07	0.82	0.07
Fleet block 2	5	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
	6	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	7	0.90	0.20	0.91	0.19	0.95	0.17	0.95	0.17	0.95	0.17	0.95	0.17	0.92	0.17	0.92	0.17	0.87	0.19
	8	0.88	0.33	0.89	0.32	0.90	0.29	0.90	0.29	0.90	0.29	0.89	0.29	0.88	0.27	0.88	0.27	0.86	0.31
	9	0.67	0.54	0.68	0.54	0.70	0.51	0.70	0.51	0.70	0.51	0.70	0.51	0.77	0.50	0.77	0.50	0.77	0.53
	1	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19	0.04	0.19
	2	0.12	0.16	0.12	0.16	0.14	0.16	0.14	0.16	0.14	0.16	0.14	0.16	0.14	0.16	0.14	0.16	0.12	0.16
	3	0.26	0.16	0.26	0.16	0.30	0.15	0.30	0.15	0.30	0.15	0.30	0.15	0.30	0.15	0.30	0.15	0.26	0.15
	4	0.46	0.15	0.47	0.15	0.51	0.15	0.51	0.15	0.51	0.15	0.51	0.15	0.51	0.15	0.51	0.15	0.48	0.15
Index 1	5	0.71	0.15	0.72	0.15	0.75	0.15	0.75	0.15	0.75	0.15	0.75	0.15	0.75	0.15	0.75	0.15	0.72	0.15
	6	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	7	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	8	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	9	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	1	0.14	0.22	0.14	0.21	0.17	0.15	0.17	0.15	0.17	0.15	0.17	0.15	0.17	0.15	0.17	0.15	0.14	0.21
	2	0.33	0.21	0.34	0.21	0.40	0.14	0.40	0.14	0.40	0.14	0.40	0.14	0.40	0.14	0.40	0.14	0.34	0.20
	3	0.51	0.21	0.52	0.21	0.59	0.14	0.59	0.14	0.59	0.14	0.59	0.14	0.59	0.14	0.59	0.14	0.52	0.20
	4	0.82	0.21	0.83	0.21	0.89	0.14	0.89	0.14	0.89	0.14	0.89	0.14	0.89	0.14	0.89	0.14	0.83	0.20
Index 2	5	0.97	0.21	0.97	0.21	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.98	0.20
	6	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	7	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	8	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	9	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	A50 ascend	0.00	3000.09	0.00	3000.09	0.00	3000.00	0.00	3000.00	0.00	3000.18	0.00	3000.10	0.00	3000.30	0.00	3000.30	0.00	3000.10
Index 3	Slope ascend	10.00		10.00		10.00		10.00		10.00		10.00		10.00		10.00		10.00	
	A50 descend	0.00	3000.42	0.00	2999.92	0.00	2999.98	0.00	2999.98	0.00	2999.54	0.00	2999.96	0.00	2994.57	0.00	2994.57	0.00	3000.00
	Slope descend	4.22	0.22	4.10	0.21	3.54	0.17	3.54	0.17	3.54	0.17	3.51	0.18	3.50	0.18	3.50	0.18	4.29	0.22

Table A.77. Summary of Gulf of Maine Atlantic cod ASAP model configurations that explored alternate formulations of a two-selectivity block structure by altering the starting point of the second selectivity block.

Model		SAW55_BASE_1987		SAW55_BASE_1989		SAW55_BASE		SAW55_BASE_1993	
Block 2 start year		1987		1989		1991		1993	
Parameters		101		101		101		101	
Objective function		2544		2544		2554		2551	
Catch RMSE		0.28		0.29		0.29		0.28	
SSB_{1982} (mt)		23551		23390		23320		23269	
SSB_{2011} (mt)		11921		11967		11874		11888	
$F_{age5, 2011}$		0.58		0.58		0.59		0.60	
Block 1	Age1	0.06	*0.21*	0.04	*0.19*	0.04	*0.18*	0.04	*0.18*
	Age2	0.37	*0.13*	0.31	*0.11*	0.25	*0.10*	0.22	*0.12*
	Age3	0.74	*0.13*	0.67	*0.11*	0.57	*0.09*	0.52	*0.12*
	Age4	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	0.90	*0.13*
	Age5	1.00		1.00		1.00		1.00	
	Age6	0.86	*0.30*	0.83	*0.27*	0.78	*0.25*	0.80	*0.23*
	Age7	1.00	*0.00*	1.00	*0.03*	1.00	*0.07*	0.99	*0.33*
	Age8	1.00	*0.01*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	Age9+	0.32	*0.56*	0.33	*0.49*	0.33	*0.45*	0.30	*0.45*
Block 2	Age1	0.02	*0.16*	0.02	*0.18*	0.02	*0.18*	0.01	*0.20*
	Age2	0.08	*0.09*	0.07	*0.10*	0.07	*0.11*	0.06	*0.12*
	Age3	0.33	*0.07*	0.33	*0.07*	0.32	*0.08*	0.31	*0.08*
	Age4	0.81	*0.07*	0.81	*0.07*	0.79	*0.07*	0.78	*0.07*
	Age5	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	Age6	1.00		1.00		1.00		1.00	
	Age7	0.89	*0.17*	0.91	*0.17*	0.92	*0.17*	0.90	*0.18*
	Age8	0.84	*0.27*	0.86	*0.27*	0.88	*0.27*	0.87	*0.28*
	Age9+	0.79	*0.48*	0.79	*0.51*	0.77	*0.50*	0.79	*0.48*

Table A.78. Summary of Gulf of Maine Atlantic cod ASAP model configurations that fit the Massachusetts Department of Marine Fisheries (MADMF) spring survey using both parametric (double logistic; e.g., SAW55_BASE) and non-parametric (at-age; e.g. all other models) approaches.

Model		SAW55_BASE	SAW55_BASE_FIXED_MADMF_AGE1_9	SAW55_BASE_FIXED_MADMF_AGE1_6
Parameters		101	103	100
Objective function		2554	2552	2543
Maximum gradient		1.6E-03	3.9E-05	1.8E-03
Components of objective function	Suvey age comps	860	858	846
	Catch age comps	395	395	378
	Index fit	794	795	797
	Catch fit	211	211	211
	Recruit devs	293	294	293
RMSE	Catch	0.29	0.29	0.28
	Index1	1.14	1.14	1.15
	Index2	0.97	0.97	1.01
	Index3	1.13	1.14	1.15
	Index total	1.08	1.09	1.11
	Recruit devs	1.42	1.43	1.41
Mean age RMSE	Fleet1	1.34	1.34	0.98
	Index1	1.50	1.50	1.44
	Index2	1.74	1.73	1.62
	Index3	1.37	1.36	1.40
SSB_{1982} (mt)		23320	23152	23232
SSB_{2011} (mt)		11874	11669	11653
$F_{age5, 2011}$		0.59	0.60	0.60

Table A.79. Summary of Gulf of Maine Atlantic cod ASAP model configurations which explored various configurations of a three-selectivity block model. The SAW55_BASE model is the two-block reference model.

Model		SAW55_BASE	SAW55_3BLOCK	SAW55_3BLOCK_DL	SAW55_3BLOCK_SL	SAW55_3BLOCK_SL_1989	SAW55_3BLOCK_SL_MADMF_1_6	SAW55_3BLOCK_BASE
Selectivity blocks		2	3	3	3	3	3	3
Year splits		1991	1991, 2005	1991, 2005	1991, 2004	1989, 2005	1989, 2005	1989, 2005
Parameters		101	109	97	91	91	93	93
Objective function		2554	2538	2544	2548	2536	2524	2055
Components of objective function	Suvey age comps	860	856	858	861	858	846	602
	Catch age comps	395	383	386	388	378	378	390
	Index fit	794	796	796	796	796	797	794
	Catch fit	211	211	211	211	211	211	210
	Recruit devs	293	293	293	293	293	293	59
RMSE	Catch	0.29	0.27	0.27	0.27	0.28	0.28	0.21
	Index1	1.14	1.15	0.15	1.15	1.15	1.15	1.13
	Index2	0.97	1.00	1.00	1.00	1.01	1.01	0.97
	Index3	1.13	1.15	1.14	1.15	1.14	1.15	1.14
	Recruit devs	1.42	1.40	1.40	1.10	1.10	1.11	1.51
Mean age RMSE	Fleet1	1.34	1.10	1.11	1.16	0.98	0.98	0.96
	Index1	1.50	1.44	1.45	1.44	1.44	1.44	1.02
	Index2	1.74	1.61	1.62	1.61	1.62	1.62	1.18
	Index3	1.37	1.38	1.38	1.38	1.37	1.40	1.06
SSB_{1982} (mt)		23,320	22,992	23,103	22,410	22,546	22,446	22,036
SSB_{2011} (mt)		11,874	12,069	12,184	11,971	12,020	11,841	9,903
$F_{age5, 2011}$		0.59	0.63	0.63	0.63	0.62	0.64	0.78

Table A.80. Summary of Gulf of Maine Atlantic cod ASAP model selectivity parameter estimates and the corresponding coefficients of variation (CV) from model configurations which explored various configurations of a three-selectivity block model. The SAW55_BASE model is the two-block reference model.

Model		SAW55_BASE		SAW55_3BLOCK		SAW55_3BLOCK_DL		SAW55_3BLOCK_SL		SAW55_3BLOCK_SL_1989		SAW55_3BLOCK_SL_MADMF_1_6		SAW55_3BLOCK_BASE	
Selectivity blocks		2		3		3		3		3		3		3	
Year splits		1991		1991, 2005		1991, 2005		1991, 2004		1989, 2005		1989, 2005		1989, 2005	
Block 1	A50% up					2.69	*0.05*	2.60	*0.04*	2.34	*0.04*	2.35	*0.04*	2.33	*0.05*
	Slope up					0.56	*0.08*	0.53	*0.08*	0.46	*0.09*	0.46	*0.09*	0.46	*0.10*
	A50% down					8.96	*2.36*								
	Slope down					0.06	*517.24*								
Block 2	A50% up					3.50	*0.04*	3.30	*0.03*	3.30	*0.02*	3.30	*0.02*	3.32	*0.02*
	Slope up					0.56	*0.05*	0.56	*0.05*	0.56	*0.05*	0.56	*0.05*	0.56	*0.05*
	A50% down					0.00	*3001.61*								
	Slope down					7.31	*0.48*								
Block 3	A50% up					3.76	*0.03*	3.75	*0.03*	3.75	*0.03*	3.76	*0.03*	3.77	*0.04*
	Slope up					0.52	*0.07*	0.52	*0.07*	0.52	*0.07*	0.52	*0.07*	0.53	*0.07*
	A50% down					9.00	*0.00*								
	Slope down					0.01	*3000.08*								
Block 1	Age1	0.04	*0.18*	0.04	*0.18*	0.05		0.05		0.05		0.05		0.05	
	Age2	0.25	*0.10*	0.24	*0.10*	0.22		0.24		0.32		0.32		0.33	
	Age3	0.57	*0.09*	0.56	*0.09*	0.64		0.68		0.81		0.80		0.81	
	Age4	1.00	*0.00*	1.00	*0.00*	0.91		0.93		0.97		0.97		0.97	
	Age5	1.00		1.00		0.98		0.99		1.00		1.00		1.00	
	Age6	0.78	*0.25*	0.78	*0.25*	1.00		1.00		1.00		1.00		1.00	
	Age7	1.00	*0.07*	1.00	*0.05*	1.00		1.00		1.00		1.00		1.00	
	Age8	1.00	*0.00*	1.00	*0.00*	1.00		1.00		1.00		1.00		1.00	
	Age9+	0.33	*0.45*	0.33	*0.45*	0.32		1.00		1.00		1.00		1.00	
Block 2	Age1	0.02	*0.18*	0.02	*0.19*	0.02		0.02		0.02		0.02		0.02	
	Age2	0.07	*0.11*	0.09	*0.12*	0.09		0.09		0.09		0.09		0.09	
	Age3	0.32	*0.08*	0.39	*0.09*	0.37		0.37		0.37		0.37		0.36	
	Age4	0.79	*0.07*	0.87	*0.09*	0.83		0.78		0.78		0.78		0.77	
	Age5	1.00	*0.00*	1.00	*0.00*	1.00		0.96		0.95		0.95		0.95	
	Age6	1.00		1.00		0.96		0.99		0.99		0.99		0.99	
	Age7	0.92	*0.17*	0.97	*0.22*	0.88		1.00		1.00		1.00		1.00	
	Age8	0.88	*0.27*	0.94	*0.38*	0.80		1.00		1.00		1.00		1.00	
	Age9+	0.77	*0.50*	0.66	*0.66*	0.72		1.00		1.00		1.00		1.00	
Block 3	Age1			0.00	*0.54*	0.01		0.01		0.01		0.01		0.01	
	Age2			0.03	*0.25*	0.03		0.03		0.03		0.03		0.03	
	Age3			0.18	*0.19*	0.19		0.19		0.19		0.19		0.19	
	Age4			0.58	*0.17*	0.61		0.62		0.62		0.61		0.61	
	Age5			0.89	*0.18*	0.91		0.92		0.92		0.91		0.91	
	Age6			1.00		0.99		0.99		0.99		0.99		0.98	
	Age7			0.81	*0.29*	1.00		1.00		1.00		1.00		1.00	
	Age8			0.83	*0.44*	1.00		1.00		1.00		1.00		1.00	
	Age9+			0.77	*0.73*	0.50		1.00		1.00		1.00		1.00	

Table A.81. Summary of the sensitivity runs conducted on the final Gulf of Maine Atlantic cod ASAP model, SAW55_3BLOCK_BASE.

Run description	Flat top fleet selectivity	Domed fleet selectivity
Base run	SAW55_3BLOCK_BASE	SAW55_3BLOCK_BASE_DOME
100% discard mortality	SAW55_3BLOCK_BASE_100MORT	SAW55_3BLOCK_BASE_DOME_100MORT
M split	SAW55_3BLOCK_BASE_M_SPLIT	SAW55_3BLOCK_BASE_DOME_M_SPLIT
M split and 100% discard mortality	SAW55_3BLOCK_BASE_M_SPLIT_100MORT	SAW55_3BLOCK_BASE_DOME_M_SPLIT_100MORT

Table A.82. Summary of Gulf of Maine Atlantic cod ASAP model configurations which explored various configurations of the final base model SAW55_3BLOCK_BASE under fleet flat topped-selectivity assumptions.

Model		SAW55_3BLOCK_BASE	SAW55_3BLOCK_BASE_100MORT	SAW55_3BLOCK_BASE_M_SPLIT	SAW55_3BLOCK_BASE_M_SPLIT_M6	SAW55_3BLOCK_BASE_M_SPLIT_100MORT
Selectivity blocks		3	3	3	3	3
Year splits		1989, 2005	1989, 2005	1989, 2005	1989, 2005	1989, 2005
Parameters		93	93	93	93	93
Objective function		2055	2041	2047	2069	2039
Maximum gradient		9.2E-05	9.0E-04	3.6E-05	3.7E-04	9.5E-05
Components of objective function	Suvey age comps	602	602	601	604	602
	Catch age comps	390	378	390	394	378
	Index fit	794	789	786	798	786
	Catch fit	210	212	210	210	212
	Recruit devs	59	60	60	63	61
RMSE	Catch	0.21	0.18	0.15	0.25	0.15
	Index1	1.13	1.08	0.99	0.98	0.98
	Index2	0.97	0.93	0.98	1.25	1.01
	Index3	1.14	1.07	1.03	1.11	1.00
	Index total	1.08	1.03	1.00	1.12	1.00
	Recruit devs	1.51	1.46	1.26	1.31	1.24
Mean age RMSE	Fleet1	0.96	0.94	0.96	0.99	0.93
	Index1	1.02	1.00	1.02	1.04	1.00
	Index2	1.18	1.21	1.17	1.19	1.21
	Index3	1.06	1.05	1.07	1.10	1.06
SSB_{1982} (mt)		22036	22052	21531	20884	21560
SSB_{2011} (mt)		9903	9521	10221	10256	10034
$F_{age5, 2011}$		0.78	0.97	0.82	1.00	0.99
Mohn's rho (5 year peel)	SSB	0.40	0.26	-0.01		-0.08
	F_{mult}	-0.27	-0.19	0.06		0.14
	Age 1 N	0.76	0.57	0.24		0.12
Comments		Based on SAW55_3BLOCK_FINAL, but rec. dev. lamda=0.2 and took out MADMF spring age 7-9.	Assumption of 100% discard mortality	2 block natural mortality: 1982-88 = 0.2, 1989-2002 = linear ramp, 2003-2011 = 0.4	2 block natural mortality: 1982-88 = 0.2, 1989-2002 = linear ramp, 2003-2011 = 0.6	Assumption of 100% discard mortality and 2 block natural mortality: 1982-88 = 0.2, 1989-2002 = linear ramp, 2003-2011 = 0.4

Table A.83. Summary of Gulf of Maine Atlantic cod ASAP model configurations which explored various configurations of the final base model SAW55_3BLOCK_BASE under fleet domed-selectivity assumptions.

Model		SAW55_3BLOCK_BASE	SAW55_3BLOCK_BASE_DOME	SAW55_3BLOCK_BASE_DOME_100MORT	SAW55_3BLOCK_BASE_DOME_M_SPLIT	SAW55_3BLOCK_BASE_DOME_M_SPLIT_100MORT
Selectivity blocks		3	3	3	3	3
Year splits		1989, 2005	1989, 2005	1989, 2005	1989, 2005	1989, 2005
Parameters		93	107	107	107	107
Objective function		2055	2048	2034	2040	2031
Maximum gradient		9.2E-05	4.5E-05	1.5E-04	4.4E-05	9.3E-04
Components of objective function	Suvey age comps	602	600	600	598	599
	Catch age comps	390	385	373	386	374
	Index fit	794	794	789	786	786
	Catch fit	210	210	212	210	212
	Recruit devs	59	59	60	60	61
RMSE	Catch	0.21	0.21	0.18	0.15	0.16
	Index1	1.13	1.12	1.07	0.98	0.97
	Index2	0.97	0.97	0.93	0.98	1.01
	Index3	1.14	1.14	1.08	1.04	1.01
	Index total	1.08	1.08	1.03	1.00	1.00
	Recruit devs	1.51	1.51	1.45	1.26	1.24
Mean age RMSE	Fleet1	0.96	0.94	0.92	0.94	0.91
	Index1	1.02	1.03	1.00	1.02	1.00
	Index2	1.18	1.17	1.20	1.16	1.20
	Index3	1.06	1.06	1.05	1.07	1.06
SSB_{1982} (mt)		22036	23156	22941	21531	22511
SSB_{2011} (mt)		9903	10017	9597	10221	10141
$F_{age5,2011}$		0.78	0.77	0.99	0.82	1.00
Mohn's rho (5 year peel)	SSB	0.40	0.47	0.28	0.00	-0.07
	F_{mult}	-0.27	-0.29	-0.19	0.05	0.14
	Age 1 N	0.76	0.78	0.65	0.15	0.19
Comments		Based on SAW55_3BLOCK_FINAL, but rec. dev. lamda=0.2 and took out MADMF spring age 7-9.	Allow for domed shaped commercial selectivity	Allow for domed shaped commercial selectivity and assume 100% discard mortality	Allow for domed shaped commercial selectivity with 2 block natural mortality: 1982-88 = 0.2, 1989-2002 = linear ramp, 2003-2011 = 0.4	Allow for domed shaped commercial selectivity with 2 block natural mortality: 1982-88 = 0.2, 1989-2002 = linear ramp, 2003-2011 = 0.4 and assume 100% discard mortality

Table A.84. Comparison of the fleet and index selectivity parameters and the corresponding coefficients of variation (CV) from the Gulf of Maine Atlantic cod ASAP SAW55_3BLOCK_BASE (*M* = *0.2*) and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) models.

Block/Index	Parameter	SAW55_3BLOCK_BASE		SAW55_3BLOCK_BASE_M_SPLIT	
		Parameter estimate	CV	Parameter estimate	CV
1982-1988	A50% up	2.33	*0.05*	2.33	*0.05*
	Slope up	0.46	*0.10*	0.45	*0.09*
1989-2004	A50% up	3.32	*0.02*	3.35	*0.02*
	Slope up	0.56	*0.05*	0.53	*0.05*
2005-2011	A50% up	3.77	*0.04*	3.82	*0.03*
	Slope up	0.53	*0.07*	0.51	*0.07*
NEFSC spring	Age1	0.04	0.24	0.03	0.24
	Age2	0.13	0.20	0.11	0.20
	Age3	0.27	0.19	0.24	0.19
	Age4	0.48	0.19	0.46	0.19
	Age5	0.68	0.20	0.67	0.20
	Age6	1.00		1.00	
	Age7	1.00		1.00	
	Age8	1.00		1.00	
	Age9+	1.00		1.00	
NEFSC fall	Age1	0.15	0.26	0.12	0.26
	Age2	0.33	0.25	0.29	0.25
	Age3	0.50	0.25	0.47	0.25
	Age4	0.73	0.25	0.72	0.25
	Age5	0.86	0.27	0.87	0.27
	Age6	1.00		1.00	
	Age7	1.00		1.00	
	Age8	1.00		1.00	
	Age9+	1.00		1.00	
MADMF spring	Age1	1.00		1.00	
	Age2	0.73	0.15	0.81	0.15
	Age3	0.64	0.18	0.77	0.18
	Age4	0.64	0.23	0.81	0.23
	Age5	0.63	0.34	0.83	0.33
	Age6	0.57	0.58	0.76	0.58

Table A.85. Gulf of Maine Atlantic cod January 1 biomass (mt) and spawning stock biomass (SSB, mt) from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE (*M = 0.2*) and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) models.

Year	SAW55_3BLOCK_BASE		SAW55_3BLOCK_BASE_M_SPLIT	
	January 1 biomass (mt)	Spawning stock biomass (mt)	January 1 biomass (mt)	Spawning stock biomass (mt)
1982	38,309	22,036	37,911	21,531
1983	28,575	16,343	28,332	15,989
1984	23,081	13,454	22,944	13,186
1985	21,526	12,380	21,459	12,177
1986	20,540	11,537	20,536	11,390
1987	19,892	11,211	19,955	11,130
1988	20,231	11,621	20,529	11,694
1989	27,593	15,516	28,621	15,894
1990	34,120	19,988	35,959	20,821
1991	28,227	17,253	29,861	18,062
1992	18,989	10,842	20,446	11,473
1993	14,097	7,575	15,633	8,229
1994	13,050	6,988	15,026	7,930
1995	13,276	7,975	15,939	9,442
1996	13,512	8,371	16,756	10,245
1997	11,364	7,091	14,959	9,176
1998	9,959	6,268	13,971	8,621
1999	10,577	6,812	15,878	9,778
2000	15,003	9,070	22,822	12,976
2001	18,755	11,885	28,082	17,222
2002	17,077	11,951	25,502	17,208
2003	14,334	10,005	20,786	13,966
2004	12,646	8,594	18,344	11,878
2005	11,038	7,213	15,800	9,831
2006	10,852	6,752	16,075	9,311
2007	14,311	8,725	20,846	11,693
2008	16,670	10,282	22,921	13,297
2009	18,506	11,457	24,493	14,332
2010	17,178	11,141	21,184	12,979
2011	14,728	9,903	16,312	10,221

Table A.86. Gulf of Maine Atlantic cod fully recruited fishing mortality (F_{full}) from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE ($M = 0.2$) and SAW55_3BLOCK_BASE_M_SPLIT (M-ramp) models.

Year	SAW55_3BLOCK_BASE	SAW55_3BLOCK_BASE_M_SPLIT
	Fully recruited F (F_{full})	Fully recruited F (F_{full})
1982	0.73	0.75
1983	0.87	0.89
1984	0.78	0.80
1985	0.91	0.93
1986	0.83	0.85
1987	0.82	0.83
1988	0.62	0.62
1989	0.92	0.93
1990	1.13	1.13
1991	1.26	1.23
1992	1.35	1.31
1993	1.53	1.46
1994	1.45	1.32
1995	0.99	0.86
1996	1.03	0.85
1997	0.92	0.72
1998	0.82	0.61
1999	0.48	0.35
2000	0.62	0.45
2001	0.72	0.51
2002	0.57	0.40
2003	0.67	0.48
2004	0.68	0.50
2005	0.92	0.70
2006	0.78	0.60
2007	0.75	0.60
2008	0.94	0.77
2009	0.98	0.83
2010	0.87	0.79
2011	0.86	0.90

Table A.87. Gulf of Maine Atlantic cod fishing mortality-at-age from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE (*M* = *0.2*) model.

Year	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	0.04	0.24	0.60	0.71	0.73	0.73	0.73	0.73	0.73
1983	0.05	0.29	0.71	0.85	0.87	0.87	0.87	0.87	0.87
1984	0.04	0.26	0.63	0.76	0.78	0.78	0.78	0.78	0.78
1985	0.05	0.30	0.74	0.89	0.91	0.91	0.91	0.91	0.91
1986	0.04	0.27	0.68	0.81	0.83	0.83	0.83	0.83	0.83
1987	0.04	0.27	0.67	0.80	0.82	0.82	0.82	0.82	0.82
1988	0.03	0.20	0.51	0.61	0.62	0.62	0.62	0.62	0.62
1989	0.01	0.08	0.33	0.71	0.87	0.91	0.92	0.92	0.92
1990	0.02	0.10	0.41	0.87	1.08	1.12	1.13	1.13	1.13
1991	0.02	0.11	0.46	0.97	1.20	1.25	1.26	1.26	1.26
1992	0.02	0.12	0.49	1.04	1.29	1.34	1.35	1.35	1.35
1993	0.02	0.13	0.55	1.18	1.46	1.52	1.53	1.53	1.53
1994	0.02	0.13	0.52	1.12	1.38	1.44	1.45	1.45	1.45
1995	0.02	0.09	0.36	0.77	0.95	0.98	0.99	0.99	0.99
1996	0.02	0.09	0.37	0.79	0.98	1.02	1.03	1.03	1.03
1997	0.01	0.08	0.33	0.71	0.88	0.91	0.92	0.92	0.92
1998	0.01	0.07	0.30	0.63	0.78	0.82	0.82	0.82	0.82
1999	0.01	0.04	0.17	0.37	0.46	0.48	0.48	0.48	0.48
2000	0.01	0.05	0.22	0.48	0.59	0.62	0.62	0.62	0.62
2001	0.01	0.06	0.26	0.55	0.68	0.71	0.72	0.72	0.72
2002	0.01	0.05	0.21	0.44	0.54	0.56	0.57	0.57	0.57
2003	0.01	0.06	0.24	0.52	0.64	0.67	0.67	0.67	0.67
2004	0.01	0.06	0.25	0.52	0.65	0.67	0.68	0.68	0.68
2005	0.01	0.03	0.17	0.56	0.83	0.90	0.92	0.92	0.92
2006	0.00	0.03	0.15	0.47	0.71	0.77	0.78	0.78	0.78
2007	0.00	0.03	0.14	0.45	0.68	0.74	0.75	0.75	0.75
2008	0.01	0.03	0.18	0.57	0.85	0.92	0.93	0.94	0.94
2009	0.01	0.03	0.19	0.59	0.89	0.96	0.97	0.98	0.98
2010	0.00	0.03	0.17	0.53	0.79	0.86	0.87	0.87	0.87
2011	0.00	0.03	0.16	0.52	0.78	0.84	0.86	0.86	0.86

Table A.88. Gulf of Maine Atlantic cod January 1 numbers-at-age (000s) from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE ($M = 0.2$) model. Summary statistics reported (i.e., median, mean and geometric mean) include only the years 1982-2009, which was the recruitment series used in the reference points determination and stock projections.

Year	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	10,579	12,112	5,124	2,988	1,708	157	222	148	232
1983	11,545	8,337	7,799	2,313	1,198	673	62	87	149
1984	11,450	9,033	5,128	3,143	809	411	231	21	81
1985	8,912	9,002	5,727	2,228	1,203	305	154	87	38
1986	14,069	6,958	5,466	2,236	750	397	100	51	41
1987	15,005	11,031	4,337	2,277	814	268	142	36	33
1988	27,950	11,771	6,901	1,823	838	294	97	51	25
1989	4,279	22,155	7,860	3,409	814	369	129	42	33
1990	4,224	3,453	16,754	4,623	1,377	278	122	42	25
1991	7,479	3,398	2,564	9,128	1,585	384	74	32	18
1992	7,445	6,004	2,494	1,332	2,826	390	90	17	12
1993	9,665	5,968	4,374	1,255	386	640	84	19	6
1994	3,254	7,726	4,280	2,063	316	74	115	15	4
1995	3,451	2,604	5,579	2,077	552	65	14	22	4
1996	2,741	2,782	1,957	3,193	791	176	20	4	8
1997	4,503	2,208	2,084	1,105	1,183	243	52	6	4
1998	3,939	3,634	1,669	1,223	445	402	80	17	3
1999	7,865	3,184	2,770	1,015	531	166	145	29	7
2000	4,693	6,391	2,500	1,905	572	274	84	73	18
2001	1,170	3,805	4,959	1,636	967	260	121	37	40
2002	5,171	947	2,927	3,134	770	399	104	48	31
2003	1,904	4,196	738	1,952	1,654	367	186	48	37
2004	6,304	1,542	3,241	474	951	713	154	78	36
2005	3,922	5,106	1,190	2,077	230	408	298	64	47
2006	6,590	3,195	4,050	819	976	82	135	98	36
2007	5,296	5,373	2,546	2,859	418	393	31	51	50
2008	4,513	4,319	4,286	1,808	1,487	173	154	12	39
2009	3,532	3,676	3,423	2,938	840	520	56	49	16
2010	2,177	2,876	2,910	2,329	1,333	283	163	17	20
2011	1,175	1,774	2,285	2,020	1,127	495	99	56	13
1982-2009 median recruitment	5,234								
1982-2009 mean recruitment	7,195								
1982-2009 geometric mean	5,792								

Table A.89. Gulf of Maine Atlantic cod fishing mortality-at-age from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) model.

Year	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	0.04	0.24	0.61	0.73	0.75	0.75	0.75	0.75	0.75
1983	0.05	0.29	0.73	0.87	0.89	0.89	0.89	0.89	0.89
1984	0.04	0.26	0.65	0.78	0.80	0.80	0.80	0.80	0.80
1985	0.05	0.30	0.76	0.91	0.93	0.93	0.93	0.93	0.93
1986	0.04	0.28	0.69	0.83	0.85	0.85	0.85	0.85	0.85
1987	0.04	0.27	0.68	0.81	0.83	0.83	0.83	0.83	0.83
1988	0.03	0.20	0.50	0.60	0.62	0.62	0.62	0.62	0.62
1989	0.01	0.07	0.32	0.72	0.89	0.92	0.93	0.93	0.93
1990	0.01	0.08	0.39	0.87	1.08	1.12	1.13	1.13	1.13
1991	0.01	0.09	0.42	0.95	1.18	1.22	1.23	1.23	1.23
1992	0.02	0.10	0.45	1.01	1.25	1.30	1.31	1.31	1.31
1993	0.02	0.11	0.50	1.13	1.40	1.45	1.46	1.46	1.46
1994	0.02	0.10	0.45	1.02	1.26	1.31	1.32	1.32	1.32
1995	0.01	0.06	0.29	0.67	0.82	0.86	0.86	0.86	0.86
1996	0.01	0.06	0.29	0.66	0.82	0.85	0.85	0.85	0.85
1997	0.01	0.05	0.25	0.56	0.69	0.72	0.72	0.72	0.72
1998	0.01	0.04	0.21	0.47	0.58	0.60	0.60	0.61	0.61
1999	0.00	0.03	0.12	0.27	0.33	0.35	0.35	0.35	0.35
2000	0.01	0.03	0.15	0.35	0.43	0.44	0.45	0.45	0.45
2001	0.01	0.04	0.17	0.39	0.49	0.50	0.51	0.51	0.51
2002	0.00	0.03	0.14	0.31	0.38	0.40	0.40	0.40	0.40
2003	0.01	0.04	0.17	0.37	0.46	0.48	0.48	0.48	0.48
2004	0.01	0.04	0.17	0.39	0.48	0.50	0.50	0.50	0.50
2005	0.00	0.02	0.12	0.41	0.64	0.69	0.70	0.70	0.70
2006	0.00	0.02	0.10	0.35	0.55	0.60	0.60	0.60	0.60
2007	0.00	0.02	0.10	0.35	0.55	0.59	0.60	0.60	0.60
2008	0.00	0.02	0.13	0.45	0.70	0.76	0.77	0.77	0.77
2009	0.00	0.02	0.14	0.49	0.76	0.82	0.83	0.83	0.83
2010	0.00	0.02	0.13	0.47	0.72	0.78	0.79	0.79	0.79
2011	0.00	0.02	0.15	0.53	0.82	0.88	0.89	0.90	0.90

Table A.90. Gulf of Maine Atlantic cod January 1 numbers-at-age (000s) from 1982 to 2011 as estimated from the ASAP SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) model. Summary statistics reported (i.e., median, mean and geometric mean) include only the years 1982-2009, which was the recruitment series used in the reference points determination and stock projections.

Year	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+
1982	10,904	12,271	5,154	2,969	1,670	153	213	141	218
1983	11,913	8,594	7,873	2,293	1,170	647	59	82	139
1984	11,755	9,322	5,263	3,119	786	393	217	20	74
1985	9,226	9,242	5,886	2,251	1,172	290	145	80	35
1986	14,398	7,205	5,585	2,256	741	378	93	47	37
1987	15,699	11,292	4,478	2,296	808	261	133	33	29
1988	30,113	12,322	7,054	1,864	835	289	93	47	22
1989	4,771	23,893	8,250	3,492	835	369	127	41	31
1990	4,931	3,824	18,087	4,867	1,381	278	119	41	23
1991	9,056	3,865	2,797	9,773	1,618	373	72	31	16
1992	9,558	7,019	2,777	1,445	2,973	393	87	17	11
1993	13,358	7,328	4,964	1,382	409	662	83	18	6
1994	4,846	10,020	5,023	2,299	341	77	118	15	4
1995	5,602	3,605	6,872	2,418	627	73	16	24	4
1996	4,862	4,149	2,532	3,830	930	206	23	5	9
1997	8,555	3,530	2,858	1,387	1,454	302	65	7	4
1998	7,851	6,159	2,431	1,621	577	529	107	23	4
1999	16,584	5,603	4,235	1,421	730	232	209	42	11
2000	10,157	11,638	3,849	2,649	765	369	116	104	26
2001	2,553	7,048	7,856	2,304	1,308	348	165	52	58
2002	11,472	1,753	4,690	4,562	1,075	556	145	69	46
2003	4,316	7,730	1,152	2,770	2,269	497	253	66	52
2004	14,342	2,877	5,001	655	1,279	959	206	105	49
2005	8,744	9,556	1,859	2,825	298	531	391	84	62
2006	14,456	5,845	6,287	1,110	1,257	106	179	131	49
2007	11,031	9,668	3,856	3,814	522	486	39	66	66
2008	8,695	7,378	6,377	2,340	1,797	203	180	14	48
2009	6,254	5,812	4,844	3,762	996	595	63	56	19
2010	3,511	4,179	3,810	2,830	1,547	313	176	19	22
2011	1,749	2,347	2,742	2,240	1,190	503	96	53	12
1982-2009 median recruitment	9,392								
1982-2009 mean recruitment	10,214								
1982-2009 geometric mean	9,007								

Table A.91. Summary of the Gulf of Maine Atlantic cod 2011 point estimates and their corresponding 90% probability intervals for the ASAP SAW55_3BLOCK_BASE (*M = 0.2*) and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) models.

Model	SSB_{2011} (mt)	B_{2011} (mt)	F_{full}
SAW55_3BLOCK_BASE	9,903 (7,644 - 13,503)	14,728 (11,890 - 19,149)	0.86 (0.53 - 1.05)
SAW55_3BLOCK_BASE_MSPLIT	10,221 (7,943 - 13,676)	16,312 (13,173 - 20,771)	0.90 (0.57 - 1.09)

Table A.92. Summary of Gulf of Maine Atlantic cod ASAP model configurations which explored assessment starting years of 1932 with Beverton-Holt stock recruit functions fit internally within the model. The two model configurations that were explored were the SAW55_3BLOCK_BASE_1932_F2N1_NOPRIOR_BH ($M = 0.2$) and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NOPRIOR_BH (M-ramp).

Model		SAW55_3BLOCK_BASE_1932_F2N1_NOPRIOR_BH	SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NOPRIOR_BH
Starting year		1932	1932
Parameters		186	186
Objective function		3626	3643
Maximum gradient		2.0E-04	3.3E-04
Components of objective function	Suvey age comps	814	815
	Catch age comps	390	391
	Index fit	1146	1145
	Catch fit	651	651
	Recruit devs	625	642
RMSE	Catch	0.409	0.396
	Index1	1.13	0.993
	Index2	1.11	1.19
	Index3	1.27	1.28
	Index total	1.16	1.15
	Recruit devs	1.06	1.01
Mean age RMSE	Fleet1	0.99	0.97
	Index1	0.97	0.99
	Index2	1.15	1.17
	Index3	1.08	1.09
SSBStart (mt)		13,382	13,151
SSB_{1982} (mt)		23,715	22,759
SSB_{2011} (mt)		9,316	8,442
$F_{MULT,2011}$		0.92	1.12
Mohn's rho (5 year peel)	SSB	0.11	-0.27
	F_{mult}	-0.09	0.47
	Age 1 N	0.17	-0.18
Alpha		8218.1	9221.3
Beta		4949.0	2052.5
SSB0 (mt)		165,840	36,000
R0 (000s)		7,980	8,723.90
Steepness		0.90 (0.05)	0.82 (0.12)
Fmsy		0.26 (0.04)	0.89 (0.03)
SSBmsy (mt)		42,769 (0.13)	7,713 (0.10)
MSY (mt)		11,081 (0.13)	4,838 (0.08)
Comments		1932-1981 selectivity block fixed at A50=2 and slope up=0.6	1932-1981 selectivity block fixed at A50=2 and slope up=0.6

Table A.93. Inputs to the Gulf of Maine Atlantic cod yield per recruit (YPR) analysis for the ASAP $M = 0.2$ (ASAP SAW55_3BLOCK_BASE) and M-ramp (ASAP_3BLOCK_BASE_M_SPLIT) models.

Age	Catch weights (kg)	Stock weights (kg)	Fishery selectivity (M = 0.2)	Fishery selectivity (M-ramp)	Fraction mature	Natural mortality
1	0.31	0.12	0.01	0.00	0.08	0.20
2	1.01	0.52	0.03	0.03	0.26	0.20
3	2.07	1.26	0.19	0.17	0.59	0.20
4	3.07	2.19	0.61	0.59	0.84	0.20
5	3.79	3.12	0.91	0.91	0.95	0.20
6	4.55	3.82	0.98	0.99	0.99	0.20
7	5.79	4.77	1.00	1.00	1.00	0.20
8	7.56	6.55	1.00	1.00	1.00	0.20
9	12.49	12.50	1.00	1.00	1.00	0.20

Table A.94. Yield per recruit proxy reference points for Gulf of Maine Atlantic cod under both the *M* = 0.2 (ASAP SAW55_3BLOCK_BASE) and *M*-ramp (ASAP_3BLOCK_BASE_M_SPLIT) models.

Model	F_{MSY} (proxy)	F_{MSY}	SSB_{MSY} proxy (mt)	MSY proxy (mt)	Median age1 recruitment	SSB hinge (mt)	Hinge year
M = 0.2 (SAW55_3BLOCK_BASE)	$F_{40\%}$	0.18	54,743 (40,207 - 73,354)	9,399 (6,806 - 13,153)	5,254	6,300	1998
M-ramp (SAW55_3BLOCK_BASE_M_SPLIT)	$F_{40\%}$	0.18	80,200 (64,081 - 99,972)	13,786 (10,900 - 17,329)	9,446	7,900	1994

Table A.95. Short-term projections (3 years) for Gulf of Maine Atlantic cod under an assumed harvest of 75% F_{MSY} based on the ASAP M = 0.2 and M-ramp models. The M-ramp projections were conducted under two assumptions of natural mortality: 0.2 and 0.4. **Note, the projections have not been adjusted for retrospective bias.*

Year	Input	ASAP, 1982 BASE			ASAP, 1982 M-RAMP					
		M=0.2			M=0.2			M=0.4		
		Fmsy = 0.18, Bmsy = 54,743 mt			Fmsy = 0.18, Bmsy = 80,200 mt			Fmsy = 0.18, Bmsy = 80,200 mt		
		Rebuild year at 75% F_{MSY} = 2022			Rebuild year at 75% F_{MSY} = 2022			NO REBUILD at 75% F_{MSY}		
		Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
2011	Model result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
2012	Assumed catch	3,767	8,995	0.46	3,767	8,196	0.52	3,767	7,711	0.58
2013	Projection	1,249	9,406	0.14	1,142	9,163	0.14	822	6,927	0.14
2014	Projection	1,503	12,143	0.14	1,563	13,916	0.14	935	8,875	0.14
2015	Projection	2,030	16,802	0.14	2,582	22,124	0.14	1,313	12,234	0.14

Table A.96. Results of consequence analysis of Gulf of Maine cod; column and row headers indicate 'true' state of nature and basis of management action (75% F_{MSY} for 2013 – 2015) under assumed states of nature; cells provide projections of SSB and fully recruited fishing mortality for 'true' states of nature for catch set according to assumed state of nature; diagonals (shaded) indicate that management actions were correctly specified for the state of nature.

Management actions - catches in 2013-2015	Year	Input	ASAP, 1982 start, M=0.2			ASAP, 1982 start, M-ramp (project M=0.2)			ASAP, 1982 start, M-ramp (project M=0.4)		
			SSBmsy = 54,743 mt; MSY=9,399 mt; Fmsy = 0.18			SSBmsy = 80,200 mt; MSY=13,786 mt; Fmsy = 0.18			SSBmsy = 80,200 mt; MSY=13,786 mt; Fmsy = 0.18		
			Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}
ASAP, 1982 start, M=0.2	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
	2012	Assumed catch	3,767	8,995	0.46	3,767	8,195	0.52	3,767	7,711	0.58
	2013	Projection	1,249	9,406	0.14	1,249	9,137	0.15	1,249	6,834	0.21
	2014	Projection	1,503	12,143	0.14	1,503	13,825	0.13	1,503	8,432	0.24
	2015	Projection	2,030	16,802	0.14	2,030	22,210	0.11	2,030	11,428	0.23
ASAP, 1982 start, M-ramp (project M=0.2)	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
	2012	Assumed catch	3,767	8,995	0.46	3,767	8,196	0.52	3,767	7,711	0.58
	2013	Projection	1,142	9,425	0.12	1,142	9,163	0.14	1,142	6,858	0.19
	2014	Projection	1,563	12,221	0.14	1,563	13,916	0.14	1,563	8,498	0.24
	2015	Projection	2,582	16,800	0.17	2,582	22,124	0.14	2,582	11,344	0.30
ASAP, 1982 start, M-ramp (project M=0.4)	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
	2012	Assumed catch	3,767	8,995	0.46	3,767	8,195	0.52	3,767	7,711	0.58
	2013	Projection	822	9,493	0.09	822	9,226	0.10	822	6,927	0.14
	2014	Projection	935	12,645	0.08	935	14,319	0.08	935	8,875	0.14
	2015	Projection	1,313	17,969	0.08	1,313	23,276	0.06	1,313	12,234	0.14

Table A.97. Status of 2013 spawning stock biomass and fishing mortality of Gulf of Maine cod; column and row headings indicate 'true' state of nature and basis of management action respectively; cells indicate 2013 stock status resulting from application of management actions under assumed state of nature (rows) to 'true' state of nature.

	States of Nature		
Management actions - catches in 2013-2015	**ASAP, 1982 start, M=0.2**	**ASAP, 1982 start, M-ramp (project M=0.2)**	**ASAP, 1982 start, M-ramp (project M=0.4)**
ASAP, 1982 start, M=0.2	Overfished, overfishing is not occurring	Overfished, overfishing is not occurring	Overfished, overfishing is occuring
ASAP, 1982 start, M-ramp (project M=0.2)	Overfished, overfishing is not occurring	Overfished, overfishing is not occurring	Overfished, overfishing is occuring
ASAP, 1982 start, M-ramp (project M=0.4)	Overfished, overfishing is not occurring	Overfished, overfishing is not occurring	Overfished, overfishing is not occurring

Figures

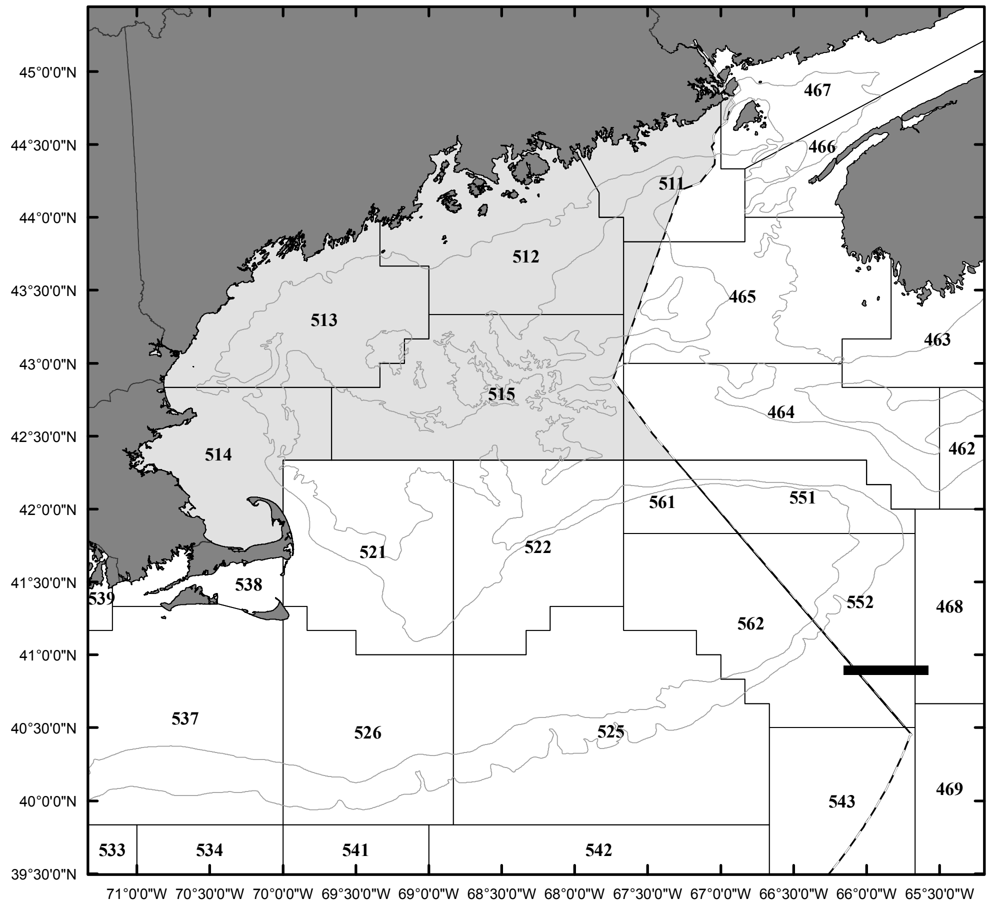


Figure A.1. Map of the Gulf of Maine Atlantic cod (*Gadus morhua*) management and assessment area (shaded grey). The United States exclusive economic zone (EEZ) is defined by the dashed line. Within the Gulf of Maine region, this line is informally referred to as the “Hague Line”.

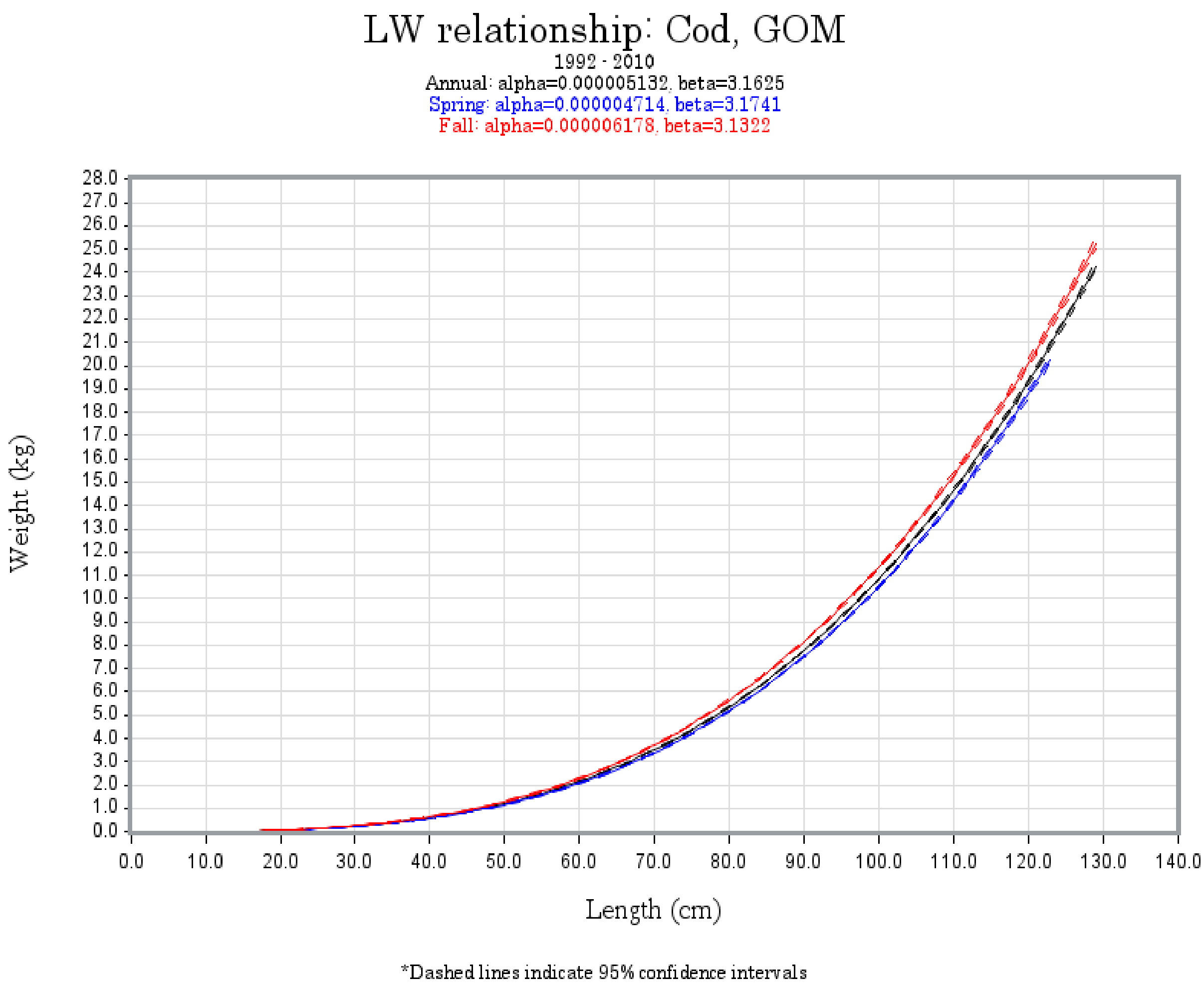


Figure A.2. Gulf of Maine Atlantic cod seasonal and annual length-weight relationships as estimated from NEFSC bottom trawl survey data.

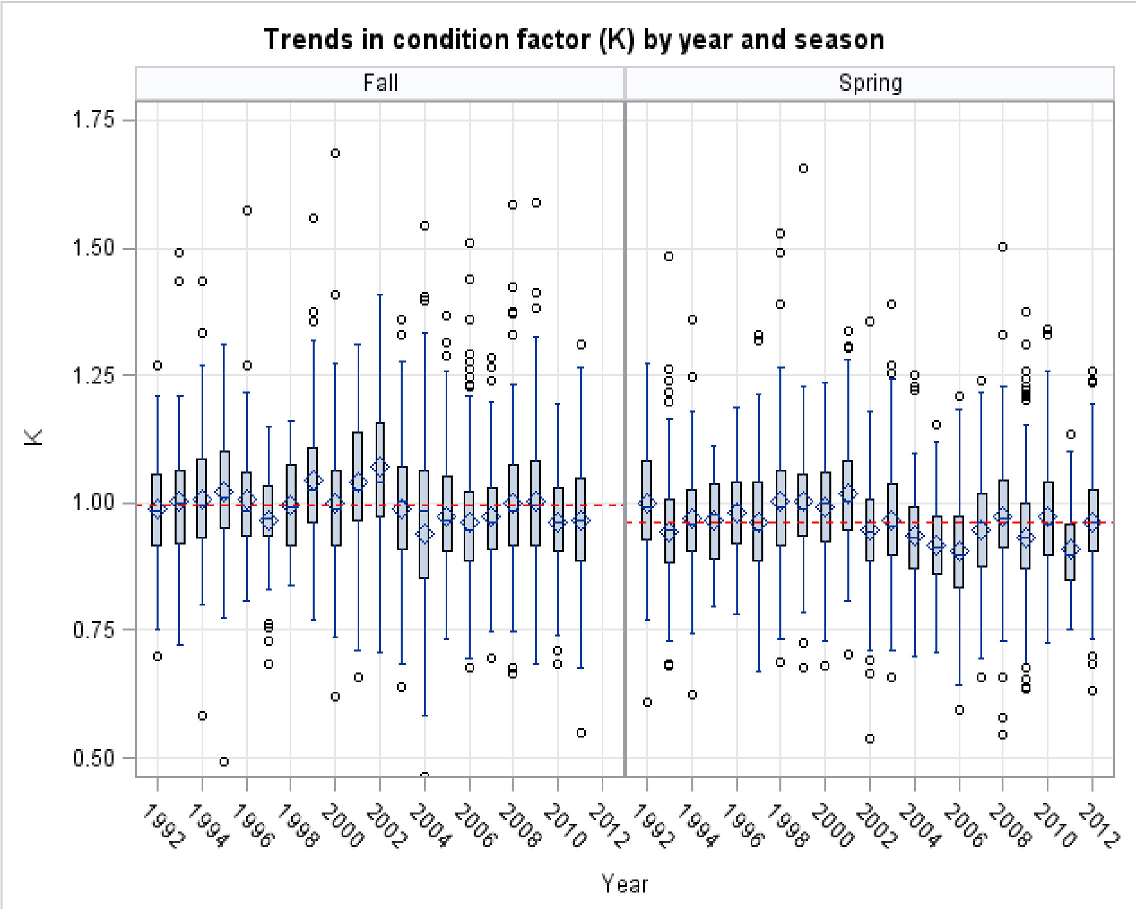


Figure A.3. Annual trends in the seasonal condition factor of Gulf of Maine Atlantic cod based on length and weight data collected from the NEFSC bottom trawl survey.

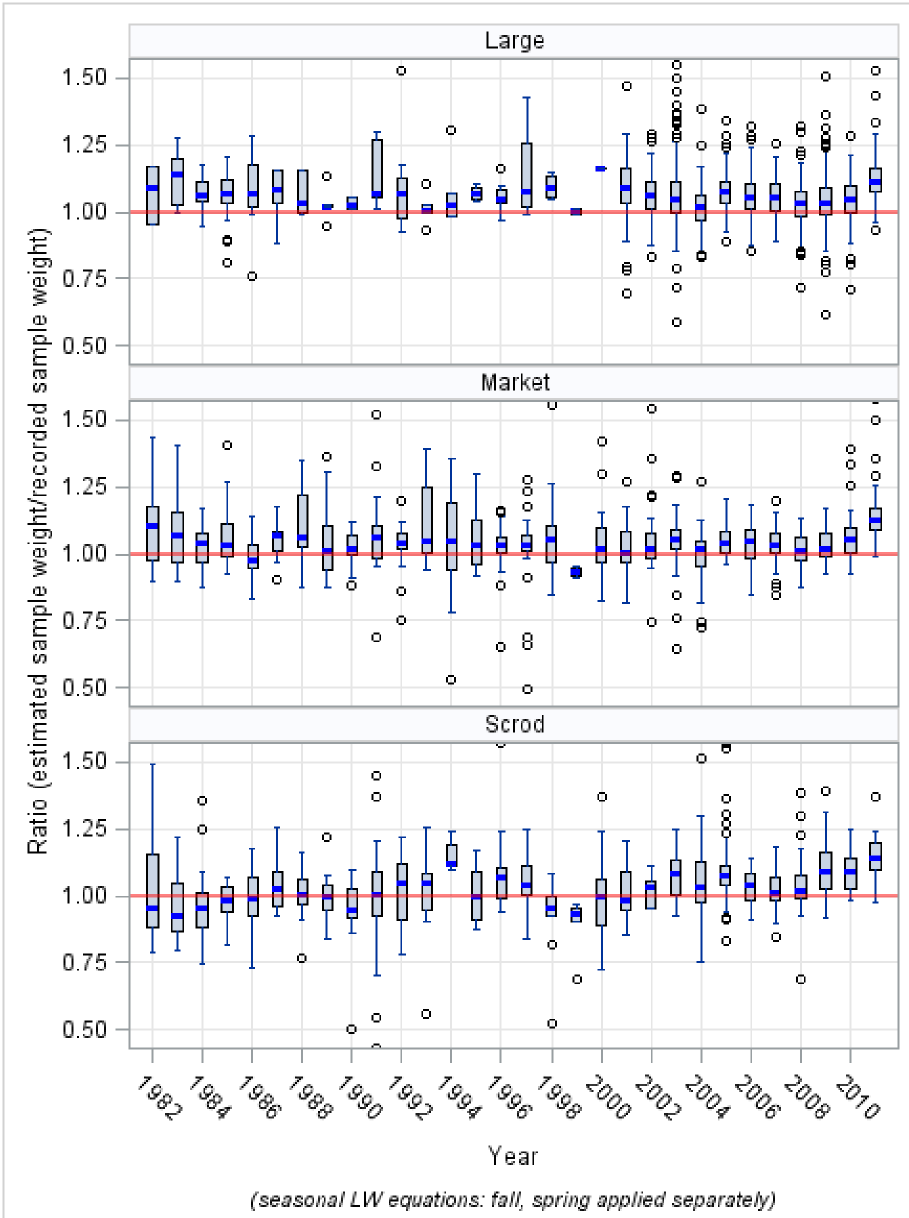


Figure A.4. Distribution of the ratios of estimate commercial biological sample weights to the recorded sample weight by market category and year using the established gutted-to-live conversion factor of 1.17. Estimated sample weights were obtained by applying the season (spring, fall) length weight equation to the recorded length distribution of the sample. The solid red line indicates the 1.0 equality line.

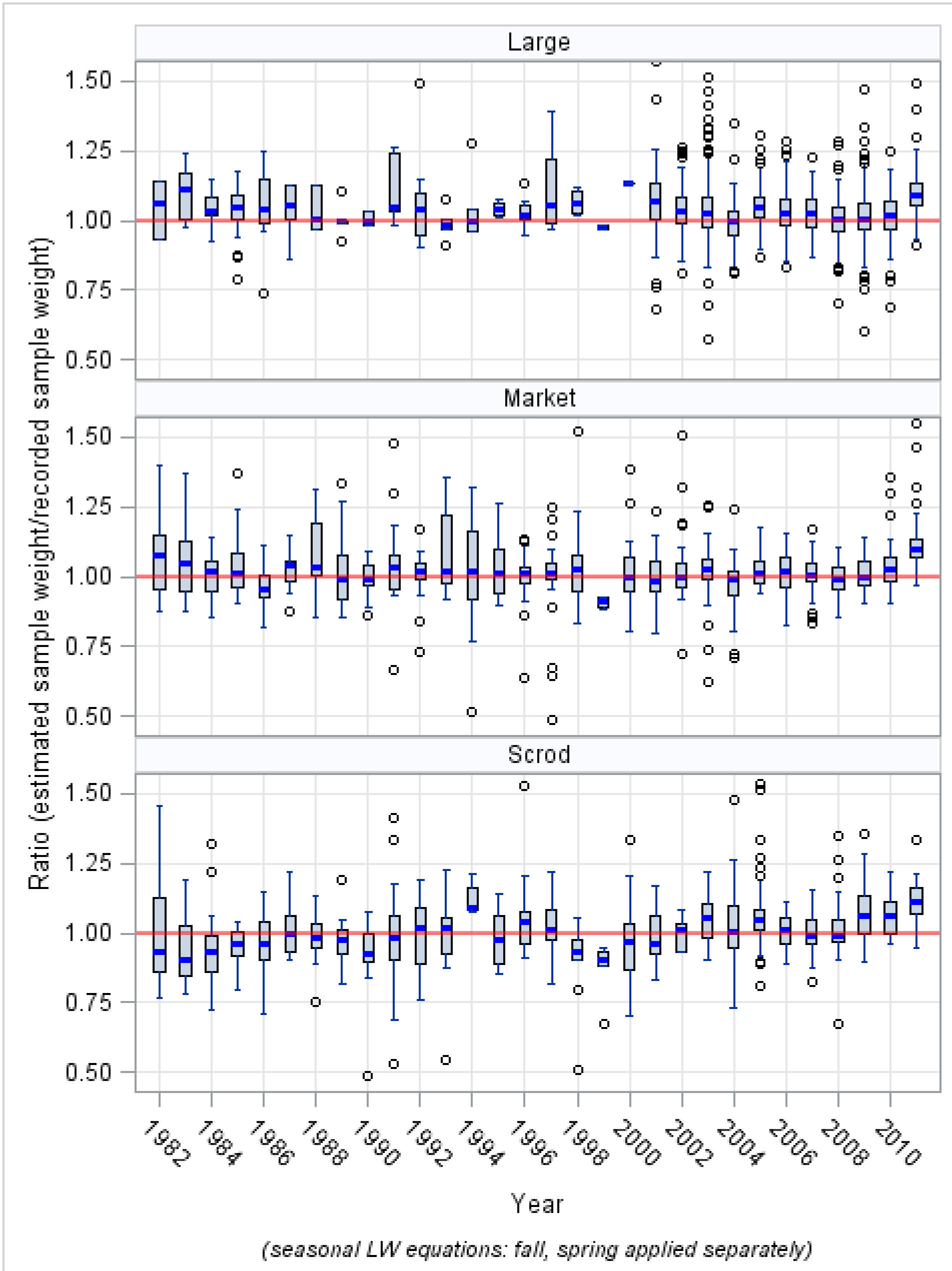


Figure A.5. Distribution of the ratios of estimate commercial biological sample weights to the recorded sample weight by market category and year using a preliminary gutted-to-live conversion factor of 1.20. Estimated sample weights were obtained by applying the season (spring, fall) length weight equation to the recorded length distribution of the sample. The solid red line indicates the 1.0 equality line.

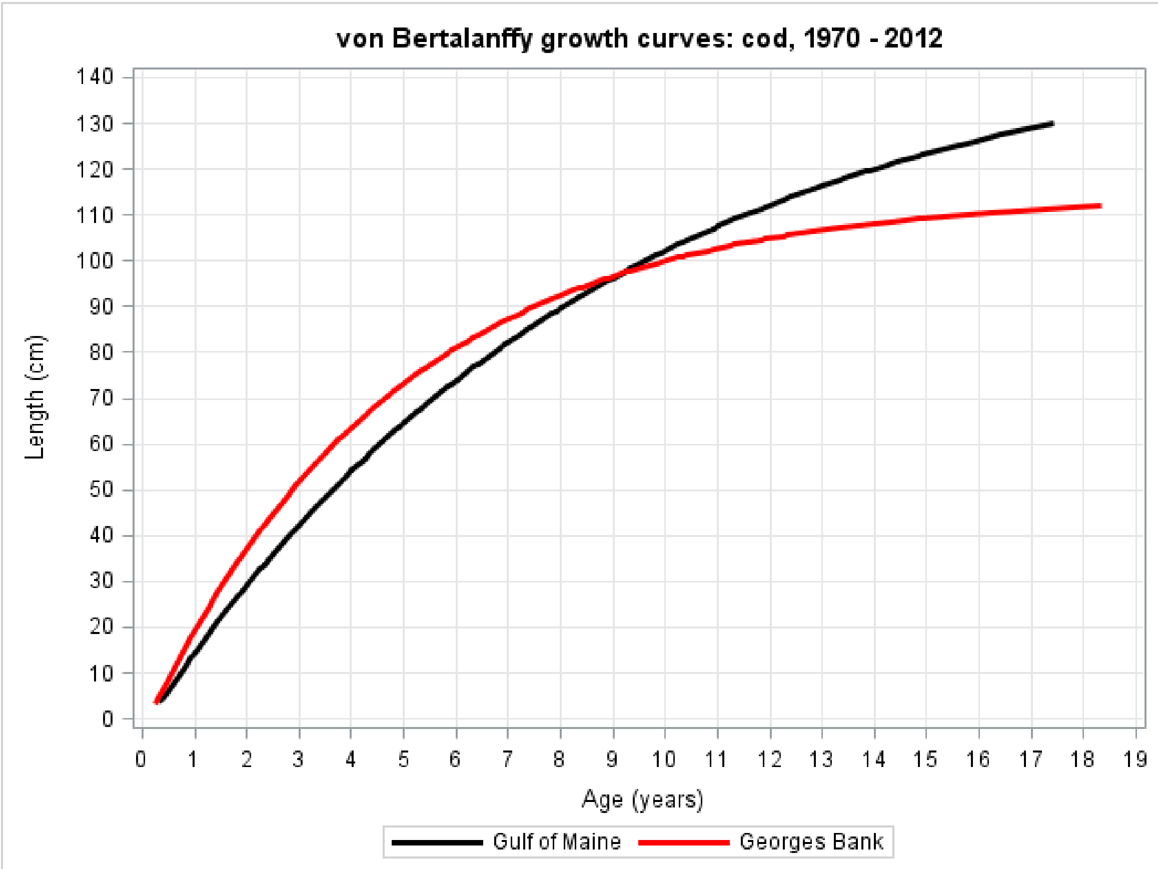


Figure A.6. Comparison of von Bertalanffy growth curves for the Gulf of Maine and Georges Banks Atlantic cod stocks as estimated from data collected from the Northeast Fisheries Science Center bottom trawl survey between 1970 and 2011.

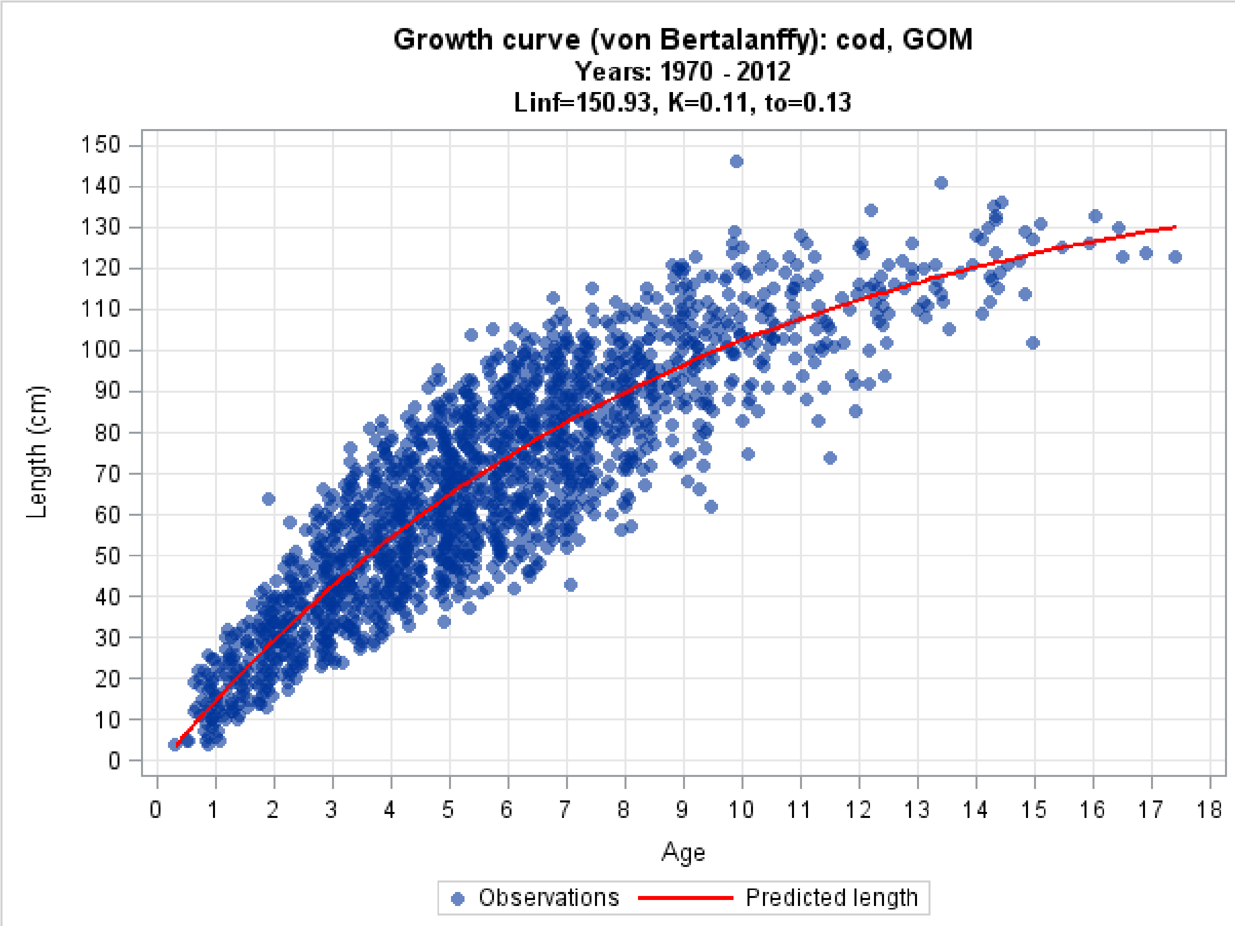


Figure A.7. Gulf of Maine Atlantic cod von Bertalanffy growth curve estimated from data collected from the Northeast Fisheries Science Center bottom trawl survey between 1970 and 2011. Growth paremeters estimated for the Gulf of Maine stock were: L_{inf}=150.93 cm, K=0.11, t_0=0.13.

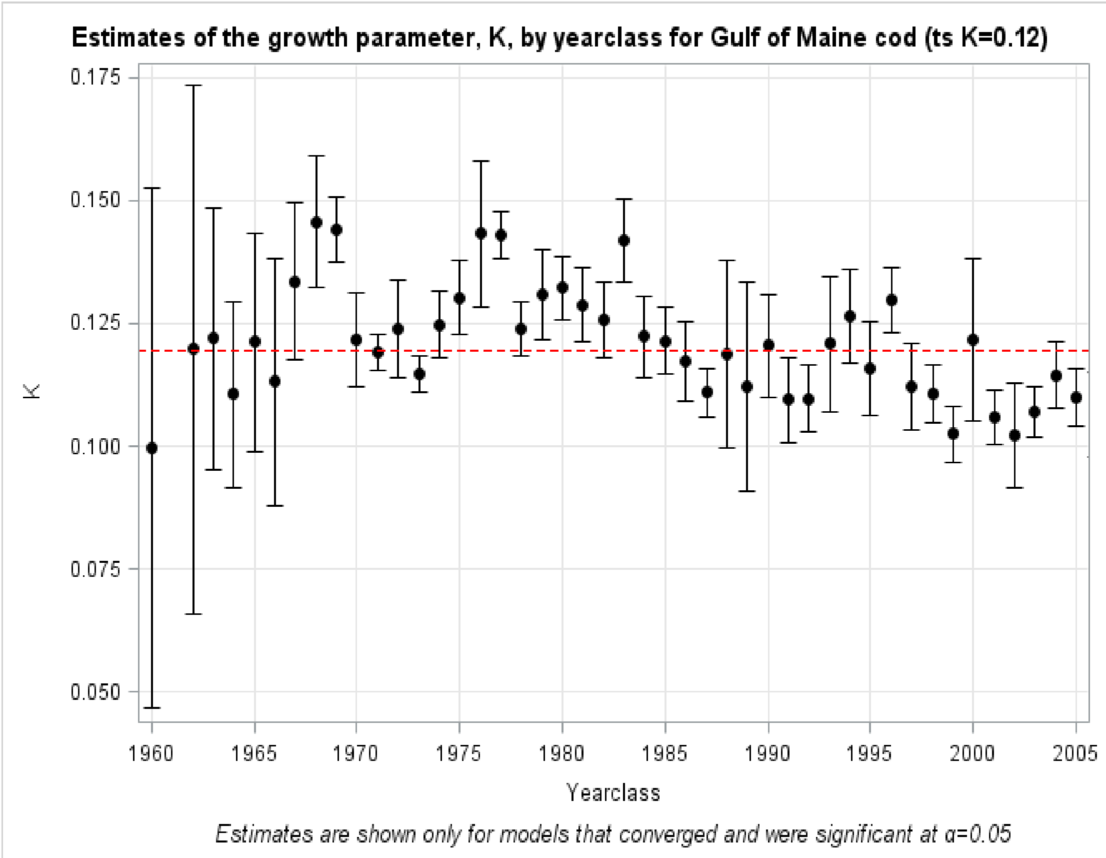


Figure A.8. Trends in the growth parameter , *K*, by year class for Gulf of Maine Atlantic cod. Errors bars indicate 95% confidence intervals about the parameter estimate. The dashed red line corresponds to the average cohort *K* estimate for the entire time series (0.12).

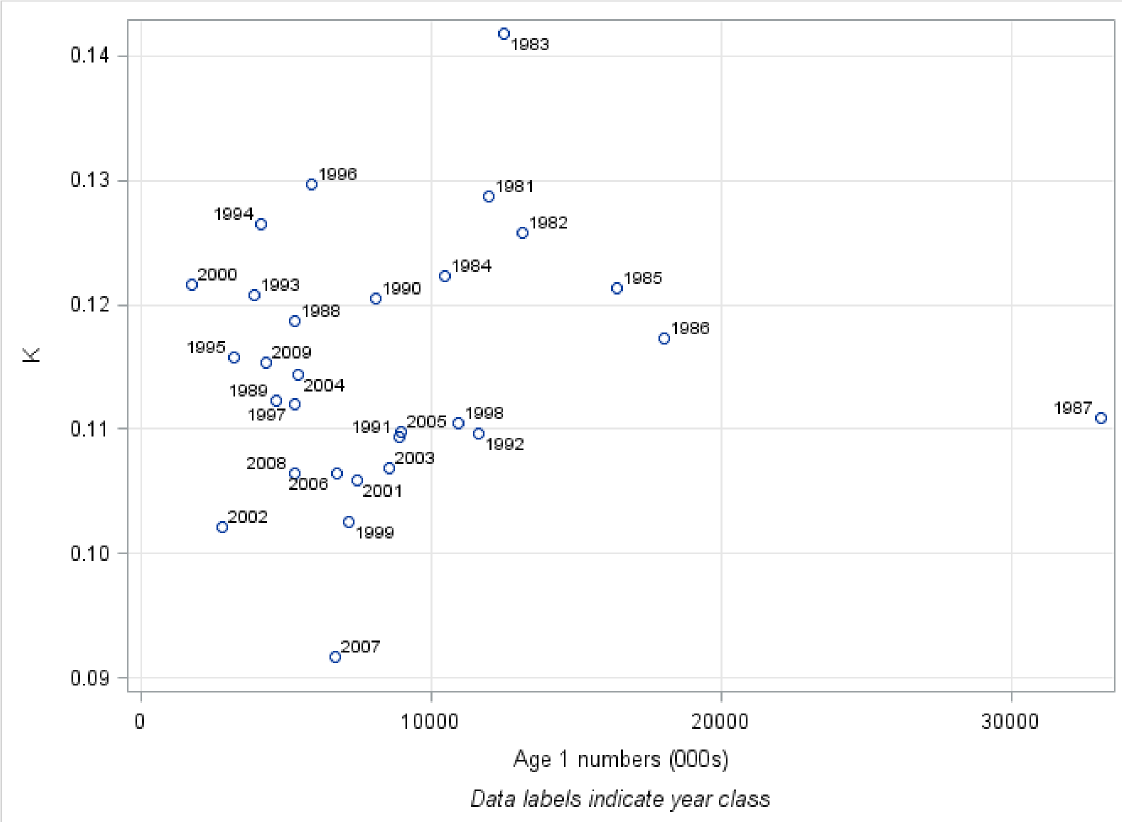


Figure A.9. Scatter plot of the growth parameter, *K*, relative to year class strength (age 1 numbers) for Gulf of Maine Atlantic cod. Age 1 recruitment estimates are based on the 2011 assessment of the Gulf of Maine cod stock (NEFSC 2012).

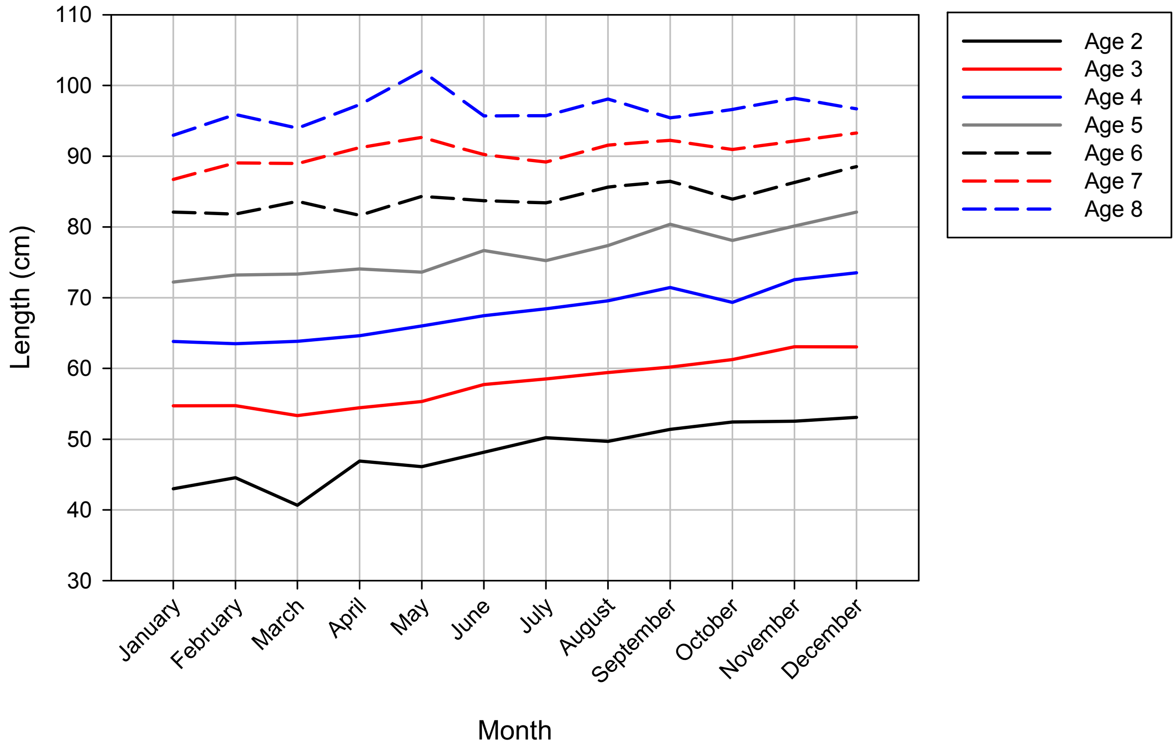
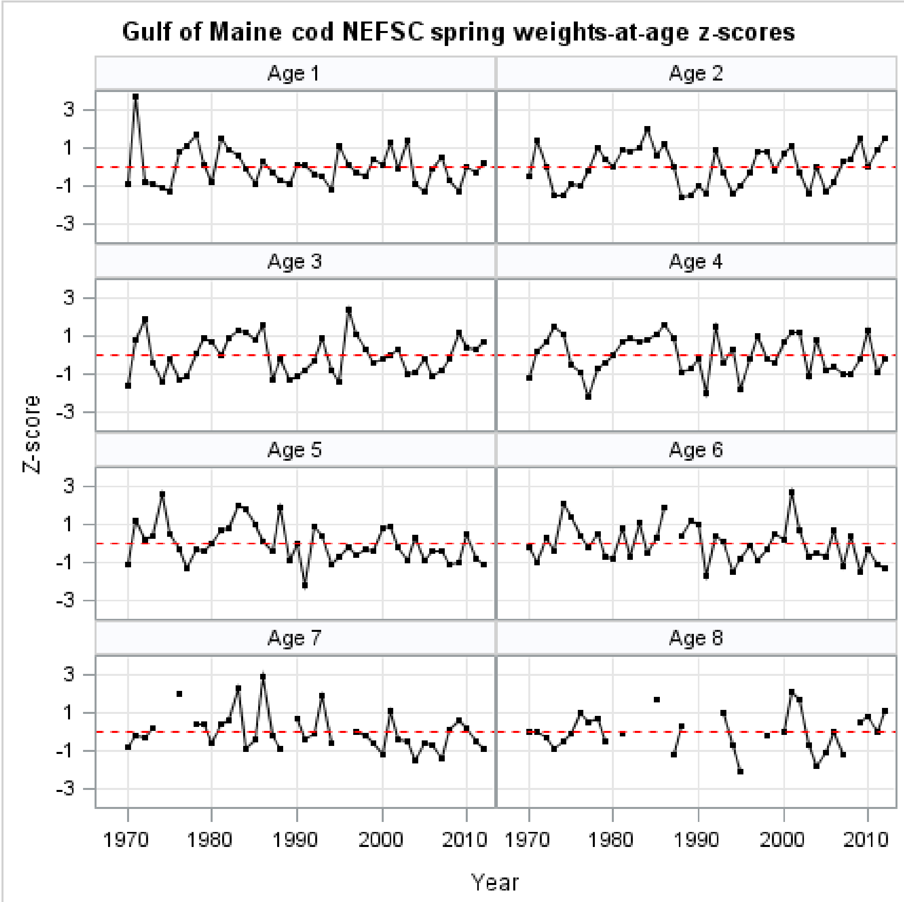
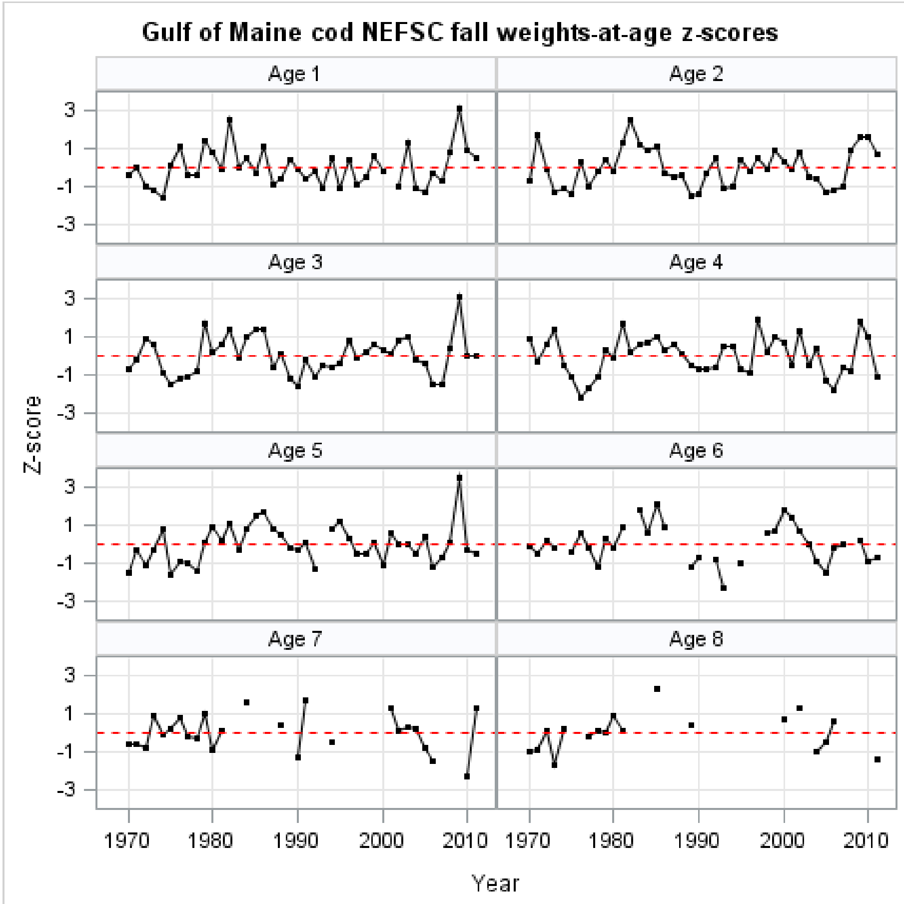


Figure A.10. Mean length-at-age of Altantic cod by month. Estimated from commercial port samples taken between 1981 and 2010.



Figue A.11 Average spring survey weights-at-age of Gulf of Maine Atlantic cod ages 1-8 from 1982 to 2012. Survey weights are based on the average weight-at-age of cod sampled from the Northeast Fisheries Science Center spring bottom trawl survey . Average weights are presented as z-scores ([*x*-μ]/σ).



Figue A.12. Average fall survey weights-at-age of Gulf of Maine Atlantic cod ages 1-8 from 1982 to 2011. Survey weights are based on the average weight-at-age of cod sampled from the Northeast Fisheries Science Center fall bottom trawl survey. Average weights are presented as z-scores ([x-μ]/σ).

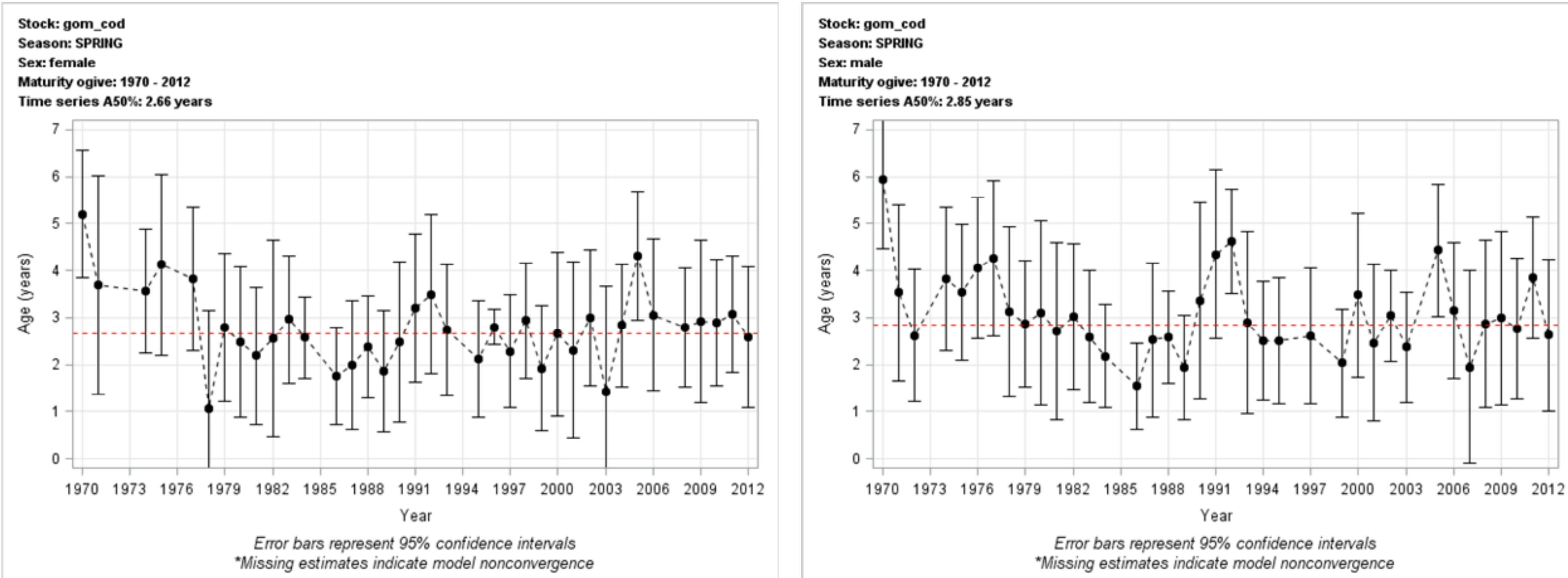


Figure A.13. Annual average age-at-50% maturity ($A_{50\%}$) and corresponding 95% confidence intervals for female (left panels) and male (right panels) Gulf of Maine Atlantic cod from 1970 to 2012. Average maturity has been estimated from data collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey. Years in which the A*50%* could not be estimated are omitted from the plots.

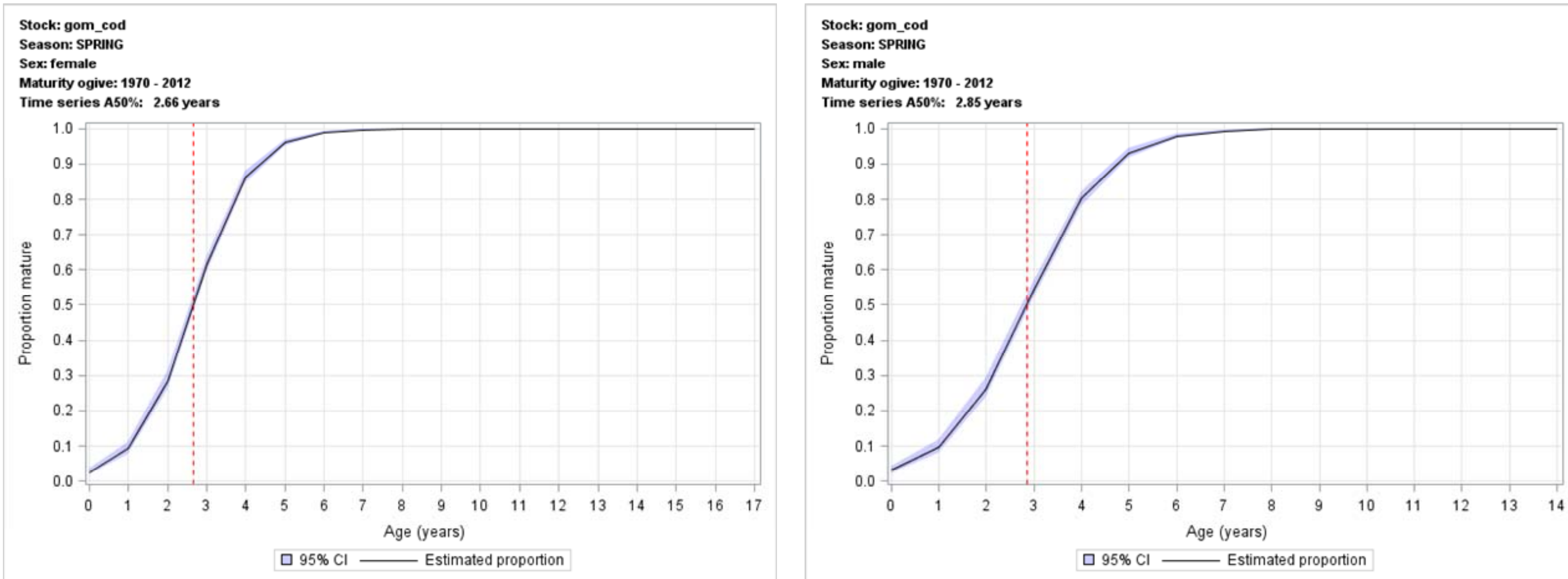


Figure A.14. Age-based maturity ogives for female (left) and male (right) Gulf of Maine Atlantic cod based on time series averages of maturity and age information collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey from 1970 to 2012. The dashed red line indicates the age at 50% maturity ($A_{50\%}$).

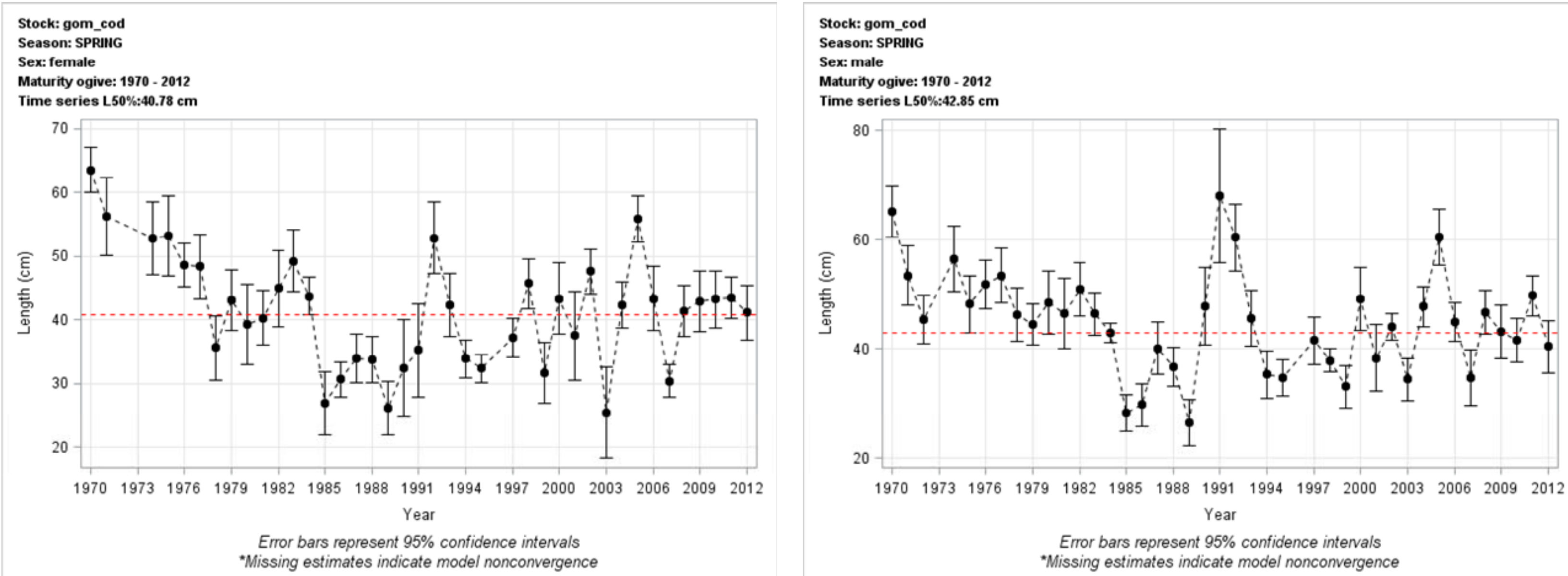


Figure A.15. Annual average length-at-50% maturity ($L_{50\%}$) and corresponding 95% confidence intervals for female (left panels) and male (right panels) Gulf of Maine Atlantic cod from 1970 to 2012. Average maturity has been estimated from data collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey. Years in which the $L_{50\%}$ could not be estimated are omitted from the plots.

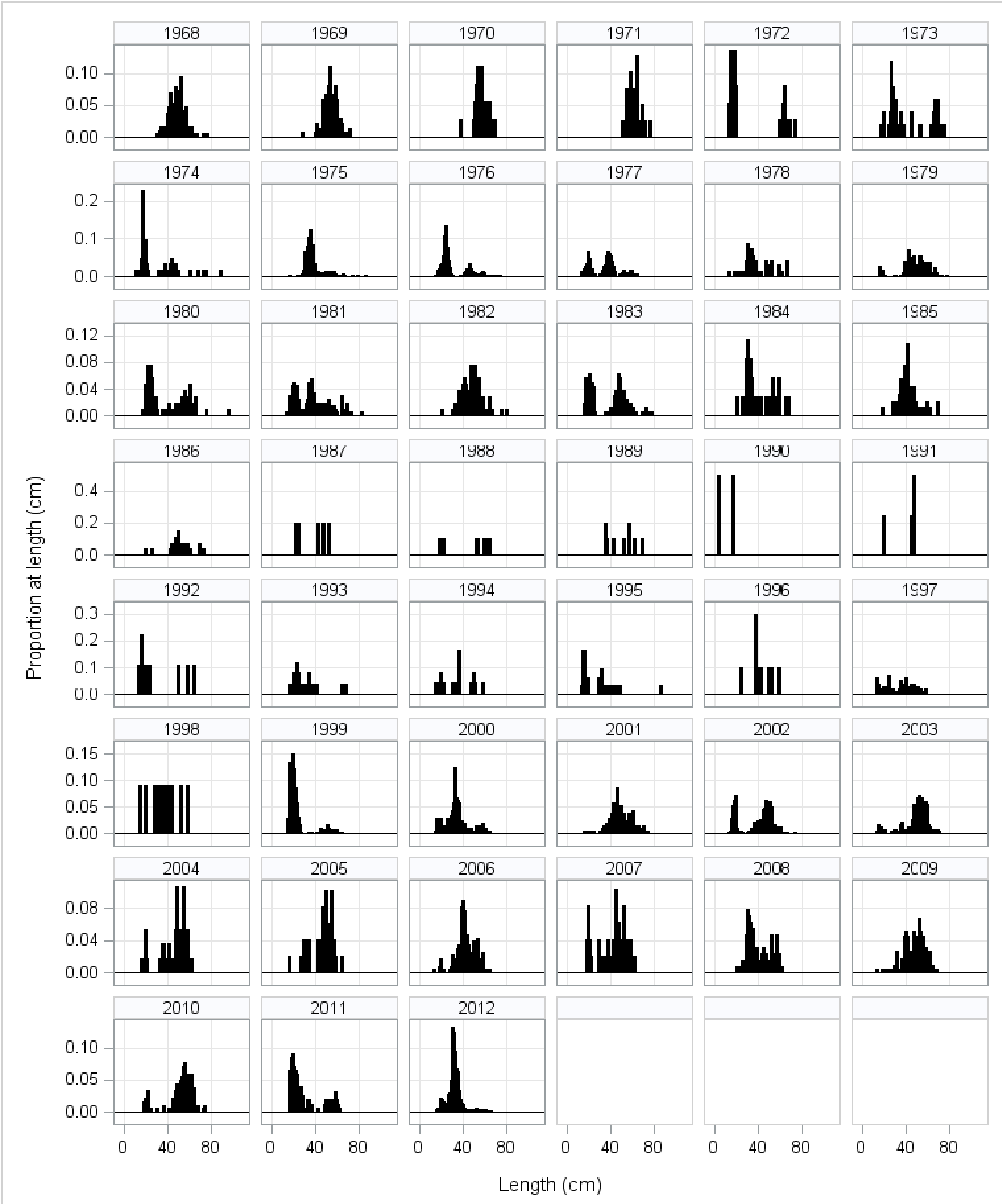
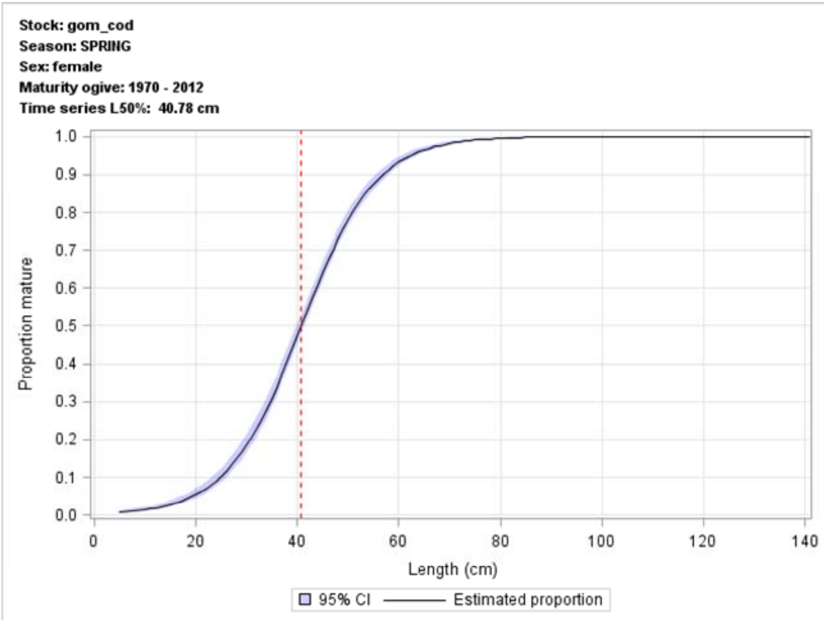


Figure A.16. Gulf of Maine Atlantic cod proportion at length observed in the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey between 1968 and 2012.



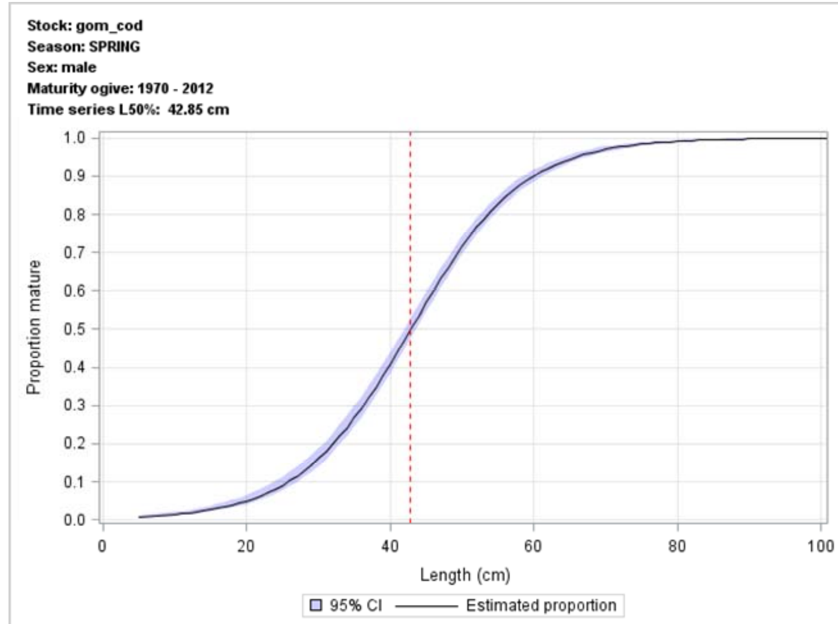


Figure A.17. Length-based maturity ogives for female (left) and male (right) Gulf of Maine Atlantic cod based on time series averages of maturity and length information collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey from 1970 to 2012. The dashed red line indicates the length at 50% maturity ($L_{50\%}$).

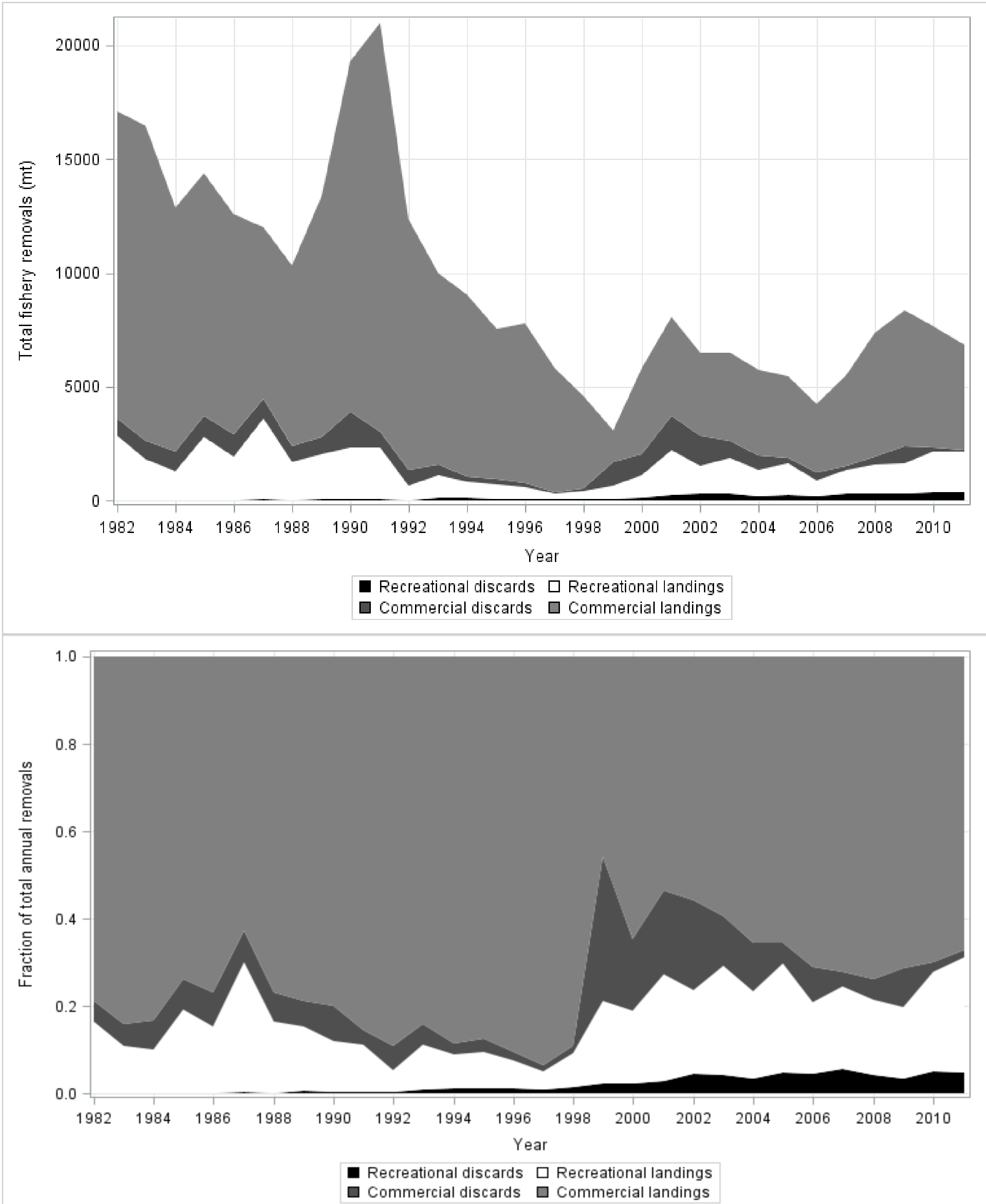


Figure A.18. Total (top) and fractional (as a fraction of the total, bottom) catch of Gulf of Maine Atlantic cod from 1982 to 2011 by fleet (commercial and recreational) and disposition (landed, discarded).

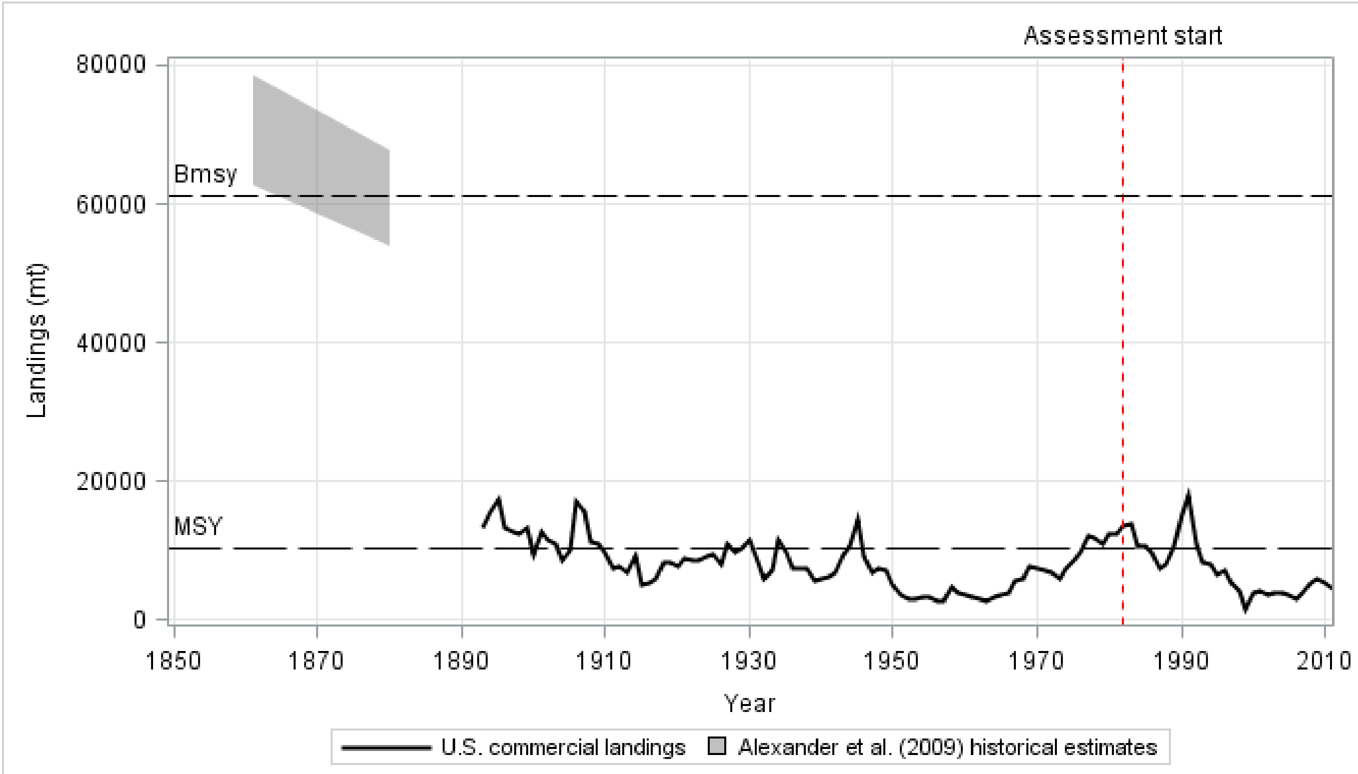


Figure A.19. United States commercial landings of Gulf of Maine Atlantic cod from 1861 to 2011. The grey-shaded polygon represents estimates of landings in 1861 and 1870 using two different conversion factors for converting cured salted cod to live fish (Alexander et al. 2009). Biological reference points (B_{MSY} = 61,218 mt, MSY = 10,392 mt) from the most recent assessment (NEFSC 2012) are shown by the dashed lines.

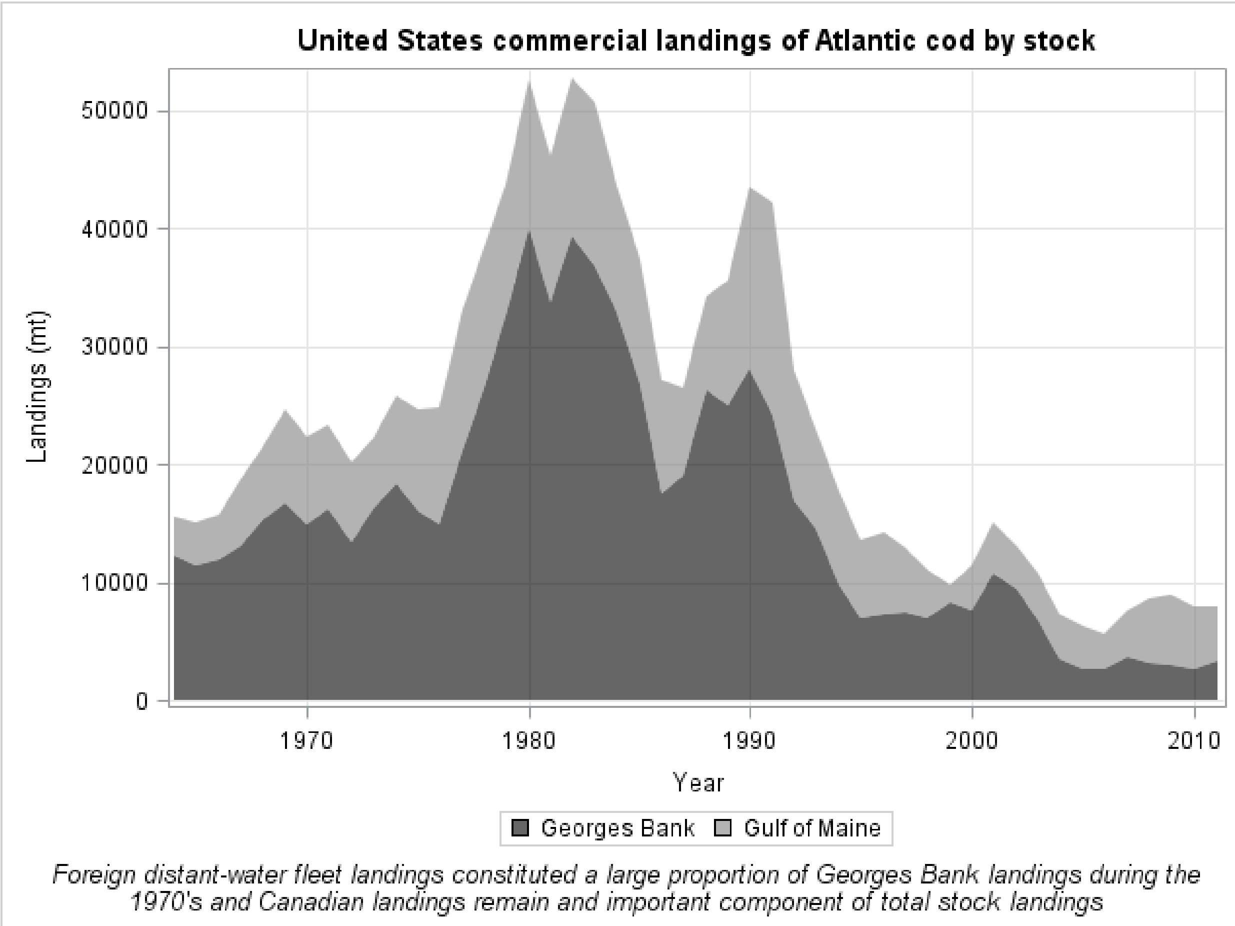


Figure A.20. Total United States commercial landings of Gulf of Maine and Georges Bank Atlantic cod from 1964 to 2011.

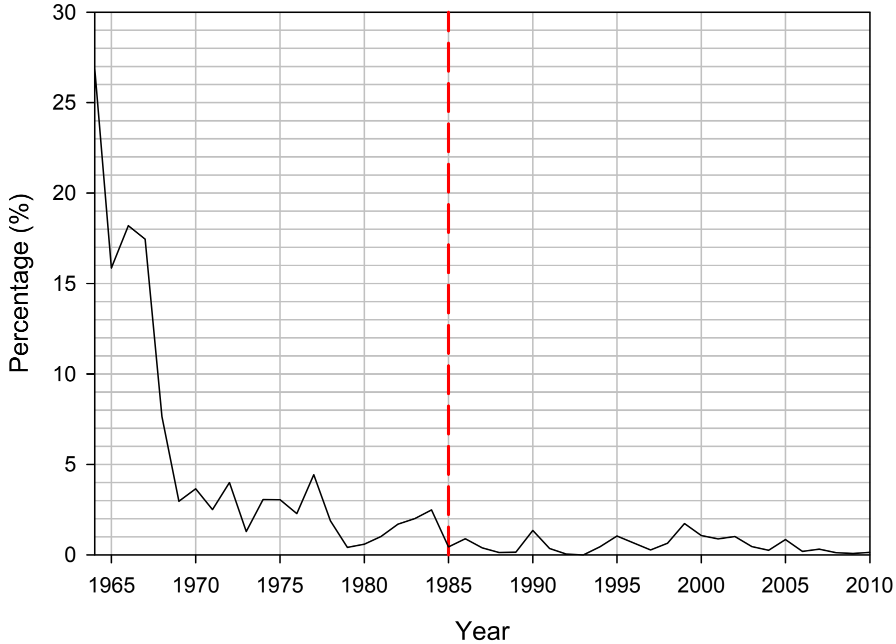


Figure A.21. Percentage of total commercial landings of Gulf of Maine Atlantic cod from statistical areas 464, 465 and 467 between 1964 and 2010. The Hague Line, which formally defined the Exclusive Econonimic Zones of the United States and Canada was adopted on October 12, 1984 (dashed red line).

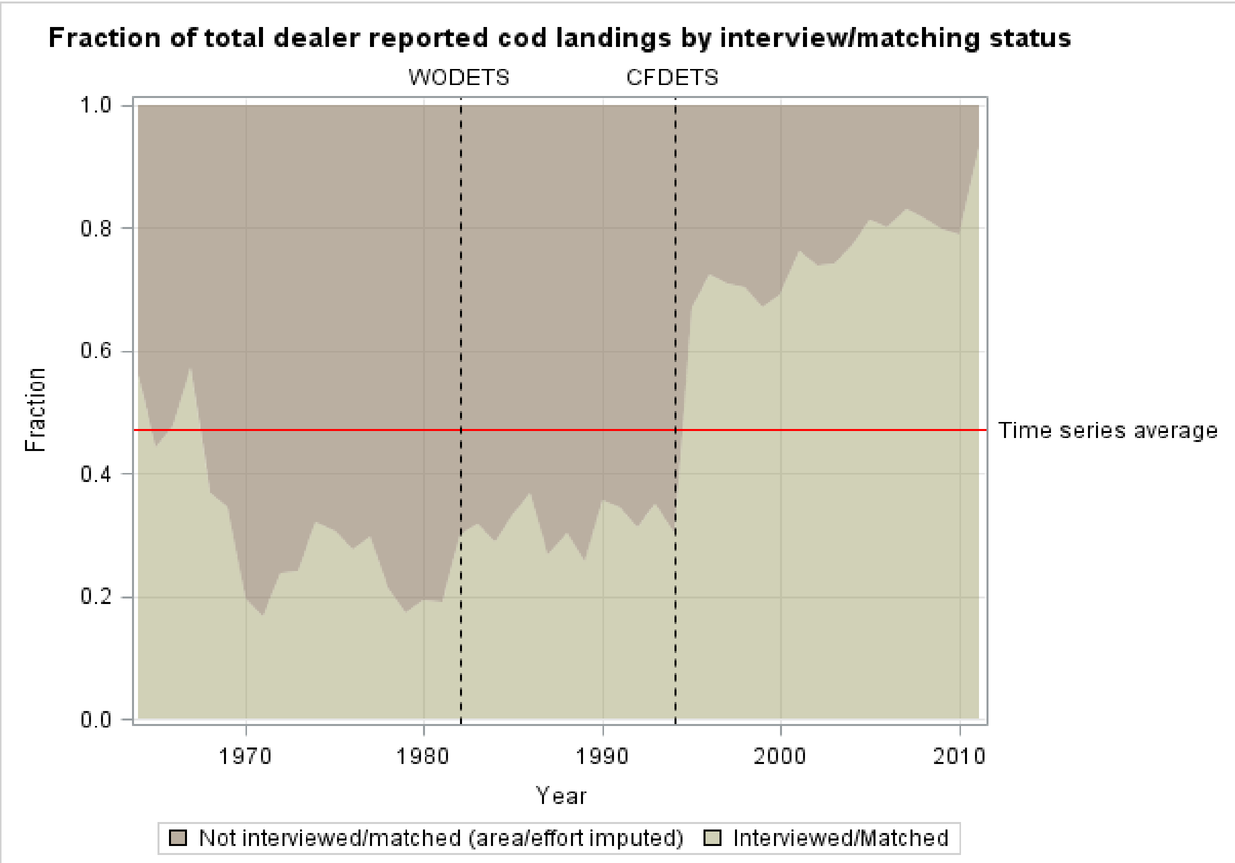


Figure A.22. Fraction of the Gulf of Maine Atlantic cod commercial landings from either interviewed trips (1964-1994) or those trips that could be directly matched to a vessel trip report (1994-2011). The red line indicates the time series average fraction of landings from interviewed/matched trips.

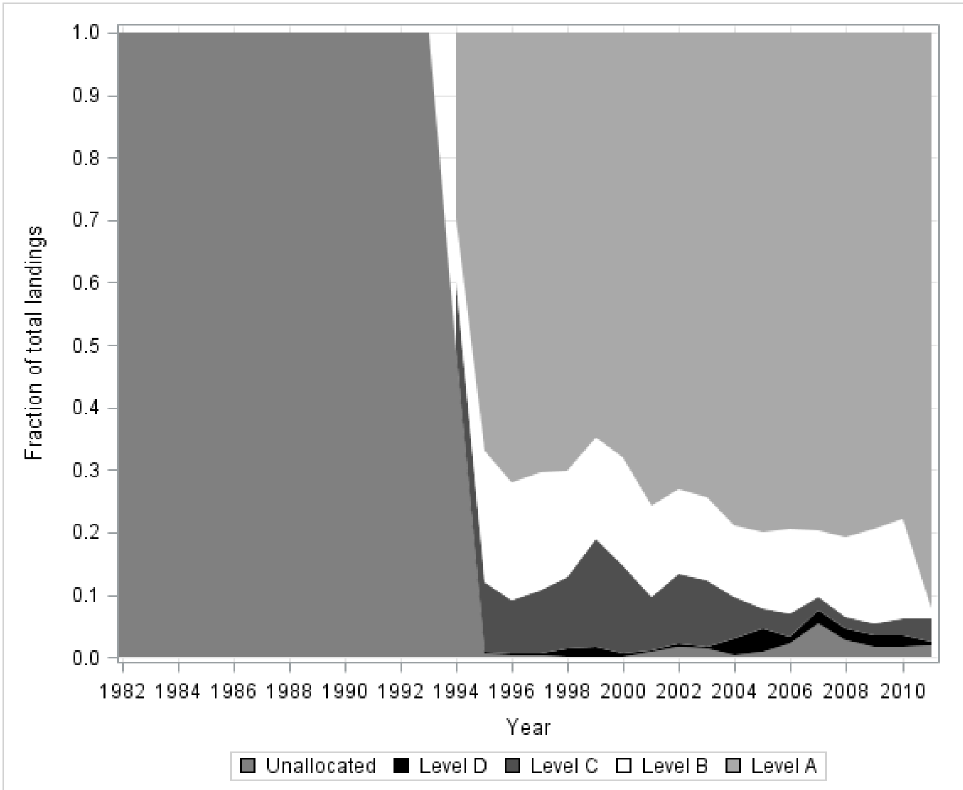


Figure A.23. Fraction of the Gulf of Maine Atlantic cod commercial landings by allocation level between 1982 and 2011. Prior to 1994 landings were allocated based on a port interview process. From 1994 onward landings were allocated to statistical area and gear type based on a standardized allocation scheme described in Wigley et al. (2008).

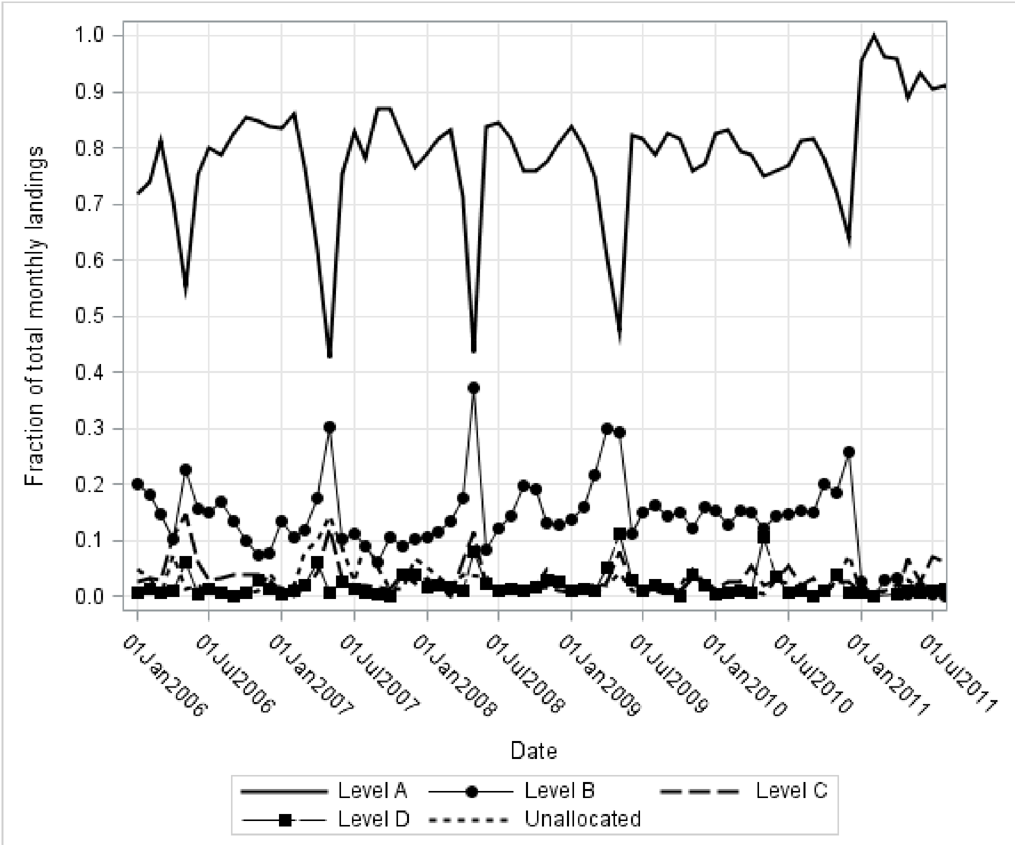
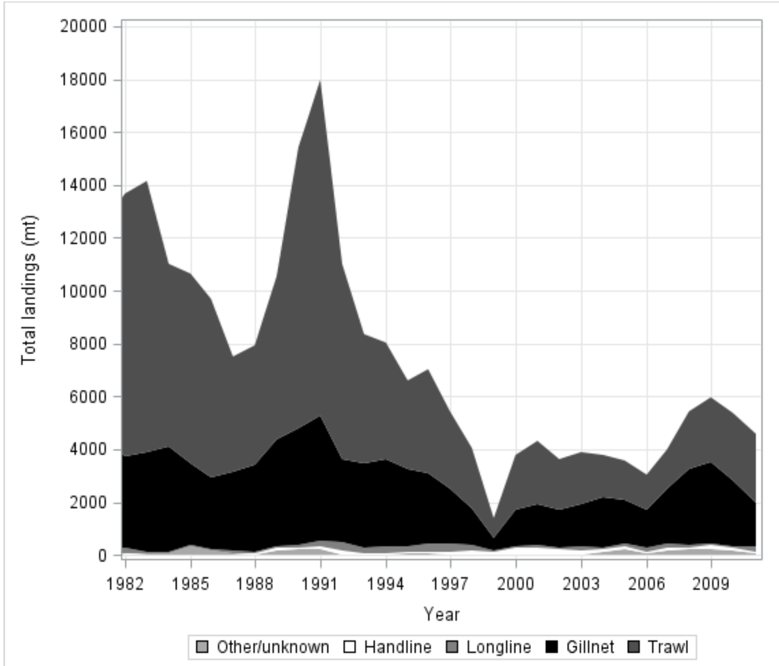


Figure A.24. Fraction of the Gulf of Maine Atlantic cod commercial landings by allocation level between 2006 and 2011 by month.



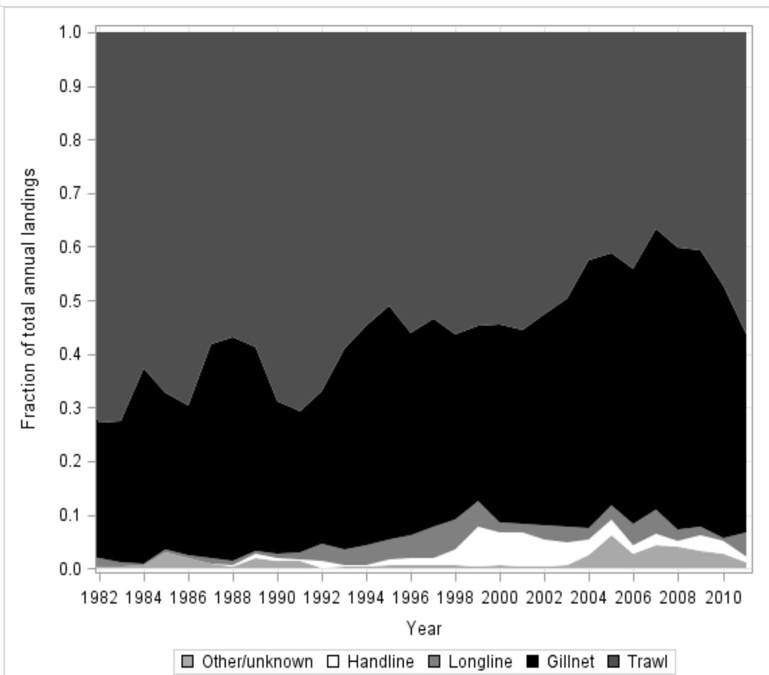


Figure A.25. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by gear from 1982 to 2011.

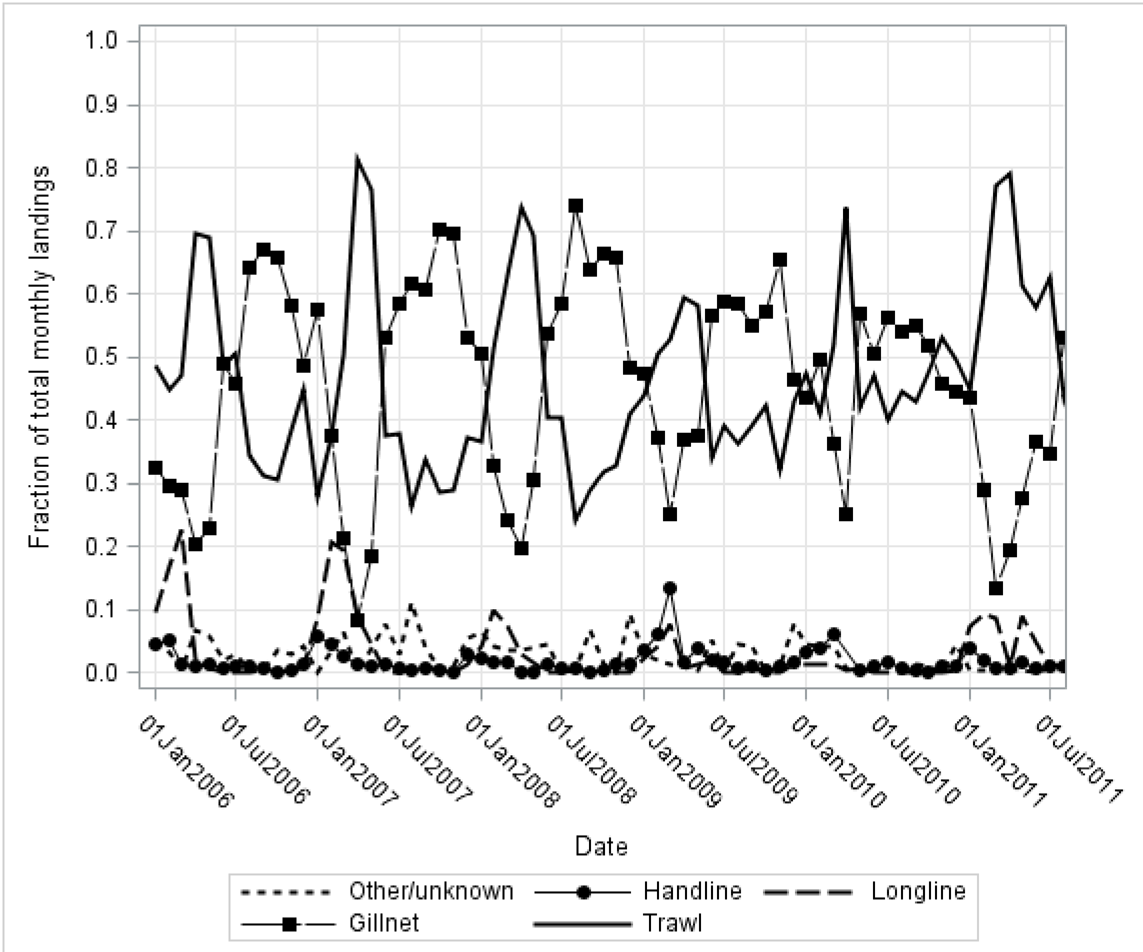


Figure A.26. Monthly commercial landings patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by gear from 2006 to 2011.

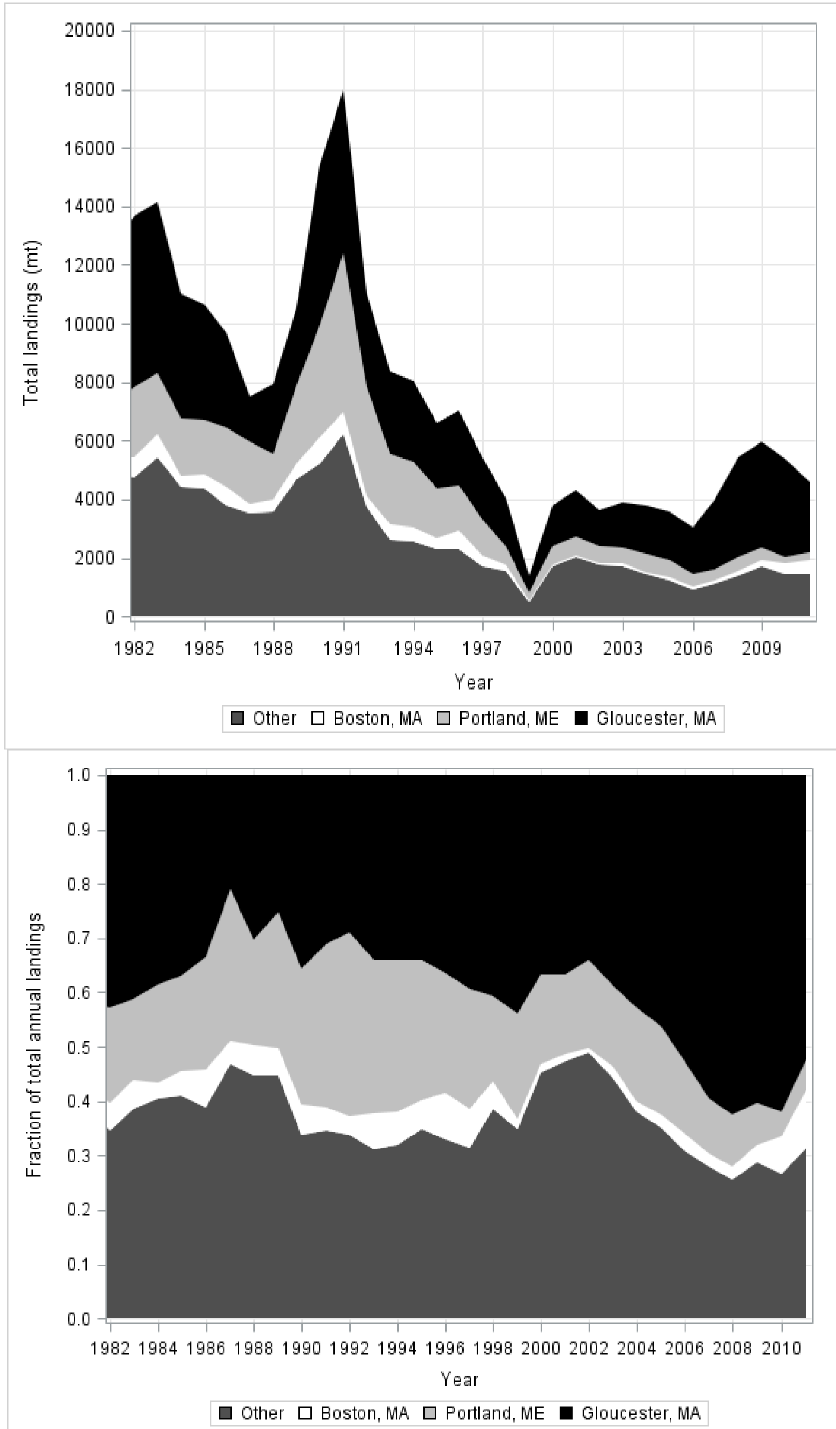


Figure A.27. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by port from 1982 to 2011.

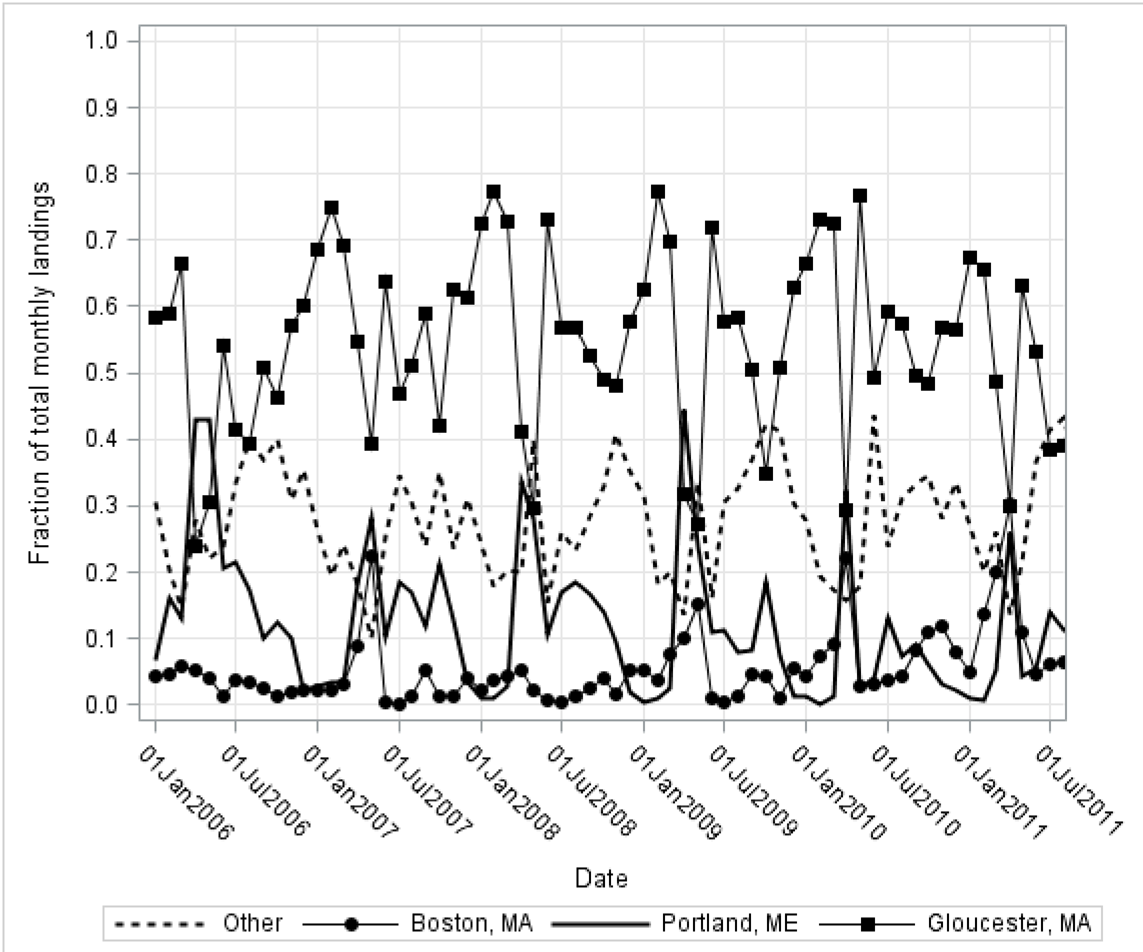
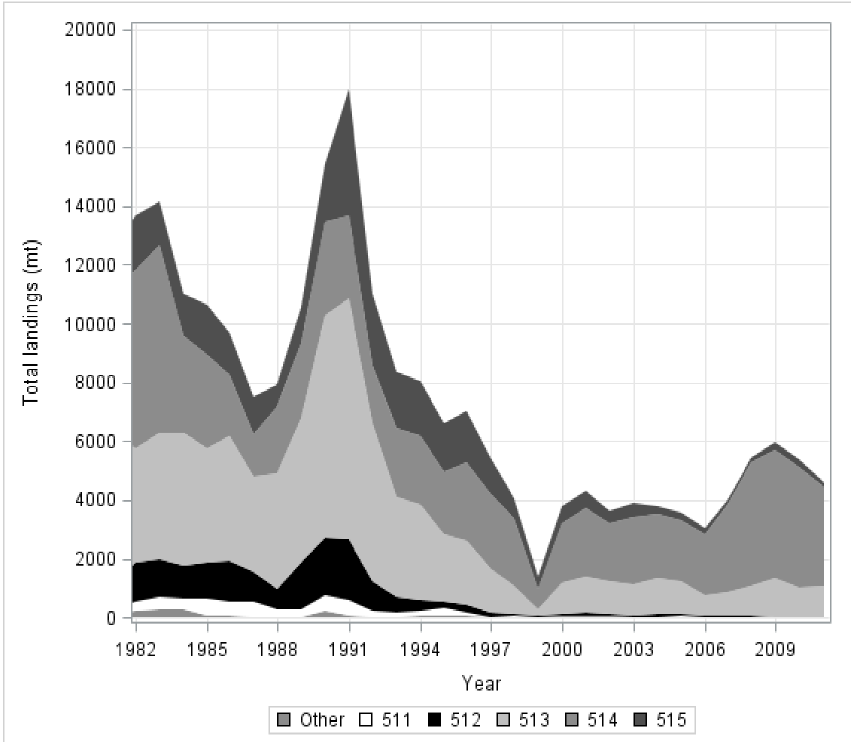


Figure A.28. Monthly commercial landings patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by port from 2006 to 2011.



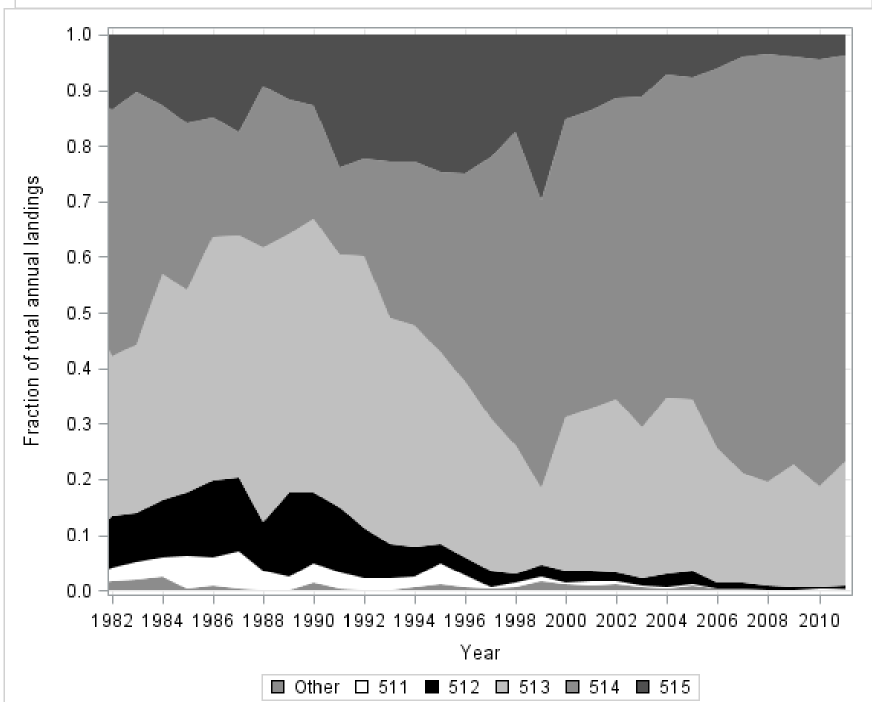


Figure A.29. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by statistical area from 1982 to 2011.

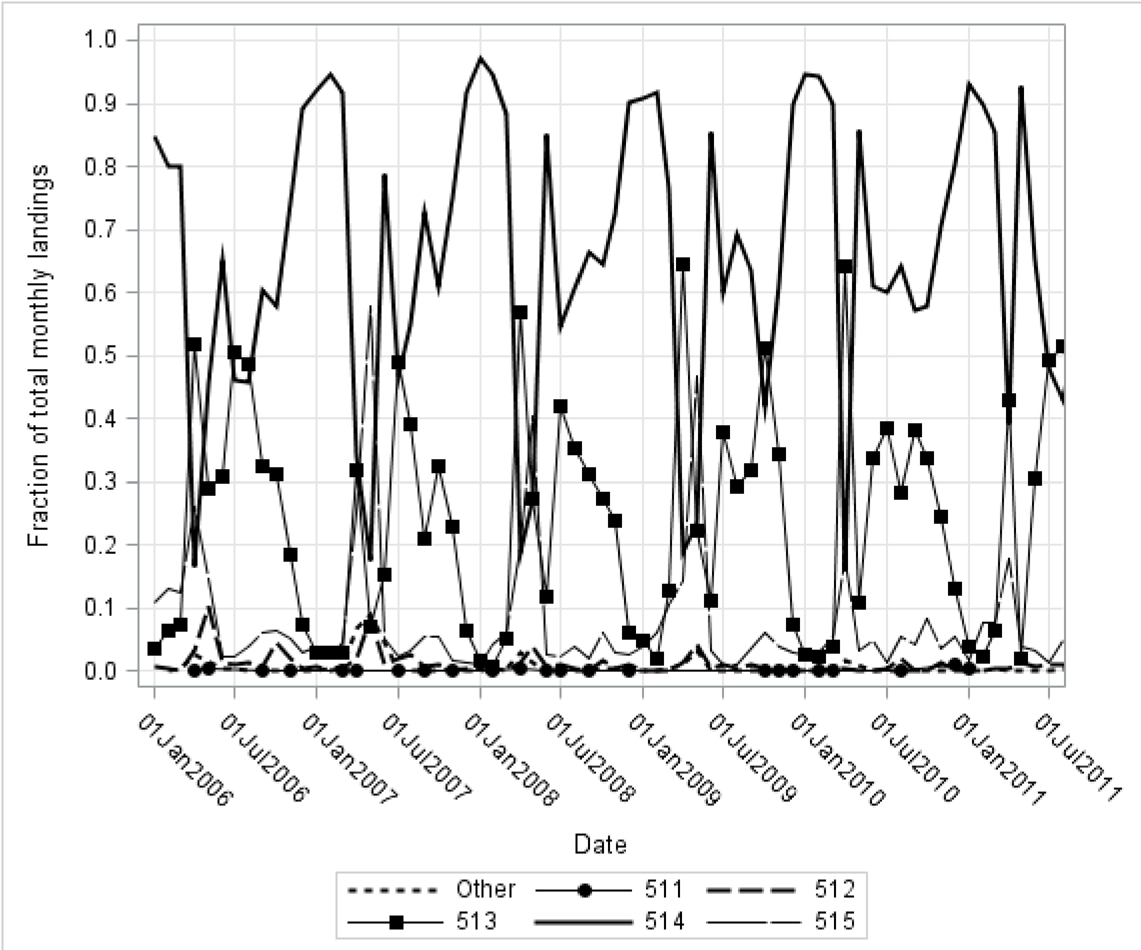


Figure A.30. Monthly commercial landings patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by statistical area from 2006 to 2011.

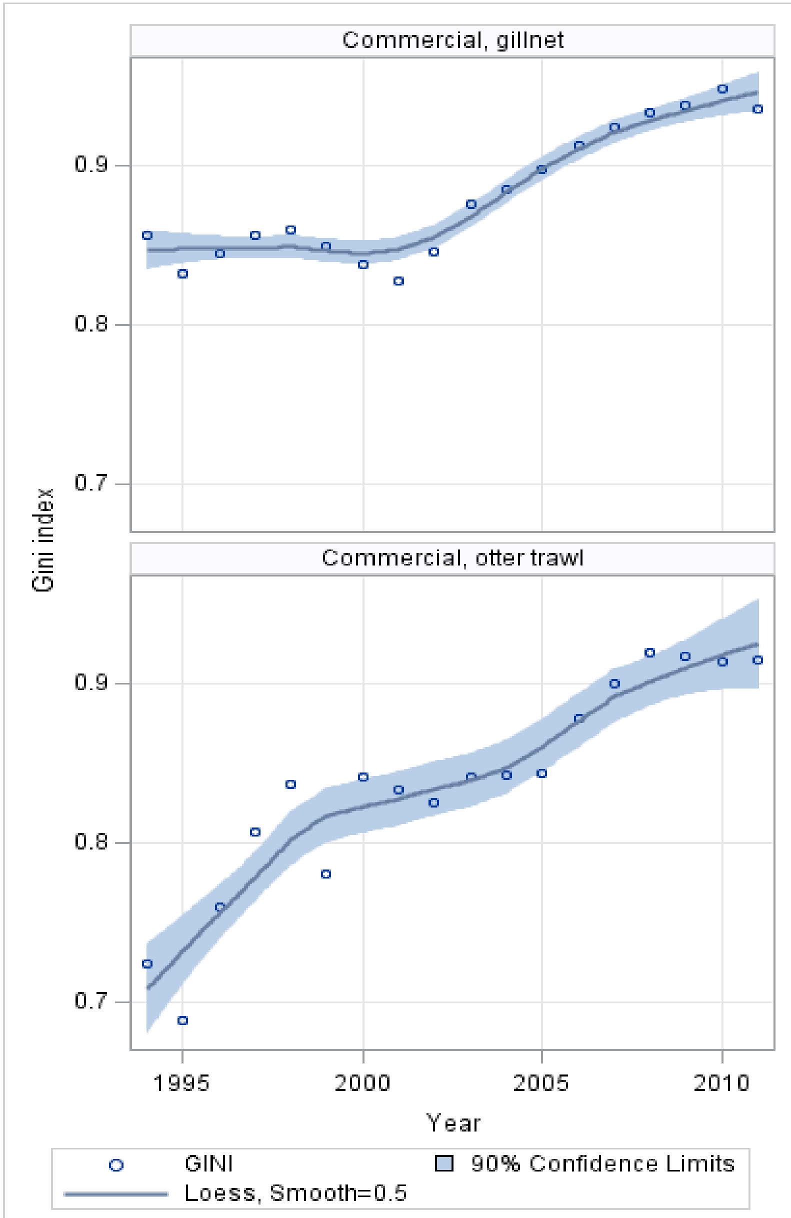


Figure A.31. Gini indices for the commercial otter trawl (050) and sink gillnet (100) fleets from 1994-2011. Indices were based on the spatial distribution of the retained catch reported on vessel trip reports.

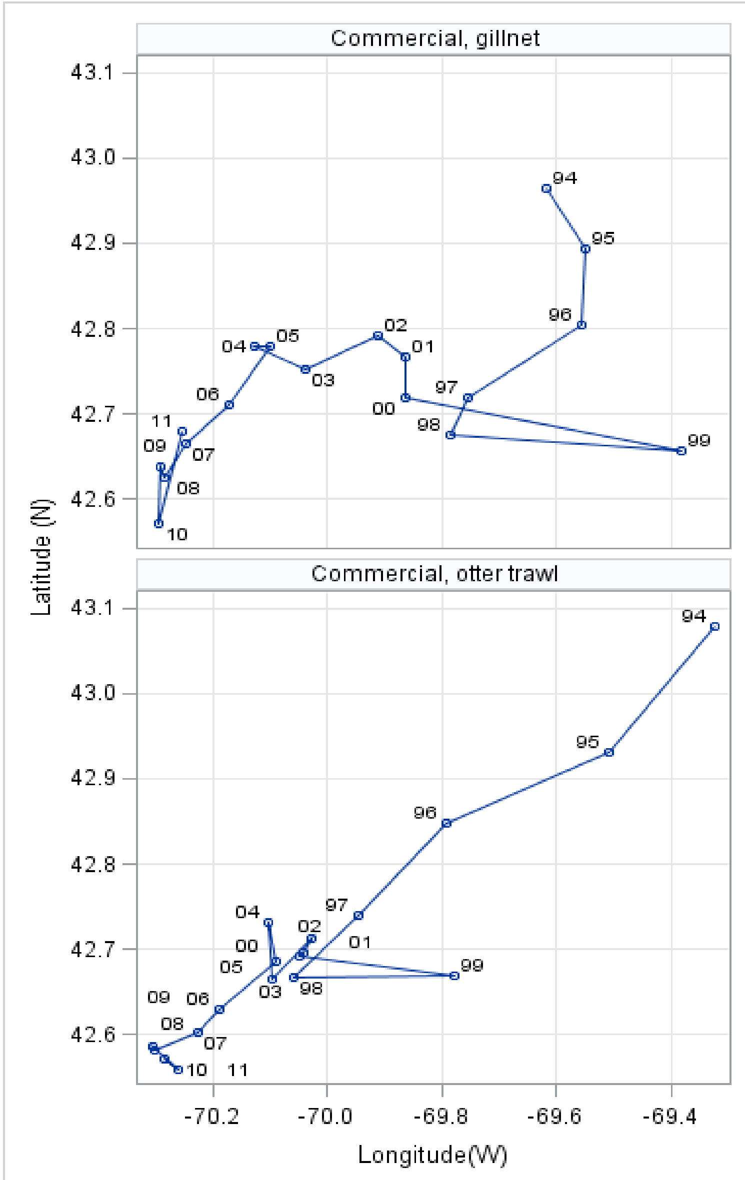


Figure A.32. Landings-weighted mean location (centroid) of Gulf of Maine cod catch by the commercial gillnet (GNS) and otter trawl (OTF) fleets from 1994 to 2011. Centroids were based on the spatial distribution of the retained catch reported on vessel trip reports.

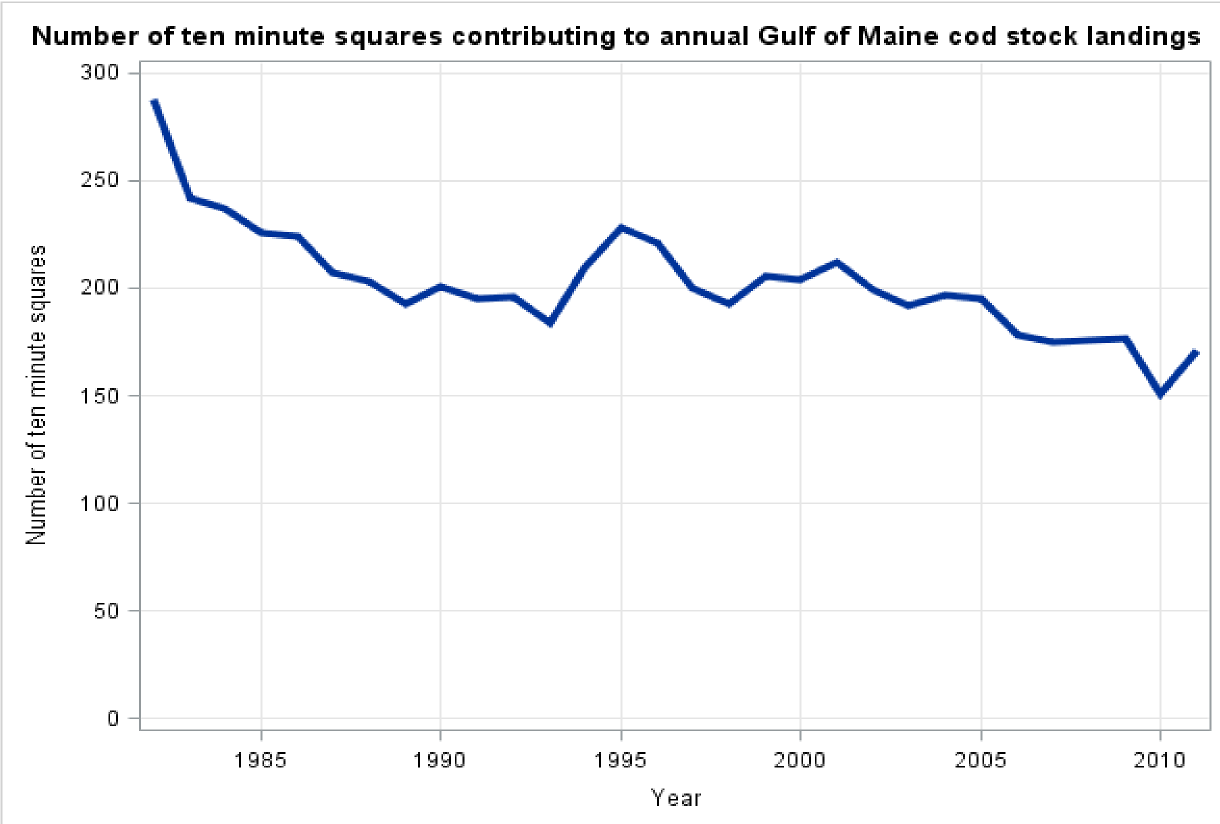


Figure A.33. Number of ten minute squares contributing to the annual landings of Gulf of Maine Atlantic cod between 1982 and 2011.

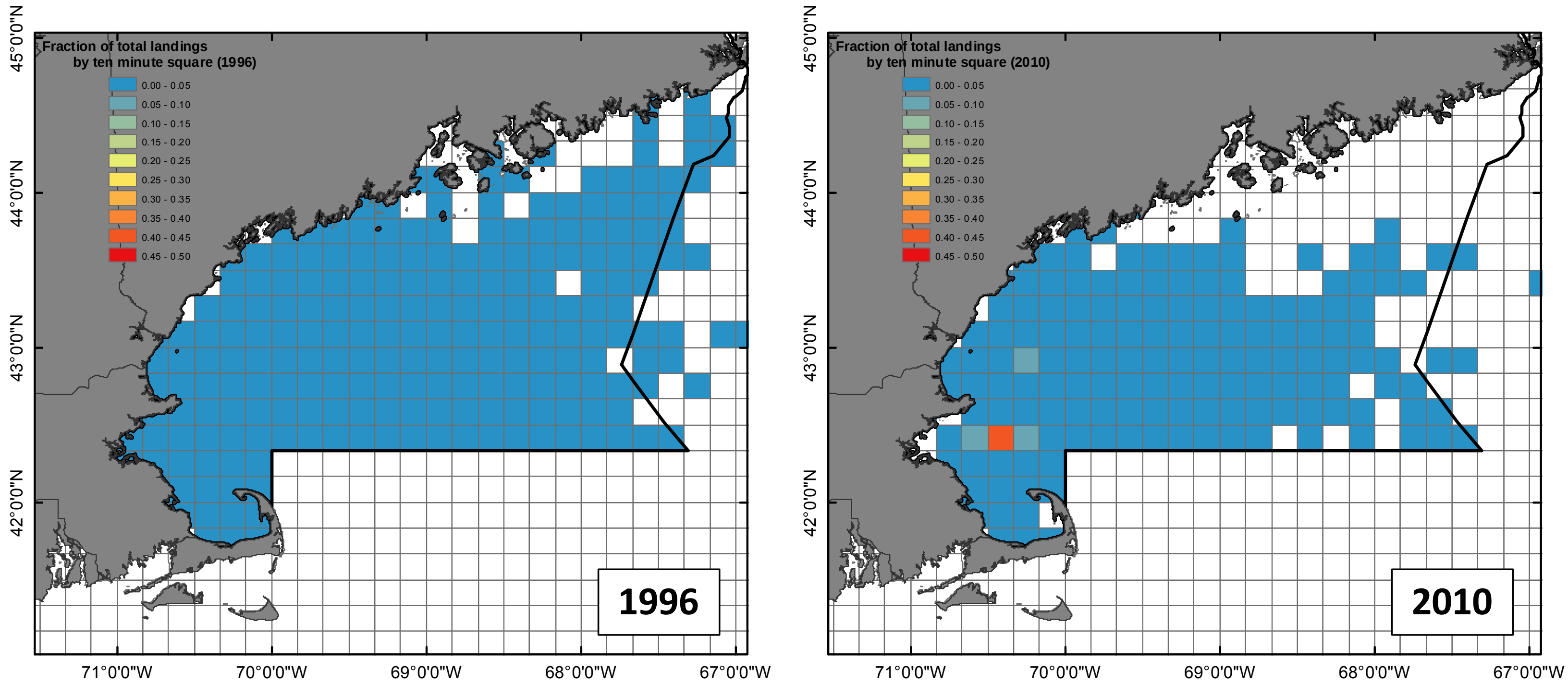


Figure A.34. Comparison of the fraction of annual landings per ten minute square in 1996 (left) to the distribution in 2010 (right).

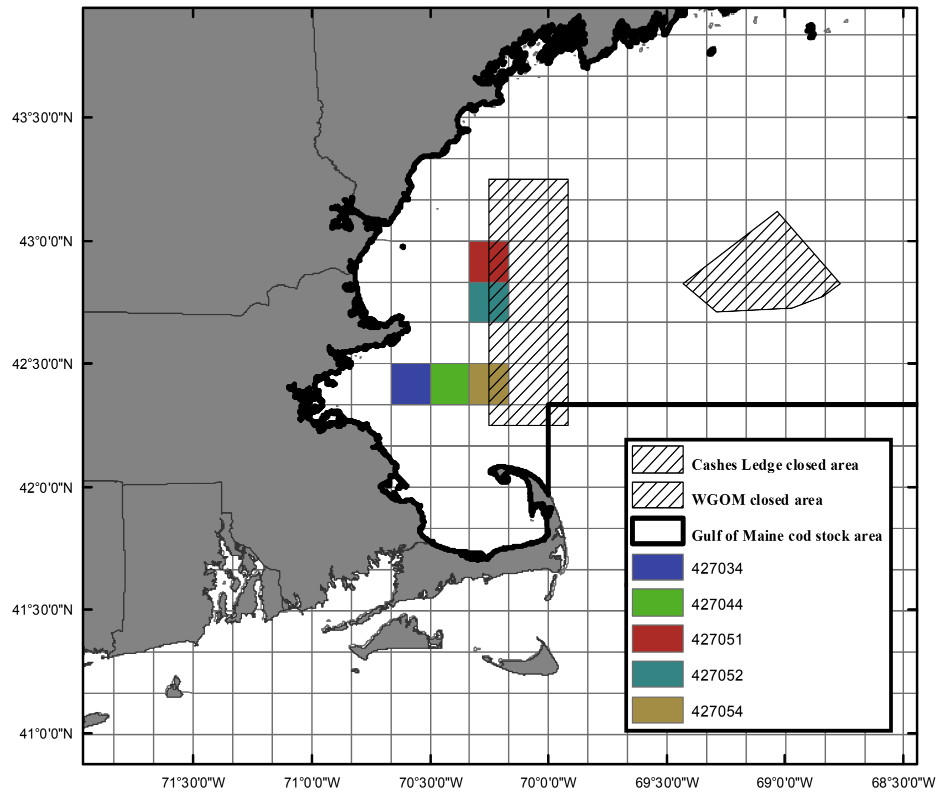


Figure A.35. Location of the top 5 ten minute squares with respect to the fraction of annual commercial landings of Gulf of Maine Atlantic cod between 1994 and 2011.

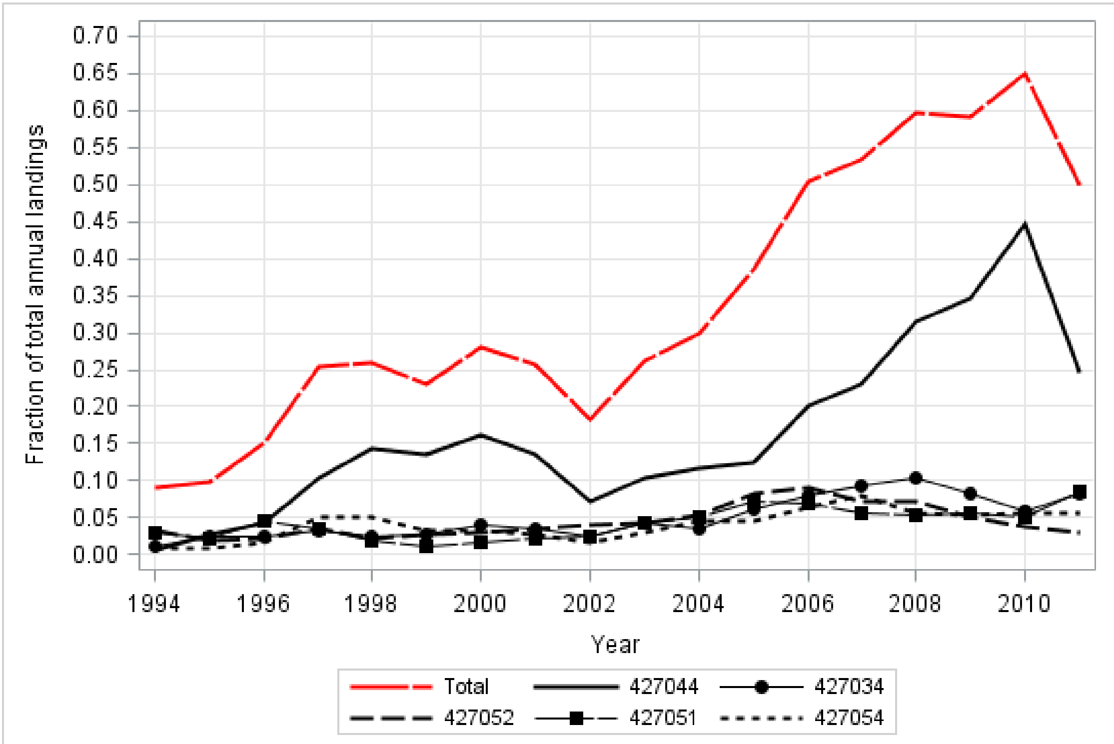


Figure A.36. Contribution of the top 5 ten minute squares to the annual commercial landings of Gulf of Maine Atlantic cod between 1994 and 2011.

Figure A.37. Fraction of the total annual Gulf of Maine cod commercial gillnet and otter trawl landings from ten minute square 427044. Fractional landings have been calculated using three data sources: vessel trip reports (VTR), vessel monitoring data (VMS), and data collected by at-sea observers (Observers). Not all data sources are available for all years.

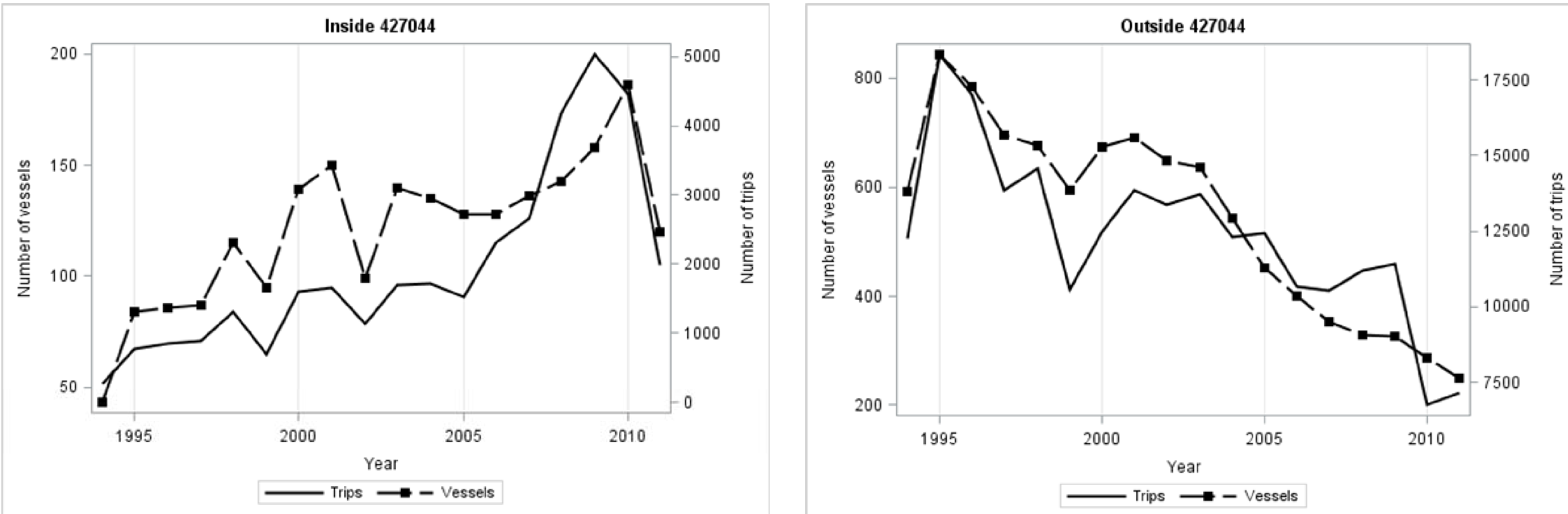


Figure A.38. Number of vessels and trips landing Gulf of Maine cod both inside (top) and outside (bottom) ten minute square 427044 between 1994 and 2011.

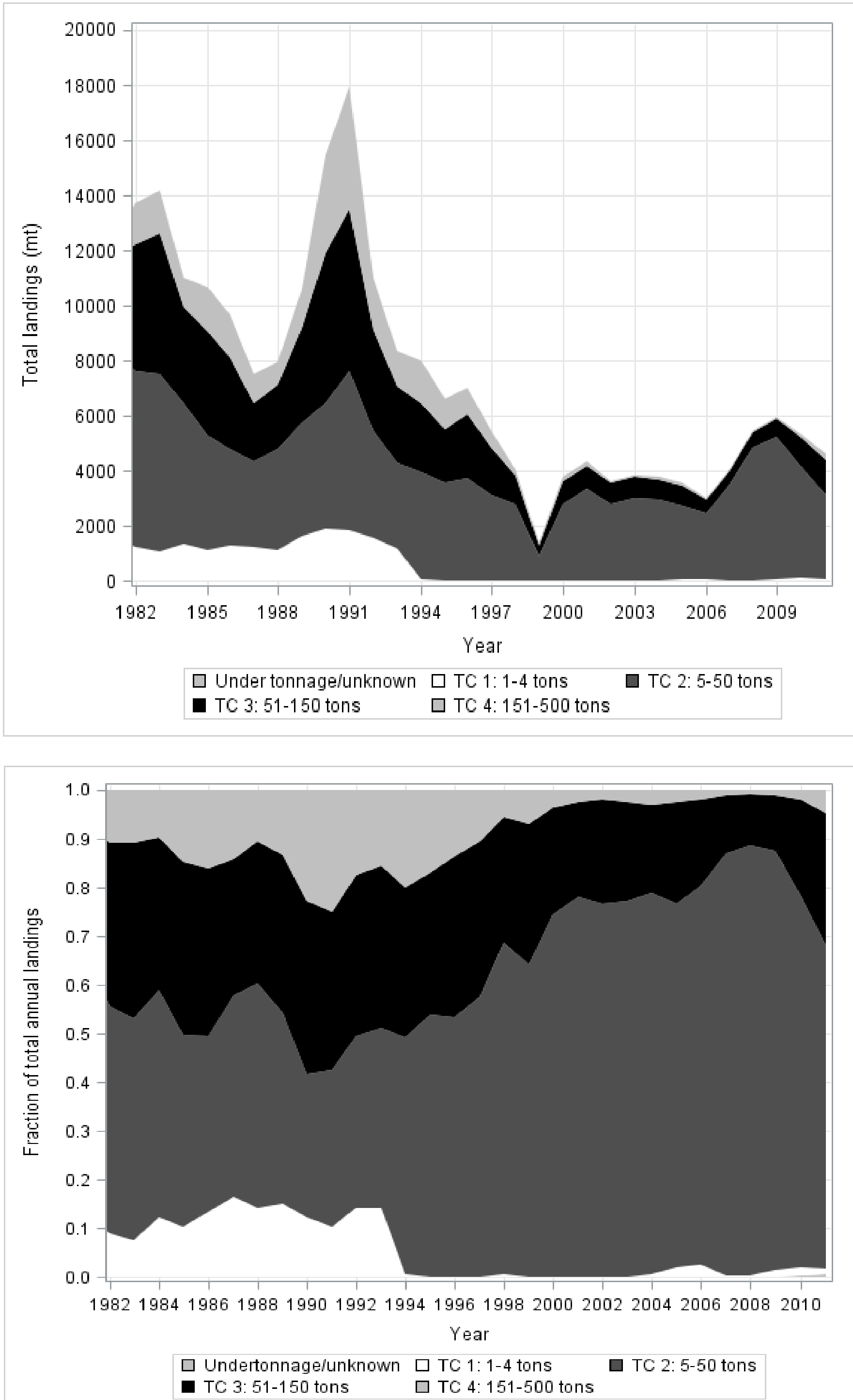


Figure A.39. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by vessel ton class from 1982 to 2011.

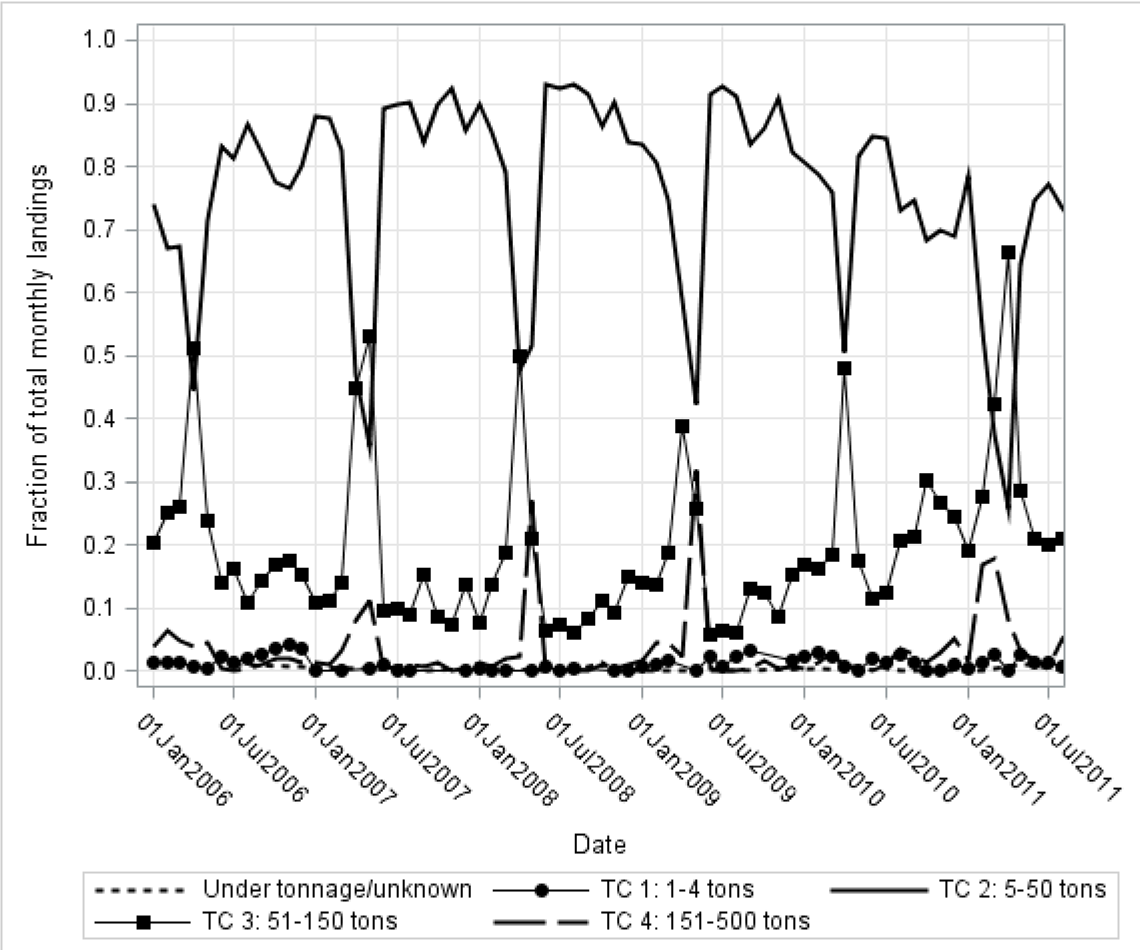


Figure A.40. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by ton class from 2006 to 2011.

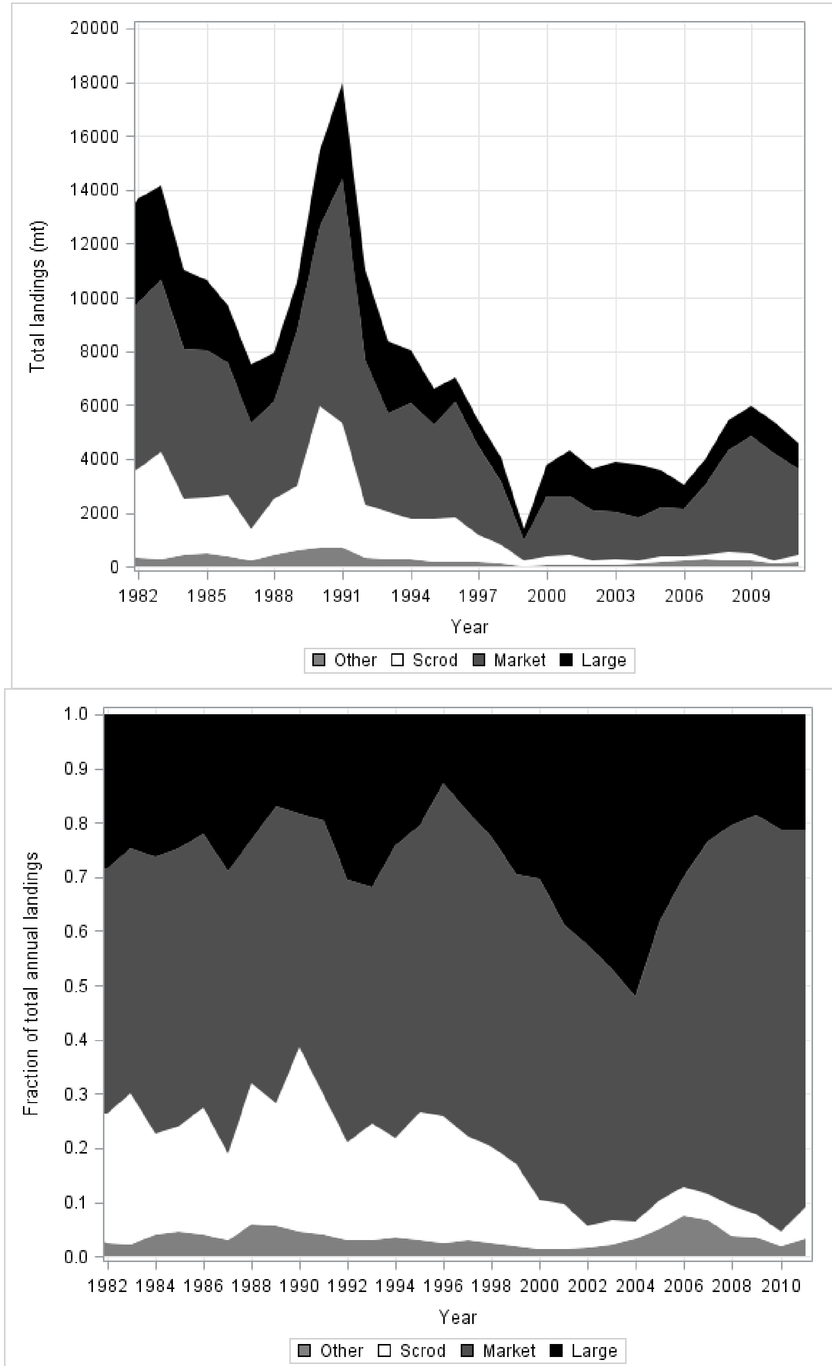


Figure A.41. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by market category from 1982 to 2011.

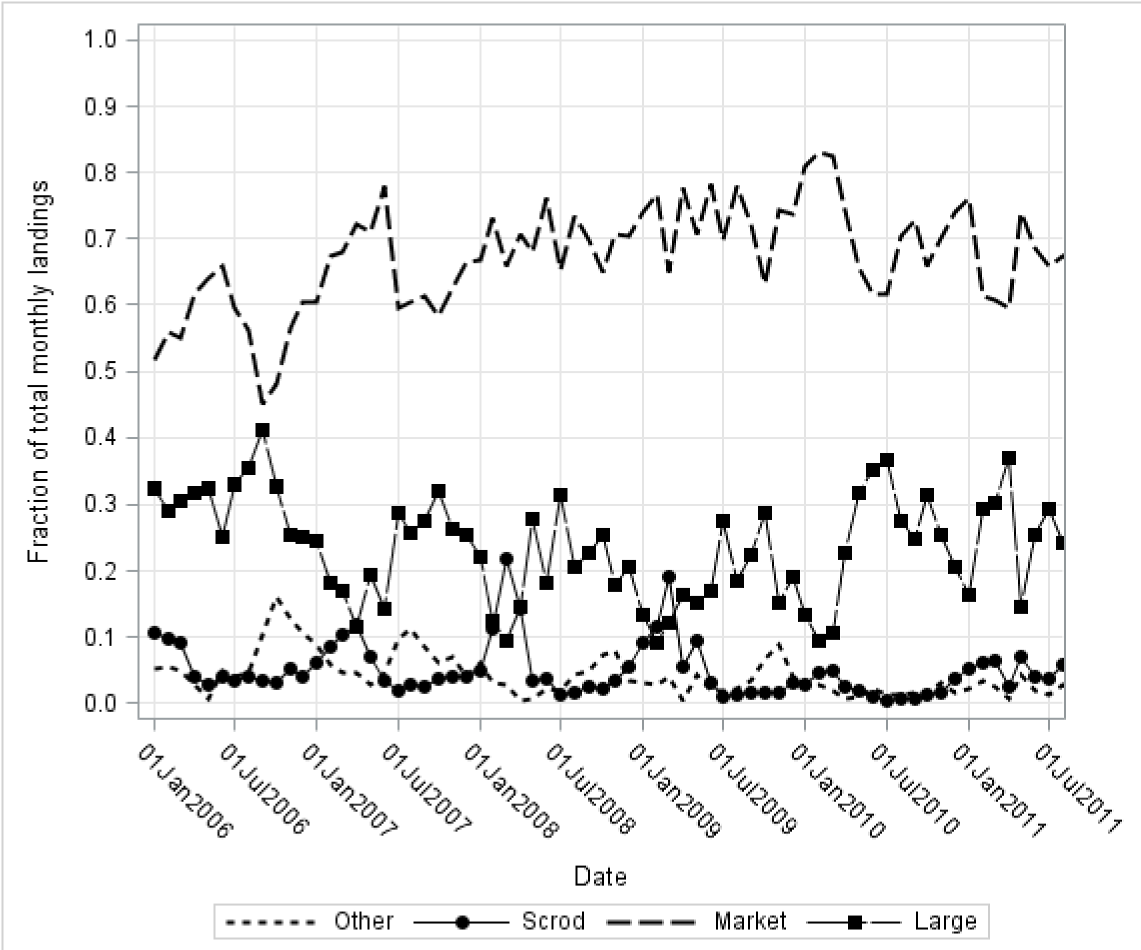


Figure A.42. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by market category from 2006 to 2011.

