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(This will be a chapter in the 53rd SAW Assessment Report when the full report is published)

A. GULF OF MAINE ATLANTIC COD (*GADUS MORHUA*) STOCK ASSESSMENT FOR 2011, UPDATED THROUGH 2010

A report of the Northern Demersal Working Group

A. Gulf of Maine Atlantic cod (*Gadus morhua*) stock assessment updated through 2010

The Northern Demersal Working Group (NDWG) prepared the assessment. The working group held three different meetings over a three month period. The meeting dates and locations are listed below. Working group participation differed by meeting. A complete summary of working group participants by meeting and day are presented in Appendix A.

- NDWG Gulf of Maine Cod Industry Meeting (NDIM)
    - August 16, 2011
    - Massachusetts Department of Marine Fisheries (MADMF) Annisquam Field Station, Gloucester, MA

- NDWG Gulf of Maine Cod Data Working Group (NDDWG) Meeting
    - September 7-9, 2011
    - Northeast Fisheries Science Center (NEFSC), Woods Hole, MA

- NDWG Gulf of Maine Cod Models and Biological Reference Points Working Group (NDMBRPWG) Meeting
    - October 17-21, 2011
    - Falmouth Technology Park, Falmouth, MA

SAW 53 Terms of Reference

A. 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. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.

2. Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age length data, etc.). 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. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. 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.

4. Perform a sensitivity analysis which examines the impact of allocation of catch to stock areas on model performance (TOR-3).

5. If time permits, consider the small-scale distribution of cod (e.g., spawning sites, resource distribution, fishing effort) in the Gulf of Maine and advise on its management implications.

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. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "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.

Executive Summary

1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data. 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 5,000 mt to 11,000 mt. Catch estimates prior to 1981 do not include commercial discards or estimates of recreational removals. 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 catch. Major uncertainties in the commercial catch include 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 likely to be small (5%). In recent years precision of the estimated discards has been high with coefficients of variation (CV) <20%. The updated assessment has included hindcasted commercial discard back to 1982 and the uncertainty on these estimates is unknown.

There is a large recreational fishery in the Gulf of Maine that, over the last decade, has accounted for approximately 30-50% of the total catch. Recreational discards have become an increasingly important component of fishery removal and as of 2010, constitute 20% of total catch. Uncertainty in the 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. The updated assessment has attempted to hindcast recreational discard length frequency distributions back to 1981 so that this fraction of the catch could be incorporated into an age-based assessment. Previous Gulf of Maine cod assessments have not accounted for recreational discards.

The Northern Demersal Data Working Group (NDDWG) reviewed findings from the scientific literature about the discard survival of Atlantic cod and other similar species. It must be emphasized that the working group found this TOR very difficult to address. The working group discussed all gears for which discards were estimated in the updated SAW 53 assessment, with each gear being evaluated separately based on the gear-specific information available from the literature. While each study provided an estimate of survival, no single study could address every factor implicated in mortality. Important factors in determining discard survival from the available scientific literature include: water and air temperature, sunlight exposure, depth of capture, time of handling, type of handling, length of time on deck, short term and long term survival (one study estimated that only about 50% of mortality occurred in first few days—the length of most observation periods), impacts on growth due to reduced feeding ability, whether predator avoidance was compromised or predator exposure was increased at release time (birds, mammals, other fish predators), whether fish were held on deck in tanks or in an aquarium or held in a cage at depth. Each gear was evaluated with respect to available studies with survival estimates, what factors had been accounted for, what factors had not been accounted for, and whether it was possible to determine what conditions were likely to have existed for unobserved trips. Because it is not possible to characterize the temperature/depth/season for all unobserved trips, a single, annual discard mortality rate is required. The working group was consistent in how it approached the evaluation of each gear, first by reviewing the available studies, discussing what factors were and were not controlled for, and whether the estimates in the literature were likely to be biased high or low. In the end, the working group did agree that the published studies probably overestimated survival, although it was difficult to characterize the extent of the bias. The discard mortality rates to be used in SARC53 for Gulf of Maine cod are 100% for all gears.

2. Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age length data, etc.). 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 impacts of including the inshore survey strata in the NEFSC survey indices was examined by the NDDWG and resulted in increased indices of age 0 through 2 fish. The overall trend in the age specific indices of older fish was not markedly different with the inclusion of the inshore strata, and there were several strata/year combinations with poor sampling. For this reason, and because the inshore areas are largely covered by the Massachusetts Department of Marine Fisheries (MADMF) bottom trawl survey, the NDDWG decided to maintain the status quo and exclude the inshore strata from NEFSC indices. The NEFSC survey vessel was replaced in spring 2009 resulting 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 2009-2011 NEFSC indices in units equivalent to the longer time series.

The MADMF bottom trawl survey began in 1978, with two surveys (spring and fall) conducted annually. Age-specific indices are available beginning in 1981 for the fall and 1982 for the spring. In previous assessments the MADMF fall survey has been used primarily as a recruitment index. In the updated assessment, the utility of this survey was evaluated and was not included in the final base model.

Previous Gulf of Maine cod assessments have included a landings per unit effort (LPUE) index that extended from 1982 to 1993. The time series has not been extended beyond 1994 due to uncertainties in VTR reported fishing effort since 1994, the impact of reductions in days at sea, rolling closures and trip limits. All of these issues would 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 continued inclusion of the existing LPUE index was evaluated by the Northern Demersal Models and Biological Reference Point Working Group (NDMBRPWG). Model results were found to be insensitive to this index, and the decision was made to exclude this index from the final base model.

Several other surveys were evaluated including the Maine – New Hampshire inshore trawl survey and the MADMF Cod Industry Based Survey. For several reasons including lack of age-specific information and short time series, these surveys were not included in the assessment models. The surveys were however used to inform several decisions made by the NDDWG and NDMBRPWG with respect to assumptions about spawning time and gear selectivity.

3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. 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.

The VPA assessment model used for the most recent assessment of Gulf of Maine Atlantic cod (GARM III, 2008) was updated to account for the major changes to the data inputs as well as three additional years of catch and survey data. The major changes to the input data include:

- *Updated length-weight equations.*
- *Updated maturity ogive.*

- *Re-estimated commercial landings-at-age.*
- *Re-estimated discards-at-age including extension of discards back to the beginning of the assessment time series.*
- *Re-estimated recreational landings-at-age.*
- *Estimation of recreational discards-at-age.*
- *Updated catch and stock weights-at-age.*
- *Re-estimated survey indices.*

The updated VPA estimates SSB_{2010} at 12,270 mt and $F_{5\text{-}7(2010)}$ at 1.48. The GARM III VPA assessment estimated SSB_{2007} at 33,877 mt and $F_{5\text{-}7(2007)}$ at 0.46. Comparatively, the updated VPA now estimates SSB_{2007} at 10,714 mt and $F_{5\text{-}7(2007)}$ at 0.68. The general conclusions from the updated VPA are that the weights-at-age used in GARM III likely overestimated the true stock weights-at-age. In addition, the GARM III results overestimated the size of the 2003 and 2005 year classes. The size of these year classes was derived almost exclusively from survey information. As of 2007 these year classes were only partially recruited to the fishery, so there was little information to counter the signals coming from the surveys. Relative to the 2010 update of the VPA assessment, the 2008 VPA assessment over estimated spawning stock biomass, the strength of incoming year classes and underestimated fishing mortality. ***The updated VPA is not the base model for this assessment.***

In this updated assessment a statistical catch-at-age model (ASAP) represents the new base model. The reasons for selecting the ASAP model include: 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.

The ASAP base model configuration (BASE) reflects the best model with which to evaluate stock status and provide catch advice. The assessment indicates that total SSB has ranged from 7,270 mt to 23,675 mt during the assessment time period, with current SSB in 2010 estimated at 11,868 mt (90% CI = 9,479 – 16,301 mt). The base model estimates SSB in 2007 at 12,561, 37% of the 33,877 mt estimated at GARM III. Currently, total biomass is estimated at 20,589 mt (90% CI = 17,638 – 25,996 mt). Current F's are near historic highs with fully recruited F_{full} = 1.14 (0.79 – 1.54) and $F_{5\text{-}7}$ = 1.10 (90% CI =0.74 – 1.46).

A retrospective analysis for the 2003-2010 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB. The F retrospective error ranged from -0.10 in 2009 to -0.52 in 2003. SSB retrospective error ranged from 0.09 in 2009 to 0.90 in 2003. Over the last 5 years, retrospective pattern has resulted in a 22% overestimation of SSB and 22% underestimation of fishing mortality. Retrospective error in age 1 recruitment varied from -0.07 in 2005 to 4.32 in 2003. It is worth noting the decreased retrospective pattern in age-1 recruitment in the ASAP BASE run, relative to the updated VPA model. The ASAP model does not exhibit the severe retrospective pattern in the recent period, particularly in the 2008 assessment peel (coinciding with the timing of the GARM III assessment). Consequently, had an ASAP model been used at GARM III, it is likely that the 2005 year class would have been estimated to have been much lower and the perception of the stock would have been far less optimistic than the GARM III results suggested.

4. Perform a sensitivity analysis which examines the impact of allocation of catch to stock areas on model performance (TOR-3).

Historically, the recreational fishery has been split between Georges Bank and the Gulf of Maine. Since 1999, recreational landings of Atlantic cod have been predominately in the Gulf of Maine region (NEFSC 2008). The potential for misallocation of recreational landings is unknown; however, given the behavior of the recreational fleet operating in the Gulf of Maine, the magnitude of impacts is likely to be small. The issue is misallocation of commercial landings is likely to be larger and have a greater impact on model performance. With respect to Gulf of Maine Atlantic cod, the allocation procedure itself does not likely contribute additional uncertainty as indicated by the low CVs on the allocated landings. A more likely source of allocation uncertainty arises from the misreporting of statistical area on the VTRs. The work of Palmer and Wigley (2007, 2008, and 2010) suggests that these impacts are likely to be small (<5%), but consistently unidirectional (under-reporting of total Gulf Maine cod catch).

Sensitivity runs were conducted to bound the potential impacts of mis-allocation. Two sensitivity runs were conducted, one which inflated landings by 5% and another which decreased landings by 5%. Spawning stock biomass changed +/- 5% with no change in F. The 2010 estimates of SSB were within the 90% confidence intervals achieved from the MCMC estimate of uncertainty (9,479 – 16,301 mt).

5. If time permits, consider the small-scale distribution of cod (e.g., spawning sites, resource distribution, fishing effort) in the Gulf of Maine and advise on its management implications.

Discussion related to resource distributions occurred throughout the NDDWG meeting as both surveys (NEFSC, MADMF, ME-NH, and the Industry Based Survey) and fleet activity were reviewed. Given the full agenda, and extent of reanalysis of data, there was not an abundance of time available to delve into this TOR. Nevertheless, some time was set aside and the working group attempted to review as much as possible during that time block. One presentation summarizing tagging in the western Gulf of Maine was presented, however further discussion of this TOR was reserved until after the discard mortality TOR had been completed. The work examined confirmed that most of the fish on the spawning aggregations show site fidelity; that the timing and extent of the closures is appropriate; and that when fishing resumes at the end of the closure, it can be very disruptive to the cod (interrupts any residual spawning because the fish rapidly disperse from the spawning grounds).Moreover, the industry based survey confirms generalized patterns observed in both MADMF and NEFSC surveys, with cod moving offshore in the fall and inshore in the spring. Additionally, information from a preliminary longline survey in Downeast Maine identified the scarcity of cod in that region.

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. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The existing MSY reference points are based on a spawning potential ratio (SPR) of 40%. The overfishing definition is $F_{MSY} = F_{40\%} = 0.237$. *A stock is considered to be overfished if spawning biomass is less than half of* SSB_{MSY}. *The existing overfished definition is* $0.5xSSB_{MSY} = 0.5xSSB_{40\%} = 0.5x58{,}248$ *mt = 29,124 mt. The existing MSY reference points were derived from a VPA model with a plus group-at-age 11. There are a number of reasons why new reference points are needed for the proposed base model for the current assessment. The number of age classes modeled is 9 instead of 11 (this changes the weight and selectivity in the plus group), commercial and recreational discards are included (this changes the weights and selectivities at all ages), the parameters of the L-W equation were re-estimated (this also affects weights at all ages), and the time elapsed before spawning was increased from 0.1667(March 1) to 0.25 (April 1) which will affect biomass discounting in the YPR calculations.*

The current reference points were derived at GARM III, and are based on $F_{40\%}$. The decision to use $F_{40\%}$ as a proxy for F_{MSY} was endorsed by the independent reviewers at the GARM III meeting, who commented that $F_{40\%}$ is supported by published studies on sustainability. It was pointed out that the published studies focused on F_{MSY} proxies that emphasized sustainability while minimizing yield loss rather than the implications for rebuilding. There were different views within the NDMBRPWG as to the relative priorities of focusing on sustainability and minimization of yield loss, versus implications for biomass targets and rebuilding. Several F_{MSY} proxies were debated: $F_{22\%}$ (F_{MAX}), $F_{35\%}$, and $F_{40\%}$ (status quo). The SARC Panel determined that $F_{40\%}$ was an appropriate reference point for the analyses considered.

To arrive at estimates for $SSB_{40\%}$ and corresponding MSY, long term projections were run, sampling from the empirical distribution of recruitment estimates from the preferred ASAP model (recruitment estimates from 1982-2008, final two years excluded). The resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy}$=$F_{40\%}$=0.20 are SSB_{MSY} = 61,218 mt (46,905 – 81,089 mt), MSY = 10,392 mt (7,825 – 14,146 mt).

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 existing peer reviewed assessment model is a VPA. A meticulous bridge was built from the existing VPA model structure to the updated VPA model structure. The updated VPA model, which includes changes to the catch (inclusion of discards), weights-at-age, etc., estimates that in 2010 SSB is 12,270 mt. This is less than the existing overfished threshold of 29,124 mt; therefore, the stock is overfished. The updated VPA estimate of average fishing mortality on ages 5-7 in 2010, F_{5-7} is 1.48, while the fully recruited F from the VPA is F_{full}=2.46. These are both greater than the overfishing limit, 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).

The revised reference points are F_{MSY} proxy=$F_{40\%}$=0.20 and SSB_{MSY} = 61,218 mt (0.5xSSB_{MSY} = 30,609 mt). The proposed ASAP base model estimate of 2010 SSB is 11,868 mt. This is less than the overfished threshold of 30,609 mt; therefore, the stock is overfished. The 2010 estimate of average fishing mortality on ages 5-7 from ASAP is F_{5-7}=1.10, while the fully recruited F_{full} is 1.14. This is greater than the overfishing limit of 0.20, and therefore, overfishing is occurring.

Accounting for the retrospective pattern does not result in a change of stock status and the revised stock status lies within the confidence intervals of the unadjusted point. The NDMBRPWG reached consensus that the stock status determination from the ASAP base model without accounting for retrospective pattern was preferred. The precedence established at GARM III was to only make retrospective adjustments when the adjusted point fell outside the confidence intervals of the unadjusted point. This approach was supported by the SARC Panel.

For both the existing VPA model with respect to existing reference points and the new proposed ASAP base model with respect to updated reference points, the stock is overfished and overfishing is occurring. Consequently, for both models and reference point sets, the stock is not rebuilt.

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 pattern. The NDMBRPWG did not support the use of hindcasted recruitment for the same reasons they rejected the historical ASAP sensitivity runs; recruitment estimates based solely on survey information have proven unreliable to use as the basis for stock determination. Projections were run under three different F assumptions: F_0*=0.00,* $F_{MSY(F40\%)}$ *= 0.20, and* $F_{75\%FMSY}$ *= 0.15.*

Projection results indicate that even the most optimistic scenario in terms of rebuilding (F_0*), the stock cannot rebuild to* SSB_{MSY} *by the current rebuilding date of 2014.*

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.

Given the noted retrospective patterns, there should be additional uncertainty in catch advice based on these projections. Moreover, the projections will be sensitive to realized recruitment. Recent recruitment has been weak with no strong recruitment observed in the last twenty years. Continued weak recruitment will impede the ability for this stock to rebuild. Given the poor performance of past projections beyond a time period of two to three years, the longer term projections presented in this report should be considered highly uncertain.

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

Uncertainties that were not accounted for by assessment and reference point models were evaluated using model diagnostics. Standard model diagnostics (e.g., residual analyses, retrospective analyses) were used for model validation. Vulnerabilities that were not accounted for by assessment and reference point models were evaluated using exploratory modeling, habitat observations and preliminary results from studies conducted in the spawning closure areas. Those studies indicate strong site fidelity to the spawning grounds, and the almost immediate disruption of spawning activity when those areas are opened. This would suggest that area closures to protect spawning grounds is beneficial and could reduce vulnerability. Additional considerations of vulnerability and productivity are the implications of shifts in distribution, recruitment dynamics and increased natural mortality. Consumption of Atlantic cod by other fishes and mammals may be increasing as predator populations increase, however empirical evidence is lacking to support this hypothesis directly. A considerable source of additional vulnerability is the continued weak recruitment and low reproductive rate (e.g., recruits per spawner) of Gulf of Maine cod. If weak recruitment and low reproductive rate continues, productivity and rebuilding of the stock will be less than projected.

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.

Five of the six previous research recommendations have either been addressed or shown to be no longer relevant. The one research recommendation that has not been addressed (Maine-New Hampshire Inshore Trawl Survey) has been carried forward as a new research recommendation for SARC 53. There were a total of four new research recommendations to come out of the NDDWG.

Introduction

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. Recent reviews of historical and contemporary tagging studies (O'Brien et al. 2005, Tallack 2007, Loehrke and Cadrin 2007) suggest, that while there is movement of fish between the Gulf of Maine and Georges Bank stocks, the degree of mixing is less than 20% (Tallack 2009, T. Miller pers. comm..). Additionally, within the Gulf of Maine there are likely localized metapopulations (Ames 2004), between which, the degree of mixing is unknown. The 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).

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). 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 Multispeices 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 redefining 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^+ $biomass_{MSY}$ =33,000 mt and age 1^+ 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 decade, the Gulf of Maine cod stock has undergone four peer-reviewed assessments: SAW 33 (NEFSC 2001), the Groundfish Assessment Review Meeting (GARM, NEFSC 2002), GARM II (NEFSC 2005) and GARM III (NEFSC 2008). Summaries of these assessments and the resulting stock status are provided in Table A.1 and A.2. All of these assessments were conducted using the ADAPT VPA model with a starting year of 1982. 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. Recreational landings were included in these assessments, but recreational discards were not. Additionally, 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.

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. Given that these fish were only age 2 in 2007, they 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.

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 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.

Length-weight relationship

Previous assessments of the Gulf of Maine cod stock have used an annual NEFSC research vessel survey length-weight (LW) equation as the basis for converting catch weights to numbers-at-age (Equation 1). The origin of the equation and nature of the data used to estimate it (survey or commercial landings) are uncertain. The equation differs from updated NEFSC survey-based LW equations estimated by Wigley et al. (2003). Because the source of the original equation could not be documented and because continued use of it would not account for seasonal differences in the LW relationship, a decision was made to re-evaluate the existing LW relationship with respect to re-estimated length-weight equations.

(1) $W = 0.000008104L^{3.0521}$ (GARM III and prior)

There are two schools of thought as to whether it is more appropriate to use a landings-based length-weight equation versus a survey-based length-weight equation. 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 comes from 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.

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. First, to address concerns that Gulf of Maine cod condition have changed over time, the 1992-2010 time series was divided into roughly five year blocks and the relationships from each of the blocks examined (Fig. A.2). The relationships were nearly identical for both spring and fall seasons for all but one block (1996-2000). The 1996-2000 periods suffered from low sampling in both seasons and it was believed that these differences were more an artifact of sampling variability rather than a biological difference. Overall, the results suggested temporal stability of the seasonal LW relationships and indicated that cod condition has been constant, at least within the 1992 to 2010 period examined. Given this stability, the 1992-2010 data were aggregated to estimate updated spring, fall and annual relationships (Equations 2-4). These were then compared to the existing LW relationship (Fig. A.3). The updated relationships were statistically significant from one another as evidenced by the non-overlap of the 95% confidence intervals. All three updated LW relationships tended to estimate heavier fish at length than the existing length weight equation.

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

Based on these results a decision was made to use the revised LW relationships in the SAW 53 assessment update. Application of these LW equations back to the start of the assessment time period in 1982 requires an assumption that the stationarity observed in cod condition between 1992 and 2010 persisted back in time.

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.4). For the SAW 53 assessment update, von Bertalanffy growth parameters were re-estimated using NEFSC survey data from 1970 to 2011 (Equations 5 and 6). A summary of the number of ages included in the analysis are presented in Table A.4. Given the sparseness of the sampling of older ages, the L_∞ may be poorly estimated. 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).

(5) $L = 142.6 \cdot (1 - e^{-0.1261(t-0.1303)})$ (Spring)
(6) $L = 162.4 \cdot (1 - e^{-0.1034(t-0.8103)})$ (Fall)

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.5). Examination of mean catch weights-at-age suggests that fish size-at-age may have declined in recent years, particularly at older ages (ages 5^+; Fig. A.6). The declines are less evident in survey data (Fig. A.7), with many of the ages showing increases in the most recent two to three years. Generally, both current catch and survey weights-at-age are below those observed in the early 2000-period.

A logistic regression method (O'Brien et al. 1993) was used to fit maturity-at-age from the NEFSC spring survey data. In an attempt to smooth the noise in the data and increase sample sizes for those years with low sampling (Table A.5) a 3-year centered moving average was applied (Fig. A.8). The use of a 3-year moving average as opposed to some other time interval was based in part on the precedence of the GARM III assessment and also due to the fact that the 3-year average was sufficient to increase the sample size so that ogives could be estimated for years with few observations. The Northern Demersal Data Working Group (NDDWG) examined the 3-year moving average, and determined that the estimated A_{50} (age at which 50% of fish are mature) varied about the time series average A_{50}, but without any persistent trends.

The number of distinct stations from which fish were sampled for maturity was compared among years, to determine if differences in sampling protocol could explain the two high A_{50} estimates at the beginning of the time series. The age sampling design from 1970 to 1990 was based on achieving a sampling target number per watch; since 1991, the design has been to sample a target number per tow. The number of distinct stations was variable through time, but nothing indicated that sampling was more clustered earlier in the data compared to recent years. In fact, the number of stations sampled in the 1970s was higher than the middle of the time series, probably because abundance was so low in the 1990s that sample sizes suffered in general. As the length of a survey watch has been 6 hours for most of the time series, it is likely that the protocol to target sample sizes by watch still managed to spread out the stations sampled. An alternative analysis was suggested to fit models that tested for year effects in the slope, the intercept, or both. These analyses encountered the same problem with small sample size in some years, leading to infeasible solutions in certain years. Because no persistent trends were detected, and sampling protocol did not appear to have produced non-representative measurements, the NDDWG decided to use a single time series average maturity ogive estimated from data in years 1970-2011 (Fig. A.9). The time series $A_{50\%}$ for male cod was 2.86 and 2.67 for females.

Natural mortality (*M*)

Previous assessments of Gulf of Maine cod have assumed a constant, age-invariant rate of instantaneous natural mortality (*M*) or 0.2 (NEFSC 2008, Mayo et al. 2009). The NDDWG 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 7). Depending on whether the maximum age observed from the surveys (t_{max}=17) or the maximum age observed in the fishery (t_{max}=15) is used, this approach yields estimates of *M* = 0.246 or 0.279. This approach was further refined by Hewitt and Hoenig (2005; Equation 8), though the revised approach yields similar results of *M* = 0.248 or 0.281. Because the Gulf of Maine cod stock has been heavily exploited for most of its recent history, 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 is the ratio of gonad weight to somatic weight (Gunderson 1997). The general premise it that *M* is positively correlated with reproductive effort (*ibid*; Equation 9), 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 10) 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.

From this the meta-analysis of life history-based estimates the working group decided that the evidence available suggested that 0.2 was reasonable. As in all previous assessments for this stock, natural mortality will be assumed to be 0.2 for this assessment for all years. 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.

The NDDWG did discuss the possible impacts of seal predation on assumptions of natural mortality. There is a general presumption that seal populations have been increasing in the region over the past twenty years, though no definitive estimates exists to evaluate the trends or relative scale of a population increase. It is possible that increases in the seal population could lead to increased cod predation which could suggest that *M* should be temporally increasing in the more recent time period. While these concerns were noted, there is no empirical basis to evaluate the current size of the seal populations and trends over the last thirty years, nor are there estimates of cod consumption of cod and how rates may have varied over time. 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).

TOR A.1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.

Overview

In the recent period (1982 to present) total catch has ranged from 22.3 thousand metric tons (mt) to 3.8 thousand mt (Table A.6, Fig. A10). Prior to 1999, commercial landings constituted 70-80% of the total catch, but since 1999 they have constituted only about 40-60% of the total catch (Fig. A.11). There were 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.11). 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 15% of the overall catch, whereas they accounted for, on average, about 20% from 1999 through 2010. 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.

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 results 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.12), the NDDWG concluded it was important to include these landings in the current assessment to maintain consistency with current ACL monitoring. 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 (Table A.6). Landings statistics for area 5 (Gulf of Maine and part of Georges Bank stocks) exist back to 1893 (e.g., Mayo et al. 2009). The methods used to apportion landings to individual stock complex are not well documented and generally, these stock landings are considered less certain. It is worth noting that the estimates of historical Gulf of Maine cod landings reported in past assessment documents are of similar magnitude as landings between 1964 and 2010. Total species landings are derived from the weighout reports of commercial seafood dealers and these data are generally considered a census of total landings. A secondary source is required to apportion out the species landings to statistical area (stock) and assign basic information on fishing effort (e.g., gear and mesh). 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).

In 1994, with the requirement of vessel-reported VTRs, the port interview process stopped and the area and effort information had to be 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 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 (Fig. A.13). Interestingly, there is a seasonal component to the matching success, with generally poor matching success around the month of May (Fig. A.14). This phenomenon has not been fully explained, but does coincide with the start of the groundfish fishing year and annual renewal of vessel permits. The overall precision associated with this process, in terms of a CV is estimated at less than 0.1 (Table A.7).

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 2011). The impacts of this misreporting on Gulf of Maine landings estimates are thought to be small. Between 2004 and 2008, the errors are estimated to have only resulted in small (<5%) underestimates of total stock landings, with the impacts decreasing over time (<1% in 2007 and 2008; Palmer and Wigley 2011).

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 represent the largest likely fraction of landings that would not be reported by seafood dealers. Estimates of home consumption can be derived from VTRs, but these estimates probably represent underestimates of total home consumption landings due to incomplete reporting. From 1994 to 2010, home consumption landings are estimated at < 0.3% of total commercial landings (Table A.8). Even if these represent underestimates, it is unlikely that home consumption landings represent a significant source of fishery removals. Given this, home consumption estimates were not included in total 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.15). 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 whereby gillnet landings drop in 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.16).

The ports of Gloucester and Portland have historically been the primary offload ports of Gulf of Maine cod (Fig. A.17). Portland landings have declined over the last twenty years and Gloucester now accounts for over 60% of total commercial landings. The impacts of the rolling closures in the western Gulf of Maine impacts 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 are closed to groundfishing (Fig. A.18). 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 nearly identical to the port trends. Over the last twenty years landings have become increasingly concentrated in statistical area 514 which is the statistical area in closest proximity to Gloucester (Fig. A.19). 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 similar impacts on the statistical area landing patterns (Fig. A.21). The spatial aggregation of the fishery in the western Gulf of Maine over the past twenty years is also evident in observer data (Fig. A.20). It is not fully understood whether the aggregation of the fishery in the western Gulf of Maine has been driven by regulations, stock availability/distribution, or some combination of the two.

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.22). Over the past five years, market cod have accounted for approximately 70% of the total landings (Fig. A.23).

The temporal landing patterns of Gulf of Maine cod has changed slightly over the past five years, likely in response to the major changes brought about by Amendment 16. 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 (Fig. A.24). Presumably, the low landings during these months were as result of a combination of limited availability of DAS and rolling closures. In 2010 landings were more constant over the course of the year. It is not exactly clear how the transition to a sector management scheme altered the landings in March and April 2010, but 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.

Commercial landings: biosampling

Biological sampling (length and age) of Gulf of Maine cod prior to 1982 was poor (Table A.9). 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., 1999, 1407 mt).

Length sampling of the commercial landings has varied from 28.1 to 517.9 mt per 100 lengths (Table A.10). A 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. 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.11).

Previous Gulf of Maine cod assessments have estimated numbers-at-age by aggregating lengths into 3 cm bins. The current assessment performed a complete update of the catch-at-age. In doing so, an attempt was made to use 1 cm intervals. This requires a greater degree of age imputation to manually fill in gaps in the age length key (ALK). An examination of the amount of imputation that would be required suggested that the level of imputation was not unacceptable (Table A.12). 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%. 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 criteria 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 4) was used to convert landings to numbers-at-age. Otherwise, the appropriate seasonal LW equation was applied (Equations 2 and 3). A summary of the amount of binning that was required is presented in Table A.12. Total numbers-at-age are presented in Table A.13. The bootstrapped generated CVs on the landings-at-age estimates are shown in Table A.14. 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.25). Older fish were less common in the landings back in the late 1990's, likely due to a truncated population age structure.

Changes in the methods used to estimate landings-at-age relative to GARM III included: revised LW equations, 1 cm length bins compared to 3 cm length bins and complete re-estimation of the landings-at-age time series. Given these changes the revised estimates were compared to the GARM III estimates. Overall the differences were small (<10%), with the revised landings-at-age tending to be lower than the GARM III estimates (Table A.15). This was expected given that the revised LW relationships estimated heavier fish at length. Large differences were observed at older ages, but these represent large changes of a small number of fish (see Table A.13). Estimates of weights-at-age from landings in the commercial fishery are presented in Table A.16.

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.26). 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 inappropriate and 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 observed 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.17). GARM III discard estimates included otter trawl, shrimp trawl and sink gillnet, but no distinction was made for the different mesh sizes.

The total number of trips observed of these gear types ranged from a low of 62 in 1997 to a current high of 2250 trips (Table A.18). 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 was undertaken in SARC 52 (Wigley et al. 2011) and 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 (Fig. A.27).

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. Attempts were made to estimate discards for this gear type, but the NDDWG concluded that the proportion of observed trips for handline was too low to give confidence in the derived estimates of discard amount (maximum number of observed trips in any year was 9).

The previous GARM III assessment used a variant of the Standardized Bycatch Reporting Method (SBRM; Wigley et al. 2007). The ratio method applied for Gulf of Maine cod was similar to that used for other groundfish stocks except that rather than using the amount of all catch retained in the ratio denominator, the amount of retained cod was used. This decision was made on the basis that it was thought that the discard estimates provided by the d_{cod}/k_{cod} ratio better represented the high discarding that likely occurred under the severe trip limits that existed in 1999 (30-200 lb/day). It is unknown whether this is true, but the methodology used in GARM III is inconsistent with that used for other groundfish stocks as well as the current in-season groundfish monitoring programs, which also utilizes a d_{cod}/k_{all}

ratio. To resolve this discrepancy, the SAW 53 Gulf of Maine cod assessment utilizes the d_{cod}/k_{all} ratio estimator.

Prior to arriving at the final estimates of commercial discards, several different temporal stratification schemes were evaluated 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% (Fig. A.28). 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.

Final estimates of discards ranged from under 100 mt in 1998 to a high of 2,198.2 mt in 1990 (Table A.19). 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.20). Comparison of the updated discard estimates to those of GARM III shows close agreement between the two, with both showing similar trends and scales and having overlapping 95% confidence intervals in all of the years (Fig. A.29). The largest difference between the two estimates occurs in 1999.

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.30).

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.21). The length distributions by gear are shown in Figure A.31 on an aggregate basis and by year in Figures A.32 through A.38. 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 is occurring 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 structure of the commercial landing. Previous assessments have made no attempts to hindcast discards back to 1982. In this assessment update 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) has been used 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.

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:

(11.a) $C_i/f = q \bullet (N_i \bullet m_i)$, then

(11.b) $C_i = (q \bullet f) \bullet (N_i \bullet m_i)$ as above.

If :

(11.c) $K_i = C_i \bullet s_i$, and

(11.d) $D_i = C_i \bullet (1\text{-}s_i)$, then

(11.e) $D_i = (q \bullet f) \bullet (N_i \bullet m_i) \bullet (1\text{-}s_i)$, and

(11.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.39). 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 the major changes in the shrimp trawl discard patterns that occurred in 1992 (i.e., Nordmore grate).

Using Pope's (1966) '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.40). Equation 12 (Wileman et al. 1996) is then fit to the aggregate ratios (across all years) to generate selectivity ogives (Fig. A.41). 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.42 and A.43). 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.44). 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.45 – A.47). 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.

(12)

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

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 11.f, Fig. A.48). 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. Based on the GARM III assessment, the 1987 year class was the largest year class observed during the assessment time series (Mayo et al. 2009).

Total discards estimated using the survey filter approach reflected the relative trends and scales from the direct estimates (Table A.22). 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 NDDWG considered an alternative metric to the survey-filter hindcast: use 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 NDDWG 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 NDDWG suggested a third calculation of hindcasted discards using the average d_{cod}/k_{all} ratio for years 1989 to 1993, *excluding 1990* (Fig. A.49). The NDDWG discussed the appropriateness of hindcasting, and whether assuming that discards are zero is better than making assumptions to derive estimated amounts. Ultimately, the NDDWG 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. Commercial discards-at-age and weights-at-age are presented in Tables A.23 and A.24 respectively. Bubble plots of discards-at-age over time are shown in Fig. A.50.

Recreational landings

Estimates of the recreational Gulf of Maine cod catch were obtained from the Marine Recreational Fishery Statistics Survey (MRFSS). This survey has been conducted annually since 1979. MRFSS breaks the total catch into three components: directly observed landings (A), unobserved landings (B1), and unobserved discards (B2). Similar to the treatment of MRFSS data in GARM III, recreational catches were partitioned into Gulf of Maine and Georges Bank stocks using updated MRFSS data and site register lists. Recreational catches attributed to site register lists 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 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. 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 catch in a given year (Table A.25), thus VTR-based estimates will underestimate the total recreational landings (Fig. A.51). The MRFSS program does 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.26). 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.27). It may be important to note that an anonymously high proportion of the 2010 MRFSS catch was estimated in wave 2. Since wave 2 was only open to the recreational fishery beyond state waters for two weeks in 2010 it seems unlikely that wave 2 could be responsible for 50% of the total recreational catch. The majority of VTR-reported recreational landings come almost exclusively from statistical areas 513 – 515 (Table A.28). Based on the VTRs, there are virtually no landings of Gulf of Maine cod in ports south of Massachusetts (Table A.29). This finding supports the existing allocation scheme based on the site register lists that is used to partition MRFSS recreational catch into Gulf of Maine and Georges Bank stocks.

The MRFSS survey is a numbers based survey and conversion of MRFSS estimates to removals in terms of total weight 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.30). An alternative method is to use the annual length frequency distributions (Fig. A.52) 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 (Fig. A.53).

The SAW 53 assessment update will use Method 3 for all final estimates of catch removals. Total landings estimated in terms of weight track closely with the numbers-based estimates of landings (Fig. A.54). Since 1997, there has been a proportional increase in the weight-based estimates relative to numbers due to incremental increases in the recreational minimum retention size. 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.55). Recreational landings-at-age show similar trends with respect to the impacts of increasing minimum retention sizes (Fig. A.56). Like the commercial landings, older ages are absent from the recreational landings throughout much of the 1990s.

Recreational discards

In previous Gulf of Maine cod assessments, recreational discards have been reported, but they have not been included in the catch-at-age. The primary reason was that there has historically been no length sampling of discarded component of the recreational fishery, 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.31). Beginning in 2005 direct sampling of cod discards from party boats began in the Gulf of Maine (i9 sampling; Table A.32). 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.

With increases in the minimum recreational retention sizes, the contribution of recreational discards to total recreational catch has been increasing over time (Fig. A.57). Currently, recreational discards are approximately double the recreational landings in terms of numbers. Because of the increasing importance of recreational discards over time the NDDWG concluded it was worthwhile to attempt a hindcast of recreational discards using the available length frequency information and a variant of the survey filter method was 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 survey. 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.58). Using the alternate-tow approach used for commercial discards, a gear selectivity ogive was constructed (Fig. A.59). Comparing the survey-filter length frequency distributions to the observed length frequency distributions showed close agreement (Fig. A.60). Applying the survey filter method back to 1981 (start of the length sampling of recreational landings) yielded the length distributions shown in Fig. A.61. 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.62.

A summary of recreational catch from 1981 to 2010 is presented in Table A.33. Recreational catch has ranged between 5.8 thousand mt and 0.6 thousand mt. The large increase in the 2010 catch should be noted for the reasons described previously. Because of the method used to apportion MRFSS cod estimates to stock areas, there are no direct estimates of precision available for recreational catches; however, the MRFSS-published estimates of percent standard error (PSE) provide some gauge as to the relative precision of the recreational catch estimates (Table A.34). Overall the general precision of these estimates is about equal to the commercial discards. It is worth noting that despite the large Wave 2 catch in 2010, PSE values appear comparable to previous years.

Total cumulative recreational landings-at-age and landing weights-at-age are presented in Tables A.35 and A.36. Recreational discards-at-age and discard weights-at-age are presented in Table A.37 and A.38.

Discard mortality

The NDDWG reviewed a working paper (Palmer et al. 2011) which summarized findings from literature about the discard survival of Atlantic cod and other similar species. It must be emphasized that the NDDWG found this TOR very difficult to address. Discard mortality was evaluated for all gears for which discards were estimated in the updated SAW 52 assessment, with each gear being evaluated separately based on the gear-specific information available from the literature. Some members of the NDDWG argued that a presumption of discard mortalities less than 100% would 'provide an incentive' to influence handling the fish in such a way that mortality might actually be lowered. The majority of the working group disagreed with the rationale and considered these concerns external to an objective determination based solely on the scientific merits of each study.

While each study provided an estimate of survival, no single study could address every factor implicated in mortality. These factors include: temperature and seasonal effects, depth of capture, time of handling, type of handling, length of time on deck, short term and long term survival (one study estimated that only about 50% of mortality occurred in first few days—the length of most observation periods), impacts on growth due to reduced feeding ability, whether predator avoidance was compromised or predator exposure was increased at release time (birds, mammals, other fish predators), whether the field studies held fish on deck in tanks or in an aquarium or held in a cage at depth. It was noted that studies where fish were held in cages to evaluate survival could be biased either high or low. On the one hand, being held in a cage reduces exposure to predation, which could inflate estimates of survival. On the other hand, the cage could induce stress, damage to fish from contact with the cage, and even mortality due to cannibalism—all factors that could potentially increase mortality.