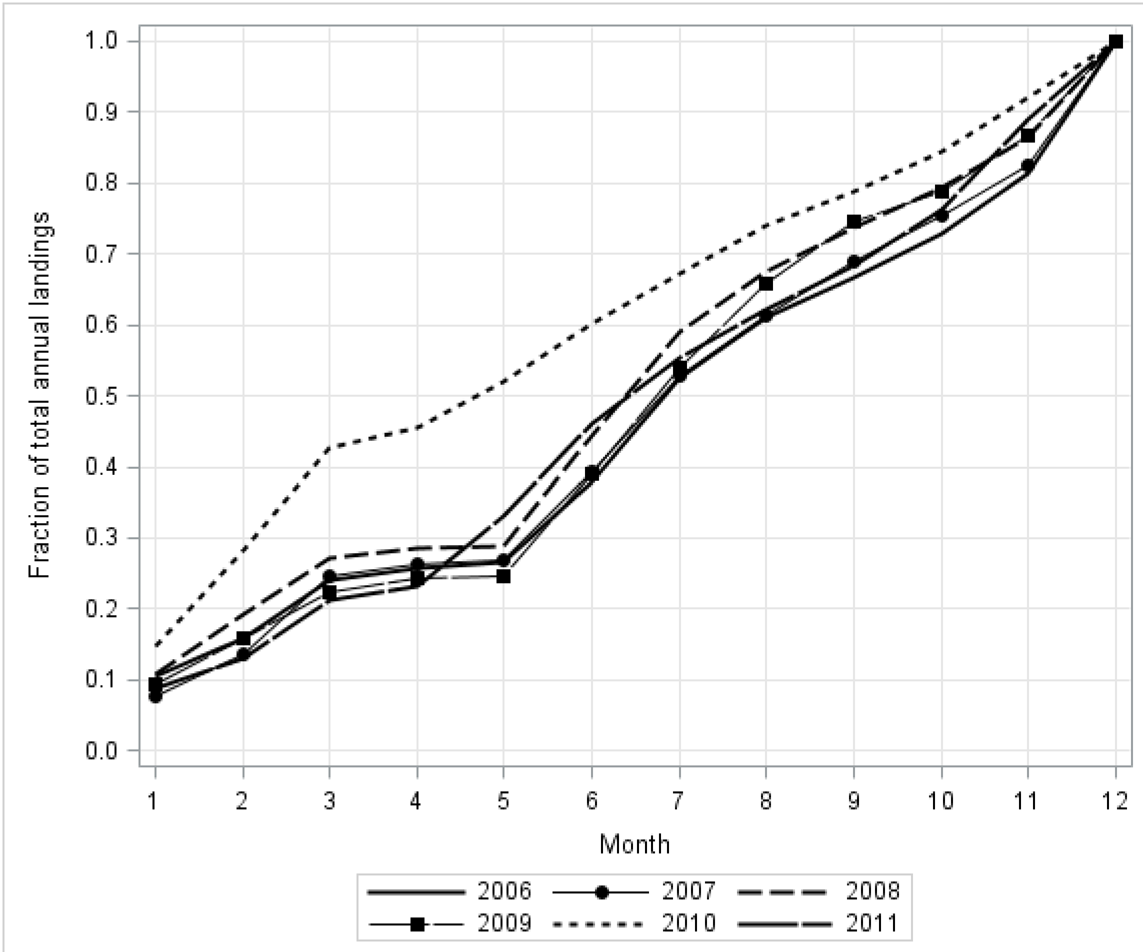


Figure A.43. Cumulative monthly commercial landings of Gulf of Maine Atlantic cod by year from 2006 to 2011.

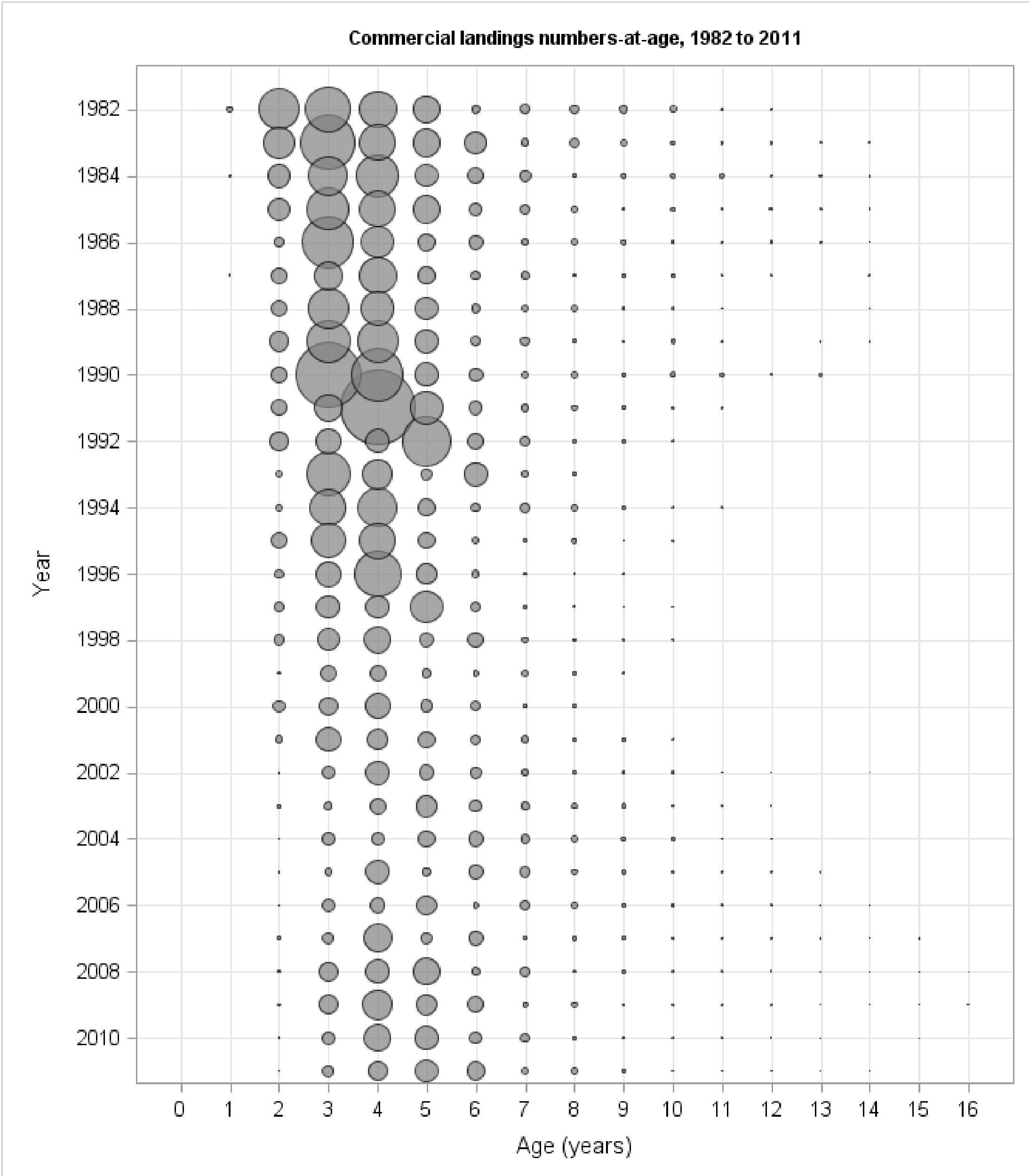


Figure A.44. Commercial landings-at-age of Gulf of Maine Atlantic cod from 1982 to 2011.

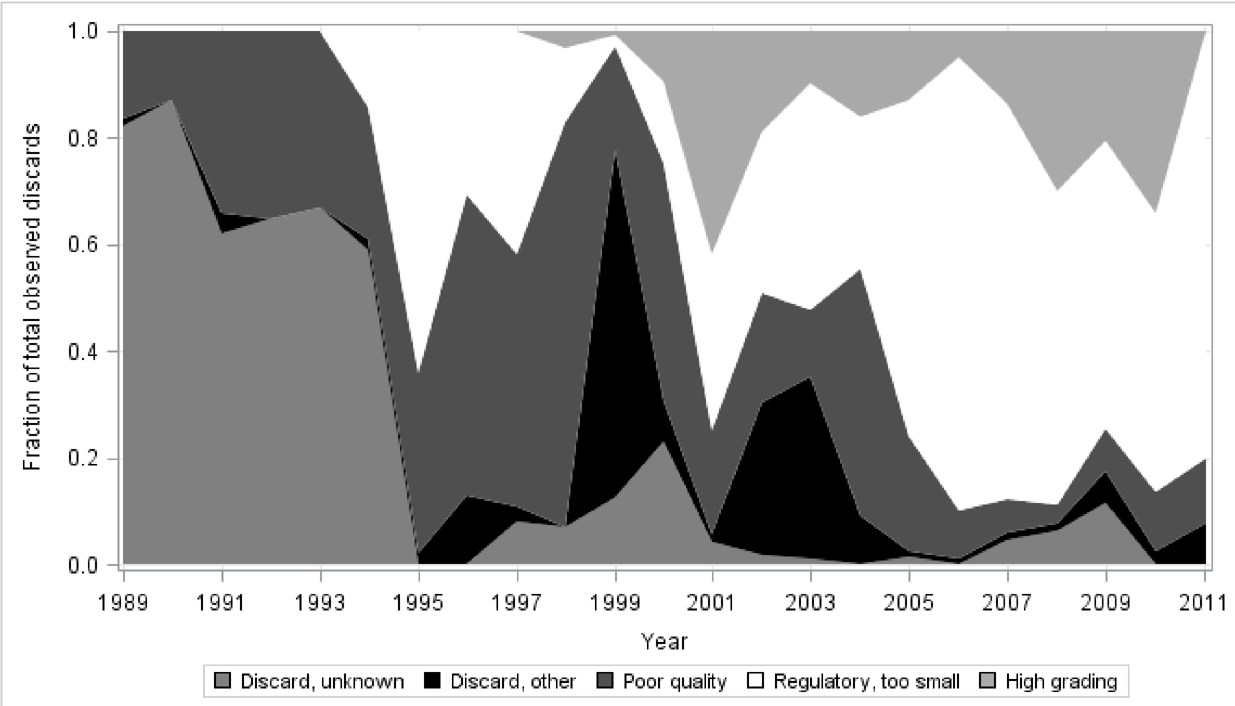


Figure A.45. Discard reasons for Gulf of Maine Atlantic cod as recorded by fisheries observers between 1989 and 2011.

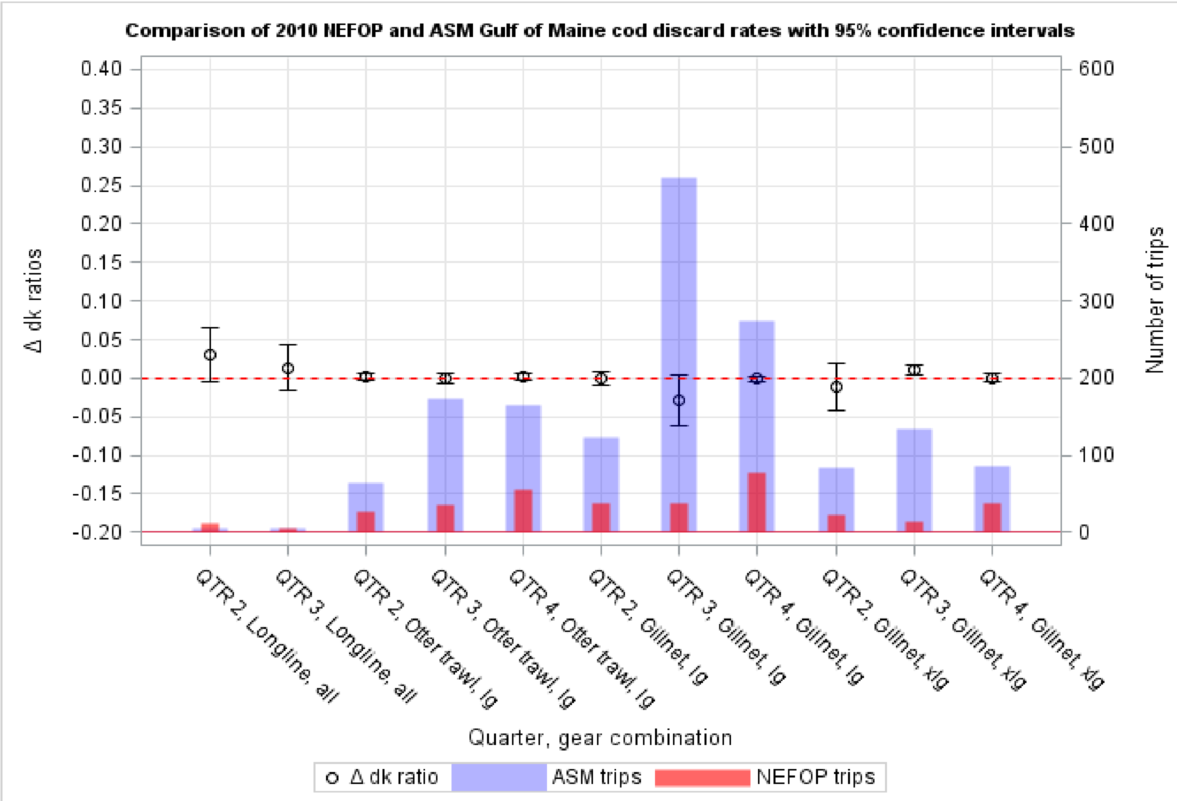


Figure A.46. Differences between the 2010 Gulf of Maine Atlantic cod discard rates estimated from data collected by groundfish at-sea monitors (ASMs) and certified observers showing 95% confidence intervals (top panel) and the number of trips included in each analysis (bottom panel) broken down by gear-mesh combination and quarter (adapted from Wigley et al. 2012).

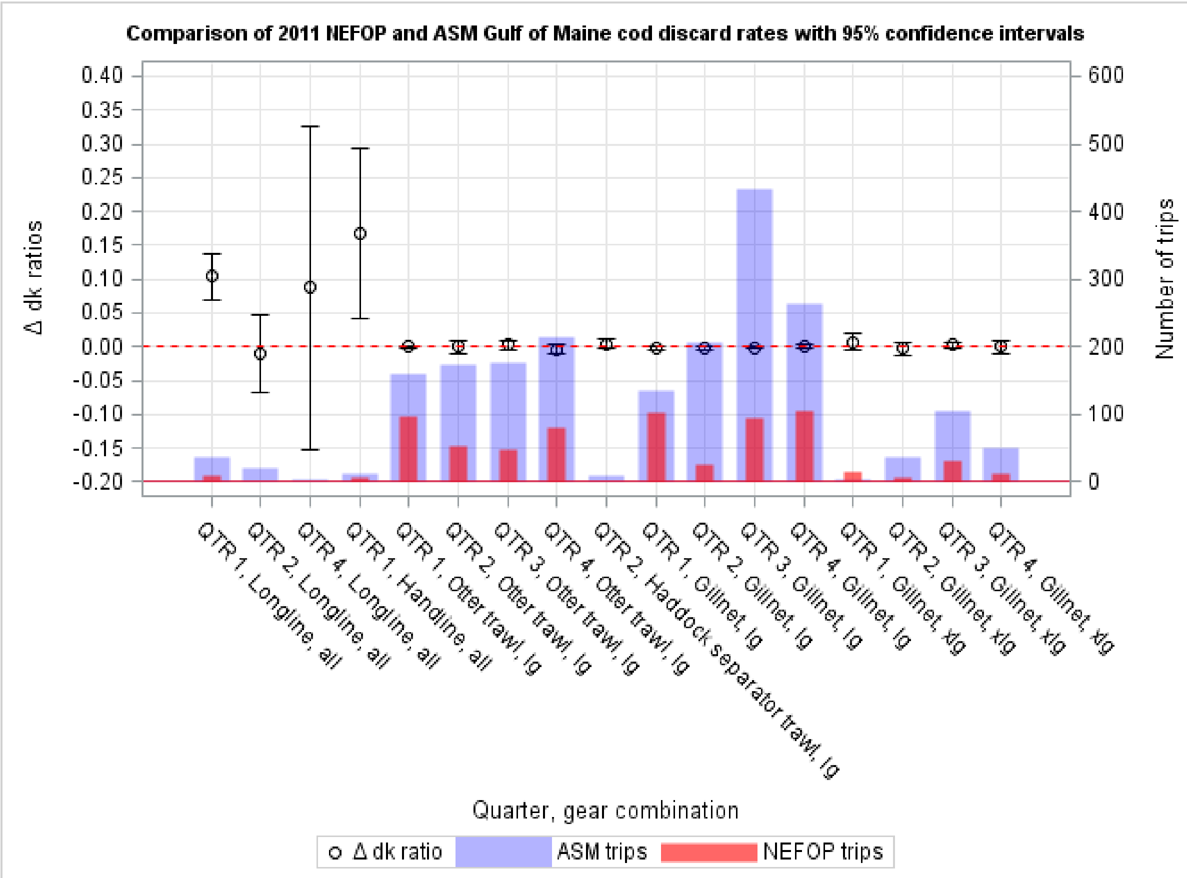


Figure A.47. Differences between the 2011 Gulf of Maine Atlantic cod discard rates estimated from data collected by groundfish at-sea monitors (ASMs) and certified observers showing 95% confidence intervals (top panel) and the number of trips included in each analysis (bottom panel) broken down by gear-mesh combination and quarter (adapted from Wigley et al. 2012).

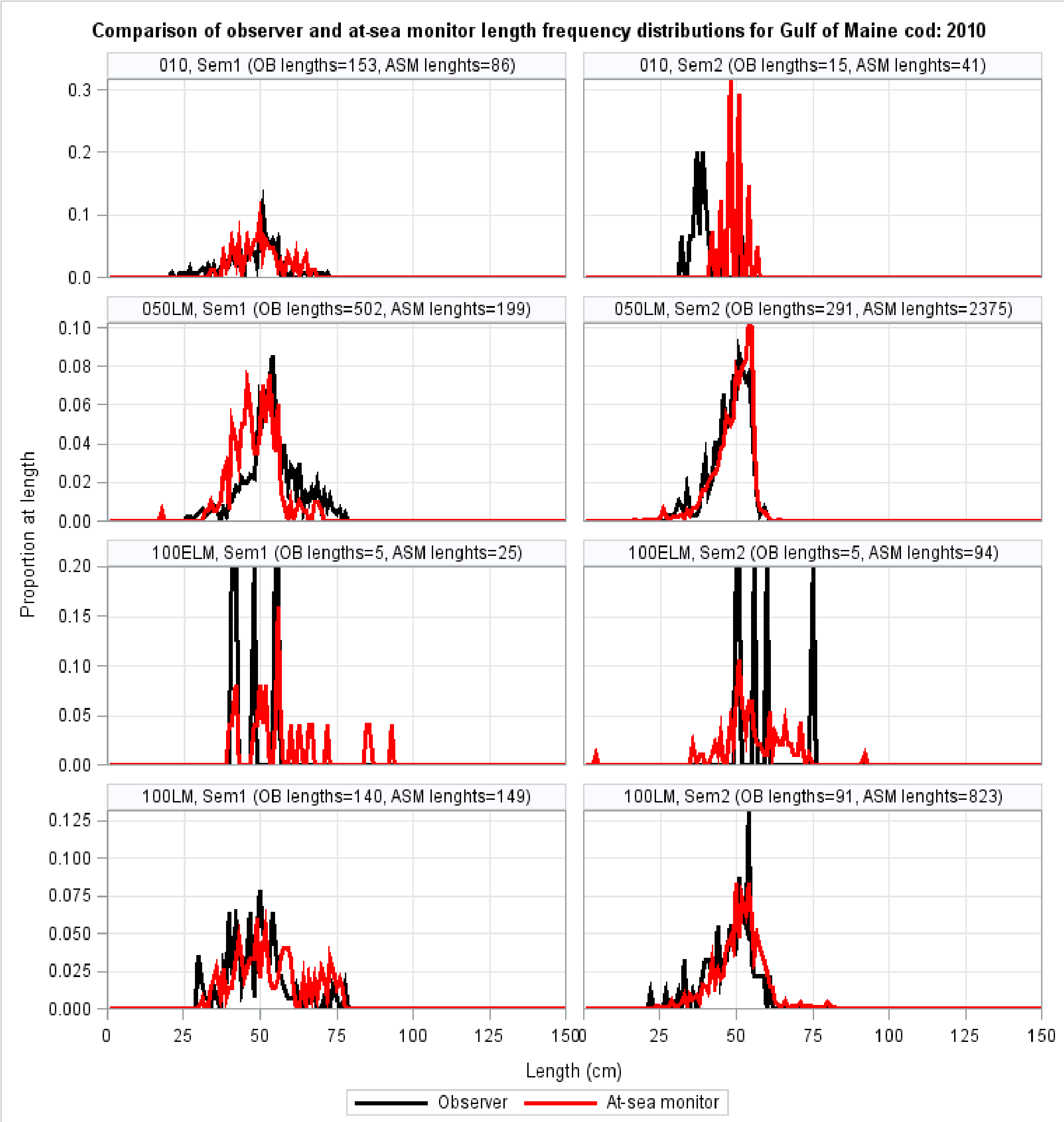


Figure A.48. Length frequency distributions of Gulf of Maine Atlantic cod commercials discards estimated from data collected by groundfish at-sea monitors (ASMs) and certified observers in 2010.

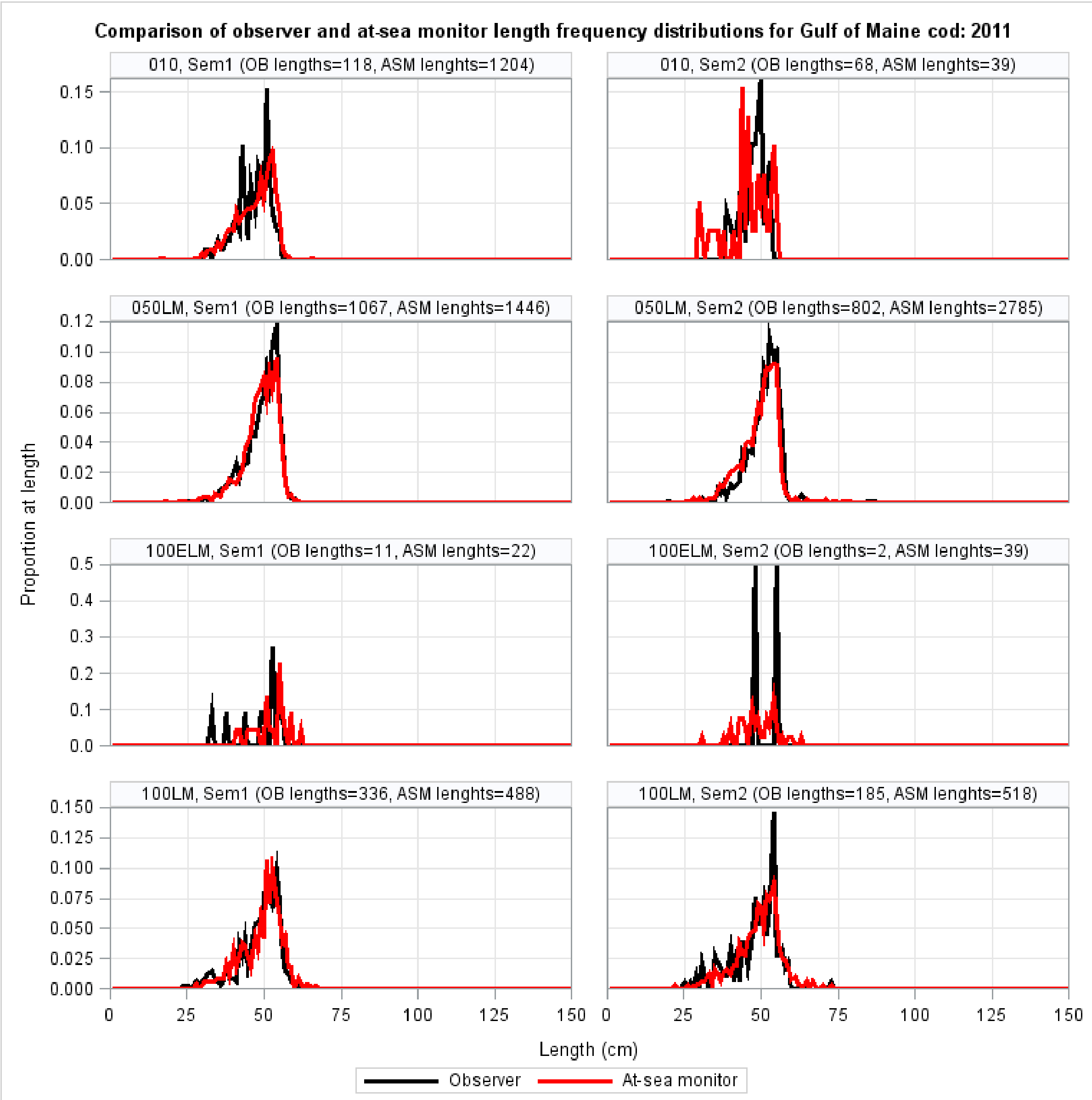


Figure A.49. Length frequency distributions of Gulf of Maine Atlantic cod commercials discards estimated from data collected by groundfish at-sea monitors (ASMs) and certified observers in 2011.

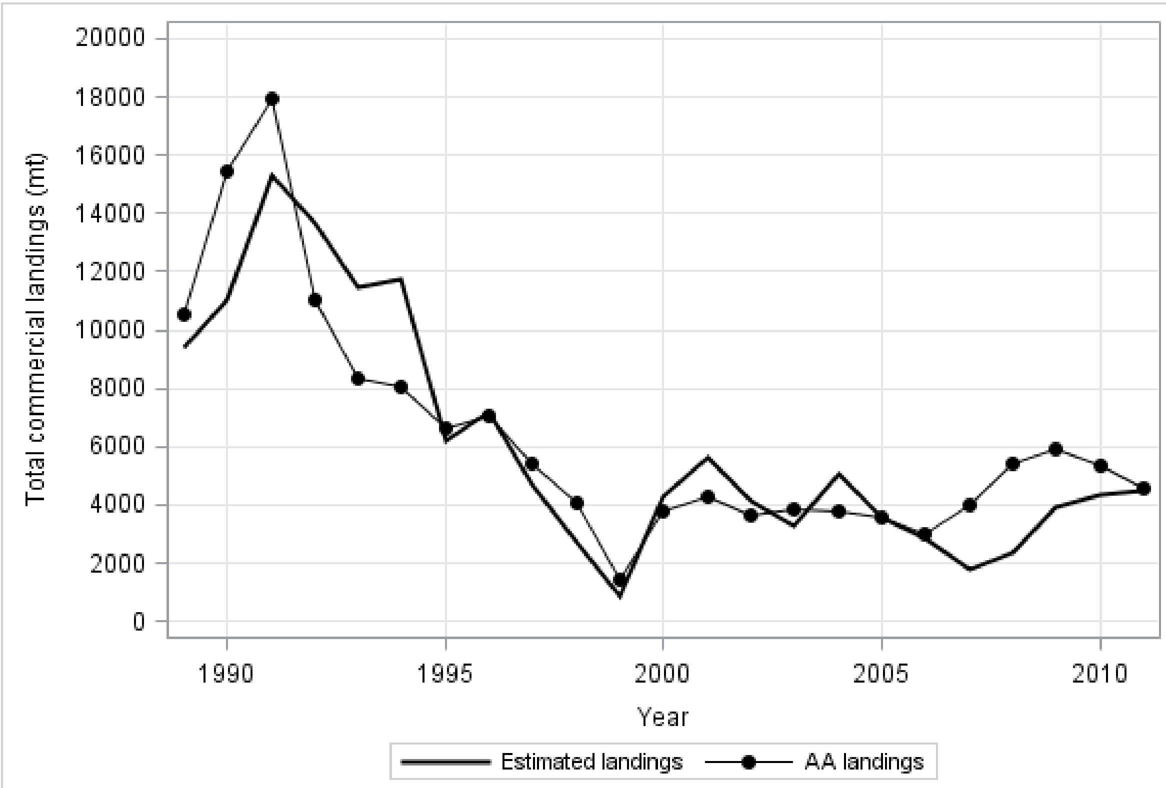


Figure A.50. Comparison of Gulf of Maine Atlantic cod landings estimates generated using the Standardized Bycatch Reporting Methodology (SBRM, Wigley et al. 2007) combined ratio approach to the stock landings from the Commercial Fisheries Database AA tables. Landings are shown only for longline, gillnet and otter trawl gears; all gear types not included in the discard estimation procedure were considered ‘other’ gear types and excluded. The comparison provides a cross validation of both the discard estimation and landings allocation procedure.

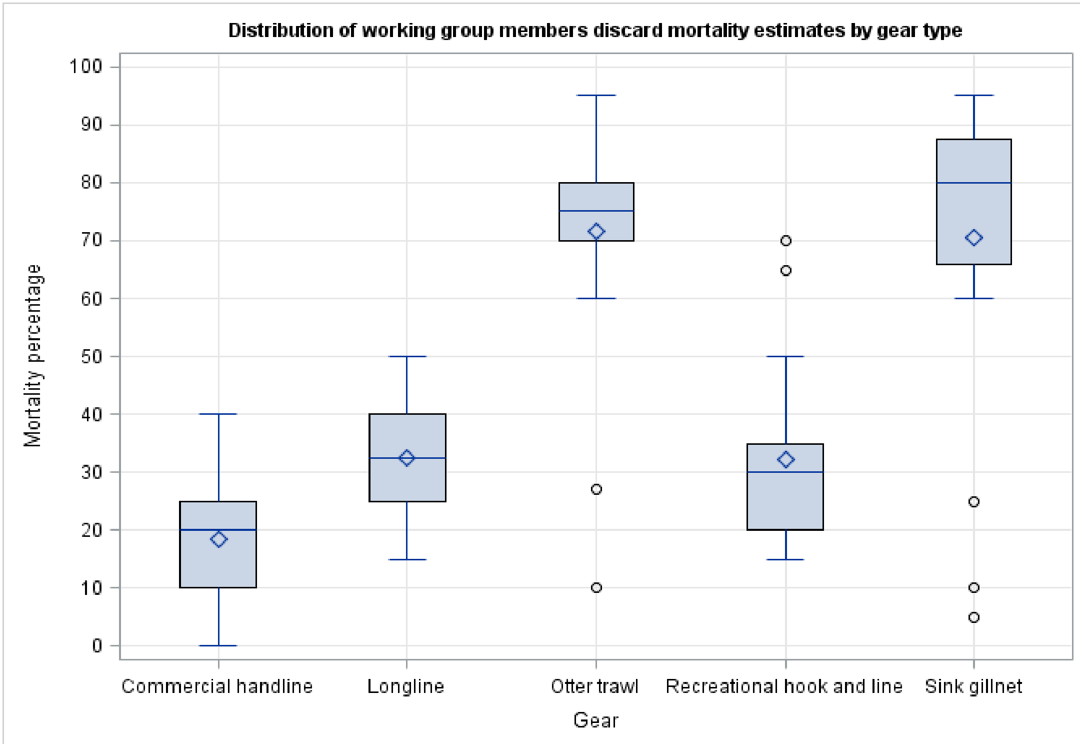


Figure A.51. Box plot distribution of the discard survival estimates by gear type developed by the Discard Mortality Working Group (expressed as percent mortality; NEFSC 2012b). Median estimates (horizontal blue line within the interquartile boxes) were used to adjust discard estimates in the current assessment.

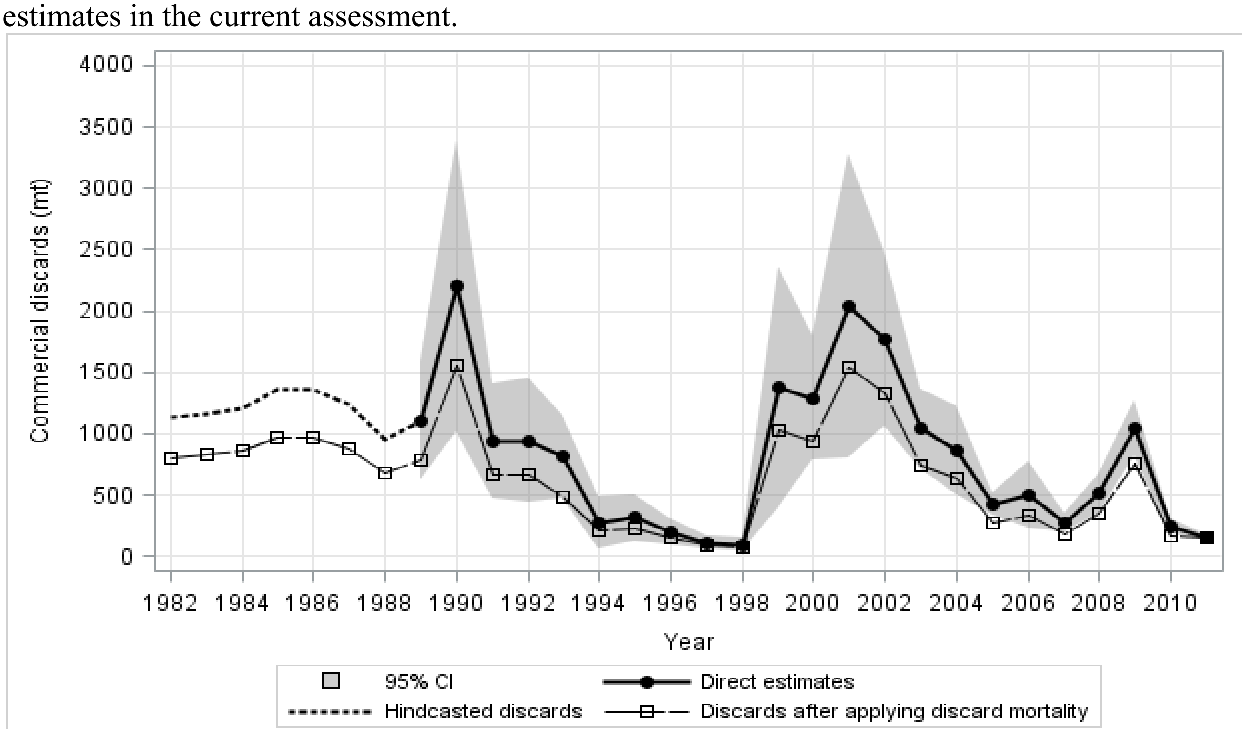


Figure A.52. Impacts of the revised discard mortality estimates on the estimates of commercial discards in terms of biomass (mt).

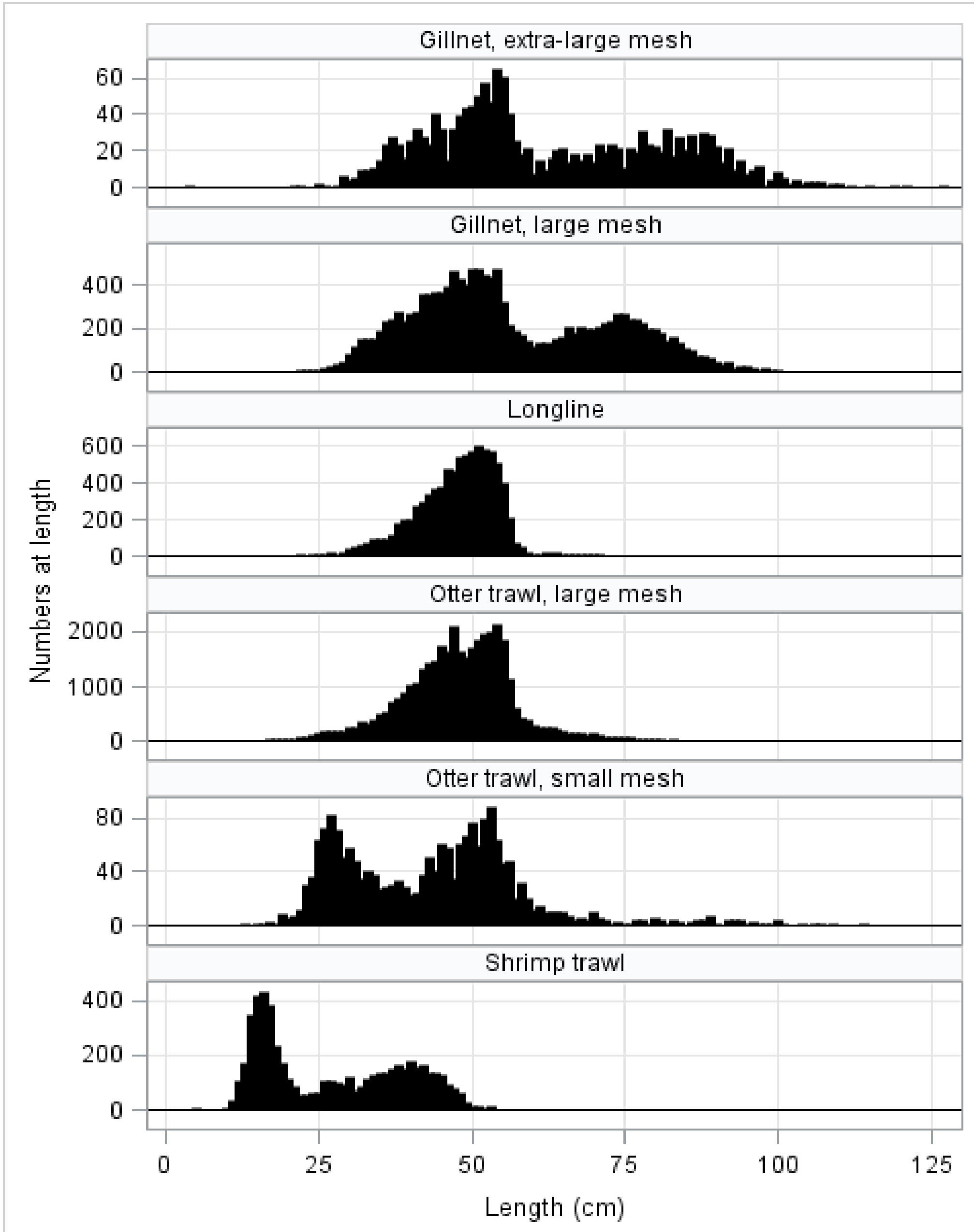


Figure A.53. Aggregate length frequency distributions, by gear type, of Gulf of Maine Atlantic cod discarded in the commercial fishery between 1989 and 2011.

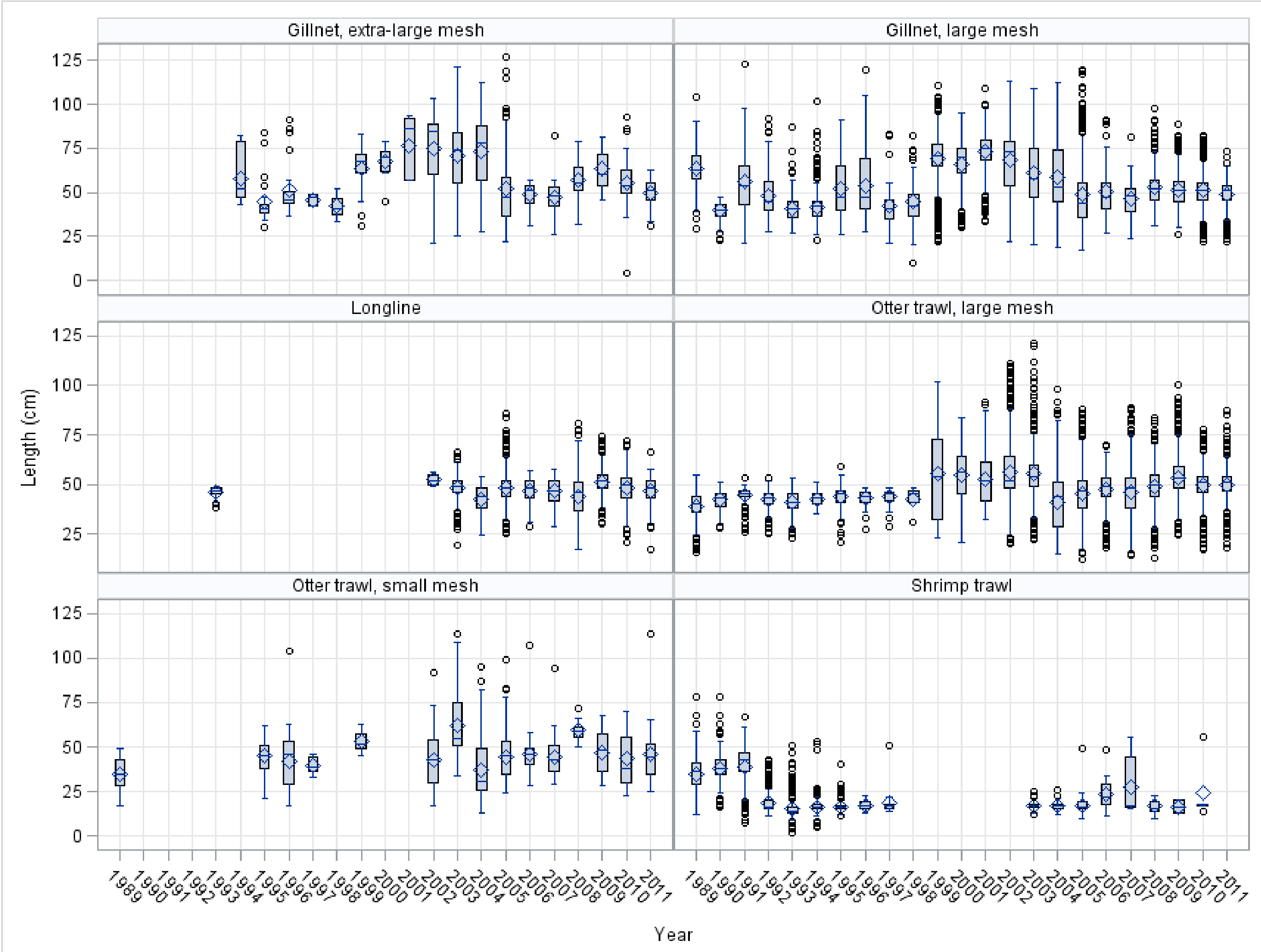


Figure A.54. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by gear type between 1989 and 2011. Missing years indicate that there were either no observed trips for that gear in the Gulf of Maine or no cod were observed to have been discarded.

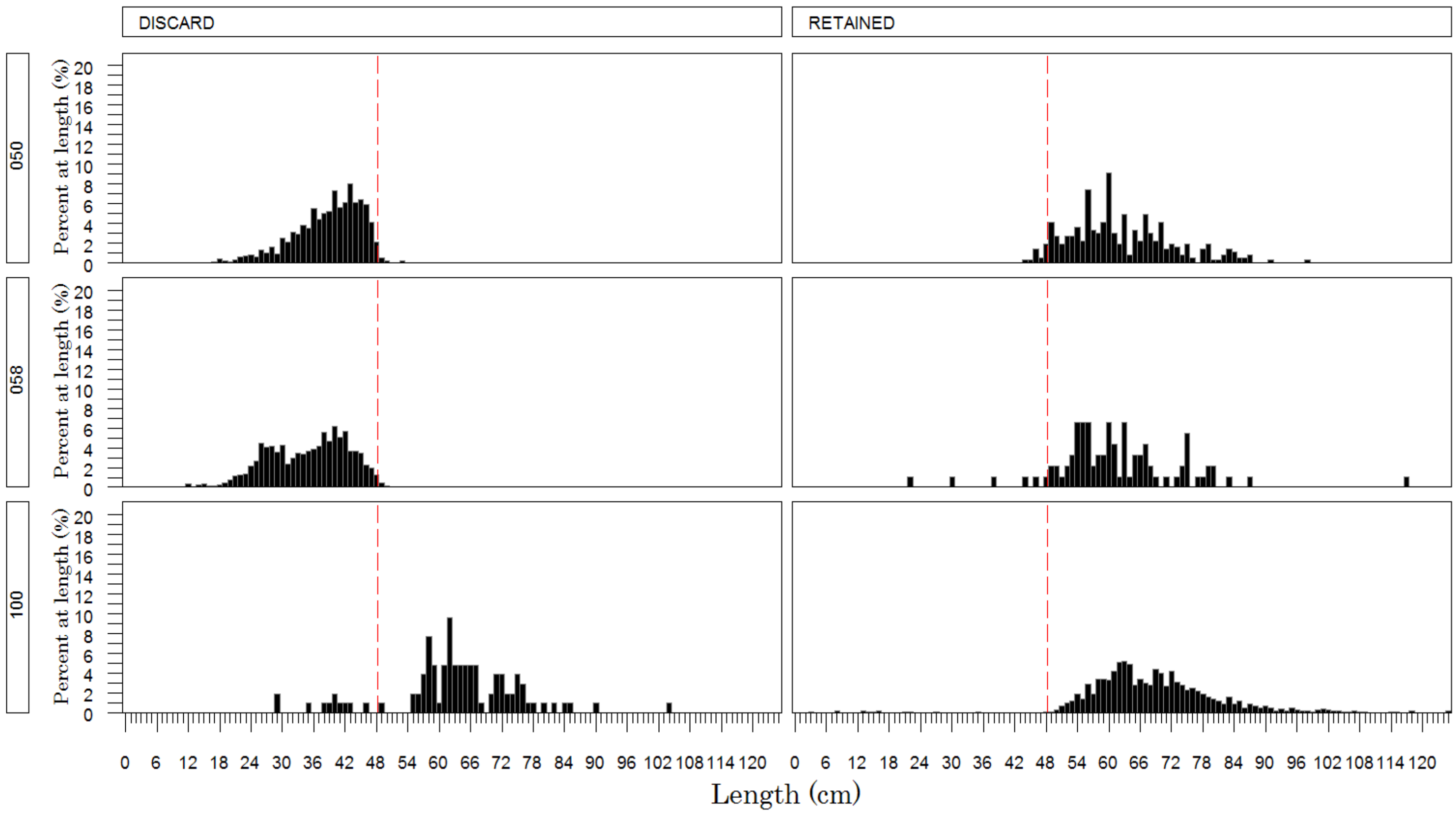


Figure A.55. Example of the length frequency distributions of Gulf of Maine Atlantic cod observed caught in the commercial fishery by large mesh otter trawl (050), shrimp trawl (058) and large mesh sink gillnet (100) gear in 1989. The 1989 – 1996 commercial minimum retention size of 19 inches (48.3 cm) is indicated by a dashed red line.

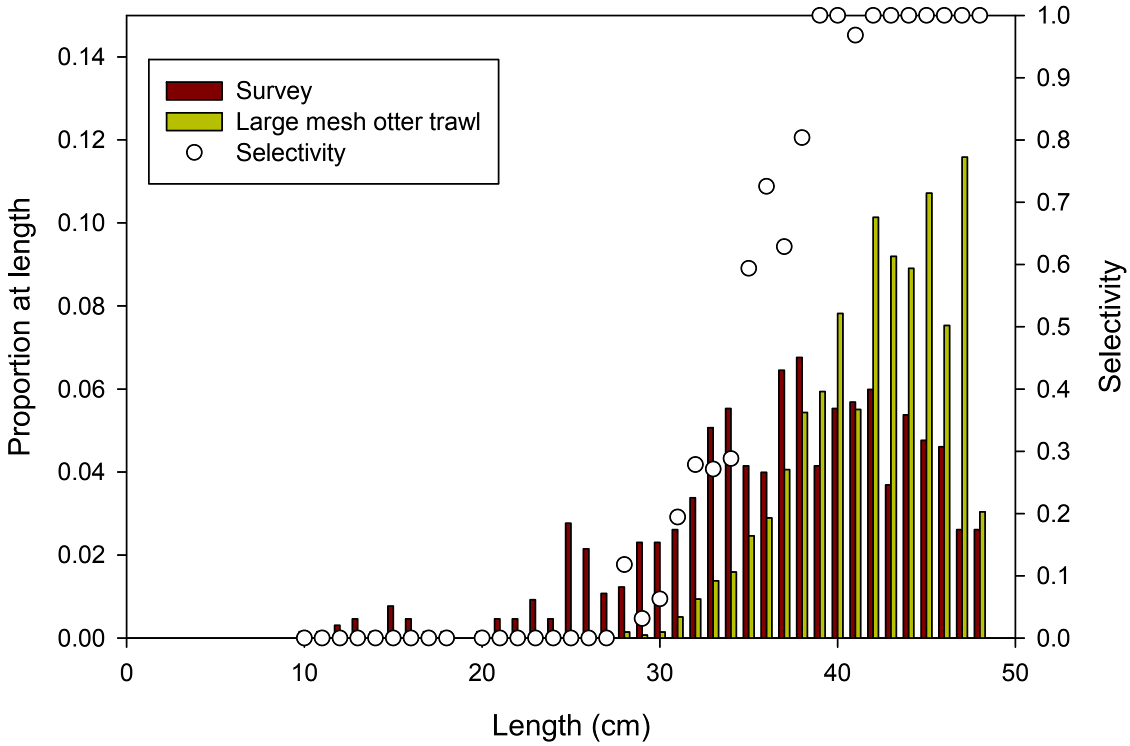


Figure A.56. Example of applying the survey-filter method to estimate the selectivity-at-length of fishing gears for Gulf of Maine Atlantic cod. In this example the proportion caught at length by large mesh otter trawl are compared to the proportion caught at-length from the Northeast Fishery Science Center spring and fall surveys (combined) to estimate the selectivity-at-length of large mesh otter trawl.

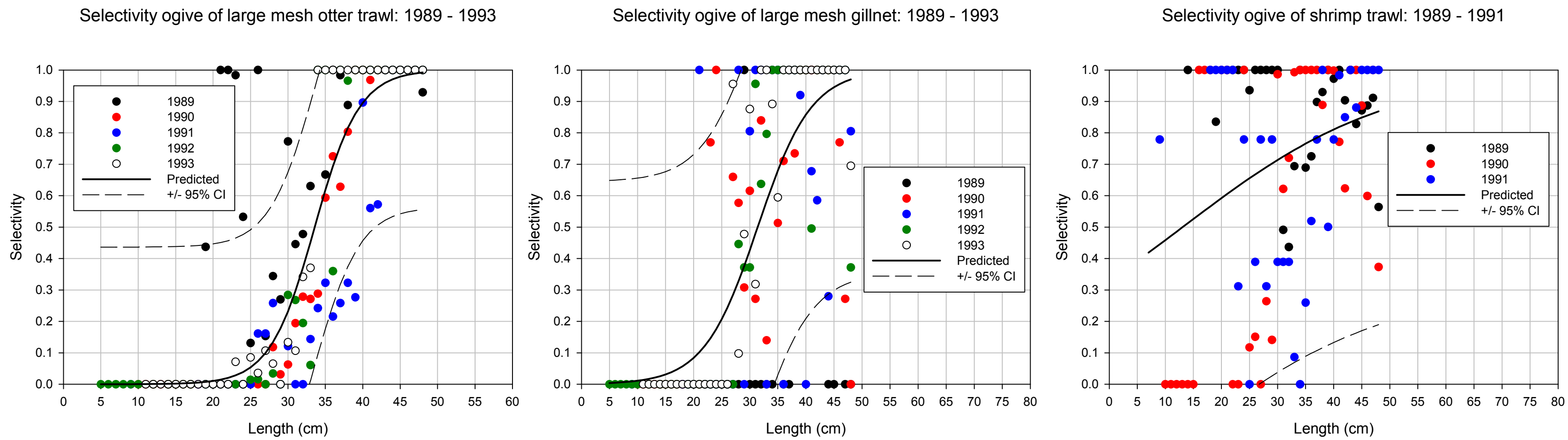


Figure A.57. Estimated selectivity ogives for large mesh otter trawl, large mesh sink gillnet and shrimp trawl and the corresponding 95% confidence intervals (CI) for Gulf of Maine Atlantic cod. Selectivity ogives were estimated from logistic fits to the aggregated annual estimates of selectivity-at-length.

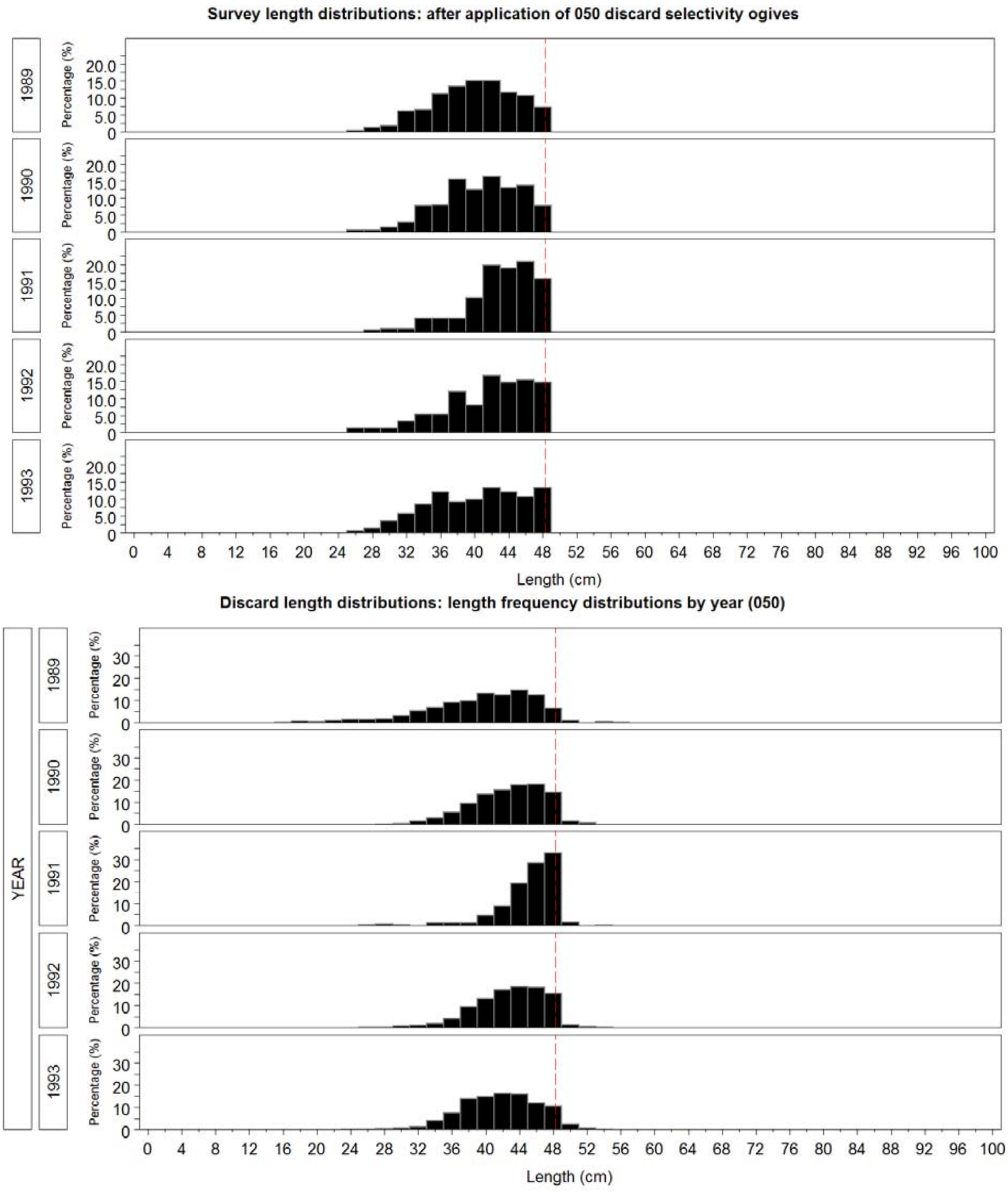


Figure A.58. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh otter trawl gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.

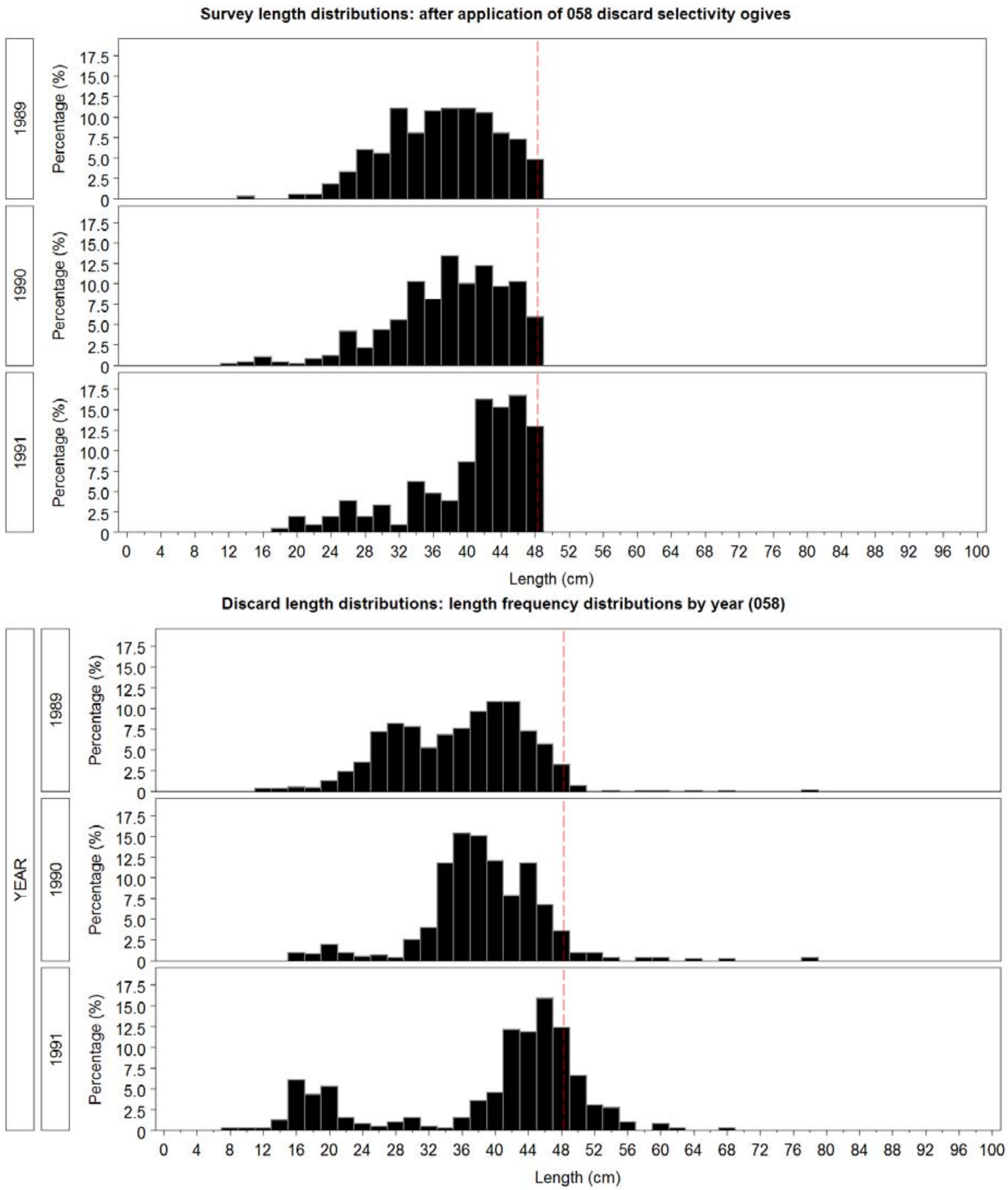
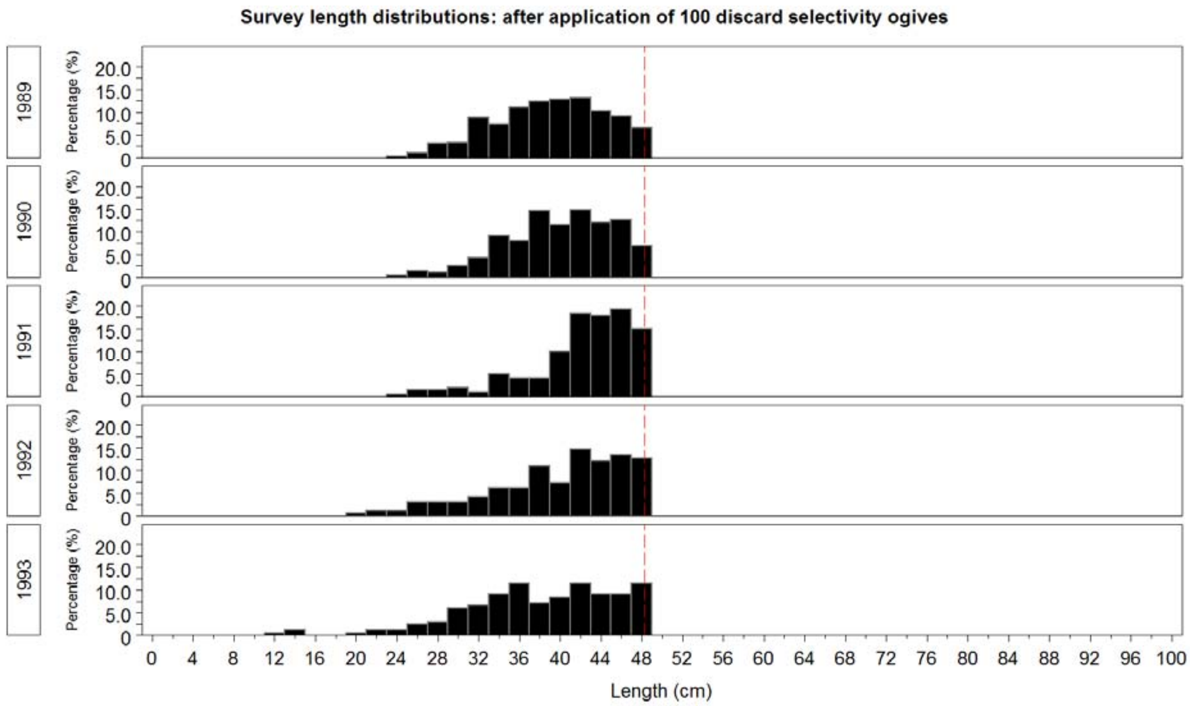


Figure A.59. Comparison of the survey filter-based estimates (top) of discards-at-length for shrimp trawl gear to the direct observer observations (bottom) from 1989 to 1991 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.



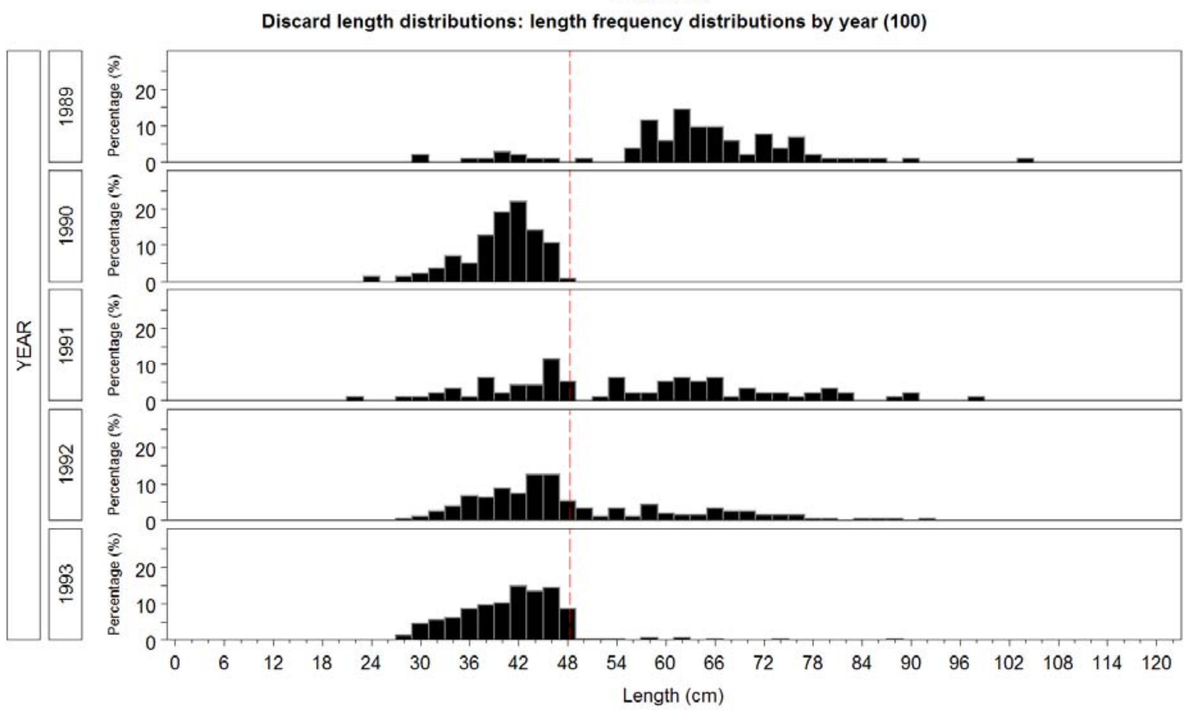


Figure A.60. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh sink gillnet gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.

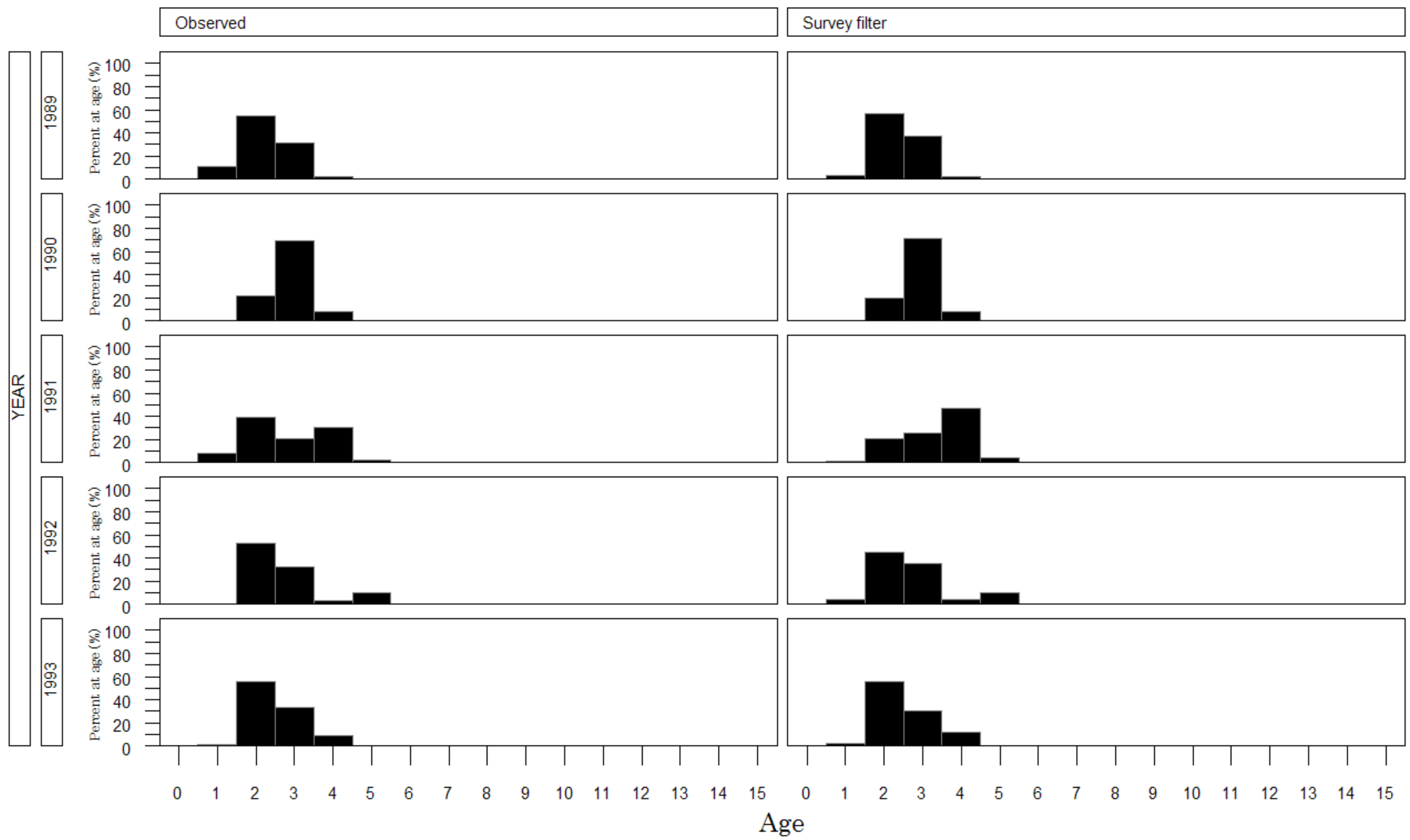


Figure A.61. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh otter trawl gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

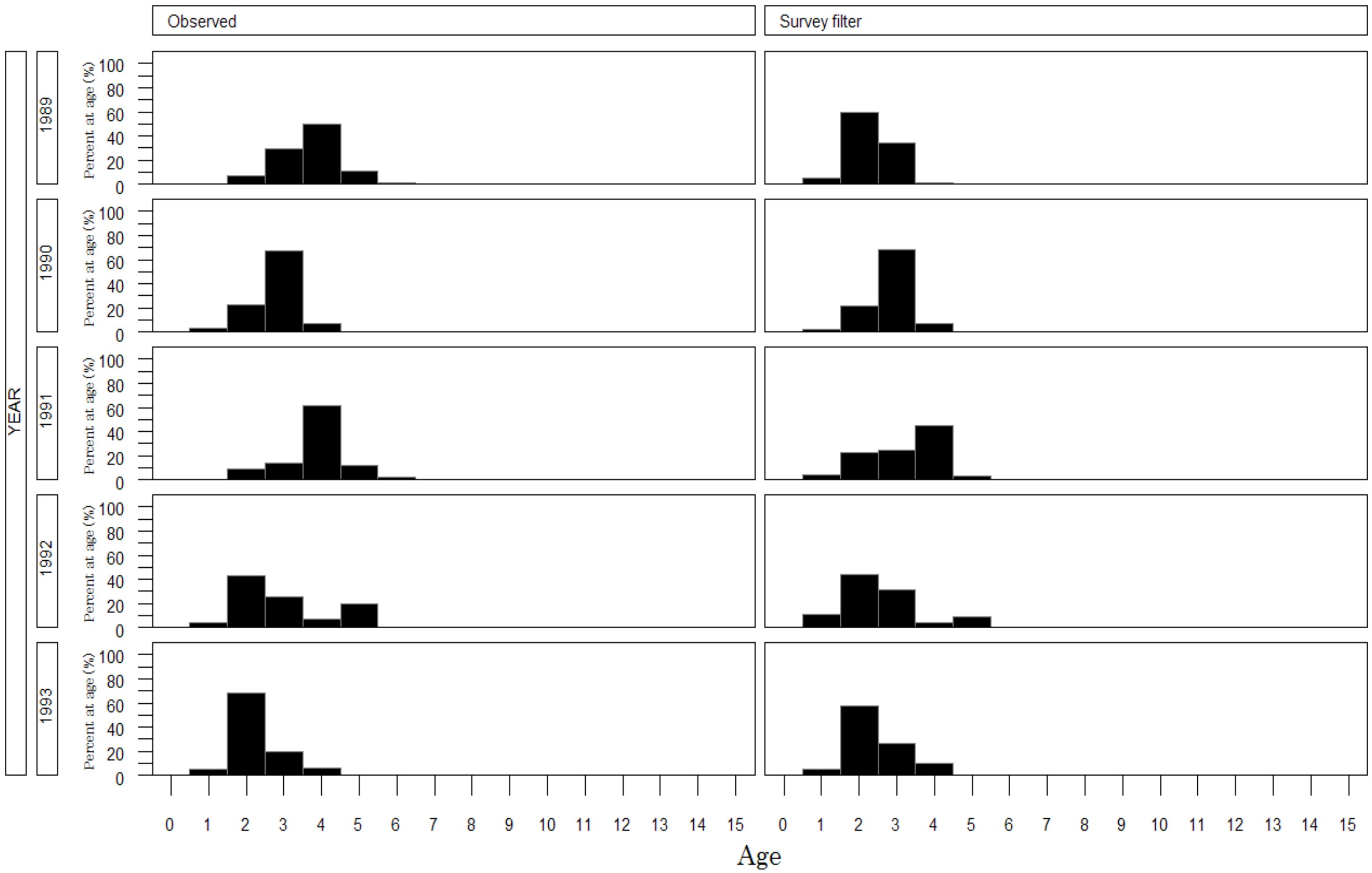


Figure A.62. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh sink gillnet gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

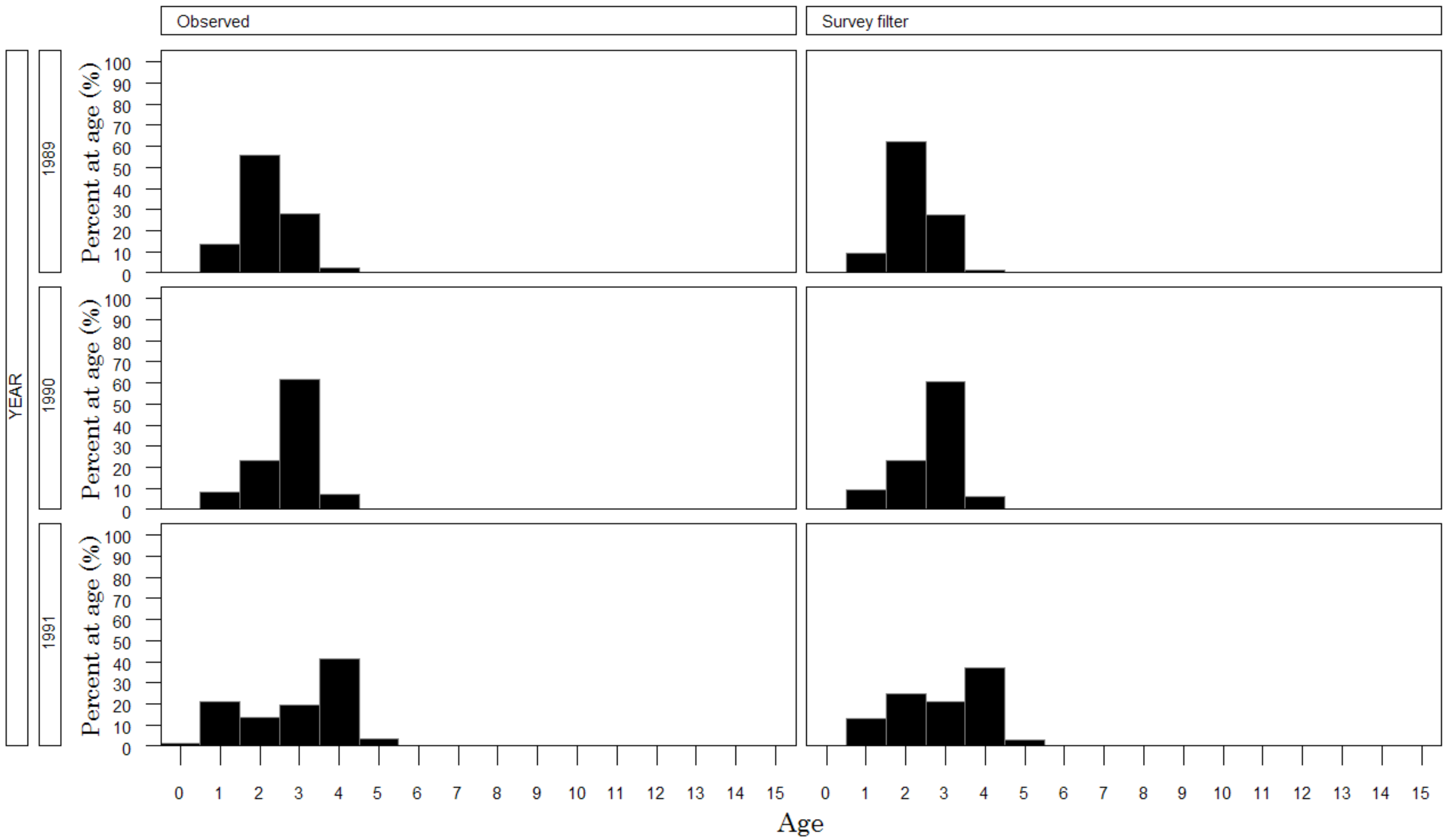


Figure A.63. Comparison of the survey filter-based estimates (right) of numbers-at-age for shrimp trawl gear to the direct observer observations (left) from 1989 to 1991 for Gulf of Maine Atlantic cod.

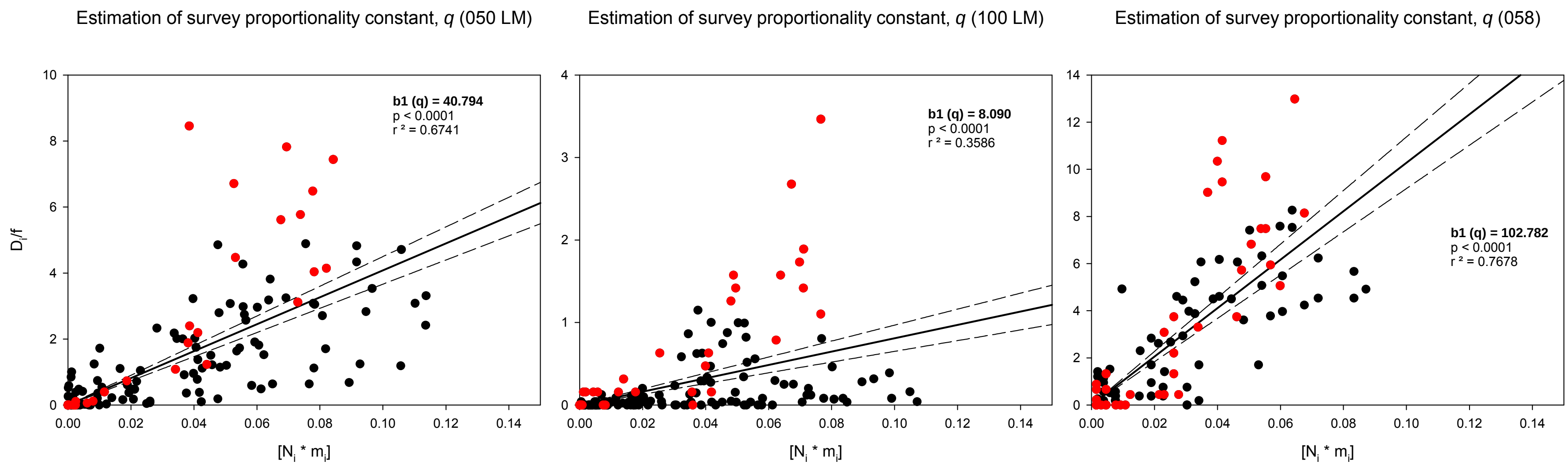


Figure A.64. Plots of the relationship by gear type between fraction of fish observed discarded-at-length (D_i/f) and the estimated number at length from the survey-filter method (N_i•m_i) for Gulf of Maine Atlantic cod. Large mesh otter trawl (050 LM), large mesh sink gillnet (100 LM) and shrimp trawl gear (058) are shown. The slope of the relationship (q) is the proportionality constant required to expand the survey-filter estimates of numbers at length to estimates of total discards at length. The dots colored red represent observations from 1990.

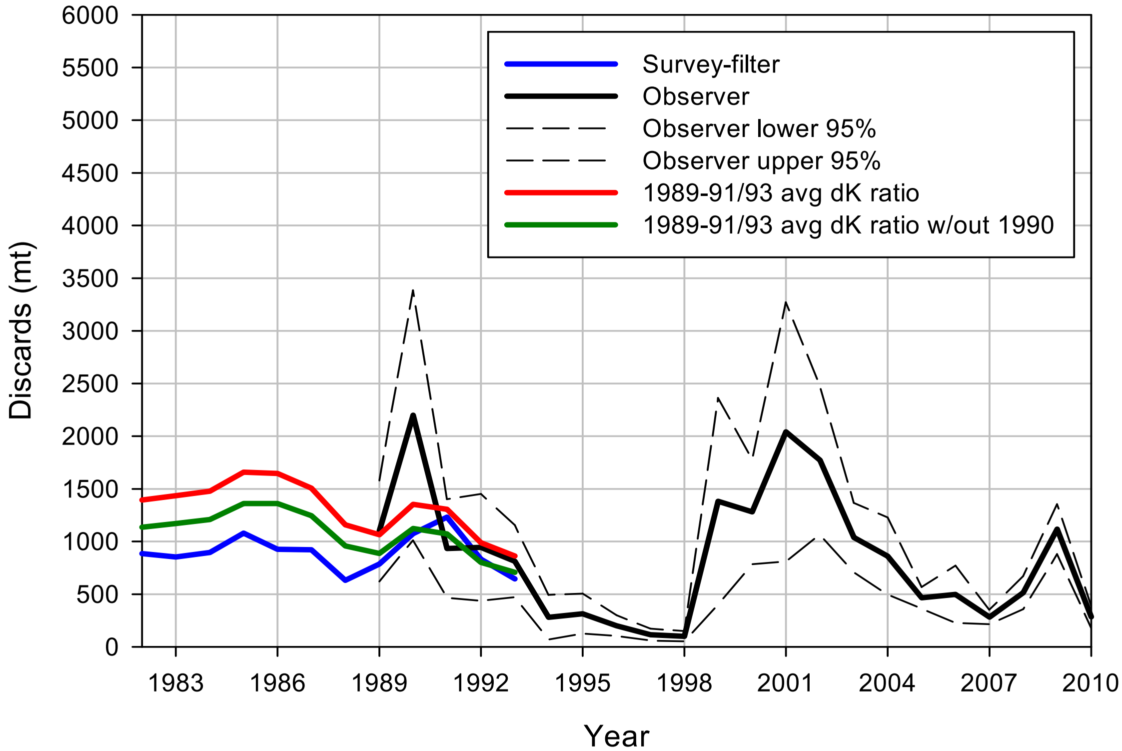


Figure A.65. Comparison of three different methods for achieving hindcasted estimates of Gulf of Maine Atlantic cod commercial discards from 1982 to 1988. (1) The survey-filter method uses the proportionality constant (q) multiplied by an index of fishing effort (total retained catch, K_{all}) to estimate total discards (blue line). (2) Use of the average ratio of discarded cod to total retained catch (d_{cod}/k_{all}) from 1989 to 1993 multiplied by total retained catch (K_{all}, red line). (3) Use of the average ratio of discarded cod to total retained catch (d_{cod}/k_{all}) from 1989 to 1993, excluding 1990, multiplied by total retained catch (K_{all}, green line). The 'observer' line shows the direct estimates of discards from 1989 to 2010 achieved using the Standardized Bycatch Reporting Methodology (Wigley et al. 2007) and the corresponding 95% confidence intervals.

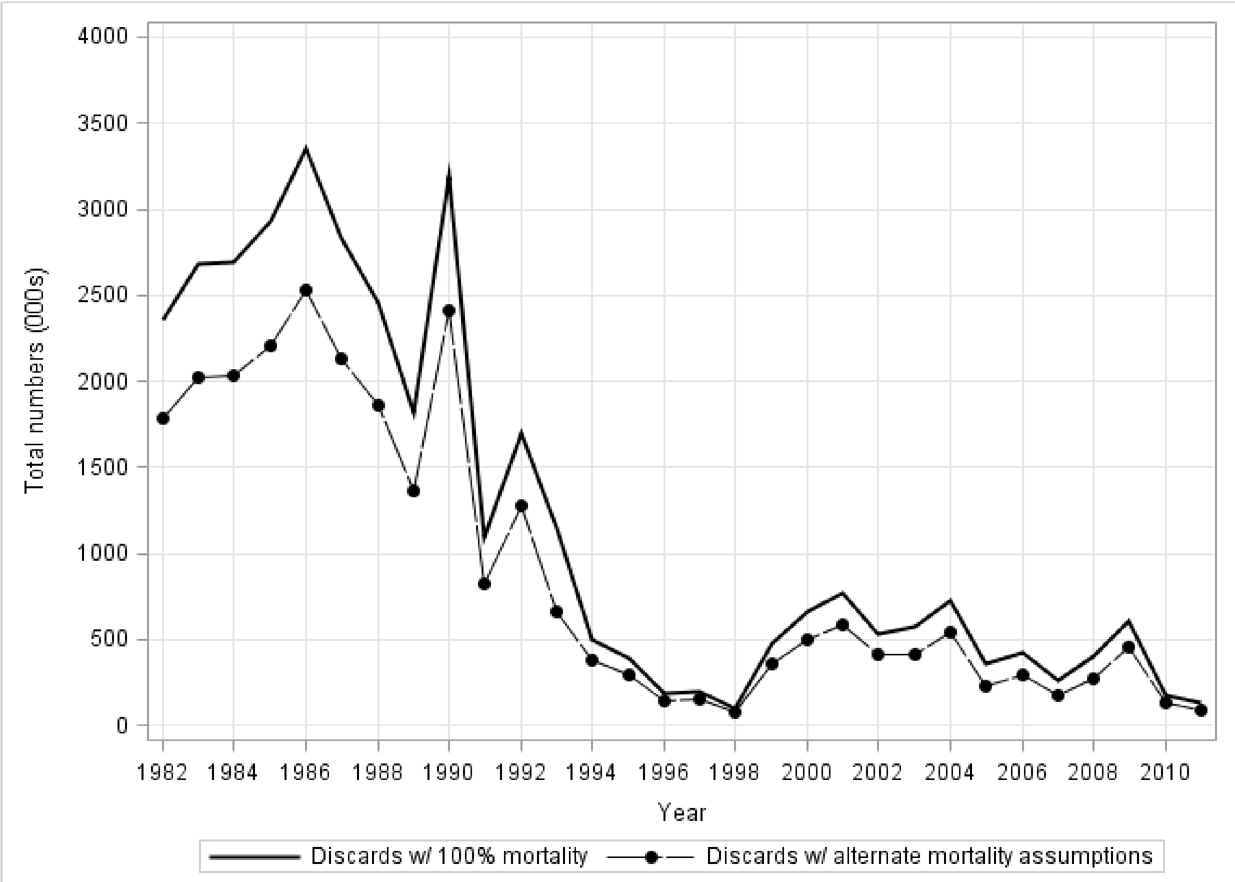


Figure A.66. Impacts of the revised discard mortality estimates on the estimates of Gulf of Maine Atlantic cod commercial discards in terms of numbers of fish (thousands).

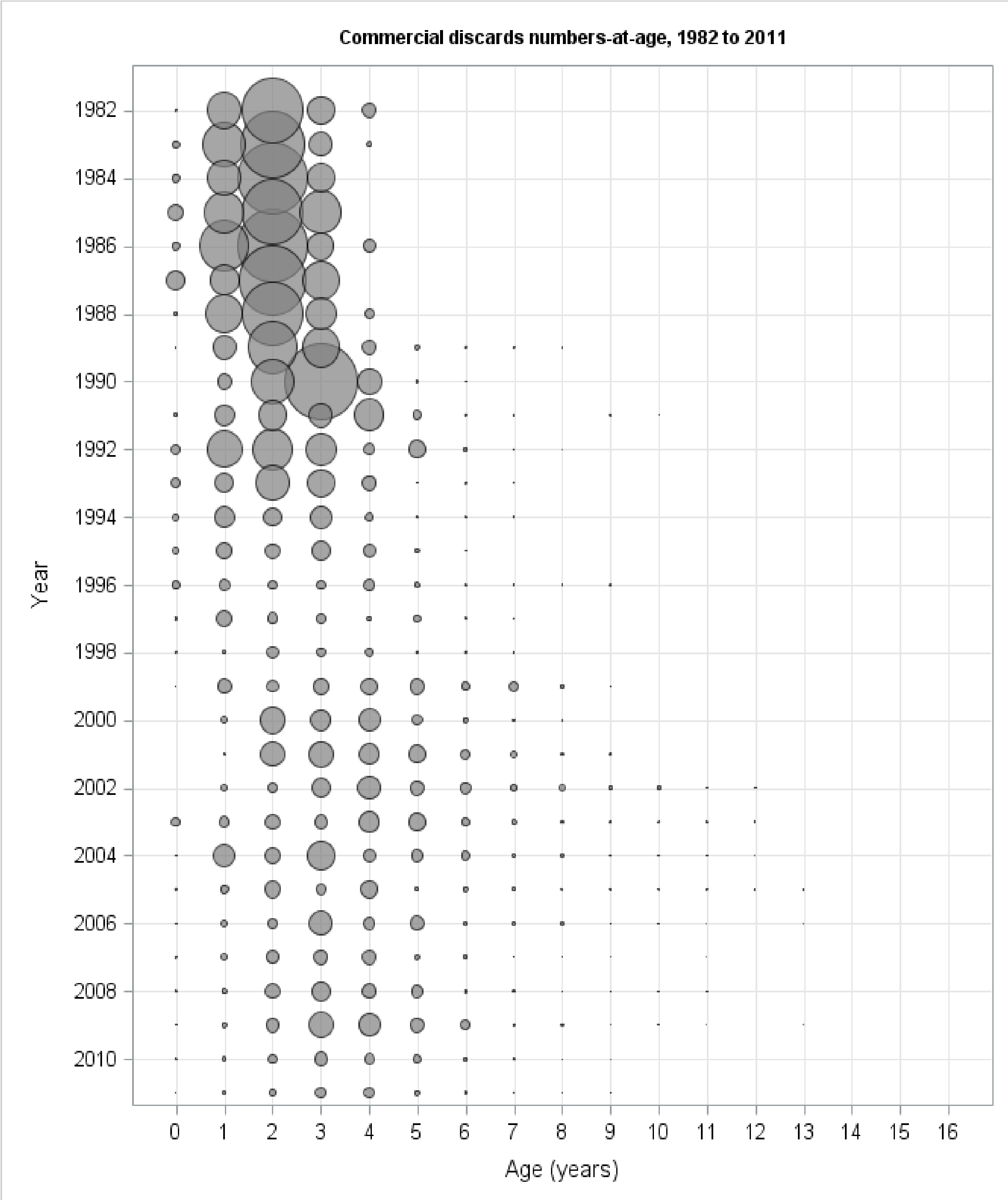


Figure A.67. Commercial discards-at-age of Gulf of Maine Atlantic cod from 1982 to 2011.

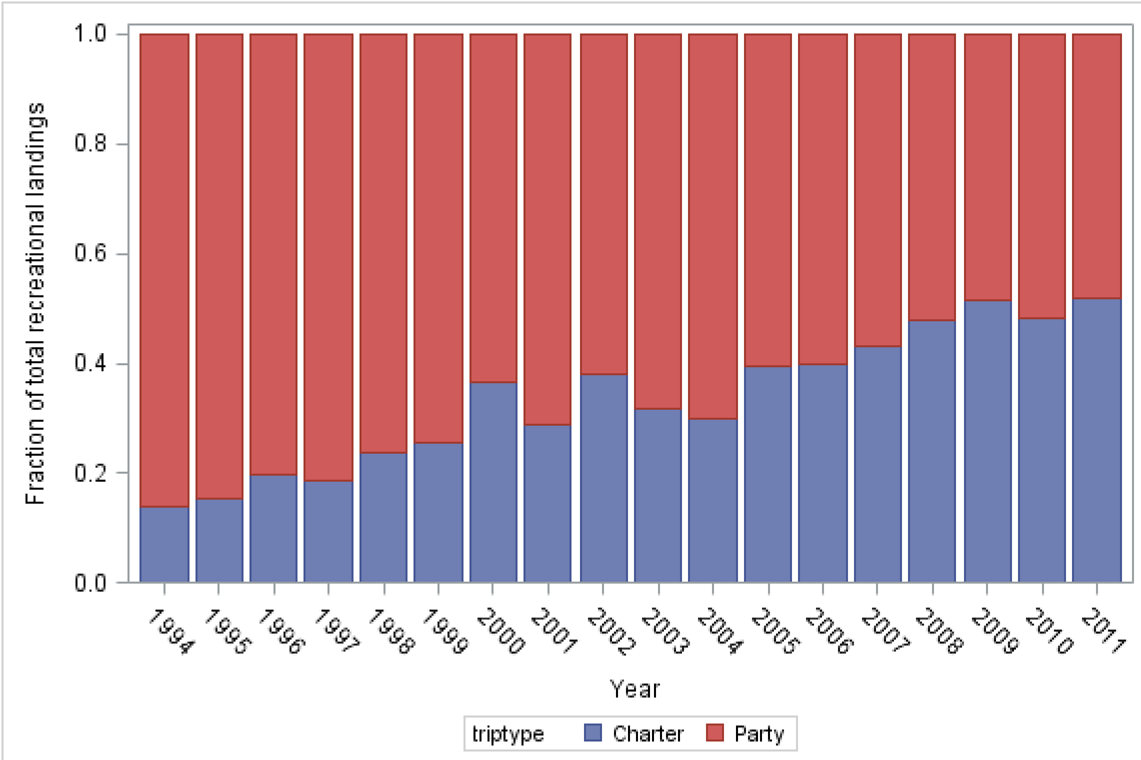


Figure A.68. Fraction of the total annual VTR-reported recreational Gulf of Maine Atlantic cod catch, by trip type, from 1994-2011.

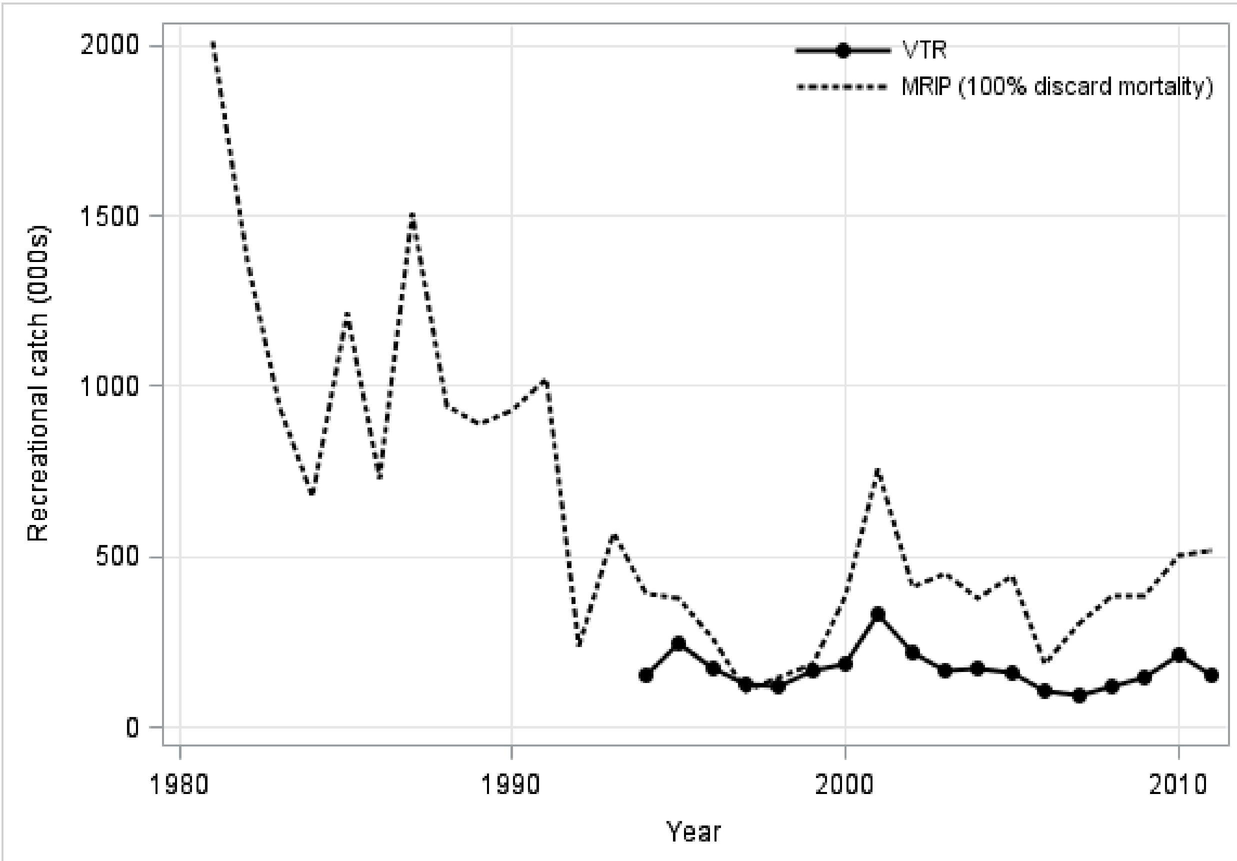


Figure A.69. Comparison of Gulf of Maine Atlantic cod recreational landings estimates derived through the Marine Recreational Information Program (MRIP) to recreational landings reported on Vessel Trip Reports (VTRs) between 1981 and 2011. **Note: VTR data collection began in 1994.*

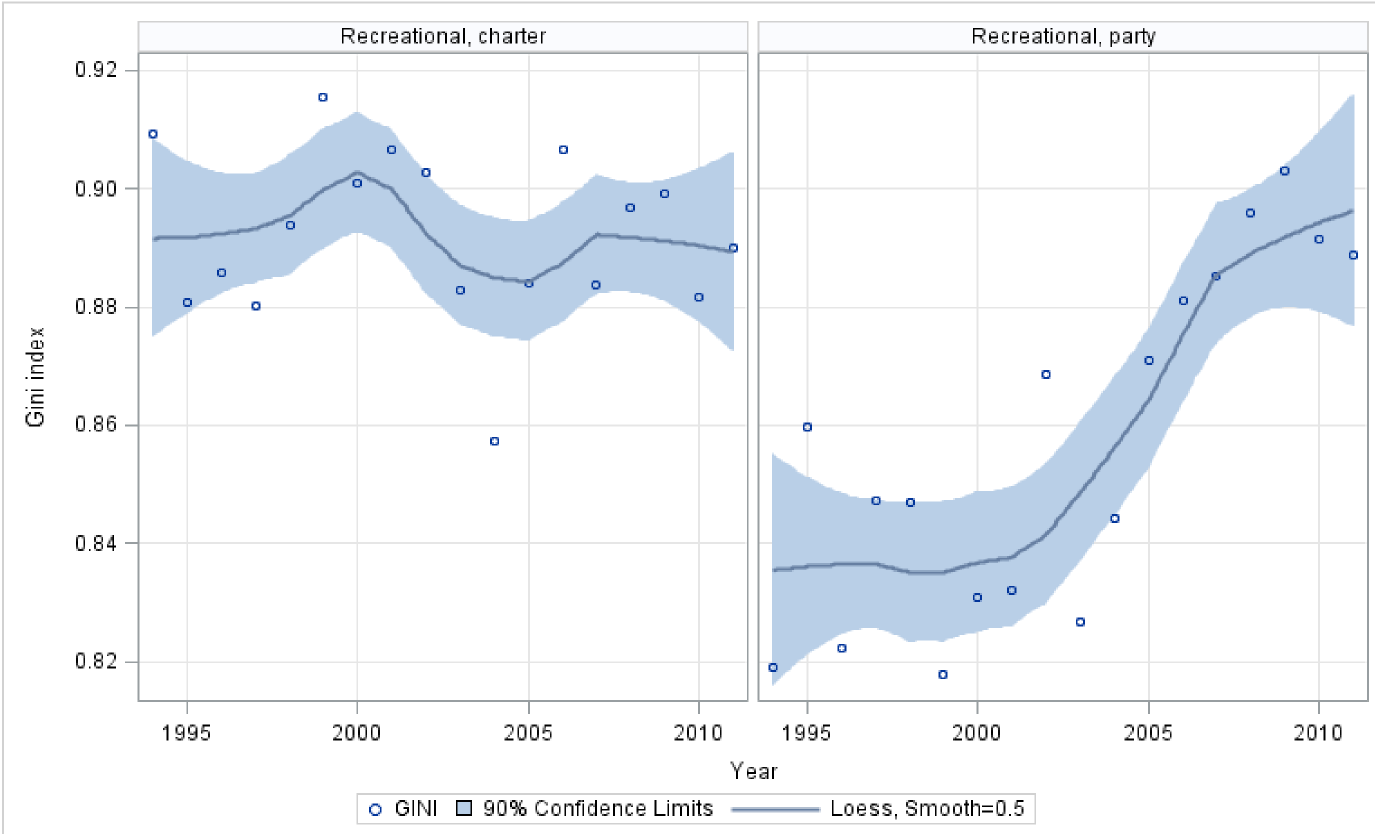


Figure A.70. Gini indices for the recreational charter and party boat fleets fleets from 1994-2011. Indices were based on the spatial distribution of the retained catch reported on vessel trip reports.

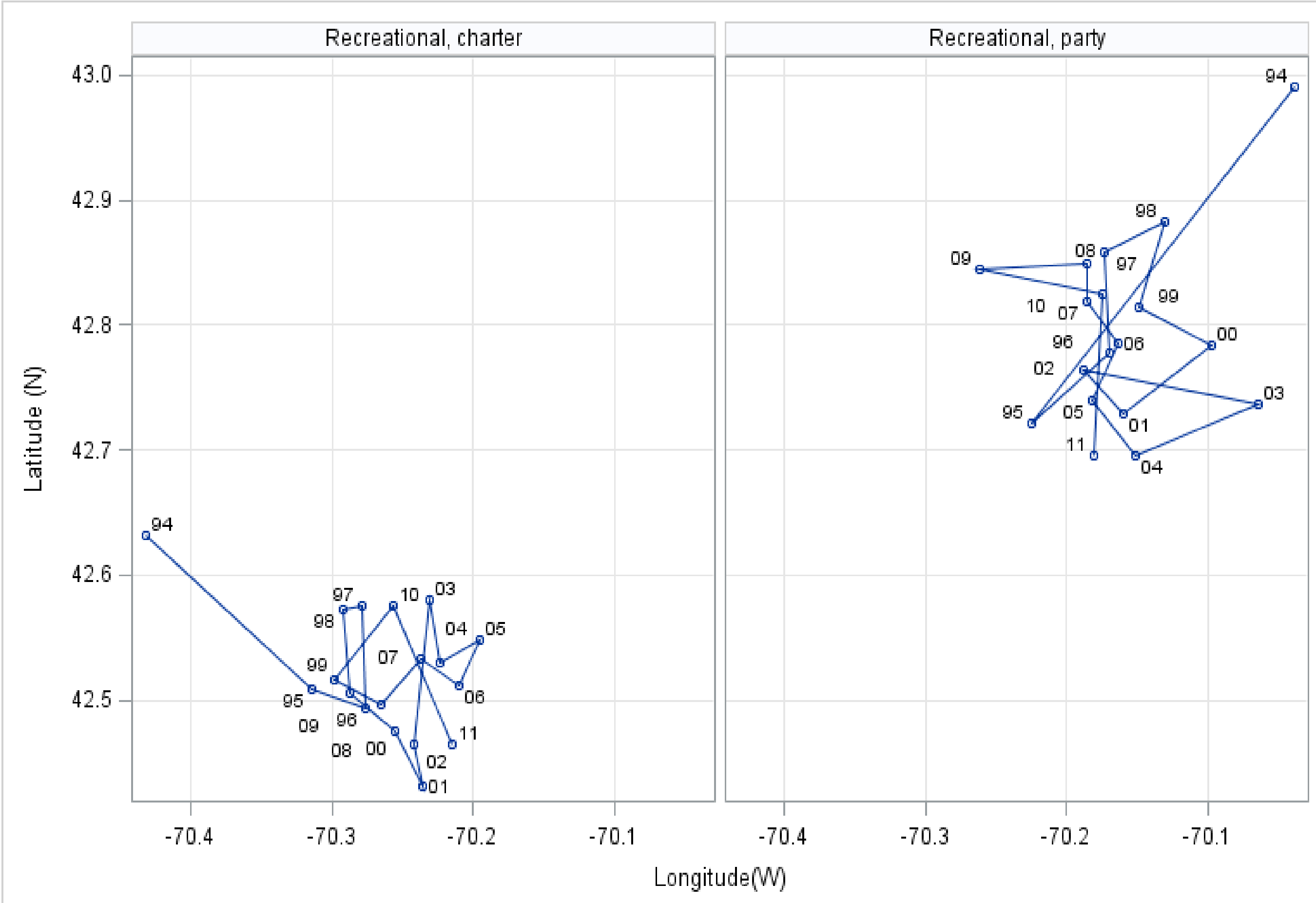


Figure A.71. Landings-weighted mean location (centroid) of Gulf of Maine cod catch by the recreational charter and party boat fleets from 1994 to 2011. Centroids were based on the spatial distribution of the retained catch reported on vessel trip reports.

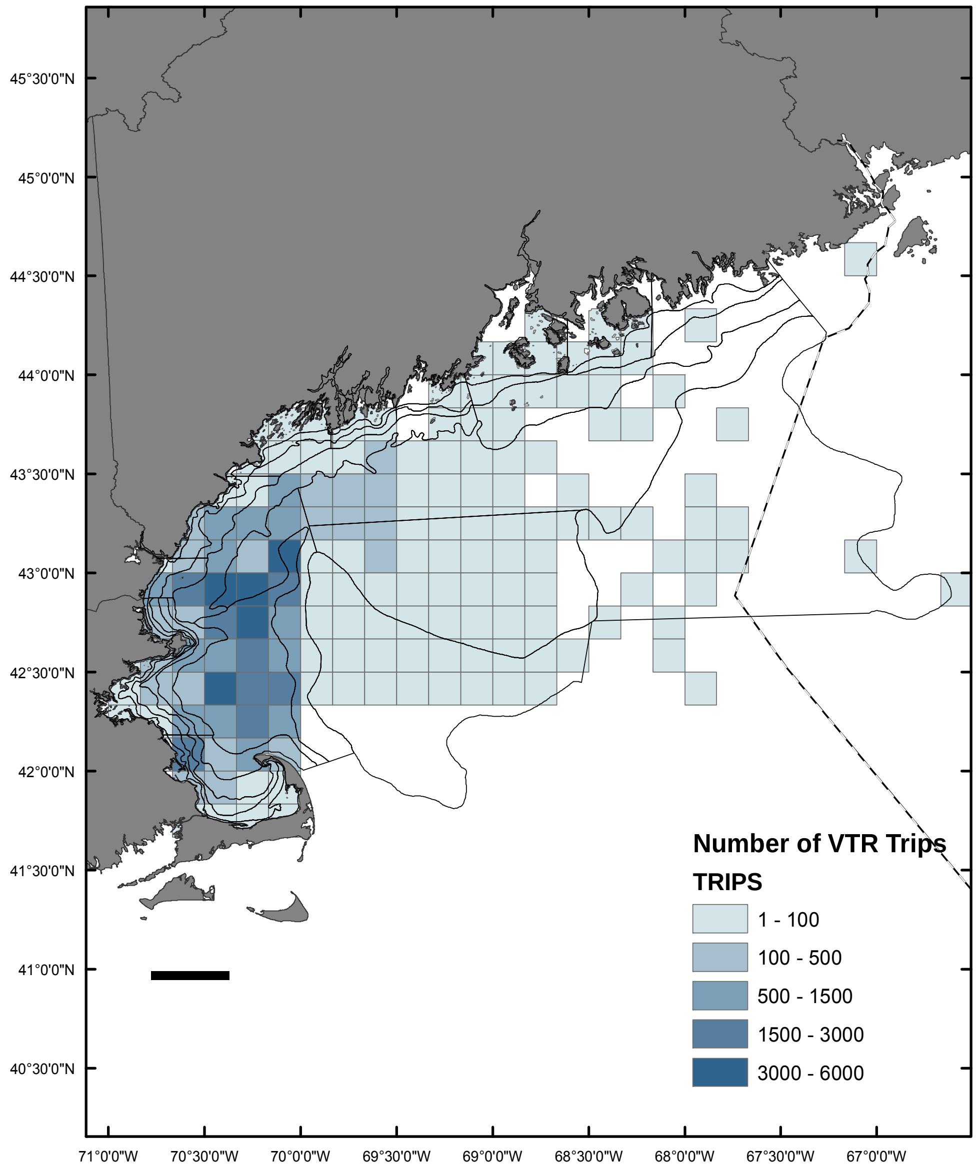


Figure A.72. Spatial distribution of recreational effort on trips reported catching Gulf of Maine Atlantic cod between 1994 and 2011 as determined from vessel trip reports (VTRs). VTR-based recreation effort has been binned to ten minute squares and overlaid on the Northeast Fisheries Science Center bottom trawl survey sampling strata

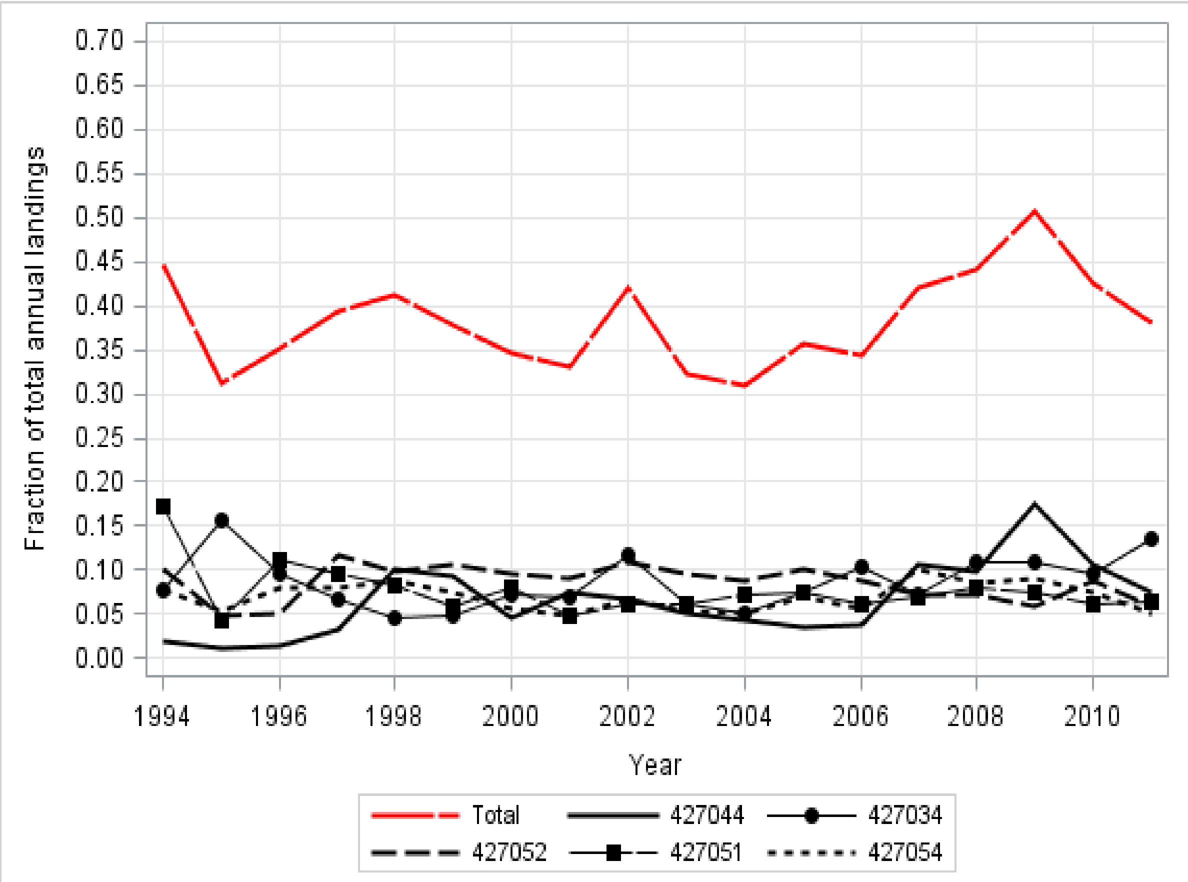


Figure A.73. Recreational utilization of the top ten minute squares between 1994 and 2011 expressed as an annual fraction of the total retained catch of Gulf of Maine Atlantic cod reported on vessel trip reports.

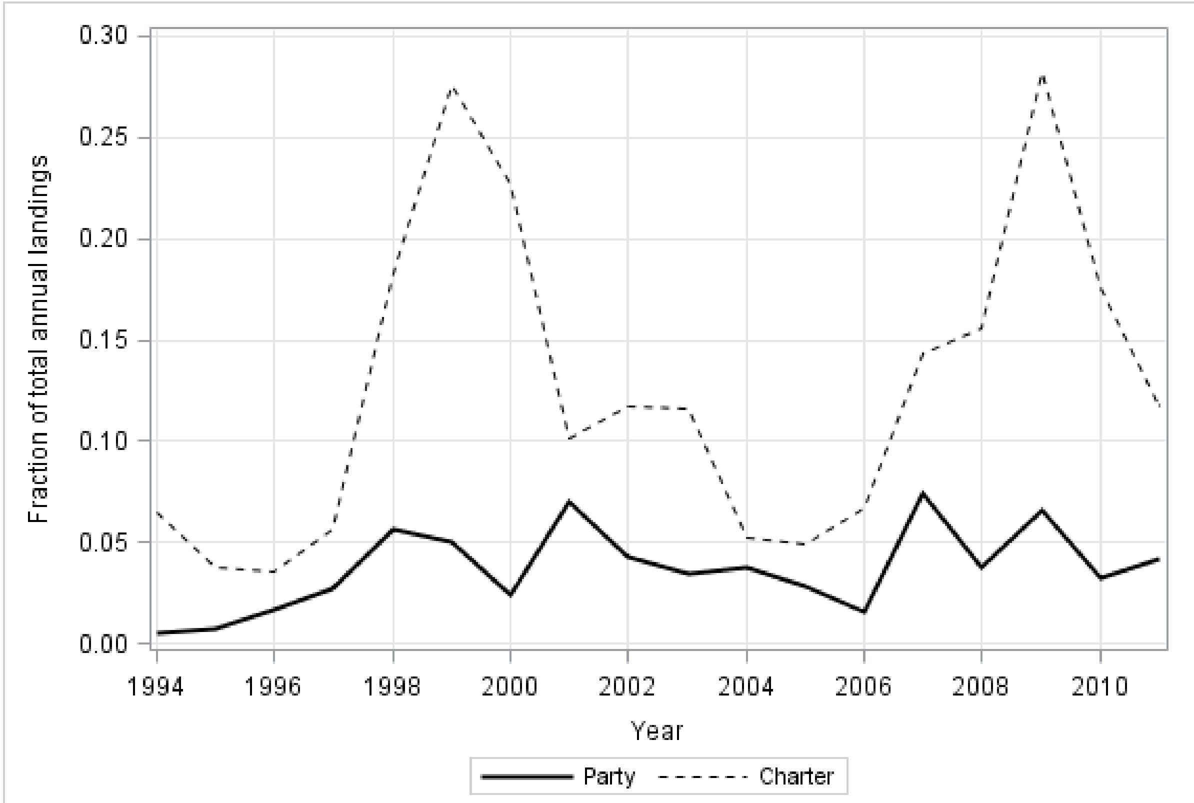


Figure A.74. Utilization of ten minute square 427044 by the recreational charter and party boat fishery between 1994 and 2011 expressed as annual fraction of the total retained catch of Gulf of Maine Atlantic cod reported on vessel trip reports.

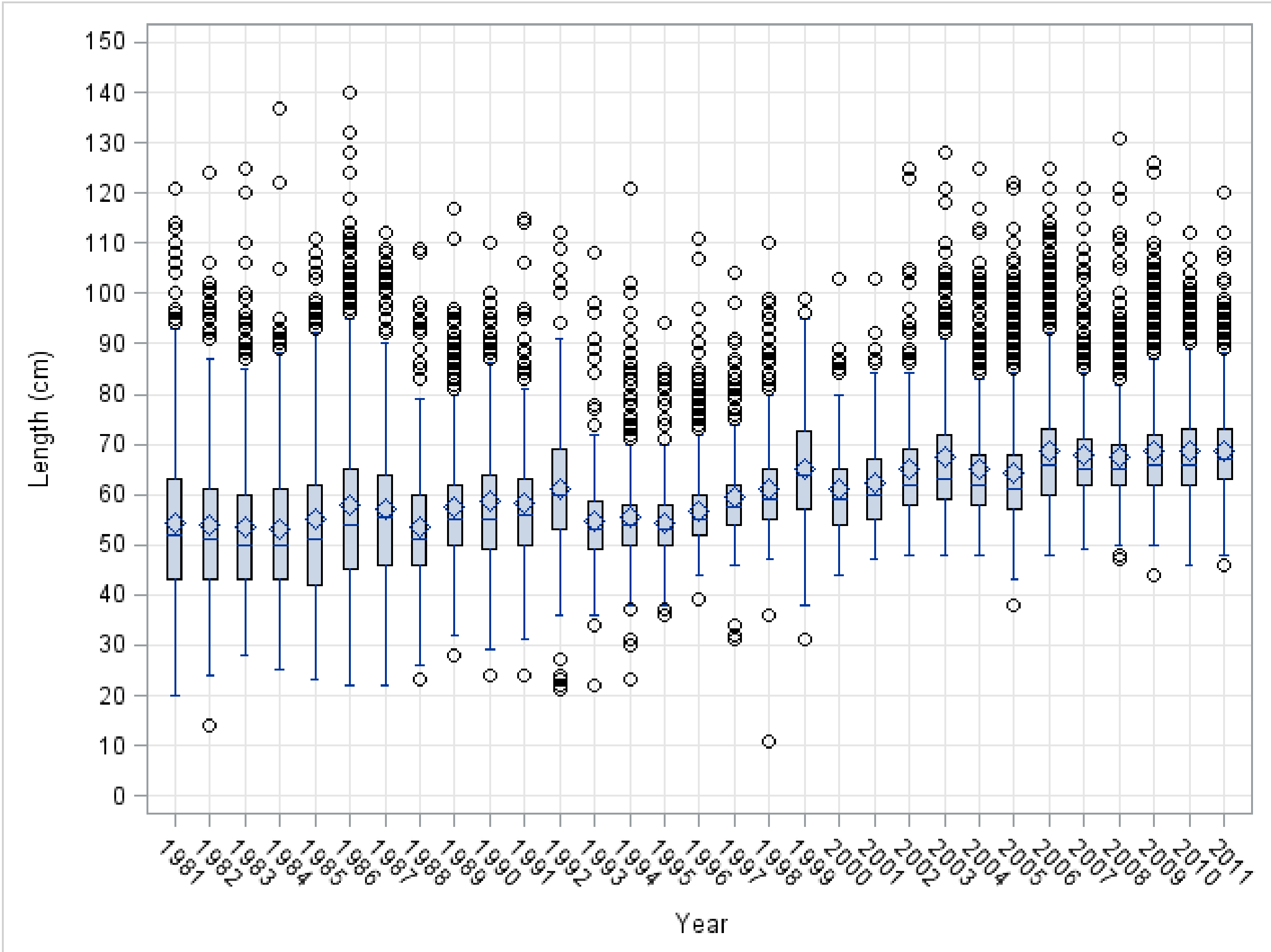


Figure A.75. Box plots showing the length distribution of Gulf of Maine Atlantic cod recreational harvest (AB1 catch) between 1981 and 2011.

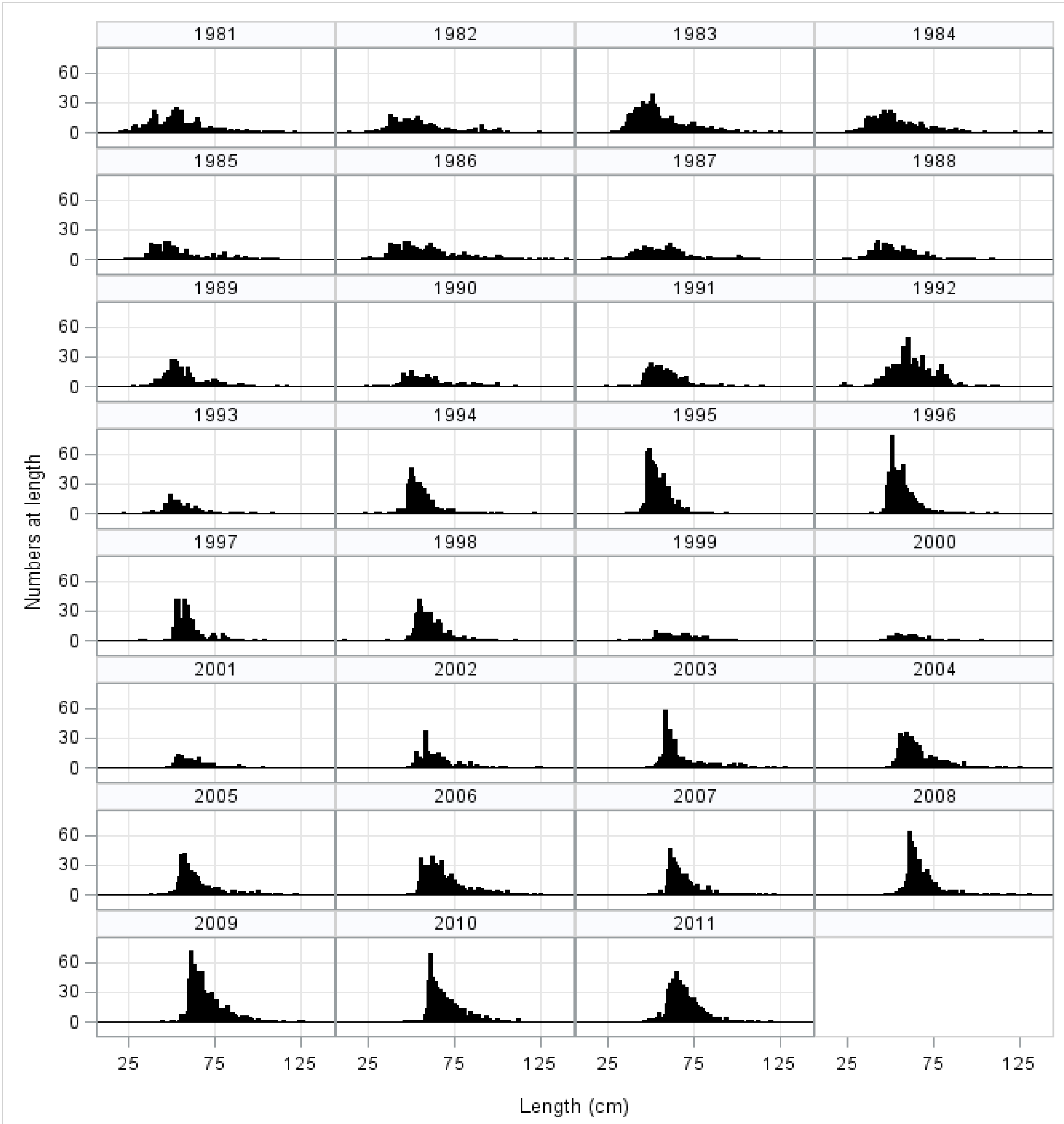


Figure A.76. Length frequency distribution of Gulf of Maine Atlantic cod recreational harvest (AB1 catch) between 1981 and 2011.

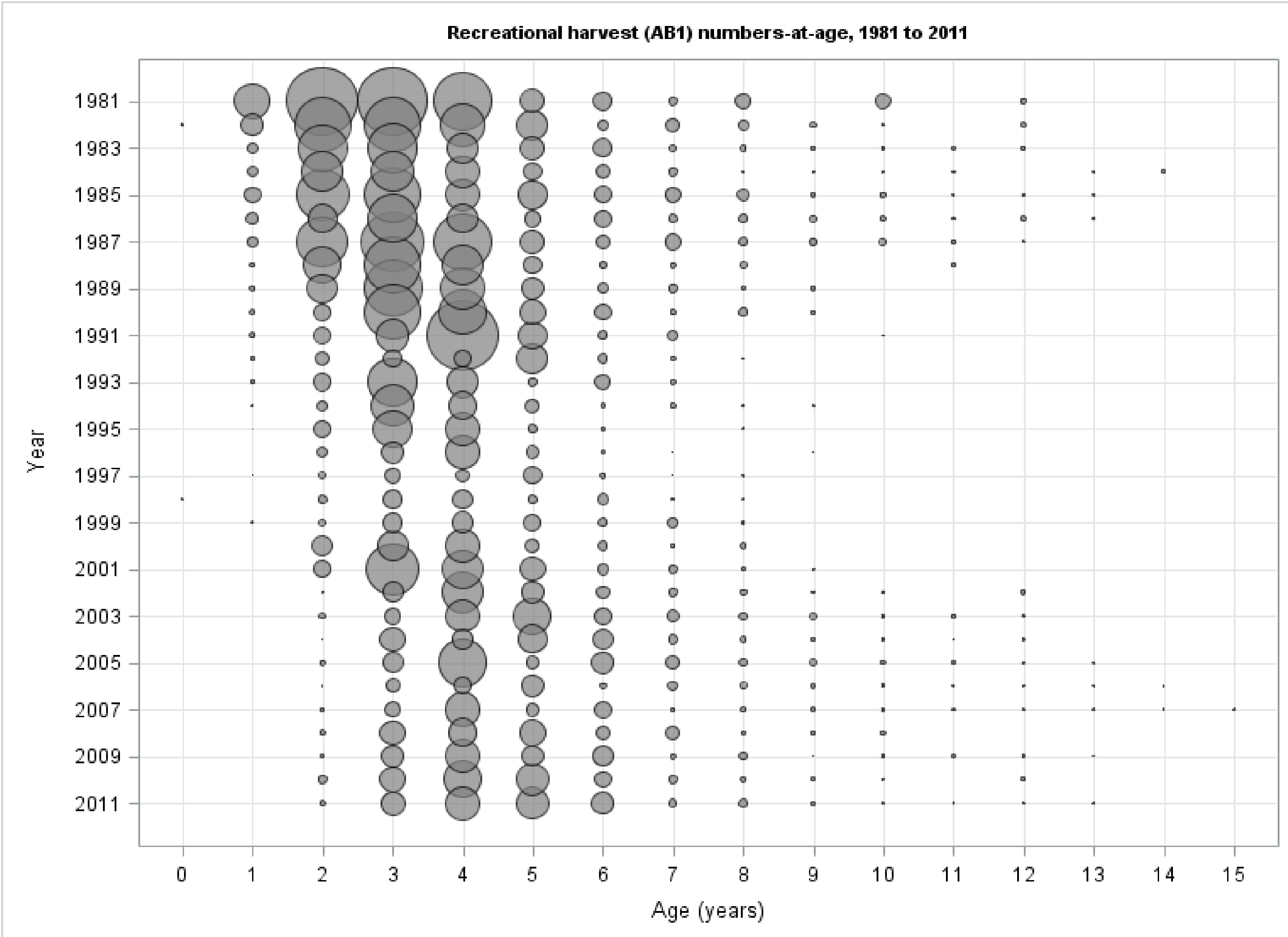


Figure A.77. Recreational landings-at-age of Gulf of Maine Atlantic cod from 1981 to 2011.

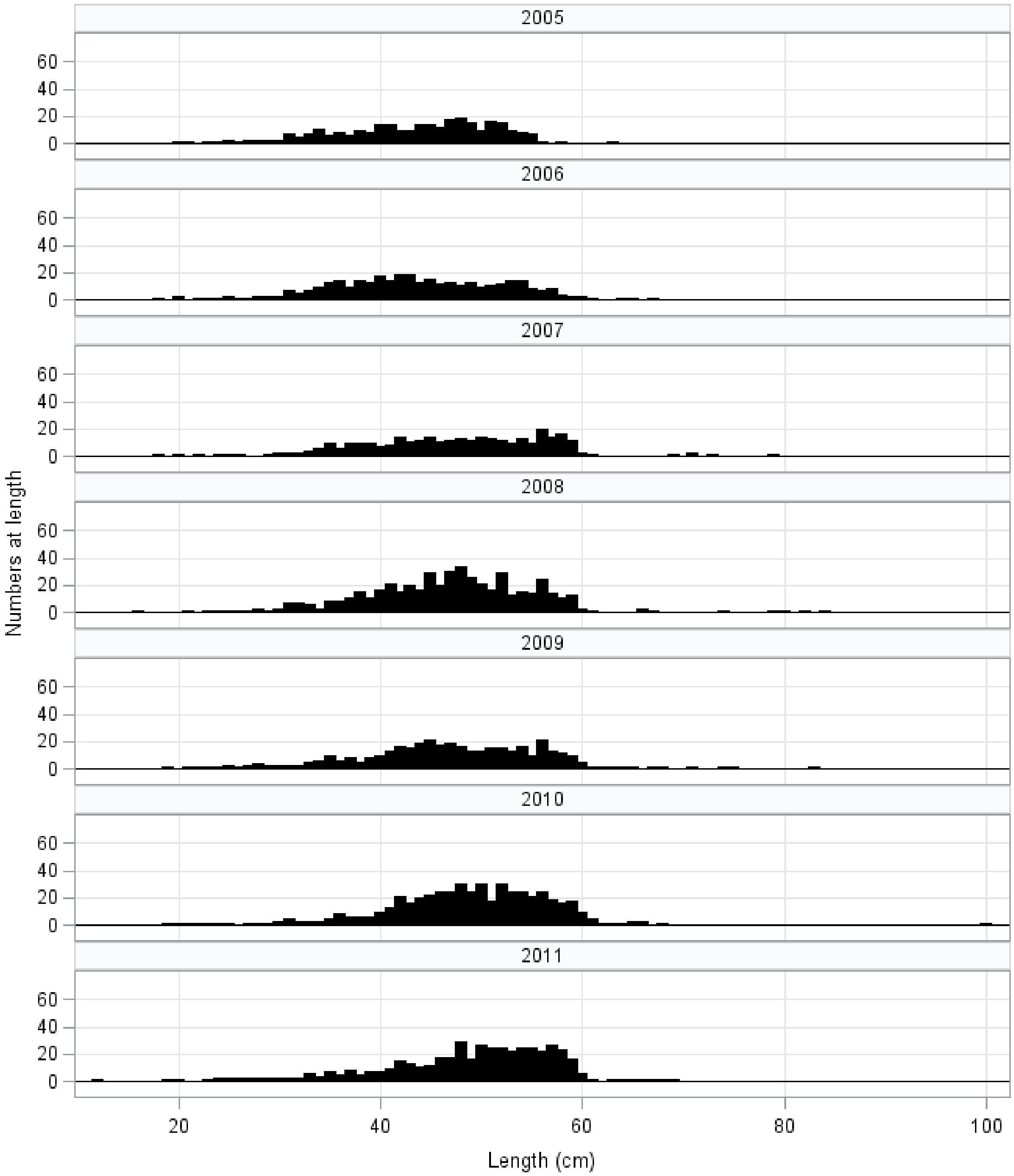


Figure A.78. Annual length frequency distributions of Gulf of Maine Atlantic cod discarded in the recreational fishery between 2005 and 2011. *No sampling of recreational discards occurred prior to 2005.*

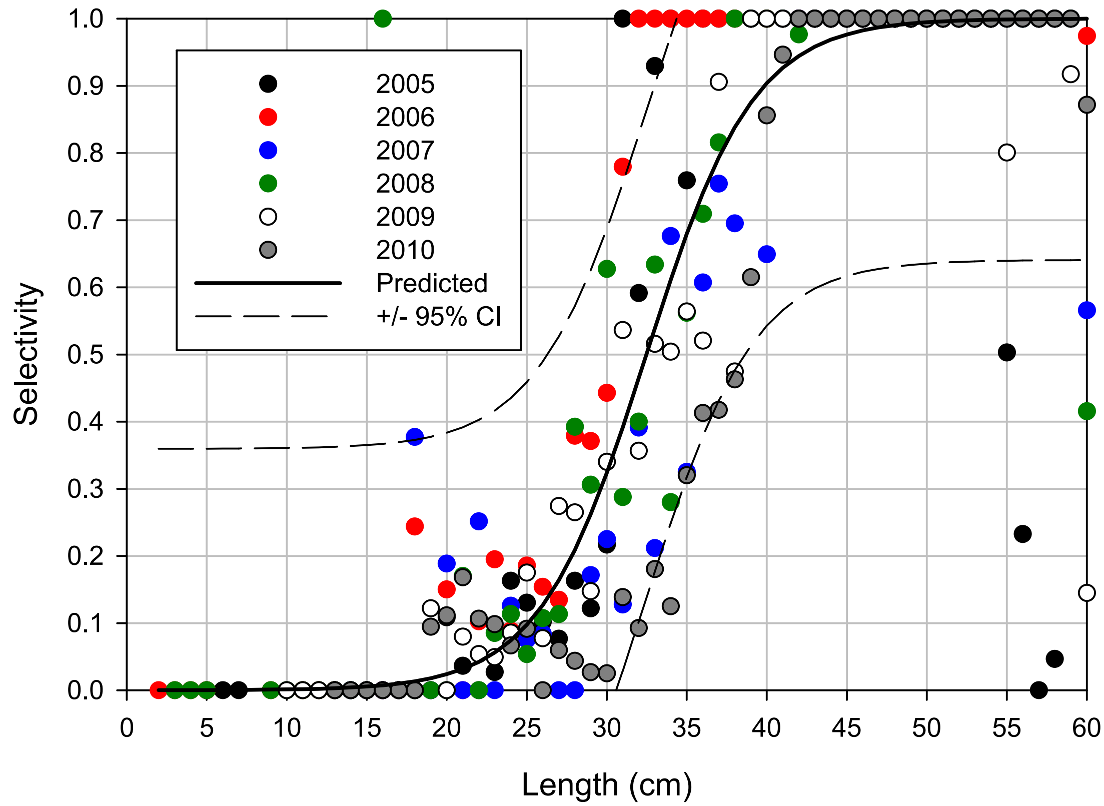
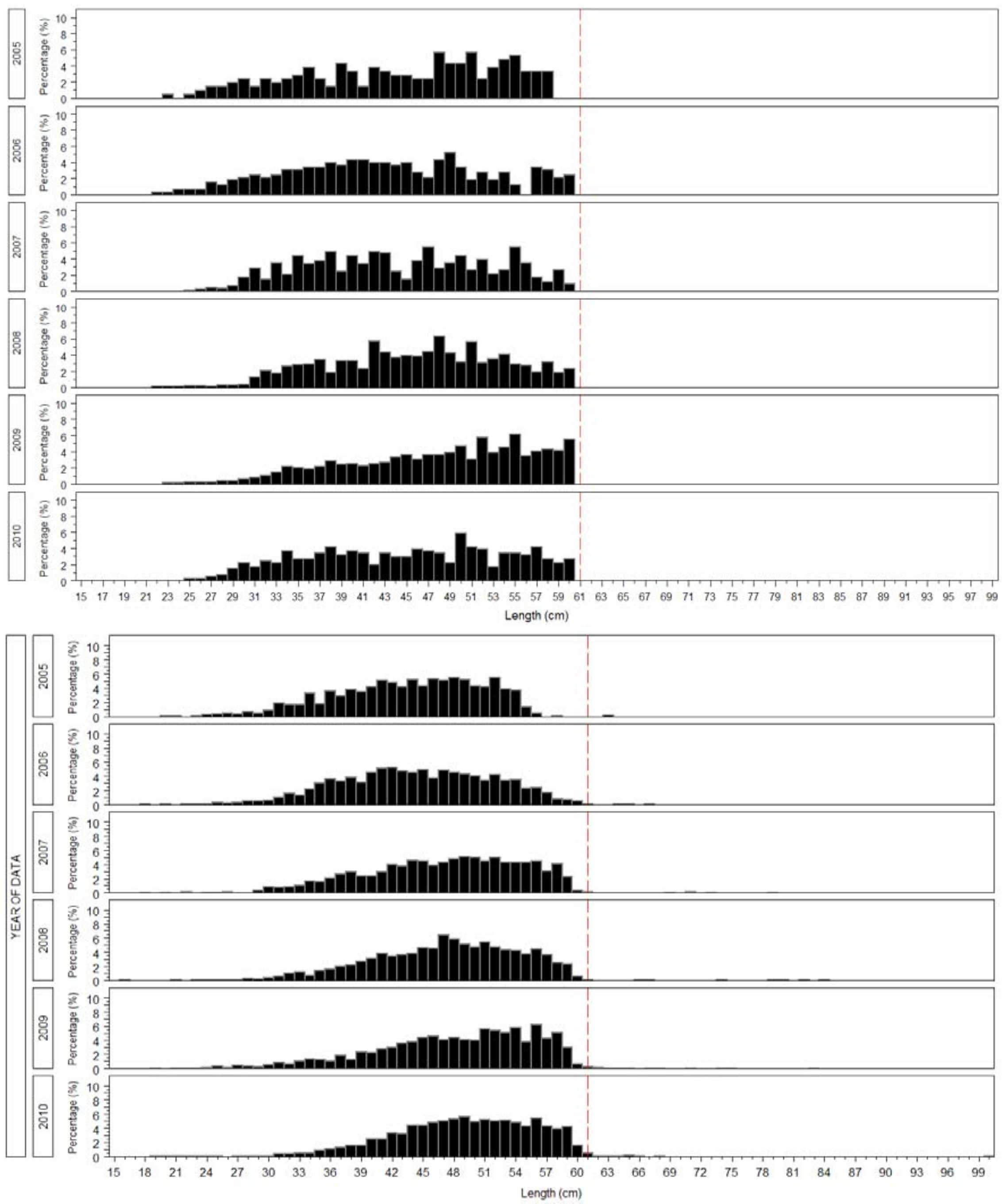


Figure A.79. Estimated selectivity ogive for the recreational fishery and the corresponding 95% confidence interval (CI) for Gulf of Maine Atlantic cod. The selectivity ogive was estimated from the logistic fits to the aggregated annual estimates of selectivity-at-length.



Figures A.80. Comparison of recreational discard length frequency distributions estimated using the survey filter approach (top) to those generated from the B2 sampling of the I9 catch (bottom) between 2005 and 2010 for Gulf of Maine Atlantic cod. The dashed red line represents the recreational minimum retention size of 24 inches (61.0 cm) from May 1, 2006-2010. The minimum retention size from January 1, 2005 to May 1, 2006 was 23 inches (58.4cm).

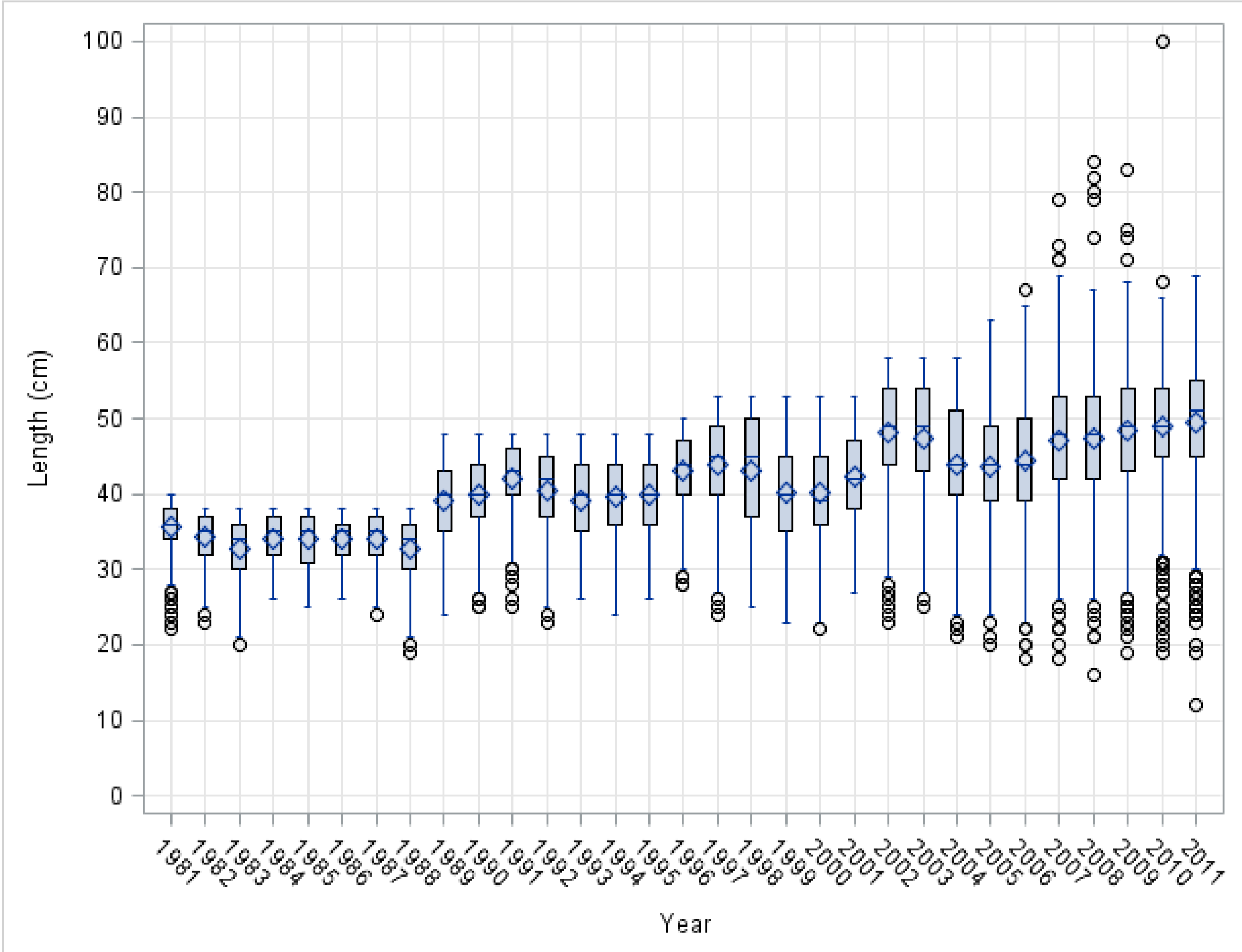


Figure A.81. Box plots showing the length distribution of Gulf of Maine Atlantic cod recreational releases (B2 catch) between 1981 and 2011.

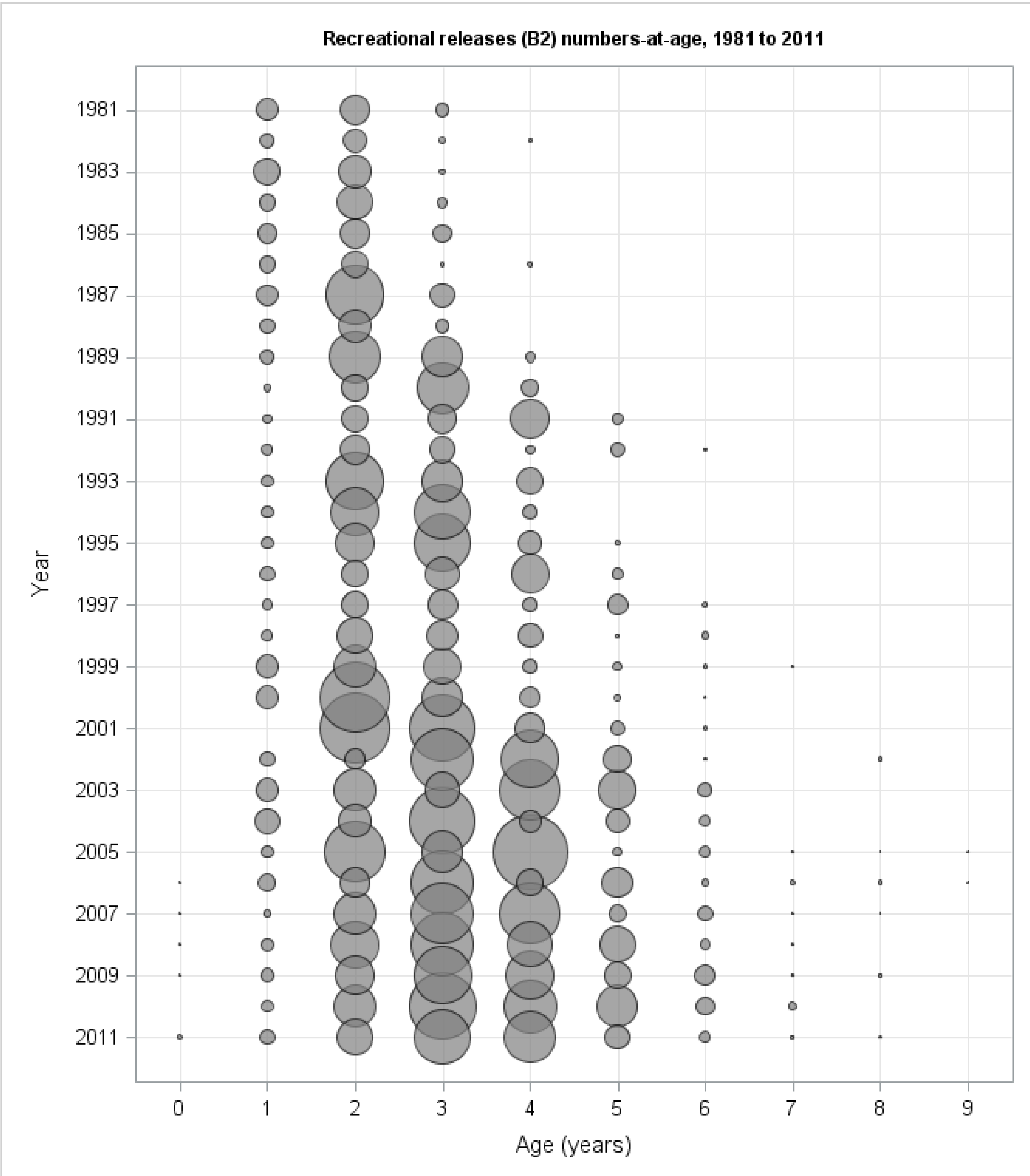


Figure A.82. Recreational discards-at-age of Gulf of Maine Atlantic cod from 1981 to 2011.

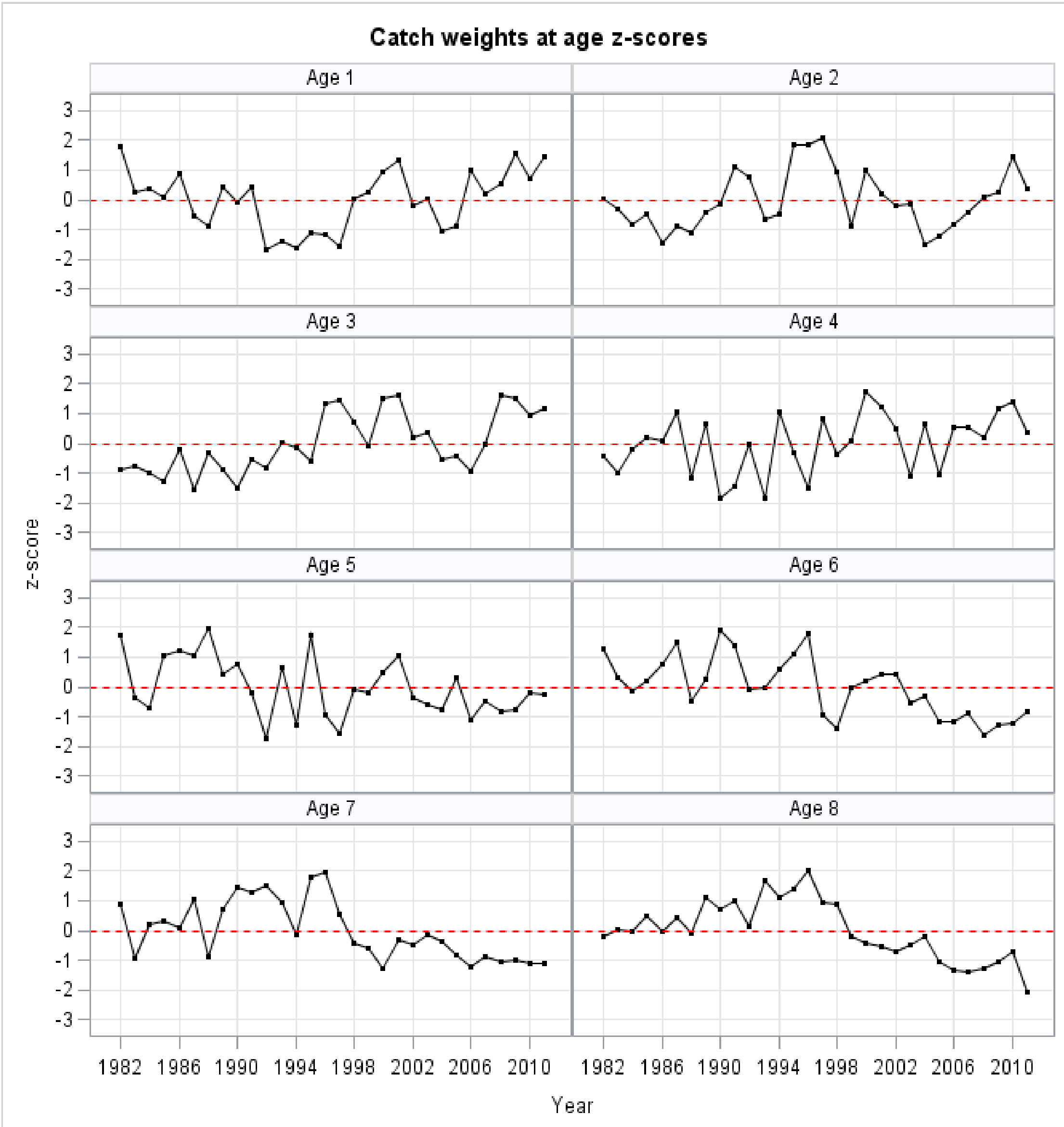


Figure A.83. Average catch weights-at-age of age1-8 Gulf of Maine Atlantic cod from 1982 to 2011. Weights-at-age were estimated using a number weighted average of commercial landing, commercial discard, recreational landings, and recreational discards weights-at-age. Average weights are presented as z-scores ([x-μ]/σ).

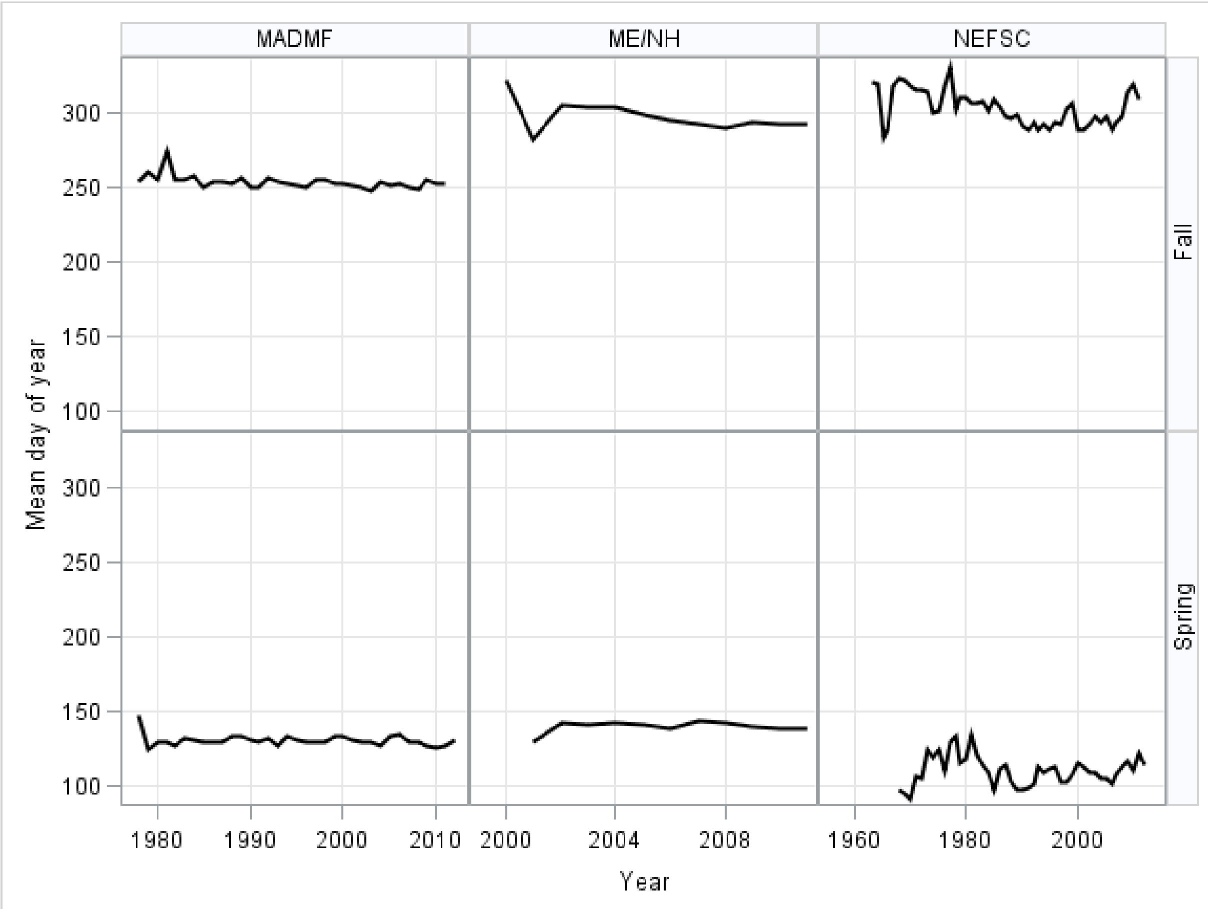


Figure A.84. Mean day of the year of sampling in the Gulf of Maine by each of the three ongoing regional bottom trawl surveys: Northeast Fisheries Scienc Center (NEFSC), Massachusetts Department of Marine Fisheries (MADMF) and the Maine – New Hampshire inshore bottom trawl survey (ME/NH). Days are expressed as Julian days (e.g., January 1 is day 1 and December 31 is day 365/66).

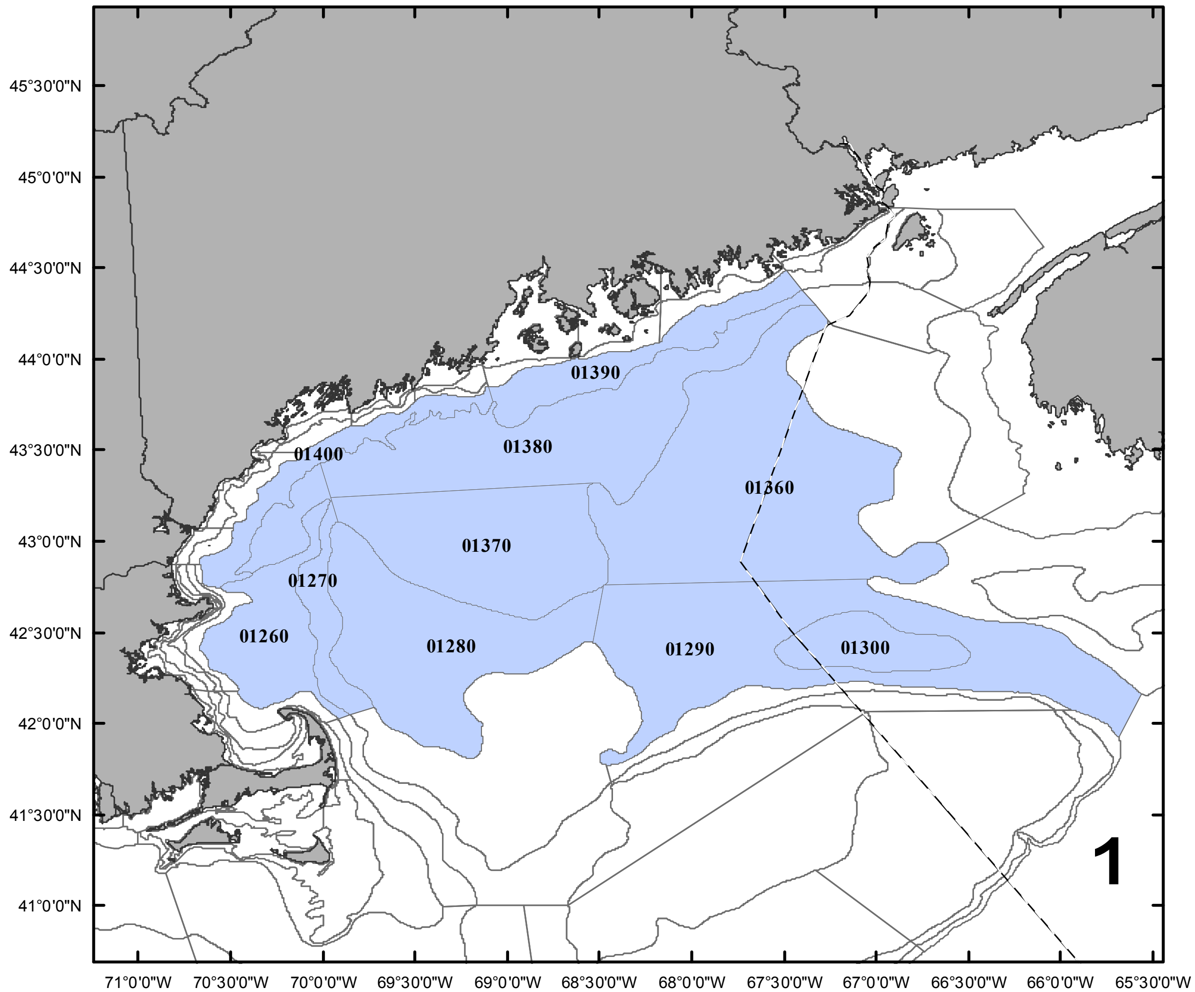


Figure A.85. Map of the Notheast Fisheries Science Center (NEFSC) bottom trawl offshore survey strata included in the Gulf of Maine Atlantic cod stock assessment (shaded blue).

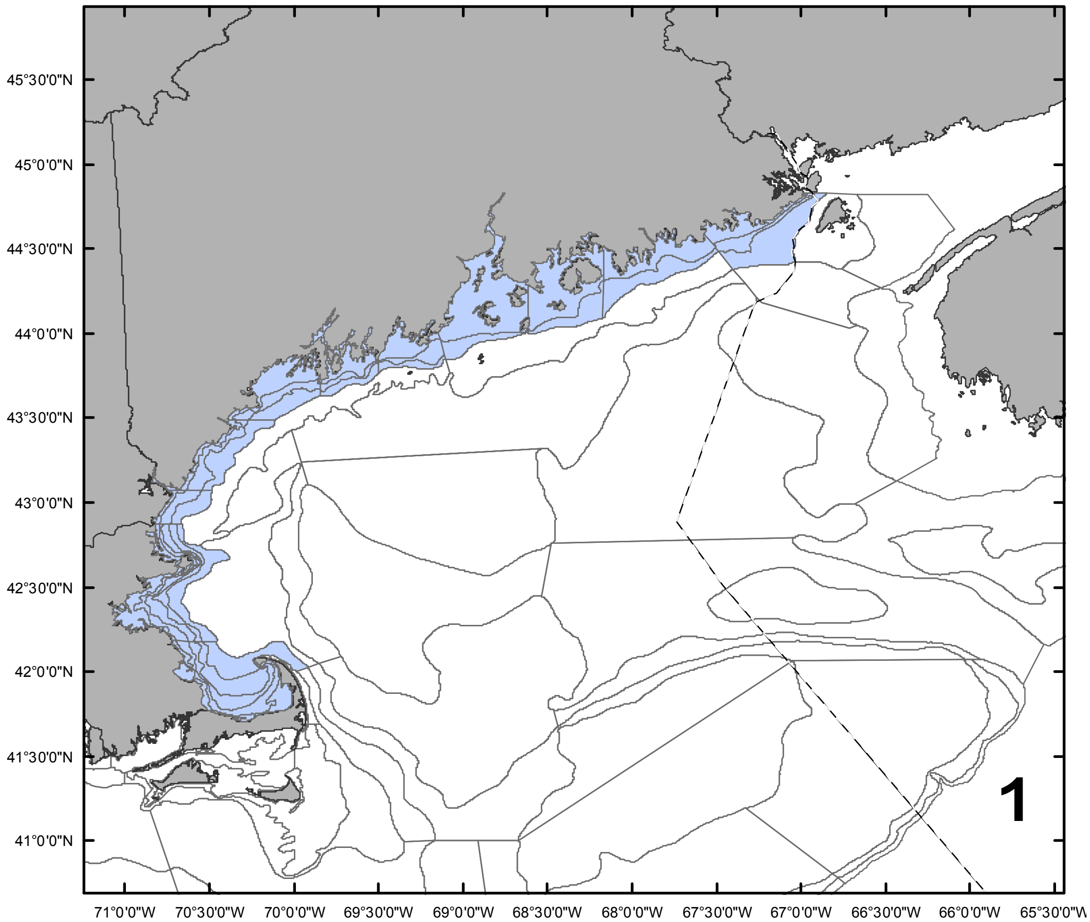


Figure A.86. Map of the Notheast Fisheries Science Center (NEFSC) bottom trawl inshore survey strata in the Gulf of Maine region (shaded blue).

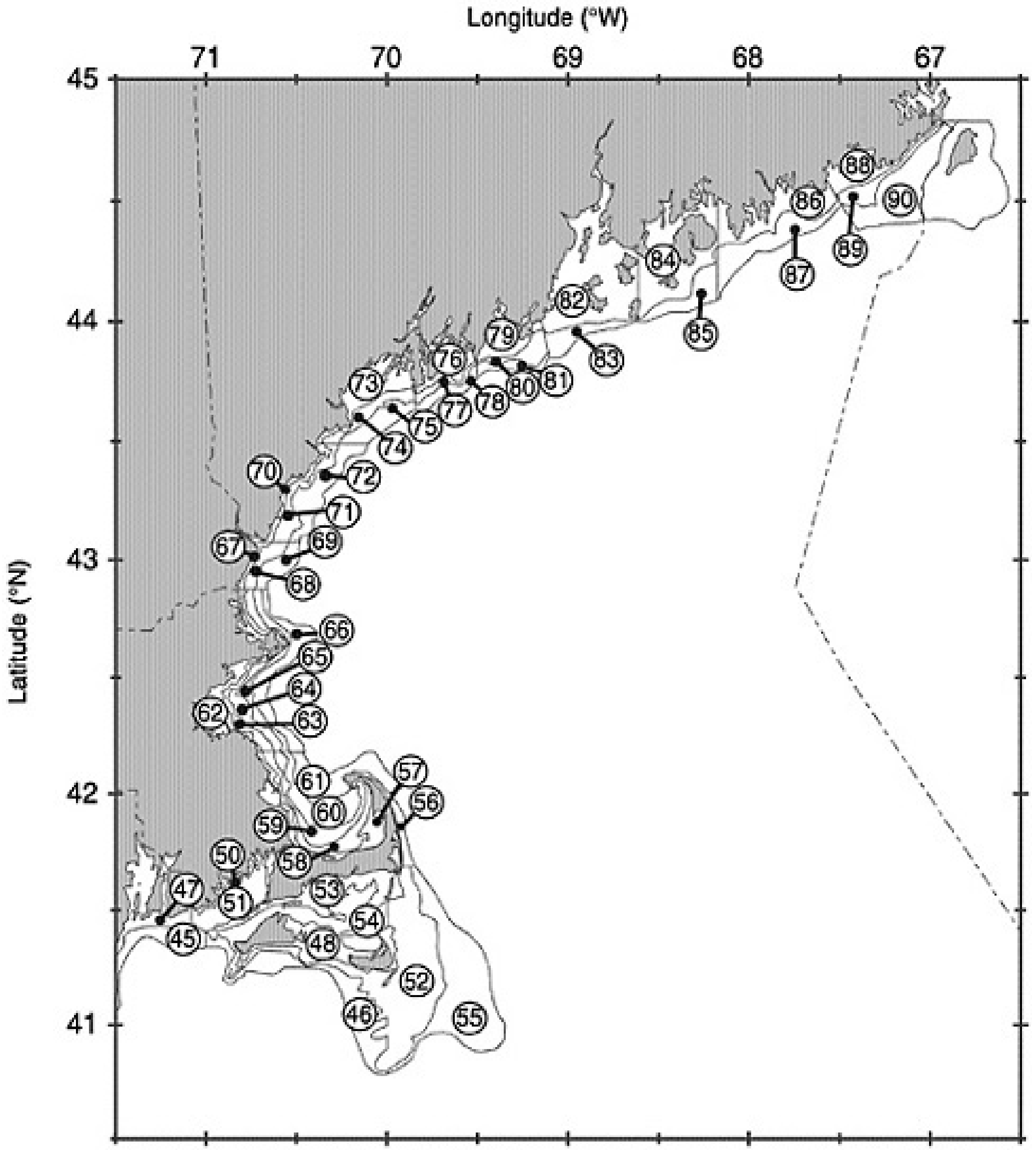


Figure A.87. Map identifying the inshore survey strata of the Notheast Fisheries Science Center (NEFSC) bottom trawl survey. **Note the survey strata are identified using their 2-digit labels. Strata identifiers are five-digit identifiers beginning with a two-digit prefix and one-digit suffix (e.g., the full identifier for inshore strata 66 is 03660).*

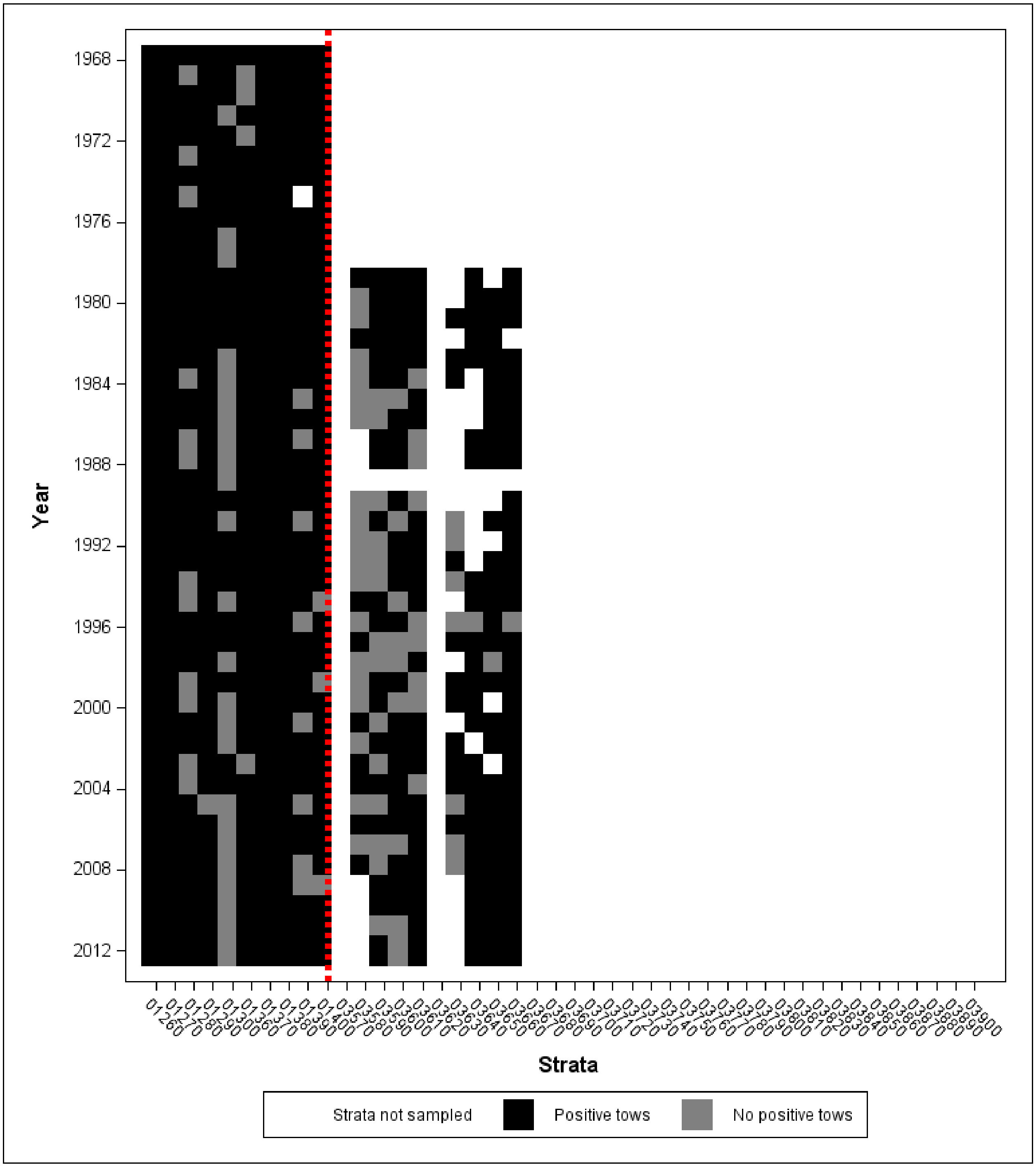


Figure A.88. Sampling summary of offshore (01 prefix) and inshore (03 prefix) strata in the Notheast Fisheries Science Center (NEFSC) spring bottom trawl survey from 1968-2012. Positive and negative tows are indicated with respect to catches of Gulf of Maine Atlantic cod.

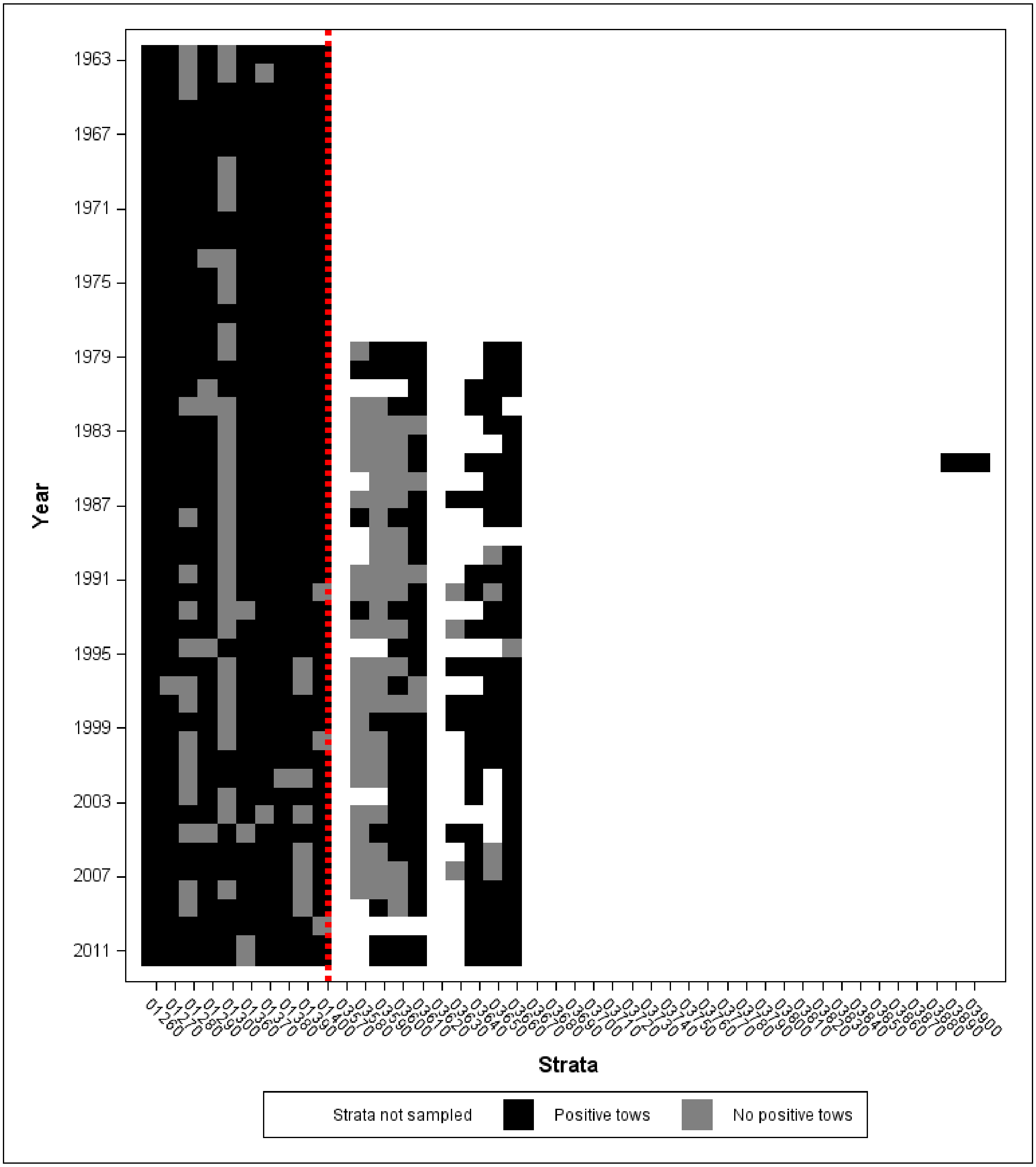


Figure A.89. Sampling summary of offshore (01 prefix) and inshore (03 prefix) strata in the Notheast Fisheries Science Center (NEFSC) fall bottom trawl survey from 1963-2011. Positive and negative tows are indicated with respect to catches of Gulf of Maine Atlantic cod.

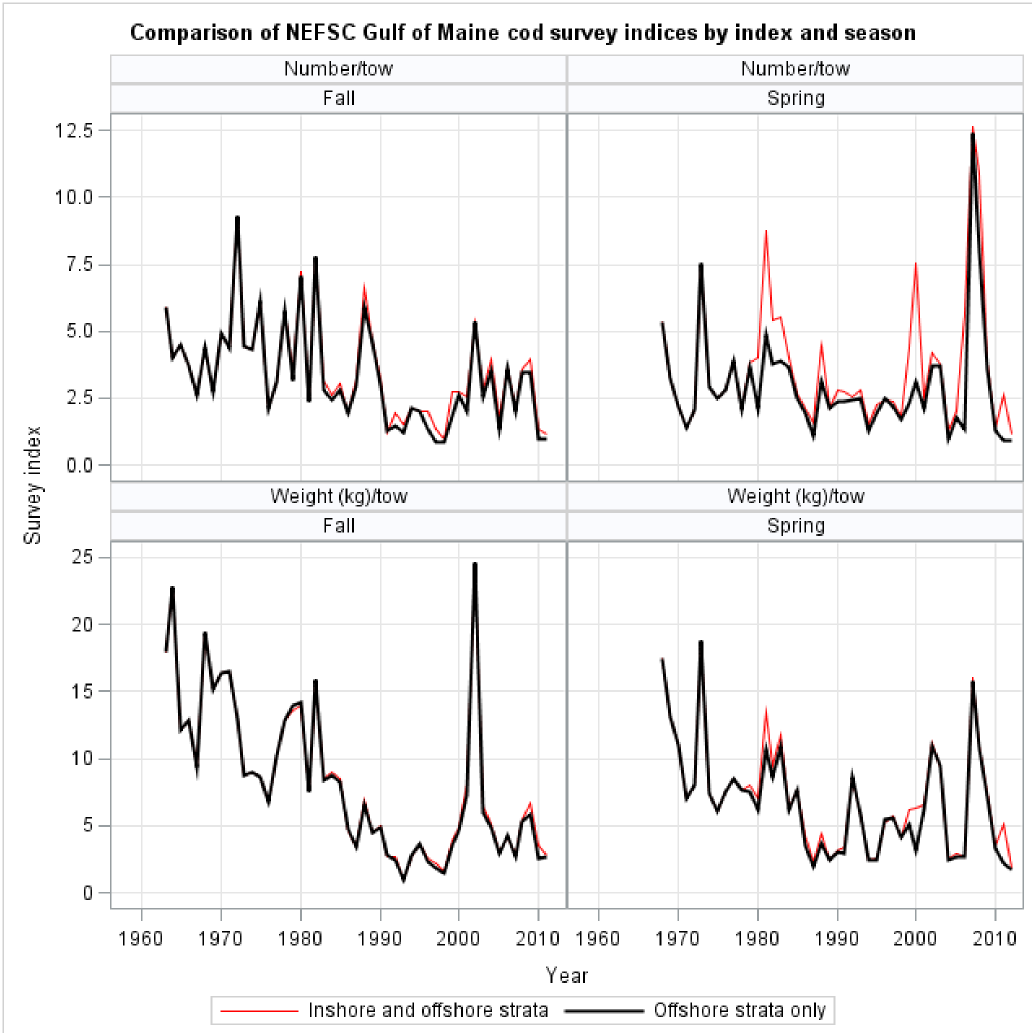
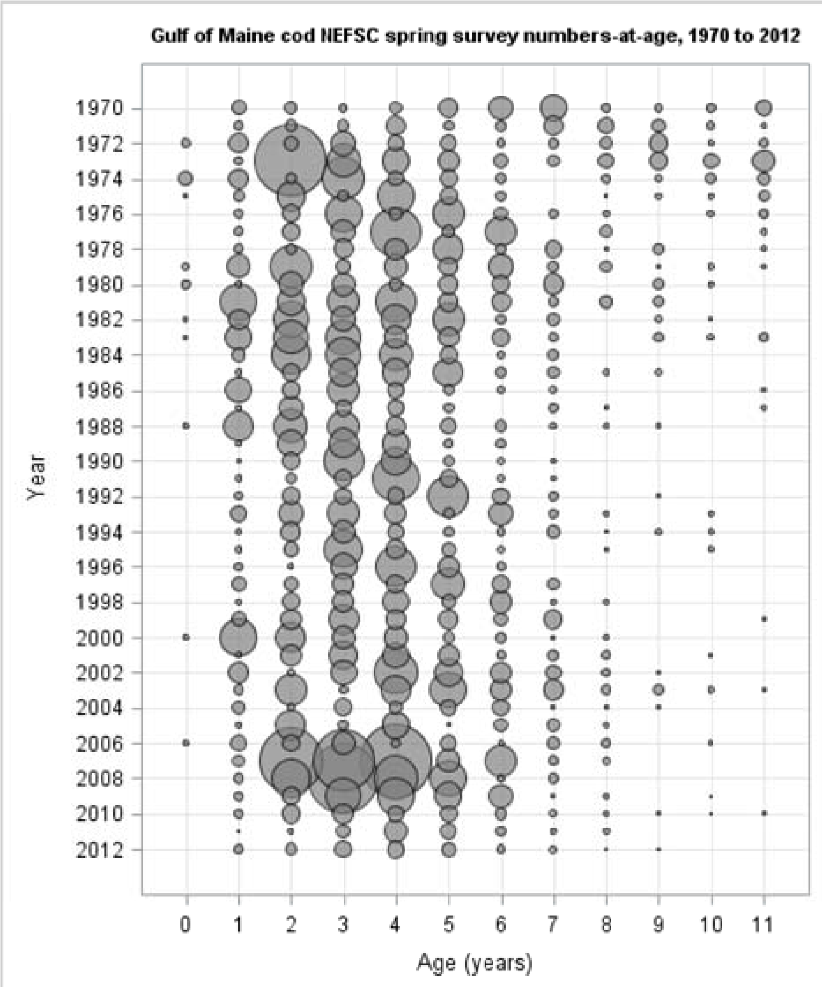


Figure A.90. Comparison of Notheast Fisheries Science Center (NEFSC) bottom trawl survey indices for Gulf of Maine Atlantic cod calculated using offshore strata (black) and both inshore and offshore survey strata (red).



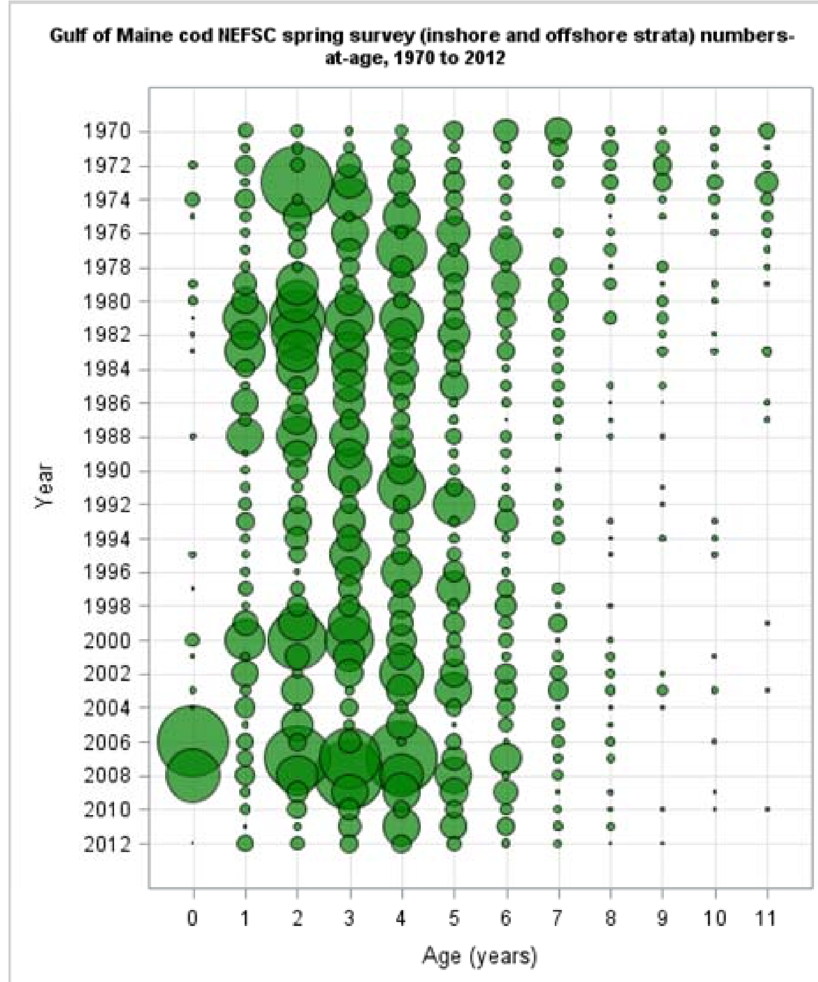
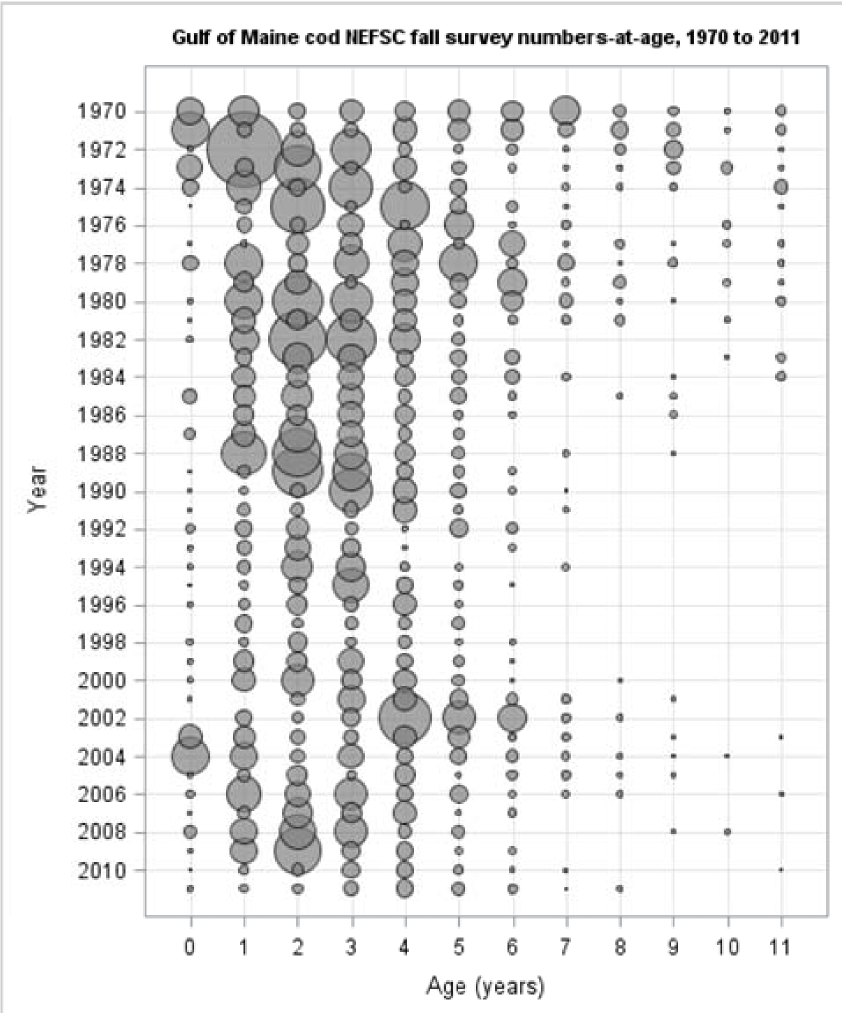


Figure A.91. Comparison of Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey numbers at age indices for Gulf of Maine Atlantic cod calculated using offshore strata (grey) and both inshore and offshore survey strata (green).



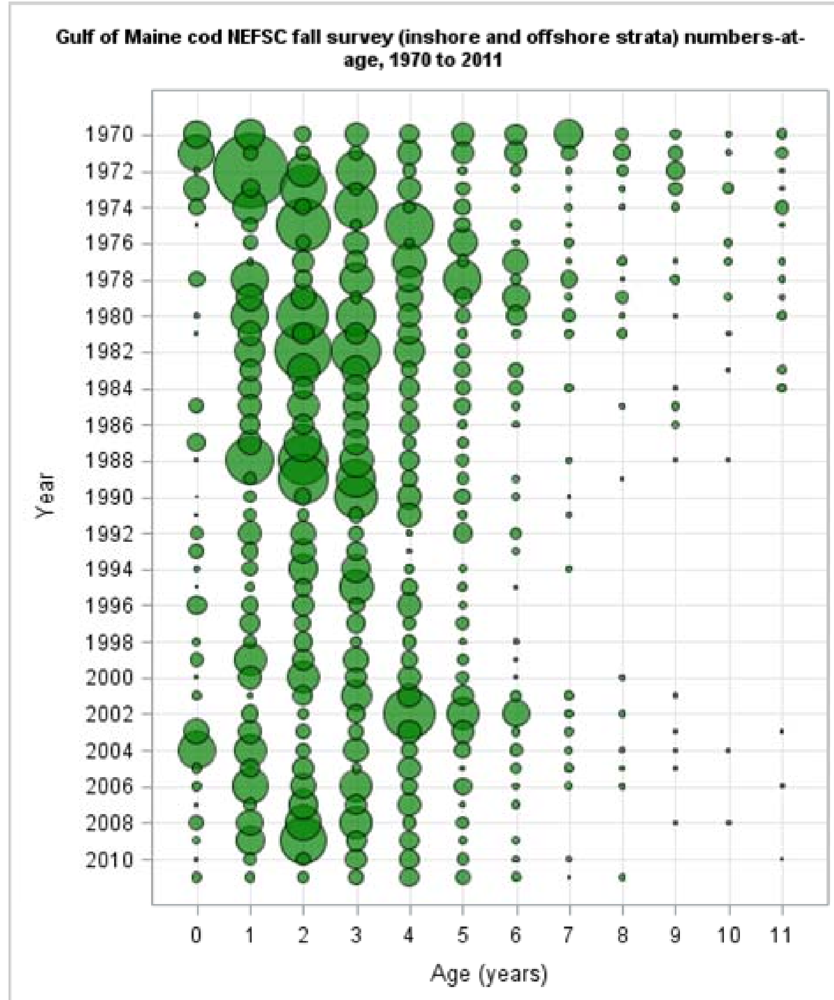


Figure A.92. Comparison of Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey numbers at age indices for Gulf of Maine Atlantic cod calculated using offshore strata (grey) and both inshore and offshore survey strata (green).

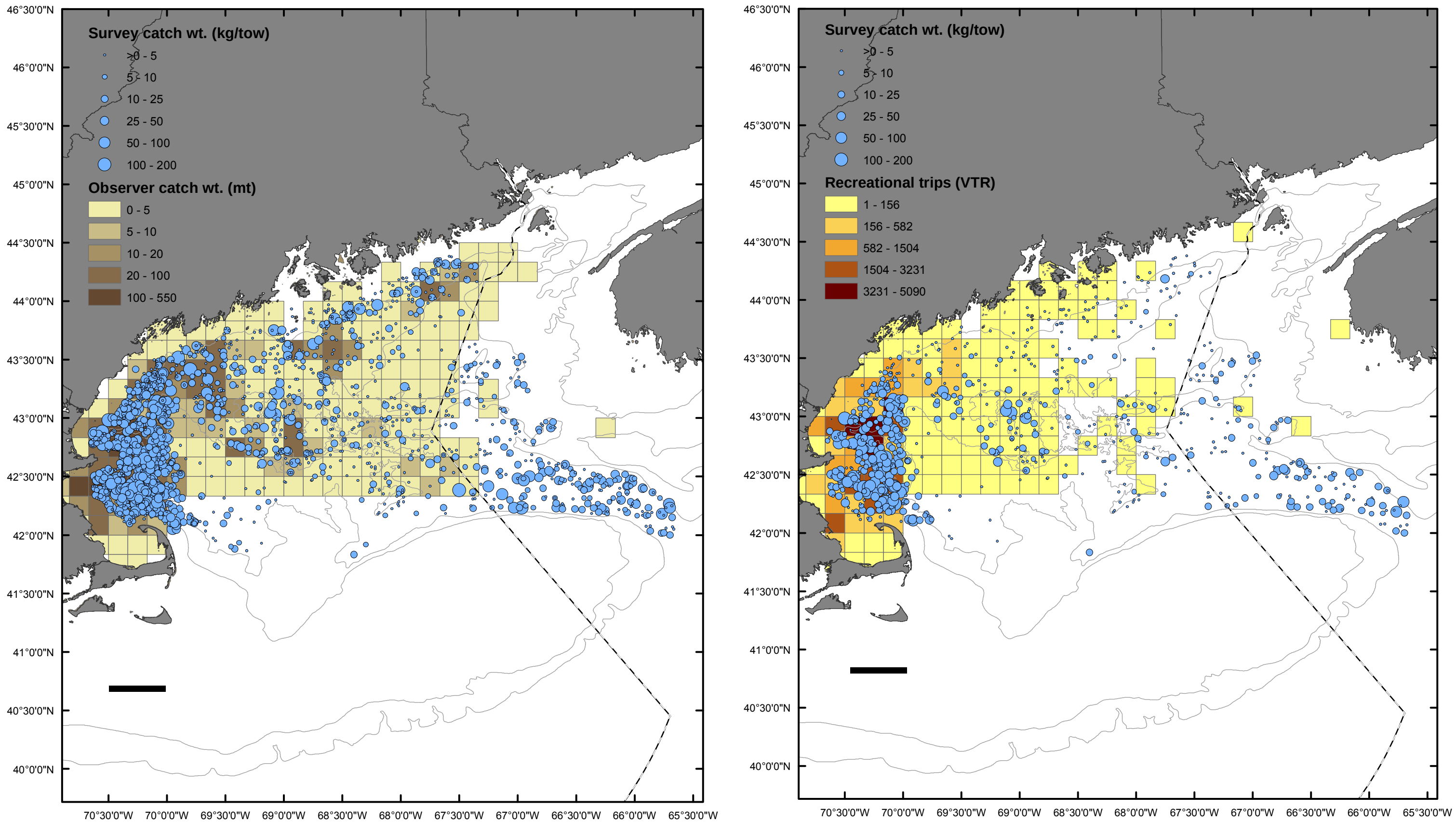


Figure A.93. Spatial overlap of survey catches (kg/tow) of Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey (spring and fall combined) and commercial and recreational fishing effort. On the left, NEFSC survey catches from 1989 – 2010 are overlayed on total observed cod catch (landings and discards) binned to ten minute squares from the same time period. On the right, NEFSC survey catches from 1994 – 2010 are overlayed on the number of VTR-reported recreational trips that caught cod binned to ten minute squares. **Note the different time periods used in each plot.*

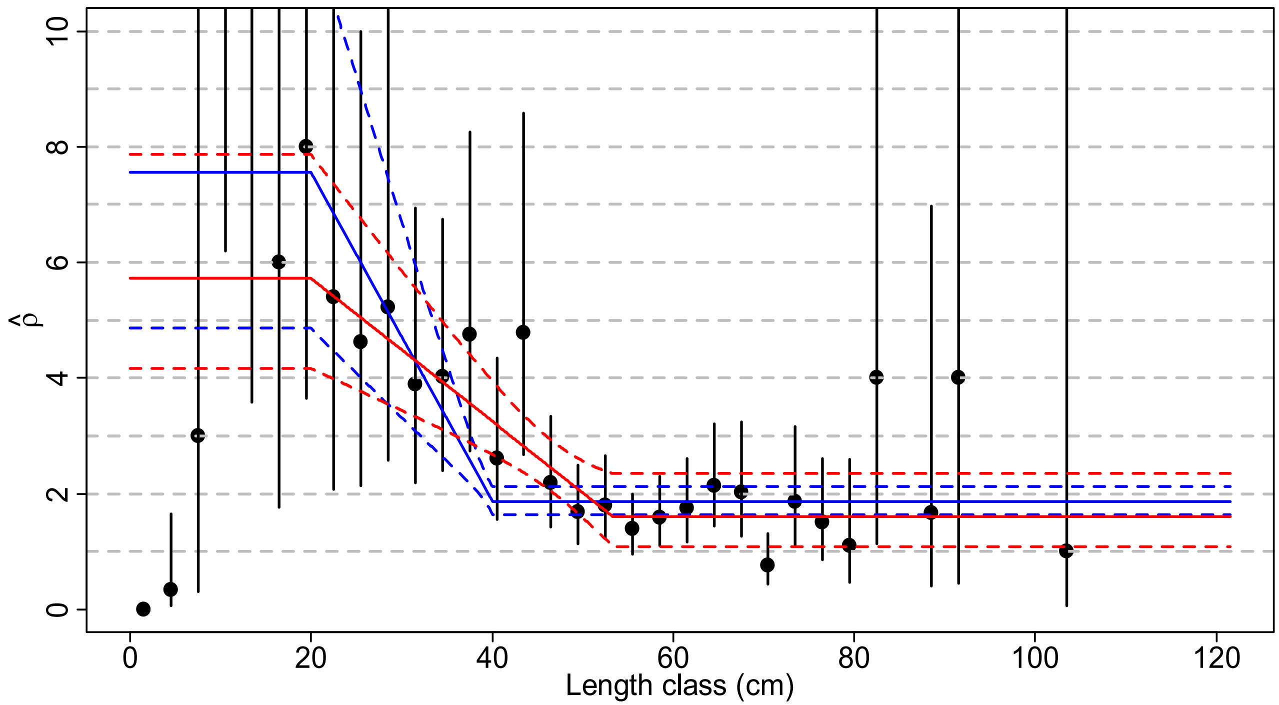


Figure A.94. Beta-binomial-based estimates of calibration factors and corresponding 95% confidence intervals by length class (3 cm bins) for Atlantic cod. The black points and vertical bars represent results where different calibration factors are estimated for each length class. The blue lines represent results from a segmented regression model where the two points connecting the segments are known (20 and 40 cm) and the red lines represent results from a segmented regression model where the first point (20 cm) is known but the second is estimated. Segmented regression fits are based on data from fish ≥20 cm (from Brooks et al. 2010).

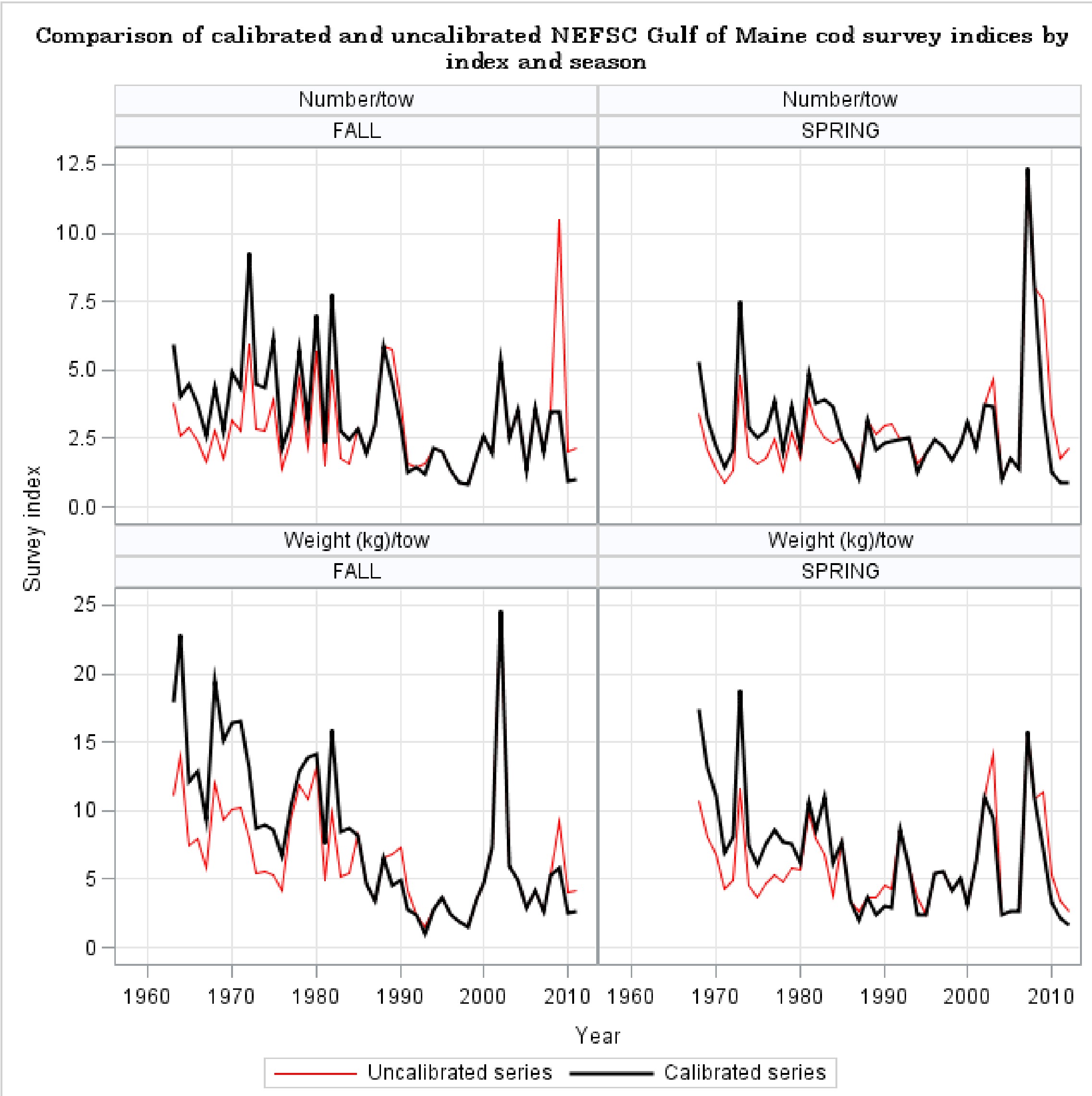


Figure A.95. Northeast Fisheries Science Center spring (right panels) and fall (left panels) survey indices of abundance (top panels) and biomass (bottom panels) showing both raw (unconverted) and vessel, door and survey converted indices over time for Gulf of Maine Atlantic cod.

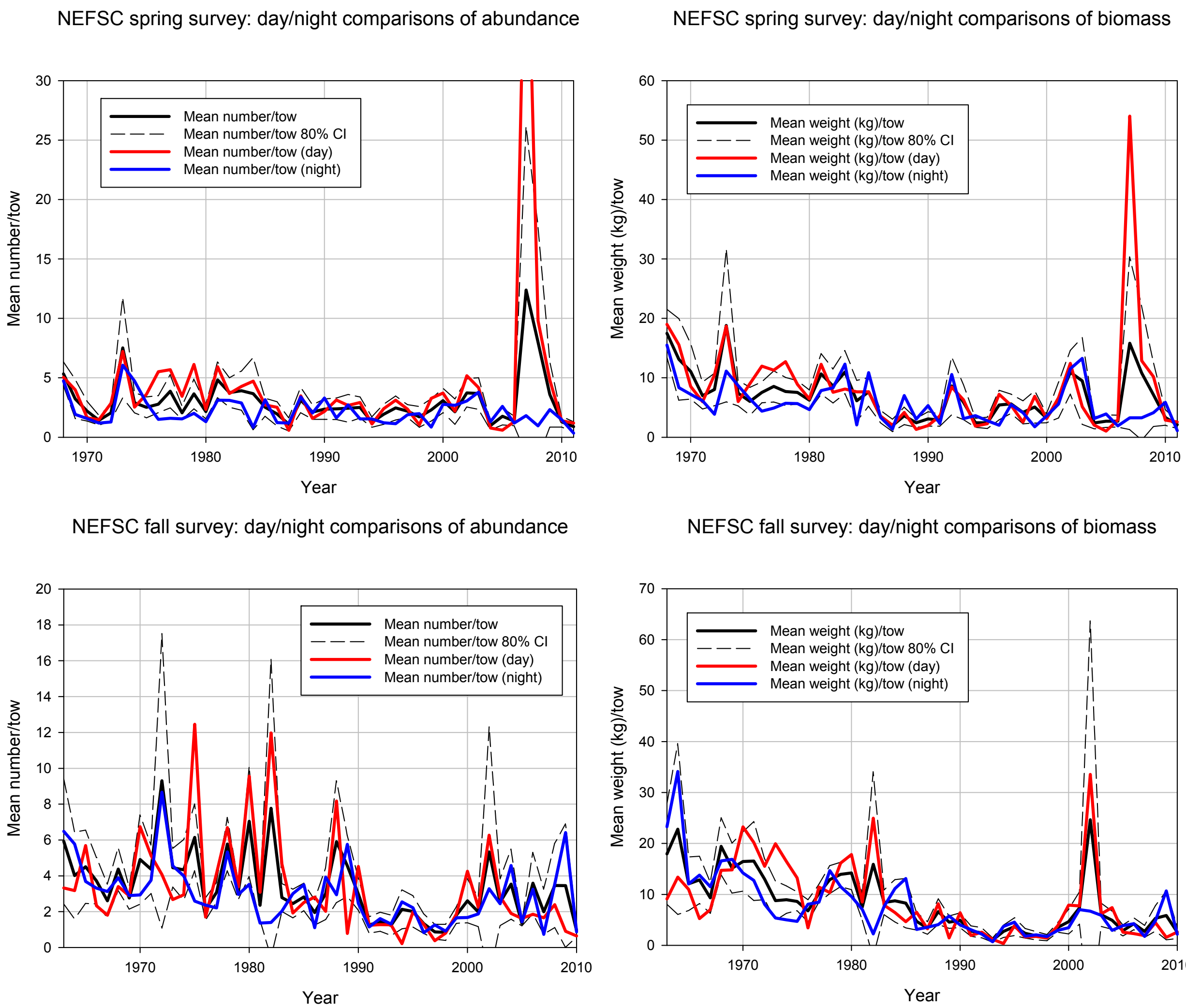
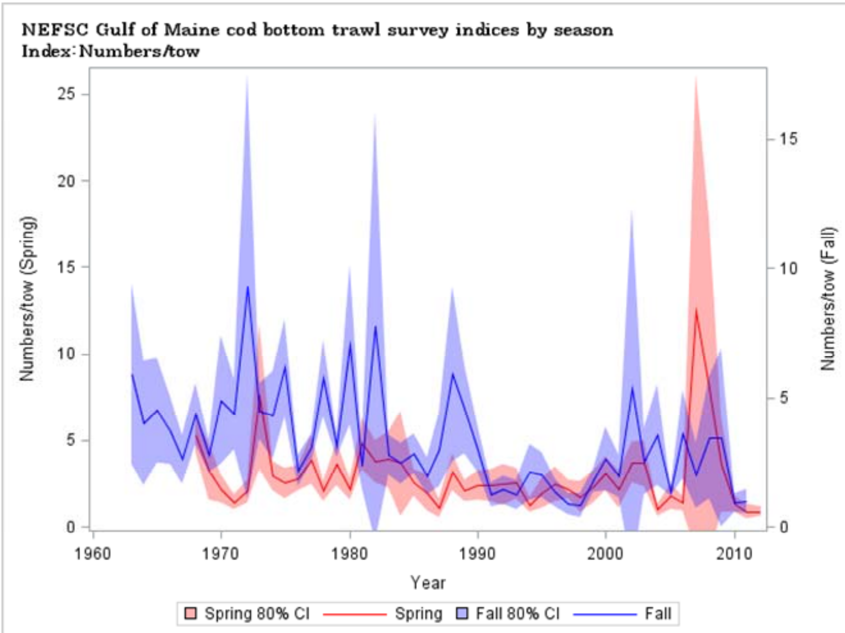


Figure A.96. Northeast Fisheries Science Center spring (top panels) and fall (bottom panels) survey indices of abundance (left panels) and biomass (right panels) broken down by day- and night-only tows compared to the aggregate index (day and night tows combined) and its associated 80% confidence interval (CI) for Gulf of Maine Atlantic cod.



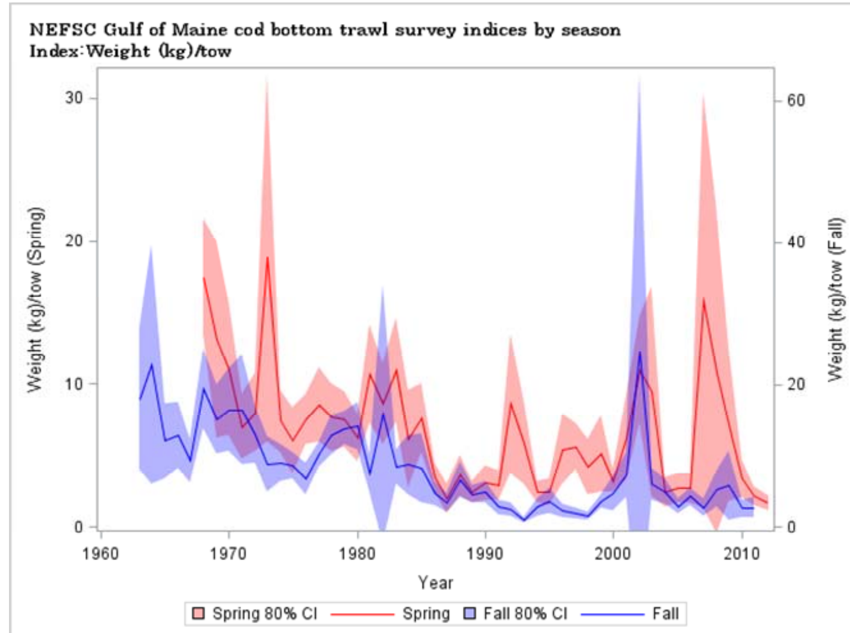
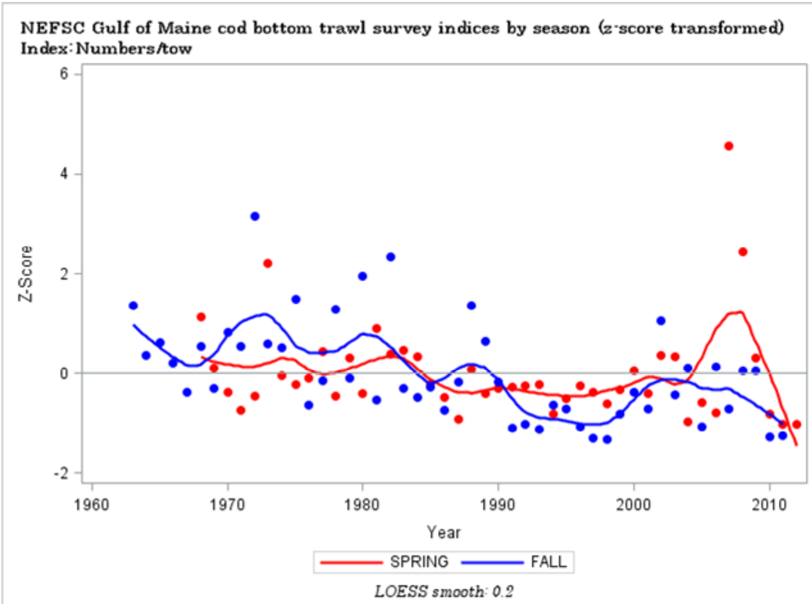


Figure A.97. Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl survey abundance (left) and biomass (right) indices for Gulf of Maine Atlantic cod from 1963 to 2012. **Note, the spring survey did not begin until 1968, 2012 fall survey data not available at time of this report.*



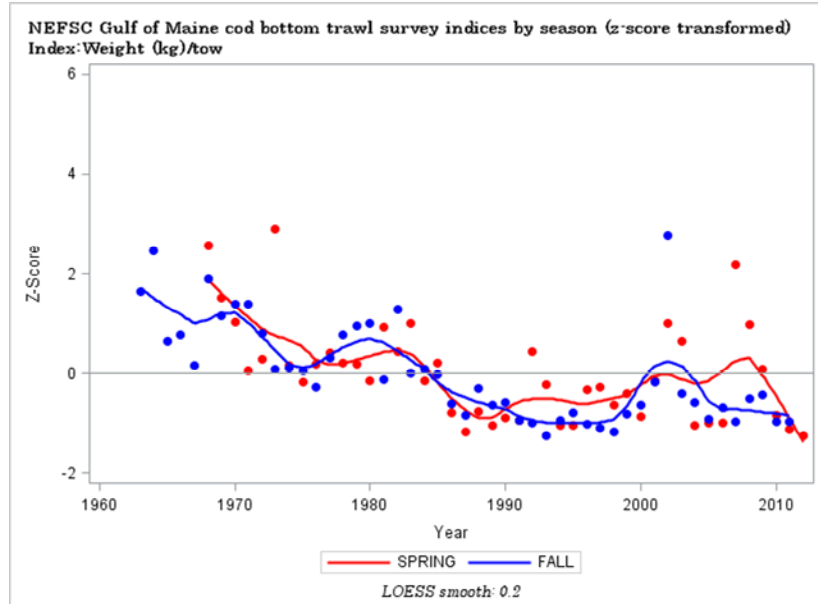


Figure A.98. Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl survey abundance (left) and biomass (right) indices for Gulf of Maine Atlantic cod from 1963 to 2012 expressed as z-scores ([*x*-µ]/σ). **Note, the spring survey did not begin until 1968, 2012 fall survey data not available at time of this report.*

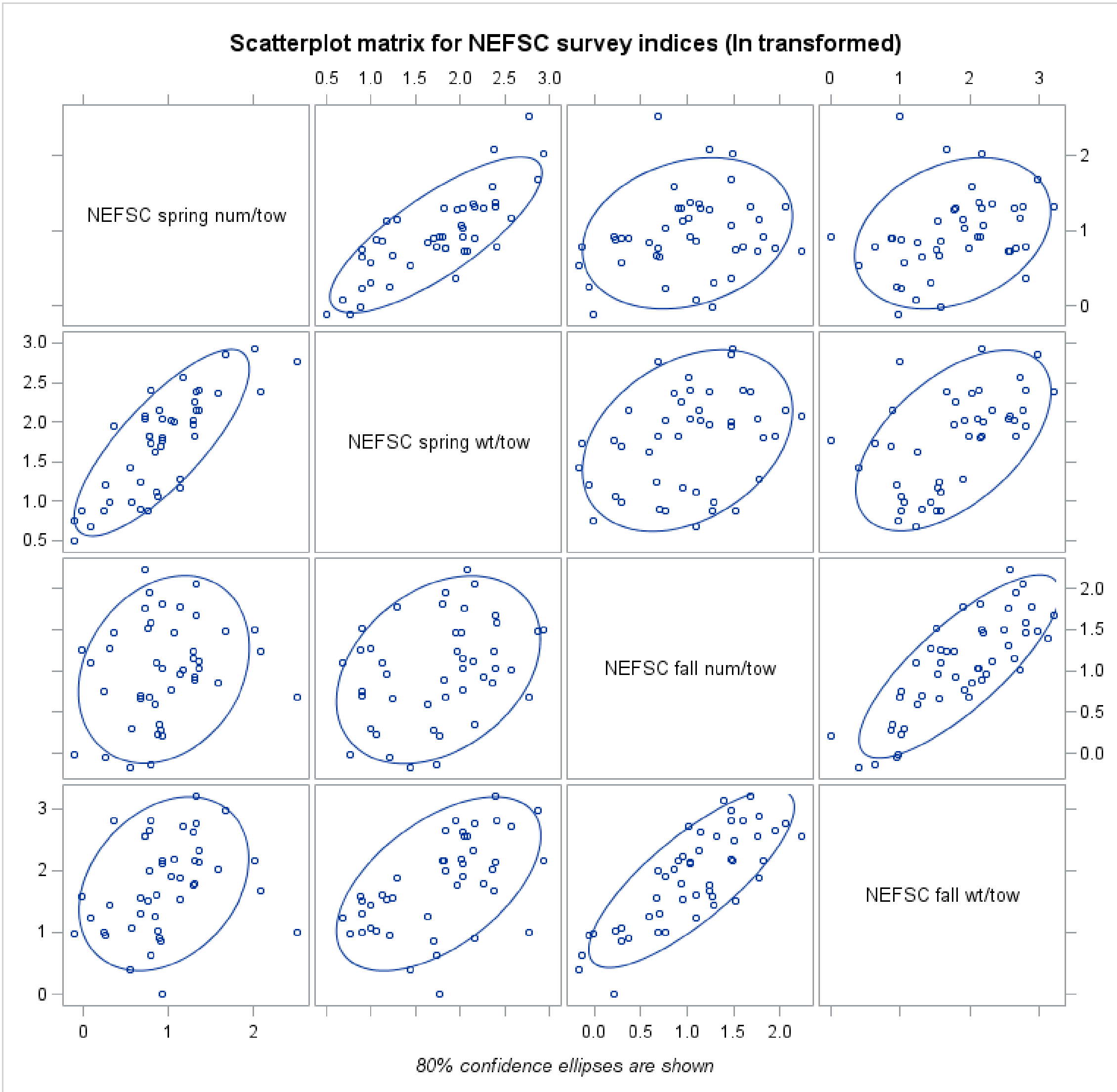


Figure A.99. Scatter plots showing the level of agreement between Northeast Fisheries Science Center (NEFSC) bottom trawl survey indices (log transformed) of Gulf of Maine Atlantic cod. 80% confidence ellipses are shown.

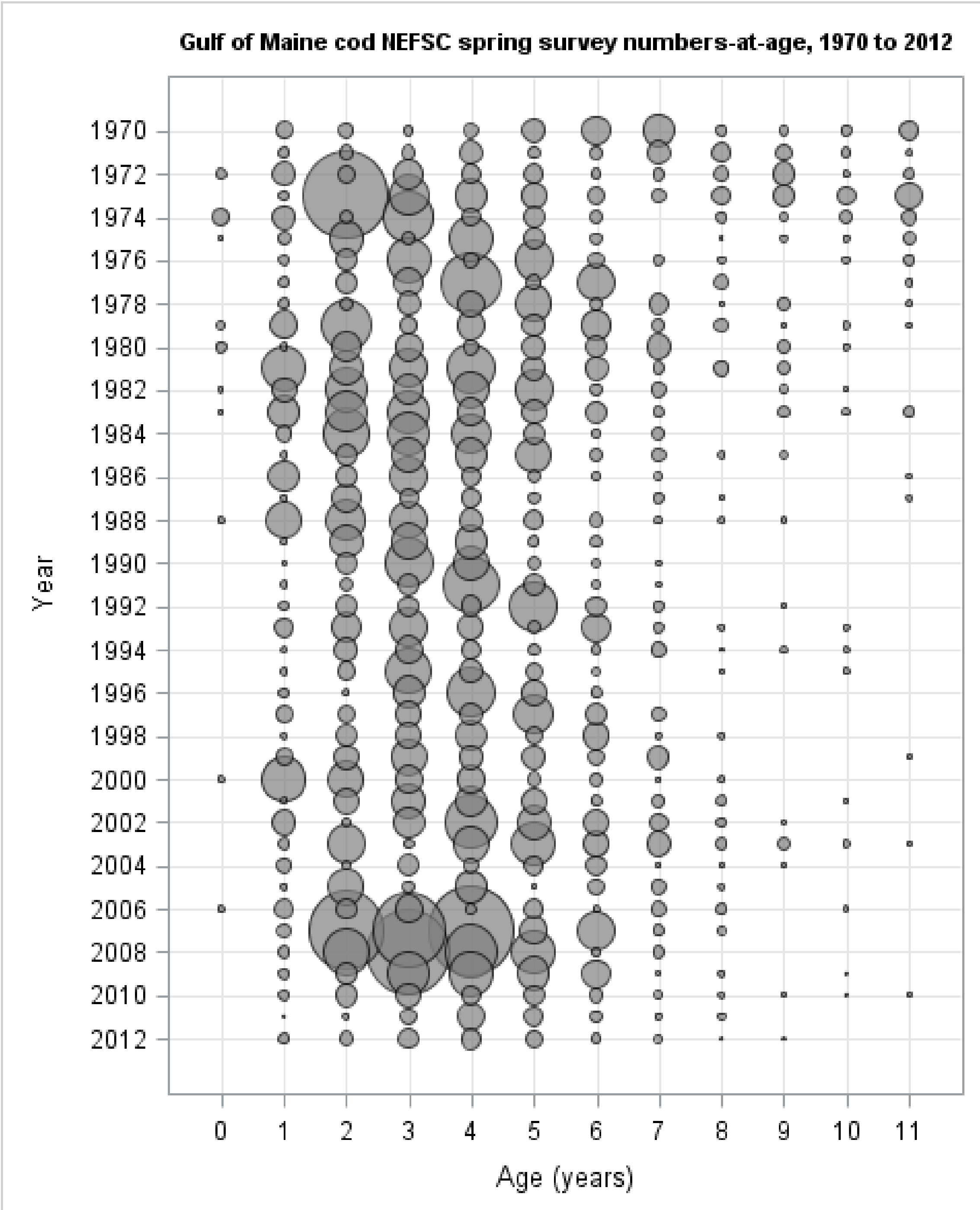


Figure A.100. Numbers-at-age from NEFSC spring bottom trawl survey from 1970 to 2012 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

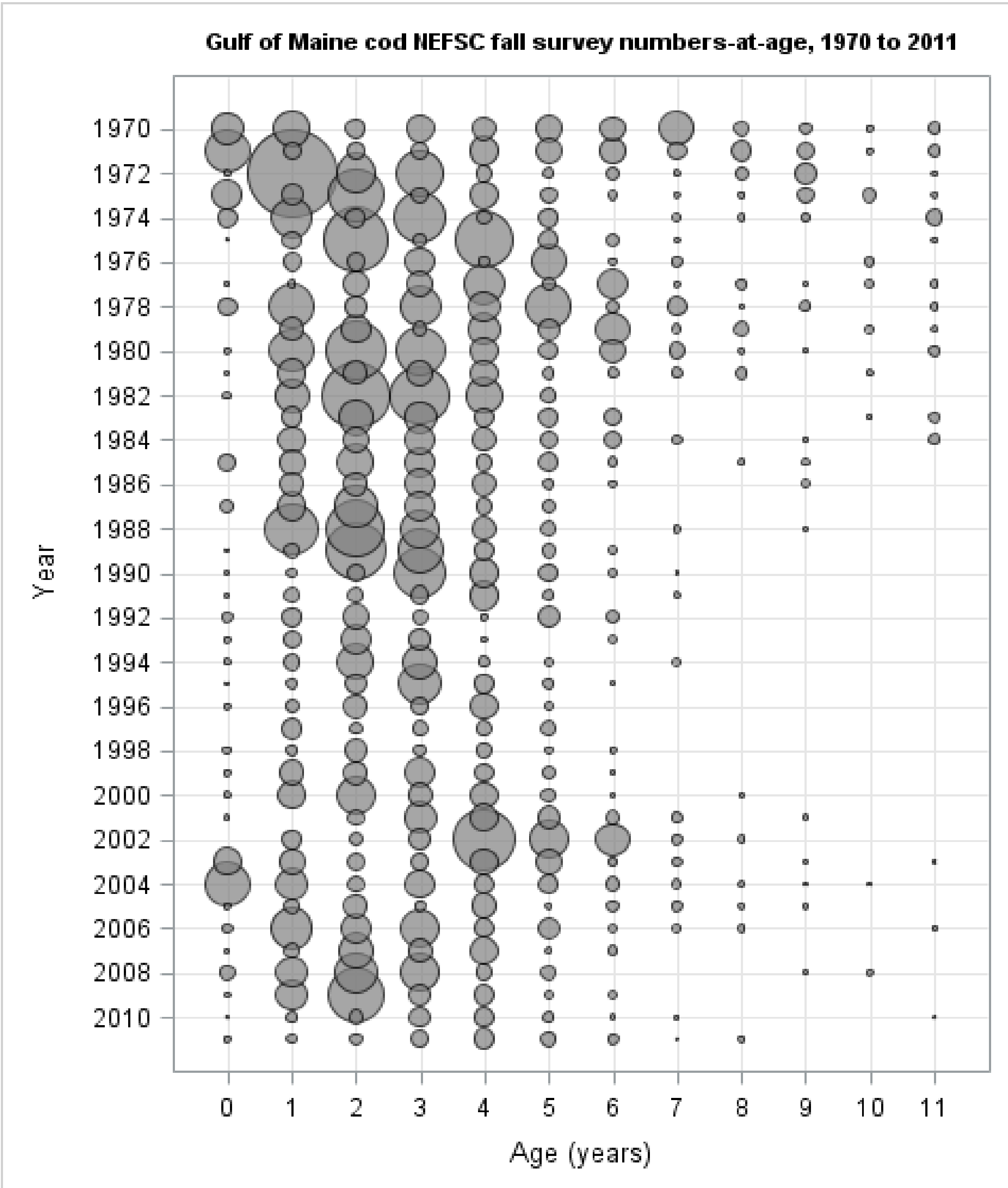


Figure A.101. Numbers-at-age from NEFSC fall bottom trawl survey from 1970 to 2011 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

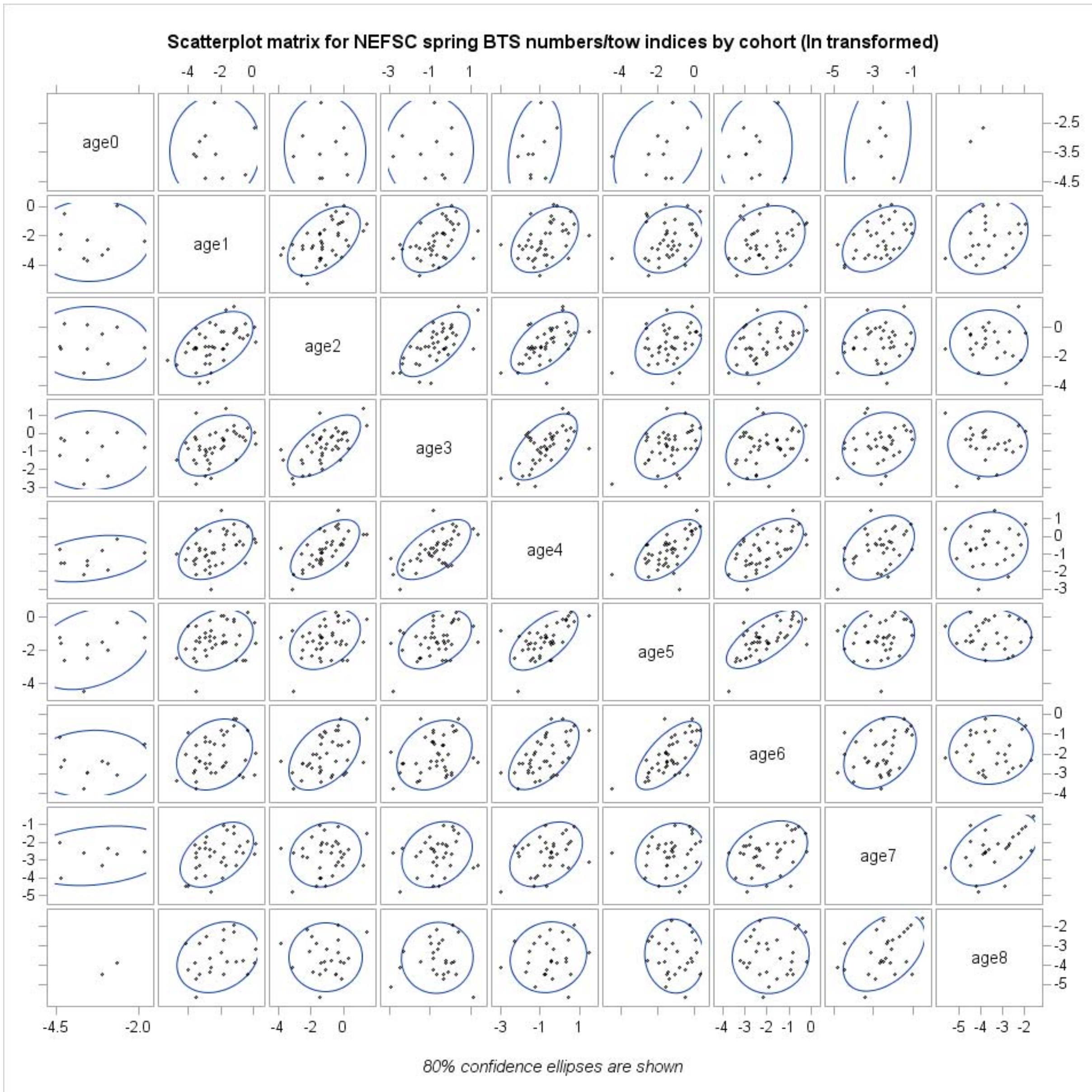


Figure A.102. Scatter plots showing the level of agreement between Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey Gulf of Maine Atlantic cod indices at age (log transformed) on a cohort basis. 80% confidence ellipses are shown.

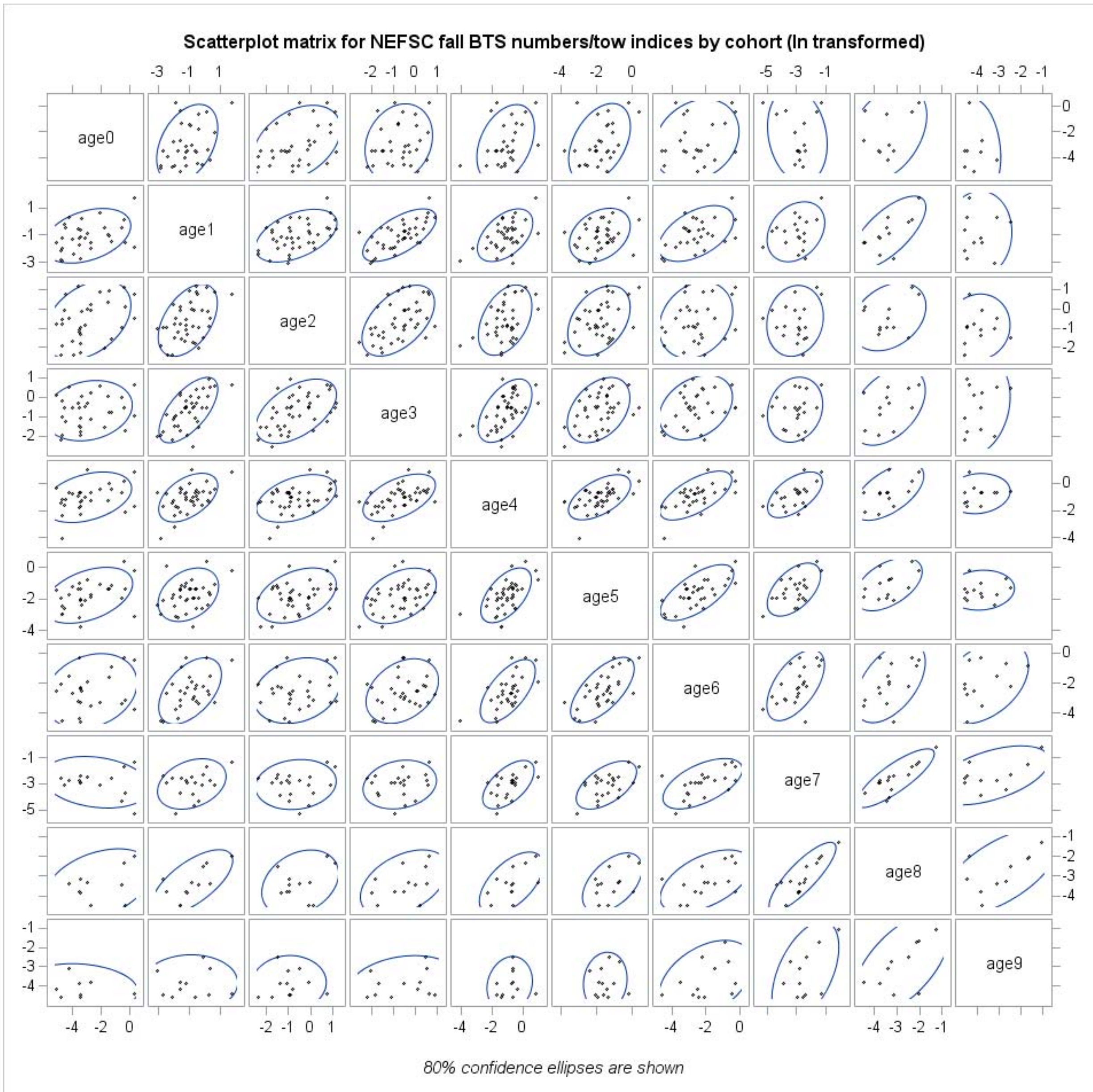


Figure A.103. Scatter plots showing the level of agreement between Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey Gulf of Maine Atlantic cod indices at age (log transformed) on a cohort basis. 80% confidence ellipses are shown.

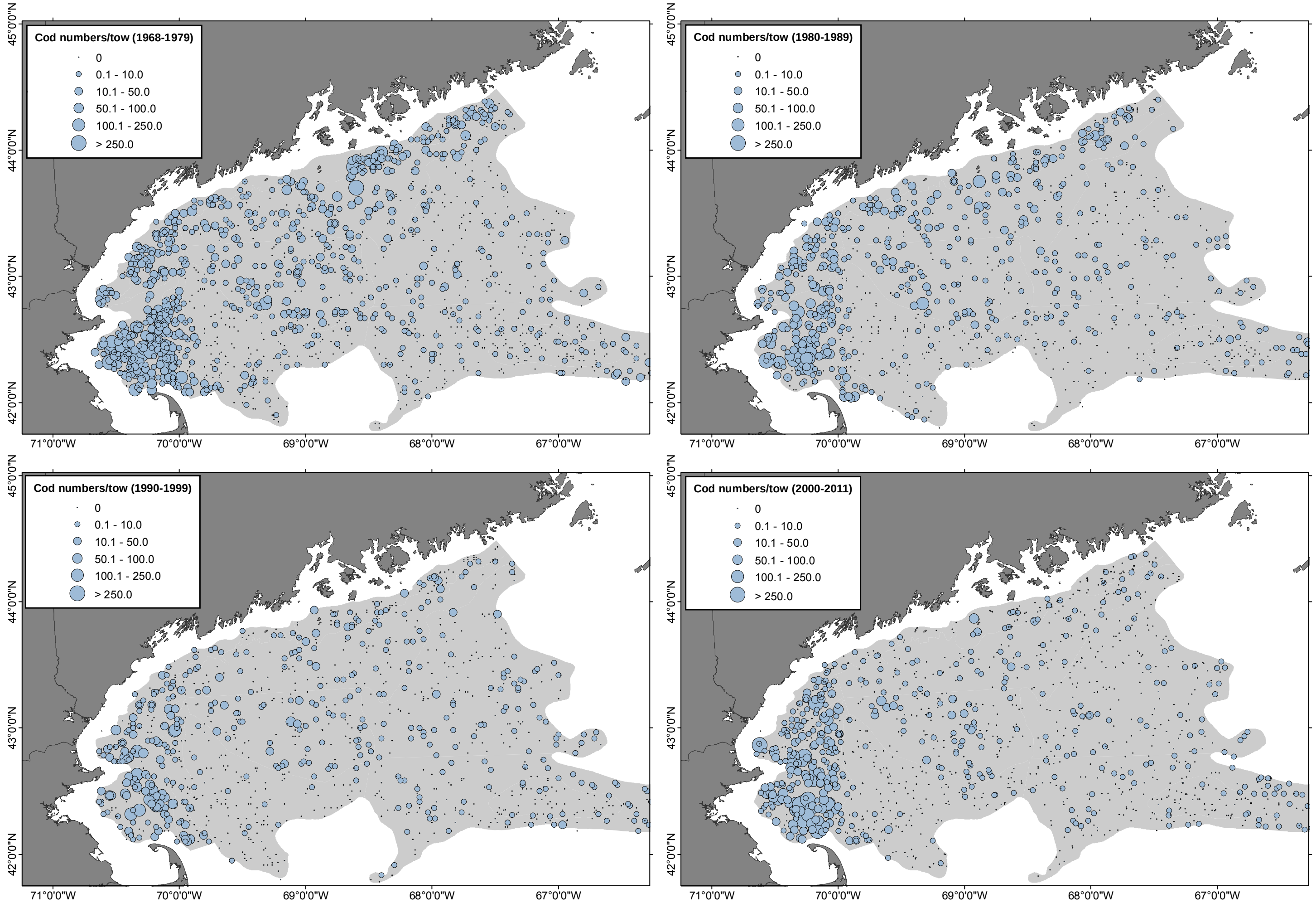


Figure A.104. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the Northeast Fisheries Science Center spring bottom trawl survey from 1968 – 2011. Periods are as follows: 1968 – 1979 (top left), 1980 – 1989 (top right), 1990 – 1999 (bottom left), 2000-2011 (bottom right).

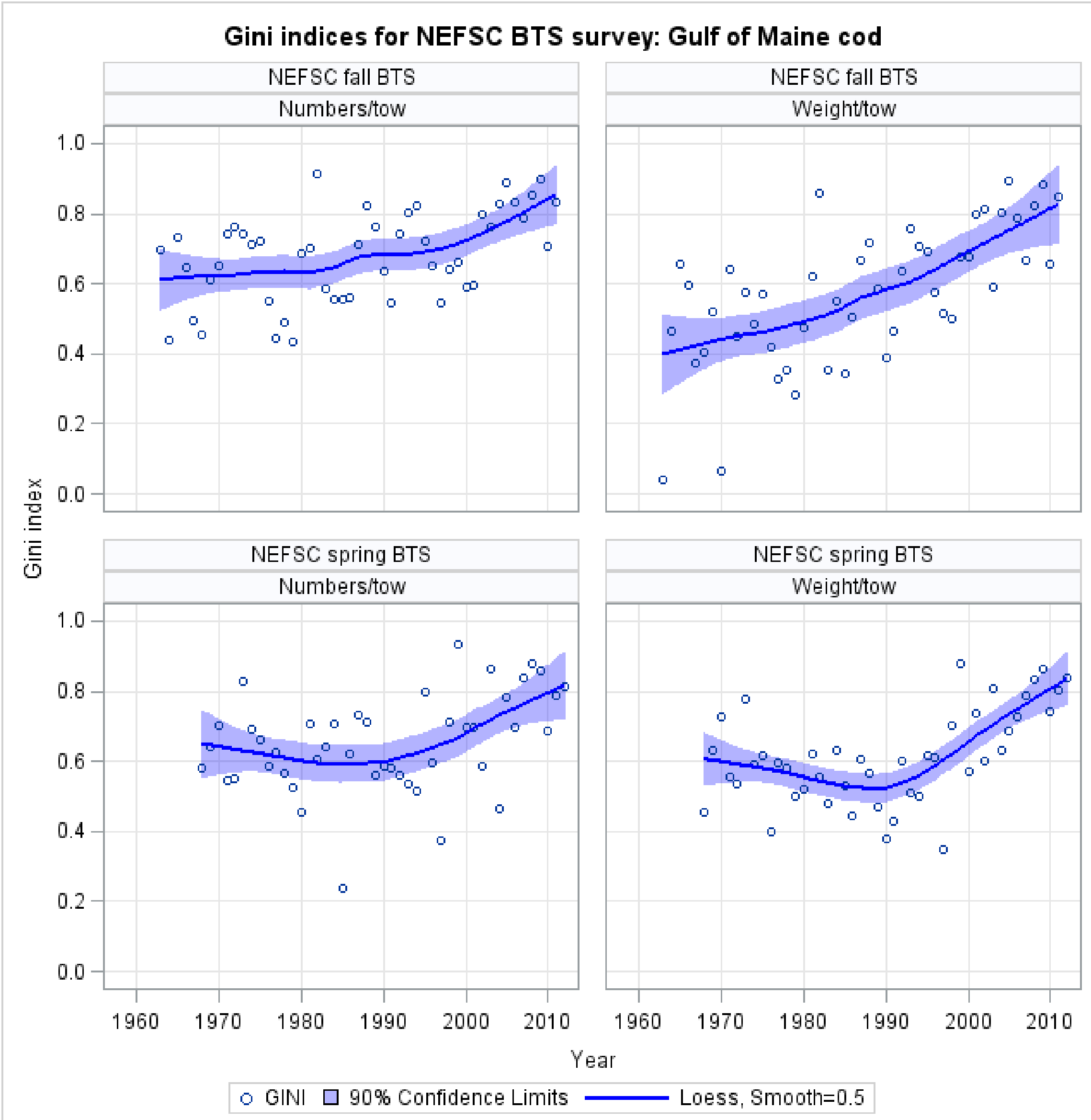


Figure A.105. Gini indices for Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) fall (top) and spring (bottom) bottom trawl surveys in terms of abundance (numbers/tow, left) and biomass (kg/tow, right). A loess smooth has been fit to the data with smoothing parameter of 0.5. The loess smooth is shown by the solid blue line along with the corresponding 90% confidence interval.

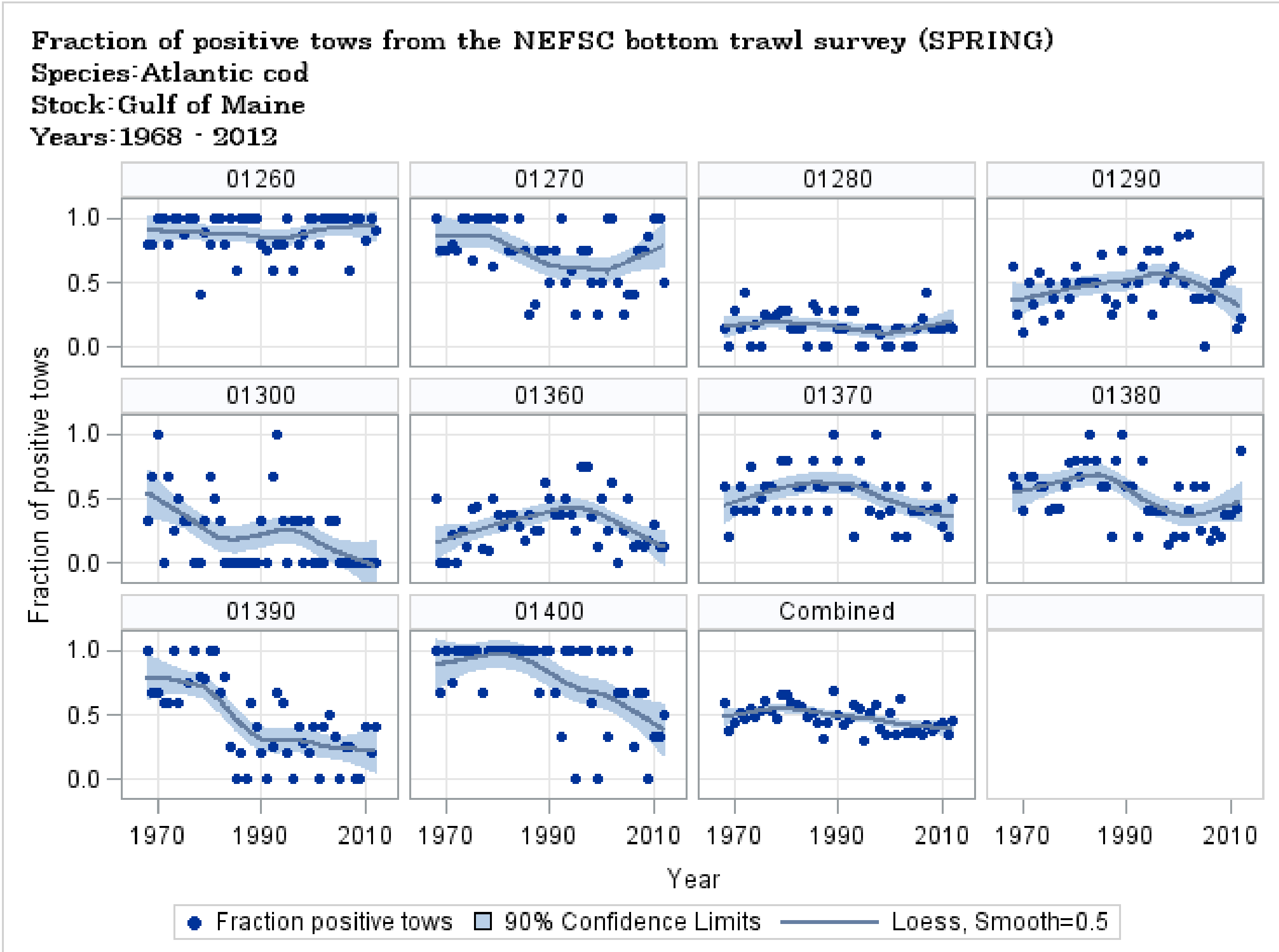


Figure A.106. Fraction of Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey tows with positive catches of Gulf of Maine Atlantic cod by strata from 1968-2012.

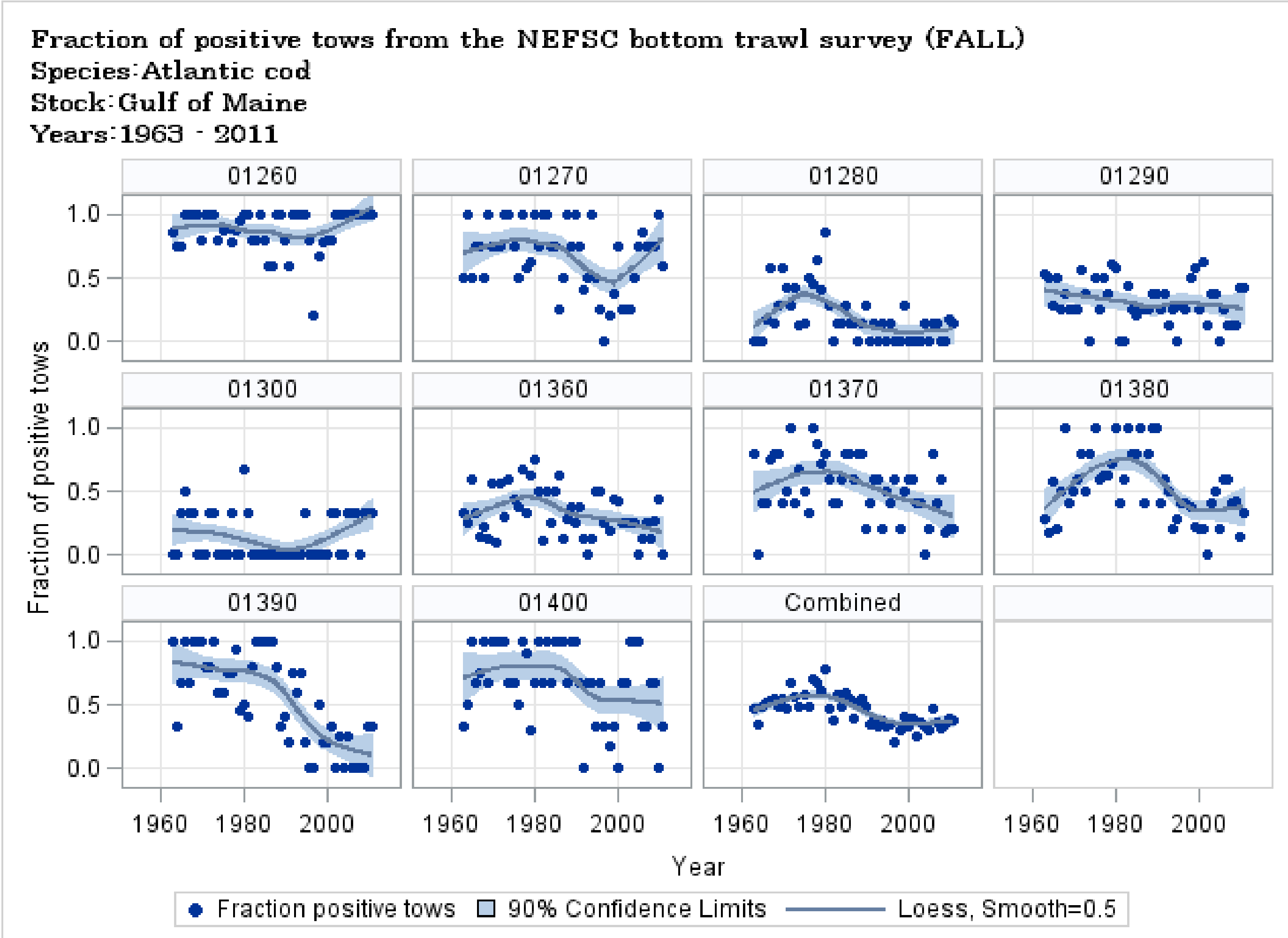


Figure A.107. Fraction of Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey tows with positive catches of Gulf of Maine Atlantic cod by strata from 1963-2012.

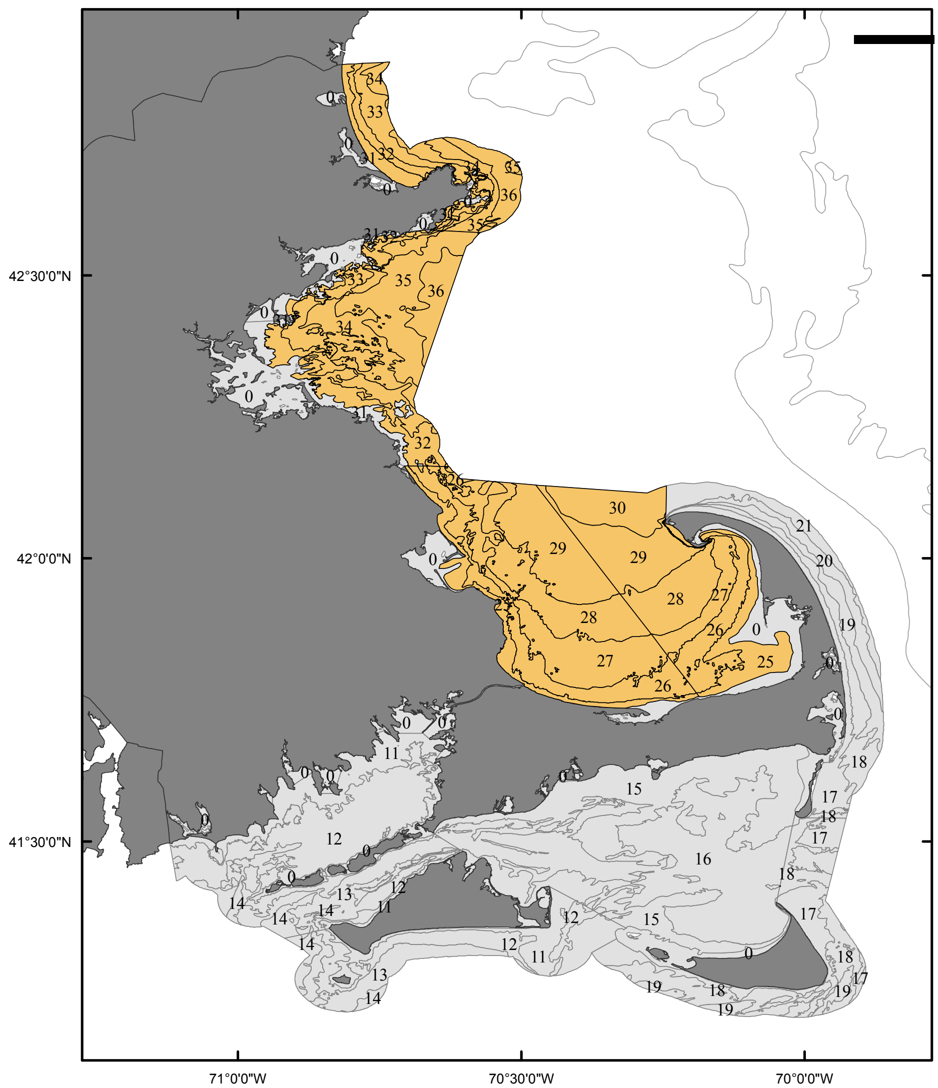
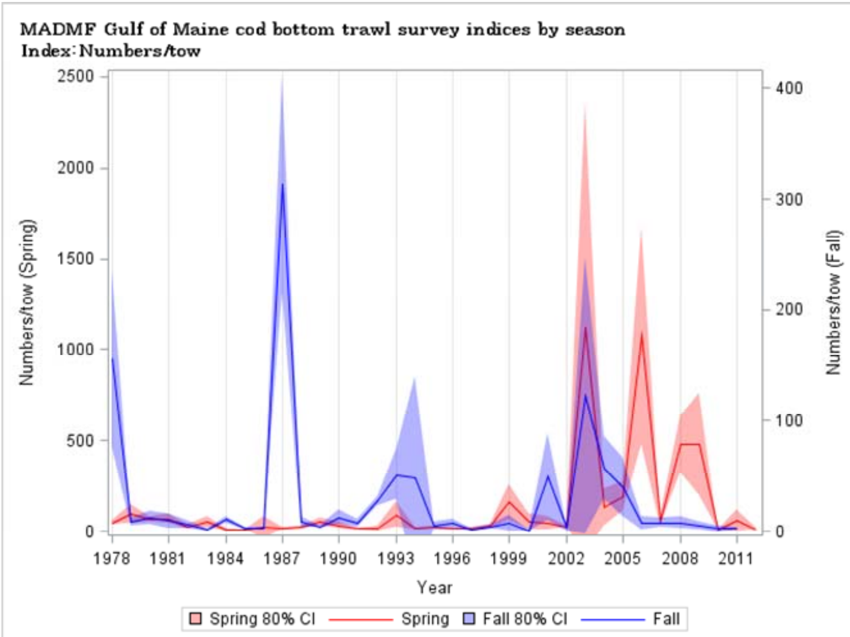


Figure A.108. Map of the Massachusetts Deparment of Marine Fisheries (MADMF) bottom trawl survey strata included in the Gulf of Maine Atlantic cod stock assessment (shaded orange).



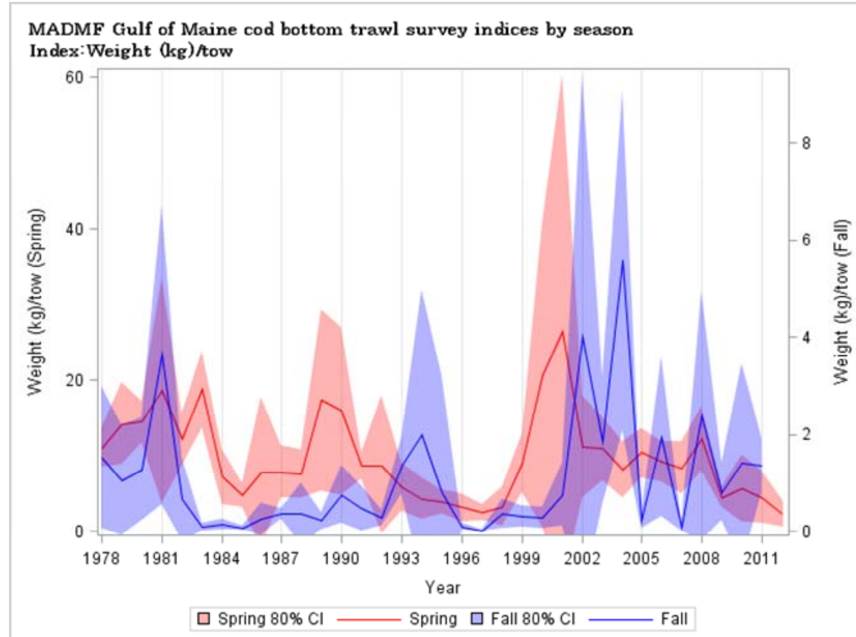


Figure A.109. Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey abundance (top) and biomass (bottom) indices of Gulf of Maine Atlantic cod from 1978 to 2012. **Note, 2012 fall survey data not available at time of this report.*

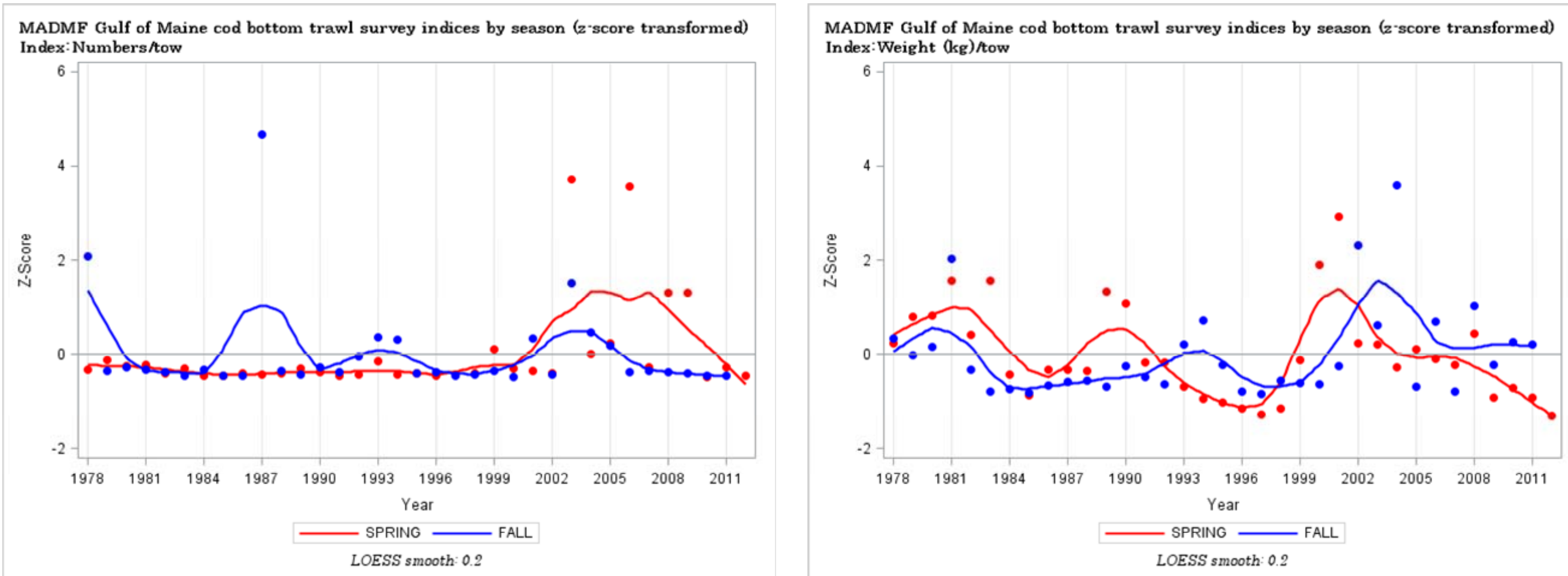


Figure A.110. Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey abundance (top) and biomass (bottom) indices of Gulf of Maine Atlantic cod from 1978 to 2012 expressed as z-scores ([x-μ]/σ). **Note, 2012 fall survey data not available at time of this report.*

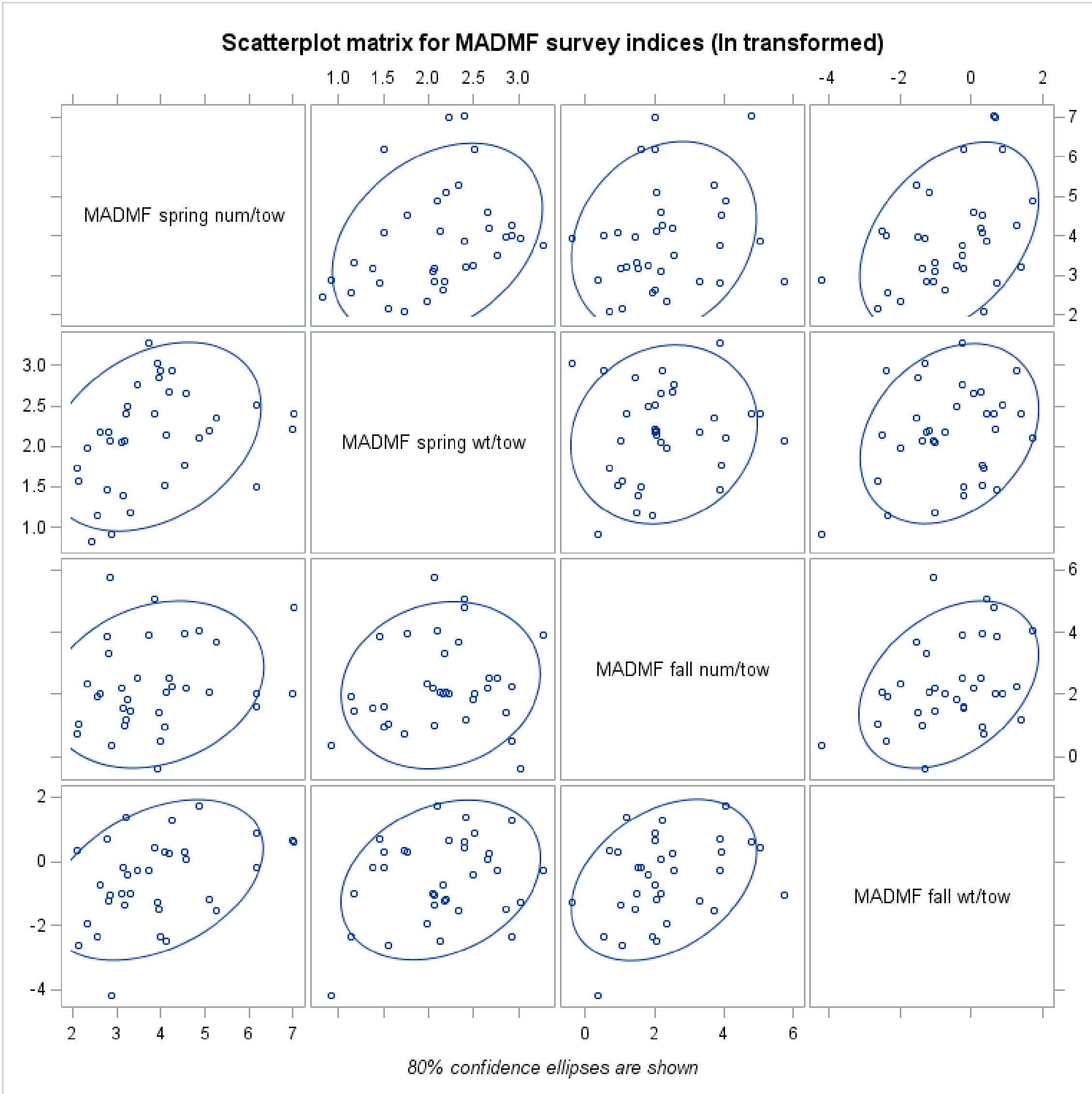


Figure A.111. Scatter plots showing the level of agreement between the Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey Gulf of Maine Atlantic cod indices (log transformed). 80% confidence ellipses are shown.

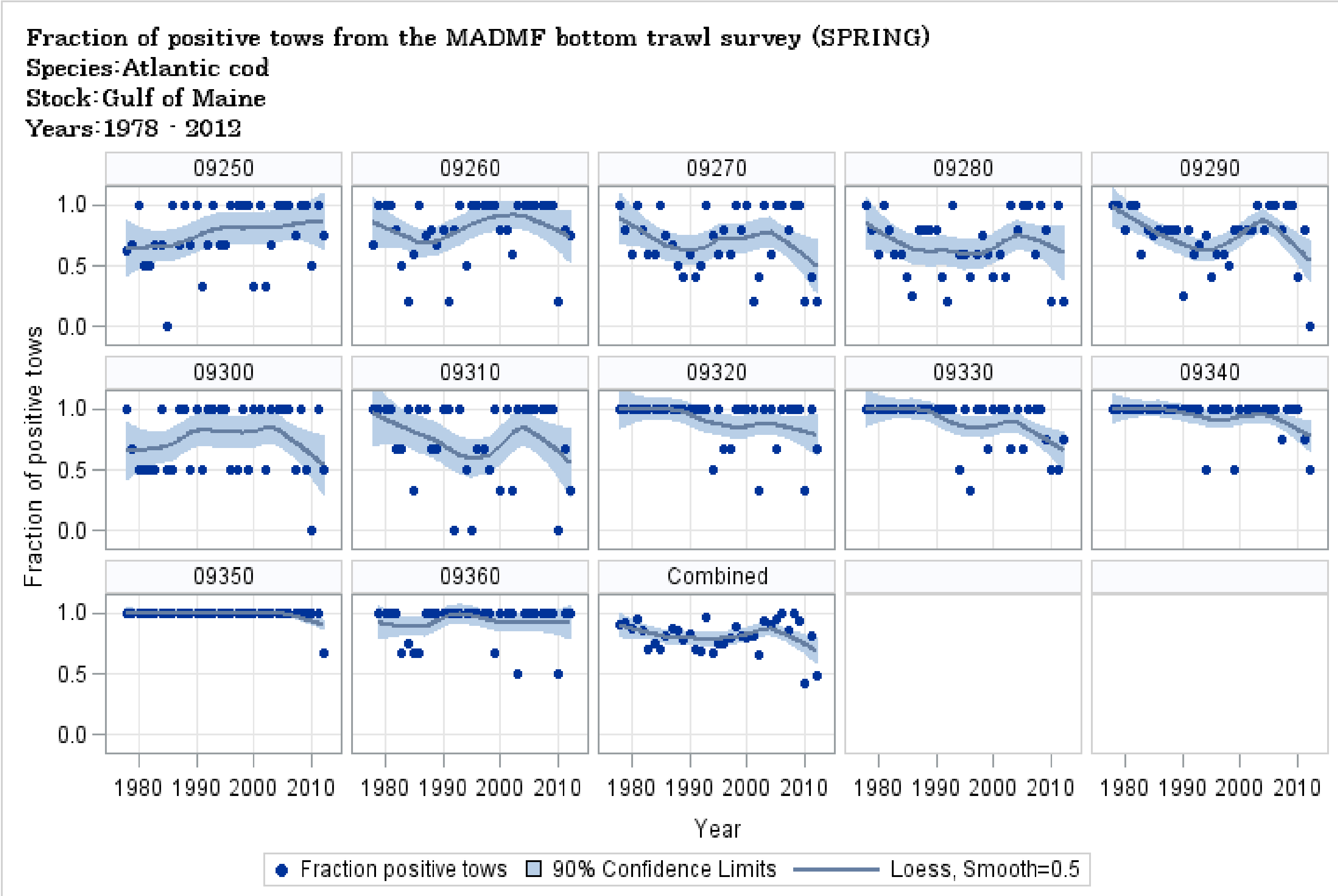


Figure A.112. Fraction of Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey survey tows with positive catches of Gulf of Maine Atlantic cod by strata from 1978-2012.

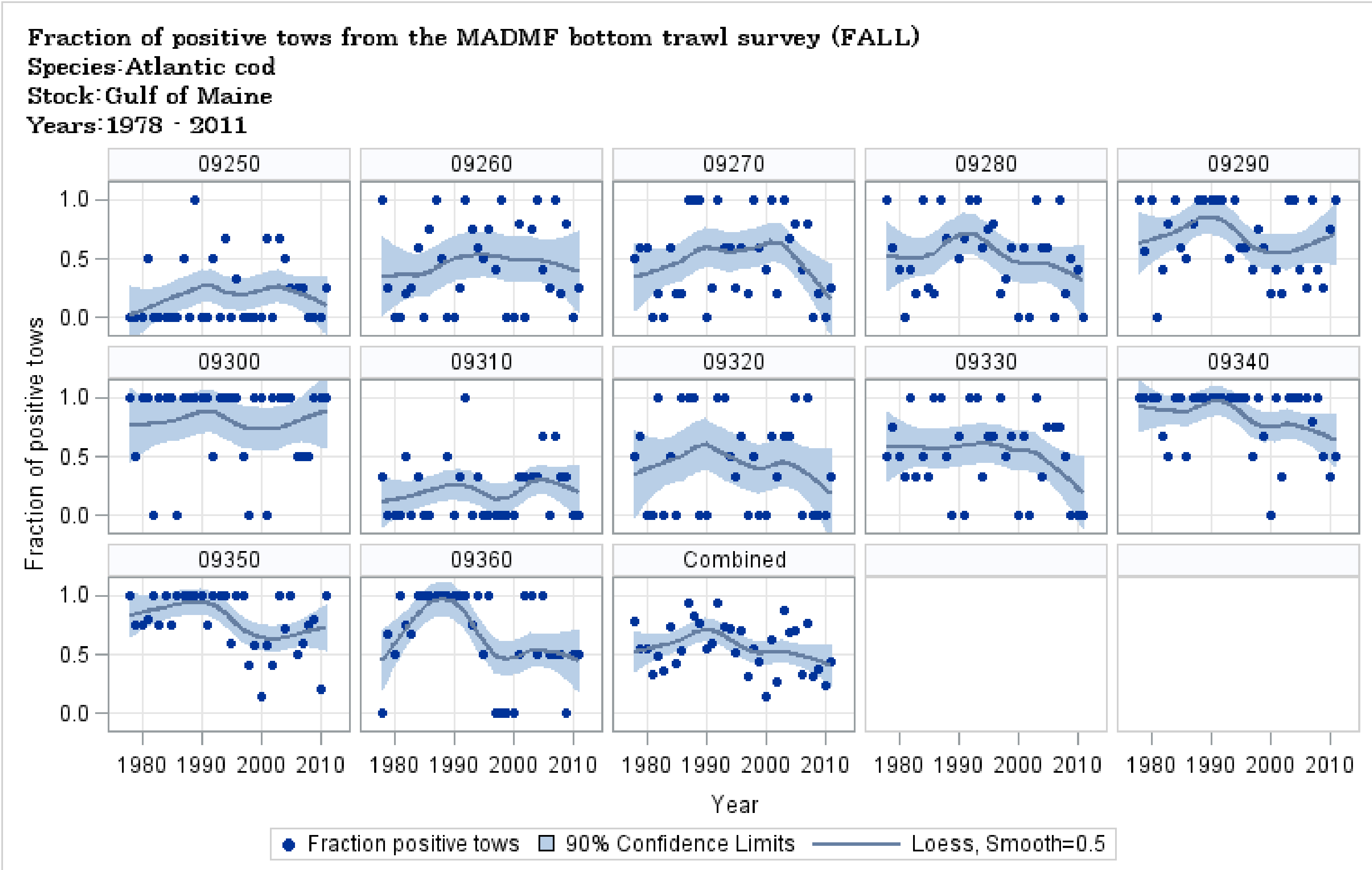


Figure A.113. Fraction of Massachusetts Department of Marine Fisheries (MADMF) fall bottom trawl survey survey tows with positive catches of Gulf of Maine Atlantic cod by strata from 1978-2011.

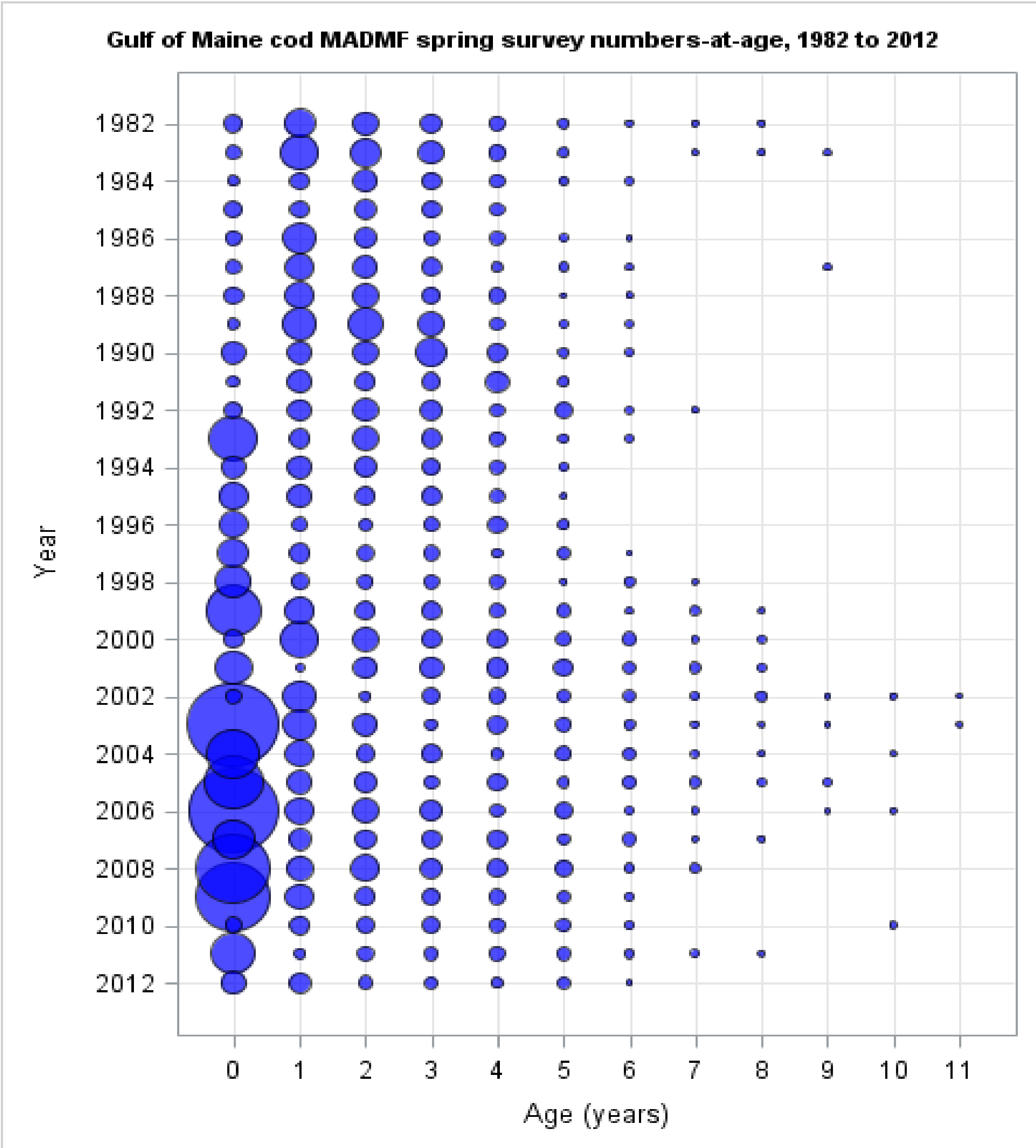


Figure A.114. Gulf of Maine cod numbers-at-age from the Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey, 1982-2012. There was insufficient age information available from the MADMF spring survey prior to 1982. **Note that age11 is a plus group.*

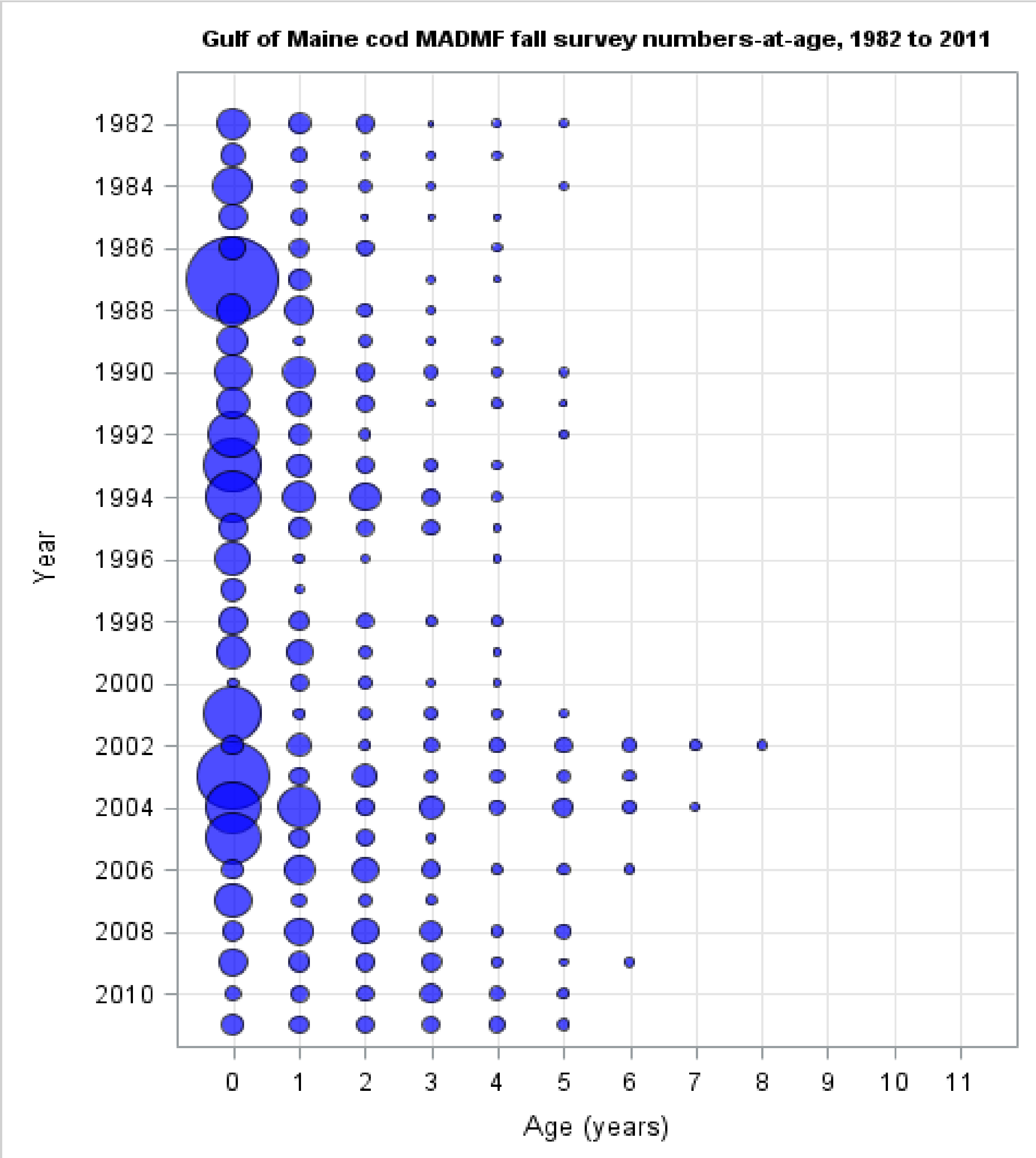


Figure A.115. Gulf of Maine cod numbers-at-age from the Massachusetts Department of Marine Fisheries (MADMF) fall bottom trawl survey, 1982-2011. There was insufficient age information available from the MADMF fall survey prior to 1982. **Note that age11 is a plus group.*

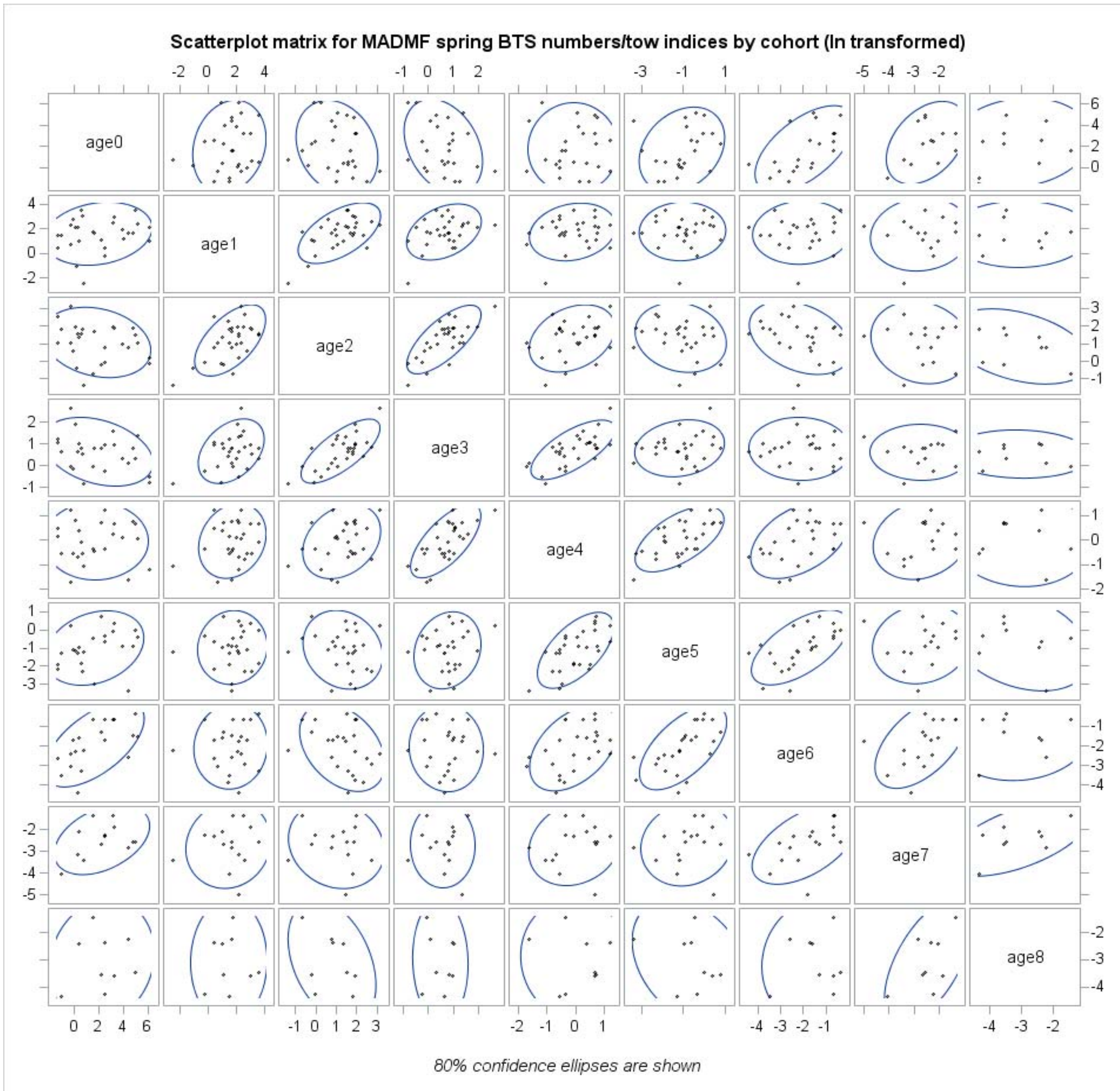


Figure A.116. Scatter plots showing the level of agreement between Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl Gulf of Maine Atlantic cod survey indices at age (log transformed) on a cohort basis. 80% confidence ellipses are shown.

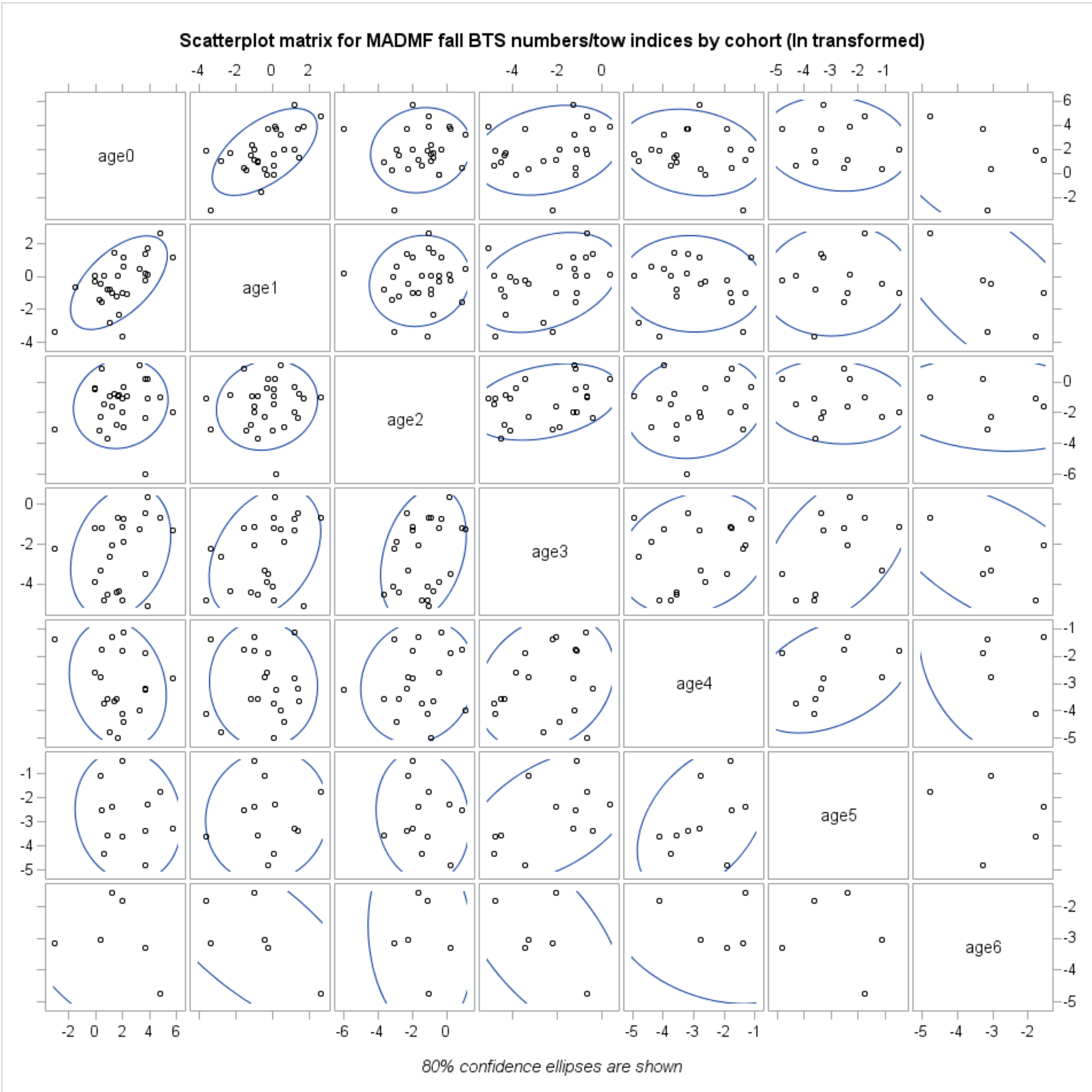


Figure A.117. Scatter plots showing the level of agreement between Massachusetts Department of Marine Fisheries (MADMF) fall bottom trawl Gulf of Maine Atlantic cod survey indices at age (log transformed) on a cohort basis. 80% confidence ellipses are shown.

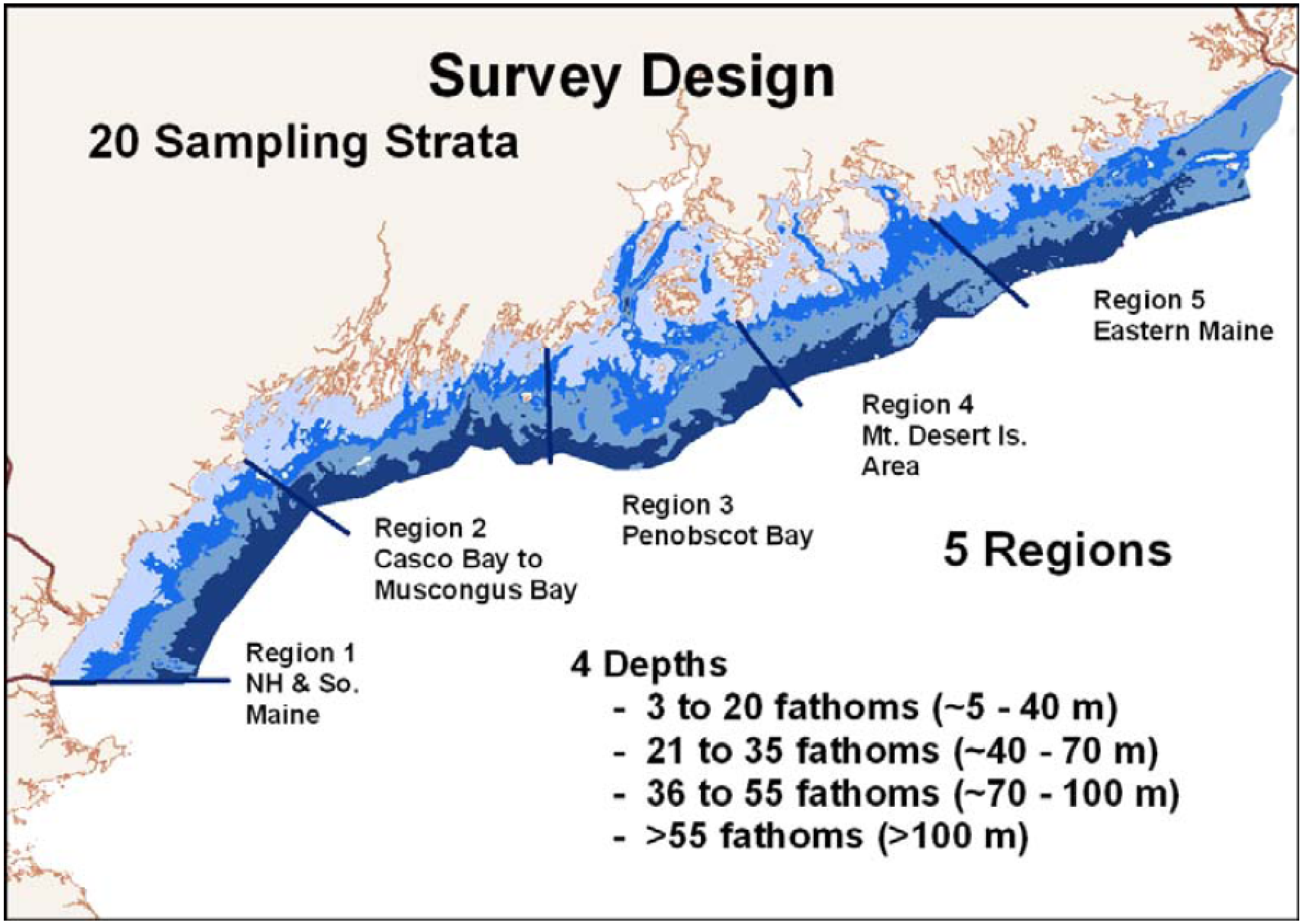


Figure A. 118. Map of the Maine – New Hampshire inshore groundfish trawl survey strata set (map from Sherman et al. 2005).

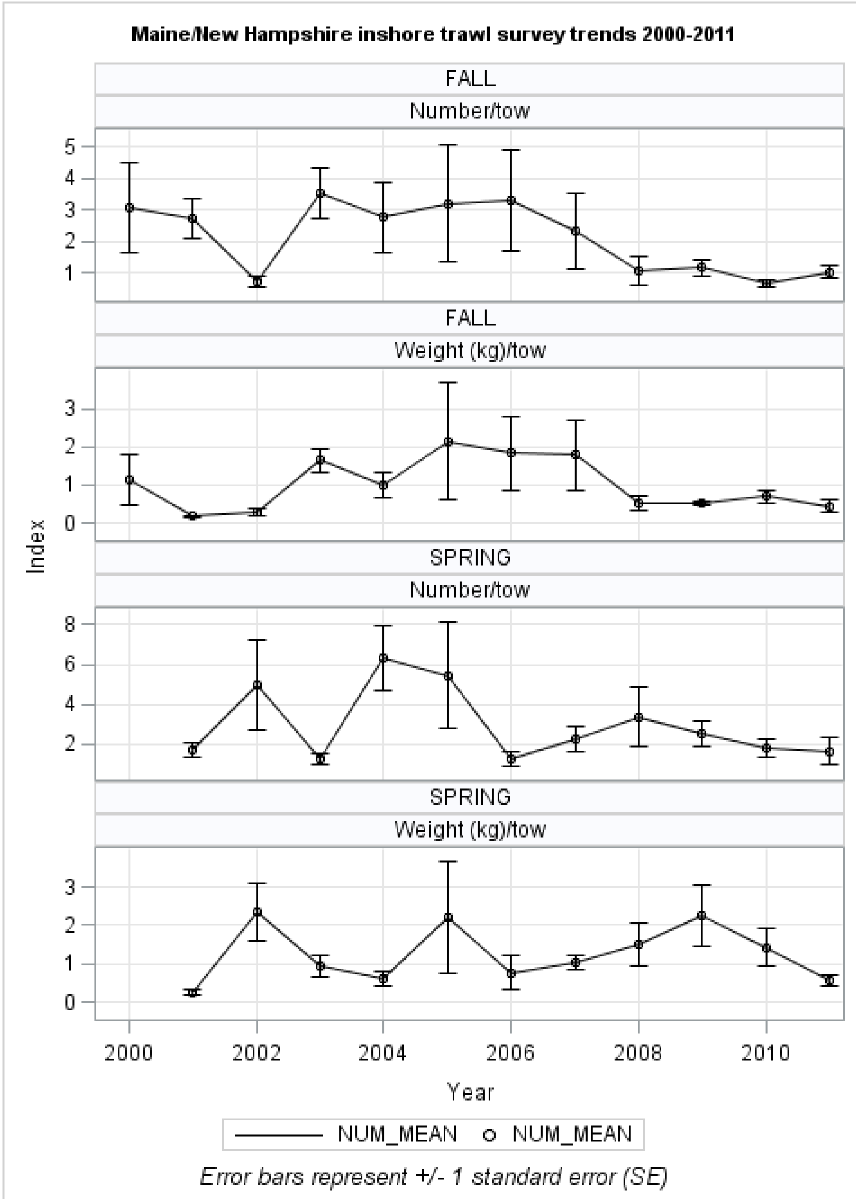


Figure A.119. Maine – New Hampshire inshore groundfish trawl survey spring and fall survey abundance from 1978 to 2011 for Gulf of Maine Atlantic cod. Bars indicate ± 1 standard error (SE). Data provided by S. Sherman (pers. comm.).

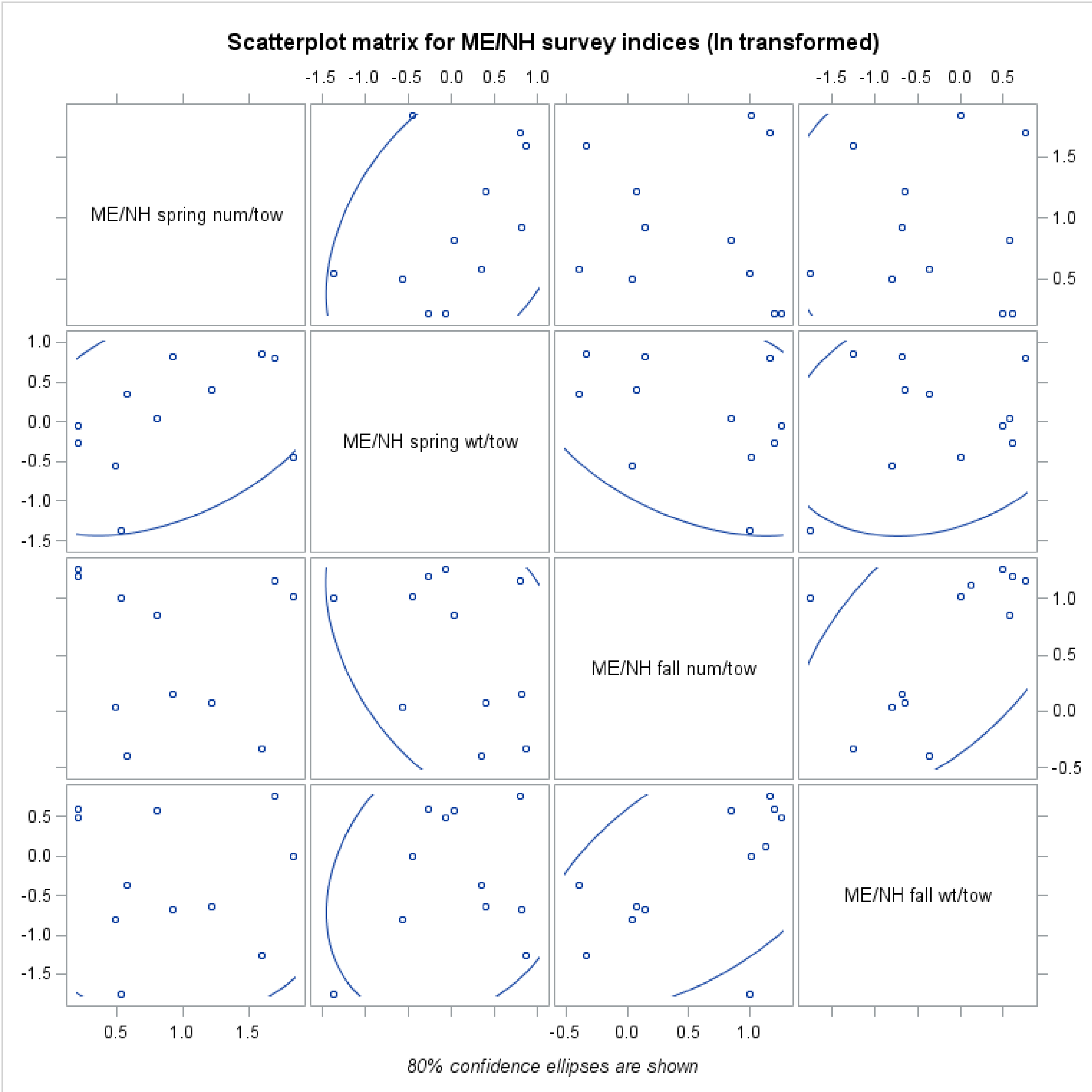


Figure A.120. Scatter plots showing the level of agreement between the Maine – New Hampshire (ME/NH) inshore groundfish trawl survey Gulf of Maine Atlantic cod indices (log transformed). 80% confidence ellipses are shown.

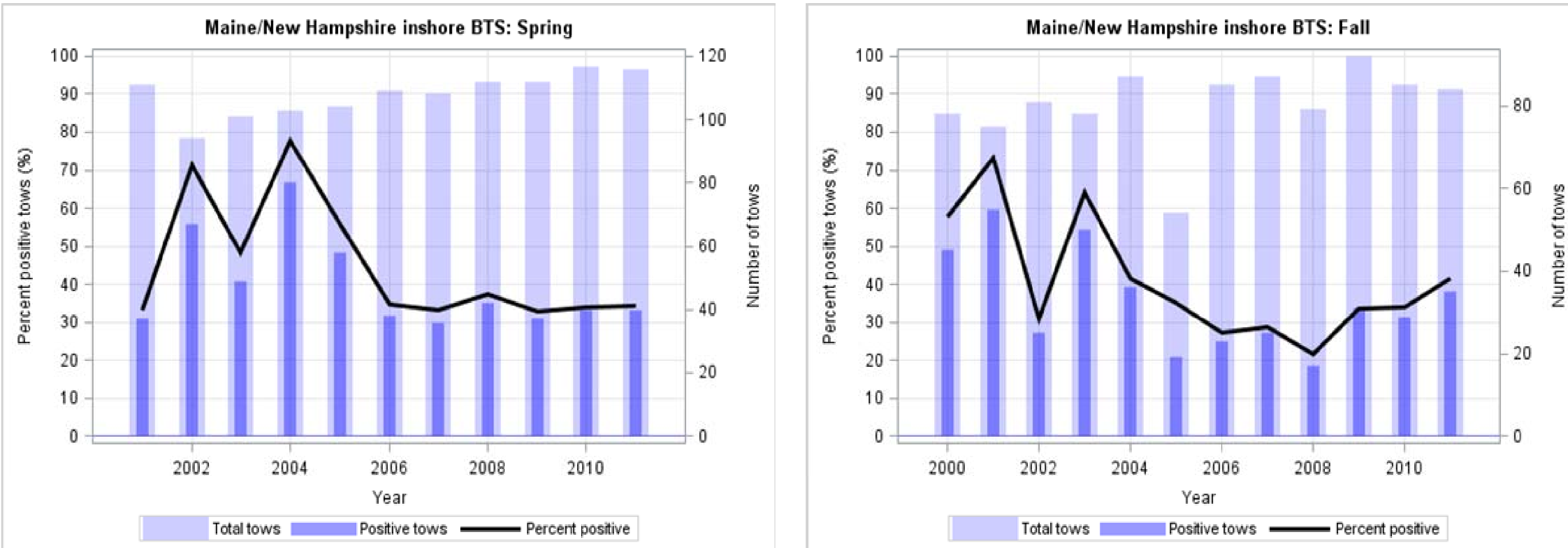


Figure A.121. Fraction of Maine – New Hamphire inshore groundfish trawl survey Tows with positive catches of Gulf of Maine Atlantic cod from 2000-2011.

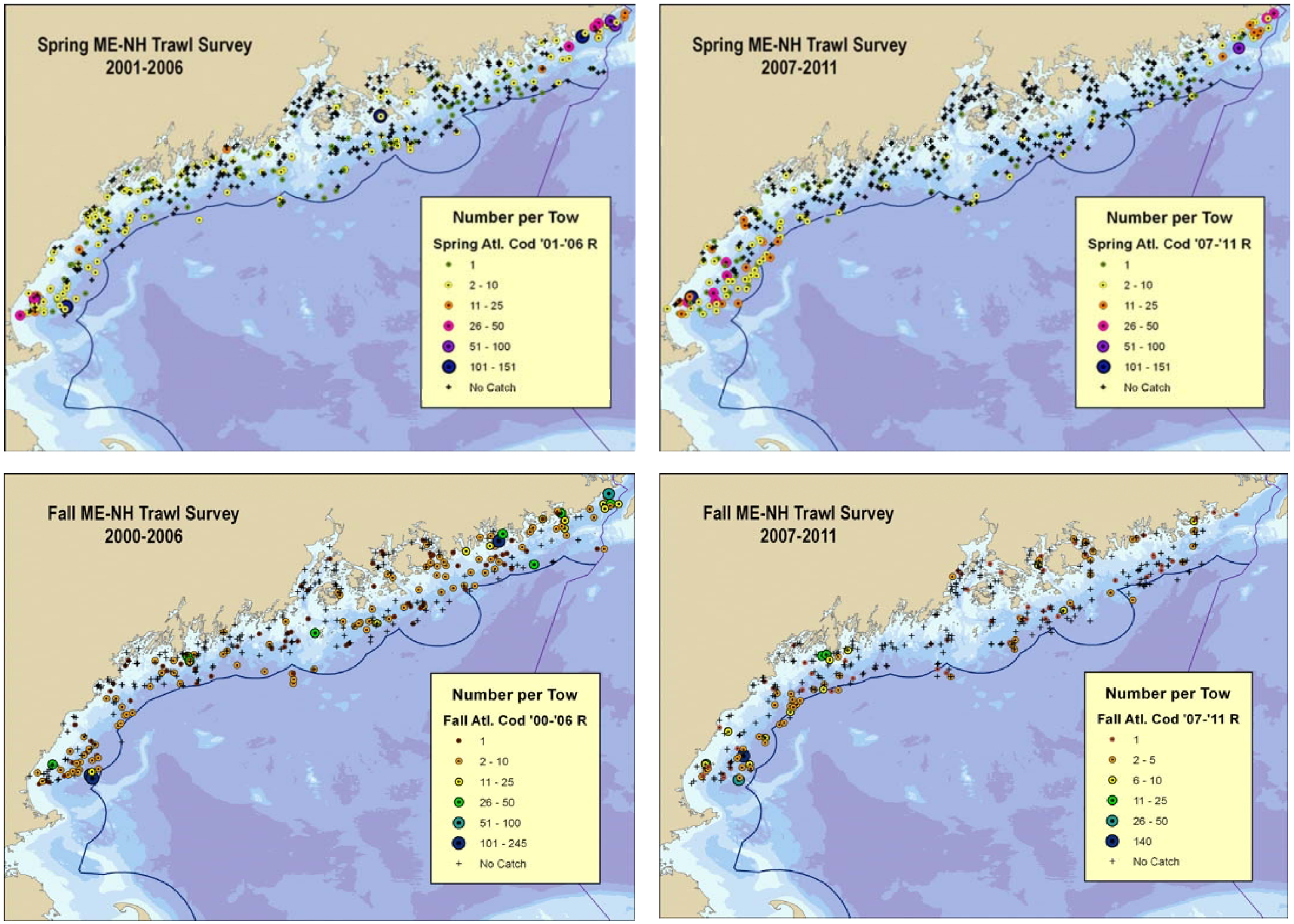


Figure A.122. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the spring (top) and fall (bottom) Maine – New Hampshire inshore groundfish trawl survey from 2001-2006 (top) and 2007-2011 (left). Map provided by S. Sherman (pers. comm.).

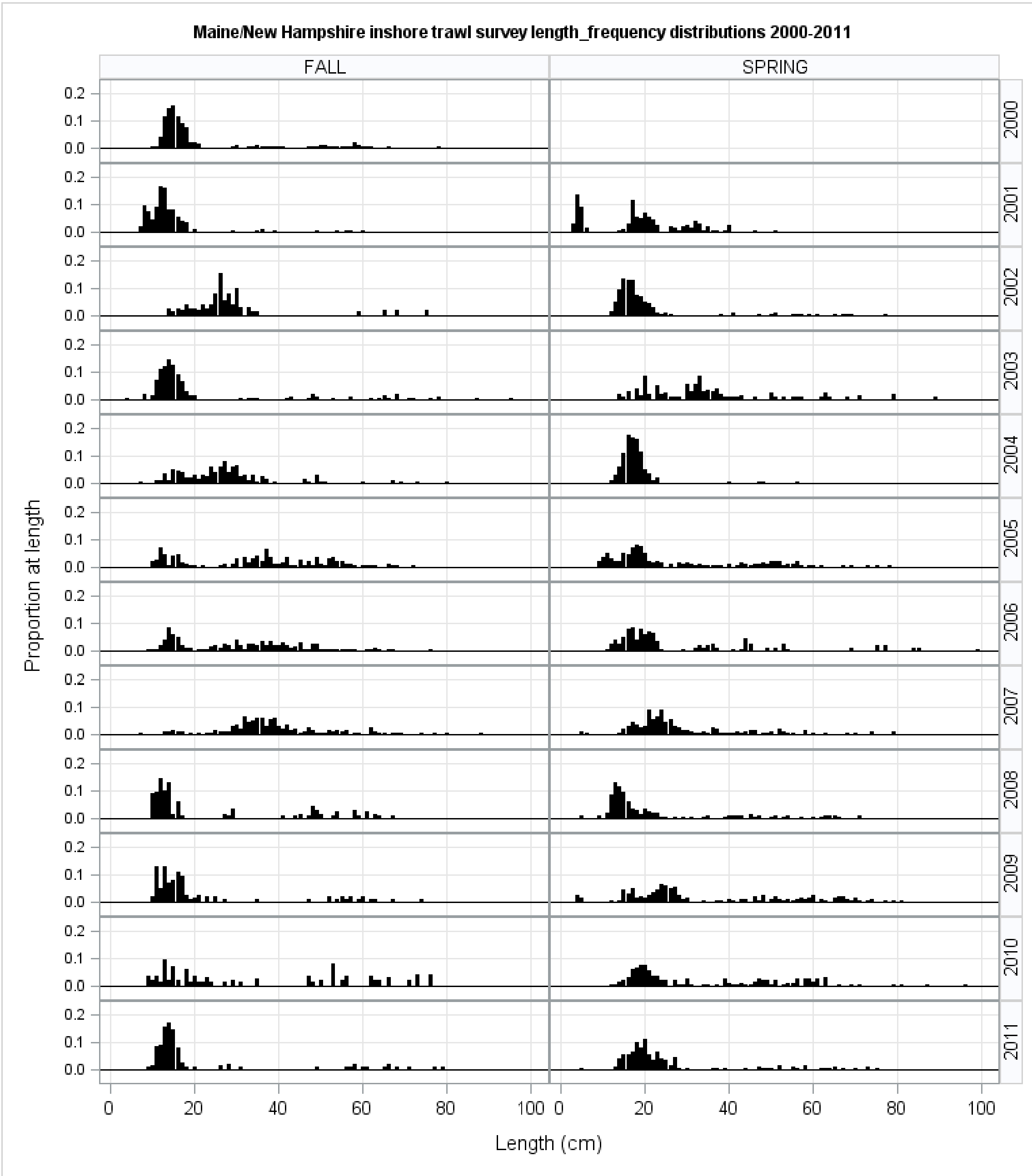
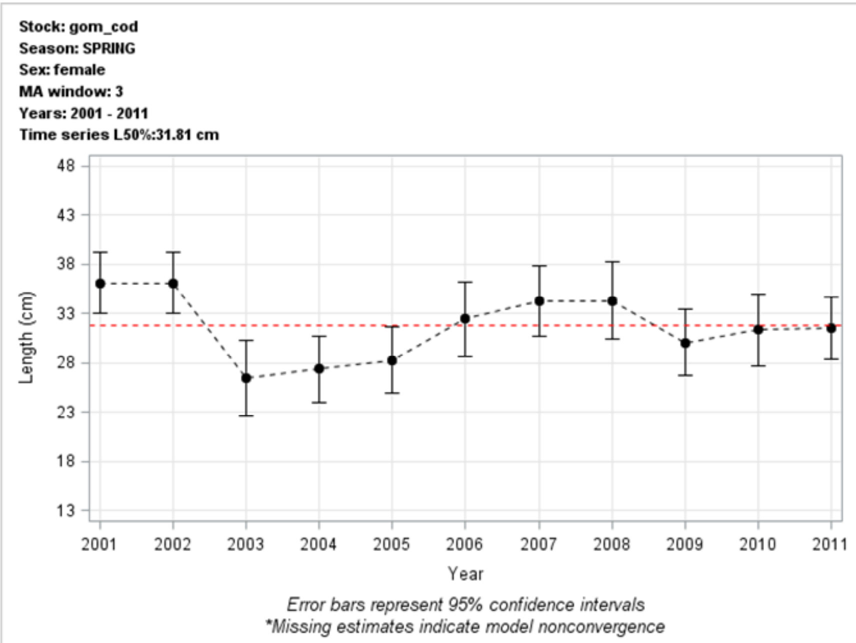


Figure A.123. Length distributions of Gulf of Maine Atlantic cod sampled in the Maine – New Hampshire inshore groundfish trawl spring (top) and fall (bottom) surveys from 2006 to 2009.



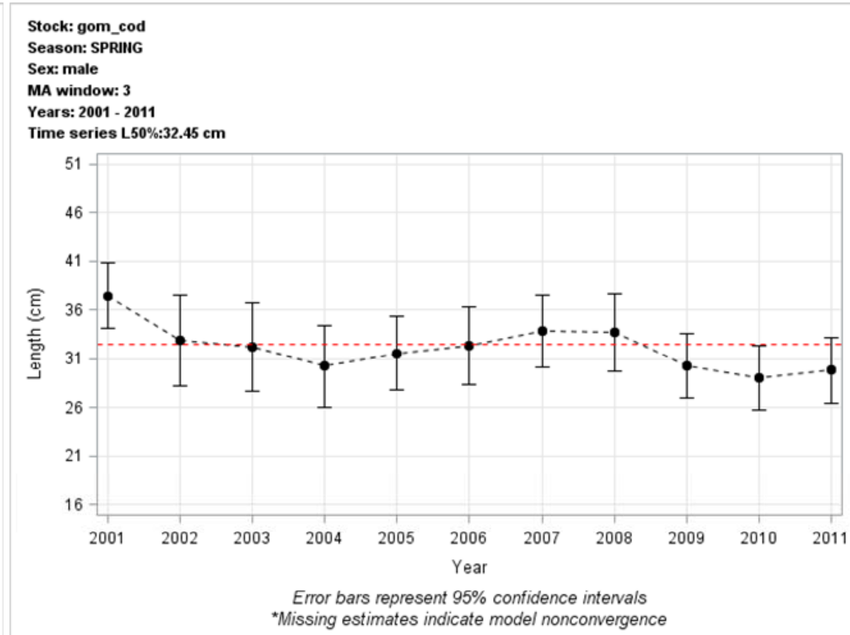


Figure A.124. Annual average length-at-50% maturity (L50) and corresponding 95% confidence intervals for female (left panels) and male (right panels) Gulf of Maine Atlantic cod from 2001 to 2011. Average maturity has been estimated from data collected from the Maine – New Hampshire spring inshore groundfish trawl survey. Years in which maturity ogives could not be estimated are omitted from the plots.

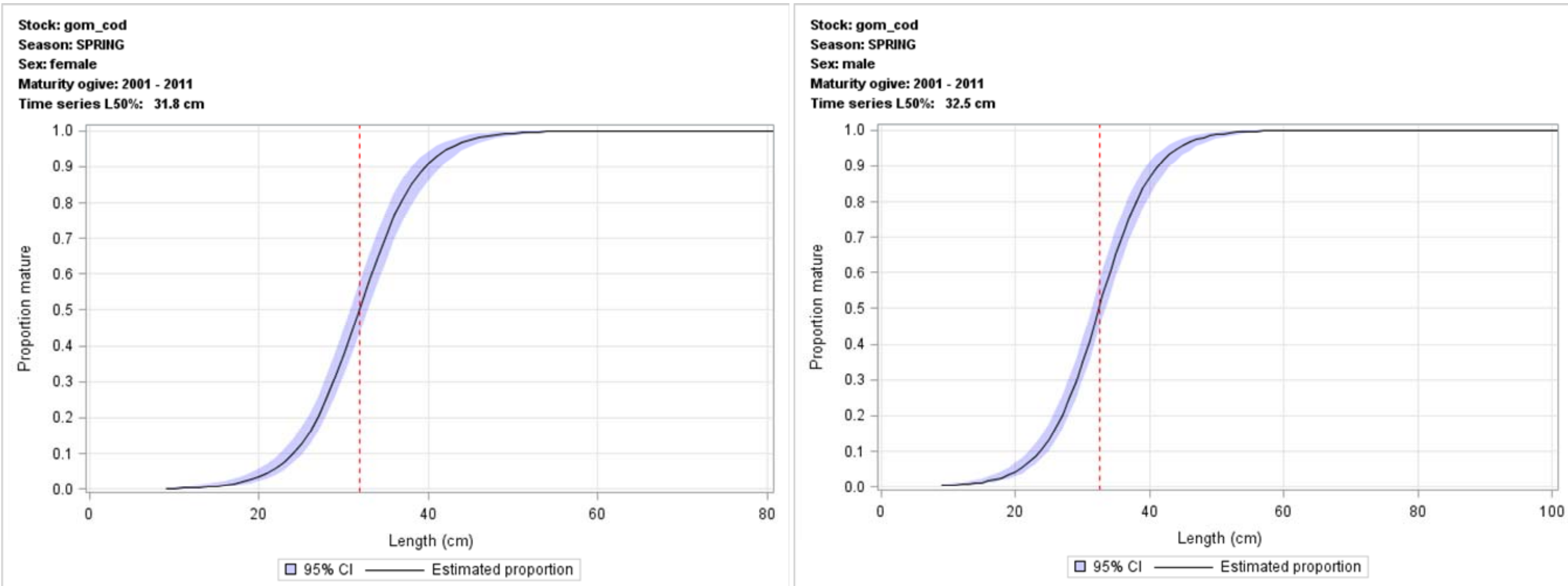


Figure A.125. Annual Length-based maturity ogives for female (left) and male (right) Gulf of Maine Atlantic cod based on time series averages of maturity and length information collected from the Maine – New Hampshire spring inshore groundfish trawl survey between 2001 and 2011. The dashed red line indicates the length at 50% maturity.

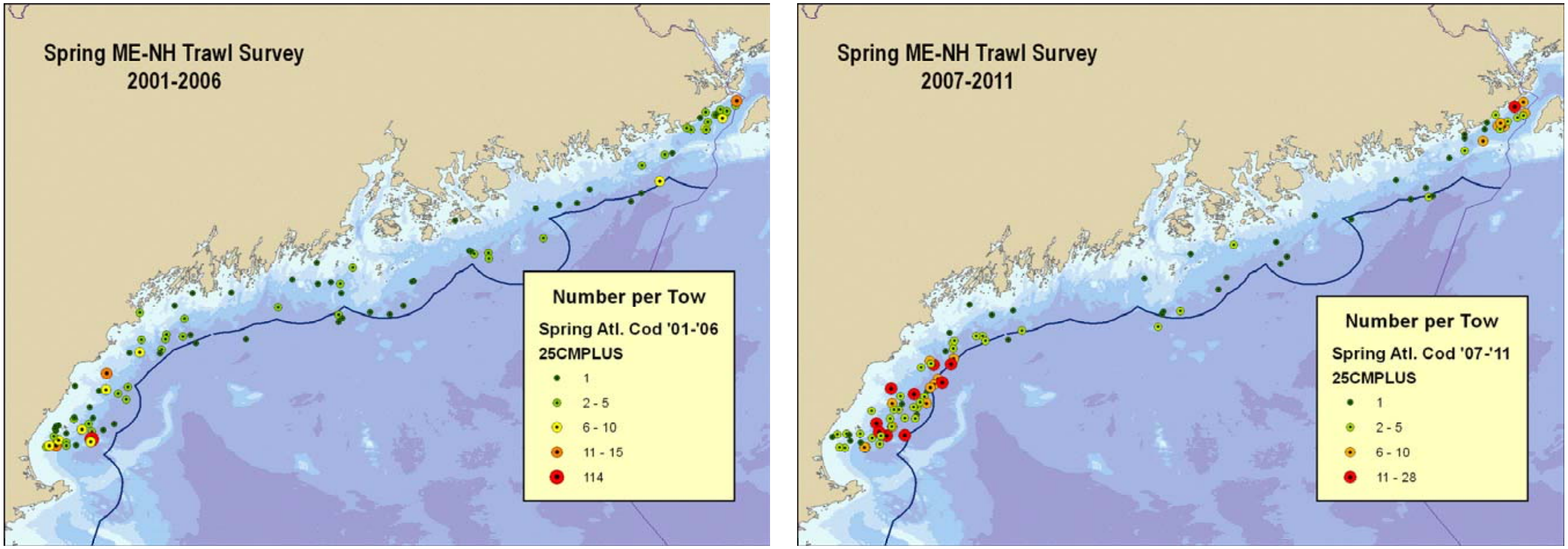


Figure A.126. Distribution of fish ≥ 25 cm from the Maine – New Hampshire spring inshore groundfish trawl survey from 2001-2006 (left) and 2007-2011 (right).

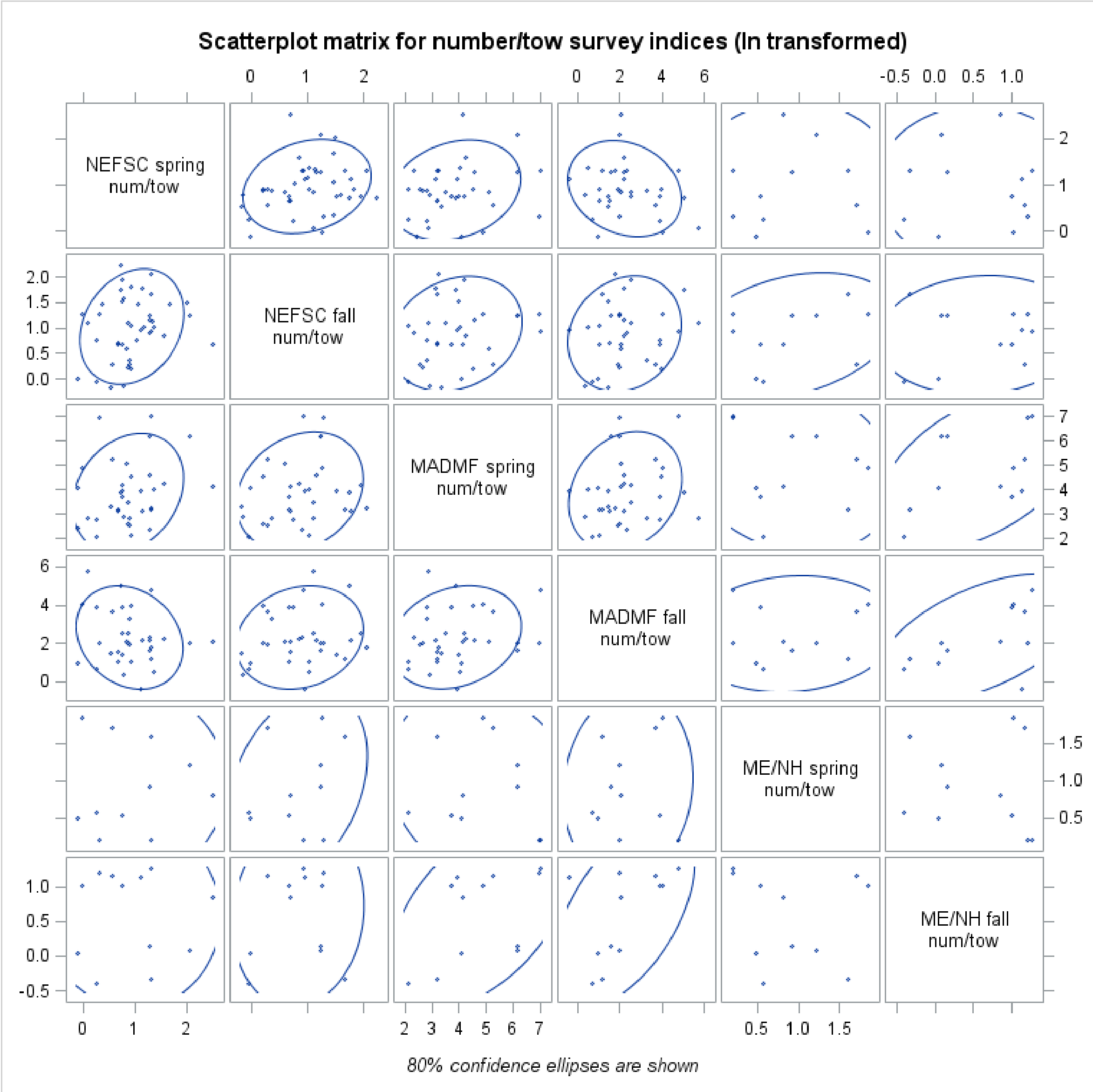


Figure A.127. Scatter plots showing the level of agreement between the Northeast Fisheries Science Center (NEFSC), Massachusetts Department of Marine Fisheries (MADMF) and the Maine – New Hampshire (ME/NH) inshore groundfish trawl survey Gulf of Maine Atlantic cod abundance (numbers/tow) indices (log transformed). 80% confidence ellipses are shown.

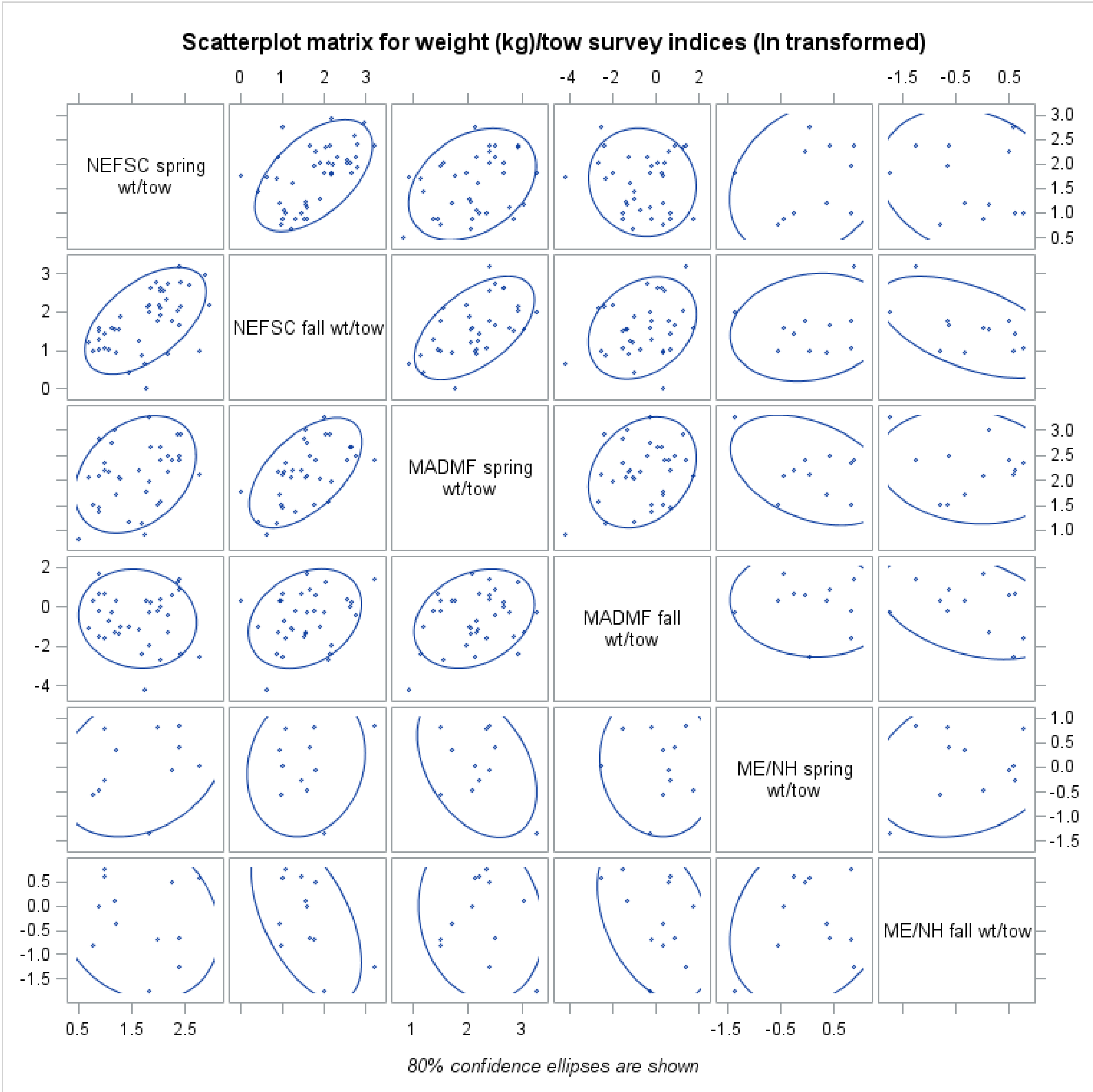


Figure A.128. Scatter plots showing the level of agreement between the Northeast Fisheries Science Center (NEFSC), Massachusetts Department of Marine Fisheries (MADMF) and the Maine – New Hampshire (ME/NH) inshore groundfish trawl survey Gulf of Maine Atlantic cod biomass (weight/tow) indices (log transformed). 80% confidence ellipses are shown.

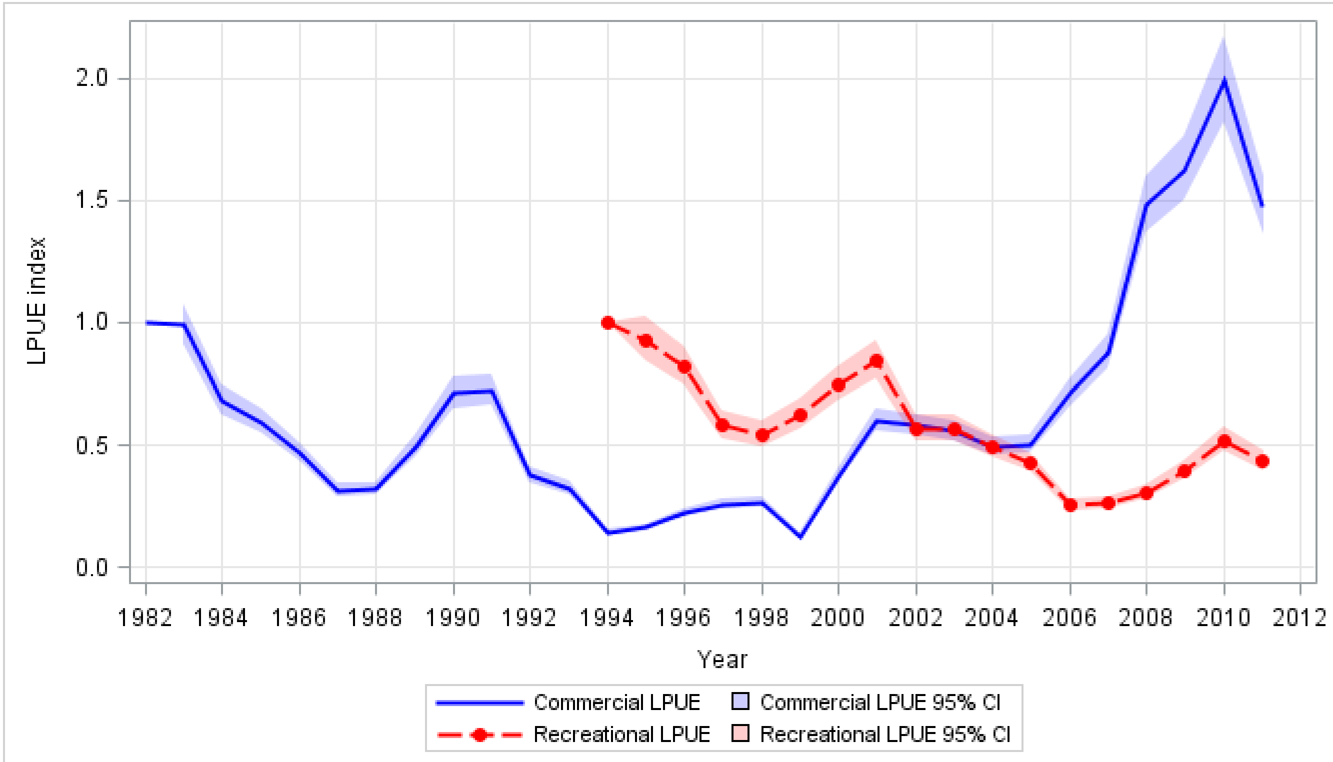


Figure A.129. Commercial otter trawl and recreational landings per unit effort (LPUE) indices for Gulf of Maine Atlantic cod. The development of the commercial otter trawl LPUE index is described in Palmer (2012b). The development of the recreational LPUE index is described in Wood (2012).

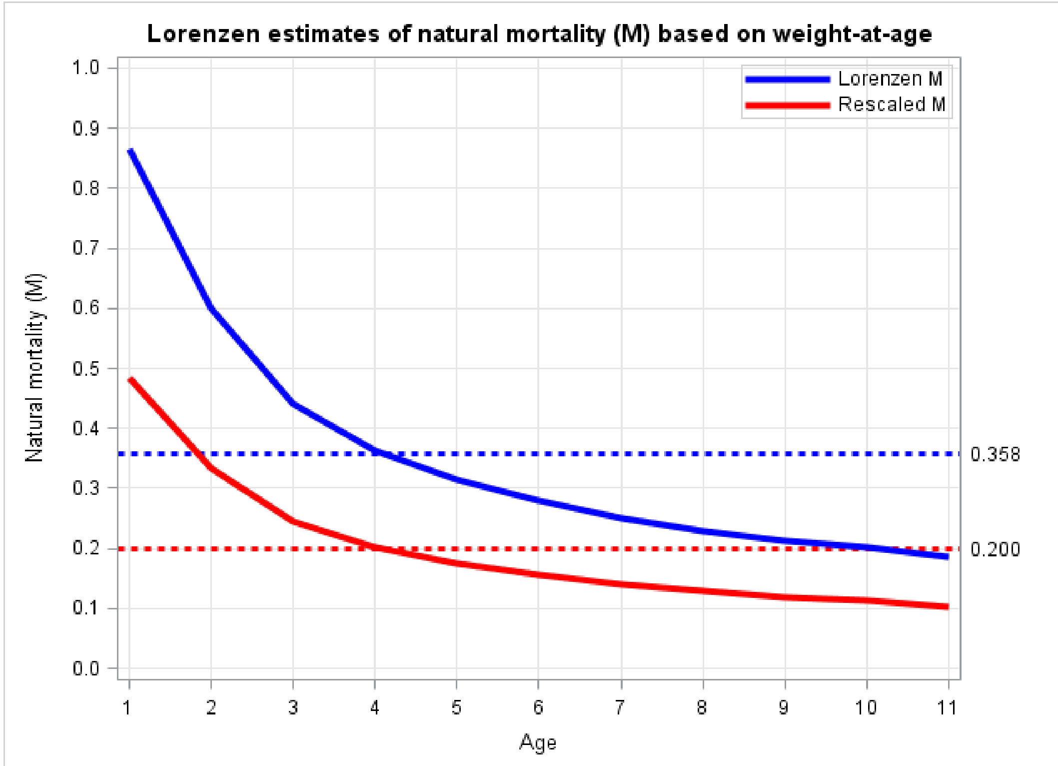


Figure A.130. Example of Lorenzen (1996) based estimates of natural mortality (*M*) at age based on time series average of stock weights at age. The blue line indicates the unadjusted Lorenzen estimate of natural mortality. The red line has been rescaled based on a constant *M* assumption of 0.2.

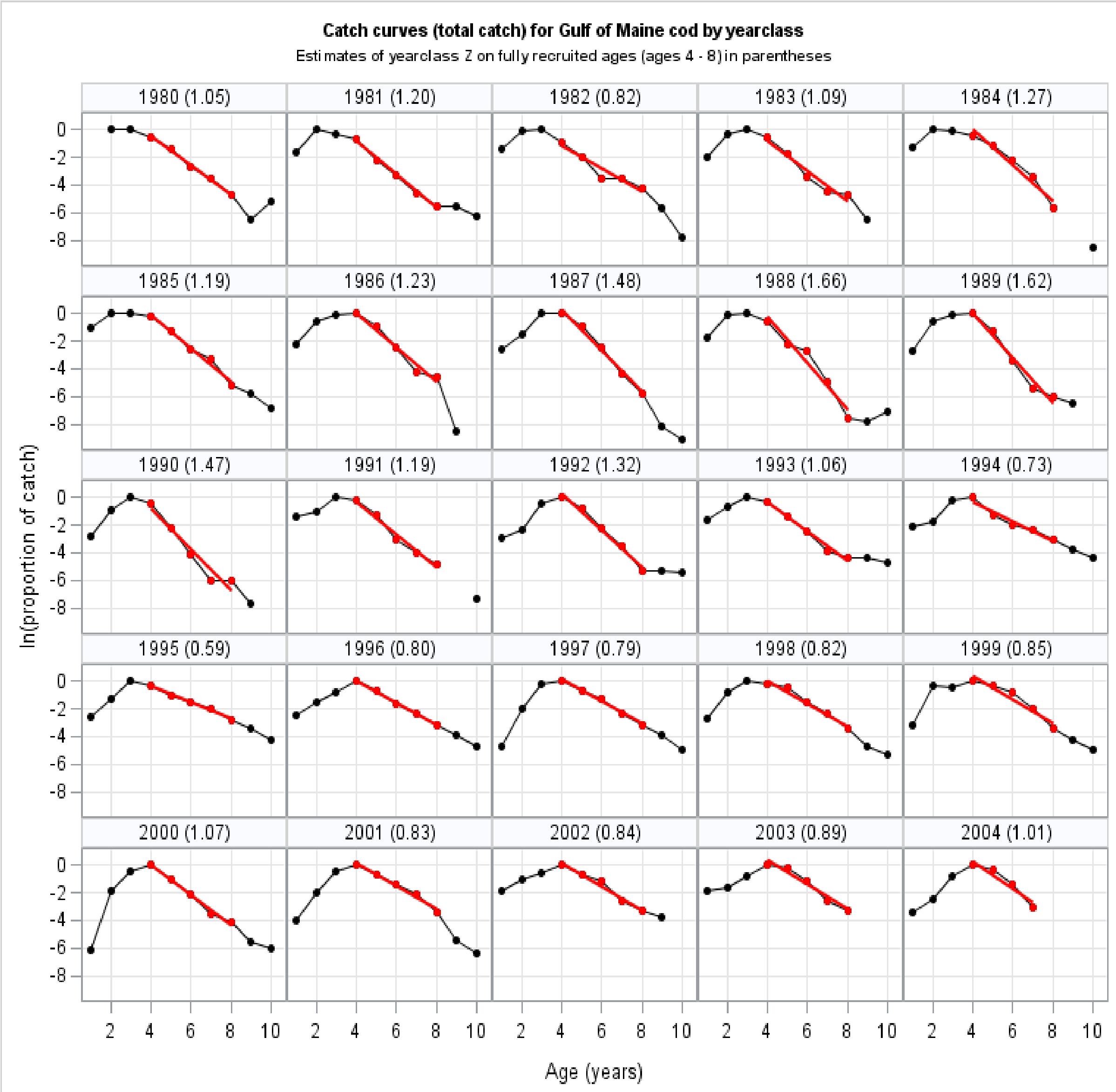


Figure A.131. Gulf of Maine Atlantic cod year class curves computed on ages 4-8 (red circles) log-transformed catch (commercial and recreational landigns and discards). The corresponding slope of each regression line is shown next to the year class label above each plot.

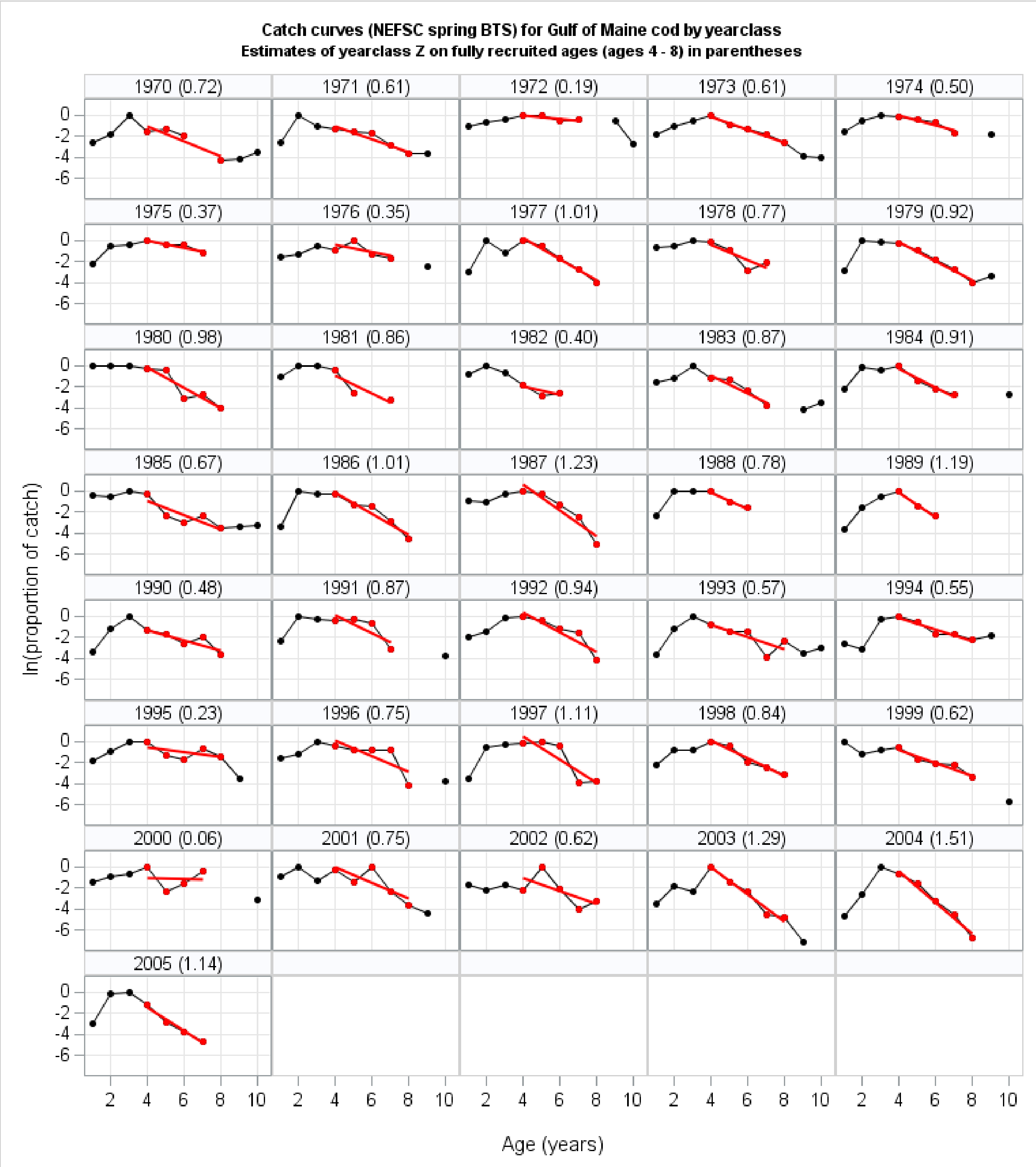


Figure A.132. Gulf of Maine Atlantic cod year class curves computed on ages 4-8 (red circles) log-transformed Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey abundance (numbers/tow) indices. The corresponding slope of each regression line is shown next to the year class label above each plot.

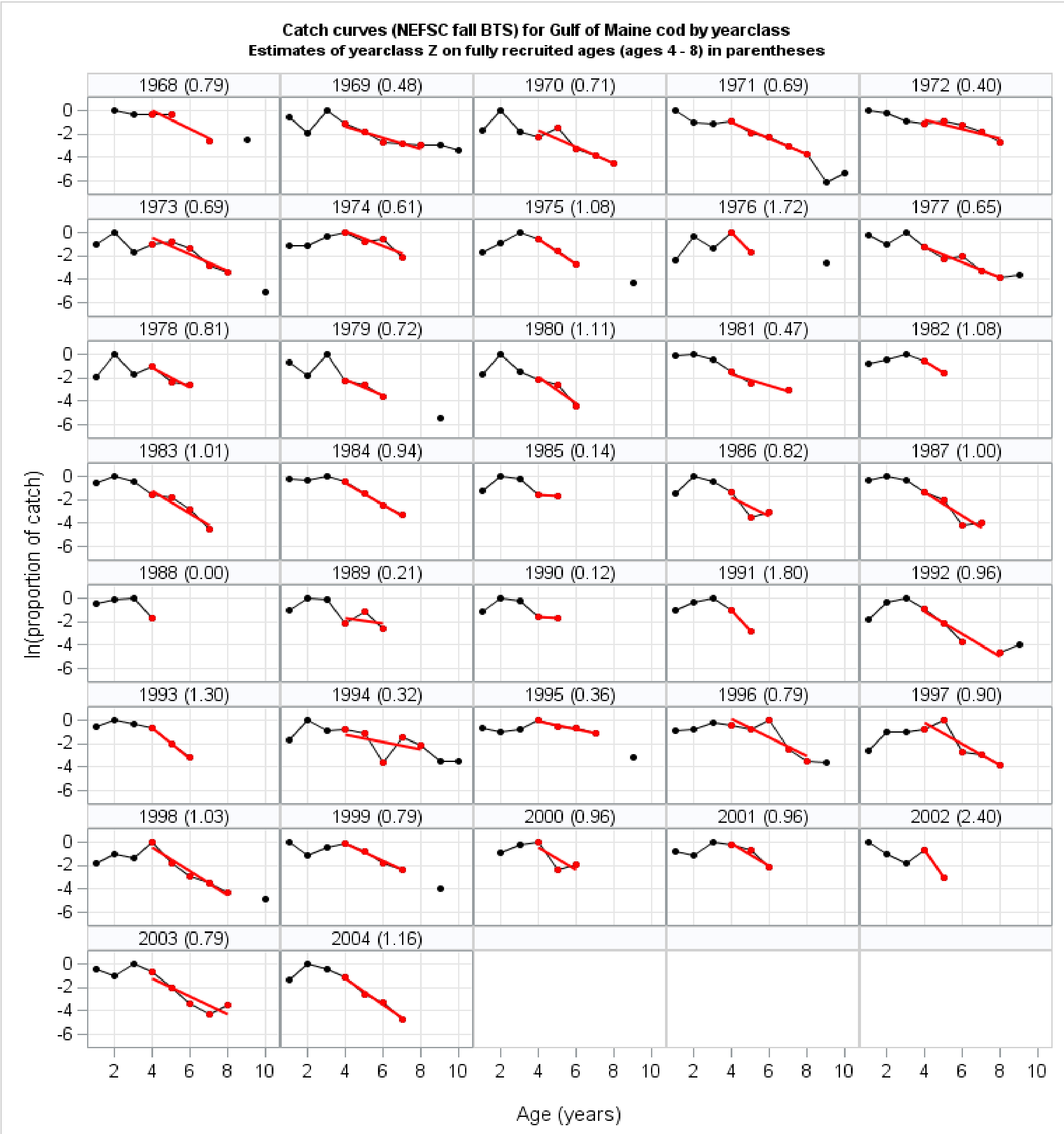


Figure A.133. Gulf of Maine Atlantic cod year class curves computed on ages 4-8 (red circles) log-transformed Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey abundance (numbers/tow) indices. The corresponding slope of each regression line is shown next to the year class label above each plot.

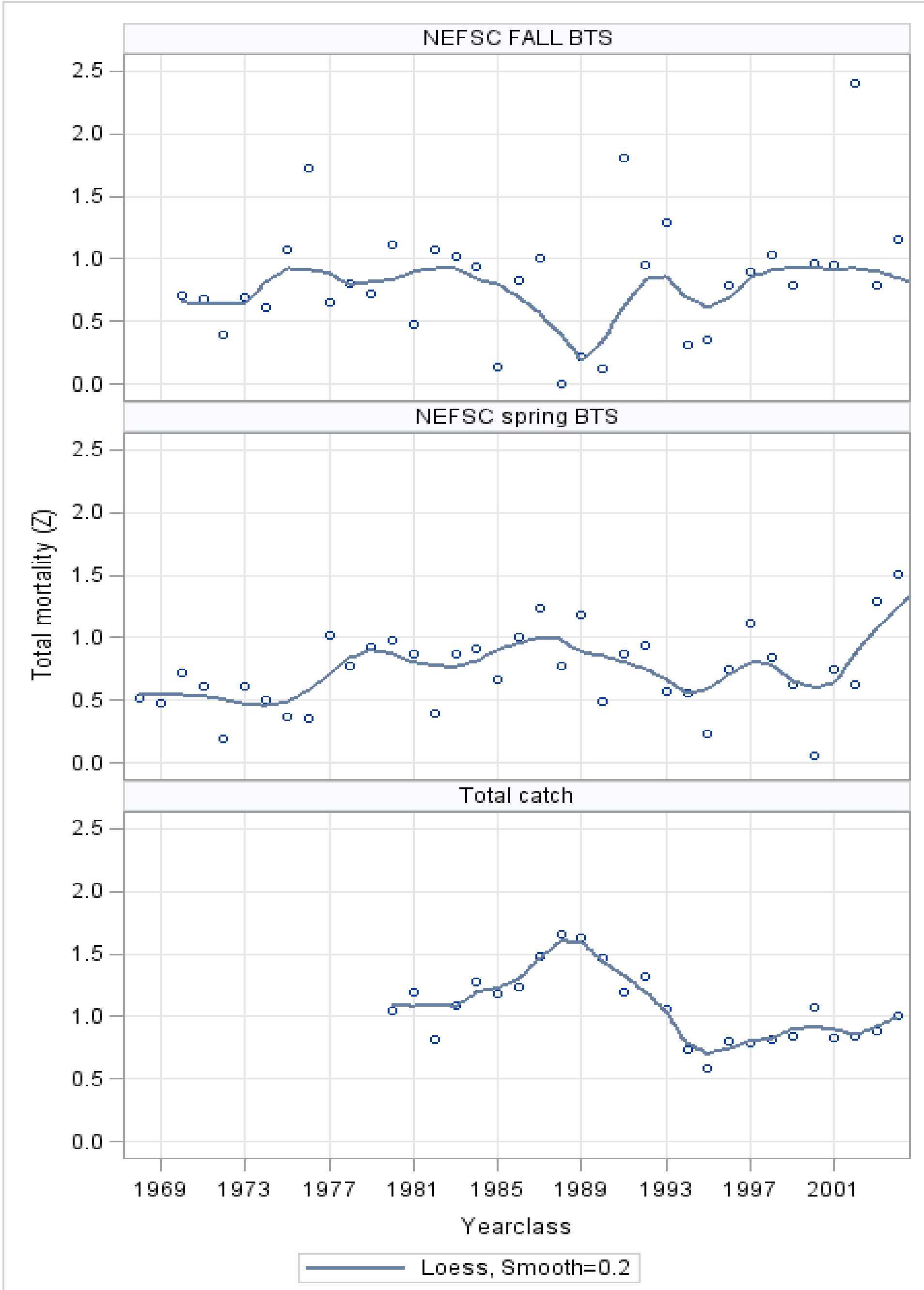


Figure A.134. Plots of the annual estimates of Gulf of Maine Atlantic cod total mortality (Z) as estimated from the year class curve analsyses for total catch and Northeeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys.

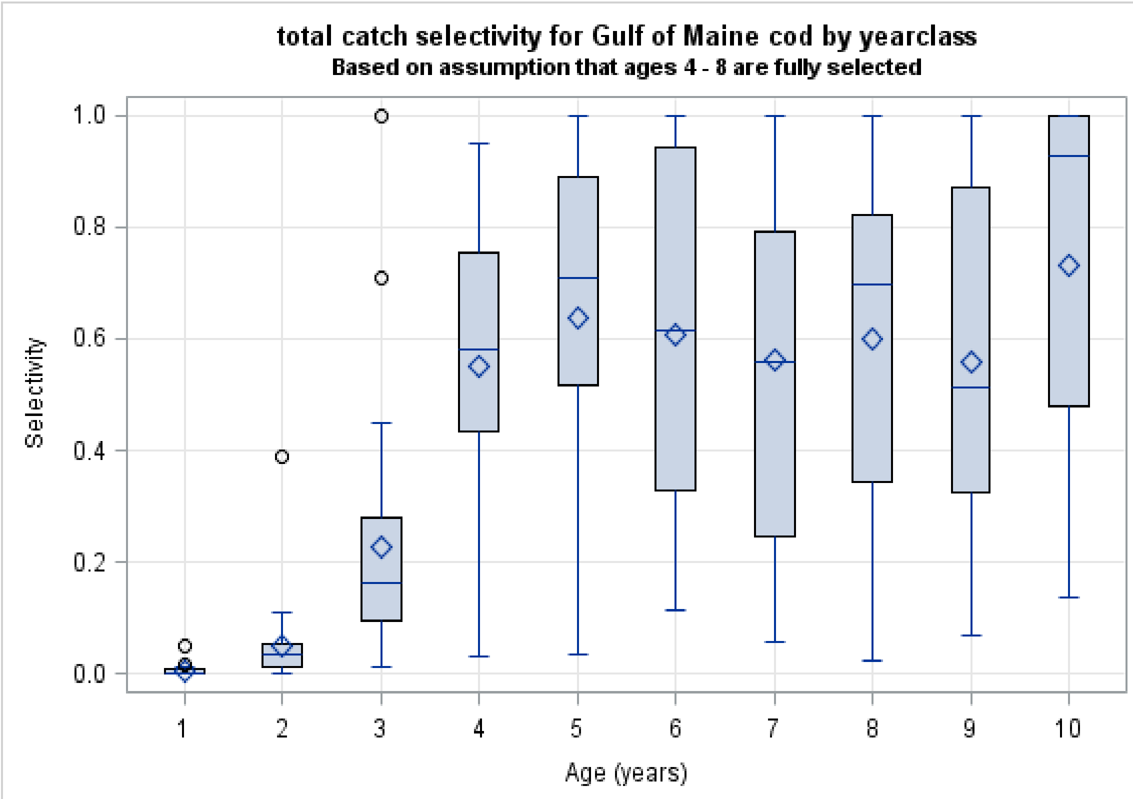


Figure A.135. Box plot distribution of the residuals fits to the Gulf of Maine Atlantic cod year class linear regression relationship by age from the total catch year class curve analysis.

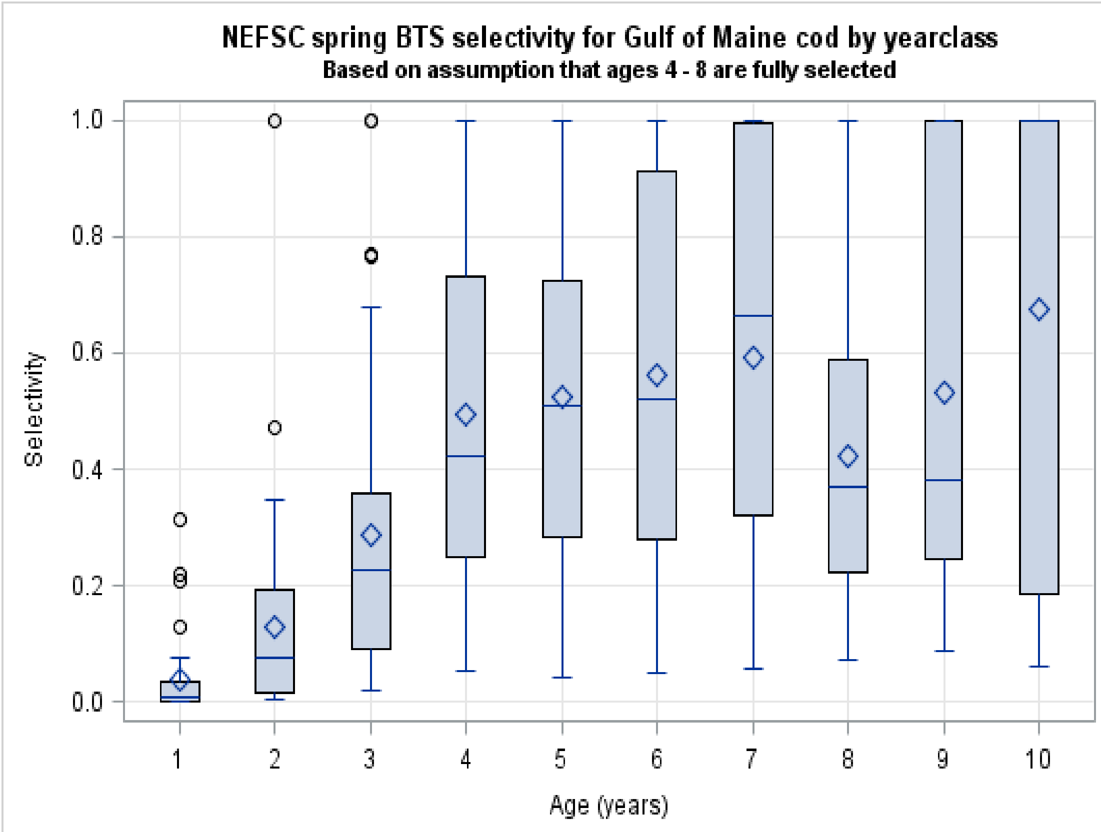


Figure A.136. Box plot distribution of the residuals fits to the Gulf of Maine Atlantic cod year class linear regression relationship by age from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey year class curve analysis.

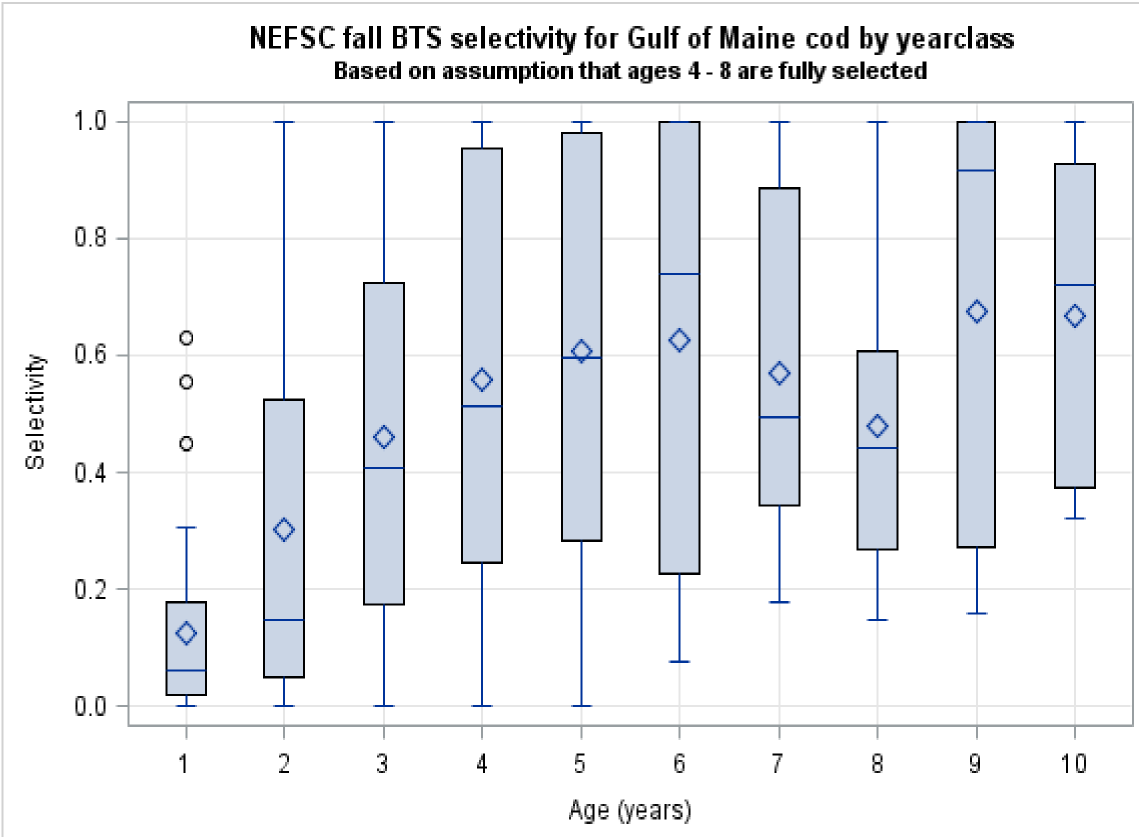


Figure A.137. Box plot distribution of the residuals fits to the Gulf of Maine Atlantic cod year class linear regression relationship by age from the Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey year class curve analysis.

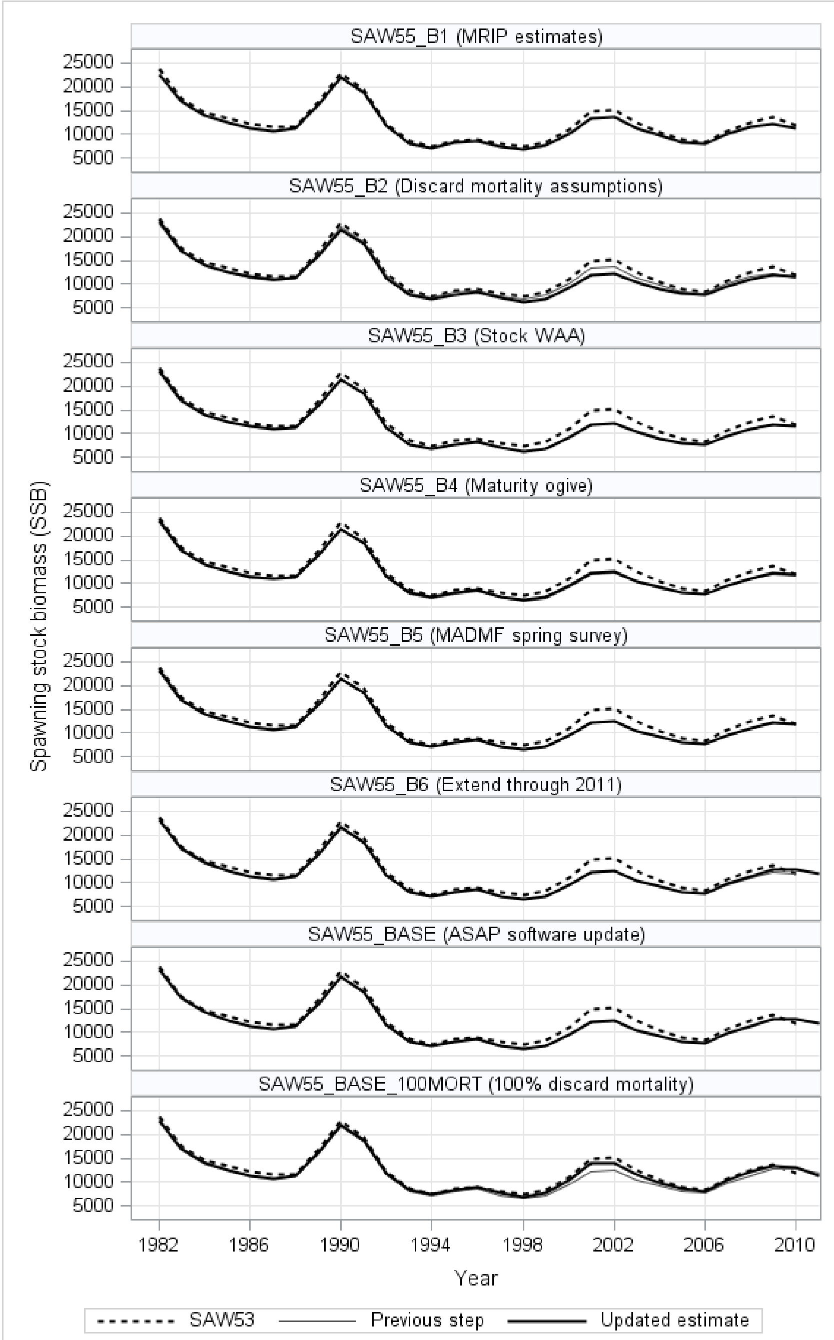


Figure A.138. Summary of the impacts on the time series of spawning stock biomass resulting from the update of the SAW 53 Gulf of Maine cod ASAP model with new data. In each plot, the SAWQ 53 model results are shown by a dashed line with the model results based on the updated data input shown by a solid black line. The solid grey line indicates the model results from the previous step such that the impacts can be understood not only compared to the SAW 53 model, but also to the previous step.

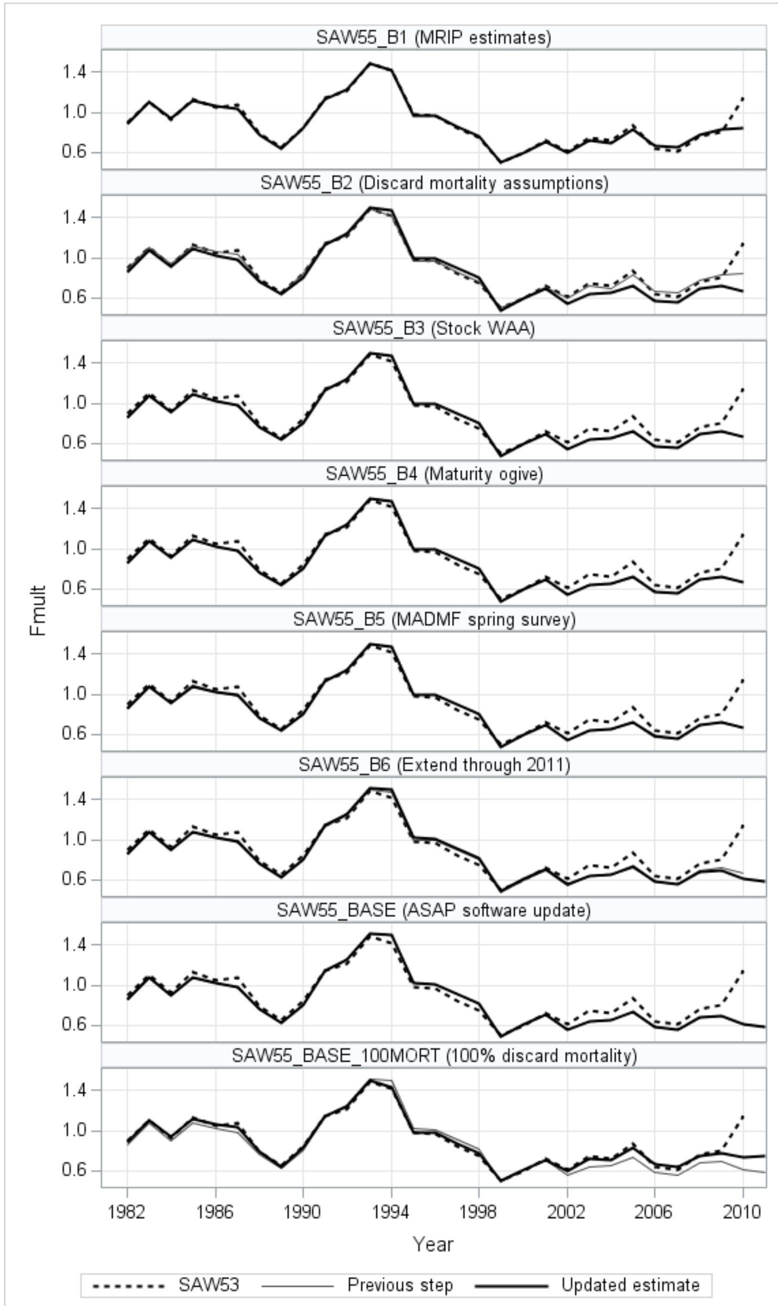


Figure A.139. Summary of the impacts on the time series of fishing mortality (age 5) resulting from the update of the SAW 53 Gulf of Maine Atlantic cod ASAP model with new data. In each plot, the SAWQ 53 model results are shown by a dashed line with the model results based on the updated data input shown by a solid black line. The solid grey line indicates the model results from the previous step such that the impacts can be understood not only compared to the SAW 53 model, but also to the previous step.

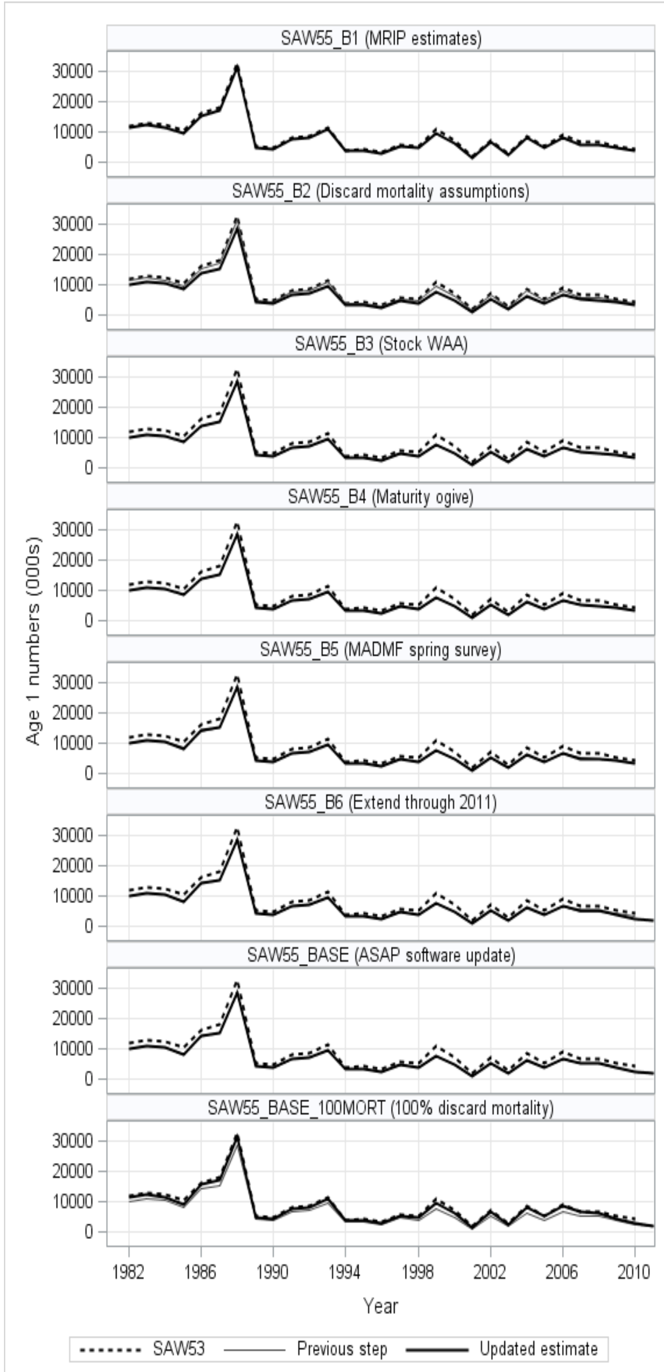


Figure A.140. Summary of the impacts on the time series of age 1 recruitment resulting from the update of the SAW 53 Gulf of Maine Atlantic cod ASAP model with new data. In each plot, the SAWQ 53 model results are shown by a dashed line with the model results based on the updated data input shown by a solid black line. The solid grey line indicates the model results from the previous step such that the impacts can be understood not only compared to the SAW 53 model, but also to the previous step.

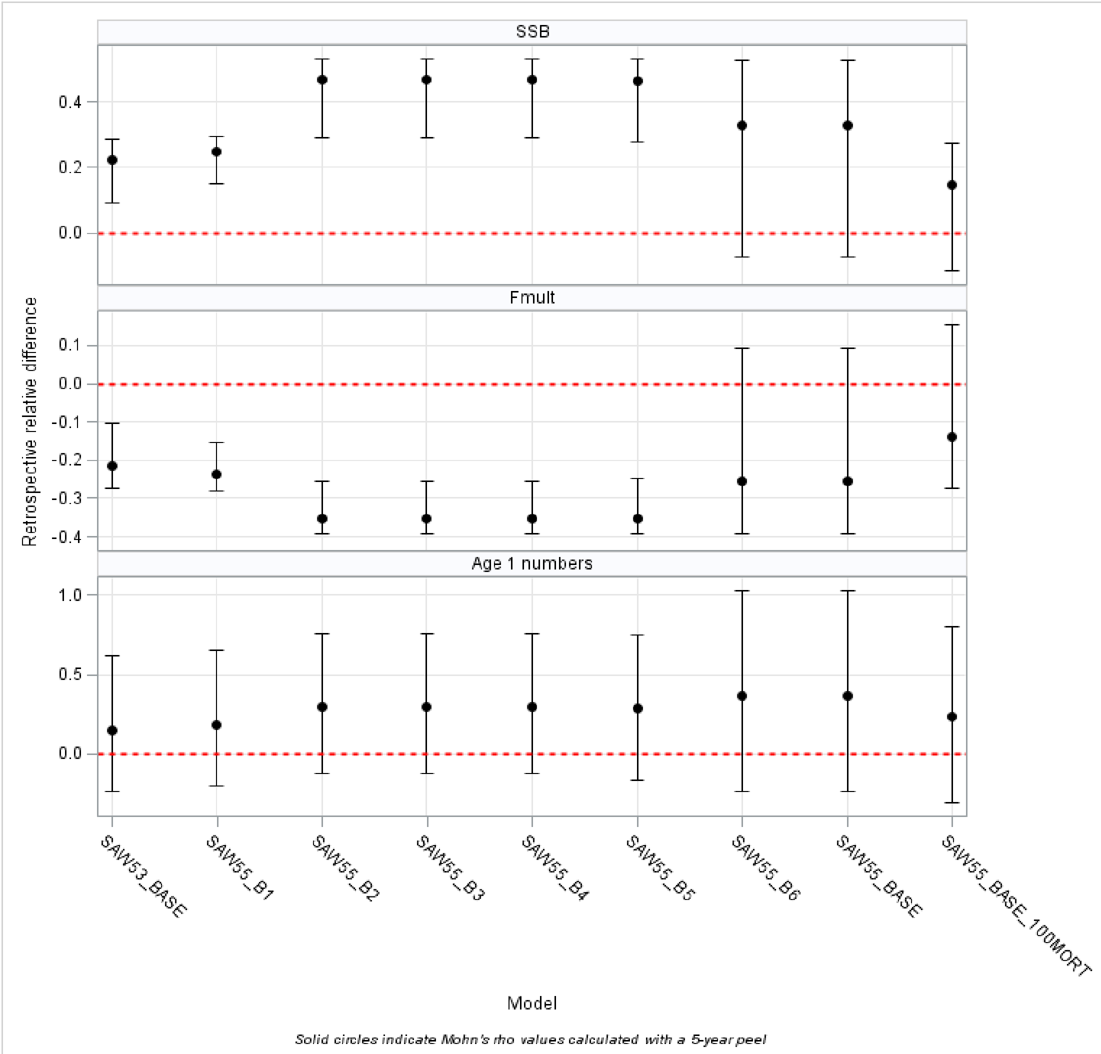


Figure A.141. Summary of the Mohn's rho values (dots) and minimum and maximum observed relative difference resulting from a five year retrospective peel for the eight model runs considered in the update of the SAW 53 Gulf of Maine Atlantic cod assessment model.