Each gear was evaluated with respect to available studies with survival estimates, what factors had been accounted for, what factors had not been accounted for, and whether it was possible to determine what conditions were likely to have existed for unobserved trips. The NDDWG concluded that it would not be possible to characterize the temperature/depth/season for all unobserved trips and therefore a single, annual discard mortality rate would be decided on. The working group was consistent in how it approached the evaluation of each gear, first by reviewing the available studies, discussing what factors were, and were not controlled for, and whether the estimates in the literature were likely to be biased high or low. In the end, the working group did agree that the published studies probably overestimated survival, although it was difficult to characterize the extent of that bias. The discard mortality rates to be used in SARC53 for Gulf of Maine cod are 100% for all gears. Sensitivity analyses at lower discard mortality rates were not explicitly explored. Building the bridge from the previous assessment to an updated VPA assessment will constitute a *de facto* evaluation of including discards with 100% mortality since many of the gears/fleets did not have discards estimated in the previous assessment (e.g., commercial longline and recreational).

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.39). 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 and have become less common in the fishery catches over the most recent three 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.40). This is a major difference relative to previous Gulf of Maine cod assessments which have estimated catch weights using only the landed fraction of the catch. The net impact is that previous assessments likely overestimated the true catch weights by not including the smaller fish-at-age in the estimation of catch weights-at-age. The relative differences between the weights used in the current assessment and those used in GARM III are presented in Table A.41. The largest differences in weights occur at the younger ages classes (i.e., those ages most likely to be in the discarded fraction of the catch). From age 5 and older, the relative differences are generally less than ten percent.

Mean weights were generally greater than average during the mid- to late-1990s, with below average mean weights being observed across many age classes during the early- to mid-2000s. Mean weights of the older age classes (≥ age 5) appear to still be below average, but an increase has been observed in the younger ages (Fig. A.6).

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 ages 10 and 11, Table A.40). 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.5), 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.42.

TOR A.2. Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age length data, etc.). 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.

NEFSC bottom trawl survey

The NEFSC spring and fall bottom trawl surveys began in 1968 and 1963 respectively, providing a long time series of fishery independent indices. All previous Gulf of Maine cod assessments used only the offshore survey strata (Fig. A.63). During the NDDWG meeting, it was suggested that the indices be evaluated with and without the inshore strata. The current approach to generating NEFSC indices ignores the inshore strata because they are not consistently sampled. Additionally, 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 was examined by the NDDWG and resulted in increased indices of age 0 through 2 fish. The overall trend in the age-specific indices of older fish was not markedly different with the inclusion of the inshore strata and there were several strata/year combinations with poor sampling. For this reason, the NDDWG decided to maintain the status quo and exclude the inshore strata from NEFSC indices.

A frequent criticism of the NEFSC bottom trawl surveys is that they do not cover the same areas where the commercial and recreational fisheries catch cod, and thus are 'missing' 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 survey and industry catches (Fig. A.64).

The NEFSC bottom trawl survey has utilized three different vessels and three different door configurations throughout the time series of the survey (Table A.43). 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.44). The largest change in the survey time series occurred in 2009 when the FSV 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.45). 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 then 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.65). A comparison of the converted and unconverted spring and fall survey indices is presented in Figure A.66.

During a pre-SARC 53 meeting with the fishing industry (held 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.67). 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.46), 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.47 along with the corresponding CVs. Generally survey indices were higher in the earlier time periods, reaching lows in the mid-1990s. There has been a slight increase in survey indices relative to the mid-1990, but survey indices have remained constant over the past decade (Fig. A.68). 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? Indices-at-age for both the spring and fall surveys are presented in Tables A.48 and A.49 and Figures A.69 and A.70. 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.

The NDDWG examined spatial trends in the NEFSC survey catches over time to see if these could inform the understanding of small-scale distributions of cod (TOR A.5). Plots of the spring and fall survey catches (number/tow) show a general decline in the overall abundance from the 1970s through the 1990s. There is a notable increase evident in the 2000-2010 period, but the increase appears to be restricted to the western Gulf of Maine (Fig. A.71 and A.72). 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 that the resource has contracted into the western Gulf of Maine over the last twenty years (Fig. A.73). These patterns are similar to the spatial aggregation that has occurred in the commercial fishery.

MADMF bottom trawl survey

The MADMF has conducted research bottom trawl surveys during the spring and fall since 1978. 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.74). The MADF survey strata closely coincide with the NEFSC inshore survey strata occurring in Massachusetts state waters (Fig. A.75). Both surveys occur around the same time of the year, though the MADMF spring survey occurs about 20 days later in the spring and 45 days earlier in the fall relative to the NEFSC survey (Table A.50). 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). A complete description of the MADMF trawl survey is provided in King et al. (2010).

In constructing MADMF survey indices-at-age, ALK information was borrowed from the NEFSC inshore survey strata shown in Figure A.75. Given the similarities in the survey extent and timing, this approach was preferred over manual imputation (Table A.51). Aggregate survey indices and the corresponding CVs are presented in Table A.52 and Figure A.76. Abundance-at-age indices for the spring and fall surveys are presented in Tables A.53 and A.54 and Figures A.77 and A.78, respectively.

Maine – New Hampshire inshore trawl survey

The Maine – New Hampshire (MENH) inshore 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 (GARM I, NEFSC 2002b). The MENH survey began in 2000 and has been conducted in the spring and fall annually in the nearshore waters of the Gulf of Maine (Fig. A.79; Sherman et al. 2005). The ten year time series of abundance and biomass indices do not exhibit strong interannual fluctuations (Fig. A.80). 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 Massachusetts and New Hampshire (Fig. A.81). There were some indications of high catches along the eastern Maine coast, though annual plots examined by the NDDWG showed that these catches occurred early in the time series and have not persisted over time. A cursory examination of length frequency distributions suggests that the spring survey captures primarily age 0 through 2 fish (<35 cm) with the fall survey capturing age 0 and 1 fish as well as juvenile fish less than 60 cm (Fig. A.82). The size frequencies seem to suggest that MENH captures the same age classes observed in MADMF survey.

The biggest impediment to inclusion of this survey is the absence of age information. While otoliths have been collected, they have not been aged. It would be easier to incorporate this survey into an assessment if ages were available, and the NDDWG wanted to encourage that this be pursued. Additionally, the NDDWG encouraged that reproductive information be evaluated for the early years where Downeast

Maine stations were sampled to evaluate whether any of the fish were mature and whether there was evidence to suggest the presence of a spawning aggregation. In the meantime, because the length frequencies are similar to MADMF, the working group did not feel that any important signals were being excluded from the model because there are age specific indices from MADMF in the model. The MENH survey was not included in the SAW 53 assessment update of the Gulf of Maine cod.

MADMF Atlantic cod industry based survey

The MADMF Atlantic cod industry based survey (IBS) was conducted from November 2003 through March 2007 (Hoffman et al. 2006). The survey was primarily conducted during the months cod are believed to spawn in the southwestern Gulf of Maine (November through May). Given the short time series, the survey was not considered for inclusion as an assessment tuning index. The NDDWG did however examine results from the survey as they relate to spawning times which indicate that peak spawning in the southwestern Gulf of Maine occurs in the April to May time period.

LPUE index

Trends in commercial landings per unit effort (LPUE) have been used in previous Gulf of Maine cod stock assessments. The 1982-1993 age composition of the landings corresponding to the effort of an otter trawl sub-fleet (summarized in Mayo et al. 1994) has been used to calculate LPUE-at-age indices for ages 2 through 6 (Table A.55; Mayo et al. 2009). The time series has not been extended beyond 1994 due to uncertainties in VTR reported fishing effort since 1994, the impact of reductions in days at sea, rolling closures and trip limits. All of these issues would 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.

There is high correlation between the LPUE-at-age indices and the NEFSC abundance-at-age indices, particularly among older ages (Table A.56). While the aggregate indices do not exhibit as high a degree of correlation, they do exhibit the same basic trends (Fig. A.83). Given that the LPUE index has been used in previous assessments and it is unknown how its removal could impact assessment results, the NDDWG suggested model sensitivity runs to assess the utility of including the LPUE index. If model results were insensitive to the index, the NDDWG concluded it would be appropriate to remove the index from the SAW 53 assessment update.

TOR A.3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. 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.

Update of the GARM III VPA model

There were major changes in the treatment of the underlying data for the SAW 53 assessment update relative to the data used in the GARM III assessment. The major changes include: updated LW relationships, re-estimated landings-at-age, and inclusion of commercial discards in the catch-at-age, extension of the commercial discards-at-age back to the beginning of the model time series (1982), estimation of recreational discards-at-age back to beginning of the model time series, new estimates of weights-at-age that reflect landings and discards, and a revised maturity ogive. Additionally, there are three more years of catch and survey information that needed to be incorporated into the model. To fully understand how these data changes impact the VPA update, a bridge as constructed to transition from the GARM III assessment to a fully updated assessment.

The GARM III assessment was conducted using the Adaptive Framework Virtual Population Analysis (ADAPT-VPA) model (NOAA Fisheries Toolbox ADAPT-VPA version 2.7, 2007). This version relied on Pope's approximation to solve the catch equation and only allowed for the 'backward' calculation of the plus group. The most recent version of the ADAPT-VPA software (version 3.1.1, 2011) solves the catch equation exactly and supports both the 'backward' calculation of the plus group and the 'combined' calculation advocated by Butterworth and Rademeyer (2008a). In addition to the data changes, these model changes must also be accounted for when building the bridge from the GARM III assessment.

The model formulation used in GARM III utilized an extended age range out to age 11^+ relative to previous assessments which had used a 7^+ age group. Commercial and recreational landings from 1982 to 2007 as well as discards from 1999 to 2007 were accounted for in the model. Tuning indices included the NEFSC spring ages 2-8, NEFSC fall ages 1-7 lagged forward by an age and a year (e.g., 2006 age 2 fish become 2007 age 3 fish in the model), MADMF spring ages 2-4, MADMF age 1 lagged forward and commercial LPUE ages 2-6. The fully recruited F is determined as the unweighted average F on ages 5 to 7. The terminal year F on age 10 is estimated as the mean of the fishing mortality on ages 5 through 9. In years prior to the terminal year, F on age 10 was determined from weighted estimates of ages 5 through 9. The age 10 F was applied to the age 11^+ group. Maturity-at-age was calculated from the three year moving average of maturity observations. Spawning stock biomass was calculated assuming a March 1 spawning period (0.1667 into the calendar year; **note this is inconsistent with the start of the spawning period noted elsewhere in the document and is revised in the final assessment model*).

The general approach used to build the bridge from the GARM III VPA to an updated VPA was as follows (run numbers correspond to the run summaries presented in Tables A.57 and A.58):

- **Run 1:** Recreate GARM III results using v2.7 with GARM III data set to confirm that model and data were correctly applied.
- **Run 2b:** Migrate to v3.1.1 using the GARM III data set to quantify the impact of using an 'exact' solution to the catch equation. Continue to handle plus-group using the GARM III formulation with backward calculation.
- Update the GARM III data set incrementally to understand the impacts of updated data inputs:
    - **Run 3a:** Update commercial landings and discards (exclude discards prior to 1999) and recreational landings through 2007; survey indices not updated, stock and SSB weights unchanged.
    - **Run 3b:** Update stock and SSB weights using the updated weights through 2007 that are presented in Table A.42. Everything else left untouched.
    - **Run 4:** Include commercial discards back to 1982 (full time series); survey indices not updated.
    - **Run 5:** Include recreational discards through 2007 (full catch update); survey indices not updated.
    - **Run 6:** Update the survey indices through 2007, spring surveys through 2008. Update the maturity ogive.
    - **Run 7:** Drop the commercial LPUE survey index.
    - **Run 8:** Handle the plus-group using 'combined method'.
        - ***This model provides an evaluation of the sensitivity of the GARM III results to the differences in models and treatment of the data.***

- **Run 10:** Update time series through 2010; spring surveys through 2011. ***This model represents an updated VPA model.***

The results from the bridge building exercise are presented in Table A.58. There were no major diagnostic problems with the GARM III model following the VPA software update (**Run 2b**). Survey residuals were largely un-patterned (Fig. A.84.a-d). NEFSC survey selectivities suggested constantly increasing selectivity up to the maximum age, with no declines in subsequent ages (i.e., flat-top selectivity) while MADMF spring selectivity decreased sharply with age (Fig. A.85). Fleet selectivity decreased slightly at older ages beyond a maximum-at-age 6, suggestive of some doming (Fig. A.86). A small retrospective pattern was evident in SSB (Fig. A.87) but there was no clear patterning in either F (Fig. A.88) or age-1 recruitment (Fig. A.89). Overall, the results were nearly identical to those of GARM III.

The largest change with respect to the GARM III results occurred from the update of the SSB/January 1 stock weights (Run 3b). In previous assessments stock weights-at-age had been derived from only the landed catch. This approach likely overestimated the true weights-at-age for ages 1 through 3. Based on the updated maturity ogive these ages range from 9.4% to 61% mature (Fig. A.9) and based on the GARM III assessment (Mayo et al. 2009) accounted for 80% of the 2007 population in terms of numbers. Overestimation of the weights-at-age for these younger fish can significantly impact estimates of SSB. The introduction of the recreational discards had minor impacts on the 2007 terminal estimates, primarily in the way of increasing F by 0.13 and decreasing SSB by 3,700 mt (approximately 15%). Minor changes resulted from the survey updates, but dropping the LPUE indices had no impact on the overall results. The net impact from all software and data changes (Run 8) relative to the GARM III results was an increase in F by 0.1 (21.7% increase), and a drop in SSB of 14,428 mt (42.6%). There was a general improvement in the overall retrospective statistics. Time series plots of the major intermediate models are presented in Figures A.90 through A.92.

Updated VPA model (through 2010)

The 2010 update of the Gulf of Maine cod VPA model (Run 10) added three additional years of data: catch and fall survey data were extended through 2010 and spring survey data through 2011. No other changes were made from the Run 8 model formulation. The updated VPA estimates 2010 SSB at 12,270 mt and $F_{5\text{-}7}$ at 1.48. The survey fits to Model 10 did not exhibit any strong residual patterns (Fig. A.93.a-c), and survey catchabilities (q) were very similar to those from the GARM III model (Fig. A.94, **note q-values are plotted in terms of area swept in this plot to compare with subsequent ASAP runs*). The fleet selectivities decreased slightly at older ages beyond a maximum between ages 5 and 7, suggestive of some doming similar to the GARM III results (Fig. A.95). Run 10 exhibited extremely high CVs on the population estimates of age 9 and 10 in the terminal year +1 (Table A.58). These high CVs are a product of imprecise estimates of very small numbers of fish (there were an estimated 1000 age 9 and 10 fish in year t_{+1}). There is evidence that there has been further truncation of the age structure since the GARM III assessment. Continued handling of the plus group as age 11's may no longer be appropriate given this truncation. Retrospective patterning increased in Run 10 relative to Run 2b, particularly in the estimation of SSB (Fig. A.96) and age-1 recruitment (Fig. A.97). The absolute magnitude of the F retrospective statistic (*rho*) remained relatively unchanged (0.05 to -0.06), although there was a change in the overall patterning (Fig. A.98).

Relative to Run 8, Run 10 estimated higher fishing mortality (Fig. A.99) and lower SSB (Fig. A.100) in the overlapping years from 2001 onward. These large differences are driven primarily by a difference in the perception of the recruitment strength of the 2003 year class and to a greater extent, the 2005 year class (Fig. A.101). The strength of these year classes in the GARM III assessment, as well as Run 8 were derived primarily from the NEFSC spring survey (Table A.48) and MADMF fall survey (Table A.54). In the 2010 update (Run 10) not only were there three more years of survey observations with which to gauge the strength of these incoming year classes, but there were additional signals coming from the catch to balance out the high survey data points in 2007 and 2008. By 2010, the 2005 year class was almost fully recruited to the fishery. The catch-at-age (Table A.39) does not show large catches of either the 2003 or 2005 year classes, at least not to the level that would be suggestive of a strong year class. The conflict in the data between early signals of a strong 2005 year class (surveys in 2007 and 2008) and more recent signals that do not suggest a strong year class (surveys and catch for 2009-2010/2011) created tension in the model that manifested itself in the increased retrospective pattern in SSB, and the higher CVs associated with age 5 (2005 year class in 2010) between Run 10 and all earlier model runs (Table A.58). As noted above, precision was also poorer-at-ages 9 and 10, but this is likely be due to there being so few fish at those ages,

The NEFSC spring 2007 and 2008 indices have the highest CVs within the 1968 to 2011 NEFSC spring survey time series (Fig. A.102). Examination of the individual station catches for these two years shows that the high survey data points were driven by single tows in each of the years (Table A.59). The high survey abundances indicated by the NEFSC spring 2007 and 2008 indices are likely not representative of the resource. A contributing factor to uncertainty in recruitment estimates is the MADMF fall survey, which has traditionally been treated as a recruitment index in the VPA model through the inclusion of the age 1 survey index lagged forward a year and an age. Comparison of the MADMF fall age-1 index values to Run 10 age-1 recruitment estimates suggests that the MADMF fall survey is a poor index of recruitment (Fig. A.103). A sensitivity run was conducted to evaluate the performance of the Run 10 model after removal of the MADMF fall index and down weighting of the NEFSC spring survey indices in 2007 and 2008 (all ages set to weighting of 0.1) to account for the high variance of these survey indices (Run 10f). Overall, there was little change in the perception of the stock in terms of terminal estimates of F and SSB (Table A.58 and Figs. A.104 to A.106); however, there was marked improvements in the retrospective patterns, particularly with respect to age-1 recruitment (Fig. A.107) and SSB (Fig. A.108). The comparison of retrospective patterns between runs 10 and 10f suggest that had the GARM III assessment treated the survey indices similarly, the perception of the stock would have been less optimistic back in 2008. Specifically, the 2008 estimate of just under 22,000 mt of SSB would have dropped to about 16,000 mt, and the estimate of age-1 recruitment would have dropped from over 17.9 million to just under 9 million

General conclusions from the updated VPA are:

- Weights-at-age used in GARM III were estimated from only the landed fraction of the catch and likely overestimated the true stock weights-at-age.

- The 2005 year class signal that appeared in the 2007/2008 survey indices was not evident in either later surveys or in the catch.

    - As of GARM III, the 2005 year class would have been unavailable to the fishery and the 2003 year class would have only been partially available to the fishery (PR patterns from GARM III suggest approx. 30%).

    - The entire signal of the 2005 year class and to some extent the 2003 year class was derived primarily from the survey indices. Compared to the GARM III VPA, the updated VPA estimate of the 2005 year class decreased by 66% and the 2003 year class decreased by 22%.

- **Relative to the 2010 update of the VPA assessment, the 2008 VPA assessment over estimated spawning stock biomass, the strength of incoming year classes and underestimated fishing mortality.**

It should be noted that the VPA model reviewed at GARM III was not alone in overestimating spawning stock biomass. An alternative statistical catch-at-age model (SCAA; Butterworth and Rademeyer, 2008) also reviewed at GARM III (but not accepted as the basis for stock determination) was even more optimistic with respect to stock determination. Admittedly, as described above, there were other issues that lead to the optimistic view of the resource at GARM III, namely the handling of the stock weights, but the assumptions about the strength of the incoming year class were the greatest contributor to the optimistic view of Gulf of Maine cod at GARM III. Both models reviewed at GARM III, the VPA and the SCAA, failed to account for the uncertainty in the 2003 year class and to a larger degree the 2005 year class. Problems predicting the strength of incoming year classes has historically plagued the Gulf of Maine cod assessment:

- From GARM II (NEFSC 2005):
    - *"The estimate of the strength of the 2003 year class <u>is very sensitive</u> to the MA DMF 2004 autumn age 1 index, included as the 2005 age 2 index in the VPA calibration. Exclusion of this single datum results in an estimate of 15 million fish vs. 22 million fish at age 1 in 2004. This value does not substantially affect the estimate of 2004 spawning stock biomass, but does influence starting conditions for projections."*

- From GARM III (Mayo et al. 2009):
    - *"…biomass indices began to increase substantially in 2001 and spring 2002, but the large apparent increase evident in autumn 2002 resulted from a single large haul unduly influencing the stratified mean."*
    - *"A retrospective pattern is also evident for age 1 recruitment estimates whereby recruitment was well overestimated for the 2001 and 2003 year classes…The estimate of the size of the 2005 year class appears to not suffer the same fate, as it is supported by an additional year of data in the present assessment…"*

Sensitivity of model results to assumptions of peak spawning period

During the NDDWG's review of the MADMF cod IBS survey data, time was spent evaluating the period of peak spawning in the Gulf of Maine. The available data suggests that peak cod spawning, particularly in the western Gulf of Maine where the stock is most heavily concentrated, seems to occur at the beginning of April and extend into May. Previous Gulf of Maine cod assessments, including the Run 10 VPA model examined in this report, have used an assumption that the spawning period occurs at the end of February/beginning of March. The assumption of an April 1 spawning period is likely a more accurate estimate for the Gulf of Maine stock. The impacts of this change were evaluated in the context of the Run 10 VPA by performing a sensitivity run that moved the spawning period to April 1 (Run 10g). This change has virtually no impact on estimates of F (Fig. 104) or recruitment (Fig. A.105) and only minor changes in SSB (Fig. A.106). Because the revised spawning period occurs later in the year, there is an additional month of natural mortality and fishing mortality prior to the spawning period, hence a decrease in estimated SSB. This change was examined by the Northern Demersal Models and Biological Reference Point Working Group (NDMBRPWG) and it was agreed that an April 1 spawning period would be used in the base case model.

Development of an ASAP statistical catch-at-age model

The use of a statistical catch-at-age model for the Gulf of Maine cod assessment was explored. More specifically, the statistical catch-at-age model, ASAP (Age Structured Assessment Program v2.0.20, Legault and Restrepo 1998), which can be obtained from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). The reasons for selecting the ASAP model include: 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 2008).

In developing the base ASAP model configuration over 20 preliminary models configurations were explored. These preliminary model configurations attempted to take advantage of ASAP's flexibility by handling commercial and recreational fleets separately and breaking out catch components into landings and discards. These complex model formulations suffered from strong residual patterning and/or overall model instability from being over-parameterized. Minor changes to model parameters would often lead to non-convergence. Moreover the model results from these complex models were nearly identical to some of the simpler models explored. A more in depth overview of these preliminary model configurations as well as other ASAP sensitivity runs is provided in Appendix 2. The difficulties encountered in these initial explorations led to a more parsimonious approach to the model formulation with the use of a single aggregated fleet (i.e., identical to the VPA). Sensitivity runs on these simpler model formulations examined the impacts of inclusion/exclusion of the MADMF fall and LPUE survey indices. Model performance and stock perception were robust to the inclusion/exclusion of these data and were therefore left out of the base ASAP configuration.

ASAP base model configuration (BASE)

A decision was made to use an age 9 plus group in the ASAP base model configuration (BASE). This decision was based on the difficulties of the VPA to precisely estimate older ages due to what appears to be continued 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. An 11^{+} ASAP sensitivity to the base configuration will be explored later.

Selectivity-at-age was freely estimated for each of the two fishery selectivity blocks, but the two NEFSC surveys were fixed at 1.0 for ages 6 and older (i.e., flat top selectivity) and the MADMF indices were fit using a double logistic functional form to capture the decreasing selectivity-at-age apparent in the VPA selectivity patterns. The choice of the flat-topped selectivity pattern for the NEFSC survey indices was informed in part by the VPA 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 (Table A.60). 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. 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 MENH 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.82). 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 NDDWG cursory examination of the Cod IBS survey length frequencies 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. The VPA results, however, do show some propensity for moderate doming in the fishery (Fig. A.95), but do not support the severe doming suggested by some models (e.g., Butterworth and Rademeyer 2008a). Further sensitivities to the doming assumptions will be explored later in this report. It should be noted that many of the preliminary ASAP runs allowed for domed survey selectivity and the results of these runs were generally similar to the ASAP BASE model results (Appendix 2).

Beginning with a single selectivity function for the fishery, model diagnostics were examined for trends in age composition residuals. With only one selectivity block (i.e., the same selectivity assumed for years 1982-2010), there were notable trends in age composition residuals with runs of positives and negatives. An additional selectivity block was introduced beginning in 1989 and several intermediate models were run exploring splits from 1989 to 1994. The period from 1989 to 1994 encompassed major changes in data availability, reporting sources and fisheries management. The model with a 1990/1991 split had the lowest objective function and offered improved fit to the age composition in the way of reduced residual patterning. The base model contains two fleet selectivity blocks: 1982-1990 (block 1) and 1991-2010 (block 2).

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 age 1 to age 5 and fixed at age 6 and older. 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 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 model but had little impact on the model results (e.g., see earlier models presented in Appendix 2 where survey CV vectors were not adjusted).

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 are explored in Appendix 2, but overall, the model results are robust to alternate estimates of catch precision.

ASAP base model (BASE) diagnostics

ASAP 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.109). A ESS of 75 on the fishery catch-at-age appeared reasonable (Fig. A.110), and achieved reasonable fits to the observed catch-at-age (Fig. A.111.a-d) with no large residual runs or obvious year class effects apparent in the residual patterning (Fig. A.112). Model fits to the observed mean catch-at-age are good, with a root mean square error (RMSE) of 1.28 (Fig. A.113). Fishery selectivities were moderately domed in both blocks (Fig. A.114). The selectivity patterns in block 1 are somewhat noisy and not well explained by biological or management-based mechanisms.

The overall fits to the survey indices were good, with the relationship of observed to predicted survey indices generally falling around the 1:1 equality line (Fig. A.115). Fits to the NEFSC spring survey index exhibited no strong residual patterning (Fig. A.116). 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 30 were generally supported by the modeled estimates (Fig. A.117) and decent fit of observed to predicted age compositions (Fig. A.118). There was no strong residual patterning to the index age composition fits (Fig. A.119), although there are some transient year class effects in the early to mid-1990s. Fits to the mean age were comparable to the fishery mean ages (Fig. A.120, RMSE=1.47) lending additional support to the input ESS.

Models fits to the NEFSC fall survey were better than the spring fits, with stronger coherence between the observed index and modeled estimate (Fig. A.121). ESS values of 30 are generally supported by the modeled estimates, though there is some suggestion of decreased ESS more recently in the time series (Fig. A.122). The fit to the age composition was good, with observed to predicted indices-at-age, generally falling around the 1:1 equality line (Fig. A.123) and very little patterning to the survey indices age composition residuals (Fig. A.124). 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.125) as suggested by the comparison of the input ESS to the modeled ESS values.

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.126). The modeled ESS is noisy, but overall, the input ESS appears reasonable (Fig. A.127). The

MADMF spring age compositions were not fit as well as the NEFSC surveys (Fig. A.128), with the magnitude of residuals being somewhat larger for this survey relative to the others, though no long runs of residuals (either positive or negative) are observed (Fig. A.129). Estimated mean ages were fairly close to the observed mean ages, with a RMSE of 1.32 (Fig. A.130).

The NEFSC fall survey exhibits higher selectivity at younger ages relative to the spring survey (Fig. A.131). Survey catchabilities (*q*) are presented in Figure A.132. 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 2 along with model independent estimates of total stock biomass which support the general scale of biomass estimated by the BASE model.

Additional ASAP sensitivity runs

Over ten different sensitivity runs were explored to evaluate the sensitivity of the ASAP model to alternate assumptions. A full documentation of the range of sensitivity runs is presented in Appendix 2. Four specific sensitivity runs that were critical to the final formulation of the BASE model are presented: sensitivity to the age of the plus group (BASE_11, a plus group at 11 instead of 9), assumptions about survey selection (flat top vs. dome; BASE_DOME), model starting points (e.g., including data before age composition information was available). Two different starting point assumptions were investigated: 1970 (BASE_1970), which extends the time series back to the start of the time series where survey age composition information is available; and, 1964 (BASE_1964), back to the start of modern landings statistics.

In all sensitivity runs the model configurations were kept identical to the BASE model except where noted. For the BASE_DOME run, survey selectivity on age 6 was fixed with the model allowed to freely estimate selectivity at all other ages. With the historical runs, the average weights-at-age from the period 1982 to 1990 (block 1) were extended backward to the beginning of the time series. Additionally, since hindcasted time series only extend as far back as 1982 for commercial discards and 1981 for recreational discards, a 25% ‘bump-up’ factor was applied to the ‘Total catch (mt)’ column in Table A.6 in the years prior to 1981. A summary of all sensitivity model configurations is provided in Table A.61.

The BASE model was insensitive to the plus group specification; the BASE and BASE_11 models achieved nearly identical results throughout the time series with respect to SSB (Fig. A.133), F (Fig. A.134) and age-1 recruitment (Fig. A.135). Fits to the total catch and aggregate survey indices were nearly identical between the two runs (Table A.62). 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.63). 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 age 9 as the plus group is supported.

Relative to the BASE model, the influence of allowing survey selectivities to be domed resulted in a positive rescaling of SSB (e.g., 21% increase in 2010 SSB) and a decrease in F, particularly in the second fishery block (1991-2010). There was virtually no change in estimated recruitment. The majority of the increase in SSB was driven by increases in the older ages (e.g., age 9^+, Fig. A.136) due to more severe doming of fishery selectivities (Table. A.63). 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 3 objective points.

The historical runs, BASE_1970 and BASE_1964, did not alter the perception of the stock. Nearly identical trends were observed in F (Fig. A137) and SSB (Fig. A.138). The small differences in F and SSB observed at the end of the series are being driven almost exclusively by differences in recruitment (Fig. A.139), as fleet and index selectivities are almost identical between the BASE run and the two historical runs. 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. There is a high degree of uncertainty in the recruitment estimates pre-1982 since they are driven solely off of survey age compositions run. Given the experience of the GARM III VPA update, caution should be taken in placing too much weight on recruitment estimates driven entirely off of survey information that cannot be corroborated with catch-at-age information.

ASAP base (BASE) model results

The ASAP BASE model configuration reflects the consensus opinion of the NDMBRPWG as the best model with which to evaluate stock status and provide catch advice. The assessment indicates that total SSB has ranged from 7,270 mt to 23,675 mt during the assessment time period, with current SSB in 2010 estimated at 11,868 mt (Table A.64, Fig. A.140). The base model estimates SSB in 2007 at 12,561, 37% of the 33,877 mt estimated at GARM III. Total biomass in 2010 is estimated at 20,589 mt and F's at the end of the time series are near historic highs (Fig. A.140) with the 2010 fully recruited, F_{full} = 1.14 and F_{5-7} = 1.10 (Table A.65). Fishing mortalities-at-age are presented in Table A.66. 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.

Recruitment over the past decade has been poor despite modest increases in SSB (Fig. A.141 and A.142). Age-1 recruitment has not exceeded 10 million fish since 1999 and has exceeded that threshold only twice in the past twenty years (Table A.67). While there is an absence of a well defined stock-recruit relationship there is some indication of a relationship. 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 15,000 mt annually. The current population structure is comprised primarily of fish that have not yet recruited to the fishery (fish age 1-3), with approximately 25% of the population age 4 and older (Table A.67 and Fig. A.143).

MCMC simulation was performed to obtain posterior distributions of the SSB, total B, F_{full} and F_{5-7} time series. Two MCMC chains of initial length 1 million were simulated with every 100^{th} value saved. The trace of each chain's saved draws suggests good mixing (Fig. A.144). The lagged autocorrelations showed decreasing correlation with increased lag with correlations < 0.1 beyond lag 6. Ultimately, a subsequent thin was applied by saving every 10^{th} value to create an MCMC chain with a length of 1000. Finally, the Gelman-Rubin potential scale reduction factor (psrf) was calculated for the time series of F_{5-7} and SSB. All psrf were between 1.0 and 1.01, which again, suggests convergence of the chains. As the MCMC simulations appear to have converged, 90% probability intervals (PI) were calculated to provide a measure of uncertainty for the model point estimates. Time series plots of the 90% PIs as well as plots of the posterior for B_{2010}, SSB_{2010} and $F_{5-7(2010)}$, F_{full} are shown in Figures A.145 through A.148. ASAP point estimates and the 90% PIs are reported below:

Metric	ASAP point estimate	90% probability interval
SSB_{2010} (mt)	11,868	9,479 - 16,301
B_{2010} (mt)	20,589	17,638 - 25,996
F_{full}	1.14	0.79 - 1.54
$F_{5\text{-}7}$	1.10	0.74 - 1.46

Retrospective analysis for the 2003-2010 terminal years indicates retrospective error in both F and SSB with the tendency for the model to underestimate F and overestimate SSB (Fig. A.149 and Fig. A.150). The F retrospective error ranged from -0.10 in 2009 to -0.52 in 2003 (Table A.68). SSB retrospective error ranged from 0.09 in 2009 to 0.90 in 2003. Retrospective error in age 1 recruitment varied from -0.07 in 2005 to 4.32 in 2003. It is worth noting the decreased retrospective pattern in Age 1 recruitment in the ASAP BASE run (Fig. A.151), relative to the updated VPA run (Run 10, Fig. A.97). The ASAP model does not exhibit nearly as severe a retrospective pattern in the recent period, particularly in the 2008 assessment peel (coinciding with the timing of the GARM III assessment). This suggests that had ASAP been used as the base model in GARM III, the assessment results would not have been as susceptible to the uncertainty in the 2007 and 2008 NEFSC spring survey indices. Retrospective statistics calculated using both seven year peels and five year peels are presented in Table A.68. However, the NDMBRPWG noted that the there was a notable shift in the retrospective pattern such that retrospective statistics (Mohn's rho) calculated using a five year peel (back to 2005) more accurately capture the current retrospective patterns.

Historical assessment retrospective

A comparison between the results of the current assessment (including the updated VPA for perspective) and the four previous assessment (SARC 53, GARM I, GARM II and GARM III) is provided in Figures A.152-A.155. 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 the most recent update, 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., weights-at-age) and not as a result of the assessment or choice of model. It is important to note that the updated VPA and ASAP BASE model achieve nearly identical results; however, given the capacity of the ASAP BASE model to better account for data uncertainty, it is considered the preferred model on which to base fisheries management advice.

Sensitivity analysis to assessment model (Butterworth & Rademeyer SCAA)

An additional statistical catch-at-age (SCAA) assessment model was considered by the NDMBRPWG (mathematical details of which are provided in Appendix 4). In the course of the NDMBRPWG meeting, attempts were made to bring the two models (based on an assessment time series of 1982-2010) into as close agreement as possible. The following list of items was identified as methodological differences between the two models.

- Equilibrium age structure under estimated F parameter (SCAA) versus freely estimated age structure (ASAP).

- Likelihood to fit indices (SCAA estimates an additional variance when fitting survey indices; described in Appendix 4)
- Likelihood for age compositions (SCAA adjusted lognormal, ASAP multinomial)
- Use of biomass (SCAA) versus abundance survey indices (ASAP) for tuning
- Use of Baranov (ASAP) versus Pope's approximation (SCAA) under high F conditions (model F's are near 1)

The NDMBRPWG was able to ascribe most of the differences between model estimates as likely due to the following three items: different estimates of selectivity (arising from likelihood form for age composition data), use of Pope's approximation rather than Baranov to estimate F, and the time of the year when SSB was calculated (0.25 in ASAP versus 0.1667 in SCAA). Of these three items, the only one that would require further research is the form of the likelihood. For the estimation of F, Baranov is preferred when fishing mortality rates are high.

A comparison of the results of the base ASAP (BASE) results to the SCAA results are presented below. In an effort to address one of the differences highlighted above, SCAA results are presented using both Baranov and Pope's approximation to estimate F. While the SCAA Baranov results were not reviewed by the NDMBRPWG, they do help address the difference noted above.

Biomass estimate	ASAP (BASE)		SCAA Pope		SCAA Baranov	
SSB_{1982} (mt)	23,675	(20,760 - 26,958)	31,549	(19,831 - 43,267)	30,294	(19,642 - 40,946)
SSB_{2010} (mt)	11,868	(9,479 - 16,301)	17,373	(13,713 - 21,033)	16,481	(11,695 - 21,267)
SSB_0 (mt)	171,417	(136,351 - 218,992)	214,258	(7,481 - 421,035)	188,342	(59,499 - 317,181)
SSB_{MSY} (mt)	54,247	(41,394 - 72,462)	68,118	(59,626 - 76,609)	65,943	(53,936 - 71,446)
MSY (mt)	10,691	(8,012 - 14,687)	10,250	(8,891 - 11,609)	10,107	(8,462 - 10,754)

**Note that ASAP reference points were not estimated internally within the model but estimated through long term projections described in TOR. Also, confidence intervals (CI) presented for ASAP are 90% CI, while the SCAA are 95% CI.*

At the close of the NDMBRPWG meeting, the group was comfortable that despite the structural differences between the two models, they were capable of producing similar results when configured similarly. The scale of the SCAA model is slightly higher than the ASAP (BASE) model, though the trends are similar. Thus, the SCAA model provided valuable feedback regarding model sensitivity to assumed error distributions, estimation of starting conditions, and selectivity fitting.

TOR A.4. Perform a sensitivity analysis which examines the impact of allocation of catch to stock areas on model performance (TOR-3).

Historically, the recreational fishery has been split between Georges Bank and Gulf of Maine. Since 1999, recreational landings of Atlantic cod have been predominately in the Gulf of Maine region (NEFSC 2008). The potential for misallocation of recreational landings is unknown, however, given the behavior of the recreational fleet operating in the Gulf of Maine, the magnitude of the impacts is likely to be small. The issue is misallocation of commercial landings is likely to be larger and have a greater impact on model performance. With respect to Gulf of Maine Atlantic cod, the allocation procedure itself does not contribute additional uncertainty as indicated by the low CVs on the allocated landings (Table A.7). A more likely source of allocation uncertainty arises from the misreporting of statistical area on VTRs.

The previously discussed work of Palmer and Wigley (2007, 2008, and 2010) suggests that these impacts are likely to be small (<5%), but consistently unidirectional (under-reporting of total Gulf Maine cod catch).

Sensitivity runs were conducted to bound the potential impacts of mis-allocation. Two sensitivity runs were conducted, one which inflated landings by 5% and another which decreased landings by 5%. Spawning stock biomass changed +/- 5% with no change in F. The 2010 estimates of SSB were within the 95% confidence intervals achieved from the MCMC estimate of uncertainty (9,479 – 16,301 mt; Fig. A.156).