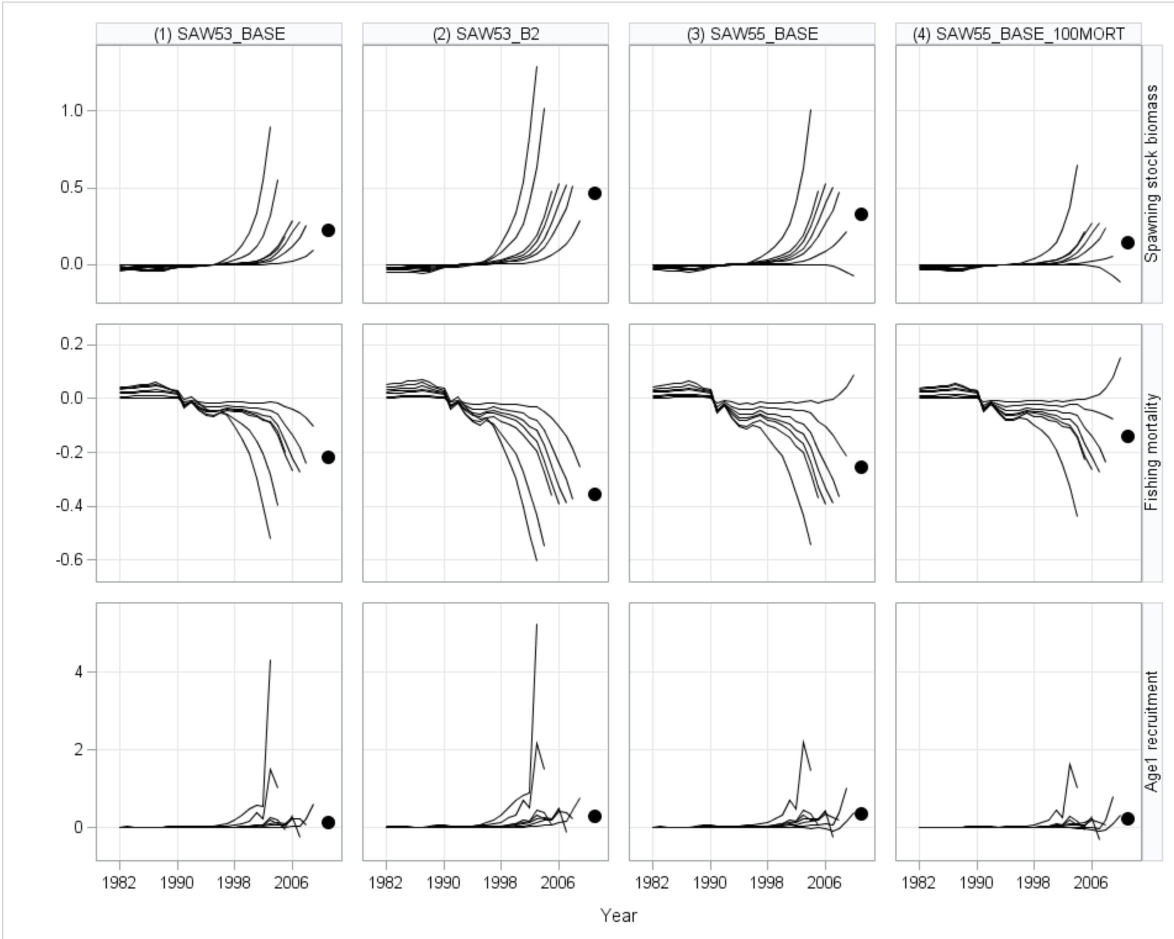


Figure A.142. ASAP BASE model retrospective patterns for the Gulf of Maine Atlantic cod SAW53 model (SAW53_BASE), SAW 53 model after application of revised discard mortality rates (SAW53_B2), updated SAW 55 base model (SAW55_BASE) and the SAW 55 base model under an assumption of 100% discard mortality (SAW55_BASE_100MORT). The black circles indicate the Mohn's rho value based on a five year retrospective peel.

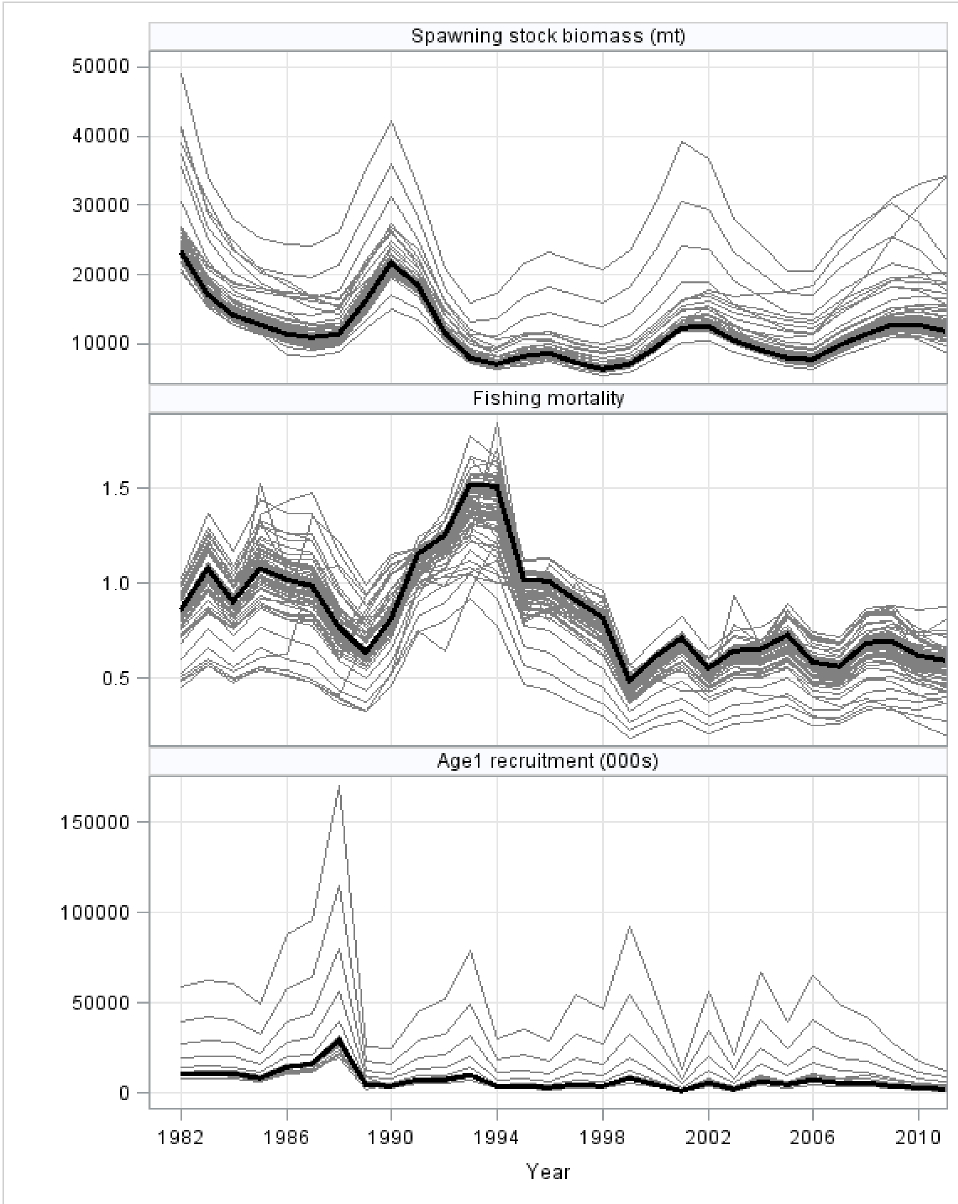


Figure A.143. Estimates of Gulf of Maine Atlantic cod spawning stock biomass (top), average age 5 fishing mortality (middle) and age 1 recruitment (bottom) from the 100-plus ASAP sensitivity runs. The results of the SAW55_BASE model are shown by a solid black line. A full description of the major sensitivity runs that were conducted can be found in Appendix A.6.

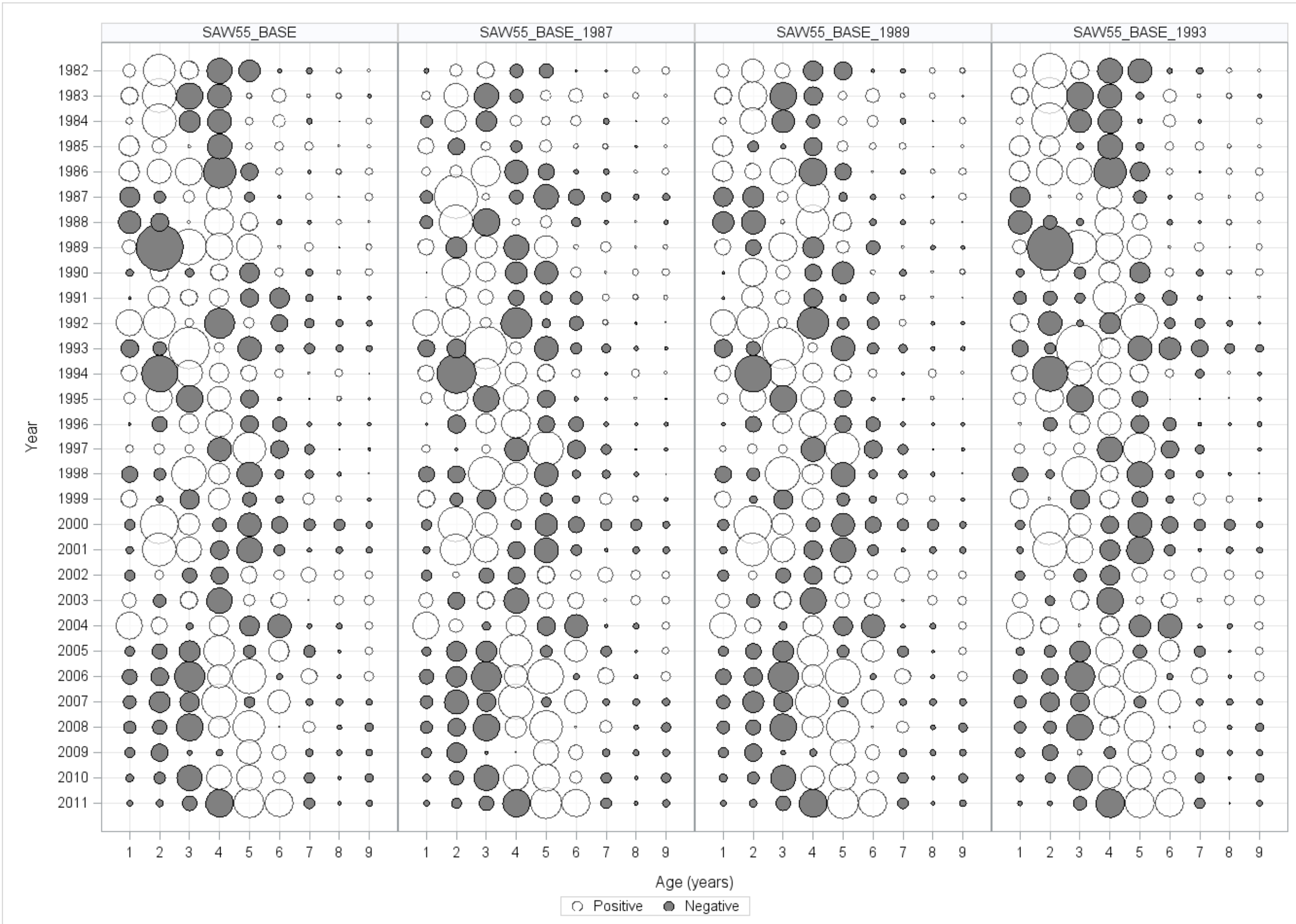


Figure A.144. ASAP model residuals for the fits to the fishery catch-at-age of Gulf of Maine Atlantic cod for four different 2-selectivity block models. The models vary by the transition year between blocks 1 and 2 (i.e., year in which block 2 begins). In all sensitivity runs the transition year is indicated by the model suffix; for the SAW55_BASE model block 2 begins in 1991.

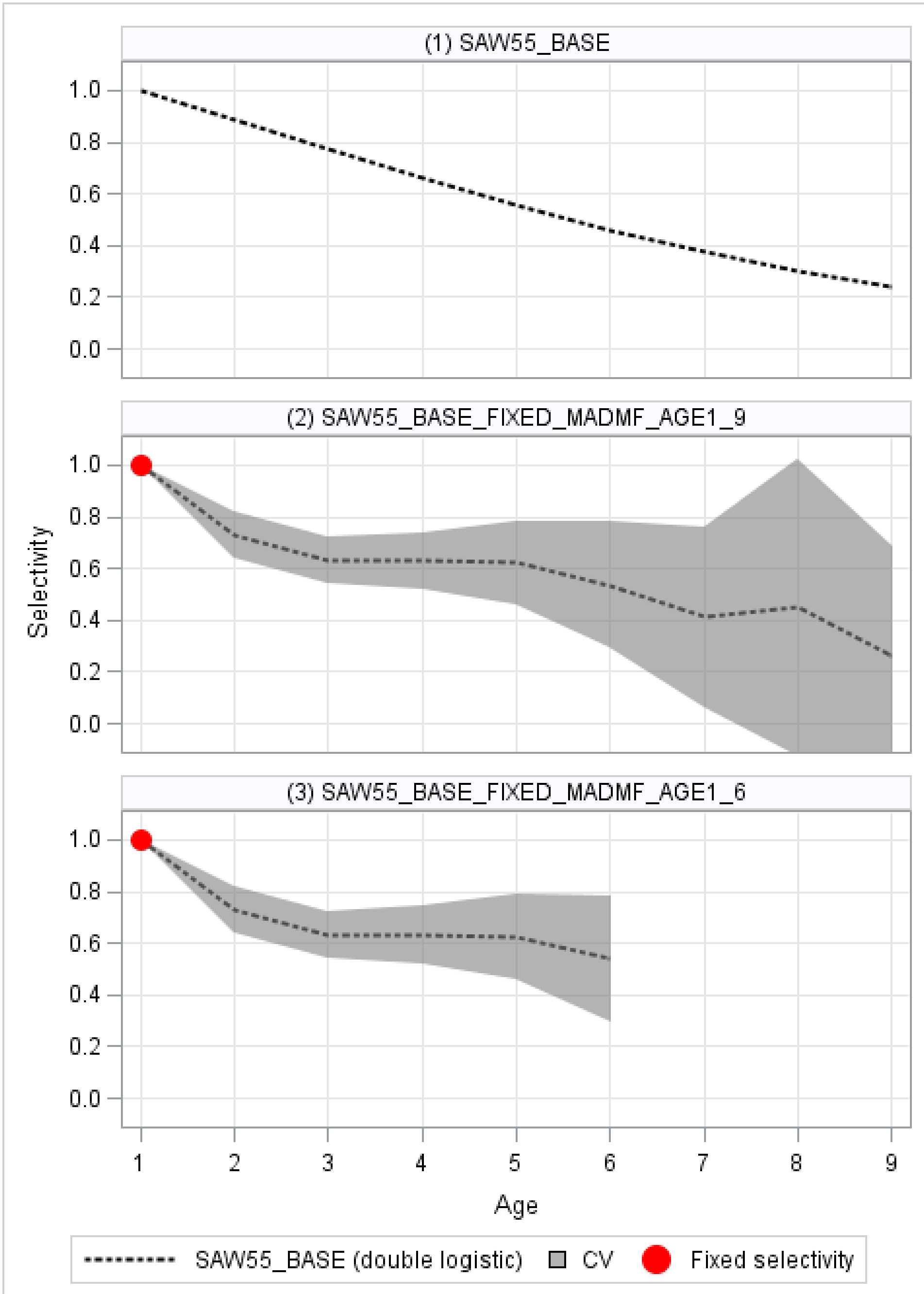


Figure A.145. Model estimated Gulf of Maine Atlantic cod selectivity at age for the Massachusetts Department of Marine Fisheries (MADMF) spring survey based on ASAP model explorations of fitting the survey using both parametric (double logistic, SAW55_BASE) and non-parametric (at-age, all other models) approaches.

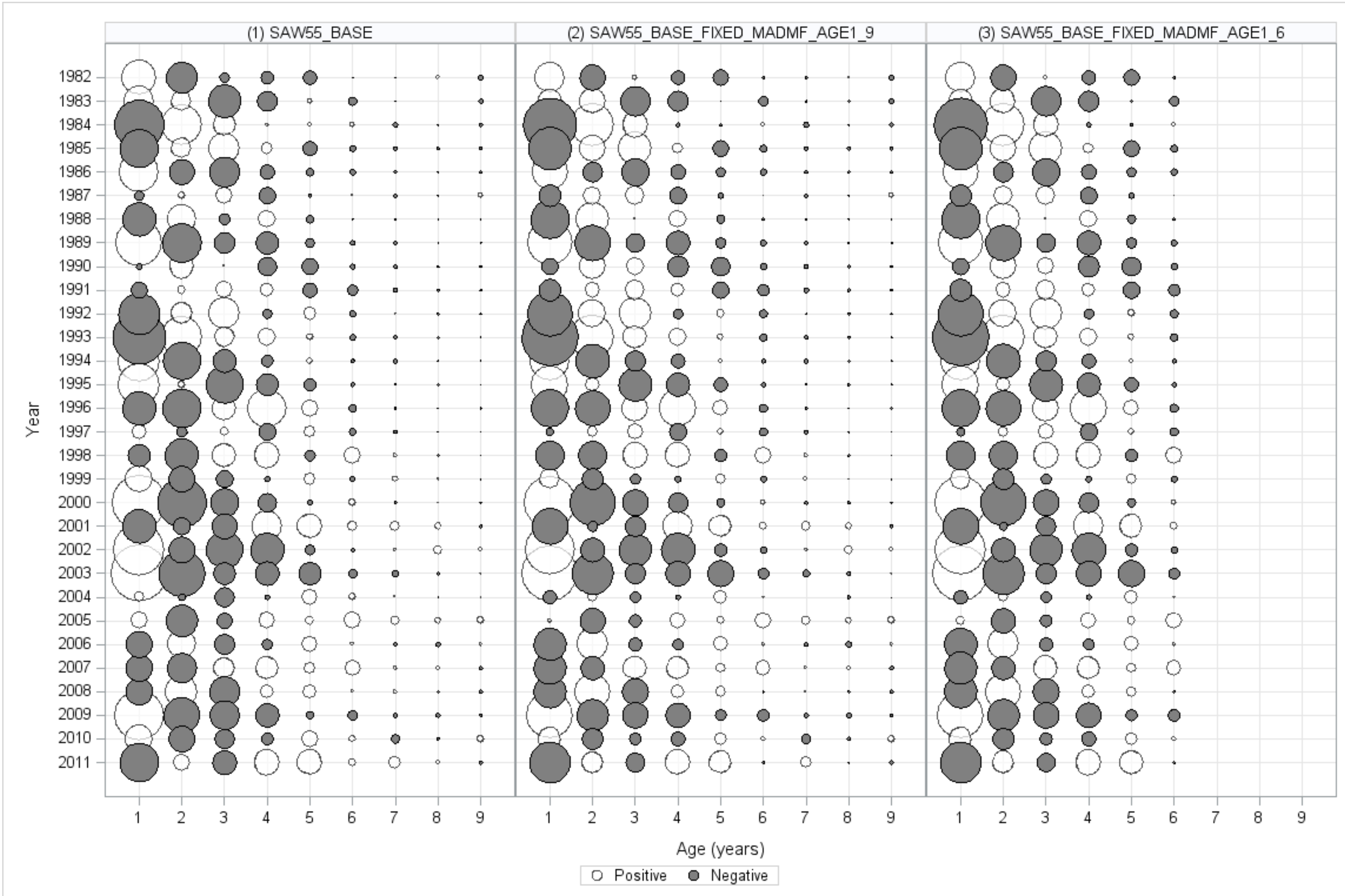


Figure A.146. Residual plots from the fitting of Massachusetts Department of Marine Fisheries (MADMF) spring survey Gulf of Maine Atlantic cod indices at age from ASAP model explorations using both parametric (double logistic, SAW55_BASE) and non-parametric (at-age, all other models) approaches.

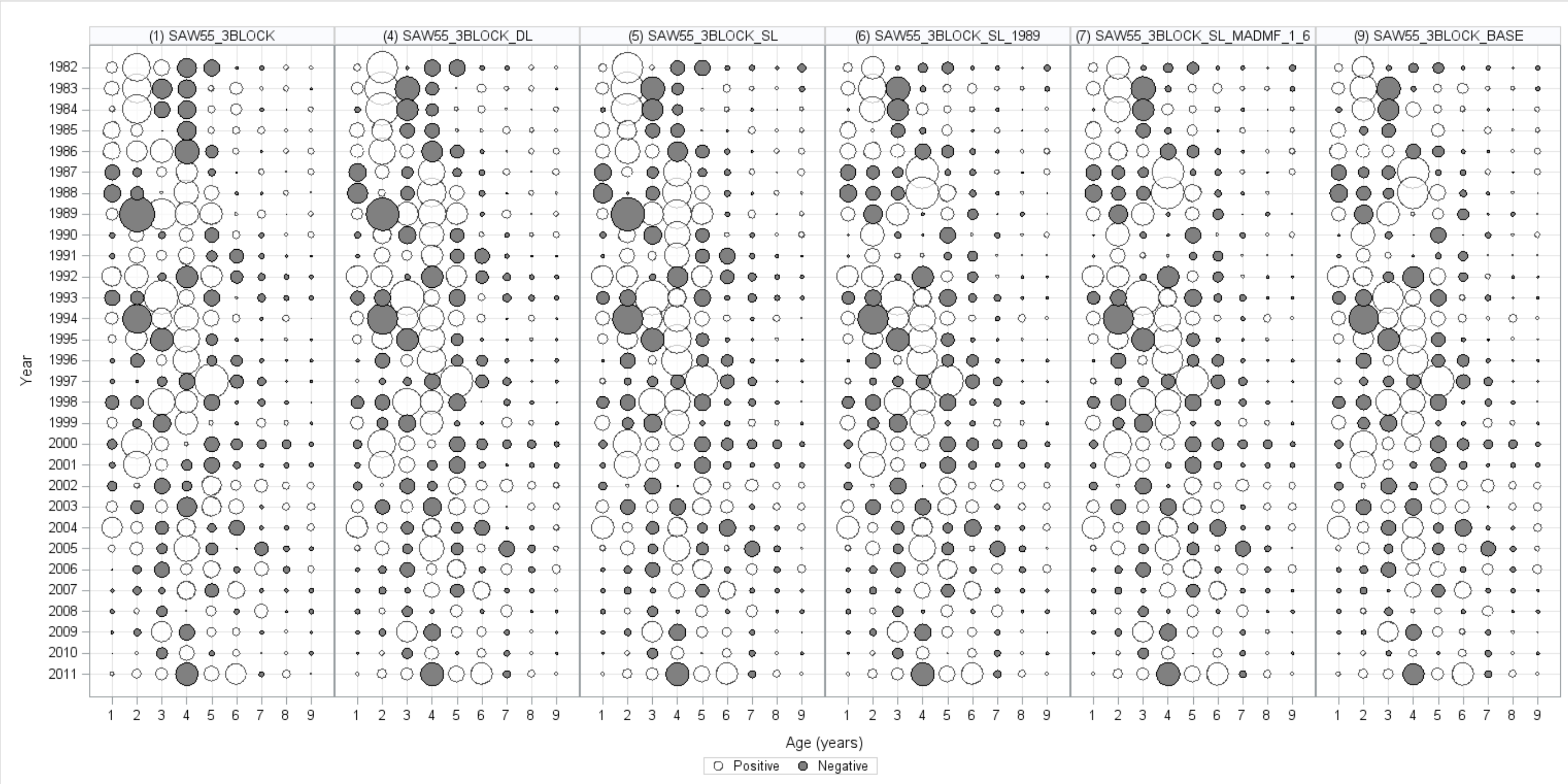


Figure A.147. ASAP model residuals for the fits to the fishery catch-at-age of Gulf of Maine Atlantic cod for six different 3-selectivity block models.

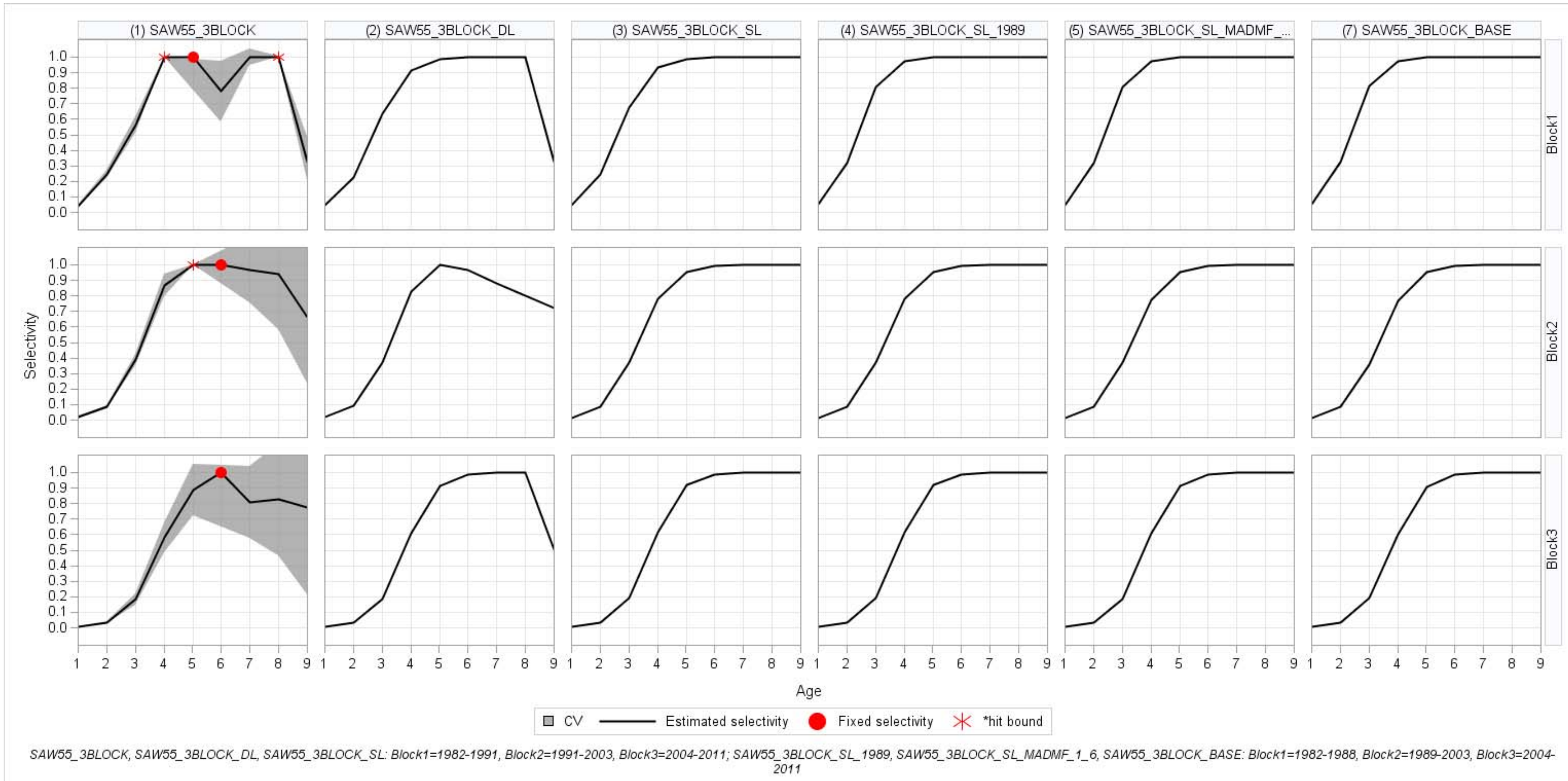


Figure A.148. ASAP estimated fishery selectivities for Gulf of Maine Atlantic cod from six different 3-selectivity block models.

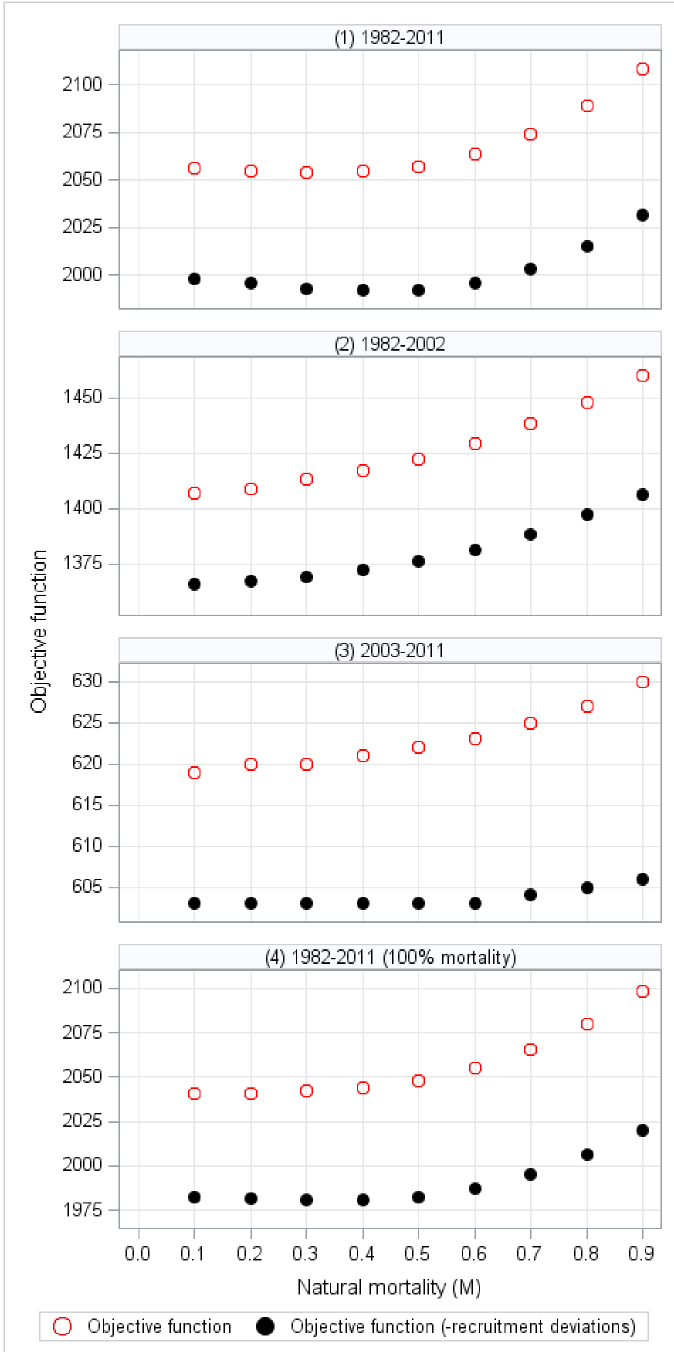


Figure A.149. Response of the model objective function to profiling over a range of Gulf of Maine cod natural mortality values. Four different models configurations are explored: (1) 1982-2011, (2) 1982-2002, (3) 2003-2011, and (4) 1982-2011 under assumption of 100% discard mortality.

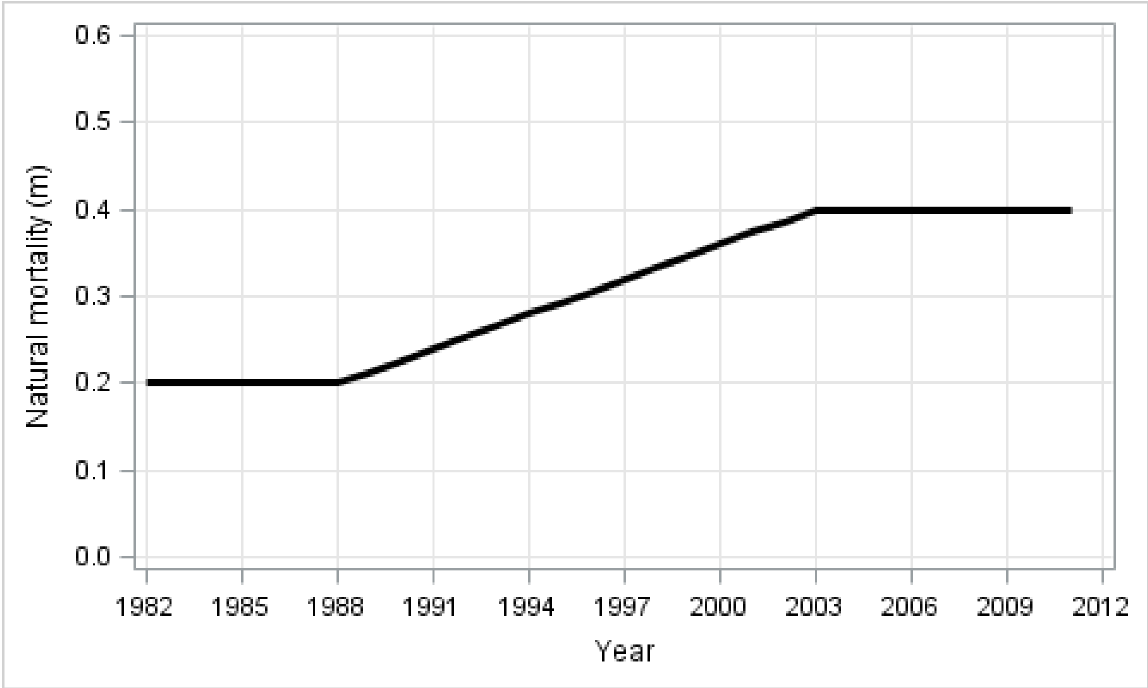


Figure A.150. Time series of natural mortality used in the Gulf of Maine cod natural mortality ramp assessment models.

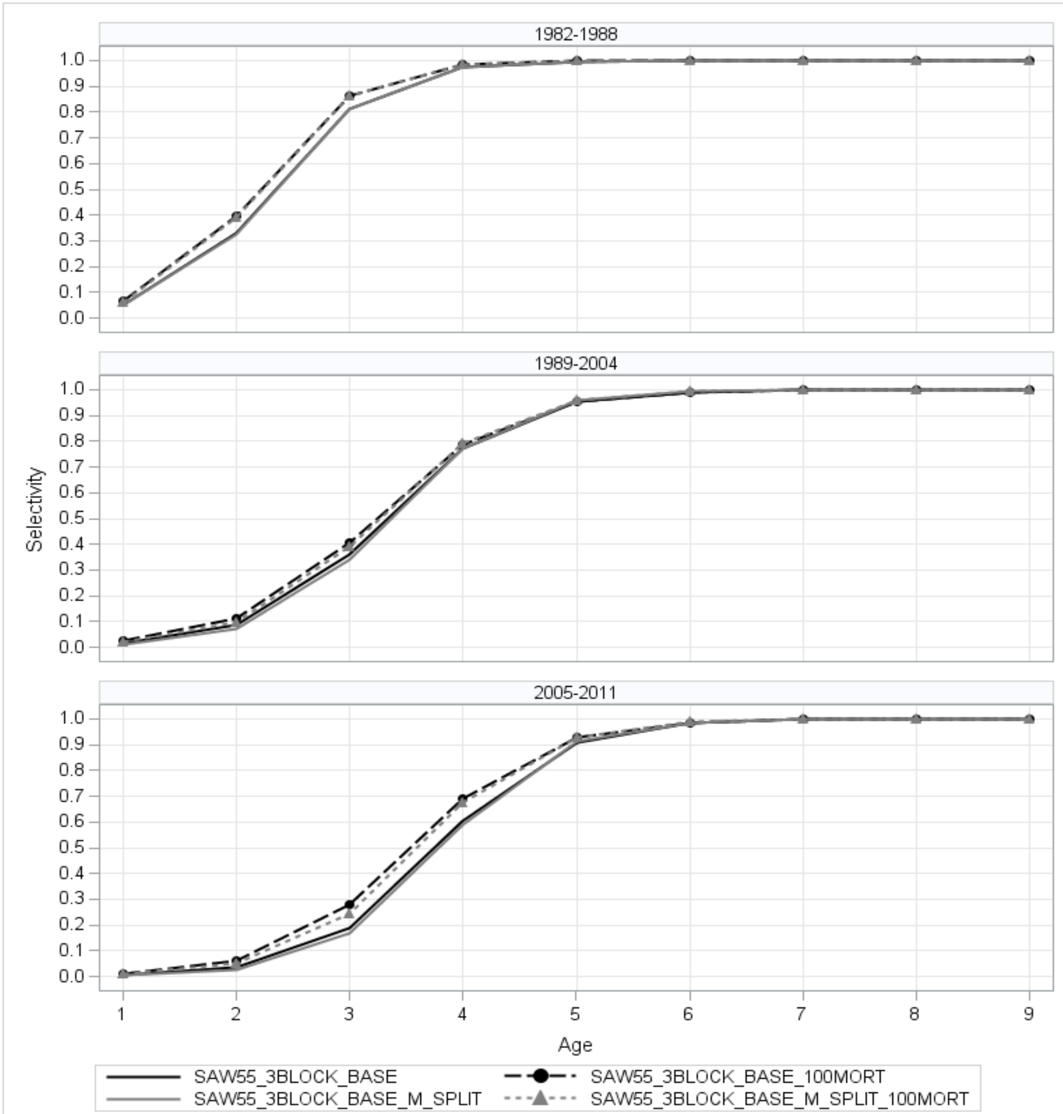


Figure A.151. Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1988), block 2 (1989-2004) and block 3 (2005-2011) estimated by sensitivity runs of the ASAP SAW55_3BLOCK_BASE model.

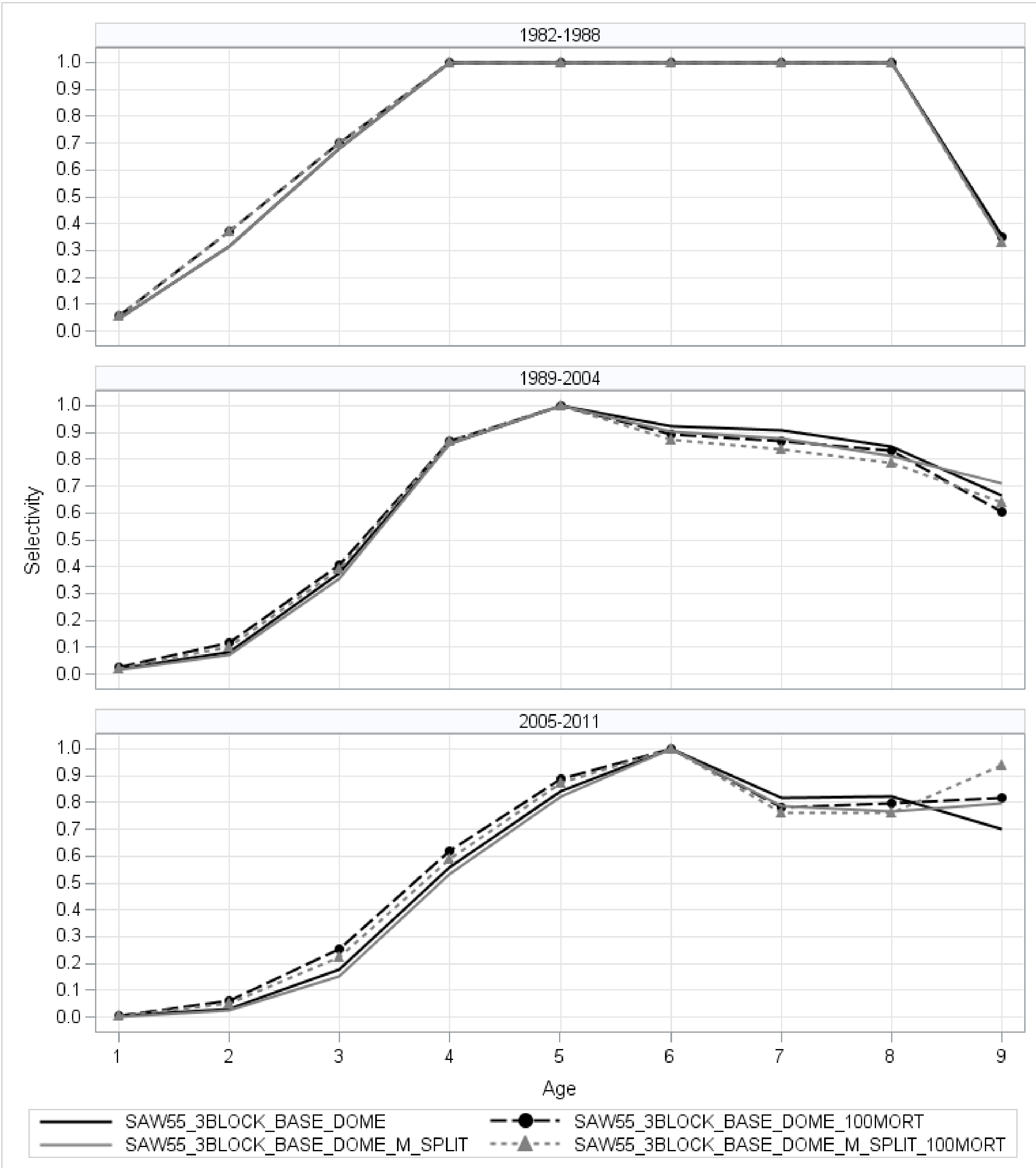


Figure A.152. Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1988), block 2 (1989-2004) and block 3 (2005-2011) estimated by sensitivity runs of the ASAP SAW55_3BLOCK_BASE_DOME model.

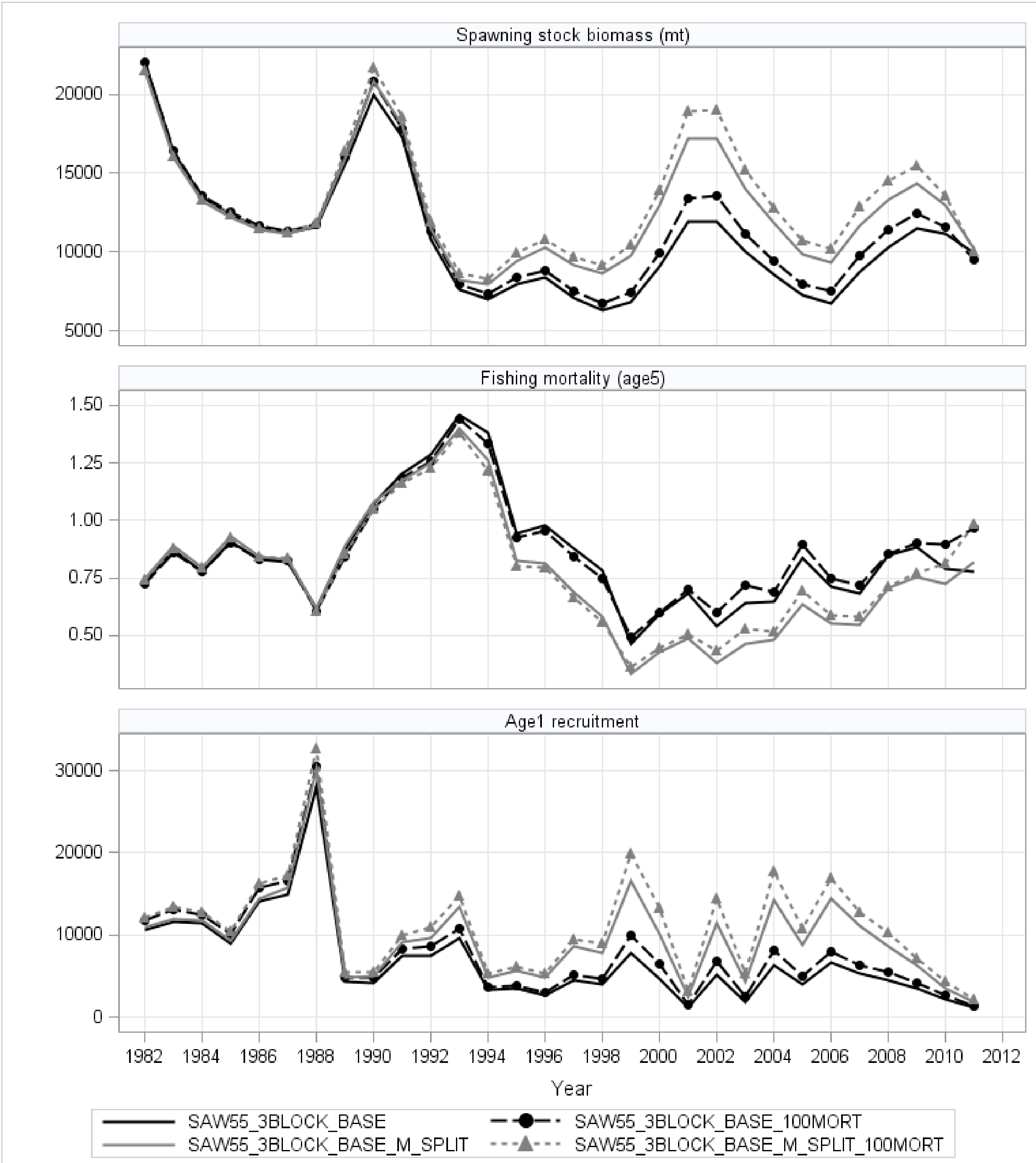


Figure A.153. Gulf of Maine Atlantic cod spawning stock biomass, age 5 fishing mortality and age 1 recruitment estimated by sensitivity runs of the ASAP SAW55_3BLOCK_BASE model.

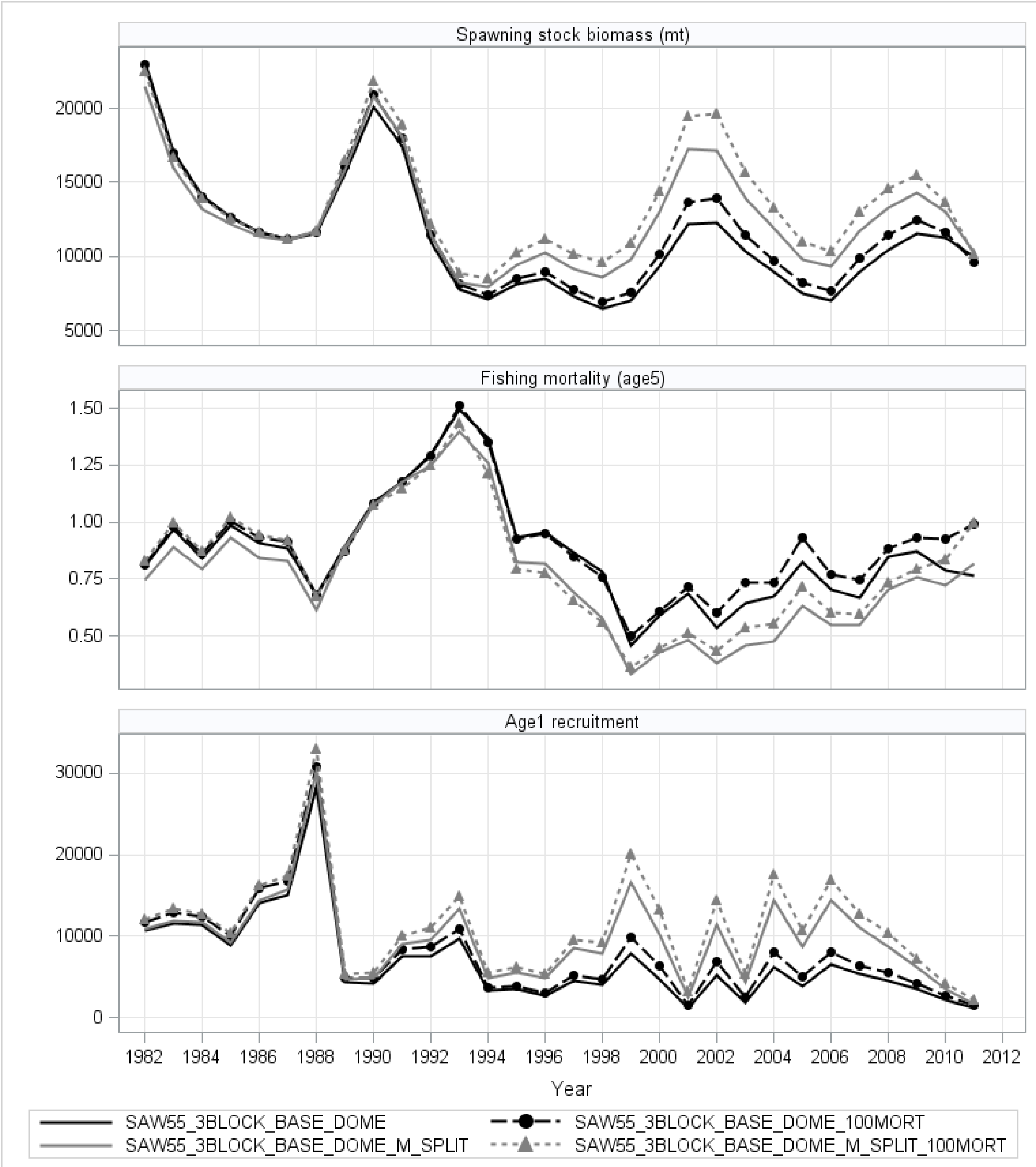


Figure A.154. Gulf of Maine Atlantic cod spawning stock biomass, age 5 fishing mortality and age 1 recruitment estimated by sensitivity runs of the ASAP SAW55_3BLOCK_BASE_DOME model.

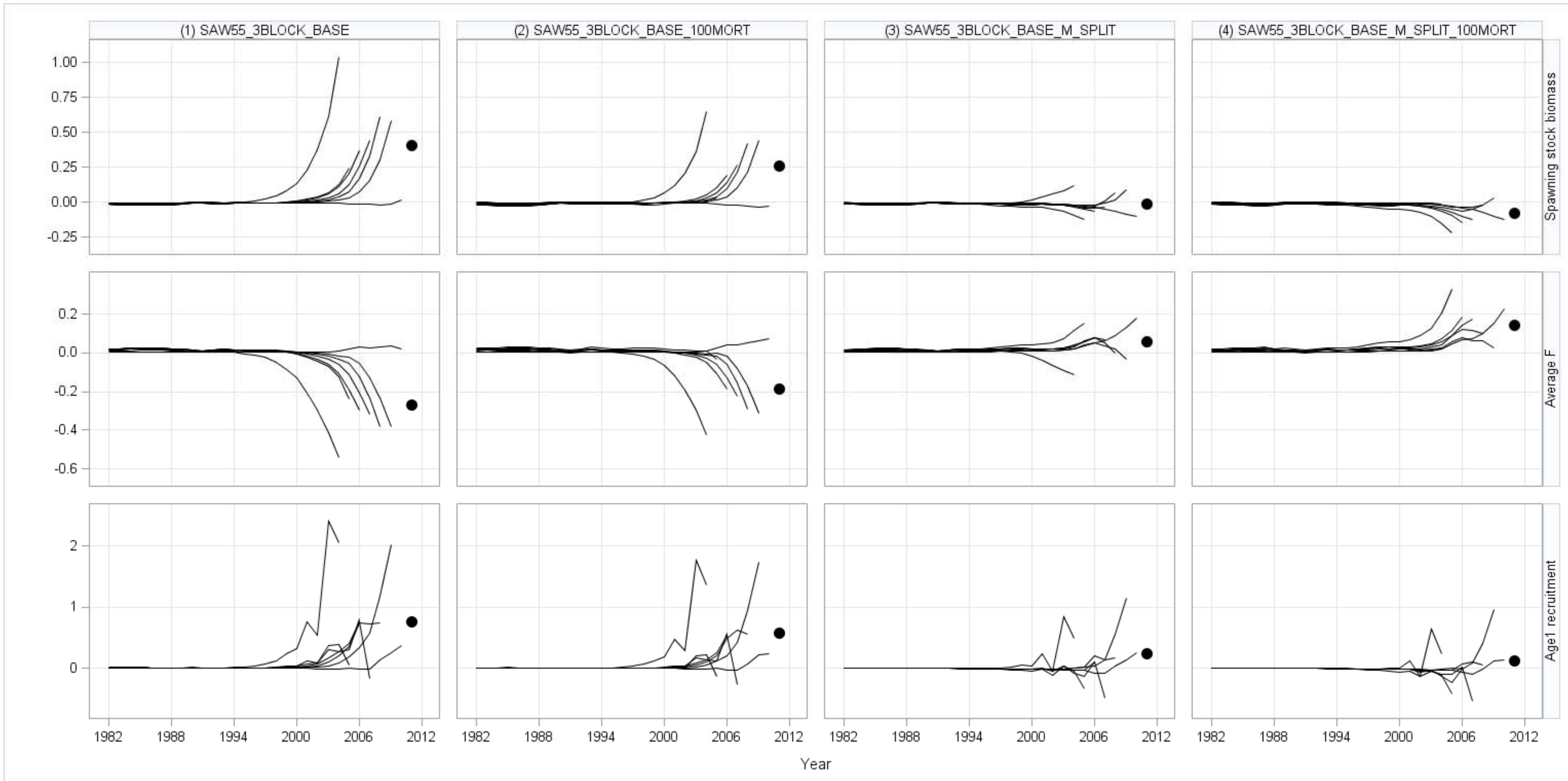


Figure A.155. Model retrospective patterns for sensitivity runs of the Gulf of Maine Atlantic ASAP SAW55_3BLOCK_BASE model. The black circles indicates the Mohn's rho value based on a five year retrospective peel.

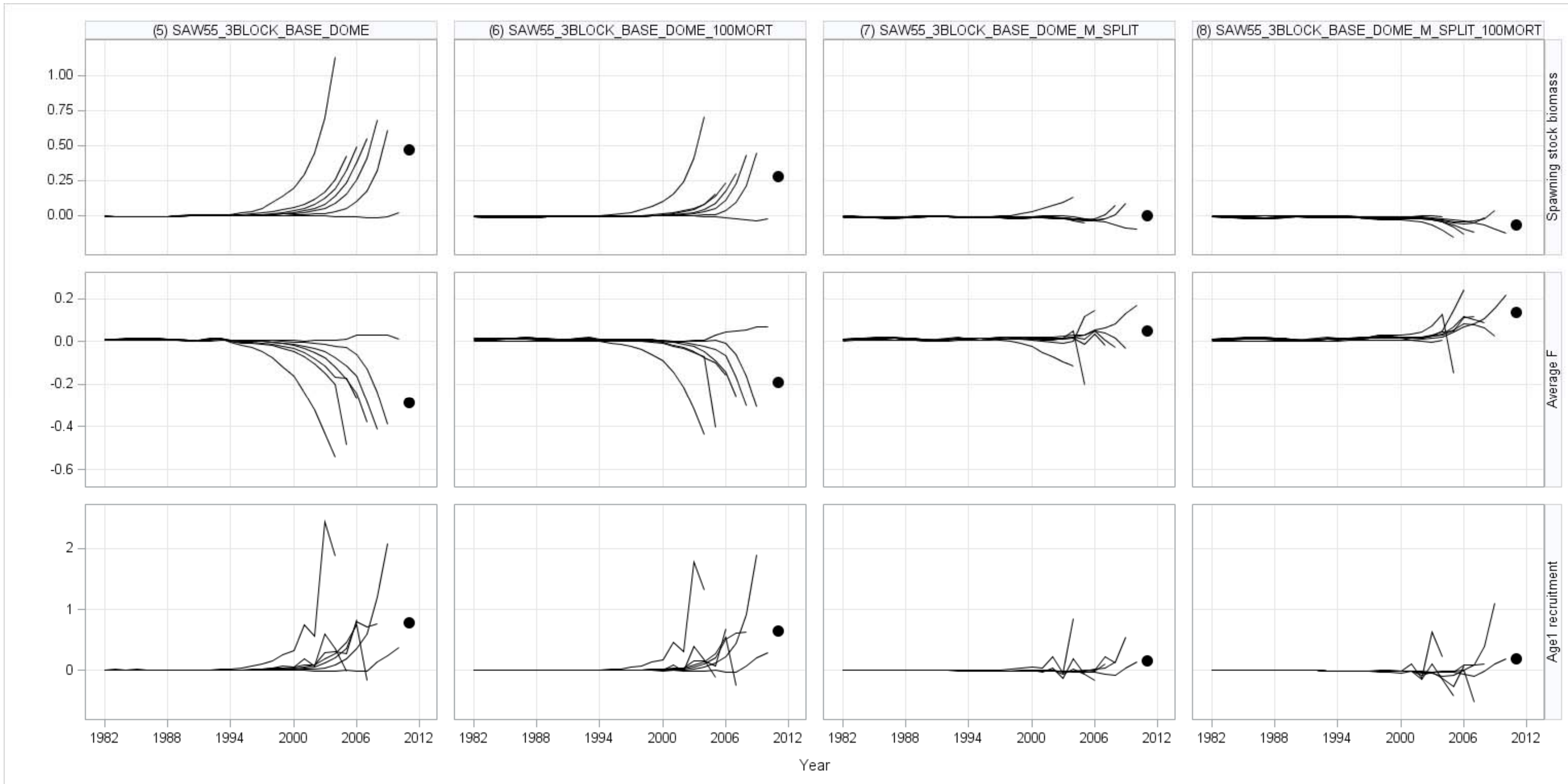


Figure A.156. Model retrospective patterns for sensitivity runs of the Gulf of Maine Atlantic ASAP SAW55_3BLOCK_BASE_DOME model. The black circles indicate the Mohn's rho value based on a five year retrospective peel.

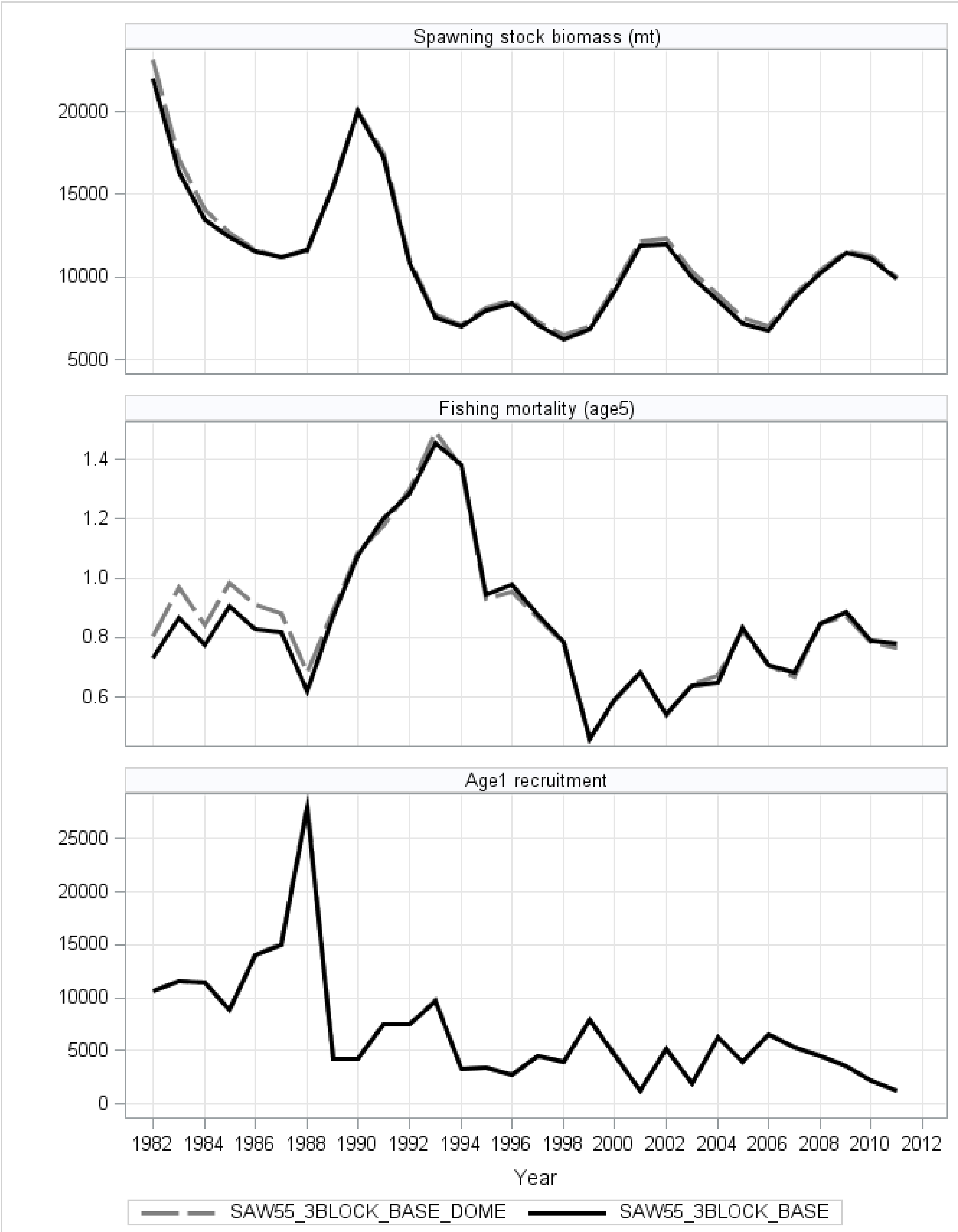


Figure A.157. Comparison of the Gulf of Maine Atlantic cod spawning stock biomass, age 5 fishing mortality and age 1 recruitment from the ASAP SAW55_3BLOCK_BASE and SAW55_3BLOCK_BASE_DOME models.

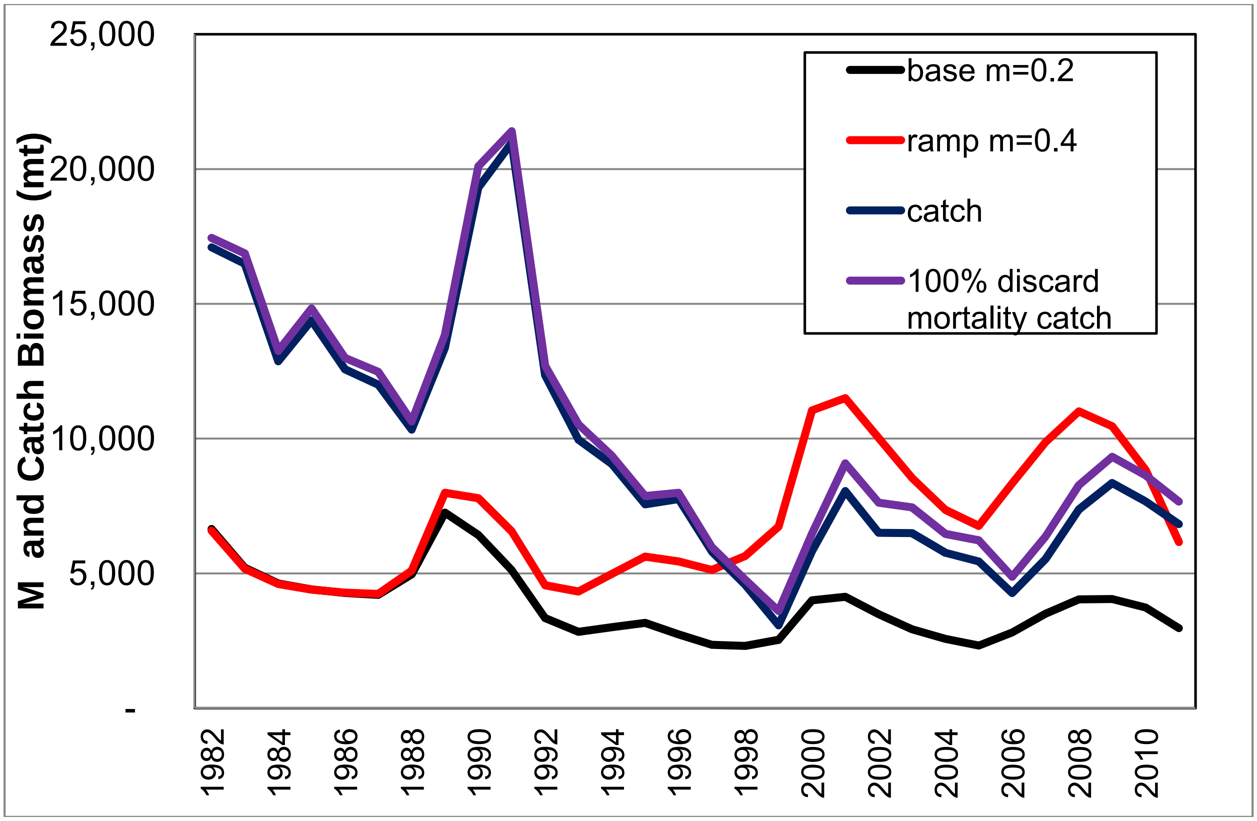


Figure A.158. Comparison of fishery (catch) and natural mortality removals under the $M_{0.2}$ (SAW55_3BLOCK_BASE)and M_{Ramp} (SAW55_3BLOCK_BASE_M_SPLIT) models. Fishery removals are shown using both the revised discard mortality assumptions and the 100% discard mortality assumption.

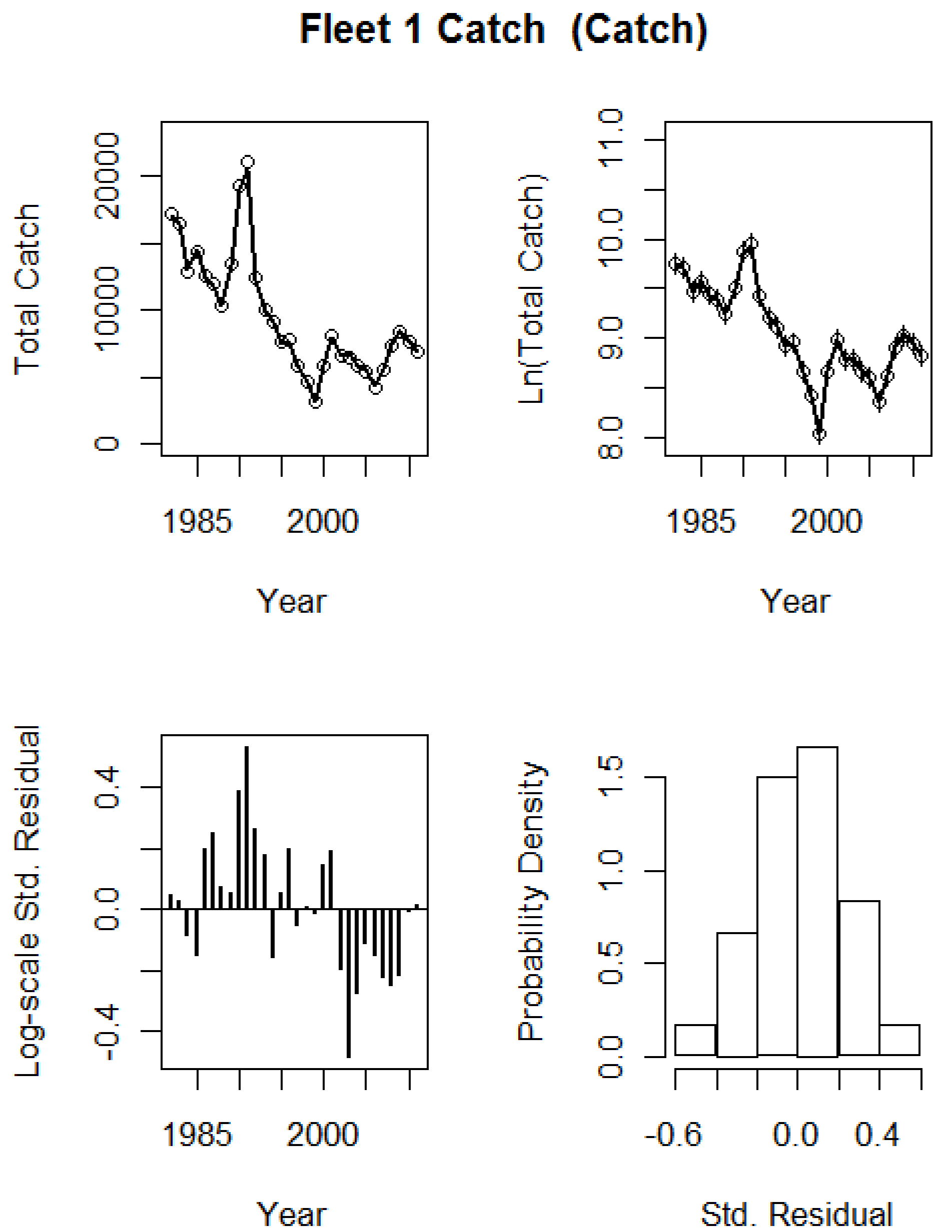


Figure A.159. ASAP SAW55_3BLOCK_BASE model fit to the total Gulf of Maine Atlantic cod fishery catch (Fleet 1).

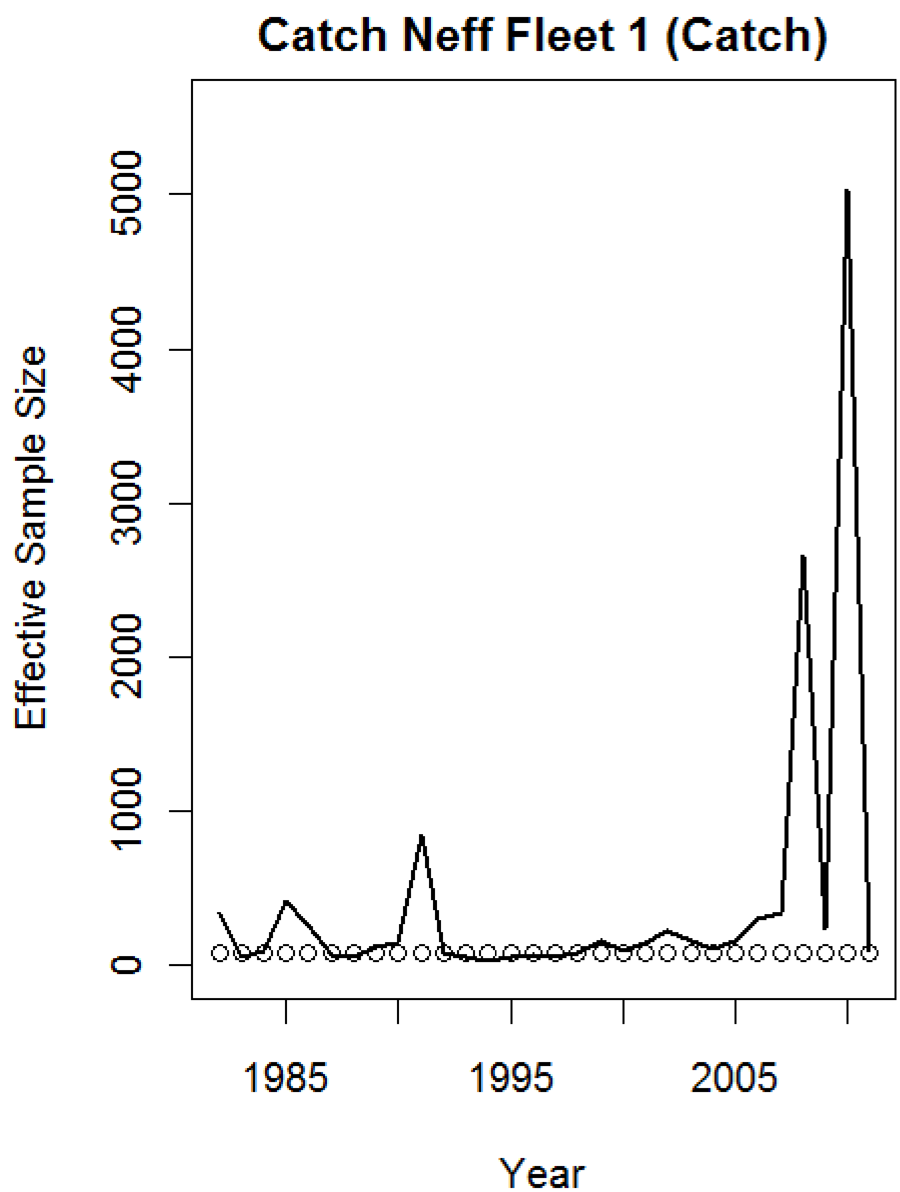


Figure A.160. ASAP SAW55_3BLOCK_BASE model comparison of input effective sample size versus the model estimated effective sample size for the Gulf of Maine Atlantic cod fishery catch.

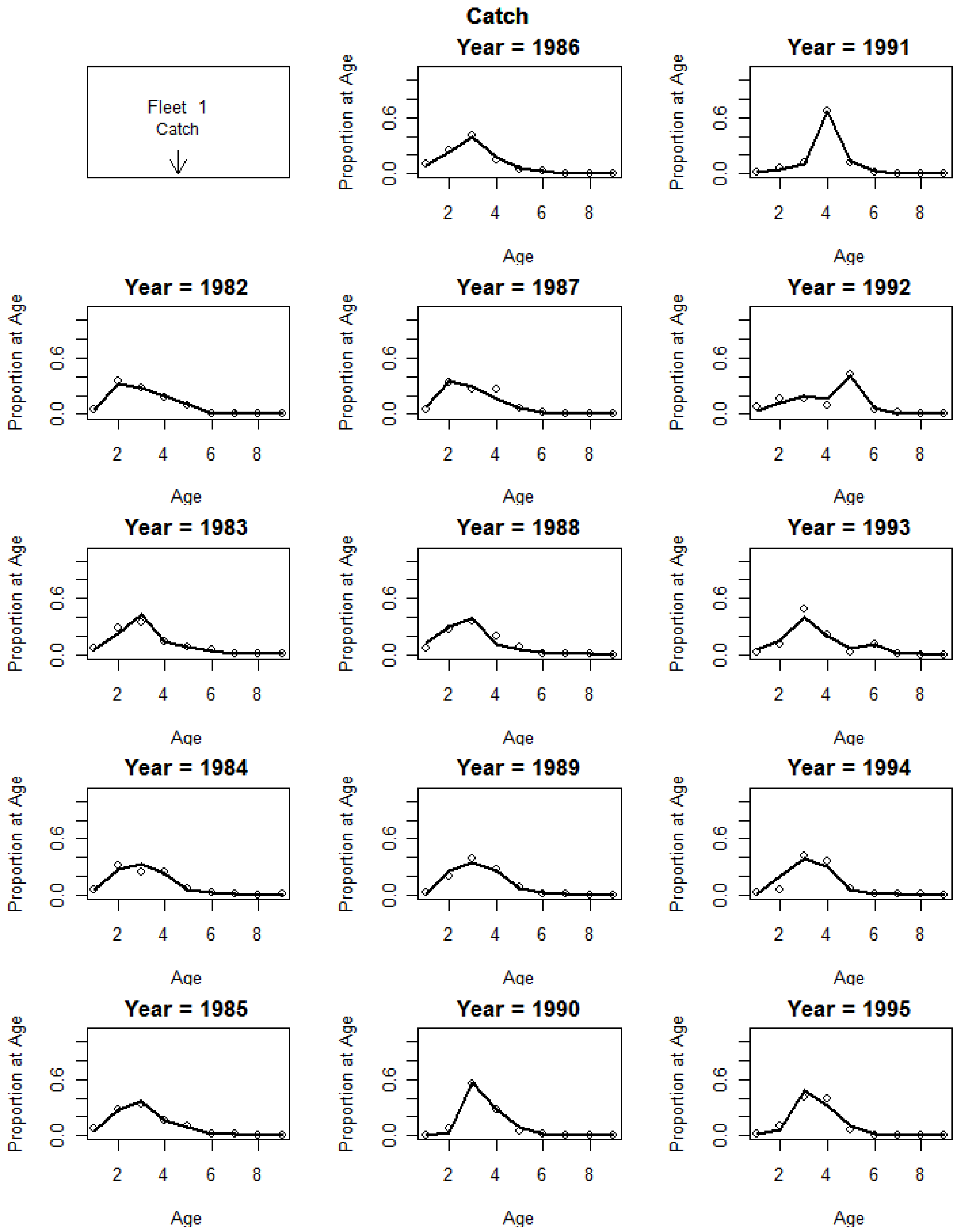


Figure A.161.a. Comparison of the ASAP SAW55_3BLOCK_BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

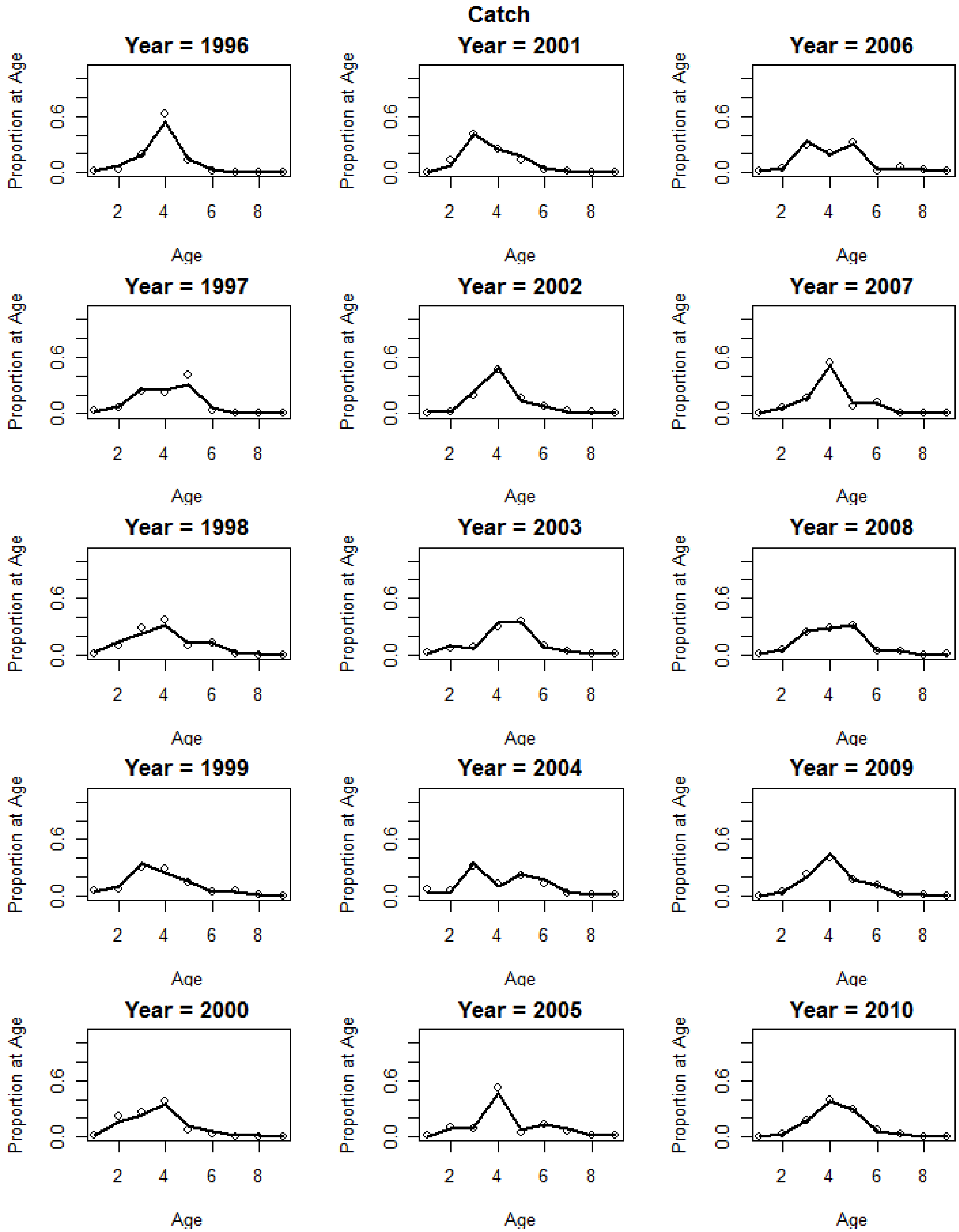


Figure A.161.b. Comparison of the ASAP SAW55_3BLOCK_BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

Catch

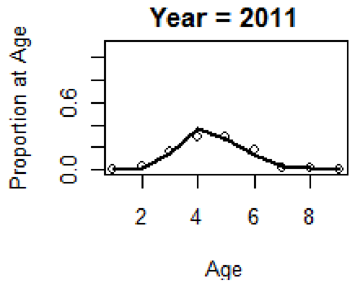


Figure A.161.c. Comparison of the ASAP SAW55_3BLOCK_BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

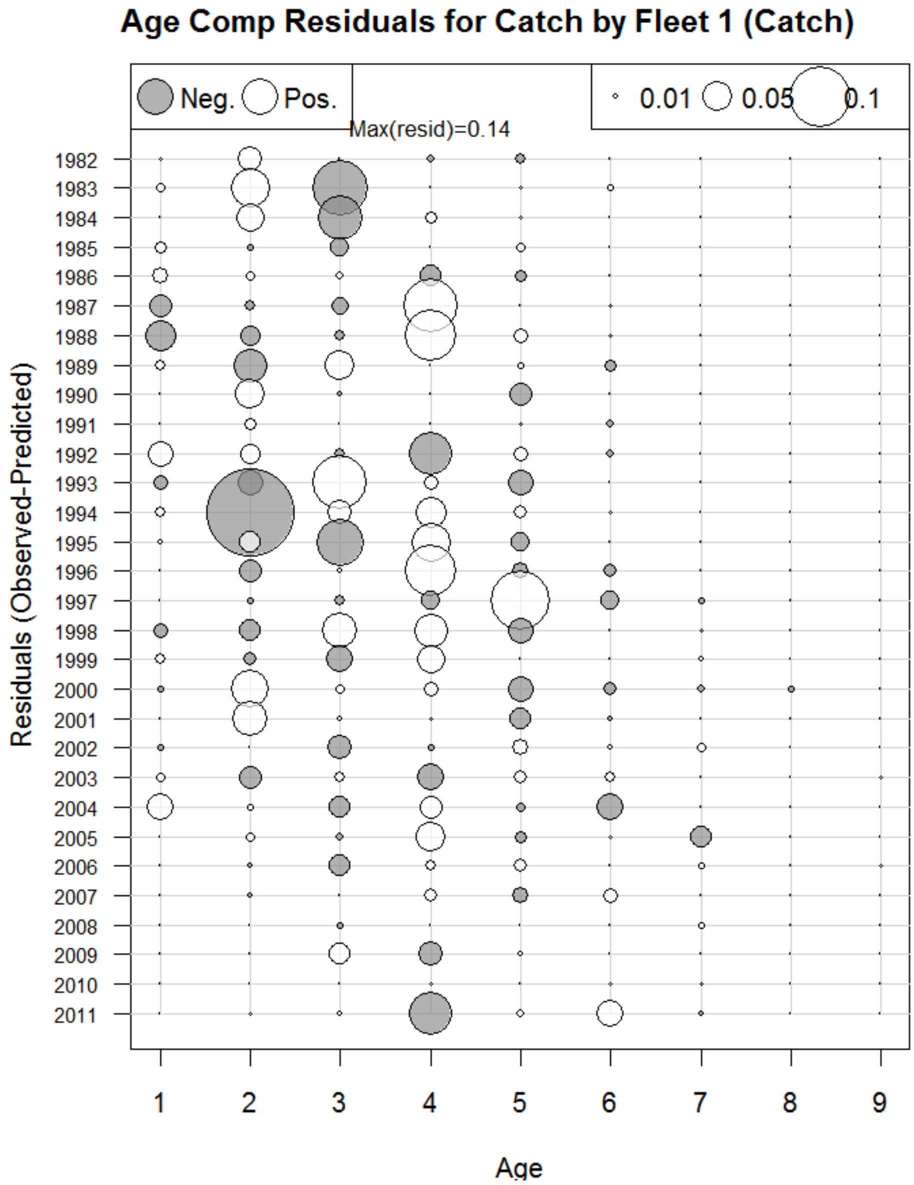


Figure A.162. ASAP SAW55_3BLOCK_BASE model fit residuals for the fishery (Fleet 1) catch-at-age of Gulf of Maine Atlantic cod.

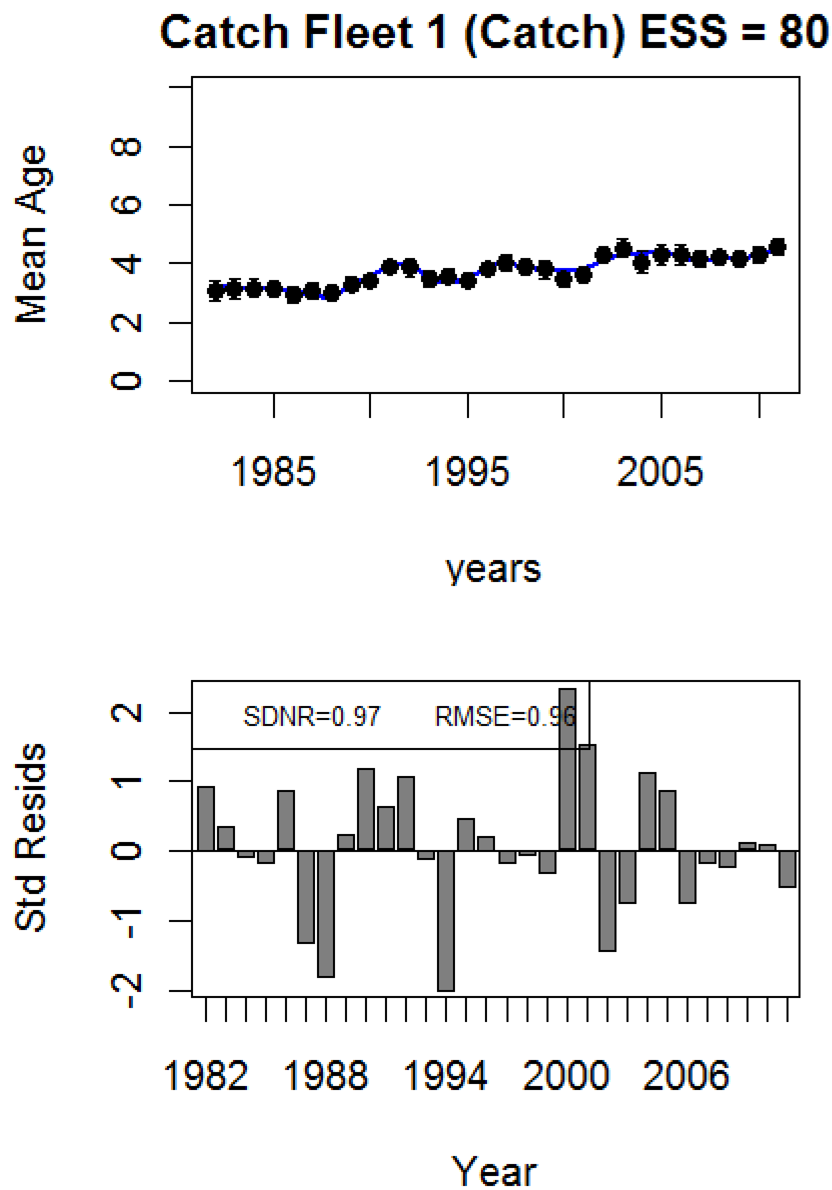


Figure A.163. ASAP SAW55_3BLOCK_BASE predicted mean age of Gulf of Maine Atlantic cod in the fishery catch (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

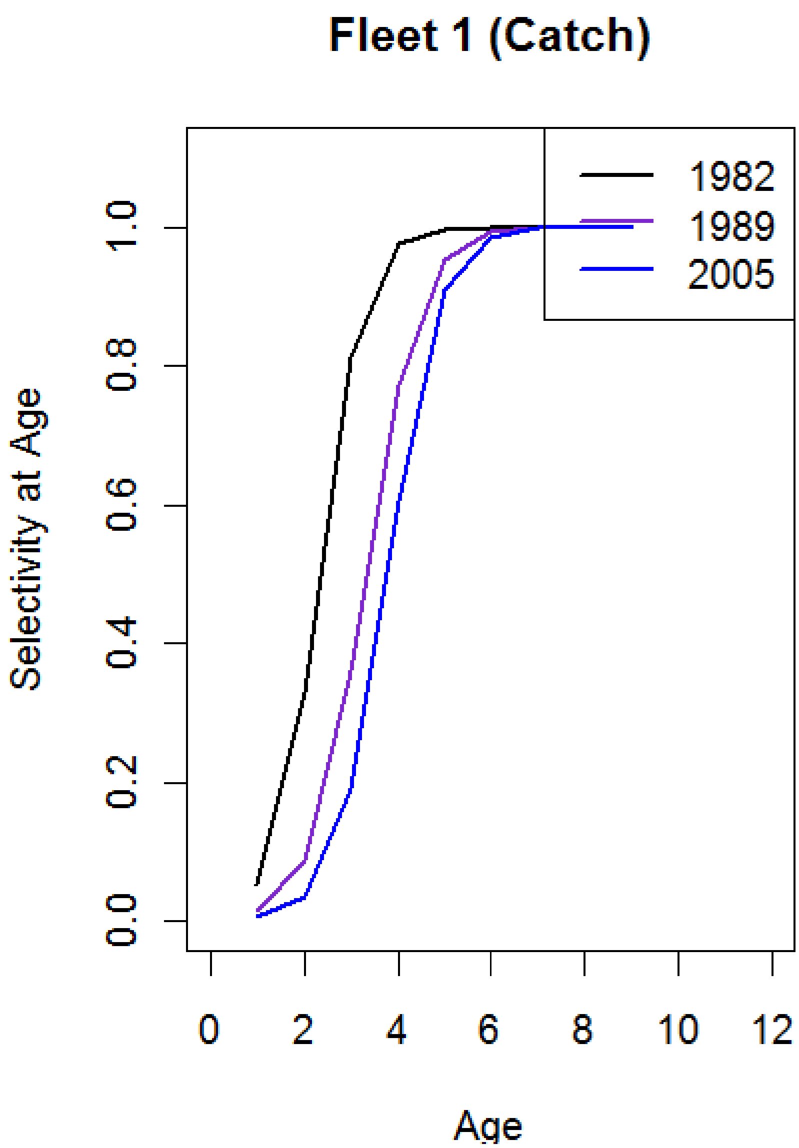


Figure A.164. Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1989), block 2 (1990-2004) and block 3 (2005-2011) estimated by the ASAP SAW55_3BLOCK_BASE model.

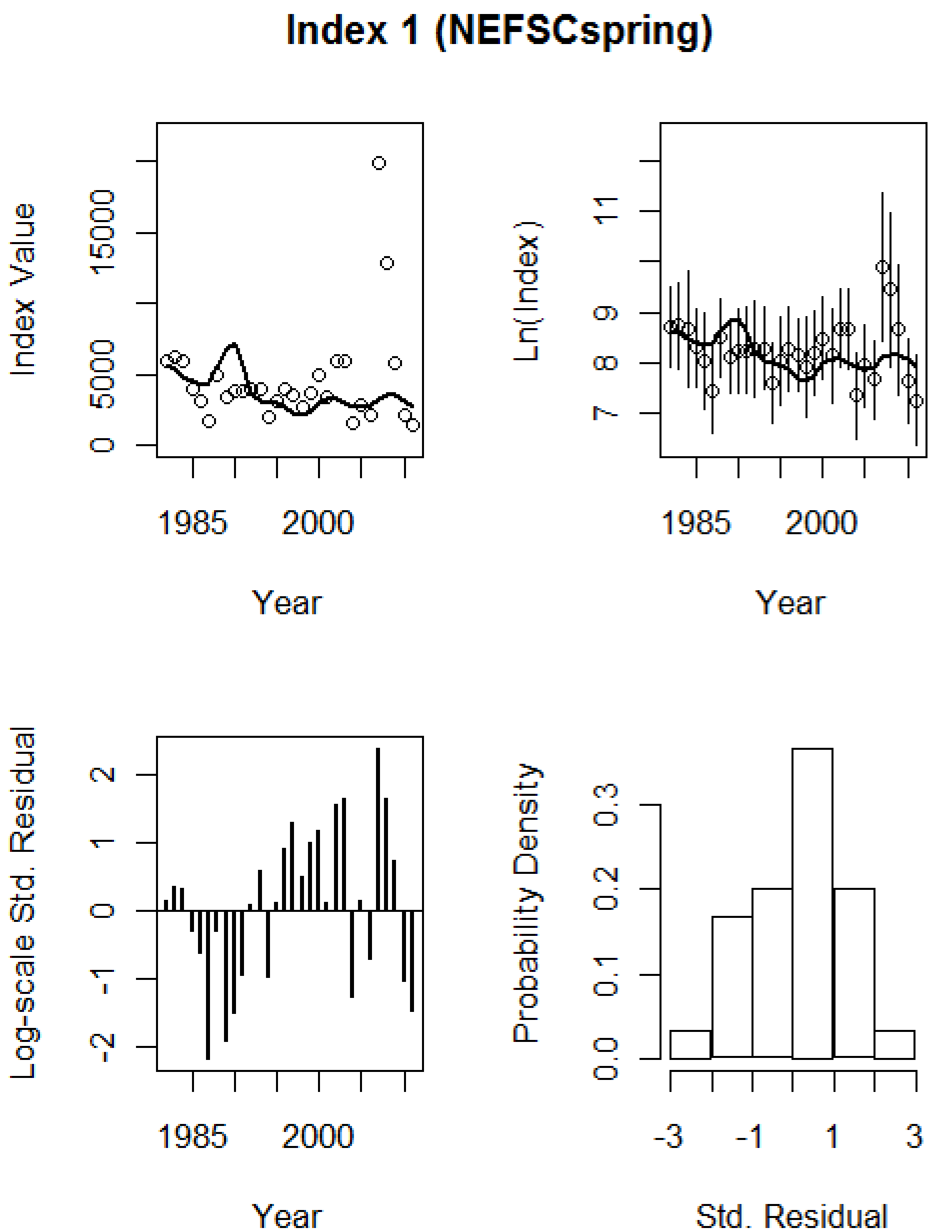


Figure A.165. ASAP SAW55_3BLOCK_BASE model fit to the NEFSC Gulf of Maine Atlantic cod spring (Index 1) survey.

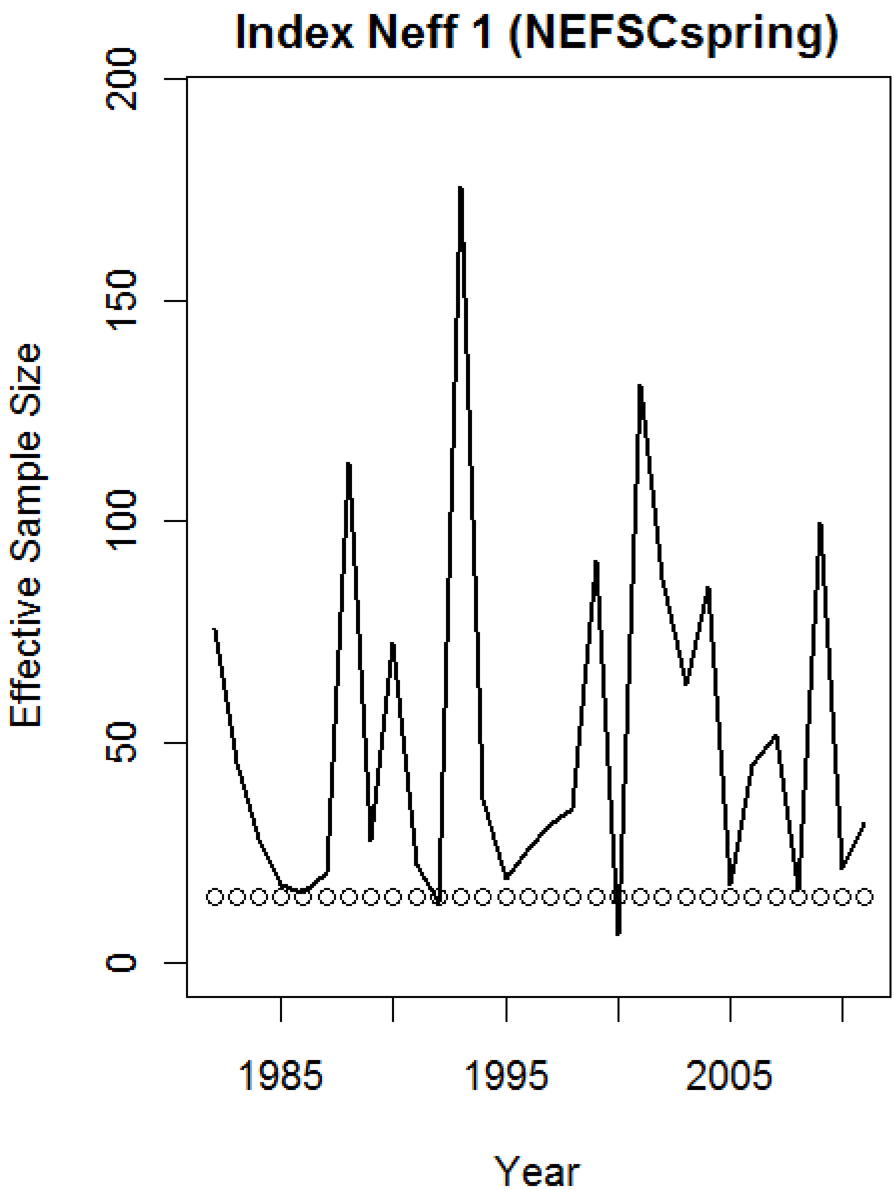


Figure A.166. ASAP SAW55_3BLOCK_BASE model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC spring (Index 1) Gulf of Maine Atlantic cod index.

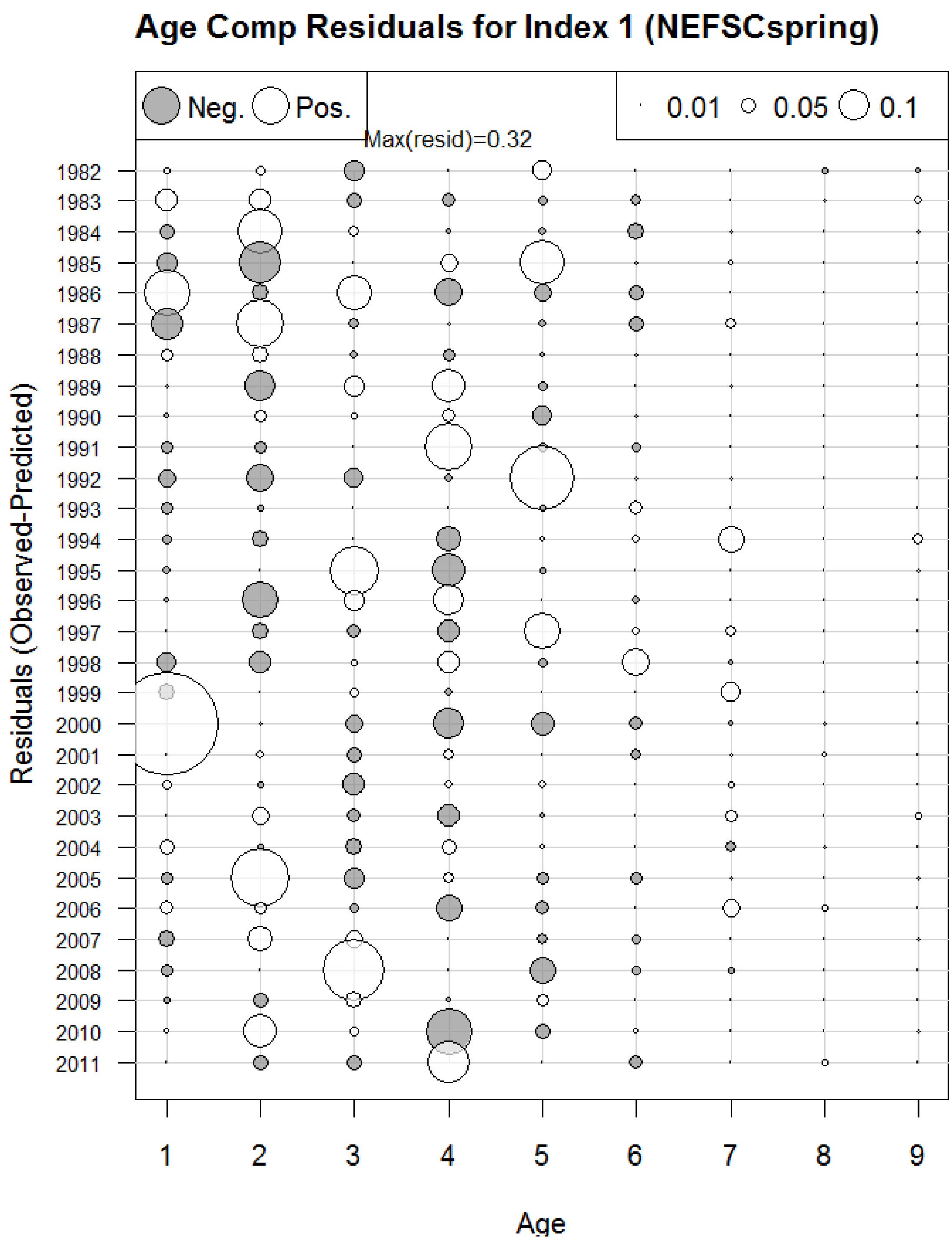


Figure A.167. ASAP SAW55_3BLOCK_BASE model fit residuals for the NEFSC spring survey (Index 1) Gulf of Maine Atlantic cod age composition.

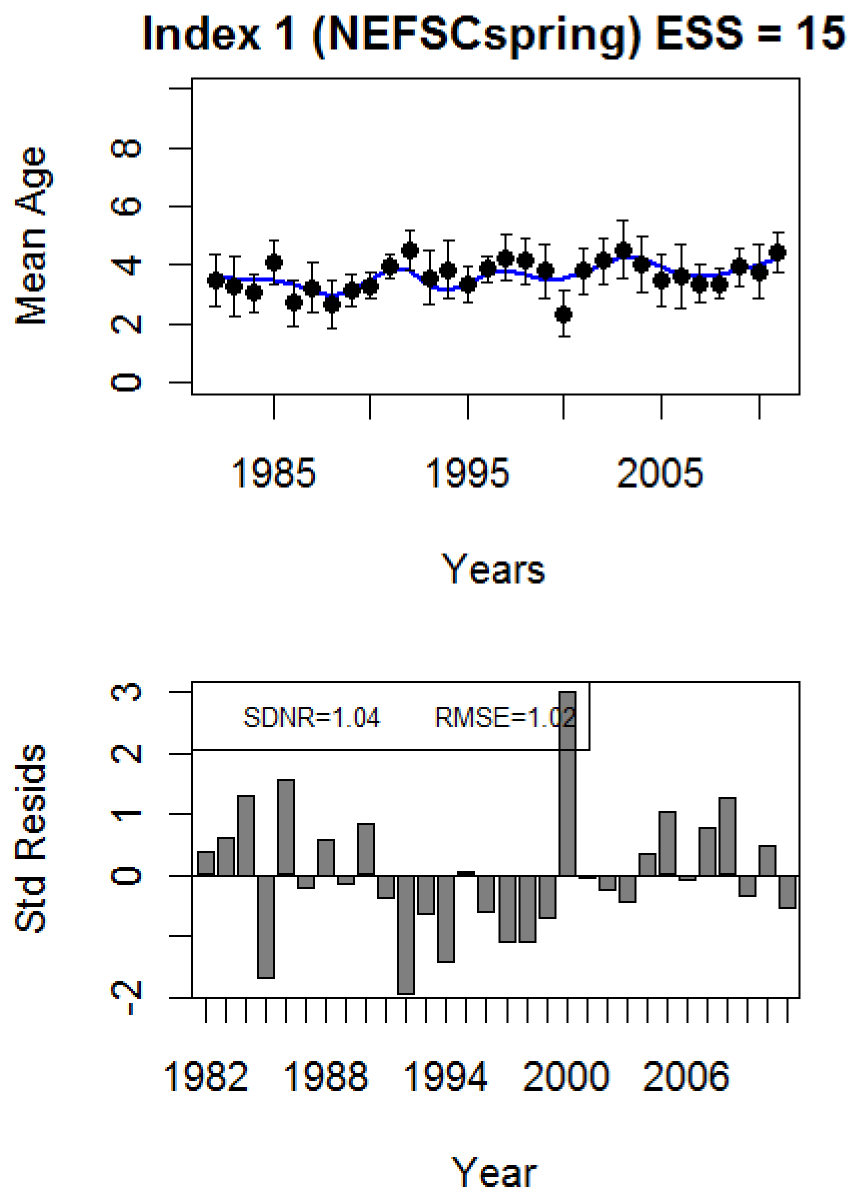


Figure A.168. ASAP SAW55_3BLOCK_BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC spring (Index 1) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

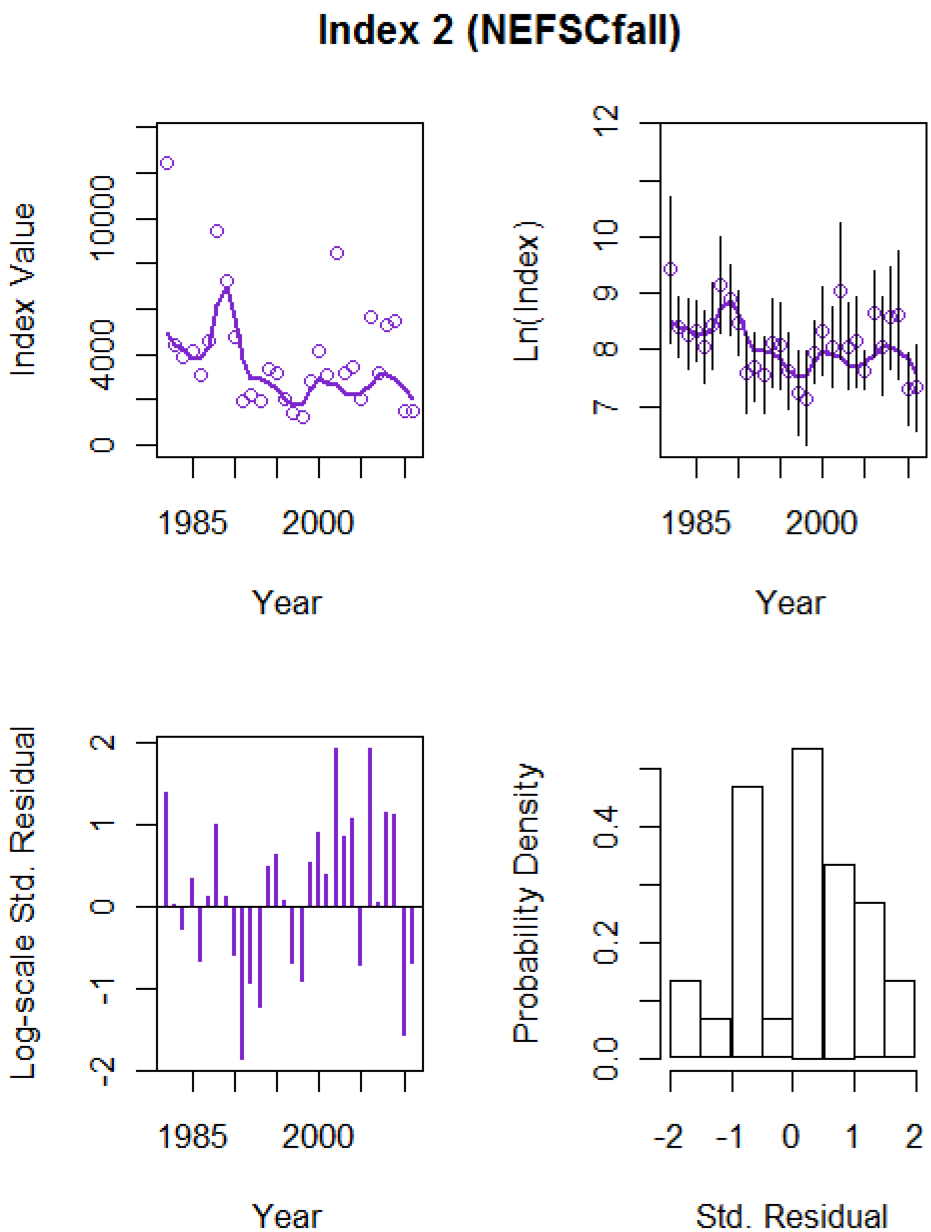


Figure A.169. ASAP SAW55_3BLOCK_BASE model fit to the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

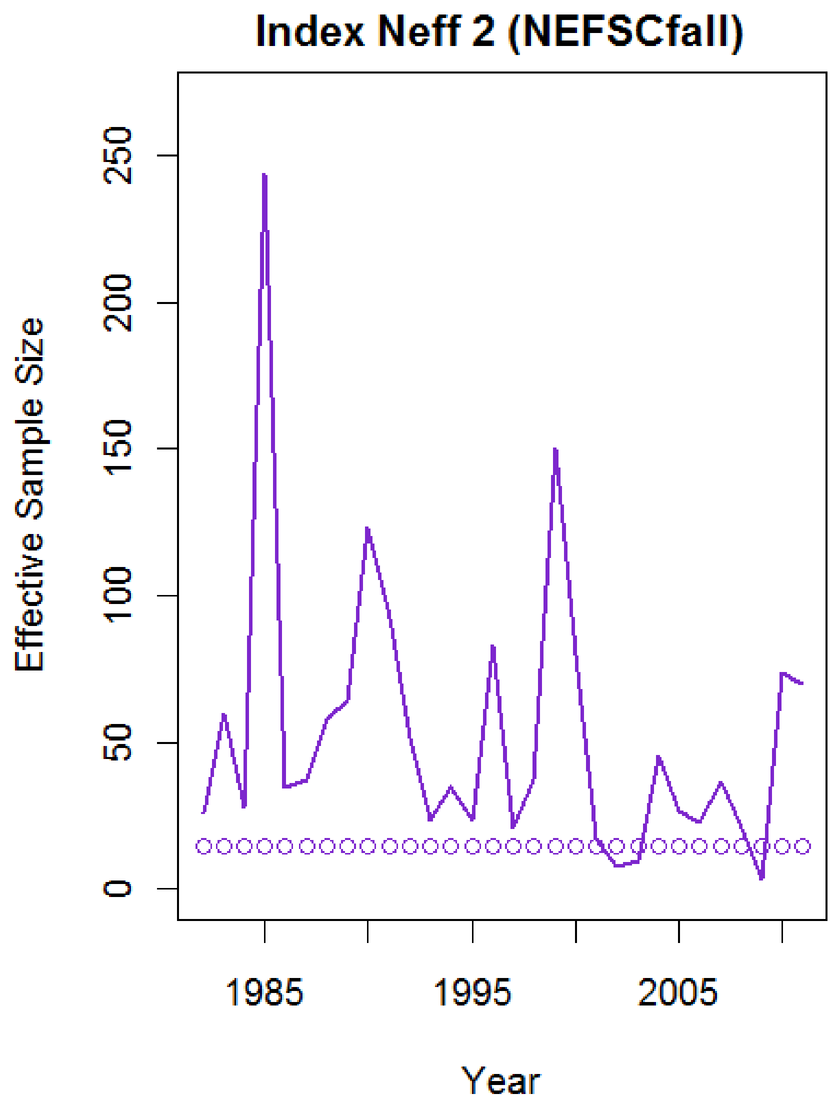


Figure A.170. ASAP SAW55_3BLOCK_BASE model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

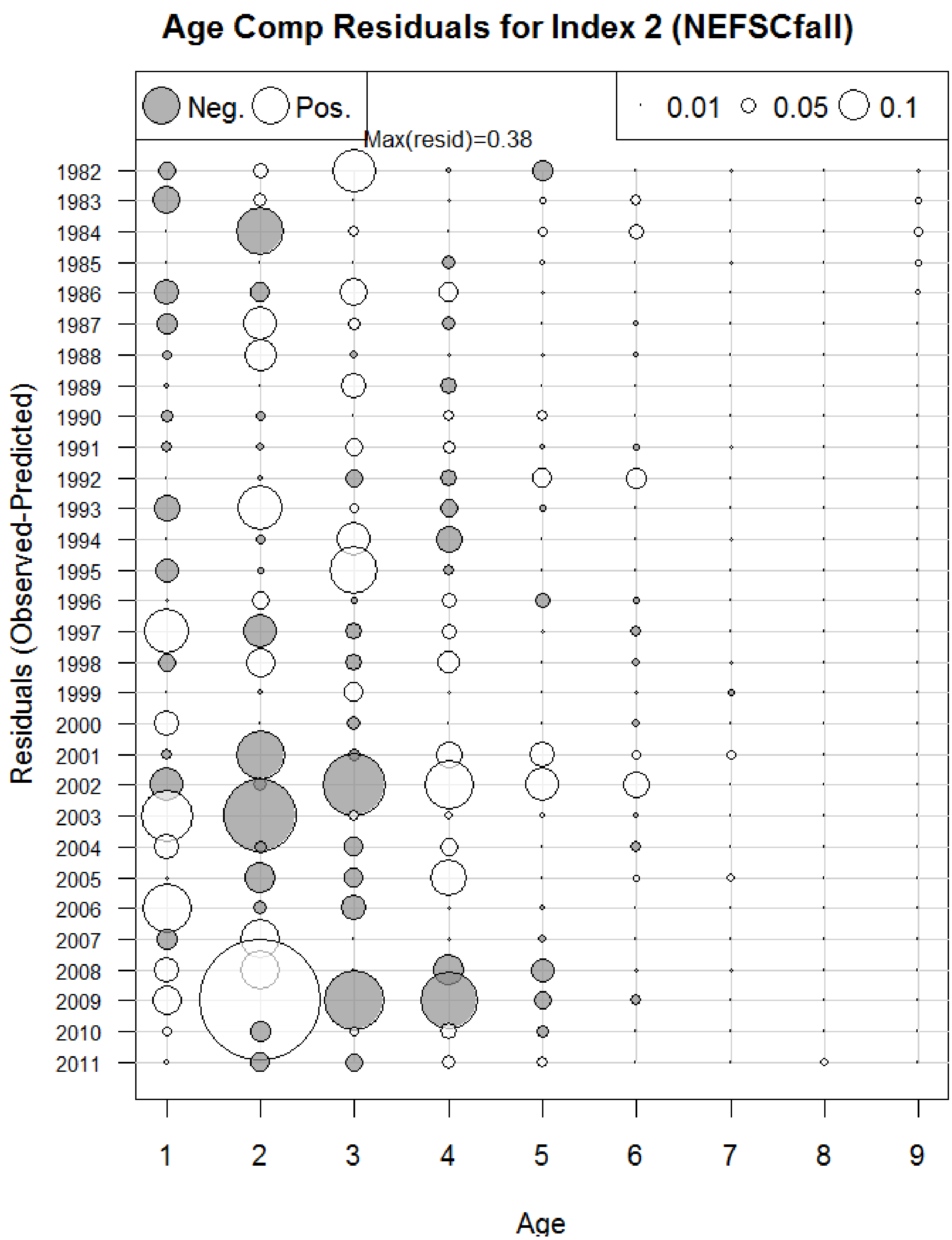


Figure A.171. ASAP SAW55_3BLOCK_BASE model fit residuals for the NEFSC fall survey (Index 2) Gulf of Maine Atlantic cod age composition.

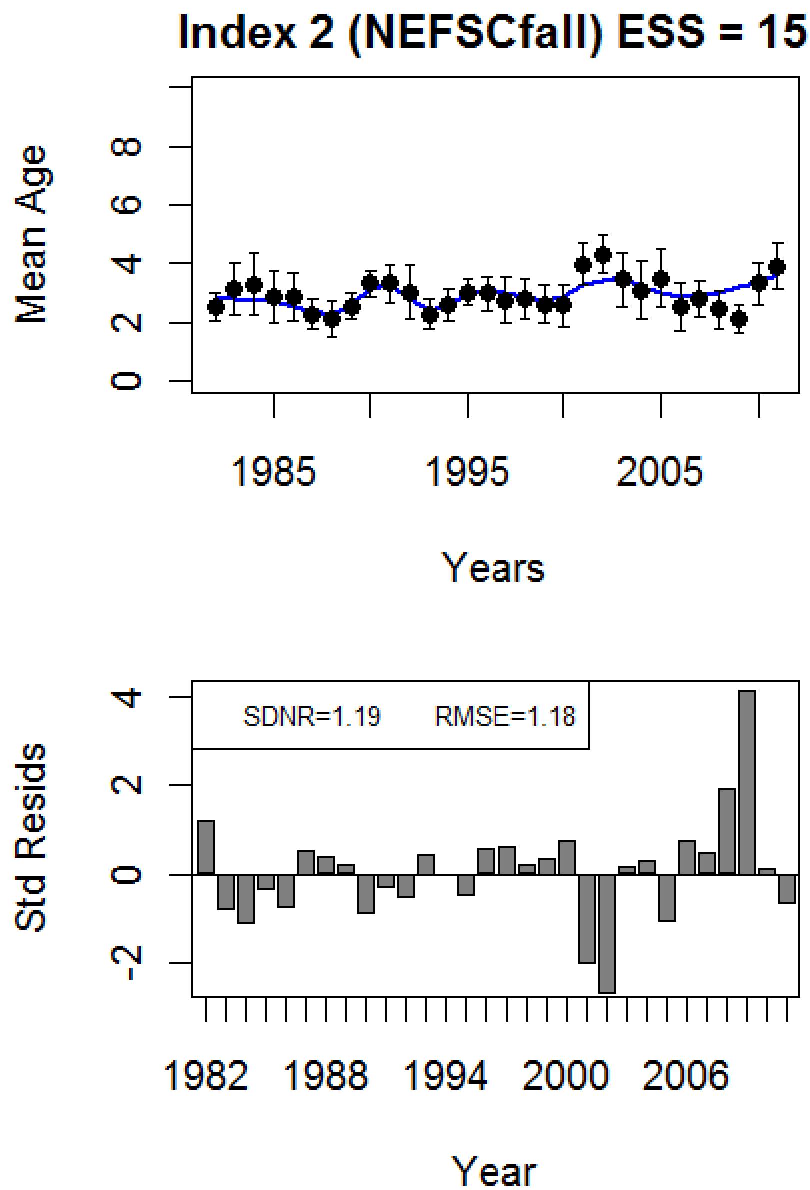


Figure A.172. ASAP SAW55_3BLOCK_BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC fall (Index 2) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

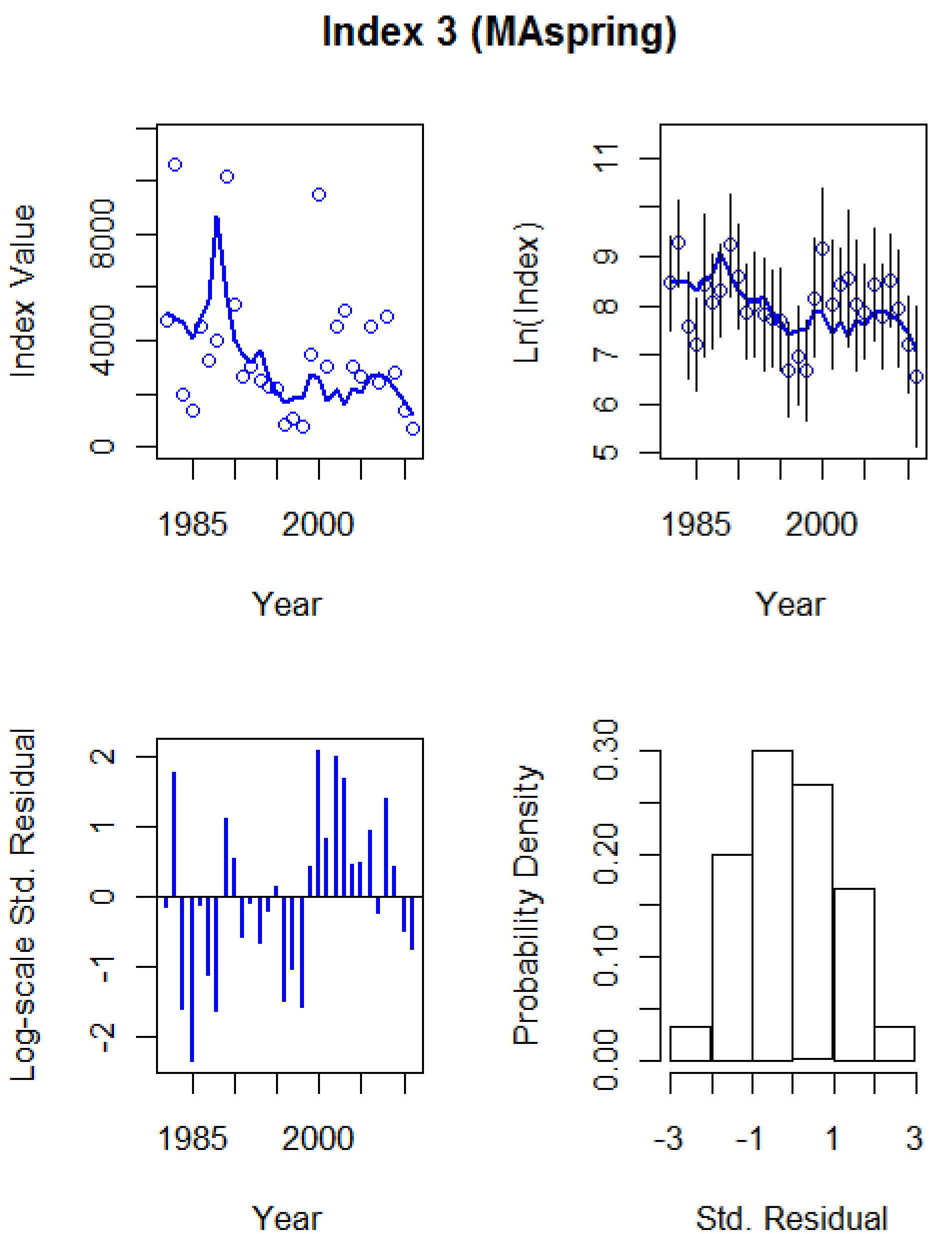


Figure A.173. ASAP SAW55_3BLOCK_BASE model fit to the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

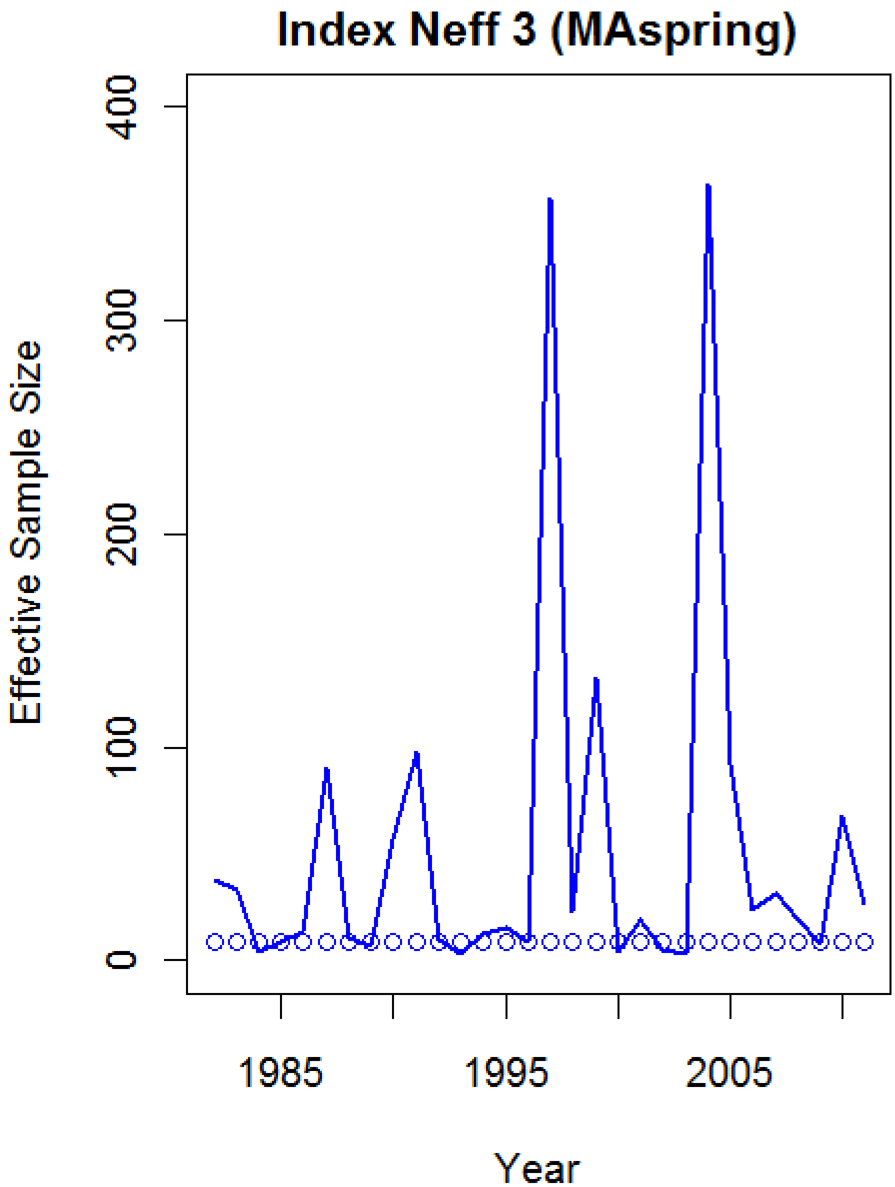


Figure A.174. ASAP SAW55_3BLOCK_BASE model comparison of input effective sample size versus the model estimated effective sample size for the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

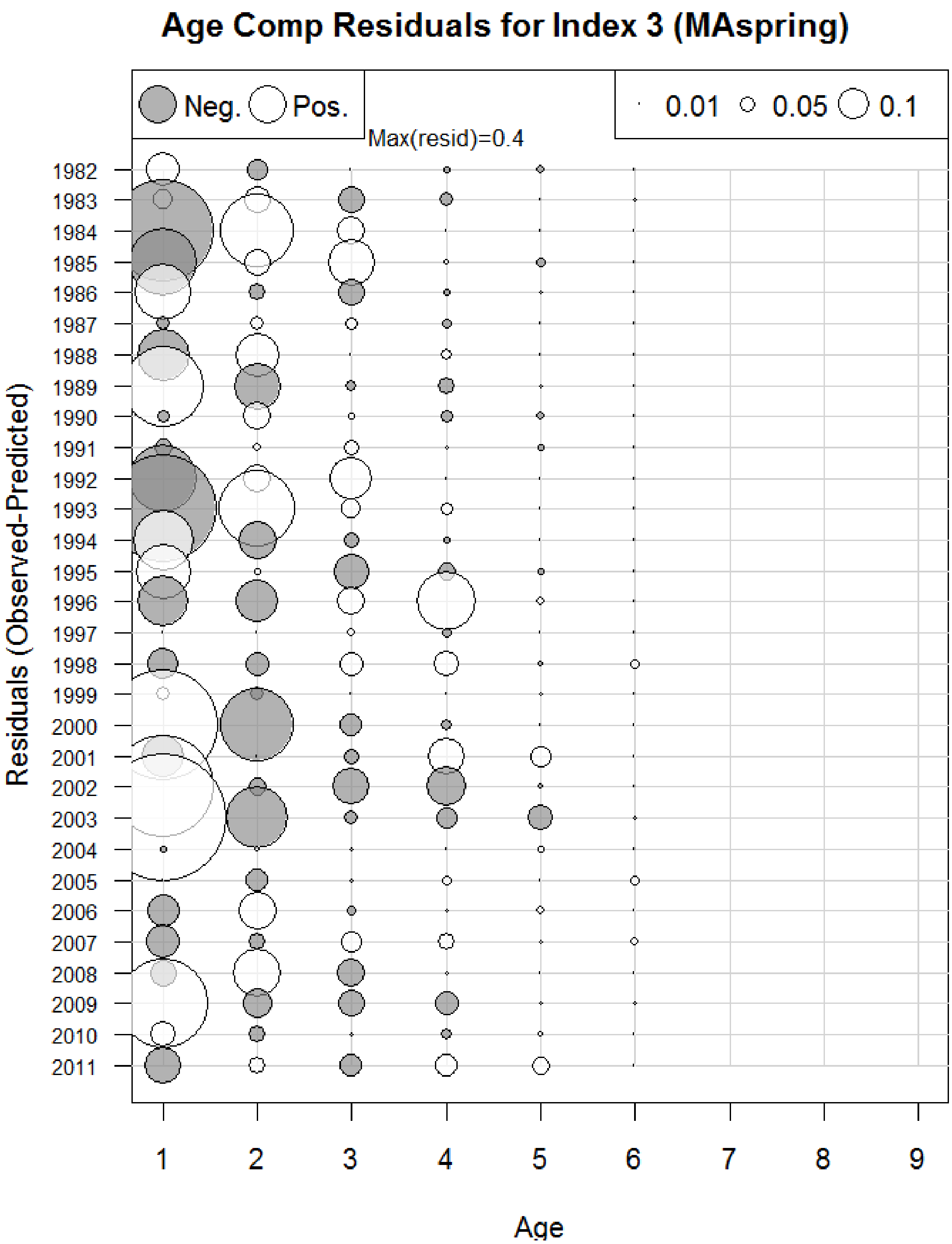


Figure A.175. ASAP SAW55_3BLOCK_BASE model fit residuals for the MADMF spring survey (Index 3) Gulf of Maine Atlantic cod age composition.

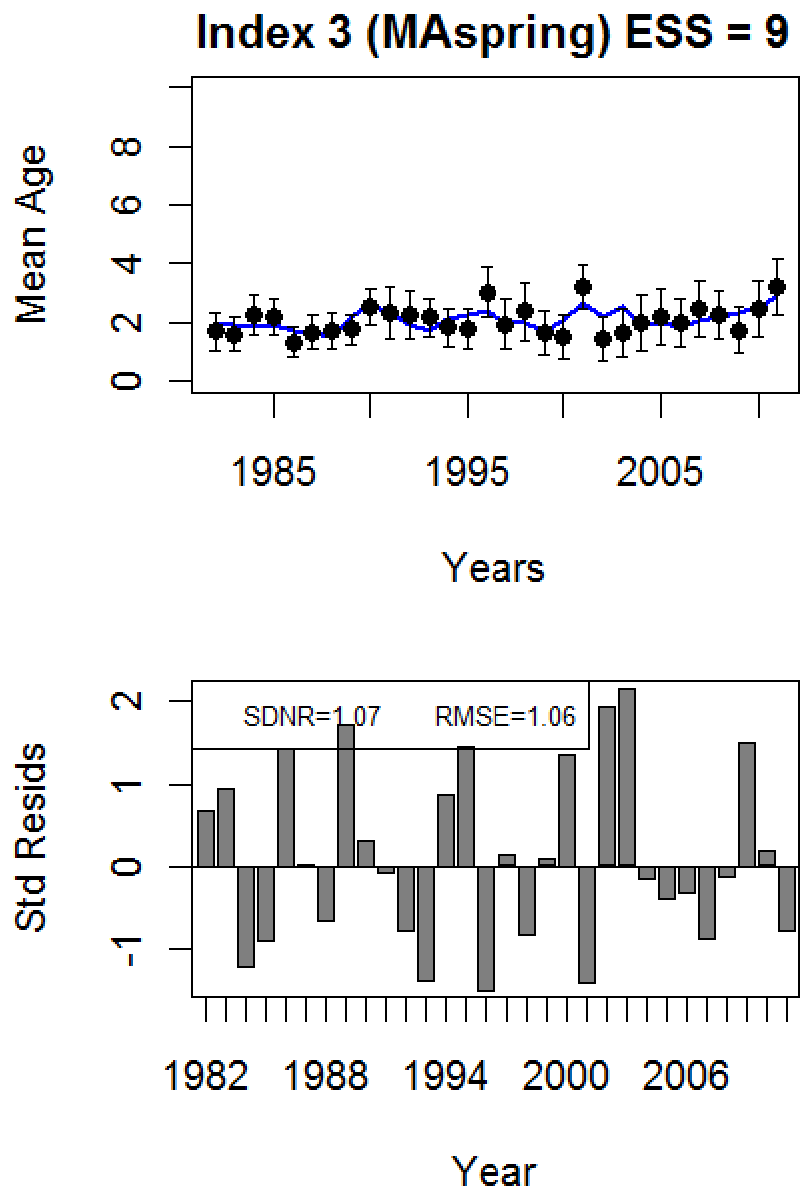


Figure A.176. ASAP SAW55_3BLOCK_BASE predicted mean age of Gulf of Maine Atlantic cod in the MADMF spring (Index 3) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

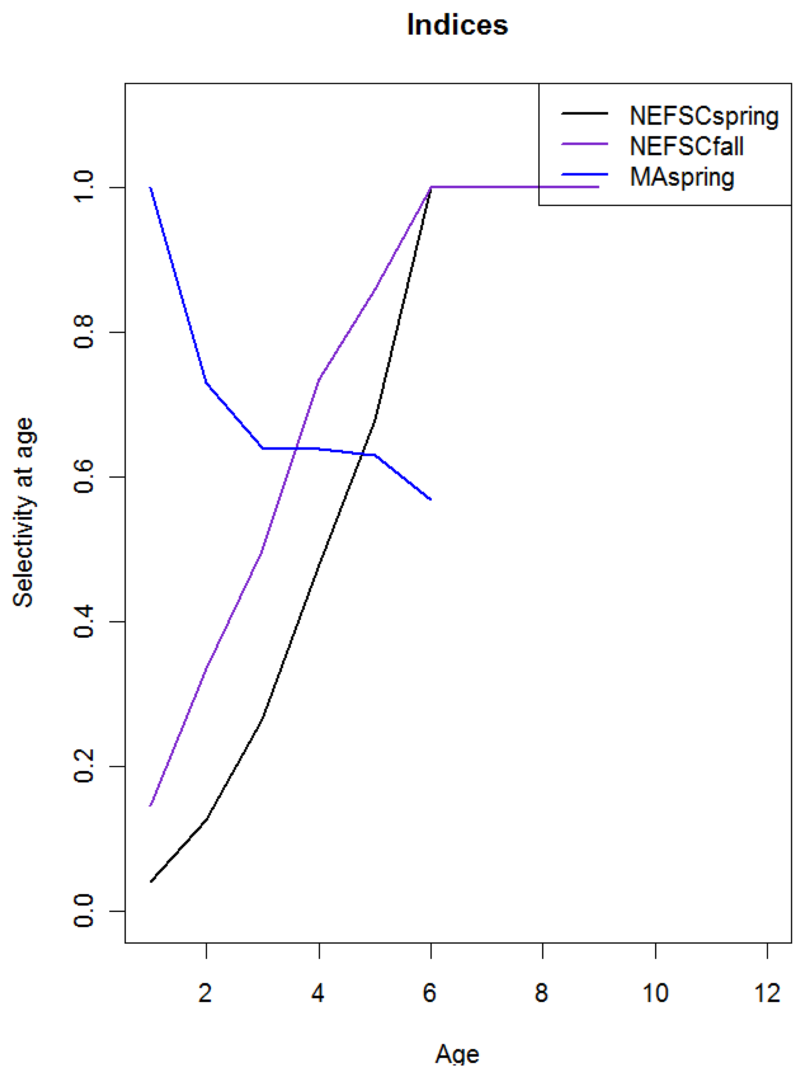


Figure A.177. Gulf of Maine Atlantic cod selectivity-at-age for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP SAW55_3BLOCK_BASE model.

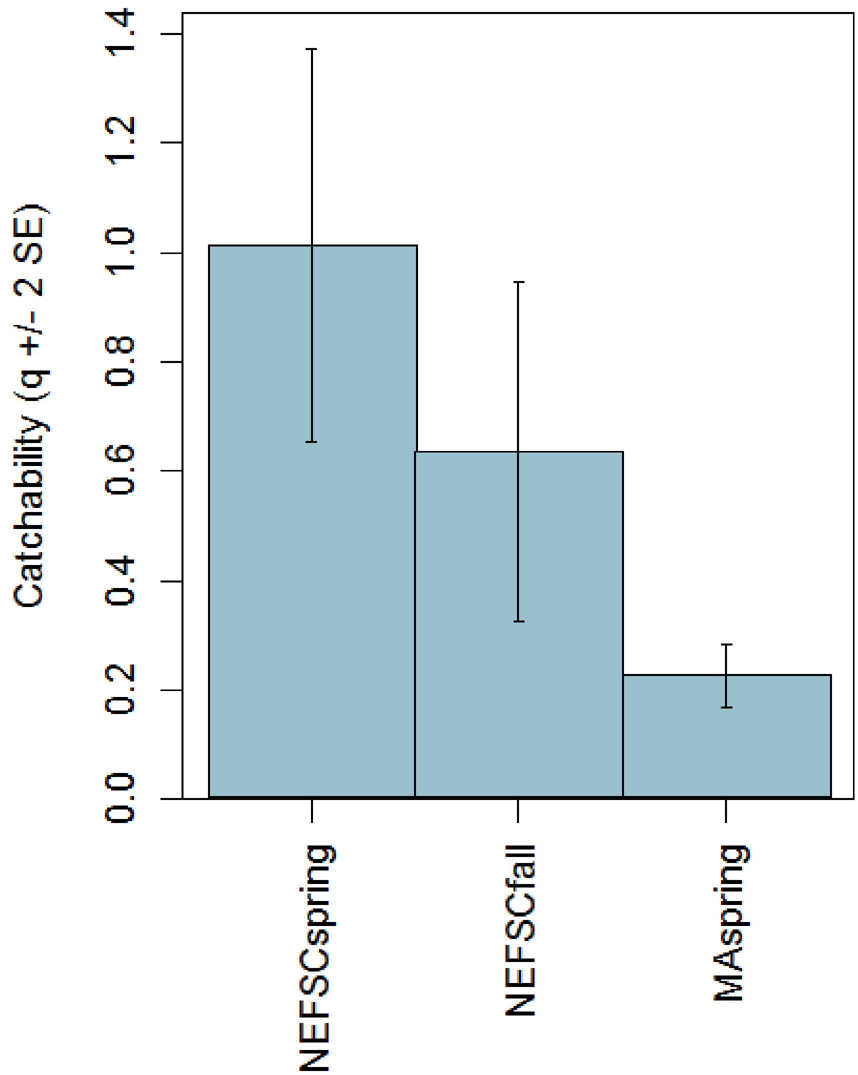


Figure A.178. Gulf of Maine Atlantic cod survey catchability, *q*, for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP SAW55_3BLOCK_BASE model.

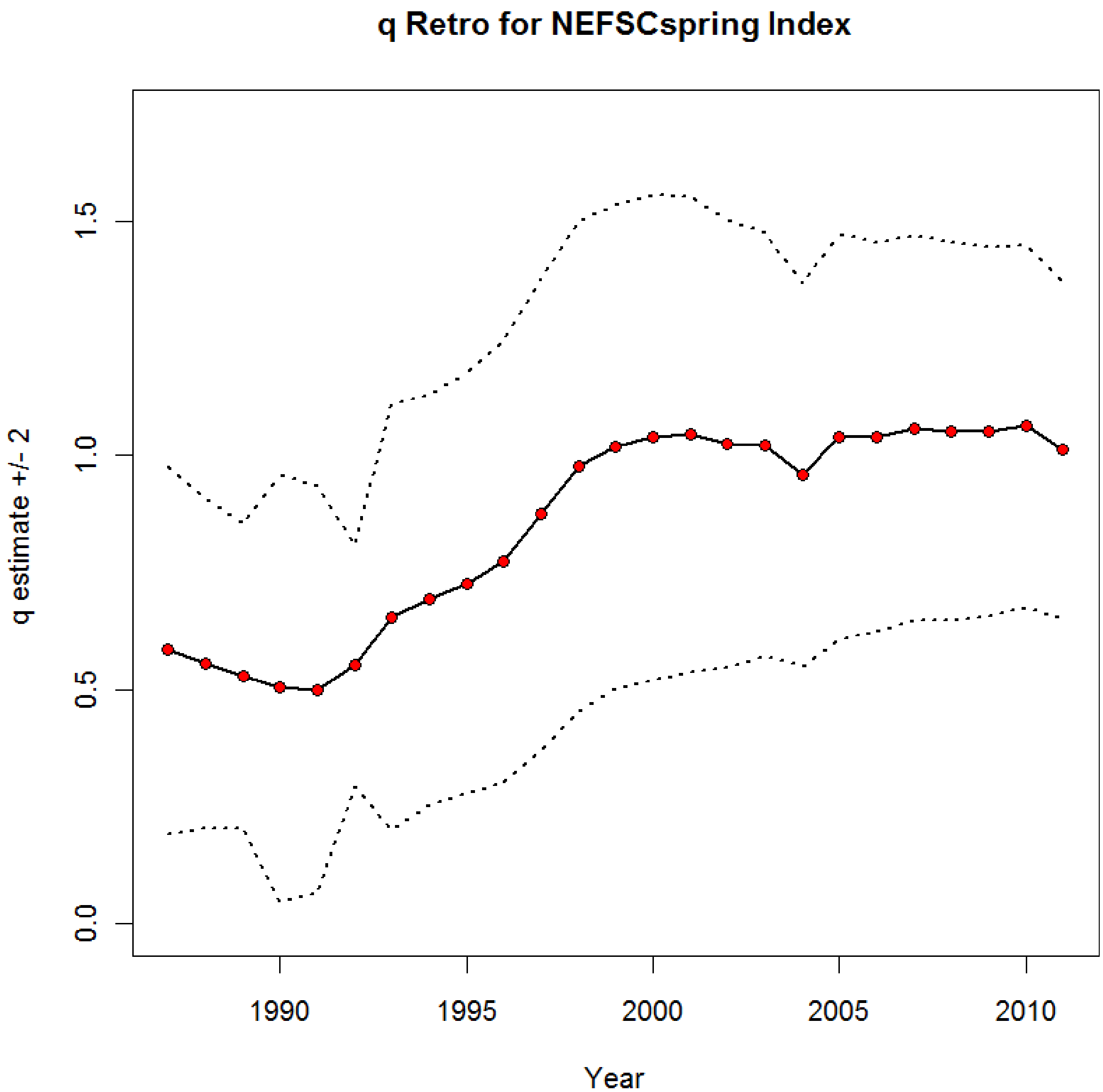


Figure A.179. Retrospective changes in the NEFSC spring survey catchability estimates, *q*, as years are removed from the ASAP SAW55_3BLOCK_BASE model.

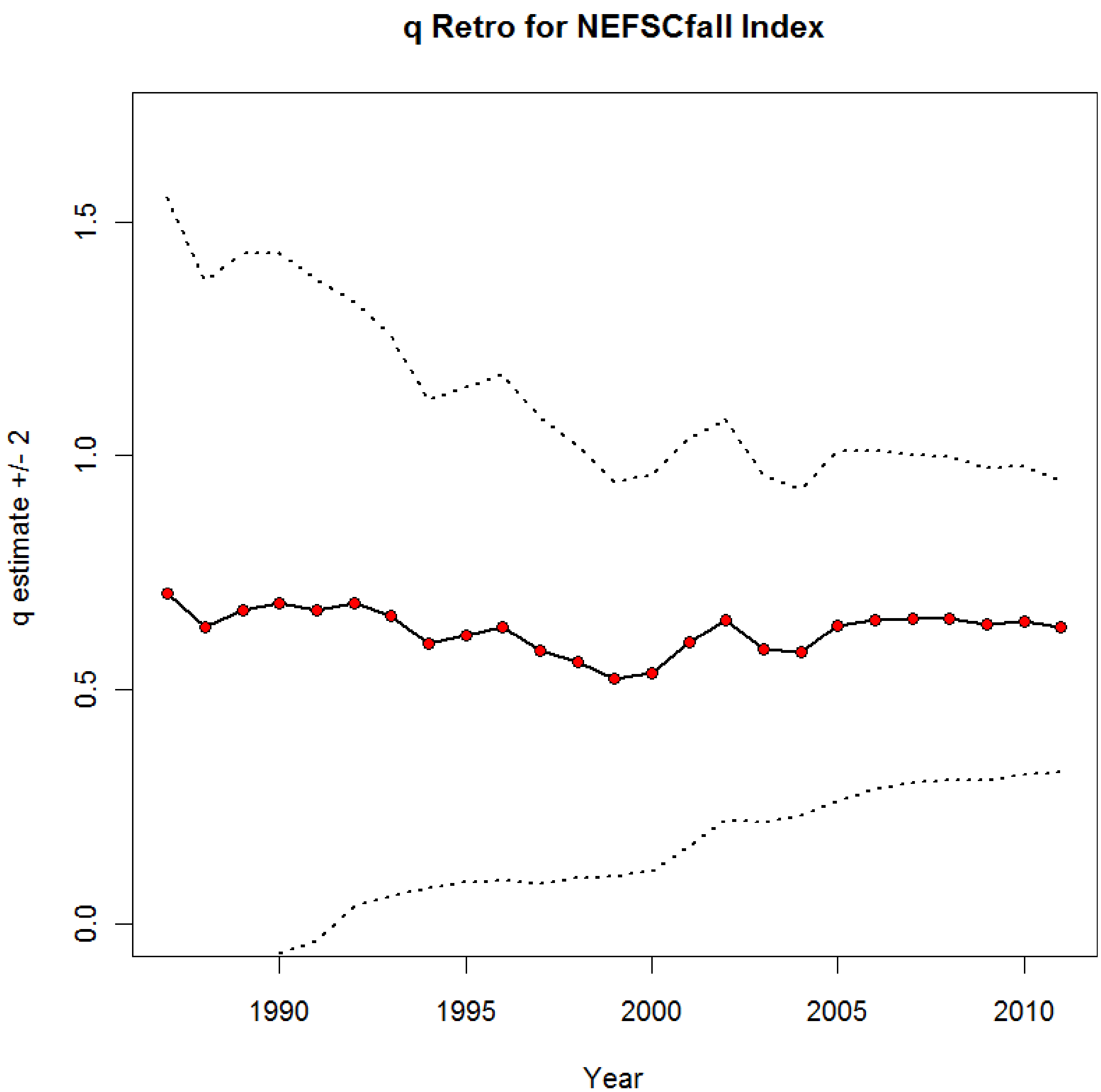


Figure A.180. Retrospective changes in the NEFSC fall survey catchability estimates, *q*, as years are removed from the ASAP SAW55_3BLOCK_BASE model.

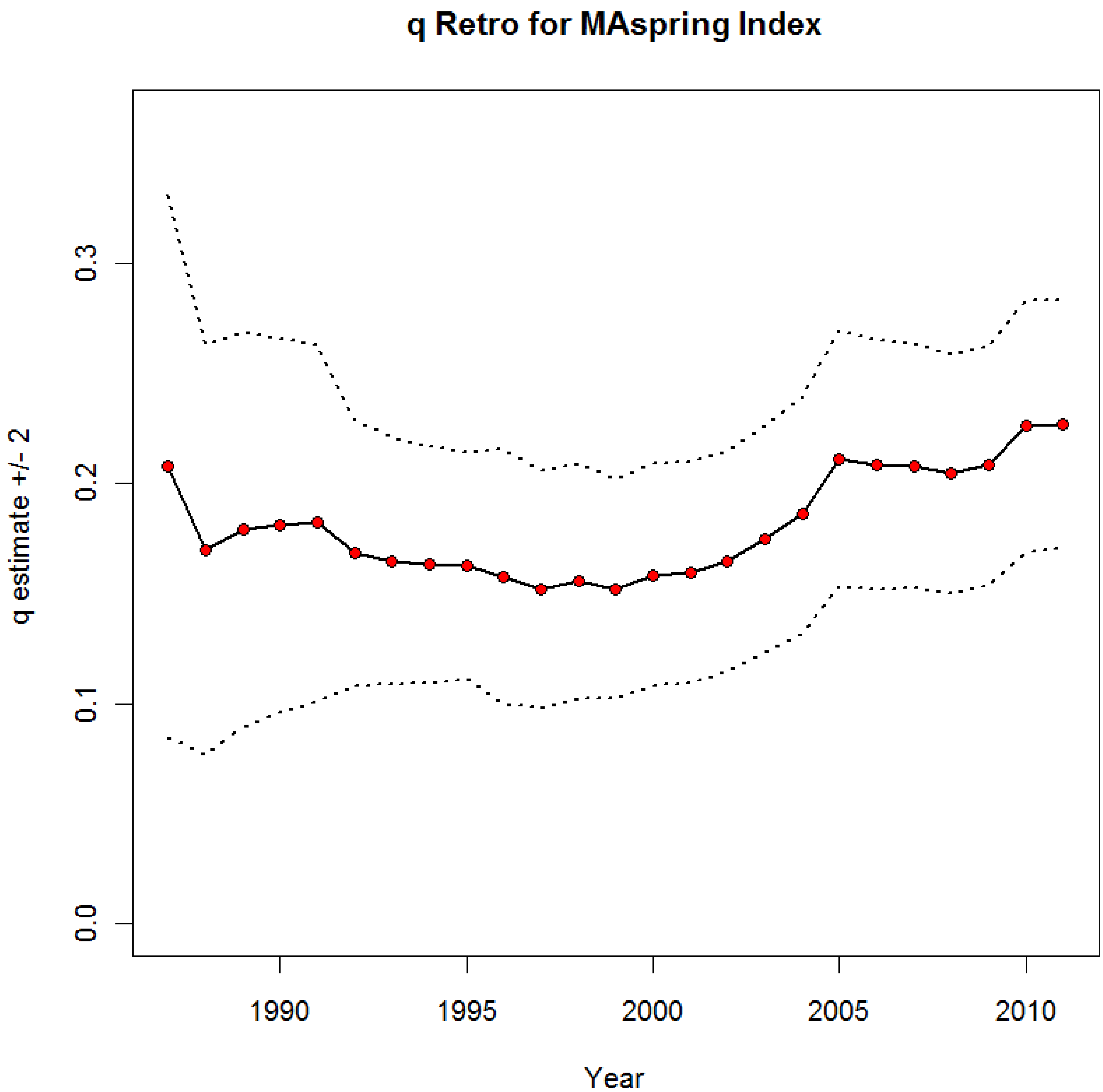


Figure A.181. Retrospective changes in the MADMF spring survey catchability estimates, *q*, as years are removed from the ASAP SAW55_3BLOCK_BASE model.

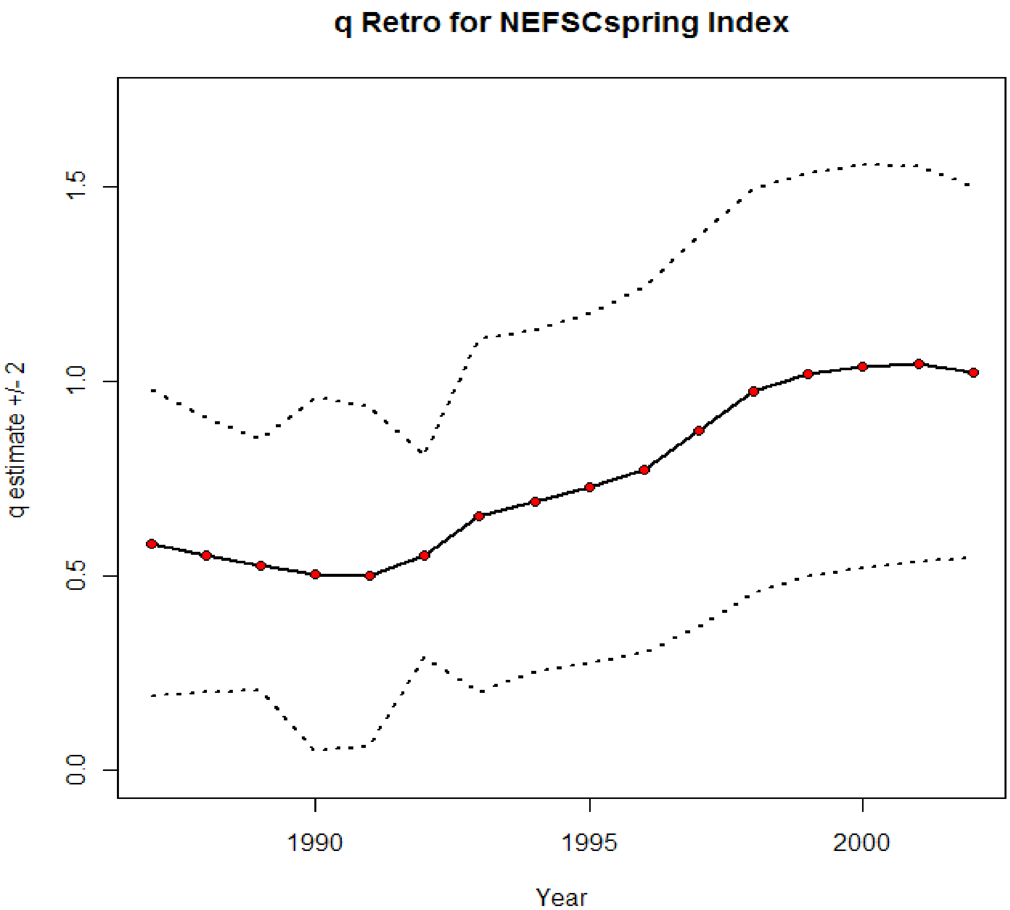


Figure A.182. Retrospective changes in the NEFSC spring survey catchability estimates, *q*, as years are removed from the ASAP SAW55_3BLOCK_BASE_1982_2002 model.

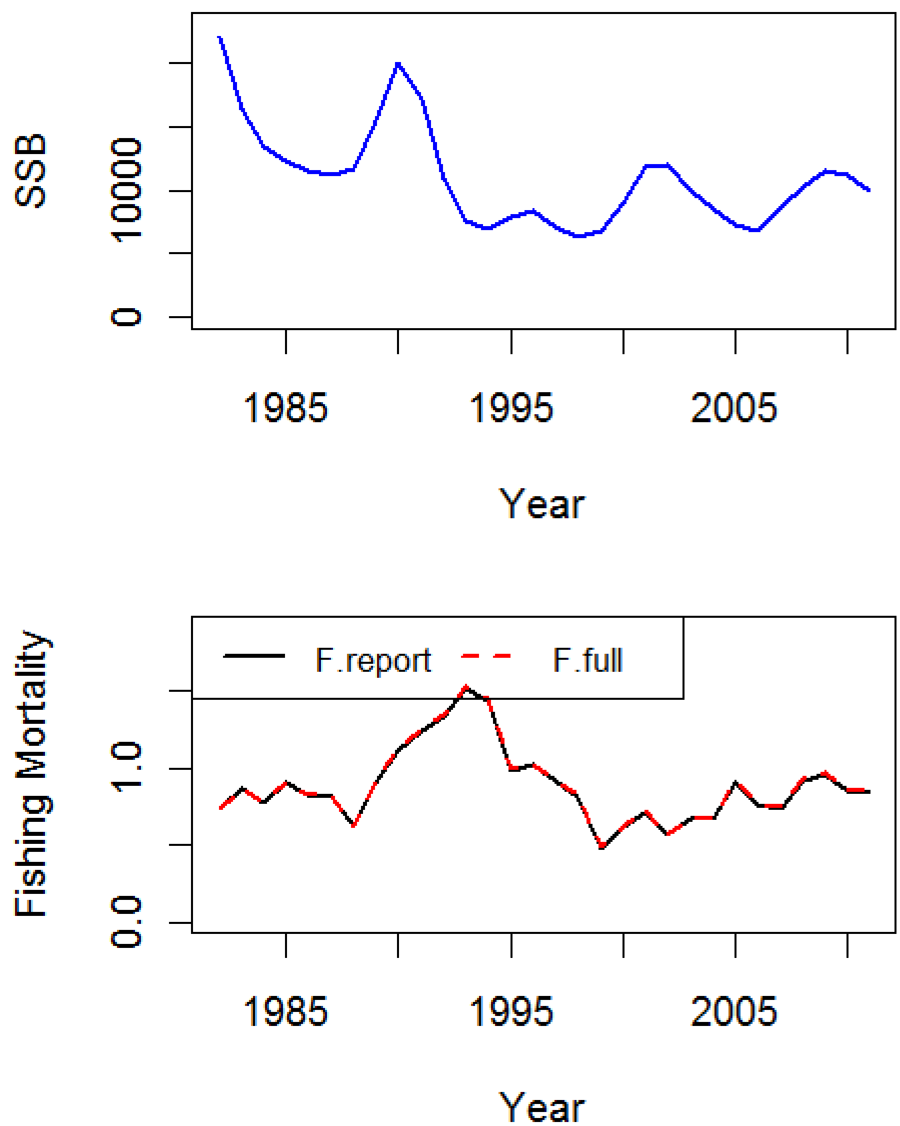


Figure A.183. ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) and fishing mortality (F_{full} = fully recruited fishing mortality, F_{report} = fishing mortality on age 5).

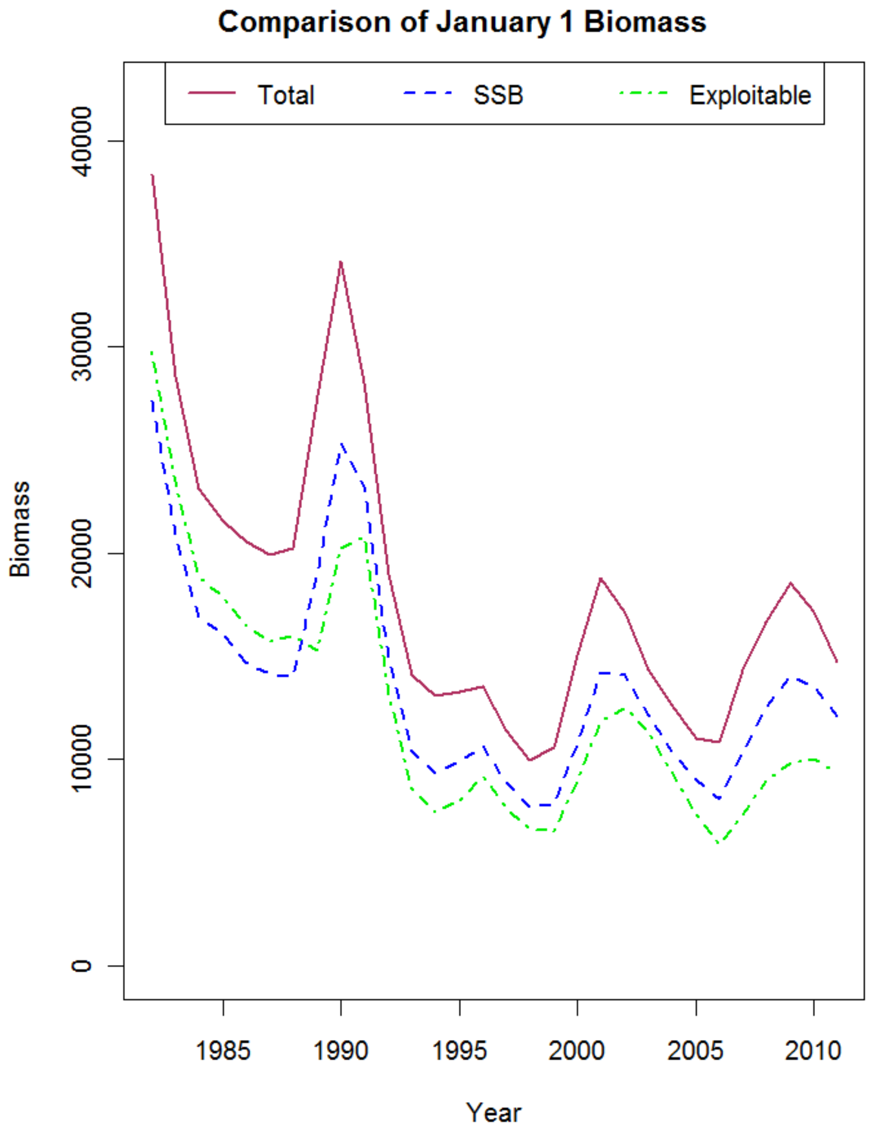


Figure A.184. Comparison of ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine Atlantic cod January 1 biomass after application of maturity ogive (SSB) and fleet selectivity ogives (exploitable).

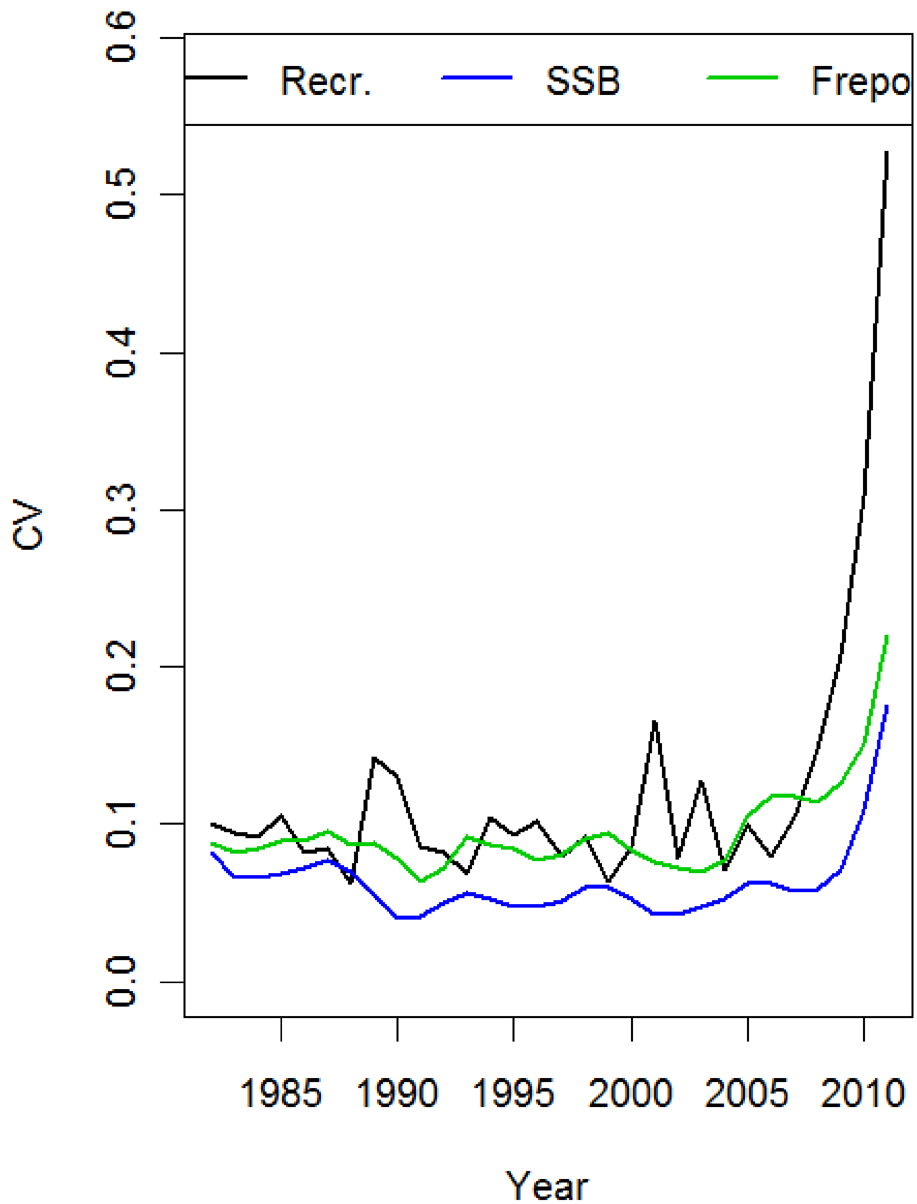


Figure A.185. Coeffecients of variation (CV) for the ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB), average fishing mortality (F_{report} = age 5 fishing mortality) and age 1 recruitment.

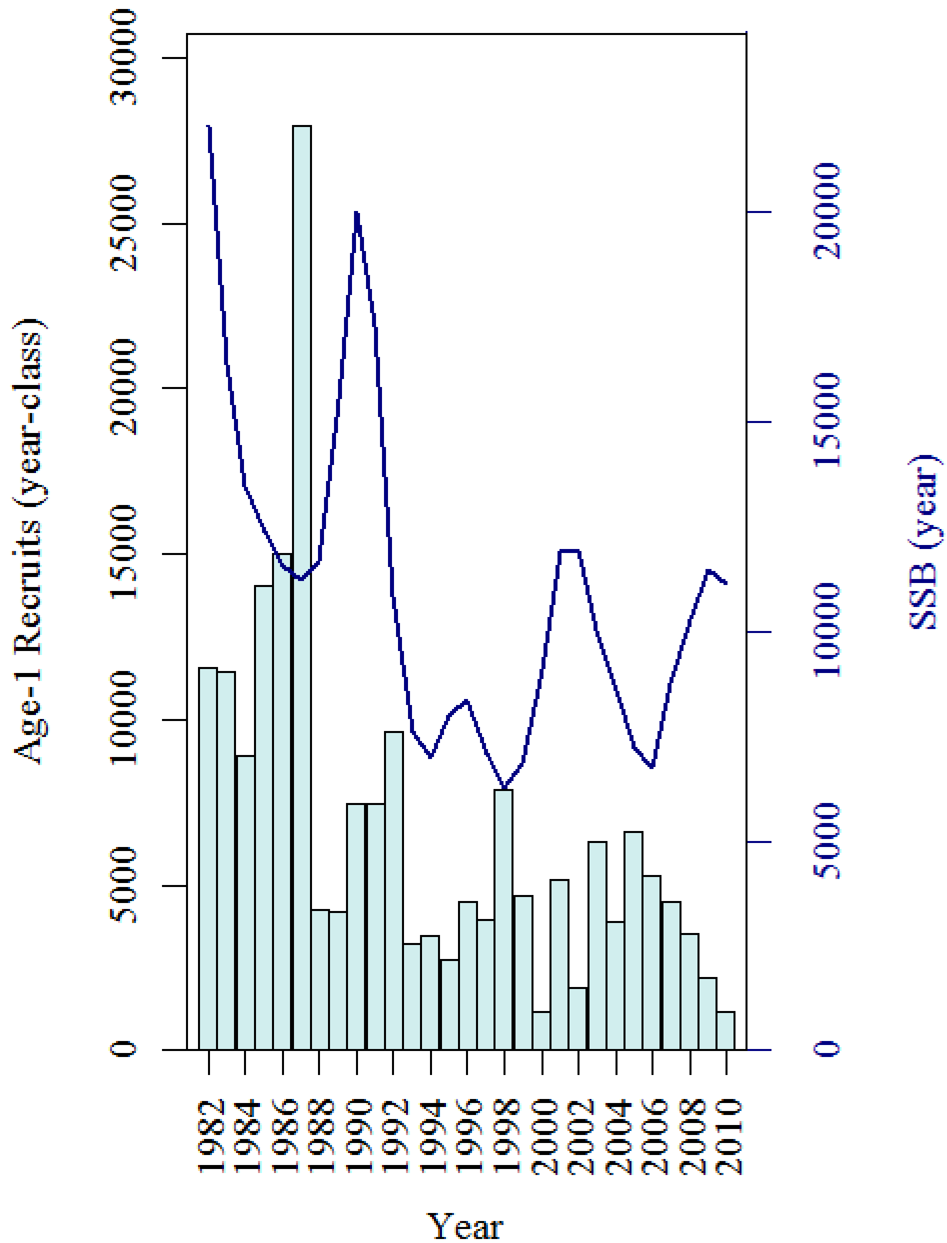


Figure A.186. ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine cod spawning stock biomass (SSB; solid blue line) and lagged age 1 recruitment (light blue bars).

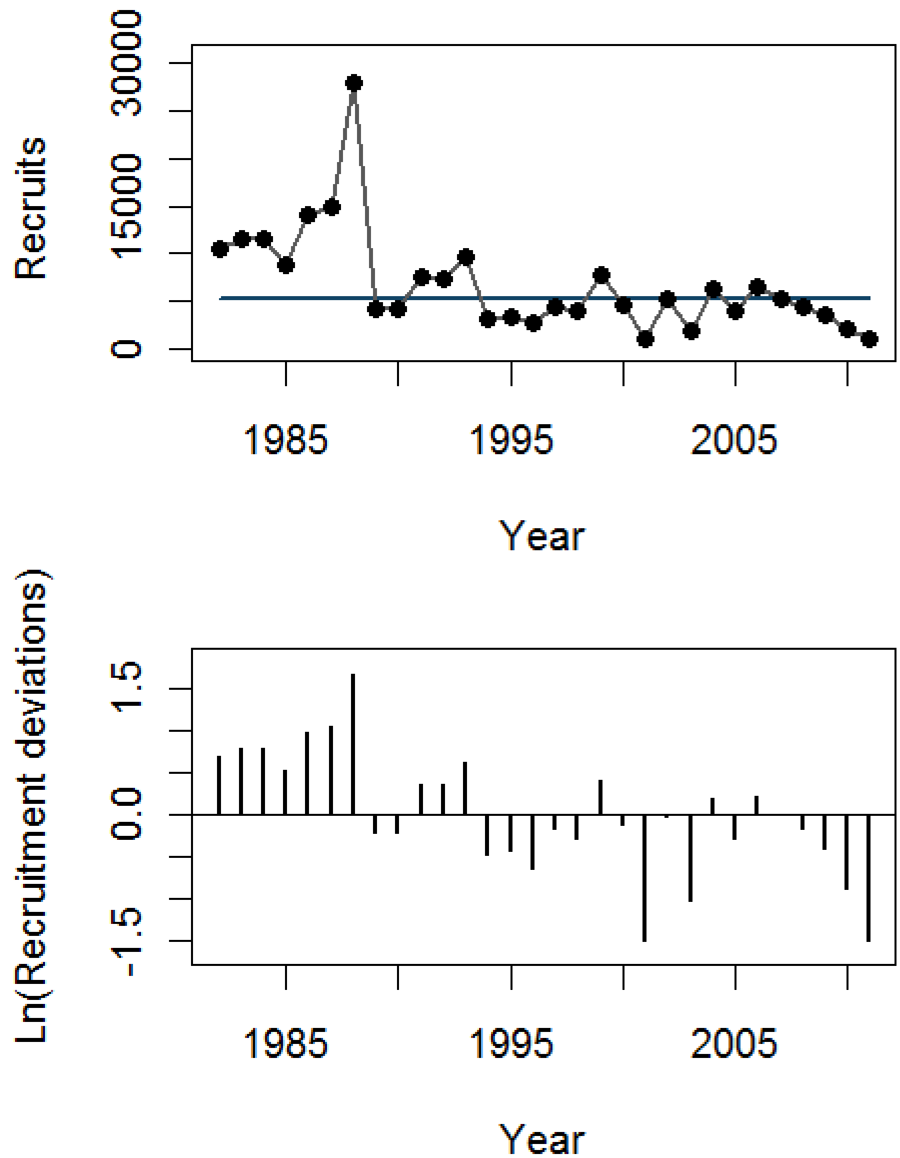


Figure A.187. ASAP SAW55_3BLOCK_BASE estimated Gulf of Maine Atlantic cod age 1 recruitment and recruitment residuals from the geometric mean.

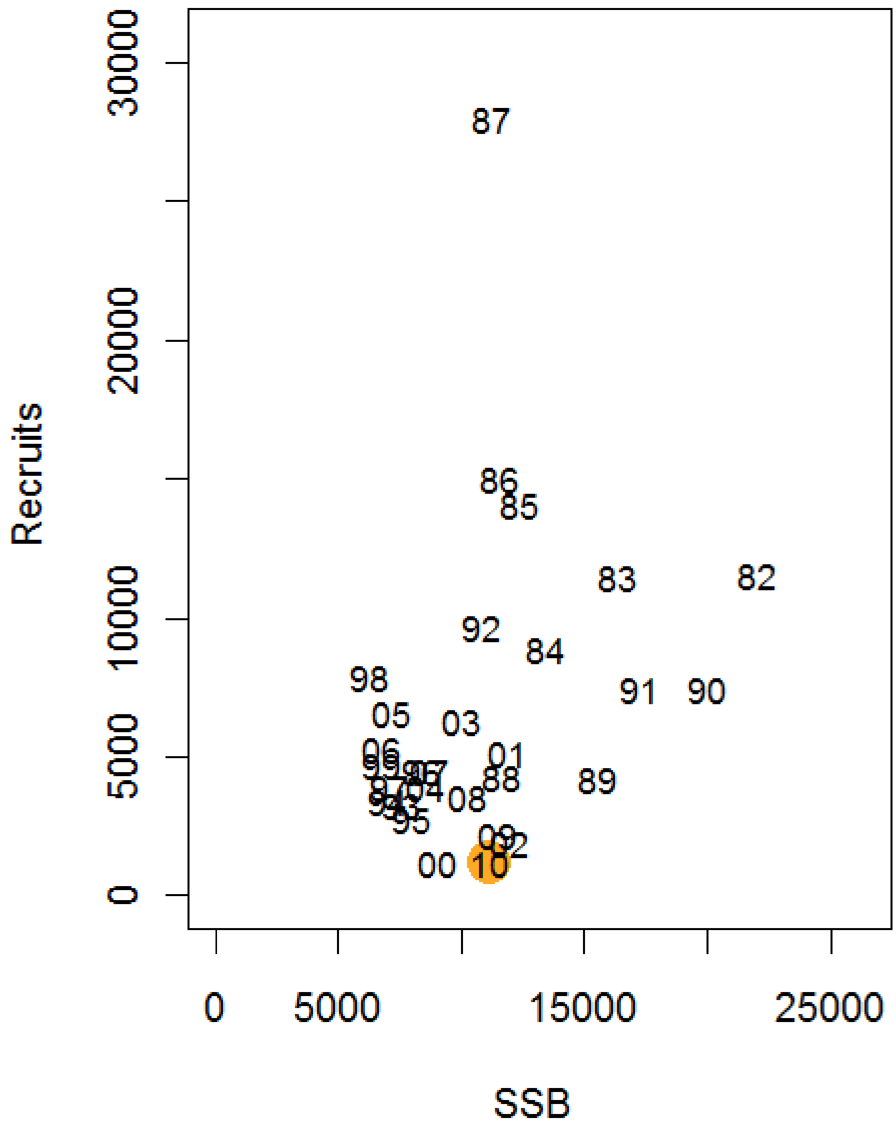


Figure A.188. Scatterplot of ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) versus recruitment at age 1 (000s). The symbol for each observation is the last two digits of the year (e.g., 88 indicated age 1 estimates of the 1987 year class). The most recent recruitment estimate is highlighted by an orange circle.

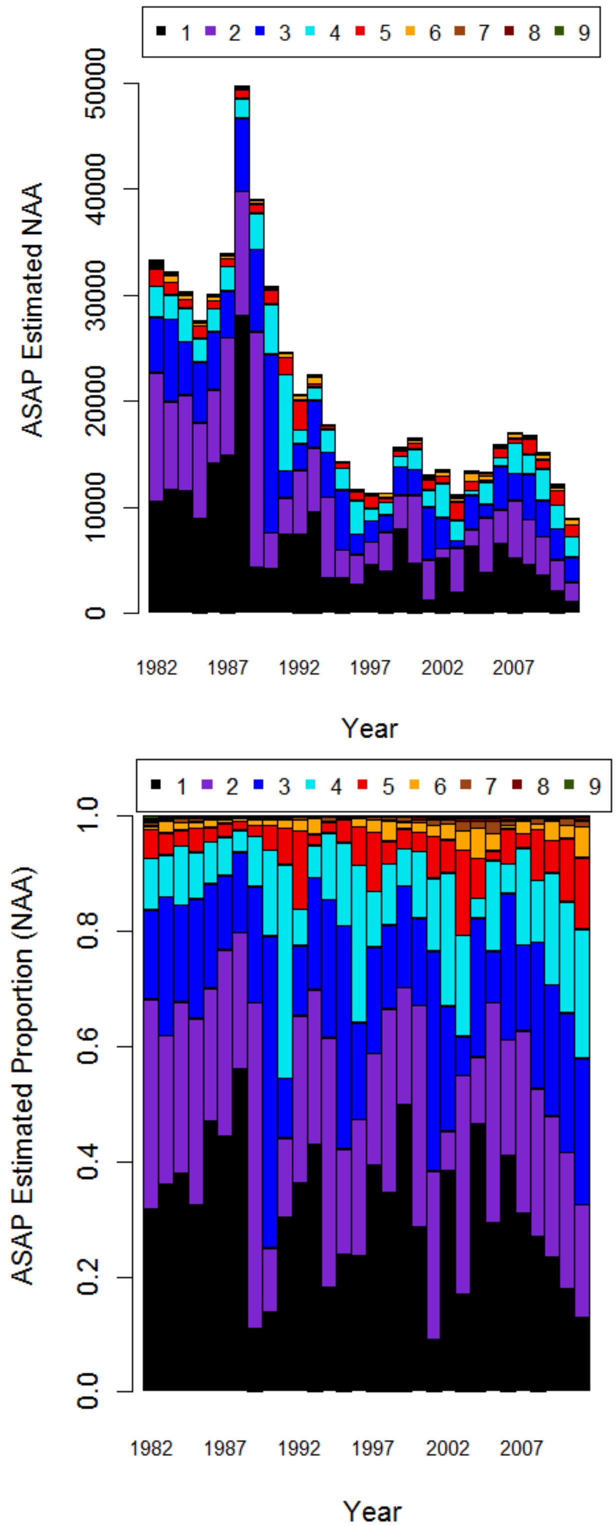


Figure A.189. ASAP SAW55_3BLOCK_BASE model estimates of Gulf of Maine Atlantic cod numbers-at-age in absolute (top) numbers (000s) and relative (bottom) terms.

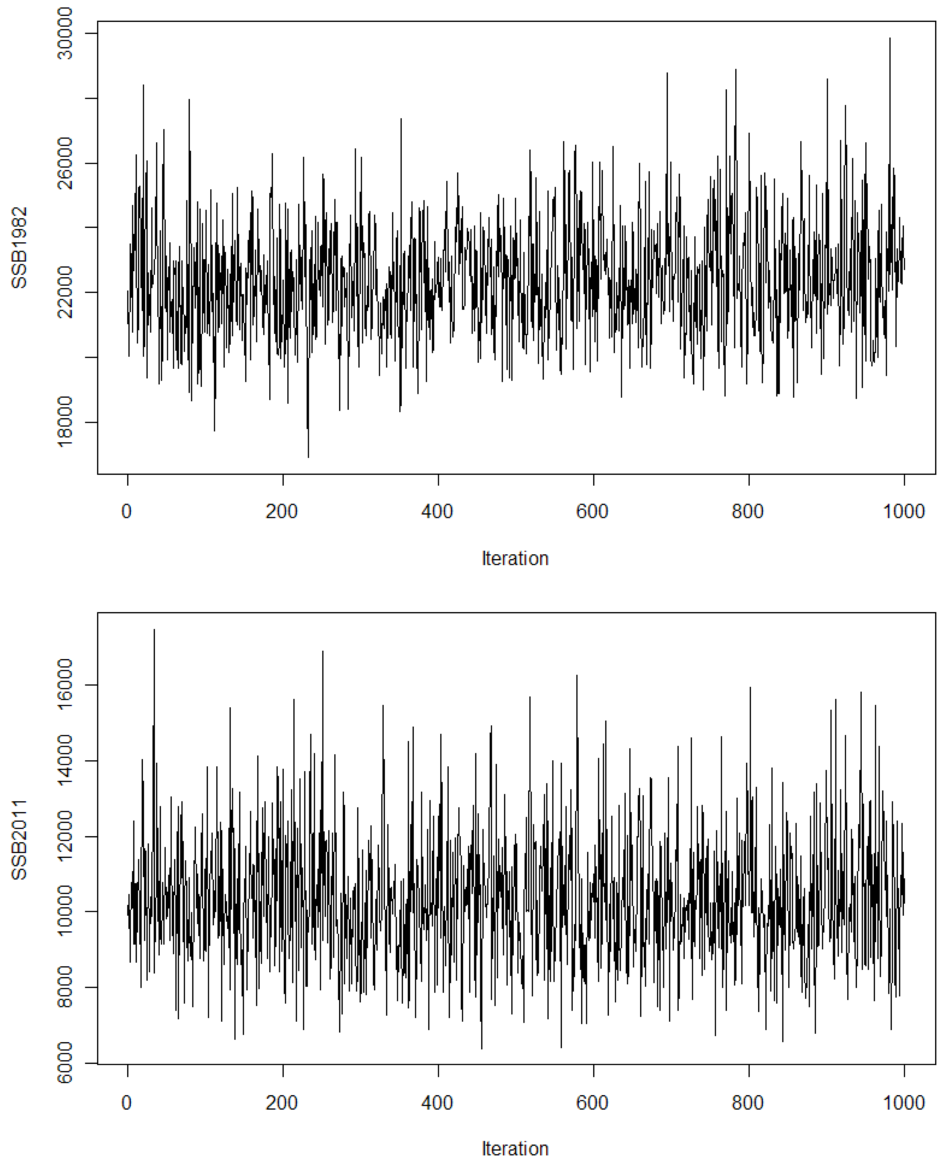


Figure A.190. Trace of MCMC chains for Gulf of Maine Atlantic cod 1982 and 2011 spawning stock biomass, showing good mixing (ASAP SAW55_3BLOCK_BASE model). Each chain had initial length of 1,000,000 and was thinned at a rate of one out of every 1000th resulting in a final chain length of 1000.