TOR A.5. If time permits, consider the small-scale distribution of cod (e.g., spawning sites, resource distribution, fishing effort) in the Gulf of Maine and advise on its management implications.

Discussion related to resource distributions occurred throughout the NDDWG meeting as both surveys (NEFSC, MADMF, MENH, IBS) and fleet activity were reviewed. Given the full agenda, and extent of reanalysis of data, there was not an abundance of time available to delve into this TOR. The NDDWG did attempt to review as much with the time available. The main points relating to Gulf of Maine cod distributions discussed by the NDDWG are summarized below as bullet points:

• There is a body of work that has attempted to investigate small-scale distributions of Gulf of Maine cod. This work includes collaborative work between University of Massachusetts School for Marine Science and Technology (SMAST) and MADMF in the Cod Conservation Zone (CCZ) in the western Gulf of Maine; University of New Hampshire (UNH) research around the Whaleback Closure; and a longline sentinel survey from Downeast Maine.

• The studies in the western Gulf of Maine confirmed that many of the fish on the spawning aggregations show site fidelity; that the timing of the closures is appropriate; and that when fishing resumes at the end of the closure it can be very disruptive to the cod (interrupts any residual spawning because the fish rapidly disperse from the spawning grounds). Wandering from spawning grounds was detected with the aid of acoustic tags and arrays. It was suggested to evaluate the size of fish on the spawning ground as a function of when they arrive to see if large fish enter first with smaller fish moving in only towards the end of the spawning area closure. Feeding patterns could also be examined to see if that is the reason for wandering.

• Recreational fishermen are aware of the spawning sites but it is unclear whether they have always known about them, or whether they have just starting going there since the commercial vessels stopped. It would be interesting to plot VTR information for recreational data on a map of habitats to try to identify any patterns that might indicate the existence of other important spawning areas. It would also be interesting to identify whether there were physical, ecological characteristics that make these areas preferred habitat.

• UNH studies confirmed that spawning sites exist off the coast of New Hampshire and the Whaleback Closure encompasses the majority of the density identified in those studies.

• The Downeast Maine sentinel survey has completed some pilot field work. The longline survey sets approximately 2000 hooks/day for 30 days in summer with the goal of establishing a baseline of cod abudnance so that any rebuilding or recolonization of the Maine coast can be detected. The low abundance observed to date in the survey confirms distributions seen in annual plots for the ME-NH survey. These results are also consistent with the Northeast Regional Cod Tagging Program, which suggests that there few cod in the Downeast Maine region from 2003-2005.

• The MADMF IBS survey distribution data confirm the patterns seen in MADMF and NEFSC surveys, with cod moving offshore in the fall compared to the spring.

TOR A.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. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The existing MSY reference points are based on a spawning potential ratio (SPR) of 40%. The overfishing definition is $F_{MSY} = F_{40\%} = 0.237$. A stock is considered to be overfished if spawning biomass is less than half of SSB_{MSY}. The existing overfished definition is ½ SSB_{MSY} = ½ $SSB_{40\%}$ = 0.5 · 58,248 mt = 29,124 mt. A history of Gulf of Maine cod reference point values since 2001 is provided in Table A.2.

The existing MSY reference points were derived from a VPA model with a plus group at age 11. There are a number of reasons why new reference points are needed for the proposed base model for the current assessment including: the number of age classes modeled in the BASE model is 9 instead of 11 (this changes the weight and selectivity in the plus group), commercial and recreational discards are included (this changes the weights and selectivities at all ages), the parameters of the LW equation were re-estimated (this also affects weights at all ages), and the time elapsed before spawning was increased from 0.1667 to 0.25 (this affects discounting in YPR calculations).

The ASAP model has the capability to estimate a stock recruit function within the model; however, initial model runs attempting to fit a Beverton-Holt function were unsuccesful. Analytic model-based reference points are not estimable because there is insufficient contrast in the ASAP base model time series of estimated SSB and recruitment (1982-2010). There was consensus among the NDMBRPWG that a proxy reference point approach was the preferred method to estimate updated reference points given an assessment time series of 1982 to 2010. Yield per recruit (YPR) analysis was performed with a 3-year average of weights-at-age. The remaining YPR inputs were time invariant (maturity-at-age) or were constant in the most recent time block of the assessment model (selectivity). YPR inputs are summarized in Table A.69. The NDMBRPWG evaluated the sensitivity of YPR estimates to the number of years in the average weight calculation by comparing the results from the 3-year average approach to those of a 10-year average. The YPR estimates were insensitive to alternate averaging time blocks.

Despite the inability to estimate a stock recruit function, there was consensus that F_{MAX} was not a sensible overfishing reference point for the Gulf of Maine cod. Use of F_{MAX} implies that there is no relationship between spawners and recruits. In the context of the current Gulf of Maine cod assessment, not having contrast in the data series to reliably estimate a stock recruit function is not saying that there is no relationship between spawners and recruits. Given the consensus that F_{MAX} was not acceptable as a reference point, the working group debated what would be an appropriate %SPR for the resource.

The current reference points were derived at GARM-III, and are based on $F_{40\%}$. The decision to use $F_{40\%}$ as a proxy for F_{MSY} was endorsed by the independent reviewers at the GARM III meeting, who wrote that *"If the recruitment and spawning stock biomass derived from the assessments are not informative about a relationship, the Panel recommended use of F40%MSP as a proxy for FMSY (NEFSC 2002) and a* B_{MSY}

proxy computed using the stochastic projection approach (herein termed the 'non-parametric' approach)" (NEFSC 2008, p979). Furthermore, it was noted that $F_{40\%}$ is supported by published studies on sustainability (NEFSC 2008; Overholtz et al. 1986; Gabriel et al. 1989; Clark 1991; Clark 1993; Goodyear 1993; Clark 2002). It was pointed out by a member of the NDMBRPWG that the published studies focused on F_{MSY} proxies that emphasized sustainability while minimizing yield loss rather than the implications for rebuilding and that the use of $F_{40\%}$ does not fully consider the biomass implications of the overfishing proxy. There were different views within the NDMBRPWG as to the relative priorities of focusing on sustainability and minimization of yield loss, versus implications for biomass targets and rebuilding. With respect to the yield minimization argument, the updated estimate of $F_{40\%}$ was nearly the same as $F_{0.1}$ (0.20 versus 0.21 respectively). The amount of SSB that corresponds to $F_{40\%}$ is 61,218 mt, whereas the 1982-2010 time series of spawning biomass estimates from the preferred ASAP model is 7,270 mt – 23,675 mt. While the SSB_{MSY} reference point is outside the range of SSB that has been seen in model estimates, it should be noted that the model begins in 1982 while the Gulf of Maine cod stock has been exploited for centuries and may already be quite depleted. If the stock is highly depleted within the years modeled, one would not expect to have observed SSB on the scale of estimated SSB_{MSY}. Given the limited contrast in model estimates from the past 30 years there are few data to support estimation of unexploited conditions. Nevertheless, there was consensus that extrapolation beyond the range of ASAP estimates of SSB was necessary to define SSB_{MSY}. This decision, and the observation that reference points would be beyond abundance levels observed since 1982, is consistent with the conclusions from the working group that re-evaluated biological reference points for New England groundfish at GARM II (NEFSC 2002a).

Survey data were examined to determine if there was support for a positive relationship between spawners and recruits. There was a weak trend for higher age 1 fall survey indices to be associated with larger fall survey biomass indices (Fig. A.157). The working group agreed that this analysis provided some additional support that recruitment is higher when spawning abundance is higher, however the question of an appropriate %SPR could not be resolved from this work. An alternative exploratory analysis to address this question considered historical catch and survey data. Although the ASAP preferred model begins in 1982, sensitivity models were conducted during the working group meeting that began in either 1970 or 1964 that could potentially provide more contrast in SSB and recruitment. The working group decided to look at the 1970 run rather than the 1964 run, because there is survey age composition beginning in 1970 from which recruitment fluctuations could be estimated. The 1970 sensitivity run provides some evidence that larger recruitment was associated with higher spawning biomass (Fig. A.158). A Beverton-Holt stock recruit relationship was fit within ASAP for the model that began in 1970 as an exercise to determine whether there was sufficient contrast with the additional data to inform the group about productivity and an appropriate %SPR (Fig. A.159). The 1970 ASAP sensitivity model was able to estimate a Beverton-Holt stock recruit relationship, and the residual diagnostics were not unreasonable (Fig. A.160). The estimate of steepness was 0.89 and the implied unexploited conditions were 315,152 mt. The estimate of F_{MSY}, and corresponding $\%SPR_{MSY}$, from this exercise informed the decision about an appropriate $F_{\%SPR}$ proxy. The estimate of F_{MSY} from the 1970 ASAP run was 0.24, which corresponds to a %SPR in the YPR analysis of about 35%.

The proxies for F_{MSY} that were debated were $F_{22\%}$ (F_{MAX}), $F_{35\%}$ (F_{MSY} in the 1970 ASAP sensitivity run), and $F_{40\%}$ (status quo). Ultimately, the SARC Panel did not feel that there was sufficient justification for the $F_{35\%}$ approach. An $F_{40\%}$ approach will be used for reference point determination.

To arrive at estimates for $SSB_{40\%}$ and corresponding MSY, long term projections were run, sampling from the empirical distribution of recruitment estimates from the preferred ASAP model (recruitment estimates from 1982-2008, final two years excluded). Based on suggestions made by the SARC 53 Panel, the modeling approach used to estimate reference points in GARM III was modified to better account for uncertainty in projections at low stock sizes. Identical to the modeling used in GARM III, 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. For all projections, the threshold SSB was set at 7.3 thousand mt, which coincides with the lowest observed SSB in the time series. To approximate the distribution of the SSB and MSY distributions, the long term projections were made from 1000 estimates of NAA in 2011, which were estimated by performing MCMC simulation of the ASAP base model (described above under TOR 3). The resulting reference points and their 90% confidence intervals corresponding to $F_{MSYproxy}$=$F_{40\%}$=0.20 are SSB_{MSY} = 61,218 mt (46,905 – 81,089 mt), MSY = 10,392 mt (7,825 – 14,146 mt). All projections were conducted with the AGEPRO software (Age Structured Projection Model v4.1).

TOR A.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.

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 existing peer reviewed assessment model is a VPA. A meticulous bridge was built from the existing VPA model structure to the updated VPA model structure. The updated VPA model, which includes changes to the catch (inclusion of discards), weights-at-age, etc., estimates that in SSB_{2010} is 12,270 mt. This is less than the existing overfished threshold of 29,124 mt; therefore, the stock is overfished. The updated VPA estimate of average fishing mortality on ages 5-7, $F_{(5\text{-}7)2010}$ is 1.48, while the fully recruited F from the VPA is F_{full}=2.46. These are both greater than the overfishing limit, 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).

The revised reference points are $F_{MSYproxy}$=$F_{40\%}$=0.20 and SSB_{MSY} = 61,218 mt (0.5xSSB_{MSY} = 30,609 mt). The proposed ASAP base model 2010 estimate of SSB is 11,868 mt. This is less than the overfished threshold of 30,609 mt; therefore, the stock is overfished. The estimate of 2010 average fishing mortality on ages 5-7 from ASAP is $F_{5\text{-}7}$=1.10, while the fully recruited F_{2010} is 1.14. This is greater than the overfishing limit of 0.20, and therefore, overfishing is occurring.

The NDMBRPWG reached consensus that the stock status determination offered by the ASAP base model was preferred. However, given the retrospective pattern for the base model, alternative stock status determinations were conducted based on retrospective adjustments to F_{full} and SSB_{2010} to account for the relative model bias observed in the retrospective patterns over the past 5 years. Retrospective adjustments were accomplished using Equations 13 and 14.

(13) $SSB_{2010adjusted} = SSB_{2010}/(1+\boldsymbol{\rho_{SSB}})$

(14) $F_{full2010adjusted} = F_{mult2010}/(1+\boldsymbol{\rho_{F}})$

where:
$\boldsymbol{\rho}_{SSB}$ = Mohn's rho for spawning stock biomass (from Table A.68)
$\boldsymbol{\rho}_{F}$ = Mohn's rho for F_{full} (from Table A.68)

Accounting for the retrospective pattern does not result in a change of stock status (Table A.70), though the revised stock status phase plot (Fig. A.161) shows that the revised point lies just inside the confidence intervals of the unadjusted point. The precedence established at GARM III (NEFSC 2008) was to only make retrospective adjustments when the adjusted point fell outside the confidence intervals of the unadjusted point. Based on the GARM III precedence, the SARC 53 Panel recommended that stock status determination should not be based on adjusted estimates of SSB and F.

For both the existing VPA model with respect to existing reference points and the new proposed ASAP base model with respect to updated reference points, the stock is overfished and overfishing is occurring. Consequently, for both models and reference point sets, the stock is not rebuilt.

TOR A.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).

TOR A.8.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 pattern. This rationale was identical to that of stock status determination. Numbers-at-age in 2011 were derived from 1000 different vectors of numbers-at-age produced from the MCMC chain. Short term projections have assumed catch in 2011 to be equal to the catch in 2010. The NDMBRPWG concluded that this was a reasonable assumption given that the total ACLs in these two years were similar (2010=8,088 mt, 2011=8,545 mt).

Recruitment was sampled from a cumulative density function (CDF) of estimated age 1 recruitment from 1982 to 2008. 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 7.3 thousand mt). The NDMBRPWG did not support the use of hindcasted recruitment for the same reasons they rejected the historical ASAP sensitivity runs; recruitment estimates based solely on survey information have proven unreliable to use as the basis for stock determination. Projections were run under three different F assumptions: $F_0 = 0.00$, $F_{MSYproxy} = F_{40\%} = 0.20$, and $F_{75\%FMSY} = 0.15$.

Projection results are summarized in terms of median SSB and fishery catch (yield) under all three scenarios outlined above in Table A.71. Under even the most optimistic scenario in terms of rebuilding (F_0), the stock cannot rebuild to SSB_{MSY} by the current rebuilding date of 2014. Plots showing the most optimistic (F_0, unadjusted) and pessimistic ($F_{40\%}$) scenarios in terms of rebuilding are shown in Figure A.162.

TOR A.8.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 major uncertainties are the moderate retrospective patterns that have been observed over the last five years. Given these patterns, there is additional uncertainty in catch advice based on these projections. Moreover, the projections will be sensitive to realized recruitment. Recent recruitment has been weak with no strong recruitment observed in the last twenty years. Continued weak recruitment will impede the ability for this stock to rebuild. Given the poor performance of past projections beyond a time period of two to three years, the longer term projections presented in this report should be considered highly uncertain.

TOR A.8.c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

Uncertainties that were not accounted for by assessment and reference point models were evaluated using model diagnostics. Standard model diagnostics (e.g., residual analyses, retrospective analyses) were used for model validation. Vulnerabilities that were not accounted for by assessment and reference point models were evaluated using exploratory modeling, habitat observations and preliminary results from studies conducted in the spawning closure areas. Those studies indicate strong site fidelity to the spawning grounds, and the almost immediate disruption of spawning activity when those areas are opened. This would suggest that area closures to protect spawning grounds is beneficial and could reduce vulnerability. Additional considerations of vulnerability and productivity are the implications of shifts in distribution, recruitment dynamics and increased natural mortality. Consumption of Atlantic cod by other fishes and mammals may be increasing as predator populations increase, however empirical evidence is lacking to support testing this hypothesis directly. A considerable source of additional vulnerability is the continued weak recruitment and low reproductive rate (e.g., recruits per spawner) of Gulf of Maine cod. If weak recruitment and low reproductive rate continues, productivity and rebuilding of the stock will be less than projected.

TOR A.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.

Previous from GARM I (October 2002)

- Explore a VPA formulation where autumn tuning indices are adjusted back to Jan 1, instead of shifted forward one year and one age.
    - *Unknown whether this was explicitly addressed during GARM II. This will not be explored in this benchmark, but alternate models (e.g., ASAP) which allow for explicit definition of survey timing will be explored.*

- Given the overall truncation in the age composition, investigate possible trends in size/age composition of the inshore versus offshore areas.
    - *Unknown whether this was explicitly addressed during GARM II. The size/age composition of the present period has expanded relative to the size/age composition observed during the mid/late-1990s.*

- Request the Methods Working Group to investigate means of deriving an appropriate sampling intensity for commercial landings.
    - *NOAA Toolbox Biostat software includes an option to estimate CVs associated with the landings-at-age. This provides a precision-based approach to determining the sufficiency of the commercial biosampling effort.*

- Explore the use of the state of Maine – New Hampshire Inshore Trawl Survey as tuning indices.
    - *These surveys have not historically been used. There is no explicit age information available for this survey, and as such, no age-specific indices. The survey information*

was examined by the NDDWG, and specific avenues for further exploration are listed as a new research recommendation (see below).

Previous from GARM II (August 2005)

- For the 2008 benchmark assessment use biological data from the Cod Industry Based Survey (IBS) in the Gulf of Maine.
    - *The previous assessment applied the ALK information to the recreational fishery; however, the age data are limited in their temporal coverage and the timing of the IBS does not coincide well with the recreational fishery. For this reason, these data were not used in the updated assessment.*
    - *Additionally, sampling of the commercial discards and landings was largely sufficient during the 2004 – 2007 period, such that the augmented information from the IBS has little utility.*
    - *The NDDWG did review the IBS data to corroborate the general presumptions on spawning activity in the Gulf of Maine. The IBS collected spawning condition male and females in the western Gulf of Maine during the March-May time period.*

Previous from GARM III (August 2008)

- As with Georges Bank cod, 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.
    - *This research recommendation was discussed by the Northern Demersal Models and BRP Working Group (NDMBRPWG). For the same reasons the group recommended against extending the base ASAP model out beyond years when age information was available, the group concluded that it was not appropriate to hindcast the recruitment time series.*

New from SAW 53

- Further pursue the incorporation of the Maine – New Hampshire Inshore Trawl 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. The Data Working Group suggested exploration of the maturity information collected by this survey to examine agreement with the NEFSC maturity ogives.

- Examine the reproductive information collected from the Maine/New Hampshire inshore trawl 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.

- 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.

- 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.

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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 ten 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+

Table A.2. Summary of the results of the Gulf of Maine Atlantic cod assessments over the last ten 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, $F_{MSY}=F_{40\%}$.

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]	78,000 (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

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, 1500 lbs/day			
05/01/98	Framework 25				700 lbs/day		WGOM (Jeffreys Ledge, Stellwagen Bank)	
06/25/98					400 lbs/day			
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			
05/28/99					30 lbs/day			
08/03/99	Interim rule				100 lbs/day			
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
11/22/06	FW 42			24		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				Common pool: 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
07/30/10					Common pool: 200 lb/day (1000 lb/trip)			
09/22/10					Common pool: 100 lb/day (1000 lb/trip)			
10/18/10					Handgear A: 50 lb/trip			

Table A.4. Summary of the number of Atlantic cod otiliths sampled from Northeast Fisheries Science Center (NEFSC) surveys from 1970 to 2011 by stock, survey and age. Otiliths that have not been aged are not included in this summary.

Age	Gulf of Maine		Georges Bank	
	Spring	Fall	Spring	Fall
0	5	175	140	519
1	403	935	1177	2014
2	996	1499	2966	2394
3	1308	1429	2816	1755
4	1325	1037	2183	964
5	830	526	1341	342
6	480	278	672	186
7	251	118	322	84
8	97	69	171	53
9	74	41	76	16
10	36	23	43	19
11	19	14	26	6
12	21	9	12	7
13	11	5	4	4
14	12	6	5	
15	1	2	3	
16	2	1	1	
18	1		1	

Table A.5. Summary of the number of Atlantic maturity samples taken from Northeast Fisheries Science Center (NEFSC) spring survey from 1970 to 2011 by year.

Year	Males	Females
1970	47	57
1971	23	40
1972	33	52
1973	0	0
1974	36	67
1975	45	78
1976	78	74
1977	70	88
1978	37	64
1979	109	132
1980	35	56
1981	117	111
1982	78	95
1983	79	68
1984	41	66
1985	47	81
1986	45	57
1987	79	48
1988	96	91
1989	70	76
1990	57	58
1991	63	71
1992	52	62
1993	45	63
1994	62	46
1995	39	36
1996	58	60
1997	60	63
1998	73	55
1999	85	76
2000	87	79
2001	47	80
2002	124	138
2003	156	121
2004	25	42
2005	52	52
2006	70	66
2007	85	127
2008	61	80
2009	154	235
2010	118	130
2011	46	58

Table A.6. Estimates of total catch (mt) of Atlantic cod from the Gulf of Maine stock complex by fleet (commercial, recreational) and disposition (landed, discarded). Estimates of both United States (US) and foreign fleet catch are shown.

Year	US recreational landings (mt)	US recreational discards (mt)	US commercial discards (mt)	US commercial landings (mt)	Foreign fleet landings (mt)	Foreign fleet discards (mt)	Total catch (mt)
1964	--	--	--	3217.4	25.0	--	3242.4
1965	--	--	--	3611.5	148.0	--	3759.5
1966	--	--	--	3841.1	384.0	--	4225.1
1967	--	--	--	5526.6	297.0	--	5823.6
1968	--	--	--	6076.0	61.0	--	6137.0
1969	--	--	--	7828.4	327.0	--	8155.4
1970	--	--	--	7511.7	449.0	--	7960.7
1971	--	--	--	7192.5	282.0	--	7474.5
1972	--	--	--	6786.1	141.0	--	6927.1
1973	--	--	--	6061.1	77.0	--	6138.1
1974	--	--	--	7425.4	125.0	--	7550.4
1975	--	--	--	8676.1	112.0	--	8788.1
1976	--	--	--	9877.7	16.0	--	9893.7
1977	--	--	--	11992.8	0.0	0.0	11992.8
1978	--	--	--	11890.1	0.0	0.0	11890.1
1979	--	--	--	10972.3	0.0	0.0	10972.3
1980	--	--	--	12514.9	0.0	0.0	12514.9
1981	5417.5	83.0	--	12381.6	0.0	0.0	17882.2
1982	3805.7	35.9	1135.2	13465.9	0.0	0.0	18442.6
1983	2379.5	77.5	1169.4	13867.4	0.0	0.0	17493.8
1984	1699.3	73.1	1209.9	10725.3	0.0	0.0	13707.7
1985	3727.1	74.3	1360.5	10645.3	0.0	0.0	15807.1
1986	2607.3	44.5	1359.5	9669.6	0.0	0.0	13681.0
1987	4788.7	211.7	1245.0	7526.2	0.0	0.0	13771.5
1988	2277.7	59.7	957.2	7948.2	0.0	0.0	11242.8
1989	2635.9	335.4	1101.1	10550.7	0.0	0.0	14623.1
1990	3027.5	294.0	2198.2	15439.7	0.0	0.0	20959.4
1991	3080.4	299.8	933.5	17959.0	0.0	0.0	22272.7
1992	841.2	156.3	943.8	11019.4	0.0	0.0	12960.8
1993	1364.9	449.4	812.4	8366.7	0.0	0.0	10993.4
1994	972.8	443.5	280.8	8030.2	0.0	0.0	9727.3
1995	844.3	423.9	314.9	6606.8	0.0	0.0	8189.9
1996	672.3	357.2	200.4	7019.8	0.0	0.0	8249.8
1997	314.7	259.1	115.0	5432.1	0.0	0.0	6120.9
1998	475.6	318.5	99.5	4074.3	0.0	0.0	4967.9
1999	777.7	315.9	1382.1	1407.4	0.0	0.0	3883.1
2000	1301.4	606.9	1281.3	3771.8	0.0	0.0	6961.4
2001	2651.6	1002.9	2040.9	4314.4	0.0	0.0	10009.8
2002	1691.5	1264.6	1772.0	3638.3	0.0	0.0	8366.5
2003	2166.1	1245.0	1037.6	3865.6	0.0	0.0	8314.4
2004	1613.1	816.0	860.6	3782.3	0.0	0.0	7072.0
2005	1775.1	1081.7	431.0	3557.6	0.0	0.0	6845.4
2006	844.7	623.9	498.4	3029.4	0.0	0.0	4996.5
2007	1054.1	1128.1	275.7	3989.8	0.0	0.0	6447.8
2008	1575.7	1283.8	514.5	5443.5	0.0	0.0	8817.5
2009	1676.1	1247.4	1041.8	5952.9	0.0	0.0	9918.2
2010	3506.0	2288.9	241.1	5356.4	0.0	0.0	11392.4

Table A.7. Estimates of total United States landings of Gulf of Maine Atlantic cod from 1994 to 2010 and the coefficient of variation (CV) associated with the landings allocation procedure (AA tables, Wigley et al. 2008).

Year	Landings (mt)	CV
1994	8030.2	0.003
1995	6606.8	0.012
1996	7019.8	0.003
1997	5432.1	0.003
1998	4074.3	0.003
1999	1407.4	0.007
2000	3771.8	0.003
2001	4314.4	0.002
2002	3638.3	0.003
2003	3865.6	0.002
2004	3782.3	0.003
2005	3557.6	0.002
2006	3029.4	0.002
2007	3989.8	0.001
2008	5443.5	0.001
2009	5952.9	0.001
2010	5356.4	0.003

Table A.8. Estimates of total United States landings of Gulf of Maine Atlantic cod utilized for home consumption from 1994 to 2010. These estimates are obtained from information reported on Vessel Trip Reports (VTRs).

Year	Commerical landings (mt)	VTR home consumption (mt)	Percentage of total commercial landings (%)
1994	8030.2	0.9	0.01
1995	6606.8	3.5	0.05
1996	7019.8	8.3	0.12
1997	5432.1	3.2	0.06
1998	4074.3	3.3	0.08
1999	1407.4	4.0	0.29
2000	3771.8	5.3	0.14
2001	4314.4	6.7	0.16
2002	3638.3	6.6	0.18
2003	3865.6	6.3	0.16
2004	3782.3	4.0	0.10
2005	3557.6	3.1	0.09
2006	3029.4	2.4	0.08
2007	3989.8	1.6	0.04
2008	5443.5	2.0	0.04
2009	5952.9	1.2	0.02
2010	5356.4	3.6	0.07

Table A.9. Total number of Gulf of Maine Atlantic cod biological samples taken from the commercial landings by market category and year from 1969 to 2010.

Year	Large (0811)				Market (0813)				0814				Total
	Quarter				Quarter				Quarter				
	1	2	3	4	1	2	3	4	1	2	3	4	
1969													
1970					1								1
1971													
1972													
1973													
1974								1	1				2
1975										1		1	2
1976													
1977		1	1			1	2	1	1	1	3	3	14
1978			1		2	2	2	1	3	2	1		14
1979						1	2	1	1		1	2	8
1980									3	1	1		5
1981			1				1	3	1	1	1	3	11
1982		2	1	2	2	2	3	1	2	3	3	2	23
1983	1	2	2	2	3	3	3	1	3	3	3	3	29
1984	1	6	3	2	4	3	5	6	7	5	6	7	55
1985	7	5	3	6	9	6	7	4	5	6	7	5	70
1986	1	5	4	3	5	6	8	3	5	5	6	3	54
1987	4	2	3	1	4	5	3	5	5	4	3	4	43
1988	1	2	2		1	5	3	5	4	2	4	4	33
1989	2	1	1	1	4	2	5	4	3	3	4	3	33
1990		2	1		4	7	4	3	3	7	3	5	39
1991		3	3	1	5	11	12	3	2	10	4	4	58
1992	3	1	1	4	6	7	7	3	2	8	6	3	51
1993	1	1	2	1	1	2	4	1	3	3	3	1	23
1994		2	3	2	1	6	3	5		2	2	4	30
1995		3		1	2	8	2	2	4	3	2	4	31
1996	1	2	3	3	6	9	11	11	5	4	7	9	71
1997	2	8	2	2	12	11	10	9	7	13	3	10	89
1998	1		2	1	9	9	9	5	4	7		3	50
1999	2				3	1	1		6				13
2000				1	16	14	5	9	13	6	5	7	76
2001	2	15	18	20	4	10	8	16	4	4	4	7	112
2002	50	8	16	19	16	3	6	5	3	2		1	129
2003	50	34	34	33	14	8	25	19	5	1	17	8	248
2004	37	20	11	27	18	23	15	15	17	11	6	22	222
2005	21	41	72	64	14	15	22	19	23	29	33	16	369
2006	48	49	62	63	17	21	18	12	15	8	8	3	324
2007	43	73	102	60	7	14	18	17	10	6	11	8	371
2008	58	72	73	71	12	15	13	11	13	7	5	7	357
2009	61	97	114	135	10	17	20	37	9		2	14	516
2010	79	52	77	33	30	22	42	21	4	2		9	371

Table A.10. Total number of Gulf of Maine Atlantic cod lengths sampled from the commercial landings by market category and year from 1969 to 2010. 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	7828.4	6867.0
1970					100								287				387	7511.7	1941.0
1971																		7192.5	
1972																		6786.1	
1973																		6061.1	
1974	102							101									203	7425.4	3657.8
1975		186		62													248	8676.1	3498.4
1976														101		56	157	9877.7	6291.5
1977	101	66	402	1012		277	371	64		80	152						2525	11992.8	475.0
1978	407	455	65		370	304	500	100			55						2256	11890.1	527.0
1979	56		58	116		100	237	188									755	10972.3	1453.3
1980	213	100	51										212				576	12514.9	2172.7
1981	52	57	81	236			82	471			210						1189	12381.6	1041.3
1982	401	488	484	308	418	309	665	345		208	64	158	97	102	122		4169	13465.9	323.0
1983	712	626	578	253	396	1021	583	200	56	205	514	97		53			5294	13867.4	261.9
1984	344	271	342	378	396	264	443	551	75	552	204	105	94				4019	10725.3	266.9
1985	263	352	449	241	837	565	677	351	542	341	263	403					5284	10645.3	201.5
1986	229	264	319	160	520	608	834	329	75	279	269	183					4069	9669.6	237.6
1987	281	232	165	271	344	490	351	399	157	150	258	90					3188	7526.2	236.1
1988	298	99	215	249	59	539	291	481	59	194	135						2619	7948.2	303.5
1989	154	170	201	174	401	204	506	***409***	195	102	104	98					2718	10550.7	388.2
1990	156	362	165	260	409	715	370	300		136	108						2981	15439.7	517.9
1991	100	533	192	215	514	1034	***1137***	275		302	273	101					4676	17959.0	384.1
1992	***118***	443	320	180	633	725	592	263	297	142	75	298					4086	11019.4	269.7
1993	159	173	174	55	97	173	393	106	65	87	141	63		67			1753	8366.7	477.3
1994		102	107	181	97	576	324	567		184	322	198					2658	8030.2	302.1
1995	211	196	107	249	170	807	215	224		280		98					2557	6606.8	258.4
1996	278	275	491	691	596	961	1165	1178	68	200	303	280					6486	7019.8	108.2
1997	520	848	188	751	1235	1071	991	880	190	539	201	145					7559	5432.1	71.9
1998	295	383		101	911	951	1103	436	99		175	82					4536	4074.3	89.8
1999	385				311	108	58		***211***								1073	1407.4	131.2
2000	694	304	294	426	1588	1167	409	924				115					5921	3771.8	63.7
2001	189	215	216	404	428	984	697	1548	172	474	892	898					7117	4314.4	60.6
2002	106	80		39	1365	260	411	395	1192	397	524	494					5263	3638.3	69.1
2003	254	66	214	73	1121	705	1762	1402	1179	1432	1583	1688					11479	3865.6	33.7
2004	361	299	233	73	1384	1887	1288	994	2049	***1419***	283	940	25				11235	3782.3	33.7
2005	73	193	324	506	919	1095	1384	1362	790	709	1330	1478		61	180		10404	3557.6	34.2
2006	494	167	294	125	1291	1412	1075	753	***1552***	871	1348	1388					10770	3029.4	28.1
2007	291	174	315	293	584	1188	1521	1488	654	811	1887	1417			66		10702	3989.8	37.3
2008	536	251	203	85	969	1403	1196	927	712	1314	1753	1573					10922	5443.5	49.8
2009	407		62	141	800	1601	1791	2601	954	1656	2304	2554					14871	5952.9	40.0
2010	150	53		199	2679	1762	2788	1741	1428	2106	2561	1984					17451	5356.4	30.7

Table A.11. Total number of Gulf of Maine Atlantic cod ages sampled from the commercial landings by quarter from 1977 to 2010.

	Quarter					Landings (mt)	Metric tons/100 ages
Year	1	2	3	4	Total		
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

Table A.12. 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 were 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

Table A.13. Total commercial landings-at-age (numbers) of Gulf of Maine Atlantic cod from 1982 to 2010.

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	Total
1982	0	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	0	0	0	0	4,995,975
1983	0	0	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	0	0	5,501,666
1984	0	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	0	0	3,908,675
1985	0	0	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	0	0	3,698,380
1986	0	0	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	0	0	3,591,812
1987	0	442	193,735	627,766	1,116,907	267,706	64,579	45,981	5,481	8,410	9,270	182	607	0	2,129	0	0	2,343,195
1988	0	0	167,468	1,356,369	907,960	400,942	58,792	21,864	20,247	3,257	2,438	1,213	0	0	606	0	0	2,941,157
1989	0	0	322,130	1,486,592	1,354,890	451,857	70,570	58,876	7,931	2,238	9,000	3,945	0	1,127	1,127	0	0	3,770,281
1990	0	0	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	0	0	0	6,537,855
1991	0	0	198,915	609,915	4,543,525	904,421	138,556	42,961	25,983	7,877	4,698	2,571	0	0	0	0	0	6,479,420
1992	0	0	302,552	527,720	432,280	1,969,905	213,021	77,420	5,837	4,488	1,042	0	0	0	0	0	0	3,534,267
1993	0	0	25,866	1,543,228	729,548	92,745	464,198	37,780	11,264	0	0	0	0	0	0	0	0	2,904,629
1994	0	0	29,014	1,055,313	1,170,244	240,940	63,586	69,917	28,114	6,108	384	1,008	0	0	0	0	0	2,664,627
1995	0	0	183,724	938,703	1,056,404	207,195	28,494	6,521	17,992	580	2,228	0	0	0	0	0	0	2,441,841
1996	0	0	55,763	507,349	1,763,068	375,559	35,144	3,903	413	845	0	0	0	0	0	0	0	2,742,043
1997	0	0	77,455	434,378	435,036	800,750	67,415	5,368	2,080	393	636	0	0	0	0	0	0	1,823,511
1998	0	0	87,919	391,916	544,744	139,369	187,088	27,507	4,853	1,495	762	0	0	0	0	0	0	1,395,142
1999	0	0	2,858	179,688	191,438	66,127	23,995	22,398	7,504	1,035	0	0	0	0	0	0	0	513,615
2000	0	0	102,341	258,469	501,545	124,105	66,295	9,007	6,465	0	0	0	0	0	0	0	0	1,074,447
2001	0	0	43,737	471,763	326,442	206,475	65,902	38,490	5,509	8,803	1,006	0	0	0	0	0	0	1,168,126
2002	0	0	1,439	111,287	433,957	170,415	102,971	41,667	12,019	3,750	4,055	434	80	0	40	0	0	885,817
2003	0	0	8,113	47,543	198,476	380,859	120,697	52,001	19,769	9,173	4,250	2,812	472	0	0	0	0	844,165
2004	0	0	492	142,749	130,172	220,142	170,502	52,305	26,442	13,941	6,789	1,414	620	0	0	0	0	765,569
2005	0	0	1,217	37,890	423,154	64,419	178,040	83,220	21,459	12,366	5,056	3,125	1,817	500	0	0	0	832,264
2006	0	0	777	115,306	181,958	300,653	21,412	62,692	29,111	10,477	5,994	2,537	1,242	953	180	0	0	733,291
2007	0	0	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	0	1,045,711
2008	0	0	4,142	283,069	465,757	600,316	53,944	82,494	2,490	6,652	3,224	986	473	367	234	104	21	1,504,273
2009	0	0	2,700	283,610	718,934	333,800	199,827	16,653	20,518	857	2,311	1,072	952	224	127	61	49	1,581,695
2010	0	0	1,683	121,449	578,192	463,641	114,076	59,845	8,069	2,947	446	476	162	112	17	28	0	1,351,144

Table A.14. Coefficients of variation (CV) associated with the Gulf of Maine Atlantic cod commercial landings estimates of numbers-at-age from 1982 to 2010. 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	
Average		0.43	0.11	0.07	0.10	0.14	0.19	0.27	0.37	0.44	0.42	0.47	0.48	0.85	0.90	1.22

Table A.15. Relative differences in the estimates of Gulf of Maine Atlantic cod numbers-at-age from the 2008 Groundfish Assessment Review Meeting (GARM) assessment compared to the current assessment (through 2007). Differences are expressed relative to the 2008 assessment numbers-at-age (*negative differences indicate fewer numbers-at-age in the updated assessment*). The current assessment uses a 9^{+} group.