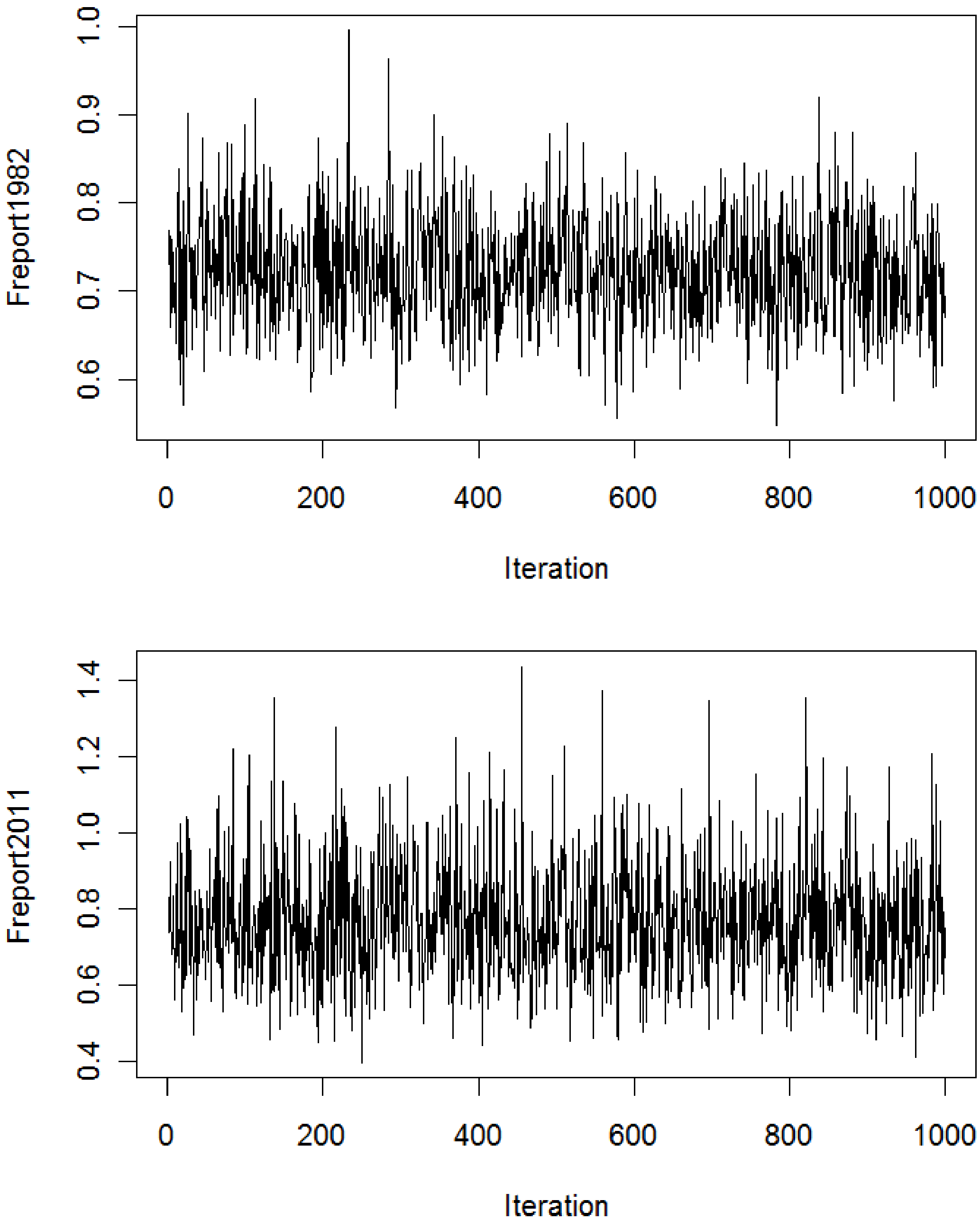
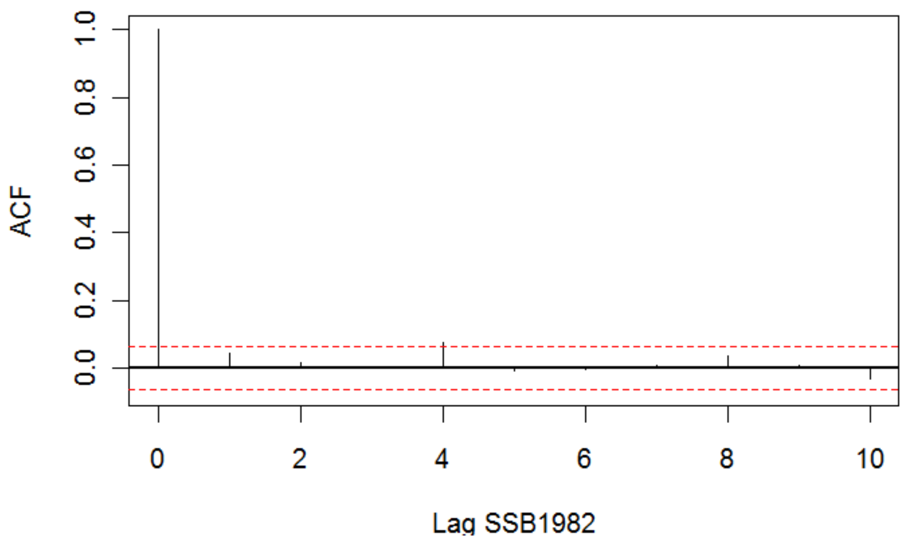


Figure A.191. Trace of MCMC chains for Gulf of Maine Atlantic cod 1982 and 2011 fishing mortality at age 5 (Freport), showing good mixing (ASAP SAW55_3BLOCK_BASE model). Each chain had initial length of 1,000,000 and was thinned at a rate of one out of every 1000th resulting in a final chain length of 1000.



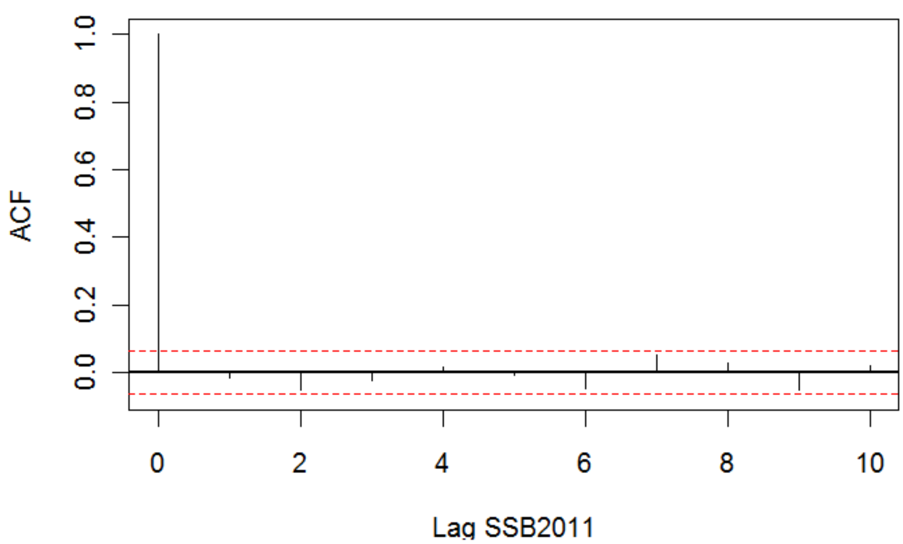
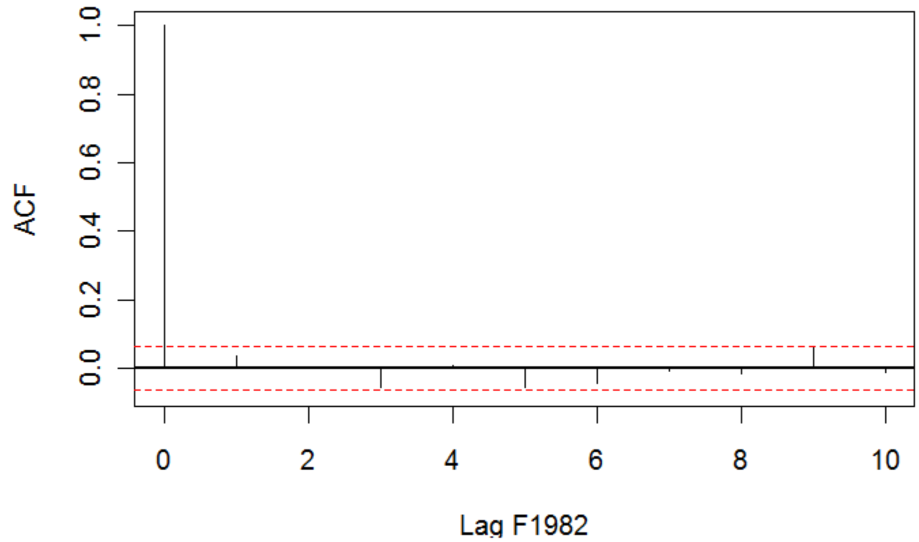


Figure A.192. Autocorrelation within the 1982 and 2011 Gulf of Maine Atlantic cod spawning stock biomass (SSB) MCMC chains from the ASAP SAW55_3BLOCK_BASE model.



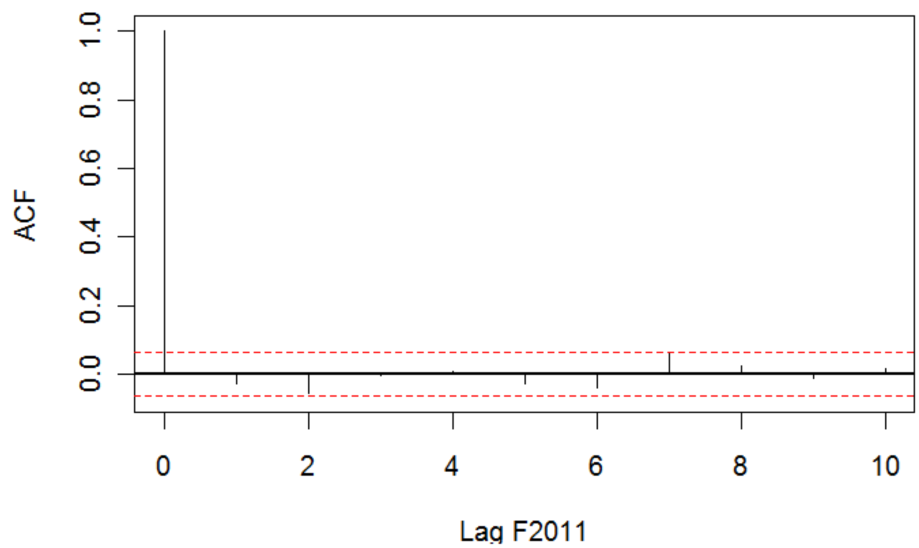


Figure A.193. Autocorrelation within the 1982 and 2011 Gulf of Maine Atlantic cod fishing mortality at age 5 (Freport) MCMC chains from the ASAP SAW55_3BLOCK_BASE model.

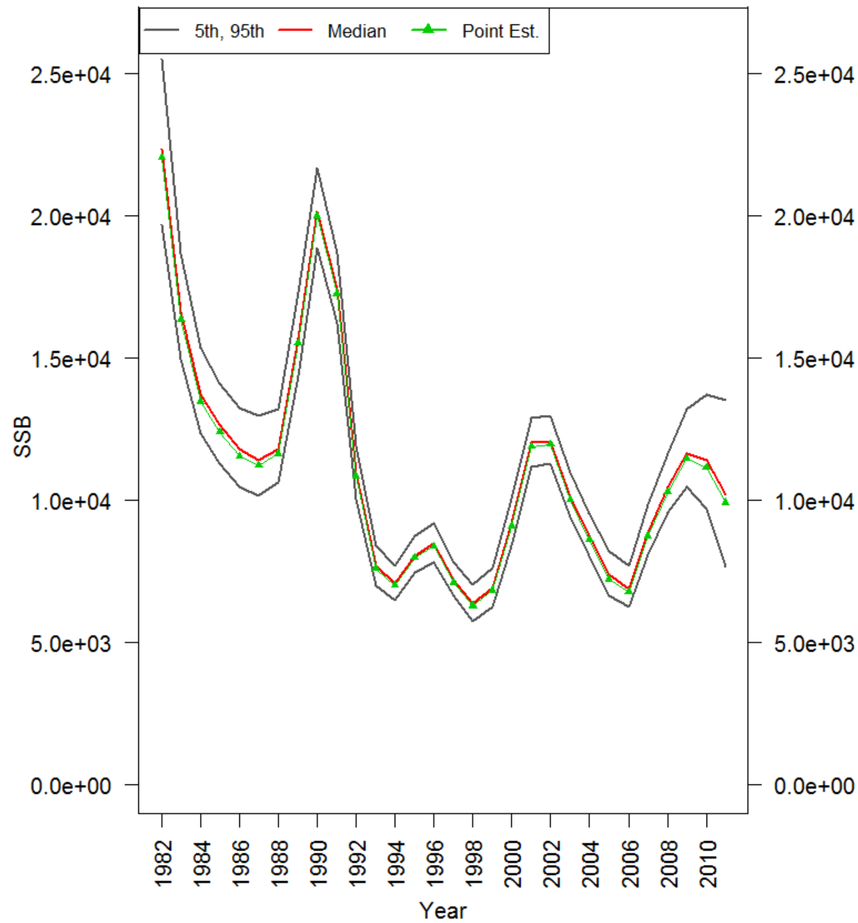


Figure A.194. 90% probability interval for Gulf of Maine Atlantic cod spawning stock biomass (SSB) from the ASAP SAW55_3BLOCK_BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles.

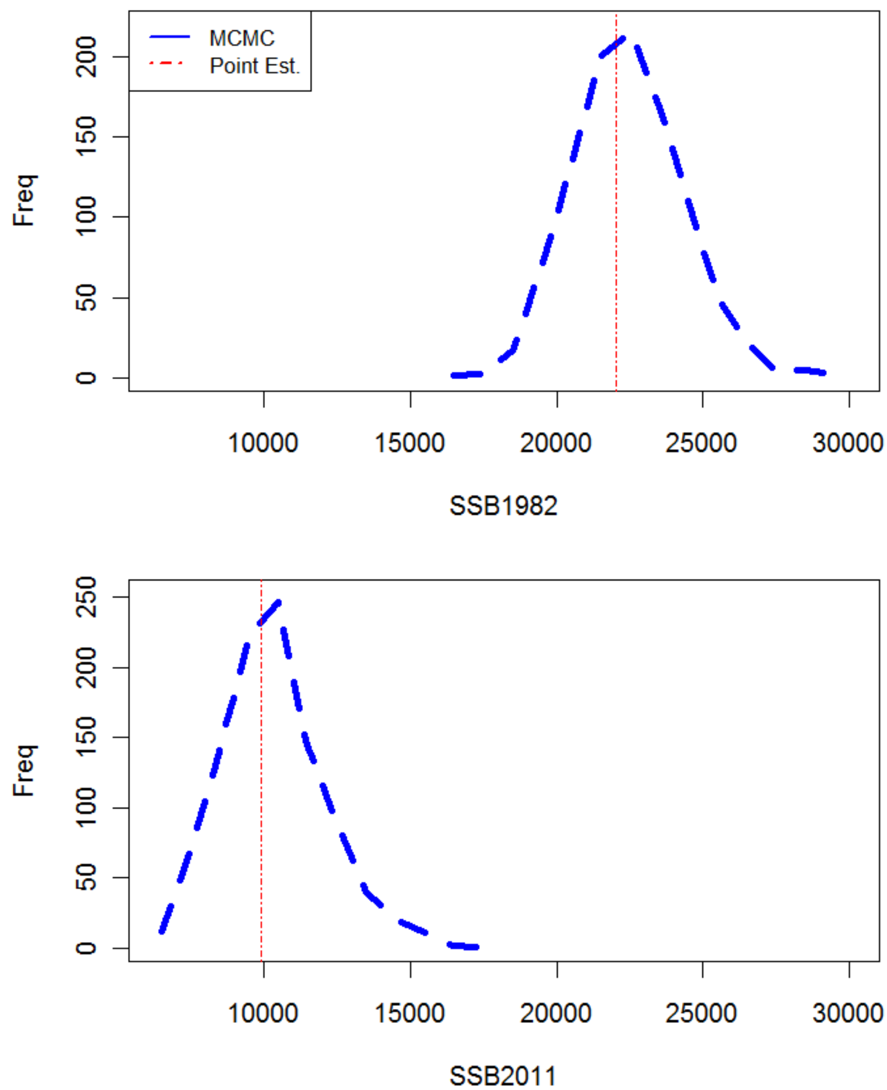


Figure A.195. MCMC distribution of Gulf of Maine Atlantic cod spawning stock biomass in 1982 and 2011 estimated from the ASAP SAW55_3BLOCK_BASE model. The model point estimate is indicated by the dashed red line.

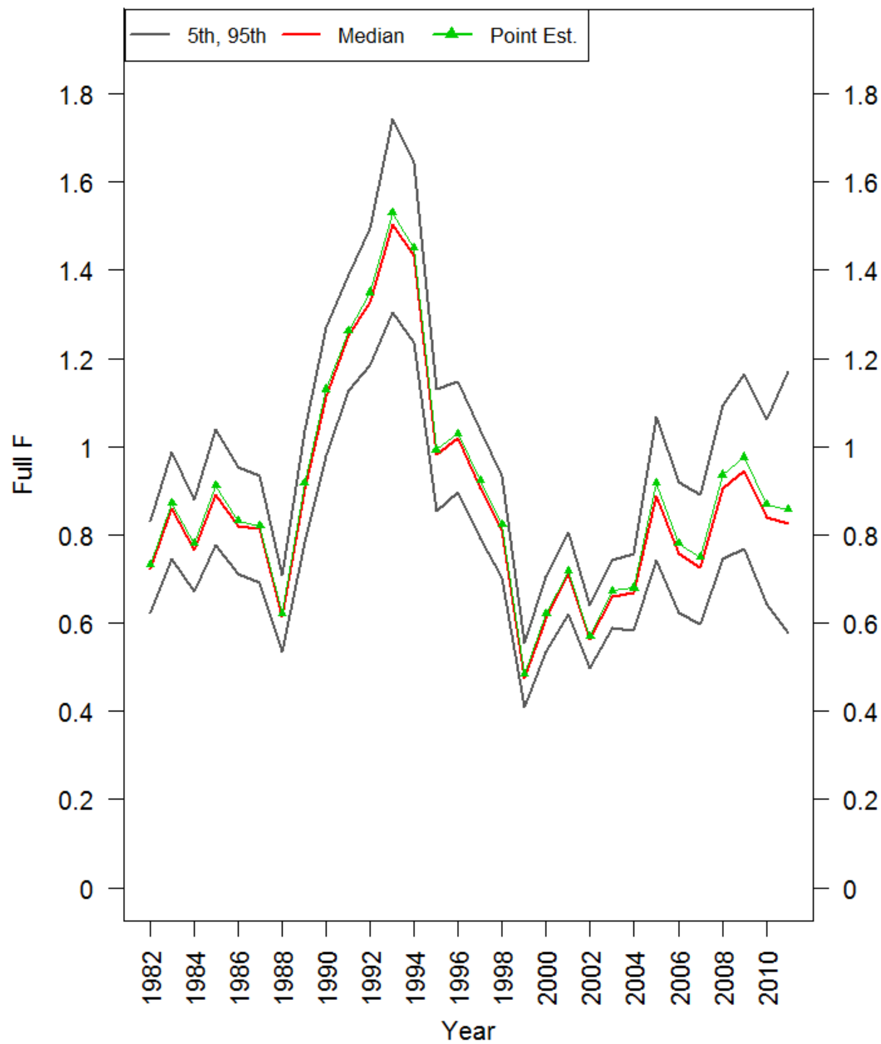


Figure A.196. 90% probability interval for Gulf of Maine Atlantic fully recruited fishing mortality (Full F) from the ASAP SAW55_3BLOCK_BASE model. The median value is in red, while the 5^{th} and 95^{th} percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles.

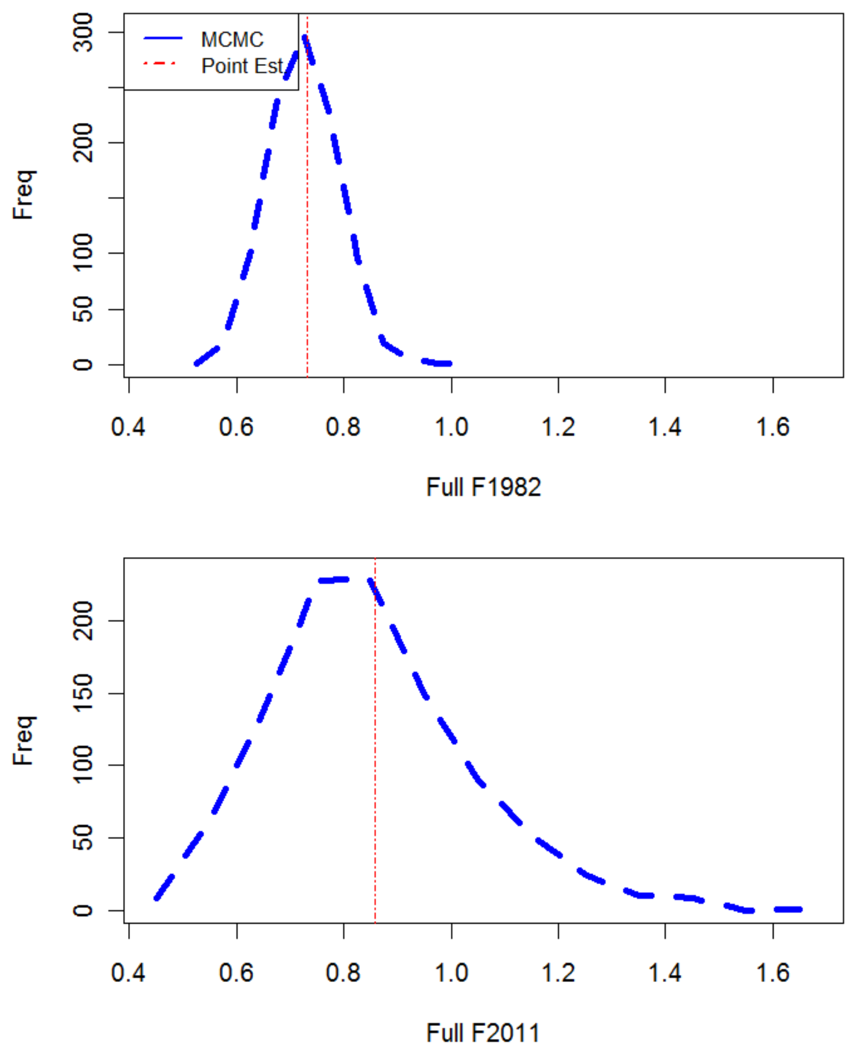


Figure A.197. MCMC distribution of Gulf of Maine Atlantic cod fully recruited fishing mortality (Full F) in 1982 and 2011 estimated from the ASAP SAW55_3BLOCK_BASE model. The model point estimate is indicated by the dashed red line.

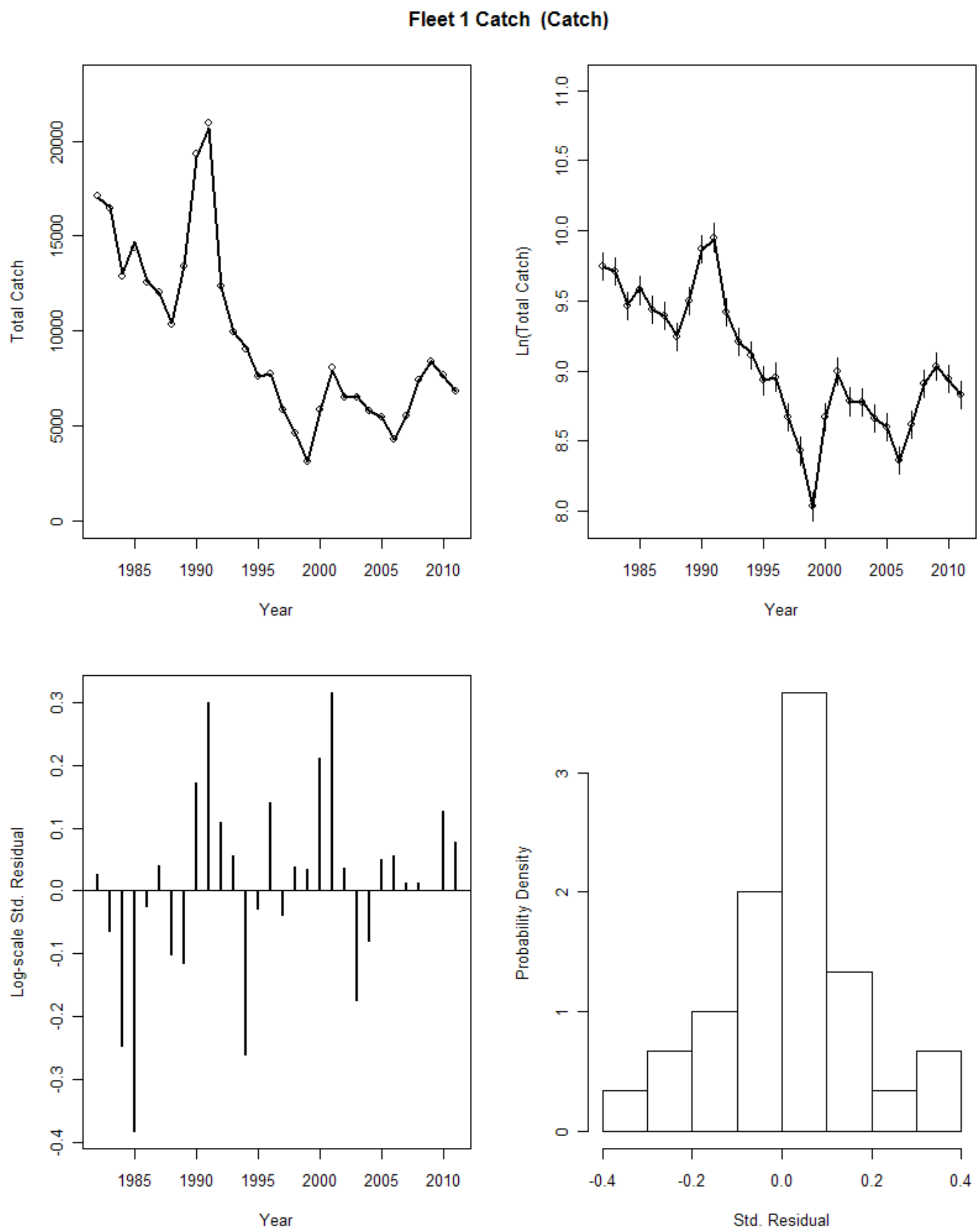


Figure A.198. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit to the total Gulf of Maine Atlantic cod fishery catch (Fleet 1).

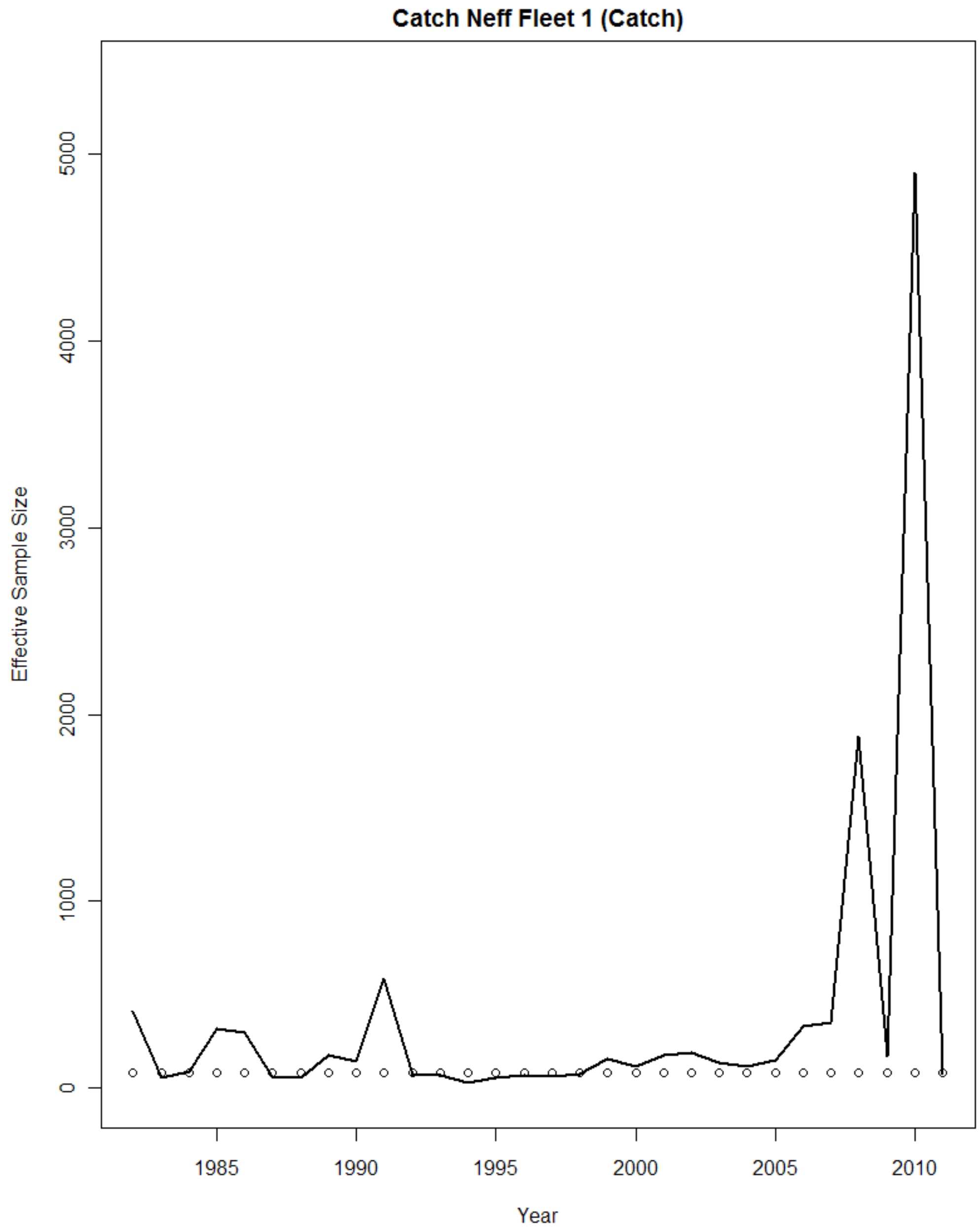


Figure A.199. ASAP SAW55_3BLOCK_BASE_M_SPLIT model comparison of input effective sample size versus the model estimated effective sample size for the Gulf of Maine Atlantic cod fishery catch.

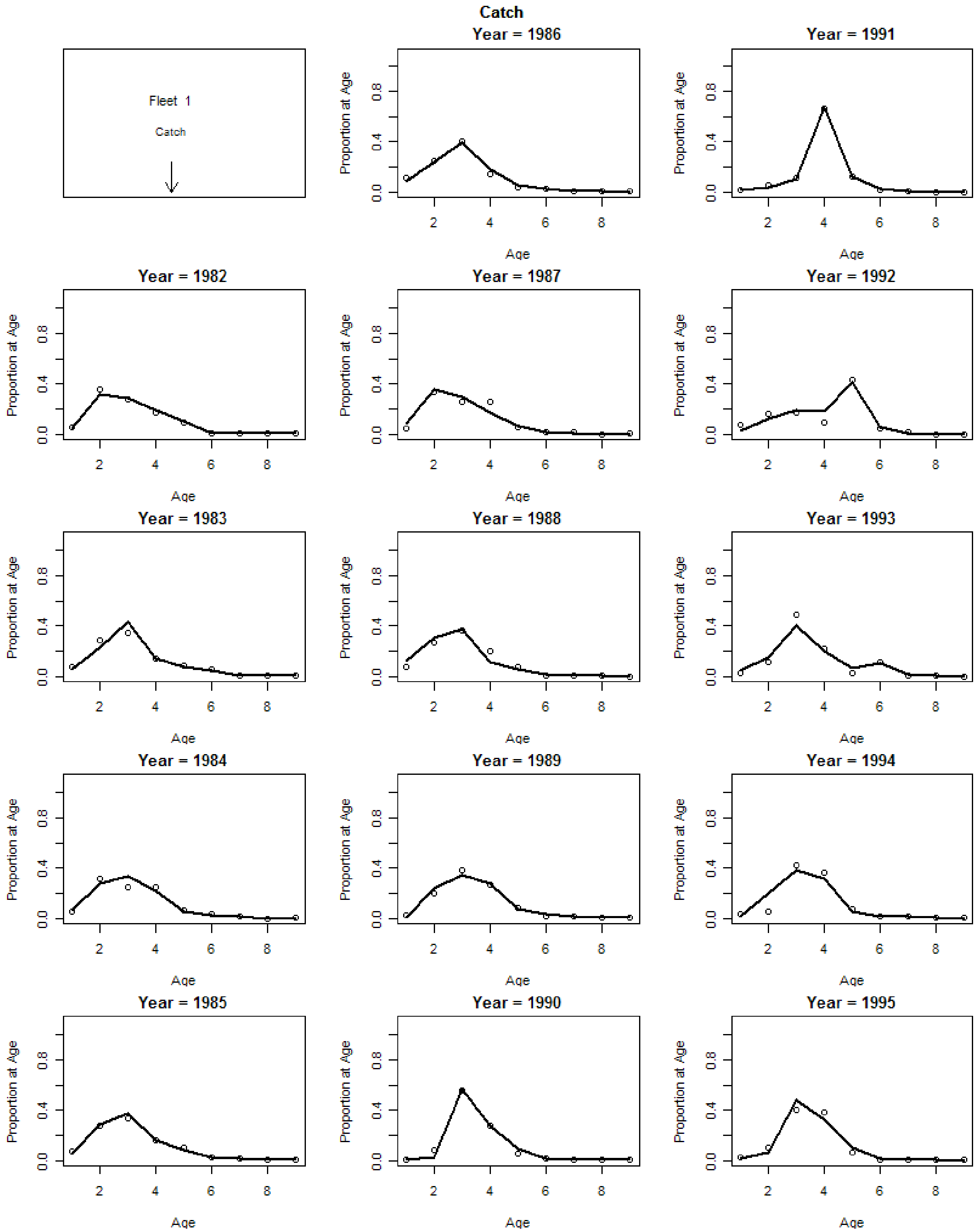


Figure A.200.a. Comparison of the ASAP SAW55_3BLOCK_BASE_M_SPLIT estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

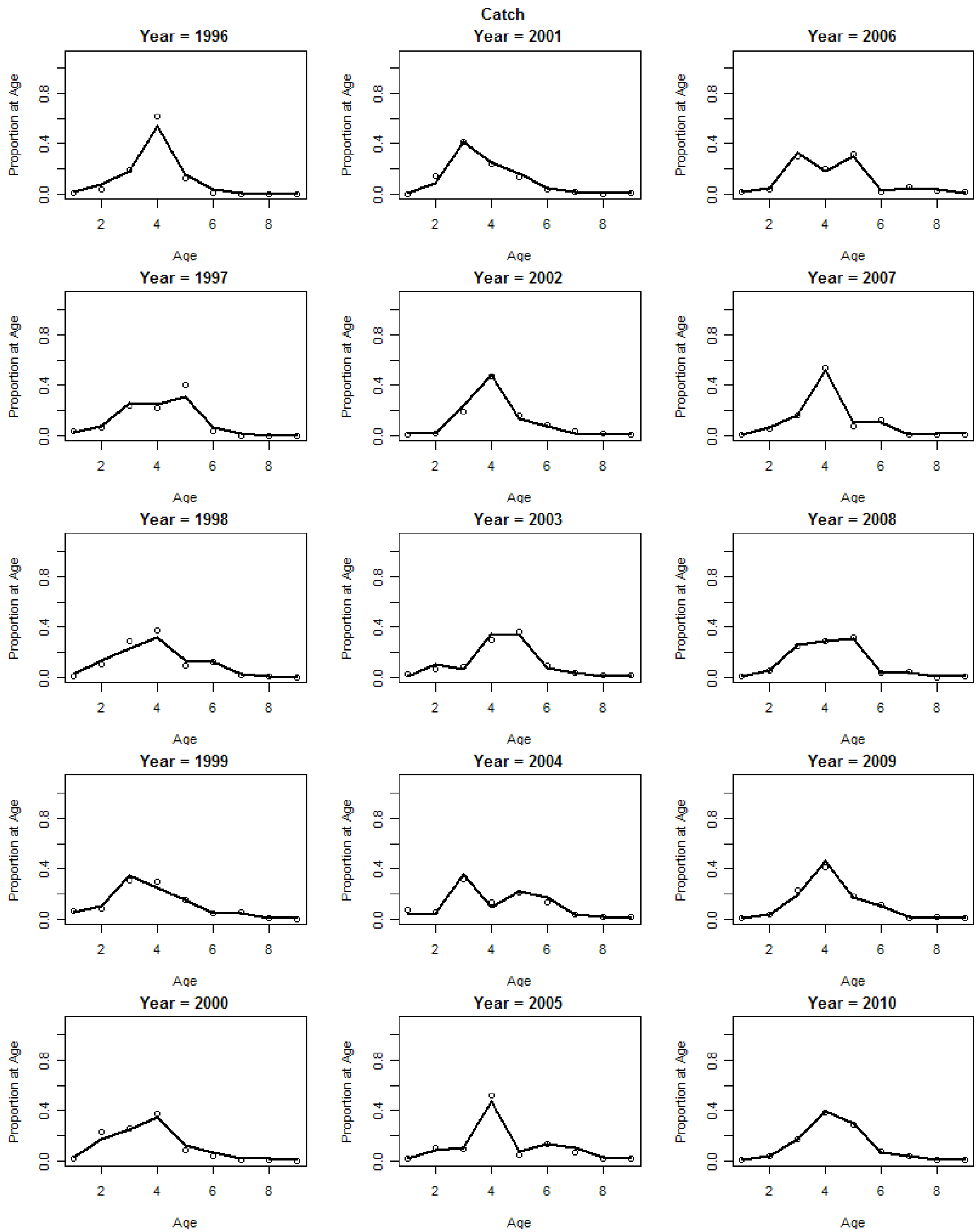


Figure A.200.b. Comparison of the ASAP SAW55_3BLOCK_BASE_M_SPLIT estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

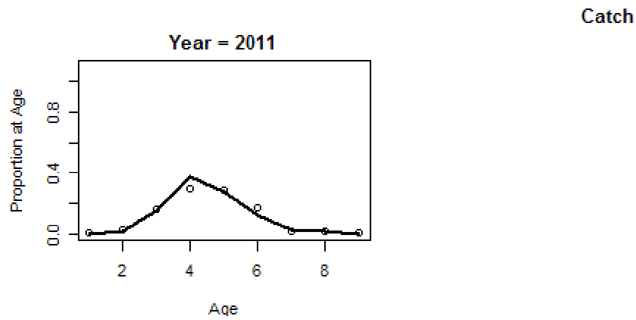


Figure A.200.c. Comparison of the ASAP SAW55_3BLOCK_BASE_M_SPLIT estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

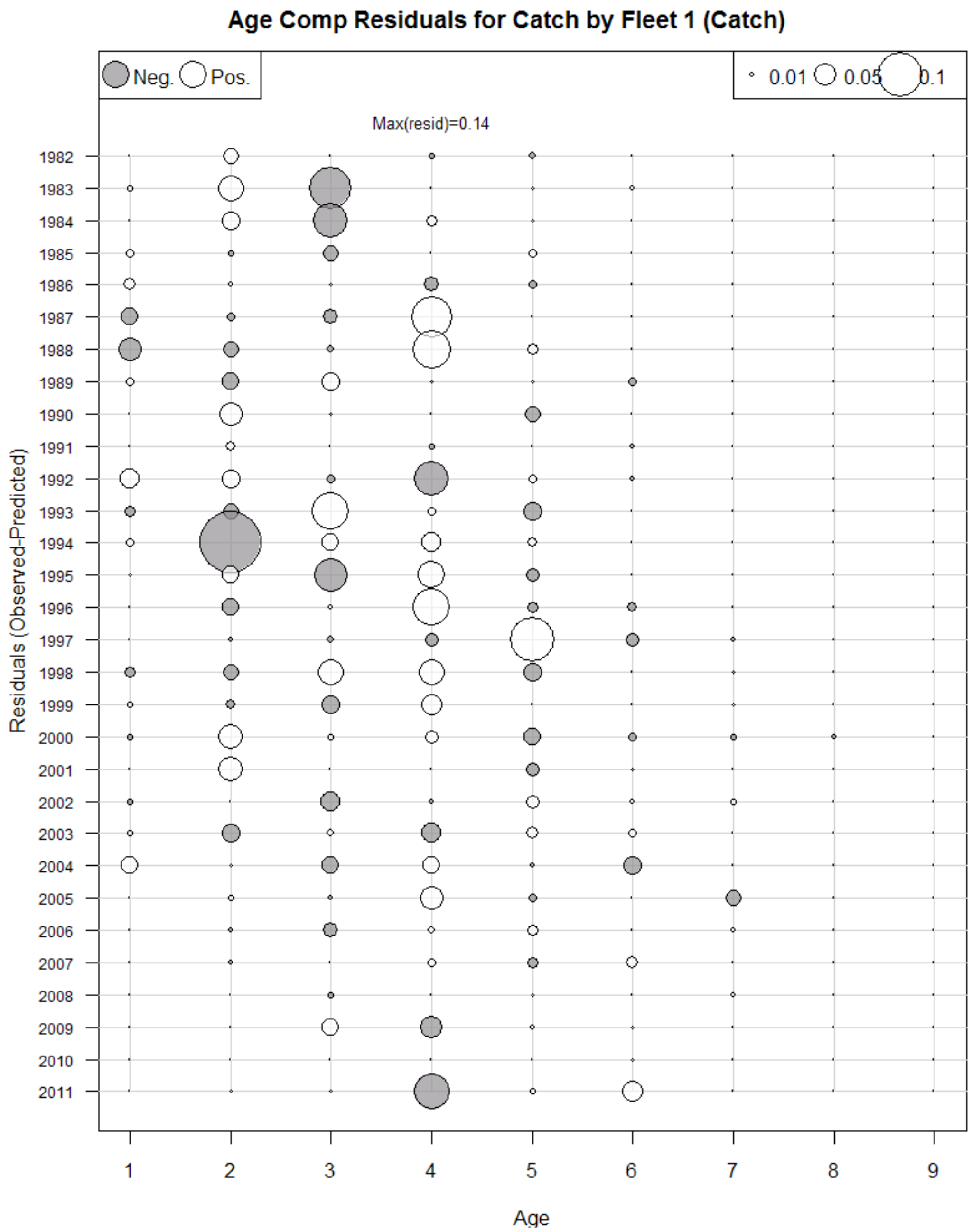


Figure A.201. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit residuals for the fishery (Fleet 1) catch-at-age of Gulf of Maine Atlantic cod.

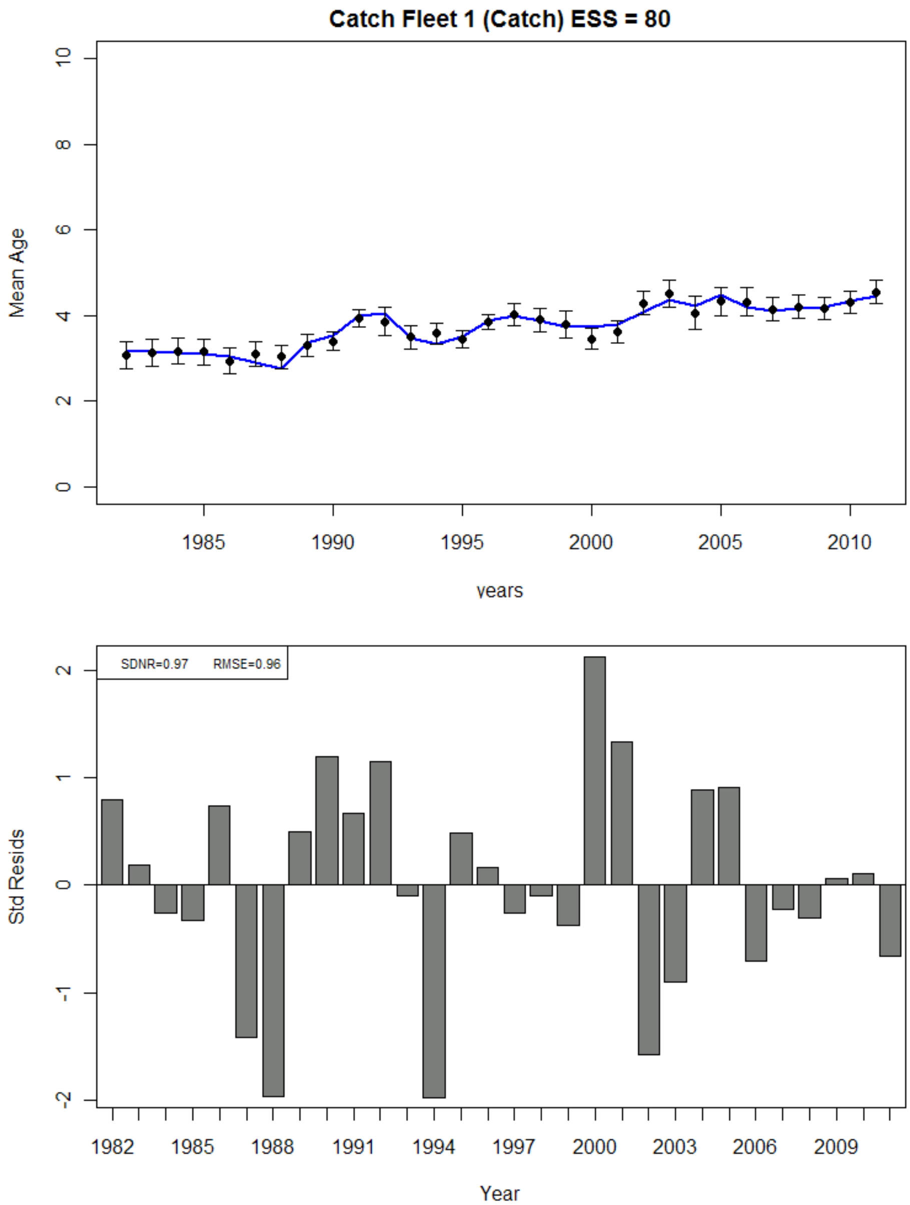


Figure A.202. ASAP SAW55_3BLOCK_BASE_M_SPLIT predicted mean age of Gulf of Maine Atlantic cod in the fishery catch (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

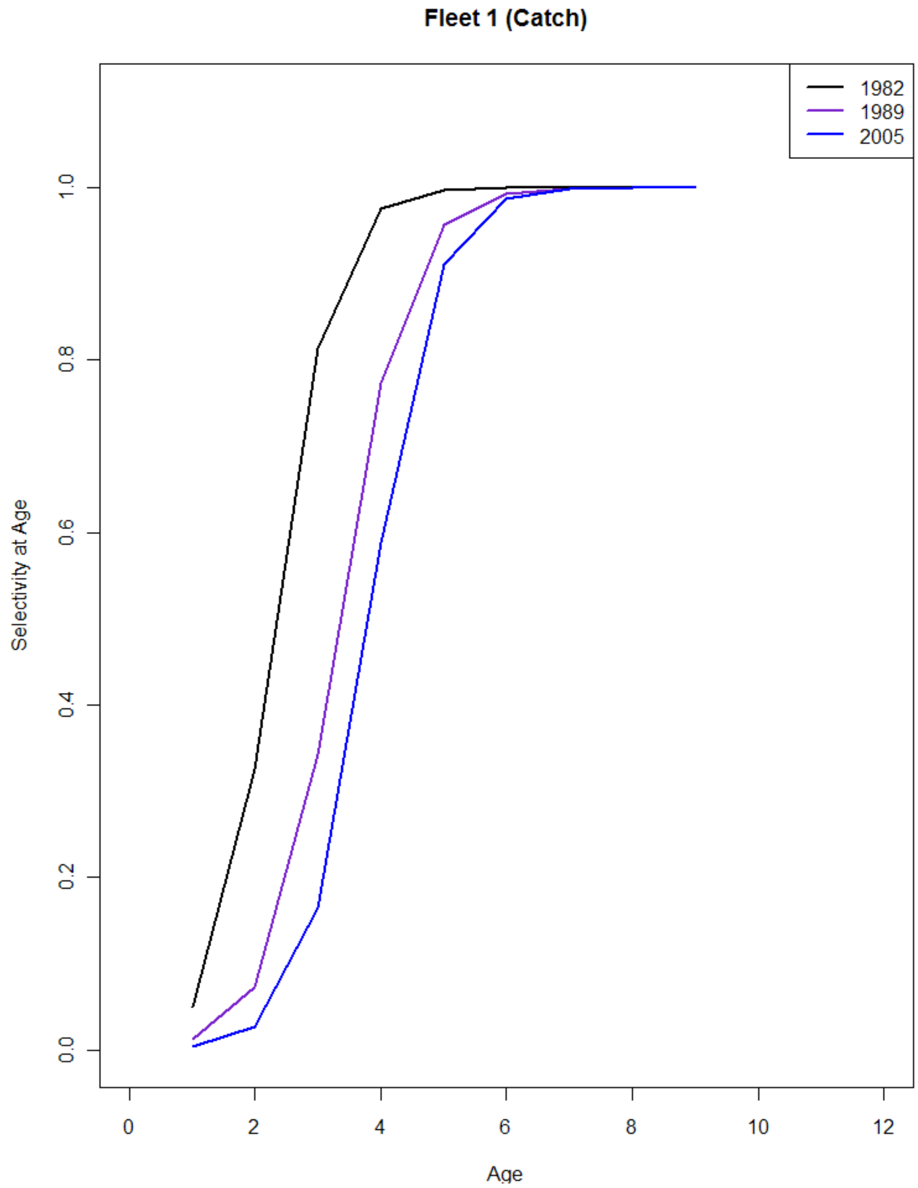


Figure A.203. Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1989), block 2 (1990-2004) and block 3 (2005-2011) estimated by the ASAP SAW55_3BLOCK_BASE_M_SPLIT model.

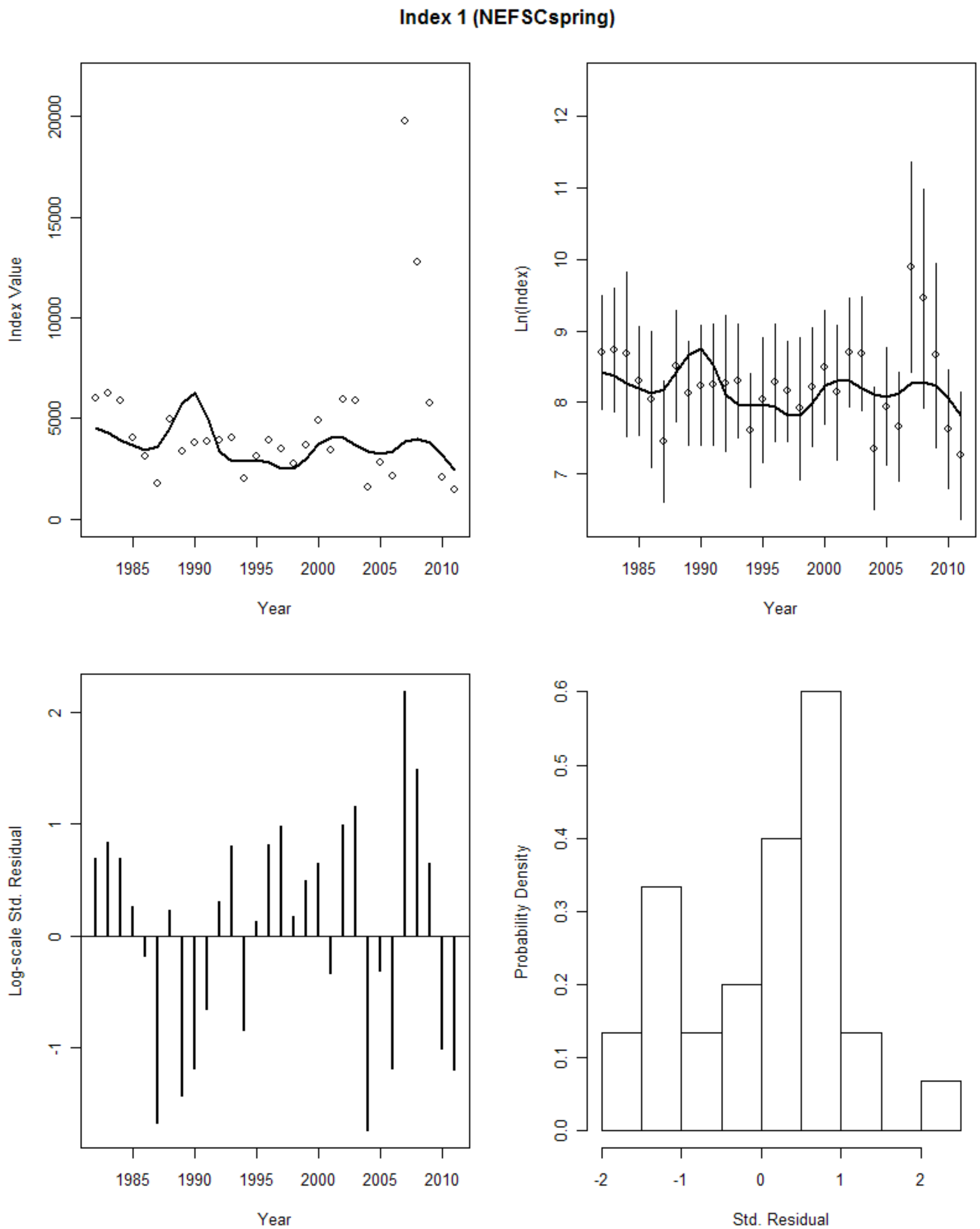


Figure A.204. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit to the NEFSC Gulf of Maine Atlantic cod spring (Index 1) survey.

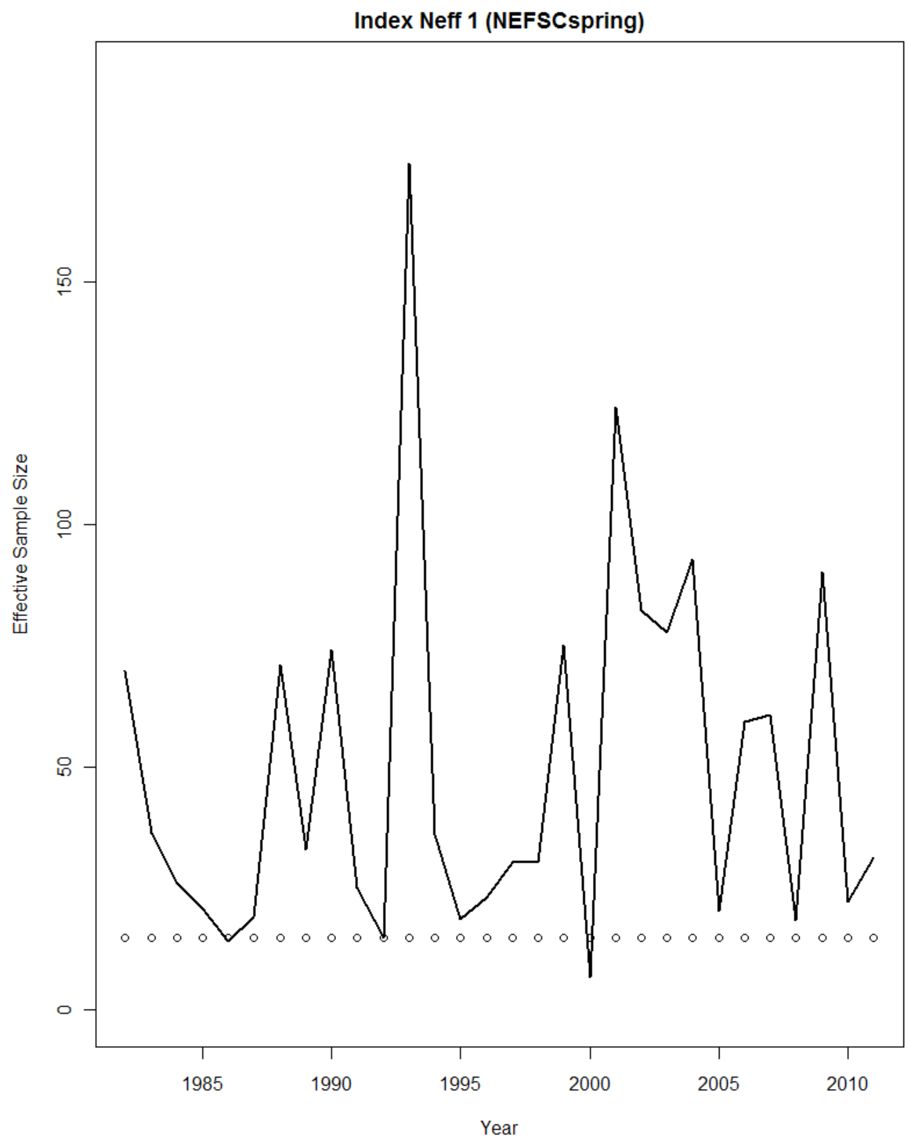


Figure A.205. ASAP SAW55_3BLOCK_BASE_M_SPLIT model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC spring (Index 1) Gulf of Maine Atlantic cod index.

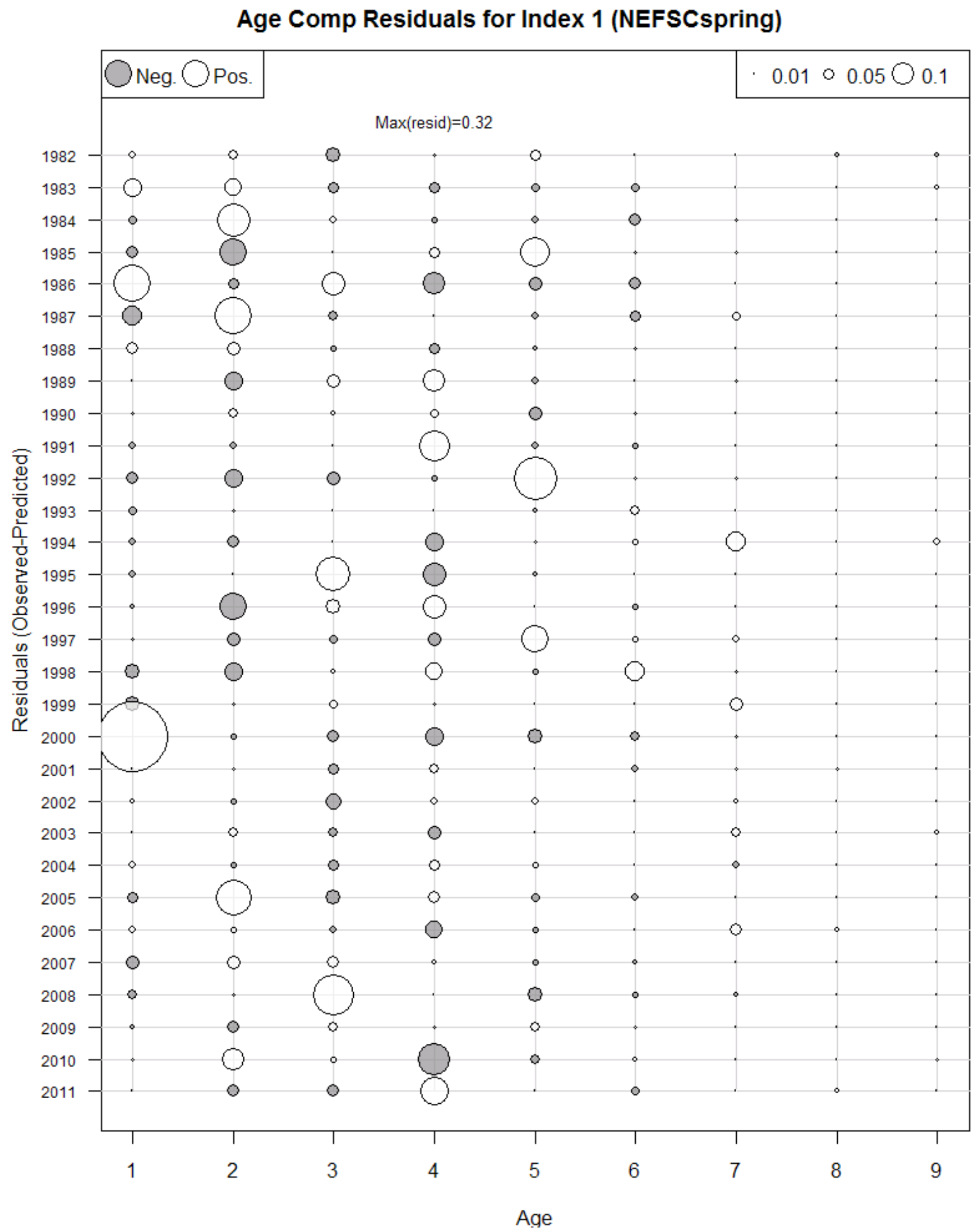
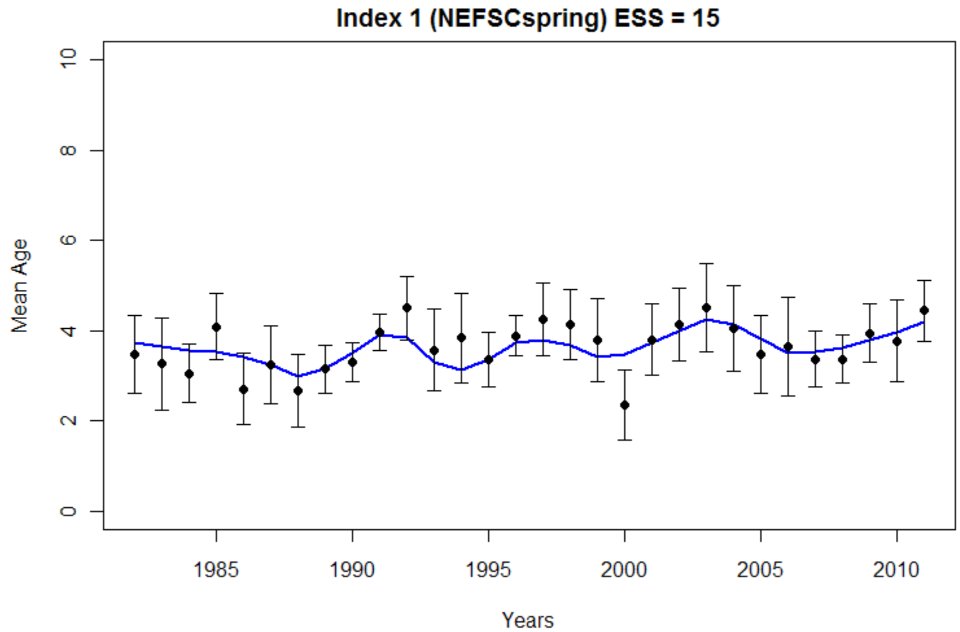


Figure A.206. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit residuals for the NEFSC spring survey (Index 1) Gulf of Maine Atlantic cod age composition.



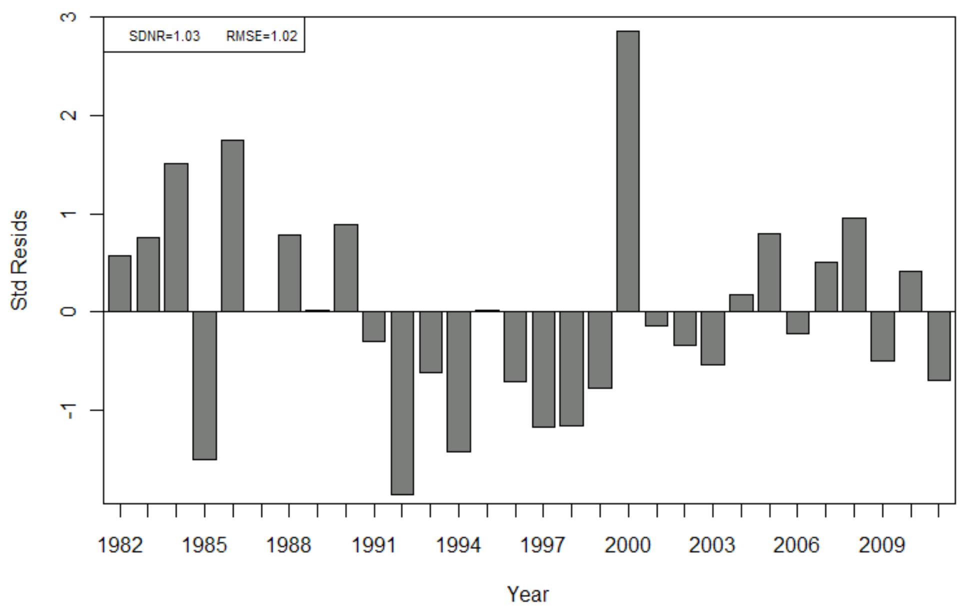


Figure A.207. ASAP SAW55_3BLOCK_BASE_M_SPLIT predicted mean age of Gulf of Maine Atlantic cod in the NEFSC spring (Index 1) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

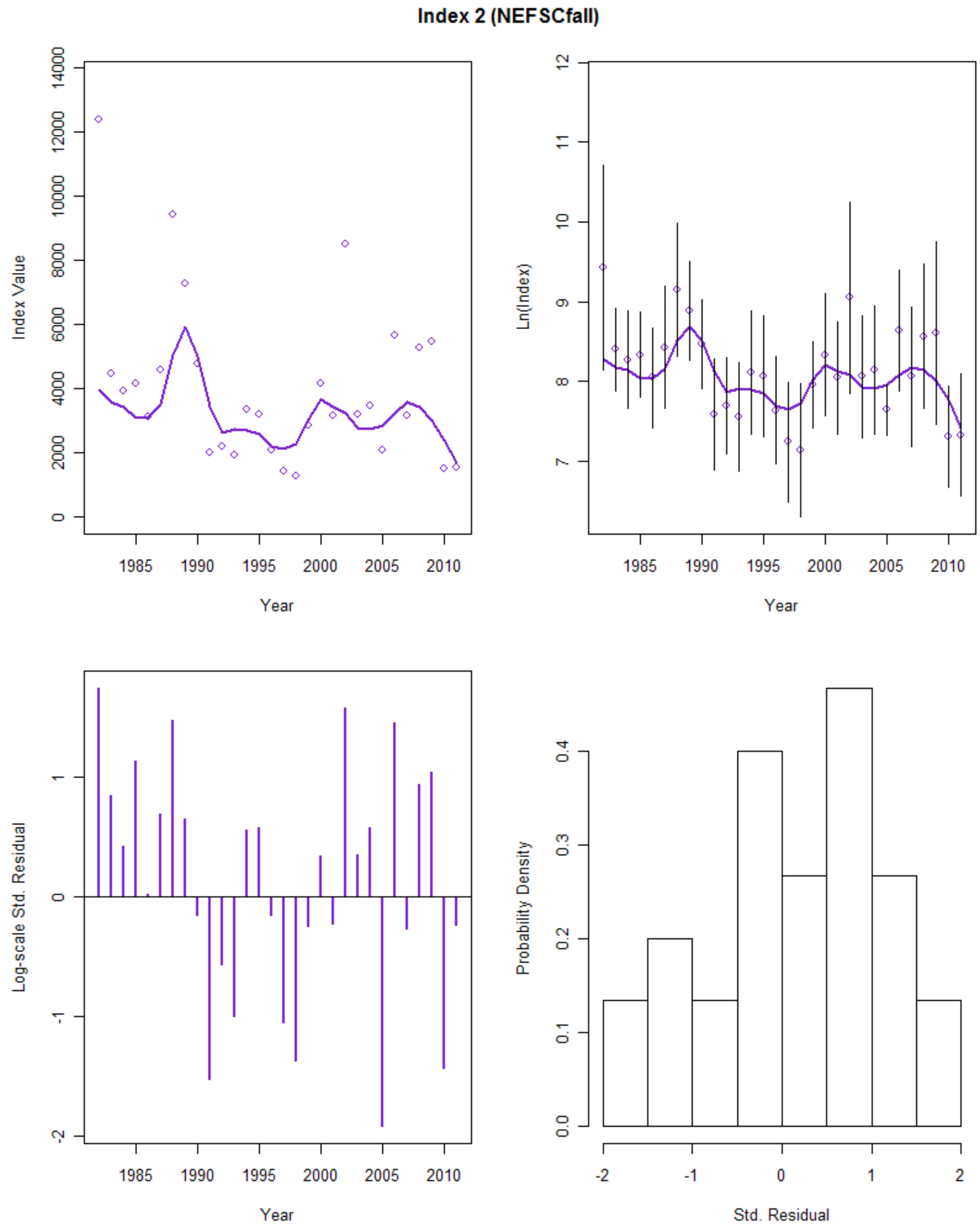


Figure A.208. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit to the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

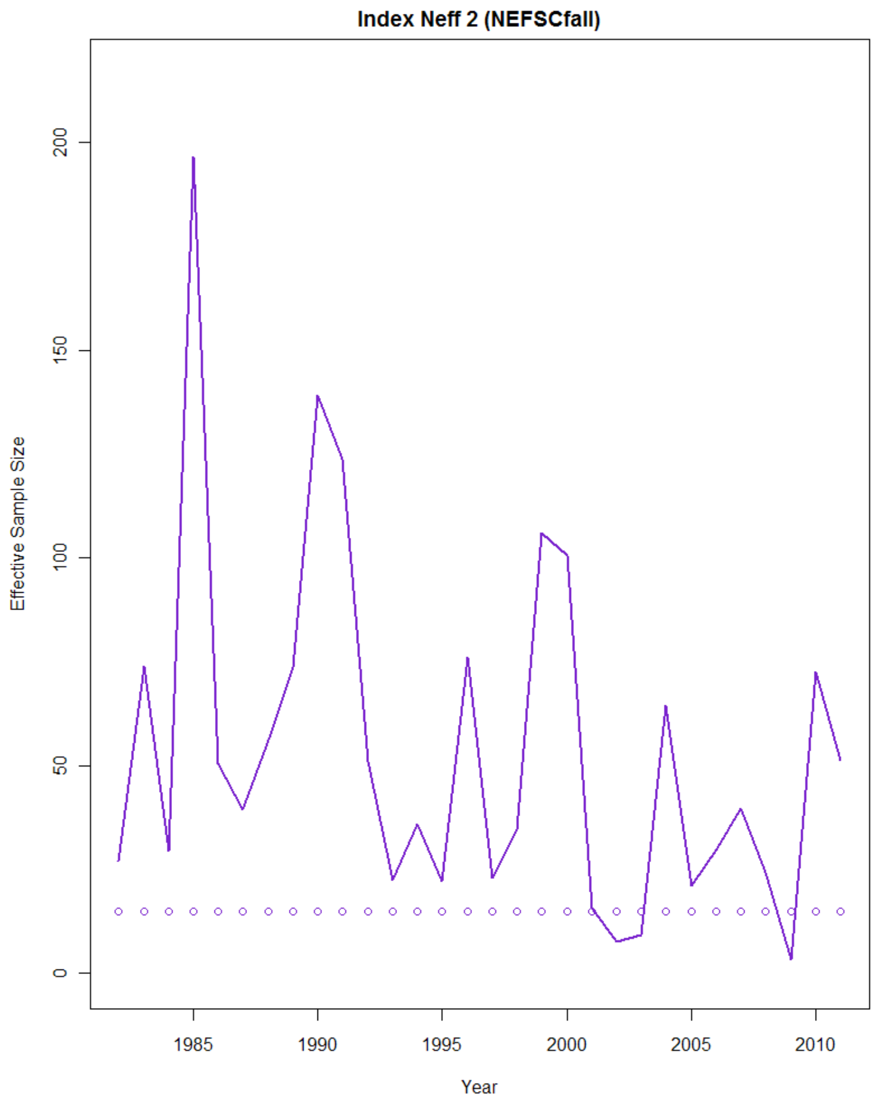


Figure A.209. ASAP SAW55_3BLOCK_BASE_M_SPLIT model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

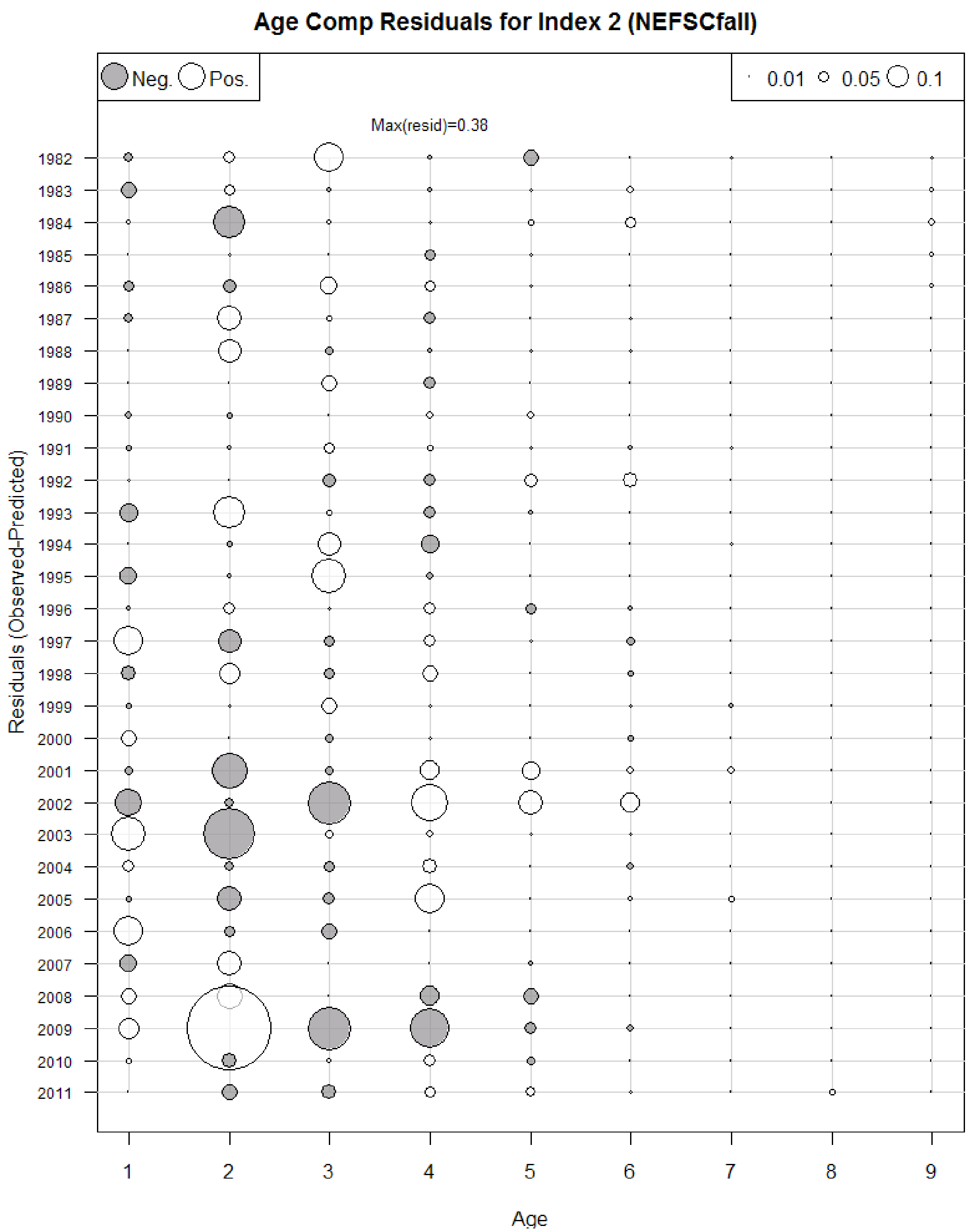


Figure A.210. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit residuals for the NEFSC fall survey (Index 2) Gulf of Maine Atlantic cod age composition.

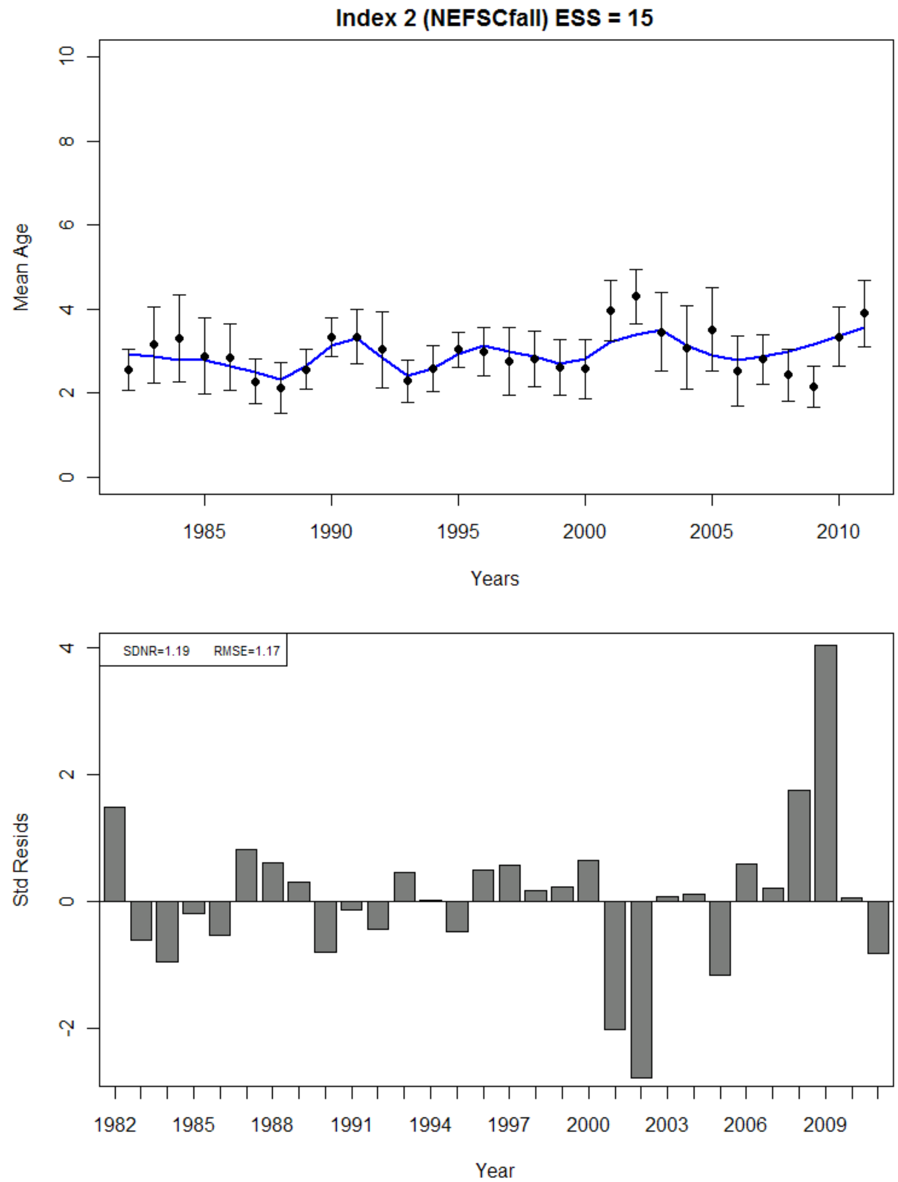


Figure A.211. ASAP SAW55_3BLOCK_BASE_M_SPLIT predicted mean age of Gulf of Maine Atlantic cod in the NEFSC fall (Index 2) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

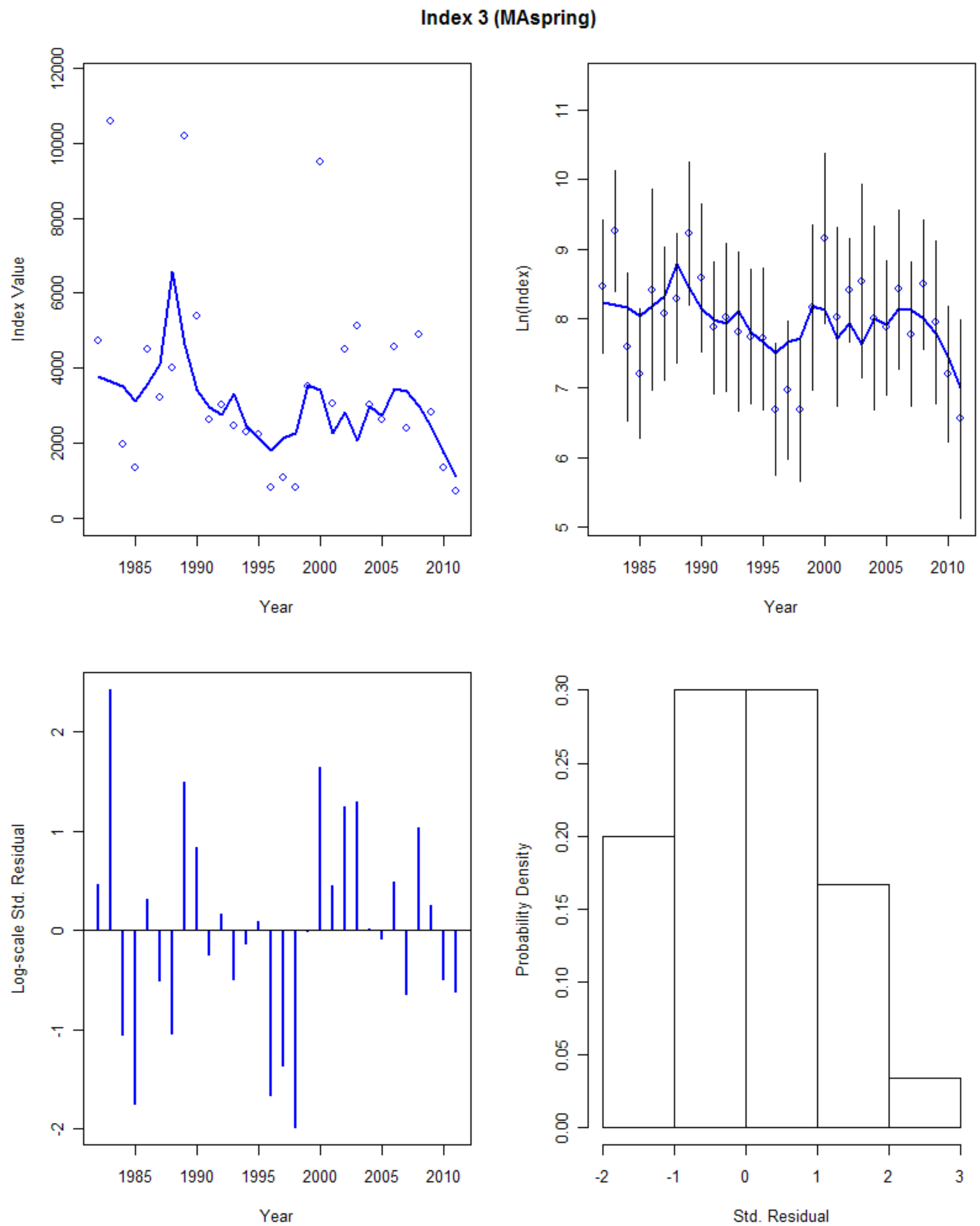


Figure A.212. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit to the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

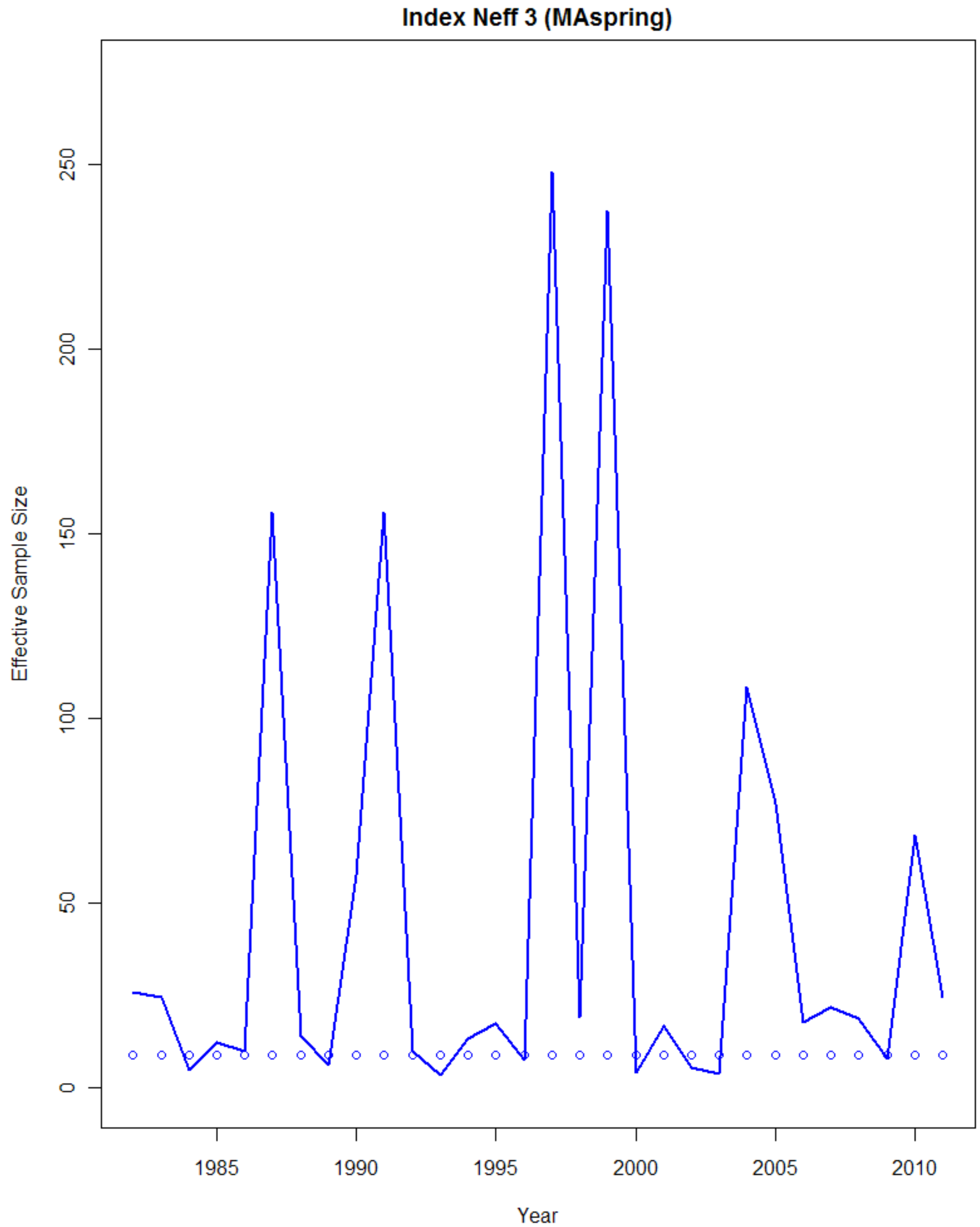


Figure A.213. ASAP SAW55_3BLOCK_BASE_M_SPLIT model comparison of input effective sample size versus the model estimated effective sample size for the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

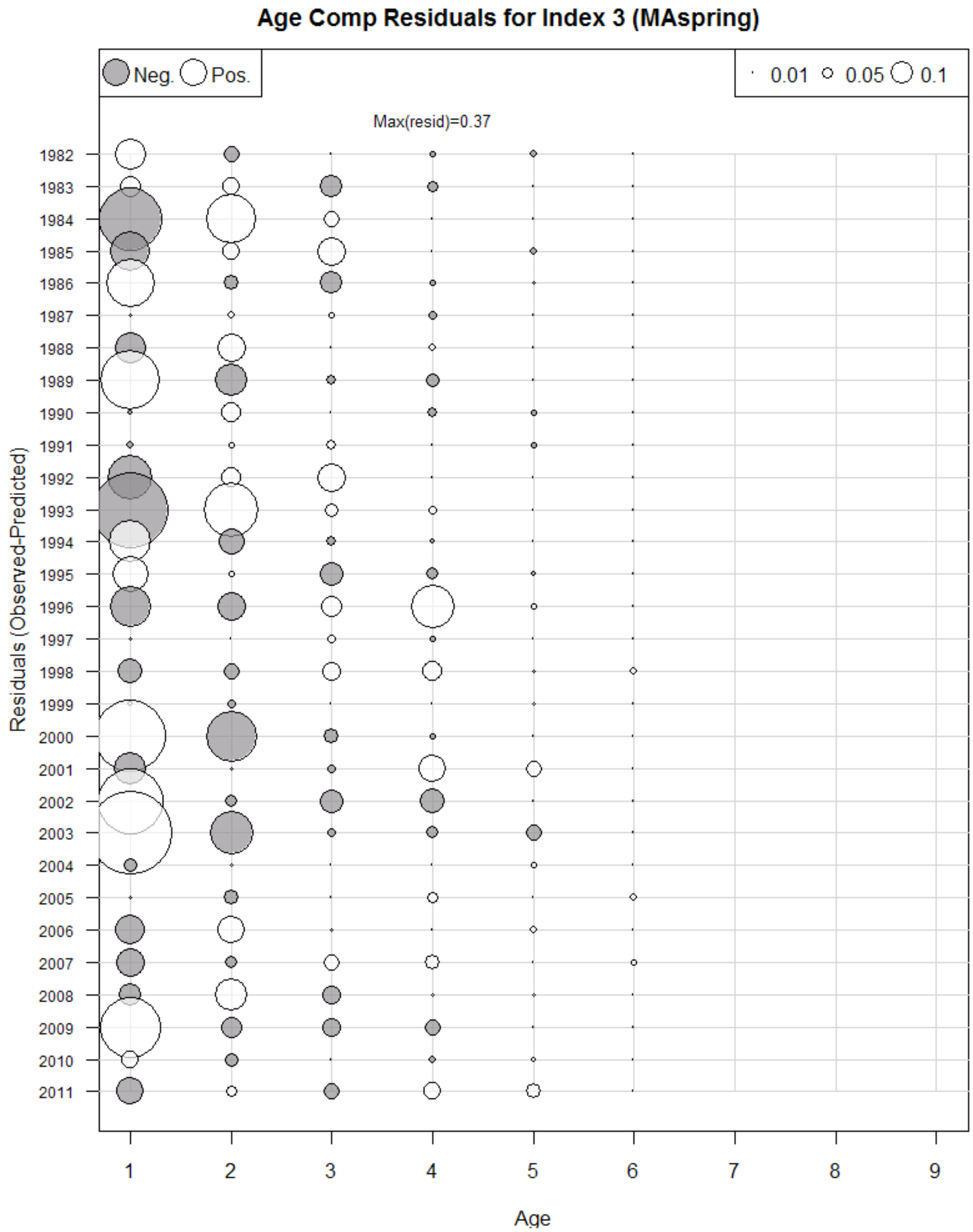


Figure A.214. ASAP SAW55_3BLOCK_BASE_M_SPLIT model fit residuals for the MADMF spring survey (Index 3) Gulf of Maine Atlantic cod age composition.

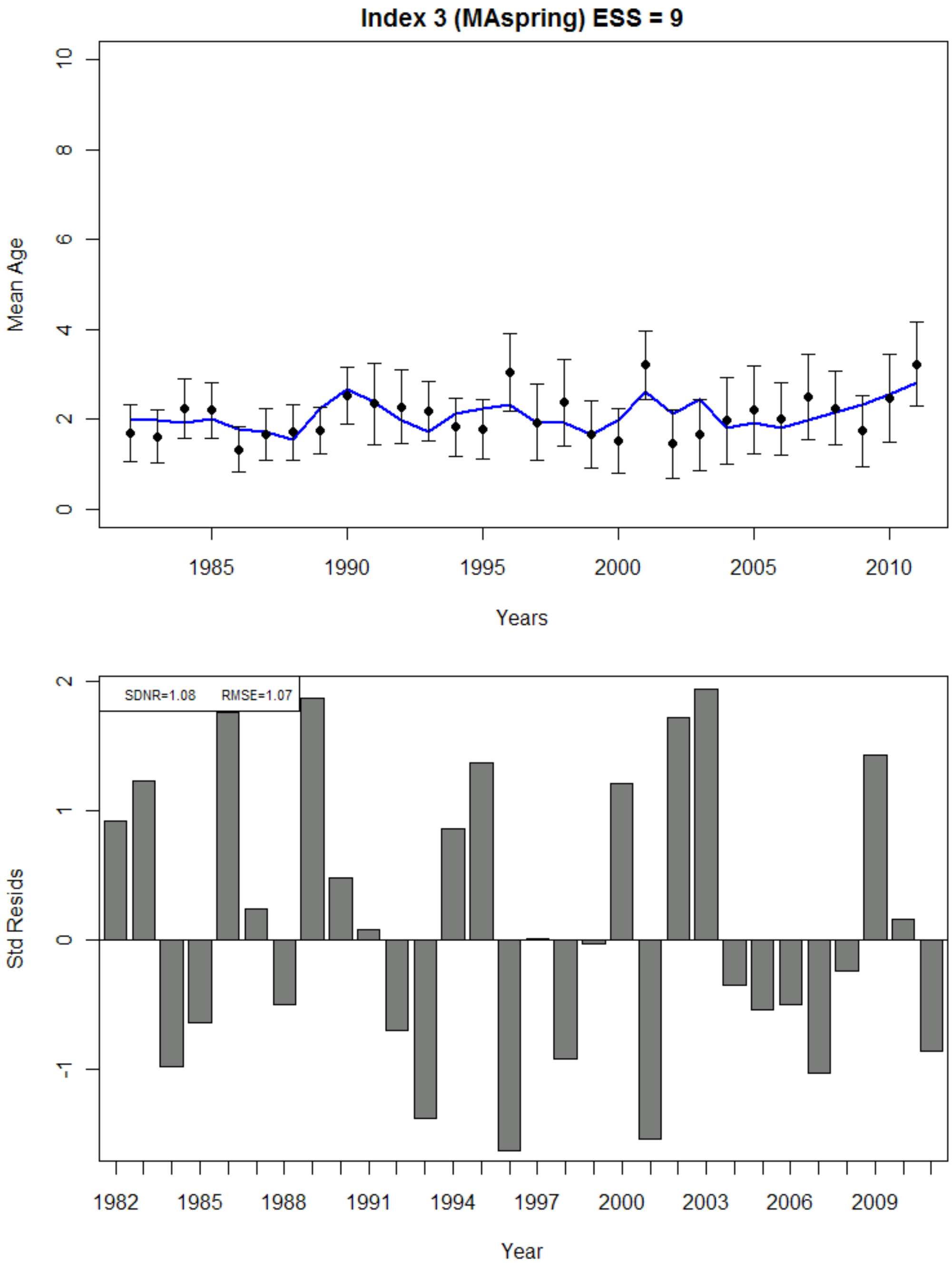


Figure A.215. ASAP SAW55_3BLOCK_BASE_M_SPLIT predicted mean age of Gulf of Maine Atlantic cod in the MADMF spring (Index 3) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

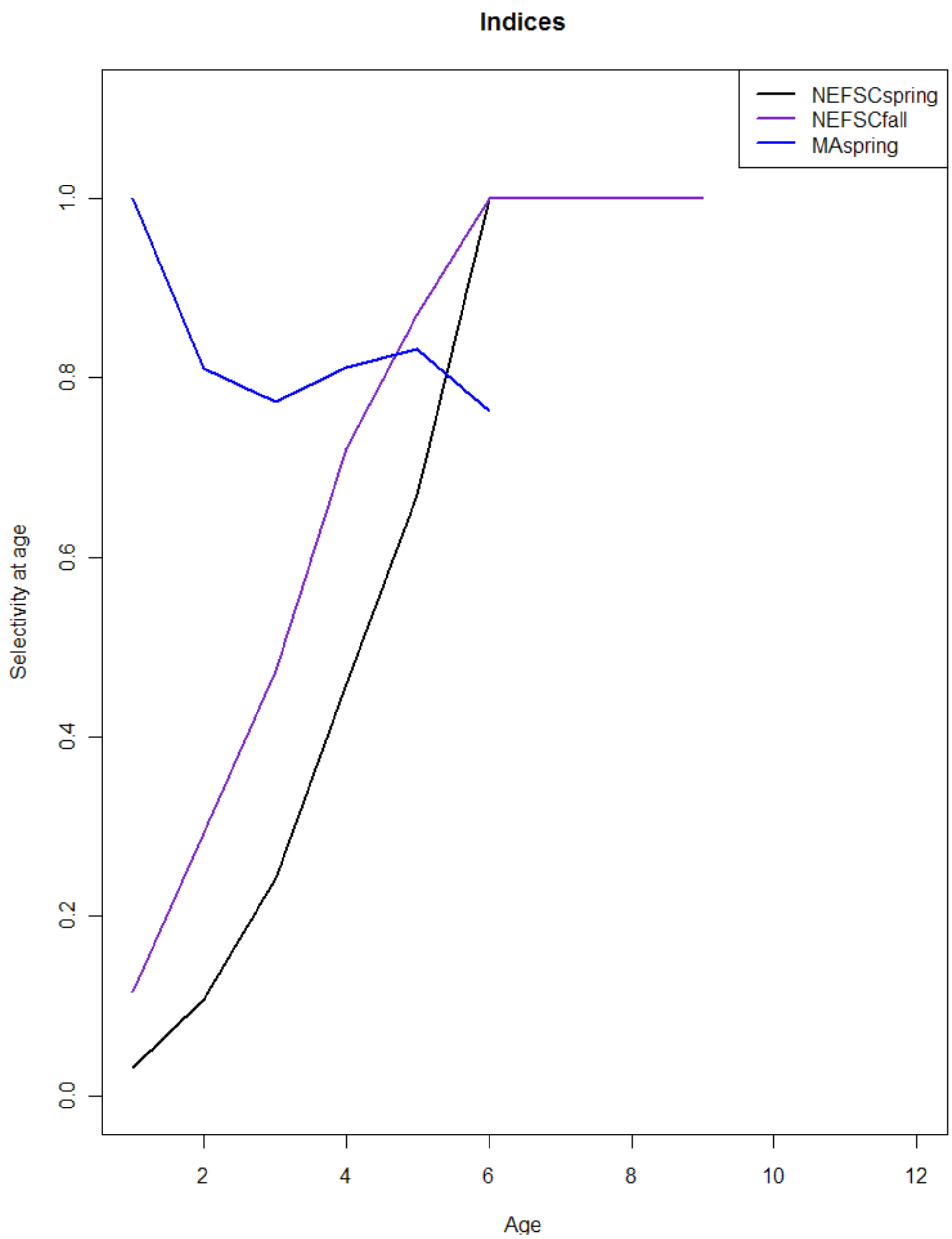


Figure A.216. Gulf of Maine Atlantic cod selectivity-at-age for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model.

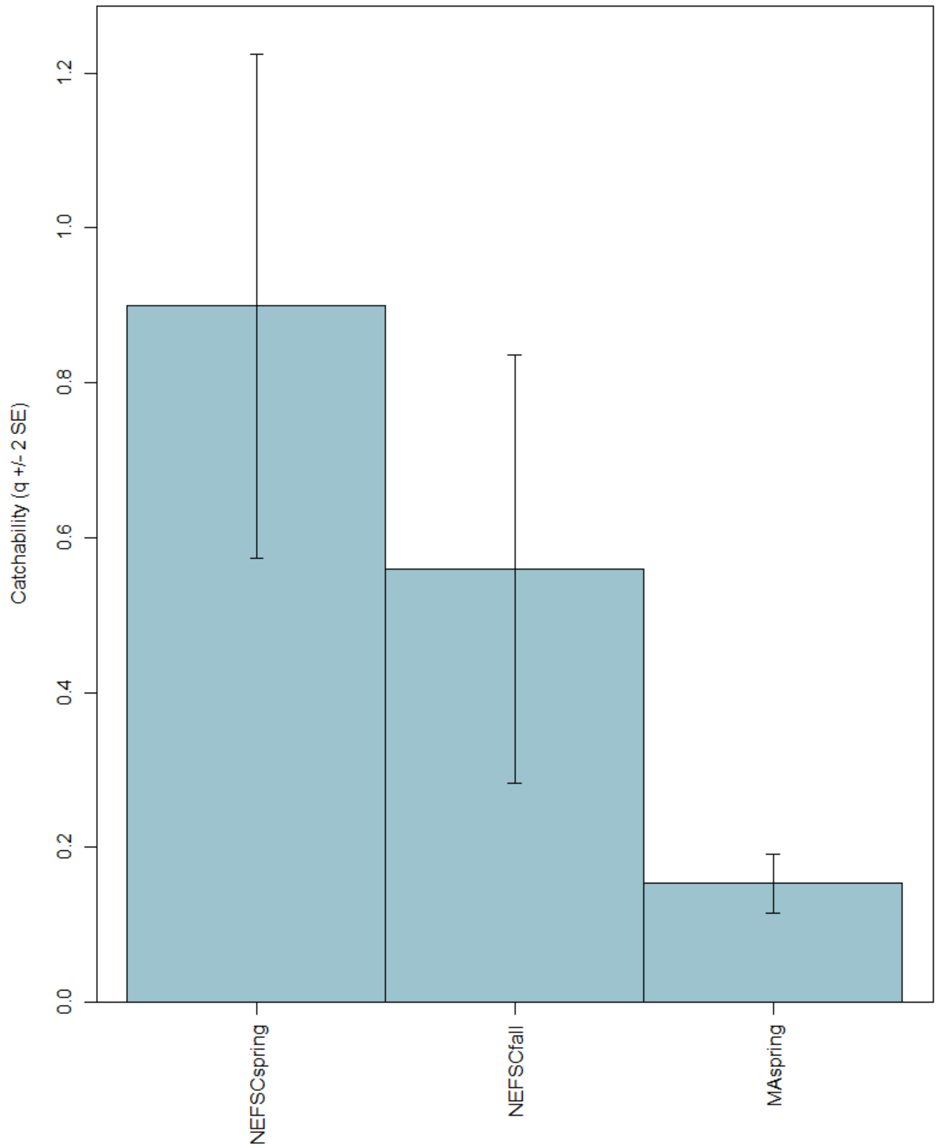
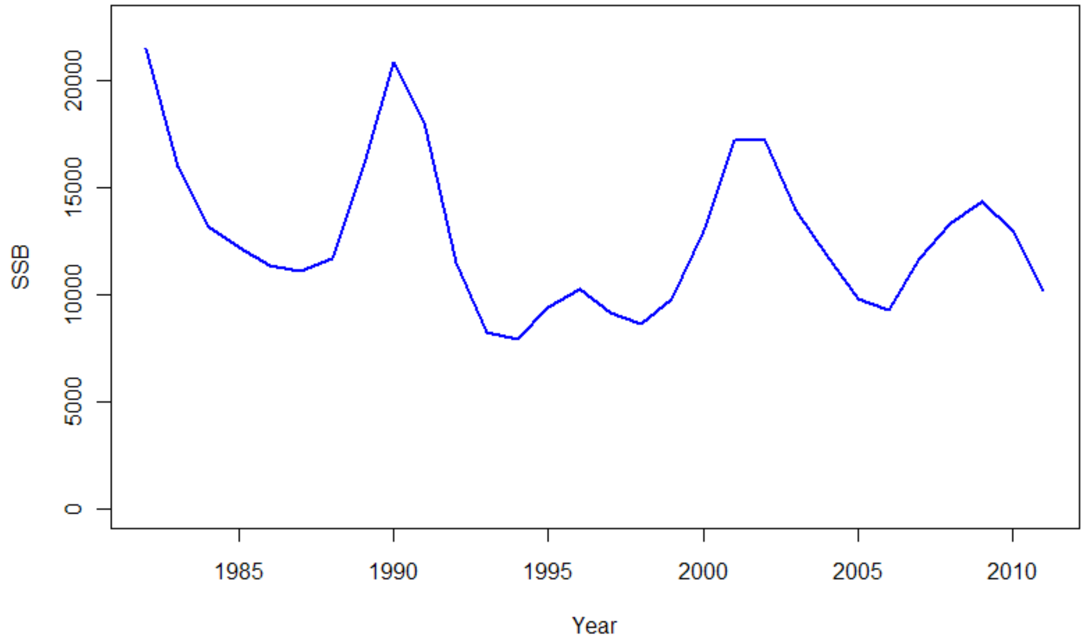


Figure A.217. Gulf of Maine Atlantic cod survey catchability, *q*, for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model.



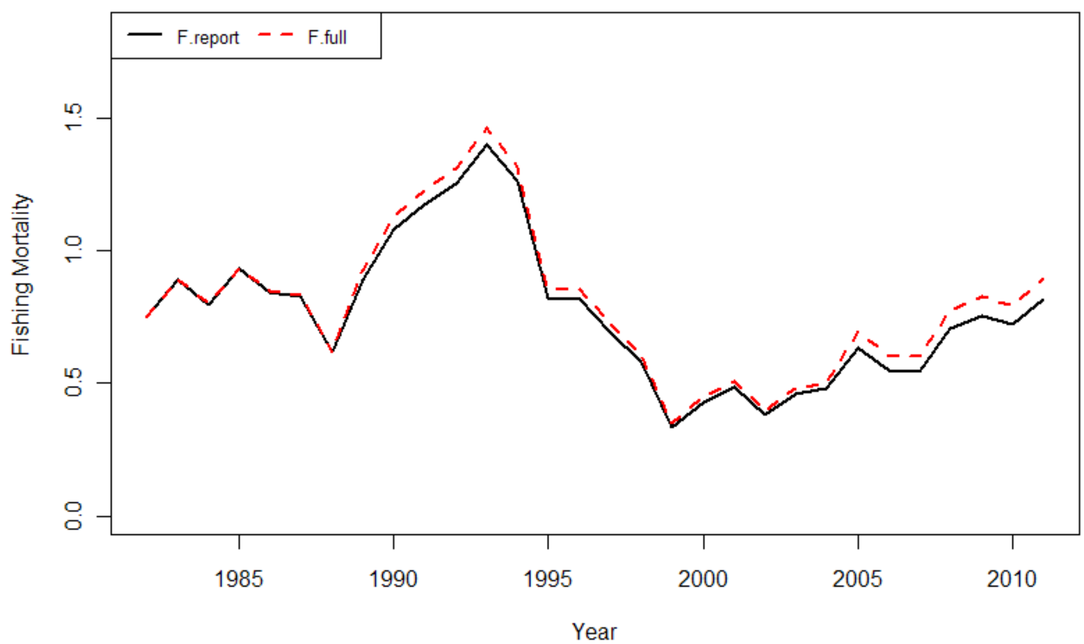


Figure A.218. ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) and fishing mortality (F_{full} = fully recruited fishing mortality, F_{report} = fishing mortality on age 5).

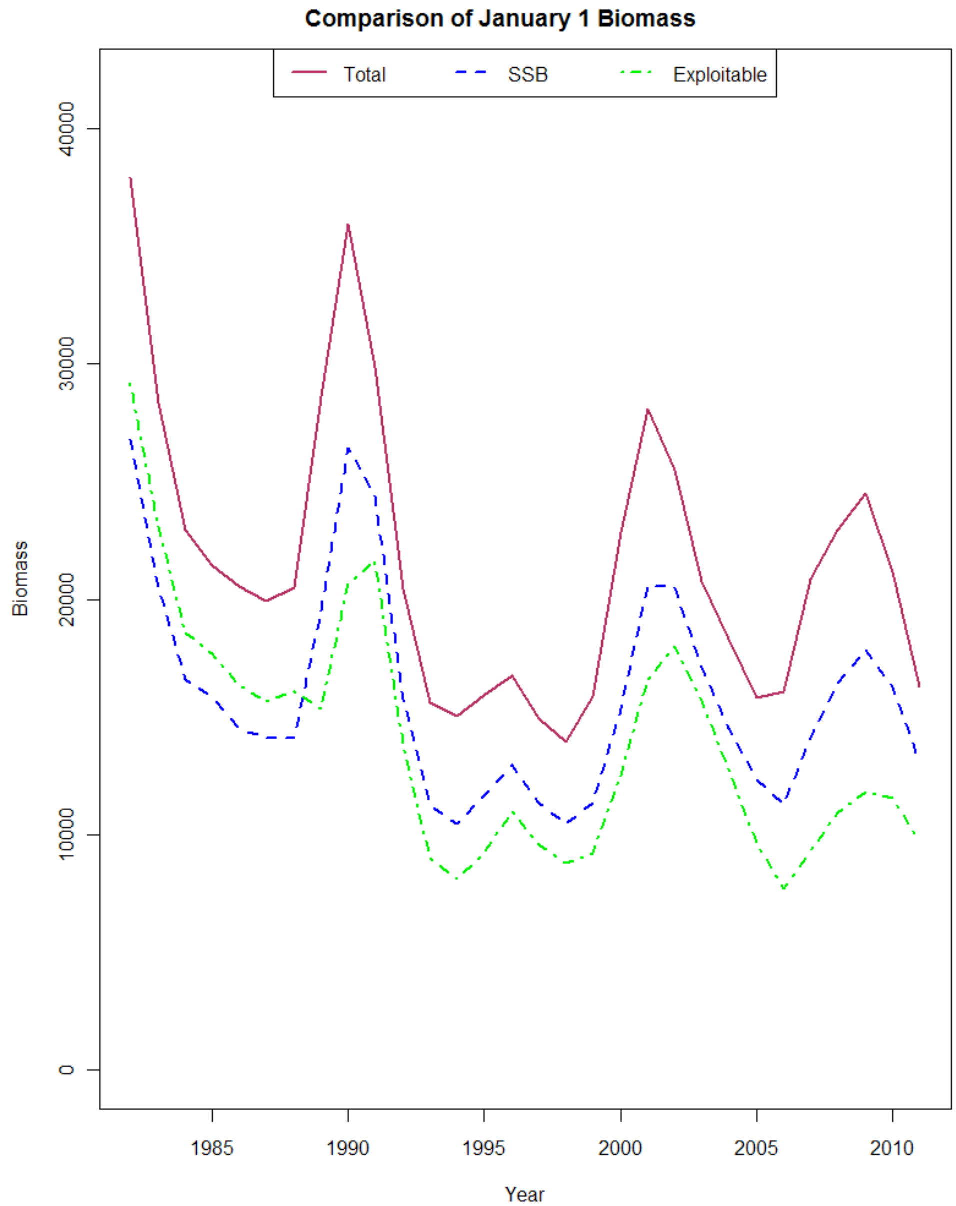


Figure A.219. Comparison of ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine Atlantic cod January 1 biomass after application of maturity ogive (SSB) and fleet selectivity ogives (exploitable).

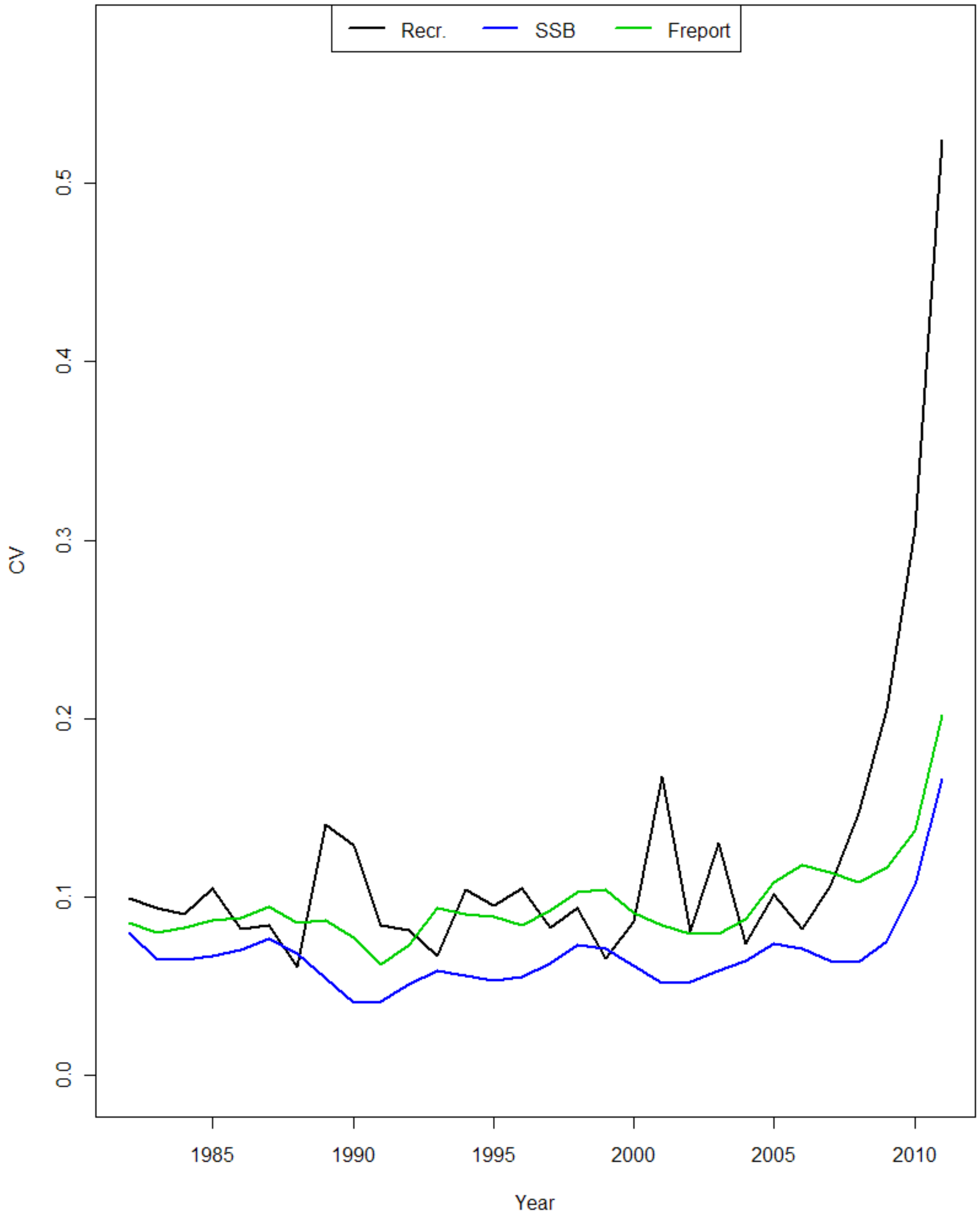


Figure A.220. Coeffecients of variation (CV) for the ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB), average fishing mortality (F_{report} = age 5 fishing mortality) and age 1 recruitment.

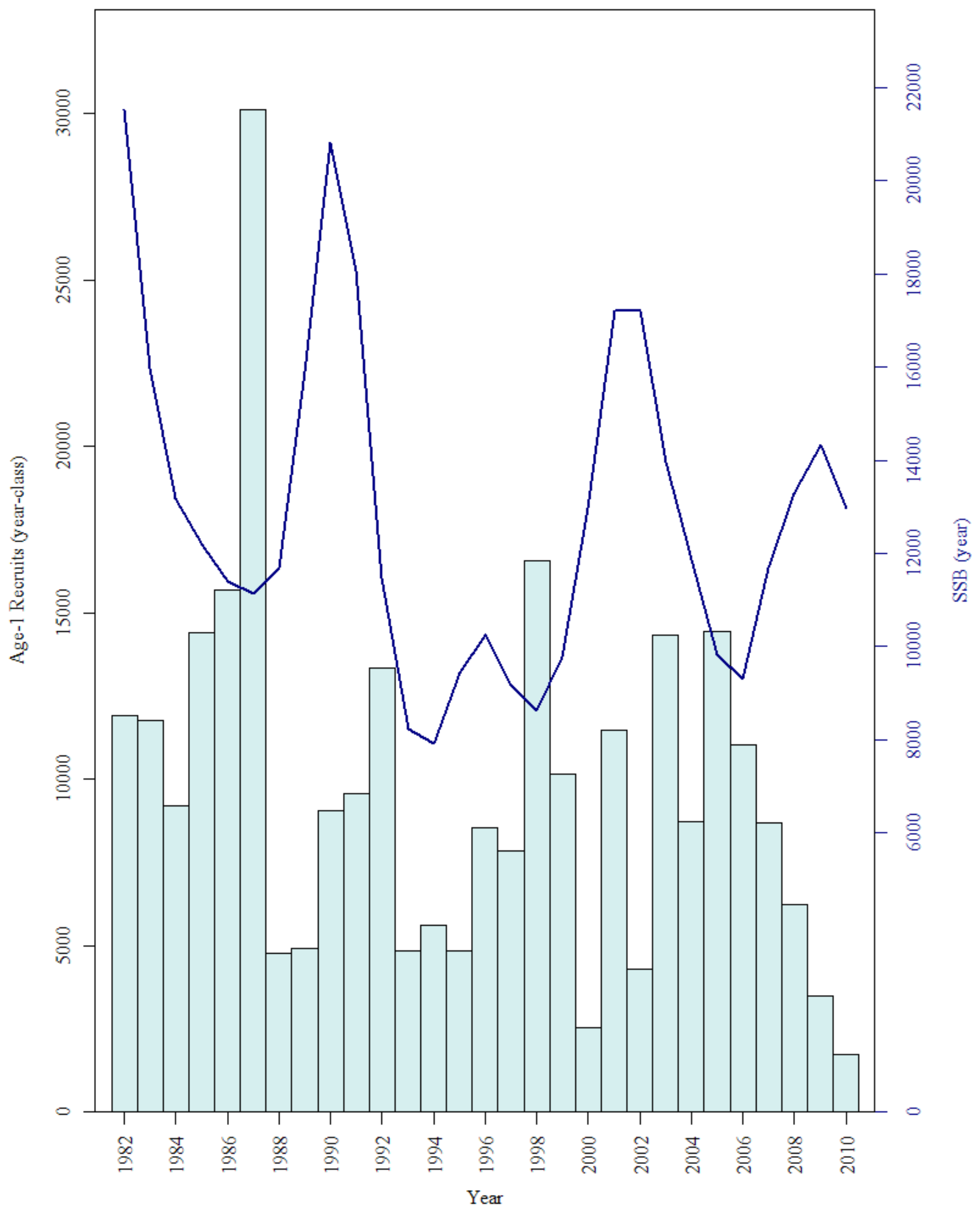


Figure A.221. ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine cod spawning stock biomass (SSB; solid blue line) and lagged age 1 recruitment (light blue bars).

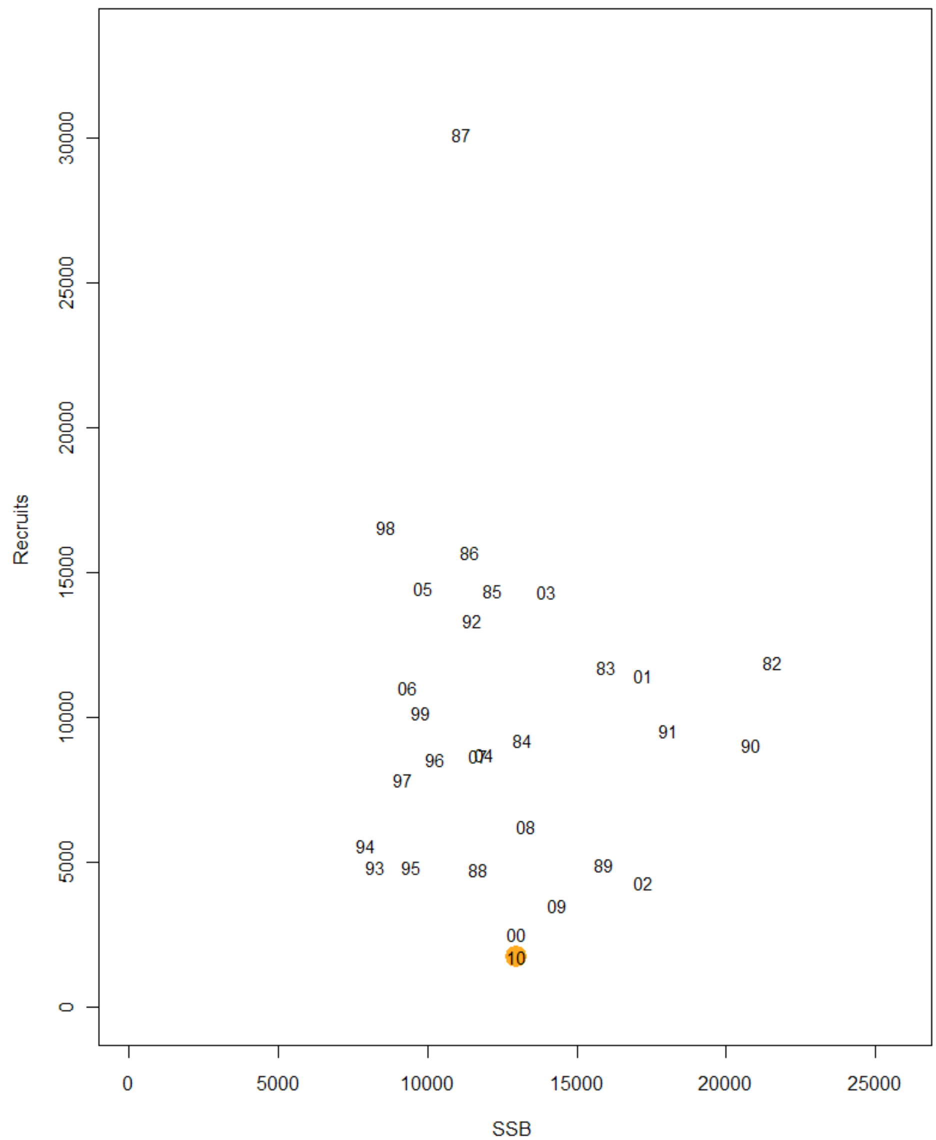
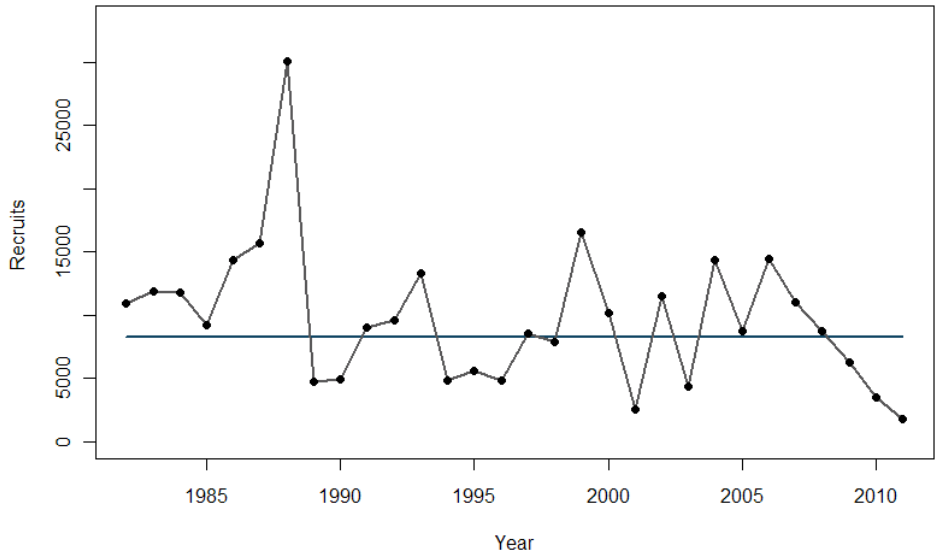


Figure A.222. Scatterplot of ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) versus recruitment at age 1 (000s). The symbol for each observation is the last two digits of the year (e.g., 88 indicated age 1 estimates of the 1987 year class). The most recent recruitment estimate is highlighted by an orange circle.



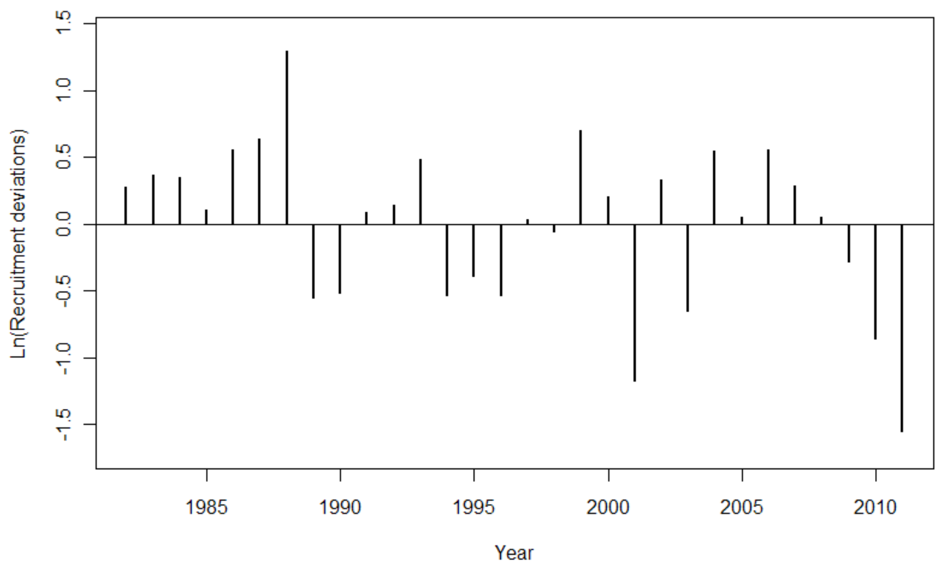


Figure A.223. ASAP SAW55_3BLOCK_BASE_M_SPLIT estimated Gulf of Maine Atlantic cod age 1 recruitment and recruitment residuals from the geometric mean.

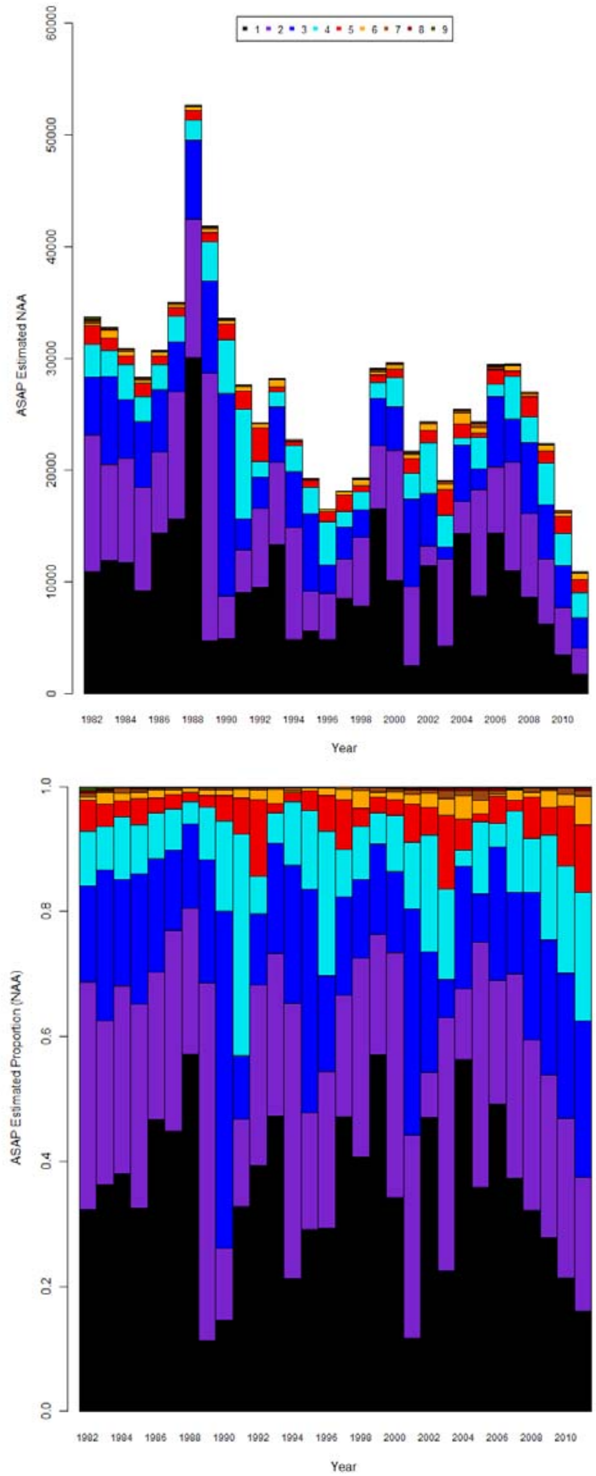
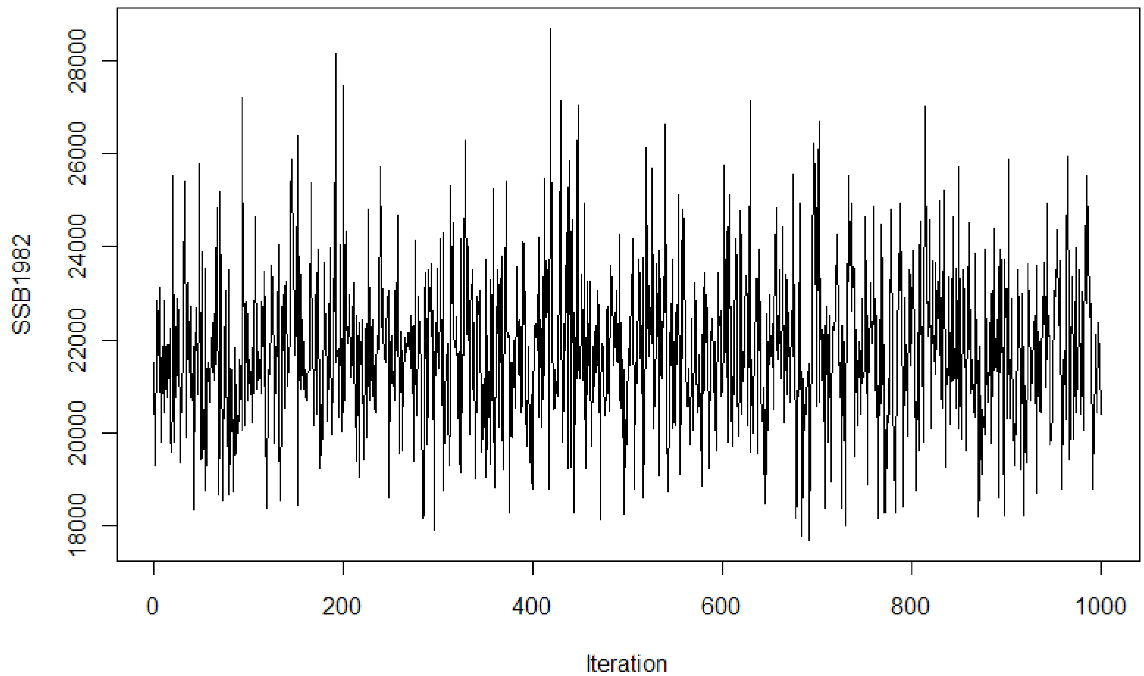


Figure A.224. ASAP SAW55_3BLOCK_BASE_M_SPLIT model estimates of Gulf of Maine Atlantic cod numbers-at-age in absolute (top) numbers (000s) and relative (bottom) terms.



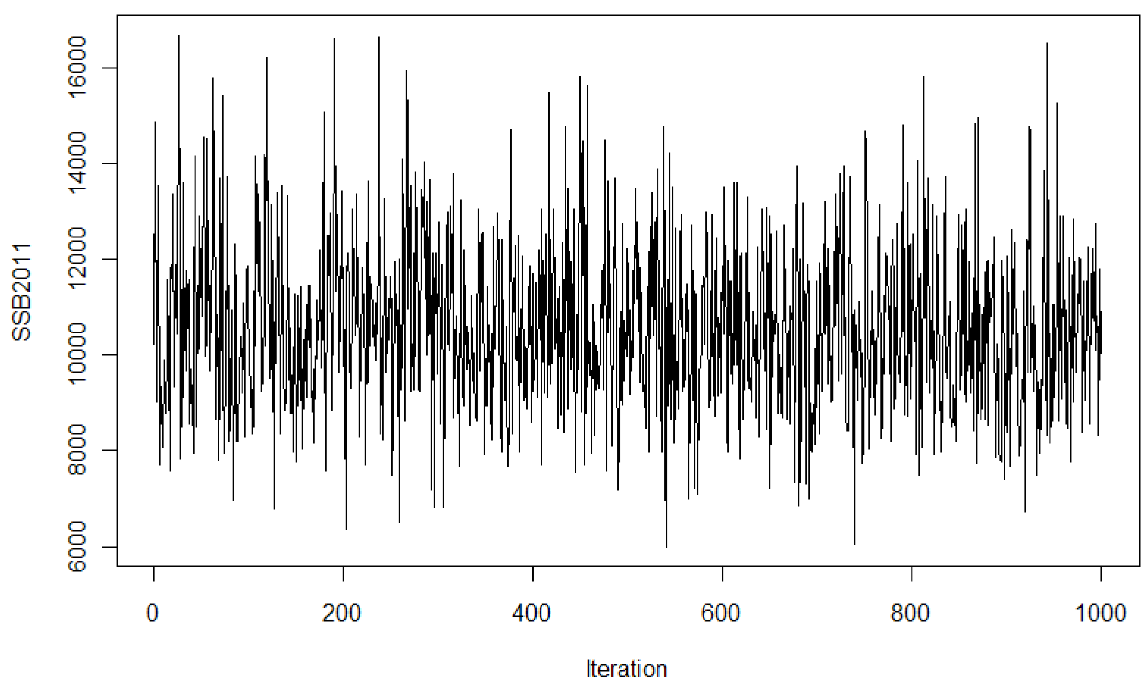


Figure A.225. Trace of MCMC chains for Gulf of Maine Atlantic cod 1982 and 2011 spawning stock biomass, showing good mixing (ASAP SAW55_3BLOCK_BASE_M_SPLIT model). Each chain had initial length of 100,000 and was thinned at a rate of one out of every 1000th resulting in a final chain length of 1000.

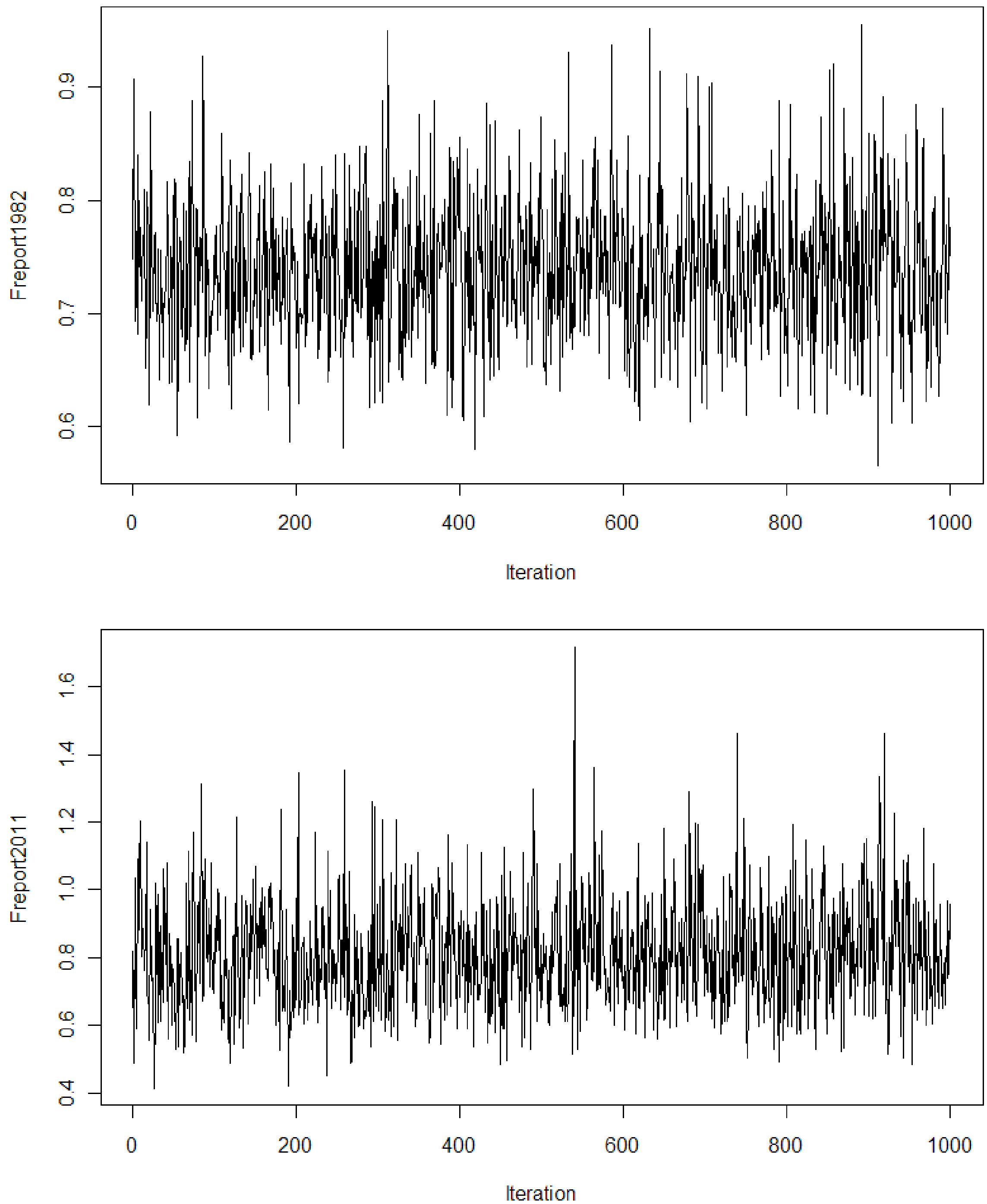


Figure A.226. Trace of MCMC chains for Gulf of Maine Atlantic cod 1982 and 2011 fishing mortality at age 5 (Freport), showing good mixing (ASAP SAW55_3BLOCK_BASE_M_SPLIT model). Each chain had initial length of 100,000 and was thinned at a rate of one out of every 1000th resulting in a final chain length of 1000.

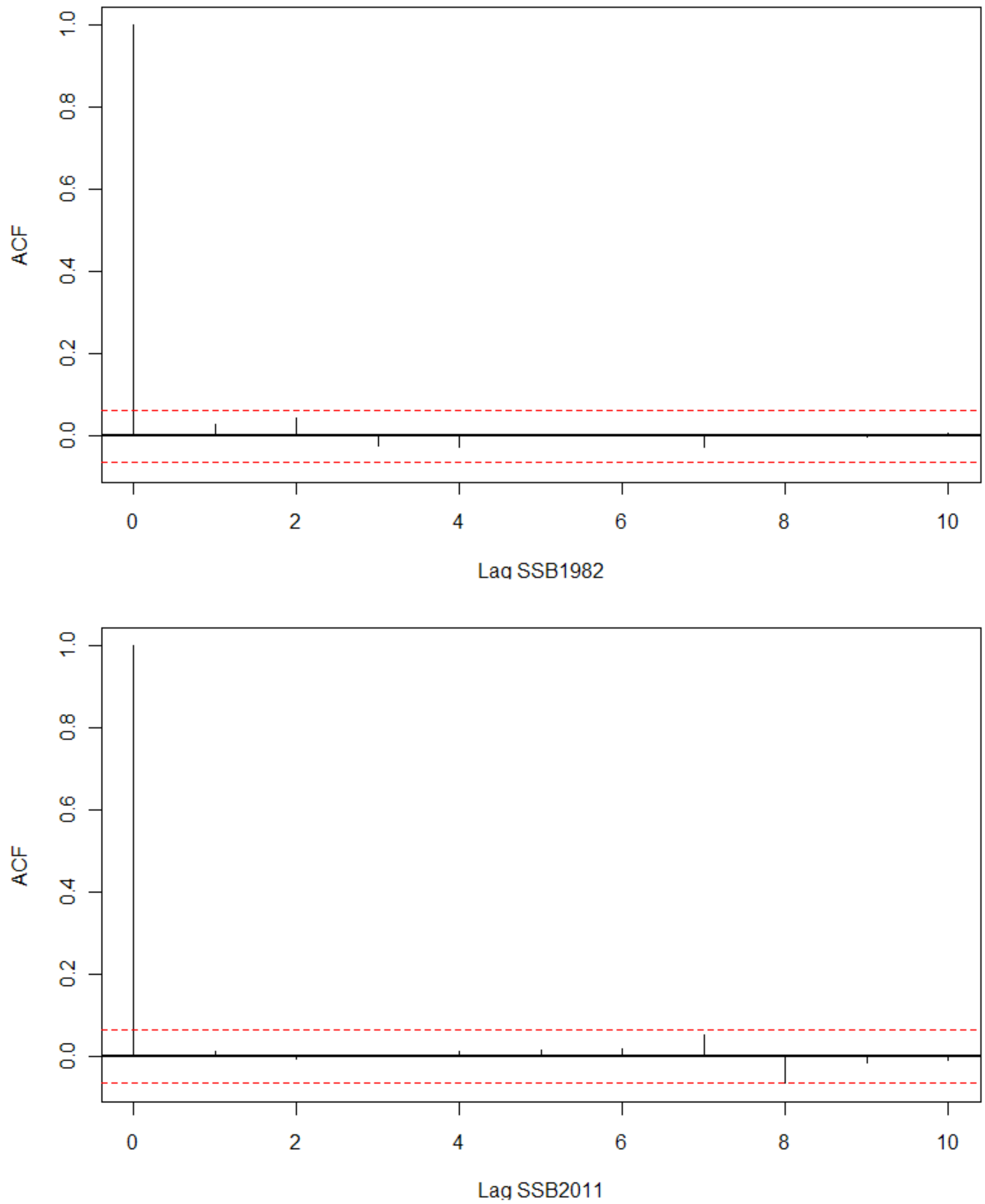


Figure A.227. Autocorrelation within the 1982 and 2011 Gulf of Maine Atlantic cod spawning stock biomass (SSB) MCMC chains from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model.

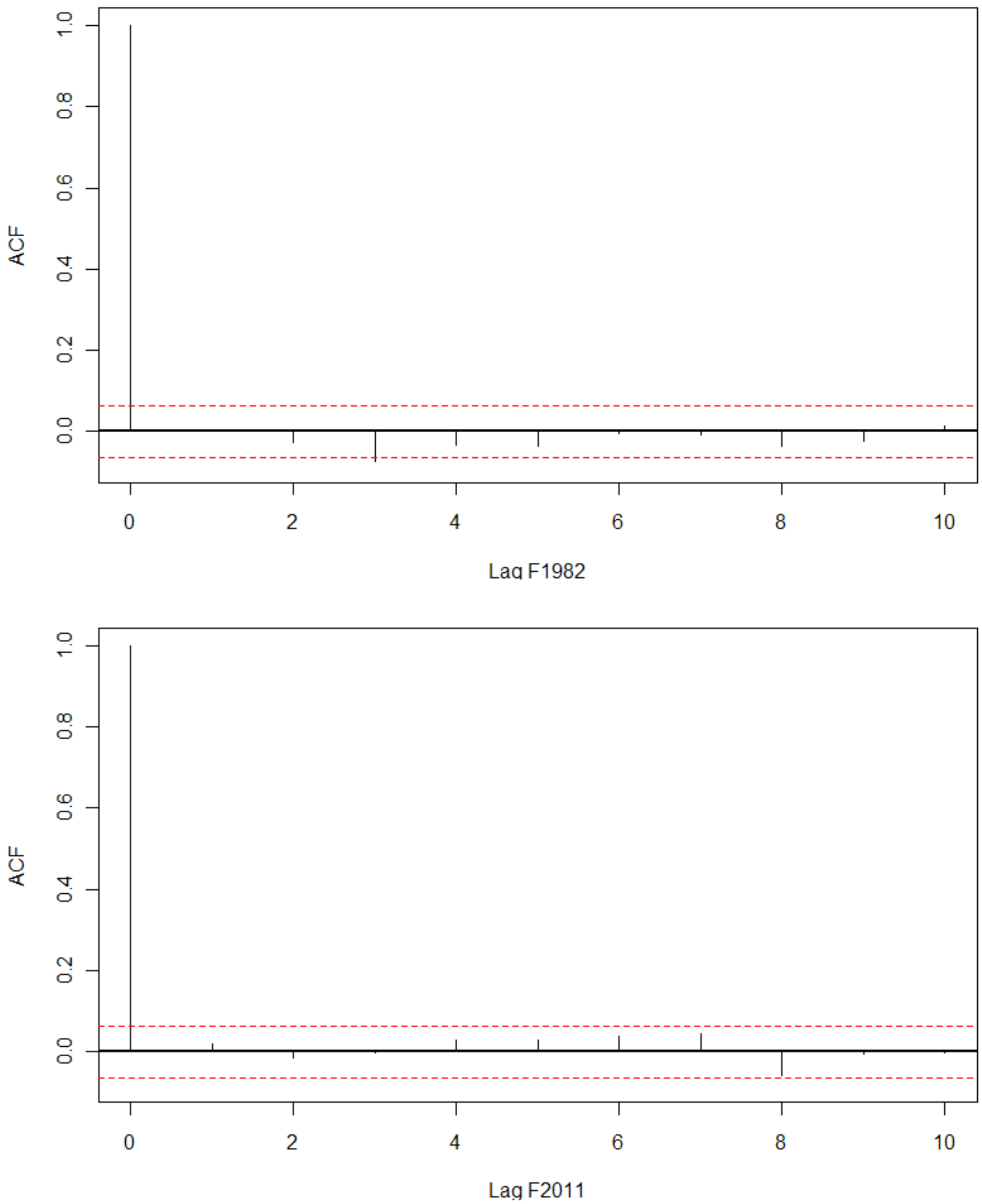


Figure A.228. Autocorrelation within the 1982 and 2011 Gulf of Maine Atlantic cod fishing mortality at age 5 (Freport) MCMC chains from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model.

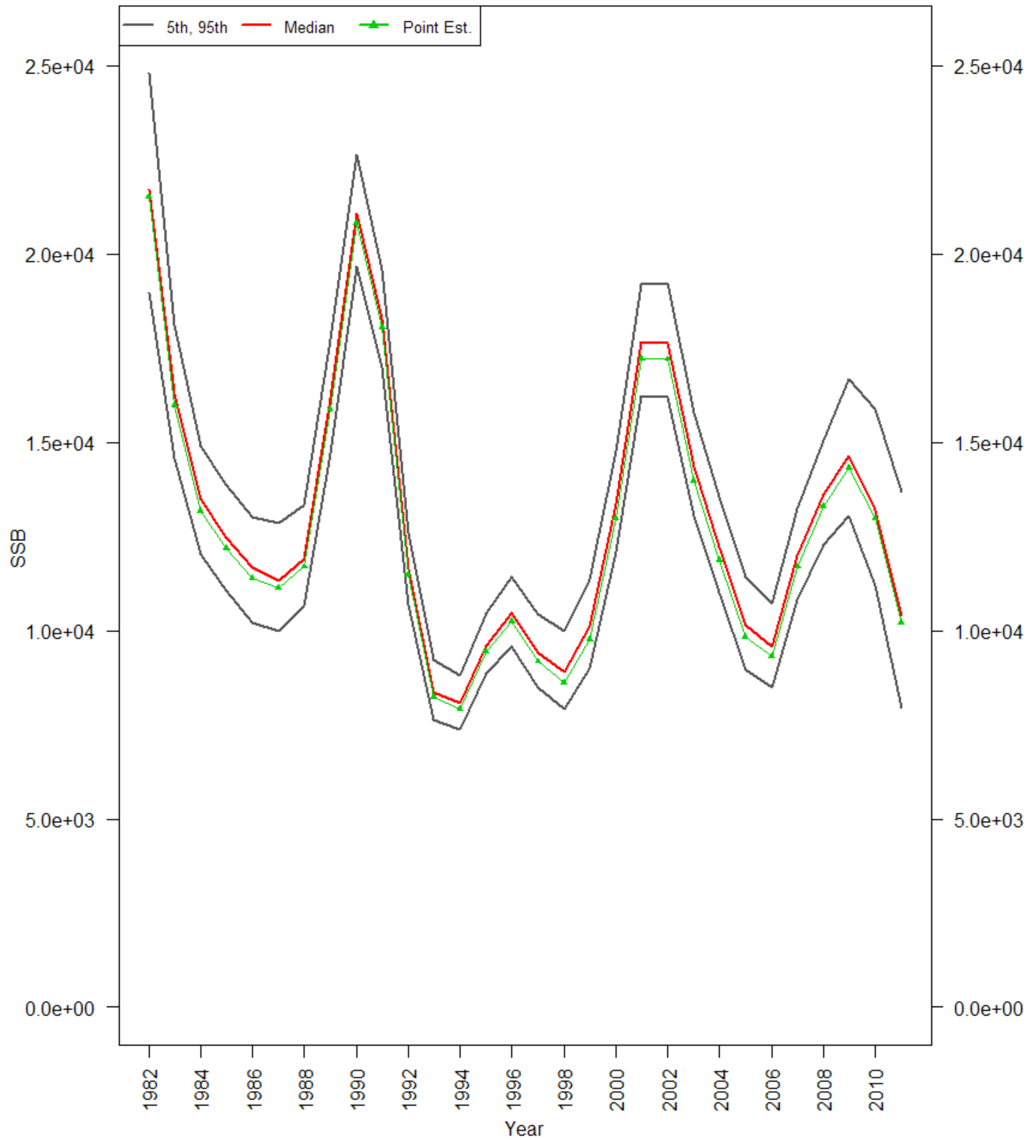


Figure A.229. 90% probability interval for Gulf of Maine Atlantic cod spawning stock biomass (SSB) from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles.

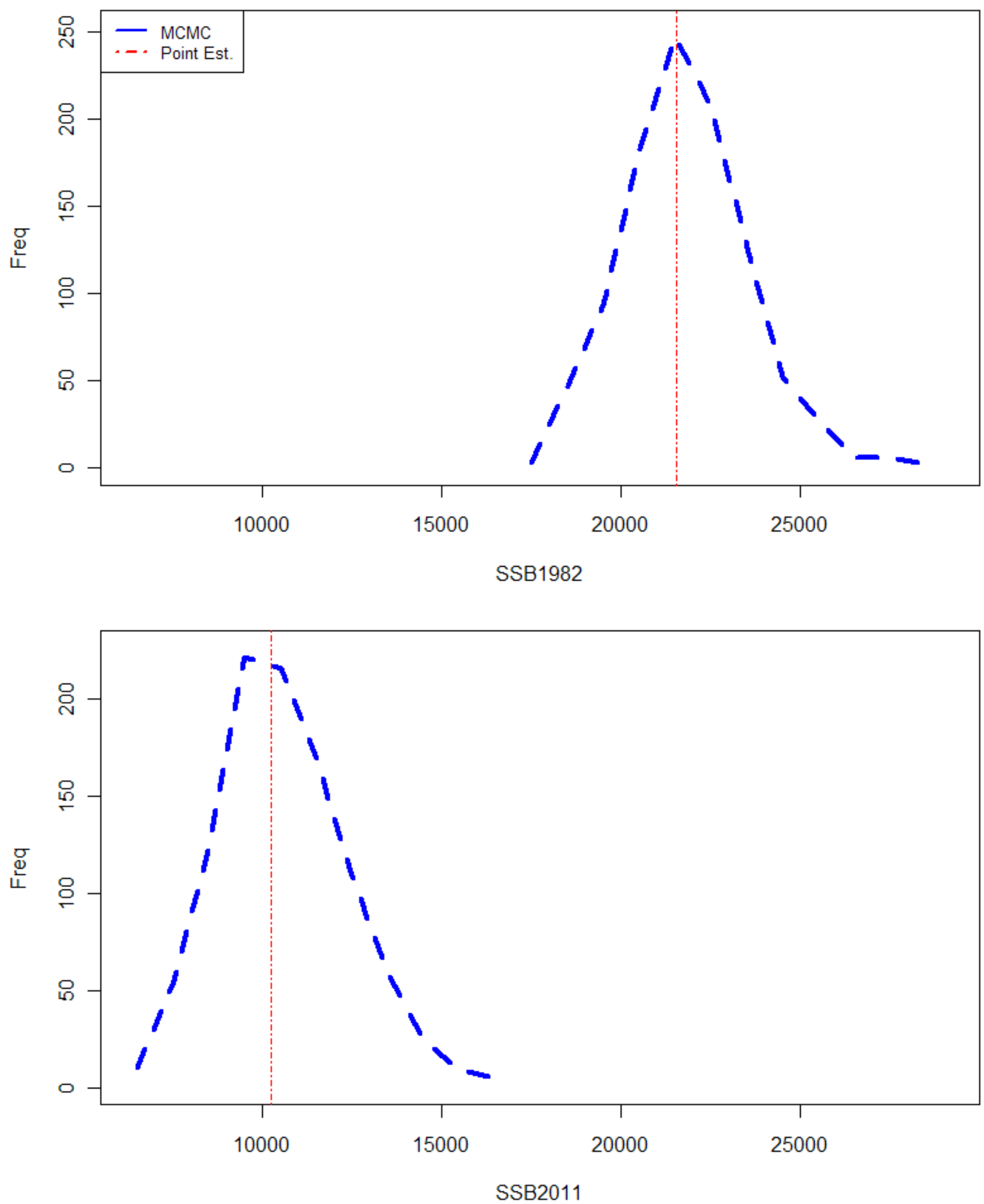


Figure A.230. MCMC distribution of Gulf of Maine Atlantic cod spawning stock biomass in 1982 and 2011 estimated from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model. The model point estimate is indicated by the dashed red line.

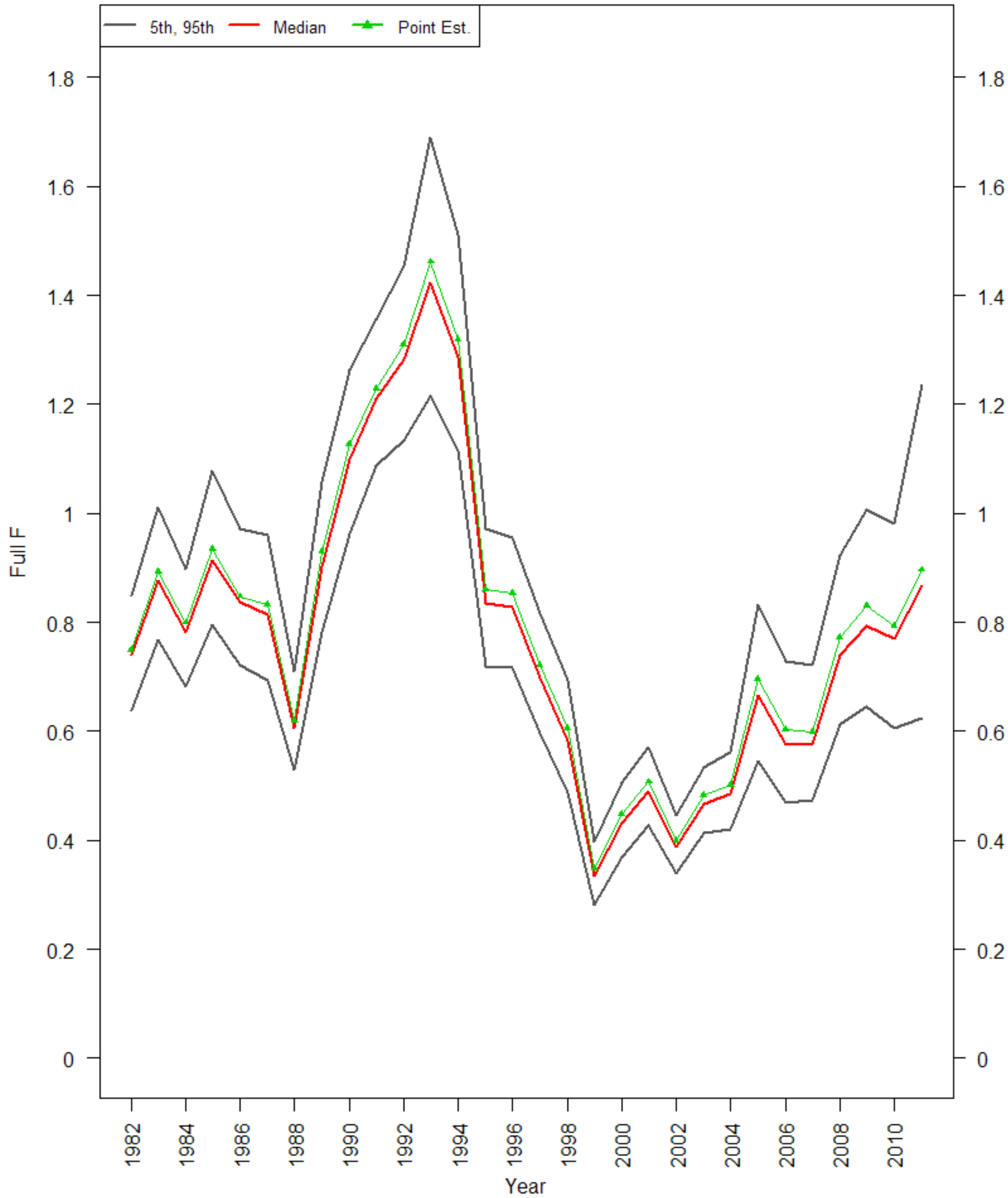


Figure A.231. 90% probability interval for Gulf of Maine Atlantic fully recruited fishing mortality (Full F) from the ASAP SAW55_3BLOCK_BASE_M_SPLIT model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles.

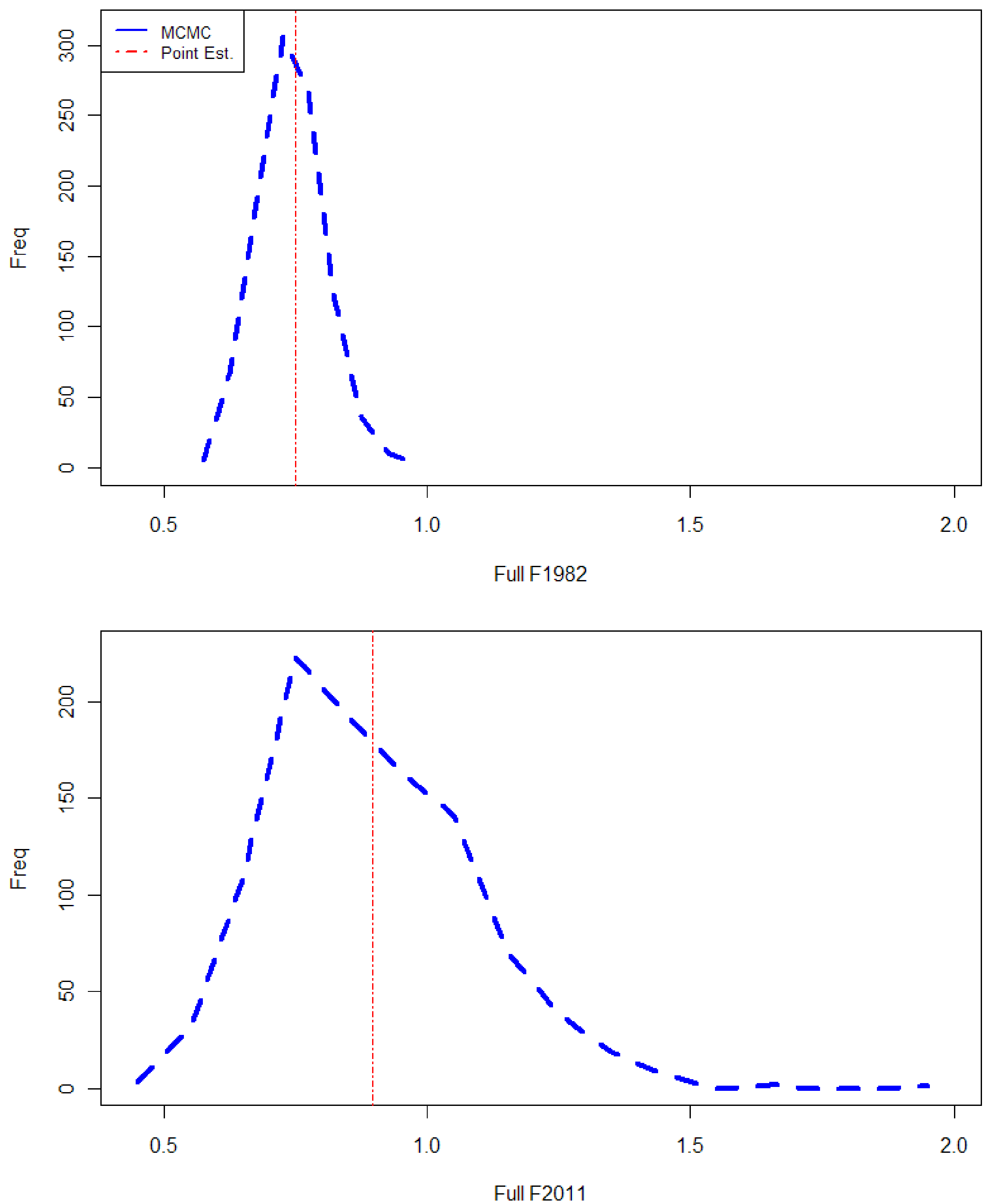


Figure A.232. MCMC distribution of Gulf of Maine Atlantic cod fully recruited fishing mortality (Full F) in 1982 and 2011 estimated from the ASAP SAW55_3BLOCK_BASE model. The model point estimate is indicated by the dashed red line.

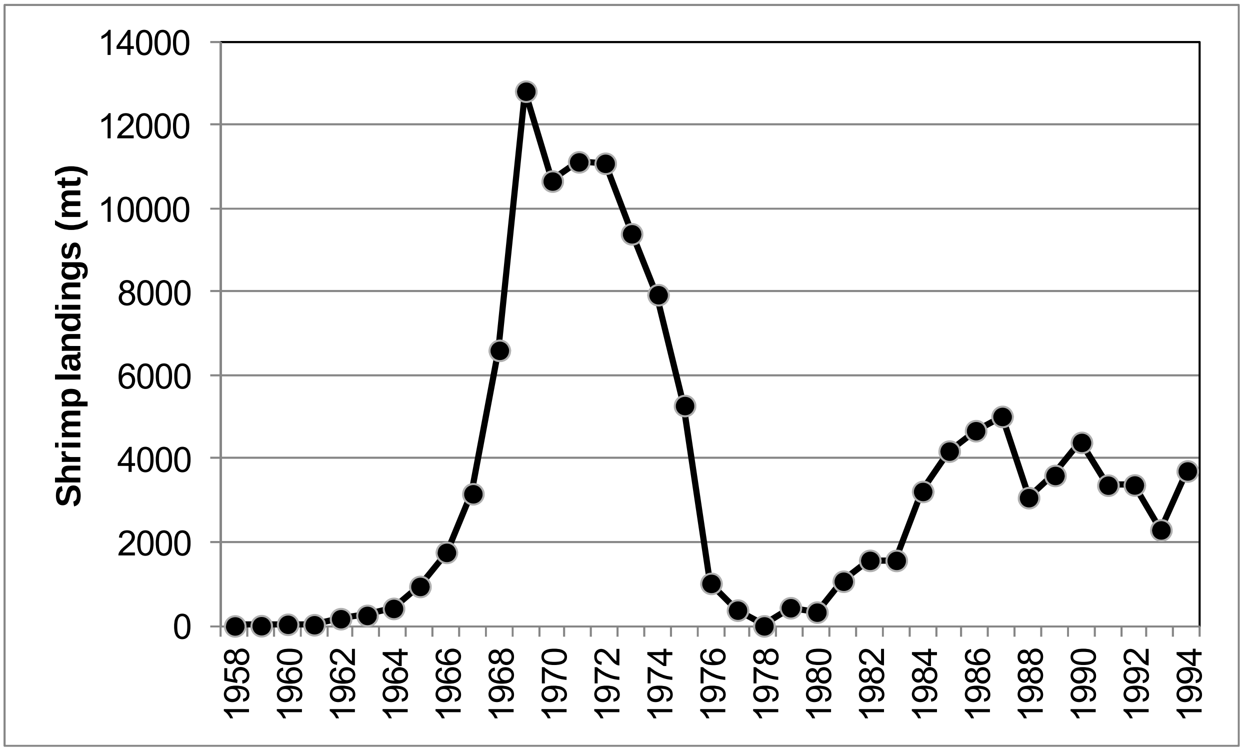


Figure A.233. Northern shrimp landings (mt) between 1958 and 1994.

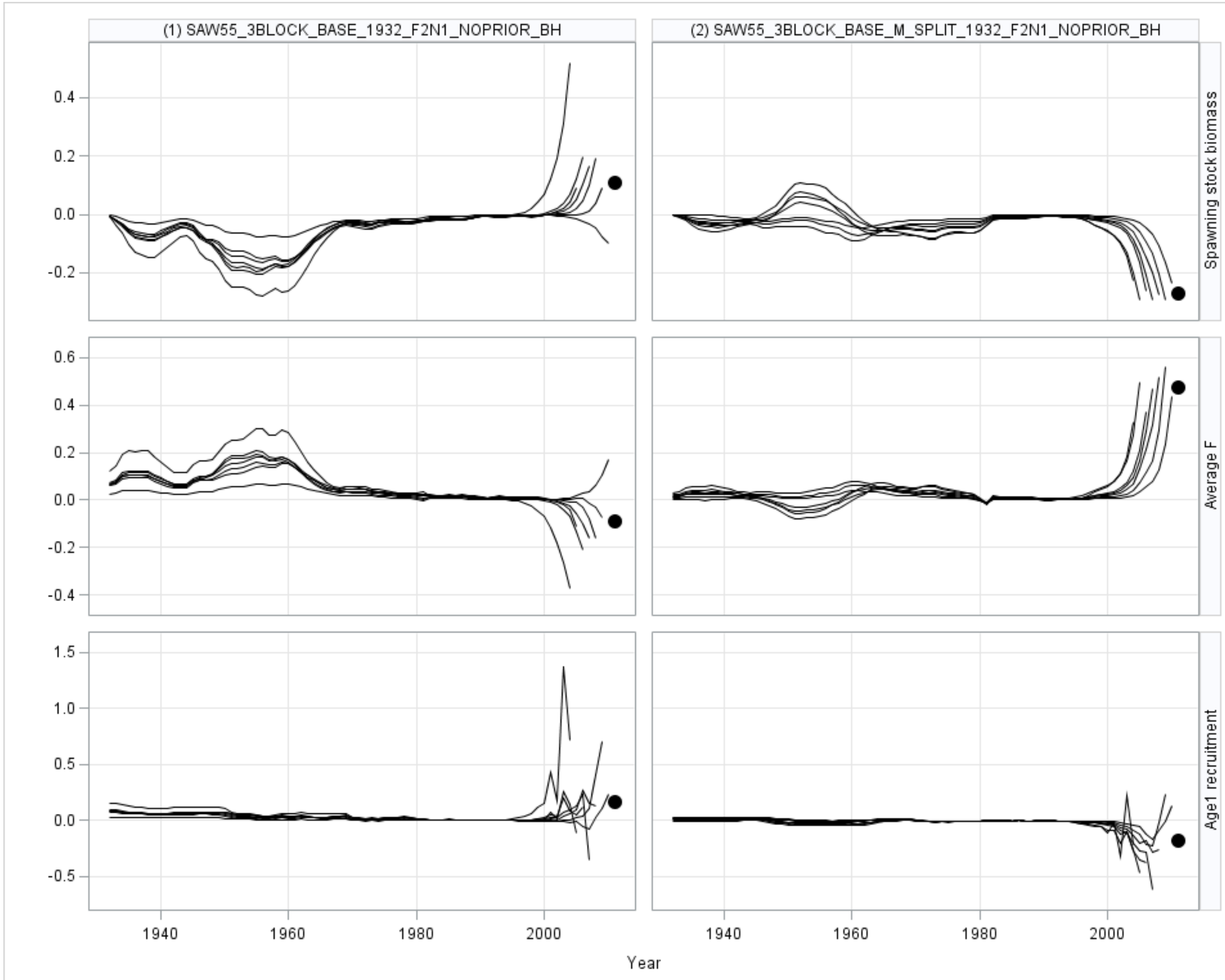


Figure A.234. Model retrospective patterns for sensitivity runs of the Gulf of Maine Atlantic ASAP SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH, and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH models. The black circles indicates the Mohn’s rho value based on a five year retrospective peel.

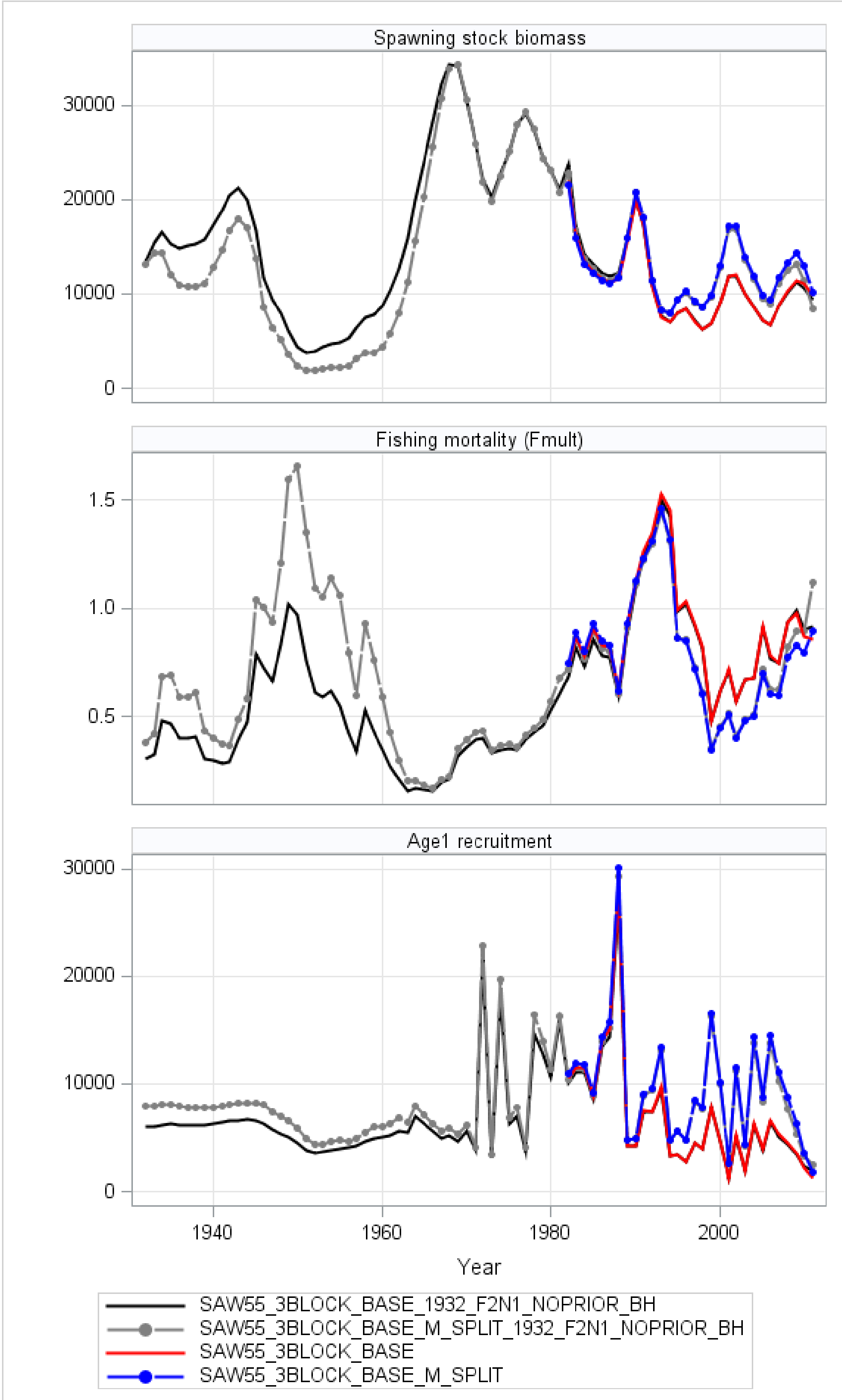


Figure A.235. Comparison of the Gulf of Maine Atlantic cod spawning stock biomass, fully recruited fishing mortality and age 1 recruitment from the ASAP SAW55_3BLOCK_BASE, SAW55_3BLOCK_BASE_M_SPLIT, SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH, and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH models.

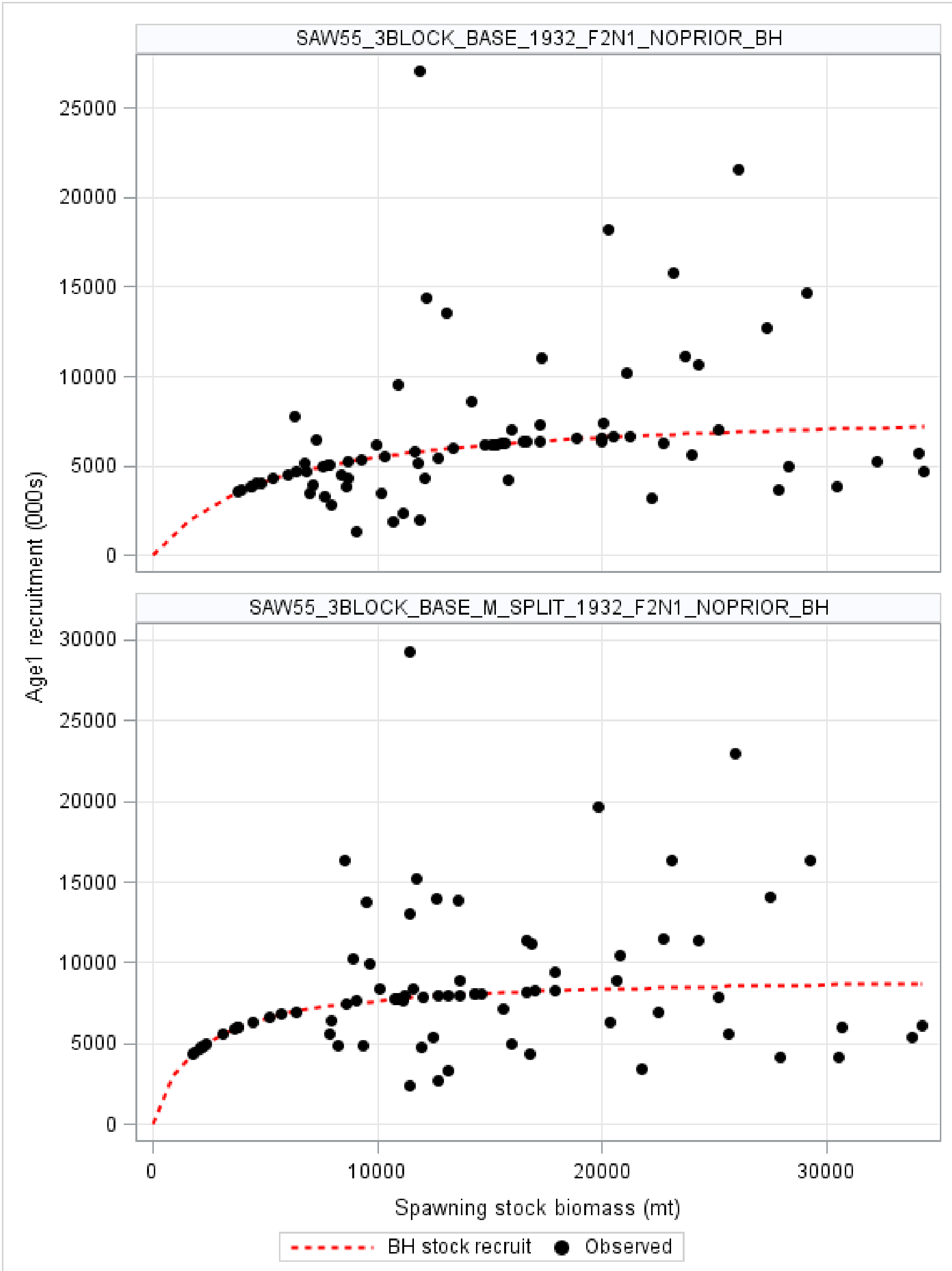


Figure A.236. Estimated Beverton Holt stock recruitment relationships for the ASAP SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH, and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH models.

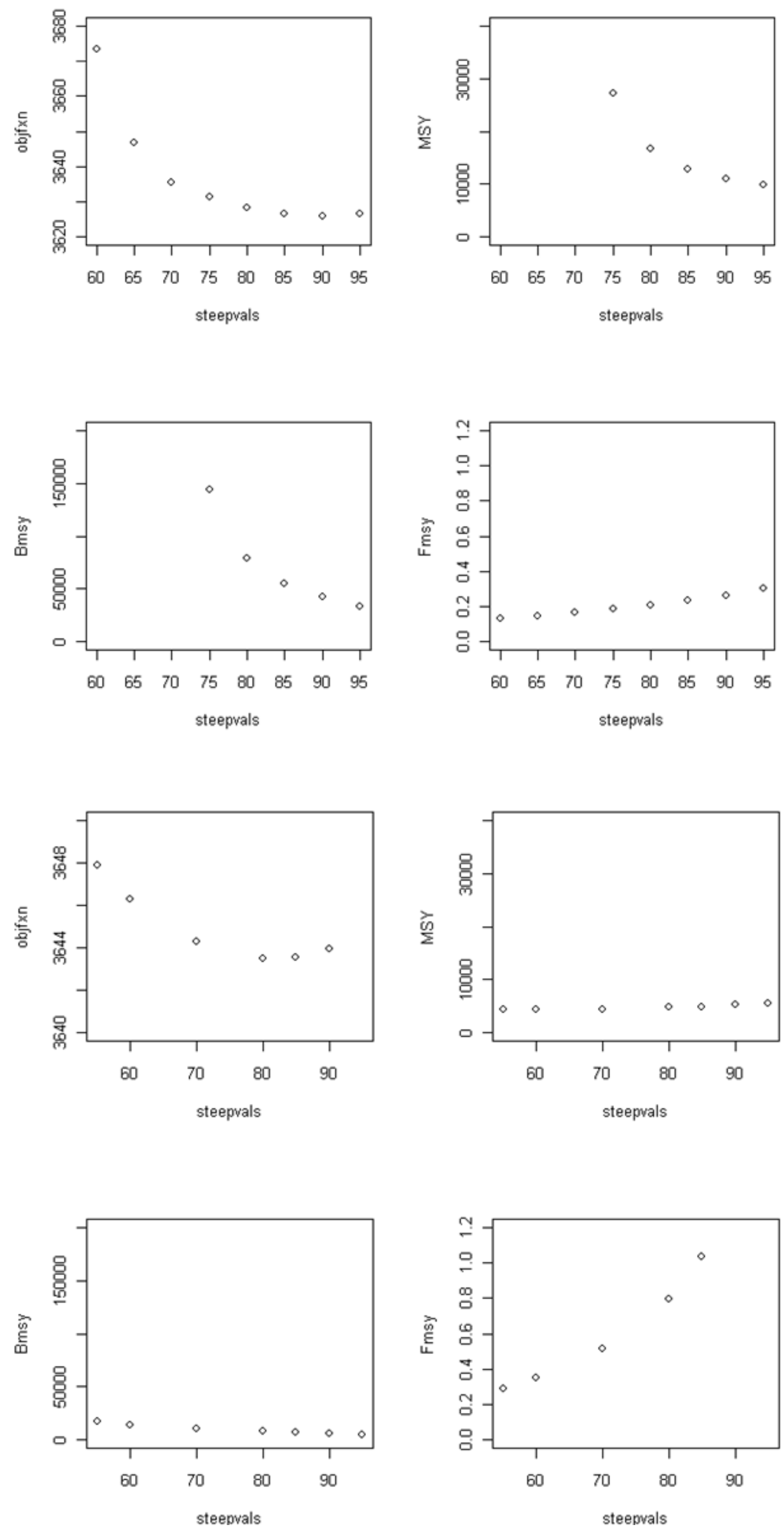


Figure A.237. Impacts of profiling over the Beverton and Holt steepness on the reference point estimates for the ASAP SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH (top four plots), and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH (bottom four plots) models.

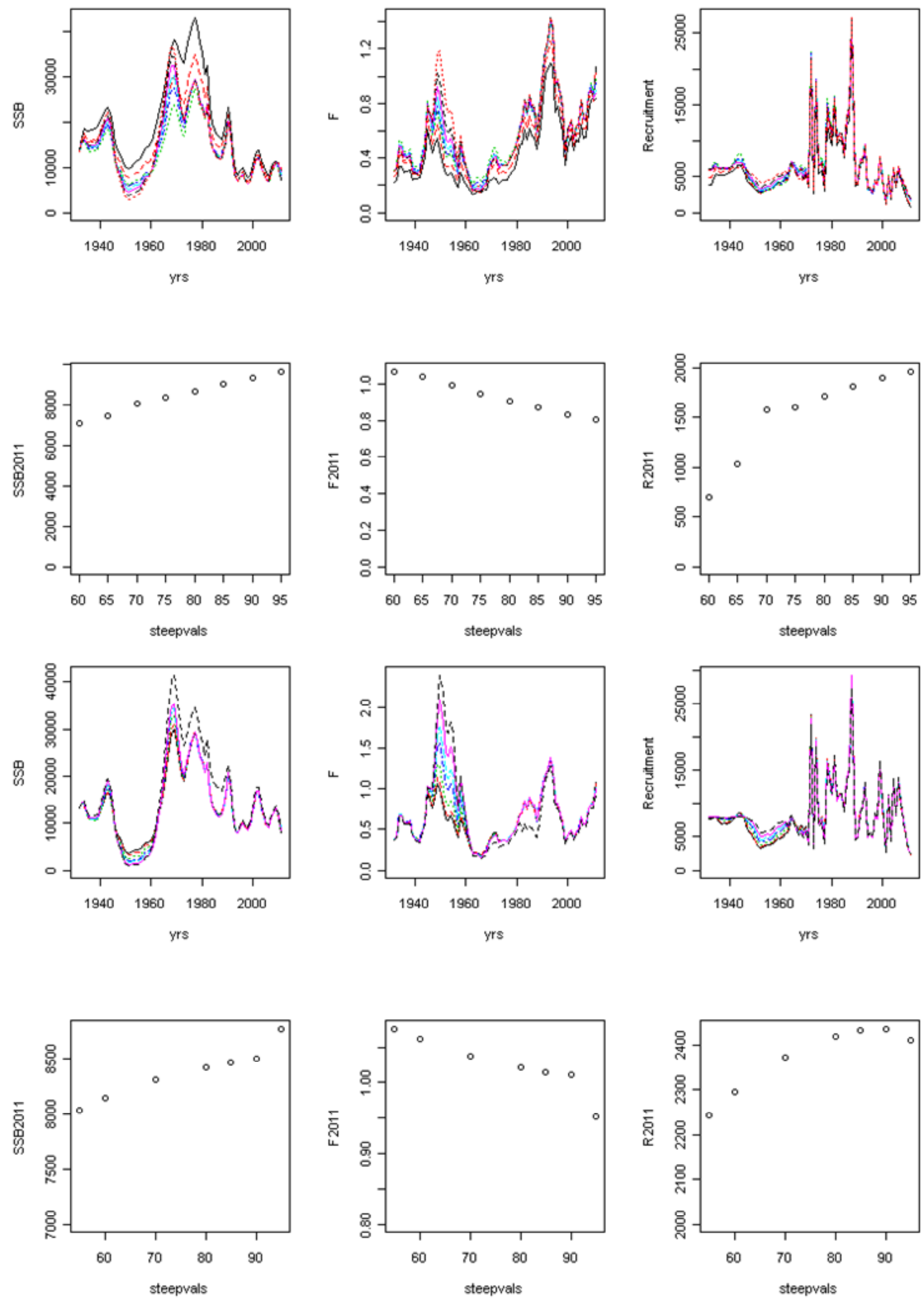


Figure A.238. Impacts of profiling over the Beverton and Holt steepness parameter on estimates of spawning stock biomass, fishing mortality and recruitment for the ASAP SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH (top six plots), and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH (bottom six plots) models.