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+	Total
1982		-0.08	-0.03	0.00	-0.02	-0.02	**-0.26**	**-0.24**	-0.03	0.06	**7.17**	**-0.78**	-0.02
1983			-0.04	0.02	0.01	-0.02	-0.03	-0.06	-0.05	**0.12**	**0.42**	**-0.22**	0.00
1984		**-0.30**	-0.05	-0.01	0.00	-0.09	0.01	**0.30**	**-0.52**	**0.12**	**0.29**	**0.14**	-0.01
1985			-0.05	0.00	0.01	-0.02	-0.04	-0.06	0.01	-0.01	-0.03	**-0.18**	-0.01
1986			0.02	0.01	0.01	-0.04	-0.09	-0.01	**0.15**	-0.01	**0.19**	0.02	0.00
1987		**-0.78**	**-0.10**	0.06	0.01	-0.03	-0.02	-0.10	**-0.39**	0.05	**0.16**	-0.03	0.00
1988			0.05	-0.06	-0.05	-0.01	**0.37**	**1.43**	**0.19**	**2.26**	**0.22**	**0.82**	-0.03
1989			-0.04	-0.06	-0.07	0.01	**-0.13**	**0.68**	**0.32**	**-0.25**	**0.80**	**-0.11**	-0.05
1990			0.03	-0.01	0.08	0.05	-0.03	-0.06	**-0.18**	**-0.23**	0.07	0.04	0.02
1991			**-0.42**	**-0.35**	0.09	0.06	-0.03	0.05	**-0.13**	**0.31**	**3.70**	**1.57**	-0.01
1992			-0.03	0.00	**-0.11**	-0.02	0.05	**0.25**	**-0.17**	**-0.63**	**-0.65**		-0.03
1993			**-0.66**	0.04	**0.14**	**-0.28**	0.02	**0.35**	**0.88**	**-1.00**			0.03
1994			**-0.23**	-0.04	0.05	**-0.21**	-0.09	**-0.17**	-0.04	-0.07	**-0.36**	**-0.16**	-0.03
1995		**-1.00**	**-0.17**	0.06	0.02	-0.07	0.06	**-0.53**	-0.02	**-0.28**	**0.39**	**-1.00**	0.00
1996			**-0.19**	-0.01	0.01	0.03	-0.04	**-0.11**	**-0.17**	**-0.30**			0.00
1997			-0.02	-0.02	0.02	0.00	-0.01	0.07	**-0.20**	**0.31**	-0.09	**-1.00**	0.00
1998			-0.06	-0.01	0.03	-0.05	0.06	0.09	**0.28**	**2.74**	**-0.31**	**-1.00**	0.01
1999			-0.01	-0.02	0.09	**-0.19**	**0.48**	0.00	**2.26**		**-1.00**		0.02
2000			0.01	0.01	0.00	0.02	-0.04	**-0.19**	**0.18**				0.00
2001			-0.05	-0.02	0.01	-0.03	-0.03	0.00	-0.03	-0.05	**0.12**	**-1.00**	-0.02
2002			**-0.10**	-0.03	-0.01	-0.01	-0.03	-0.03	-0.01	-0.06	-0.03	**0.39**	-0.02
2003			**0.16**	-0.01	-0.03	-0.03	-0.03	-0.03	-0.04	-0.02	**-0.11**	-0.03	-0.03
2004			-0.02	-0.08	-0.02	-0.02	-0.04	-0.03	-0.05	-0.05	**-0.13**	-0.03	-0.04
2005			0.01	-0.04	-0.03	-0.01	-0.02	-0.02	-0.05	-0.06	-0.08	-0.01	-0.03
2006			**-0.22**	-0.04	-0.05	-0.02	-0.04	-0.05	-0.05	-0.05	-0.05	-0.02	-0.04
2007			-0.04	-0.05	-0.02	-0.02	-0.05	-0.06	-0.08	-0.05	-0.08	-0.04	-0.03

Table A.16. Mean weights-at-age (kg) of commercially landed Gulf of Maine Atlantic cod from 1982 to 2010. The current assessment uses a 9^+ group.

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	5.55	8.478	10.152	11.016	13.209	12.519	16.891	20.103	16.834	

Table A.17. Fraction of observed Gulf of Maine Atlantic cod discarded by gear from the commercial fishery from 1989 to 2010. Gears contributing greater than 5% of the total observed discards in any year are shaded grey.

Year	Total observed landings (mt)	Fraction of total observed landings								
		Longline	Handline	Otter trawl (mt)		Shrimp trawl	Sink Gillnet (mt)			Other
				Small mesh (< 5.5")	Large mesh (>= 5.5")		Small mesh (< 5.5")	Large mesh (5.5 - 7.99")	Extra large mesh (>= 8.0")	
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

Table A.18. Total number of Gulf of Maine trips (statistical areas 464, 465, 467, 511-515) observed by gear from 1989 to 2010. *In 2010, the number of observed trips includes 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		1049
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	1339
2005	58	69	534	17	505	251	1438
2006	36	24	209	20	109	35	435
2007	36	16	234	14	92	46	443
2008	20	12	260	19	130	49	490
2009	35	22	428	12	271	30	801
2010	52	30	685	15	1080	379	2250

Table A.19. Estimates of total Gulf of Maine Atlantic cod commercial discards (mt) by gear from 1982 to 2010 by gear. Estimates from 1989 to 2010 were estimated using an approach consistent with the Standardized Bycatch Report Methodology (Wigley et al., 2007). Estimates from 1982 to 1989 were hindcasted using an approach documented in this report.

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")	
1982			882.9	144.0	108.3		1135.2
1983			904.5	160.1	104.9		1169.4
1984			861.4	228.6	120.0		1209.9
1985			943.4	311.2	105.9		1360.5
1986			853.5	380.6	125.5		1359.5
1987			774.1	345.9	125.1		1245.0
1988			612.0	216.7	128.5		957.2
1989		6.1	677.3	256.4	161.2		1101.1
1990		0.9	1567.6	410.7	219.0		2198.2
1991	0.3	0.8	621.1	205.2	106.0		933.5
1992	8.0	0.0	778.7	48.9	108.2		943.8
1993	281.7	0.0	370.8	6.3	153.6		812.4
1994			163.8	7.5	105.1	4.3	280.8
1995		8.3	152.5	4.0	129.7	20.3	314.9
1996		3.3	25.1	3.0	145.2	23.7	200.4
1997		16.6	27.9	4.7	59.1	6.8	115.0
1998			11.6		82.4	5.5	99.5
1999		11.6	826.5		536.0	8.1	1382.1
2000			789.0		473.8	18.5	1281.3
2001		0.2	873.0	0.0	1113.5	54.2	2040.9
2002		16.4	868.6		828.6	58.4	1772.0
2003	66.4	22.0	553.8	2.6	321.8	71.0	1037.6
2004	7.9	2.9	532.4	0.9	231.8	84.6	860.6
2005	123.9	3.8	166.0	1.1	109.5	26.7	431.0
2006	47.7	2.6	337.7	0.3	94.3	15.8	498.4
2007	67.3	2.0	102.6	0.9	83.6	19.3	275.7
2008	58.4	6.1	343.1	0.2	84.8	21.8	514.5
2009	19.1	2.1	719.9	0.1	263.2	37.4	1041.8
2010	11.6	6.3	159.6	0.3	52.6	10.6	241.1

Table A.20. Coefficients of variation (CV) of the Gulf of Maine Atlantic cod commercial discard (mt) estimates from 1982 to 2010 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

Table A.21. Length sampling of commercially discarded Gulf of Maine Atlantic cod from 1989 to 2010 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 and 2007/08 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	1191.4	30.3
1990			**		587	818	607	31	138	3			2184	2065.5	94.6
1991	*		**		706	124	397		65	30			1322	882.2	66.7
1992	*		**		924	924	401	10	78	130			2467	786.2	31.9
1993	48		**		68	866	591		90	223			1886	808.7	42.9
1994					194		563	40	274	112		7	1190	331.8	27.9
1995				69	225	473	377	3	60	147	20	3	1377	303.8	22.1
1996			52	19	15	73	44	21	109	31	16	20	400	205.4	51.3
1997			7***		104	1	17*****		34	11	1	2	177	113.1	63.9
1998					5****				43	40	9	3	100	98.9	98.9
1999				6***		220			130	1156		14	1526	1359.5	89.1
2000					248	85			125	157	6	6	627	1317.2	210.1
2001			***		61	647			223	144	3	4	1082	2062.8	190.6
2002				192	104	1162			412	845	1	39	2759	1775.0	64.3
2003	718		173	131	1109	234	192		603	1352	38	205	4755	1022.1	21.5
2004	197		103	519	385	771	76		1165	1524	27	536	5303	783.1	14.8
2005	2283	147	180	183	986	2939	70		190	663	47	104	7792	493.3	6.3
2006	880	3	43	9	1899	339	96		44	59	6	15	3393	465.1	13.7
2007	817	327	1	62	1172	1103	12******		91	310	53	164	4112	278.3	6.8
2008	958			18	2316	1639	42******		142	73	72	26	5286	512.1	9.7
2009	552	187		22	2219	1744	2******		502	112	7	15	5362	1114.4	20.8
2010	153	16		51	502	291	5******		140	91	5	5	1259	262.1	20.8

**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.22. Comparison of the survey-filter discard estimates to direct observed 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.23. Total commercial discards-at-age (numbers) of Gulf of Maine Atlantic cod from 1982 to 2010.

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	Total
1982	774	460,286	1,531,482	297,532	67,450	0	0	0	0	0	0	0	0	0	0	0	0	2,357,524
1983	18,159	744,885	1,699,037	210,576	7,181	0	0	0	0	0	0	0	0	0	0	0	0	2,679,838
1984	24,361	460,440	1,914,404	290,974	0	0	0	0	0	0	0	0	0	0	0	0	0	2,690,179
1985	89,337	610,285	1,542,183	685,210	0	0	0	0	0	0	0	0	0	0	0	0	0	2,927,015
1986	23,683	969,318	2,017,781	275,912	63,622	0	0	0	0	0	0	0	0	0	0	0	0	3,350,316
1987	134,239	334,731	1,822,277	538,068	0	0	0	0	0	0	0	0	0	0	0	0	0	2,829,315
1988	4,593	536,739	1,518,625	363,884	30,807	0	0	0	0	0	0	0	0	0	0	0	0	2,454,648
1989	57	209,741	977,661	552,886	66,761	6,435	1,737	628	136	0	0	0	0	0	0	0	0	1,816,042
1990	0	81,184	713,847	2,142,719	245,748	1,583	288	0	0	0	0	0	0	0	0	0	0	3,185,369
1991	4,335	154,094	326,022	208,120	362,857	31,219	1,185	264	0	618	27	0	0	0	0	0	0	1,088,742
1992	31,737	486,120	641,320	371,300	42,957	122,173	3,704	149	18	0	0	0	0	0	0	0	0	1,699,477
1993	35,427	132,795	494,162	376,468	111,699	59	853	234	0	0	0	0	0	0	0	0	0	1,151,695
1994	15,645	158,501	121,606	183,292	18,866	1,022	292	337	0	0	0	0	0	0	0	0	0	499,562
1995	15,429	99,830	75,644	136,776	55,399	4,938	516	0	0	0	0	0	0	0	0	0	0	388,532
1996	29,423	42,167	28,696	31,258	48,465	8,716	824	127	97	678	0	0	0	0	0	0	0	190,451
1997	1,963	87,725	43,264	36,158	6,794	17,807	973	155	0	0	0	0	0	0	0	0	0	194,839
1998	874	3,211	45,521	26,513	17,262	2,019	1,920	103	0	0	0	0	0	0	0	0	0	97,424
1999	84	77,765	46,795	101,460	101,444	84,261	25,772	29,390	4,940	42	0	0	0	0	0	0	0	471,951
2000	0	14,578	255,521	161,043	178,505	33,596	10,391	1,887	403	0	0	0	0	0	0	0	0	655,924
2001	0	779	221,436	238,047	151,127	114,237	29,397	12,083	1,821	1,633	0	0	0	0	0	0	0	770,560
2002	0	13,780	35,005	124,276	195,369	74,510	46,563	19,469	12,574	4,998	4,246	355	289	0	0	0	0	531,434
2003	30,493	40,583	83,948	68,681	189,556	130,314	24,613	7,147	2,550	1,056	405	260	20	0	0	0	0	579,627
2004	249	174,381	96,238	312,825	55,809	54,352	24,355	5,413	2,414	715	290	112	14	0	0	0	0	727,167
2005	1,980	26,156	105,365	48,176	154,881	4,379	10,928	3,603	758	584	195	221	100	54	0	0	0	357,379
2006	272	14,287	41,688	225,318	53,609	75,277	3,367	2,818	2,565	117	43	6	0	1	0	0	0	419,369
2007	543	14,198	70,560	89,836	78,281	6,614	4,329	65	70	8	0	2	0	0	0	0	0	264,506
2008	560	12,761	86,808	150,817	84,695	57,850	2,229	1,752	96	24	34	33	0	0	0	0	0	397,659
2009	108	7,594	69,851	223,112	190,796	74,844	35,721	967	1,689	17	45	9	0	11	0	0	0	604,762
2010	265	7,836	35,552	73,500	36,932	21,035	4,396	1,234	20	0	0	0	0	0	0	0	0	180,771

Table A.24. Mean weights-at-age (kg) of commercially discarded Gulf of Maine Atlantic cod from 1982 to 2010.

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	0.000	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	0.022	0.281	0.989	1.218	1.718	1.880	1.935	2.106	3.476								

Table A.25. Proportion of recreationally caught (Type A, B1 and B2) Gulf of Maine Atlantic cod by mode and area as estimated by the Marine Recreational Fishing Statistical Survey from 1981 to 2010. **The summary only includes catch from Maine, New Hampshire and Massachusetts. The 'Shore' category includes man-made and beach catch.*

Year	Party/charter			Private/rental			Shore	
	Inland	Ocean <= 3 miles	Ocean > 3 miles	Inland	Ocean <= 3 miles	Ocean > 3 miles	Inland	Ocean <= 3 miles
1981	4.1	6.0	53.7	3.1	27.5	5.3	0.2	0.1
1982	0.0	2.4	46.1	10.3	31.8	8.9	0.1	0.3
1983	1.2	1.5	34.6	1.4	40.0	20.1	0.5	0.7
1984	0.6	5.4	35.6	3.2	28.1	26.4	0.5	0.2
1985	0.0	7.4	26.9	12.8	25.6	26.6	0.6	0.2
1986	0.2	8.5	59.2	4.6	12.4	9.6	0.1	5.4
1987	0.0	18.5	52.5	0.9	14.3	13.8	0.0	0.0
1988	1.0	3.3	35.6	3.0	8.5	46.9	0.0	1.7
1989	5.1	5.3	36.7	22.5	7.8	22.5	0.0	0.1
1990	0.7	5.4	53.4	2.0	10.0	26.8	0.2	1.4
1991	0.0	0.1	33.7	5.3	9.6	51.2	0.0	0.1
1992	0.0	0.0	38.9	2.4	8.7	47.3	0.2	2.6
1993	0.0	0.8	66.3	3.1	10.5	19.4	0.0	0.0
1994	0.3	1.7	36.7	17.3	15.6	28.4	0.0	0.0
1995	0.0	3.9	69.0	4.2	5.4	17.4	0.0	0.0
1996	1.6	2.7	55.5	1.0	5.5	33.7	0.0	0.0
1997	1.4	8.7	65.5	2.4	4.5	17.4	0.0	0.1
1998	0.0	4.6	56.8	1.7	8.6	28.3	0.0	0.0
1999	0.0	3.1	51.3	0.5	11.1	33.9	0.0	0.1
2000	0.6	0.6	50.6	4.4	16.0	27.7	0.0	0.1
2001	2.4	0.7	24.1	12.1	19.6	40.8	0.1	0.1
2002	0.0	0.3	16.8	2.9	23.2	56.6	0.0	0.1
2003	0.1	0.0	26.5	0.2	10.7	62.5	0.0	0.0
2004	0.3	0.9	20.9	5.8	10.3	61.8	0.2	0.0
2005	0.0	0.2	28.6	2.5	12.2	56.5	0.1	0.0
2006	0.0	0.2	52.0	3.2	13.9	30.6	0.0	0.1
2007	0.0	0.5	34.6	18.5	1.7	44.5	0.2	0.0
2008	0.2	0.0	34.0	13.0	1.9	50.9	0.0	0.0
2009	1.6	0.0	37.9	4.9	0.5	55.0	0.0	0.0
2010	0.5	0.0	14.3	7.8	0.8	76.6	0.0	0.0

Table A.26. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by month from 1994 to 2010. 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.

	Month											
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	0.29	0.18	0.10	0.09	0.11	0.06	0.00	0.00
2010	0.00	0.00	0.00	0.14	0.26	0.24	0.12	0.13	0.08	0.04	0.00	0.00
Average	0.00	0.01	0.02	0.15	0.21	0.17	0.14	0.13	0.10	0.05	0.01	0.01

Table A.27. Proportion of recreationally caught (Type A, B1 and B2) Gulf of Maine Atlantic cod by sampling wave as estimated by the Marine Recreational Fishing Statistical Survey from 1981 to 2010.

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	0.03	0.36	0.09	0.28	0.24
2005	0.27	0.33	0.20	0.11	0.09
2006	0.20	0.33	0.26	0.16	0.05
2007	0.19	0.29	0.22	0.13	0.16
2008	0.17	0.52	0.18	0.13	0.01
2009	0.11	0.49	0.13	0.11	0.16
2010	0.50	0.28	0.11	0.10	0.01

Table A.28. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by statistical area from 1994 to 2010.

	Area								
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	0.49	0.46	0.05	
Average	0.00	0.00	0.00	0.00	0.00	0.39	0.55	0.05	

Table A.29. Proportion of recreationally landed Gulf of Maine Atlantic cod reported on Vessel Trip Reports (VTRs) by state from 1994 to 2010.

	State								
Year	CT	MA	ME	NH	NJ	NK	NY	RI	VA
1994	0.00	0.59	0.32	0.08	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.72	0.18	0.10	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.69	0.21	0.10	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.63	0.25	0.12	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.59	0.27	0.14	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.67	0.19	0.14	0.00	0.00	0.01	0.00	0.00
2000	0.00	0.67	0.17	0.16	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.71	0.13	0.16	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.64	0.11	0.24	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.66	0.14	0.19	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.60	0.12	0.26	0.00	0.00	0.00	0.01	0.00
2005	0.00	0.56	0.10	0.33	0.00	0.00	0.00	0.01	0.00
2006	0.00	0.55	0.13	0.32	0.00	0.00	0.00	0.00	0.00
2007	0.00	0.48	0.17	0.34	0.00	0.00	0.01	0.00	0.00
2008	0.00	0.52	0.15	0.34	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.50	0.17	0.33	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.50	0.12	0.37	0.00	0.00	0.00	0.00	0.00
Average	0.00	0.60	0.17	0.22	0.00	0.00	0.00	0.00	0.00

Table A.30. Length sampling intensity of recreationally landed (Type A, and B1) Gulf of Maine Atlantic cod by semester and year as estimated by the Marine Recreational Fishing Statistical Survey from 1981 to 2010. 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	A,B1 estimated numbers (000s)	AB1 Landings (mt)	Lengths per 1000 fish	mt per 100 lengths
	1	2					
1981	355	366	721	2650.0	5417.5	0.3	751.4
1982	320	276	596	1849.2	3805.7	0.3	638.5
1983	609	560	1169	1257.8	2379.5	0.9	203.6
1984	394	391	785	910.8	1699.3	0.9	216.5
1985	272	155	427	1633.9	3727.1	0.3	872.8
1986	77	90	167	990.1	2607.3	0.2	1561.2
1987	167	367	534	2031.1	4788.7	0.3	896.8
1988	325	213	538	1272.3	2277.7	0.4	423.4
1989	208	352	560	1203.0	2635.9	0.5	470.7
1990	160	210	370	1254.5	3027.5	0.3	818.2
1991	377	83	460	1377.8	3080.4	0.3	669.7
1992	710	268	978	321.6	841.2	3.0	86.0
1993	136	200	336	766.6	1364.9	0.4	406.2
1994	333	485	818	529.6	972.8	1.5	118.9
1995	663	434	1097	509.6	844.3	2.2	77.0
1996	585	515	1100	350.6	672.3	3.1	61.1
1997	190	392	582	139.8	314.7	4.2	54.1
1998	447	215	662	194.3	475.6	3.4	71.8
1999	111	117	228	248.9	777.7	0.9	341.1
2000	70	77	147	1233.1	1301.4	0.1	885.3
2001	124	121	245	1018.3	2651.6	0.2	1082.3
2002	181	196	377	551.4	1691.5	0.7	448.7
2003	361	322	683	613.0	2166.1	1.1	317.2
2004	422	473	895	531.9	1613.1	1.7	180.2
2005	391	382	773	589.0	1775.1	1.3	229.6
2006	681	155	836	227.0	844.7	3.7	101.0
2007	479	220	699	307.0	1054.1	2.3	150.8
2008	590	231	821	475.7	1575.7	1.7	191.9
2009	852	488	1340	477.9	1676.1	2.8	125.1
2010	621	508	1129	1004.8	3506.0	1.1	310.5

Table A.31. Percentage of recreationally discarded (Type B2) Gulf of Maine Atlantic cod by mode and area as estimated by the Marine Recreational Fishing Statistical Survey from 1981 to 2010. **The summary only includes catch from Maine, New Hampshire and Massachusetts. The 'Shore' category includes man-made and beach catch.*

Year	Party/charter			Private/rental			Shore	
	Inland	Ocean <= 3 miles	Ocean > 3 miles	Inland	Ocean <= 3 miles	Ocean > 3 miles	Inland	Ocean <= 3 miles
1981	0.0	0.0	15.8	11.2	63.2	9.7	0.1	0.0
1982	0.0	0.0	44.3	1.1	26.1	28.6	0.0	0.0
1983	0.0	0.5	14.5	10.0	54.4	16.9	0.0	3.7
1984	0.0	2.5	26.3	0.0	45.0	24.6	1.1	0.5
1985	0.0	22.6	35.3	2.0	3.3	35.8	1.0	0.0
1986	0.7	16.4	36.5	5.8	19.4	21.2	0.0	0.0
1987	0.0	28.7	47.3	2.0	8.4	13.7	0.0	0.0
1988	1.9	4.2	49.1	1.1	12.5	31.1	0.0	0.2
1989	3.5	6.5	37.2	13.8	8.2	30.4	0.0	0.3
1990	1.7	6.0	43.8	2.3	7.9	37.7	0.2	0.5
1991	0.0	0.1	35.4	3.8	9.3	50.9	0.0	0.4
1992	0.0	0.0	34.2	5.2	7.3	49.9	0.5	2.9
1993	0.0	0.8	65.0	4.1	13.9	16.2	0.0	0.0
1994	0.4	1.2	36.6	21.7	13.4	26.7	0.0	0.0
1995	0.0	5.0	67.8	4.2	6.1	16.7	0.0	0.0
1996	0.6	2.5	55.5	1.5	5.7	34.1	0.0	0.0
1997	2.6	9.7	56.4	3.5	6.0	21.8	0.0	0.0
1998	0.0	5.9	51.9	2.2	11.5	28.4	0.0	0.0
1999	0.0	2.6	43.6	0.8	10.9	41.9	0.0	0.2
2000	0.6	0.7	48.0	2.9	18.5	29.2	0.0	0.1
2001	3.3	0.7	21.3	13.0	22.0	39.2	0.2	0.3
2002	0.0	0.2	13.8	2.9	25.0	57.9	0.0	0.2
2003	0.1	0.0	22.9	0.2	11.9	64.9	0.0	0.0
2004	0.0	0.9	15.9	6.4	10.7	65.8	0.3	0.0
2005	0.0	0.2	26.5	2.9	13.1	57.3	0.1	0.0
2006	0.0	0.1	49.3	3.9	13.3	33.2	0.0	0.1
2007	0.0	0.1	32.8	15.2	1.7	50.0	0.2	0.0
2008	0.2	0.0	33.1	14.1	2.2	50.4	0.0	0.0
2009	1.3	0.0	35.3	5.3	0.3	57.7	0.0	0.0
2010	0.4	0.1	13.3	9.1	0.9	76.3	0.0	0.0

Table A.32. Length sampling intensity of recreationally discarded (Type B2) Gulf of Maine Atlantic cod by semester and year as estimated by the Marine Recreational Fishing Statistical Survey from 2005 to 2010. 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	1260.3	1849.3	1.0	208.1
2006	952	599	1551	683.4	910.4	2.3	162.9
2007	728	846	1574	1030.1	1337.1	1.5	216.2
2008	1258	709	1967	1162.8	1638.5	1.7	156.4
2009	765	889	1654	1057.0	1534.9	1.6	216.2
2010	715	1024	1739	1874.3	2879.1	0.9	243.2

Table A.33. Estimates of Gulf of Maine Atlantic cod recreational catch in numbers (000's) and weight (mt).

Year	Landings (000s)			Discards (000s)	Total catch	Landings (mt)	Discards (mt)	Total catch (mt)	Discard/landings
	Type A	Type B1	Total	Type B2	(000s)	Types A+B1	Type B2		ratio
1981	2059.9	590.1	2650.0	191.8	2841.9	5417.5	83.0	5500.6	0.07
1982	512.1	1337.2	1849.2	94.7	1943.9	3805.7	35.9	3841.6	0.05
1983	499.7	758.1	1257.8	230.3	1488.2	2379.5	77.5	2457.0	0.18
1984	465.1	445.7	910.8	196.7	1107.5	1699.3	73.1	1772.5	0.22
1985	439.5	1194.4	1633.9	199.6	1833.5	3727.1	74.3	3801.4	0.12
1986	38.4	951.6	990.1	121.5	1111.6	2607.3	44.5	2651.8	0.12
1987	520.6	1510.5	2031.1	566.7	2597.8	4788.7	211.7	5000.3	0.28
1988	179.2	1093.1	1272.3	176.4	1448.7	2277.7	59.7	2337.4	0.14
1989	563.8	639.1	1203.0	572.1	1775.1	2635.9	335.4	2971.3	0.48
1990	172.7	1081.7	1254.5	472.7	1727.1	3027.5	294.0	3321.5	0.38
1991	268.5	1109.3	1377.8	410.4	1788.2	3080.4	299.8	3380.2	0.30
1992	171.2	150.5	321.6	239.1	560.7	841.2	156.3	997.5	0.74
1993	210.2	556.4	766.6	751.2	1517.8	1364.9	449.4	1814.3	0.98
1994	176.9	352.8	529.6	718.9	1248.6	972.8	443.5	1416.2	1.36
1995	332.9	176.7	509.6	682.7	1192.3	844.3	423.9	1268.2	1.34
1996	144.0	206.6	350.6	450.8	801.4	672.3	357.2	1029.5	1.29
1997	34.9	104.9	139.8	300.2	440.0	314.7	259.1	573.8	2.15
1998	36.0	158.3	194.3	383.0	577.3	475.6	318.5	794.1	1.97
1999	94.8	154.1	248.9	475.8	724.7	777.7	315.9	1093.6	1.91
2000	66.6	456.2	522.8	921.0	1443.8	1301.4	606.9	1908.3	1.76
2001	186.6	831.7	1018.3	1312.0	2330.3	2651.6	1002.9	3654.4	1.29
2002	120.9	430.5	551.4	1089.1	1640.6	1691.5	1264.6	2956.1	1.98
2003	199.0	413.9	613.0	1108.0	1721.0	2166.1	1245.0	3411.2	1.81
2004	156.8	375.0	531.9	895.7	1427.6	1613.1	816.0	2429.1	1.68
2005	81.2	507.8	589.0	1260.3	1849.3	1775.1	1081.7	2856.8	2.14
2006	82.0	144.9	227.0	683.4	910.4	844.7	623.9	1468.6	3.01
2007	65.8	241.2	307.0	1030.1	1337.1	1054.1	1128.1	2182.3	3.36
2008	106.3	369.4	475.7	1162.8	1638.5	1575.7	1283.8	2859.6	2.44
2009	131.1	346.7	477.9	1057.0	1534.9	1676.1	1247.4	2923.5	2.21
2010	68.1	936.7	1004.8	1874.3	2879.1	3506.0	2288.9	5794.9	1.87

Table A.34. Percent standard error (PSE) of recreation catch (A, B1 and B2) number estimates by state as estimated by the Marine Recreational Fishing Statistical Survey from 1991 to 2010 for Gulf of Maine Atlantic cod. **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	26.2	13.6	10.3
2005	11.1	13.3	12.9
2006	8.1	8.5	8.3
2007	19.7	11.4	15.7
2008	13.2	7.2	9.3
2009	20.3	7.0	15.2
2010	16.5	11.7	21.7

Table A.35. Total recreational landings-at-age (numbers) of Gulf of Maine Atlantic cod from 1982 to 2010.

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	Total
1981	0	210,719	822,198	819,693	562,058	92,170	56,148	9,740	38,693		33,079	0	5,513	0	0	0	0	2,650,011
1982	1,034	91,749	568,082	577,515	355,926	174,538	19,778	33,649	17,805	5,275	776	0	3,103	0	0	0	0	1,849,230
1983	0	20,032	423,731	455,861	172,162	102,920	60,785	7,798	6,540	2,385	1,865	1,076	2,690	0	0	0	0	1,257,845
1984	0	15,749	301,723	303,427	186,475	54,654	31,802	12,404	523	563	470	840	0	580	1,547	0	0	910,757
1985	0	47,383	496,811	590,776	201,619	165,874	51,269	45,808	21,465	2,973	7,424	425	1,354	717	0	0	0	1,633,898
1986	0	28,604	161,182	475,797	168,493	53,476	55,436	12,599	14,459	8,495	4,840	1,170	4,330	1,170	0	0	0	990,051
1987	0	22,785	470,809	699,099	617,743	104,822	33,528	47,319	12,120	11,411	8,558	2,536	380	0	0	0	0	2,031,110
1988	0	4,228	266,933	606,546	304,394	63,112	11,652	4,986	8,093	0	0	2,365	0	0	0	0	0	1,272,309
1989	0	4,874	157,121	587,640	327,141	86,361	20,468	14,695	1,790	2,864	0	0	0	0	0	0	0	1,202,954
1990	0	3,789	54,176	606,059	398,543	117,733	49,813	6,006	15,822	2,543	0	0	0	0	0	0	0	1,254,484
1991	0	4,867	47,573	205,657	944,862	142,988	15,043	16,657	0	0	193	0	0	0	0	0	0	1,377,840
1992	0	2,834	28,937	58,851	47,476	166,030	13,683	3,565	261	0	0	0	0	0	0	0	0	321,637
1993	0	2,580	57,738	463,710	179,997	14,210	43,481	4,848	0	0	0	0	0	0	0	0	0	766,564
1994	0	640	18,822	327,802	139,397	33,069	3,240	5,352	809	498	0	0	0	0	0	0	0	529,629
1995	0	33	47,779	251,839	194,943	13,413	1,378	0	258	0	0	0	0	0	0	0	0	509,643
1996	0	0	16,148	87,181	219,140	26,632	1,146	46	0	319	0	0	0	0	0	0	0	350,612
1997	0	104	6,758	42,394	28,364	57,024	4,835	46	256	0	0	0	0	0	0	0	0	139,781
1998	293	0	12,541	71,242	71,385	15,554	21,353	1,491	424	0	0	0	0	0	0	0	0	194,283
1999	0	744	7,142	72,122	82,218	52,603	13,003	19,558	1,489	0	0	0	0	0	0	0	0	248,879
2000	0	0	70,791	175,323	220,497	34,113	14,359	2,701	5,035	0	0	0	0	0	0	0	0	522,819
2001	0	0	57,044	520,864	288,724	113,637	23,149	12,505	1,778	625	0	0	0	0	0	0	0	1,018,326
2002	0	0	417	77,874	315,043	98,889	32,135	12,971	8,151	1,059	1,959	0	2,925	0	0	0	0	551,423
2003	0	0	6,580	50,108	201,240	253,366	55,395	24,393	10,064	6,835	1,576	2,323	1,101	0	0	0	0	612,981
2004	0	0	136	138,126	101,929	180,992	82,273	16,548	6,553	2,472	1,656	315	854	0	0	0	0	531,854
2005	0	0	4,192	62,854	369,984	26,230	76,351	30,524	8,436	6,029	2,110	1,094	855	330	0	0	0	588,989
2006	0	0	201	35,969	57,035	94,415	6,201	17,180	8,975	3,445	2,108	765	414	222	49	0	0	226,979
2007	0	0	1,782	36,186	188,443	25,996	42,834	1,959	3,639	2,813	1,410	746	396	602	98	110	0	307,014
2008	0	0	4,906	115,771	153,245	126,610	34,762	33,064	1,835	2,607	2,897	0	0	0	0	0	0	475,697
2009	0	0	1,888	91,438	201,011	82,381	81,770	4,107	10,406	259	2,081	1,150	1,129	238	0	0	0	477,858
2010	0	0	20,250	186,460	408,587	282,673	74,903	18,879	6,230	2,818	445	0	3,560	0	0	0	0	1,004,805

Table A.36. Mean weights-at-age (kg) of recreationally landed Gulf of Maine Atlantic cod from 1982 to 2010.

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
1981		0.341	0.995	1.524	2.915	4.715	5.645	5.861	8.359		12.340		18.100				
1982	0.022	0.372	0.848	1.401	2.209	5.362	6.956	9.733	8.989	11.010	11.547		21.416				
1983		0.378	0.791	1.398	2.401	3.772	6.032	6.748	8.395	9.633	15.186	19.306	19.183				
1984		0.372	0.775	1.365	2.668	4.005	5.348	6.560	6.551	8.958	11.746	13.514		17.785	27.100		
1985		0.346	0.752	1.281	2.811	5.310	6.770	8.646	11.256	11.851	12.244	8.049	9.298	8.332			
1986		0.376	0.672	1.589	2.771	5.308	7.418	8.583	11.188	11.842	14.268	14.577	22.392	14.577			
1987		0.243	0.900	1.472	2.696	4.196	8.163	10.977	11.302	12.674	13.143	13.835	8.332				
1988		0.170	0.787	1.528	2.188	4.549	4.413	5.123	10.615			10.175					
1989		0.539	0.989	1.500	2.700	4.579	6.191	8.716	7.610	17.137							
1990		0.132	0.916	1.439	2.261	4.966	7.351	8.500	10.659	13.166							
1991		0.180	1.088	1.499	2.025	3.388	6.934	13.033			3.838						
1992		0.106	1.361	1.716	2.541	2.923	4.437	9.321	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	5.377	5.753	18.163	2.156							
1995		0.509	1.432	1.514	1.769	3.382	2.481		4.238								
1996			1.483	1.809	1.863	2.502	9.643	8.622		13.434							
1997		0.302	1.626	1.924	2.389	2.396	2.966	6.149	11.932								
1998	0.010		1.600	2.071	2.435	3.491	3.179	4.597	12.196								
1999		0.290	1.296	1.943	2.951	3.687	5.492	5.562	7.639								
2000			1.561	1.961	2.718	3.199	5.102	5.022	10.275								
2001			1.709	2.199	2.659	3.732	5.019	6.260	10.563	5.812							
2002			1.278	2.135	2.581	3.048	5.265	6.429	7.920	8.986	10.569		21.428				
2003			1.954	2.237	2.525	3.225	4.823	8.064	9.803	11.164	11.121	15.396	21.529				
2004			1.545	2.045	2.612	2.829	3.911	5.746	9.387	12.103	13.597	13.197	20.148				
2005			1.510	1.968	2.374	3.567	3.904	6.089	7.851	9.762	13.577	14.618	16.371	17.539			
2006			2.326	2.270	2.969	3.301	4.685	5.472	8.335	10.100	12.470	15.117	15.100	18.191	17.759		
2007			2.229	2.503	2.965	3.535	4.419	5.156	7.858	11.708	12.736	14.450	14.284	16.547	15.964	19.820	
2008			1.922	2.746	2.910	3.415	2.747	5.123	10.005	12.290	18.929						
2009			2.196	2.506	3.066	3.518	4.444	6.379	8.036	9.776	10.021	12.265	18.750	19.711			
2010			2.563	2.728	3.151	3.771	4.115	7.441	9.409	9.586	9.850		15.000				

Table A.37. Total recreational discards-at-age (numbers) of Gulf of Maine Atlantic cod from 1982 to 2010.

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	Total
1981	0	59,850	108,357	23,641	0	0	0	0	0	0	0	0	0	0	0	0	0	191,848
1982	0	24,740	64,077	4,637	1,223	0	0	0	0	0	0	0	0	0	0	0	0	94,677
1983	0	88,294	138,076	3,971	0	0	0	0	0	0	0	0	0	0	0	0	0	230,341
1984	0	35,742	148,378	12,589	0	0	0	0	0	0	0	0	0	0	0	0	0	196,709
1985	0	47,682	111,590	40,340	0	0	0	0	0	0	0	0	0	0	0	0	0	199,612
1986	0	34,936	81,442	2,170	2,974	0	0	0	0	0	0	0	0	0	0	0	0	121,522
1987	0	53,899	440,307	72,518	0	0	0	0	0	0	0	0	0	0	0	0	0	566,724
1988	0	29,483	123,603	23,272	0	0	0	0	0	0	0	0	0	0	0	0	0	176,358
1989	0	24,149	330,477	205,909	11,579	0	0	0	0	0	0	0	0	0	0	0	0	572,114
1990	0	5,609	97,866	330,733	38,455	0	0	0	0	0	0	0	0	0	0	0	0	472,663
1991	0	10,368	90,813	104,551	188,769	15,883	0	0	0	0	0	0	0	0	0	0	0	410,384
1992	0	15,194	108,711	80,221	10,784	23,310	872	0	0	0	0	0	0	0	0	0	0	239,092
1993	0	16,715	431,310	218,026	85,168	0	0	0	0	0	0	0	0	0	0	0	0	751,219
1994	0	19,069	290,361	383,364	26,143	0	0	0	0	0	0	0	0	0	0	0	0	718,937
1995	0	16,967	188,067	402,380	72,699	2,551	0	0	0	0	0	0	0	0	0	0	0	682,664
1996	0	25,642	94,423	137,687	176,953	16,056	0	0	0	0	0	0	0	0	0	0	0	450,761
1997	0	13,006	93,180	111,984	27,228	51,919	2,911	0	0	0	0	0	0	0	0	0	0	300,228
1998	0	14,884	166,469	116,843	77,385	1,274	6,164	0	0	0	0	0	0	0	0	0	0	383,019
1999	0	65,141	208,315	163,899	26,475	10,206	1,380	371	0	0	0	0	0	0	0	0	0	475,787
2000	0	60,773	605,093	200,757	48,814	5,047	492	0	0	0	0	0	0	0	0	0	0	920,976
2001	0	0	623,824	547,600	116,012	22,696	1,864	0	0	0	0	0	0	0	0	0	0	1,311,996
2002	0	28,442	58,267	487,548	415,152	96,907	1,076	0	1,738	0	0	0	0	0	0	0	0	1,089,130
2003	0	64,684	231,504	152,218	451,807	182,405	25,396	0	0	0	0	0	0	0	0	0	0	1,108,014
2004	0	75,961	136,696	543,033	59,109	67,118	13,803	0	0	0	0	0	0	0	0	0	0	895,720
2005	0	15,375	416,173	186,450	620,454	8,290	13,140	320	37	58	0	0	0	0	0	0	0	1,260,297
2006	86	28,069	91,470	391,882	72,015	92,050	4,400	1,704	1,742	15	0	0	0	0	0	0	0	683,433
2007	82	5,164	185,316	393,489	392,873	29,572	23,506	31	40	0	0	0	0	0	0	0	0	1,030,073
2008	448	18,556	262,177	478,304	239,076	152,243	11,504	532	0	0	0	0	0	0	0	0	0	1,162,840
2009	75	20,725	189,483	414,621	289,384	90,045	50,598	786	1,291	0	0	0	0	0	0	0	0	1,057,008
2010	0	21,147	287,186	757,344	465,188	279,427	55,749	8,230	0	0	0	0	0	0	0	0	0	1,874,271

Table A.38. Mean weights-at-age (kg) of recreationally discarded Gulf of Maine Atlantic cod from 1982 to 2010.