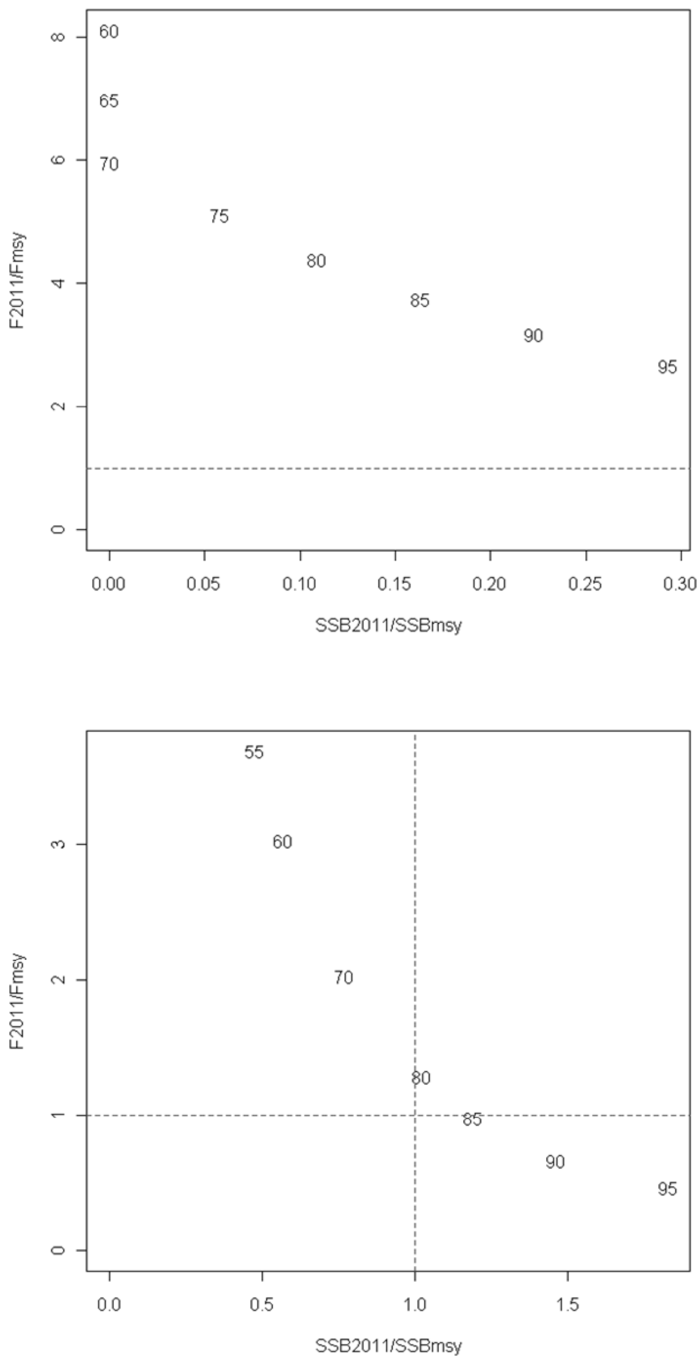


Figure A.239. Impacts of profiling over the Beverton and Holt steepness on stock status for the ASAP SAW55_3BLOCK_BASE_1932_F2N1_NORPIOR_BH (top plot), and SAW55_3BLOCK_BASE_M_SPLIT_1932_F2N1_NORPIOR_BH (bottom plot) models.

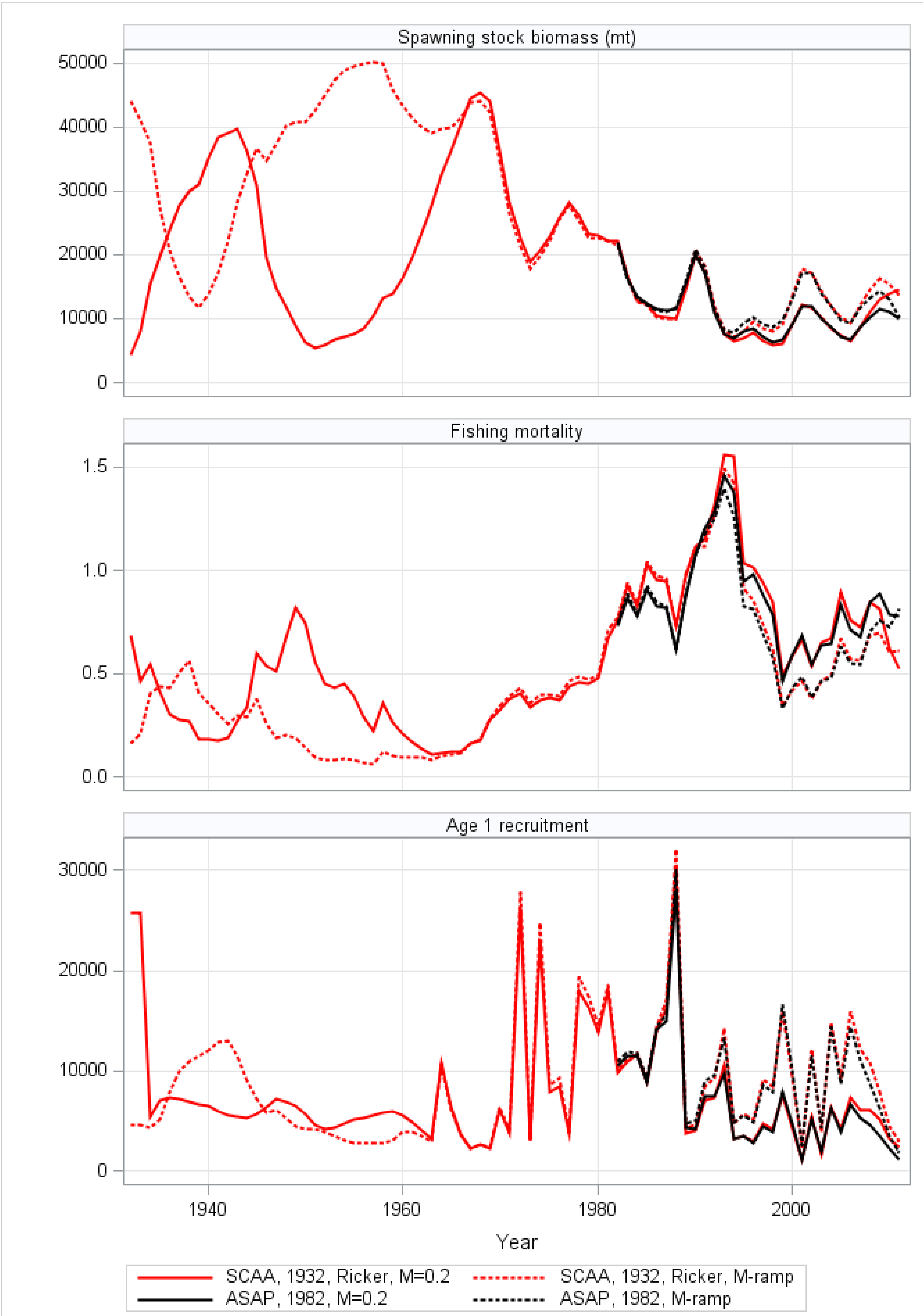


Figure A.240. Comparison of the Gulf of Maine Atlantic cod spawning stock biomass, fishing mortality and age 1 recruitment estimated by the ASAP (1982 start) and SCAA (1932 start) models with assumptions of constant natural mortality, M, of 0.2 and a ramped *M* changing from 0.2 to 0.4.

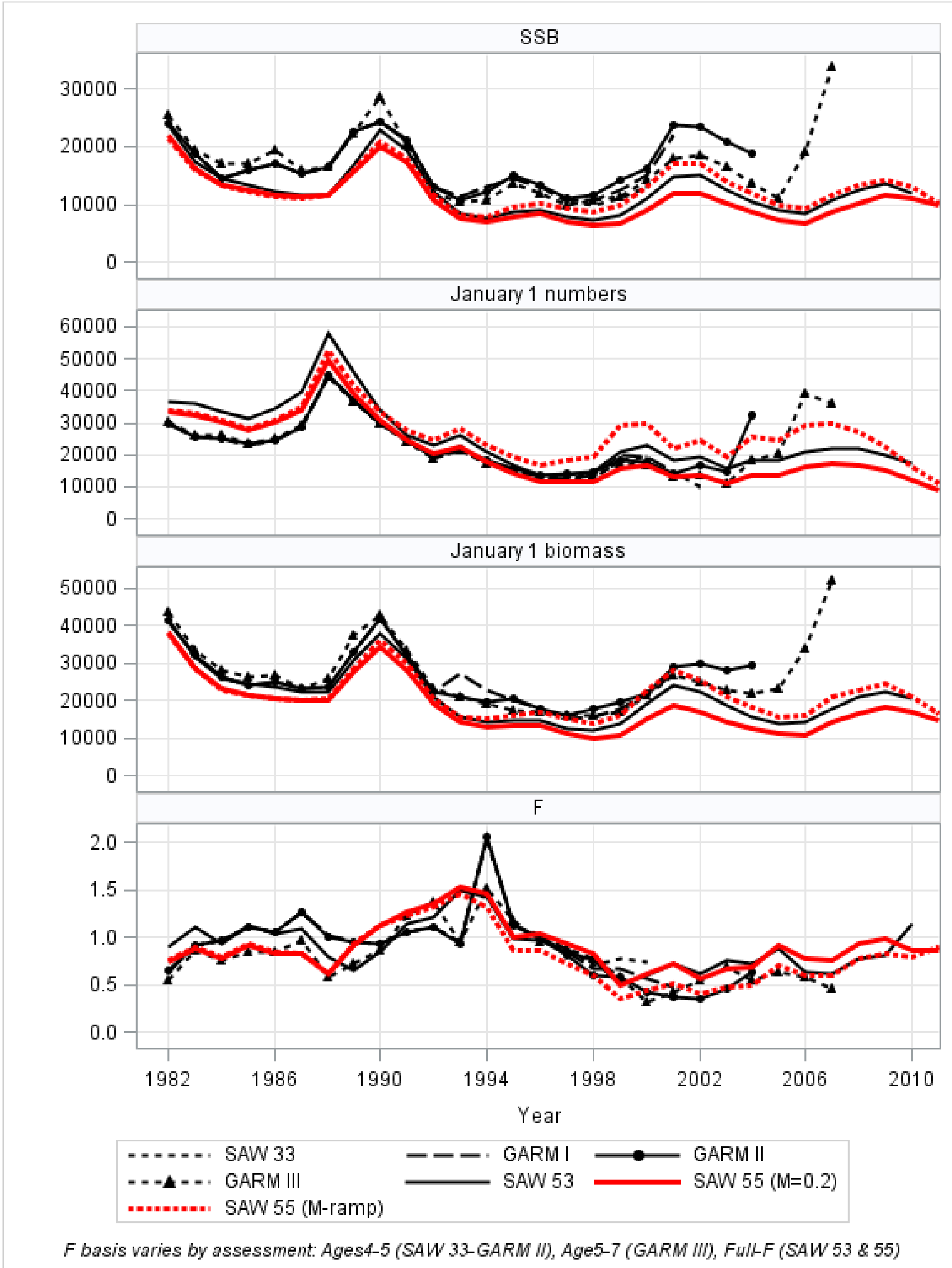


Figure A.241. Comparison of estimates of average spawning stock biomass (SSB), January 1 stock numbers, January 1 stock biomass, and fishing mortality from previous Gulf of Maine Atlantic cod stock assessments including estimates from the ASAP SAW55_3BLOCK_BASE (M = 0.2) and SAW55_3BLOCK_BASE_M_SPLIT (M-ramp) models. **Note that the ages included in the average F calculation are not constant across assessments.*

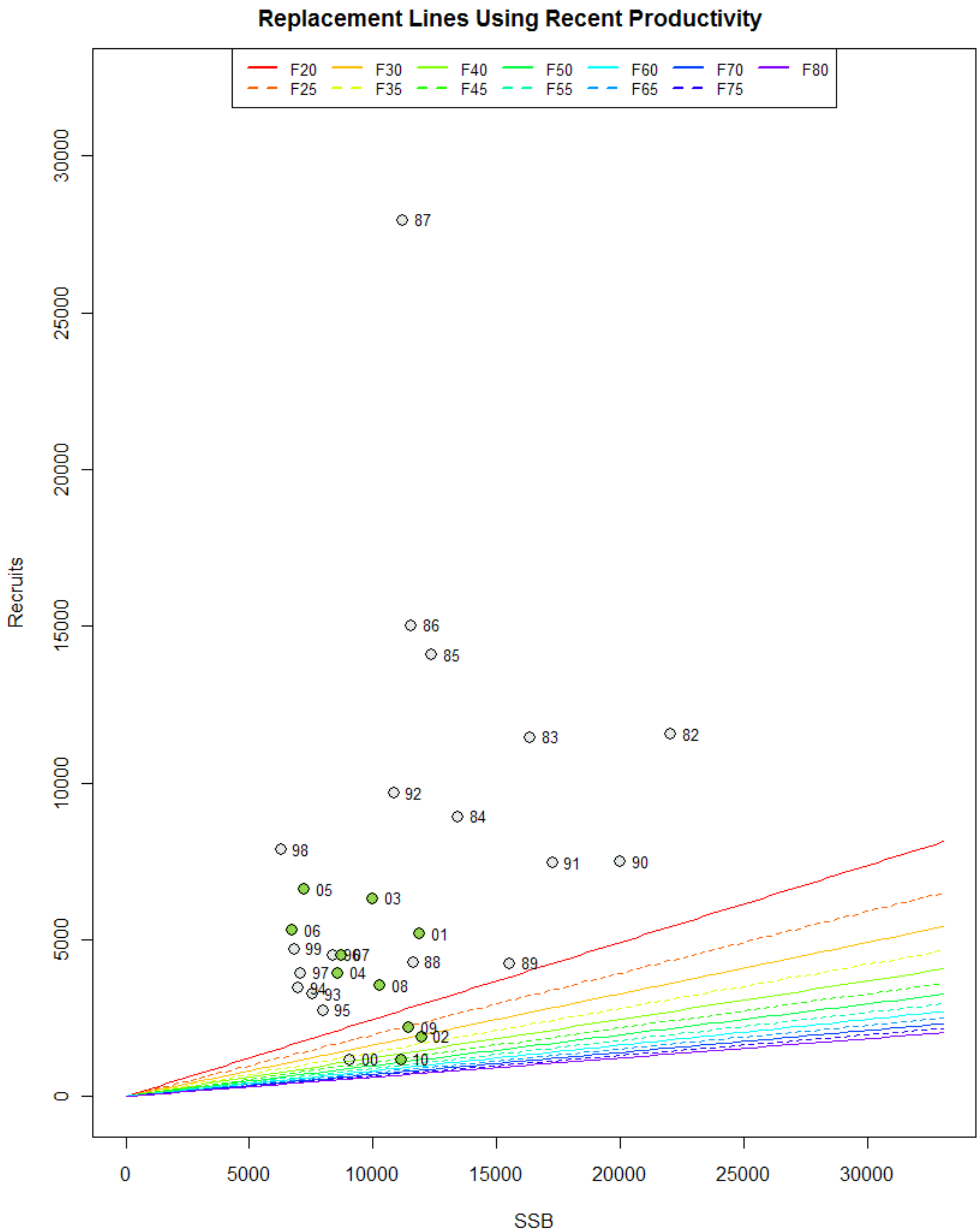


Figure A.242. Comparison Gulf of Maine Atlantic cod replacement lines under a range of percent spawner per recruit values based on an assumption of $M = 0.2$ (based on SAW55_3BLOCK_BASE model). The most recent ten years of recruitment observations (2001-2010) are highlighted green.

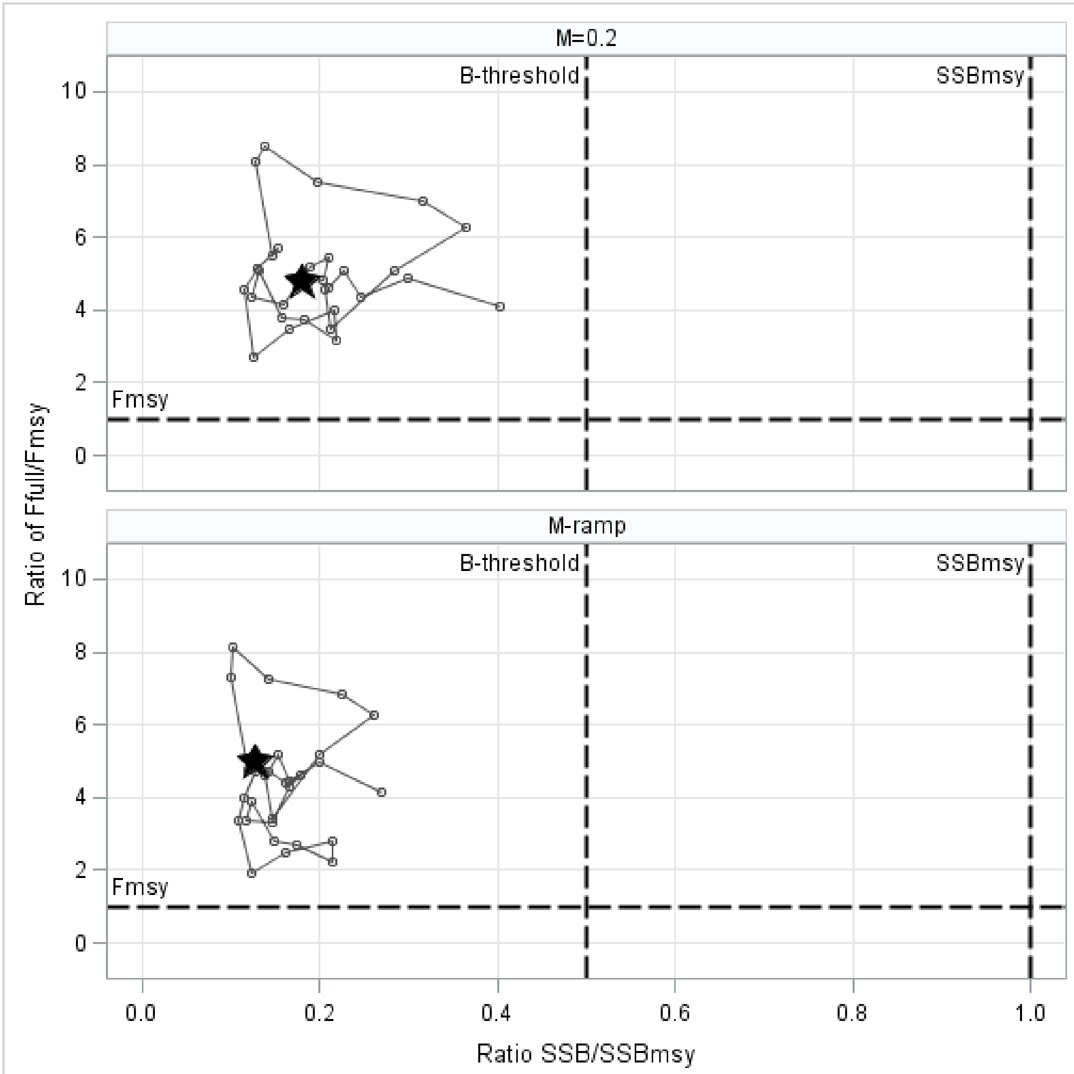


Figure A.243. Time series plot of the Gulf of Maine Atlantic cod fully selected fishing mortality/2011 F_{MSY} ratio relative to the spawning stock biomass/2011 SSB_{MSY} ratio from 1982 to 2011. The 2011 data point is indicated by a black star. Results are shown for both the $M = 0.2$ (top) and M-ramp (bottom) models.

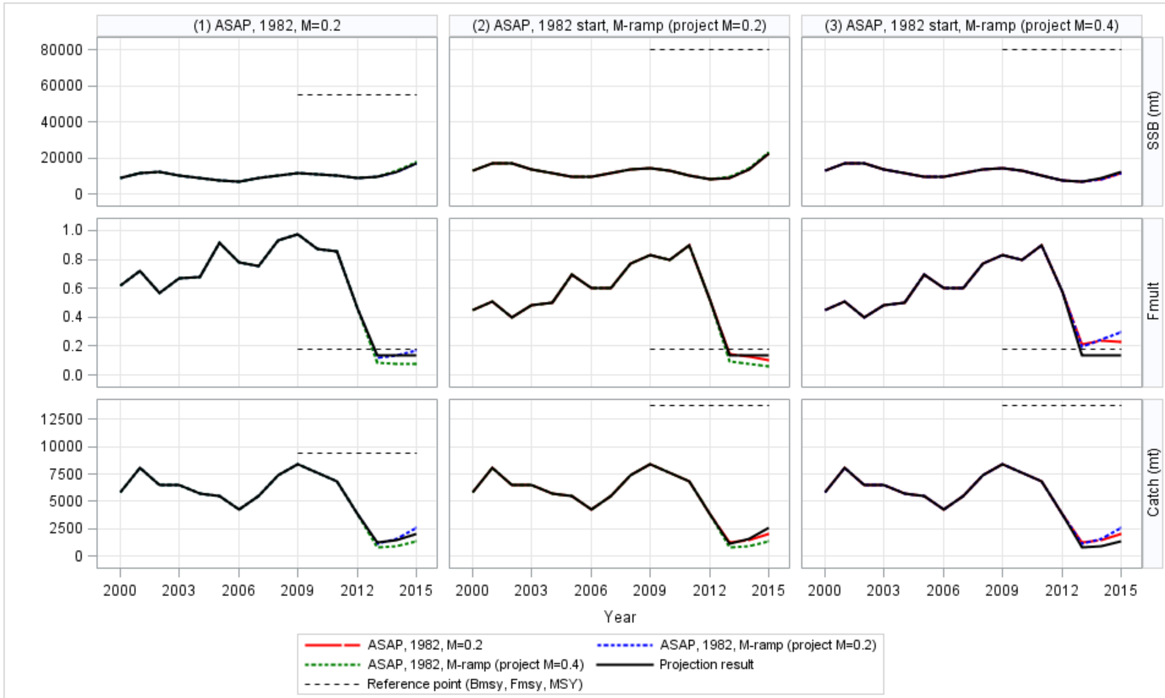


Figure A.244. Trends in Gulf of Maine cod SSB (top row), fully recruited fishing mortality (middle row) and catch (bottom row) during 2000 – 2015; column headers indicate 'true' state of nature; cells provide trend in indicator under 'true' state of nature when catch during projection period (based on 75% F_{MSY} is correctly specified (black) and mis-specified (red: ASAP, 1982, M = 0.2; blue: ASAP, 1982, M-ramp (project at M = 0.2); green: ASAP, 1982, M-ramp (project at M = 0.4); MSY proxy reference points indicated in dashed line on each plot.

APPENDICES

Appendix A.1. List of 55th Stock Assessment Workshop (SAW 55) Working Group (WG) participants

Note: participants of at least one day of a working group meeting are listed

Participant Last Name	Participant First Name	Affiliation	SAW 55 WG - Data Meeting	SAW 55 WG - Modeling Meeting	SAW 55 WG - BRP and Modeling Meeting	SAW 55 WG - Follow up BRP and Reports Organization
Alade	Larry	NEFSC	■			
Blaylock	Jessica	NEFSC	■	■	■	
Brazer	Eric	CCCHFA	■			
Brooks	Liz	NEFSC	■	■	■	
Butterworth	Doug	UCT		■	■	■
Cadrin	Steve	SMAST		■		■
Clark	Don	DFO	■			
Col	Laurel	NEFSC	■			
Correia	Steve	MA DMF	■			
Crawford	Jud	Pew Charitable Trusts			■	
Curti	Kiersten	NEFSC			■	
Dean	Micah	MA DMF	■			
Deroba	Jon	NEFSC		■	■	
Dority	Aaron	Penobscot East	■			
Fairbrother	Alison	Public Trust Project		■		■
Giacalone	Vito	Northeast Seafood Coalition		■	■	
Hart	Dvora	NEFSC		■	■	
Hendrickson	Lisa	NEFSC	■			
Hogan	Fiona	NEFMC	■	■		■
King	Jeremy	MA DMF	■			
Legault	Chris	NEFSC	■		■	
Link	Jason	NEFSC	■			
Miller	Tim	NEFSC	■	■	■	
Nieland	Julie	NEFSC	■	■	■	
Nies	Tom	NEFMC	■	■		
Nitschke	Paul	NEFSC	■	■	■	■
O'Boyle	Robert	Beta Scientific Consulting (WG Chair)	■	■	■	■
O'Brien	Loretta	NEFSC (GBK cod assessment lead)	■	■	■	■
Odell	Jackie	Northeast Seafood Coalition		■	■	
Palmer	Michael	NEFSC (GOM cod assessment lead)	■	■	■	■
Pol	Mike	MA DMF	■			
Rago	Paul	NEFSC	■			■
Raymond	Maggie	AFM			■	
Richardson	David	NEFSC - Naragansett		■		
Serchuk	Fred	NEFSC	■	■		
Shepherd	Gary	NEFSC		■		
Sherman	Sally	ME DMR	■			
Sosebee	Kathy	NEFSC	■	■	■	
Terceiro	Mark	NEFSC	■	■		
Traver	Michelle	NEFSC		■	■	
Vecchio	Victor	NERO	■			
Wang	Yanjun	Fisheries and Oceans Canada	■	■		
Waring	Gordon	NEFSC	■			
Weinberg	James	NEFSC	■	■		■
Wigley	Susan	NEFSC	■	■	■	
Wood	Tony	NEFSC	■	■	■	
Zemeckis	Doug	SMAST	■			

[SAW55 Editor's Note: The SARC-55 review panel did not recommend adopting the GOM cod Statistical Catch-at-Age (SCAA) assessment results that are in Appendices A.2 – A.5. These appendices are included in this report to document and demonstrate the work that was done by the SAW Working Group for the December 2012 peer review.]

Appendix A.2. Preferred Statistical Catch-at-Age Assessments of Gulf of Maine Cod, November 2012.

Introduction

This Appendix summarizes the development of the Statistical Catch-at-Age (SCAA) methodology applied to Gulf of Maine cod as presented to the NEFMC SSC in March 2012 (Butterworth and Rademeyer 2012) and further refined during deliberations at SAW/SARC 55 Working Group meetings held at Woods Hole over 15-19 October and 30 October-2 November 2012. It also summarises the process leading to the authors' choice of their "preferred" variant of the approach at this time. The primary reason for adopting the SCAA methodology is that it allows age-based assessments to be extended to cover a longer period without, for example, requiring catch-at-age data to be available for every year, and thus tends to provide the enhanced contrast desirable for more precise estimates of Biological Reference Points (BRPs) related to MSY.

The text first outlines the methodology used, and then provides estimates for current stock status and BRPs for a set of four final assessments which cross two factors to which results are particularly sensitive:

- Natural mortality: $M = 0.2$ and time invariant, or ramping linearly from a constant 0.2 to a constant 0.4 yr^{-1} over the period from 1988 to 2003 (*M* ramp).
- Stock-recruitment functional form: Ricker or Beverton-Holt (BH).

It concludes with a summary of the results as they relate to the SAW/SARC55 TORs.

Methodology

The algebraic details of the methods used for the SCAA assessments, BRP estimation and future projections are set out in Appendix A3.

For the SCAA assessments, there are a number of factors for which choices amongst different options (as detailed in Appendix A3) may be made. The options chosen for the assessments reported here are specified (where this is relevant) in **bold** at the end of each section of Appendix A3. In broad terms, the primary reasons underlying these choices were AIC-based selection or lower variance of estimates. However in cases where these criteria did not lead to clear-cut guidance (e.g. domes in selectivity) and/or the impact on results was small (e.g. refining of the *Bigelow-Albatross* calibration function within the assessment) relative to factors such as natural mortality or stock-recruitment function choice, the choices made reflect a consensus agreed for practical purposes during the recent Working Group meetings referenced above, rather than necessarily the options the authors' consider to be the most appropriate.

These choices have also been informed by extensive sensitivity tests reported in papers presented to those Working Group meetings, and reproduced here as Appendices A4 and A5[1]. These showed, for example, that the assumptions that have to be made about commercial selectivity for the period prior to 1982 for which commercial catch-at-age data are not available, have very little impact on estimates of past spawning biomass and recruitment trajectories, as well as on BRP estimates. Those tests included a comparison of internal (within assessment) compared to external estimation of stock-recruitment relationships and hence of BRPs, revealing that this made little difference to results. The former was preferred for the results that follow because it take full account of the variance-covariance structure of the estimates of recruitment and spawning biomass used to obtain these relationships (rather than only of the variance of recruitment estimates treated as independent in external estimation), and hence provides more reliable estimates of their precision.

The choice of an early starting year for these assessments is to be consistent with the intent of using as long a time-series of data as possible to potentially better inform BRP estimates. The specific choice of 1932 is not critical, as the information content of available abundance index and size/age data extends back only to year-classes from about 1960. However commencing calculations earlier is convenient in allowing transient effects associated with uncertainties linked to the estimation of the components of the initial numbers-at-age vector to damp out before the abundance index and size/age information start having an influence on the results.

Results

App. A2, Table A2.1 lists estimates of primary parameters and management-related quantities for Gulf of Maine cod for the four final assessments listed above, together with estimates for BRPs and projected future catches under a $0.75F_{MSY}$ strategy evaluated on the basis set out in the final section of Appendix A3. BRP and current stock status estimates are summarized in App. A2, Table A2.2.

As the Ricker is preferred over the BH form of the stock-recruitment relationship for reasons given below, a number of the plots that follow show results for only the two Ricker assessments, rather than for all four variants. App. A2, Fig. A2.1 shows point estimate trajectories for spawning biomass, recruitment (0-year class strength) and fully

1 An error was subsequently found in the code used to estimate the stock-recruitment function parameters in this paper. This does not change results qualitatively. The error has been corrected for the results reported in this paper.

selected fishing mortality for the four assessments, while App. A2, Fig. A2.2 repeats some of these plots for the two Ricker assessments with the addition of Hessian based estimates of precision, together with a similar plot for the input time-series of annual catches. Note that moving backwards in time, recruitment estimates are generally reasonably precise up to and including the low estimates of the mid- to late 1960s, but are poorly estimated prior to that, whereas the precision of the spawning biomass estimates reduces in the 1970s and reduces further before that in a manner that depends on the natural mortality assumptions made.

App. A2, Fig. A2.3 shows survey and commercial selectivity-at-age estimates for the two Ricker assessments, and App. A2, Fig. A2.4 the (mean-unbiased) stock-recruitment curves fitted internally, together with the associated "data" for all four assessments. For $M = 0.2$ assessments, higher recruitments tend to occur only for intermediate spawning biomass levels, whereas for M ramp assessments these are absent at the higher spawning biomass levels only, leading to the BH curve estimated hitting an upper bound for the steepness parameter h. These features have an impact on the estimates of the spawning biomass at MSY, which are indicated on each plot as well as reported in App. A2, Tables A2.1 and A2.2.

Diagnostics for the fits of the two Ricker assessments to the abundance indices and catch-at-age and –at-length proportions for commercial catches and surveys (as relevant) are shown in App. A2, Figs A2.5 and A2.6, and Fig. A2.7 shows the retrospective analyses for these two cases.

Preference amongst four final assessments

Some WG members prefer the Ricker to the BH based assessments based on the former's better fits to the "data". This is a reflection of the six or seven points at the highest spawning biomasses in App. A2, Fig. A2.4 which all correspond to the rather low but still reasonably precisely determined recruitments in the 1960s (see App. A2, Fig. A2.2). More quantitatively, Ricker is preferred over BH by 3 log-likelihood points for $M = 0.2$, and by a more substantial 8 points for M ramp (see App. A2, Table A2.1). Of course a continuum is possible across the BH to Ricker shapes and beyond. If the shape parameter γ of the modified Ricker (equation A3.6 of Appendix A3) is estimated, the result is greater than 1 in both cases, suggesting stronger doming than for the classical Ricker form, and increasing the log-likelihood points difference for BH to 5 for $M = 0.2$.

Of the two Ricker assessments, the authors prefer the M ramp case for three reasons:

- the indications from tagging data (see Working Group reports) that M is distinctly larger than 0.2, at least in the 2000s;
- an 11 point improvement in the log-likelihood (see App. A2, Table A2.1), reflecting mainly improved fits to the survey indices of abundance and to the stock-recruitment function; and
- a lesser retrospective pattern (see App. A2, Fig. A2.7).

Relationships to ToR

ToR 5 (relating to assessment results)

The assessment results required are to be found in App. A2, Table A2.1 and Figs A2.1-3 and A2.5-7. No survey catchability q estimate exceeds 1. Model details are provided in Appendix A3.

Historical retrospective results are shown in App. A2, Fig. A2.8. They are referenced by the time at which they were developed, as they don't always correspond to the times of advice given in GARM/SAW exercises, and did not always correspond to the authors' preference at the time. For example the Ricker G option of August 2008 was the final documented "preference" in GARM III, but invoked increasing natural mortality at age rather than domed selectivity in response to the preference of the penultimate GARM panel that year – a preference with which the final GARM panel disagreed. The 2007 and March 2012 assessments estimate domed survey selectivity, but the other two shown force this to be asymptotically flat. There is a notable difference in post-1990 estimated trends between the two earlier and two later assessments in this set of four. The reason relates primarily to a revision of the catch (and discard) inputs with their associated age structure information in the intervening period. The earlier data were statistically incompatible with the joint assumptions of $M = 0.2$ and asymptotically flat survey selectivity. After revision of these data, the evidence against this option became much less clear-cut, and the size of any possible effect on assessment results also much less.

<u>ToRs 6 and 7</u> (relating to stock status and BRP estimates)

The requisite information here is provided in App. A2, Table A2.2. In terms of the authors' preferred assessment (Ricker and *M* ramp), at present the stock is not overfished and overfishing is not taking place. Estimates of the precision of BRP estimates may be found in App. A2, Table A2.1.

ToR 8 (relating to projections)

Projected catches under a $0.75F_{MSY}$ harvesting strategy are given in App. A2, Table A2.1. These and their implications are discussed further in the main text.

References

Butterworth DS and Rademeyer RA. 2008a. Statistical catch-at-age analysis vs. ADAPT-VPA: the case of Gulf of Maine cod. ICES Journal of Marine Science, 65. pp 1717-1732.

Butterworth DS and Rademeyer RA. 2008b. Further SCAA/ASPM Assessments of Gulf of Maine Cod Including Data for 2007 and Exploring the Impact of Age-Dependence in Natural Mortality. GARM WP 1.Fb. 19pp.

Butterworth DS and Rademeyer RA. 2012. An investigation of differences amongst SCAA and ASAP assessment (including Reference Point) estimates for Gulf of Maine Cod. Document submitted to the March 2012 meeting of the New England Fisheries Management Council SSC . 34pp.

Appendix A.2 Tables

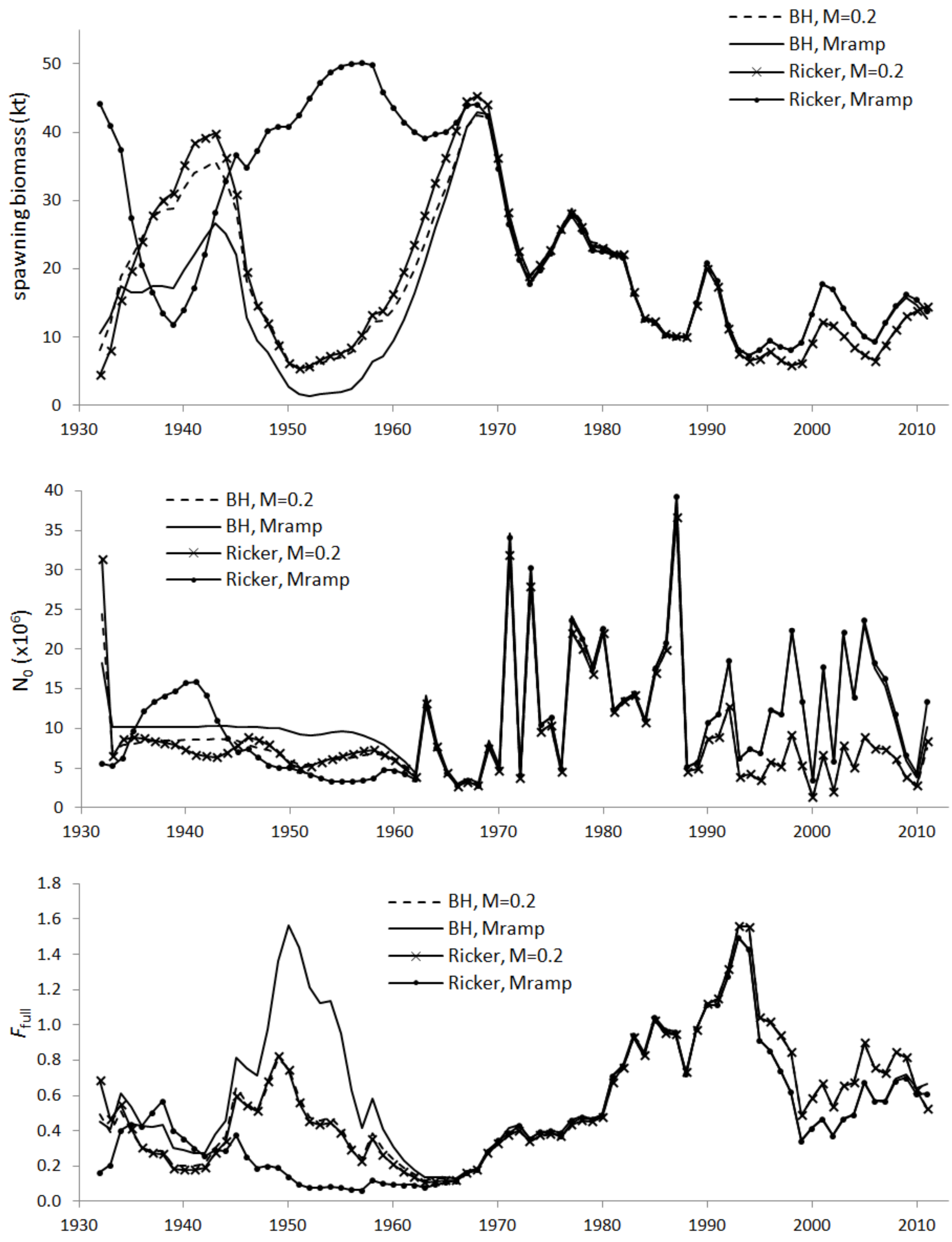
App. A2, Table A2.1: Estimates of abundance, MSY-related biological reference points (BRPs), and related quantities for the Gulf of Maine cod SCAA assessments for all combinations of two assessment factors: the form of the stock-recruitment relationship, and the time dependence of natural mortality M (see text for further details). Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix A3 for definitions of some of the symbols used.

	Start year 1932 M =0.2				Start year 1932 M ramp			
	Ricker		BH		Ricker		BH	
-lnL: overall	-2748		-2745		-2759		-2751	
-lnL: survey	-24.2		-24.1		-29.8		-31.8	
-lnL: comCAA	-786.7		-786.6		-783.4		-783.3	
-lnL: survCAA	-1812.6		-1813		-1812.6		-1812	
-lnL: survCAL	-160.7		-160.2		-161.6		-160.2	
-lnL: RecRes	32.8		35.6		25.0		31.8	
-lnL: Catch	3.4		3.0		3.2		4.0	
Maximum gradient	0.620*		0.172*		0.000		1.544+	
$N_{y1,0}$	31.40	(0.66)	24.42	(341.15)	5.51	(1.39)	18.28	(497.47)
ϕ	0.96	(0.75)	0.72	(383.39)	0.12	(4.13)	0.58	(520.66)
B^{sp}_{2011}	14.51	(0.05)	14.38	(0.05)	13.73	(0.05)	12.74	(0.05)
B^{sp}_{1982}	22.12	(0.17)	22.16	(0.16)	21.55	(0.15)	21.64	(0.14)
B^{sp}_{y1}	4.45	(1.61)	8.12	(740.87)	44.16	(2.32)	10.49	(870.98)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	0.84	0.16	0.79	0.11	0.79	0.11
NEFSC fall	0.67	0.10	0.68	0.10	0.64	0.12	0.64	0.11
MADMF spring	0.22	0.30	0.22	0.30	0.15	0.24	0.15	0.24
K	62.32	(0.12)	193.02	(0.22)	29.54	(0.08)	33.97	(0.09)
h	2.62	(0.14)	0.92	(0.06)	1.15	(0.17)	0.98++	(0.00)
MSY	12.84	(0.08)	13.29	(0.18)	7.17	(0.14)	5.51	(0.09)
F_{MSY}	0.75		0.31		0.95		0.95	
B^{sp}_{MSY}	20.91	(0.08)	46.31	(0.18)	11.18	(0.14)	8.57	(0.09)
B^{sp}_{MSY}/K^{sp}	0.34	(0.11)	0.24	(0.05)	0.38	(0.17)	0.25	(0.02)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.69	(0.08)	0.31	(0.18)	1.23	(0.14)	1.49	(0.09)
Projected catch:								
2013	8.423		3.870		5.803		5.066	
2014	7.621		4.336		4.507		3.847	
2015	8.424		5.229		5.020		4.041	

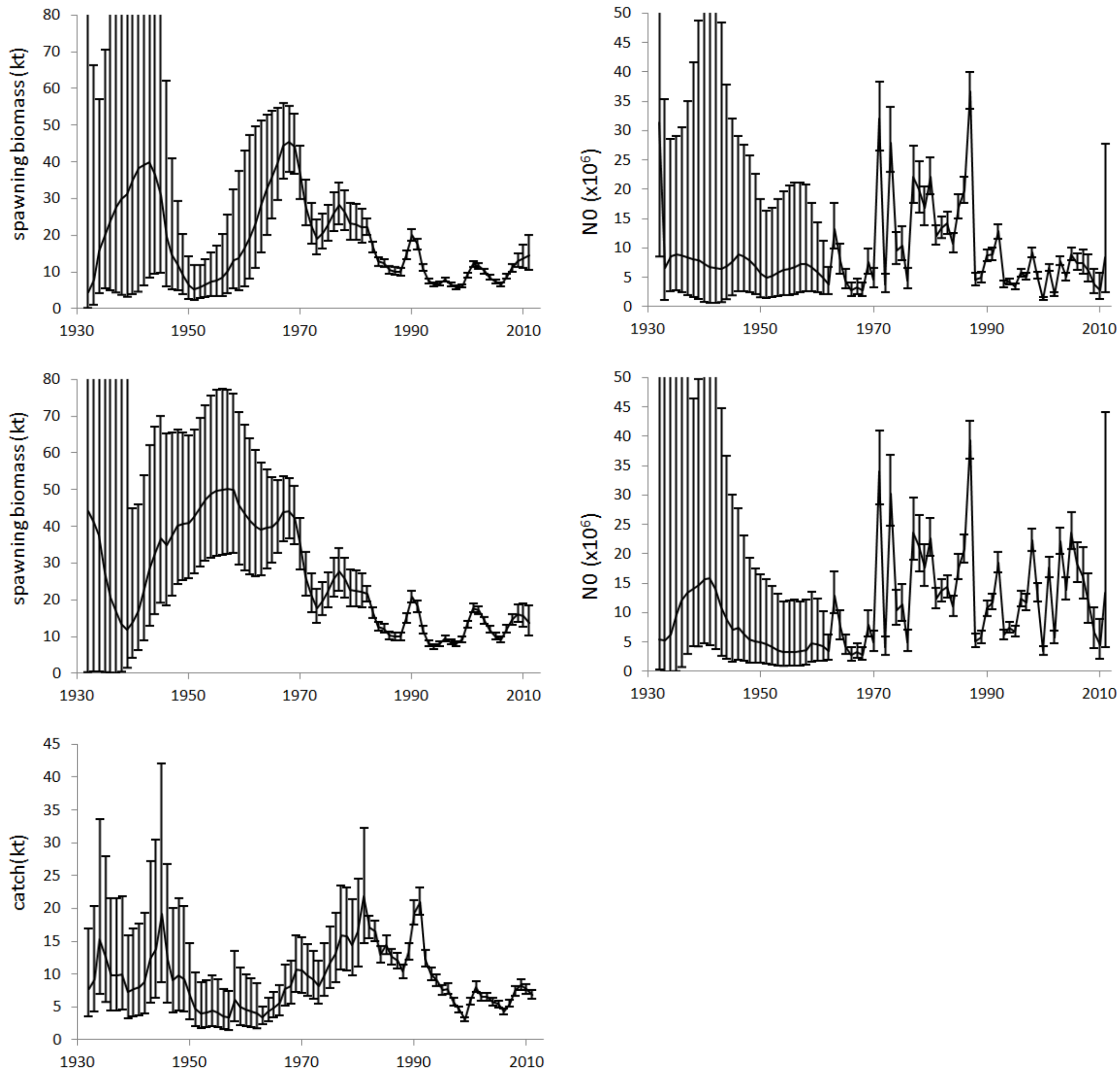
* This occurs for the selectivity parameters for ages 3 and 4 in the Massachusetts survey. The selectivity is constrained not to increase with age, and the estimation in these cases hits this bound. + This occurs for a single selectivity parameter (age 4) for the period 1982-1988 of the commercial selectivity. ++ This steepness estimate is at its upper bound.

App. A2, Table A2.2: Biological Reference Points and current status for four SCAA assessments of Gulf of Maine cod.

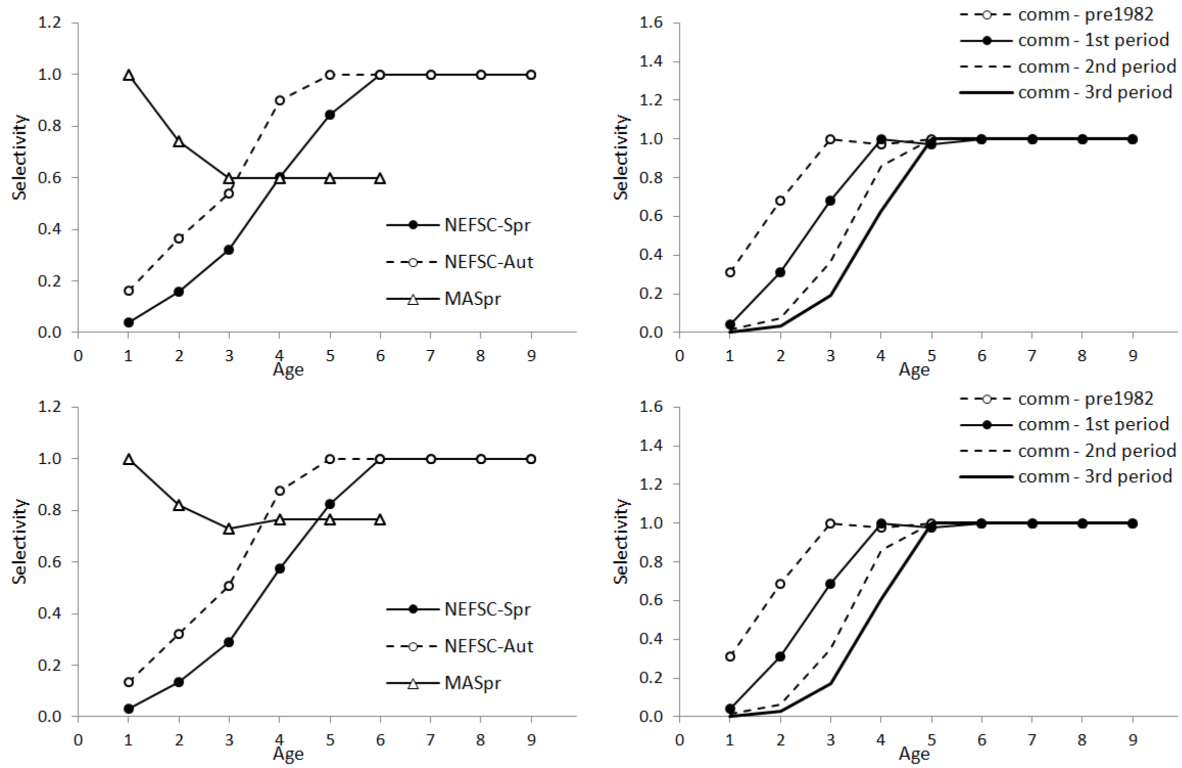
	Start year 1932 M =0.2		Start year 1932 M ramp	
	Ricker	BH	Ricker	BH
B^{sp}_{MSY}	20.91	46.31	11.18	8.57
$1/2\ B^{sp}_{MSY}$	10.45	23.15	5.59	4.29
MSY	12.84	13.29	7.17	5.51
F_{MSY}	0.75	0.31	0.95	0.95
$0.75\ F_{MSY}$	0.56	0.23	0.71	0.71
B^{sp}_{2011}	14.51	14.38	13.73	12.74
F_{2011}	0.52	0.53	0.61	0.66
$B^{sp}_{2011}/(1/2\ B^{sp}_{MSY})$	1.39	0.62	2.46	2.97
F_{2011}/F_{MSY}	0.70	1.73	0.64	0.70
Status	Not overfished No overfishing	Overfished Overfishing	Not overfished No overfishing	Not overfished No overfishing



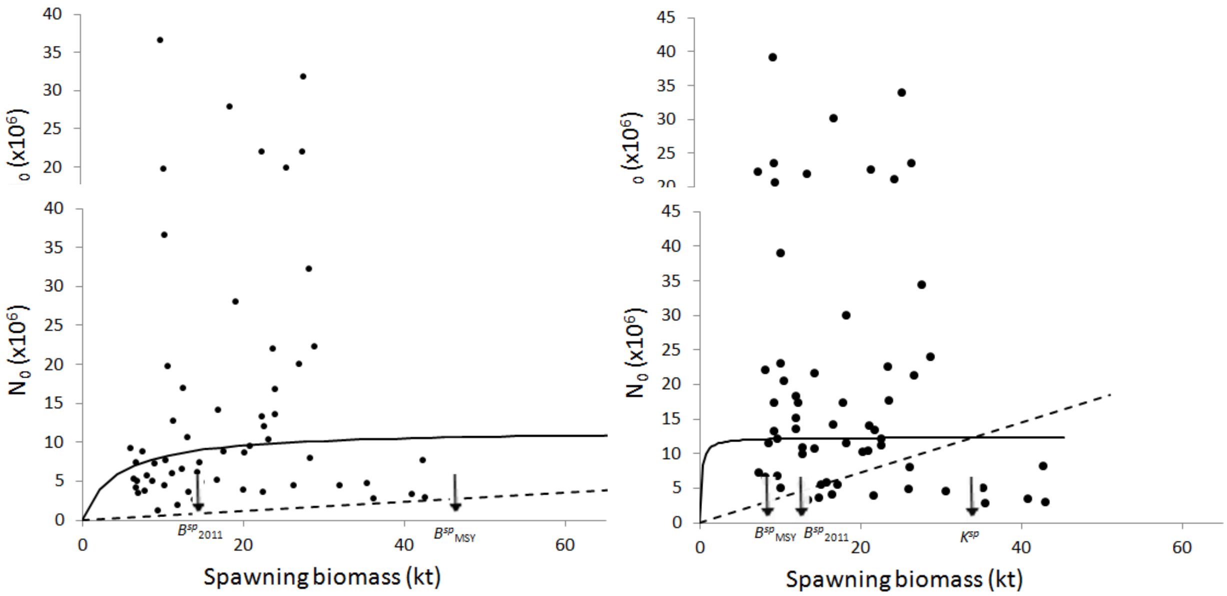
App. A2, Fig. A2.1: Spawning biomass, recruitment (0-year-class strength) and fully selected fishing mortality trajectories for the two Ricker and two Beverton-Holt SCAA assessments.



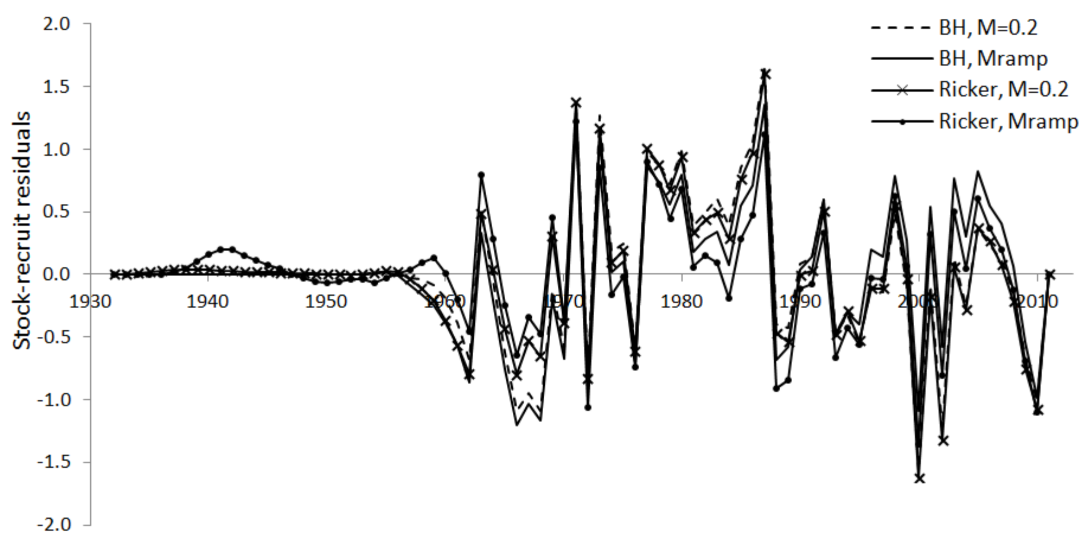
App. A2, Fig. A2.2: Spawning biomass, recruitment and catch trajectories for the Ricker internal assessment, with the start in 1932, and with *M = 0.2* (top row) and *M* ramp (bottom row) with CIs based on Hessian CVs and the assumption of distribution lognormality.



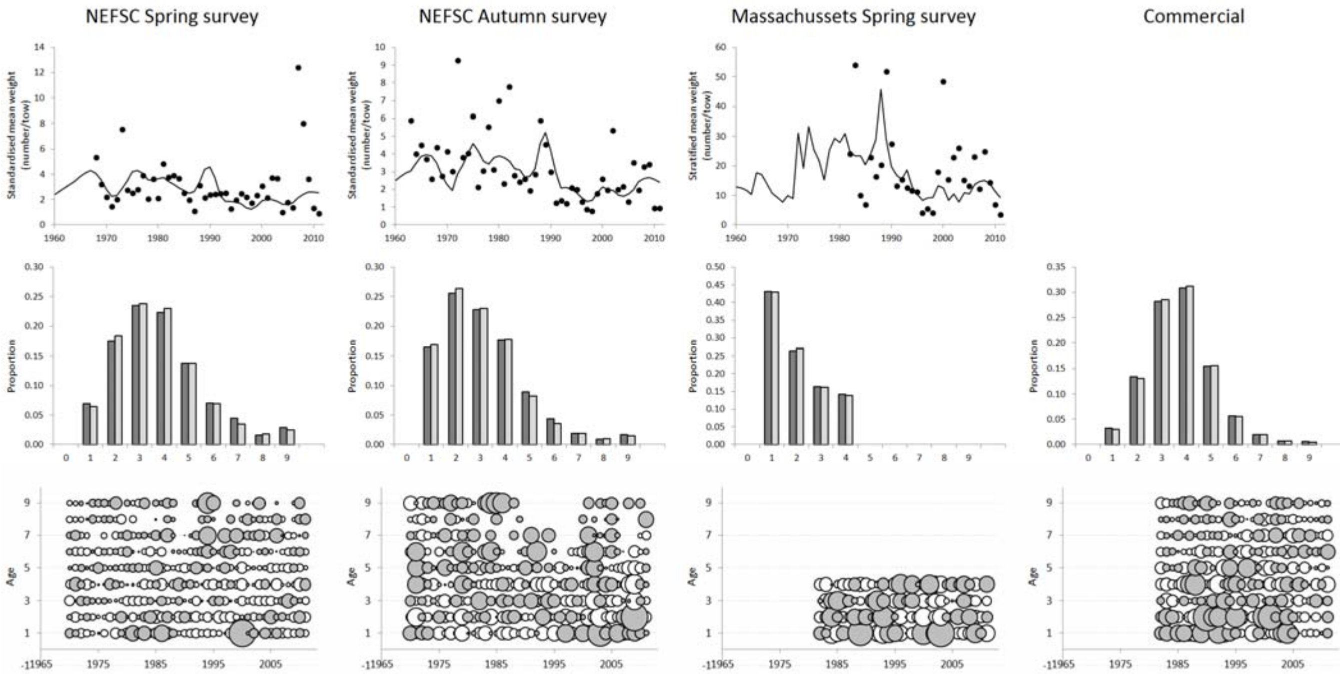
App. A2, Fig. A2.3: Pre-1982 commercial selectivities and the NEFSC survey selectivities for the Ricker internal assessment, with the start in 1932, and with *M = 0.2* (top row) and *M* ramp (bottom row).



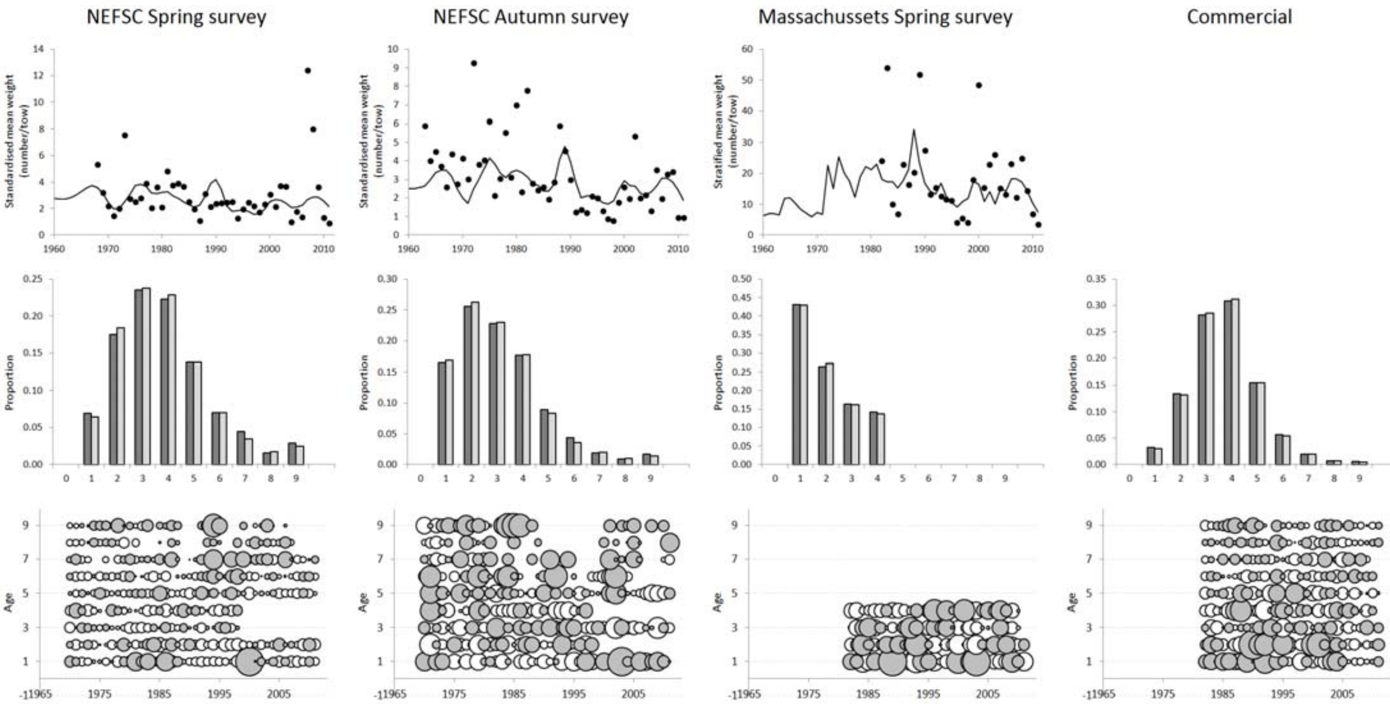
App. A2, Fig. A2.4a: Stock-recruitment curve and estimated recruitment for assessments starting in 1932 for the Ricker internal cases (top row), with $M = 0.2$ (left) and M ramp (right), and for the Beverton-Holt cases (bottom row), with $M = 0.2$ (left) and M ramp (right). Only values reasonably informed by the data (from 1960 onwards) are shown. Replacement lines are shown dashed; for the M ramp cases these correspond to the current M value of 0.4.



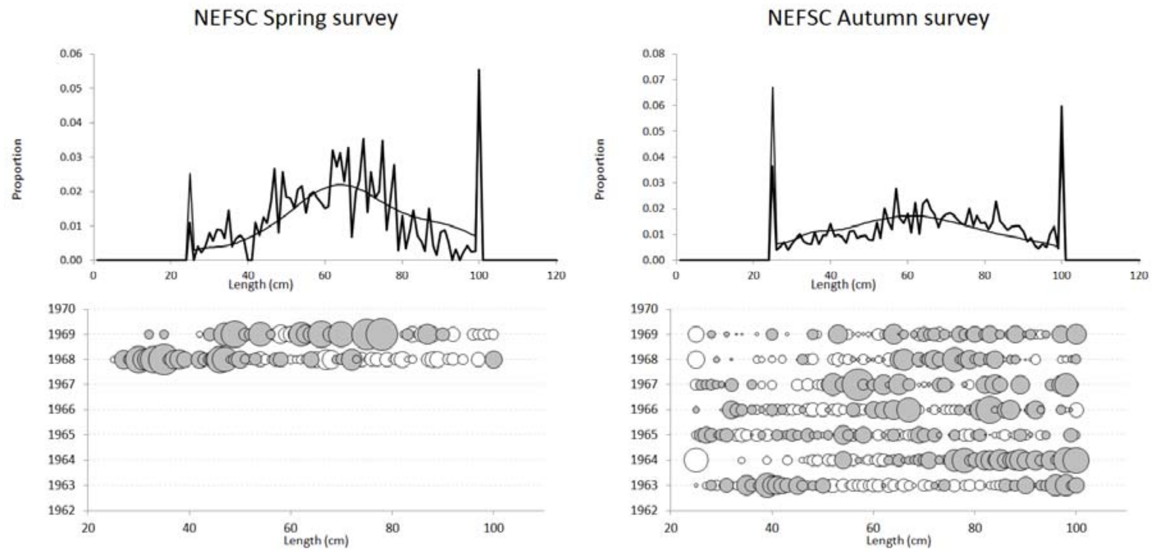
App. A2, Fig. A2.4b: Time series of stock-recruit residuals ς_y (see equation A3.5 of Appendix A3) for the two Ricker and two Beverton-Holt assessments.



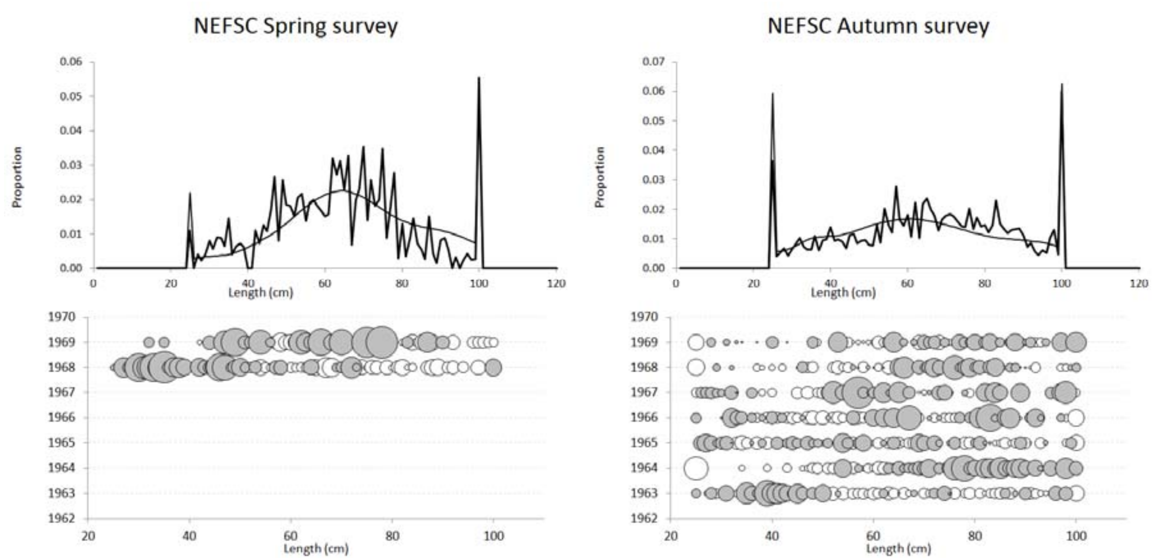
App. A2, Fig. A2.5a: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the Ricker internal assessment, with the start in 1932, and with *M = 0.2*. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



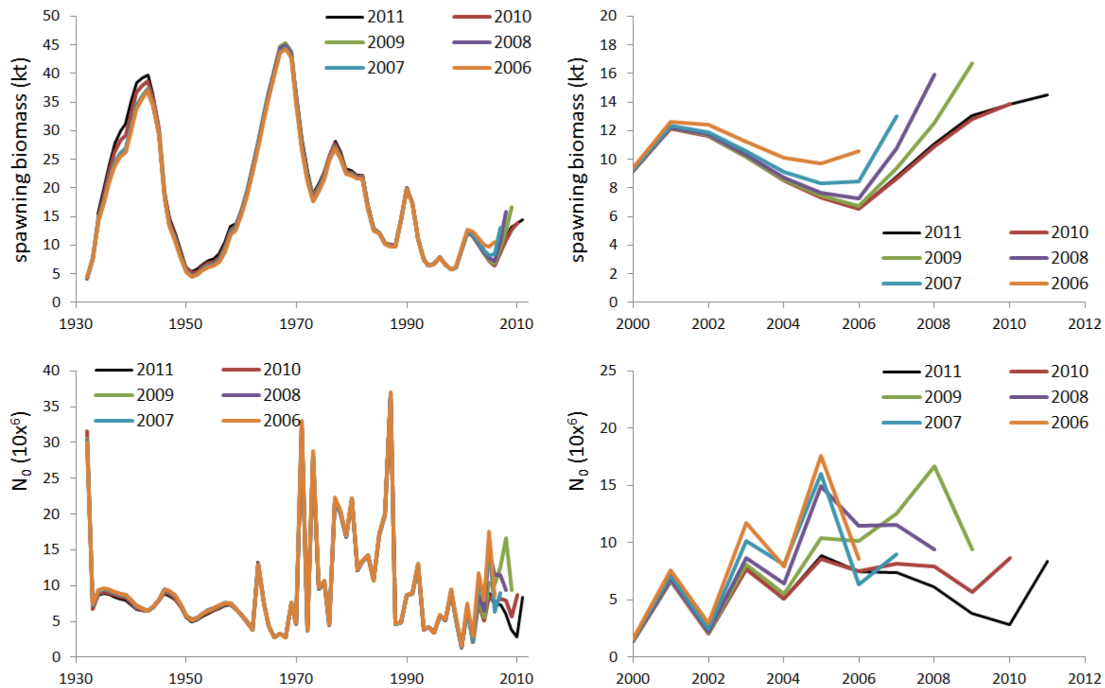
App. A2, Fig. A2.5b: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the Ricker internal assessment, with the start in 1932, and with *M* ramp. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



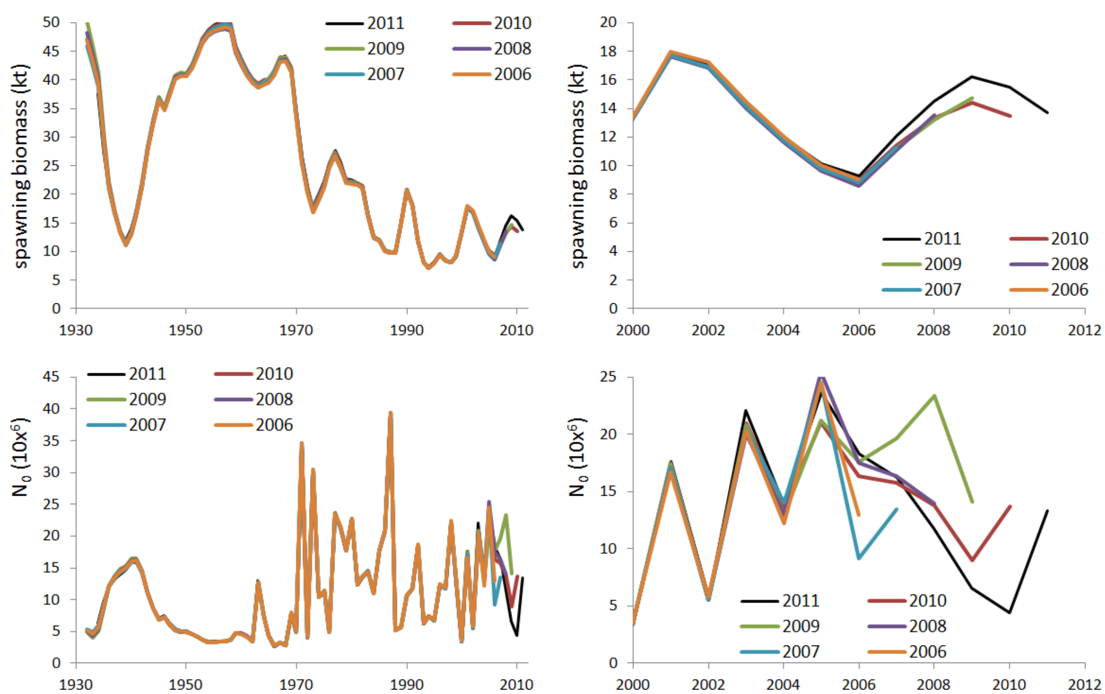
App. A2, Fig. A2.6a: Fits to the survey catch-at-length data for the Ricker internal assessment, with the start in 1932, and with *M* =0.2. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available (the spikes correspond to minus and plus groups), while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



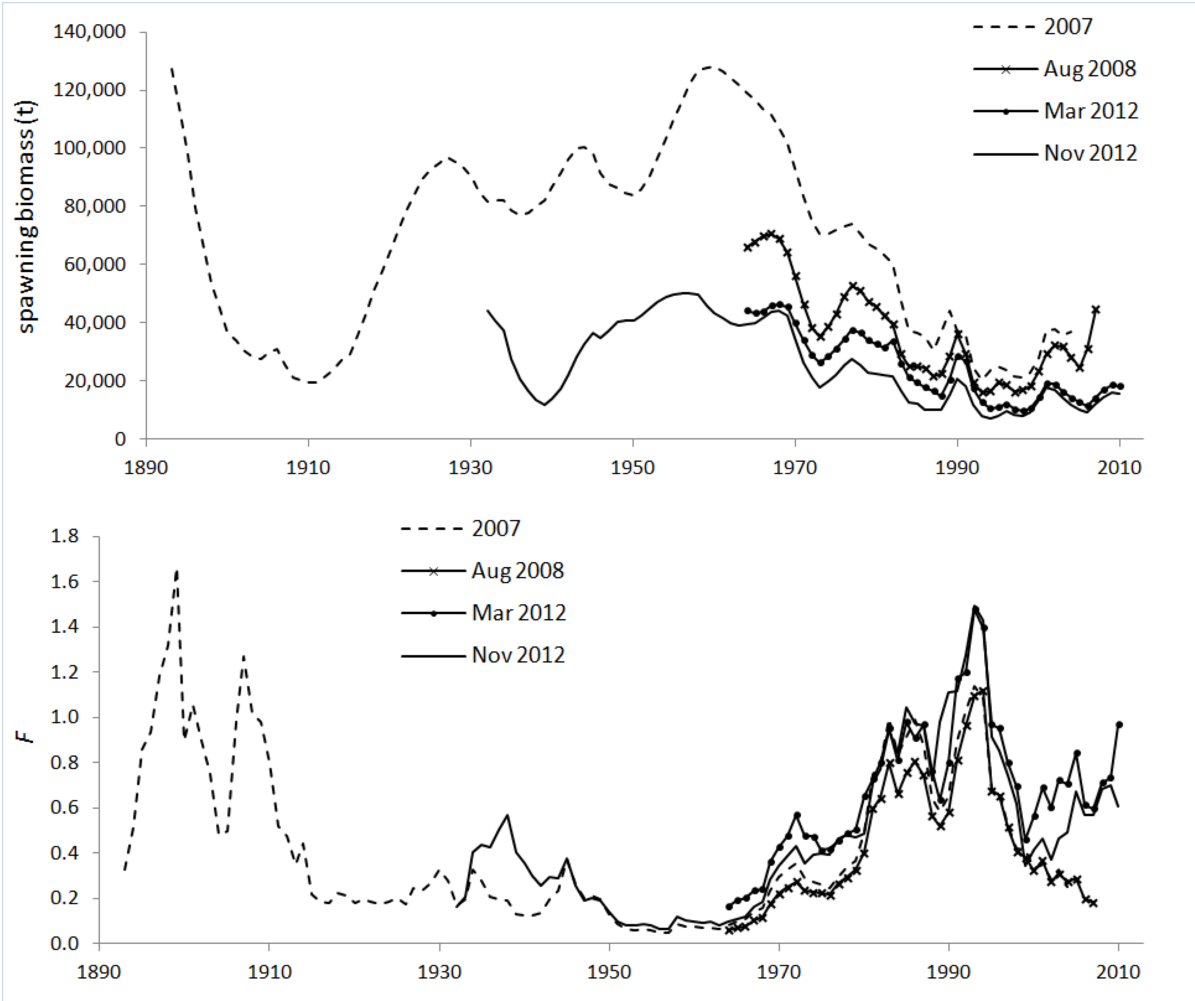
App. A2, Fig. A2.6b: Fits to the survey catch-at-length data for the Ricker internal assessment, with the start in 1932, and with *M* ramp. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available (the spikes correspond to minus and plus groups), while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



App. A2, Fig. A2.7a: Retrospective analysis for the Ricker internal assessment, with the start in 1932 and *M = 0.2*.



App. A2, Fig. A2.7b: Retrospective analysis for the Ricker internal assessment, with the start 1932 and *M* ramp.



App. A2, Fig. A2.8: Comparison of spawning biomass and fishing mortality trajectories from previous SCAA assessment of Gulf of Maine cod, including "2007" (Reference Case of Butterworth and Rademeyer, 2008a), "Aug 2008" (Ricker G of Butterworth and Rademeyer, 2008b), "Mar 2012" (NBC2 of Butterworth and Rademeyer, 2012) and "Nov 2012" (Ricker, *M* ramp, this analysis). The fishing mortality shown is the fully selected fishing mortality, but this corresponds to different ages for the different assessments: ages 5 for "2007", 5 for "Aug 2008", 4 (pre 1991) or 5 (post 1990) for "Mar 2012" and 6+ for "Nov 2012". The fishing mortality plot for "2007" after 1995 is virtually identical to that for "Aug 2008", and hence is not readily evident over that period in the plot.

[SAW55 Editor's Note: The SARC-55 review panel did not recommend adopting the GOM cod Statistical Catch-at-Age (SCAA) assessment results that are in Appendices A.2 – A.5. These appendices are included in this report to document and demonstrate the work that was done by the SAW cod Working Group for the December 2012 peer review.]

Appendix A.3. Algebraic details of the Statistical Catch-at-Age Model.

The text following sets out the equations and other general specifications of the Statistical Catch-at-Age (SCAA) assessment model applied to Gulf of Maine cod, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

Where options are provided under a particular section, the section concludes with a statement in **bold** as to which option was selected for the final assessment run selected.

A3.1. Population dynamics

A3.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \qquad \text{(A3.1)}$$

$$N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}} \qquad \text{for } 0 \le a \le M-2 \qquad \text{(A3.2)}$$

$$N_{y+1,m} = N_{y,m-1}e^{-Z_{y,m-1}} + N_{y,m}e^{-Z_{y,m}} \qquad \text{(A3.3)}$$

where

$N_{y,a}$ is the number of fish of age a at the start of year y,

R_y is the recruitment (number of 0-year-old fish) at the start of year y,

m is the maximum age considered (taken to be a plus-group).

$Z_{y,a} = F_y S_{y,a} + M_a$ is the total mortality in year y on fish of age a, where

M_a denotes the natural mortality rate for fish of age a,

F_y is the fishing mortality of a fully selected age class in year y, and

$S_{y,a}$ is the commercial selectivity at age a for year y.

Note that for the "M ramp" scenario for which M increases linearly from 0.2 to 0.4 over the period from 1988 to 2003, M is year dependent but this complication is omitted from the equations above to avoid clutter.

A3.1.2. Recruitment

The number of recruits (i.e. new 0-year old) at the start of year y is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a standard or adjusted Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

For the modified Ricker:

$$R_y = \alpha B_y^{\mathrm{sp}} \exp\left[-\beta\left(B_y^{\mathrm{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_{\mathrm{R}})^2/2)} \tag{A3.4}$$

for the (standard) Beverton-Holt:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_{\mathrm{R}})^2/2)} \tag{A3.5}$$

and for the adjusted Beverton-Holt:

$$R_y = \begin{cases} \dfrac{\alpha B_y^{sp}}{\beta + B_y^{sp}} & \text{if } B_y^{sp} \le B^* \\ \dfrac{\alpha B^*}{\beta + B^*} \exp\left(-\left(\dfrac{B_y^{sp} - B^*}{\sigma_N}\right)^2\right) & \text{if } B_y^{sp} > B^* \end{cases} \tag{A3.6}$$

where

α, β, γ, $B^*$and σ_N are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year y, which is assumed to be normally distributed with standard deviation σ_{R} (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B_y^{sp} is the spawning biomass at the start of year y, computed as:

$$B_y^{\mathrm{sp}} = \sum_{a=1}^{m} f_a w_{y,a}^{\mathrm{strt}} N_{y,a} e^{-Z_{y,a}/4} \tag{A3.7}$$

because spawning for the cod stock under consideration is taken to occur three months after the start of the year and some mortality has therefore occurred,

where

$w_{y,a}^{\mathrm{strt}}$ is the mass of fish of age a during spawning, and

f_a is the proportion of fish of age a that are mature.

Section *A3.2.6* details the procedure adopted when recruitment is not assumed to be related to spawning biomass , at least internal to the assessment.

For the final run, the modified Ricker, with γ fixed to 1, has been used, i.e. the classical Ricker function.

A3.1.3. Total catch and catches-at-age

The total catch by mass in year y is given by:

$$C_y = \sum_{a=1}^{m} w_{y,a}^{\text{mid}} \, C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{\text{mid}} \, N_{y,a} \;\; S_{y,a} \, F_y \left(1 - e^{-Z_{y,a}}\right) \Big/ Z_{y,a} \tag{A3.8}$$

where

$w_{y,a}^{\text{mid}}$ denotes the mass of fish of age a landed in year y,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age a, caught in year y,

The model estimate of survey index is computed as:

$$B_y^{\text{surv}} = \sum_{a=1}^{m} w_{y,a}^{\text{surv}} S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \tag{A3.9}$$

for biomass indices and

$$N_y^{\text{surv}} = \sum_{a=1}^{m} S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \tag{A3.10}$$

for numbers indices

where

S_a^{surv} is the survey selectivity for age a, which is taken to be year-independent.

T^{surv} is the season in which the survey is taking place (T^{surv} =1 for spring surveys and T^{surv} =3 for fall surveys), and

$w_{y,a}^{surv}$ denotes the mass of fish of age a from survey *surv* year y.

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

The final run is fitted to numbers indices.

A3.1.4. Initial conditions

For the first year (y_0) considered in the model, the numbers-at-age are estimated directly for ages 0 to a^{est}, with a parameter ϕ mimicking recent average fishing mortality for ages above a^{est}, i.e.

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 0 \le a \le a^{est} \tag{A3.11}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1 - \phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \tag{A3.12}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1 - \phi S_{m-1}) \Big/ (1 - e^{-M_m} (1 - \phi S_m)) \tag{A3.13}$$

For the final run which starts in 1932 only the number for age 0 is estimated, with equation A3.12 applying from age 1.

A3 B.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age and catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood ($-\ell n L$) are as follows. Details related to fitting to CPUE series are not included below, as such series are not considered in the analyses of this paper.

A3.2.1. Survey abundance data

The likelihood is calculated assuming that a survey biomass index is lognormally distributed about its expected value:

$$I_y^{surv} = \hat{I}_y^{surv} \exp\left(\varepsilon_y^{surv}\right) \quad \text{or} \quad \varepsilon_y^{surv} = \ell n\left(I_y^{surv}\right) - \ell n\left(\hat{I}_y^{surv}\right) \tag{A3.14}$$

where

I_y^{surv} is the survey biomass index for survey *surv* in year *y*,

$\hat{I}_y^{surv} = \hat{q}^{surv} \hat{B}_y^{surv}$ is the corresponding model estimate, where

$\hat{q}^{surv}$ is the constant of proportionality (catchability) for the survey biomass series *surv*, and

ε_y^{surv} from $N\left(0,\left(\sigma_y^{surv}\right)^2\right)$.

The contribution of the survey biomass data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n L^{\text{survey}} = \sum_{surv}\sum_{y}\left\{\ell n\left(\sqrt{\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2}\right) + \left(\varepsilon_y^{surv}\right)^2 / \left[2\left(\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2\right)\right]\right\} \tag{A3.15}$$

where

σ_y^{surv} is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

σ_{Add}^{surv} is the square root of the additional variance for survey biomass series *surv*, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^{surv} for survey biomass index *surv* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^{surv} = 1/n_{surv} \sum_y \left(\ln I_y^{surv} - \ln \hat{B}_y^{surv}\right) \tag{A3.16}$$

A3.2.3. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell n L^{\text{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_a^{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_a^{com}\right)^2\right] \tag{A3.17}$$

where
$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year y that are of age a,
$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year y that are of age a,
where

$$\hat{C}_{y,a} = N_{y,a} \; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \qquad \text{(A3.18)}$$

and
σ_a^{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y p_{y,a} \left(\ell n \, p_{y,a} - \ell n \, \hat{p}_{y,a}\right)^2 / \sum_y 1} \qquad \text{(A3.19)}$$

Evaluations in Butterworth and Rademeyer (2012) demonstrated the need for allowing for age dependence in σ_a^{com}.

Commercial catches-at-age are incorporated in the likelihood function using equation (A3.17), for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).
In application of this approach ages are often aggregated to avoid values of $p_{y,a}$ or $\hat{p}_{y,a}$ that are too small in the interests of estimation robustness. In this paper individual ages have been maintained between the selected minus and plus-groups to provide potential discrimination of different shapes for the selectivity functions at older ages in particular. This however does mean that there are certain cells for which $p_{y,a}$ values are zero. That does not cause any problems because the limit of $p_{y,a}\left(\ln p_{y,a}\right)^2$ as $p_{y,a} \to 0$ is 0, so these terms can be omitted from the summation in equation B17. One could argue that they should nevertheless be included in the summations in equation B18, but exclusion seems more appropriate as the structural zero contributions then included would seem likely to bias the estimates of $\hat{\sigma}_a^{com}$ downwards.

In addition to this "adjusted" lognormal error distribution, some computations use an alternative "sqrt(p)" formulation, for which equation A3.20 is modified to:

$$-\ell \text{n} \, L^{\text{CAA}} = \sum_y \sum_a \left[\ell n \left(\sigma_a^{com}\right) + \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / 2 \left(\sigma_a^{\text{com}}\right)^2 \right] \qquad \text{(A3.21)}$$

and equation B21 is adjusted similarly:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / \sum_y 1} \qquad \text{(A3.22)}$$

This formulation mimics a multinomial form for the error distribution by forcing a near-equivalent variance-mean relationship for the error distributions.

The final run uses "sqrt(p)" formulation for the error distribution of the commercial catches-at-age, survey catches-at-age and survey catches-at-length.

A3.2.4. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an "adjusted" lognormal error distribution (equation (A19)) where:

$p_{y,a}^{surv} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of fish of age a in year y for survey *surv*,

$\hat{p}_{y,a}^{surv}$ is the expected proportion of fish of age a in year y in the survey *surv*, given by:

$$\hat{p}_{y,a}^{surv} = S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \Bigg/ \sum_{a'=1}^{m} S_{a'}^{\text{surv}} N_{y,a'} e^{-Z_{y,a'} T^{surv}/12} \quad . \tag{A3.23}$$

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

A3.2.5. Survey catches-at-length

In some runs, catches-at-length are also incorporated in the likelihood function. These data are incorporated in the similar manner as the catches-at-age. When the model is fit to catches-at-length, the predicted catches-at-age are converted to catches-at-length:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{strt} \tag{A3.24}$$

for the spring survey, and

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{mid} \tag{A3.25}$$

for the fall survey,

where $A_{a,l}^{strt}$ and $A_{a,l}^{mid}$ are the proportions of fish of age a that fall in the length group l (i.e., $\sum_l A_{a,l}^{strt} = 1$ and $\sum_l A_{a,l}^{mid} = 1$ for all ages) at the beginning of the year and at the middle of the year respectively.

The matrices $A_{a,l}^{strt}$ and $A_{a,l}^{mid}$ are calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a^{strt} \sim N\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right); \left(\theta_a^{strt}\right)^2\right] \tag{A3.26}$$

for the spring survey and

$$L_a^{mid} \sim N\left[L_\infty\left(1 - e^{-\kappa(a+0.5-t_o)}\right); \left(\theta_a^{mid}\right)^2\right] \tag{A3.27}$$

for the fall survey,

where

θ_a^{strt} and θ_a^{mid} are the standard deviation of begin and mid-year length-at-age a respectively, which are modelled to be proportional to the expected length-at-age a, i.e.:

$$\theta_a^{strt} = \beta\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right)\right]^\gamma \tag{A3.28}$$

and

$$\theta_a^{mid} = \beta\left[L_\infty\left(1 - e^{-\kappa(a+0.5-t_o)}\right)\right]^\gamma \tag{A3.29}$$

with β an estimable parameter and $\gamma = 0.5$ (a value which was found to lead to reasonable fits to the data).

$L_\infty = 150.93\,cm$,
$\kappa = 0.11\,yr^{-1}$,
$t_o = 0.13\,yr$,

The following term is then added to the negative log-likelihood:

$$-\ell n\, L^{\mathrm{CAL}} = w_{len} \sum_{surv}\sum_{y}\sum_{l}\left[\ell n\left(\sigma_{\mathrm{len}}^{surv} / \sqrt{p_{y,l}^{surv}}\right) + p_{y,l}^{surv}\left(\ell n\, p_{y,l}^{surv} - \ell n\, \hat{p}_{y,l}^{surv}\right)^2 / 2\left(\sigma_{\mathrm{len}}^{surv}\right)^2\right] \tag{A3.30}$$

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups because the length distributions for adjacent ages overlap) to the overall negative log-likelihood compared to that of the CPUE data. The value used for w_{len} is 0.1, being roughly equivalent to the ratio of the number to length groups to the number of age groups considered. Instances of observed proportions of zero are dealt with in the same manner as for catches-at-age, as is the alternative "sqrt(p)" error distribution formulation.

The final run incorporates these catch-at-length data and uses the "sqrt(p)" formulation.

A3.2.6. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be lognormally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{\mathrm{pen}} = \sum_{y=y_1+1}^{y_2}\left[\varepsilon_y^2 \big/ 2\sigma_{\mathrm{R}}^2\right] \tag{A31}$$

where

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_{R} is the standard deviation of the log-residuals, which is input.

Equation A3.31 is used when the stock-recruitment curve is estimated internally. In some analyses reported in this paper where BRP estimates are based on stock-recruitment curves estimated "externally" using the assessment outputs,, this "stock-recruitment" term is included for the last two years only, simply to stabilise these estimates which are not well determined by the other data. In these cases, the ε_y are calculated as the deviations from the mean log recruitment for the ten preceding years, i.e. recruitment estimates for 2010 and 2011 are shrunk towards the geometric mean recruitment over the preceding decade.

A3.2.7. Catches

$$-\ell n L^{\mathrm{Catch}} = \sum_{y}\left[\frac{\ell n\, C_y - \ell n\, \hat{C}_y}{2\sigma_{\mathrm{C}}^2}\right] \tag{A3.32}$$

where

C_y is the observed catch in year y,

$\hat{C}_y$ is the predicted catch in year y (equation A3.8), and

σ_C is the CV input: 0.4 for pre-1964 catches, 0.2 for catches between 1964 and 1981 and 0.05 for catches from 1982 onwards.

A3.2.8 Incorporation of Bigelow vs Albatross survey calibration

The survey data provided are adjusted for the years 2009 to 2012 which were obtained from *Bigelow* surveys have been adjusted to "*Albatross* equivalents" through use of calibration factors estimated independently from paired tow experiments (Miller *et al*., 2010). However the survey data before and after the switch of vessels also provide information on the calibration factors because they sample the same cohorts. Incorporation of this information in assessments in this paper has been effected by treating the estimates, with their variance-covariance matrix, as a form of "joint-prior" which is effectively updated in the penalised likelihood estimation when fitting the model. The process is as follows.

First *Bigelow* length frequency distributions are converted to *Albatross* equivalent length frequency distributions:

$$C_{y,l}^{surv,A} = C_{y,l}^{surv,B} \Big/ F_l \qquad \text{(A3.33)}$$

where

$C_{y,l}^{surv,B}$ is the measured catch-at-length for the *Bigelow* in year y for survey *surv,*

$C_{y,l}^{surv,A}$ is the inferred catch-at-length for the *Albatross* equivalent in year y for survey *surv,*

F_l is the length-based calibration factor (*Bigelow/Albatross*),

The *Albatross* equivalent length distributions are then converted to age distributions:

$$C_{y,a}^{surv,A} = \sum_l C_{y,l}^{surv,A} ALK_{y,a,l}^{surv} \qquad \text{(A3.34)}$$

where

$ALK_{y,a,l}^{surv}$ is the age-length key (proportion of fish of length l that have age a) in year y for survey *surv*.

Indices are then obtained from the *Albatross* equivalent age distributions as follows:

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} w_{y,a}^{surv} \qquad \text{(A3.35)}$$

for biomass indices and

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} \qquad \text{(A3.36)}$$

for numbers indices,

where

$w_{y,a}^{surv}$ is the weight-at-age in year y for survey *surv*.

The calibration factor has four parameters, three of which are estimable and the other input: X_1=20cm, X_2, F_1 and F_2

$$F_l = \begin{cases} F_1 & \text{if } l \le X_1 \\ \frac{(F_2 - F_1)}{(X_2 - X_1)} l + \frac{(F_1 X_2 - F_2 X_1)}{(X_2 - X_1)} & \text{if } X1 < l < X_2 \\ F_2 & \text{if } l \ge X_2 \end{cases} \quad \text{(A3.37)}$$

The following contribution is therefore added to the negative log-likelihood in the assessment:

$$-\ln L^{calib} = \frac{1}{2}\ln|\boldsymbol{\Sigma}| + \frac{1}{2}(\mathbf{x} - \boldsymbol{\mu})^{\mathrm{T}} \boldsymbol{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \quad \text{(A3.38)}$$

where the parameters X_2, F_1 and F_2 are components of the vector $\boldsymbol{x}$,
$\boldsymbol{\Sigma}$ is the variance covariance matrix as estimated by Miller *et al.* (2010), and
$\boldsymbol{\mu}$ is a vector which contains the Miller *et al.* (2010) estimates of the parameters.
These estimates and the variance-covariance matrix are given in table A3.1 below:

In the final run, the calibration parameters are fixed to those estimated by Miller *et al*. (2010).

App. A3, Table A3.1: Estimates and variance-covariance matrix for the calibration parameters (Miller, pers. commn).

μ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
	0.4713	1.4163	3.5086
Σ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
$ln(F_2)$	0.006674	-0.002515	-0.002559
$ln(F_1\text{-}F_2)$	-0.002515	0.051592	-0.007601
$ln(X_2\text{-}X_1)$	-0.002559	-0.007601	0.006757

A3.3. Estimation of precision

Where quoted, CV's or 95% probability interval estimates are based on the Hessian.

A3.4. Model parameters

A3.4.1. Fishing selectivity-at-age:

For the NEFSC offshore surveys, the fishing selectivities are estimated separately for ages 1 to age 6 and are flat thereafter. For the Massachusetts inshore spring survey, the selectivities are estimated separately for ages 1 to 4. The estimated proportional decrease from ages 3 to 4 is assumed to continue multiplicatively to age 6; this decrease parameter is bounded by 0, i.e. no increase is permitted. For all three surveys, age 0 is not considered.

The commercial fishing selectivity, S_a, is estimated separately for ages a_{minus} to a_{plus} (1 to 9) It is taken to differ over four periods: a) pre-1982, b) 1982-1988, c)1989-2004, and d) 2005-present. The selectivities are estimated directly for the last three periods. For the pre-1982 period, the selectivity is taken as that for the 1989-1988 block, but shifted one year to the left. For the implementations in this paper, given that there were difficulties with imprecise estimates at larger ages for period d) given its shortness, a common selectivity at age was estimated across all periods for ages 7 and above.

In the final run, the commercial fishing selectivities are taken to be flat from age 5 onwards.

A3.4.2. Other parameters

Model plus group			
m	9		
Commercial CAA			
a_{minus}*	1		
a_{plus}	9		
Survey CAA	NEFSC spr	NEFSC fall	MASS spr
a_{minus}*	1	1	1
a_{plus}	9	9	4
Natural mortality:			
M	Age independent: i) 0.2 for all years ii) 0.2 until 1988, thereafter a linear increase to 0.4 in 2003 and constant at 0.4 thereafter		
Proportion mature-at-age:			
f_a	Input, see main text		
Weight-at-age:			
$w_{y,a}^{strt}$	input, see main text		
$w_{y,a}^{mid}$	input, see main text		
$w_{y,a}^{surv}$	input, see main text		
Stock recruit residuals std dev:			
σ_R	0.6		
Initial conditions :			
$N_{y0,a}$	estimated directly for ages 0 to xx depending on AIC criterion		
ϕ	estimated		

* Strictly not a minus group anymore since the catches at age zero are ignored.

A3.5.Biological Reference Points (BRPs)

It is possible to estimate BRPs internally within the assessment by fitting the stock-recruitment relationship directly within the assessment itself. The F_{MSY} estimate is obtained by using a bisection routine to find where the derivative of the equilibrium catch vs F relationship has a zero derivative. This has to be based on point estimates, so that the estimate of other BRPs are conditional on this point estimate of F_{MSY}, with no Hessian based CV available for this quantity.

For some results reported here, however, the stock-recruitment relationships are fitted to the estimates of recruitment and spawning biomass provided by the various assessments to provide a basis to estimate BRPs. The rationale for estimation external to the assessment itself is to avoid assumptions about the form of the relationship influencing the assessment results. These fits are achieved by minimising the following negative log-likelihood, where the $e^{-\frac{\sigma_R^2}{2}}$ term is added for consistency with equation A3.4, i.e. the stock-recruitment curves estimated are mean-unbiased rather than median unbiased:

$$-\ln L = \sum_{y=y1}^{2009} \left[\frac{\left(\ln(N_{y,0}) - \ln\left(\hat{N}_{y,0} e^{-\frac{\sigma_R^2}{2}} \right) \right)^2}{2\left((\sigma_R)^2 + (CV_y)^2 \right)} \right] \tag{A3.39}$$

where

$N_{y,0}$ is the "observed" (assessment estimated) recruitment in year y,

$\hat{N}_{y,0}$ is the stock-recruitment model predicted recruitment in year y,

σ_R is the standard deviation of the log-residuals which is input (and set here to 0.6), and

CV_y is the Hessian-based CV for the "observed" recruitment in year y.

Note that the differential precision of the assessment estimates of recruitment is taken into account, and that the summation ends at 2009 because little by way of direct observation is as yet available to inform estimates of recruitment for 2010 and 2011.

For the final run, the stock-recruitment relationship and hence also the BRP's are estimated internally in the model fitting minimisation process.

A3.6. Projections

The first step in the projections process is generating a future catch vector corresponding to a harvesting strategy, with $0.75F_{MSY}$ being the strategy chosen for this purpose, where this corresponds to a fishing mortality vector with a maximum F of $0.75F_{MSY}$ and a selectivity-at-age equal to that estimated for the most recent commercial block (2005-2011).

The starting numbers at age vector for ages 0 to 9+ is the best estimate obtained from the assessment for the start of the year 2012. Error is included for ages 0 to 3 because these are poorly estimated in the assessment given limited information on these year-classes; thus: $N_{2012,a} \to N_{2012,a}e^{\varepsilon_a}$ with ε_a from $N\left(0,(\sigma_R)^2\right)$. For subsequent years, age-0 recruitment is determined by the stock-recruitment relationship of equation (A3.4), i.e. incorporating a stochastic component with σ_R set to the same value as used in the assessment, i.e. 0.6. For 2012, for which a fixed catch estimate of 3767 t is provided, the catch equation is solved to provide a value for F. For subsequent years, the harvest strategy chosen determines the F vector, and the catch taken is calculated from that together with the projected numbers-at-age vector.

A total of 1000 forward simulations are run incorporating recruitment variability. This provides a distribution of catches for each future year. For the selected catch vector, the value for each year is then set equal to the median of the distribution calculated for that year.

For “consequences” plots, the process set out above provides the results reported in the main text for the case where the catches are implemented for a real situation corresponding to the assessment from which those catches were derived. However, when the catches implemented were derived from a different assessment, the process is then repeated, though now with fixed input catches for each year to which the catch equation is applied to find the corresponding full-selectivity *F* value, and hence project the numbers-at-age vector forwards. This then yields 1000 values each year for quantities such as spawning biomass and fully selected fishing mortality. The medians of these distributions for each year then provide the trajectories for the quantities shown in the consequences plots.

Weights-at-age for the projections are taken as the average of the 2009-2011 values (tables in main text) to compute spawning biomass and catches.

References

Butterworth DS and Rademeyer RA. 2012. An investigation of differences amongst SCAA and ASAP assessment (including Reference Point) estimates for Gulf of Maine Cod. Document submitted to the March 2012 meeting of the New England Fisheries Management Council SSC . 34pp.

Miller TJ, Das, C, Politis PJ, Miller AS, Lucey SM, Legault CM, Brown RW and Rago PJ. 2010. Estimation of *Albatross IV* to *Henry B. Bigelow* Calibration Factors. U.S. Depart. of Commerce, Northeast Fisheries Science Center Ref. Doc. 10-05; 233 pp.

[SAW55 Editor's Note: The SARC-55 review panel did not recommend adopting the GOM cod Statistical Catch-at-Age (SCAA) assessment results that are in Appendices A.2 – A.5. These appendices are included in this report to document and demonstrate the work that was done by the SAW cod Working Group for the December 2012 peer review.]

Appendix A.4. Applications of Statistical Catch-at-Age Assessment Methodology to Gulf of Maine cod, October 2012.

Summary

The Statistical Catch-at-Age assessment conducted by the authors earlier in 2012 is updated to take account of more recent data, and refined by introducing two new features: fitting to length distribution data for the NEFSC surveys in the 1960s for which age information is not available, and adjusting the externally provided estimates of the *Bigelow-Albatross* calibration function through adding the calibration information contained in cohorts present both before and after the survey vessel change to the model fitting process. The options selected for the Base Case assessment are those motivated in the assessment conducted earlier in the year. The resultant estimate of the 2011 spawning biomass is 12.0 thousand tons with a CV of 13%. The survey calibration function is slightly modified, resulting in an increase of about 3% in the 2011 spawning biomass. The survey catch-at-length data are consistent with previous estimates of poor recruitments from relatively large spawning biomasses in the 1960s. This last result is robust under a range of sensitivity tests, and is suggestive of a Ricker-like stock-recruitment relationship for the stock. These sensitivity tests also suggest that the 2011 spawning biomass estimate of 12.0 thousand tons is robustly determined. The range of this estimate across these sensitivities is 9.9 to 16.6 thousand tons, with lower values arising from the sqrt(p) weighting approach for proportions data and from forcing selectivities above age 6 to be flat, and the higher values coming from inclusion of the stock-recruitment function in the assessment and increasing the value of *M*. The evidence for commercial selectivities to be domed relative to the NEFSC surveys appears reasonably strong, but less so that for the selectivities for these surveys themselves to be domed.

Introduction

This paper is an extension of the Statistical Catch-at-Age (SCAA) assessment advocated in Butterworth and Rademeyer (2012) which was presented to a meeting of the NEFMC SSC in March earlier this year (2012). The NBC2 variant selected there is extended here to incorporate one further year's data, and refined to also take account of length distribution data available for the un-aged pre-1970 NEFSC surveys, and to use the population model fit to improve estimates of the *Bigelow-Albatross* survey calibration relationship.

The paper also checks the sensitivity of results for its Base Case assessment to some of the factors on which discussions at the SSC indicated an absence of unanimity. For the most part, only single factor changes to the Base Case have been run. Further runs combining more than one change to such factors could be specified by the coming October assessment meeting, and run during its duration, if required.

This paper focuses on assessment aspects, with a further paper on the estimation of reference points to follow shortly.

Data and Methodology

The catch and survey based data (including catch-at-length information) and some biological data used for the analyses are listed in Tables in App. A4, Appendix A.

The details of the SCAA assessment methodology are provided in App. A4, Appendix B of this appendix.

Results

Results are given for a Base Case (Run 1) and various sensitivities. As indicated in the Introduction, this Base Case makes choices for various options in the assessment in line with those motivated in Butterworth and Rademeyer (2012), specifically:

- Start in 1964
- Estimate the first three numbers-at-age for 1964, and then the parameter ϕ (see equation B11) to provide estimates for the numbers at older ages – note that unlike in Butterworth and Rademeyer (2012), the value of ϕ is not restricted by bounds in this estimation process
- Set $M = 0.2$ for all ages
- Use the "adjusted" lognormal formulation of equation B.16 to describe the distribution of proportions-at-age (in relation to numbers of fish)
- Admit the possible estimation of domed selectivity for the NEFSC surveys and for the commercial fishery
- Do not fit the stock-recruitment function is within the population model fitting procedure
- Make allowance for additional variance when fitting to time series of abundance indices

- Fit to the aggregated abundance indices as expressed in terms of biomass rather than numbers.

In addition, this Base Case incorporates what are considered to be improvements to the model:

- Allow the assessment data to update the independent estimate of the *Bigelow-Albatross* calibration function parameters that have been determined from experimental paired trawls (see section B.2.7)
- Incorporate data on NEFSC survey length compositions from the 1960s when catches from these surveys were not aged.

App. A4, Tables 1-4 list results for Base Case and various sensitivities, focusing on the contributions to the assessment period considered, as well values for the survey catchabilities *q*.

App. A4, Figs 1-4 provide estimates and diagnostic plots for the Base Case fit, while App. A4, Fig. 5 shows how the *Bigelow-Albatross* survey calibration function has been updated. App. A4, Figs 6-12 and 14-15 show results for various sensitivities to the Base Case, while App. A4, Fig. 13 shows results for a retrospective analysis of the Base Case.

Discussion

The Base Case results in App. A4, Table 1 and Fig. 1 show a spawning biomass that has been decreasing somewhat over the last two years, essentially as a consequence of a decline in recruitment since 2005. As to be expected, the precision of spawning biomass estimates is less in the 1960s and 70s when less age information is available, and also drops for the most recent few years. In contrast the annual recruitment estimates are all fairly precise except for the final year (2011). Survey catchability (*q*) estimates are all below 1, and non-trivial levels of additional variance are estimated for all three abundance indices. The 2011 spawning biomass is estimated at 12.0 thousand tons with an associated CV of 13%.

For this Base Case, both commercial and NEFSC survey selectivities are estimated to be appreciably domed (Fig. 2). Standard fit diagnostics for both abundance indices and proportion-at-age data in Fig. 3 show broadly reasonable fits, though there is some evidence of systematic trends in the proportion-at-age residuals for the Massachusetts Spring survey and for the commercial catch. The last might be ameliorated by allowing for a change in the recent commercial selectivity pattern (for whose values the model often struggles to obtain convergence) to occur in the mid-2000s. The fits to the survey proportions-at-length data over the 1960s (App. A4, Fig. 4) is fair, but does evidence some data conflict with proportions at the smaller lengths underestimated for the spring surveys and overestimated for the autumn surveys, with the reverse effect at larger lengths.

Updating the *Bigelow-Albatross* calibration function in the model suggests that the results from the paired trawls experiment slightly overestimated the factor at larger lengths, but similarly underestimated it at smaller lengths (App. A4, Fig. 5). Using the existing *Bigelow-Albatross* calibration function without this model-fitting refinement would result in a slightly lower 2011 spawning biomass of 11.7 thousand tons

Moving on to sensitivity tests, alternative starting years for the assessment have a negligible impact on estimates of the current spawning biomass, but there is some sensitivity shown by the estimates of spawning biomass in the 1960s, though these still remain high relative to estimates for the last two decades (App. A4, Table 1, Runs 2a-d and App. A4, Fig. 6). For a 1982 start, the catchability coefficient (q) estimate for the NEFSC Spring survey increases above 1 to 1.09.

The parameter ϕ related to the starting numbers-at-age vector for 1964 is estimable, but with quite a high CV of 47%, so that it is not surprising that the starting spawning biomass is not that well determined (App. A4, Table 1, Runs 3a-e and App. A4, Figs 1 and 6). The selection of how many ages to estimate starting numbers-at-ages to estimate in this starting vector is clearly suggested to be three (ages 0-2) for the Base Case by the process of considering successive improvements in –lnL as this number is increased (App. A4, Table 2, Runs 4a-h). Alternative selections for both these factors have minimal impact on estimates of the 2011 spawning biomass.

Increasing the weight given to the survey catch-at-length data from the 1960s suggests a slight decrease in recruitment in the 1960s (App. A4, Table 3, Runs 5a-b and Fig. 8, so that these data do not contradict earlier inferences of poor recruitment over this period (when spawning biomass was relatively high) which were made in the absence of this information (Butterworth and Rademeyer, 2011 and 2012). If less weight is placed on the input information for the *Bigelow-Albatross* calibration function, the calibration factor moves still lower at higher lengths, and still higher at lower lengths (App. A4, Table 3, Run 6 and Fig.9). This indicates that the information on calibration provided by the presence of common cohorts in both the pre- and post-vessel-change periods points somewhat differently from the independent experiment in regard to the values of the calibration function, so that estimates of this may change further as more data from these cohorts accumulates over the next few years.

Including estimation of a Ricker stock recruitment function in the assessment leads to a higher estimate of the 2011 spawning biomass of about 14 thousand tons as a result of increased estimates of recruitment over recent years (App. A4, Table 3, Run 7 and Fig. 10). In contrast using the sqrt(p) option of weighting proportion-at-age data in the log likelihood in place of the “adjusted” lognormal see this estimate drop to some 11 thousand tons (App. A4, Table 3, Run 8). App. A4, Fig. 3 also shows the fit residuals for age and length distribution data under this alternative; there is no obvious improvement or deterioration in the pattern of these residuals for the sqrt(p) compared to the “adjusted” lognormal run, and so no clear reason from these plots to prefer one distributional form over the other.

Sensitivities which modify the commercial selectivity-at-age for the pre-1982 period to reflect a relatively greater catch of smaller fish (Palmer, pers. commn, advises that nets in that period tended to have smaller mesh sizes) have scarcely any impact on spawning biomass trends, and are somewhat less preferred in likelihood terms (App. A4, Table 3, Runs 9a-b, and Fig. 11). Increasing natural mortality *M* from 0.2 to 0.3 increases spawning biomass estimates as would be expected, and is slightly preferred in likelihood terms (App. A4, Table 3, Run 10 and Fig. 12).

App. A4, Fig. 13 shows the results from a retrospective analysis for the Base Case assessment. There is a large difference evident for assessments carried out in 2007 and 2008 (possibly linked to the high NEFSC Spring survey estimates at that time), but thereafter any retrospective effect is fairly small.

Runs 11 and 12 in Table 4 show the consequences of forcing either the survey selectivity or both the survey and commercial selectivities to be flat at older ages above 6. These correspond to estimating 3 or 9 fewer parameter values, with associate deterioration in –lnL by some 7 or 24 points respectively. Assuming domes is thus AIC justified in both cases. Forcing this flatness results in lower spawning biomass (App. A4, Fig. 14), though most of this effect comes from forcing flatness in the commercial selectivity function, e.g. with the survey selectivities only forced to be flat, the 2011 spawning biomass estimate drops only from 12.0 to 11.6 thousand tons (a 4% effect).

App. A4, Table 4 and Fig. 15 show results from repeating the flat selectivity sensitivities of Runs 11 and 12, but here under the sqrt(p) weighting approach for proportions data in place of the "adjusted" lognormal distribution assumption. Again the assumption of a dome in the commercial selectivity is AIC justified, but the extension of that to the NEFSC survey data is marginal in that respect. Butterworth and Rademeyer (2012) found that the Massachusetts Spring survey showed a selectivity pattern which was flat for the sqrt(p) case rather than decreasing at ages above 3 as in the case of the "adjusted" lognormal, which they considered of questionable realism given the more near-shore area which this survey covers. However this argument for preferring the "adjusted" lognormal is less clear for these updated computations. These results may be compromised by failure to achieved convergence in some of these runs (see App. A4, Tables 3 and 4 captions), though as this arises only from sensitivity of the process to estimation of the commercial selectivity parameters for the more recent period, this seems unlikely to have a great influence on abundance estimates and trends. Overall the case for a dome in the commercial relative to the NEFSC survey catches seems reasonably strong, but that for a dome in these survey selectivities themselves less so.

Conclusions

Key features of these results are:

a) Although there is some uncertainty about spawning biomass estimates in the 1960s, nevertheless these are robustly estimated to be towards the higher end of the range of spawning biomasses through the 1964-2011 period considered. Further the recruitments at that time are precisely and robustly estimated to have been towards the low end of the range of recruitment levels throughout this period. This is suggestive of a Ricker-type stock-recruitment relationship, something that is not *a priori* surprising for a cod stock given the species' cannibalistic behaviour.

b) The spawning biomass in 2011 is relatively robustly estimated at 12.0 thousand tons. The range of this estimate across the sensitivities examined is 9.9 to 16.6 thousand tons, with lower values arising from the sqrt(p) weighting for proportions data and from forcing selectivities above age 6 to be flat, and the higher values coming from including the stock-recruitment function in the assessment and increasing the value of *M*.

Some Working Group members prefer including a stock recruitment relationship in fitting assessment models. This was not included in the Base Case here so that other sensitivities could be examined without the inclusion of the relationship perhaps confounding interpretation of the results.

Acknowledgements

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References

Butterworth DS and Rademeyer RA. 2011. Applications of statistical catch-at-age assessment methodology to Gulf of Maine cod. Document submitted to the 17-21 October, 2011 workshop on the assessment of Gulf of Maine cod, Falmouth. 31pp.

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Appendix A4. Tables

App. A4, Table 1: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix for definition of some of the symbols used. Note that Runs 2a) to 2d) were conducted with the same number of ages in the starting numbers-at-age vector as for the Base Case (*viz*. ages 0-2); later starting years, it is probable that extending this estimation to further ages is statistically justifiable.

	1) Base Case		2) Alternative start year								3) Alternative fixed values of ϕ									
			2a)		2b)		2c)		2d)		3a) ϕ=0.0		3b) ϕ=0.05		3c) ϕ=0.1		3d) ϕ=0.2		3e) ϕ=0.3	
Start year	1964		1965		1967		1970		1982		1964		1964		1964		1964			
-lnL: overall	-162.8		-158.9		-148.5		-147.9		-95.0		-160.2		-161.7		-162.3		-162.2		-159.4	
-lnL: survey	-37.5		-37.4		-35.5		-32.4		-17.3		-37.5		-37.5		-37.5		-37.3		-36.8	
-lnL: comCAA	-129.6		-129.6		-129.5		-129.5		-120.8		-129.6		-129.6		-129.3		-129.7		-129.5	
-lnL: survCAA	-13.9		-6.4		6.8		17.7		47.6		-13.2		-13.7		-13.9		-13.5		-12.6	
-lnL: survCAL	22.1		18.1		13.3		0.0		0.0		24.0		23.1		22.3		22.1		23.5	
-lnL: RecRes	1.3		1.3		1.3		1.3		1.2		1.3		1.3		1.3		1.3		1.3	
-lnL: calibration	-5.2		-5.0		-5.0		-5.1		-5.6		-5.2		-5.2		-5.3		-5.2		-5.2	
$N_{y1,0}$	7.49	(0.13)	4.15	(0.17)	3.63	(0.17)	4.21	(0.16)	12.94	(0.07)	7.55	(0.13)	7.53	(0.13)	7.42	(0.13)	7.45	(0.13)	7.43	(0.13)
ϕ	0.14	(0.47)	0.45	(0.14)	0.29	(0.15)	0.10	(0.70)	0.52	(0.07)	0.00	-	0.05	-	0.10	-	0.20	-	0.30	-
B^{sp}_{2011}	12.02	(0.13)	12.01	(0.13)	11.97	(0.14)	11.98	(0.16)	12.03	(0.17)	12.03	(0.14)	12.03	(0.13)	12.04	(0.13)	12.03	(0.13)	12.00	(0.13)
B^{sp}_{1982}	32.25	(0.06)	32.24	(0.07)	32.25	(0.06)	32.25	(0.12)	32.31	(0.10)	32.25	(0.06)	32.25	(0.06)	32.40	(0.06)	32.21	(0.06)	32.25	(0.06)
B^{sp}_{y1}	42.40	(0.24)	25.32	(0.20)	42.52	(0.16)	45.17	(0.32)	32.31	(0.10)	56.88	(0.15)	51.58	(0.14)	46.82	(0.14)	36.68	(0.14)	28.46	(0.14)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.91	0.19	0.91	0.19	0.91	0.19	1.09	0.24	0.91	0.19	0.91	0.19	0.90	0.19	0.91	0.19	0.91	0.19
NEFSC fall	0.83	0.07	0.84	0.07	0.84	0.07	0.84	0.07	0.73	0.10	0.82	0.07	0.83	0.07	0.83	0.07	0.84	0.07	0.85	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.16	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13

App. A4, Table 2: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities relating to the initial numbers-at-age vector. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used.

	4) Fewer or more $N_{y1,a}$ values estimated															
	4a) age 0		4b) ages 0-1		4c) ages 0-2 (BC)		4d) ages 0-3		4e) ages 0-4		4f) ages 0-5		4g) ages 0-6		4h) ages 0-7	
Start year	1964		1964		1964		1964		1964		1964		1964		1964	
-lnL: overall	-146.7		-147.4		-162.8		-163.1		-163.7		-163.8		-164.9		-164.9	
-lnL: survey	-36.8		-36.7		-37.5		-37.3		-37.4		-37.3		-37.6		-37.6	
-lnL: comCAA	-129.7		-129.8		-129.6		-129.8		-129.6		-130.0		-129.6		-129.5	
-lnL: survCAA	-1.1		-2.2		-13.9		-13.7		-13.9		-13.5		-14.0		-14.0	
-lnL: survCAL	24.6		25.0		22.1		21.7		21.1		20.9		20.2		20.2	
-lnL: RecRes	1.3		1.3		1.3		1.3		1.3		1.3		1.3		1.3	
-lnL: calibration	-5.0		-5.0		-5.2		-5.2		-5.2		-5.2		-5.2		-5.2	
$N_{y1,0}$	7.93	(0.08)	7.17	(0.14)	7.49	(0.13)	7.48	(0.13)	7.57	(0.13)	7.71	(0.13)	7.56	(0.13)	7.57	(0.13)
ϕ	0.38	(0.15)	0.40	(0.16)	0.14	(0.47)	0.19	(0.45)	0.29	(0.44)	0.43	(0.44)	0.68	(0.39)	0.87	(1.19)
B^{sp}_{2011}	12.01	(0.13)	12.02	(0.13)	12.02	(0.13)	12.01	(0.13)	12.01	(0.18)	11.97	(0.14)	12.03	(0.13)	12.03	(0.13)
B^{sp}_{1982}	32.29	(0.07)	32.34	(0.08)	32.25	(0.06)	32.39	(0.06)	32.29	(0.06)	32.58	(0.06)	32.31	(0.06)	32.31	(0.06)
B^{sp}_{y1}	26.88	(0.24)	26.20	(0.24)	42.40	(0.24)	39.90	(0.25)	38.50	(0.24)	36.46	(0.24)	34.55	(0.22)	33.95	(0.23)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.92	0.19	0.91	0.19	0.91	0.19	0.91	0.19	0.90	0.19	0.91	0.19	0.91	0.19
NEFSC fall	0.84	0.07	0.84	0.07	0.83	0.07	0.83	0.07	0.83	0.07	0.82	0.07	0.83	0.07	0.83	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13

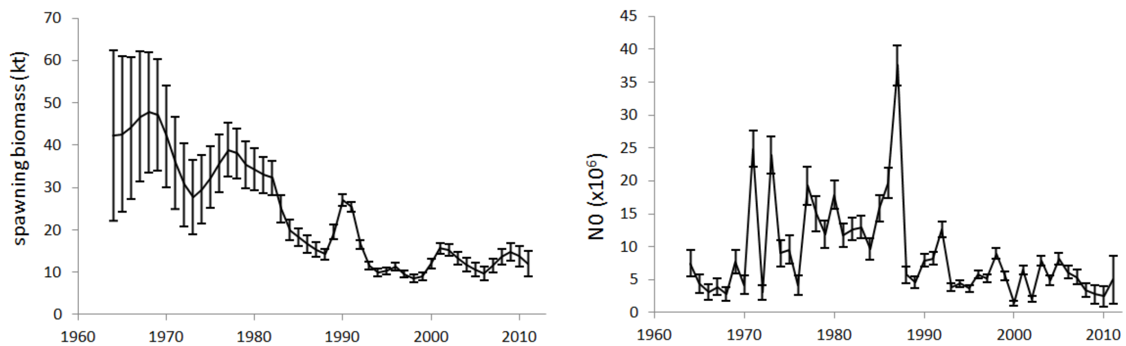
App. A4, Table 3: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used. Runs marked * did not converge fully. The associated sensitivity of the fitting process arises in estimating the selectivity vector for the second commercial period. In all such cases, a rerun was conducted with this vector fixed at the best estimates that had been achieved thus far, and convergence was readily achieved.

	1) Base Case		5) Higher weight for CAL				6) Less weight input calibration		7) Ricker internal		8) sqrt(p) option for CAA and CAL weighting		9) Alternative pre-1982 commercial selectivity				10) Higher *M*	
			5a) W_{CAL}=1		5b) W_{CAL}=5								9a) option 1		9b) option 2		10a) M=0.3	
Start year	1964		1964		1964	*	1964	*	1964		1964	*	1964		1964		1964	*
-lnL: overall	-162.8		15.1		660.2		-160.2		-125.5		-2503.7		-161.2		-158.4		-164.6	
-lnL: survey	-37.5		-37.6		-39.1		-38.0		-35.4		-36.7		-37.8		-37.8		-37.9	
-lnL: comCAA	-129.6		-129.3		-131.0		-129.7		-129.5		-737.6		-128.8		-128.0		-131.3	
-lnL: survCAA	-13.9		2.1		89.6		-16.1		-12.6		-1611.9		-13.0		-10.8		-12.9	
-lnL: survCAL	22.1		183.9		744.8		22.1		22.0		-113.4		22.2		22.3		21.8	
-lnL: RecRes	1.3		1.2		1.3		1.3		35.3		1.4		1.2		1.2		0.7	
-lnL: calibration	-5.2		-5.2		-5.3		1.8		-5.3		-5.5		-5.2		-5.2		-5.0	
$N_{y1,0}$	7.49	(0.13)	6.89	(0.12)	7.45	(0.11)	7.52	(0.13)	7.26	(0.13)	7.23	(0.14)	8.19	(0.13)	8.65	(0.13)	16.30	(0.13)
ϕ	0.14	(0.47)	0.11	(1.21)	0.18	(0.23)	0.14	(0.46)	0.08	(0.99)	0.17	(0.37)	0.12	(0.48)	0.12	(0.45)	0.01	(0.03)
B^{sp}_{2011}	12.02	(0.13)	12.89	(0.48)	11.38	(0.14)	12.04	(0.19)	14.03	(0.17)	10.83	(0.10)	11.94	(0.13)	11.88	(0.11)	16.61	(0.11)
B^{sp}_{1982}	32.25	(0.06)	33.72	(0.25)	29.91	(0.07)	32.24	(0.06)	33.30	(0.07)	28.91	(0.03)	33.29	(0.07)	33.96	(0.04)	39.23	(0.06)
B^{sp}_{y1}	42.40	(0.24)	58.53	(0.86)	34.60	(0.26)	42.15	(0.25)	53.65	(0.29)	33.69	(0.19)	42.54	(0.24)	42.54	(0.18)	74.73	(0.11)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.86	0.18	0.89	0.17	0.91	0.19	0.89	0.20	0.95	0.19	0.92	0.18	0.93	0.17	0.63	0.19
NEFSC fall	0.83	0.07	1.03	0.08	1.57	0.07	0.84	0.07	0.82	0.07	0.85	0.07	0.86	0.08	0.87	0.08	0.58	0.07
MADMF spring	0.20	0.13	0.19	0.13	0.20	0.13	0.20	0.13	0.19	0.14	0.32	0.13	0.20	0.13	0.20	0.13	0.13	0.12

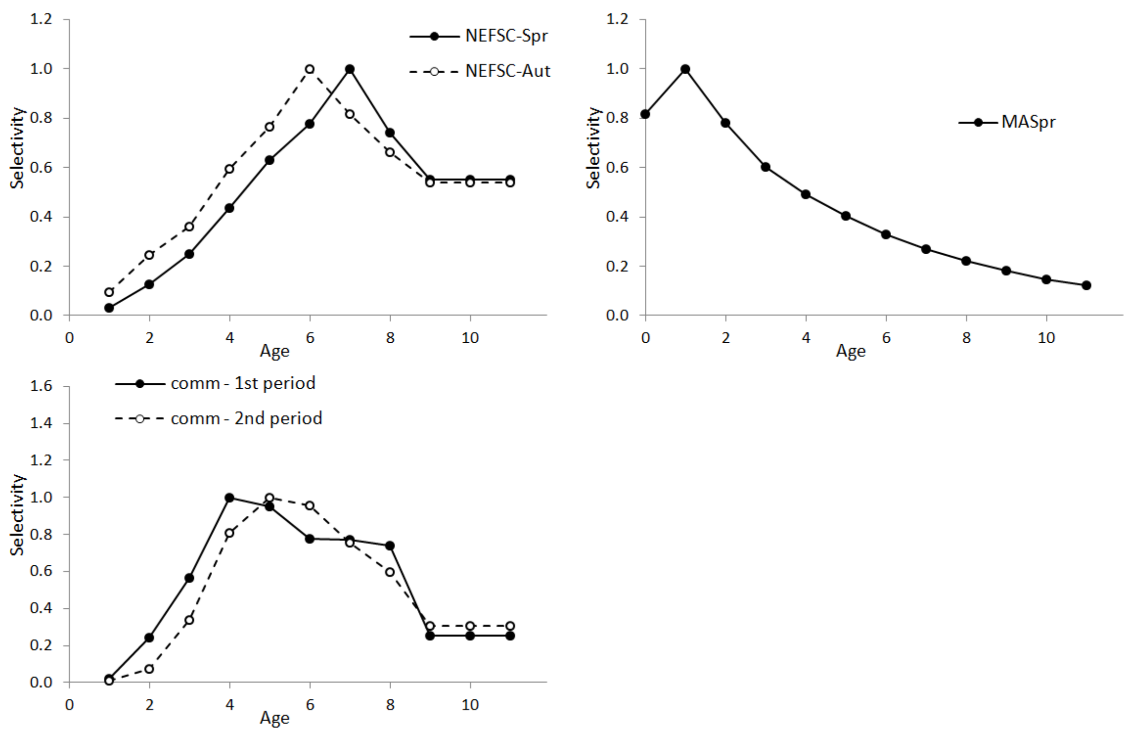
App. A4, Table 4: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. $y1$ refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used. Runs marked * did not converge fully. The associated sensitivity of the fitting process arises in estimating the selectivity vector for the second commercial period. In all such cases, a rerun was conducted with this vector fixed at the best estimates that had been achieved thus far, and convergence was readily achieved.

	1) Base Case		11) Flat NEFSC survey selectivities		12) Flat NEFSC survey and commercial selectivities		8) sqrt(p) option for CAA and CAL weighting		13) sqrt(p) option and flat NEFSC surv sel		14) sqrt(p) option and flat NEFSC surv and com sel	
Start year	1964		1964	*	1964	*	1964	*	1964	*	1964	*
-lnL: overall	-162.8		-155.6		-138.5		-2503.7		-2501.0		-2491.6	
-lnL: survey	-37.5		-39.3		-36.8		-36.7		-37.8		-37.1	
-lnL: comCAA	-129.6		-129.2		-120.5		-737.6		-737.3		-735.0	
-lnL: survCAA	-13.9		-6.8		1.3		-1611.9		-1609.3		-1601.5	
-lnL: survCAL	22.1		23.3		21.6		-113.4		-112.4		-113.8	
-lnL: RecRes	1.3		1.4		1.4		1.4		1.4		1.5	
-lnL: calibration	-5.2		-5.0		-5.4		-5.5		-5.5		-5.7	
$N_{y1,0}$	7.49	(0.13)	7.39	(0.13)	6.89	(0.13)	7.23	(0.14)	7.56	(0.13)	6.70	(0.14)
ϕ	0.14	(0.47)	0.17	(0.35)	0.17	(0.36)	0.17	(0.37)	0.20	(0.31)	0.17	(0.37)
B^{sp}_{2011}	12.02	(0.13)	11.63	(0.11)	9.94	(0.10)	10.83	(0.10)	10.78	(0.10)	10.03	(0.09)
B^{sp}_{1982}	32.25	(0.06)	29.80	(0.03)	28.09	(0.03)	28.91	(0.03)	28.56	(0.03)	27.03	(0.03)
B^{sp}_{y1}	42.40	(0.24)	31.88	(0.15)	29.72	(0.16)	33.69	(0.19)	28.61	(0.16)	30.19	(0.16)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.75	0.18	0.90	0.19	0.95	0.19	0.84	0.19	0.92	0.19
NEFSC fall	0.83	0.07	0.73	0.07	0.87	0.07	0.85	0.07	0.79	0.07	0.84	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.14	0.32	0.13	0.32	0.13	0.32	0.13

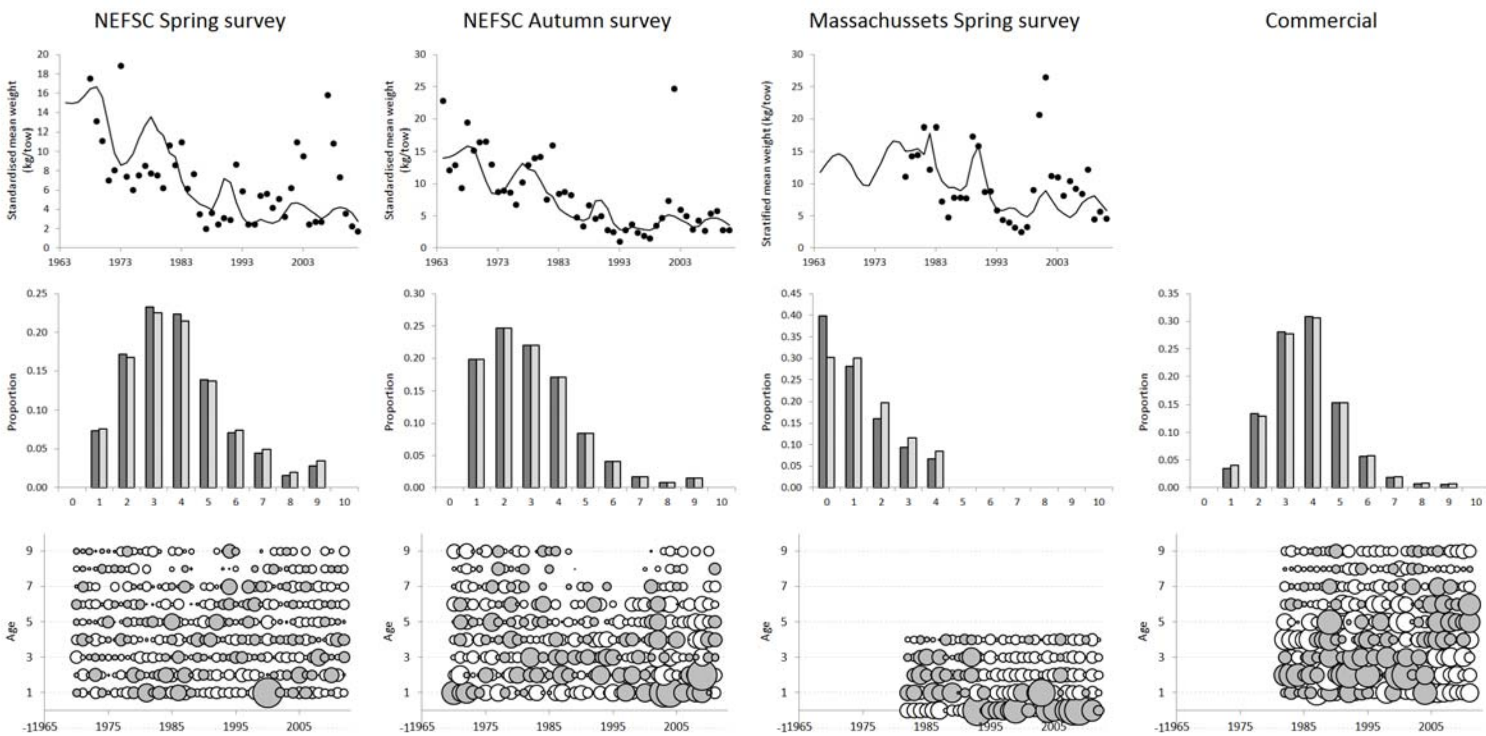
Appendix A4. Figures.



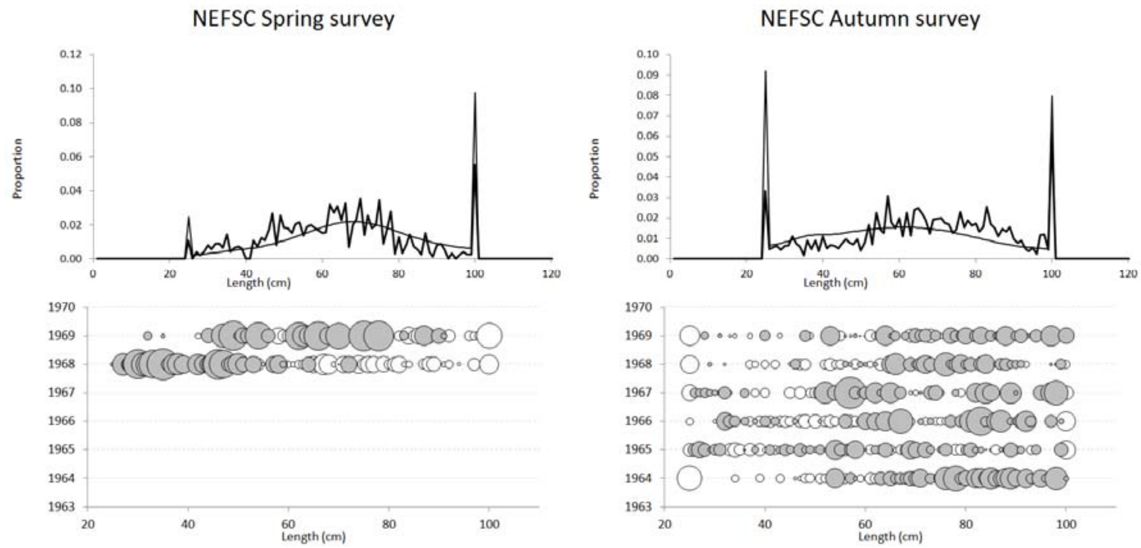
App. A4, Fig. 1: Spawning biomass and recruitment trajectories for the Base Case with ±2 s.e.



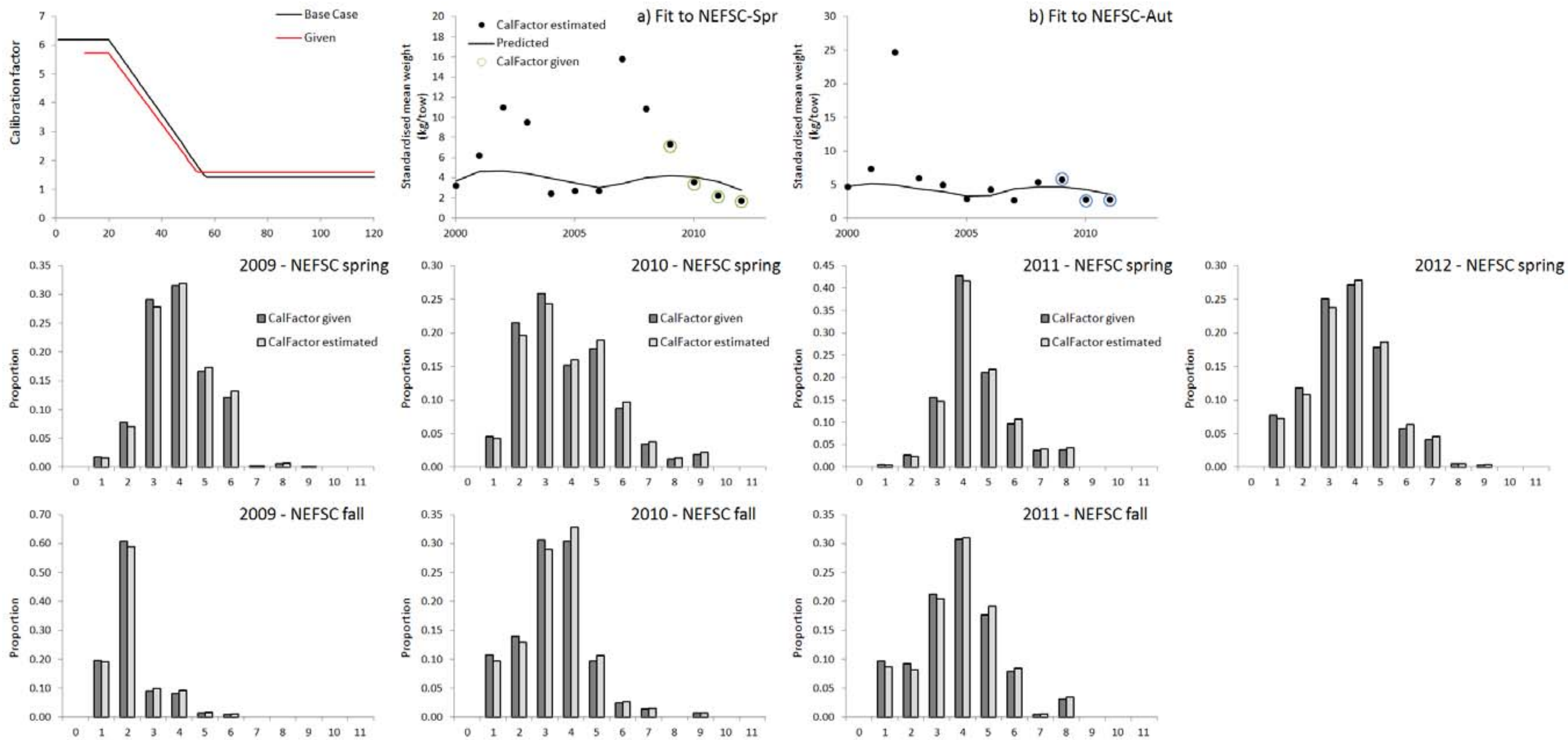
App. A4, Fig. 2: Survey and commercial selectivities-at-age estimated for the Base Case.



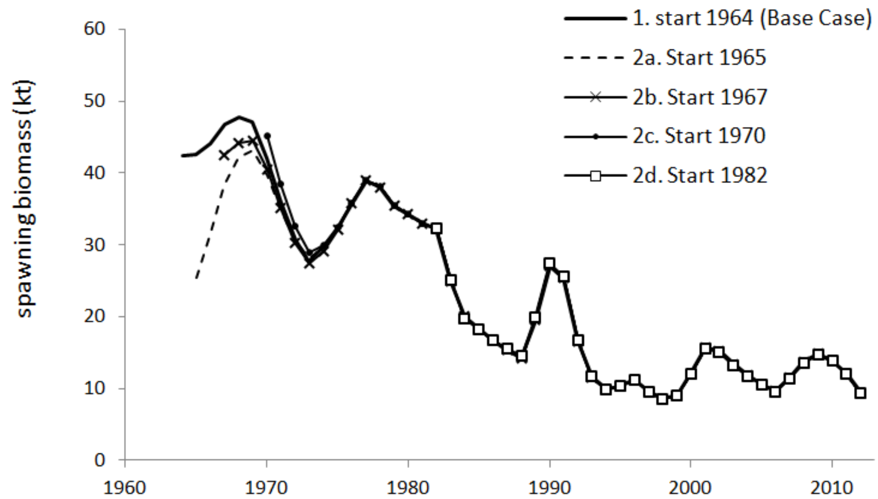
App. A4, Fig. 3: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the Base Case. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white. The last row plots show the comparable standardised residuals for Case 8 (sqrt(p)).



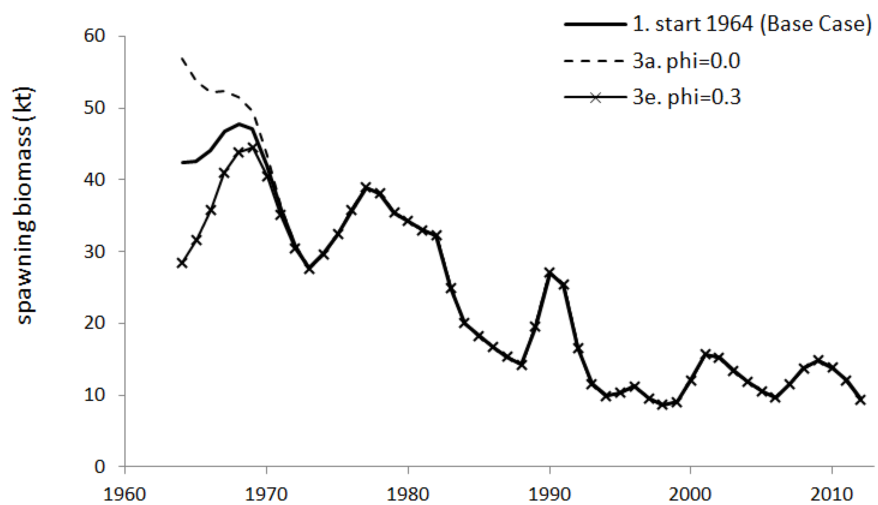
App. A4, Fig. 4: Fits to the survey catch-at-length data for the Base Case. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



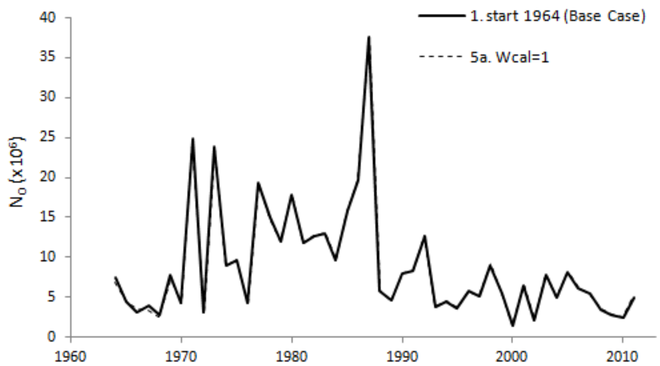
App. A4, Fig. 5: Comparison of calibration results for the calibration factor estimated within the assessment (Base Case) and calibration factor given.



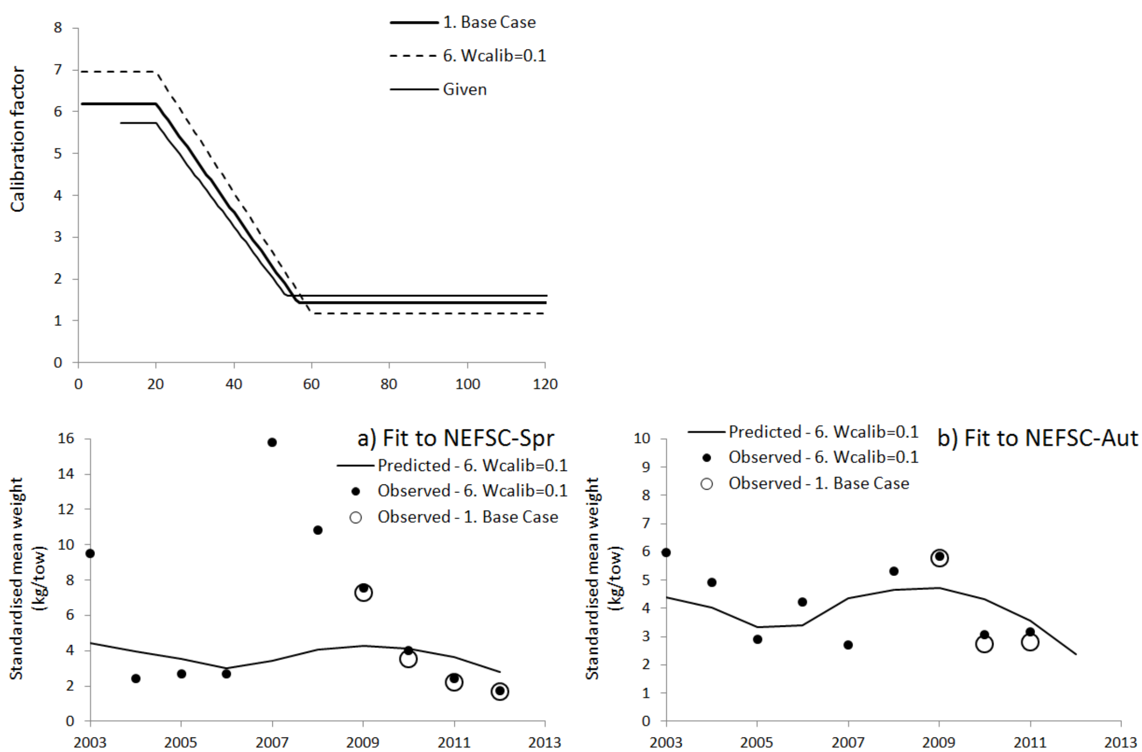
App. A4, Fig. 6: Spawning biomass trajectories for the Base Case and four sensitivities with different starting year.



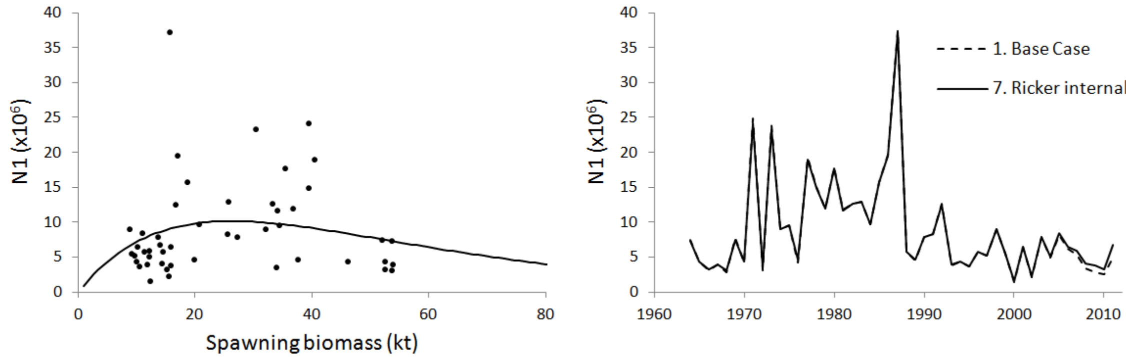
App. A4, Fig. 7: Spawning biomass trajectories for the Base Case and two sensitivities with different fixed ϕ values. For the Base Case, ϕ is estimated (ϕ=0.14).



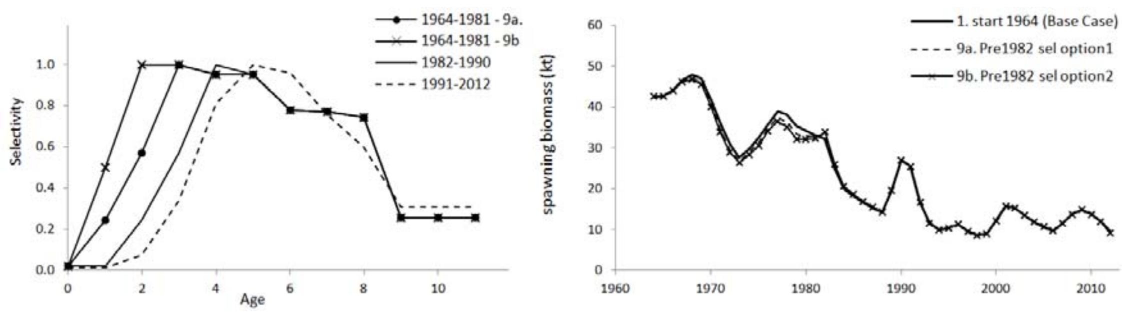
App. A4, Fig. 8: Recruitment trajectories for the Base Case and Case 5a for which more weight is given to the CAL data.



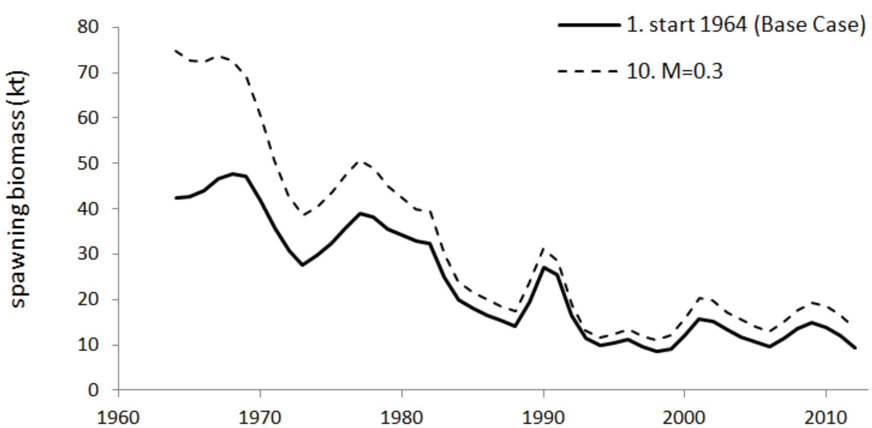
App. A4, Fig. 9: Calibration factor.



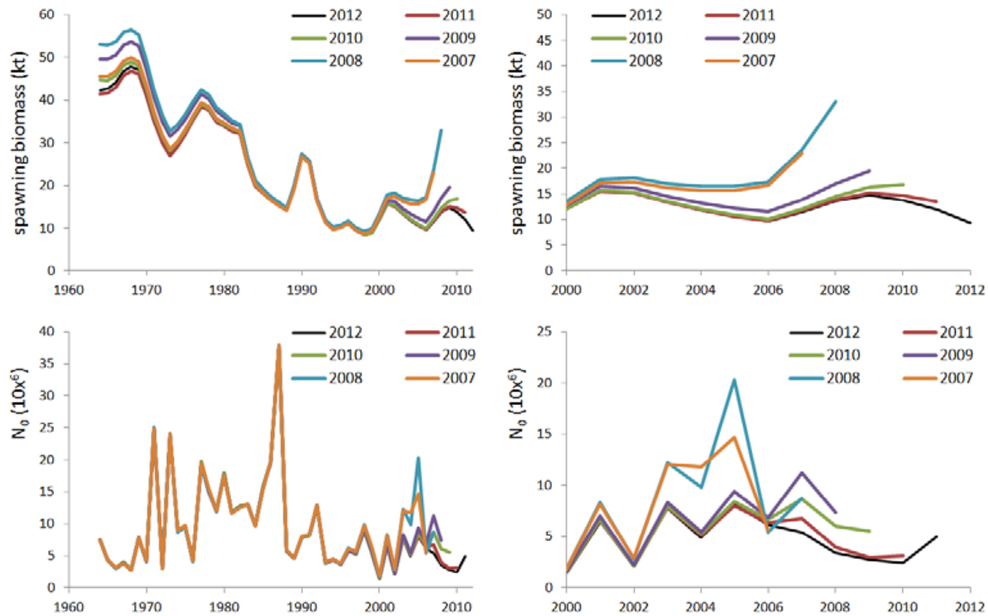
App. A4, Fig. 10: Fits to the stock-recruitment data for the case with an internal Ricker stock-recruitment curve estimated (Case 7) (left-hand plot) and trajectories of recruitment for the Base Case and Case 7.



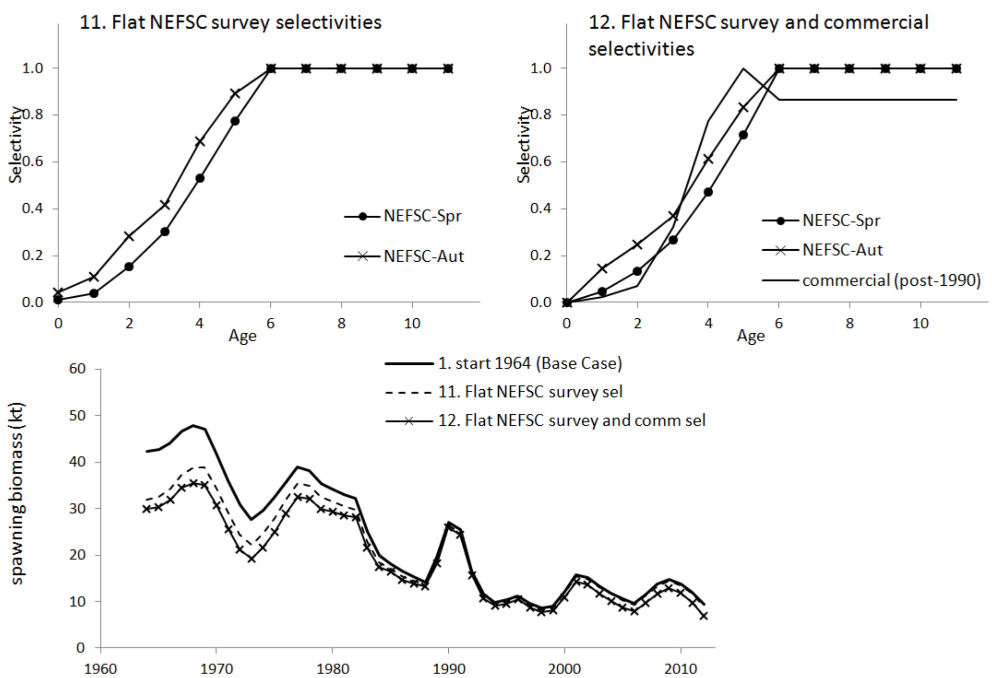
App. A4, Fig. 11: Commercial selectivities (left-hand plot) for cases 9a-b with alternative pre-1982 commercial selectivities and spawning biomass trajectories.



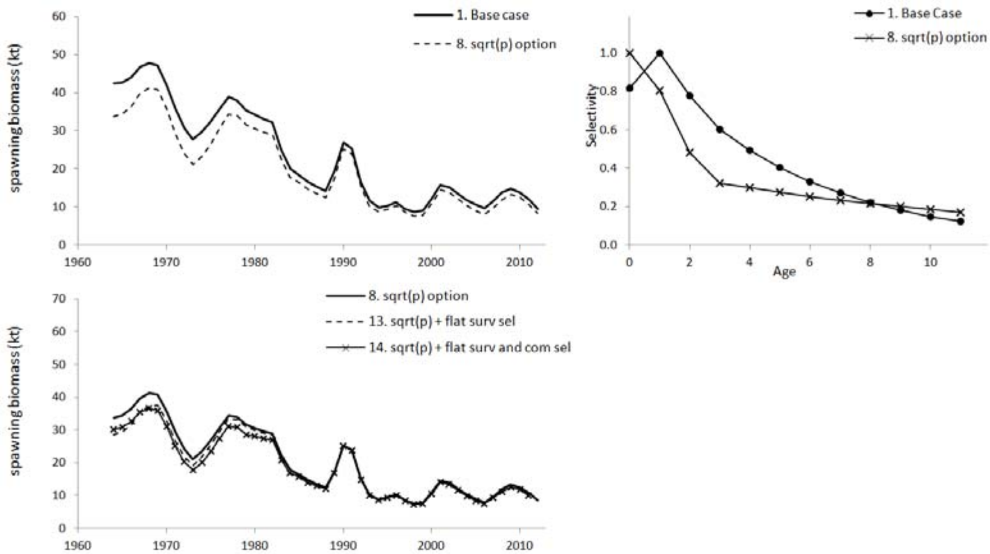
App. A4, Fig. 12: Spawning biomass trajectories for the Base Case and Case 10 with *M*=0.3.



App. A4, Fig. 13 Retrospective analysis for the **Base Case A** for spawning biomass and recruitment.



App. A4, Fig. 14: Selectivities and spawning biomass trajectories for the Base Case and Cases 11 and 12 for which the selectivity functions indicated are forced to be flat above age 6.



App. A4, Fig. 15: Selectivities and spawning biomass trajectories for the Base Case and the sqrt(p) cases (Cases 8, 13 and 14).

Appendix A4 (Appendices A and B within App. A4)

APPENDIX A – Data

App. A4 (Append. A), Table A1: Total catch (incl. USA, DWF and recreational landings, and discards) (thousand metric tons) of Atlantic cod from the Gulf of Maine (NAFO Division 5Y), 1964-2012 (Michael Palmer, pers. commn). The revised discard mortality assumptions have been applied. Note that pre-1982 catches have been increased by 25% in the Base Case to allow for levels of discards suggested by recent analyses by the NEFSC. The 2012 catch is assumed to be 6.830 thousand metric tons, as in 2011; some assumption is needed to be able to take account of the Spring 2012 NEFSC survey given that this occurs though equation B.9 which requires this input.

Year	Total catch	Year	Total catch	Year	Total catch
1964	3.242	1980	12.515	1996	7.757
1965	3.759	1981	16.512	1997	5.814
1966	4.225	1982	17.096	1998	4.578
1967	5.824	1983	16.487	1999	3.078
1968	6.137	1984	12.868	2000	5.823
1969	8.155	1985	14.391	2001	8.055
1970	7.961	1986	12.572	2002	6.509
1971	7.475	1987	12.005	2003	6.497
1972	6.927	1988	10.333	2004	5.766
1973	6.138	1989	13.371	2005	5.441
1974	7.550	1990	19.314	2006	4.268
1975	8.788	1991	20.978	2007	5.527
1976	9.894	1992	12.347	2008	7.375
1977	11.993	1993	9.960	2009	8.355
1978	11.890	1994	9.060	2010	7.670
1979	10.972	1995	7.566	2011	6.830

App. A4 (Append. A), Table A2: Mean weight-at-age (kg) at the beginning of the year for the Gulf of Maine cod stock. Values derived from aggregated commercial landings and discard mean weight-at-age data (mid-year) using procedures described by Rivard (1980) (Michael Palmer, pers. commn) and applying the revised mortality assumptions. Pre-1982, the 1982-1991 average mean weight-at-age is assumed; for 2012, the 2002-2011 average mean weight-at-age is used.

	0	1	2	3	4	5	6	7	8	9	10	11+
1982	0.0024	0.241	0.594	1.165	2.127	4.635	7.622	9.289	9.037	13.235	15.592	18.240
1983	0.0077	0.050	0.501	1.114	1.894	3.136	5.539	6.549	9.962	10.565	12.076	18.713
1984	0.0001	0.075	0.372	1.019	2.021	2.952	4.593	7.118	7.845	11.843	12.834	16.087
1985	0.0146	0.014	0.403	0.910	2.013	3.532	4.608	6.863	9.700	11.147	13.591	14.610
1986	0.0009	0.104	0.316	1.077	1.917	3.670	5.504	6.908	9.315	12.169	13.018	18.102
1987	0.0007	0.028	0.406	0.777	2.273	3.574	5.889	8.079	9.487	11.842	14.008	16.407
1988	0.0003	0.022	0.293	0.980	1.709	4.010	4.927	6.705	10.069	10.761	15.633	12.054
1989	0.0223	0.027	0.292	0.887	2.179	3.172	5.578	6.945	8.799	13.032	14.593	24.532
1990	0.0063	0.095	0.431	0.937	1.742	3.627	5.750	8.043	10.440	13.894	16.575	22.637
1991	0.0069	0.071	0.450	1.083	1.689	2.846	5.654	8.972	11.518	13.416	9.721	24.937
1992	0.0116	0.028	0.476	1.215	2.026	2.564	4.629	8.832	10.453	12.827	17.092	23.406
1993	0.0116	0.046	0.191	1.254	1.702	3.449	4.083	7.388	12.219	12.332	15.361	23.790
1994	0.0095	0.038	0.236	1.003	2.244	2.571	5.294	6.601	11.095	11.435	17.872	22.643
1995	0.0122	0.051	0.275	0.946	2.021	3.934	4.722	8.526	10.045	15.741	14.877	22.643
1996	0.0223	0.060	0.356	1.462	1.784	2.971	6.185	8.967	12.844	14.654	19.623	22.643
1997	0.0049	0.049	0.391	1.466	2.407	2.571	3.973	8.245	11.940	14.994	17.039	17.655
1998	0.0015	0.059	0.256	1.445	2.245	3.423	3.558	5.739	10.442	14.585	15.340	17.655
1999	0.0224	0.044	0.343	1.196	2.237	3.139	4.752	5.301	8.351	12.198	17.158	17.655
2000	0.0092	0.120	0.461	1.063	2.257	3.422	4.773	5.508	7.882	11.040	13.348	18.741
2001	0.0229	0.097	0.456	1.305	2.420	3.851	5.091	6.513	6.912	9.042	14.823	16.934
2002	0.0115	0.089	0.465	1.050	2.249	3.247	5.296	6.514	7.924	10.032	9.746	18.741
2003	0.0217	0.089	0.346	1.053	1.742	2.977	4.118	6.837	8.011	9.693	11.538	15.128
2004	0.0105	0.066	0.351	0.971	2.110	2.620	4.199	5.908	8.627	10.747	12.280	15.612
2005	0.0082	0.060	0.248	0.821	1.654	3.338	3.841	5.758	7.593	10.204	13.212	15.649
2006	0.0428	0.089	0.295	0.808	1.890	2.467	4.076	4.912	6.744	8.837	11.620	16.704
2007	0.0086	0.124	0.450	0.925	1.771	3.005	3.723	5.020	6.329	8.703	10.979	15.470
2008	0.0464	0.085	0.420	1.117	1.888	2.892	3.630	5.147	6.803	8.308	12.351	16.157
2009	0.0137	0.171	0.480	1.248	2.283	2.908	3.658	4.735	6.735	9.047	9.942	15.516
2010	0.0061	0.100	0.589	1.168	2.328	3.198	3.685	4.778	7.153	8.815	10.755	14.649
2011	0.0836	0.087	0.492	1.353	1.972	3.262	4.114	4.788	5.751	10.189	11.448	18.157
2012	0.0253	0.096	0.414	1.052	1.989	2.991	4.034	5.440	7.167	9.457	11.387	16.178

App. A4 (Append. A), Table A3: Mean weight-at-age (kg) of landings for the Gulf of Maine cod stock applying the revised mortality assumptions (Michael Palmer, pers. commn). Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9	10	11+
1982	0.013	0.356	0.858	1.514	2.606	5.067	7.065	9.620	9.772	12.642	19.230	18.240
1983	0.024	0.224	0.768	1.542	2.418	3.808	6.055	6.071	10.317	11.424	11.535	18.713
1984	0.001	0.234	0.653	1.478	2.678	3.609	5.540	8.368	10.138	13.595	14.419	16.087
1985	0.039	0.206	0.733	1.404	2.819	4.658	5.884	8.502	11.244	12.256	13.587	14.610
1986	0.005	0.277	0.501	1.699	2.774	4.778	6.504	8.109	10.207	13.170	13.827	18.102
1987	0.004	0.154	0.642	1.323	3.090	4.668	7.259	10.036	11.099	13.739	14.899	16.407
1988	0.003	0.122	0.577	1.667	2.360	5.206	5.200	6.193	10.103	10.434	17.787	12.054
1989	0.046	0.237	0.752	1.518	2.959	4.282	5.980	9.276	12.519	16.810	20.410	24.532
1990	0.021	0.193	0.811	1.349	2.141	4.474	7.721	10.820	11.750	15.440	16.344	22.637
1991	0.014	0.236	1.113	1.601	2.281	3.894	7.144	10.429	12.261	15.276	6.122	24.937
1992	0.023	0.055	1.033	1.530	2.747	2.976	5.588	10.921	10.483	13.418	19.072	23.406
1993	0.021	0.081	0.690	1.748	2.150	4.420	5.670	9.817	13.673	12.332	17.586	23.790
1994	0.022	0.058	0.730	1.712	3.085	3.251	6.335	7.684	12.542	9.563	22.008	22.643
1995	0.027	0.103	1.288	1.591	2.649	5.090	6.865	11.466	13.128	19.756	23.143	22.643
1996	0.033	0.100	1.293	2.096	2.260	3.462	7.558	11.728	14.455	16.269	19.490	22.643
1997	0.017	0.064	1.351	2.128	3.022	3.074	4.699	9.000	12.156	15.625	17.749	17.655
1998	0.008	0.202	1.071	1.931	2.633	3.972	4.255	7.122	12.118	17.500	15.060	17.655
1999	0.052	0.222	0.635	1.723	2.777	3.892	5.670	6.704	9.811	12.279	16.823	17.655
2000	0.030	0.282	1.081	2.150	3.316	4.325	5.898	5.352	9.331	12.401	14.506	19.056
2001	0.045	0.316	0.890	2.176	3.144	4.666	6.140	7.273	9.072	8.788	17.660	15.417
2002	0.032	0.185	0.795	1.797	2.906	3.792	6.132	6.969	8.809	11.036	10.796	19.056
2003	0.038	0.202	0.809	1.843	2.378	3.654	5.112	7.649	9.191	10.871	11.890	15.176
2004	0.025	0.111	0.483	1.606	2.965	3.547	5.350	7.220	9.764	12.557	13.931	15.657
2005	0.027	0.126	0.558	1.625	2.401	4.233	4.502	6.350	8.002	10.698	13.899	15.627
2006	0.071	0.289	0.648	1.493	2.932	3.357	4.463	5.562	7.430	9.779	12.646	16.704
2007	0.025	0.220	0.744	1.731	2.922	3.735	4.771	6.167	7.302	10.554	12.338	15.470
2008	0.085	0.247	0.862	2.179	2.818	3.530	3.988	5.819	7.528	9.464	14.461	16.174
2009	0.032	0.337	0.911	2.153	3.126	3.575	4.368	5.959	8.000	10.894	10.454	15.523
2010	0.023	0.264	1.200	1.995	3.203	3.914	4.447	5.708	8.730	9.967	10.628	14.650
2011	0.0856	0.3289	0.9331	2.0561	2.874	3.8696	4.839	5.7166	5.9528	11.876	13.15	18.157

App. A4 (Append. A), Table A4: Mean weight-at-age (kg) in the NEFSC spring and fall surveys, used to compute Albatross converted survey biomass indices.

	0	1	2	3	4	5	6	7	8	9	10	11+
NEFSC spring survey												
2009	0.000	0.031	0.523	1.441	2.067	2.601	2.876	8.067	9.930	0.000	12.919	-
2010	0.000	0.076	0.356	1.203	2.805	3.849	4.602	7.314	10.712	10.247	22.407	17.019
2011	0.000	0.064	0.453	1.177	1.717	2.706	3.509	5.906	8.521	-	-	-
2012	0.000	0.082	0.517	1.299	2.060	2.462	3.235	5.047	11.576	6.323	-	-
NEFSC fall survey												
2009	0.035	0.555	1.174	3.366	4.503	10.575	6.618	-	-	-	-	-
2010	0.019	0.335	1.170	1.774	3.904	4.784	4.548	3.461	-	-	-	25.000
2011	0.022	0.286	0.942	1.775	2.323	4.581	4.931	10.775	7.135	-	-	-

App. A4 (Append. A), Table A5: Total (commercial and recreational landings and discards) catches-at-age for the Gulf of Maine cod stock, applying the revised mortality assumptions (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9+
1982	1346	448849	2926542	2287192	1430682	748755	65880	94051	72553	90055
1983	13645	597496	2462037	2913215	1201593	704010	452680	50022	62542	56198
1984	18275	370324	2129556	1675931	1643588	437453	219625	105649	9495	53395
1985	67101	505660	1944327	2405137	1151815	738096	161362	107192	48359	33213
1986	17767	760701	1747046	2747811	991982	279282	202725	48016	38188	47527
1987	100702	281794	2018317	1568334	1574499	345353	89415	81032	14459	37549
1988	3446	415081	1542790	2086633	1156925	447729	67430	25560	26247	9267
1989	43	166436	1247203	2385088	1651856	521108	87147	70289	9369	19564
1990	0	65527	812544	5547767	2717623	541353	189069	29703	36417	43315
1991	3251	121627	499588	942731	5561272	1037852	150670	55540	25983	15805
1992	23803	370302	830147	867564	502084	2189957	226167	80181	6044	5530
1993	26570	105929	512307	2149041	944709	103328	497117	41561	11264	0
1994	11734	123996	201923	1525603	1294203	266291	66224	74158	28714	7870
1995	11572	78932	319462	1321833	1260435	221653	29931	6521	18184	2808
1996	22067	37536	111569	627693	2003886	405881	36651	4039	491	1623
1997	1472	69144	137484	519557	467768	869161	72472	5523	2272	1029
1998	917	5941	171062	492301	628941	152820	205873	28696	5168	2257
1999	63	73948	90853	347840	336596	172344	53699	59469	12388	1067
2000	0	24758	485043	556537	813684	176640	85157	12485	10521	0
2001	0	584	393951	1163770	684449	385530	106600	57232	8262	11577
2002	0	16831	41591	374949	912638	323797	163476	66392	28087	20263
2003	22873	44899	125587	167812	582079	706098	186022	75694	29224	26844
2004	187	149420	105917	609344	259720	407447	251632	68378	33017	27442
2005	1487	23545	180064	159581	945815	89223	246596	109148	28457	31674
2006	231	19249	59082	426566	290132	461742	30341	79655	39016	27343
2007	430	12171	108471	299416	976424	137404	230163	7947	19244	21999
2008	415	12156	130508	598424	707392	780450	86355	110576	4041	16558
2009	99	10651	101492	622453	1093273	477852	304754	20896	30506	9646
2010	213	8159	83580	394486	888549	668256	164291	71683	11213	7611
2011	653	8683	60526	322164	589583	573856	339910	34926	38408	9433

App. A4 (Append. A), Table A6: Standardized stratified mean numbers per tow at age and standardized mean weight (kg) per tow of Atlantic cod in NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine, 1968-2012 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1968													17.480	(0.153)
1969													13.100	(0.329)
1970	0.000	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.045	0.076	0.210	11.089	(0.237)
1971	0.000	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.142	0.050	0.013	7.004	(0.211)
1972	0.053	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.300	0.027	0.059	8.031	(0.233)
1973	0.000	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.276	0.186	0.386	18.807	(0.415)
1974	0.164	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.038	0.089	0.131	7.419	(0.199)
1975	0.012	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.025	0.028	0.088	6.039	(0.249)
1976	0.000	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.000	0.036	0.081	7.556	(0.166)
1977	0.000	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.000	0.000	0.038	8.541	(0.208)
1978	0.000	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.108	0.000	0.022	7.697	(0.207)
1979	0.044	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.013	0.031	0.020	7.555	(0.176)
1980	0.070	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.105	0.026	0.000	6.232	(0.182)
1981	0.000	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	0.000	0.000	10.650	(0.205)
1982	0.014	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.040	0.010	0.000	8.616	(0.223)
1983	0.013	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.071	0.033	0.077	10.962	(0.225)
1984	0.000	0.151	1.309	0.987	0.853	0.229	0.047	0.090	0.000	0.000	0.000	0.000	6.143	(0.324)
1985	0.000	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	0.000	0.000	7.645	(0.223)
1986	0.000	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.000	0.000	0.018	3.476	(0.197)
1987	0.000	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.000	0.000	0.015	1.976	(0.314)
1988	0.029	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	0.000	0.000	3.603	(0.281)
1989	0.000	0.025	0.609	0.712	0.630	0.069	0.068	0.000	0.000	0.000	0.000	0.000	2.424	(0.207)
1990	0.000	0.009	0.233	1.325	0.669	0.076	0.032	0.018	0.000	0.000	0.000	0.000	3.077	(0.280)
1991	0.000	0.028	0.077	0.233	1.750	0.247	0.041	0.018	0.000	0.000	0.000	0.000	2.891	(0.240)
1992	0.000	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	0.000	0.000	8.627	(0.374)
1993	0.000	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.000	0.023	0.000	5.875	(0.347)
1994	0.000	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.027	0.018	0.000	2.428	(0.216)
1995	0.000	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.000	0.028	0.000	2.432	(0.257)
1996	0.000	0.057	0.022	0.586	1.355	0.385	0.060	0.000	0.000	0.000	0.000	0.000	5.427	(0.275)
1997	0.000	0.159	0.139	0.390	0.271	0.874	0.244	0.115	0.000	0.000	0.000	0.000	5.616	(0.192)
1998	0.000	0.018	0.228	0.359	0.513	0.143	0.408	0.021	0.020	0.000	0.000	0.000	4.180	(0.324)
1999	0.000	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.000	0.000	0.011	5.090	(0.320)
2000	0.026	1.173	0.737	0.438	0.485	0.099	0.092	0.011	0.022	0.000	0.000	0.000	3.211	(0.155)
2001	0.000	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.000	0.011	0.000	6.215	(0.327)
2002	0.000	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	0.000	0.000	10.934	(0.215)
2003	0.000	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.082	0.030	0.011	9.495	(0.368)
2004	0.000	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.000	0.000	2.412	(0.293)
2005	0.000	0.029	0.739	0.081	0.623	0.011	0.138	0.128	0.015	0.000	0.000	0.000	2.701	(0.248)
2006	0.028	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.000	0.015	0.000	2.702	(0.249)
2007	0.000	0.100	3.422	3.077	4.446	0.437	0.796	0.075	0.041	0.000	0.000	0.000	15.811	(0.540)
2008	0.000	0.079	1.165	3.930	1.582	1.099	0.053	0.082	0.000	0.000	0.000	0.000	10.823	(0.609)
2009	0.000	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.000	0.004	0.000	7.161	(0.491)
2010	0.000	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.010	0.005	0.010	3.336	(0.264)
2011	0.000	0.005	0.024	0.140	0.383	0.189	0.086	0.033	0.035	0.000	0.000	0.000	2.133	(0.201)
2012	0.000	0.069	0.105	0.224	0.243	0.159	0.051	0.036	0.004	0.003	0.000	0.000	1.645	(0.209)

App. A4 (Append. A), Table A7: Standardized stratified mean numbers per tow at age and standardized mean weight (kg) per tow of Atlantic cod in NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine, 1964-2011 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1964	-	-	-	-	-	-	-	-	-	-	-	-	22.799	(0.496)
1965	-	-	-	-	-	-	-	-	-	-	-	-	12.089	(0.273)
1966	-	-	-	-	-	-	-	-	-	-	-	-	12.838	(0.227)
1967	-	-	-	-	-	-	-	-	-	-	-	-	9.313	(0.219)
1968	-	-	-	-	-	-	-	-	-	-	-	-	19.437	(0.198)
1969	-	-	-	-	-	-	-	-	-	-	-	-	15.154	(0.217)
1970	0.743	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.090	0.037	0.110	16.442	(0.248)
1971	1.334	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.193	0.031	0.121	16.529	(0.307)
1972	0.031	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.351	0.000	0.016	12.988	(0.199)
1973	0.638	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.182	0.122	0.016	8.764	(0.267)
1974	0.265	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.066	0.000	0.189	8.959	(0.201)
1975	0.006	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.000	0.000	0.018	8.619	(0.153)
1976	0.000	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.000	0.063	0.000	6.740	(0.214)
1977	0.000	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.021	0.061	0.048	10.199	(0.126)
1978	0.241	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.082	0.000	0.047	12.899	(0.151)
1979	0.000	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.000	0.053	0.018	13.927	(0.128)
1980	0.027	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.012	0.000	0.085	14.202	(0.153)
1981	0.010	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.000	0.028	0.000	7.533	(0.233)
1982	0.000	0.835	3.264	2.476	0.971	0.222	0.000	0.000	0.000	0.000	0.000	0.000	15.919	(0.670)
1983	0.000	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.000	0.018	0.065	8.416	(0.188)
1984	0.000	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.016	0.000	0.080	8.735	(0.334)
1985	0.218	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	0.000	0.000	8.264	(0.354)
1986	0.000	0.394	0.404	0.626	0.368	0.073	0.041	0.000	0.000	0.045	0.000	0.000	4.715	(0.228)
1987	0.128	0.570	1.388	0.586	0.198	0.125	0.000	0.000	0.000	0.000	0.000	0.000	3.394	(0.234)
1988	0.000	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.011	0.011	0.000	6.616	(0.232)
1989	0.000	0.145	2.468	1.458	0.283	0.138	0.053	0.000	0.009	0.000	0.000	0.000	4.535	(0.181)
1990	0.000	0.057	0.218	1.788	0.611	0.255	0.048	0.010	0.000	0.000	0.000	0.000	4.912	(0.204)
1991	0.009	0.144	0.151	0.230	0.621	0.075	0.000	0.023	0.000	0.000	0.000	0.000	2.782	(0.246)
1992	0.059	0.289	0.448	0.144	0.041	0.327	0.126	0.000	0.000	0.000	0.000	0.000	2.448	(0.243)
1993	0.031	0.210	0.575	0.361	0.017	0.000	0.038	0.000	0.000	0.000	0.000	0.000	1.003	(0.263)
1994	0.032	0.184	0.909	0.816	0.093	0.051	0.000	0.045	0.000	0.000	0.000	0.000	2.737	(0.292)
1995	0.008	0.068	0.308	1.226	0.304	0.082	0.011	0.000	0.000	0.000	0.000	0.000	3.665	(0.325)
1996	0.029	0.122	0.379	0.231	0.516	0.050	0.000	0.000	0.000	0.000	0.000	0.000	2.352	(0.249)
1997	0.000	0.297	0.091	0.165	0.168	0.151	0.000	0.000	0.000	0.000	0.000	0.000	1.872	(0.307)
1998	0.050	0.085	0.342	0.110	0.185	0.041	0.031	0.000	0.000	0.000	0.000	0.000	1.501	(0.287)
1999	0.025	0.432	0.375	0.590	0.244	0.122	0.019	0.000	0.000	0.000	0.000	0.000	3.505	(0.193)
2000	0.008	0.540	0.981	0.399	0.492	0.140	0.010	0.000	0.034	0.000	0.000	0.000	4.652	(0.332)
2001	0.018	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	0.000	0.000	7.324	(0.279)
2002	0.000	0.269	0.104	0.333	2.683	1.070	0.750	0.077	0.043	0.000	0.000	0.000	24.659	(0.686)
2003	0.542	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.011	0.000	0.011	5.988	(0.251)
2004	1.369	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.010	0.011	0.000	4.906	(0.214)
2005	0.034	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	0.000	0.000	2.897	(0.228)
2006	0.064	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.000	0.000	0.014	4.229	(0.188)
2007	0.011	0.136	0.863	0.395	0.496	0.023	0.067	0.000	0.000	0.000	0.000	0.000	2.714	(0.277)
2008	0.165	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.010	0.021	0.000	5.307	(0.285)
2009	0.020	0.660	2.096	0.314	0.277	0.045	0.035	0.000	0.000	0.000	0.000	0.000	5.845	(0.429)
2010	0.008	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.000	0.000	0.006	2.572	(0.304)
2011	0.036	0.060	0.091	0.210	0.304	0.175	0.078	0.005	0.031	0.000	0.000	0.000	2.647	(0.336)

App. A4 (Append. A), Table A8: Stratified mean catch per tow in numbers and weight (kg) of Atlantic cod in State of Massachusetts inshore spring bottom trawl surveys in territorial waters adjacent to the Gulf of Maine (Mass. Regions 4-5), 1978-2012 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1978													11.058	(0.138)
1979													14.276	(0.219)
1980													14.509	(0.128)
1981													18.689	(0.265)
1982	1.668	13.218	6.649	2.921	1.024	0.216	0.049	0.046	0.050	0.000	0.000	0.000	12.161	(0.175)
1983	0.718	30.253	17.570	4.710	0.347	1.121	0.075	0.023	0.033	0.000	0.000	0.000	18.746	(0.153)
1984	0.257	1.898	5.090	2.101	0.751	0.147	0.086	0.000	0.000	0.000	0.000	0.000	7.240	(0.259)
1985	1.569	1.670	2.695	2.024	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.765	(0.194)
1986	1.075	18.031	3.376	0.903	0.582	0.100	0.023	0.000	0.000	0.000	0.000	0.000	7.841	(0.354)
1987	0.725	8.622	5.376	2.045	0.168	0.147	0.053	0.000	0.000	0.070	0.000	0.000	7.865	(0.271)
1988	1.895	10.409	6.750	1.927	1.211	0.016	0.033	0.000	0.000	0.000	0.000	0.000	7.703	(0.237)
1989	0.298	21.463	22.947	6.868	0.513	0.108	0.048	0.000	0.000	0.000	0.000	0.000	17.346	(0.342)
1990	4.930	4.972	5.938	14.182	2.149	0.155	0.083	0.000	0.000	0.000	0.000	0.000	15.879	(0.341)
1991	0.355	5.331	2.295	1.801	3.669	0.249	0.000	0.000	0.000	0.000	0.000	0.000	8.730	(0.122)
1992	1.506	4.379	5.699	3.444	0.484	1.301	0.066	0.044	0.000	0.000	0.000	0.000	8.766	(0.321)
1993	80.090	2.842	6.100	2.509	0.879	0.166	0.074	0.000	0.000	0.000	0.000	0.000	5.861	(0.270)
1994	4.627	5.406	3.883	1.703	0.608	0.131	0.000	0.000	0.000	0.000	0.000	0.000	4.334	(0.241)
1995	11.998	5.985	2.420	2.408	0.525	0.028	0.000	0.000	0.000	0.000	0.000	0.000	3.993	(0.225)
1996	8.843	0.777	0.497	0.955	1.590	0.299	0.000	0.000	0.000	0.000	0.000	0.000	3.152	(0.305)
1997	12.431	2.910	1.035	0.920	0.190	0.383	0.018	0.000	0.000	0.000	0.000	0.000	2.500	(0.250)
1998	23.481	1.487	0.924	0.779	0.637	0.034	0.211	0.017	0.000	0.000	0.000	0.000	3.250	(0.468)
1999	143.000	11.832	2.407	2.275	0.735	0.630	0.036	0.127	0.017	0.000	0.000	0.000	8.997	(0.261)
2000	2.151	35.360	6.995	2.371	2.316	0.784	0.663	0.059	0.073	0.000	0.000	0.000	20.604	(0.459)
2001	25.987	0.084	4.998	4.710	3.448	1.961	0.323	0.227	0.106	0.000	0.000	0.000	26.445	(0.536)
2002	0.924	19.340	0.220	1.379	1.145	0.561	0.318	0.111	0.253	0.025	0.049	0.012	11.158	(0.390)
2003	0.000	17.109	5.496	0.439	1.938	0.937	0.221	0.074	0.014	0.025	0.000	0.014	10.984	(0.219)
2004	116.135	8.927	1.882	2.627	0.361	1.083	0.455	0.076	0.029	0.000	0.014	0.000	8.147	(0.278)
2005	179.479	5.524	4.141	0.795	1.955	0.263	0.663	0.243	0.094	0.105	0.000	0.000	10.402	(0.197)
2006	0.000	9.992	7.139	3.930	0.525	1.532	0.109	0.057	0.000	0.017	0.028	0.000	9.177	(0.181)
2007	49.323	3.776	3.078	2.303	2.163	0.343	0.519	0.025	0.046	0.000	0.000	0.000	8.430	(0.251)
2008	456.954	7.275	10.336	3.242	2.287	1.695	0.155	0.155	0.000	0.000	0.000	0.000	12.229	(0.215)
2009	466.098	8.907	2.350	1.654	1.045	0.348	0.112	0.000	0.000	0.000	0.000	0.000	4.489	(0.187)
2010	1.165	2.415	1.393	1.423	0.819	0.678	0.129	0.000	0.000	0.000	0.052	0.000	5.645	(0.456)
2011	55.378	0.326	1.001	0.621	0.933	0.558	0.139	0.086	0.021	0.000	0.000	0.000	4.519	(0.424)
2012	6.239	3.368	0.671	0.446	0.304	0.415	0.021	0.000	0.000	0.000	0.000	0.000	2.276	(0.401)

App. A4 (Append. A), Table A9: Percentage of mature females for each age for the Gulf of Maine cod stock (Michael Palmer, pers. commn).