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
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	0.498												
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	0.836	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	1.939	2.516	1.734							
2006	0.087	0.304	0.565	0.869	1.216	1.346	1.262	1.773	1.655	2.837							
2007	0.048	0.167	0.642	1.062	1.289	1.603	1.548	2.736	3.953								
2008	0.105	0.320	0.817	1.119	1.296	1.285	1.744	5.263									
2009	0.057	0.314	0.803	1.194	1.338	1.381	1.544	2.141	1.739								
2010		0.282	0.952	1.059	1.448	1.528	1.449	3.198									

Table A.39. Total catch-at-age (numbers, 000s of fish) of Gulf of Maine Atlantic cod from 1982 to 2010 with both age 9 and age 11 plus groups.
**Only ages 1 through plus group are used as model inputs.*

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+	Age 9	Age 10	Age 11+
1982	1.8	604.4	3499.2	2513.9	1540.7	794.1	71.0	102.8	77.2	92.4	48.7	33.5	10.3
1983	18.2	853.2	3093.9	3084.3	1247.3	730.3	468.2	52.0	64.2	58.2	28.2	14.6	15.4
1984	24.4	514.7	2790.0	1834.2	1691.1	451.4	227.7	108.8	9.6	54.4	17.4	14.7	22.4
1985	89.3	705.4	2538.2	2757.3	1203.8	780.9	174.6	119.0	53.9	36.5	6.9	18.0	11.6
1986	23.7	1032.9	2345.8	2941.2	1053.8	293.2	217.2	51.3	42.0	52.7	28.3	9.6	14.8
1987	134.2	411.9	2927.1	1937.5	1734.7	372.5	98.1	93.3	17.6	43.5	19.8	17.8	5.8
1988	4.6	570.5	2076.6	2350.1	1243.2	464.1	70.4	26.9	28.3	9.9	3.3	2.4	4.2
1989	0.1	238.8	1787.4	2833.0	1760.4	544.7	92.8	74.2	9.9	20.3	5.1	9.0	6.2
1990	0.0	90.6	1076.5	6483.1	2910.3	572.1	202.0	31.3	40.5	44.0	10.2	16.0	17.7
1991	4.3	169.3	663.3	1128.2	6040.0	1094.5	154.8	59.9	26.0	16.0	8.5	4.9	2.6
1992	31.7	504.1	1081.5	1038.1	533.5	2281.4	231.3	81.1	6.1	5.5	4.5	1.0	0.0
1993	35.4	152.1	1009.1	2601.4	1106.4	107.0	508.5	42.9	11.3	0.0	0.0	0.0	0.0
1994	15.6	178.2	459.8	1949.8	1354.7	275.0	67.1	75.6	28.9	8.0	6.6	0.4	1.0
1995	15.4	116.8	495.2	1729.7	1379.4	228.1	30.4	6.5	18.3	2.8	0.6	2.2	0.0
1996	29.4	67.8	195.0	763.5	2207.6	427.0	37.1	4.1	0.5	1.8	1.8	0.0	0.0
1997	2.0	100.8	220.7	624.9	497.4	927.5	76.1	5.6	2.3	1.0	0.4	0.6	0.0
1998	1.2	18.1	312.5	606.5	710.8	158.2	216.5	29.1	5.3	2.3	1.5	0.8	0.0
1999	0.1	143.7	265.1	517.2	401.6	213.2	64.2	71.7	13.9	1.1	1.1	0.0	0.0
2000	0.0	75.4	1033.7	795.6	949.4	196.9	91.5	13.6	11.9	0.0	0.0	0.0	0.0
2001	0.0	0.8	946.0	1778.3	882.3	457.0	120.3	63.1	9.1	12.1	11.1	1.0	0.0
2002	0.0	42.2	95.1	801.0	1359.5	440.7	182.7	74.1	34.5	24.2	9.8	10.3	4.1
2003	30.5	105.3	330.1	318.6	1041.1	946.9	226.1	83.5	32.4	30.3	17.1	6.2	7.0
2004	0.2	250.3	233.6	1136.7	347.0	522.6	290.9	74.3	35.4	29.2	17.1	8.7	3.3
2005	2.0	41.5	526.9	335.4	1568.5	103.3	278.5	117.7	30.7	34.5	19.0	7.4	8.1
2006	0.4	42.4	134.1	768.5	364.6	562.4	35.4	84.4	42.4	28.6	14.1	8.1	6.4
2007	0.6	19.4	262.9	615.2	1289.4	161.3	249.1	8.0	19.3	22.1	10.5	5.2	6.4
2008	1.0	31.3	358.0	1028.0	942.8	937.0	102.4	117.8	4.4	17.7	9.3	6.2	2.2
2009	0.2	28.3	263.9	1012.8	1400.1	581.1	367.9	22.5	33.9	10.6	1.1	4.4	5.0
2010	0.3	29.0	344.7	1138.8	1488.9	1046.8	249.1	88.2	14.3	11.0	5.8	0.9	4.4

Table A.40. Mean weights-at-age (kg) of the total catch Gulf of Maine Atlantic cod from 1982 to 2010 with both age 9 and age 11 plus groups. Mean catch weights-at-age 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 plus group are used as model inputs.*

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+	Age 9	Age 10	Age 11+
1982	0.013	0.347	0.813	1.480	2.560	5.084	7.058	9.630	9.724	15.637	12.596	19.184	18.490
1983	0.024	0.226	0.720	1.520	2.415	3.806	6.055	6.097	10.268	13.399	11.386	11.655	18.745
1984	0.001	0.236	0.617	1.434	2.678	3.621	5.533	8.315	10.087	14.898	13.557	14.397	16.269
1985	0.039	0.210	0.694	1.336	2.818	4.694	5.951	8.517	11.245	13.476	12.210	13.442	14.287
1986	0.005	0.278	0.488	1.668	2.736	4.803	6.565	8.139	10.295	14.686	13.067	13.886	18.289
1987	0.004	0.160	0.600	1.257	3.054	4.634	7.340	10.159	11.136	14.354	13.580	14.681	15.981
1988	0.003	0.124	0.550	1.606	2.339	5.182	5.166	6.142	10.141	12.818	10.434	17.787	11.779
1989	0.046	0.248	0.689	1.433	2.925	4.294	5.990	9.247	12.272	20.776	16.858	20.410	24.532
1990	0.021	0.195	0.766	1.271	2.104	4.500	7.697	10.705	11.641	18.635	15.294	16.344	22.637
1991	0.014	0.236	1.020	1.506	2.216	3.825	7.138	10.613	12.261	14.028	15.318	6.096	24.937
1992	0.023	0.058	0.949	1.416	2.679	2.935	5.541	10.900	10.389	14.483	13.418	19.072	23.502
1993	0.021	0.095	0.624	1.625	2.001	4.367	5.628	9.869	13.673	15.661	14.478	17.580	23.790
1994	0.022	0.074	0.601	1.536	3.023	3.221	6.328	7.650	12.583	11.691	9.420	22.008	22.643
1995	0.027	0.123	1.048	1.404	2.535	5.028	6.806	11.466	13.096	22.443	19.756	23.143	23.025
1996	0.033	0.146	1.038	1.902	2.164	3.374	7.572	11.717	14.388	16.225	16.225	19.490	22.643
1997	0.017	0.076	1.103	1.941	2.928	2.973	4.570	8.993	12.150	16.938	15.625	17.749	17.822
1998	0.008	0.203	0.881	1.790	2.491	3.941	4.163	7.086	12.118	16.676	17.500	15.060	17.822
1999	0.052	0.247	0.577	1.532	2.733	3.845	5.671	6.593	9.736	12.279	12.279	16.823	17.822
2000	0.030	0.278	0.853	1.882	3.181	4.192	5.821	5.302	9.409	12.704	12.415	14.506	19.237
2001	0.045	0.316	0.733	1.866	2.919	4.482	6.014	7.193	9.066	9.488	8.745	17.660	17.323
2002	0.032	0.171	0.652	1.433	2.535	3.366	6.078	6.948	8.542	12.374	11.138	10.797	19.237
2003	0.038	0.263	0.671	1.600	1.994	3.273	4.745	7.666	9.252	12.116	10.870	11.838	15.409
2004	0.025	0.117	0.498	1.357	2.696	3.262	5.094	7.118	9.729	13.320	12.530	13.897	15.875
2005	0.027	0.148	0.531	1.356	1.955	3.984	4.337	6.319	7.983	12.490	10.605	13.887	15.653
2006	0.073	0.295	0.611	1.243	2.639	3.062	4.125	5.493	7.226	12.131	9.782	12.635	16.669
2007	0.027	0.211	0.685	1.389	2.531	3.424	4.535	6.153	7.295	12.400	10.557	12.346	15.478
2008	0.090	0.272	0.833	1.779	2.496	3.219	3.710	5.780	7.723	12.267	9.616	14.863	16.157
2009	0.039	0.326	0.854	1.823	2.804	3.266	4.027	5.852	7.760	12.895	10.836	10.416	15.550
2010	0.022	0.281	1.057	1.521	2.730	3.354	3.828	5.687	8.876	11.865	9.875	10.434	14.792
Average 1982-2010	0.028	0.206	0.750	1.548	2.582	3.897	5.624	7.978	10.347	14.247	12.758	15.244	18.496
Average 1982-1991	0.017	0.226	0.696	1.451	2.585	4.444	6.449	8.756	10.907	15.271	13.430	14.788	18.595

Table A.41. Relative differences in the estimates of Gulf of Maine Atlantic cod weights-at-age from the 2008 Groundfish Assessment Review Meeting (GARM) assessment compared to the current assessment (through 2007). Differences are expressed relative to the 2008 assessment weights-at-age (*negative differences indicate lighter fish-at-age in the updated assessment*).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
1982	-0.46	-0.27	-0.09	-0.05	0.08	0.07	0.10	0.00	-0.03	0.87	0.00
1983	-0.49	-0.32	-0.06	-0.01	0.01	0.00	0.06	-0.01	0.14	-0.09	0.03
1984	-0.53	-0.40	-0.11	-0.01	-0.01	-0.05	0.03	0.04	0.06	0.03	0.09
1985	-0.55	-0.30	-0.17	0.02	0.07	0.10	0.08	-0.01	-0.04	0.05	0.03
1986	-0.30	-0.57	-0.07	-0.05	0.05	0.09	0.00	-0.05	-0.04	0.02	-0.07
1987	-0.22	-0.37	-0.19	-0.02	-0.04	0.02	0.07	0.11	0.03	0.12	0.20
1988	-0.61	-0.43	-0.08	-0.02	0.02	-0.20	-0.31	-0.08	-0.05	-0.01	-0.16
1989	-0.64	-0.43	-0.17	0.00	0.12	0.39	0.03	0.11	0.18	0.17	0.05
1990	-0.53	-0.29	-0.25	-0.09	0.07	0.04	0.00	-0.01	0.00	0.15	0.10
1991	-0.43	-0.14	-0.02	-0.09	-0.05	-0.04	0.10	0.00	0.09	-0.76	0.47
1992	-0.86	-0.39	-0.27	-0.02	-0.05	0.11	0.15	-0.14	0.00	0.17	0.34
1993	-0.77	-0.48	-0.11	-0.17	0.03	-0.08	-0.02	0.04	0.07	0.19	0.35
1994	-0.44	-0.57	-0.15	0.02	-0.04	0.01	0.06	0.20	-0.09	0.19	0.10
1995	-0.55	-0.26	-0.22	-0.05	0.00	0.22	0.07	0.14	0.05	0.15	0.13
1996	-0.75	-0.33	-0.11	-0.06	-0.03	0.03	0.12	0.03	0.10	0.32	0.29
1997	-0.82	-0.38	-0.12	-0.04	-0.05	-0.05	0.07	0.05	0.06	0.12	-0.19
1998	-0.51	-0.36	-0.14	-0.12	-0.05	-0.01	0.37	0.07	-0.07	0.01	-0.12
1999	-0.26	-0.57	-0.17	0.07	0.00	-0.02	-0.08	-0.02	-0.05	0.26	0.01
2000	-0.33	-0.47	-0.18	-0.07	-0.05	0.02	-0.12	0.10	-0.04	-0.02	0.09
2001	-0.24	-0.59	-0.22	-0.09	-0.05	-0.04	-0.01	0.09	0.01	0.42	-0.29
2002	-0.59	-0.52	-0.42	-0.22	-0.16	0.03	0.04	-0.26	0.09	0.01	0.34
2003	-0.37	-0.65	-0.34	-0.35	-0.18	-0.10	0.02	0.06	0.00	-0.04	0.18
2004	-0.72	-0.66	-0.42	-0.16	-0.11	-0.03	0.03	0.04	0.06	0.07	0.20
2005	-0.65	-0.66	-0.34	-0.31	-0.07	-0.04	0.01	0.02	0.02	0.03	0.09
2006	-0.29	-0.73	-0.49	-0.19	-0.18	-0.15	0.00	-0.05	0.01	0.04	0.06
2007	-0.49	-0.66	-0.45	-0.21	-0.13	-0.05	-0.03	0.03	0.04	0.05	0.08

Table A.42. Mean January 1/spawning stock weights-at-age (kg) of Gulf of Maine Atlantic cod from 1982 to 2010 with both age 9 and age 11 plus groups. Weights were estimated from catch weights using Rivard (1980, 1982) approach.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+	Age 9	Age 10	Age 11+
1982	0.241	0.595	1.159	2.100	4.659	7.594	9.326	9.677	15.637	13.095	15.545	18.490
1983	0.137	0.500	1.112	1.891	3.121	5.548	6.560	9.944	13.399	10.522	12.116	18.745
1984	0.138	0.373	1.016	2.018	2.957	4.589	7.096	7.842	14.898	11.798	12.803	16.269
1985	0.138	0.405	0.908	2.010	3.546	4.642	6.865	9.670	13.476	11.098	13.499	14.287
1986	0.189	0.320	1.076	1.912	3.679	5.551	6.960	9.364	14.686	12.122	13.021	18.289
1987	0.086	0.408	0.783	2.257	3.561	5.938	8.167	9.520	14.354	11.824	13.851	15.981
1988	0.053	0.297	0.982	1.715	3.978	4.893	6.714	10.150	12.818	10.779	15.542	11.779
1989	0.141	0.292	0.888	2.167	3.169	5.571	6.912	8.682	20.776	13.075	14.593	24.532
1990	0.085	0.436	0.936	1.736	3.628	5.749	8.008	10.375	18.635	13.700	16.599	22.637
1991	0.118	0.446	1.074	1.678	2.837	5.668	9.038	11.457	14.028	13.354	9.656	24.937
1992	0.018	0.473	1.202	2.009	2.550	4.604	8.821	10.500	14.483	12.827	17.092	23.502
1993	0.038	0.190	1.242	1.683	3.420	4.064	7.395	12.208	15.661	12.264	15.359	23.790
1994	0.020	0.239	0.979	2.216	2.539	5.257	6.562	11.144	11.691	11.349	17.850	22.643
1995	0.042	0.279	0.919	1.973	3.899	4.682	8.518	10.009	22.443	15.767	14.765	23.025
1996	0.053	0.357	1.412	1.743	2.925	6.170	8.930	12.844	16.225	14.577	19.623	22.643
1997	0.022	0.401	1.419	2.360	2.536	3.927	8.252	11.932	16.938	14.994	16.970	17.822
1998	0.120	0.259	1.405	2.199	3.397	3.518	5.691	10.439	16.676	14.582	15.340	17.822
1999	0.133	0.342	1.162	2.212	3.095	4.728	5.239	8.306	12.279	12.198	17.158	17.822
2000	0.171	0.459	1.042	2.208	3.385	4.731	5.483	7.876	12.704	10.994	13.346	19.237
2001	0.220	0.451	1.262	2.344	3.776	5.021	6.471	6.933	9.488	9.071	14.807	17.323
2002	0.086	0.454	1.025	2.175	3.135	5.219	6.464	7.839	12.374	10.049	9.717	19.237
2003	0.191	0.339	1.021	1.690	2.881	3.997	6.826	8.018	12.116	9.636	11.483	15.409
2004	0.055	0.362	0.954	2.077	2.550	4.083	5.812	8.636	13.320	10.767	12.291	15.875
2005	0.073	0.249	0.822	1.629	3.277	3.761	5.674	7.538	12.490	10.158	13.191	15.653
2006	0.194	0.301	0.812	1.892	2.447	4.054	4.881	6.757	12.131	8.837	11.576	16.669
2007	0.106	0.450	0.921	1.774	3.006	3.726	5.038	6.330	12.400	8.734	10.990	15.478
2008	0.154	0.419	1.104	1.862	2.854	3.564	5.120	6.893	12.267	8.376	12.526	16.157
2009	0.181	0.482	1.232	2.234	2.855	3.600	4.660	6.697	12.895	9.148	10.008	15.550
2010	0.135	0.587	1.140	2.231	3.067	3.536	4.786	7.207	11.865	8.754	10.633	14.792
$\text{Average}_{1982\text{-}2010}$	0.115	0.385	1.069	2.000	3.198	4.758	6.768	9.131	14.247	11.533	13.860	18.496
$\text{Average}_{1982\text{-}1991}$	0.133	0.407	0.993	1.948	3.513	5.574	7.564	9.668	15.271	12.137	13.723	18.595

Table A.43. Summary of vessels and trawl doors used in the Northeast Fisheries Science Center (NEFSC) spring and fall surveys from 1963 to 2011. All survey indices are standardized to Albatross IV, Polyvalent door equivalents. **Spring survey did not begin until 1968, 2011 fall survey data 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		PolyIce oval

Table A.44. Summary of survey calibration coefficients for converting survey index values to Albatross IV, Polyvalent door equivalent units.

Calibration type	Index	Length (cm)	Calibration coefficient	Source
Deleware II to Albatross IV	Biomass (weight)	*NA*	0.670	Forrester et al., 1997
	Abundance (numbers)	*NA*	0.790	
BMV door to Polyvalent door	Biomass (weight)	*NA*	1.620	
	Abundance (numbers)	*NA*	1.560	
Bigelow to Albatross IV	Biomass (weight)	*NA*	1.580	Miller et al. 2010
	Abundance (numbers)	≤ 20	5.724	Brooks et al. 2010
		21	5.600	
		22	5.477	
		23	5.353	
		24	5.230	
		25	5.106	
		26	4.983	
		27	4.859	
		28	4.736	
		29	4.612	
		30	4.489	
		31	4.365	
		32	4.242	
		33	4.118	
		34	3.995	
		35	3.871	
		36	3.748	
		37	3.624	
		38	3.501	
		39	3.377	
		40	3.254	
		41	3.130	
		42	3.007	
		43	2.883	
		44	2.760	
		45	2.636	
		46	2.513	
		47	2.389	
		48	2.266	
		49	2.142	
		50	2.019	
		51	1.895	
		52	1.772	
		53	1.648	
		≥ 54	1.602	

Table A.45. Summary of differences in survey protocol from the FSV Alabatross 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.46. Summary of the Northeast Fisheries Science Center (NEFSC) Gulf of Maine offshore survey strata and number of tows sampled broken down by survey (spring/fall) and time of day (day/night). The day/night classification is based on sunrise/sunset (zenith angle of 90°50'). **Spring survey did not begin until 1968, 2011 fall survey data not available at time of this report.*

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.47. Northeast Fisheries Science Center (NEFSC) spring and fall survey indices and coefficients of variation (CV) from 1963 to 2011 for Gulf of Maine Atlantic cod. CVs greater than 0.5 are shaded grey. **Spring survey did not begin until 1968, 2011 fall survey data not available at time of this report.*

Year	Spring				Fall			
	Mean number/tow	*CV*	Mean weight/tow (kg)	*CV*	Mean number/tow	*CV*	Mean weight/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	5.329	*0.127*	17.480	*0.153*	4.374	*0.181*	19.437	*0.198*
1969	3.215	*0.328*	13.100	*0.329*	2.758	*0.152*	15.154	*0.217*
1970	2.191	*0.214*	11.089	*0.237*	4.905	*0.318*	16.442	*0.248*
1971	1.429	*0.190*	7.004	*0.211*	4.361	*0.205*	16.529	*0.307*
1972	2.057	*0.208*	8.031	*0.233*	9.301	*0.535*	12.988	*0.199*
1973	7.525	*0.328*	18.807	*0.415*	4.452	*0.151*	8.764	*0.267*
1974	2.902	*0.188*	7.419	*0.199*	4.328	*0.260*	8.959	*0.201*
1975	2.512	*0.222*	6.039	*0.249*	6.143	*0.226*	8.619	*0.153*
1976	2.782	*0.181*	7.556	*0.166*	2.148	*0.197*	6.740	*0.214*
1977	3.872	*0.269*	8.541	*0.208*	3.073	*0.124*	10.199	*0.126*
1978	2.050	*0.191*	7.697	*0.207*	5.773	*0.188*	12.899	*0.151*
1979	3.644	*0.234*	7.555	*0.176*	3.142	*0.112*	13.927	*0.128*
1980	2.155	*0.171*	6.232	*0.182*	7.035	*0.261*	14.202	*0.153*
1981	4.832	*0.194*	10.650	*0.205*	2.349	*0.224*	7.533	*0.233*
1982	3.763	*0.219*	8.616	*0.223*	7.769	*0.636*	15.919	*0.670*
1983	3.912	*0.263*	10.962	*0.225*	2.786	*0.170*	8.416	*0.188*
1984	3.667	*0.443*	6.143	*0.324*	2.449	*0.220*	8.735	*0.334*
1985	2.517	*0.202*	7.645	*0.223*	2.821	*0.176*	8.264	*0.354*
1986	1.957	*0.314*	3.476	*0.197*	1.950	*0.230*	4.715	*0.228*
1987	1.083	*0.257*	1.976	*0.314*	2.996	*0.308*	3.394	*0.234*
1988	3.127	*0.211*	3.603	*0.281*	5.903	*0.349*	6.616	*0.232*
1989	2.112	*0.184*	2.424	*0.207*	4.553	*0.223*	4.535	*0.181*
1990	2.362	*0.249*	3.077	*0.280*	2.986	*0.190*	4.912	*0.204*
1991	2.393	*0.251*	2.891	*0.240*	1.252	*0.267*	2.782	*0.246*
1992	2.435	*0.317*	8.627	*0.374*	1.434	*0.213*	2.448	*0.243*
1993	2.507	*0.223*	5.875	*0.347*	1.232	*0.259*	1.003	*0.263*
1994	1.271	*0.223*	2.428	*0.216*	2.130	*0.309*	2.737	*0.292*
1995	1.930	*0.273*	2.432	*0.257*	2.008	*0.301*	3.665	*0.325*
1996	2.465	*0.240*	5.427	*0.275*	1.327	*0.254*	2.352	*0.249*
1997	2.192	*0.168*	5.616	*0.192*	0.872	*0.299*	1.872	*0.307*
1998	1.710	*0.344*	4.180	*0.324*	0.843	*0.346*	1.501	*0.287*
1999	2.301	*0.242*	5.090	*0.320*	1.807	*0.181*	3.505	*0.193*
2000	3.083	*0.221*	3.211	*0.155*	2.604	*0.306*	4.652	*0.332*
2001	2.147	*0.311*	6.215	*0.327*	1.980	*0.271*	7.324	*0.279*
2002	3.724	*0.203*	10.934	*0.215*	5.328	*0.578*	24.659	*0.686*
2003	3.677	*0.223*	9.495	*0.368*	2.529	*0.307*	5.988	*0.251*
2004	0.981	*0.256*	2.412	*0.293*	3.533	*0.327*	4.906	*0.214*
2005	1.765	*0.241*	2.701	*0.248*	1.338	*0.065*	2.897	*0.228*
2006	1.363	*0.203*	2.702	*0.249*	3.594	*0.301*	4.229	*0.188*
2007	12.393	*0.665*	15.811	*0.540*	1.992	*0.368*	2.714	*0.277*
2008	7.990	*0.716*	10.823	*0.609*	3.460	*0.389*	5.307	*0.285*
2009	3.599	*0.531*	7.161	*0.491*	3.447	*0.535*	5.845	*0.429*
2010	1.296	*0.243*	3.336	*0.264*	0.948	*0.233*	2.572	*0.304*
2011	0.894	*0.279*	2.133	*0.201*				

Table A.48. Northeast Fisheries Science Center (NEFSC) spring survey abundance indices-at-age (numbers/tow) with both age 9 and age 11 plus groups from 1970 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970. The current assessment uses age 9^{+} group.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9^{+}	Age 9	Age 10	Age 11^{+}
1970	0.000	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.330	0.045	0.076	0.210
1971	0.000	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.204	0.142	0.050	0.013
1972	0.053	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.386	0.300	0.027	0.059
1973	0.000	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.848	0.276	0.186	0.386
1974	0.164	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.258	0.038	0.089	0.131
1975	0.012	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.140	0.025	0.028	0.088
1976	0.000	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.117	0.000	0.036	0.081
1977	0.000	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.038	0.000	0.000	0.038
1978	0.000	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.131	0.108	0.000	0.022
1979	0.044	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.064	0.013	0.031	0.020
1980	0.070	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.132	0.105	0.026	0.000
1981	0.000	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	0.091	0.000	0.000
1982	0.014	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.050	0.040	0.010	0.000
1983	0.013	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.181	0.071	0.033	0.077
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
1985	0.000	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	0.026	0.000	0.000
1986	0.000	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.018	0.000	0.000	0.018
1987	0.000	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.015	0.000	0.000	0.015
1988	0.029	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	0.020	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
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
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
1992	0.000	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	0.012	0.000	0.000
1993	0.000	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.023	0.000	0.023	0.000
1994	0.000	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.045	0.027	0.018	0.000
1995	0.000	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.028	0.000	0.028	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
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
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
1999	0.000	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.011	0.000	0.000	0.011
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
2001	0.000	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.011	0.000	0.011	0.000
2002	0.000	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	0.017	0.000	0.000
2003	0.000	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.122	0.082	0.030	0.011
2004	0.000	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.010	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
2006	0.028	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.015	0.000	0.015	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
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
2009	0.000	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.004	0.000	0.004	0.000
2010	0.000	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.025	0.010	0.005	0.010
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

Table A.49. Northeast Fisheries Science Center (NEFSC) fall survey abundance indices-at-age (numbers/tow) with both age 9 and age 11 plus groups from 1970 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1970. The current assessment uses age 9^{+} group.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9^{+}	Age 9	Age 10	Age 11^{+}
1970	0.743	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.236	0.090	0.037	0.110
1971	1.334	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.345	0.193	0.031	0.121
1972	0.031	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.367	0.351	0.000	0.016
1973	0.638	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.319	0.182	0.122	0.016
1974	0.265	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.255	0.066	0.000	0.189
1975	0.006	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.018	0.000	0.000	0.018
1976	0.000	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.063	0.000	0.063	0.000
1977	0.000	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.130	0.021	0.061	0.048
1978	0.241	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.129	0.082	0.000	0.047
1979	0.000	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.070	0.000	0.053	0.018
1980	0.027	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.097	0.012	0.000	0.085
1981	0.010	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.028	0.000	0.028	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
1983	0.000	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.083	0.000	0.018	0.065
1984	0.000	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.096	0.016	0.000	0.080
1985	0.218	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	0.070	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	0.045	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
1988	0.000	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.023	0.011	0.011	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
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
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
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
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
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
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
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
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
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
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
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
2001	0.018	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	0.023	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
2003	0.542	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.023	0.011	0.000	0.011
2004	1.369	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.021	0.010	0.011	0.000
2005	0.034	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	0.021	0.000	0.000
2006	0.064	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.014	0.000	0.000	0.014
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
2008	0.165	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.031	0.010	0.021	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
2010	0.008	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.006	0.000	0.000	0.006

Table A.50. Comparison of the timing of the Northeast Fisheries Science Center (NEFSC) and Massachusetts Department of Marine Fisheries (MADMF) surveys based on the mean day of year from 1978 to 2011. **2011 fall survey data not available at time of this report.*

	Average day of the year					
Year	MADMF Spring	NEFSC Spring	$\Delta_{MADMF-NEFSC}$	MADMF Fall	NEFSC Fall	$\Delta_{MADMF-NEFSC}$
1978	148	133	15	254	303	-49
1979	125	115	10	261	311	-50
1980	130	118	12	255	310	-55
1981	129	135	-6	274	307	-33
1982	127	121	6	255	306	-51
1983	132	114	18	255	308	-53
1984	131	109	22	258	302	-44
1985	129	98	31	250	309	-59
1986	130	111	19	254	304	-50
1987	129	114	15	254	297	-43
1988	133	102	31	253	296	-43
1989	134	98	36	256	299	-43
1990	131	98	33	250	291	-41
1991	129	99	30	250	289	-39
1992	132	101	31	256	294	-38
1993	127	113	14	254	288	-34
1994	133	109	24	253	292	-39
1995	131	111	20	252	289	-37
1996	130	113	17	250	294	-44
1997	129	102	27	255	293	-38
1998	130	103	27	255	303	-48
1999	134	108	26	253	307	-54
2000	133	116	17	253	288	-35
2001	131	113	18	251	289	-38
2002	130	109	21	250	293	-43
2003	129	109	20	248	297	-49
2004	127	105	22	254	294	-40
2005	134	105	29	252	297	-45
2006	135	101	34	253	288	-35
2007	130	108	22	250	294	-44
2008	130	113	17	249	298	-49
2009	127	117	10	255	314	-59
2010	126	110	16	253	319	-66
2011	127	122	5			
Average	130.6	110.4	20.3	253.8	298.9	-45.1

Table A.51. Summary of age structures sampled from the Massachusetts Department of Marine Fisheries (MADMF) and the inshore strata of the Northeast Fisheries Science Center (NEFSC) spring and fall surveys between 1978 to 2011 for Gulf of Maine Atlantic cod. **2011 fall survey data not available at time of this report.*

Year	Spring			Fall		
	MADMF	NEFSC	Total	MADMF	NEFSC	Total
1979		20	20		41	41
1980		110	110		36	36
1981		87	87		24	24
1982	162	101	263	35	47	82
1983	80	87	167	6	66	72
1984	130	62	192	23	38	61
1985	84	75	159	14	41	55
1986	60	65	125	33	26	59
1987	99	81	180	113	80	193
1988	47	105	152	50	59	109
1989	199		199	14	33	47
1990	148	72	220	41	73	114
1991	252	109	361	33	5	38
1992	204	72	276	62	61	123
1993	196	71	267	59	25	84
1994	133	50	183	30	13	43
1995	155	65	220	27	4	31
1996	172	22	194	8	81	89
1997	153	57	210		91	91
1998	165	49	214	53	42	95
1999	243	177	420	16	112	128
2000	278	83	361	32	75	107
2001	308	96	404	16	27	43
2002	270	123	393	51	44	95
2003	191	67	258	67	102	169
2004	218	53	271	112	64	176
2005	274	73	347	99	99	198
2006	327	60	387	64	77	141
2007	232	144	376	12	35	47
2008	304	116	420	100	57	157
2009	204	251	455	70	275	345
2010	132	130	372	47	171	171
2011	110	144	144			

Table A.52. Massachusetts Department of Marine Fisheries (MADMF) spring and fall survey indices and coefficients of variation (CV) from 1963 to 2011 for Gulf of Maine Atlantic cod. *Spring survey did not begin until 1968, 2011 fall survey data not available at time of this report.

Year	Spring				Fall			
	Mean numbers/tow	CV	Mean weight/tow	CV	Mean numbers/tow	CV	Mean weight/tow	CV
1978	47.887	0.147	11.058	0.138	156.060	0.322	1.515	0.555
1979	96.559	0.278	14.276	0.219	8.924	0.260	1.052	0.377
1980	65.979	0.124	14.509	0.128	12.531	0.266	1.286	0.345
1981	69.406	0.207	18.689	0.265	9.291	0.422	3.638	0.453
1982	25.842	0.217	12.162	0.178	6.125	0.321	0.662	0.700
1983	54.850	0.155	18.746	0.159	1.676	0.335	0.094	0.533
1984	10.330	0.281	7.241	0.250	10.548	0.190	0.139	0.416
1985	8.455	0.206	4.765	0.202	2.871	0.300	0.071	0.390
1986	24.089	0.549	7.842	0.369	2.750	0.299	0.250	0.803
1987	17.206	0.219	7.866	0.289	313.148	0.182	0.353	0.184
1988	22.242	0.205	7.705	0.231	8.872	0.239	0.368	0.429
1989	52.244	0.270	17.346	0.331	4.150	0.065	0.222	0.422
1990	32.409	0.283	15.880	0.342	12.708	0.271	0.761	0.440
1991	13.699	0.218	8.730	0.123	7.483	0.266	0.485	0.516
1992	16.924	0.273	8.766	0.321	27.496	0.077	0.286	0.314
1993	92.659	0.354	5.866	0.278	51.500	0.249	1.358	0.235
1994	16.358	0.233	4.338	0.250	48.997	0.490	2.003	0.783
1995	23.364	0.265	3.994	0.234	4.658	0.297	0.810	0.658
1996	12.961	0.217	3.153	0.309	7.007	0.366	0.096	0.375
1997	17.887	0.239	2.505	0.256	1.456	0.242	0.015	0.404
1998	27.570	0.259	3.254	0.475	4.335	0.264	0.363	0.499
1999	161.058	0.366	8.998	0.254	8.005	0.554	0.310	0.454
2000	50.771	0.380	20.605	0.447	0.679	0.360	0.272	0.386
2001	41.844	0.428	26.446	0.533	49.555	0.460	0.760	0.552
2002	24.338	0.092	11.160	0.404	3.299	0.571	3.996	0.768
2003	1120.371	0.509	10.986	0.222	122.284	0.478	1.859	0.446
2004	131.589	0.453	8.151	0.258	57.620	0.292	5.582	0.400
2005	193.262	0.231	10.402	0.195	40.350	0.411	0.212	0.389
2006	1077.030	0.329	9.178	0.180	7.505	0.392	1.940	0.460
2007	61.576	0.271	8.432	0.243	7.918	0.268	0.082	0.613
2008	482.100	0.198	12.231	0.220	7.549	0.406	2.380	0.462
2009	480.516	0.366	4.490	0.189	5.042	0.426	0.811	0.416
2010	8.075	0.238	5.645	0.471	2.022	0.439	1.400	0.488
2011	59.064	0.522	4.519	0.428				

Table A.53. Massachusetts Department of Marine Fisheries (MADMF) spring survey abundance indices-at-age (numbers/tow) with both age 9 and age 11 plus groups from 1982 to 2011 for Gulf of Maine Atlantic cod. Age data are not available prior to 1982. The current assessment uses age 9^+ group.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9^+	Age 9	Age 10	Age 11^+
1982	1.691	13.261	6.765	2.830	0.943	0.221	0.046	0.035	0.050	0.000	0.000	0.000	0.000
1983	0.718	34.471	14.940	2.775	1.641	0.151	0.081	0.073	0.000	0.000	0.000	0.000	0.000
1984	0.257	2.038	4.916	2.304	0.582	0.147	0.086	0.000	0.000	0.000	0.000	0.000	0.000
1985	1.319	1.517	2.828	2.205	0.449	0.038	0.000	0.100	0.000	0.000	0.000	0.000	0.000
1986	1.075	8.694	12.316	0.948	0.935	0.099	0.023	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.725	8.325	4.795	2.903	0.182	0.154	0.053	0.000	0.000	0.070	0.070	0.000	0.000
1988	1.881	9.997	6.867	1.852	1.574	0.000	0.038	0.033	0.000	0.000	0.000	0.000	0.000
1989	0.265	21.496	22.947	6.879	0.497	0.113	0.048	0.000	0.000	0.000	0.000	0.000	0.000
1990	4.942	4.485	6.206	14.159	2.263	0.282	0.072	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.355	5.208	2.778	1.717	3.323	0.307	0.012	0.000	0.000	0.000	0.000	0.000	0.000
1992	1.506	4.461	5.526	3.419	0.576	1.290	0.102	0.044	0.000	0.000	0.000	0.000	0.000
1993	80.115	2.739	6.197	2.248	1.171	0.101	0.087	0.000	0.000	0.000	0.000	0.000	0.000
1994	4.627	5.142	3.907	1.901	0.632	0.149	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	11.998	5.890	2.153	2.689	0.583	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	8.843	0.777	0.497	1.091	1.482	0.272	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	12.445	2.917	0.967	0.948	0.200	0.380	0.030	0.000	0.000	0.000	0.000	0.000	0.000
1998	23.481	1.531	0.823	0.772	0.707	0.034	0.205	0.017	0.000	0.000	0.000	0.000	0.000
1999	143.000	11.967	2.248	2.279	0.706	0.645	0.075	0.126	0.013	0.000	0.000	0.000	0.000
2000	2.151	35.402	7.197	2.592	2.048	0.712	0.523	0.059	0.087	0.000	0.000	0.000	0.000
2001	25.987	0.084	4.560	4.812	3.375	2.145	0.516	0.258	0.106	0.000	0.000	0.000	0.000
2002	0.924	19.299	0.255	1.352	1.287	0.526	0.270	0.104	0.235	0.086	0.025	0.049	0.012
2003	0.000	15.767	6.834	0.444	1.968	0.909	0.185	0.068	0.014	0.039	0.025	0.000	0.014
2004	116.149	8.955	1.799	2.661	0.351	1.000	0.534	0.098	0.029	0.014	0.000	0.014	0.000
2005	179.479	5.274	4.243	0.864	1.963	0.302	0.706	0.252	0.094	0.085	0.085	0.000	0.000
2006	0.000	10.634	6.601	3.844	0.566	1.464	0.106	0.077	0.000	0.036	0.009	0.028	0.000
2007	49.323	4.211	2.907	2.220	1.980	0.344	0.527	0.033	0.031	0.000	0.000	0.000	0.000
2008	456.954	7.181	10.018	3.920	2.097	1.588	0.187	0.155	0.000	0.000	0.000	0.000	0.000
2009	466.098	8.588	2.610	1.558	1.056	0.409	0.168	0.000	0.028	0.000	0.000	0.000	0.000
2010	1.165	2.626	1.261	1.398	0.680	0.656	0.231	0.007	0.000	0.052	0.000	0.052	0.000
2011	55.378	0.347	0.895	0.604	1.114	0.436	0.212	0.077	0.000	0.000	0.000	0.000	0.000

Table A.54. Massachusetts Department of Marine Fisheries (MADMF) fall survey abundance indices-at-age (numbers/tow) with age 9 plus group from 1981 to 2011 for Gulf of Maine Atlantic cod. Age information is not available prior to 1981. **Note absence of any fish older than age 9 in this survey.*

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
1981	1.402	4.996	1.974	0.884	0.034	0.000	0.000	0.000	0.000	0.000
1982	4.593	1.009	0.334	0.131	0.046	0.000	0.000	0.011	0.000	0.000
1983	1.317	0.300	0.043	0.016	0.000	0.000	0.000	0.000	0.000	0.000
1984	10.228	0.244	0.060	0.016	0.000	0.000	0.000	0.000	0.000	0.000
1985	2.479	0.337	0.042	0.012	0.000	0.000	0.000	0.000	0.000	0.000
1986	1.883	0.447	0.392	0.000	0.029	0.000	0.000	0.000	0.000	0.000
1987	312.050	1.072	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	5.396	3.230	0.236	0.011	0.000	0.000	0.000	0.000	0.000	0.000
1989	3.877	0.099	0.138	0.008	0.028	0.000	0.000	0.000	0.000	0.000
1990	7.660	4.286	0.443	0.269	0.024	0.028	0.000	0.000	0.000	0.000
1991	5.019	1.916	0.462	0.013	0.060	0.013	0.000	0.000	0.000	0.000
1992	26.311	1.093	0.054	0.000	0.000	0.038	0.000	0.000	0.000	0.000
1993	49.322	1.618	0.387	0.148	0.026	0.000	0.000	0.000	0.000	0.000
1994	39.877	5.624	2.977	0.507	0.012	0.000	0.000	0.000	0.000	0.000
1995	2.809	1.203	0.350	0.288	0.007	0.000	0.000	0.000	0.000	0.000
1996	6.921	0.059	0.003	0.006	0.018	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
1998	3.248	0.644	0.332	0.071	0.039	0.000	0.000	0.000	0.000	0.000
1999	7.515	0.372	0.102	0.008	0.008	0.000	0.000	0.000	0.000	0.000
2000	0.046	0.383	0.198	0.036	0.016	0.000	0.000	0.000	0.000	0.000
2001	49.171	0.035	0.135	0.125	0.063	0.027	0.000	0.000	0.000	0.000
2002	0.913	1.126	0.046	0.326	0.269	0.335	0.166	0.086	0.034	0.000
2003	119.971	0.731	1.168	0.110	0.164	0.092	0.048	0.000	0.000	0.000
2004	40.322	14.121	0.650	1.428	0.248	0.624	0.211	0.016	0.000	0.000
2005	39.189	0.785	0.355	0.021	0.000	0.000	0.000	0.000	0.000	0.000
2006	1.609	3.947	1.217	0.514	0.074	0.101	0.043	0.000	0.000	0.000
2007	7.573	0.217	0.096	0.031	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.899	3.300	2.382	0.645	0.151	0.172	0.000	0.000	0.000	0.000
2009	2.908	1.046	0.733	0.298	0.041	0.008	0.009	0.000	0.000	0.000
2010	0.209	0.446	0.639	0.486	0.171	0.034	0.037	0.000	0.000	0.000

Table A.55. Indices of Gulf of Maine Atlantic cod commercial landings (numbers, 000s) per days fished (LPUE) by age from 1982 to 1993 (from Mayo et al. 2009).