0	1	2	3	4	5	6	7	8	9	10	11+
0.025	0.092	0.287	0.613	0.862	0.961	0.990	0.997	0.999	1.000	1.000	1.000

App. A4 (Append. A), Table A10: Length frequency distributions for NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC spring survey				NEFSC call survey		
Year	2009	2010	2011	2012	2009	2010	2011
-25cm	0.5634	0.4138	0.0286	0.4159	0.3967	0.0605	0.2489
26cm	0.0496	0.0189	0.0000	0.0113	0.1330	0.0283	0.0850
27cm	0.0425	0.0756	0.0000	0.0057	0.1731	0.0142	0.0283
28cm	0.0638	0.1501	0.0000	0.0170	0.1251	0.0000	0.0142
29cm	0.0553	0.0945	0.0000	0.0057	0.1330	0.0283	0.0000
30cm	0.0283	0.1134	0.0000	0.0113	0.2330	0.0567	0.0142
31cm	0.0544	0.1397	0.0486	0.0057	0.2834	0.0283	0.0136
32cm	0.0142	0.0945	0.0113	0.0337	0.4412	0.1134	0.0377
33cm	0.0213	0.0935	0.0113	0.0113	0.5951	0.0425	0.0142
34cm	0.0958	0.1572	0.0000	0.0404	0.9068	0.0567	0.0506
35cm	0.0743	0.1407	0.0227	0.0170	0.7147	0.0142	0.0283
36cm	0.0887	0.1029	0.0000	0.0582	0.6659	0.0394	0.0142
37cm	0.0695	0.0853	0.0340	0.0283	0.5014	0.0278	0.0000
38cm	0.1204	0.0945	0.0113	0.0207	0.6155	0.0425	0.0000
39cm	0.1748	0.0567	0.0000	0.0659	0.3400	0.0142	0.0543
40cm	0.1559	0.0283	0.0431	0.0548	0.2516	0.0242	0.0283
41cm	0.1629	0.0283	0.0227	0.0453	0.2888	0.0425	0.0364
42cm	0.1771	0.0276	0.0599	0.0639	0.3103	0.0850	0.0380
43cm	0.1565	0.0378	0.0793	0.0564	0.2834	0.0425	0.0401
44cm	0.2125	0.0378	0.0907	0.0860	0.3400	0.0283	0.0222
45cm	0.2287	0.0378	0.0340	0.0746	0.3280	0.0384	0.0640
46cm	0.2196	0.0283	0.0214	0.0380	0.2776	0.0283	0.0567
47cm	0.1913	0.0189	0.0340	0.0434	0.1901	0.0242	0.0000
48cm	0.2371	0.0095	0.0340	0.0283	0.2692	0.0425	0.0364
49cm	0.2017	0.0283	0.0214	0.0394	0.2125	0.0343	0.0623
50cm	0.2240	0.0647	0.0793	0.0510	0.1700	0.0283	0.0647
51cm	0.1845	0.0095	0.0441	0.0264	0.0951	0.0394	0.0364
52cm	0.3077	0.0953	0.0768	0.0944	0.1199	0.0778	0.0383
53cm	0.2122	0.0000	0.0680	0.0394	0.0992	0.0142	0.0425
54cm	0.2517	0.1236	0.0826	0.0567	0.0809	0.0425	0.0506
55cm	0.3245	0.0322	0.0340	0.0453	0.0708	0.0384	0.0330
56cm	0.1946	0.0646	0.0700	0.0491	0.0000	0.0425	0.0599
57cm	0.2046	0.0276	0.0441	0.0377	0.0492	0.0567	0.0000
58cm	0.2358	0.0370	0.0582	0.0644	0.0384	0.0242	0.0000
59cm	0.2347	0.0455	0.0000	0.0519	0.0686	0.0257	0.0161
60cm	0.2537	0.0444	0.0227	0.0349	0.0425	0.0142	0.0383
61cm	0.2547	0.0000	0.0803	0.0511	0.0447	0.0242	0.0588
62cm	0.1164	0.0081	0.0214	0.0227	0.0307	0.0401	0.0383
63cm	0.2003	0.0180	0.0113	0.0154	0.0142	0.0236	0.0222
64cm	0.1725	0.0227	0.0214	0.0406	0.0874	0.0142	0.1130
65cm	0.0341	0.0000	0.0302	0.0227	0.0142	0.0336	0.0222
66cm	0.0611	0.0189	0.0467	0.0170	0.0667	0.0401	0.0303
67cm	0.0850	0.0544	0.0101	0.0321	0.0201	0.0242	0.0303
68cm	0.0414	0.0276	0.0227	0.0154	0.0196	0.0848	0.0401
69cm	0.0370	0.0000	0.0372	0.0154	0.0142	0.0000	0.0481
70cm	0.0923	0.0632	0.0259	0.0170	0.0283	0.0201	0.0581
71cm	0.0387	0.0161	0.0101	0.0097	0.0142	0.0353	0.0283
72cm	0.0287	0.0719	0.0322	0.0057	0.0696	0.0236	0.0259
73cm	0.0259	0.0322	0.0349	0.0000	0.0350	0.0310	0.0420
74cm	0.0128	0.0423	0.0113	0.0097	0.0108	0.0142	0.0081
75cm	0.0199	0.0000	0.0101	0.0000	0.0101	0.0360	0.0081
76cm	0.0704	0.0081	0.0000	0.0000	0.0283	0.0840	0.0222
77cm	0.0058	0.0161	0.0000	0.0196	0.0142	0.0000	0.0222
78cm	0.0115	0.0181	0.0101	0.0057	0.0000	0.0201	0.0000
79cm	0.0058	0.0563	0.0227	0.0057	0.0283	0.0283	0.0108
80cm	0.0270	0.0181	0.0101	0.0040	0.0000	0.0101	0.0000
81cm	0.0270	0.0343	0.0000	0.0054	0.0000	0.0000	0.0540
82cm	0.0000	0.0000	0.0101	0.0000	0.0101	0.0000	0.0222
83cm	0.0283	0.0000	0.0000	0.0000	0.0000	0.0000	0.0161
84cm	0.0115	0.0489	0.0000	0.0000	0.0000	0.0454	0.0000
85cm	0.0115	0.0081	0.0259	0.0000	0.0000	0.0236	0.0081
86cm	0.0071	0.0262	0.0101	0.0000	0.0000	0.0101	0.0000
87cm	0.0186	0.0081	0.0000	0.0000	0.0000	0.0000	0.0000
88cm	0.0058	0.0000	0.0000	0.0057	0.0142	0.0101	0.0142
89cm	0.0058	0.0161	0.0000	0.0000	0.0000	0.0000	0.0000
90cm	0.0071	0.0081	0.0113	0.0000	0.0101	0.0000	0.0000
91cm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92cm	0.0058	0.0000	0.0000	0.0057	0.0000	0.0000	0.0142
93cm	0.0000	0.0000	0.0000	0.0000	0.0101	0.0000	0.0081
94cm	0.0058	0.0081	0.0340	0.0000	0.0000	0.0000	0.0000
95cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0000	0.0081
96cm	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
97cm	0.0000	0.0000	0.0000	0.0000	0.0142	0.0000	0.0000
98cm	0.0000	0.0081	0.0000	0.0057	0.0000	0.0000	0.0081
99cm	0.0000	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000
100cm+	0.0115	0.0403	0.0214	0.0000	0.0000	0.0101	0.0081

App. A4 (Append. A), Table A11a: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2009					Age							NEFSC Spring, 2010					Age						
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	39	24	0	0	0	0	0	0	0	0	0	0	28	11	0	0	0	0	0	0	0	0	0
26	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
27	0	0	4	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
28	0	0	3	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
29	0	0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
30	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
31	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
33	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
34	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
35	0	0	4	3	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
36	0	0	4	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
37	0	0	2	4	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0
38	0	0	2	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
39	0	0	1	2	1	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0
40	0	0	2	6	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
41	0	0	2	2	1	1	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0
42	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	5	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
44	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0	0
45	0	0	1	6	4	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
46	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0
47	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
48	0	0	0	2	4	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
49	0	0	0	3	4	1	2	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0
50	0	0	0	2	5	1	0	0	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0
51	0	0	1	2	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
52	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	4	2	1	0	0	0	0	0	0
53	0	0	0	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	7	1	2	0	0	0	0	0	0
55	0	0	0	5	1	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0
57	0	0	0	2	3	2	1	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
58	0	0	0	0	5	3	1	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0
59	0	0	0	1	3	1	5	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
60	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
61	0	0	0	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
62	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
63	0	0	0	0	3	3	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
64	0	0	0	1	5	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
67	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
68	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0
71	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
72	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0
73	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
77	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
78	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
79	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
80	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0
85	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
86	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
87	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
88	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
90	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
95	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2

App. A4 (Append. A), Table A11b: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2011						Age						NEFSC Spring, 2012						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	2	0	0	0	0	0	0	0	0	0	0	1	38	3	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
31	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
33	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0
37	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
38	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
40	0	0	1	2	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	0
41	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0
42	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3	7	1	0	0	0	0	0	0	0
43	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	7	2	1	0	0	0	0	0	0
44	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	9	1	0	0	0	0	0	0	0
45	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	5	2	2	0	0	0	0	0	0
46	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0
47	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4	1	0	0	0	0	0	0
48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	0
49	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0
50	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	4	1	3	0	0	0	0	0	0
51	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0
52	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	3	7	4	1	0	0	0	0	0
53	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	5	1	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0
55	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	6	1	0	0	0	0	0	0
56	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	5	4	5	2	0	0	0	0	0
57	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0	0
58	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	6	3	1	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	1	2	0	0	0	0
60	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0
61	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
62	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0
63	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0
64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0
65	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0
66	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
67	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0
68	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
71	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
72	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
79	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
80	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
82	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

App. A4 (Append. A), Table A12: Age-length keys for NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Autumn, 2009 Age												NEFSC Autumn, 2010 Age												NEFSC Autumn, 2011 Age											
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	9	11	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	15	4	0	0	0	0	0	0	0	0	0	0
26	0	4	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
27	0	4	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
28	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
29	0	4	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	3	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
32	0	4	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
33	0	2	4	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
35	0	2	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	2	5	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
40	0	1	3	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
41	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
42	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
43	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
44	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0
46	0	0	7	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
47	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0
49	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
50	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	3	0	1	0	0	0	0	0	0
51	0	0	3	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
52	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	1	3	0	0	0	0	0	0	0
53	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0
54	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
55	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
57	0	0	1	1	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
58	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
59	0	0	0	4	2	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
60	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0
61	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0
62	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	4	6	1	0	0	0	0	0	0
65	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
66	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
67	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
68	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
69	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
70	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0
71	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
72	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
74	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
75	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
76	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
77	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
82	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
93	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0

Appendix B (within App. A4) - The Statistical Catch-at-Age Model

The text following sets out the equations and other general specifications of the SCAA followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is then applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

For the convenience of readers, details which are changed or newly added relative to the specifications used for the analyses reported in Butterworth and Rademeyer (2012) are shown highlighted.

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \tag{B1}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \qquad \text{for } 0 \le a \le M-2 \tag{B2}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \tag{B3}$$

where

$N_{y,a}$ is the number of fish of age a at the start of year y,

R_y is the recruitment (number of 0-year-old fish) at the start of year y,

m is the maximum age considered (taken to be a plus-group).

$Z_{y,a} = F_y S_{y,a} + M_a$ is the total mortality in year y on fish of age a, where

M_a denotes the natural mortality rate for fish of age a,

F_y is the fishing mortality of a fully selected age class in year y, and

$S_{y,a}$ is the commercial selectivity at age a for year y.

B.1.2. Recruitment

The number of recruits (i.e. new 0-year old) at the start of year y is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a standard or adjusted Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

For the modified Ricker:

$$R_y = \alpha B_y^{\text{sp}} \exp\left[-\beta\left(B_y^{\text{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_R)^2/2)} \tag{B4}$$

for the (standard) Beverton-Holt:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_R)^2/2)} \tag{B5}$$

and for the adjusted Beverton-Holt:

$$R_y = \begin{cases} \dfrac{\alpha B_y^{sp}}{\beta + B_y^{sp}} & \text{if } B_y^{sp} \le B^* \\ \dfrac{\alpha B^*}{\beta + B^*} \exp\left(-\left(\dfrac{B_y^{sp} - B^*}{\sigma_N}\right)^2\right) & \text{if } B_y^{sp} > B^* \end{cases} \tag{B6}$$

where

α, β, γ, $B^*$and σ_N are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year y, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B_y^{sp} is the spawning biomass at the start of year y, computed as:

$$B_y^{\text{sp}} = \sum_{a=0}^{m} f_a w_{y,a}^{\text{strt}} N_{y,a} e^{-M_a/4} \tag{B7}$$

because spawning for the cod stock under consideration is taken to occur three months after the start of the year and some mortality has therefore occurred,

where

$w_{y,a}^{\text{strt}}$ is the mass of fish of age a during spawning, and

f_a is the proportion of fish of age a that are mature.

Section *B.2.6* details the procedure adopted when recruitment is not assumed to be related to spawning biomass , at least internal to the assessment.

B.1.3. Total catch and catches-at-age

The total catch by mass in year y is given by:

$$C_y = \sum_{a=0}^{m} w_{y,a}^{\text{mid}} C_{y,a} = \sum_{a=0}^{m} w_{y,a}^{\text{mid}} N_{y,a} \; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{B8}$$

where

$w^{\text{mid}}_{y,a}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y*,

The model estimate of survey biomass is computed as:

$$B^{\text{surv}}_y = \sum_{a=0}^{m} w^{\text{surv}}_{y,a} S^{\text{surv}}_a N_{y,a} e^{-Z_{y,a} T^{surv}/12} \quad \text{(B9)}$$

where

S^{surv}_a is the survey selectivity for age *a*, which is taken to be year-independent.

T^{surv} is the season in which the survey is taking place (T^{surv}=1 for spring surveys and T^{surv}=3 for fall surveys), and

$w^{surv}_{y,a} = w^{strt}_{y,a}$ for spring surveys and $w^{surv}_{y,a} = w^{mid}_{y,a}$ for fall surveys.

B.1.4. Initial conditions

For the first year (y_0) considered in the model, the numbers-at-age are estimated directly for ages 0 to a^{est}, with a parameter ϕ mimicking recent average fishing mortality for ages above a^{est}, i.e.

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 0 \le a \le a^{est} \quad \text{(B10)}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1 - \phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \quad \text{(B11)}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1 - \phi S_{m-1}) \big/ (1 - e^{-M_m} (1 - \phi S_m)) \quad \text{(B12)}$$

B.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age and catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood ($-\ell nL$) are as follows. Details related to fitting to CPUE series are not included below, as such series are not considered in the analyses of this paper.

B2.1. Survey abundance data

The likelihood is calculated assuming that a survey biomass index is lognormally distributed about its expected value:

$$I_y^{surv} = \hat{I}_y^{surv} \exp\left(\varepsilon_y^{surv}\right) \quad \text{or} \quad \varepsilon_y^{surv} = \ell\text{n}\left(I_y^{surv}\right) - \ell\text{n}\left(\hat{I}_y^{surv}\right) \tag{B13}$$

where

I_y^{surv} is the survey biomass index for survey *surv* in year *y*,

$\hat{I}_y^{surv} = \hat{q}^{surv} \hat{B}_y^{surv}$ is the corresponding model estimate, where

$\hat{q}^{surv}$ is the constant of proportionality (catchability) for the survey biomass series *surv*, and

ε_y^{surv} from $N\left(0, \left(\sigma_y^{surv}\right)^2\right)$.

The contribution of the survey biomass data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{\text{survey}} = \sum_{surv} \sum_{y} \left\{ \ell\text{n}\left(\sqrt{\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2} \right) + \left(\varepsilon_y^{surv}\right)^2 / \left[2\left(\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2 \right) \right] \right\} \tag{B14}$$

where

σ_y^{surv} is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

σ_{Add}^{surv} is the square root of the additional variance for survey biomass series *surv*, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^{surv} for survey biomass index *surv* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^{surv} = 1/n_{surv} \sum_{y} \left(\ln I_y^{surv} - \ln \hat{B}_y^{surv} \right) \tag{B15}$$

B.2.3. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n}\, L^{\text{CAA}} = \sum_{y} \sum_{a} \left[\ell n\left(\sigma_a^{com} / \sqrt{p_{y,a}} \right) + p_{y,a} \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a} \right)^2 / 2\left(\sigma_a^{com} \right)^2 \right] \tag{B16}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age a,

where

$$\hat{C}_{y,a} = N_{y,a}\ S_{y,a}\, F_y\ \left(1-e^{-Z_{y,a}}\right)\!/Z_{y,a} \tag{B17}$$

and

σ_a^{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y 1} \tag{B18}$$

Commercial catches-at-age are incorporated in the likelihood function using equation (B16), for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

In application of this approach ages are often aggregated to avoid values of $p_{y,a}$ or $\hat{p}_{y,a}$ that are too small in the interests of estimation robustness. In this paper individual ages have been maintained between the selected minus and plus-groups to provide potential discrimination of different shapes for the selectivity functions at older ages in particular. This however does mean that there are certain cells for which $p_{y,a}$ values are zero. That does not cause any problems because the limit of $p_{y,a}\left(\ln p_{y,a}\right)^2$ as $p_{y,a} \to 0$ is 0, so these terms can be omitted from the summation in equation B16. One could argue that they should nevertheless be included in the summations in equation B18, but exclusion seems more appropriate as the structural zero contributions then included would seem likely to bias the estimates of $\hat{\sigma}_a^{com}$ downwards.

In addition to this "adjusted" lognormal error distribution, some computations use an alternative "sqrt(p)" formulation, for which equation B19 is modified to:

$$-\ell\mathrm{n}\, L^{\mathrm{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_a^{com}\right) + \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / 2\left(\sigma_a^{\mathrm{com}}\right)^2\right] \tag{B19}$$

and equation B21 is adjusted similarly:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / \sum_y 1} \tag{B20}$$

This formulation mimics a multinomial form for the error distribution by forcing a near-equivalent variance-mean relationship for the error distributions.

B.2.4. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an "adjusted" lognormal error distribution (equation (B19)) where:

$p_{y,a}^{surv} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of fish of age a in year y for survey *surv*,

$\hat{p}_{y,a}^{surv}$ is the expected proportion of fish of age a in year y in the survey *surv*, given by:

$$\hat{p}_{y,a}^{surv} = S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \Big/ \sum_{a'=0}^{m} S_{a'}^{\text{surv}} N_{y,a'} e^{-Z_{y,a'} T^{surv}/12} \quad . \tag{B21}$$

B.2.5. Survey catches-at-length

In some runs, catches-at-length are also incorporated in the likelihood function. These data are incorporated in the similar manner as the catches-at-age. When the model is fit to catches-at-length, the predicted catches-at-age are converted to catches-at-length:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l} \tag{B22}$$

where $A_{a,l}$ is the proportion of fish of age a that fall in the length group l (i.e., $\sum_l A_{a,l} = 1$ for all ages).

The matrix $A_{a,l}$ is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a \sim N\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right); \theta_a^2\right] \tag{B23}$$

where

θ_a is the standard deviation of mid-year length-at-age a, which is modelled to be proportional to the expected length-at-age a, i.e.:

$$\theta_a = \beta\left[L_\infty\left(1 - e^{-\kappa(a+0.5-t_o)}\right)\right]^\gamma \tag{B24}$$

with β an estimable parameter and $\gamma = 0.5$ (a value which was found to lead to reasonable fits to the data).

$L_\infty = 150.93\, cm$,

$\kappa = 0.11\, yr^{-1}$,

$t_o = 0.13\, yr$,

The following term is then added to the negative log-likelihood:

$$-\ell n\, L^{\text{CAL}} = w_{len} \sum_{surv} \sum_y \sum_l \left[\ell n\left(\sigma_{\text{len}}^{surv} / \sqrt{p_{y,l}^{surv}}\right) + p_{y,l}^{surv}\left(\ell n\, p_{y,l}^{surv} - \ell n\, \hat{p}_{y,l}^{surv}\right)^2 / 2\left(\sigma_{\text{len}}^{surv}\right)^2\right] \tag{B25}$$

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups because the length distributions for adjacent ages overlap) to the overall negative log-likelihood compared to that of the CPUE data. The value used for w_{len} is 0.1, being roughly equivalent to the ratio of the number to length groups to the number of age groups considered. Instances of observed proportions of zero are dealt with in the same manner as for catches-at-age, as is the alternative "sqrt(p)" error distribution formulation.

B.2.6. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be lognormally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{\text{pen}} = \sum_{y=y_1+1}^{y_2} \left[\varepsilon_y^2 / 2\sigma_{\text{R}}^2 \right] \qquad \text{(B26)}$$

where

ε_y from $N(0,(\sigma_R)^2)$,

σ_{R} is the standard deviation of the log-residuals, which is input.

In the analyses reported in this paper, unless otherwise stated, this "stock-recruitment" term is included for the last two years only, simply to stabilise these estimates which are not well determined by the other data. The ε_y are calculated as the deviations from the mean log recruitment for the ten preceding years, i.e. recruitment estimates for 2010 and 2011 are shrunk towards the geometric mean recruitment over the preceding decade.

B.2.7 Incorporation of Bigelow vs Albatross survey calibration

The survey data provided are adjusted for the years 2009 to 2012 which were obtained from *Bigelow* surveys have been adjusted to "*Albatross* equivalents" through use of calibration factors estimated independently from paired tow experiments (Miller *et al*., 2010). However the survey data before and after the switch of vessels also provide information on the calibration factors because they sample the same cohorts. Incorporation of this information in assessments in this paper has been effected by treating the estimates, with their variance-covariance matrix, as a form of "joint-prior" which is effectively updated in the penalised likelihood estimation when fitting the model. The process is as follows.

First *Bigelow* length frequency distributions are converted to *Albatross* equivalent length frequency distributions:

$$C_{y,l}^{surv,A} = C_{y,l}^{surv,B} / F_l \qquad \text{(B27)}$$

where

$C_{y,l}^{surv,B}$ is the measured catch-at-length for the *Bigelow* in year y for survey *surv,*

$C_{y,l}^{surv,A}$ is the inferred catch-at-length for the *Albatross* equivalent in year y for survey *surv*,

F_l is the length-based calibration factor (*Bigelow/Albatross*),

The Albatross equivalent length distributions are then converted to age distributions:

$$C_{y,a}^{surv,A} = \sum_l C_{y,l}^{surv,A} ALK_{y,a,l}^{surv} \qquad \text{(B28)}$$

where

$ALK_{y,a,l}^{surv}$ is the age-length key (proportion of fish of length l that have age a) in year y for survey *surv*.

Biomass indices are then obtained from the *Albatross* equivalent age distributions as follows:

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} w_{y,a}^{surv} \qquad \text{(B29)}$$

where

$w_{y,a}^{surv}$ is the weight-at-age in year y for survey *surv*.

The calibration factor has four parameters, three of which are estimable and the other input: X_1=20cm, X_2, F_1 and F_2

$$F_l = \begin{cases} F_1 & \text{if } l \le X_1 \\ \dfrac{(F_2 - F_1)}{(X_2 - X_1)} l + \dfrac{(F_1 X_2 - F_2 X_1)}{(X_2 - X_1)} & \text{if } X1 < l < X_2 \\ F_2 & \text{if } l \ge X_2 \end{cases} \qquad \text{(B30)}$$

The following contribution is therefore added to the negative log-likelihood in the assessment:

$$-\ln L^{calib} = \frac{1}{2}\ln|\mathbf{\Sigma}| + \frac{1}{2}(\mathbf{x} - \boldsymbol{\mu})^{\mathrm{T}} \mathbf{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu})$$

where the parameters X_2, F_1 and F_2 are components of the vector ***x***,

$\mathbf{\Sigma}$ is the variance covariance matrix as estimated by Miller *et al.* (2010), and

$\boldsymbol{\mu}$ is a vector which contains the Miller *et al.* (2010) estimates of the parameters. These estimates and the variance-covariance matrix are given in table B1 below:

Table B1: Estimates and variance-covariance matrix for the calibration parameters (Miller, pers. commn).

$\boldsymbol{\mu}$	$ln(F_2)$	$ln(F_1$-$F_2)$	$ln(X_2$-$X_1)$
	0.4713	1.4163	3.5086
$\boldsymbol{\Sigma}$	$ln(F_2)$	$ln(F_1$-$F_2)$	$ln(X_2$-$X_1)$
$ln(F_2)$	0.006674	-0.002515	-0.002559
$ln(F_1$-$F_2)$	-0.002515	0.051592	-0.007601
$ln(X_2$-$X_1)$	-0.002559	-0.007601	0.006757

B.3. Estimation of precision

Where quoted, CV's or 95% probability interval estimates are based on the Hessian.

B.4. Model parameters

B.4.1. Fishing selectivity-at-age:

The commercial fishing selectivity, S_a, as well as the fishing selectivities for the Massachusetts inshore spring survey, are estimated separately for ages a_{minus} to a_{plus}. The estimated proportional decrease from ages a_{plus}-1 to a_{plus} is assumed to continue multiplicatively to age 9+ for the commercial selectivity and to age 11+ (the model plus group) for the Massachusetts spring survey (if not otherwise specified) (see Table below for a_{minus} to a_{plus}). For the NEFSC offshore surveys, the fishing selectivities are estimated separately for ages a_{minus} to age 7 for the spring survey, and to age 6 for the fall survey, and thereafter an exponential decline to age 9+ is estimated separately for each survey.

The commercial selectivity is taken to differ over the 1893-1991 and 1992+ periods. The decision to incorporate a change after 1991 was made to remove non-random residual patterns in the fit to the commercial catch-at-age data if time-independence in selectivity was assumed.

B.4.2. Other parameters

Model plus group			
m	11		
Commercial CAA			
a_{minus}	1		
a_{plus}	9		
Survey CAA	NEFSC spr	NEFSC fall	MASS spr
a_{minus}	1	1	0
a_{plus}	9	9	4
Natural mortality:			
M	0.2 and age independent		
Proportion mature-at-age:			
f_a	input, see Table A8		
Weight-at-age:			
$w_{y,a}^{strt}$	input, see Table A2		
$w_{y,a}^{mid}$	input, see Table A3		
Initial conditions for a 1964 starting year:			
$N_{y0,a}$	estimated directly for ages 0 to 2		
ϕ	estimated, eqns B9-B10 for ages 3+		

B.5.Reference points

It is possible to estimate reference points internally within the assessment by fitting the stock-recruitment relationship directly within the assessment itself.

For most results reported here, however, the stock-recruitment relationships are fitted to the estimates of recruitment and spawning biomass provided by the various assessments to provide a basis to estimate reference points. The rationale for estimation external to the assessment itself is to avoid assumptions about the form of the relationship influencing the assessment results. These fits are achieved by minimising the following negative log-likelihood:

$$-\ln L = \sum_{y=y1}^{2009} \left[\frac{\left(\ln(N_{y,0}) - \ln\left(\hat{N}_{y,0}\right)\right)^2}{2\left((\sigma_R)^2 + \left(CV_y\right)^2\right)} + \ln\left(\sqrt{(\sigma_R)^2 + \left(CV_y\right)^2}\right) \right] \tag{B31}$$

where

$N_{y,0}$ is the "observed" (assessment estimated) recruitment in year y,

$\hat{N}_{y,0}$ is the stock-recruitment model predicted recruitment in year y,

σ_R is the standard deviation of the log-residuals, and

CV_y is the Hessian-based CV for the "observed" recruitment in year y.

Note that the differential precision of the assessment estimates of recruitment is taken into account, and that the summation ends at 2009 because little by way of direct observation is as yet available to inform estimates of recruitment for 2010 and 2011.

[SAW55 Editor's Note: The SARC-55 review panel did not recommend adopting the GOM cod Statistical Catch-at-Age (SCAA) assessment results that are in Appendices A.2 – A.5. These appendices are included in this report to document and demonstrate the work that was done by the SAW cod Working Group for the December 2012 peer review.]

Appendix A.5. Further Statistical Catch-at-Age Assessment Results together with Biological Reference Point estimates for Gulf of Maine cod, October 2012

Summary

The Statistical Catch-at-Age assessments of the Gulf of Maine cod stock by Butterworth and Rademeyer (2012) are extended, with a particular focus on the estimation of Biological Reference Points (BRPs). The analysis supports starting these assessments from an early year to provide precise estimates of these BRPs, and the estimation n of the Ricker form of the stock –recruitment relationship within the assessment is found to be preferred. Across a wide range of sensitivity tests the 2011 spawning biomass is robustly estimated at about 14 thousand tons with specific estimates ranging from about 12.5 to 16 thousand tons. When starting the assessments in the 1960s or earlier with a Ricker stock-recruitment function, most estimates of the spawning biomass which provides MSY are around 25 thousand tons for the M = 0.2 scenario, and around 13 thousand tons for the M increasing scenario; the corresponding estimates of MSY itself are about 13 and 6 thousand tons respectively. The AIC selection criterion and a reduced retrospective pattern suggest that greater weight should be accorded to results for the M increasing compared to the M = 0.2 scenario.

Introduction

This paper continues from that (Butterworth and Rademeyer, 2012) submitted to the earlier SAW/SARC 55 Modeling Meeting. Taking account of advances made and some agreements reached at that meeting, it extends SCAA assessment analyses for Gulf of Maine cod, now particularly focusing also on the estimation of MSY-related biological reference points. (BRPs)

Data and Methodology

The catch and survey based data (including catch-at-length information) and some biological data used for the analyses are listed in Tables in Appendix A (within Appendix

A5). These have been updated in a few respects in the light of discussions at the earlier Modeling Meeting; the consequent changes are indicates through highlighting.

The details of the SCAA assessment methodology are provided in Appendix B (within Appendix A5). As in Appendix A, there are some recent changes which are highlighted.

Results

Results are first given for variants on an assessment run which incorporates the following choices, based primarily on those made for a comparison exercise with ASAP outputs run during the Modeling Meeting. These include:

- Use the sqrt(p) formulation of equation B.21 to describe the distribution of proportions-at-age (in relation to numbers of fish).
- No refinement of the *Bigelow-Albatross* calibration function within the assessment.
- Force flat selectivity at ages of 5/6 and above for the NEFSC autumn/spring surveys (though estimation of a common doming trend in the commercial selectivities is allowed – see Section B.4.1).
- Make allowance for additional variance when fitting to time series of abundance indices
- Fit to the aggregated abundance indices as expressed in terms of numbers (equation B10) rather than biomass.
- Where pertinent given the starting year, incorporate data on NEFSC survey length compositions from the 1960s when catches from these surveys were not aged.

The first sensitivity exercise conducted is run conduct assessments comprising a full cross of the following factors:

a) Start in 1963 (estimating the first three numbers-at-age in the starting vector and then the parameter ϕ) *vs* start in 1982 (estimating all elements of the starting numbers at age vector).
b) $M = 0.2$ *v*s M increasing linearly from 0.2 prior to 1989 to 0.4 from 2003
c) Internal (equation B31) *vs* external (equation B39) estimation of the stock-recruitment relationship; note that with external estimation, the assessment shrinks only the last two recruitment estimates as detailed in section B.2.6
d) Use of a Ricker (equation B4 with $\gamma = 1$) *vs* a Beverton Holt (equation B5) stock-recruitment relationship.

App. A5, Tables 1 and 2 list the results of this examination, showing log likelihood contributions and model parameter estimates, and also now estimates of BRPs.

For the purpose of further evaluation, a Reference Case (RC) is selected from the cases considered above, with the same specifications for each of the $M = 0.2$ and M increasing scenarios. This RC starts the assessment in 1963, and estimates a Ricker stock-recruitment curve internally.

App. A5, Table 3 shows results for sensitivities to the RC for $M = 0.2$. First sensitivities to different starting years are shown, and then some other factors investigated. For the different starting years, the numbers of ages which are estimated individually in the starting vector are (1, 3, 3, 4, 5, all, all) for the years (1934, 1963, 1964, 1965, 1967, 1970 and 1982) respectively. These choices were made on an AIC basis. App. A5, Table 4 is similar to Table 3, but for the RC with *M* increasing and with somewhat fewer sensitivities.

App. A5, Table 5 gives results for the authors' "preferred" runs for the two different *M* scenarios. These "preferred" runs differ from the RC only in starting in 1934 rather than 1963, and in incorporating refinement of the *Bigelow-Albatross* calibration function within the assessment. The reasons for the various choices made for these "preferred" runs are given in the Discussion section following.

App. A5, Figs 1-7 are constructed to illustrate some of the sensitivities associated with different choices for a number of the factors requiring specification in the assessment. App. A5, Figs 1-3 show various trajectory plots for spawning biomass and recruitment, some of which also show approximate Hessian-based 95% CIs, and Fig. 1 also shows the total catch trajectory. Fig. 4 plots some of the selectivity functions that differ across the sensitivities investigated, while Fig. 5 compares spawning biomass trajectories for the two different *M* scenarios for the RC. App. A5, Figs 6-7 compare different estimated stock recruitment functions.

App. A5, Figs 8-13 show diagnostic plots for the "preferred" case with $M = 0.2$. These include spawning biomass and recruitment trajectories showing approximate 95% CIs, selectivity-at-age plots, fits/residuals to abundance indices and proportions-at-age and -at-length data, refined *Bigelow-Albatross* calibration functions, and retrospective analyses. App. A5, Figs 14-19 repeat these same plots for the other "preferred" case with *M* increasing. App. A5, Fig. 20 shows the fitted stock-recruiment relationships for each case.

Discussion

Several features are evident from the exploratory results in App. A5, Tables 1 and 2:

- Starting the assessment in 1982 provides no basis to discriminate alternative stock-recruitment relations, and the estimates of spawning biomass at MSY are hopelessly imprecise for the $M = 0.2$ case.
- For a 1963 start to the assessment, the Ricker form is preferred over the Beverton-Holt form in terms of AIC, particularly for the *M* increasing scenario. For $M = 0.2$, the Beverton-Holt estimate of spawning biomass at MSY is appreciably larger than its Ricker counterpart.
- Internal estimates of the spawning biomass at MSY for a 1963 start to the assessment are both somewhat higher and less precise than their external estimation counterparts, but this last result is not unexpected since the internal estimates take account of errors in estimates of spawning biomass and correlations amongst estimates over time, unlike the external estimates.
- Estimates of current (2011) spawning biomass are typically 1000 tons lower without internal estimation of the stock-recruitment function.

With BRP estimation in mind, and given the results summarised in the first three bullets above, preference is indicated for internal estimation using a Ricker form for the stock-recruitment relationship, and for starting the assessment in an early year. Hence the Reference Case (RC) was selected to include these specifications, and with a 1963 start because that corresponded to the beginning of the NEFSC survey time series.

Further results shown in App. A5, Table 3 and plotted in App. A5, Figs 1-7 suggest little sensitivity of recruitment estimates to most of the assessment options examined, and also of the spawning biomass trajectory except for some variability in the early years depending on the 1960s starting year chosen (App. A5, Figs 1-3). However when the starting year is taken back to 1934, this results in a clear and relatively precise trend in spawning biomass of an increase over the 1950s and early 1960s co-incident with the low catches over that period (App. A5, Fig. 2). The survey CAL data from the 1960s also support this trend (lowest left plot in Fig. 3). Another feature of the results for BRPs is that once the contrast provided by the assessment estimates from the 1960s is lost, the ability for precise estimation of the stock-recruitment relationship, and hence of BRPs such as the spawning biomass at MSY, is lost with it (App. A5, Table 3 and Fig. 7). Comparison of relationships found by internal and external stock-recruit function estimation shows little difference (App. A5, Fig. 6).

The above points towards preferring an earlier start to the assessment than the 1963 of the RC, as the combination of the data and the stock-recruit relationship assumption inform the overall BRP estimation process further through providing meaningful information on stock dynamics back into the 1950s at least.

Regarding the other sensitivity tests for M = 0.2, alternative assumptions about selectivity-at-age pre-1982 make little difference to results (App. A5, Table 3 and Fig.3, third row). Fitting to abundance indices in terms of biomass rather than numbers decreases the current spawning biomass estimate slightly, but makes little difference otherwise (App. A5, Table 3, and Fig. 3, second row). Use of the adjusted log-normal form for the proportions data appreciably increases the variance of the BRP estimates (App. A5, Table 3). A domed survey selectivity is preferred under AIC, but trends into the 1960s (App. A5, Fig. 3, second row) seem at variance with the pattern suggested by Fig. 1 when earlier years are included in the assessment. Inclusion of the *Bigelow* calibration refinement has little impact on results (App. A5, Table 3).

Where examined, these same features seem broadly present for the increasing M case, though to lesser extents. Unsurprisingly once M becomes higher, both spawning biomass and recruitment estimates increase (App. A5, Fig. 5).

Based on these results, the authors' preference is to leave the RC specifications unchanged except to move to a 1934 starting year to make maximal use of data contrast in estimating BRPs, and to include the *Bigelow* calibration refinement because of its in principle desirability.

In broad terms the diagnostics for both the consequent "preferred" cases in App. A5, Figs 8-19 are satisfactory. The M increasing scenario shows an appreciably reduced retrospective pattern compared to the M = 0.2 case (App. A5, Fig. 19 compared to Fig. 13), and further is preferred in AIC terms (App. A5, Table 5). Accordingly it would seem that more weight should be placed on the results provided by the M increasing scenario.

Conclusions

Key conclusions from these results are:

- Assessments should start from as early a year as possible to maximise the contrast in data required to provide BRP estimates with better precision.
- Internal over external estimation of stock-recruitment functions is preferred to best take the variance-covariance of spawning biomass and recruitment estimates into account. The Ricker form for this relationship is AIC preferred to the Beverton-Holt form.
- Across a wide range of sensitivity tests (including treatment of the stock-recruitment relationship), the 2011 spawning biomass is robustly estimated at about 14 thousand tons with specific estimates ranging from about 12.5 to 16 thousand tons.
- Given a start to the assessments in the 1960s or earlier, with internal estimation of a Ricker stock-recruitment function, most estimates of the spawning biomass which provides MSY are around 25 thousand tons for the $M = 0.2$ scenario, and around 13 thousand tons for the M increasing scenario; the corresponding estimates of MSY itself are about 13 and 6 thousand tons respectively.
- The AIC selection criterion and a reduced retrospective pattern suggest that greater weight should be accorded to results for the M increasing compared to the $M = 0.2$ scenario.

Acknowledgements

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References

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Appendix A5. Tables

App. A5, Table 1: Estimates of abundance, MSY-related biological reference points (BRPs), and related quantities for the Gulf of Maine cod for a comparative exercise across four assessments factors: start date, internal or external estimation of the stock-recruitment relationship, the form of the stock-recruitment relationship, and the time dependence of natural mortality *M* (see text for further details). Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood values shown in square parentheses denote non-comparability with values given in adjacent columns. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

	Start in y1=1963											
	M =0.2						*M* increasing					
	Ricker internal		BH internal		No SR		Ricker internal		BH internal		No SR	
-lnL: overall	-2765		-2763		-[2797]		-2774		-2769		-[2801]	
-lnL: survey	-24.2		-24.0		-25.4		-30.2		-30.6		-31.4	
-lnL: comCAA	-787.0		-786.9		-785.6		-783.9		-785.6		-782.4	
-lnL: survCAA	-1819		-1819		-1821		-1819		-1818		-1821	
-lnL: survCAL	-160.5		-160.4		-161.0		-161.0		-160.8		-161.5	
-lnL: RecRes	29.3		31.9		[0.0]		24.4		28.6		[0.0]	
-lnL: Catch	3.1		3.0		2.1		3.2		3.8		2.5	
-lnL: calibration	-6.7		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	0.000		0.000		0.000		0.000		0.000		0.000	
$N_{y1,0}$	15.10	(0.14)	15.88	(0.14)	15.18	(0.14)	15.10	(0.14)	15.91	(0.14)	15.51	(0.14)
ϕ	0.09	(1.06)	0.19	(0.58)	0.16	(0.64)	0.08	(0.86)	0.16	(0.62)	0.16	(0.63)
B^{sp}_{2011}	14.51	(0.16)	14.26	(0.16)	13.13	(0.17)	13.57	(0.14)	13.18	(0.14)	12.57	(0.15)
B^{sp}_{1982}	22.83	(0.05)	22.93	(0.05)	22.53	(0.05)	22.27	(0.05)	22.51	(0.05)	22.15	(0.05)
B^{sp}_{y1}	43.41	(0.28)	29.78	(0.34)	33.38	(0.31)	42.90	(0.22)	32.49	(0.31)	32.76	(0.31)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	0.84	0.16	0.84	0.16	0.79	0.11	0.79	0.11	0.78	0.11
NEFSC fall	0.67	0.10	0.68	0.10	0.68	0.10	0.64	0.12	0.64	0.12	0.64	0.12
MADMF spring	0.22	0.30	0.22	0.30	0.22	0.30	0.15	0.24	0.15	0.24	0.15	0.24
K	70.79	(0.13)	245.16	(0.26)			31.22	(0.08)	36.39	(0.09)		
h	2.44	(0.14)	0.88	(0.05)			1.00	(0.16)	0.98+	(0.00)		
MSY	13.48	(0.10)	15.27	(0.22)			6.31	(0.16)	5.83	(0.09)		
F_{MSY}	0.59		0.27				0.67		0.95			
B^{sp}_{MSY}	23.88	(0.10)	57.05	(0.23)			11.54	(0.16)	8.27	(0.10)		
B^{sp}_{MSY}/K^{sp}	0.34	(0.11)	0.23	(0.06)			0.37	(0.17)	0.23	(0.03)		
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.61	(0.10)	0.25	(0.23)			1.18	(0.16)	1.59	(0.10)		

	Start in y1=1982											
	M =0.2						*M* increasing					
	Ricker internal		BH internal		No SR		Ricker internal		BH internal		No SR	
-lnL: overall	-2128		-2128		-[2145]		-2137		-2137		-[2151]	
-lnL: survey	-15.5		-15.5		-17.0		-24.1		-24.3		-25.5	
-lnL: comCAA	-793.8		-793.8		-792.3		-791.1		-791.2		-790.1	
-lnL: survCAA	-1329		-1329		-1330		-1329		-1329		-1330	
-lnL: survCAL	-		-		0.0		-		-		0.0	
-lnL: RecRes	15.2		15.2		[0.0]		13.1		13.1		[0.0]	
-lnL: Catch	1.4		1.4		1.2		1.1		1.1		1.1	
-lnL: calibration	-6.7		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	2.600*		2.589*		1.073*		0.000		0.000		0.000	
$N_{y1,0}$	13.30	(0.07)	13.30	(0.07)	13.27	(0.07)	13.52	(0.07)	13.52	(0.07)	13.50	(0.07)
ϕ	-		-		-		-		-		-	
B^{sp}_{2011}	13.51	(0.16)	13.52	(0.16)	12.59	(0.17)	13.54	(0.14)	13.40	(0.14)	12.67	(0.15)
B^{sp}_{1982}	26.37	(0.04)	26.36	(0.04)	26.27	(0.04)	26.08	(0.04)	26.10	(0.04)	26.09	(0.04)
B^{sp}_{y1}	26.37	(0.04)	26.36	(0.04)	26.27	(0.04)	26.08	(0.04)	26.10	(0.04)	26.09	(0.04)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.96	0.18	0.96	0.18	0.96	0.18	0.83	0.12	0.83	0.12	0.83	0.11
NEFSC fall	0.54	0.06	0.54	0.06	0.54	0.05	0.47	0.06	0.47	0.06	0.47	0.05
MADMF spring	0.22	0.30	0.22	0.30	0.23	0.30	0.15	0.24	0.15	0.24	0.15	0.24
K	157.95	(1.35)	625.38	(1.47)			31.26	(0.26)	43.49	(0.35)		
h	1.79	(0.25)	0.80	(0.08)			0.94	(0.29)	0.82	(0.39)		
MSY	23.77	(1.17)	36.66	(1.40)			5.88	(0.17)	5.76	(0.23)		
F_{MSY}	0.42		0.22				0.60		0.86			
B^{sp}_{MSY}	58.07	(1.17)	168.72	(1.40)			11.80	(0.17)	8.79	(0.23)		
B^{sp}_{MSY}/K^{sp}	0.37	(0.20)	0.27	(0.08)			0.38	(0.32)	0.20	(0.50)		
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.23	(1.17)	0.08	(1.40)			1.15	(0.17)	1.53	(0.23)		

* This applies to the gradient for the age 4 parameter for selectivity in the first 1982-1988 block. All other estimated parameters have gradient $<10^{-3}$.

+ Estimate on bound of h=0.98 imposed on Beverton-Holt stock-recruitment curve fits.

App. A5, Table 2: An extension of Table 1 which provides BRP values for external estimation of the stock-recruitment functions.

	Start in 1963								Start in 1982							
	M =0.2				*M* increasing				*M* =0.2				*M* increasing			
	Ricker		Beverton-Holt		Ricker		Beverton-Holt		Ricker		Beverton-Holt		Ricker		Beverton-Holt	
-lnL	8.7		11.4		1.5		6.1		2.8		2.7		-1.9		-1.8	
h	2.65	(0.14)	0.91	(0.05)	1.14	(0.16)	1.00	(0.00)	2.16	(0.24)	0.86	(0.08)	1.18	(0.29)	1.00	(0.00)
K^{sp}	66.41	(0.13)	220.04	(0.22)	29.83	(0.06)	36.86	(0.09)	89.51	(0.65)	324.35	(0.76)	27.22	(0.17)	39.44	(0.11)
F_{MSY}	0.87		0.38		1.11		5.00*		0.67		0.31		1.20		5.00*	
$MSYL^{sp}$	0.33	(0.11)	0.22	(0.05)	0.36	(0.16)	0.11	(0.00)	0.35	(0.18)	0.26	(0.07)	0.36	(0.29)	0.11	(0.00)
B^{sp}_{MSY}	21.94	(0.09)	49.41	(0.18)	10.88	(0.15)	3.87	(0.09)	31.57	(0.50)	83.96	(0.69)	9.86	(0.18)	4.15	(0.11)
MSY	13.55	(0.09)	14.32	(0.18)	7.01	(0.15)	6.59	(0.09)	15.62	(0.50)	20.36	(0.69)	6.65	(0.18)	7.05	(0.11)
B^{sp}_{2011}	13.11	(0.17)	13.11	(0.17)	12.57	(0.15)	12.57	(0.15)	12.59	(0.17)	12.59	(0.17)	12.67	(0.17)	12.67	(0.15)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.60	(0.09)	0.27	(0.18)	1.16	(0.15)	3.25	(0.09)	0.40	(0.50)	0.15	(0.69)	1.29	(0.18)	3.05	(0.11)
B^{sp}_{2011}/K^{sp}	0.20	(0.13)	0.06	(0.22)	0.42	(0.06)	0.34	(0.09)	0.14	(0.65)	0.04	(0.76)	0.47	(0.17)	0.32	(0.11)

* Estimate on upper bound of F=5.00 imposed on the search for F_{MSY}, which may occur in the limit of h=1 for the Beverton-Holt form. (Note that unlike for the internal estimation where a bound of h=0.98 is imposed, the bound imposed here is h=1.)

App. A5, Table 3: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for different sensitivities about the Reference Case (start in 1963 with a Ricker stock-recruitment curve estimated internally) with $M = 0.2$, which is shown in **bold**. Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood overall values shown in square parentheses denote non-comparability with values of all likelihood components given in adjacent columns. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

	Different start year													
			Reference Case											
Start year y1=	1934		**1963**		1964		1965		1967		1970		1982	
-lnL: overall	-[2762]		**-2765**		-[2748]		-[2732]		-[2697]		-[2610]		-[2128]	
-lnL: survey	-24.5		**-24.2**		-25.4		-25.1		-23.2		-19.4		-15.5	
-lnL: comCAA	-787.0		**-787.0**		-787.0		-786.8		-786.6		-787.2		-793.8	
-lnL: survCAA	-1819		**-1819**		-1819		-1820		-1820		-1820		-1329	
-lnL: survCAL	-160.0		**-160.5**		-141.6		-126.1		-89.3		-		-	
-lnL: RecRes	[31.9]		**29.3**		[29.1]		[29.7]		[26.4]		[21.3]		[15.2]	
-lnL: Catch	3.2		**3.1**		3.0		2.9		2.4		1.9		1.4	
-lnL: calibration	-6.7		**-6.7**		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	0.000		**0.000**		0.000		0.000		0.000		0.000		2.600*	
$N_{y1,0}$	9.52	(76.22)	**15.10**	**(0.14)**	8.56	(0.17)	4.65	(0.20)	3.25	(0.21)	4.84	(0.19)	13.30	(0.07)
ϕ	0.25	(152.54)	**0.09**	**(1.06)**	0.04	(2.05)	0.14	(0.78)	0.16	(0.73)	-		-	
B^{sp}_{2011}	14.25	(0.16)	**14.51**	**(0.16)**	14.42	(0.16)	14.33	(0.16)	14.35	(0.16)	14.22	(0.16)	13.51	(0.16)
B^{sp}_{1982}	22.92	(0.05)	**22.83**	**(0.05)**	22.84	(0.05)	22.96	(0.05)	22.99	(0.05)	22.94	(0.05)	26.37	(0.04)
B^{sp}_{y1}	41.17	(140.75)	**43.41**	**(0.28)**	46.74	(0.24)	34.80	(0.27)	38.66	(0.13)	34.58	(0.10)	26.37	(0.04)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	**0.84**	**0.16**	0.84	0.16	0.84	0.16	0.84	0.16	0.84	0.17	0.96	0.18
NEFSC fall	0.67	0.10	**0.67**	**0.10**	0.66	0.09	0.65	0.09	0.64	0.10	0.64	0.11	0.54	0.06
MADMF spring	0.22	0.30	**0.22**	**0.30**	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30
K	74.78	(0.19)	**70.79**	**(0.13)**	70.11	(0.14)	75.18	(0.19)	94.80	(0.27)	383.89	(1.81)	157.95	(1.35)
h	2.24	(0.15)	**2.44**	**(0.14)**	2.46	(0.14)	2.32	(0.16)	2.11	(0.16)	1.65	(0.18)	1.79	(0.25)
MSY	13.34	(0.12)	**13.48**	**(0.10)**	13.44	(0.10)	13.75	(0.12)	16.09	(0.19)	53.41	(1.69)	23.77	(1.17)
F_{MSY}	0.53		**0.59**		0.59		0.56		0.50		0.38		0.42	
B^{sp}_{MSY}	25.73	(0.12)	**23.88**	**(0.10)**	23.59	(0.10)	25.61	(0.12)	32.96	(0.19)	140.96	(1.69)	58.07	(1.17)
B^{sp}_{MSY}/K^{sp}	0.34	(0.12)	**0.34**	**(0.11)**	0.34	(0.11)	0.34	(0.13)	0.35	(0.13)	0.37	(0.15)	0.37	(0.20)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.55	(0.12)	**0.61**	**(0.10)**	0.61	(0.10)	0.56	(0.12)	0.44	(0.19)	0.10	(1.69)	0.23	(1.17)

	Adjusted log-normal CAA error		Fit to biomass instead of numbers		Domed NEFSC survey selectivity		Alternative pre-1982 commercial selectivities				Bigelow internal calibration		No CAL data	
							Same as 82-88		Shifted 2yrs left					
Start year y1=	1963		1963		1963		1963		1963		1963		1963	
-lnL: overall	-[298]		-[2777]		-2781		-2768		-2761		-2766		-[2605]	
-lnL: survey	-24.2		-37.5		-25.3		-24.7		-23.8		-25.3		-24.1	
-lnL: comCAA	-177.8		-786.3		-786.7		-790.6		-788.6		-787.0		-787.2	
-lnL: survCAA	-134		-1818		-1828		-1817		-1815		-1821		-1819	
-lnL: survCAL	16.6		-160.3		-162.1		-160.6		-160.2		-160.6		0.0	
-lnL: RecRes	[25.0]		[29.9]		26.0		27.9		30.1		29.6		[28.7]	
-lnL: Catch	2.9		2.5		2.5		3.1		3.3		3.2		3.1	
-lnL: calibration	-6.7		-6.7		-6.7		-6.7		-6.7		-5.4		-6.7	
Maximum gradient	0.000		0.000		0.000		0.000		30.774		18.6[&]		0.000	
$N_{y1,0}$	16.02	(0.11)	15.41	(0.14)	16.29	(0.14)	14.08	(0.14)	15.41	(0.15)	15.09	(0.14)	15.17	(0.16)
ϕ	0.21	(0.35)	0.09	(0.91)	0.01	(0.08)	0.09	(0.97)	0.08	(1.08)	0.09	(1.05)	0.01	(0.02)
B^{sp}_{2011}	16.04	(0.17)	13.59	(0.15)	15.30	(0.17)	14.30	(0.16)	14.39	(0.16)	14.67	(0.16)	14.50	(0.16)
B^{sp}_{1982}	26.19	(0.05)	22.94	(0.05)	28.63	(0.09)	22.37	(0.05)	23.29	(0.05)	22.81	(0.05)	22.94	(0.05)
B^{sp}_{y1}	28.24	(0.23)	39.48	(0.23)	102.12	(0.17)	44.22	(0.26)	41.24	(0.32)	43.30	(0.28)	51.87	(0.13)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.89	0.16	0.83	0.15	0.86	0.16	0.84	0.16	0.85	0.16	0.84	0.16	0.84	0.16
NEFSC fall	0.79	0.11	0.66	0.07	0.69	0.09	0.66	0.10	0.68	0.10	0.67	0.10	0.66	0.10
MADMF spring	0.20	0.29	0.19	0.18	0.21	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30
K	95.45	(0.29)	71.39	(0.15)	97.48	(0.12)	66.28	(0.12)	75.81	(0.16)	70.73	(0.14)	73.03	(0.13)
h	1.99	(0.18)	2.39	(0.15)	2.03	(0.12)	2.45	(0.14)	2.41	(0.14)	2.43	(0.14)	2.40	(0.13)
MSY	15.26	(0.18)	13.39	(0.10)	15.69	(0.10)	12.69	(0.09)	14.35	(0.10)	13.46	(0.10)	13.76	(0.10)
F_{MSY}	0.48		0.58		0.53		0.60		0.57		0.59		0.58	
B^{sp}_{MSY}	32.92	(0.19)	24.14	(0.10)	32.85	(0.12)	22.41	(0.10)	25.88	(0.11)	23.87	(0.10)	24.70	(0.10)
B^{sp}_{MSY}/K^{sp}	0.34	(0.15)	0.34	(0.12)	0.34	(0.11)	0.34	(0.11)	0.34	(0.12)	0.34	(0.11)	0.34	(0.11)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.49	(0.19)	0.56	(0.10)	0.47	(0.12)	0.64	(0.10)	0.56	(0.11)	0.61	(0.10)	0.59	(0.10)

App. A5, Table 4: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for different sensitivities about the Reference Case (start in 1963 with a Ricker stock-recruitment curve estimated internally) with *M* increasing from 0.2 until 1988 to 0.4 in 2003 and constant at 0.4 thereafter. This case is shown in **bold.** Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood overall values shown in square parentheses denote non-comparability with values given for all likelihood components in adjacent columns. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used.

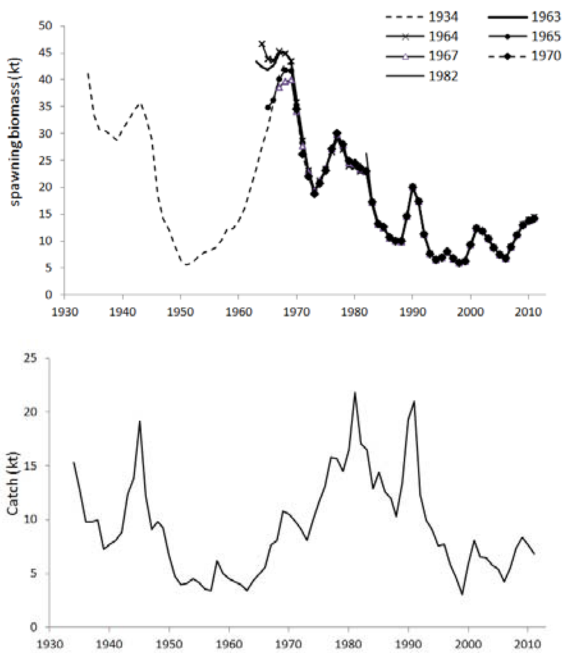
	Different start year														Adjusted log-normal CAA error	
Start year y1=	1934		**1963**		1964		1965		1967		1970		1982		1963	
-lnL: overall	-[2772]		**-[2774]**		-[2757]		-[2740]		-[2705]		-[2615]		-[2137]		-[311]	
-lnL: survey	-30.1		**-30.2**		-31.4		-31.1		-29.9		-26.4		-24.1		-29.3	
-lnL: comCAA	-785.1		**-783.9**		-785.9		-785.8		-784.5		-785.8		-791.1		-176.2	
-lnL: survCAA	-1818		**-1819**		-1818		-1818		-1820		-1819		-1329		-139	
-lnL: survCAL	-160.9		**-161.0**		-142.1		-126.1		-89.3		0.0		0.0		16.0	
-lnL: RecRes	[25.8]		**[24.4]**		[23.8]		[24.4]		[22.7]		[20.1]		[13.1]		[21.0]	
-lnL: Catch	3.4		**3.2**		3.1		3.1		2.7		2.0		1.1		3.5	
-lnL: calibration	-6.7		**-6.7**		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	0.000		**0.000**		0.000		0.000		0.000		0.000		0.000		0.000	
$N_{y1,0}$	10.74	(1.98)	**15.10**	**(0.14)**	8.70	(0.17)	4.79	(0.20)	3.56	(0.21)	5.23	(0.19)	13.52	(0.07)	15.93	(0.11)
ϕ	0.33	(2.15)	**0.08**	**(0.86)**	0.03	(2.09)	0.08	(1.02)	0.13	(0.84)	-		-		0.18	(0.40)
B^{sp}_{2011}	13.64	(0.15)	**13.57**	**(0.14)**	13.54	(0.14)	13.55	(0.14)	13.57	(0.14)	13.58	(0.15)	13.54	(0.14)	15.07	(0.15)
B^{sp}_{1982}	22.17	(0.05)	**22.27**	**(0.05)**	22.38	(0.05)	22.46	(0.05)	22.33	(0.05)	22.54	(0.05)	26.08	(0.04)	25.71	(0.05)
B^{sp}_{y1}	25.81	(2.11)	**42.90**	**(0.22)**	46.72	(0.19)	38.85	(0.21)	38.64	(0.13)	33.05	(0.10)	26.08	(0.04)	32.43	(0.20)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.80	0.11	**0.79**	**0.11**	0.79	0.11	0.79	0.11	0.79	0.11	0.78	0.11	0.83	0.12	0.78	0.11
NEFSC fall	0.64	0.12	**0.64**	**0.12**	0.63	0.11	0.62	0.11	0.61	0.11	0.59	0.12	0.47	0.06	0.70	0.13
MADMF spring	0.15	0.24	**0.15**	**0.24**	0.15	0.24	0.15	0.24	0.15	0.24	0.15	0.24	0.15	0.24	0.13	0.24
K	31.64	(0.08)	**31.22**	**(0.08)**	31.26	(0.08)	31.03	(0.08)	33.59	(0.11)	44.77	(0.27)	31.26	(0.26)	32.72	(0.09)
h	1.02	(0.16)	**1.00**	**(0.16)**	1.01	(0.16)	1.01	(0.17)	0.91	(0.18)	0.72	(0.21)	0.94	(0.29)	0.95	(0.20)
MSY	6.50	(0.15)	**6.31**	**(0.16)**	6.37	(0.15)	6.32	(0.16)	6.16	(0.15)	6.27	(0.16)	5.88	(0.17)	6.24	(0.18)
F_{MSY}	0.69		**0.67**		0.68		0.68		0.58		0.39		0.60		0.57	
B^{sp}_{MSY}	11.66	(0.15)	**11.54**	**(0.16)**	11.54	(0.16)	11.46	(0.16)	12.72	(0.16)	17.95	(0.16)	11.80	(0.17)	12.22	(0.18)
B^{sp}_{MSY}/K^{sp}	0.37	(0.18)	**0.37**	**(0.17)**	0.37	(0.17)	0.37	(0.18)	0.38	(0.20)	0.40	(0.25)	0.38	(0.32)	0.37	(0.22)
$B^{sp}_{2011}/B^{sp}_{MSY}$	1.17	(0.15)	**1.18**	**(0.16)**	1.17	(0.16)	1.18	(0.16)	1.07	(0.16)	0.76	(0.16)	1.15	(0.17)	1.23	(0.18)

App. A5, Table 5: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for the preferred cases for the two different M scenarios. Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

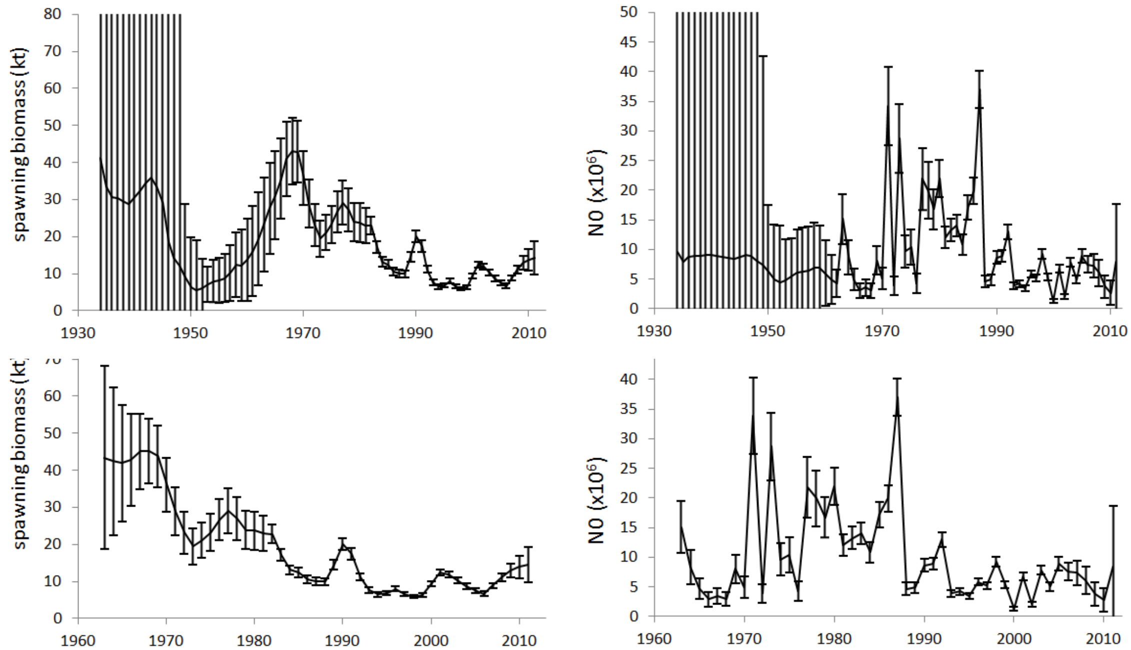
	M=0.2		M increasing	
Start year y1=	1934		1934	
-lnL: overall	-2764		-2773	
-lnL: survey	-25.4		-30.8	
-lnL: comCAA	-787.0		-785.2	
-lnL: survCAA	-1821		-1820	
-lnL: survCAL	-160.1		-161.0	
-lnL: RecRes	32.1		26.0	
-lnL: Catch	3.2		3.4	
-lnL: calibration	-5.4		-5.6	
Maximum gradient	18.5*		15.5	
$N_{y1,0}$	11.21	(175.51)	10.78	(1.97)
ϕ	0.32	(231.12)	0.33	(2.14)
B^{sp}_{2011}	14.49	(0.05)	13.79	(0.05)
B^{sp}_{1982}	22.90	(0.16)	22.15	(0.15)
B^{sp}_{y1}	32.69	(222.39)	25.73	(2.10)
	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	0.80	0.11
NEFSC fall	0.67	0.10	0.65	0.12
MADMF spring	0.22	0.30	0.15	0.24
K	74.70	(0.19)	31.58	(0.08)
h	2.24	(0.15)	1.02	(0.16)
MSY	13.33	(0.12)	6.49	(0.15)
F_{MSY}	0.53		0.69	
B^{sp}_{MSY}	25.70	(0.12)	11.64	(0.15)
B^{sp}_{MSY}/K^{sp}	0.34	(0.12)	0.37	(0.18)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.56	(0.12)	1.18	(0.15)

* This applies to the gradient for the third calibration parameter F2. All other estimated parameters have gradient $<10^{-5}$.

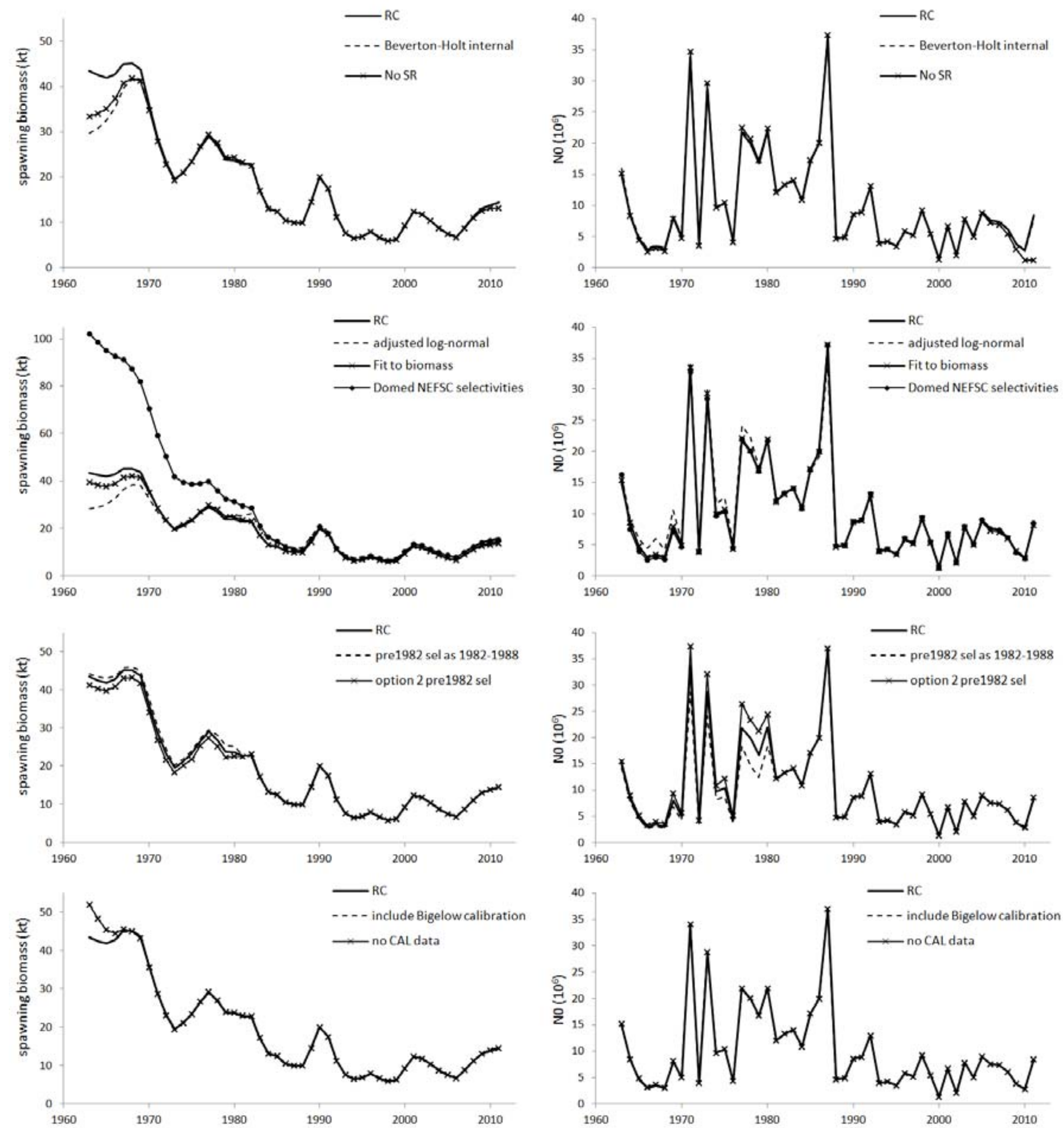
Appendix A5. Figures



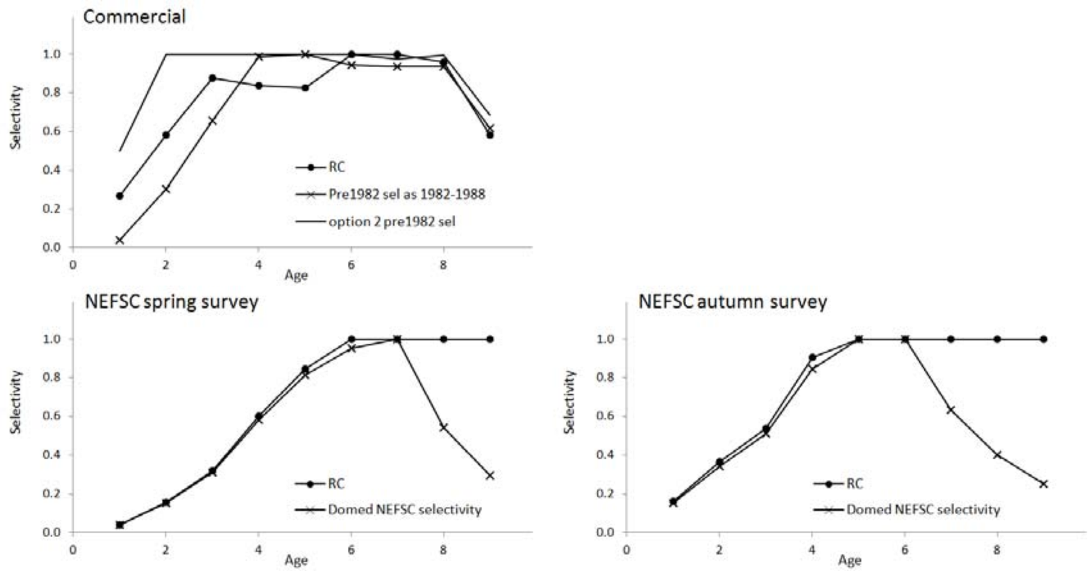
App. A5, Fig. 1: Spawning biomass and recruitment trajectories for the Ricker internal case with *M = 0.2* and different starting years. The time series of catches is also shown (including the 32% increase pre-1982 to take account of discards).



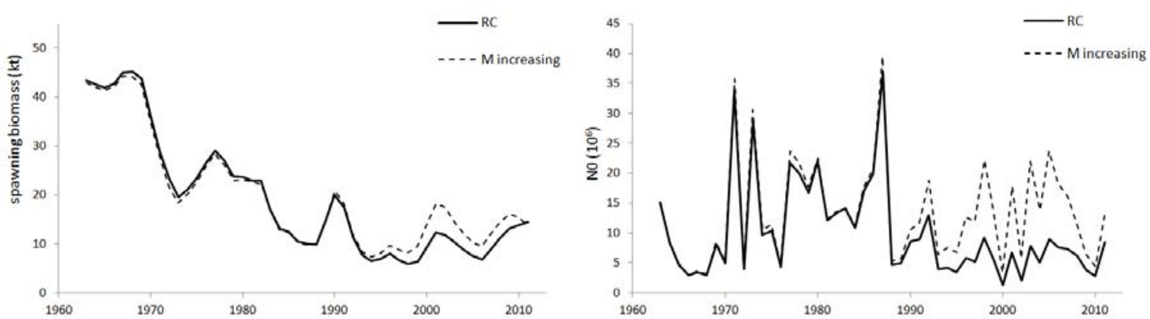
App. A5, Fig. 2: Spawning biomass and recruitment trajectories for the Ricker internal case with *M = 0.2*, start in 1934 (top row) and start in 1963 (bottom row) with ±2 se's shown to reflect approximate 95% CIs.



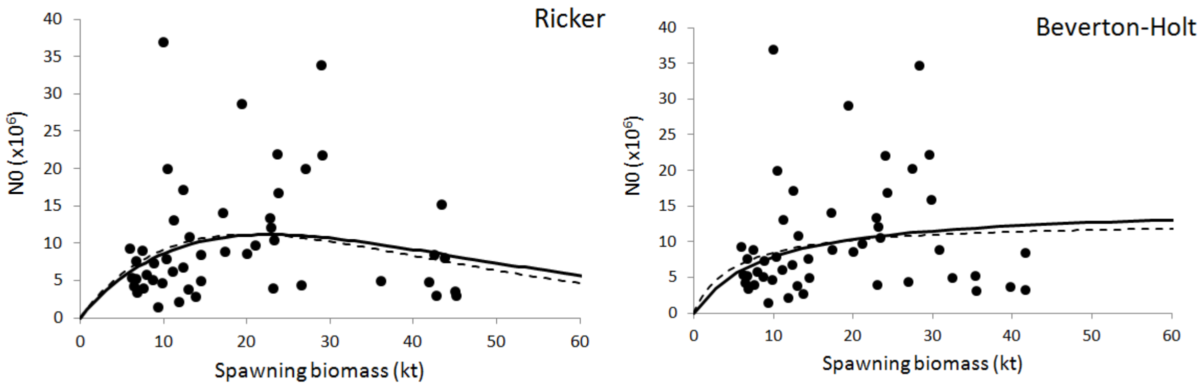
App. A5, Fig. 3: Spawning biomass and recruitment trajectories for various sensitivities about the Reference Case (RC - Ricker internal start in 1963) for *M* = 0.2.



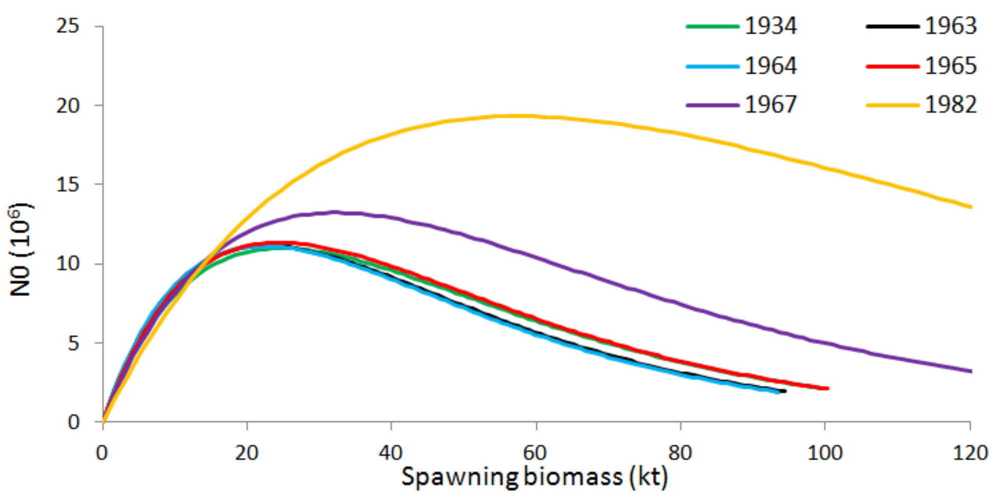
App. A5, Fig. 4: Pre-1982 commercial selectivities for the RC for M = 0.2and the two sensitivities relating to the pre-1982 commercial selectivity, and then for the NEFSC survey selectivities for the RC (flat) and the domed selectivity sensitivity.



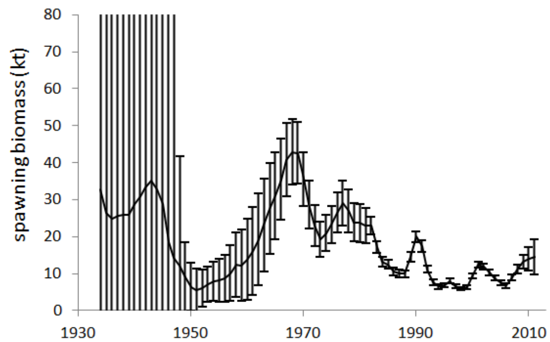
App. A5, Fig. 5: Spawning biomass and recruitment trajectories for the Reference Case with M = 0.2 and the corresponding case with M increasing.



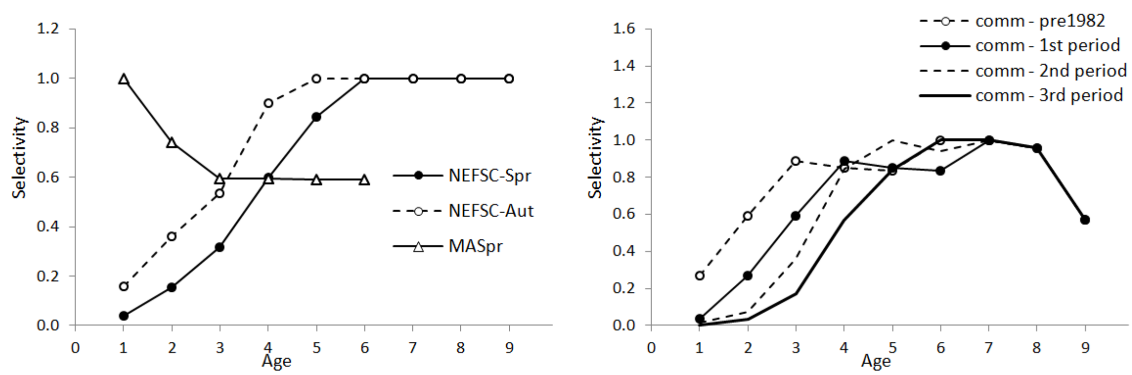
App. A5, Fig. 6: Stock-recruitment curve and "observed" recruitment for the Ricker and Beverton-Holt relationships estimated internally for the RC choice of a 1963 start year. The dashed lines show the corresponding estimated curves for external estimation.



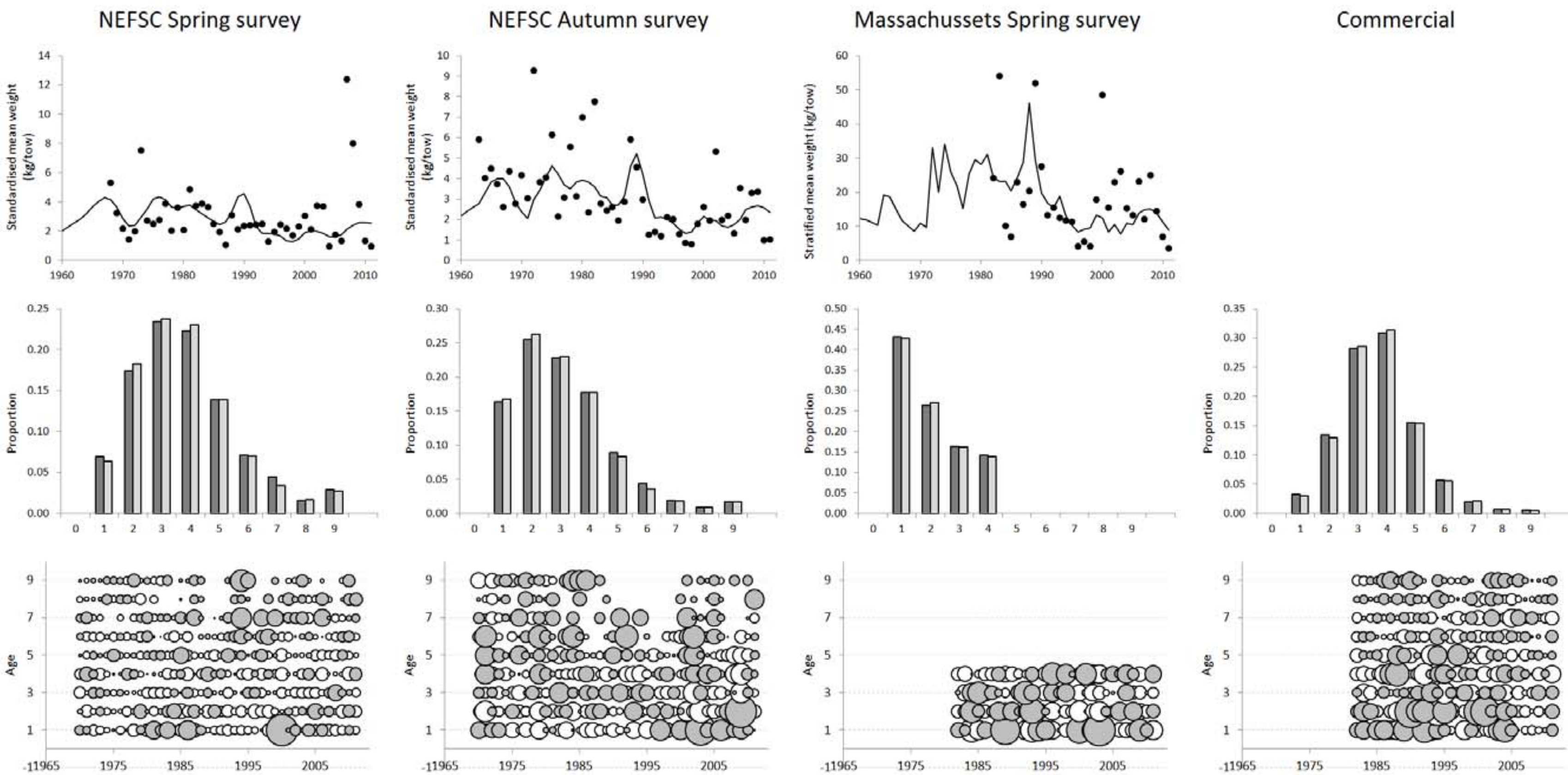
App. A5, Fig. 7: Stock-recruit relationship for the Reference Case with M = 0.2 and the cases with different start year. To improve discrimination, the very imprecisely estimated 1970 curve which goes to much higher levels than these others is omitted.



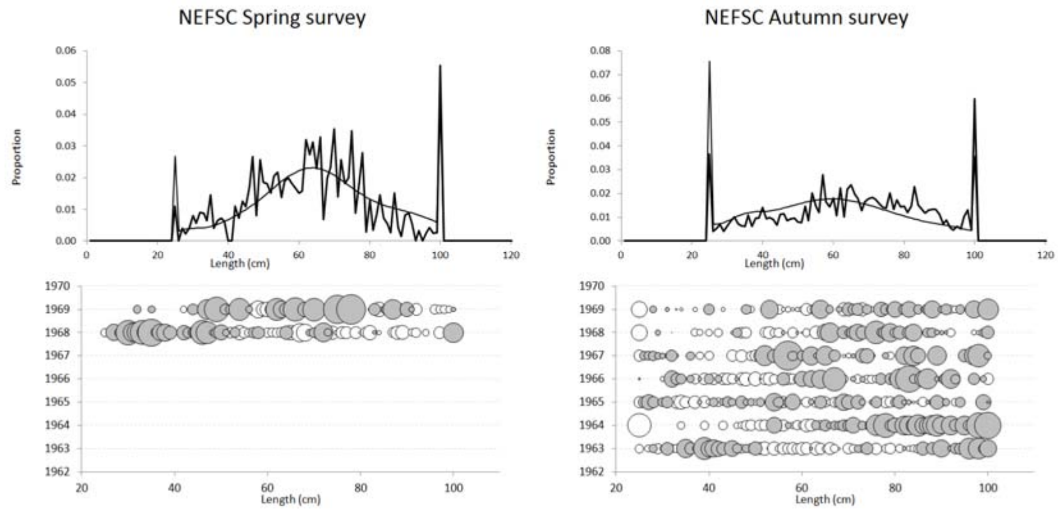
App. A5, Fig. 8. Spawning biomass and recruitment trajectories (with ±2 se's to reflect approximate 95% CIs) for the "preferred" run, $M = 0.2$.



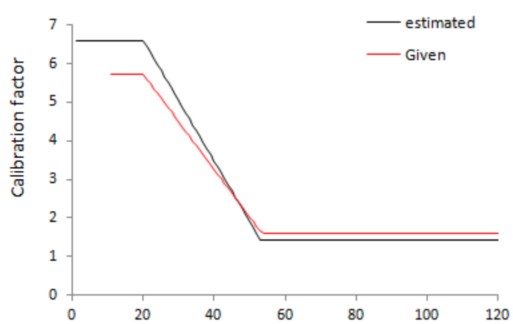
App. A5, Fig. 9. Survey and commercial selectivities estimated for the "preferred" run, $M = 0.2$.



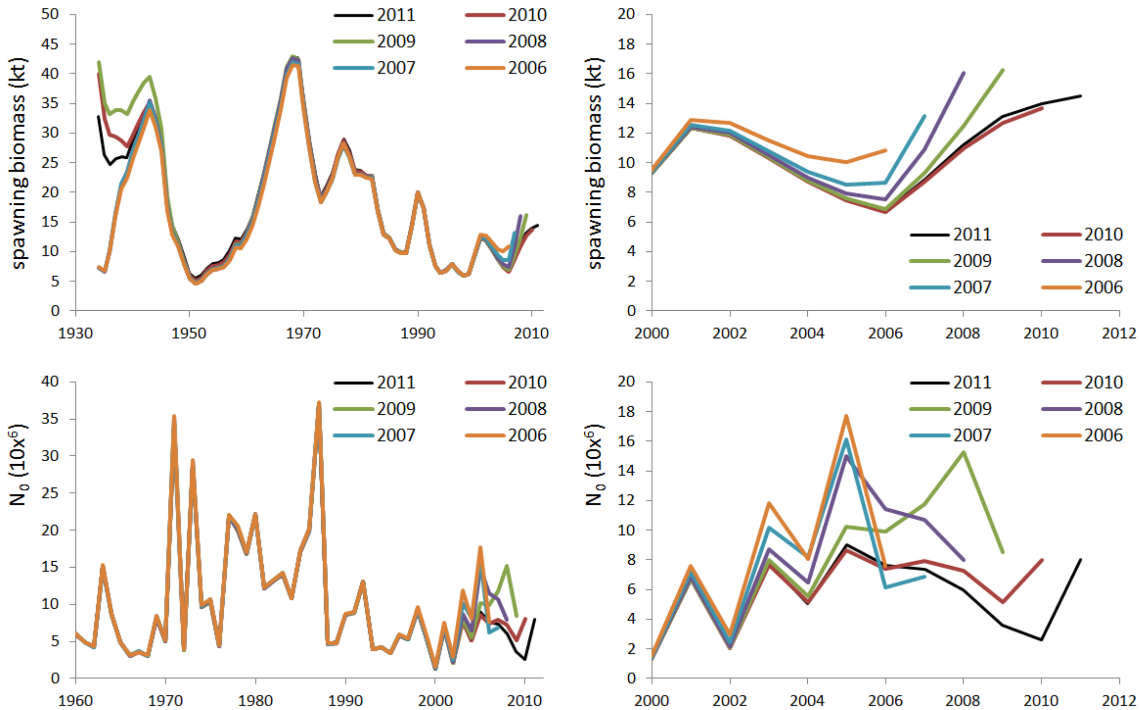
App. A5, Fig. 10: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the "preferred" run, *M = 0.2*. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



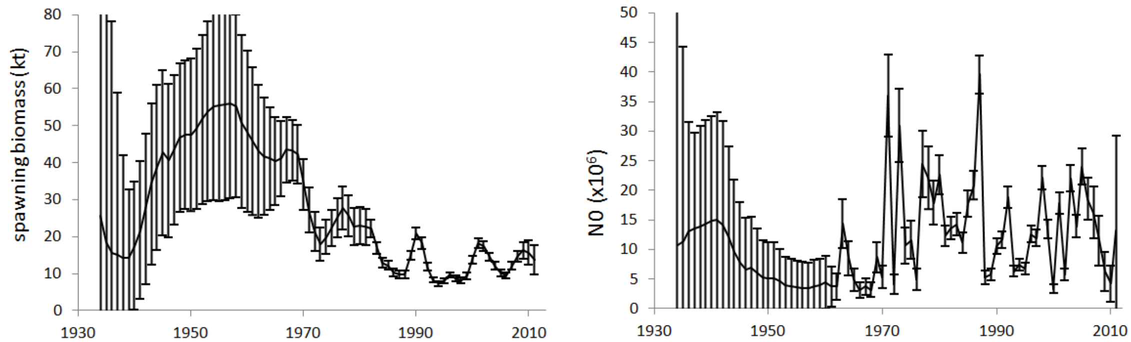
App. A5, Fig. 11: Fits to the survey catch-at-length data for the "preferred" run, $M = 0.2$. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



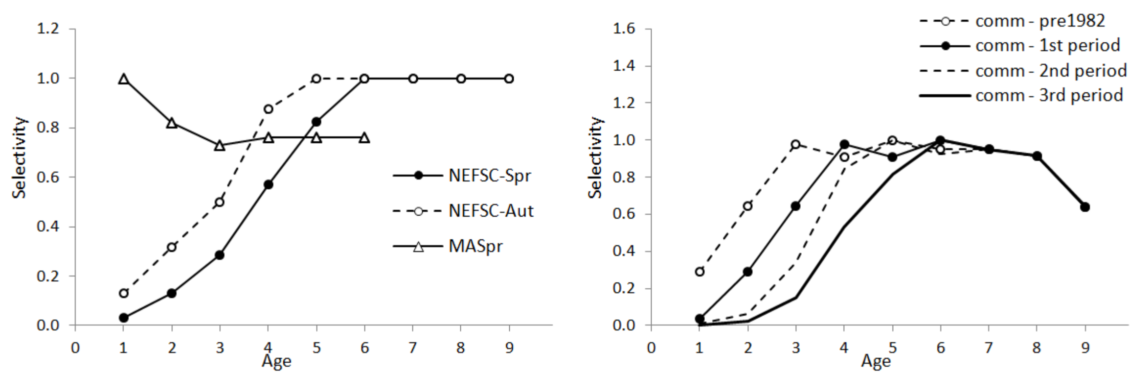
App. A5, Fig. 12: Comparison of *Bigelow-Albatross* calibration function estimated within the assessment ("preferred" run, $M = 0.2$) and calibration function given.



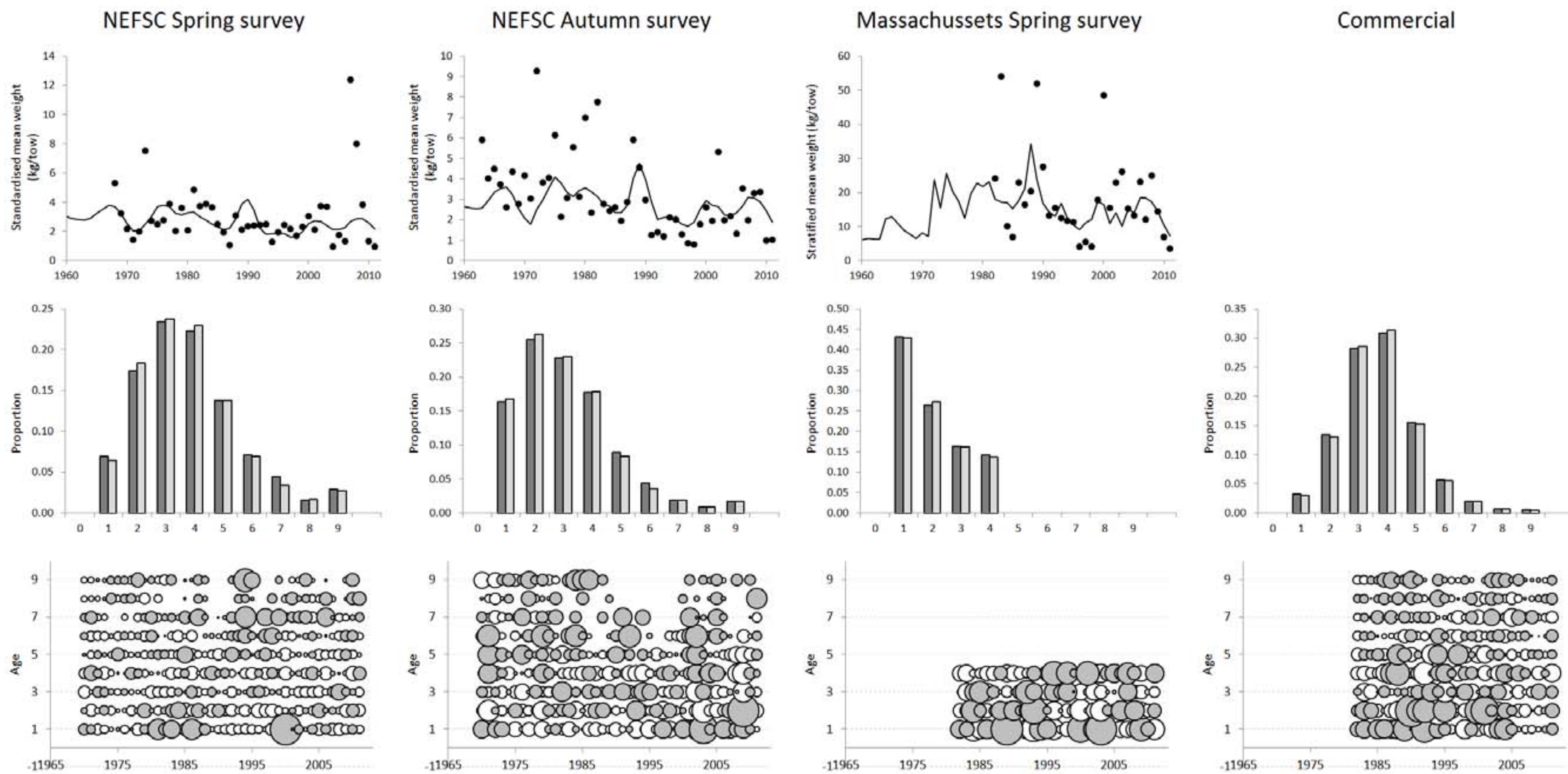
App. A5, Fig. 13: Retrospective analysis for the "preferred" run, *M = 0.2*.



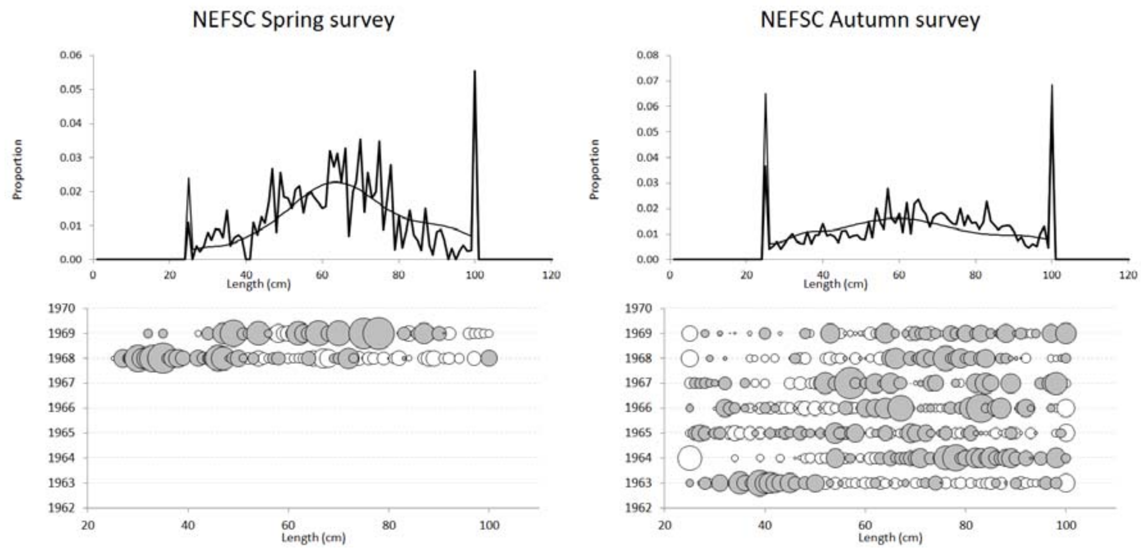
App. A5, Fig. 14. Spawning biomass and recruitment trajectories (with ±2 se's to reflect approximate 95% CIs) for the "preferred" run, *M* increasing.



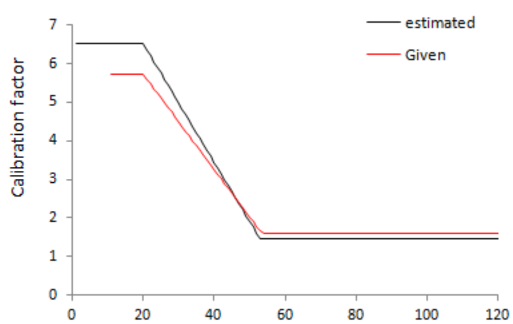
App. A5, Fig. 15. Survey and commercial selectivities estimated for the "preferred" run, *M* increasing. Note that for the Massachusetts survey as the age 4 selectivity is estimated to be greater than that for age 3, the selectivities for ages 5 and 6 are set equal to those for age 4 rather than continuing the trend from age 3 to age 4.



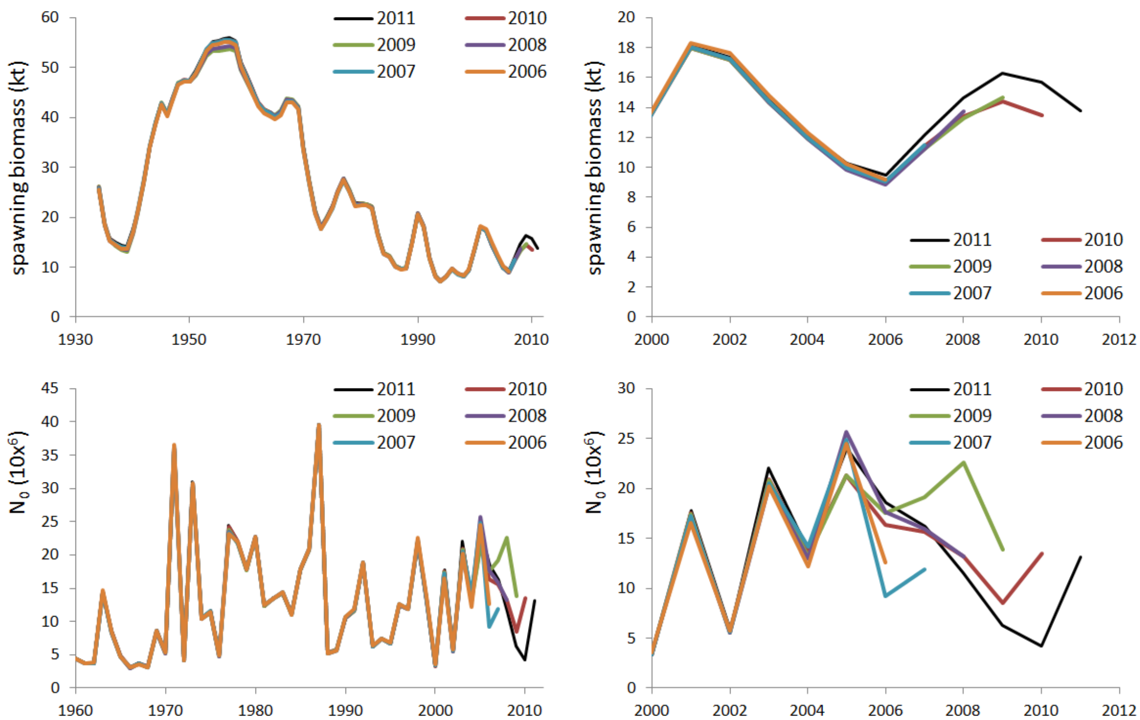
App. A5, Fig. 16: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the "preferred" run, *M* increasing. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



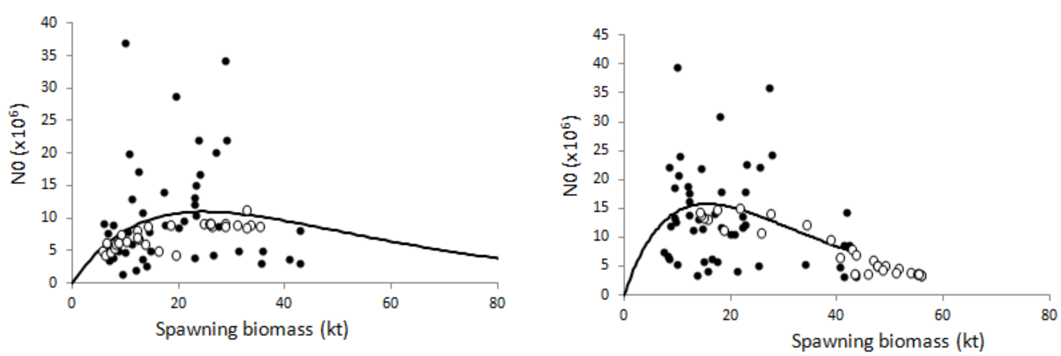
App. A5, Fig. 17: Fits to the survey catch-at-length data for the "preferred" run, *M* increasing. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.



App. A5, Fig. 18: Comparison of *Bigelow-Albatross* calibration function estimated within the assessment ("preferred" run, *M* increasing) and calibration function given.



App. A5, Fig. 19: Retrospective analysis for "preferred" run, *M* increasing.



App. A5, Fig. 20: Stock-recruitment curves and "observed" recruitment (pre-1963 data are shown as open circles) for the "preferred" runs *M = 0.2* (left-hand plot) and *M* increasing (right-hand plot).

Appendix A5 (Apendices A and B within App. A5)

APPENDIX A – Data

Note that the tables following, and the analyses reported in the main text, now exclude any 2012 data.

App. A5 (Append. A), Table A1: Total catch (incl. USA, DWF and recreational landings, and discards) (thousand metric tons) of Atlantic cod from the Gulf of Maine (NAFO Division 5Y), 1964-2012 (Michael Palmer, pers. commn). The revised discard mortality assumptions have been applied. Note that pre-1982 catches have been increased by 32% in the Base Case to allow for levels of discards suggested by recent analyses by the NEFSC.

Year	Total catch	Year	Total catch	Year	Total catch	Year	Total catch
1934	11.619	1954	3.411	1974	7.550	1994	9.060
1935	9.679	1955	3.171	1975	8.788	1995	7.566
1936	7.442	1956	2.693	1976	9.894	1996	7.757
1937	7.432	1957	2.562	1977	11.993	1997	5.814
1938	7.547	1958	4.670	1978	11.890	1998	4.578
1939	5.504	1959	3.795	1979	10.972	1999	3.078
1940	5.836	1960	3.448	1980	12.515	2000	5.823
1941	6.124	1961	3.216	1981	16.512	2001	8.055
1942	6.679	1962	2.989	1982	17.096	2002	6.509
1943	9.397	1963	2.595	1983	16.487	2003	6.497
1944	10.516	1964	3.242	1984	12.868	2004	5.766
1945	14.532	1965	3.759	1985	14.391	2005	5.441
1946	9.248	1966	4.225	1986	12.572	2006	4.268
1947	6.916	1967	5.824	1987	12.005	2007	5.527
1948	7.462	1968	6.137	1988	10.333	2008	7.375
1949	7.033	1969	8.155	1989	13.371	2009	8.355
1950	5.062	1970	7.961	1990	19.314	2010	7.670
1951	3.567	1971	7.475	1991	20.978	2011	6.830
1952	3.011	1972	6.927	1992	12.347		
1953	3.121	1973	6.138	1993	9.960		

App. A5 (Append. A), Table A2: Mean weight-at-age (kg) at the beginning of the year for the Gulf of Maine cod stock. Values derived from aggregated commercial landings and discard mean weight-at-age data (mid-year) using procedures described by Rivard (1980) (Michael Palmer, pers. commn) and applying the revised mortality assumptions. Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9+
1982	0.0024	0.241	0.594	1.165	2.127	4.635	7.622	9.289	9.695	15.664
1983	0.0077	0.050	0.501	1.114	1.894	3.136	5.539	6.549	9.962	13.325
1984	0.0001	0.075	0.372	1.019	2.021	2.952	4.593	7.118	7.845	14.828
1985	0.0146	0.014	0.403	0.910	2.013	3.532	4.608	6.863	9.700	13.676
1986	0.0009	0.104	0.316	1.077	1.917	3.670	5.504	6.908	9.315	14.646
1987	0.0007	0.028	0.406	0.777	2.273	3.574	5.889	8.079	9.487	14.582
1988	0.0003	0.022	0.293	0.980	1.709	4.010	4.927	6.705	10.069	12.993
1989	0.0223	0.027	0.292	0.887	2.179	3.172	5.578	6.945	8.799	20.913
1990	0.0063	0.095	0.431	0.937	1.742	3.627	5.750	8.043	10.440	18.718
1991	0.0069	0.071	0.450	1.083	1.689	2.846	5.654	8.972	11.518	14.060
1992	0.0116	0.028	0.476	1.215	2.026	2.564	4.629	8.832	10.453	14.483
1993	0.0116	0.046	0.191	1.254	1.702	3.449	4.083	7.388	12.219	15.708
1994	0.0095	0.038	0.236	1.003	2.244	2.571	5.294	6.601	11.095	11.846
1995	0.0122	0.051	0.275	0.946	2.021	3.934	4.722	8.526	10.045	22.443
1996	0.0223	0.060	0.356	1.462	1.784	2.971	6.185	8.967	12.844	16.357
1997	0.0049	0.049	0.391	1.466	2.407	2.571	3.973	8.245	11.940	16.938
1998	0.0015	0.059	0.256	1.445	2.245	3.423	3.558	5.739	10.442	16.676
1999	0.0224	0.044	0.343	1.196	2.237	3.139	4.752	5.301	8.351	12.279
2000	0.0092	0.120	0.461	1.063	2.257	3.422	4.773	5.508	7.882	12.661
2001	0.0229	0.097	0.456	1.305	2.420	3.851	5.091	6.513	6.912	9.538
2002	0.0115	0.089	0.465	1.050	2.249	3.247	5.296	6.514	7.924	12.152
2003	0.0217	0.089	0.346	1.053	1.742	2.977	4.118	6.837	8.011	12.023
2004	0.0105	0.066	0.351	0.971	2.110	2.620	4.199	5.908	8.627	13.288
2005	0.0082	0.060	0.248	0.821	1.654	3.338	3.841	5.758	7.593	12.546
2006	0.0428	0.089	0.295	0.808	1.890	2.467	4.076	4.912	6.744	12.137
2007	0.0086	0.124	0.450	0.925	1.771	3.005	3.723	5.020	6.329	12.394
2008	0.0464	0.085	0.420	1.117	1.888	2.892	3.630	5.147	6.803	12.040
2009	0.0137	0.171	0.480	1.248	2.283	2.908	3.658	4.735	6.735	12.878
2010	0.0061	0.100	0.589	1.168	2.328	3.198	3.685	4.778	7.153	11.612
2011	0.0836	0.087	0.492	1.353	1.972	3.262	4.114	4.788	5.751	12.995

App. A5 (Append. A), Table A3: Mean weight-at-age (kg) of landings for the Gulf of Maine cod stock applying the revised mortality assumptions (Michael Palmer, pers. commn). Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9+
1982	0.012	0.356	0.858	1.514	2.606	5.067	7.065	9.620	9.771	15.664
1983	0.024	0.224	0.768	1.542	2.418	3.808	6.055	6.071	10.317	13.325
1984	0.001	0.234	0.653	1.478	2.678	3.609	5.540	8.368	10.138	14.828
1985	0.039	0.206	0.733	1.404	2.819	4.658	5.884	8.502	11.244	13.676
1986	0.005	0.277	0.501	1.698	2.774	4.778	6.504	8.109	10.206	14.646
1987	0.004	0.154	0.642	1.323	3.090	4.668	7.259	10.036	11.099	14.582
1988	0.003	0.122	0.577	1.666	2.360	5.205	5.200	6.193	10.103	12.993
1989	0.046	0.236	0.752	1.518	2.959	4.282	5.980	9.276	12.519	20.913
1990	0.021	0.193	0.811	1.349	2.141	4.474	7.721	10.820	11.750	18.718
1991	0.014	0.236	1.113	1.601	2.281	3.894	7.144	10.429	12.261	14.031
1992	0.023	0.055	1.033	1.530	2.747	2.976	5.587	10.921	10.483	14.483
1993	0.021	0.081	0.690	1.748	2.150	4.420	5.670	9.817	13.673	15.701
1994	0.022	0.058	0.730	1.712	3.085	3.251	6.335	7.684	12.542	11.846
1995	0.027	0.103	1.288	1.591	2.649	5.090	6.865	11.466	13.128	22.443
1996	0.033	0.100	1.293	2.096	2.260	3.462	7.558	11.728	14.455	16.269
1997	0.017	0.064	1.351	2.128	3.022	3.074	4.699	9.000	12.156	16.938
1998	0.008	0.202	1.071	1.931	2.633	3.972	4.255	7.122	12.118	16.676
1999	0.052	0.222	0.635	1.723	2.777	3.892	5.670	6.704	9.811	12.279
2000	0.030	0.282	1.081	2.150	3.316	4.325	5.898	5.352	9.331	12.680
2001	0.045	0.316	0.890	2.176	3.144	4.666	6.140	7.273	9.072	9.559
2002	0.032	0.185	0.795	1.797	2.906	3.792	6.132	6.969	8.808	12.205
2003	0.038	0.202	0.809	1.843	2.378	3.654	5.112	7.649	9.191	12.058
2004	0.025	0.111	0.483	1.606	2.965	3.547	5.350	7.220	9.764	13.303
2005	0.027	0.126	0.558	1.625	2.401	4.233	4.502	6.349	8.002	12.549
2006	0.071	0.289	0.648	1.493	2.932	3.357	4.463	5.562	7.430	12.146
2007	0.025	0.220	0.744	1.731	2.922	3.735	4.771	6.167	7.302	12.394
2008	0.085	0.247	0.862	2.179	2.818	3.530	3.988	5.819	7.528	12.044
2009	0.032	0.337	0.911	2.153	3.126	3.575	4.368	5.959	8.000	12.887
2010	0.023	0.264	1.200	1.995	3.203	3.914	4.447	5.708	8.730	11.612
2011	0.0856	0.3289	0.9331	2.0561	2.874	3.8696	4.839	5.7166	5.9528	12.984

App. A5 (Append. A), Table A4: Total (commercial and recreational landings and discards) catches-at-age for the Gulf of Maine cod stock, applying the revised mortality assumptions (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+
1982	448849	2926542	2287192	1430682	748755	65880	94051	72553	90055
1983	597496	2462037	2913215	1201593	704010	452680	50022	62542	56198
1984	370324	2129556	1675931	1643588	437453	219625	105649	9495	53395
1985	505660	1944327	2405137	1151815	738096	161362	107192	48359	33213
1986	760701	1747046	2747811	991982	279282	202725	48016	38188	47527
1987	281794	2018317	1568334	1574499	345353	89415	81032	14459	37549
1988	415081	1542790	2086633	1156925	447729	67430	25560	26247	9267
1989	166436	1247203	2385088	1651856	521108	87147	70289	9369	19564
1990	65527	812544	5547767	2717623	541353	189069	29703	36417	43315
1991	121627	499588	942731	5561272	1037852	150670	55540	25983	15805
1992	370302	830147	867564	502084	2189957	226167	80181	6044	5530
1993	105929	512307	2149041	944709	103328	497117	41561	11264	0
1994	123996	201923	1525603	1294203	266291	66224	74158	28714	7870
1995	78932	319462	1321833	1260435	221653	29931	6521	18184	2808
1996	37536	111569	627693	2003886	405881	36651	4039	491	1623
1997	69144	137484	519557	467768	869161	72472	5523	2272	1029
1998	5941	171062	492301	628941	152820	205873	28696	5168	2257
1999	73948	90853	347840	336596	172344	53699	59469	12388	1067
2000	24758	485043	556537	813684	176640	85157	12485	10521	0
2001	584	393951	1163770	684449	385530	106600	57232	8262	11577
2002	16831	41591	374949	912638	323797	163476	66392	28087	20263
2003	44899	125587	167812	582079	706098	186022	75694	29224	26844
2004	149420	105917	609344	259720	407447	251632	68378	33017	27442
2005	23545	180064	159581	945815	89223	246596	109148	28457	31674
2006	19249	59082	426566	290132	461742	30341	79655	39016	27343
2007	12171	108471	299416	976424	137404	230163	7947	19244	21999
2008	12156	130508	598424	707392	780450	86355	110576	4041	16558
2009	10651	101492	622453	1093273	477852	304754	20896	30506	9646
2010	8159	83580	394486	888549	668256	164291	71683	11213	7611
2011	8683	60526	322164	589583	573856	339910	34926	38408	9433

App. A5 (Append. A), Table A5: Standardized stratified mean numbers per tow at age and standardized mean numbers and mean weight (kg) per tow for ages 1+ of Atlantic cod in NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine, 1968-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+	Stratified mean numbers/ tow	CV	Stratified mean wt/tow (kg)	CV
1968										5.329*	(0.127)	17.480*	(0.153)
1969										3.215*	(0.328)	13.100*	(0.329)
1970	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.330	2.191	(0.214)	11.089	(0.237)
1971	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.204	1.429	(0.190)	7.004	(0.211)
1972	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.386	2.004	(0.208)	8.031	(0.233)
1973	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.848	7.525	(0.328)	18.807	(0.415)
1974	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.258	2.738	(0.188)	7.417	(0.199)
1975	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.140	2.500	(0.222)	6.039	(0.249)
1976	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.117	2.782	(0.181)	7.555	(0.166)
1977	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.038	3.872	(0.269)	8.541	(0.208)
1978	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.131	2.050	(0.191)	7.697	(0.207)
1979	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.064	3.599	(0.234)	7.555	(0.176)
1980	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.132	2.084	(0.171)	6.231	(0.182)
1981	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	4.832	(0.194)	10.651	(0.205)
1982	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.050	3.749	(0.219)	8.616	(0.223)
1983	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.181	3.900	(0.263)	10.962	(0.225)
1984	0.151	1.309	0.987	0.853	0.229	0.047	0.090	0.000	0.000	3.667	(0.443)	6.143	(0.324)
1985	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	2.517	(0.202)	7.645	(0.223)
1986	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.018	1.957	(0.314)	3.476	(0.197)
1987	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.015	1.082	(0.257)	1.976	(0.314)
1988	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	3.099	(0.211)	3.603	(0.281)
1989	0.025	0.609	0.712	0.630	0.069	0.068	0.000	0.000	0.000	2.112	(0.184)	2.424	(0.207)
1990	0.009	0.233	1.325	0.669	0.076	0.032	0.018	0.000	0.000	2.362	(0.249)	3.077	(0.280)
1991	0.028	0.077	0.233	1.750	0.247	0.041	0.018	0.000	0.000	2.393	(0.251)	2.891	(0.240)
1992	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	2.435	(0.317)	8.627	(0.374)
1993	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.023	2.507	(0.223)	5.875	(0.347)
1994	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.045	1.271	(0.223)	2.428	(0.216)
1995	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.028	1.930	(0.273)	2.432	(0.257)
1996	0.057	0.022	0.586	1.355	0.385	0.060	0.000	0.000	0.000	2.465	(0.240)	5.427	(0.275)
1997	0.159	0.139	0.390	0.271	0.874	0.244	0.115	0.000	0.000	2.192	(0.168)	5.615	(0.192)
1998	0.018	0.228	0.359	0.513	0.143	0.408	0.021	0.020	0.000	1.711	(0.344)	4.180	(0.324)
1999	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.011	2.301	(0.242)	5.090	(0.320)
2000	1.173	0.737	0.438	0.485	0.099	0.092	0.011	0.022	0.000	3.057	(0.221)	3.211	(0.155)
2001	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.011	2.147	(0.311)	6.215	(0.327)
2002	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	3.724	(0.203)	10.934	(0.215)
2003	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.122	3.677	(0.223)	9.494	(0.368)
2004	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.981	(0.256)	2.412	(0.293)
2005	0.029	0.739	0.081	0.623	0.011	0.138	0.128	0.015	0.000	1.764	(0.241)	2.701	(0.248)
2006	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.015	1.334	(0.203)	2.702	(0.249)
2007	0.100	3.422	3.077	4.446	0.437	0.796	0.075	0.041	0.000	12.393	(0.665)	15.811	(0.540)
2008	0.079	1.165	3.930	1.582	1.099	0.053	0.082	0.000	0.000	7.990	(0.716)	10.824	(0.609)
2009	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.004	3.599	(0.531)	7.161	(0.491)
2010	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.025	1.296	(0.243)	3.336	(0.264)
2011	0.005	0.024	0.140	0.383	0.189	0.086	0.033	0.035	0.000	0.894	(0.279)	2.133	(0.201)

* Aggregate index for ages 0+ as numbers-at-age and biomasses-at-age are not available pre-1970.

App. A5 (Append. A), Table A6: Standardized stratified mean numbers per tow at age and standardized mean numbers and mean weight (kg) per tow for ages 1+ of Atlantic cod in NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine, 1963-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+	Stratified mean numbers/ tow	CV	Stratified mean wt/tow (kg)	CV
1963										5.914*	(0.250)	17.950*	(0.391)
1964										4.015*	(0.412)	22.799*	(0.496)
1965										4.500*	(0.274)	12.089*	(0.273)
1966										3.720*	(0.217)	12.838*	(0.227)
1967										2.602*	(0.223)	9.313*	(0.219)
1968										4.374*	(0.181)	19.437*	(0.198)
1969										2.758*	(0.152)	15.154*	(0.217)
1970	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.237	4.162	(0.318)	16.437	(0.248)
1971	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.345	3.027	(0.205)	16.196	(0.307)
1972	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.367	9.269	(0.535)	12.988	(0.199)
1973	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.320	3.814	(0.151)	8.758	(0.267)
1974	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.255	4.063	(0.260)	8.959	(0.201)
1975	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.018	6.137	(0.226)	8.619	(0.153)
1976	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.063	2.148	(0.197)	6.740	(0.214)
1977	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.130	3.073	(0.124)	10.199	(0.126)
1978	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.129	5.531	(0.188)	12.895	(0.151)
1979	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.071	3.142	(0.112)	13.927	(0.128)
1980	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.097	7.007	(0.261)	14.202	(0.153)
1981	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.028	2.339	(0.224)	7.533	(0.233)
1982	0.835	3.264	2.476	0.971	0.222	0.000	0.000	0.000	0.000	7.769	(0.636)	15.919	(0.670)
1983	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.083	2.786	(0.170)	8.416	(0.188)
1984	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.096	2.449	(0.220)	8.735	(0.334)
1985	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	2.604	(0.176)	8.261	(0.354)
1986	0.394	0.404	0.626	0.368	0.073	0.041	0.000	0.000	0.045	1.950	(0.230)	4.715	(0.228)
1987	0.570	1.388	0.586	0.198	0.125	0.000	0.000	0.000	0.000	2.868	(0.308)	3.393	(0.234)
1988	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.022	5.903	(0.349)	6.616	(0.232)
1989	0.145	2.468	1.458	0.283	0.138	0.053	0.000	0.009	0.000	4.553	(0.223)	4.535	(0.181)
1990	0.057	0.218	1.788	0.611	0.255	0.048	0.010	0.000	0.000	2.986	(0.190)	4.912	(0.204)
1991	0.144	0.151	0.230	0.621	0.075	0.000	0.023	0.000	0.000	1.243	(0.267)	2.782	(0.246)
1992	0.289	0.448	0.144	0.041	0.327	0.126	0.000	0.000	0.000	1.375	(0.213)	2.447	(0.243)
1993	0.210	0.575	0.361	0.017	0.000	0.038	0.000	0.000	0.000	1.201	(0.259)	1.002	(0.263)
1994	0.184	0.909	0.816	0.093	0.051	0.000	0.045	0.000	0.000	2.098	(0.309)	2.736	(0.292)
1995	0.068	0.308	1.226	0.304	0.082	0.011	0.000	0.000	0.000	2.000	(0.301)	3.664	(0.325)
1996	0.122	0.379	0.231	0.516	0.050	0.000	0.000	0.000	0.000	1.299	(0.254)	2.351	(0.249)
1997	0.297	0.091	0.165	0.168	0.151	0.000	0.000	0.000	0.000	0.872	(0.299)	1.872	(0.307)
1998	0.085	0.342	0.110	0.185	0.041	0.031	0.000	0.000	0.000	0.793	(0.346)	1.499	(0.287)
1999	0.432	0.375	0.590	0.244	0.122	0.019	0.000	0.000	0.000	1.782	(0.181)	3.504	(0.193)
2000	0.540	0.981	0.399	0.492	0.140	0.010	0.000	0.034	0.000	2.596	(0.306)	4.652	(0.332)
2001	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	1.963	(0.271)	7.323	(0.279)
2002	0.269	0.104	0.333	2.683	1.070	0.750	0.077	0.043	0.000	5.328	(0.578)	24.659	(0.686)
2003	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.022	1.988	(0.307)	5.974	(0.251)
2004	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.021	2.165	(0.327)	4.903	(0.214)
2005	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	1.304	(0.065)	2.896	(0.228)
2006	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.014	3.531	(0.301)	4.229	(0.188)
2007	0.136	0.863	0.395	0.496	0.023	0.067	0.000	0.000	0.000	1.981	(0.368)	2.714	(0.277)
2008	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.031	3.295	(0.389)	5.292	(0.285)
2009	0.660	2.096	0.314	0.277	0.045	0.035	0.000	0.000	0.000	3.427	(0.535)	5.844	(0.429)
2010	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.006	0.940	(0.233)	2.571	(0.304)
2011	0.060	0.091	0.210	0.304	0.175	0.078	0.005	0.031	0.000	0.954	(0.304)	2.647	(0.336)

* Aggregate index for ages 0+ as numbers-at-age and biomasses-at-age are not available pre-1970.

App. A5 (Append. A), Table A7: Stratified mean numbers at age per tow and mean number and mean weight (kg) for ages 1 to 6 of Atlantic cod in State of Massachusetts inshore spring bottom trawl surveys in territorial waters adjacent to the Gulf of Maine (Mass. Regions 4-5), 1982-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	Stratified mean numbers /tow	CV	Stratified mean wt/tow (kg)	CV
1982	13.218	6.649	2.921	1.024	0.216	0.049	24.078	(0.221)	9.783	(0.175)
1983	30.253	17.570	4.710	0.347	1.121	0.075	54.076	(0.166)	15.639	(0.153)
1984	1.898	5.090	2.101	0.751	0.147	0.086	10.073	(0.289)	7.042	(0.259)
1985	1.670	2.695	2.024	0.498	0.000	0.000	6.886	(0.206)	4.535	(0.194)
1986	18.031	3.376	0.903	0.582	0.100	0.023	23.014	(0.552)	4.778	(0.354)
1987	8.622	5.376	2.045	0.168	0.147	0.053	16.411	(0.221)	6.305	(0.271)
1988	10.409	6.750	1.927	1.211	0.016	0.033	20.347	(0.206)	7.389	(0.237)
1989	21.463	22.947	6.868	0.513	0.108	0.048	51.946	(0.268)	15.801	(0.342)
1990	4.972	5.938	14.182	2.149	0.155	0.083	27.479	(0.288)	15.612	(0.341)
1991	5.331	2.295	1.801	3.669	0.249	0.000	13.344	(0.219)	8.123	(0.122)
1992	4.379	5.699	3.444	0.484	1.301	0.066	15.374	(0.287)	8.417	(0.321)
1993	2.842	6.100	2.509	0.879	0.166	0.074	12.569	(0.340)	5.666	(0.270)
1994	5.406	3.883	1.703	0.608	0.131	0.000	11.731	(0.227)	3.908	(0.241)
1995	5.985	2.420	2.408	0.525	0.028	0.000	11.366	(0.262)	3.695	(0.225)
1996	0.777	0.497	0.955	1.590	0.299	0.000	4.119	(0.218)	3.086	(0.305)
1997	2.910	1.035	0.920	0.190	0.383	0.018	5.456	(0.240)	2.281	(0.250)
1998	1.487	0.924	0.779	0.637	0.034	0.211	4.072	(0.261)	3.098	(0.468)
1999	11.832	2.407	2.275	0.735	0.630	0.036	17.914	(0.369)	7.219	(0.261)
2000	35.360	6.995	2.371	2.316	0.784	0.663	48.488	(0.391)	16.294	(0.459)
2001	0.084	4.998	4.710	3.448	1.961	0.323	15.524	(0.435)	24.860	(0.536)
2002	19.340	0.220	1.379	1.145	0.561	0.318	22.964	(0.096)	6.924	(0.390)
2003	17.109	5.496	0.439	1.938	0.937	0.221	26.139	(0.507)	8.674	(0.219)
2004	8.927	1.882	2.627	0.361	1.083	0.455	15.335	(0.459)	7.044	(0.278)
2005	5.524	4.141	0.795	1.955	0.263	0.663	13.342	(0.223)	7.798	(0.197)
2006	9.992	7.139	3.930	0.525	1.532	0.109	23.227	(0.337)	7.001	(0.181)
2007	3.776	3.078	2.303	2.163	0.343	0.519	12.181	(0.274)	7.937	(0.251)
2008	7.275	10.336	3.242	2.287	1.695	0.155	24.991	(0.204)	10.673	(0.215)
2009	8.907	2.350	1.654	1.045	0.348	0.112	14.417	(0.352)	3.839	(0.187)
2010	2.415	1.393	1.423	0.819	0.678	0.129	6.858	(0.234)	4.953	(0.456)
2011	0.326	1.001	0.621	0.933	0.558	0.139	3.579	(0.534)	4.027	(0.424)

App. A5 (Append. A), Table A8: Percentage of mature females for each age for the Gulf of Maine cod stock (Michael Palmer, pers. commn).

1	2	3	4	5	6	7	8	9+
0.092	0.287	0.613	0.862	0.961	0.990	0.997	0.999	1.000

App. A5 (Append. A), Table A9: Length frequency distributions for NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC spring survey			NEFSC call survey		
Year	2009	2010	2011	2009	2010	2011
-25cm	0.5634	0.4138	0.0286	0.3967	0.0605	0.2489
26cm	0.0496	0.0189	0.0000	0.1330	0.0283	0.0850
27cm	0.0425	0.0756	0.0000	0.1731	0.0142	0.0283
28cm	0.0638	0.1501	0.0000	0.1251	0.0000	0.0142
29cm	0.0553	0.0945	0.0000	0.1330	0.0283	0.0000
30cm	0.0283	0.1134	0.0000	0.2330	0.0567	0.0142
31cm	0.0544	0.1397	0.0486	0.2834	0.0283	0.0136
32cm	0.0142	0.0945	0.0113	0.4412	0.1134	0.0377
33cm	0.0213	0.0935	0.0113	0.5951	0.0425	0.0142
34cm	0.0958	0.1572	0.0000	0.9068	0.0567	0.0506
35cm	0.0743	0.1407	0.0227	0.7147	0.0142	0.0283
36cm	0.0887	0.1029	0.0000	0.6659	0.0394	0.0142
37cm	0.0695	0.0853	0.0340	0.5014	0.0278	0.0000
38cm	0.1204	0.0945	0.0113	0.6155	0.0425	0.0000
39cm	0.1748	0.0567	0.0000	0.3400	0.0142	0.0543
40cm	0.1559	0.0283	0.0431	0.2516	0.0242	0.0283
41cm	0.1629	0.0283	0.0227	0.2888	0.0425	0.0364
42cm	0.1771	0.0276	0.0599	0.3103	0.0850	0.0380
43cm	0.1565	0.0378	0.0793	0.2834	0.0425	0.0401
44cm	0.2125	0.0378	0.0907	0.3400	0.0283	0.0222
45cm	0.2287	0.0378	0.0340	0.3280	0.0384	0.0640
46cm	0.2196	0.0283	0.0214	0.2776	0.0283	0.0567
47cm	0.1913	0.0189	0.0340	0.1901	0.0242	0.0000
48cm	0.2371	0.0095	0.0340	0.2692	0.0425	0.0364
49cm	0.2017	0.0283	0.0214	0.2125	0.0343	0.0623
50cm	0.2240	0.0647	0.0793	0.1700	0.0283	0.0647
51cm	0.1845	0.0095	0.0441	0.0951	0.0394	0.0364
52cm	0.3077	0.0953	0.0768	0.1199	0.0778	0.0383
53cm	0.2122	0.0000	0.0680	0.0992	0.0142	0.0425
54cm	0.2517	0.1236	0.0826	0.0809	0.0425	0.0506
55cm	0.3245	0.0322	0.0340	0.0708	0.0384	0.0330
56cm	0.1946	0.0646	0.0700	0.0000	0.0425	0.0599
57cm	0.2046	0.0276	0.0441	0.0492	0.0567	0.0000
58cm	0.2358	0.0370	0.0582	0.0384	0.0242	0.0000
59cm	0.2347	0.0455	0.0000	0.0686	0.0257	0.0161
60cm	0.2537	0.0444	0.0227	0.0425	0.0142	0.0383
61cm	0.2547	0.0000	0.0803	0.0447	0.0242	0.0588
62cm	0.1164	0.0081	0.0214	0.0307	0.0401	0.0383
63cm	0.2003	0.0180	0.0113	0.0142	0.0236	0.0222
64cm	0.1725	0.0227	0.0214	0.0874	0.0142	0.1130
65cm	0.0341	0.0000	0.0302	0.0142	0.0336	0.0222
66cm	0.0611	0.0189	0.0467	0.0667	0.0401	0.0303
67cm	0.0850	0.0544	0.0101	0.0201	0.0242	0.0303
68cm	0.0414	0.0276	0.0227	0.0196	0.0848	0.0401
69cm	0.0370	0.0000	0.0372	0.0142	0.0000	0.0481
70cm	0.0923	0.0632	0.0259	0.0283	0.0201	0.0581
71cm	0.0387	0.0161	0.0101	0.0142	0.0353	0.0283
72cm	0.0287	0.0719	0.0322	0.0696	0.0236	0.0259
73cm	0.0259	0.0322	0.0349	0.0350	0.0310	0.0420
74cm	0.0128	0.0423	0.0113	0.0108	0.0142	0.0081
75cm	0.0199	0.0000	0.0101	0.0101	0.0360	0.0081
76cm	0.0704	0.0081	0.0000	0.0283	0.0840	0.0222
77cm	0.0058	0.0161	0.0000	0.0142	0.0000	0.0222
78cm	0.0115	0.0181	0.0101	0.0000	0.0201	0.0000
79cm	0.0058	0.0563	0.0227	0.0283	0.0283	0.0108
80cm	0.0270	0.0181	0.0101	0.0000	0.0101	0.0000
81cm	0.0270	0.0343	0.0000	0.0000	0.0000	0.0540
82cm	0.0000	0.0000	0.0101	0.0101	0.0000	0.0222
83cm	0.0283	0.0000	0.0000	0.0000	0.0000	0.0161
84cm	0.0115	0.0489	0.0000	0.0000	0.0454	0.0000
85cm	0.0115	0.0081	0.0259	0.0000	0.0236	0.0081
86cm	0.0071	0.0262	0.0101	0.0000	0.0101	0.0000
87cm	0.0186	0.0081	0.0000	0.0000	0.0000	0.0000
88cm	0.0058	0.0000	0.0000	0.0142	0.0101	0.0142
89cm	0.0058	0.0161	0.0000	0.0000	0.0000	0.0000
90cm	0.0071	0.0081	0.0113	0.0101	0.0000	0.0000
91cm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0142
93cm	0.0000	0.0000	0.0000	0.0101	0.0000	0.0081
94cm	0.0058	0.0081	0.0340	0.0000	0.0000	0.0000
95cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0081
96cm	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000
97cm	0.0000	0.0000	0.0000	0.0142	0.0000	0.0000
98cm	0.0000	0.0081	0.0000	0.0000	0.0000	0.0081
99cm	0.0000	0.0175	0.0000	0.0000	0.0000	0.0000
100cm+	0.0115	0.0403	0.0214	0.0000	0.0101	0.0081

App. A5 (Append. A), Table A10a: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2009							Age					NEFSC Spring, 2010							Age				
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	39	24	0	0	0	0	0	0	0	0	0	0	28	11	0	0	0	0	0	0	0	0	0
26	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
27	0	0	4	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
28	0	0	3	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
29	0	0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
30	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
31	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
33	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
34	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
35	0	0	4	3	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
36	0	0	4	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
37	0	0	2	4	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0
38	0	0	2	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
39	0	0	1	2	1	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0
40	0	0	2	6	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
41	0	0	2	2	1	1	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0
42	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	5	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
44	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0	0
45	0	0	1	6	4	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
46	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0
47	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
48	0	0	0	2	4	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
49	0	0	0	3	4	1	2	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0
50	0	0	0	2	5	1	0	0	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0
51	0	0	1	2	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
52	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	4	2	1	0	0	0	0	0	0
53	0	0	0	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	7	1	2	0	0	0	0	0	0
55	0	0	0	5	1	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0
57	0	0	0	2	3	2	1	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
58	0	0	0	0	5	3	1	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0
59	0	0	0	1	3	1	5	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
60	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
61	0	0	0	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
62	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
63	0	0	0	0	3	3	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
64	0	0	0	1	5	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
67	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
68	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0
71	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
72	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0
73	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
77	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
78	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
79	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
80	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0
85	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
86	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
87	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
88	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
90	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
95	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2

App. A5 (Append. A), Table A10b: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2011					Age							NEFSC Spring, 2012					Age						
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	2	0	0	0	0	0	0	0	0	0	0	1	38	3	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
31	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
33	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0
37	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
38	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
40	0	0	1	2	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	0
41	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0
42	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3	7	1	0	0	0	0	0	0	0
43	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	7	2	1	0	0	0	0	0	0
44	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	9	1	0	0	0	0	0	0	0
45	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	5	2	2	0	0	0	0	0	0
46	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0
47	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4	1	0	0	0	0	0	0
48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	0
49	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0
50	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	4	1	3	0	0	0	0	0	0
51	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0
52	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	3	7	4	1	0	0	0	0	0
53	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	5	1	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0
55	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	6	1	0	0	0	0	0	0
56	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	5	4	5	2	0	0	0	0	0
57	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0	0
58	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	6	3	1	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	1	2	0	0	0	0
60	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0
61	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
62	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0
63	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0
64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0
65	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0
66	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
67	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0
68	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
71	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
72	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
79	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
80	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
82	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

App. A5 (Append. A), Table A11: Age-length keys for NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Autumn, 2009						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	9	11	2	0	0	0	0	0	0	0	0	0
26	0	4	1	0	0	0	0	0	0	0	0	0
27	0	4	2	0	0	0	0	0	0	0	0	0
28	0	3	0	0	0	0	0	0	0	0	0	0
29	0	4	2	0	0	0	0	0	0	0	0	0
30	0	3	1	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0
32	0	4	1	0	0	0	0	0	0	0	0	0
33	0	2	4	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0
35	0	2	4	0	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	2	0	0	0	0	0	0	0	0	0
38	0	2	5	0	0	0	0	0	0	0	0	0
39	0	1	2	0	0	0	0	0	0	0	0	0
40	0	1	3	0	0	0	0	0	0	0	0	0
41	0	1	1	0	0	0	0	0	0	0	0	0
42	0	0	5	0	0	0	0	0	0	0	0	0
43	0	0	4	0	0	0	0	0	0	0	0	0
44	0	0	1	0	0	0	0	0	0	0	0	0
45	0	0	3	0	0	0	0	0	0	0	0	0
46	0	0	7	0	0	0	0	0	0	0	0	0
47	0	0	3	0	0	0	0	0	0	0	0	0
48	0	0	2	0	0	0	0	0	0	0	0	0
49	0	0	1	1	0	0	0	0	0	0	0	0
50	0	0	2	1	0	0	0	0	0	0	0	0
51	0	0	3	0	1	0	0	0	0	0	0	0
52	0	0	3	0	0	0	0	0	0	0	0	0
53	0	0	0	1	1	0	0	0	0	0	0	0
54	0	0	2	1	0	0	0	0	0	0	0	0
55	0	0	2	1	2	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	1	1	2	0	0	0	0	0	0	0
58	0	0	1	0	2	0	0	0	0	0	0	0
59	0	0	0	4	2	0	0	0	0	0	0	0
60	0	0	0	3	0	0	0	0	0	0	0	0
61	0	0	0	2	1	0	0	0	0	0	0	0
62	0	0	0	2	0	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	1	1	3	0	0	0	0	0	0	0
65	0	0	0	0	0	0	1	0	0	0	0	0
66	0	0	0	2	2	0	0	0	0	0	0	0
67	0	0	0	0	1	1	0	0	0	0	0	0
68	0	0	0	0	1	0	0	0	0	0	0	0
69	0	0	0	0	0	1	0	0	0	0	0	0
70	0	0	0	2	0	0	0	0	0	0	0	0
71	0	0	0	1	0	0	0	0	0	0	0	0
72	0	0	0	2	2	0	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0
74	0	0	0	0	1	0	0	0	0	0	0	0
75	0	0	0	0	1	0	0	0	0	0	0	0
76	0	0	0	0	0	0	2	0	0	0	0	0
77	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	1	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	1	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	1	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	0

	NEFSC Autumn, 2010						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	2	1	0	0	0	0	0	0	0	0	0	0
26	0	2	0	0	0	0	0	0	0	0	0	0
27	0	1	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	2	0	0	0	0	0	0	0	0	0	0
30	0	3	0	0	0	0	0	0	0	0	0	0
31	0	5	0	0	0	0	0	0	0	0	0	0
32	0	5	0	0	0	0	0	0	0	0	0	0
33	0	1	1	0	0	0	0	0	0	0	0	0
34	0	2	2	0	0	0	0	0	0	0	0	0
35	0	0	1	0	0	0	0	0	0	0	0	0
36	0	2	0	0	0	0	0	0	0	0	0	0
37	0	1	1	0	0	0	0	0	0	0	0	0
38	0	0	2	1	0	0	0	0	0	0	0	0
39	0	1	0	0	0	0	0	0	0	0	0	0
40	0	0	2	1	0	0	0	0	0	0	0	0
41	0	0	1	2	0	0	0	0	0	0	0	0
42	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	1	0	0	0	0	0	0	0	0
44	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	1	2	0	0	0	0	0	0	0	0
46	0	0	1	1	0	0	0	0	0	0	0	0
47	0	0	1	1	0	0	0	0	0	0	0	0
48	0	0	0	3	0	0	0	0	0	0	0	0
49	0	0	1	2	0	0	0	0	0	0	0	0
50	0	0	0	2	0	0	0	0	0	0	0	0
51	0	0	1	1	0	0	0	0	0	0	0	0
52	0	0	1	3	0	0	0	0	0	0	0	0
53	0	0	1	1	0	0	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0
55	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	1	0	0	0	0	0	0	0
57	0	0	1	0	1	0	0	0	0	0	0	0
58	0	0	1	0	1	0	0	0	0	0	0	0
59	0	0	1	1	2	0	0	0	0	0	0	0
60	0	0	0	1	0	1	0	0	0	0	0	0
61	0	0	0	1	1	0	1	0	0	0	0	0
62	0	0	0	0	2	0	0	0	0	0	0	0
63	0	0	0	1	0	0	0	0	0	0	0	0
64	0	0	0	0	1	0	1	0	0	0	0	0
65	0	0	0	2	0	1	0	0	0	0	0	0
66	0	0	0	3	0	0	0	0	0	0	0	0
67	0	0	0	1	3	0	0	0	0	0	0	0
68	0	0	0	0	3	0	0	1	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	2	0	0	0	0	0	0
71	0	0	0	1	0	1	0	0	0	0	0	0
72	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	1	0	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	0	1	0	0	0	0	0
76	0	0	0	0	4	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0
78	0	0	0	0	1	1	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0
80	0	0	0	0	1	0	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0
82	0	0	0	0	1	1	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	1	2	0	0	0	0	0	0
85	0	0	0	0	1	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	1	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	1

	NEFSC Autumn, 2011						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	15	4	0	0	0	0	0	0	0	0	0	0
26	0	4	0	0	0	0	0	0	0	0	0	0
27	0	1	0	0	0	0	0	0	0	0	0	0
28	0	0	1	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	1	0	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0
32	0	2	0	0	0	0	0	0	0	0	0	0
33	0	1	0	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	2	1	0	0	0	0	0	0	0	0
40	0	0	1	0	0	0	0	0	0	0	0	0
41	0	0	2	1	0	0	0	0	0	0	0	0
42	0	1	0	1	0	0	0	0	0	0	0	0
43	0	0	1	1	0	0	0	0	0	0	0	0
44	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	2	3	0	0	0	0	0	0	0	0
46	0	0	0	1	3	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	1	2	1	0	0	0	0	0	0	0
49	0	0	0	1	3	0	0	0	0	0	0	0
50	0	0	1	3	0	1	0	0	0	0	0	0
51	0	0	1	1	1	0	0	0	0	0	0	0
52	0	0	1	1	3	0	0	0	0	0	0	0
53	0	0	0	1	2	0	0	0	0	0	0	0
54	0	0	0	1	2	0	1	0	0	0	0	0
55	0	0	0	0	3	0	0	0	0	0	0	0
56	0	0	0	2	1	0	0	0	0	0	0	0
57	0	0	1	0	0	0	0	0	0	0	0	0
58	0	0	2	0	0	0	0	0	0	0	0	0
59	0	0	0	0	2	0	0	0	0	0	0	0
60	0	0	0	0	3	0	1	0	0	0	0	0
61	0	0	1	2	2	0	0	0	0	0	0	0
62	0	0	0	2	2	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	0	4	6	1	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0
66	0	0	0	0	2	0	1	0	0	0	0	0
67	0	0	0	1	1	0	1	0	0	0	0	0
68	0	0	0	0	1	0	0	0	1	0	0	0
69	0	0	0	1	0	2	0	0	0	0	0	0
70	0	0	0	0	3	2	0	0	0	0	0	0
71	0	0	0	0	1	1	0	0	0	0	0	0
72	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	0	2	1	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0
75	0	0	0	0	0	1	0	0	0	0	0	0
76	0	0	0	0	0	2	0	0	0	0	0	0
77	0	0	0	0	0	2	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	1	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	4	0	0	0	0	0	0
82	0	0	0	0	0	1	1	0	0	0	0	0
83	0	0	0	0	0	1	1	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	1	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	1	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	1	0	0	0	0	0
93	0	0	0	0	0	0	0	0	1	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	1	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	0	0

App. A5 (Append. A), Table A12a: Mean weight-at-age (kg) from NEFSC offshore spring surveys. Pre-1970, the 1970-1979 average mean weight-at-age is assumed (Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1970	0.043	0.297	0.641	1.562	2.468	4.789	5.327	8.547	12.439
1971	0.201	0.507	1.340	2.225	4.484	3.570	6.379	8.557	9.301
1972	0.046	0.355	1.659	2.512	3.596	5.453	6.227	7.706	10.783
1973	0.043	0.180	0.972	2.898	3.730	4.518	7.229	6.216	13.401
1974	0.035	0.188	0.688	2.706	5.668	8.000	6.874	7.300	13.269
1975	0.030	0.255	1.027	1.898	3.883	7.050	6.874	8.413	14.817
1976	0.101	0.239	0.713	1.692	3.136	5.546	10.777	11.463	16.635
1977	0.112	0.328	0.780	1.058	2.315	4.787	6.874	9.953	21.006
1978	0.131	0.469	1.139	1.813	3.137	5.737	7.694	10.633	14.303
1979	0.078	0.404	1.367	1.972	3.056	4.093	7.685	7.159	17.912
1980	0.047	0.351	1.291	2.143	3.461	3.881	5.574	8.513	11.037
1981	0.125	0.460	1.103	2.477	4.056	6.138	7.568	8.456	11.041
1982	0.106	0.438	1.350	2.579	4.139	4.072	8.031	8.513	12.301
1983	0.094	0.463	1.475	2.513	5.110	6.693	11.352	8.513	20.470
1984	0.071	0.574	1.431	2.551	4.940	4.324	5.035	8.513	14.596
1985	0.045	0.426	1.329	2.707	4.293	5.492	6.065	13.198	16.558
1986	0.086	0.485	1.564	2.955	3.554	7.734	12.633	8.513	20.134
1987	0.065	0.348	0.729	2.585	3.058	5.084	6.378	5.420	25.016
1988	0.049	0.175	1.039	1.724	5.060	5.545	4.947	9.493	7.202
1989	0.043	0.182	0.728	1.828	2.631	6.784	6.874	8.513	14.596
1990	0.076	0.243	0.786	2.029	3.447	6.554	8.200	8.513	14.596
1991	0.078	0.197	0.875	1.190	1.524	2.557	6.008	8.513	14.596
1992	0.061	0.453	1.012	2.871	4.178	5.644	6.721	8.513	13.953
1993	0.057	0.323	1.368	1.963	3.809	5.255	10.622	11.372	16.642
1994	0.033	0.192	0.856	2.318	2.519	2.861	5.654	6.582	7.255
1995	0.111	0.240	0.681	1.277	2.825	3.956	6.874	2.828	20.994
1996	0.076	0.318	1.799	2.068	3.296	4.847	6.874	8.513	14.596
1997	0.064	0.445	1.416	2.658	2.954	3.745	6.749	8.513	14.596
1998	0.057	0.448	1.188	2.033	3.216	4.537	6.502	8.004	14.596
1999	0.088	0.335	0.994	1.949	3.123	5.723	5.574	8.513	31.105
2000	0.079	0.436	1.037	2.482	4.127	5.327	4.540	8.612	14.596
2001	0.119	0.474	1.107	2.738	4.242	8.950	9.035	14.481	16.784
2002	0.069	0.318	1.170	2.718	3.240	6.032	6.014	13.284	3.580
2003	0.123	0.198	0.820	1.588	2.661	3.991	5.783	6.627	10.133
2004	0.044	0.349	0.849	2.536	3.662	4.388	3.764	3.764	11.576
2005	0.031	0.211	1.031	1.739	2.628	3.979	5.597	5.494	14.596
2006	0.070	0.262	0.790	1.862	3.102	6.050	5.442	8.729	9.927
2007	0.092	0.388	0.876	1.649	3.059	3.244	4.130	5.428	14.596
2008	0.049	0.400	1.053	1.655	2.489	5.609	6.928	8.513	14.596
2009	0.031	0.523	1.441	2.067	2.601	2.876	8.067	9.930	12.919
2010	0.076	0.356	1.203	2.805	3.849	4.602	7.314	10.712	15.374
2011	0.064	0.453	1.177	1.717	2.706	3.509	5.906	8.521	14.596

App. A5 (Append. A), Table A12b: Mean weight-at-age (kg) from NEFSC offshore autumn surveys. Pre-1970, the 1970-1979 average mean weight-at-age is assumed (Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1970	0.199	0.598	1.407	3.840	3.016	6.197	6.925	8.647	12.980
1971	0.241	1.201	1.688	2.916	4.818	5.392	6.853	9.008	14.100
1972	0.136	0.744	2.240	3.570	3.680	6.655	6.631	12.278	12.002
1973	0.111	0.458	2.093	4.229	4.814	5.814	9.916	6.042	10.734
1974	0.076	0.497	1.308	2.759	6.452	6.293	8.010	12.857	12.664
1975	0.249	0.439	1.041	2.290	2.775	5.598	8.472	12.044	14.086
1976	0.348	0.843	1.173	1.481	3.869	7.508	9.737	12.044	17.898
1977	0.201	0.531	1.238	1.843	3.809	5.940	7.696	11.211	15.843
1978	0.202	0.734	1.367	2.270	3.099	4.060	7.607	12.247	17.003
1979	0.385	0.878	2.644	3.347	5.462	6.791	10.187	11.930	21.717
1980	0.324	0.718	1.899	3.071	6.694	5.996	6.408	15.249	16.793
1981	0.232	1.102	2.116	4.419	5.583	8.130	8.390	12.349	22.998
1982	0.493	1.408	2.488	3.320	6.889	6.293	8.131	12.044	16.731
1983	0.236	1.082	1.732	3.583	4.878	9.825	8.131	12.044	20.891
1984	0.287	1.008	2.295	3.699	6.565	7.550	11.342	12.044	20.333
1985	0.208	1.054	2.503	3.879	7.494	10.403	8.131	20.320	23.705
1986	0.347	0.703	2.497	3.339	7.927	8.012	8.131	12.044	13.192
1987	0.151	0.648	1.502	3.596	6.505	6.293	8.131	12.044	16.731
1988	0.175	0.670	1.854	3.195	6.010	6.293	8.841	12.044	12.403
1989	0.276	0.410	1.176	2.727	4.911	3.877	8.131	13.292	16.731
1990	0.225	0.430	0.961	2.562	4.837	4.926	5.448	12.044	16.731
1991	0.172	0.715	1.703	2.566	5.374	6.293	11.513	12.044	16.731
1992	0.213	0.892	1.236	2.689	3.365	4.757	8.131	12.044	16.731
1993	0.122	0.512	1.529	3.547	5.284	1.778	8.131	12.044	16.731
1994	0.289	0.530	1.503	3.483	6.476	6.293	7.058	12.044	16.731
1995	0.125	0.876	1.597	2.612	7.143	4.318	8.131	12.044	16.731
1996	0.283	0.723	2.194	2.414	5.779	6.293	8.131	12.044	16.731
1997	0.151	0.903	1.761	4.593	4.518	6.293	8.131	12.044	16.731
1998	0.192	0.754	1.869	3.286	4.530	7.387	8.131	12.044	16.731
1999	0.302	1.013	2.100	3.862	5.499	7.563	8.131	12.044	16.731
2000	0.220	0.866	1.941	3.699	3.558	9.768	8.131	14.548	16.731
2001	0.239	0.755	1.819	2.721	6.266	9.096	10.713	12.044	11.023
2002	0.140	0.975	2.192	4.091	5.288	7.722	8.395	16.787	16.731
2003	0.373	0.654	2.304	2.708	5.232	6.267	8.633	12.044	19.375
2004	0.125	0.627	1.694	3.452	4.499	4.471	8.560	8.478	18.167
2005	0.109	0.453	1.599	2.162	5.916	3.464	6.592	10.172	17.780
2006	0.207	0.480	1.024	1.715	3.489	5.965	5.126	14.241	14.759
2007	0.166	0.528	1.018	2.639	4.276	6.346	8.131	12.044	16.731
2008	0.317	1.015	1.986	2.486	5.421	6.293	8.131	12.044	16.613
2009	0.555	1.174	3.366	4.503	10.575	6.618	8.131	12.044	16.731
2010	0.335	1.170	1.774	3.904	4.784	4.548	3.461	12.044	24.490
2011	0.286	0.942	1.775	2.323	4.581	4.931	10.775	7.135	16.731

App. A5 (Append. A), Table A12c: Mean weight-at-age (kg) from State of Massachusetts inshore spring surveys(Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1982	0.116	0.453	1.106	2.031	5.606	5.073	6.778	10.426	10.361
1983	0.083	0.388	1.020	1.634	2.381	10.539	4.511	15.422	10.361
1984	0.104	0.415	1.295	1.884	3.717	2.893	4.519	7.652	10.361
1985	0.128	0.517	0.999	2.252	2.829	4.556	4.519	7.652	10.361
1986	0.170	0.453	1.592	2.271	3.638	5.563	4.519	7.652	10.361
1987	0.057	0.564	0.791	3.213	3.963	10.103	4.519	7.652	15.241
1988	0.030	0.335	1.216	2.041	6.171	6.392	4.519	7.652	10.361
1989	0.072	0.340	0.946	1.660	3.709	5.363	4.519	7.652	10.361
1990	0.053	0.409	0.654	1.317	3.311	6.779	4.519	7.652	10.361
1991	0.114	0.331	1.118	1.282	2.609	4.556	4.519	7.652	10.361
1992	0.049	0.447	0.753	1.410	1.716	5.513	3.018	7.652	10.361
1993	0.037	0.355	0.764	1.033	2.839	2.829	4.519	7.652	10.361
1994	0.079	0.279	0.842	1.685	2.791	4.556	4.519	7.652	10.361
1995	0.048	0.395	0.809	1.374	2.555	4.556	4.519	7.652	10.361
1996	0.081	0.426	0.806	1.010	1.664	4.556	4.519	7.652	10.361
1997	0.073	0.555	0.925	1.702	1.328	1.252	4.519	7.652	10.361
1998	0.063	0.390	1.085	1.756	2.496	3.266	2.431	7.652	10.361
1999	0.094	0.484	1.134	2.070	2.904	3.383	4.140	3.869	10.361
2000	0.094	0.466	1.366	2.031	2.802	4.363	5.546	9.013	10.361
2001	0.042	0.470	1.571	2.346	2.738	5.127	3.672	6.875	10.361
2002	0.039	0.230	0.945	1.947	3.012	5.184	5.928	7.440	11.027
2003	0.067	0.216	0.486	1.883	3.100	3.253	5.414	6.562	8.618
2004	0.039	0.383	0.810	1.760	2.143	2.730	3.770	8.342	12.697
2005	0.035	0.177	1.011	1.659	3.125	3.309	5.233	5.913	4.846
2006	0.048	0.116	0.568	1.136	2.048	1.930	4.783	7.652	9.447
2007	0.056	0.172	0.675	1.414	2.317	3.860	3.768	3.446	10.361
2008	0.064	0.277	0.747	1.375	1.013	3.419	5.194	7.652	10.361
2009	0.048	0.199	0.872	1.044	1.357	3.248	4.519	7.652	10.361
2010	0.060	0.230	0.647	1.634	2.482	5.356	4.519	7.652	10.652
2011	0.046	0.291	0.869	1.459	2.494	3.178	3.605	6.869	10.361

(Appendix B within Appendix A5)

Appendix B - The Statistical Catch-at-Age Model

The text following sets out the equations and other general specifications of the SCAA followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is then applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

For the convenience of readers, details which are changed or newly added relative to the specifications used for the analyses reported in Butterworth and Rademeyer (2012) are shown highlighted. Note that summations over ages now all exclude age a=0.

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \qquad \text{(B1)}$$

$$N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}} \qquad \text{for } 0 \le a \le M-2 \qquad \text{(B2)}$$

$$N_{y+1,m} = N_{y,m-1}e^{-Z_{y,m-1}} + N_{y,m}e^{-Z_{y,m}} \qquad \text{(B3)}$$

where

$N_{y,a}$ is the number of fish of age a at the start of year y,

R_y is the recruitment (number of 0-year-old fish) at the start of year y,

m is the maximum age considered (taken to be a plus-group).

$Z_{y,a} = F_y S_{y,a} + M_a$ is the total mortality in year y on fish of age a, where

M_a denotes the natural mortality rate for fish of age a,

F_y is the fishing mortality of a fully selected age class in year y, and

$S_{y,a}$ is the commercial selectivity at age a for year y.

B.1.2. Recruitment

The number of recruits (i.e. new 0-year old) at the start of year y is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a standard or adjusted Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

For the modified Ricker:

$$R_y = \alpha B_y^{\text{sp}} \exp\left[-\beta\left(B_y^{\text{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_{\text{R}})^2/2)} \qquad \text{(B4)}$$

for the (standard) Beverton-Holt:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_{\text{R}})^2/2)} \qquad \text{(B5)}$$

and for the adjusted Beverton-Holt:

$$R_y = \begin{cases} \dfrac{\alpha B_y^{sp}}{\beta + B_y^{sp}} & \text{if } B_y^{sp} \le B^* \\ \dfrac{\alpha B^*}{\beta + B^*} \exp\left(-\left(\dfrac{B_y^{sp} - B^*}{\sigma_N}\right)^2\right) & \text{if } B_y^{sp} > B^* \end{cases} \qquad \text{(B6)}$$

where

α, β, γ, $B^*$and σ_N are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year y, which is assumed to be normally distributed with standard deviation □$_{\text{R}}$ (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B_y^{sp} is the spawning biomass at the start of year y, computed as:

$$B_y^{\text{sp}} = \sum_{a=1}^{m} f_a w_{y,a}^{\text{strt}} N_{y,a} e^{-Z_{y,a}/4} \qquad \text{(B7)}$$

because spawning for the cod stock under consideration is taken to occur three months after the start of the year and some mortality has therefore occurred,

where

$w_{y,a}^{\text{strt}}$ is the mass of fish of age a during spawning, and

f_a is the proportion of fish of age a that are mature.

Section *B.2.6* details the procedure adopted when recruitment is not assumed to be related to spawning biomass , at least internal to the assessment.

B.1.3. Total catch and catches-at-age

The total catch by mass in year y is given by:

$$C_y = \sum_{a=1}^{m} w_{y,a}^{\text{mid}} C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{\text{mid}} N_{y,a} \; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \qquad \text{(B8)}$$

where

$w_{y,a}^{\text{mid}}$ denotes the mass of fish of age a landed in year y,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age a, caught in year y,

The model estimate of survey index is computed as:

$$B_y^{\text{surv}} = \sum_{a=1}^{m} w_{y,a}^{\text{surv}} S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \tag{B9}$$

for biomass indices and

$$N_y^{\text{surv}} = \sum_{a=1}^{m} S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \tag{B10}$$

for numbers indices

where

S_a^{surv} is the survey selectivity for age a, which is taken to be year-independent.

T^{surv} is the season in which the survey is taking place (T^{surv}=1 for spring surveys and T^{surv}=3 for fall surveys), and

$w_{y,a}^{surv}$ denotes the mass of fish of age a from survey *surv* year y (Table A12).

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

B.1.4. Initial conditions

For the first year (y_0) considered in the model, the numbers-at-age are estimated directly for ages 0 to a^{est}, with a parameter ϕ mimicking recent average fishing mortality for ages above a^{est}, i.e.

$$N_{y_0,a} = N_{\text{start},a} \quad \text{for } 0 \le a \le a^{est} \tag{B11}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \quad \text{for } a^{est} < a \le m-1 \tag{B12}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \tag{B13}$$

B.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age and catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood ($-\ell nL$) are as follows. Details related to fitting to CPUE series are not included below, as such series are not considered in the analyses of this paper.

B2.1. Survey abundance data

The likelihood is calculated assuming that a survey biomass index is lognormally distributed about its expected value:

$$I_y^{surv} = \hat{I}_y^{surv} \exp\left(\varepsilon_y^{surv}\right) \quad \text{or} \quad \varepsilon_y^{surv} = \ell\text{n}\left(I_y^{surv}\right) - \ell\text{n}\left(\hat{I}_y^{surv}\right) \tag{B14}$$

where

I_y^{surv} is the survey biomass index for survey *surv* in year *y*,

$\hat{I}_y^{surv} = \hat{q}^{surv} \hat{B}_y^{surv}$ is the corresponding model estimate, where

$\hat{q}^{surv}$ is the constant of proportionality (catchability) for the survey biomass series *surv*, and

ε_y^{surv} from $N\left(0,\left(\sigma_y^{surv}\right)^2\right)$.

The contribution of the survey biomass data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{\text{survey}} = \sum_{surv}\sum_{y}\left\{\ell\text{n}\left(\sqrt{\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2}\right) + \left(\varepsilon_y^{surv}\right)^2 / \left[2\left(\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2\right)\right]\right\} \tag{B15}$$

where

σ_y^{surv} is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

σ_{Add}^{surv} is the square root of the additional variance for survey biomass series *surv*, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^{surv} for survey biomass index *surv* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^{surv} = 1/n_{surv} \sum_{y}\left(\ln I_y^{surv} - \ln \hat{B}_y^{surv}\right) \tag{B16}$$

B.2.3. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n}\, L^{\text{CAA}} = \sum_{y}\sum_{a}\left[\ell n\left(\sigma_a^{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_a^{com}\right)^2\right] \tag{B17}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year y that are of age a,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year y that are of age a,

where

$$\hat{C}_{y,a} = N_{y,a} \; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{B18}$$

and

σ_a^{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y p_{y,a} \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y 1} \tag{B19}$$

Commercial catches-at-age are incorporated in the likelihood function using equation (B17), for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

In application of this approach ages are often aggregated to avoid values of $p_{y,a}$ or $\hat{p}_{y,a}$ that are too small in the interests of estimation robustness. In this paper individual ages have been maintained between the selected minus and plus-groups to provide potential discrimination of different shapes for the selectivity functions at older ages in particular. This however does mean that there are certain cells for which $p_{y,a}$ values are zero. That does not cause any problems because the limit of $p_{y,a}\left(\ln p_{y,a}\right)^2$ as $p_{y,a} \to 0$ is 0, so these terms can be omitted from the summation in equation B17. One could argue that they should nevertheless be included in the summations in equation B18, but exclusion seems more appropriate as the structural zero contributions then included would seem likely to bias the estimates of $\hat{\sigma}_a^{com}$ downwards.

In addition to this "adjusted" lognormal error distribution, some computations use an alternative "sqrt(p)" formulation, for which equation B20 is modified to:

$$-\ell \text{n}\, L^{\text{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_a^{com}\right) + \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / 2\left(\sigma_a^{\text{com}}\right)^2 \right] \tag{B21}$$

and equation B21 is adjusted similarly:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / \sum_y 1} \tag{B22}$$

This formulation mimics a multinomial form for the error distribution by forcing a near-equivalent variance-mean relationship for the error distributions.

B.2.4. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an “adjusted” lognormal error distribution (equation (B19)) where:

$p_{y,a}^{surv} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of fish of age a in year y for survey *surv*,

$\hat{p}_{y,a}^{surv}$ is the expected proportion of fish of age a in year y in the survey *surv*, given by:

$$\hat{p}_{y,a}^{surv} = S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \Bigg/ \sum_{a'=1}^{m} S_{a'}^{\text{surv}} N_{y,a'} e^{-Z_{y,a'} T^{surv}/12} \quad . \qquad \text{(B23)}$$

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

B.2.5. Survey catches-at-length

In some runs, catches-at-length are also incorporated in the likelihood function. These data are incorporated in the similar manner as the catches-at-age. When the model is fit to catches-at-length, the predicted catches-at-age are converted to catches-at-length:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{strt} \qquad \text{(B24)}$$

for the spring survey, and

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{mid} \qquad \text{(B25)}$$

for the fall survey,

where $A_{a,l}^{strt}$ and $A_{a,l}^{mid}$ are the proportions of fish of age a that fall in the length group l (i.e., $\sum_l A_{a,l}^{strt} = 1$ and $\sum_l A_{a,l}^{mid} = 1$ for all ages) at the beginning of the year and at the middle of the year respectively.

The matrices $A_{a,l}^{strt}$ and $A_{a,l}^{mid}$ are calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a^{strt} \sim N\left[L_\infty\left(1 - e^{-\kappa(a - t_o)}\right); \left(\theta_a^{strt}\right)^2\right] \qquad \text{(B26)}$$

for the spring survey and

$$L_a^{mid} \sim N\left[L_\infty\left(1 - e^{-\kappa(a + 0.5 - t_o)}\right); \left(\theta_a^{mid}\right)^2\right] \qquad \text{(B27)}$$

for the fall survey,

where

θ_a^{strt} and θ_a^{mid} are the standard deviation of begin and mid-year length-at-age a respectively, which are modelled to be proportional to the expected length-at-age a, i.e.:

$$\theta_a^{strt} = \beta\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right)\right]^\gamma \tag{B28}$$

and

$$\theta_a^{mid} = \beta\left[L_\infty\left(1 - e^{-\kappa(a+0.5-t_o)}\right)\right]^\gamma \tag{B29}$$

with β an estimable parameter and $\gamma = 0.5$ (a value which was found to lead to reasonable fits to the data).

$L_\infty = 150.93\,cm$,

$\kappa = 0.11\,yr^{-1}$,

$t_o = 0.13\,yr$,

The following term is then added to the negative log-likelihood:

$$-\ell\mathrm{n}\,L^{\mathrm{CAL}} = w_{len}\sum_{surv}\sum_{y}\sum_{l}\left[\ell n\left(\sigma_{\mathrm{len}}^{surv} / \sqrt{p_{y,l}^{surv}}\right) + p_{y,l}^{surv}\left(\ell n\, p_{y,l}^{surv} - \ell n\,\hat{p}_{y,l}^{surv}\right)^2 / 2\left(\sigma_{\mathrm{len}}^{surv}\right)^2\right] \tag{B30}$$

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups because the length distributions for adjacent ages overlap) to the overall negative log-likelihood compared to that of the CPUE data. The value used for w_{len} is 0.1, being roughly equivalent to the ratio of the number to length groups to the number of age groups considered. Instances of observed proportions of zero are dealt with in the same manner as for catches-at-age, as is the alternative “sqrt(p)” error distribution formulation.

B.2.6. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be lognormally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell nL^{\mathrm{pen}} = \sum_{y=y_1+1}^{y_2}\left[\varepsilon_y^2 / 2\sigma_{\mathrm{R}}^2\right] \tag{B31}$$

where

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_{R} is the standard deviation of the log-residuals, which is input.

Equation B31 is used when the stock-recruitment curve is estimated internally. In some analyses reported in this paper where BRP estimates are based on stock-recruitment curves estimated “externally” using the assessment outputs,, this “stock-recruitment” term is included for the last two years only, simply to stabilise these estimates which are not well determined by the other data. In these cases, the ε_y are calculated as the deviations from the mean log recruitment for the ten preceding years, i.e. recruitment estimates for 2010 and 2011 are shrunk towards the geometric mean recruitment over the preceding decade.

B.2.7. Catches

$$-\ell nL^{\text{Catch}} = \sum_y \left[\frac{\ell n C_y - \ell n \hat{C}_y}{2\sigma_{\text{C}}^2} \right] \tag{B32}$$

where

C_y is the observed catch in year *y*,

$\hat{C}_y$ is the predicted catch in year *y* (eqn B8), and

σ_{C} is the CV input: 0.4 for pre-1964 catches, 0.2 for catches between 1964 and 1981 and 0.05 for catches from 1982 onwards.

B.2.8Incorporation of Bigelow vs Albatross survey calibration

The survey data provided are adjusted for the years 2009 to 2012 which were obtained from *Bigelow* surveys have been adjusted to "*Albatross* equivalents" through use of calibration factors estimated independently from paired tow experiments (Miller *et al*., 2010). However the survey data before and after the switch of vessels also provide information on the calibration factors because they sample the same cohorts. Incorporation of this information in assessments in this paper has been effected by treating the estimates, with their variance-covariance matrix, as a form of "joint-prior" which is effectively updated in the penalised likelihood estimation when fitting the model. The process is as follows.

First *Bigelow* length frequency distributions are converted to *Albatross* equivalent length frequency distributions:

$$C_{y,l}^{surv,A} = C_{y,l}^{surv,B} \Big/ F_l \tag{B33}$$

where

$C_{y,l}^{surv,B}$ is the measured catch-at-length for the *Bigelow* in year *y* for survey *surv,*

$C_{y,l}^{surv,A}$ is the inferred catch-at-length for the *Albatross* equivalent in year *y* for survey *surv,*

F_l is the length-based calibration factor (*Bigelow/Albatross*),

The Albatross equivalent length distributions are then converted to age distributions:

$$C_{y,a}^{surv,A} = \sum_l C_{y,l}^{surv,A} ALK_{y,a,l}^{surv} \tag{B34}$$

where

$ALK_{y,a,l}^{surv}$ is the age-length key (proportion of fish of length *l* that have age *a*) in year *y* for survey *surv*.

Indices are then obtained from the *Albatross* equivalent age distributions as follows:

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} w_{y,a}^{surv} \qquad \text{(B35)}$$

for biomass indices and

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} \qquad \text{(B36)}$$

for numbers indices,

where

$w_{y,a}^{surv}$ is the weight-at-age in year y for survey *surv*.

The calibration factor has four parameters, three of which are estimable and the other input: X_1=20cm, X_2, F_1 and F_2

$$F_l = \begin{cases} F_1 & \text{if } l \le X_1 \\ \frac{(F_2 - F_1)}{(X_2 - X_1)} l + \frac{(F_1 X_2 - F_2 X_1)}{(X_2 - X_1)} & \text{if } X1 < l < X_2 \\ F_2 & \text{if } l \ge X_2 \end{cases} \qquad \text{(B37)}$$

The following contribution is therefore added to the negative log-likelihood in the assessment:

$$-\ln L^{calib} = \frac{1}{2}\ln|\mathbf{\Sigma}| + \frac{1}{2}(\mathbf{x} - \boldsymbol{\mu})^{\mathrm{T}} \mathbf{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \qquad \text{(B38)}$$

where the parameters X_2, F_1 and F_2 are components of the vector $\mathbf{x}$,
$\mathbf{\Sigma}$ is the variance covariance matrix as estimated by Miller *et al.* (2010), and
$\boldsymbol{\mu}$ is a vector which contains the Miller *et al.* (2010) estimates of the parameters.

These estimates and the variance-covariance matrix are given in table B1 below:

Table B1: Estimates and variance-covariance matrix for the calibration parameters (Miller, pers. commn).

μ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
	0.4713	1.4163	3.5086
Σ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
$ln(F_2)$	0.006674	-0.002515	-0.002559
$ln(F_1\text{-}F_2)$	-0.002515	0.051592	-0.007601
$ln(X_2\text{-}X_1)$	-0.002559	-0.007601	0.006757

B.3. Estimation of precision

Where quoted, CV's or 95% probability interval estimates are based on the Hessian.

B.4. Model parameters

B.4.1. Fishing selectivity-at-age:

For the NEFSC offshore surveys, the fishing selectivities are estimated separately for ages 1 to age 6 and are flat thereafter. For the Massachusetts inshore spring survey, the selectivities are estimated separately for ages 1 to 4. The estimated proportional decrease from ages 3 to 4 is assumed to continue multiplicatively to age 6; this decrease parameter is bounded by 0, i.e. no increase is permitted. For all three surveys, age 0 is not considered.

The commercial fishing selectivity, S_a, is estimated separately for ages a_{minus} to a_{plus} (1 to 9) It is taken to differ over four periods: a) pre-1982, b) 1982-1988, c)1989-2004, and d) 2005-present. The selectivities are estimated directly for the last three periods. For the pre-1982 period, the selectivity is taken as that for the 1989-1988 block, but shifted one year to the left. For the implementations in this paper, given that there were difficulties with imprecise estimates at larger ages for period d) given its shortness, a common selectivity at age was estimated across all periods for ages 7 and above.

B.4.2. Other parameters

Model plus group			
m	9		
Commercial CAA			
a_{minus}*	1		
a_{plus}	9		
Survey CAA	NEFSC spr	NEFSC fall	MASS spr
a_{minus}*	1	1	1
a_{plus}	9	9	4
Natural mortality:			
M	Age independent: i) 0.2 for all years ii) 0.2 until 1988, threafter a linear increase to 0.4 in 2003 and constant at 0.4 thereafter		
Proportion mature-at-age:			
f_a	input, see Table A8		
Weight-at-age:			
$w_{y,a}^{strt}$	input, see Table A2		
$w_{y,a}^{mid}$	input, see Table A3		
$w_{y,a}^{surv}$	input, see Table A12		
Stock recruit residuals std dev: σ_R	0.6		
Initial conditions :			
$N_{y0,a}$	estimated directly for ages 0 to xx depending on AIC criterion		
ϕ	estimated		

* Strictly not a minus group anymore since the catches at age zero are ignored.

B.5.Biological Reference Points (BRPs)

It is possible to estimate BRPs internally within the assessment by fitting the stock-recruitment relationship directly within the assessment itself.

For some results reported here, however, the stock-recruitment relationships are fitted to the estimates of recruitment and spawning biomass provided by the various assessments to provide a basis to estimate BRPs. The rationale for estimation external to the assessment itself is to avoid assumptions about the form of the relationship influencing the assessment results. These fits are achieved by minimising the following negative log-likelihood, where the $e^{-\frac{\sigma_R^2}{2}}$ term is added for consistency with equation B4, i.e. the stock-recruitment curves estimated are mean-unbiased rather than median unbiased:

$$-\ln L = \sum_{y=y1}^{2009} \left[\frac{\left(\ln(N_{y,0}) - \ln\left(\hat{N}_{y,0} e^{-\frac{\sigma_R^2}{2}} \right) \right)^2}{2\left((\sigma_R)^2 + (CV_y)^2 \right)} \right] \qquad \text{(B39)}$$

where

$N_{y,0}$ is the "observed" (assessment estimated) recruitment in year *y*,

$\hat{N}_{y,0}$ is the stock-recruitment model predicted recruitment in year *y*,

σ_R is the standard deviation of the log-residuals which is input (and set here to 0.6), and

CV_y is the Hessian-based CV for the "observed" recruitment in year *y*.

Note that the differential precision of the assessment estimates of recruitment is taken into account, and that the summation ends at 2009 because little by way of direct observation is as yet available to inform estimates of recruitment for 2010 and 2011.

Appendix A.6. Additional ASAP sensitivity runs

This appendix (tables and figures in next section) provides results from sensitivity runs that were conducted on the SAW 55 ASAP reference model (SAW55_BASE) except where noted. These sensitivity runs fell into two categories: 1) determining whether an alternate model formulation offered improved fit to the data; and 2) evaluating the sensitivity of the model with respect to a range of assumptions.

A.6.1. Survey calibration coefficients

A number of operational changes have been made to the NEFSC spring and fall surveys during over the assessment times series including a changes in vessel (Delaware/Albatross historically and introduction of the Bigelow in 2009), trawl doors (during 1984-85) and trawl net (Yankee 36/41 in spring survey). The changes are summarized in Table A.52. Trends in the calibrated and uncalibrated surveys indices were very similar and with the exception of the fall 2009 abundance index (Fig. A.95). Overall, the effects of the Bigelow calibration were less than the historical door/vessel calibration effects. The SAW 55 WG recommended that the adjusted series of each NEFSC survey time series be used during SAW 55; however, the WG recommended that sensitivity analyses be undertaken during the modeling to explore the impact of uncertainty in the calibration coefficients.

Results of the sensitivity of the SAW55_BASE model to the upper and lower 95% confidence intervals of the calibration factors are provided in Table A.6.1 and Figure A.6.1. The main effect of the calibration coefficients was an increase in the uncertainty in recent biomass rather than adding bias. The 2011 spawning stock estimate ranged from 9,804 mt (upper 95% CI) to 15,098 mt (lower 95% CI) with the calibrated estimate of 11,974 mt (SAW55_BASE). Over the majority of the time series the effects of the calibration coefficients were minimal.

A.6.2. Use of survey numbers vs. biomass indices

Analyses were undertaken to compare the use of either survey aggregate abundance (numbers/tow) or biomass (weight/tow) in the model fitting. The abundance indices at age are presented in Tables A.57, A.59, and A.63 for the NEFSC spring, NEFSC fall, and MADMF spring survey respectively. Biomass indices at age are presented in Tables A.58, A.60, and A.64 for the NEFSC spring, NEFSC fall, and MADMF spring survey respectively. To correctly convert indices-at-age to numbers (which are the units that the ASAP model is tuning to) the model requires input of survey weights-at-age (e.g., Fig. A.11 and A.12). The survey weight-at-age matrices contained several holes for age/year combinations, particularly among the older ages. The missing values were imputed using a time series average weight-at-age. The ASAP sensitivity was conducted on the ASAP preferred model SAW55_3BLOCK_BASE which was tuned to the survey abundance (numbers) indices. A comparable model was constructed using the biomass indices as described above. To provide an equal comparison across models, the biomass model, SAW55_3BLOCK_BASE_BIOMASS was run initially and then the second stage Francis (2011) ESS multipliers were applied. The final biomass-based model is

SAW55_3BLOCK_BASE_BIOMASS_ADJ. The adjusted biomass model had improved model diagnostics relative to the unadjusted model (Table A.6.2).

The working group discussed the preferred metric to evaluate model preference and agreed that the coefficient of variation (CV) on the terminal (2011) estimate of spawning stock biomass should be used. The two indices provided similar results in terms of biomass trends (Fig. A.6.2) with the terminal (2011) estimates differing by 1,662 mt. The CVs on the 2011 spawning stock biomass were 0.176 for the abundance-based model and 0.181 for the biomass-based model. While the differences were small, the WG concluded to use abundance (numbers) indices for the final ASAP preferred model.

A.6.3. Survey catchability and an evaluation of biomass scale

The scale of model estimates of biomass can be affected by assumptions of the estimated efficiency of the surveys. Further work on the ASAP model was conducted to 1) evaluate the sensitivity of the SAW55_BASE model results to alternate assumptions of survey catchability (*q*), and 2) generate model-independent estimates of total biomass and compare to the model estimates to determine whether the model results are reasonable. The second analyses were originally conducted for the SAW 53 assessment (NEFSC 2012a), however given the nearly identical biomass scales between the SAW 53 and SAW 55 assessment results (Fig. A.138), the analyses remain relevant.

Model profiling across a range of NEFSC spring survey q values

The sensitivity of the SAW55_BASE model to alternate assumptions of survey catchability was evaluated by profiling across a range of *q* values from 0.1 to 1.3 in 0.1 increments. Priors were specified for catchability values by setting the input CV on catchability to 0.1 and setting lambda values at 1 (i.e., the initial *q* values were given little latitude to deviate from the initial conditions and a penalty was imposed for any deviations).

Results of the sensitivity runs are summarized in Fig. A.6.3. On the basis of the objective function, the model preferred *q* values in the range of 0.6 to 1.2. There was a general tendency for the model to estimate higher [lower] *q* values than inputted when the inputted *q* was below [above] the model preferred value of 0.89. Within the 0.6 to 1.2 range there was little impact in terms of SSB scaling (<8% difference from SAW55_BASE run). Even when forcing *q* to a minimum believable range (≈0.4) the SSB scaling differences only amount to <18% difference from the base run *q* preference of 0.89. The tradeoff in lower *q* reduces the overall fit in the NEFSC spring survey and by necessity, reduces *q* on the NEFSC fall survey. Additionally, a lower *q* requires an approximate 22% decrease in the selectivity on the oldest age in the second fishery selectivity block (i.e., a considerable increase in the doming assumption). The profiling across a range of *q* values shows strong model preference for the BASE model results, with little impact in terms of SSB within the range of believable alternatives.

Sensitivity of BASE results and estimates of survey q to area expansion factors

The Gulf of Maine cod stock boundary (Fig. A.1) encompasses a surface area of approximately 54.5 thousand km^2. The survey strata used in the Gulf of Maine cod stock assessment (Fig. A.85) encompasses 61.4 thousand km^2; approximately 17.1% larger than the stock area. Included in the survey strata set are three strata (29, 30 and 36) that extend beyond the United States Exclusive Economic Zone (EEZ) into Canadian waters. A sensitivity analyses was conducted to evaluate whether using a survey strata set that included only survey strata contained entirely within the US EEZ would affect model results and estimates of survey *q*.

NEFSC spring and fall survey indices, including indices at age, were recalculated using only strata 26-28 and 37-40 (excluded 29, 30 and 36). The revised survey area has a surface area of 34.2 thousand km^2 (37.2% smaller than the stock area).The recalculated aggregate abundance indices were nearly identical in terms of trends, but tended to be slightly higher (Fig. A.6.4). The rescaling of the survey indices is a product of dropping survey strata that have historically not contained high abundances of cod, thus increasing the stratified mean number/tow without impacting overall survey trends. When converted to area swept indices by accounting for the survey trawl area and revised surface area, the indices tended to be lower than those that included in the full strata set. The raising factor used to convert the mean number per tow to their area-swept equivalents was disproportionately smaller than the increases in the stratified mean number per tow. The revised survey indices were inputted into a revised ASAP model (SAW55_REV_SURV_STRATA).

The SAW55_REV_SURV_STRATA model is nearly identical to the BASE model with respect to the SSB, F and the age 1 recruitment time series (Fig. A.6.5). The slight deviations in the two runs are likely due to the small differences in the survey indices when calculated using the reduced strata set. While there were no major differences in estimates of SSB and F, using the reduced strata sets resulted in *q* estimates that were much lower relative to the BASE model. The NEFSC spring q went from 0.89 to 0.56, NEFSC fall from 0.53 to 0.41 and the MADMF spring survey went from 0.21 to 0.20 (Fig. A.6.6). Model estimates of *q* are highly sensitive to the estimated survey area used to expand mean number per tow survey indices to their area-swept equivalents. In addition to the assumptions about total survey area considered here, estimates of *q* are also likely to be sensitive to assumptions about the total trawl area, effective trawl sweep and the extent of cod herding that occurs in the survey net.

Model independent estimates of total biomass

All previous analyses have examined the sensitivity of the biomass estimates to different assumptions on model parameters. While these analyses show that the model-based biomass estimates are robust to alternate model configurations, they do not provide a sense for whether the model-based estimates are realistic relative to model-independent estimates of total stock biomass. Several different model-independent approaches are taken below to evaluate whether the ASAP estimates of biomass are realistic.

Model independent estimates of total biomass from the Bigelow survey years (2009-2011)

The conversion of Bigelow survey catches to Albatross equivalents is an uncertain, but necessary step in order to maintain a consistent time series and fully utilize the short Bigelow time series. To avoid any confounding effects of the Bigelow conversion in deriving model-independent estimates of biomass, an attempt was made to use raw (i.e., unconverted) Bigelow time series data (2009 – 2011) to estimate total biomass. Total survey area-swept biomass can be estimated using Appendix 6 Equation 1.

(1) $B_{AW} = I/1000 \bullet A/f \bullet 1/q$

where:

B_{AW} = Area swept biomass
I = survey index
A = survey area
f = trawl area
q = survey catchability

The survey area depends on the strata set included. For the purposes of these analyses, the inshore survey strata were included to better characterize total catch across all age classes (strata 57-69) in addition to the offshore survey strata (strata 26-30, 36-40). The nearshore area that makes up the inshore survey strata has higher abundance of juveniles relative to the offshore areas. During the Bigelow survey years, these strata have been consistently sampled. The differences in availability of young age classes between the inshore and offshore regions is evident when comparing the selectivity of NEFSC offshore surveys to the MADMF survey in the SAW55_3BLOCK_BASE model (Fig. A.177). The total surface area of strata 26-30, 36-40 and 57-69 is 63.8 thousand km^2 and 36.5 thousand km^2 when strata 29,30 and 36 are excluded. The total trawl area of the Bigelow is 0.024 km^2 when using wing spread to define the effective trawl area and 0.061 km^2 when using door spread. Comparatively, the Albatross tow area in terms of wing spread is 0.038 km^2.

Assumptions on the effective trawl area and q can have large impacts on survey-based estimates of total biomass. Moving from a q of 1.0 to 0.2 will result in a fivefold increase in terms of biomass (Fig. A.6.7). Assuming that the door spread best characterizes the effective trawl area results in biomass estimates less than half that compared to calculations made using wing spread. If there is herding between the doors and an assumption of wing spread is used to determine area swept biomass, biomass estimates may be inflated (or in the case of the model, q estimates, may be higher than reality). The true effective trawl area and survey catchability is not known, but an assumption that a wing spread-based estimate of effective trawl area and 80% efficiency (q=0.8) appears reasonable. Using these assumptions to estimate a survey-based estimate of total biomass yielded results similar to the SAW 53 BASE model estimates of total biomass at the time of the survey (i.e., total January 1 biomass decremented by total mortality, Z, occurring before the survey; Fig. A.6.8). In 2009 and 2010 the BASE biomass estimates are all within the 80% bootstrap CI of the Bigelow-based biomass estimates. Excluding the offshore survey strata does not impact the overall perception of Bigelow-based total biomass.

Given an assumption that the Bigelow survey *q*=0.8, it's reasonable to conclude that a comparative *q* for the Albatross survey is approximately 0.5 if the Bigelow to Albatross conversion coefficient of 1.602 on fish ≥ 54 cm is used as a rough estimate of differences in catchability (i.e., the Bigelow survey is 60% more efficient at catching cod compared to the Albatross survey). By performing a similar analysis on the Albatross survey series, but using a *q* assumption of 0.5, a time series of survey-estimated total biomass can be constructed. The survey-based time series is not inconsistent with the BASE model estimates of total biomass at the time of the survey (*Z*-decremented to the time of the survey). The BASE biomass estimates generally fall within the 80% CI of both the NEFSC spring and fall survey-based biomass estimates (Fig. A.6.9). While the estimates are not exact, they are all of the same relative scale, suggesting that the scale of the biomass estimated by the ASAP model is realistic.

Thinking of q in terms of the catchability of 'survey-able' biomass

The BASE model estimate of NEFSC spring survey *q* (0.92) seems unreasonably high when thought of in terms of total survey efficiency. However, when interpreting the model *q* values, the impact of survey selectivity on the *q* estimates needs to be considered. Effectively, the ASAP model *q* estimates represent the *q* in terms of fully selected fish (i.e., after accounting for survey selectivity). To examine whether the SAW 53 BASE *q* estimates were reasonable, the model estimates have been used to estimate survey-based total biomass as was done above. Unlike the previous analysis that incorporated the inshore survey strata, only the offshore survey strata are included here, as this is consistent with the NEFSC survey indices used in the SAW 53 BASE model. This maintains consistency between the survey index and model-based estimates of *q* and selectivity at age. Survey-based biomass indices were generated using both the full offshore strata set (26-30, 36-40) and with strata 29,30 and 36 excluded. The model estimates of *q* applied to estimate total biomass were: NEFSC spring = 0.92 (full strata set), 0.57 (exclude 29, 30 and 36) and NEFSC fall = 0.53 (full strata set), 0.42 (exclude 29, 30 and 36).