	LPUE (numbers, 000s fish/days fished)					
Year	Age2	Age3	Age4	Age5	Age6	Aggregate
1982	0.074	0.074	0.045	0.022	0.003	0.218
1983	0.048	0.110	0.042	0.021	0.012	0.233
1984	0.033	0.045	0.044	0.012	0.006	0.139
1985	0.014	0.042	0.029	0.018	0.004	0.106
1986	0.004	0.069	0.023	0.007	0.004	0.106
1987	0.007	0.019	0.026	0.006	0.002	0.060
1988	0.015	0.049	0.024	0.009	0.002	0.099
1989	0.017	0.064	0.040	0.011	0.002	0.133
1990	0.011	0.160	0.078	0.012	0.005	0.266
1991	0.019	0.040	0.136	0.022	0.004	0.221
1992	0.015	0.017	0.014	0.052	0.005	0.103
1993	0.003	0.050	0.023	0.004	0.014	0.094

Table A.56. Correlation matrices comparing commercial landings per unit effort (LPUE) indices-at-age (from Mayo et al. 2009) to Northeast Fisheries Science Center (NEFSC) spring and fall indices-at-age for Gulf of Maine Atlantic cod. Relationships significant at α = 0.05 are shown in bold. The '_AGG' notation refers to the aggregate survey indices (i.e., includes all ages).

Variable	LPUE_AGE2	LPUE_AGE3	LPUE_AGE4	LPUE_AGE5	LPUE_AGE6	LPUE_AGG
SPRING_AGE2	**0.647**	0.054	-0.274	-0.181	0.134	0.068
SPRING_AGE3	0.041	**0.795**	-0.033	-0.413	0.382	0.406
SPRING_AGE4	0.240	0.042	**0.921**	0.086	-0.106	0.566
SPRING_AGE5	0.367	-0.311	-0.224	**0.899**	-0.087	-0.015
SPRING_AGE6	-0.043	-0.047	-0.331	0.126	**0.857**	-0.130
SPRING_AGG	**0.741**	0.266	0.199	0.290	0.308	0.484

Variable	LPUE_AGE2	LPUE_AGE3	LPUE_AGE4	LPUE_AGE5	LPUE_AGE6	LPUE_AGG
FALL_AGE1	0.154	0.094	-0.240	-0.215	-0.173	-0.070
FALL_AGE2	0.148	**0.755**	0.048	-0.210	0.217	0.486
FALL_AGE3	0.256	0.558	**0.608**	-0.002	0.202	**0.721**
FALL_AGE4	0.545	0.112	0.268	**0.618**	0.115	0.492
FALL_AGE5	-0.265	0.010	0.207	-0.413	**0.586**	-0.020
FALL_AGG	0.265	**0.633**	0.221	-0.104	0.182	0.554

Table A.57. Summary of the Gulf of Maine Atlantic cod ADAPT-VPA model formulation used to build a 'bridge' from the GARM III ADAPT-VPA model to the 2010 update. The model runs highlighted in grey indicate major runs and are summarized in more depth elsewhere in the report. The (+1) notation indicates that the survey index was lagged forward a year and an age in the model (e.g., Age 1 in 1981 become Age 2 in 1982). **Note: the model run numbers were used for internal tracking only and don't necessarily indicate sequential model runs.*

Run	Type	Software version	Population estimation	Years	Catch	Selectivity blocks	Plus group handling	Time of spawning	Survey selectivity	Survey indices	NEFSC		MADMF		LPUE
											Spring	Fall	Spring	Fall	
1	VPA	v2.7	Pope's approximation	1982-2007	GARM III		Backward	Feb/March	N/A	Unadjusted	2-8	1-7 (+1)	2-4	1 (+1)	2-6
2b	VPA	v3.1.1	Exact	1982-2007	GARM III		Backward	Feb/March	N/A	Unadjusted	2-8	1-7 (+1)	2-4	1 (+1)	2-6
3a	VPA	v3.1.1	Exact	1982-2007	Updated commercial landings, discards (excluded DAA pre 1999), rec landings, catch WAA		Backward	Feb/March	N/A	Unadjusted (original)	2-8	1-7 (+1)	2-4	1 (+1)	2-6
3b	VPA	v3.1.1	Exact	1982-2007	Updated commercial landings, discards (excluded DAA pre 1999), rec landings, stock/SSB WAA		Backward	Feb/March	N/A	Unadjusted (original)	2-8	1-7 (+1)	2-4	1 (+1)	2-6
4	VPA	v3.1.1	Exact	1982-2007	Updated commercial landings, discards, rec landings		Backward	Feb/March	N/A	Unadjusted (original)	2-8	1-7 (+1)	2-4	1 (+1)	2-6
5	VPA	v3.1.1	Exact	1982-2007	Full catch update (includes rec discards)		Backward	Feb/March	N/A	Unadjusted (original)	2-8	1-7 (+1)	2-4	1 (+1)	2-6
6	VPA	v3.1.1	Exact	1982-2007	Full catch update (includes rec discards)		Backward	Feb/March	N/A	Survey update (LPUE left untouched)	2-8	1-7 (+1)	2-4	1 (+1)	2-6
7	VPA	v3.1.1	Exact	1982-2007	Full catch update (includes rec discards)		Backward	Feb/March	N/A	Survey update (LPUE dropped)	2-8	1-7 (+1)	2-4	1 (+1)	N/A
8	VPA	v3.1.1	Exact	1982-2007	Full catch update (includes rec discards)		Combined	Feb/March	N/A	Survey update (LPUE dropped)	2-8	1-7 (+1)	2-4	1 (+1)	N/A
10	VPA	v3.1.1	Exact	1982-2010	Full catch update (includes rec discards)		Combined	Feb/March	N/A	Survey update (LPUE dropped)	2-8	1-7 (+1)	2-4	1 (+1)	N/A
10f	VPA	v3.1.1	Exact	1982-2010	Full catch update (includes rec discards)		Combined	Feb/March	N/A	Survey update (LPUE dropped), downweight of NEFSC spring indices	2-8	1-7 (+1)	2-4	N/A	N/A
10g	VPA	v3.1.1	Exact	1982-2010	Full catch update (includes rec discards)		Combined	March/April	N/A	Survey update (LPUE dropped)	2-8	1-7 (+1)	2-4	N/A	N/A

Table A.58. Summary Gulf of Maine Atlantic cod model results from the 'bridge building' exercise performed to update the GARM III ADAPT-VPA model to the 2010 update. Differences in model formulations are summarized in Table 56. The model runs highlighted in grey indicate major runs and are summarized in more depth elsewhere in the report. **Note: the model run numbers were used for internal tracking only and don't necessarily indicate sequential model runs.*

Run		**1**	**2b**	**3a**	**3b**	**4**	**5**	**6**	**7**	**8**	**10**	**10f**	**10g**
Model description		GARM III	Software update (catch equation)	Updated commercial landings, discards (excluded DAA pre 1999), rec landings, update only catch WAA	Updated commercial landings, discards (excluded DAA pre 1999), rec landings, update stock/SSB WAA	Updated commercial landings, discards, rec landings	Full catch update (includes rec discards)	Update survey indices and maturity ogive	Drop LPUE	Combined plus group treatment	Full update through 2010	Remove MADMF Fall survey, downweight NEFSC Spring 2008/9 indices	Update time of spawning from end of February (0.167) to end of March (0.25)
RSS		279.7	291.9	279.9	279.9	281.4	276.6	256.1	239.2	239.2	284.9	198.2	215.2
Terminal year N CVs	**Age 2**	0.44	0.45	0.44	0.44	0.44	0.44	0.37	0.38	0.38	0.39	0.39	0.40
	Age 3	0.31	0.32	0.31	0.31	0.31	0.31	0.28	0.29	0.29	0.31	0.29	0.30
	Age 4	0.26	0.27	0.27	0.27	0.27	0.28	0.25	0.26	0.26	0.30	0.27	0.30
	Age 5	0.26	0.27	0.27	0.27	0.26	0.29	0.27	0.28	0.28	0.46	0.41	0.43
	Age 6	0.39	0.40	0.39	0.39	0.38	0.43	0.43	0.44	0.44	0.52	0.46	0.48
	Age 7	0.44	0.45	0.43	0.43	0.43	0.46	0.45	0.47	0.47	0.54	0.45	0.49
	Age 8	0.55	0.56	0.53	0.53	0.53	0.54	0.51	0.52	0.52	0.54	0.45	0.48
	Age 9	0.69	0.73	0.61	0.61	0.60	0.64	0.65	0.67	0.65	7.26	7.17	1.64
	Age 10	0.72	0.78	0.61	0.61	0.59	0.67	0.78	0.80	0.78	19.38	17.53	5.26
Terminal estimates	$F_{5\text{-}7,\ 2007}$	0.46	0.47	0.42	0.42	0.39	0.52	0.56	0.56	0.56	0.68	0.68	0.65
	$F_{5\text{-}7,\ 2010}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.48	1.56	1.56
	SSB_{2007}	33,877	33,172	33,454	23,577	25,547	21,838	19,370	19,370	19,449	10,714	10,691	10,207
	SSB_{2010}	NA	NA	NA	NA	NA	NA	NA	NA	NA	12,270	11,698	10,548
Retrospective (Mohns Rho) **7 year 'peels'*	**F5-7**	0.16	0.13	0.00	0.00	-0.03	0.01	0.05	0.05	0.05	-0.06	0.41	0.14
	SSB	0.19	0.20	0.22	0.22	0.30	0.17	0.14	0.14	0.14	0.39	0.12	0.25
	Age1 N	0.71	0.71	0.54	0.54	0.75	0.49	0.38	0.38	0.38	1.24	0.61	0.86

Table A.59. Summary of individual station catches of Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center spring bottom trawl survey in 2007 and 2008. Anomalously large catches are shaded in grey.

Year	Cruise	Strata	Tow	Numbers caught	Total catch wt. (kg)
2007	200703	1280	6	1	5.98
2007	200703	1360	7	1	3.26
2007	200703	1290	5	1	2.62
2007	200703	1380	2	1	2.42
2007	200703	1370	5	1	2.04
2007	200703	1370	2	1	1.14
2007	200703	1290	7	1	1
2007	200703	1280	3	1	0.74
2007	200703	1400	2	2	5.06
2007	200703	1270	3	3	18.26
2007	200703	1370	4	3	11.18
2007	200703	1280	2	3	10.26
2007	200703	1390	3	4	0.42
2007	200703	1270	2	15	41.38
2007	200703	1400	1	15	28.88
2007	200703	1260	1	15	10.88
2007	200703	1290	6	25	74.48
2007	200703	1260	3	29	11.32
2007	200703	1270	4	33	66.88
2007	200703	1290	8	53	81.8
2007	200703	1260	2	800	834.29

Year	Cruise	Strata	Tow	Numbers caught	Total catch wt. (kg)
2008	200803	1370	5	1	5.1
2008	200803	1360	2	1	4.96
2008	200803	1270	4	1	4.84
2008	200803	1260	2	1	4.3
2008	200803	1280	6	1	3.44
2008	200803	1370	3	1	2.46
2008	200803	1270	1	1	2.22
2008	200803	1290	4	1	0.96
2008	200803	1400	1	1	0.72
2008	200803	1290	6	2	3
2008	200803	1270	3	2	1.46
2008	200803	1380	4	3	6.12
2008	200803	1290	3	6	16.46
2008	200803	1290	7	7	26.88
2008	200803	1260	5	8	19.88
2008	200803	1400	3	9	25.86
2008	200803	1260	1	15	37.88
2008	200803	1260	6	42	41.8
2008	200803	1260	4	578	674.56

Table A.60. Ratio of NEFSC spring and fall survey proportions-at-age to fishery proportions-at-age. Cells shaded red indicate where the survey proportion-at-age was greater than the fishery proportion-at-age. Cells shaded grey indicates where no survey-at-age information existed. Non-shaded cells indicate where the fishery proportions-at-age were greater than survey proportions-at-age.

NEFSC spring survey proportion at age/fishery proportion at age					
	Age				
Year	5	6	7	8	9+
1982	1.1	1.2	1.3	0.0	0.6
1983	0.8	0.9	1.9	0.0	5.2
1984	1.2	0.5	1.9	0.0	0.0
1985	1.1	0.7	1.1	0.6	0.9
1986	1.0	0.8	2.7	0.0	1.3
1987	0.7	0.0	2.7	2.4	1.3
1988	0.7	2.2	2.1	1.1	3.2
1989	0.7	4.0	0.0	0.0	0.0
1990	0.9	1.1	4.0	0.0	0.0
1991	1.0	1.2	1.3	0.0	0.0
1992	0.9	1.4	1.4	0.0	3.3
1993	0.8	0.9	1.4	2.1	NA
1994	0.4	1.1	2.6	0.4	7.7
1995	0.8	1.4	0.0	0.8	13.2
1996	1.0	1.7	0.0	0.0	0.0
1997	0.8	2.6	16.9	0.0	0.0
1998	0.6	1.3	0.5	2.7	0.0
1999	0.7	1.1	1.9	0.0	5.2
2000	0.7	1.4	1.2	2.6	NA
2001	0.9	0.6	1.8	7.0	1.1
2002	0.9	1.2	1.6	1.0	0.4
2003	0.7	1.1	2.7	1.6	2.7
2004	0.8	1.5	0.3	0.7	0.7
2005	0.2	1.0	2.1	0.9	0.0
2006	0.6	1.2	2.6	2.8	0.9
2007	0.9	1.1	3.2	0.7	0.0
2008	1.1	0.5	0.7	0.0	0.0
2009	1.0	1.1	0.3	0.6	0.3
2010	0.7	1.5	1.6	3.7	7.6

NEFSC fall survey proportion at age/fishery proportion at age					
	Age				
Year	5	6	7	8	9+
1982	1.4	0.0	0.0	0.0	0.0
1983	0.9	1.2	0.0	0.0	3.5
1984	0.7	1.3	0.9	0.0	2.7
1985	0.9	1.0	0.0	1.8	5.4
1986	1.0	0.8	0.0	0.0	3.5
1987	1.7	0.0	0.0	0.0	0.0
1988	0.9	0.0	4.6	0.0	6.4
1989	0.9	2.1	0.0	3.4	0.0
1990	1.3	0.7	0.9	0.0	0.0
1991	0.9	0.0	5.2	0.0	0.0
1992	0.8	3.1	0.0	0.0	0.0
1993	0.0	1.3	0.0	0.0	NA
1994	0.9	0.0	2.8	0.0	0.0
1995	1.1	1.1	0.0	0.0	0.0
1996	1.1	0.0	0.0	0.0	0.0
1997	1.1	0.0	0.0	0.0	0.0
1998	1.5	0.8	0.0	0.0	0.0
1999	1.5	0.8	0.0	0.0	0.0
2000	1.2	0.2	0.0	4.9	NA
2001	0.9	1.1	1.6	0.0	2.1
2002	0.9	1.6	0.4	0.5	0.0
2003	1.0	0.7	1.6	0.0	1.6
2004	0.9	1.0	1.5	1.2	1.4
2005	0.5	0.8	1.6	1.7	1.5
2006	0.9	1.8	1.1	1.5	0.8
2007	0.7	1.4	0.0	0.0	0.0
2008	1.0	0.0	0.0	0.0	12.1
2009	1.0	1.2	0.0	0.0	0.0
2010	0.9	1.0	1.6	0.0	6.0

Table A.61. Summary of Gulf of Maine Atlantic cod ASAP model configurations including the base (BASE) and various sensitivity models.

Run	Type	Software version	Years	Catch	Selectivity blocks	Time of spawning	Stock recruit	Survey selectivity	Survey indices	NEFSC		MADMF		LPUE
										Spring	Fall	Spring	Fall	
BASE	ASAP	v2.0.21	1982-2010	Single fleet (full catch update)	1982-1990, 1991-2010	March/April	Mean	NEFSC, flat topped (6+), MADMF double logistic	Survey updated (LPUE dropped)	1-9	1-9	1-9	N/A	N/A
BASE_11	ASAP	v2.0.21	1982-2010	Single fleet (full catch update)	1982-1990, 1991-2010	March/April	Mean	NEFSC, flat topped (6+), MADMF double logistic	Survey updated (LPUE dropped)	1-11	1-11	1-11	N/A	N/A
BASE_DOME	ASAP	v2.0.21	1982-2010	Single fleet (full catch update)	1982-1990, 1991-2010	March/April	Mean	NEFSC flexible, MADMF double logistic	Survey updated (LPUE dropped)	1-9	1-9	1-9	N/A	N/A
BASE_1964	ASAP	v2.0.21	1964-2010	Single fleet (full catch update)	1964-1990, 1991-2010	March/April	Mean	NEFSC, flat topped (6+), MADMF double logistic	Survey updated (LPUE dropped)	1-9	1-9	1-9	N/A	N/A
BASE_1970	ASAP	v2.0.21	1970-2010	Single fleet (full catch update)	1970-1990, 1991-2010	March/April	Mean	NEFSC, flat topped (6+), MADMF double logistic	Survey updated (LPUE dropped)	1-9	1-9	1-9	N/A	N/A

Table A.62. Summary of the Gulf of Maine Atlantic cod model fit diagnostics from the ASAP base (BASE) and various sensitivity runs.

Run		BASE	BASE_11	BASE_DOME	BASE_1964	BASE_1970
Model description		Starting year in 1982, uses 9^+ age group w/ 2 feet selectivity blocks and flat top NEFSC survey selectivity, mean (geo) recruitment	Starting year in 1982, uses 11^+ age group w/ 2 feet selectivity blocks and flat top NEFSC survey selectivity, mean (geo) recruitment	Starting year in 1982, uses 9^+ age group w/ 2 feet selectivity blocks and NEFSC survey selectivity is allowed to be flexible, mean (geo) recruitment	Starting year in 1964, uses 9^+ age group w/ 2 feet selectivity blocks and flat top NEFSC survey selectivity, mean (geo) recruitment	Starting year in 1970, uses 9^+ age group w/ 2 feet selectivity blocks and flat top NEFSC survey selectivity, mean (geo) recruitment
Number of parameters		99	105.0	105.0	135	123.0
Objective function		2467	2492.0	2464.0	3391	3235.0
Components of objective function	**Recruit devs**	286.0	286.0	286.0	468.0	410.0
	Suvey age comps	831.0	846.0	829.0	1102.0	1102.0
	Catch age comps	378.0	388.0	378.0	369.0	378.0
	Index fit	764.0	764.0	764.0	1116.0	1049.0
	Catch fit	208.0	208.0	207.0	335.0	296.0
RMSE	**Fleet 1**	0.24	0.24	0.23	0.23	0.26
	Index 1	1.05	1.05	1.04	1.05	1.33
	Index 2	0.91	0.91	0.92	1.21	1.28
	Index 3	1.07	1.08	1.07	1.26	1.35
	Recruit devs	1.28	1.28	1.26	1.37	1.35
SSB_{1982} (mt)		23,675	23,075	32,556	23,790	23,887
SSB_{2010} (mt)		11,868	11,777	14,476	10,346	9,664
$F_{mult,\ 2010}$		1.14	1.15	1.04	1.34	1.46

Table A.63. Summary Gulf of Maine Atlantic cod catch and survey selectivities from the ASAP base model (BASE) and the various sensitivity runs. Fleet block 1=starting year – 1990, fleet block 2=1991-2010, Index 1= NEFSC spring, Index 2= NEFSC fall, Index 3=MADMF spring.

Run		BASE		BASE_11		BASE_DOME		BASE_1964		BASE_1970		BASE_1970_BH	
		Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV	Selectivity	CV
Fleet block 1	1	0.05	*0.17*	0.05	*0.17*	0.05	*0.17*	0.04	*0.20*	0.04	*0.19*	0.05	*0.19*
	2	0.28	*0.10*	0.28	*0.10*	0.29	*0.10*	0.27	*0.14*	0.27	*0.14*	0.28	*0.14*
	3	0.58	*0.10*	0.58	*0.10*	0.59	*0.10*	0.55	*0.14*	0.56	*0.13*	0.57	*0.13*
	4	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	0.95	*0.15*	0.95	*0.15*	0.96	*0.15*
	5	1.00				1.00		1.00		1.00		1.00	
	6	0.77	*0.26*	0.74	*0.26*	0.74	*0.27*	0.75	*0.29*	0.79	*0.28*	0.79	*0.28*
	7	0.99	*0.39*	0.83	*0.37*	0.88	*0.42*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	8	1.00	*0.00*	0.69	*0.54*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*	1.00	*0.00*
	9	0.31	*0.47*	0.53	*0.79*	0.14	*0.69*	0.26	*0.38*	0.28	*0.38*	0.26	*0.39*
	10	n/a		1.00	*0.01*	n/a		n/a		n/a		n/a	
	11	n/a		0.27	*0.82*	n/a		n/a		n/a		n/a	
Fleet block 2	1	0.02	*0.17*	0.02	*0.17*	0.02	*0.17*	0.02	*0.18*	0.02	*0.16*	0.02	*0.16*
	2	0.11	*0.10*	0.11	*0.10*	0.12	*0.11*	0.11	*0.10*	0.11	*0.10*	0.11	*0.10*
	3	0.40	*0.08*	0.39	*0.08*	0.42	*0.10*	0.39	*0.09*	0.39	*0.08*	0.39	*0.08*
	4	0.84	*0.08*	0.84	*0.08*	0.89	*0.09*	0.84	*0.08*	0.84	*0.08*	0.84	*0.08*
	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*
	6	1.00				1.00							
	7	0.90	*0.20*	0.89	*0.19*	0.69	*0.26*	0.90	*0.21*	0.90	*0.20*	0.91	*0.20*
	8	0.88	*0.33*	0.85	*0.31*	0.52	*0.45*	0.88	*0.35*	0.88	*0.33*	0.89	*0.33*
	9	0.67	*0.54*	0.61	*0.52*	0.18	*0.79*	0.71	*0.55*	0.69	*0.53*	0.72	*0.53*
	10	n/a		0.84	*0.72*	n/a		n/a		n/a		n/a	
	11	n/a		0.95	*1.08*	n/a		n/a		n/a		n/a	
Index 1	1	0.04	*0.19*	0.04	*0.19*	0.04	*0.21*	0.04	*0.17*	0.04	*0.17*	0.04	*0.17*
	2	0.12	*0.16*	0.12	*0.16*	0.12	*0.19*	0.13	*0.15*	0.13	*0.15*	0.13	*0.14*
	3	0.26	*0.16*	0.26	*0.16*	0.27	*0.18*	0.26	*0.15*	0.27	*0.14*	0.27	*0.14*
	4	0.46	*0.15*	0.46	*0.15*	0.49	*0.18*	0.49	*0.14*	0.50	*0.13*	0.50	*0.13*
	5	0.71	*0.15*	0.71	*0.15*	0.73	*0.17*	0.75	*0.14*	0.76	*0.13*	0.76	*0.13*
	6	1.00		1.00		1.00		1.00		1.00		1.00	
	7	1.00		1.00		1.00	*0.00*	1.00		1.00		1.00	
	8	1.00		1.00		0.59	*0.44*	1.00		1.00		1.00	
	9	1.00		1.00		0.22	*0.65*	1.00		1.00		1.00	
	10	n/a		1.00		n/a		n/a		n/a		n/a	
	11	n/a		1.00		n/a		n/a		n/a		n/a	
Index 2	1	0.14	*0.22*	0.14	*0.21*	0.15	*0.26*	0.12	*0.19*	0.13	*0.17*	0.13	*0.17*
	2	0.33	*0.21*	0.33	*0.21*	0.36	*0.25*	0.28	*0.19*	0.28	*0.16*	0.28	*0.16*
	3	0.51	*0.21*	0.51	*0.21*	0.55	*0.25*	0.41	*0.18*	0.42	*0.16*	0.42	*0.16*
	4	0.82	*0.21*	0.82	*0.20*	0.87	*0.24*	0.71	*0.19*	0.73	*0.16*	0.72	*0.16*
	5	0.97	*0.21*	0.97	*0.21*	0.98	*0.24*	0.94	*0.17*	0.94	*0.16*	0.93	*0.16*
	6	1.00		1.00		1.00		1.00		1.00		1.00	
	7	1.00		1.00		0.73	*0.41*	1.00		1.00		1.00	
	8	1.00		1.00		0.41	*0.74*	1.00		1.00		1.00	
	9	1.00		1.00		0.29	*0.72*	1.00		1.00		1.00	
	10	n/a		1.00		n/a		n/a		n/a		n/a	
	11	n/a		1.00		n/a		n/a		n/a		n/a	
Index 3	A50 ascend	0.00	*3000.09*	0.00	*3316.79*	0.00	*3000.05*	0.00	*2999.97*	0.00	*3000.00*	0.00	*3000.01*
	Slope ascend	10.00		10.00		10.00		10.00		10.00		10.00	
	A50 descend	0.00	*3000.42*	0.00	*3316.18*	0.00	*2999.78*	0.00	*3001.28*	0.00	*3000.00*	0.00	*3000.09*
	Slope descend	4.22	*0.22*	4.24	*0.22*	3.81	*0.20*	4.19	*0.22*	4.09	*0.21*	4.08	*0.21*

Table A.64. Gulf of Maine Atlantic cod January 1 biomass (mt) and spawning stock biomass (SSB, mt) from 1982 to 2010 as estimated from the ASAP base model (BASE).

Year	January 1 biomass (mt)	SSB (mt)
1982	41,575	23,675
1983	31,859	17,476
1984	25,931	14,588
1985	24,729	13,241
1986	23,515	12,118
1987	22,494	11,449
1988	22,443	11,719
1989	30,842	16,941
1990	37,990	22,761
1991	31,341	19,304
1992	20,744	12,172
1993	15,674	8,472
1994	14,244	7,506
1995	14,517	8,576
1996	14,745	9,041
1997	12,564	7,889
1998	11,885	7,270
1999	13,899	8,216
2000	19,191	11,070
2001	24,221	14,854
2002	22,151	15,083
2003	18,569	12,353
2004	15,723	10,420
2005	13,958	8,874
2006	14,463	8,427
2007	17,757	10,778
2008	20,899	12,561
2009	22,468	13,559
2010	20,589	11,868

Table A.65. Gulf of Maine Atlantic cod total (F_{full}) and average (ages 5-7) fishing mortality from 1982 to 2010 as estimated from the ASAP base model (BASE).

Year	Total F (F_{full})	Average F_{5-7}		
		Unweighted	N-weighted	B-weighted
1982	0.90	0.83	0.89	0.88
1983	1.11	1.02	1.02	0.99
1984	0.93	0.85	0.87	0.86
1985	1.13	1.04	1.09	1.08
1986	1.04	0.96	0.97	0.96
1987	1.08	0.99	1.03	1.02
1988	0.80	0.73	0.75	0.75
1989	0.66	0.60	0.62	0.61
1990	0.84	0.78	0.81	0.80
1991	1.14	1.10	1.14	1.13
1992	1.22	1.18	1.21	1.20
1993	1.49	1.44	1.48	1.47
1994	1.42	1.37	1.38	1.36
1995	0.98	0.95	0.98	0.97
1996	0.97	0.94	0.97	0.97
1997	0.84	0.81	0.84	0.84
1998	0.75	0.72	0.74	0.74
1999	0.51	0.49	0.50	0.49
2000	0.60	0.58	0.59	0.59
2001	0.72	0.69	0.71	0.71
2002	0.61	0.59	0.61	0.60
2003	0.75	0.72	0.74	0.74
2004	0.72	0.70	0.72	0.71
2005	0.87	0.84	0.85	0.84
2006	0.64	0.62	0.63	0.63
2007	0.62	0.59	0.61	0.61
2008	0.77	0.74	0.76	0.75
2009	0.80	0.77	0.80	0.80
2010	1.14	1.10	1.13	1.12

Table A.66. Gulf of Maine Atlantic cod fishing mortality-at-age from 1982 to 2010 as estimated from the ASAP base model (BASE).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
1982	0.04	0.26	0.52	0.90	0.90	0.69	0.89	0.90	0.28
1983	0.05	0.31	0.64	1.11	1.11	0.85	1.10	1.11	0.35
1984	0.04	0.26	0.54	0.93	0.93	0.71	0.92	0.93	0.29
1985	0.05	0.32	0.65	1.13	1.13	0.86	1.12	1.13	0.35
1986	0.05	0.30	0.60	1.04	1.04	0.80	1.03	1.04	0.33
1987	0.05	0.31	0.63	1.08	1.08	0.83	1.07	1.08	0.34
1988	0.04	0.23	0.46	0.80	0.80	0.61	0.79	0.80	0.25
1989	0.03	0.19	0.38	0.66	0.66	0.50	0.65	0.66	0.21
1990	0.04	0.24	0.49	0.84	0.84	0.65	0.84	0.84	0.26
1991	0.02	0.13	0.45	0.96	1.14	1.14	1.02	1.01	0.77
1992	0.02	0.13	0.48	1.03	1.22	1.22	1.09	1.07	0.82
1993	0.03	0.16	0.59	1.26	1.49	1.49	1.34	1.32	1.01
1994	0.03	0.16	0.56	1.20	1.42	1.42	1.27	1.25	0.96
1995	0.02	0.11	0.39	0.83	0.98	0.98	0.88	0.86	0.66
1996	0.02	0.11	0.38	0.82	0.97	0.97	0.87	0.86	0.65
1997	0.02	0.09	0.33	0.71	0.84	0.84	0.76	0.74	0.57
1998	0.01	0.08	0.30	0.63	0.75	0.75	0.67	0.66	0.50
1999	0.01	0.06	0.20	0.43	0.51	0.51	0.45	0.45	0.34
2000	0.01	0.07	0.24	0.51	0.60	0.60	0.54	0.53	0.40
2001	0.01	0.08	0.28	0.60	0.72	0.72	0.64	0.63	0.48
2002	0.01	0.07	0.24	0.52	0.61	0.61	0.55	0.54	0.41
2003	0.01	0.08	0.30	0.63	0.75	0.75	0.67	0.66	0.50
2004	0.01	0.08	0.29	0.61	0.72	0.72	0.65	0.64	0.49
2005	0.02	0.10	0.34	0.74	0.87	0.87	0.78	0.77	0.59
2006	0.01	0.07	0.25	0.54	0.64	0.64	0.57	0.56	0.43
2007	0.01	0.07	0.24	0.52	0.62	0.62	0.55	0.54	0.41
2008	0.02	0.08	0.30	0.65	0.77	0.77	0.69	0.67	0.51
2009	0.02	0.09	0.32	0.68	0.80	0.80	0.72	0.71	0.54
2010	0.02	0.13	0.45	0.97	1.14	1.14	1.02	1.01	0.77

Table A.67. Gulf of Maine Atlantic cod January 1 numbers-at-age (000s) from 1982 to 2010 as estimated from the ASAP base model (BASE).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9^{+}
1982	11968	13226	5638	3316	1847	153	198	91	309
1983	13159	9402	8379	2736	1101	613	63	66	221
1984	12509	10241	5619	3611	740	298	215	17	146
1985	10463	9816	6445	2691	1171	240	120	70	95
1986	16376	8134	5831	2743	712	310	83	32	73
1987	18049	12782	4951	2608	791	205	114	24	53
1988	33085	14064	7699	2167	725	220	73	32	37
1989	5308	26119	9185	3975	801	268	98	27	36
1990	4677	4217	17741	5138	1687	340	133	42	35
1991	8069	3684	2717	8909	1810	594	146	47	37
1992	8890	6459	2661	1416	2779	472	155	43	28
1993	11635	7106	4629	1347	415	673	114	43	22
1994	3917	9249	4941	2100	312	76	124	25	16
1995	4124	3118	6483	2308	518	62	15	28	11
1996	3218	3312	2294	3605	827	159	19	5	14
1997	5874	2584	2438	1279	1299	256	49	7	8
1998	5299	4730	1929	1430	514	457	90	19	6
1999	10927	4275	3568	1175	622	199	177	38	11
2000	7136	8857	3311	2392	628	307	98	92	26
2001	1745	5774	6791	2139	1180	282	138	47	59
2002	7446	1409	4371	4189	957	472	113	59	50
2003	2798	6023	1079	2812	2049	425	210	53	56
2004	8570	2257	4543	657	1222	793	165	88	50
2005	5405	6917	1707	2794	292	485	315	70	63
2006	8950	4350	5148	990	1096	100	166	118	56
2007	6748	7236	3320	3271	472	472	43	77	84
2008	6679	5458	5538	2131	1592	209	209	20	82
2009	5281	5386	4110	3351	914	606	79	86	49
2010	4286	4256	4039	2451	1394	336	223	32	58
Average	8710	7257	5073	2749	1051	348	129	48	62
Geometric mean	7226	6043	4351	2404	908	294	108	39	41
Median	7136	6023	4629	2608	914	307	120	43	50

Table A.68. Retrospective rho statistics for Gulf of Maine Atlantic cod F_{mult}, F_{5-7}, and SSB calculated using both 5 and 7 year peels. The NDMBRPWG consensus opinion was that the 5 year peels more accurately characterizes the retrospective patterns.

Year	2003	2004	2005	2006	2007	2008	2009	Mohn's rho (7 year peel, 2003)	Mohn's rho (5 year peel, 2005)	Retrospective adjustment factor (5 year peel)
F_{full}	**-0.52**	-0.40	-0.20	-0.27	-0.27	-0.24	-0.10	-0.29	-0.22	1.28
F_{5-7}	-0.52	-0.40	-0.21	-0.28	-0.28	-0.24	-0.10	-0.29	-0.22	1.28
SSB	0.90	0.55	0.19	0.29	0.28	0.26	0.09	0.37	0.22	0.82
Numbers Age1	4.32	1.02	-0.07	0.34	-0.23	0.09	0.62	0.87	0.15	0.87
Numbers Age2	0.56	1.50	0.20	0.01	0.26	0.22	0.23	0.43	0.19	0.84
Numbers Age3	0.62	0.24	0.28	0.12	0.13	0.23	0.06	0.24	0.16	0.86
Numbers Age4	0.63	0.49	0.07	0.25	0.19	0.12	0.05	0.26	0.14	0.88
Numbers Age5	0.71	0.39	0.11	0.23	0.27	0.20	0.06	0.28	0.18	0.85
Numbers Age6	0.84	0.50	0.13	0.35	0.33	0.28	0.11	0.36	0.24	0.81
Numbers Age7	0.95	0.59	0.18	0.40	0.42	0.32	0.12	0.43	0.29	0.78
Numbers Age8	0.97	0.63	0.24	0.45	0.45	0.35	0.12	0.46	0.32	0.76
Numbers Age9	1.00	0.75	0.33	0.48	0.46	0.36	0.07	0.49	0.34	0.75

Table A.69. Inputs to the Gulf of Maine Atlantic cod yield per recruit (YPR) analysis.

Age	Catch weights (kg)	Stock weights (kg)	Fishery selectivity	Fraction mature	Natural mortality
1	0.29	0.16	0.02	0.09	0.20
2	0.91	0.50	0.11	0.29	0.20
3	1.71	1.16	0.40	0.61	0.20
4	2.68	2.11	0.84	0.86	0.20
5	3.28	2.93	1.00	0.96	0.20
6	3.85	3.57	1.00	0.99	0.20
7	5.77	4.85	0.90	1.00	0.20
8	8.12	6.93	0.88	1.00	0.20
9	12.34	12.34	0.67	1.00	0.20

Table A.70. Ratio of 2010 F_{full} to the F_{MSY} proxy $F_{F40\%}$ and 2010 SSB to the SSB_{MSY} for Gulf of Maine Atlantic cod.

Reference points		ASAP base model			Ratio 2010/reference point		Retrospective adjusted	
		2010 point estimate		90% probability interval	Ratio	90% probability interval	Point estimate	Ratio
$F_{MSY(F40\%)}$	0.20	F_{full}	1.14	(0.79 - 1.54)	5.83	(4.03 - 7.86)	1.47	7.33
SSB_{MSY}	61,218	SSB	11,868	(9,479 - 16,301)	0.19	(0.15 - 0.27)	9,728	0.16

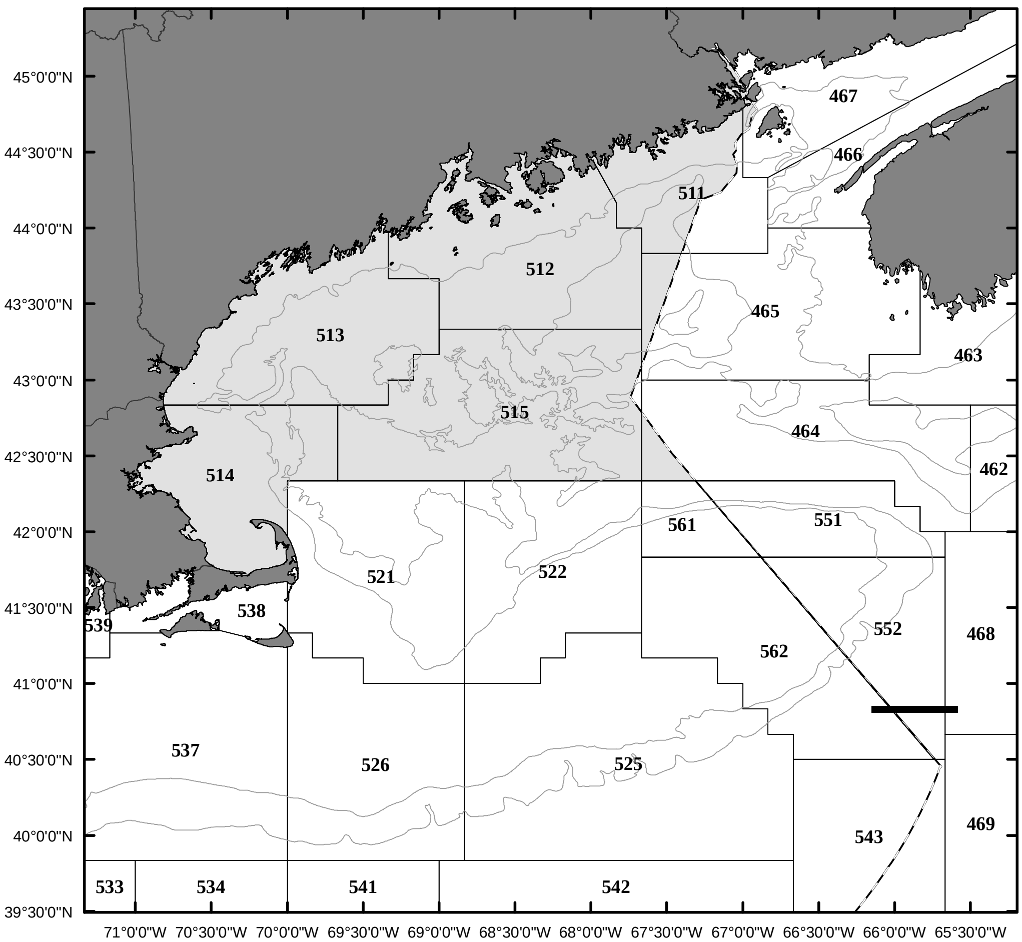
Table A.71. Summary of median (50th percentile) short term yield and spawning stock projections for Gulf of Maine Atlantic cod under three different assumptions of F (F_0, 75% F_{MSY}, $F_{40\%}$). Projections have not been adjusted for retrospective pattern.

Total fishery yield (mt)			
	F_0	75% F_{MSY} (0.15)	F_{MSY} ($F_{40\%}$ = 0.20)
Year	***Unadjusted***	***Unadjusted***	***Unadjusted***
2011	11,392	11,392	11,392
2012	0	1,001	1,313
2013	0	1,746	2,232
2014	0	2,780	3,482
2015	0	3,740	4,584
2016	0	4,629	5,562
2017	0	5,526	6,541
2018	0	6,399	7,469
2019	0	7,115	8,213
2020	0	7,682	8,777
2021	0	8,133	9,202
2022	0	8,508	9,560
2023	0	8,781	9,811
2024	0	8,972	9,981
2025	0	9,116	10,100

Spawning stock biomass (mt)			
	F_0	75% F_{MSY} (0.15)	F_{MSY} ($F_{40\%}$ = 0.20)
Year	***Unadjusted***	***Unadjusted***	***Unadjusted***
2011	8,178	8,178	8,178
2012	7,069	6,894	6,834
2013	13,073	11,838	11,463
2014	21,656	18,311	17,363
2015	31,565	24,809	23,014
2016	42,701	31,286	28,405
2017	55,765	38,067	33,884
2018	70,054	44,968	39,337
2019	85,801	51,811	44,599
2020	99,450	57,382	48,761
2021	110,811	61,576	51,821
2022	121,689	65,347	54,534
2023	130,611	68,136	56,370
2024	138,032	70,219	57,820
2025	144,000	71,759	58,819

Gulf of Maine Atlantic cod (*Gadus morhua*)

Figures



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

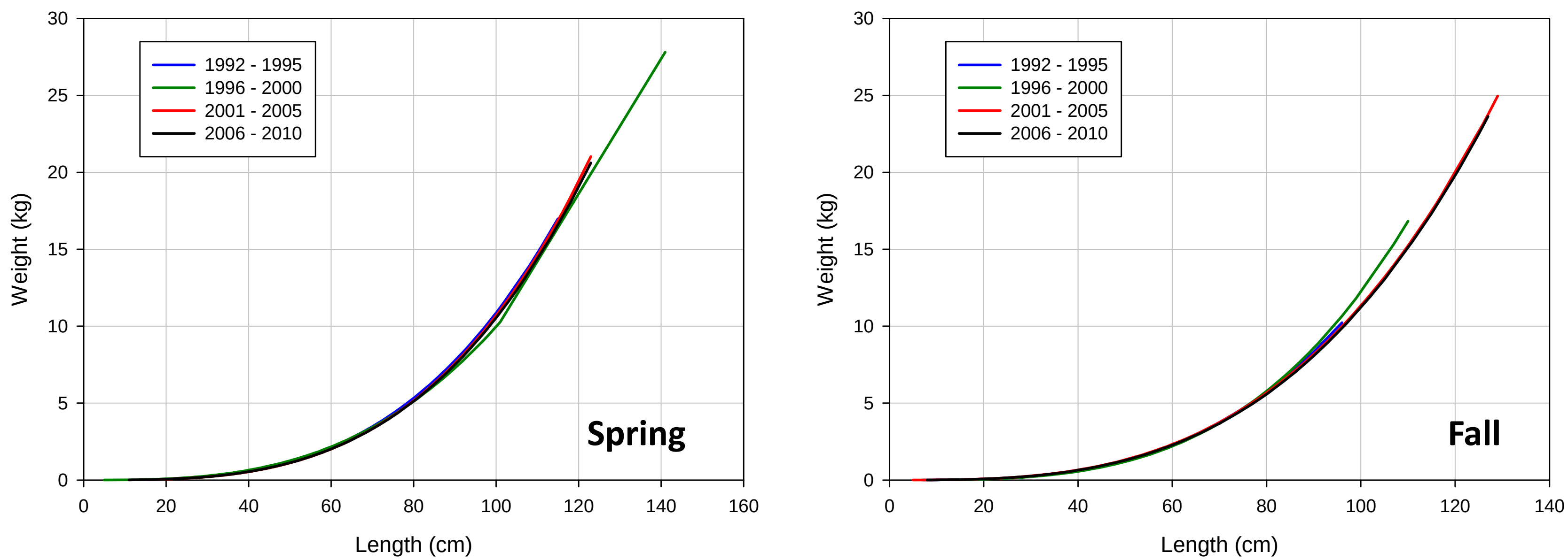


Figure A.2. Comparison of the seasonal length-weight equations estimated from NEFSC survey data relative to the length-weight equation used in previous Gulf of Maine Atlantic cod assessments.

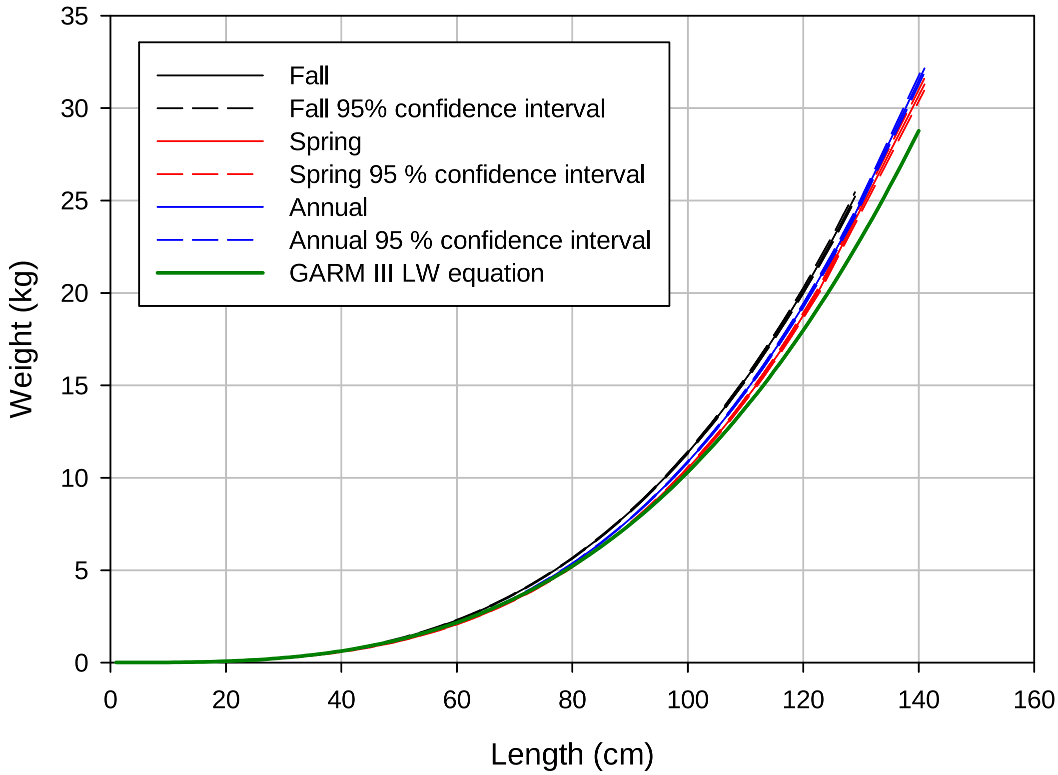


Figure A.3. Comparison of the seasonal length-weight equations estimated from NEFSC survey data relative to the length-weight equation used in previous Gulf of Maine Atlantic cod assessments.

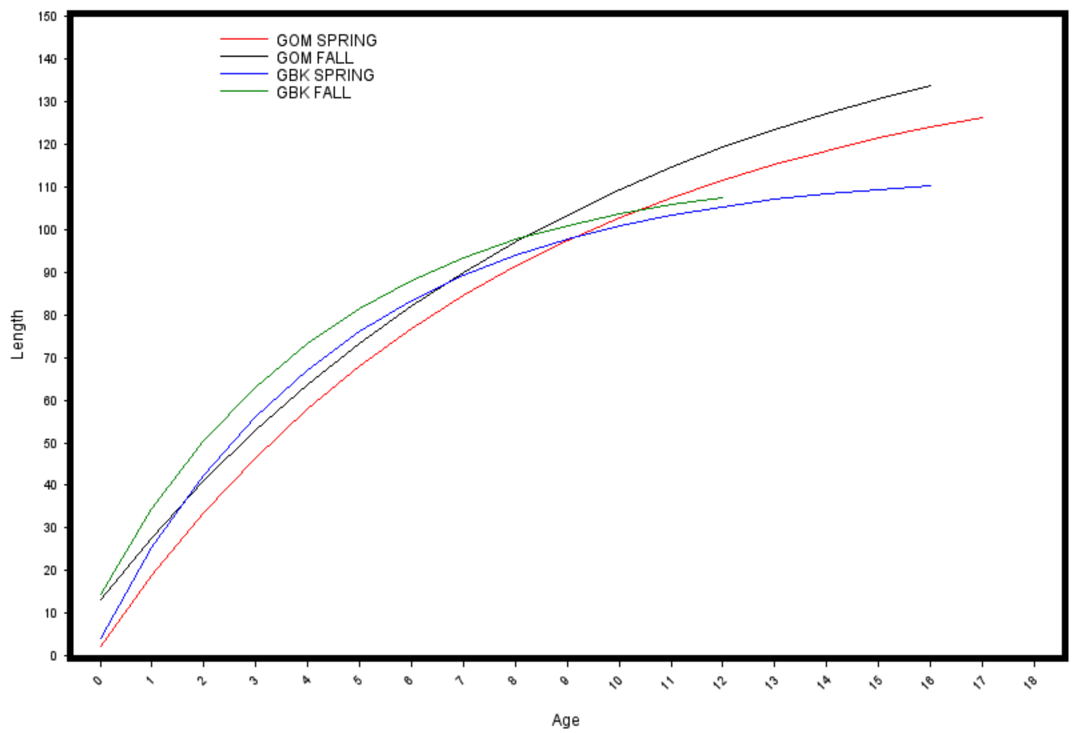


Figure A.4. Comparison of von Bertalanffy growth curves for the Gulf of Maine (GOM) and Georges Banks (GBK) Atlantic cod stocks as estimated from data collected from the Northeast Fisheries Science Center spring and fall bottom trawl survey s between 1970 and 2011. Growth paremeters estimated for the Gulf of Maine stock wer; spring: L_{inf}=142.6, K=0.126, t_0=0.130; fall: L_{inf}=162.4, K=0.103, t_0=0.810.

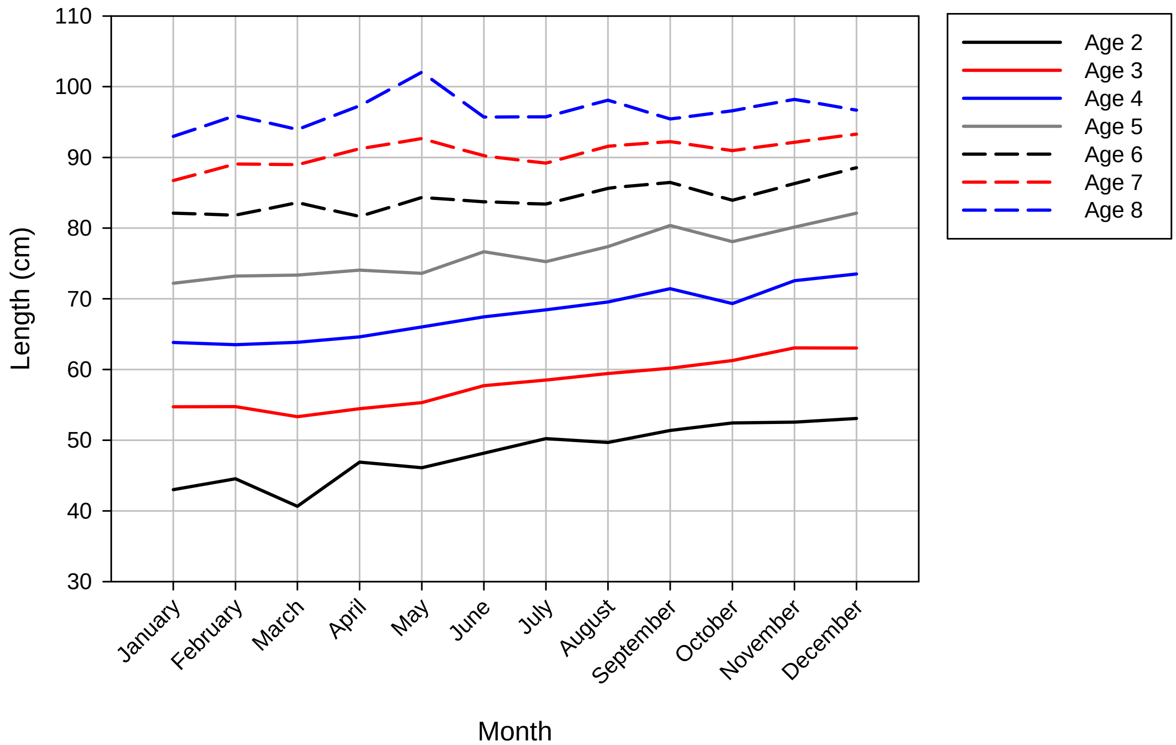
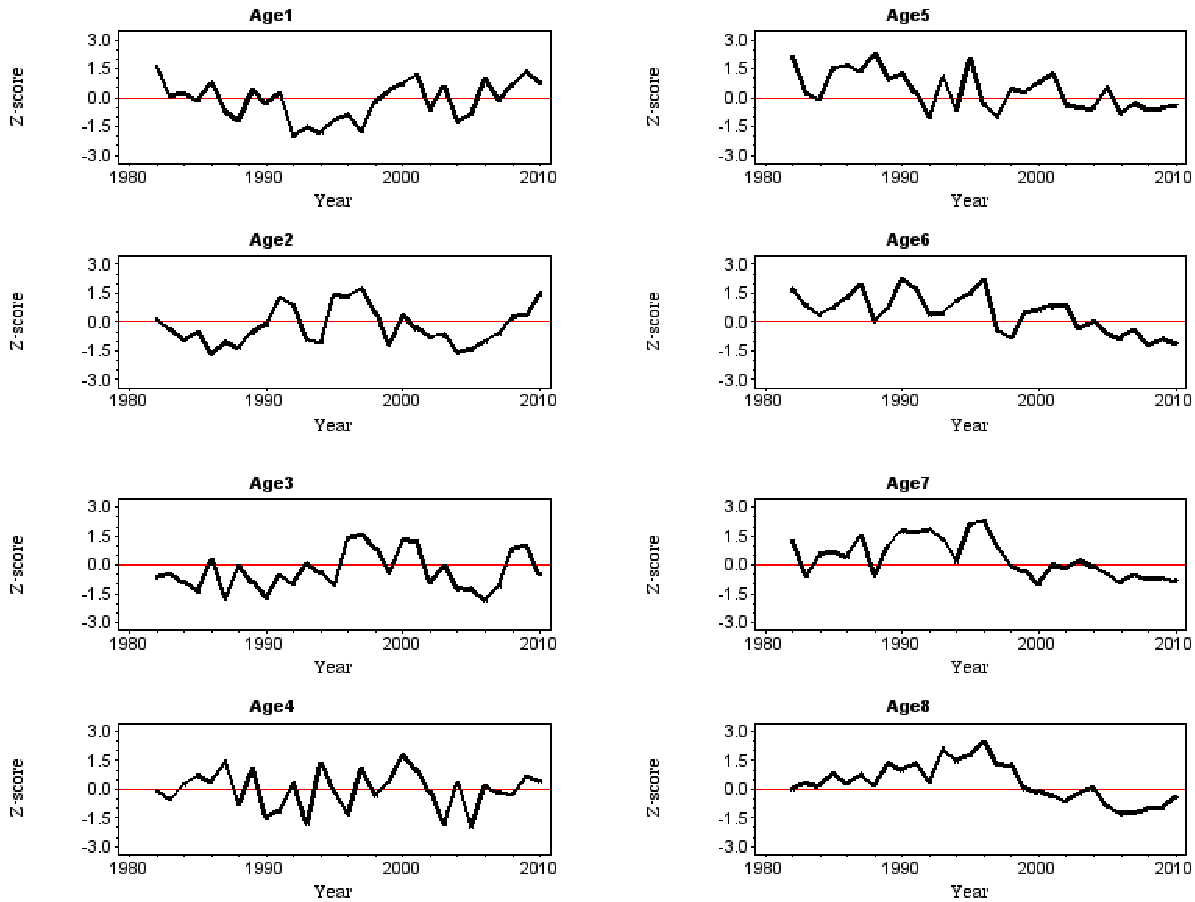
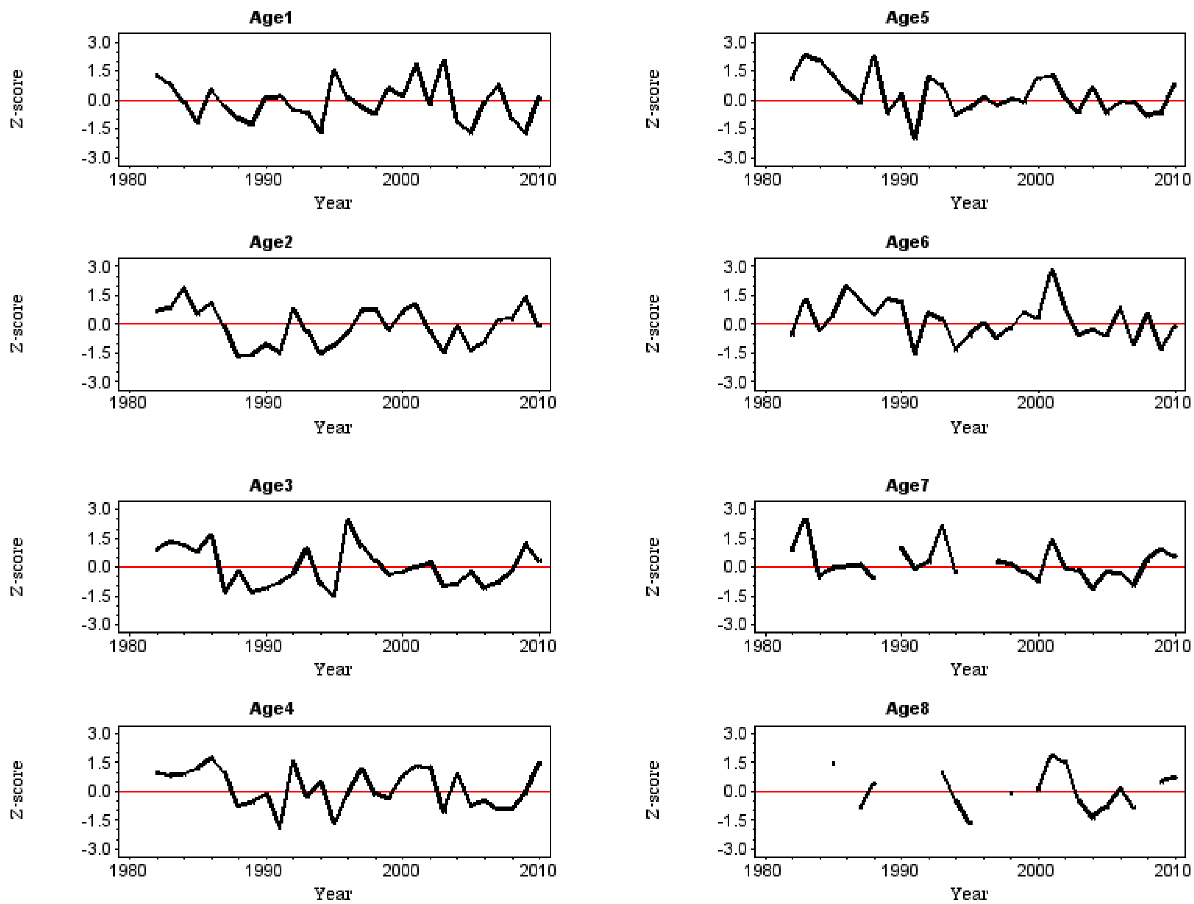


Figure A.5. Mean length-at-age of Altantic cod landed by the commercial fishery by month. Estimated from commercial port samples taken between 1981 and 2009.



Figue A.6. Average catch weights-at-age of Age 1 through Age 8 Gulf of Maine Atlantic cod from 1982 to 2010. 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 ($[x-\mu]/\sigma$).



Figue A.7. Average survey weights-at-age of Age 1 through Age 8 Gulf of Maine Atlantic cod from 1982 to 2010. 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).

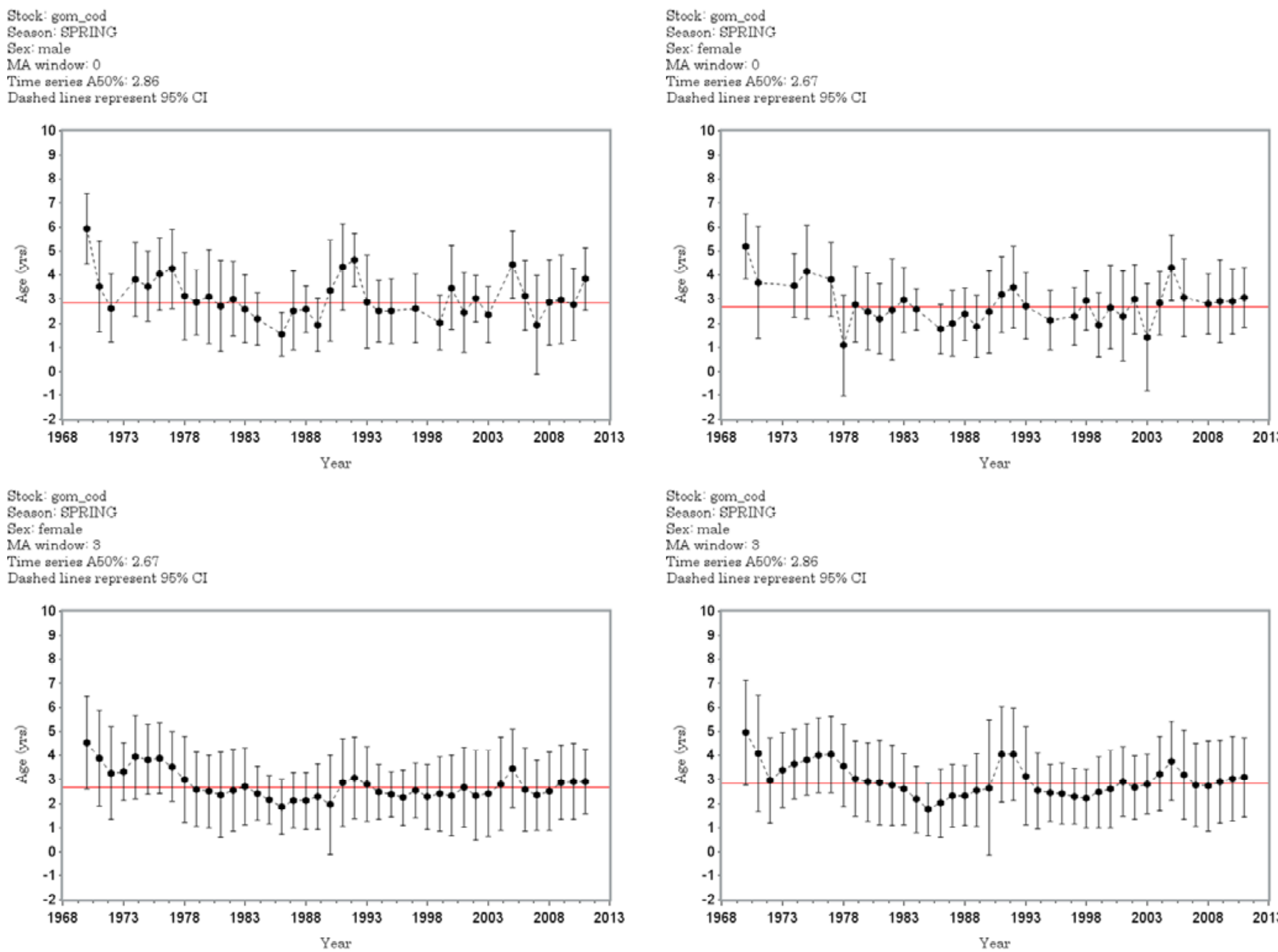


Figure A.8. Annual (top panels) and three-year moving averages (bottom panels) of the average age-at-50% maturity (A50) and corresponding 95% confidence intervals for male (left panels) and female (right panels) Gulf of Maine Atlantic cod from 1970 to 2011. Average maturity has been estimated from data collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey. Years in which maturity ogives could not be estimated are omitted from the top panel.

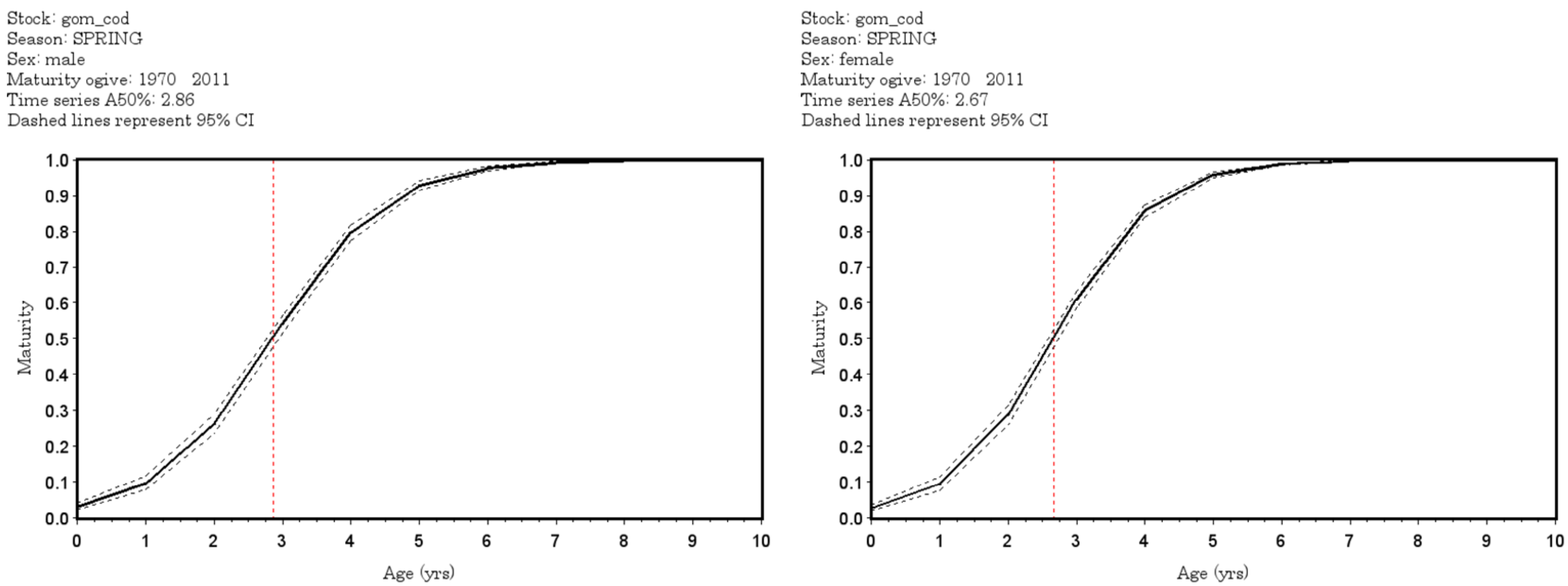


Figure A.9. Maturity ogives for male (left) and female (right) Gulf of Maine Atlantic cod based on time series averages of maturity and age information collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey from 1970 to 2011.

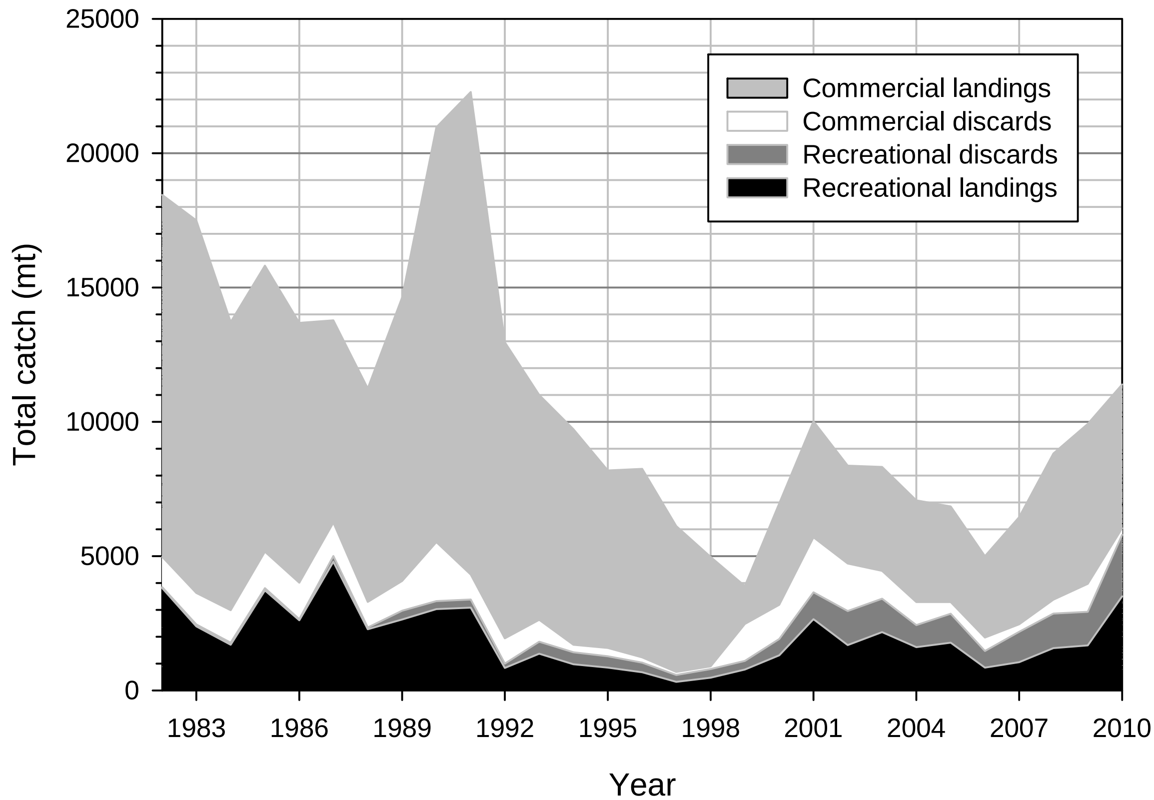


Figure A.10. Total catch of Gulf of Maine Atlantic cod from 1982 to 2010 by fleet (commercial and recreational) and disposition (landed, discarded).

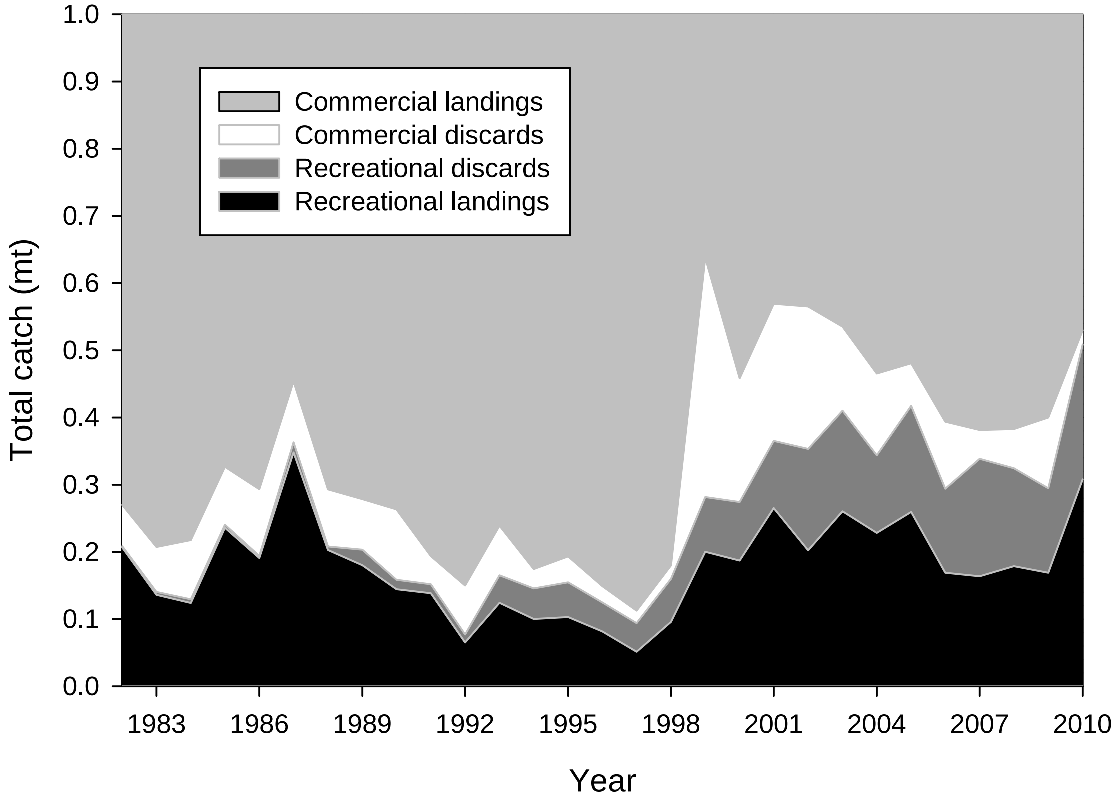


Figure A.11. Total catch of Gulf of Maine Atlantic cod of from 1982 to 2010 by fleet (commercial and recreational) and disposition (landed, discarded) expressed as proportions of the total catch.