Total survey-based estimates of biomass were compared to the 'survey-able' biomass estimated from the SAW 53 BASE model. 'Survey-able' biomass was estimated by decrementing the January 1 biomass (NEFSC 2012a, Table A.63) by total *Z* between January 1 and the time of the survey (spring vs. fall) and filtering the *Z*-decremented biomass through the survey selectivity ogive. The SAW 53 BASE-estimated 'surveyable' biomass generally fell within the 80% survey CI on total biomass for both the spring (Fig. A.6.10) and fall (A.6.11) surveys. How *q* is defined, whether in terms of absolute efficiency or in terms of the fully selected ages, does impact the *q* value. However, when the *q* is properly applied in a model-independent exercise, the calculations yield biomass estimates that are comparable with those estimated by the BASE model.

A.6.4. Multiple fleet definitions

Preliminary ASAP runs attempted to break the fishery catch into separate fleets (commercial and recreational). Selectivity was fit non-parametrically (selectivity-at-age) with two selectivity blocks per fleet. The timing of the selectivity block varied slightly by fleet, but generally the split between blocks occurred during the 1990s. The SAW55_BASE model treats commercial and recreational catch (landings and discards) as a single fleet. Three different alternate fleet formulations were explored: 1) for each fleet (commercial and recreational), catch was divided into retained and discarded catch, with each disposition constituting its own fleet such that there were 4 fleets total (SAW55_4FLEET); 2) catch was divided into commercial and recreational catch with each catch input treated as a separate fleet (SAW55_2FLEET); 3) catch was divided into landed and discarded catch with each catch input treated as a separate fleet (SAW55_SPLIT_LAND_DISC).

All of the split fleet models suffered from severe diagnostic issues. Most notably there was strong residual patterning in the fits to catch at age (Figs. A.6.12-A.6.14). Compared to the SAW55_BASE models, the split fleet models had lower estimates of 2011 spawning stock biomass and equal or higher estimates of age 5 fishing mortality (Table A.6.3). Given the problems experienced with these complex ASAP formulations and robustness of the assessment results, the SAW 55 WG supported the decision to use a simplified, single fleet, model formulation.

A.6.5. Inclusion of catch-per-unit-effort indices

During the SAW 55 Data Working Group (SAW 55 WG 2012a) commercial and recreational landings-per-unit-effort (LPUE) indices were presented. The WG expressed several concerns with the use of these indices which are summarized in detail in the assessment report. Because of these concerns, the WG recommended that the LPUE indices not be included in the GOM cod assessment model.

Sensitivity runs were however conducted to evaluate the impacts of including these LPUE indices in the SAW55_BASE model. The LPUE indices were inputted into the model both separately (SAW55_COM_LPUE and SAW55_REC_LPUE) and combined (SAW55_LPUE). Summary diagnostics of all runs are presented in Table A.6.4.

Initial attempts to fit the commercial LPUE indices revealed a poor fit the index with strong residual patterning (Fig. A.6.15). At the Data WG meeting there was considerable discussion about the contraction of the commercial fishery and intense aggregation of the fishery that occurred between 2006 and 2010. In the fits the commercial LPUE index there was a strong residual pattern that indicated differences in fleet catchability pre- and post-2006. Based on the similarities of the residual patterning to observed behavior of the fleet, a second commercial LPUE model was constructed that split the commercial LPUE index into two separate series (SAW55_COM_LPUE_SPLIT): one series included years 1982-2005 and the second included the years 2006-2011. The split model fits to the LPUE series were considerably better than those of the single series (Fig. A.6.15). There was three-fold increase in catchability (q) between the pre- and post-2006 periods. Interestingly, the model estimates of spawning stock biomass, fishing mortality and age 1 recruitment were nearly identical to that of the SAW55_BASE model (Fig. A.6.16).

Similar to the commercial LPUE index, the model fit to the recreational index was poor. There was a string of positive residuals early in the time series (pre-2002) and negative residuals in the second half of the time series (Fig. A.6.17). Attempts to fit both LPUE indices (commercial and recreational) within a single model suffered from the same problems observed in the individual runs (Fig. A.6.18).

Because the LPUE indices do not have catch-at-age components, rather they are linked to the selectivity of the fishery, there was concern that the poor fits to the survey indices were due to attempting to link commercial or recreational LPUE indices to selectivities that included combined commercial and recreational catch patterns. Attempts were made to run LPUE models on the SAW55_2FLEET model described previously to address these concerns; however, these model runs did not converge.

A.6.6. Inclusion/exclusion of survey indices

To better understand how the model results are being influenced by each of the survey indices the SAW55_BASE model was run using only one index at a time. The three sensitivity runs were SAW55_NEFSC_SPRING (NEFSC spring survey), SAW55_NEFSC_FALL (NEFSC fall survey) and SAW55_MADMF_SPRING (MADMF spring survey). In all three sensitivity runs all other model configurations were left unchanged.

All three models had similar starting biomass values in 1982 ranging from 21,628 to 25,513 mt (Table S.6.7) however the MADMF spring survey model exhibited a large increase in spawning stock biomass over time such that by 2011, the spawning stock biomass was estimated at 34,137 mt compared to the 11,874 mt of the SAW55_BASE model. The survey fits from each of the models relative to the SAW55_BASE model was similar (Fig. A.6.19), however the large difference between models was due to a large buildup of age 9^+ fish in the MADMF spring survey (Fig. A.6.20). The increase in older age fish is a product of the declining selectivity with age in the MADMF spring survey (Fig. A.176). The MADMF survey contains very little information on older fish in the population; with only this survey in the model there is nothing to constrain build-up of biomass in the 9^+ group.

A.6.7. Survey selectivity assumptions (dome vs. flat topped) and plus group assumption (age 9^+ vs. 11^+)

Explorations were conducted to evaluate the impacts of: a) extending the age matrices out to age 11^+ (SAW55_11PLUS) compared to the 9^+ formulation used in the SAW55_BASE model; and b) allowing the NEFSC survey selectivities to be domed (SAW55_DOME) relative to the flat-topped assumed in the SAW55_BASE model. Additionally a combined model was run that allowed doming of the NEFSC survey selectivity and included extended age structure out to age 11^+ (SAW55_DOME11).

The SAW55_BASE model was insensitive to the plus group specification; the BASE and BASE_11 models achieved nearly identical results (67 mt difference) with respect to estimates of 2011 spawning stock biomass (Table A.6.6). The survey selectivities of ages 10 and 11 were poorly estimated as evidenced on the large CVs on these ages in both fishery blocks 1 and 2

(Table A.6.7). Selectivity of age 10 in block 1 hit a boundary at 1. Given the insensitivity of model results to the choice of the plus group and the poorly estimated selectivities on older ages, the base model configuration using an age 9^+ group is supported.

Relative to the SAW55_BASE model, the influence of allowing survey selectivities to be domed resulted in a positive rescaling of spawning stock biomass (e.g., 46% increase in 2011 SSB) and a decrease in age 5 fishing mortality from 0.59 to 0.50. Based on the evidence presented earlier, there is little biological or scientific evidence to support such strong doming, additionally, there was little model support for this with an increase of 6 parameters and an improvement of only 4 objective points. The improvement in the objective function was identical between the SAW55_11PLUS and SAW55_DOME11 runs. Given the lack of external evidence for domed-shaped survey selectivities, the lack of model preference for domed selectivity and the cautions highlighted in Legault (2012), the WG supported the assumption of flat-topped survey selectivity.

A.6.8. Assessment starting points (e.g., 1964, 1970 vs. 1982)

The SAW55_BASE assessment begins in 1982. The rationale for this approach is described in detail the main report. Two alternate start points were explored within the framework of the SAW55_BASE model: 1964 (SAW55_HIST_1964) and 1970 (SAW55_HIST_1970). Extending the time series back in time results in a loss of information content as described in the main report. For all historical runs the same adjustments described for the 1932 Beverton-Holt ASAP runs were applied to the SAW55_BASE historical runs. A summary of model diagnostics is presented in Table A.6.8. The historical runs, BASE_1970 and BASE_1964, did not alter the perception of the stock. Nearly identical trends were observed in spawning stock biomass, fishing mortality and age 1 recruitment (Fig. A.6.21). With respect to evaluating the current condition of the stock, the choice in starting year has little impact. Where the starting year does make a difference is in establishing reference points. Extending the time series back in time established additional contrast in the spawner-recuit relationship, however there remains no clear functional form to the relationship even when the assessment time series is extended back to 1964 (Fig. A.6.22). Given the experience of the GARM III, caution should be taken in placing too much weight on recruitment estimates driven entirely off of survey information (as are the recruitment estimates pre-1982) that cannot be corroborated with catch-at-age information.

A.6.9. Catch precision assumptions

At SARC 53, the Panel expressed concern that the CVs on the aggregate catch used in the base model (CV=0.05) assumed higher precision than was warranted given the CV estimates of 0.11 – 0.38 for commercial discards (Table A.25) and recreational catch percent standard errors (PSE) around 20% (Table A.43). Given that the same assumption has been made in SAW 55, explorations have been conducted evaluating the sensitivity of the model to both higher and lower CVs. In these sensitivity runs only the CVs on the aggregate catch were adjusted; all model inputs and parameters were held constant. Four different CVs were assumed in the model: 0.01, 0.10, 0.20, and 0.30. The model runs and summary diagnostics are presented in Table

A.6.9. Increasing catch CVs lead to slight improvements in the model fits to the survey indices, but only marginally (Appendix Fig. A1.11). The root mean square error on the total index fit went from 1.08 under the SAW55_BASE model to 1.00 in the 0.30 CV model. The primary effect of the higher CVs was reduced fit to the aggregate catch with very little overall change in the residual patterns, only in the magnitude of the residuals (Fig. A.6.23). The 2011 estimates of spawning stock biomass ranged from 11,990 mt to 10,535 mt with biomass decreasing with an increasing CV. Overall, increasing CVs on the aggregate catch had negligible impacts on the assessment results.

A.6.10. Stock structure considerations

Most of the discussion related to stock structure occurred during the SAW 55 Data WG. However, there were questions raised following the completion of the SAW 53 assessment that alternative definitions of stock structure could potentially change the perception of the cod resource(s). Here two different explorations have been conducted: 1) evaluate the likely outcome of considering only a western Gulf of Maine cod assessment; and 2) evaluate the likely outcome if the Georges Bank and Gulf of Maine cod resources were assessed as a single unit stock.

A western Gulf of Maine (wGOM) assessment model was constructed by first developing western Gulf of Maine survey indices. The western Gulf of Maine was defined at strata 26, 27 and 40 (Fig. A.6.24). These strata coincide with the region of highest cod density in the Gulf of Maine over the past five years (Fig. A.6.25). A comparison of the wGOM survey indices to those of the entire Gulf of Maine show that the survey trends from the wGOM are nearly identical to those of the Gulf of Maine as a whole (Fig. A.6.26). Conversely, the eastern Gulf of Maine have exhibited sharper declines in survey abundance relative to the Gulf of Maine as a whole. The declines seen in the eastern Gulf of Maine have only minimal effects on the full Gulf of Maine indices due to the dominance of the western Gulf signal. This effect can be better understood by examining the scale of the eastern Gulf of Maine survey indices relative to the Gulf of Maine as a whole (Fig. A.6.27). The abundance indices in the eastern component are approximately two to five times lower than those of the Gulf of Maine as a whole. The survey indices at age from the wGOM compared to the full GOM strata are nearly identical for both the spring (Fig. A.6.28) and (Fig. A.6.29).

Estimates of western Gulf of Maine catch were obtained by calculating the annual fraction of total Gulf of Maine commercial landings coming from statistical areas 513 and 514. Between 1982 and 2011, these two statistical areas have accounted for > 60% of the total Gulf of Maine cod landings and > 90% over the last five years (Fig. A.6.30). The annual fractions where then applied to the aggregate landings and discards (Table A.8) as well as the catch-at-age matrices (Tables A.17 and A.29). No changes were made to the recreational fishery catches since this fishery operates primarily in the western Gulf of Maine. A combined catch-at-age matrix was constructed using the revised catch inputs and the weight-at-age matrix was updated based on a numbers-weighted approach that incorporated the revised catches.

The SAW55_BASE model inputs were then modified by updating the NEFSC survey indices (aggregate, at-age and input CVs) and the catch inputs (aggregate catch, catch-at-age, weights-at-age). All other model inputs and configurations were left the same. A comparison of the summary diagnostics of the SAW55_BASE and the SAW55_WESTERN models is provided in Table A.6.10. The trends in spawning stock biomass in the western Gulf of Maine have varied, but don't exhibit as large of long-term decline as seen over the entire Gulf of Maine region (Fig. A.6.31). While this could imply large declines in the eastern Gulf of Maine biomass, given non-linearities in the models the eastern Gulf of Maine biomass does not necessarily equal the total minus that of the wGOM. It's important to note that the 2011 estimates of spawning stock biomass and fishing mortality are nearly identical between the two models. This suggests that the current perception of the resource is not dramatically different if only the western Gulf of Maine is considered. Given that spawner-per-recruit (SPR) reference points are likely to be similar between the wGOM-only and GOM regions given the dominance of the wGOM signal in the SPR inputs, consideration of a wGOM only assessment would likely not alter the current stock status.

To construct a combined Georges Bank-Gulf of Maine assessment (SAW55_COMBINED_GOM_GBK) the following steps were taken:

- Started the model in 1982 and used age9^+ formulation.
  - Gulf of Maine assessment starts in 1982 with age 9^+ group.
  - Georges Bank assessment starts in 1978 with age 10^+ group.
- Treated Gulf of Maine and Georges Bank catches as separate fleets.
  - Used fleet-specific catch weights.
- Re-calculated Georges Bank catch weights to age9^+ formulation using numbers weighted approach.
- Re-calculated aggregate catch weights-at-age using numbers-weighted approach.
- Re-estimated stock/SSB weights-at-age using Rivard approach back to January 1.
- Assumed a mean spawning period at end of February (0.167), which is the mean spawning period used in the Georges Bank assessment.
  - It should be noted that this will have only marginal impacts on the assessment model since it is not directly used in the assessment solution, only in the calculation of spawning stock biomass.
- Used Gulf of Maine maturity ogive.
  - Similar to the spawning period assumption, this will have marginal impacts on the results because it is not directly used in the assessment solution.
- Indices inputted as stock-specific indices.
  - Both MADMF spring and DFO survey indices were included.

The combined GOM/GBK run was compared to the individual Gulf of Maine (SAW55_BASE) and Georges Bank (GBCOD_BASE_ASAP) model results as well as the sum of the individual assessments. The sum of the individual stock spawning stock biomasses and age1 recruitment are similar to the combined model results (Fig. A.6.32). The aggregate fishing mortality is an approximate average of the stock-specific fishing mortalities. Given these similarities, it is not likely that alternate stock structure assumptions will results in considerably different perceptions of resource status. Regardless of the assumptions on stock structure spawning stock biomasses are severely depleted from the highs observed in the early 1980s. Currently the Gulf of Maine assessment has a minor retrospective pattern relative to that observed for the Georges Bank assessment. Combining the two stocks in to a single unit stock assessment does not resolve the retrospective pattern (Fig. A.6.33). Given the retrospective patterns observed in the combined assessment it's likely that a combined unit-stock approach would effectively degrade the quality of management information with respect to the Gulf of Maine resource.

It should be noted that the exploratory analyses conducted here, both with respect to the western Gulf of Maine and unit stock assessment are preliminary. A number of critical issues with respect to data inputs would need to be addressed before undertaking future such analyses in a more formal manner.

Appendix A.6. Tables

Table A.6.1. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment model to the upper and lower 95% confidence intervals of the survey calibration factors used throughout the history of the assessment time series.

Model		SAW55_BASE	SAW55_SURV_CONV_LOWER	SAW55_SURV_CONV_UPPER
Parameters		101	101	101
Objective function		2554	2563	2559
Components of objective function	Suvey age comps	860	866	858
	Catch age comps	395	396	398
	Index fit	794	798	799
	Catch fit	211	211	211
	Recruit devs	293	293	294
RMSE	Catch	0.29	0.30	0.28
	Index1	1.14	1.19	1.13
	Index2	0.97	1.04	1.09
	Index3	1.13	1.14	1.14
	Index total	1.08	1.12	1.12
	Recruit devs	1.42	1.38	1.45
Mean age RMSE	Fleet1	1.34	1.34	1.38
	Index1	1.50	1.61	1.63
	Index2	1.74	1.67	1.77
	Index3	1.37	1.36	1.37
Survey catchability (q)	NEFSC spring	0.89	0.87	0.95
	NEFSC fall	0.53	0.50	0.54
	MADMF spring	0.21	0.20	0.21
SSB_{1982} (mt)		23320	23086	23299
SSB_{2011} (mt)		11874	15098	9804
$F_{age5, 2011}$		0.59	0.52	0.73

Table A.6.2. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_3BLOCK_BASE assessment to the use of survey biomass indices relative to abundance (numbers) indices.

Model		SAW55_3BLOCK_BASE	SAW55_3BLOCK_BASE_BIOMASS	SAW55_3BLOCK_BASE_BIOMASS_ADJ
Selectivity blocks		3	3	3
Year splits		1989, 2005	1989, 2005	1989, 2005
Parameters		93	93	93
Objective function		2055	2192	1997
Maximum gradient		9.2E-05	3.7E-05	3.4E-05
Components of objective function	Suvey age comps	602	685	573
	Catch age comps	390	396	350
	Index fit	794	838	806
	Catch fit	210	213	210
	Recruit devs	59	59	59
RMSE	Catch	0.21	0.50	0.20
	Index1	1.13	1.75	1.09
	Index2	0.97	1.27	0.97
	Index3	1.14	1.87	0.91
	Index total	1.08	1.65	0.99
	Recruit devs	1.51	1.49	1.47
Mean age RMSE	Fleet1	0.96	1.13	0.94
	Index1	1.02	1.49	0.99
	Index2	1.18	1.63	1.21
	Index3	1.06	0.87	1.00
SSB_{1982} (mt)		22036	23610	22795
SSB_{2011} (mt)		9903	7607	8281
$F_{age5, 2011}$		0.78	1.04	0.94

Table A.6.3. Summary of model diagnostics from a sensitivity analysis of the of Maine Atlantic cod SAW55_BASE assessment to the incorporation of multiple fleet definitions.

Model		SAW55_BASE	SAW55_4FLEET	SAW55_2FLEET	SAW55_SPLIT_LAND_DISC
Model description		Base model from SAW55	Commerical landings, discards and recreational landings/discards treated as separate fleets	Commercial and recreational fleets modelled separately	Modelled landings and discards separately
Number of parameters		101	239	147	147
Objective function		2554	3716	2970	2981
Components of objective function	Suvey age comps	860	888	859	861
	Catch age comps	395	1199	632	672
	Index fit	794	794	794	794
	Catch fit	211	546	392	361
	Recruit devs	293	289	293	293
RMSE	Fleet 1	0.29	0.21	0.23	0.27
	Fleet 2		0.05	0.20	0.12
	Fleet 3		0.05		
	Fleet 4		0.01		
	Total catch	0.29	0.11	0.21	0.21
	Index1	1.14	1.13	1.14	1.13
	Index2	0.97	0.96	0.97	0.96
	Index3	1.13	1.13	1.13	1.13
	Recruit devs	1.14	1.30	1.42	1.08
Mean age RMSE	Fleet1	1.34	1.31	1.24	1.50
	Fleet2		1.37	0.89	1.70
	Fleet3		1.48		
	Fleet4		1.65		
	Index1	1.50	1.49	1.43	1.45
	Index2	1.74	1.83	1.74	1.76
	Index3	1.37	1.36	1.38	1.38
SSB_{1982} (mt)		23,320	24,396	23,359	24,331
SSB_{2011} (mt)		11,874	10,657	11,635	10,755
$F_{age5, 2011}$		0.59	0.70	0.59	0.61
Survey catchability (q)	Index 1	0.89	0.90	0.91	0.91
	Index 2	0.53	0.53	0.54	0.54
	Index 3	0.21	0.21	0.21	0.21

Table A.6.4. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to the incorporation of commercial (COM_LPUE), recreational (REC_LPUE) and combined (_LPUE) landings-per-unit-effort indices.

Model		SAW55_BASE	SAW55_COM_LPUE	SAW55_COM_LPUE_SPLIT	SAW55_COM_LPUE_SPLIT_V2	SAW55_REC_LPUE	SAW55_LPUE	SAW55_LPUE_V2
Parameters		101	102	103		102	102	
Objective function		2554	2572	2568		2565	2582	
Components of objective function	Suvey age comps	860	860	860		860	860	
	Catch age comps	395	395	395	Did not converge	395	395	Did not converge
	Index fit	794	813	808		804	823	
	Catch fit	211	211	211		211	211	
	Recruit devs	293	293	293		293	293	
RMSE	Catch	0.29	0.29	0.29		0.28	0.29	
	Index1	1.14	1.15	1.14		1.14	1.15	
	Index2	0.97	0.99	0.97		0.97	0.98	
	Index3	1.13	1.13	1.13		1.13	1.13	
	Index5		0.55	0.24			0.56	
	Index6			0.27				
	Index7					0.37	0.38	
	Index total	1.08	0.99	0.95		1.00	0.93	
	Recruit devs	1.42	1.41	1.42		1.43	1.41	
Mean age RMSE	Fleet1	1.34	1.32	1.34		1.34	1.33	
	Index1	1.50	1.50	1.50		1.50	1.50	
	Index2	1.74	1.74	1.73		1.73	1.74	
	Index3	1.37	1.37	1.37		1.37	1.37	
SSB_{1982} (mt)		23320	23310	23383		23315	23301	
SSB_{2011} (mt)		11874	13853	11985		11635	13018	
$F_{age5,2011}$		0.59	0.52	0.59		0.60	0.53	

Table A.6.5. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to inclusion of only a single survey index at one time.

Model		SAW55_BASE	SAW55_NEFSC_SPRING	SAW55_NEFSC_FALL	SAW55_MADMF_SPRING
Parameters		101	91	91	89
Objective function		2554	1508	1459	1348
Components of objective function	Suvey age comps	860	345	312	197
	Catch age comps	395	390	391	386
	Index fit	794	271	256	266
	Catch fit	211	210	210	210
	Recruit devs	293	292	291	290
RMSE	Catch	0.29	0.21	0.17	0.14
	Index1	1.14	1.14		
	Index2	0.97		0.97	
	Index3	1.13			1.08
	Index total	1.08	1.14	0.97	1.08
	Recruit devs	1.42	1.39	1.34	1.20
Mean age RMSE	Fleet1	1.34	1.27	1.26	1.04
	Index1	1.50	1.51		
	Index2	1.74		1.74	
	Index3	1.37			1.34
SSB_{1982} (mt)		23320	22217	25513	21628
SSB_{2011} (mt)		11874	11254	12345	34137
$F_{age5, 2011}$		0.59	0.64	0.56	0.28

Table A.6.6. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to the implementation of domed selectivity in the NEFSC survey indices and extension of the age structure out to an 11^+ group.

Model		SAW55_BASE	SAW55_DOME	SAW55_11PLUS	SAW55_DOME11
Parameters		101	107	107	117
Objective function		2554	2550	2582	2578
Components of objective function	Suvey age comps	860	859	875	874
	Catch age comps	395	395	408	409
	Index fit	794	793	794	792
	Catch fit	211	210	211	210
	Recruit devs	293	293	293	293
RMSE	Fleet 1	0.29	0.24	0.29	0.24
	Index 1	1.14	1.11	1.14	1.11
	Index 2	0.97	0.96	0.97	0.95
	Index 3	1.13	1.11	1.13	1.11
	Recruit devs	1.42	1.38	1.42	1.38
Mean age RMSE	Fleet1	1.34	1.34	1.33	1.34
	Index1	1.50	1.47	1.49	1.48
	Index2	1.74	1.75	1.73	1.74
	Index3	1.37	1.37	1.37	1.36
Survey catchability (q)	Index 1	0.89	0.52	0.89	0.71
	Index 2	0.53	0.34	0.53	0.44
	Index 3	0.21	0.25	0.21	0.21
SSB_{1982} (mt)		23320	37315	22640	39066
SSB_{2011} (mt)		11874	17279	11807	18670
$F_{age5, 2011}$		0.59	0.50	0.59	0.49

Table A.6.7. Summary of selectivity parameter estimates and corresponding coefficients of variation (*italics*) from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to the implementation of domed selectivity in the NEFSC survey indices and extension of the age structure out to an 11^{+} group.

Model		SAW55_BASE		SAW55_DOME		SAW55_11PLUS		SAW55_DOME11	
Block 1	**Age1**	0.04	*0.18*	0.04	*0.18*	0.04	*0.18*	0.04	*0.18*
	Age2	0.25	*0.10*	0.26	*0.10*	0.25	*0.10*	0.26	*0.11*
	Age3	0.57	*0.09*	0.58	*0.10*	0.57	*0.09*	0.59	*0.10*
	Age4	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	Age5	1.00		1.00		1.00		1.00	
	Age6	0.78	*0.25*	0.74	*0.26*	0.75	*0.25*	0.69	*0.26*
	Age7	1.00	*0.07*	0.88	*0.41*	0.84	*0.36*	0.64	*0.40*
	Age8	1.00	*0.00*	1.00	*0.00*	0.69	*0.53*	0.50	*0.59*
	Age9/+	0.33	*0.45*	0.10	*0.67*	0.55	*0.76*	0.42	*0.86*
	Age10					1.00	*0.01*	0.85	*1.51*
	Age11+					0.27	*0.81*	0.04	*1.35*
Block 2	**Age1**	0.02	*0.18*	0.02	*0.19*	0.02	*0.18*	0.02	*0.19*
	Age2	0.07	*0.11*	0.08	*0.12*	0.07	*0.11*	0.08	*0.13*
	Age3	0.32	*0.08*	0.36	*0.10*	0.32	*0.08*	0.37	*0.10*
	Age4	0.79	*0.07*	0.87	*0.08*	0.79	*0.07*	0.88	*0.09*
	Age5	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	Age6	1.00		1.00		1.00		1.00	
	Age7	0.92	*0.17*	0.64	*0.22*	0.92	*0.17*	0.62	*0.23*
	Age8	0.88	*0.27*	0.44	*0.37*	0.87	*0.27*	0.42	*0.38*
	Age9/+	0.77	*0.50*	0.13	*0.60*	0.70	*0.44*	0.25	*0.58*
	Age10					0.86	*0.63*	0.16	*0.79*
	Age11+					1.00	*0.01*	0.04	*1.03*
Index 1	**Age1**	0.04	*0.19*	0.05	*0.21*	0.05	*0.18*	0.05	*0.22*
	Age2	0.14	*0.16*	0.17	*0.19*	0.14	*0.15*	0.17	*0.19*
	Age3	0.30	*0.15*	0.35	*0.18*	0.30	*0.15*	0.37	*0.19*
	Age4	0.51	*0.15*	0.61	*0.17*	0.53	*0.14*	0.63	*0.18*
	Age5	0.75	*0.15*	0.83	*0.16*	0.76	*0.15*	0.85	*0.16*
	Age6	1.00		1.00		1.00		1.00	
	Age7	1.00		1.00	*0.00*	1.00		1.00	*0.00*
	Age8	1.00		0.56	*0.40*	1.00		0.51	*0.40*
	Age9/+	1.00		0.16	*0.55*	1.00		0.38	*0.60*
	Age10					1.00		0.37	*0.75*
	Age11+					1.00		0.05	*1.02*
Index 2	**Age1**	0.17	*0.15*	0.20	*0.17*	0.17	*0.14*	0.20	*0.17*
	Age2	0.40	*0.14*	0.46	*0.16*	0.40	*0.13*	0.47	*0.16*
	Age3	0.59	*0.14*	0.66	*0.15*	0.58	*0.13*	0.68	*0.16*
	Age4	0.89	*0.14*	0.97	*0.15*	0.89	*0.13*	0.99	*0.15*
	Age5	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	Age6	1.00		1.00		1.00		1.00	
	Age7	1.00		0.62	*0.38*	1.00		0.58	*0.38*
	Age8	1.00		0.42	*0.61*	1.00		0.38	*0.61*
	Age9/+	1.00		0.20	*0.61*	1.00		0.54	*0.67*
	Age10					1.00		0.16	*1.37*
	Age11+					1.00		0.10	*0.97*
Index 3	**A50 ascend**	0.00	*3000.30*	0.00	*3000.05*	0.00	*3316.67*	0.00	*3316.88*
	Slope ascend	10.00		10.00		1.00		10.00	
	A50 descend	0.00	*2994.57*	0.00	*3000.00*	0.00	*3316.65*	0.00	*3316.48*
	Slope descend	3.50	*0.18*	3.16	*0.15*	3.64	*0.18*	3.15	*0.15*

Table A.6.8. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to the assessment starting year.

Model		SAW55_BASE	SAW55_HIST_1970	SAW55_HIST_1964
Starting year		1982	1970	1964
Parameters		101	133	145
Objective function		2554	3267	3439
Maximum gradient		0.0016	0.0005	0.0000
Components of objective function	Suvey age comps	860	1130	1131
	Catch age comps	395	396	396
	Index fit	794	1019	1089
	Catch fit	211	307	352
	Recruit devs	293	415	472
RMSE	Catch	0.29	0.28	0.27
	Index1	1.14	1.15	1.13
	Index2	0.97	1.14	1.08
	Index3	1.13	1.13	1.13
	Index total	1.08	1.14	1.11
	Recruit devs	1.42	1.43	1.43
Mean age RMSE	Fleet1	1.34	1.34	1.34
	Index1	1.50	1.35	1.35
	Index2	1.74	1.66	1.67
	Index3	1.37	1.37	1.37
Survey catchability (q)	NEFSC spring	0.89	0.74	0.76
	NEFSC fall	0.53	0.59	0.61
	MADMF spring	0.21	0.21	0.21
SSB_{1964} (mt)				14330
SSB_{1970} (mt)			33836	34381
SSB_{1982} (mt)		23320	23349	23228
SSB_{2011} (mt)		11874	12198	11776
$F_{age5, 2011}$		0.59	0.58	0.60

Table A.6.9. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to the assumed precision of the aggregate catch input. Precision is expressed in terms of the coefficient of variation (CV).

Model		SAW55_CATCH_CV01	SAW55_BASE	SAW55_CATCH_CV10	SAW55_CATCH_CV20	SAW55_CATCH_CV30
Catch CV		0.01	0.05	0.10	0.20	0.30
Parameters		101	101	101	101	101
Objective function		2507	2554	2572	2584	2588
Components of objective function	Suvey age comps	861	860	859	856	852
	Catch age comps	396	395	394	392	389
	Index fit	795	794	792	788	787
	Catch fit	161	211	234	259	273
	Recruit devs	294	293	292	289	287
RMSE	Catch	0.06	0.29	0.51	0.75	0.83
	Index1	1.15	1.14	1.11	1.03	0.99
	Index2	0.98	0.97	0.95	0.95	0.97
	Index3	1.14	1.13	1.11	1.06	1.04
	Index total	1.09	1.08	1.06	1.02	1.00
	Recruit devs	1.43	1.42	1.40	1.35	1.32
Mean age RMSE	Fleet1	1.34	1.34	1.33	1.31	1.29
	Index1	1.50	1.50	1.49	1.46	1.43
	Index2	1.74	1.74	1.72	1.69	1.67
	Index3	1.37	1.37	1.37	1.36	1.36
SSB_{1982} (mt)		23460	23320	22924	21702	20249
SSB_{2011} (mt)		11990	11874	11597	11026	10535
$F_{age5,\,2011}$		0.59	0.59	0.60	0.60	0.59

Table A.6.10. Summary of model diagnostics from a sensitivity analysis of the Gulf of Maine Atlantic cod SAW55_BASE assessment to considering only data from the western Gulf of Maine (NEFSC offshore survey strata 26, 27, 40).

Model		SAW55_BASE	SAW55_WESTERN
Model description		Base model from SAW55	Western Gulf of Maine only (513-514, strata 26-27, 40)
Number of parameters		101	101
Objective function		2554	2550
Components of objective function	Suvey age	860	885
	Catch age comps	395	398
	Index fit	794	778
	Catch fit	211	204
	Recruit devs	293	285
RMSE	Fleet 1	0.29	0.25
	Index 1	1.14	1.21
	Index 2	0.97	1.14
	Index 3	1.13	1.07
	Recruit devs	1.42	1.33
SSB_{1982} (mt)		23,320	16,526
SSB_{2011} (mt)		11,874	12,690
$F_{age5, 2011}$		0.59	0.53
Survey catchability (q)	Index 1	0.89	0.51
	Index 2	0.53	0.37
	Index 3	0.21	0.25

Appendix A.6. Figures

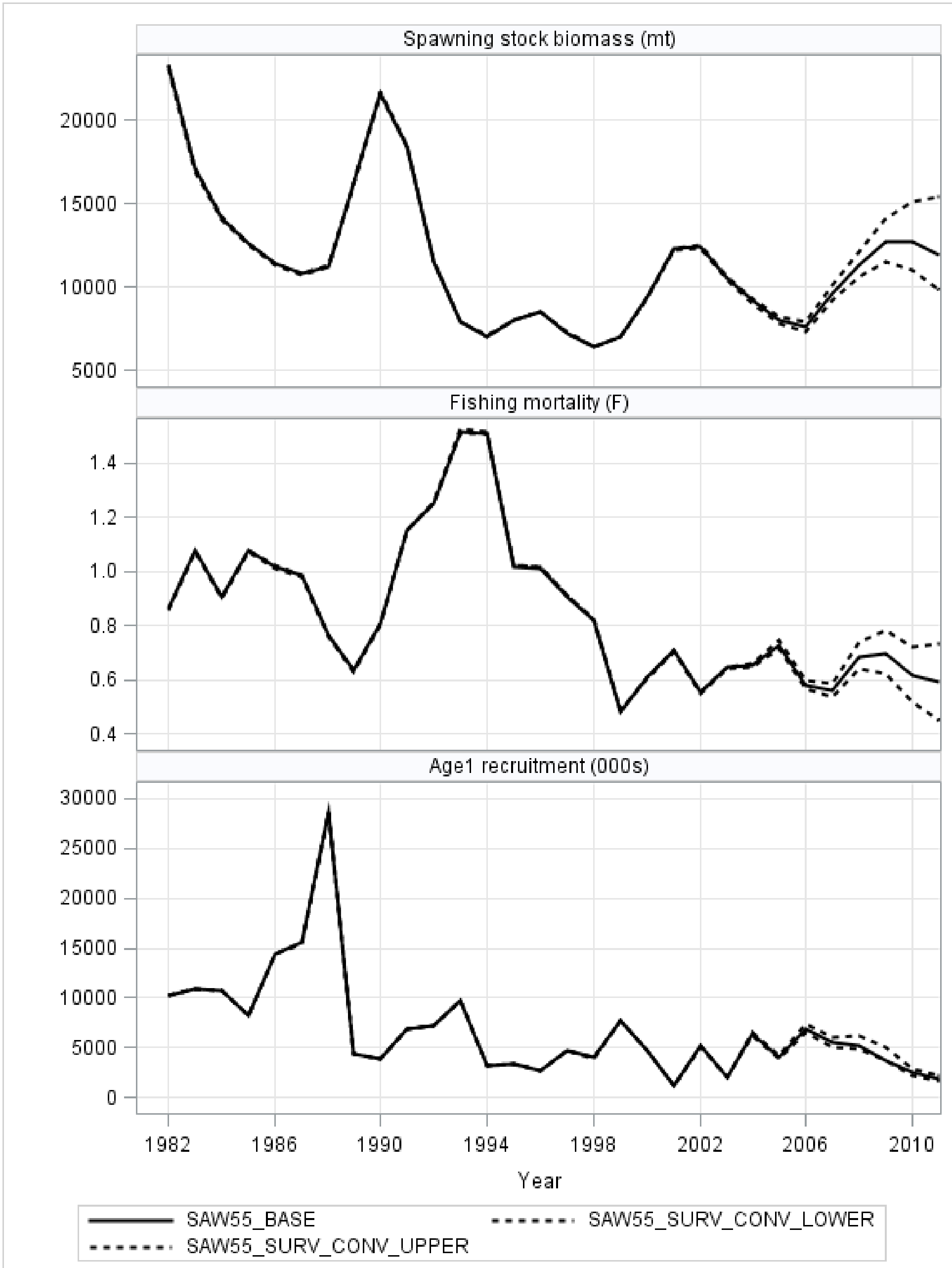


Figure A.6.1. Sensitivity of the Gulf of Maine Atlantic cod SAW55_BASE assessment model to the upper and lower 95% confidence intervals of the survey calibration factors used throughout the history of the assessment time series.

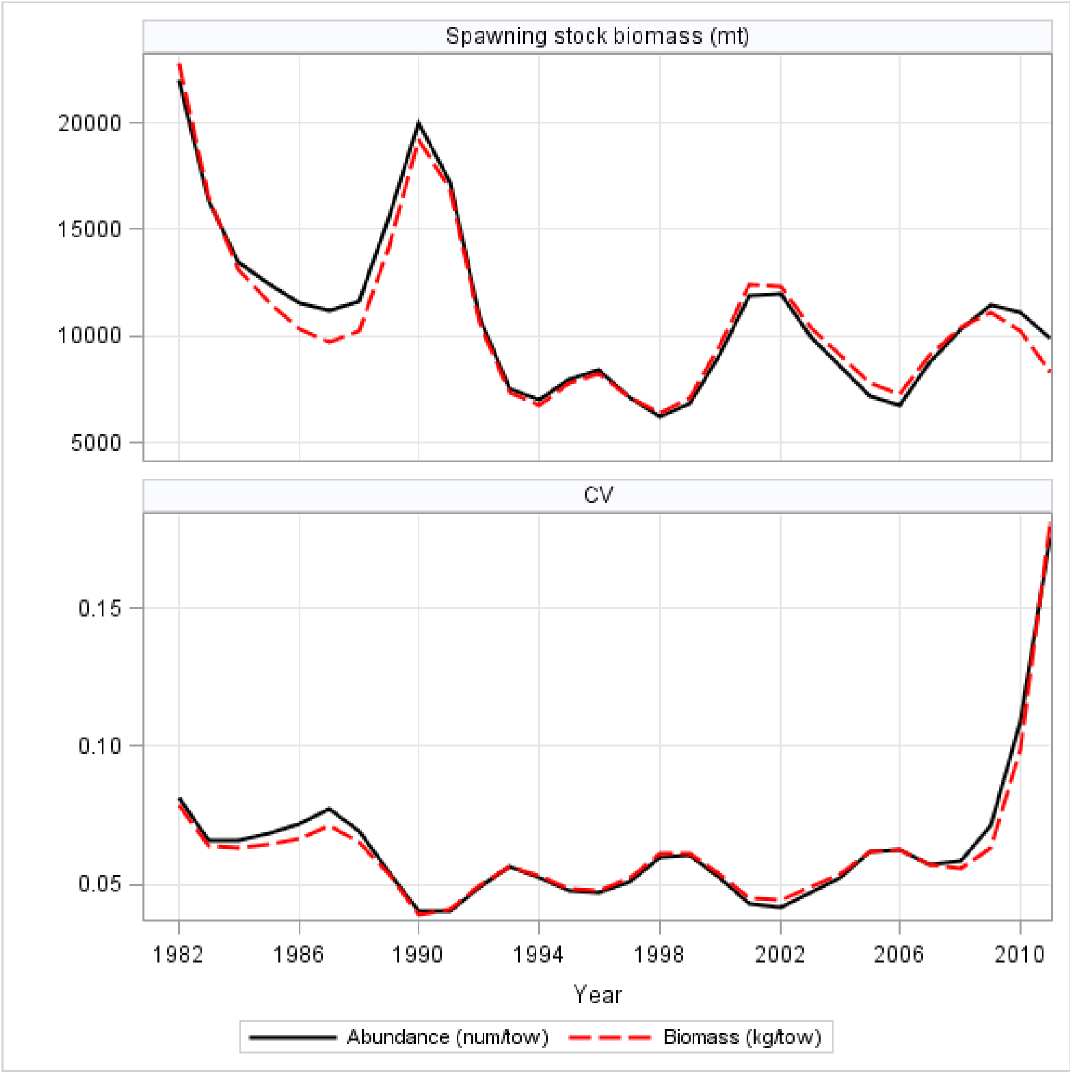


Figure A.6.2. Sensitivity of the Gulf of Maine Atlantic cod SAW55_3BLOCK_BASE assessment to the use of survey biomass indices relative to abundance (numbers) indices.

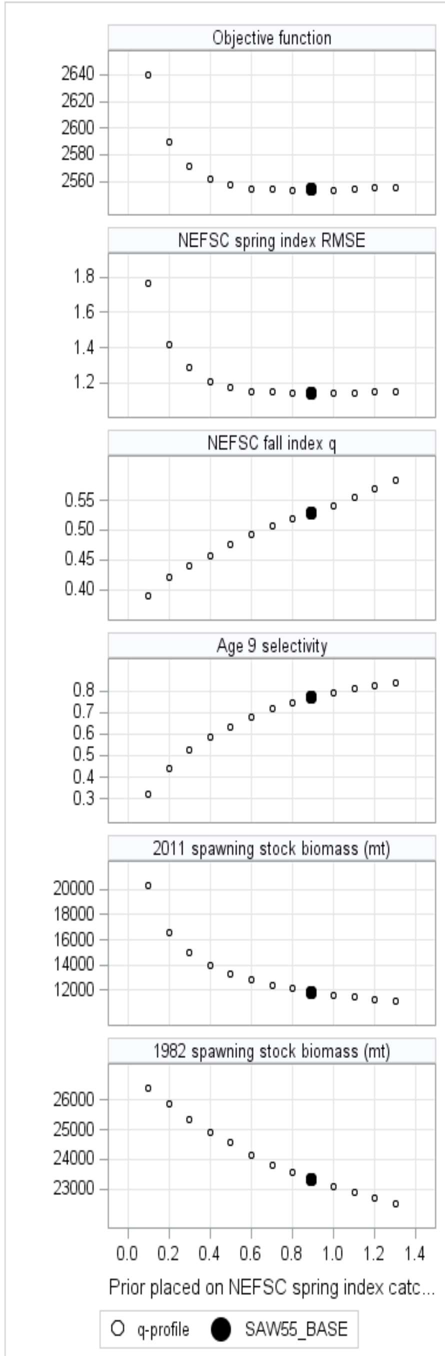


Figure A.6.3. Sensitivity analysis showing the response of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model to different assumptions of survey catchability (*q*) of the Northeast Fisheries Science Center spring survey.

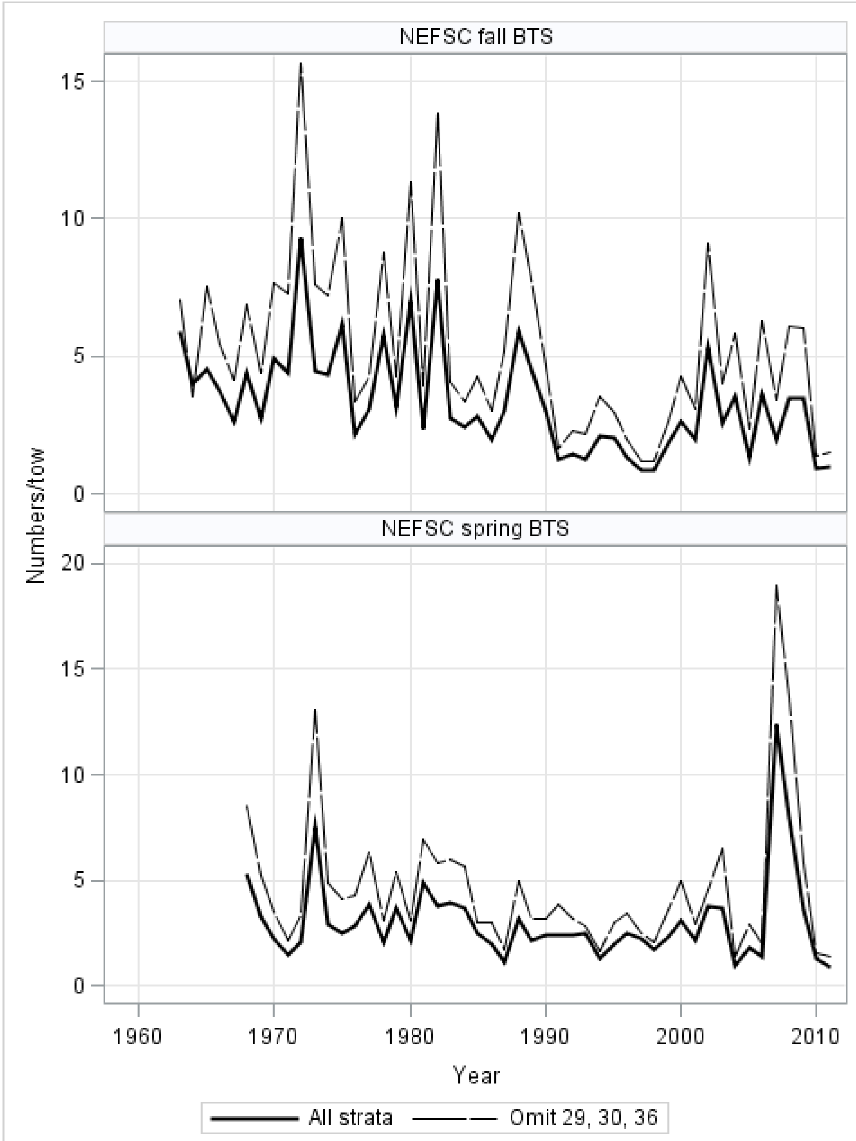


Figure A.6.4. Gulf of Maine Atlantic cod NEFSC spring (bottom) and fall (top) survey indices of abundance (numbers per tow) when estimated from all NEFSC offshore strata (26, 27, 28, 29, 30, 36, 37, 38, 39, 40; black line) and when strata 29, 30, and 36 are excluded (red line).

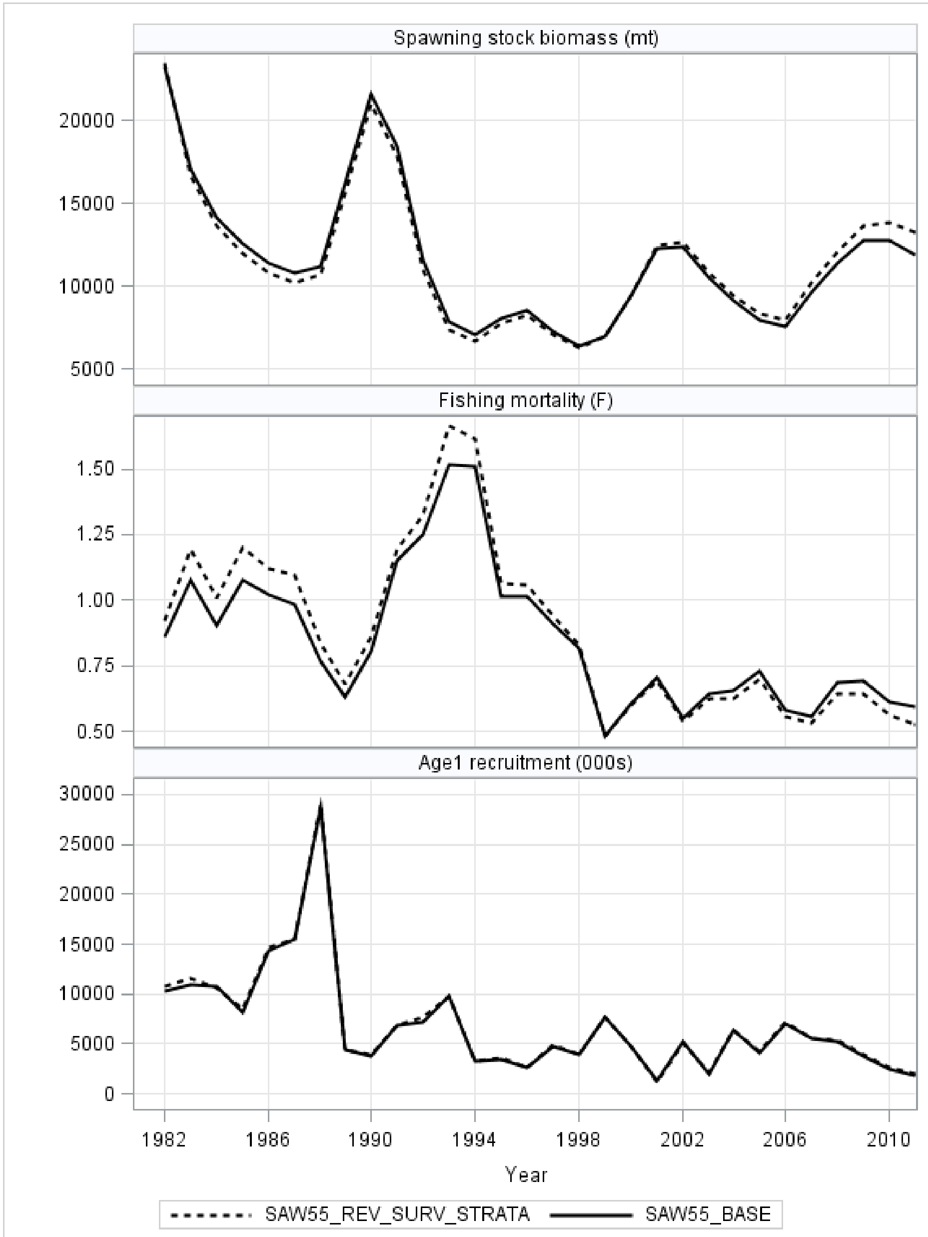


Figure A.6.5. Comparison of Gulf of Maine cod spawning stock biomass (top), age 5 fishing mortality (F) (middle) and age-1 recruitment (thousands of fish; bottom) between the SAW55_BASE model (all survey strata) and the SAW55_REV_SURV_STRATA (excludes offshore survey strata 29, 30 and 36).

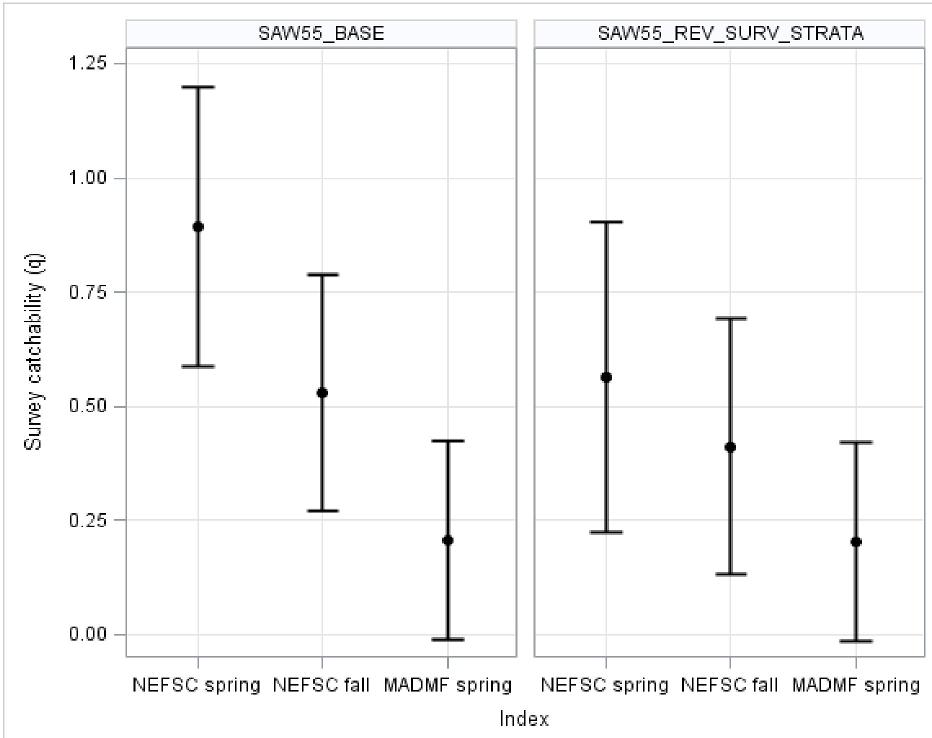


Figure A.6.6. ASAP model estimates of NEFSC survey catchability (*q*) for Gulf of Maine Atlantic cod when estimated by the SAW55_BASE model which includes swept area estimates from all survey strata and when estimated by the SAW55_REV_SURV_STRATA model which excludes offshore survey strata 29, 30, and 36.

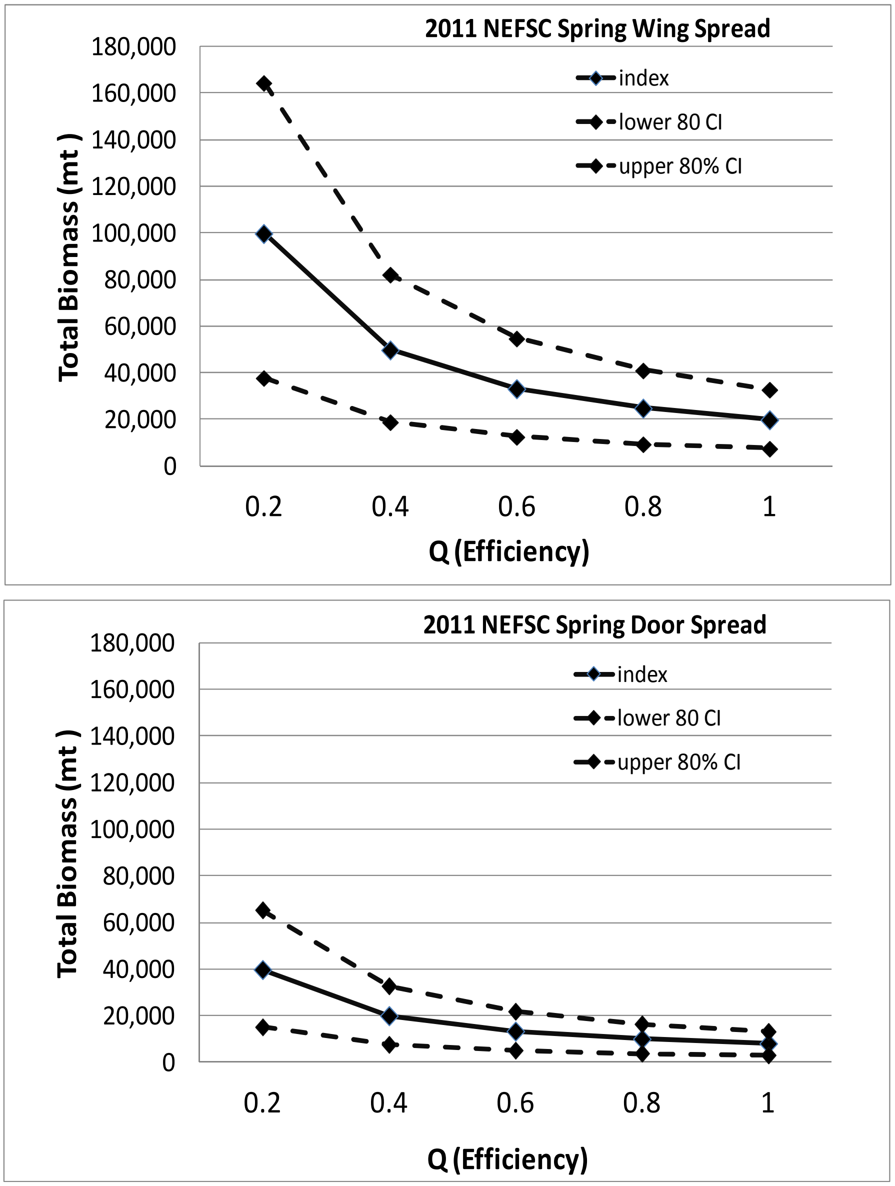
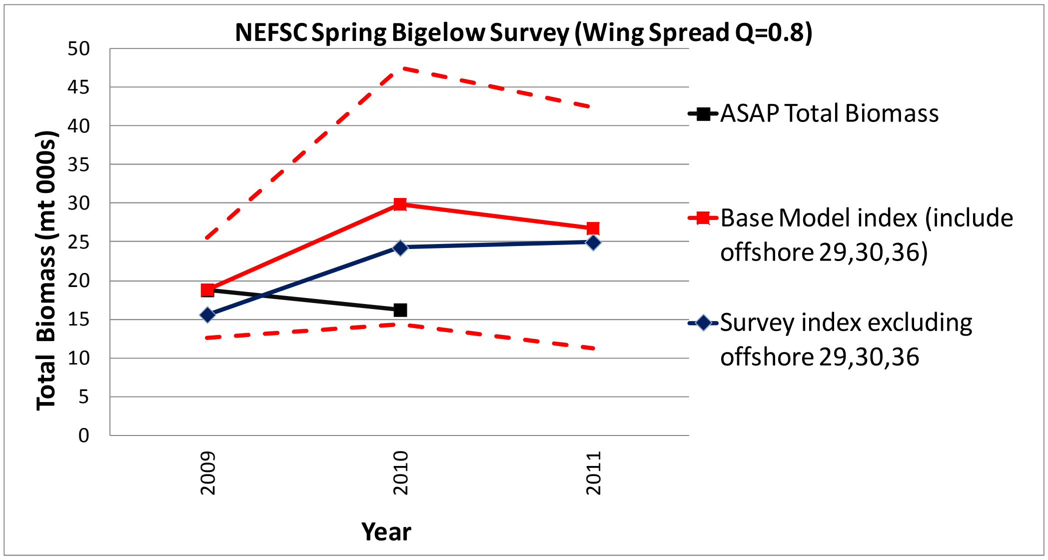


Figure A.6.7. Area swept estimates of total Gulf of Maine Atlantic cod biomass under different assumptions of NEFSC spring Bigelow survey catchability (q) and effective trawl area (wing spread vs. door spread). The 80% bootstrap confidence interval (CI) is shown by the dashed lines.



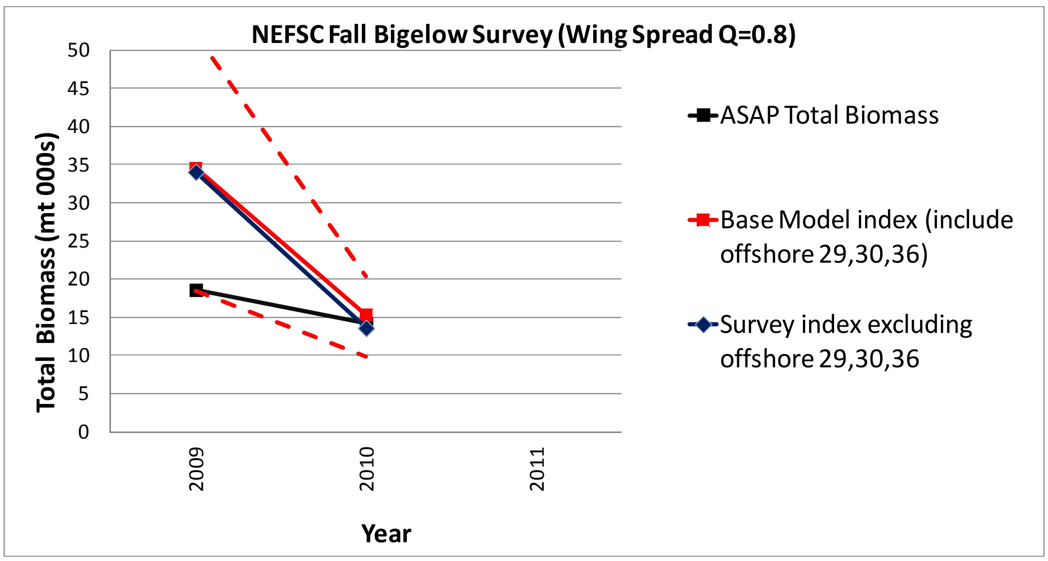
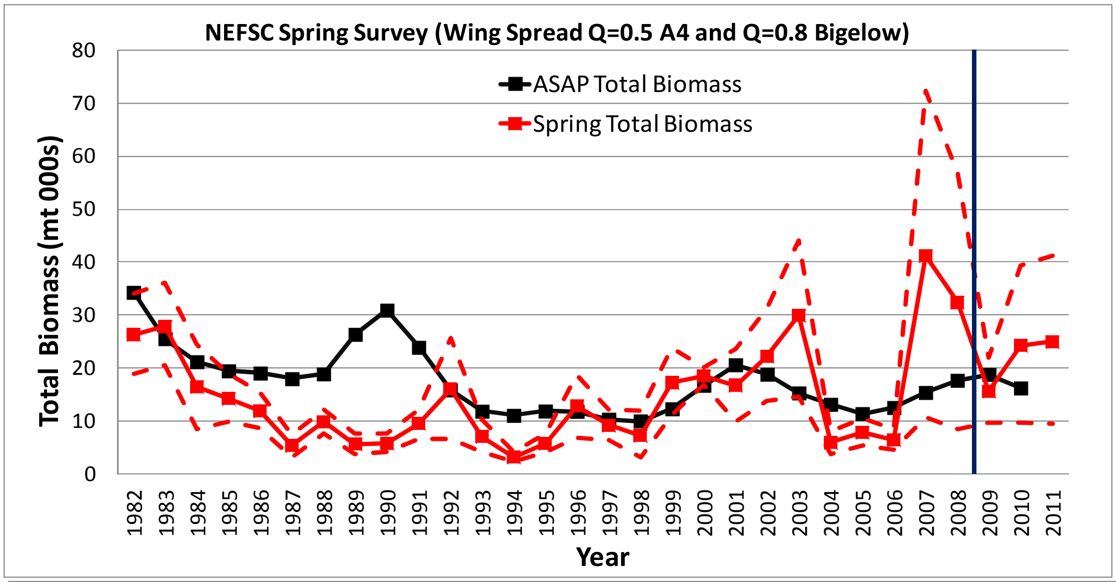


Figure A.6.8. Area swept estimates of total Gulf of Maine Atlantic cod biomass from 2009 to 2011 based on the NEFSC spring (top) and fall (bottom) Bigelow survey when the effective area is set equal to the wing spread and the survey is assumed to be 80% efficient (q=0.8). Biomass has been estimated using the full strata set (red line, with 80% bootstrap confidence intervals) and using a strata set that excludes strata 29,30 and 36 (blue line). In these analyses, the full strata set also includes inshore survey strata 57-69. Biomass estimates are compared to the annual total biomass estimated from the ASAP base model (black line) after accounting for total mortality between January 1 and the survey seasons. *NEFSC fall 2011 survey information were not available at the time of this report.*



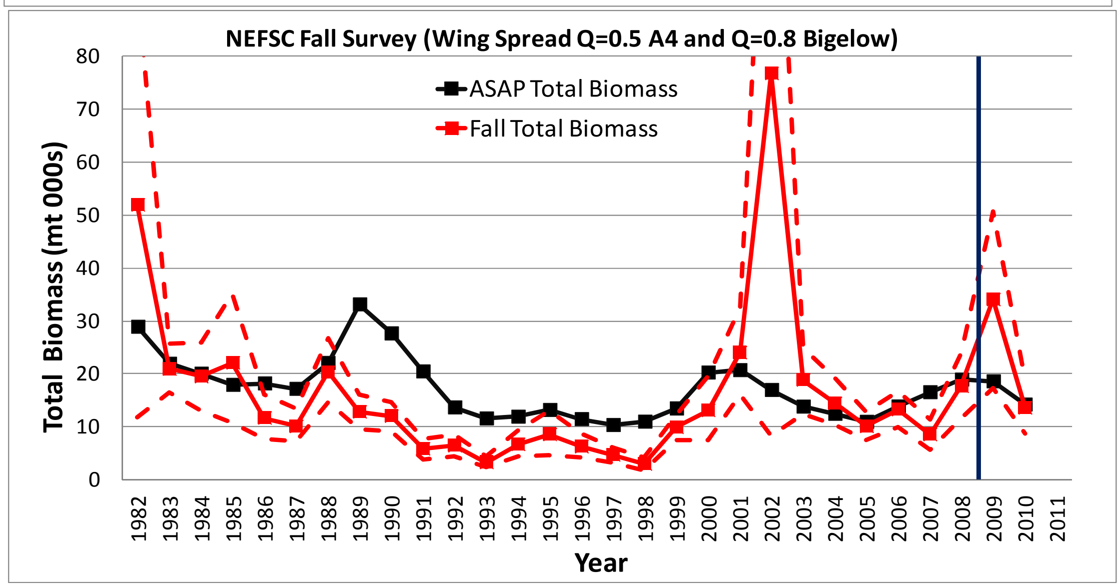


Figure A.6.9. Area swept estimates of total Gulf of Maine Atlantic cod biomass from 1982 to 2011 based on the NEFSC spring (top) and fall (bottom) survey when a the effective trawl area is set equal to the wing spread and strata set 29, 30 and 36 are excluded from the indices calculation. In these analyses, the full strata set also includes inshore survey strata 57-69. Survey efficiencies of 50% (q=0.5) and 80% (q=0.8) were assumed for the Albatross IV (1982-2008) and Bigelow (2009-2011) survey time series respectively (the vertical blue line delineates the split in survey time series). The 80% bootstrap confidence intervals of area swept estimates of biomass area shown by the dashed red lines. Biomass estimates are compared to the annual total biomass estimated from the ASAP base model (black line) after accounting for total mortality between January 1 and the survey seasons. *NEFSC fall 2011 survey information were not available at the time of this report.*

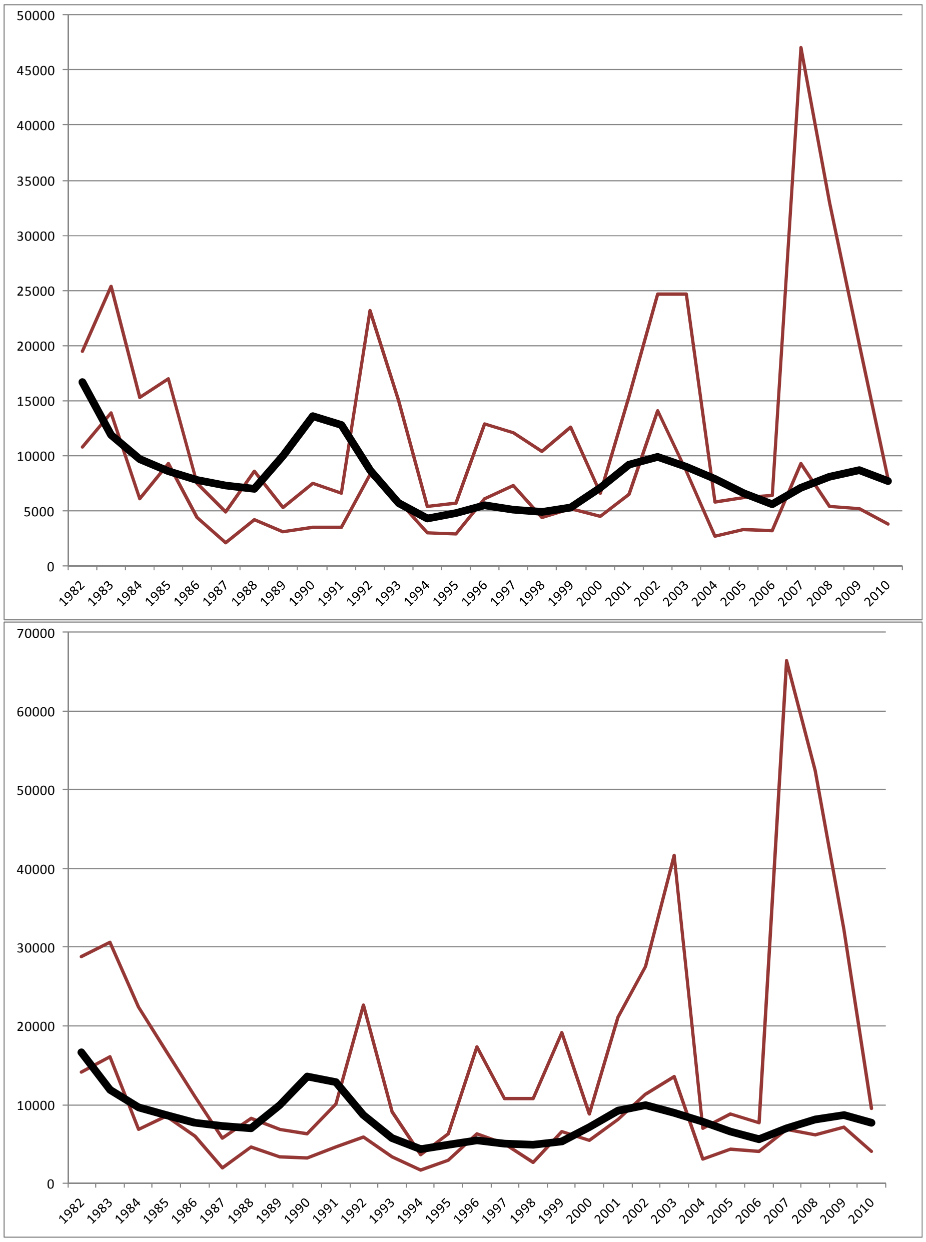


Figure A.6.10. Comparison of the SAW 53 ASAP estimated total 'survey-able' biomass (metric tons; black line) and the 80% confidence intervals (red lines) of area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC spring survey. Area swept biomass indices have been calculated using all strata (strata 26- 30 and 36- 40; top) and excluding strata 29, 30 and 36 (bottom). Survey efficiency was set at ASAP model estimates of *q*=0.92 when using all strata and *q*=0.53 when excluding strata 29, 30 and 36. ASAP 'survey-able' biomass was derived from total biomass by accounting for both total mortality since January 1 and survey selectivity at age.

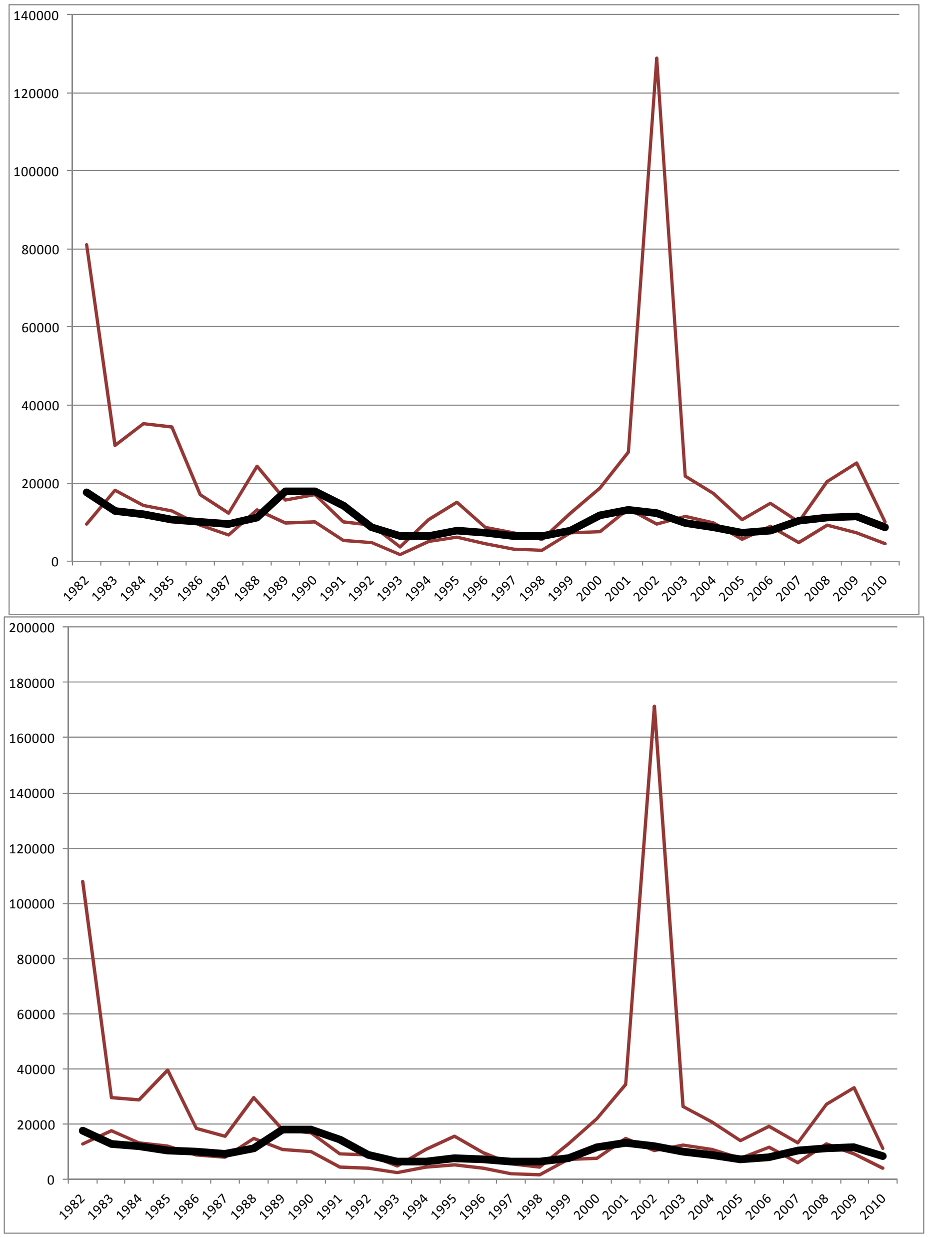


Figure A.6.11. Comparison of the SAW 53 ASAP estimated total 'survey-able' biomass (metric tons; black line) and the 80% confidence intervals (red lines) of area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC fall survey. Area swept biomass indices have been calculated using all strata (strata 26- 30 and 36- 40; top) and excluding strata 29, 30 and 36 (bottom). Survey efficiency was set at ASAP model estimates of q=0.57 when using all strata and q=0.42 when excluding strata 29, 30 and 36. ASAP 'survey-able' biomass was derived from total biomass by accounting for both total mortality since January 1 and survey selectivity at age.

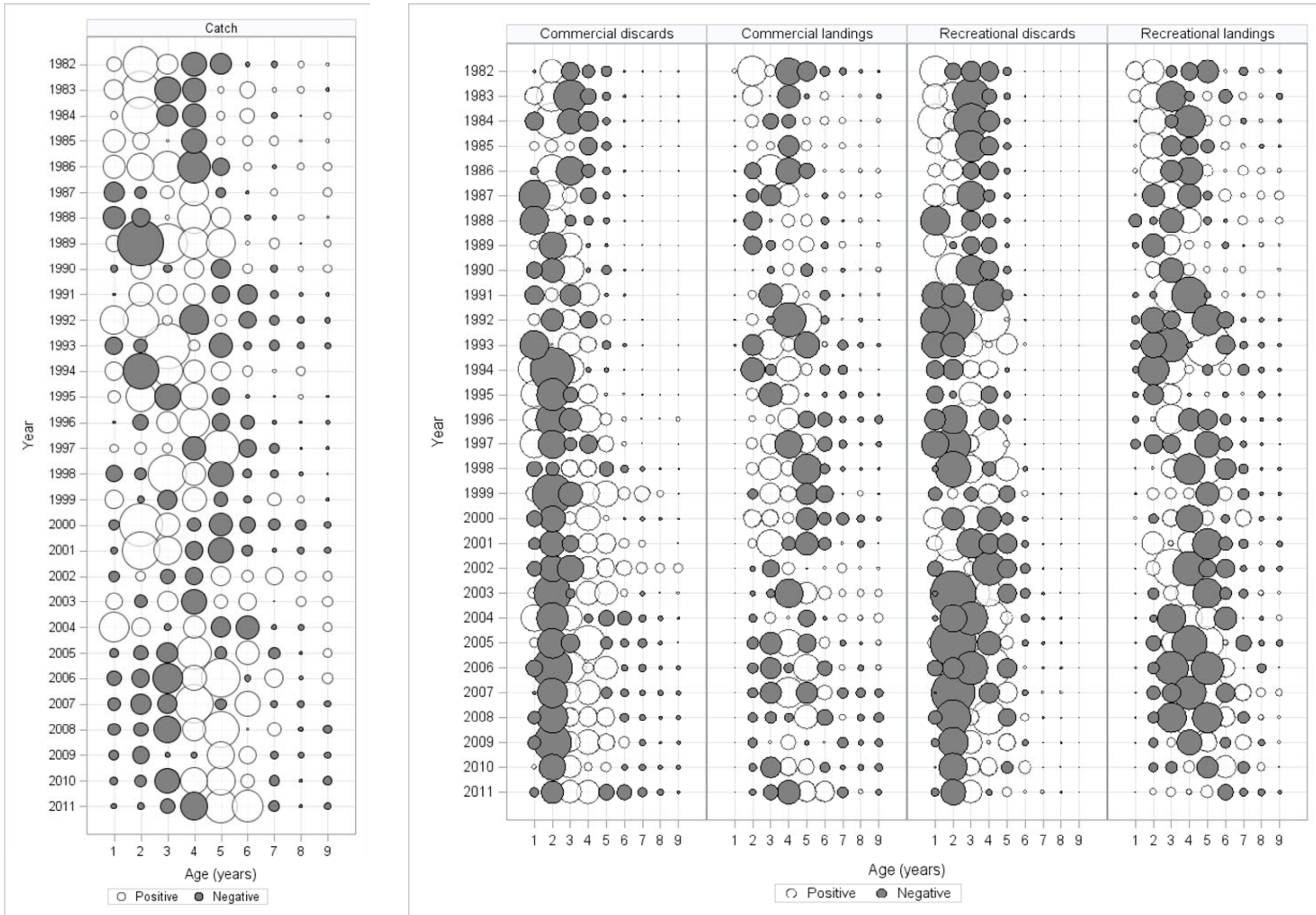


Figure A.6.12. Residual plots of the Gulf of Maine Atlantic cod catch-at-age fits compared between the SAW55_BASE model (left) and the SAW55_4FLEET (right).

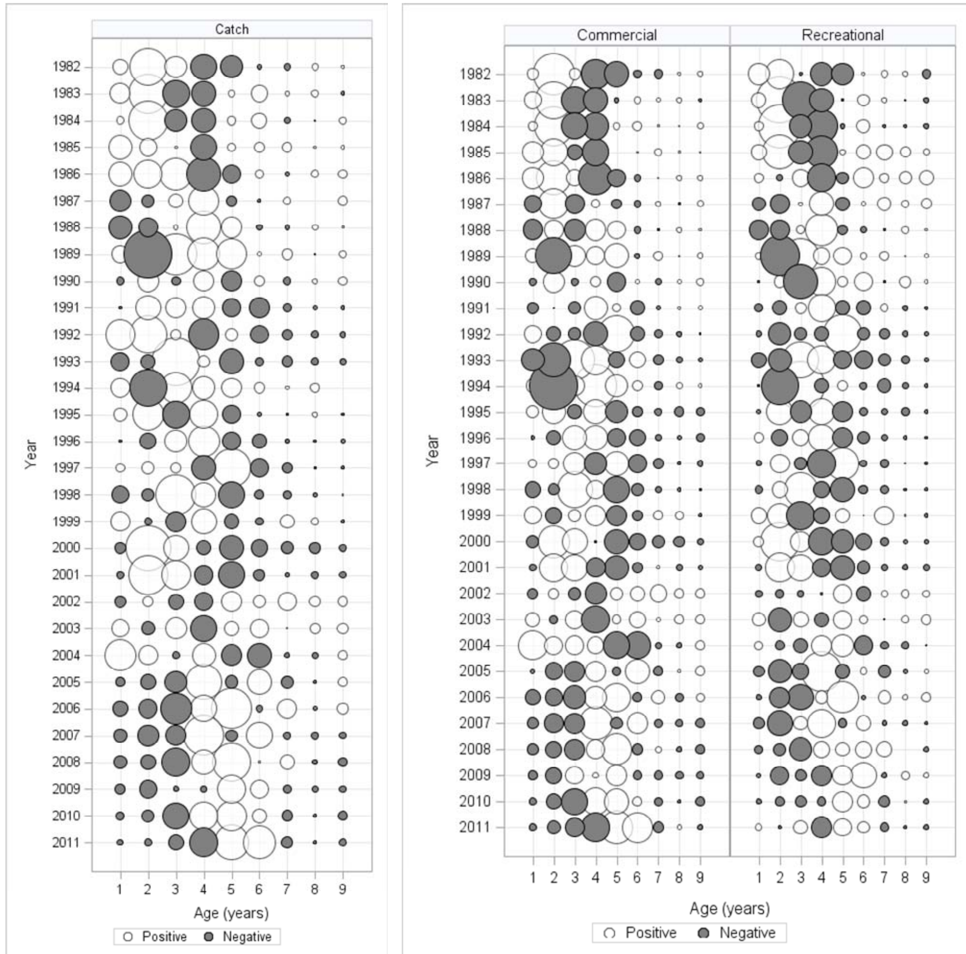


Figure A.6.13. Residual plots of the Gulf of Maine Atlantic cod catch-at-age fits compared between the SAW55_BASE model (left) and the SAW55_2FLEET (right).

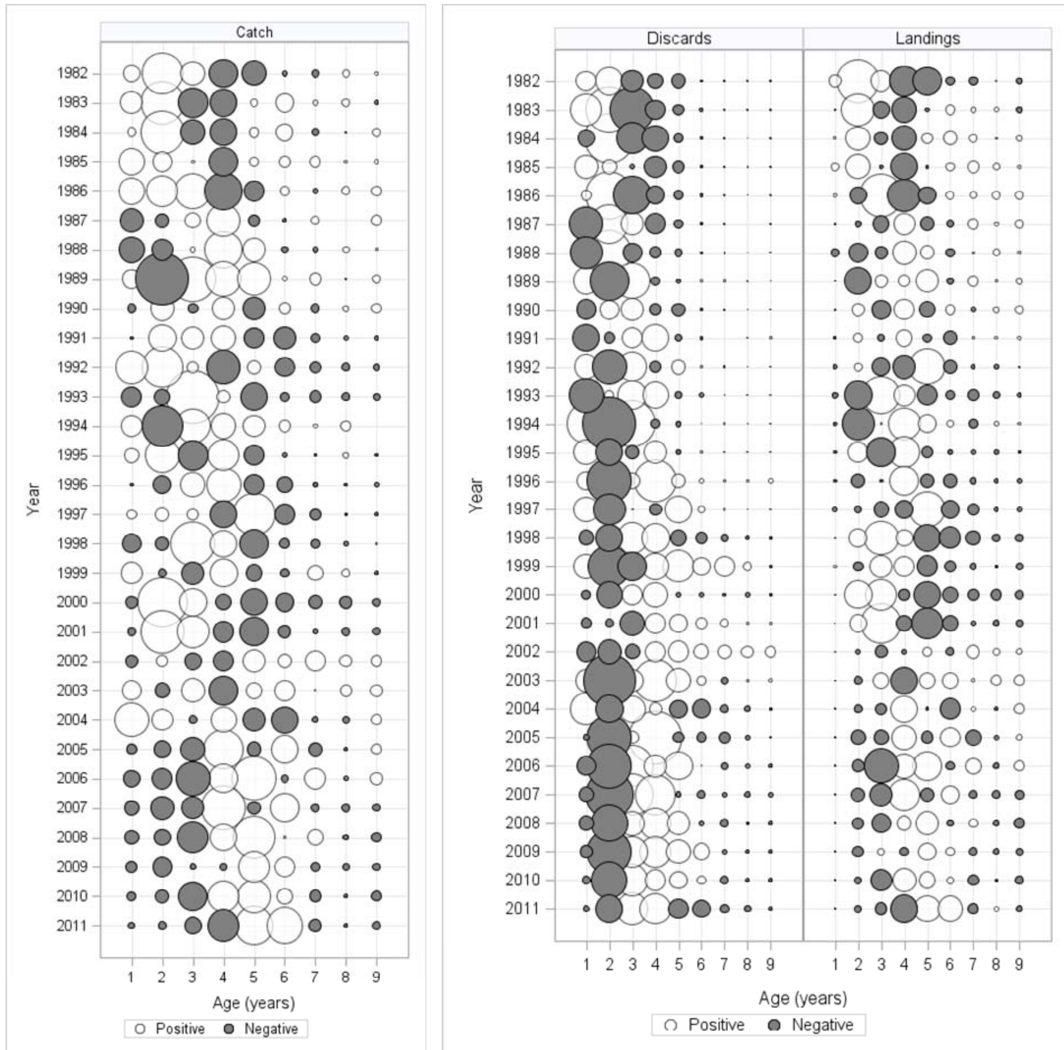


Figure A.6.14. Residual plots of the Gulf of Maine Atlantic cod catch-at-age fits compared between the SAW55_BASE model (left) and the SAW55_SPLIT_LAND_DISC (right).

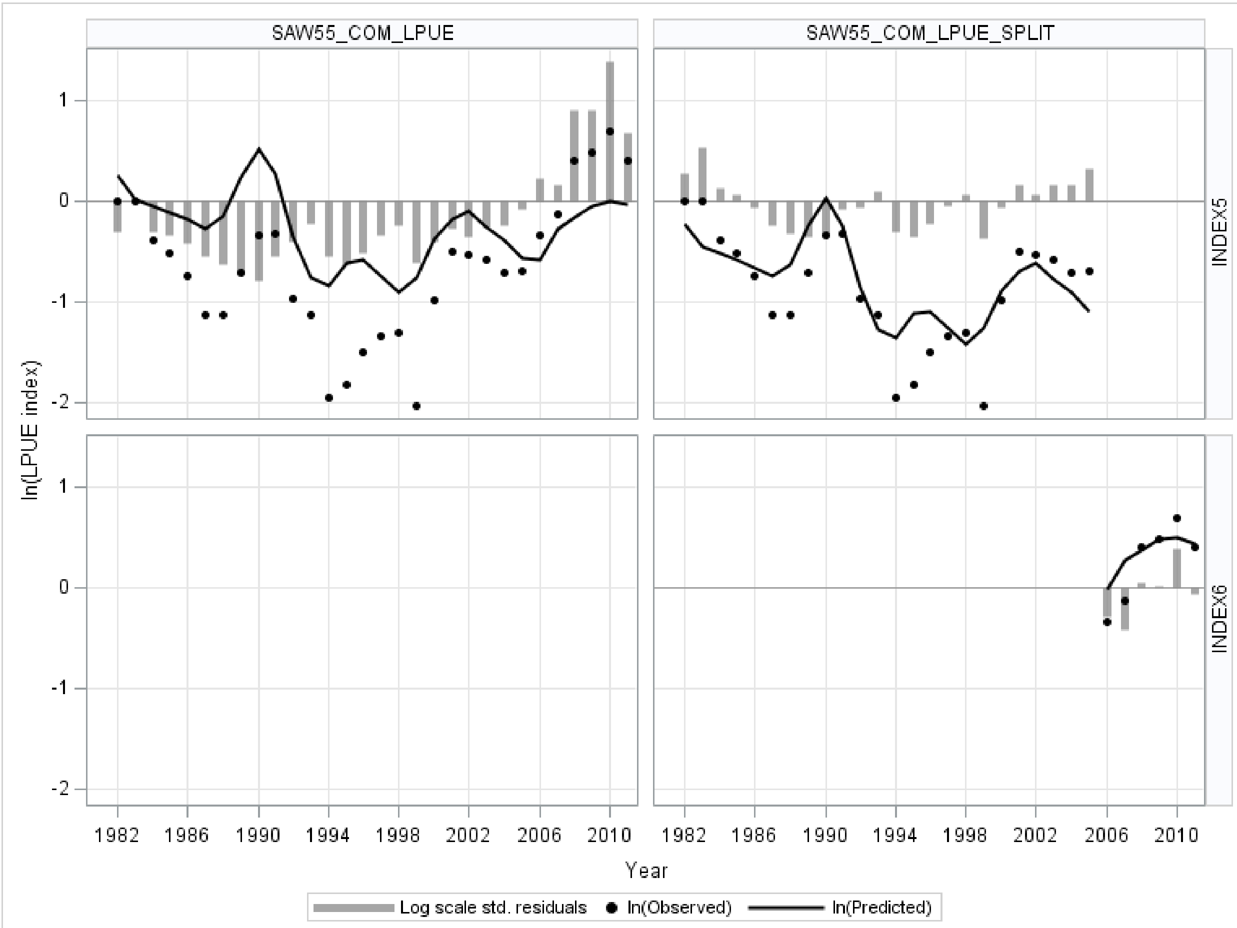


Figure A.6.15. Model fits of variants of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model to the commercial landings-per-unit-effort (LPUE) index. The SAW55_COM_LPUE uses the commercial LPUE index as a single series. The SAW55_COM_LPUE_SPLIT model splits the commercial LPUE series between 2005 and 2006.

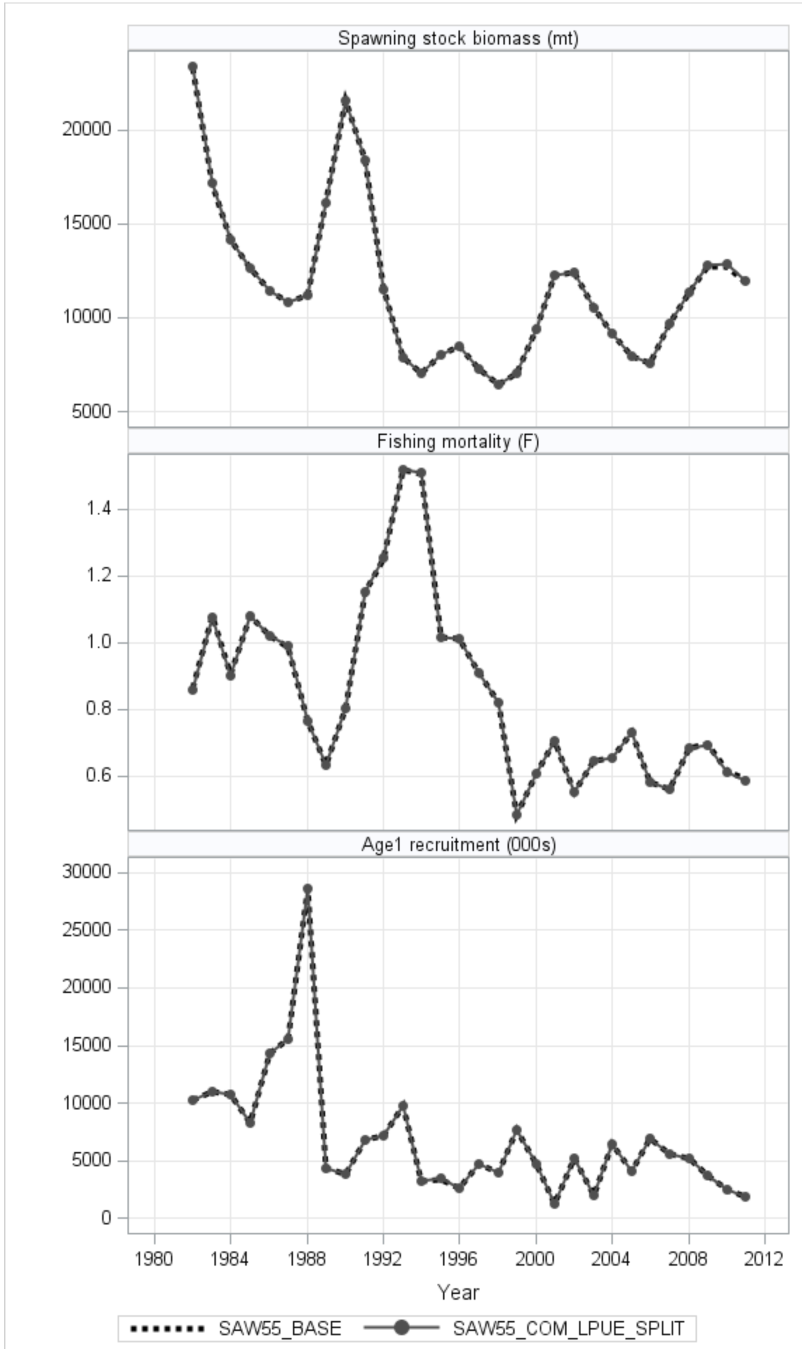


Figure A.6.16. Comparison of the Gulf of Maine Atlantic cod assessment results between the ASAP SAW55_BASE model and the SAW55_COM_LPUE_SPLIT model.

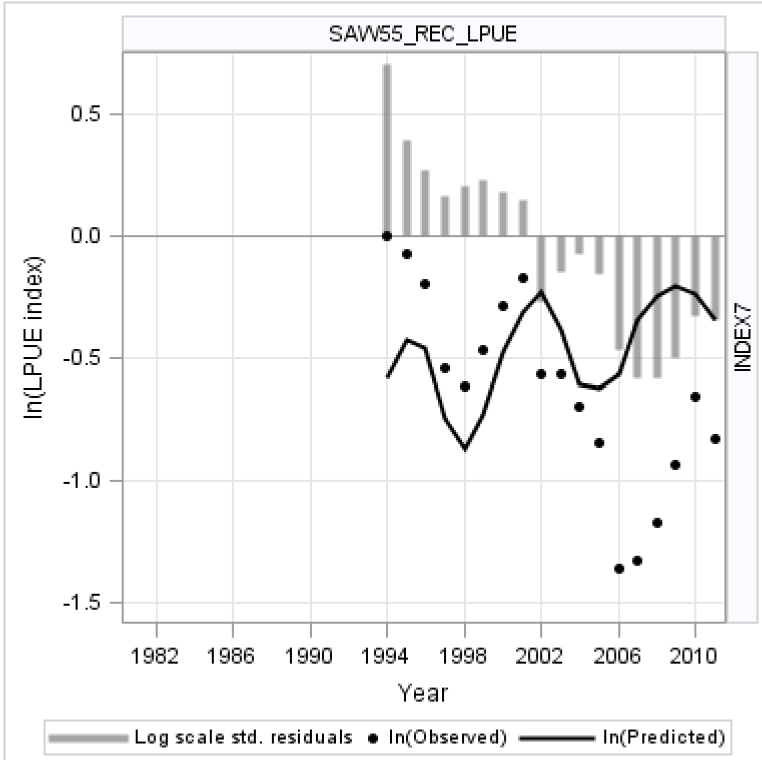


Figure A.6.17. Model fit of a variant of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model, SAW55_REC_LPUE, to the recreational landings-per-unit-effort (LPUE) index.

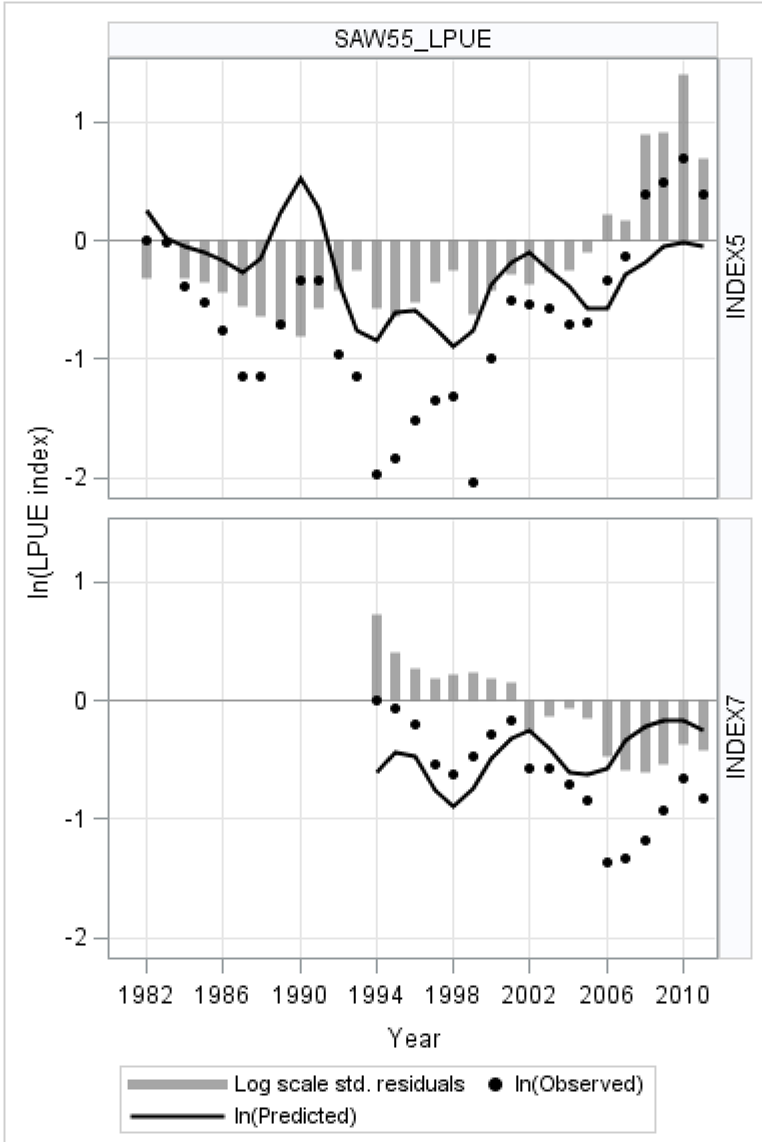


Figure A.6.18. Model fits of a variant of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model, SAW55_LPUE, to the commercial (Index 5) and recreational landings-per-unit-effort (Index7) indices.

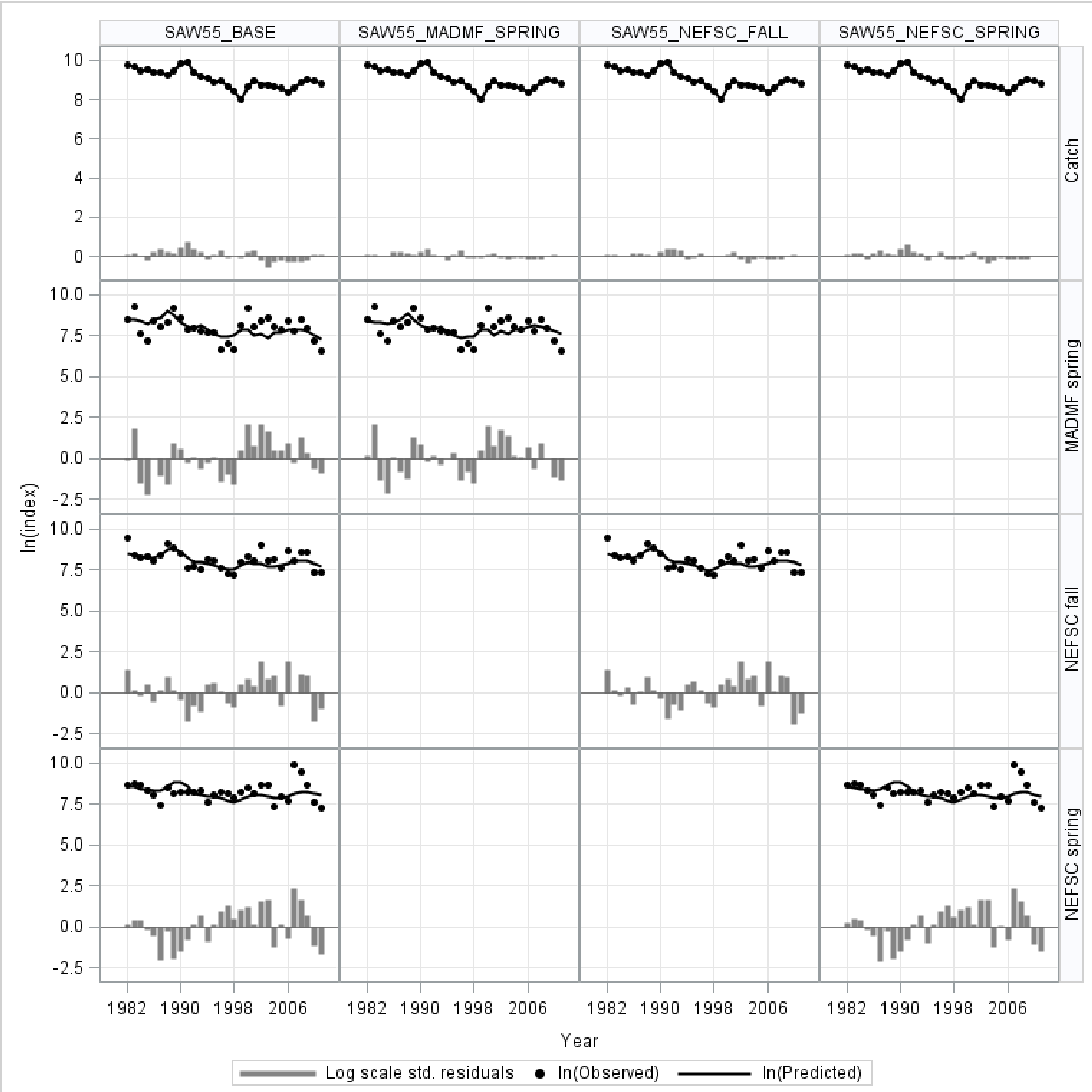


Figure A.6.19. Model fits of variants of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model to the aggregate catch, NEFSC spring, NEFSC fall and MADMF spring survey indices. Each of the alternate models only included a single survey index.

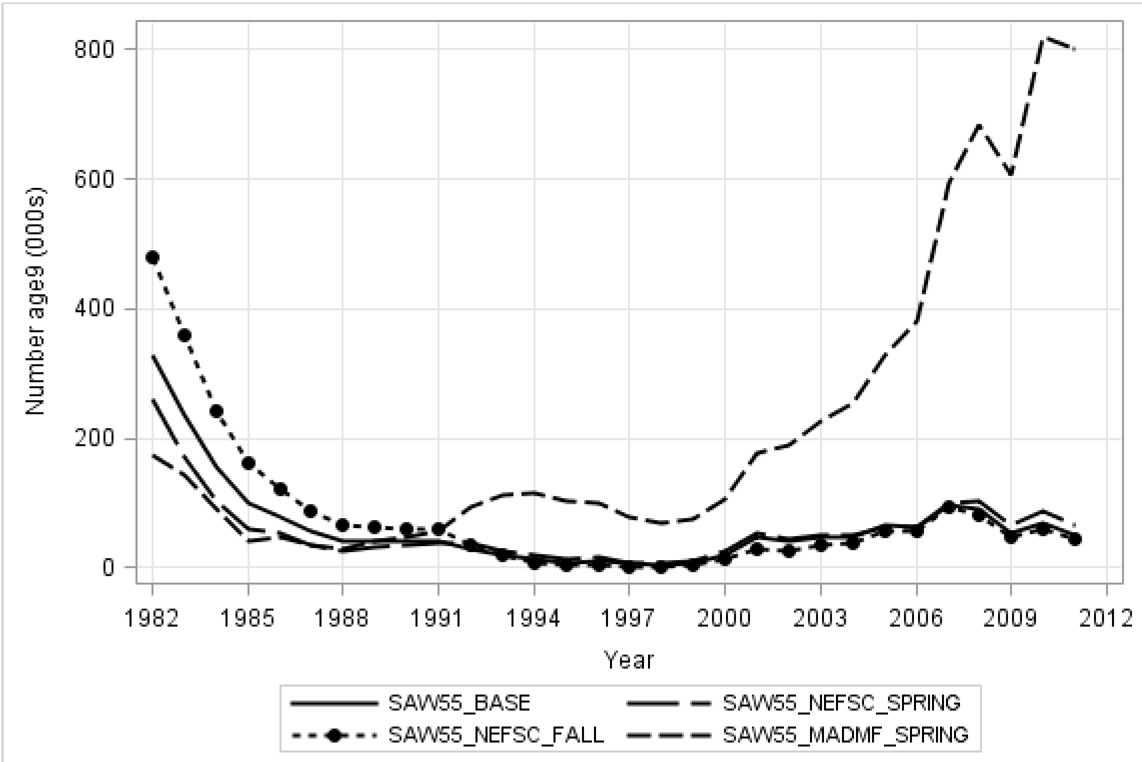


Figure A.6.20. Comparison of the Gulf of Maine Atlantic cod ASAP model estimates of numbers of age 9^{+} fish over time between models exploring the sensitivity of the SAW55_BASE model to individual survey indices.

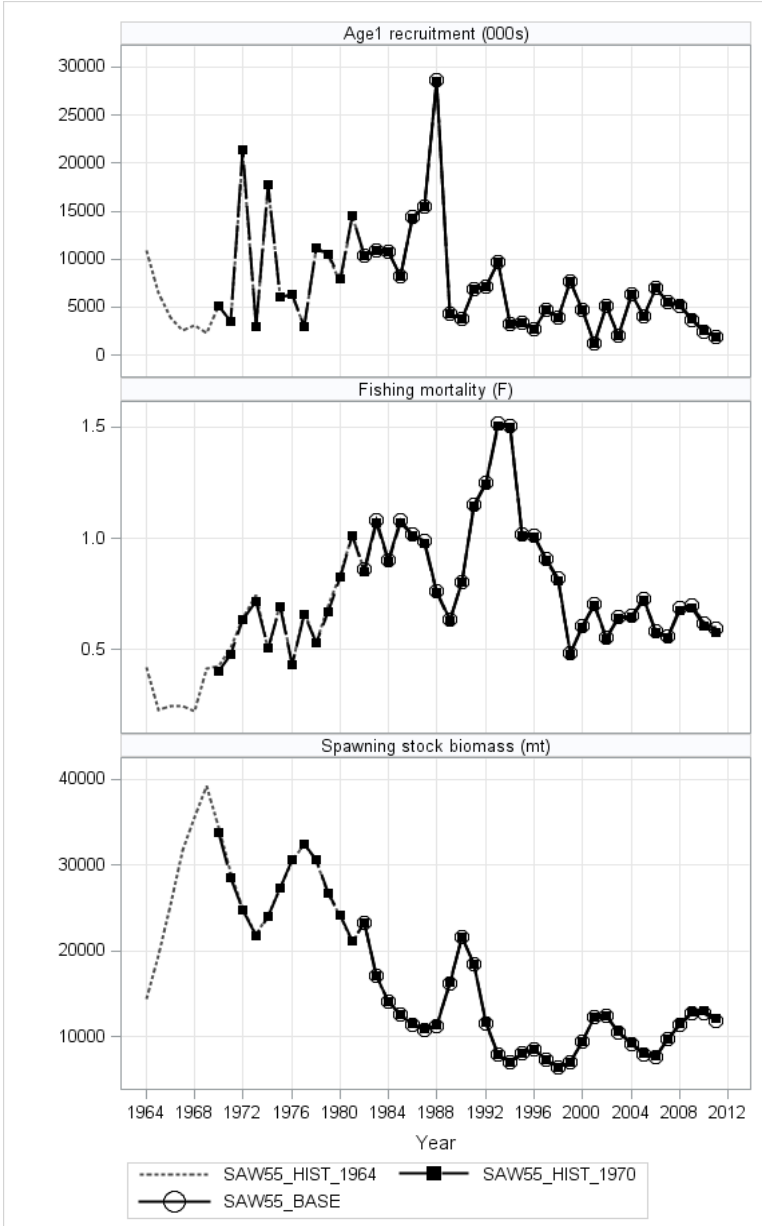


Figure A.6.21. Comparison of the Gulf of Maine Atlantic cod assessment results from models using different starting years. All models are based on the SAW55_BASE model which starts in 1982. The SAW55_HIST_1964 and SAW55_HIST_1970 models started in 1964 and 1970 respectively.

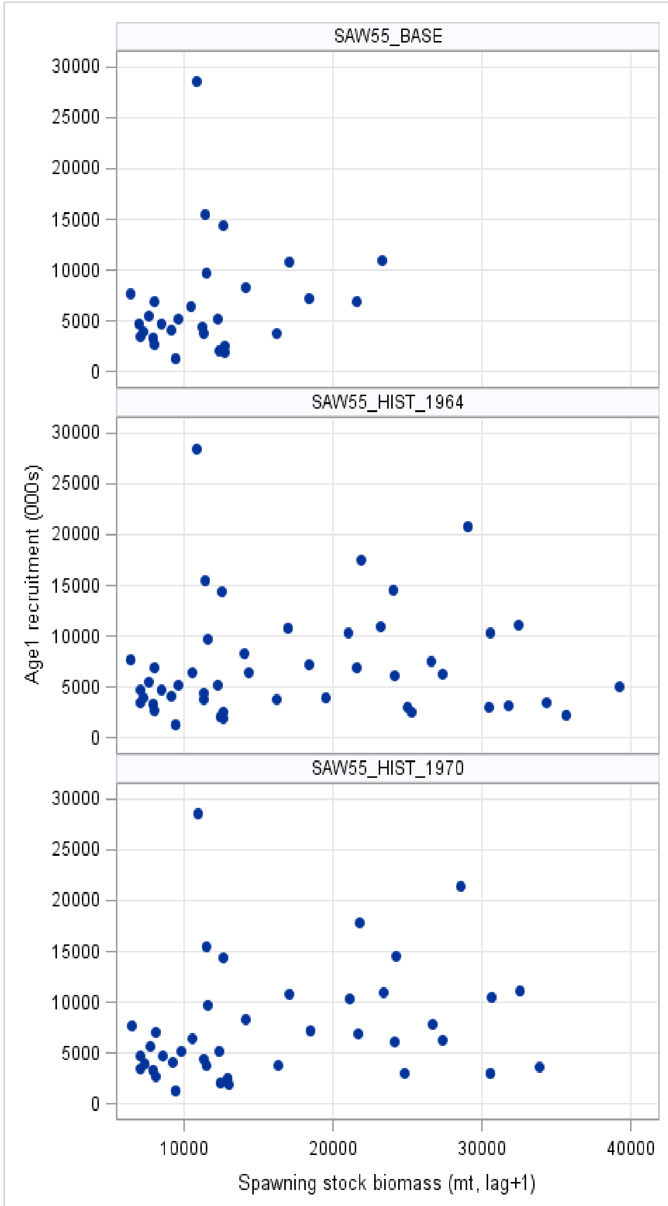


Figure A.6.22. Scatter plots of Gulf of Maine Atlantic cod age 1 recruits vs. spawning stock biomass from the SAW55_BASE, SAW55_HIST_1970, and SAW_HIST_1964 ASAP models. The starting year for each of the models was 1982, 1970 and 1964 respectively.

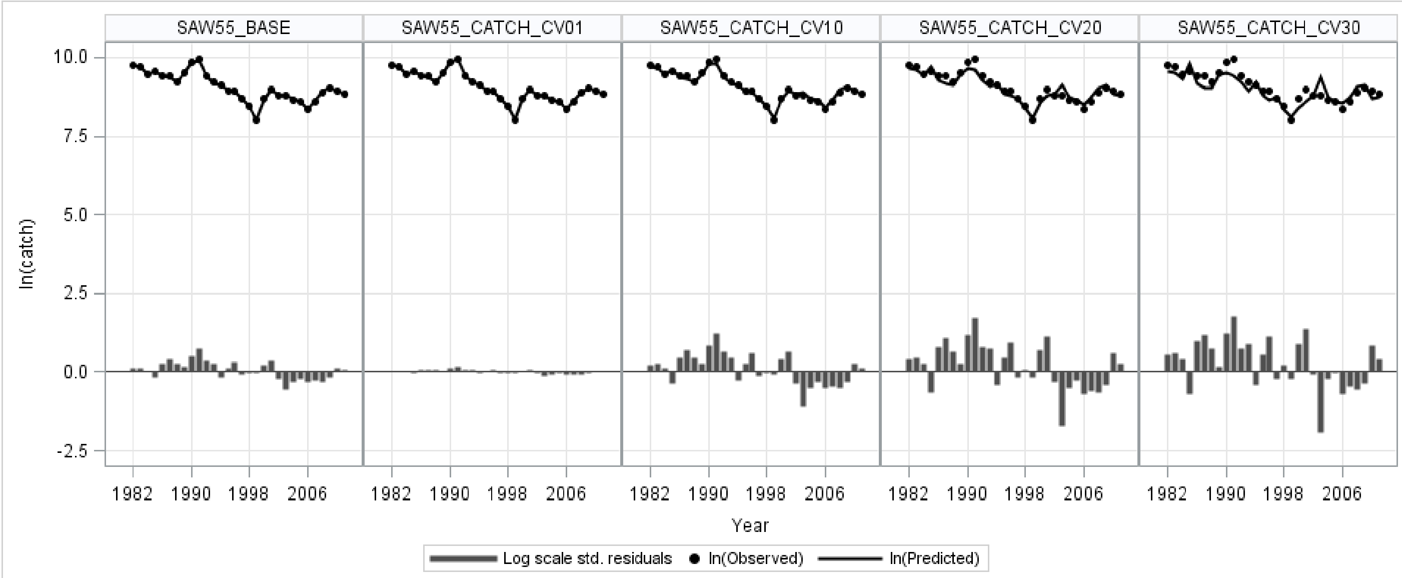


Figure A.6.23. Model fits of variants of the Gulf of Maine Atlantic cod ASAP SAW55_BASE model to the aggregate catch. The level of precision assumed for the aggregate catch was varied between models. The SAW55_BASE model assumed 0.05 coefficient of variation (CV) on the catch. The SAW55_CATCH_CV01, _CV10, _CV20, _CV30 assumed 0.01, 0.10, 0.20 and 0.30 respectively.

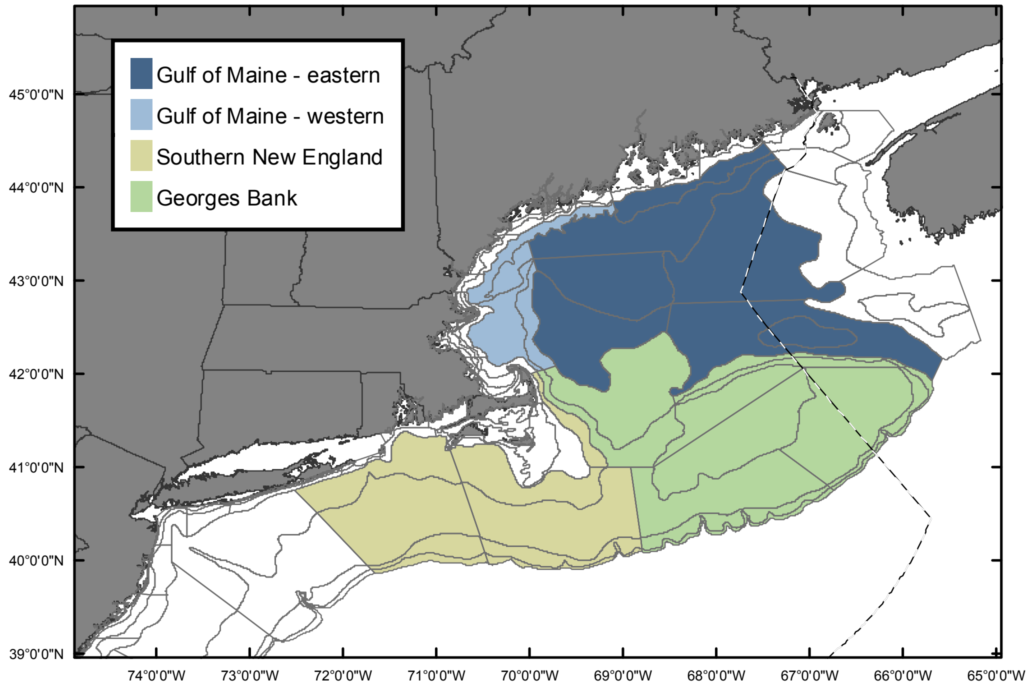


Figure A.6.24. Map of the northeast United States continental shelf showing sub-regions used to characterize NEFSC survey trends of Atlantic cod.

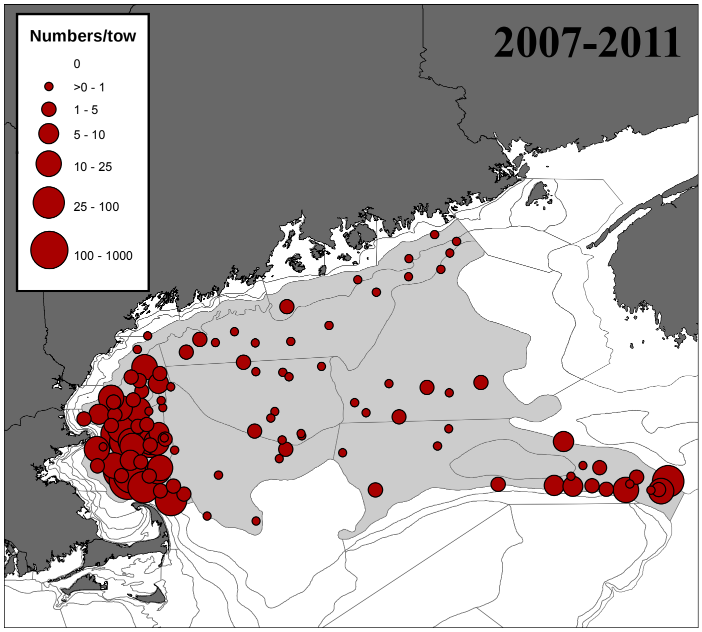


Figure A.6.25. Distribution of Gulf of Maine Atlantic cod between 2007 and 2011 from the NEFSC bottom trawl surveys (fall and spring combined).

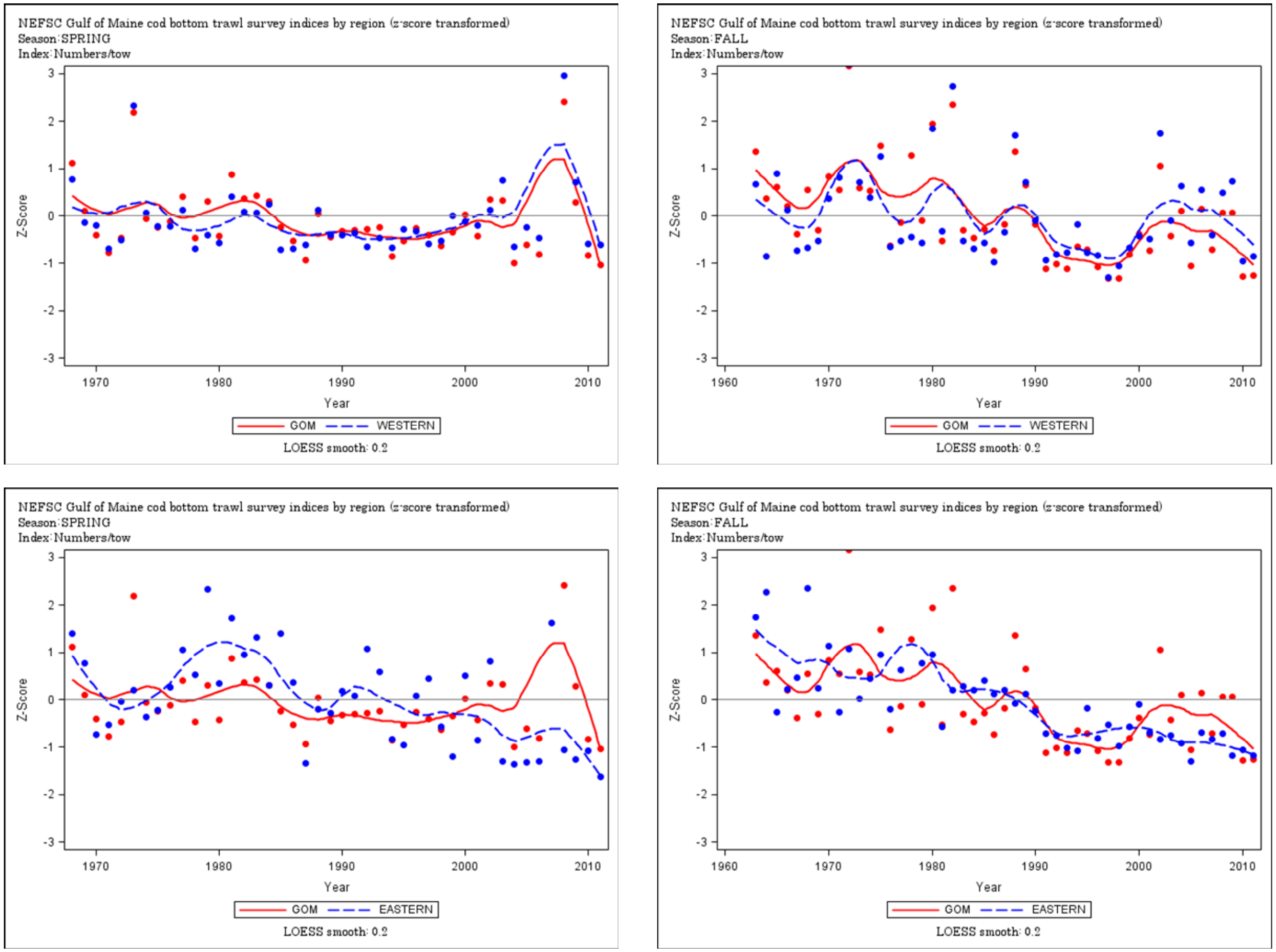


Figure A.6.26. Northeast Fisheries Science Center (NEFSC) spring (left) and fall (right) bottom trawl survey abundance (numbers/tow) indices for Gulf of Maine Atlantic cod from 1963 to 2012 expressed as z-scores ([x-μ]/σ). Plots on the top compare the indices for the entire Gulf of Maine region (red) to those from only the western Gulf of Maine (blue). Plots on the bottom compare the indices for the entire Gulf of Maine region (red) to those from only the eastern Gulf of Maine (blue).

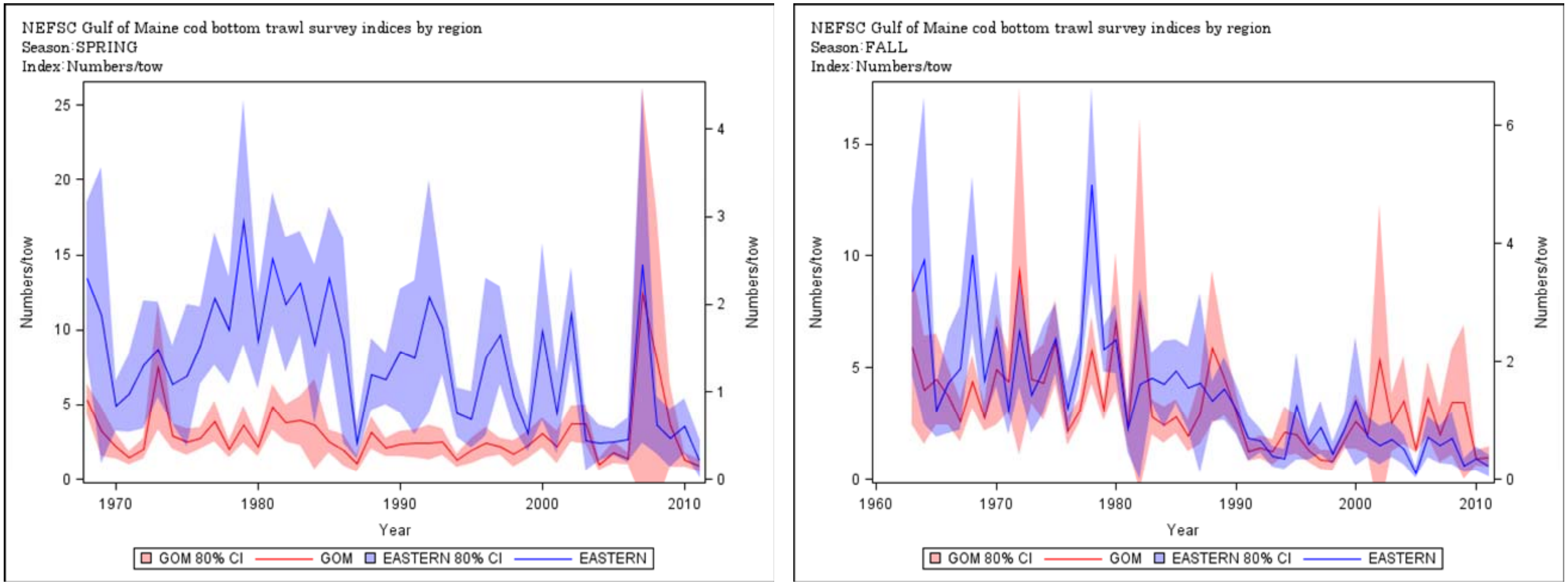
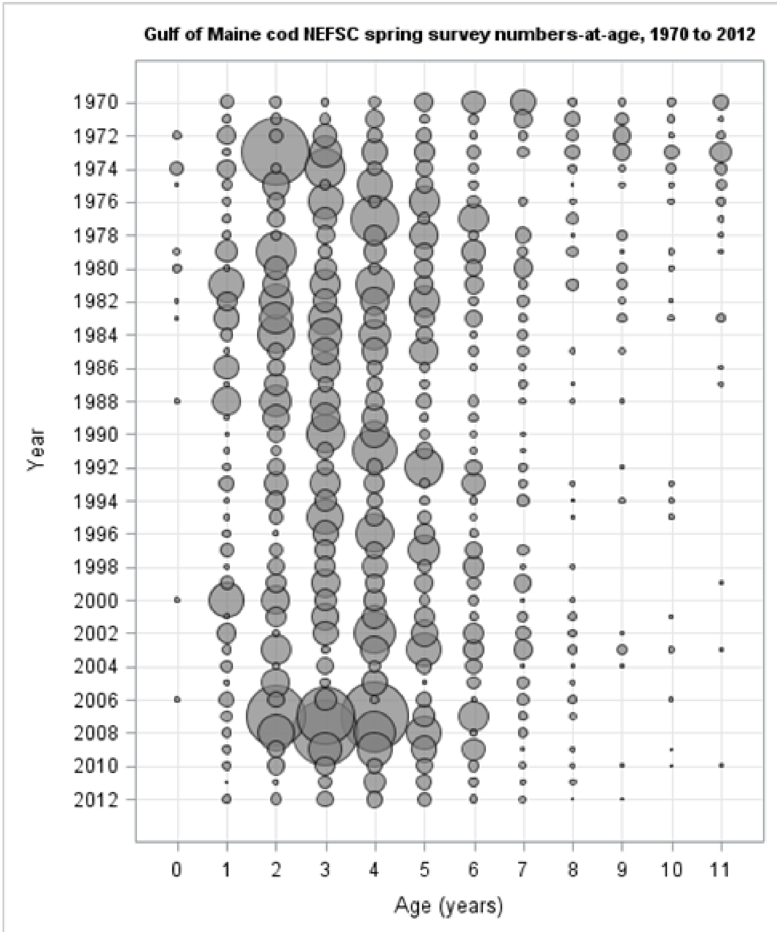


Figure A.6.27. Gulf of Maine Atlantic cod Northeast Fisheries Science Center (NEFSC) bottom trawl survey abundance indices (numbers/tow) from the spring (left) and fall (right) surveys showing the differences in scale between indices from the entire Gulf of Maine region (red) and those from only the eastern Gulf of Maine (blue).



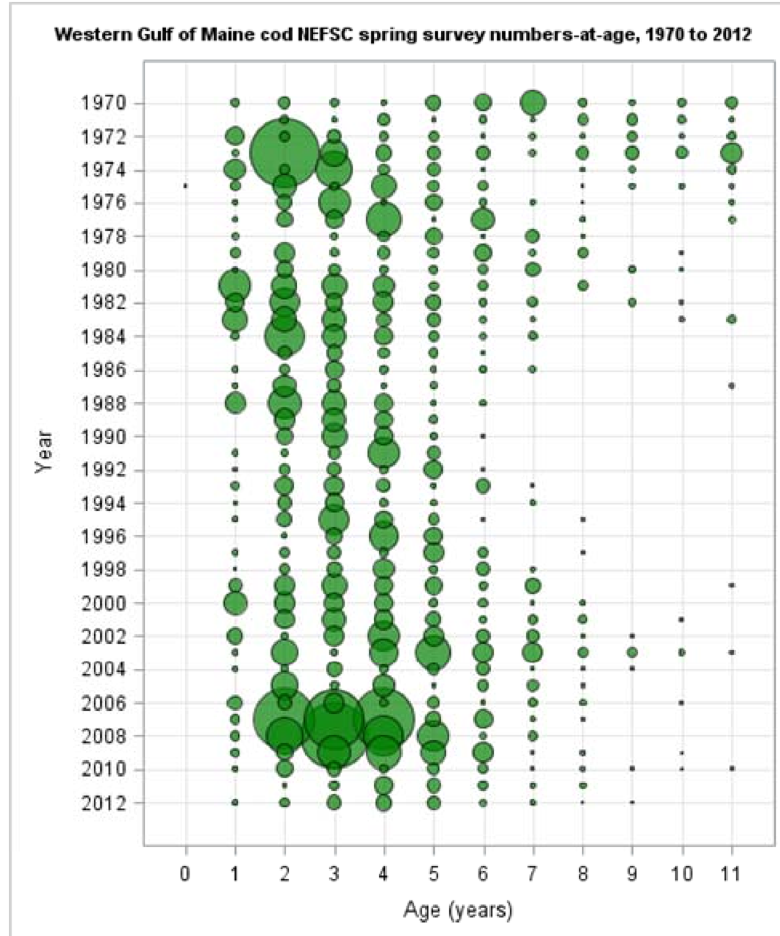


Figure A.6.28. Comparison of Notheast Fisheries Science Center (NEFSC) spring bottom trawl survey numbers at age indices for Gulf of Maine Atlantic cod calculated using all offshore strata (grey) and only those strata in the western Gulf of Maine (26, 27, 40; green).

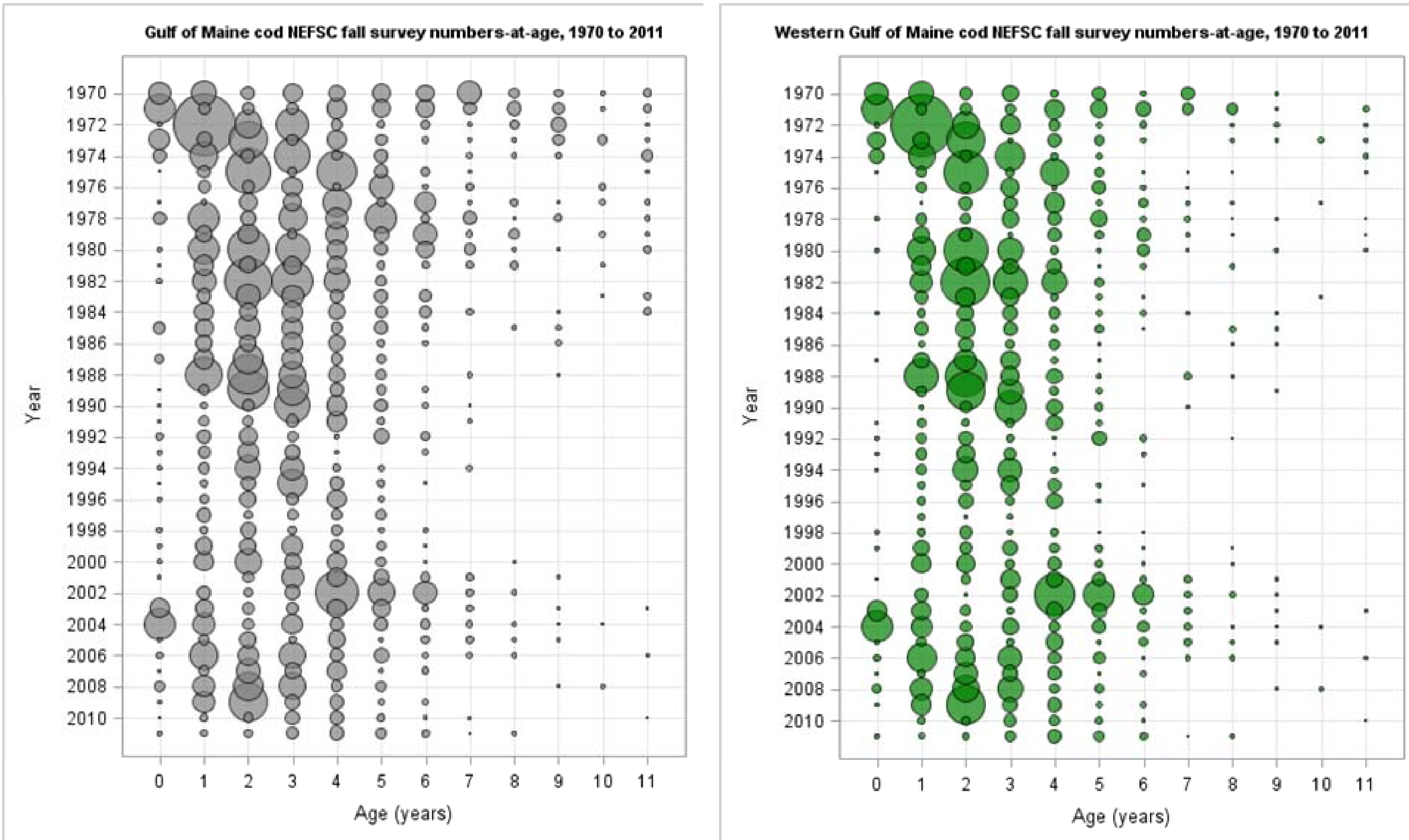


Figure A.6.29. Comparison of Notheast Fisheries Science Center (NEFSC) fall bottom trawl survey numbers at age indices for Gulf of Maine Atlantic cod calculated using all offshore strata (grey) and only those strata in the western Gulf of Maine (26, 27, 40; green).

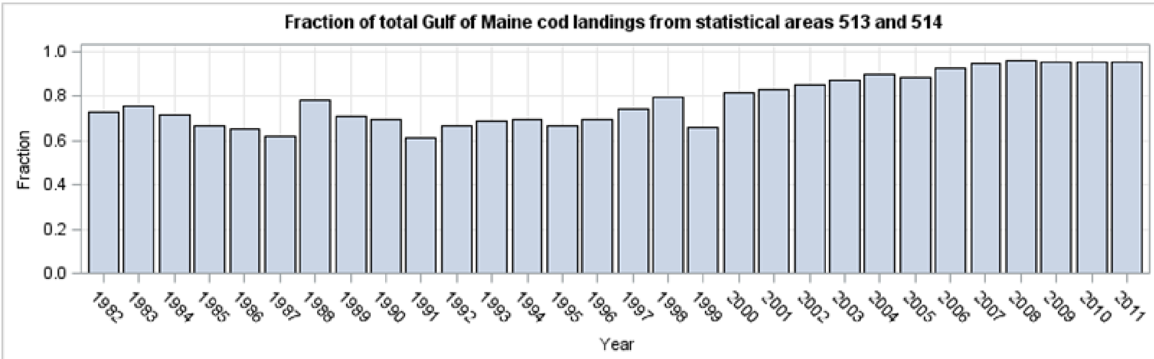


Figure A.6.30. Fraction of Gulf of Maine Atlantic cod commercial landings from statistical areas 513 and 514 between 1982 and 2011.

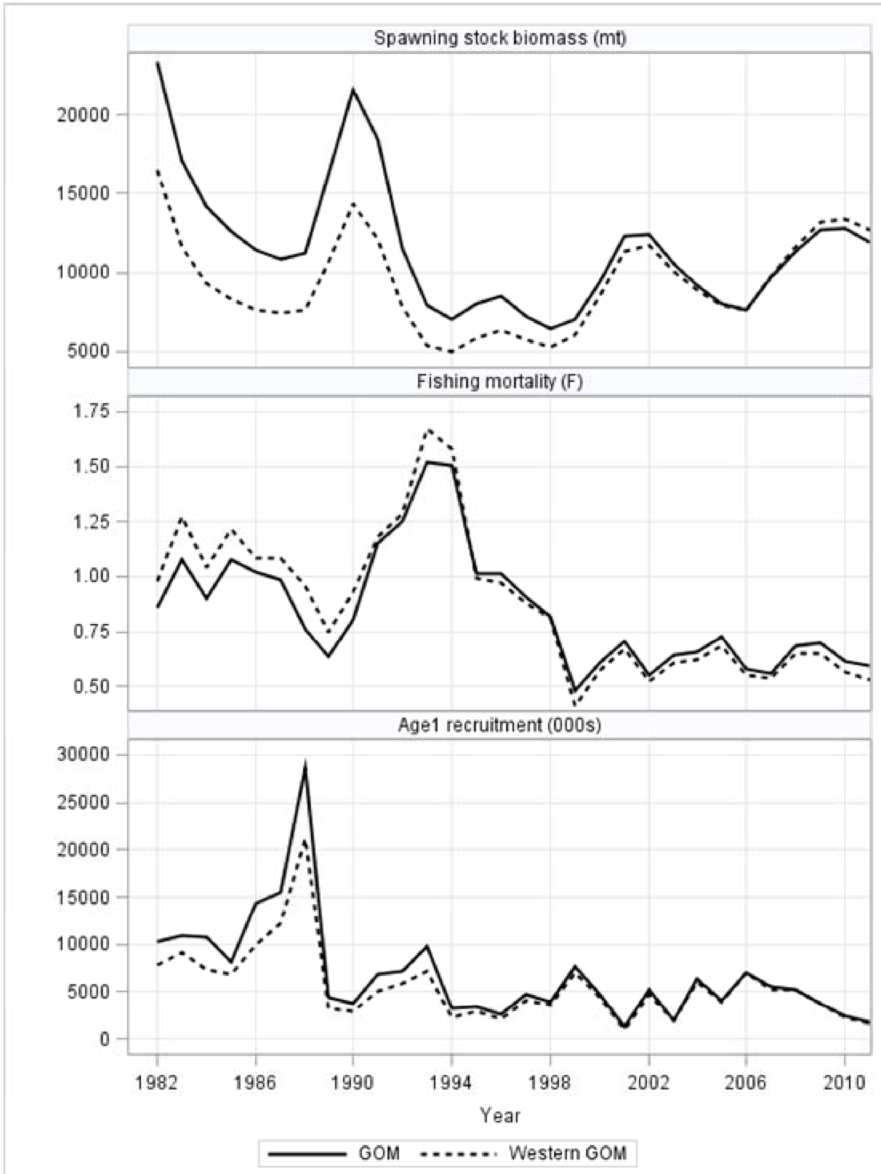


Figure A.6.31. Comparison of time series plots of spawning stock biomass, age 5 fishing mortality and age 1 recruitment from a western Gulf of Maine Atlantic cod stock assessment model to the SAW55_BASE assessment model which includes the entire western Gulf of Maine.

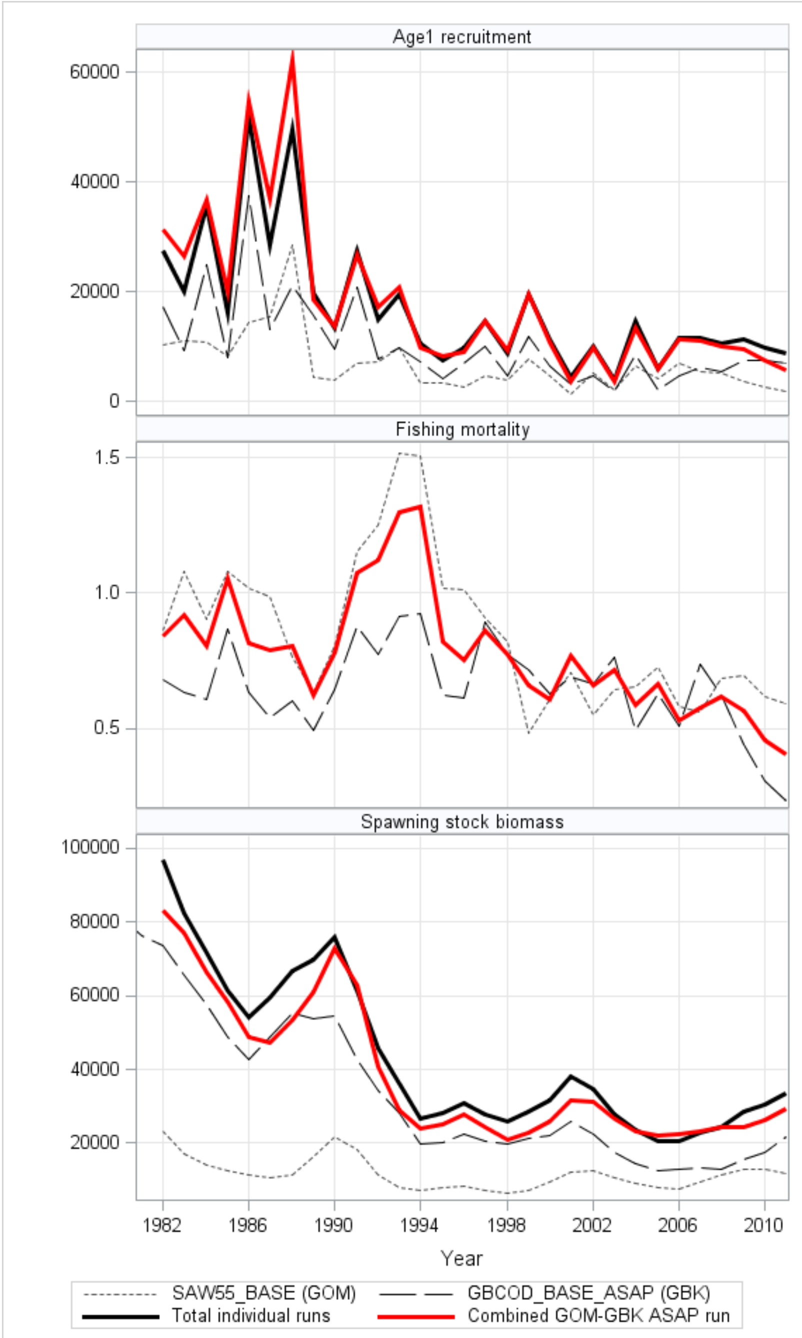


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Figure A.6.32. Time series plots of spawning stock biomass, age 5 fishing mortality and age 1 recruitment from a combined Gulf of Maine-Georges Bank Atlantic cod stock assessment model. The model results from individual stock assessment models and the cumulative results are also shown.

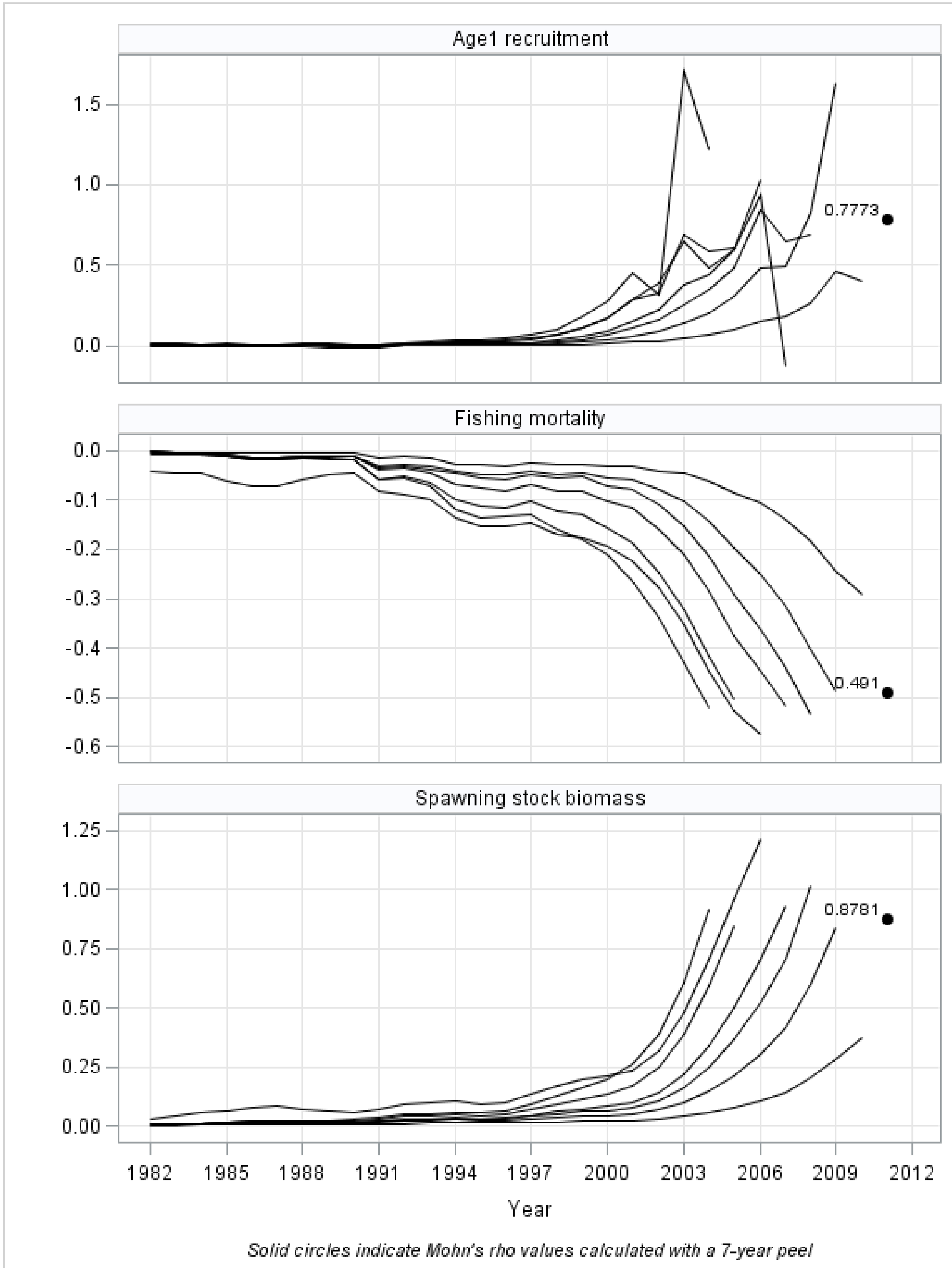

Figure A.6.33. Retrospective plots for spawning stock biomass, age 5 fishing mortality and age 1 recruitment from a combined Gulf of Maine-Georges Bank Atlantic cod stock assessment model.

[SAW55 Editor's Note: The SARC-55 review panel did not recommend adopting the GOM cod Statistical Catch-at-Age (SCAA) assessment results that are in Appendices A.2 – A.5 and referred to in Appendix A.7. Those results are included in this report to document and demonstrate the work that was done by the SAW cod Working Group]

Appendix A.7. Comparison of the four assessment models recommended by the SAW 55 Working Group and subsequent consequence analysis.

This appendix summarizes the comparison of the four assessments models and the corresponding reference points and short-term projections that were developed by the 55th Stock Assessment Workshop Working Group (SAW 55 WG) for consideration by the 55th Stock Assessment Review Committee (SARC 55) Panel. The four models for the Gulf of Maine Atlantic cod stock differed both in use of pre-1982 information and natural mortality (*M*) assumptions. Two main assessment model variants were configured as follows:

- Stock-recruit dynamics based on spawner per recruit analysis (SPR) of short-term (1982 – present) dataset with either natural mortality constant (*M* = 0.2) for the entire time series or *M* ramping up (linearly) from 0.2 during 1982 – 1988 period to 0.4 during 2003 – 2011 (*M*-ramp). These models were constructed using the statistical catch-at-age model ASAP (Age Structured Assessment Program) and are described in the main assessment report. ***It is important to note that there are differences in the estimation of the M-ramp reference points and short-term projections advanced by the SAW 55 WG compared to those ultimately accepted by the SARC 55 Panel. The details of the final M-ramp reference points and short-term projections accepted by the SARC 55 Panel are described in the main assessment report while the details of those forwarded by the SAW 55 WG are provided below.***

- Stock-recruit dynamics based on a stock recruitment model (SR) using long-term (1932 – present) dataset with either *M* constant (0.2) for the entire time series or *M* ramping up (linearly) from 0.2 during 1932 – 1988 to 0.4 during 2003 – 2011. These models were constructed using the Statistical Catch-at-Age (SCAA) formulation and are described in Appendix A.2 and A.3.

While the SAW 55 WG could not reach consensus on which model should serve as the basis of current stock status determination and management advice, it agreed that the 'newly proposed model' should be that of each lead scientist. Thus, for the ASAP formulation, the model which uses the 1982 – present dataset with *M* constant (0.2) for the entire time was preferred, while for the SCAA formulation, the model which uses the 1932 – present dataset with *M* ramping up from 0.2 to 0.4 was preferred. Notwithstanding this, the WG concurred that lack of consensus should not be interpreted as implying equal support for the models and developed pros and cons of the main features of each model to indicate their relative level of support.

M = 0.2

The features that lend support to the assumption that *M* has remained constant throughout the time series are those features which do not support the *M* ramp assumption, which is discussed below. The main feature against the assumption of constant *M* is the presence of a retrospective pattern. However, there is some evidence to suggest that this may be transitory and becoming less of an issue (SAW 55 WG, 2012c). It was for this reason that no adjustment for the retrospective pattern was made to any of the models.

M-ramp

One of the main features supporting the assumption of a recent change in natural mortality is that it employs an $M = 0.4$ which is generally consistent with the results of the 2003 – 2006 GMRI tagging data and associated analyses (if one assumes a 50% reporting rate of high reward tags). The tagging analysis indicated that *M* could be as high as 0.6. Tag reporting rates would have to be very low in order to be consistent with an *M* of 0.2.

Another line of support for this assumption is the model fits. The value of the objective function for the *M* ramp model was lower (by 8-10 log-likelihood points depending on the specific formulation) than that of the constant *M* model. Further, compared to the constant *M* model, assuming that *M* had changed more recently reduces the retrospective pattern.

The final observation supporting a recently elevated *M* in Gulf of Maine cod is evidence of increasing *M* in the adjacent NAFO Div. 4X cod stock based on both tagging analyses and assessment model fits.

A number of features don't lend support to a recently increasing *M*. There is no evidence for increased predation, either by fish or pinnipeds, in the diet compositional data collected by the NEFSC. Regarding the GMRI tagging analyses, if reporting rates of high reward tags were less than 50%, natural mortality would be less than 0.4. It is unfortunate that there are little or no historical tagging studies to which the results of the GMRI study could be compared. Besides using different assumptions, these earlier studies did not formally incorporate parameters to estimate movement. For these reasons, the tagging studies which suggested higher *M* (> 0.2) in 4X may not apply to Gulf of Maine Cod (SAW 55 WG 2012a).

Regarding model fits, the likelihood profile of *M* for the 2003 – 2011 period was relatively flat, with estimates between 0.1 and 0.6 potentially possible. Exploratory runs indicated that *M* profiling was sensitive to which years to include in the recent period of high *M*. A change of two years would result in a more informative profile (favoring higher *M*).

The final lines of evidence against a recently elevated *M* relate to the life history information. Compared to adjacent stocks, there have been little or no long-term changes in maturity at age, fish condition and growth. Meta-analyses of life history parameters suggest an *M* of 0.2 with no trend over time.

Long-term (1932 – present): recruitment productivity based on SR model

One of the features in support of using the longer term time series is the NEFSC survey dataset which contains information on Gulf of Maine cod year-class strengths during the 1960s (size frequency information during 1963 – 69 and indices of abundance at age during 1970 – 81). Sensitivity analyses (e.g. on catch CVs) did not indicate qualitative differences in the estimated reference points and alternative assumptions about fishery selectivities during the pre-1982 period also made minimal differences in the estimated reference points. Overall, the estimation process has explicitly taken into account the agreed levels of uncertainty in the catch and sampling during the historical period.

Use of the longer-term time series allows analytical estimation of MSY based reference points, due to the presence of more contrast in population dynamics, which thus avoids resorting to the use of proxies. Model fits indicate that there is a preference for Ricker stock-recruit over BH relationships, with even stronger domes in the former suggested, though as highlighted below, the model preference for a Ricker SR was small. Ricker-based estimates of B_{MSY} are reasonably precise (CVs of approx. 15%) although the 2011 spawning stock biomass is more precisely estimated when a BH relationship is assumed. Use of a Ricker relationship is consistent with evidence for cannibalism observed in other Cod stocks (Puvanendran et al., 2008) although there has been no evidence of post-larval cannibalism in either Gulf of Maine or Georges Bank Cod.

A number of features don't lend support to use of the long-term dataset. Models run with either the Ricker or BH relationship starting in 1970 provide relatively the same estimates of spawning biomass and recruitment, indicating that it is primarily the information in the 1960s which is providing the basis for differing stock-recruit relationships. This is a time period during which there is no age compositional data and fisheries statistics are most uncertain. Issues with the historical data quality are discussed in SAW 55 WG (2012a). Further, the survey aggregate numbers indices for the 1960s contains data on age 0 cod which cannot be removed from the analysis, although when aggregate biomass indices are used (in which age 0 cod would play a less prominent role), the assessment results are qualitatively similar.

Regarding model fits, there is little difference in the value of the objective function when using either a Ricker or BH relationship in a model starting in 1932 (about 3 points for $M = 0.2$ or 8 points for the M-ramp). For both M scenarios, the difference in log likelihoods between Ricker and BH was due to stock - recruit residuals during 1963 – 1969, the period with no age composition data. A pattern of positive residuals exists for both relationships during 1977 – 87, a period with high catches.

Simulation studies have indicated a propensity to fit domed stock -recruit relationships (i.e. Ricker), even when a BH is true (De Valpine and Hastings, 2002). However, the results of these studies depend heavily on the scenario being simulated (e.g. length of time series) and may not apply to the current situation. F_{MSY} (0.53) estimated using a Ricker model is generally larger than F_{MAX}, although this is to be expected when the stock-recruitment relationships are domed. On the other hand, spawning biomass did decline after the 1970s when the resource experienced fishing mortalities consistent with the Ricker-based F_{MSY}.

There is an overall concern that if there have been long-term stock productivity changes, analytically-derived estimates of B_{MSY} and F_{MSY} based on 1932 – present stock dynamics, which can be considered a weighted average over the entire time series, may not reflect current conditions.

Short-term (1982 – present): recruitment productivity based on SPR

The main feature supporting use of the shorter-term time series is that this is the period which has the highest data density. Data are available on the quantity and size composition of the landings and discards, both commercial and recreational. A number of survey indices are available, each with aggregate indices of abundance and biomass, along with data on age/size composition. Biological information such as growth, maturity and length / weight relationships are also available.

Regarding model fits, the estimates of biomass and fishing mortality, as well as the reference points are robust to a wide range of model assumptions and uncertainties.

The main issue against using the short-term time series is that it does not provide sufficient contrast to estimate stock-recruit relationships, and thus requires the use of B_{MSY} and F_{MSY} proxies which in turn has associated uncertainties (i.e. selection of percentage spawner per recruit).

Differences in the estimation of the M-ramp reference points and short-term projections advanced by the SAW 55 WG compared to those accepted by the SARC 55 Panel

There was consensus among the SAW 55 WG that a proxy reference point approach was the preferred approach for the ASAP 1982 models. A yield per recruit (YPR) analysis was performed using a 3-year average of weights-at-age which was consistent with the approach used in SAW/SARC 53 and supported by recent observed trends. The remaining YPR inputs were time invariant (maturity-at-age) or were constant in the most recent time block of the assessment model (selectivity, natural mortality). For the *M*-ramp model the SAW 55 WG assumed that *M* would remain at 0.4 and carried forward this assumption when setting reference points. **Contrary to the decisions made by the SAW 55 WG, the SARC 55 Panel concluded that "*…for long-term projections that [the] Review Panel decided that M should be 0.2, because the longer-term historical evidence seems to indicate that M = 0.2 is more plausible*" (SARC 55 2012). This had implications for the determination of appropriate F_{MSY} proxy as well as the estimation of SSB_{MSY} and MSY.** Unlike the *M*-ramp F_{MSY} proxy accepted by the SARC 55 Panel which were based on an $F_{40\%}$ SPR assuming $M = 0.2$, the SAW 55 WG *M*-Ramp F_{MSY} proxy was based on $F_{50\%}$ assuming $M = 0.4$. The basis for the existing (SAW 53; NEFSC 2012a) overfishing reference points was derived at GARM III (NEFSC 2008), and is based on $F_{40\%}$; however this decision was based on an assumed natural mortality of $M = 0.2$. Additional analyses by the SAW 55 WG evaluated various proxies for F_{MSY} by comparing estimated SSB and recruitment ratios (SSB/R) with expected spawning biomass per recruit (SPR) over a range of fishing mortalities (F=20% to F80% in 5% increments) to investigate the potential for replacement under equilibrium assumptions (i.e. constant harvest rate and biology over the lifespan). An analysis of replacement lines under recent productivity (approximately last 10 years) indicated that for the *M* = 0.2 option, $F_{40\%}$ (0.18) was still appropriate. When the *M* was increased to 0.4 (*M*-ramp), the replacement lines became steeper with $F_{40\%}$ rising to 0.44 (Fig. A.7.1). It was noted that the F_{MSY} proxy for Georges Bank cod for the *M*-ramp model was set by the SAW 55 WG at $F_{50\%}$ based upon F_{med} considerations. Recognizing that it is a judgment call, the WG decided that the F_{MSY} proxy for the GOM cod M-ramp model should be based on $F_{50\%}$ (0.29), consistent with the $F_{MSYproxy}$ used for Georges Bank cod. It should be noted that subsequent to the SAW/SARC 55 work was presented at SAW 56 WG that invalidates the replacement line approach for determining an appropriate spawning potential ratio (Legault and Brooks 2013).

To arrive at estimates for SSB_{MSY} and a corresponding MSY, long term projections were run sampling from the empirical distribution of recruitment estimates from the preferred ASAP model (recruitment estimates from 1982-2009, final two years excluded). Based on suggestions made by the SARC 53 Panel, the modeling approach was modified to better account for uncertainty in projections at low stock sizes. The revised projection model samples from a cumulative density function derived from estimated age-1 recruitment. However, the revised model adjusts projected recruitment when SSB falls below some specified spawning biomass threshold based on a linear function that declines to zero at zero spawning stock biomass. Consistent with the SAW 53 assessment, the 'hinge' was set at the lowest observed SSB in the time series. For the *M* = 0.2 scenario, this was 6,300 mt and 7,900 mt for the *M*-ramp scenario. To approximate the distribution of the SSB and MSY distributions, the long term projections were made from 1000 estimates of numbers at age in 2011, which were estimated by performing MCMC simulation of the ASAP base model (described above under TOR 5). **Note that the 2011 age 1 estimates were based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009.* All projections were conducted with the AGEPRO software (Age Structured Projection Model v4.1). The ASAP, 1982 start year reference points forwarded to the SARC 53 Panel for review are summarized in Table A.7.1.

Similar to the assumptions made for estimating reference points, the SAW 55 WG conducted short-term projections for each of the ASAP, 1982 start year scenarios assuming natural mortality to remain equal to the M in the terminal year of the assessment model. Short-term projections (3 years; 2013-2015) were conducted using 3-year averages of weights-at-age which was consistent with the approach used in SAW 53 and supported by recent observed trends. The remaining YPR inputs were time invariant (maturity-at-age) or were constant in the most recent time block of the assessment model (selectivity, natural mortality). The short term projections were conducted based on the current assessment results without accounting for retrospective bias. Numbers-at-age in 2012 were derived from 1000 different vectors of numbers-at-age produced from the MCMC chain with 2011 age 1 estimates based on sampling from the empirical distribution of recruitment estimates from only the ten year period 2000-2009. Short term projections have used an assumed catch in 2012 of 3,767 mt. This estimate is based on the current commercial and recreational catches as well as the expected catch over the remainder of the year which has been extrapolated using the harvest trajectories from the past two years (NEFMC PDT, T. Nies pers. comm.).

Recruitment was sampled from a cumulative density function (CDF) of estimated age 1 recruitment from 1982 to 2010. The same AGEPRO model used for reference point determination was used to conduct short-term projections (i.e., model adjusts projected recruitment based on a linear function that declines to zero at zero SSB when SSB falls below some 'hinge' SSB-level corresponding to the lowest SSB observed in the time series). For the M=0.2 scenario, the 'hinge' SSB value was set at 6,300 mt and 7,900 mt for the M-ramp scenario. All projections were run under the assumption of 75% F_{MSY} (M = 0.2 scenario = 0.14, M-ramp scenario = 0.22). **It is important to note that the 75% F_{MSY} assumption for the SAW 55 WG *M*-ramp projections differs from the 75% F_{MSY} proxy accepted by the SARC 55 Panel (75% of 0.18 = 0.14).**

Projection results for both the M = 0.2 and M-ramp models are summarized in terms of median SSB and fishery catch (yield) in Table A.7.2. Under 75% F_{MSY} exploitation, the stock is projected to rebuild under the M = 0.2 and M-ramp scenarios by 2022 and 2019 respectively.

Consequence Analysis

Biological reference points associated with each of the four models are presented in Table A.7.3. The risks associated with management actions taken during 2013 – 2015 were examined by undertaking short-term stock projections under the competing assumptions for the state of nature. For instance, if the true state of nature is that natural mortality has remained unchanged at 0.2 and that stock productivity is best reflected by the 1982 – present dataset (SPR, M = 0.2 model), then the consequences of management actions by setting projected catch according to 75% F_{MSY} based on the three alternative states of nature were examined (short-term (SPR) with M-ramp, long-term (SR) with M = 0.2 and long-term (SR) with M-ramp). In all cases, the 2012 catch was provided by the NEFMC Groundfish Plan Development Team. Projections were only conducted until 2015. There may be longer term consequences which might be revealed through a more extensive analysis. This is beyond the current terms of reference.

In these explorations, the assessments using the long-term dataset assumed a Ricker stock-recruitment relationship. Use of a BH relationship produced results for future catches under 50% F_{MSY} within the range of the other alternate states of nature, indicating that the analyses presented below bracket the risks to the stock of assuming one state of nature while another might be true. It should be pointed out that while these runs are not presented in detail here, the results of these BH runs are also plausible.

The column headers in Table A.7.4 and Figure A.7.2 represent the 'true' states of nature considered, these being:

- ASAP, 1982 start, $M = 0.2$: stock dynamics and assessment based on 1982 – present dataset with $M = 0.2$ for the time series
- ASAP, 1982, M-ramp: stock dynamics and assessment based on 1982 – present dataset with M ramped from 0.2 to 0.4 during 1989 – 2002
- SCAA, 1932 start, Ricker, $M = 0.2$: stock dynamics and assessment based on 1932 – present dataset with $M = 0.2$ for the time series

- SCAA, 1932, Ricker, *M*-ramp: stock dynamics and assessment based on 1932 – present dataset with *M* ramped from 0.2 to 0.4 during 1989 – 2002

The row headers in Table A.7.4 indicate the basis of the management action during the projection period (2013 – 2015). Thus, the row header 'SCAA, 1932, Ricker, *M*-ramp' indicates that catch was projected assuming that the stock conditions and reference points were as per these dynamics. All projections were conducted at 75% F_{MSY}, based on the assumed state of nature and thus which establishes the catch in each cell. This is the 'planned' catch. The cells of the table indicate the SSB and fully recruited fishing mortality (F_{full}) which are a consequence of applying the catch based on the assumed state of nature to the SSB of the 'true' state of nature. The diagonal rows represent the situation in which the management actions based upon the assumed state of nature are in fact correct. In these stochastic projections (see TOR 8a), there were cases in which the projection attempted to harvest more fish than exist in the population's exploitable biomass. The fraction of feasible projections for the eight combinations of states of nature and basis of management action are provided in Table A.7.5.

The consequence analysis is summarized in Figure A.7.2. As with Table A.7.3, the column headers indicate one of the 'true' states of nature. The row headers indicate whether or not catch, SSB or F_{full} is being displayed along the row. The content of each cell summarizes the consequences (reflected by the medians of the distributions in question) of assuming one state of nature when another is true. The black line in each cell indicates the catch, SSB and F_{full} for the 'true' state of nature. The coloured lines (for the projected period only) indicate the catch, SSB and F_{full} which result when the 75% F_{MSY} estimated catch is incorrectly based upon an alternate state of nature. The dashed lines in each figure are the B_{MSY}, F_{MSY} and MSY for the 'true' states of nature.

When management actions are correctly based upon a particular state of nature (the diagonals of Table A.97), a modest increase in SSB is projected until 2015 for the two ASAP and one of the SCAA (M = 0.2) options. Only in the case of the SCAA, 1932, Ricker, *M*-ramp option is SSB projected to decline, though this is a consequence, at least in part, of the harvest strategy being applied where the resource is estimated to be above SSB_{MSY}. The 2011 SSB estimates range 9,903 - 10,221 t and 13,735 - 14,509 t for the two ASAP and SCAA options respectively. Fully recruited fishing mortality declines for the two ASAP options (from 0.86 – 0.9 to 0.14 – 0.22), increases slightly (from 0.52 to 0.56) for the SCAA, 1932, Ricker, M = 0.2 option, and increases (from 0.61 to 0.71) for the SCAA, 1932, Ricker, *M*-ramp option. Catch for the two ASAP options declines from 6830 t in 2011 to 1,929 – 2,030 t in 2015. For the SCAA, 1932, Ricker, M = 0.2 option, catch increases from 6830 t in 2011 to 8,424 t in 2015 while it declines to 5,020 t over the same period for the SCAA, 1932, Ricker, *M*-ramp option. If the management actions are correctly based upon the 'true' state of nature, the two ASAP models indicate that, in 2013, the stock is in an overfished state (Table A.7.6). In contrast, the two SCAA models indicate that the stock would not be in an overfished state in 2013. In all cases, overfishing is not occurring in 2013.

It is useful to consider the consequences of mis-specifying natural mortality separately from stock – recruit dynamics (based on either the ASAP or SCAA models). For the two ASAP models which base stock-recruit dynamics on spawner per recruit considerations, mis-specifying the natural mortality is inconsequential, with catch, SSB and F_{full} being very similar. Consequently, the 2013 stock status would remain as overfished but that overfishing is not occurring. The natural mortality assumption is slightly more of an issue when stock dynamics are based on the long-term derived stock-recruitment relationship (SCAA models). Assuming an *M*-ramp when *M* is actually equal to 0.2 results in a lower than 'planned' fishing mortality and catch and higher than 'planned' SSB. Status in 2013 would still be not overfished and overfishing not occurring. When *M* is assumed to be 0.2 but an *M*-ramp is correct, fishing mortality and thus catch would be considerably higher than 'planned' with the result that in 2013 the stock would be experiencing overfishing although it would not be overfished (Table A.7.6).

The consequences of mis-specifying the stock-recruit dynamics are overall more severe than mis-specifying natural mortality. If management actions during 2012 – 2015 are based on stock-recruit dynamics assuming SPR dynamics (the ASAP models) when those based on SR dynamics should have been used (the SCAA models), fishing mortality and thus catch would be lower than 'planned' while SSB would be higher than 'planned'. There would, nevertheless, be no change in the 2013 status.

If management actions during 2012 – 2015 were based on stock-recruit dynamics assuming an SR function (the SCAA models), when those based on SPR should have been used (the ASAP models), fishing mortality and thus catch would be much higher than 'planned' while SSB would decline more than 'planned', particularly if *M* had also been assumed to be 0.2. This would result in the stock being determined as overfished as well as overfishing occurring in 2013 regardless of the natural mortality.

To summarize, mis-specification of stock-recruit dynamics has greater implications for management actions during 2012 – 2015 than mis-specification of natural mortality. Mis-specification of natural mortality is inconsequential if stock-recruit dynamics conform to SPR considerations but are more of an issue when recruitment is based on an SR function (in this case a Ricker relationship).

Appendix A.7 Tables

Table A.7.1. Yield per recruit proxy reference points for Gulf of Maine Atlantic cod under both the ASAP SAW55_3BLOCK_BASE and ASAP_3BLOCK_BASE_M_SPLIT models.

Model	F_{MSY} (proxy)	Fmsy	SSB_{MSY} (mt)	MSY (mt)	Median age1 recruitment	SSB hinge (mt)	Hinge year
SAW55_3BLOCK_BASE	F40%	0.18	54,743 (40,207 - 73,354)	9,399 (6,806 - 13,153)	5,254	6,300	1998
SAW55_3BLOCK_BASE_M_SPLIT	F50%	0.29	19,605 (14,746 - 25,782)	4,840 (3,586 - 6,435)	9,446	7,900	1994

Table A.7.2. Short-term projections (3 years) for Gulf of Maine Atlantic cod under an assumed harvest of 75% F_{MSY} based on the ASAP SAW55_3BLOCK_BASE and SAW55_3BLOCK_BASE_M_SPLIT (*M*-ramp) models. **Note, the projections have not been adjusted for retrospective bias.*

Year	Input	SAW55_3BLOCK_BASE Rebuild year at 75% Fmsy = 2022			SAW55_3BLOCK_BASE_M_SPLIT Rebuild year at 75% Fmsy = 2019		
		Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
2000	Result	5,823	9,070	0.62	5,823	12,976	0.45
2001	Result	8,055	11,885	0.72	8,055	17,222	0.51
2002	Result	6,509	11,951	0.57	6,509	17,208	0.40
2003	Result	6,497	10,005	0.67	6,497	13,966	0.48
2004	Result	5,766	8,594	0.68	5,766	11,878	0.50
2005	Result	5,441	7,213	0.92	5,441	9,831	0.70
2006	Result	4,268	6,752	0.78	4,268	9,311	0.60
2007	Result	5,527	8,725	0.75	5,527	11,693	0.60
2008	Result	7,375	10,282	0.94	7,375	13,297	0.77
2009	Result	8,355	11,457	0.98	8,355	14,332	0.83
2010	Result	7,670	11,141	0.87	7,670	12,979	0.79
2011	Result	6,830	9,903	0.86	6,830	10,221	0.90
2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58
2013	Projection	1,249	9,406	0.14	1,289	6,825	0.22
2014	Projection	1,503	12,143	0.14	1,396	8,426	0.22
2015	Projection	2,030	16,802	0.14	1,929	11,456	0.22

Table A.7.3. Reference points associated with states of nature of Gulf of Maine cod.

Reference Point	ASAP, 1982 start		SCAA, 1932 start, Ricker	
	M=0.2	M-ramp	M=0.2	M-ramp
SSB_{MSY} (B_{target})	54,743	19,605	20,910	11,180
1/2 SSB_{MSY} ($B_{threshold}$)	27,372	9,803	10,455	5,590
MSY	9,399	4,840	12,840	7,170
F_{MSY}	0.18	0.29	0.75	0.95
75% F_{MSY}	0.14	0.22	0.56	0.71

Table A.7.4. Results of consequence analysis of Gulf of Maine cod; column and row headers indicate 'true' state of nature and basis of management action (75% F_{MSY} for 2013 – 2015) under assumed states of nature; cells provide projections of SSB and fully recruited fishing mortality for 'true' states of nature for catch set according to assumed state of nature; diagonals (shaded) indicate that management actions were correctly specified for the state of nature.

			States of Nature											
Management actions - catches in 2013-2015	Year	Input	ASAP, 1982 start, M=0.2			ASAP, 1982 start, M-ramp			SCAA, 1932 start, Ricker, M=0.2			SCAA, 1932 start, Ricker, M-ramp		
			SSBmsy = 54,743 mt	MSY = 9,399 mt	F_{msy} = 0.18	SSBmsy = 19,605 mt	MSY = 4,840 mt	F_{msy} = 0.29	SSBmsy = 20,910 mt	MSY = 12,840 mt	F_{msy} = 0.75	SSBmsy = 11,180 mt	MSY = 7,170 mt	F_{msy} = 0.95
			Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}
ASAP, 1982 start, M=0.2	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	1,249	9,406	0.14	1,249	6,833	0.21	1,249	17,661	0.07	1,249	10,921	0.12
	2014	Projection	1,503	12,143	0.14	1,503	8,436	0.24	1,503	24,375	0.06	1,503	13,527	0.13
	2015	Projection	2,030	16,802	0.14	2,030	11,432	0.23	2,030	33,073	0.06	2,030	16,709	0.15
ASAP, 1982 start, M-ramp	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	1,289	9,389	0.14	1,289	6,825	0.22	1,289	17,661	0.07	1,289	10,921	0.13
	2014	Projection	1,396	12,145	0.13	1,396	8,426	0.22	1,396	24,328	0.06	1,396	13,488	0.12
	2015	Projection	1,929	16,937	0.13	1,929	11,456	0.22	1,929	33,161	0.06	1,929	16,791	0.14
SCAA, 1932 start, Ricker, M=0.2	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	8,423	7,215	1.41	8,423	4,942	2.63	8,423	17,661	0.56	8,423	10,921	1.10
	2014	Projection	7,621	4,719	2.77	7,621	3,231	5.00	7,621	16,266	0.56	7,621	7,706	1.91
	2015	Projection	8,424	5,134	3.09	8,424	4,043	4.89	8,424	18,367	0.56	8,424	7,032	2.42
SCAA, 1932 start, Ricker, M-ramp	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	5,803	8,214	0.81	5,803	7,711	1.46	5,803	17,661	0.34	5,803	10,921	0.71
	2014	Projection	4,507	7,354	0.81	4,507	5,450	1.84	4,507	19,447	0.25	4,507	9,252	0.71
	2015	Projection	5,020	9,159	0.76	5,020	4,636	1.46	5,020	25,272	0.22	5,020	10,385	0.71

Table A.7.5. Fraction of feasible projection runs from the Gulf of Maine Atlantic cod consequence analysis. Infeasible runs occur when the projection is attempting to harvest more fish than exist in the population's exploitable biomass will allow; Column headers indicate state of nature and row headings indicate basis of management action

Model	**ASAP, 1982 start, M=0.2**	**ASAP, 1982 start, M-ramp**	**SCAA, 1932 start, Ricker, M=0.2**	**SCAA, 1932 start, Ricker, M-ramp**
SAW55_3BLOCK_BASE	1.00	1.00	1.00	1.00
SAW55_3BLOCK_BASE_M_SPLIT	1.00	1.00	1.00	1.00
SCAA_1932_RICKER	0.44	0.13	1.00	0.69
SCAA_1932_RICKER_M_RAMP	0.97	0.93	1.00	1.00

Note:
SAW55_3BLOCK_BASE = ASAP, 1982 start, *M* = 0.2
SAW55_3BLOCK_BASE_M_SPLIT = ASAP, 1982 start, *M*-ramp
SCAA 1932 RICKER = SCAA, 1932 start, Ricker, *M* = 0.2
SCAA 1932 RICKER *M* RAMP = SCAA, 1932 start, Ricker, *M*-ramp

Table A.7.6. Status of 2013 spawning stock biomass and fishing mortality of Gulf of Maine cod; column and row headings indicate 'true' state of nature and basis of management action respectively; cells indicate 2013 stock status resulting from application of management actions under assumed state of nature (rows) to 'true' state of nature.

			True state of nature			
			ASAP, 1982 start		SCAA, 1932 start, Ricker	
			M=0.2	M-ramp	M=0.2	M-ramp
Management action basis	ASAP, 1982 start, YPR	M=0.2	Overfished, overfishing is not occuring	Overfished, overfishing is not occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring
		M-ramp	Overfished, overfishing is not occuring	Overfished, overfishing is not occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring
	SCAA, 1932 start, Ricker	M=0.2	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is occuring
		M-ramp	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring

Appendix A.7 Figures

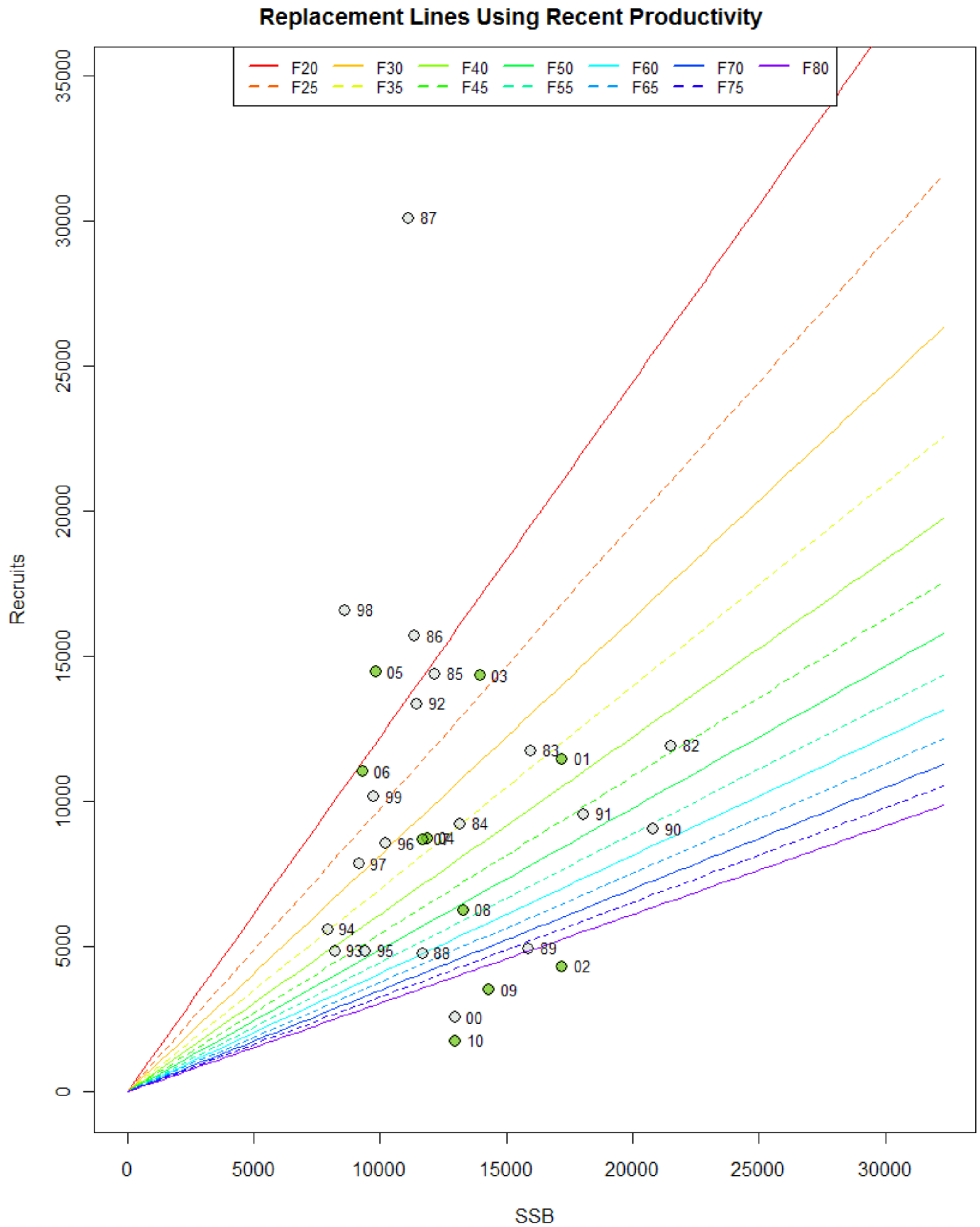

Figure A.7.1. Comparison Gulf of Maine Atlantic cod replacement lines under a range of percent spawner per recruit values based on an *M*-ramp (0.2→0.4) assumption (based on SAW55_3BLOCK_BASE_M_SPLIT model). The most recent ten years of recruitment observations (2001-2010) are highlighted green.

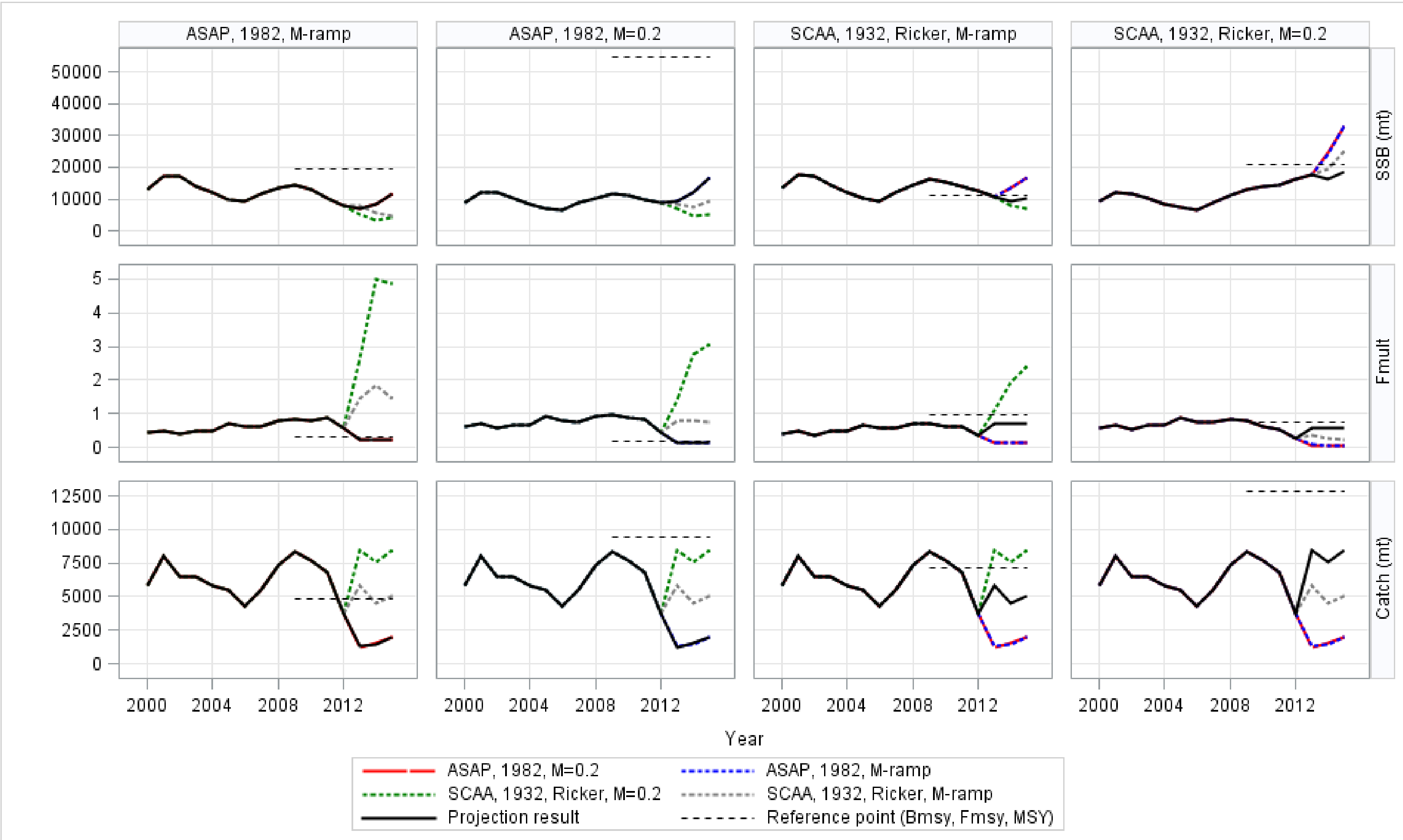

Figure A.7.2. Trends in Gulf of Maine cod SSB (top row), fully recruited fishing mortality (middle row) and catch (bottom row) during 2000 – 2015; column headers indicate 'true' state of nature; cells provide trend in indicator under 'true' state of nature when catch during projection period (based on 75% F_{MSY} is correctly specified (black) and mis-specified (red: ASAP, 1982, *M* = 0.2; blue: ASAP, 1982, *M*-ramp; green: SCAA, 1932, Ricker, *M* = 0.2; grey: SCAA, 1932, Ricker, *M*-ramp; MSY – based reference points indicated in dashed line on each pl