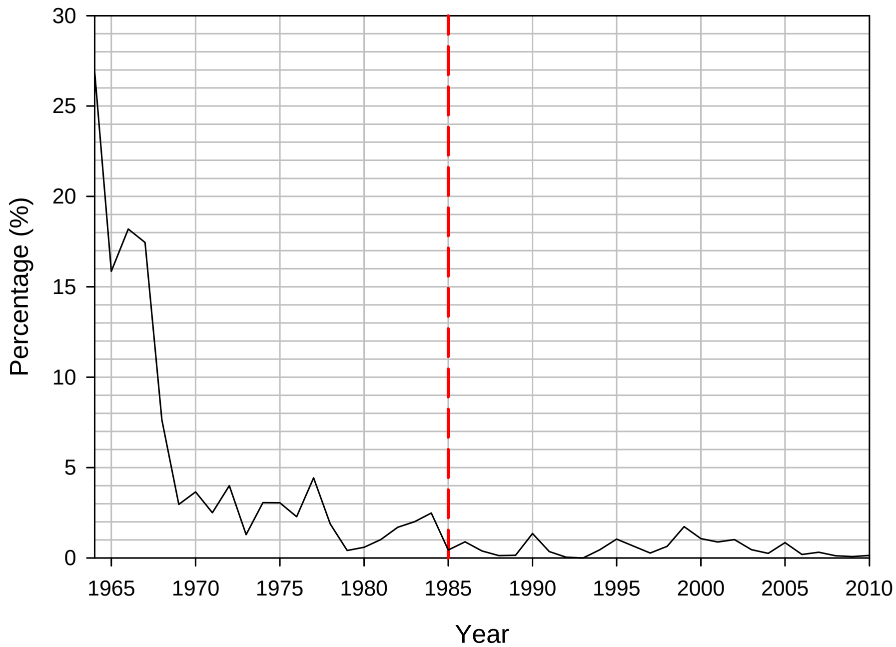


Figure A.12. Percentage of total commercial landings of Gulf of Maine Atlantic cod coming from statistical areas 464, 465 and 467 between 1964 and 2010. The Hague Line, which formaly defined the Exclusive Econonimic Zones of the Gulf of Maine into United States and Canada was adopted on October 12, 1984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

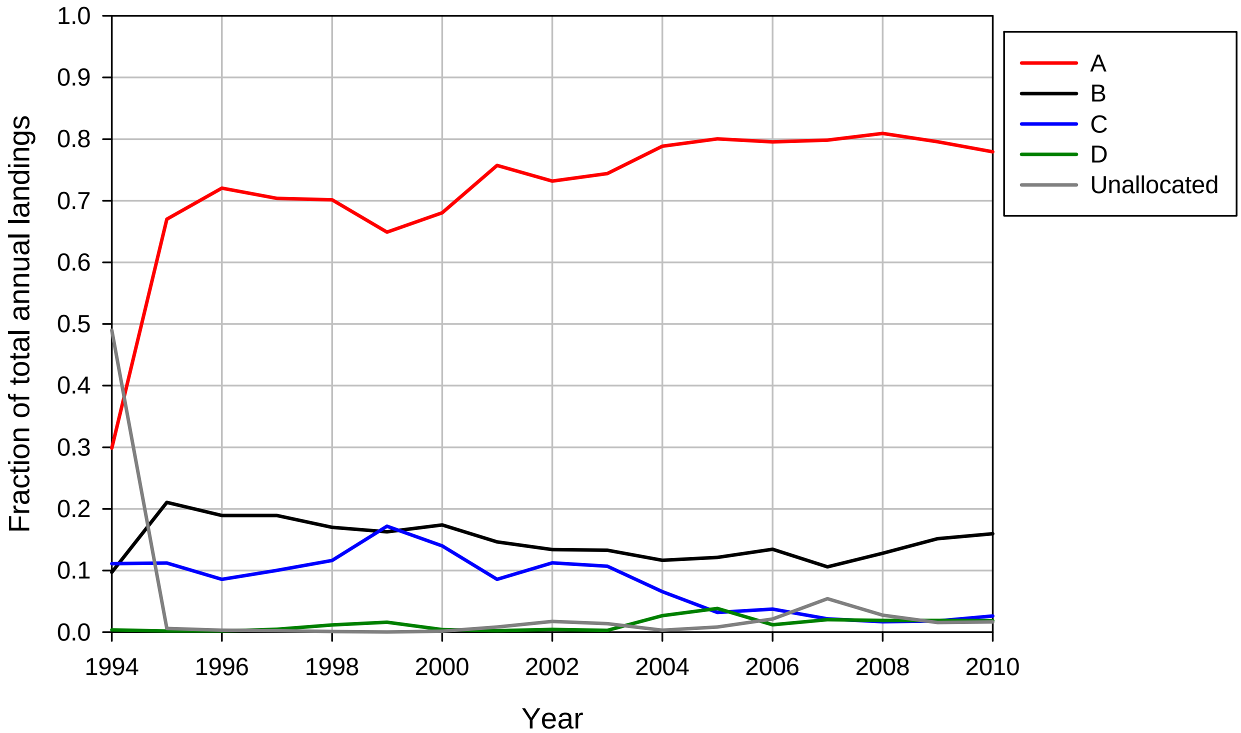


Figure A.13. Fraction of commercial landings by Area-Allocation level (AA, see Wigley et al. 2008) for Gulf of Maine Atlantic cod from 1994 to 2010. Certainty of the landings area allocation increases from level D to A. Unallocated landings do not enter the allocation procedure (e.g., state-reported landings).

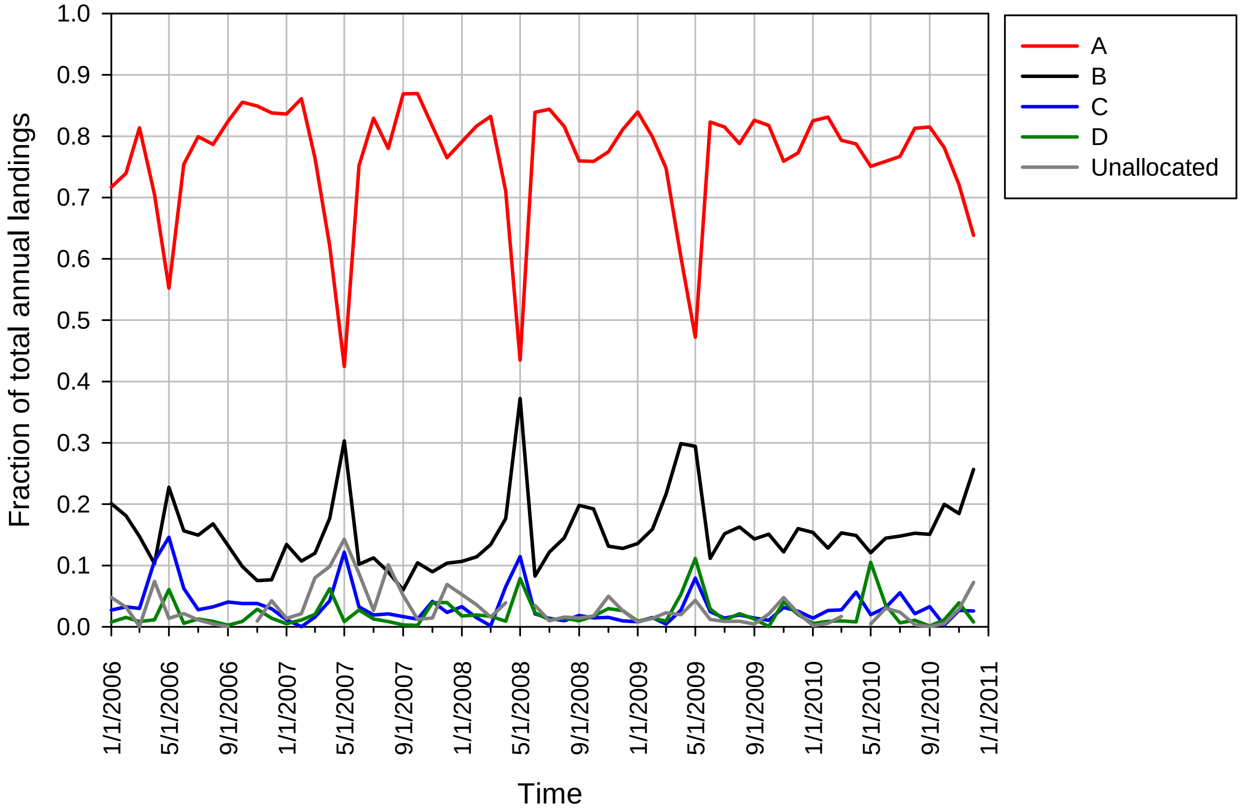
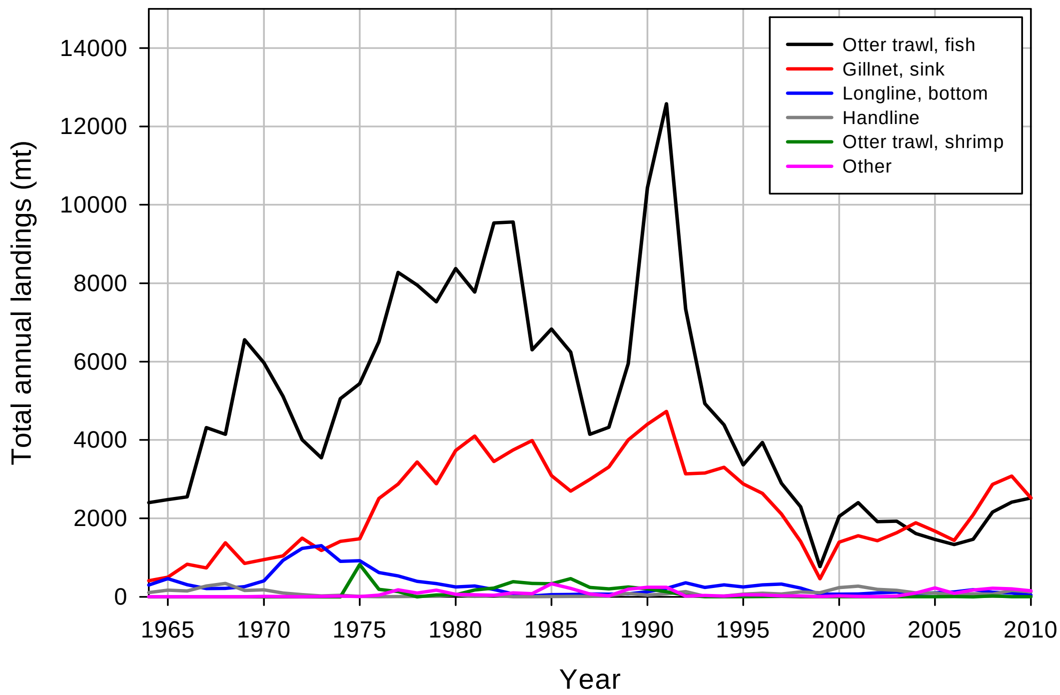


Figure A.14. Monthly commercial landing patterns (as a fraction of the total landings) by Area-Allocation level (AA, see Wigley et al. 2008) for Gulf of Maine Atlantic cod from 2006 to 2010. Certainty of the landings area allocation increases from level D to A. Unallocated landings do not enter the allocation procedure (e.g., state-reported landings).



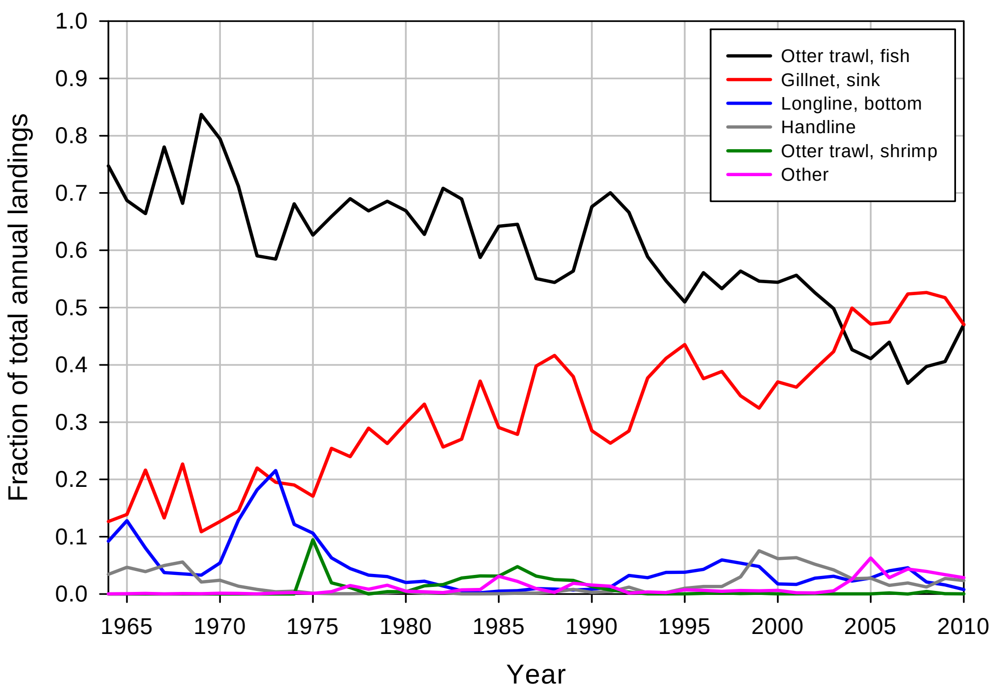


Figure A.15. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by gear from 1964 to 2010.

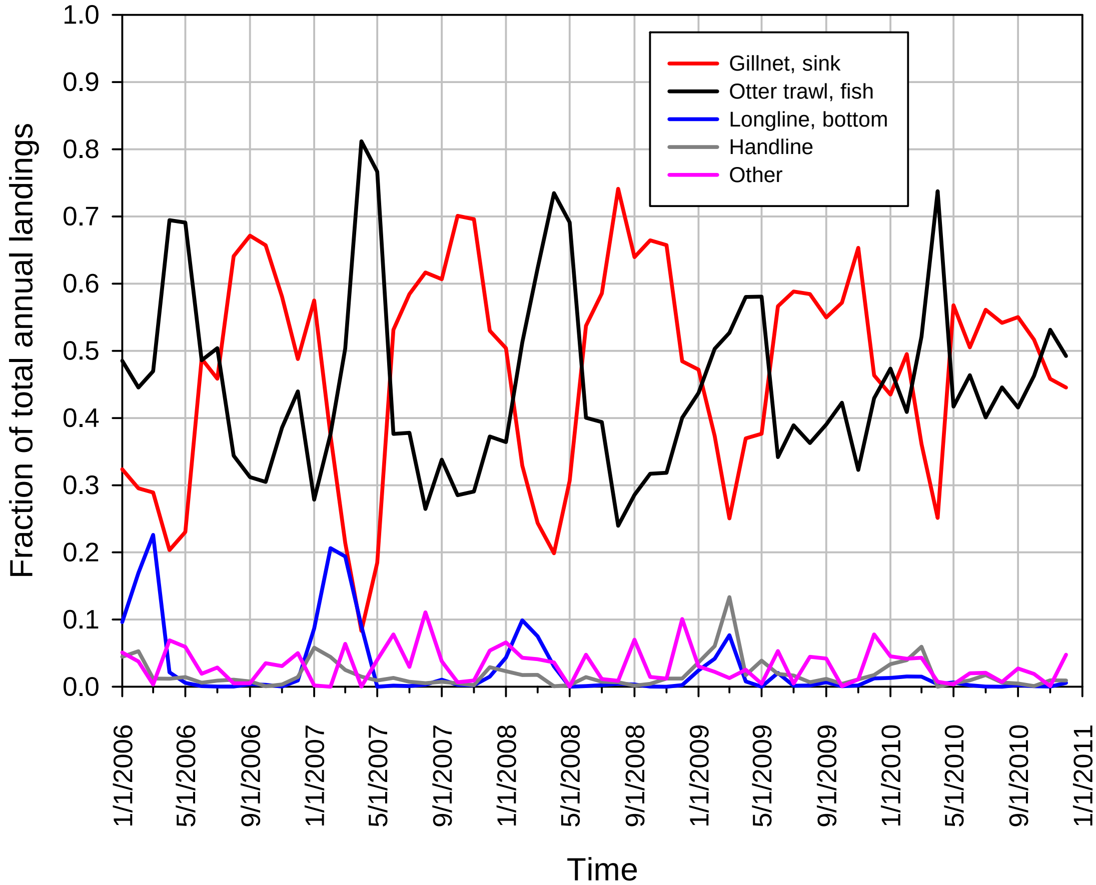


Figure A.16. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by gear from 2006 to 2010.

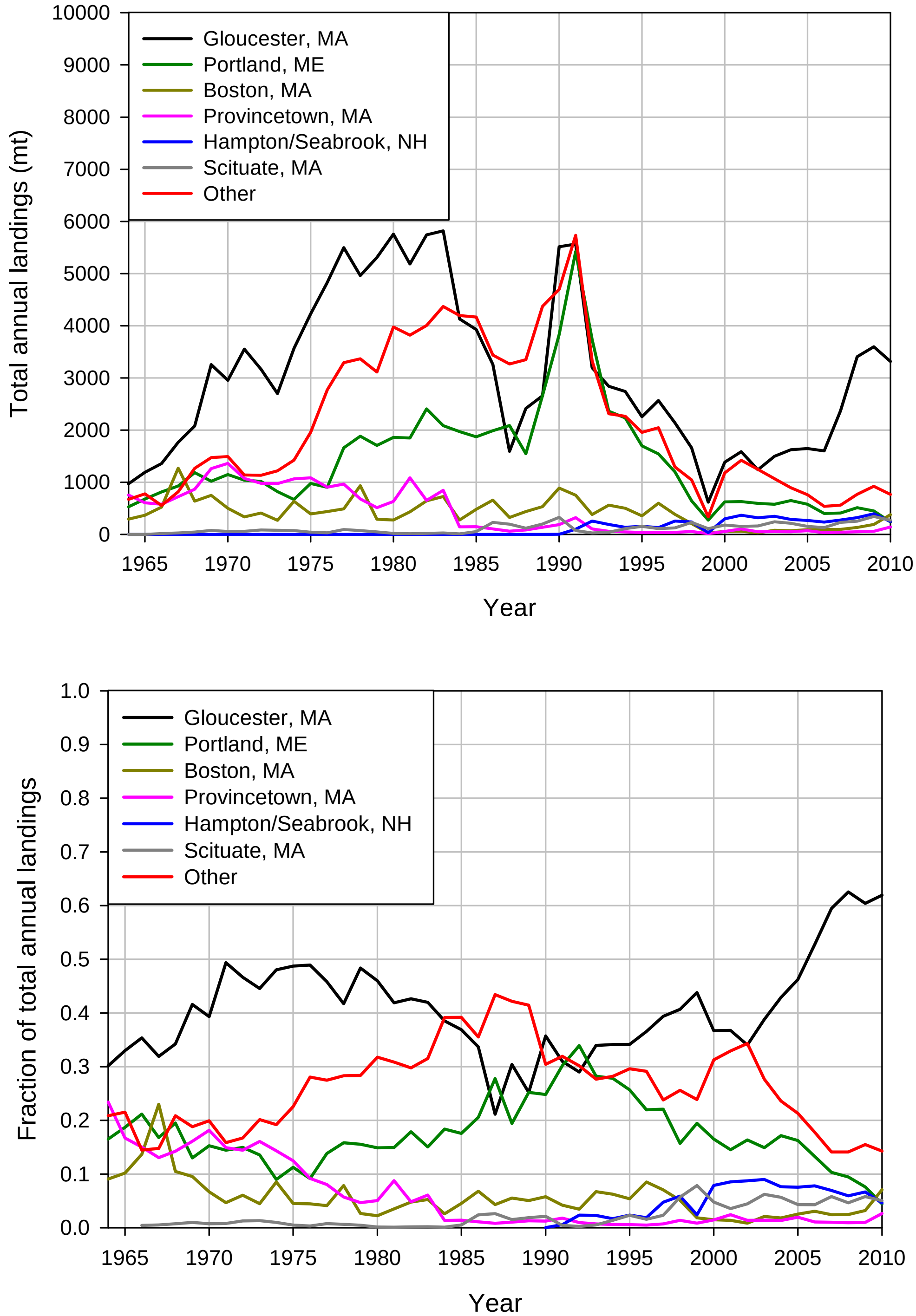


Figure A.17. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by port from 1964 to 2010.

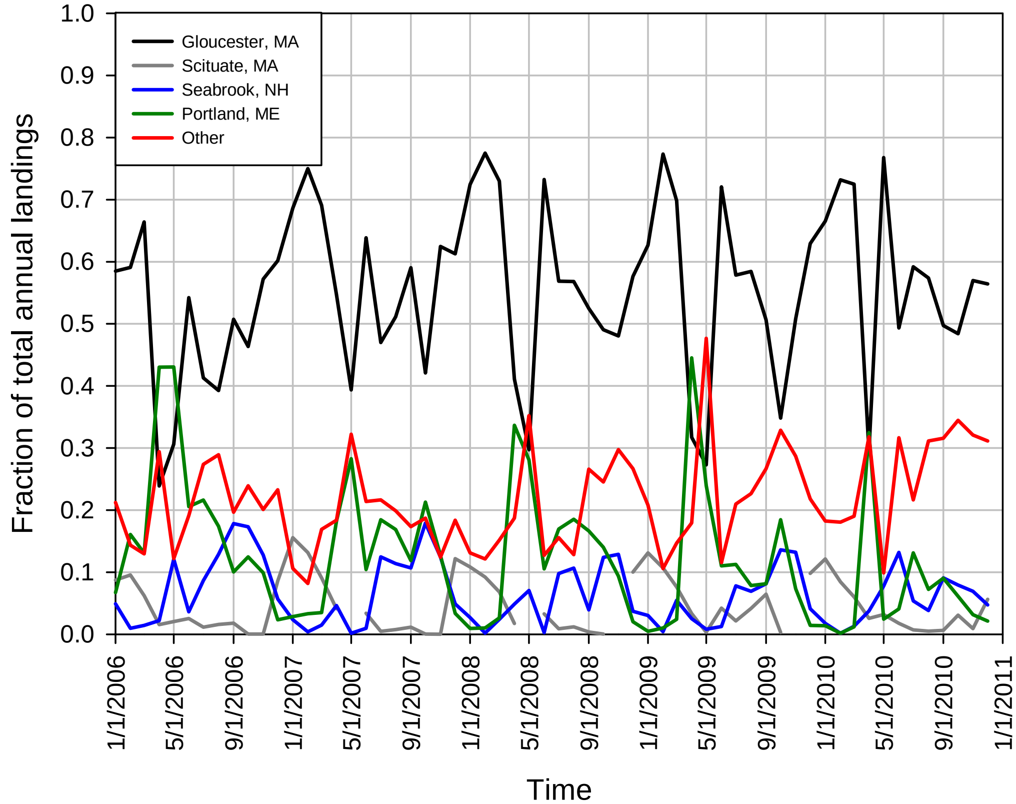


Figure A.18. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by port from 2006 to 2010.

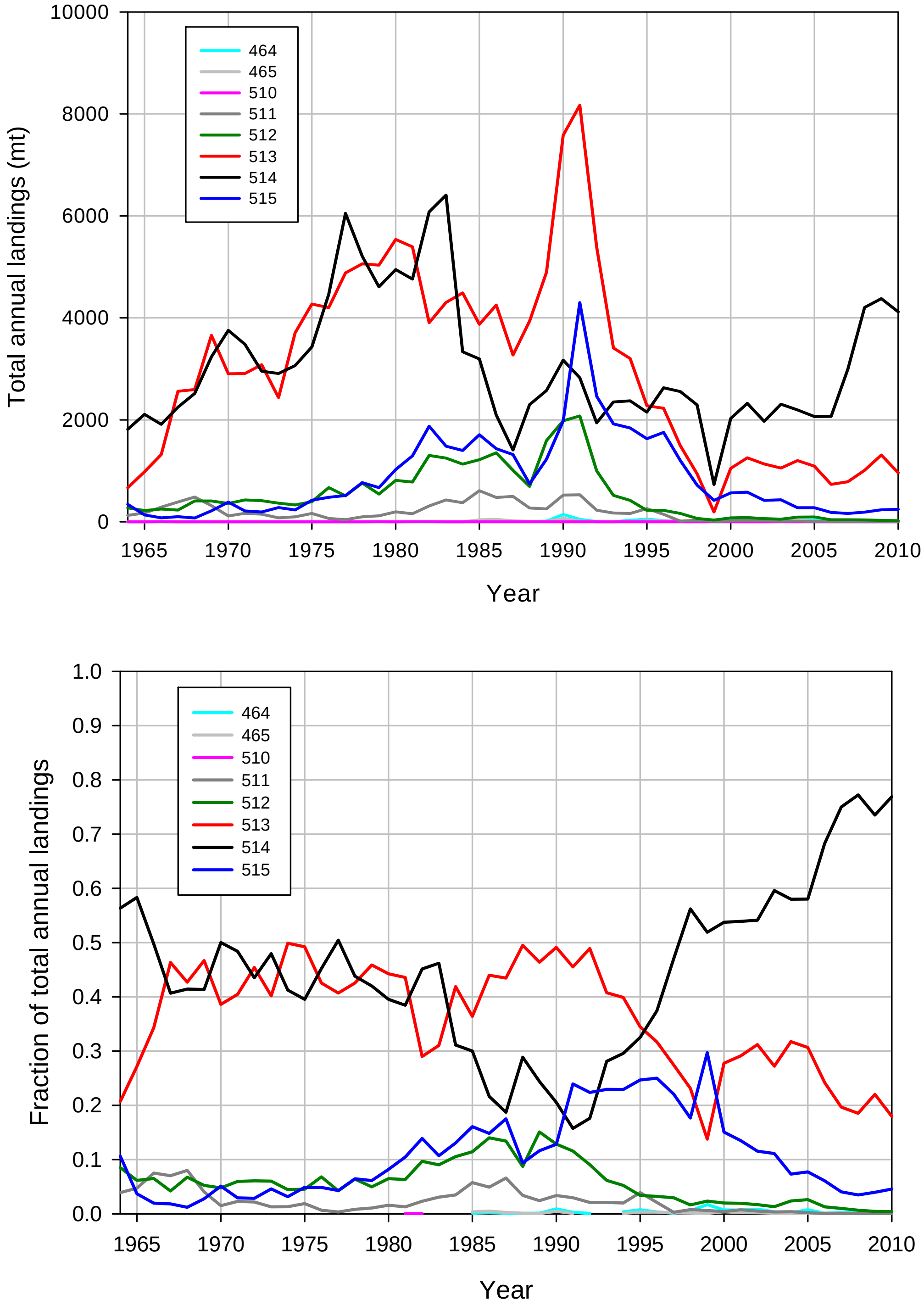


Figure A.19. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by statistical area from 1964 to 2010.

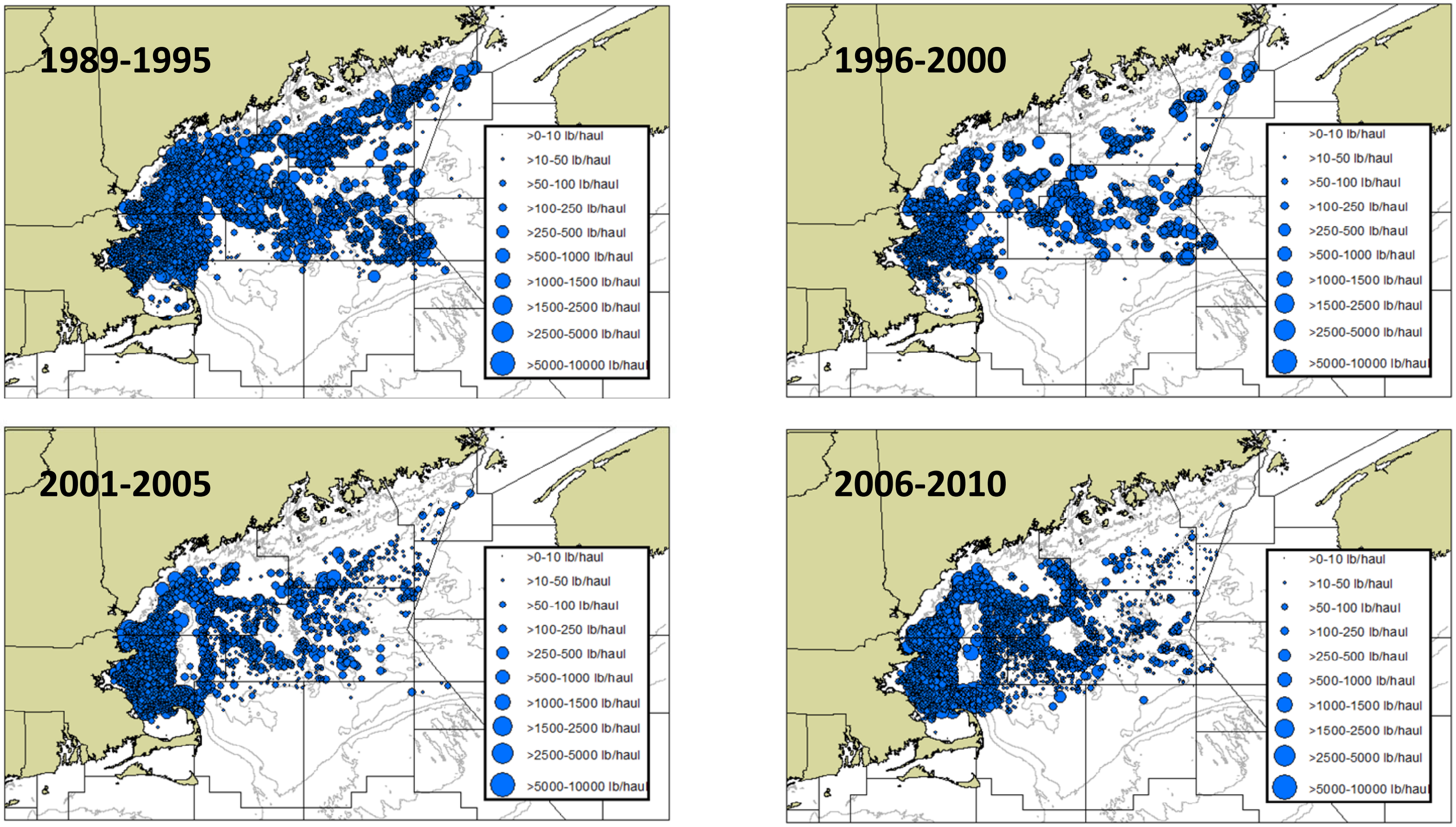


Figure A.20. Average Gulf of Maine Atlantic cod caught per haul (retained and discarded) by latitude and longitude position over approximately five year blocks from 1989 to 2010 (first block shown contains six years of data). Data come from data collected by the Northeast Fisheries Observer Program on trips which caught > 0 lbs. of cod in the Gulf of Maine.

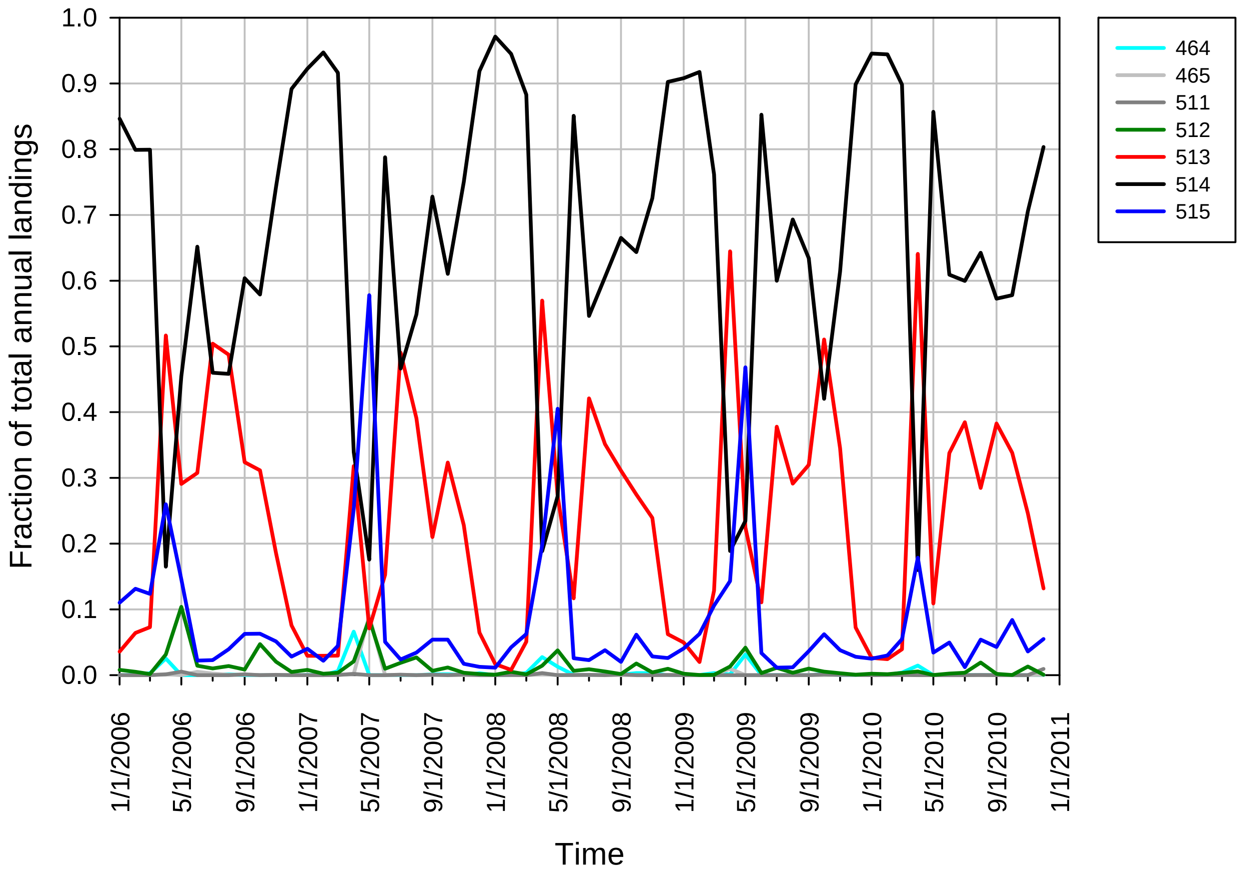
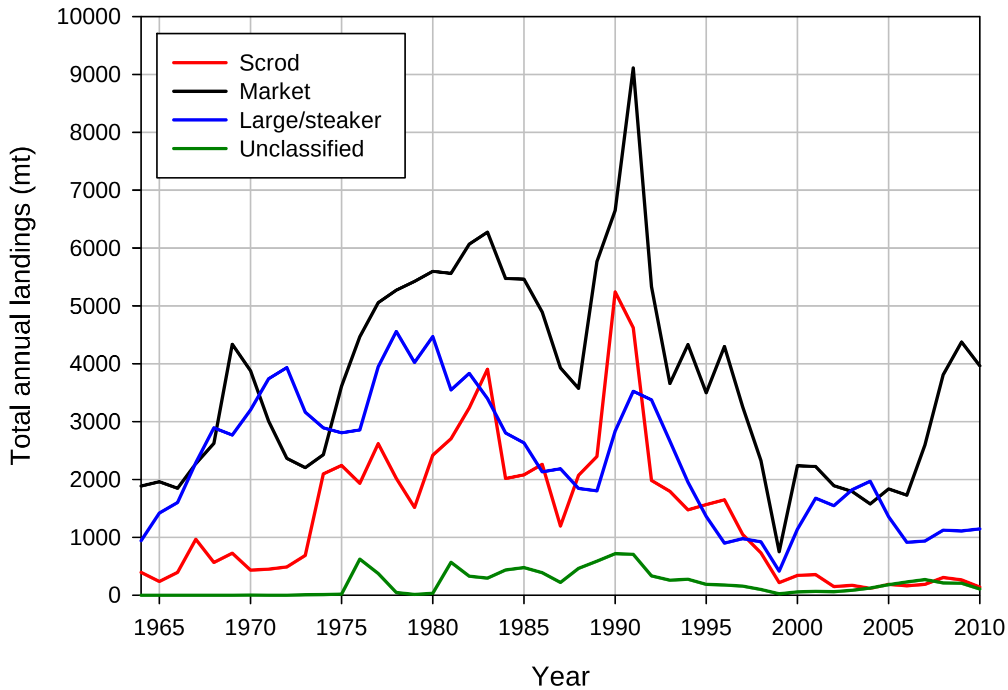


Figure A.21. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by statistical area from 2006 to 2010.



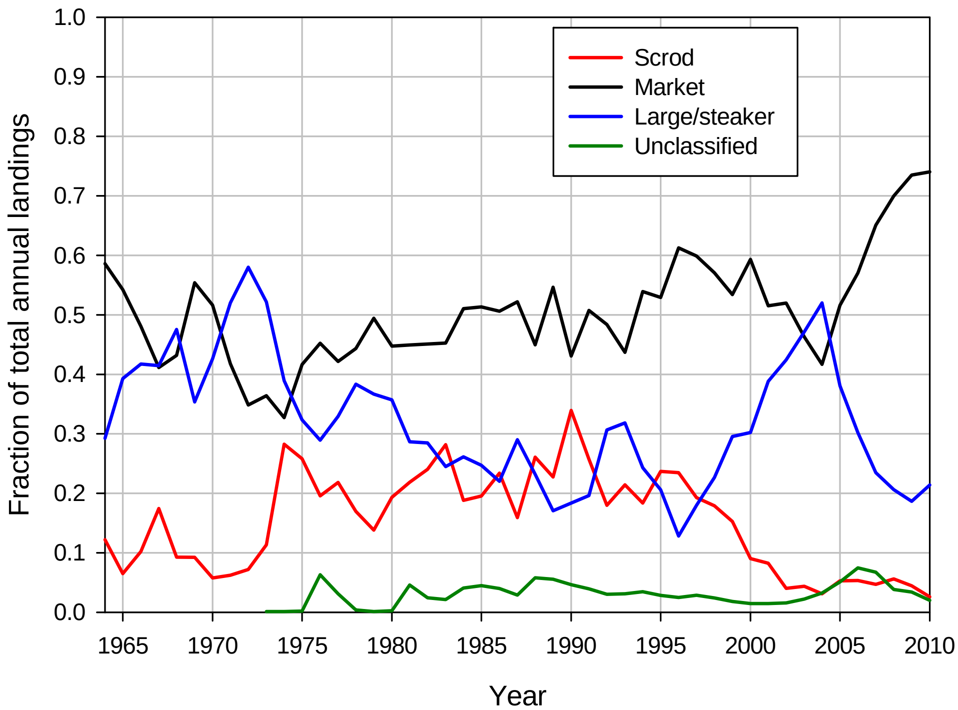


Figure A.22. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by market category from 1964 to 2010.

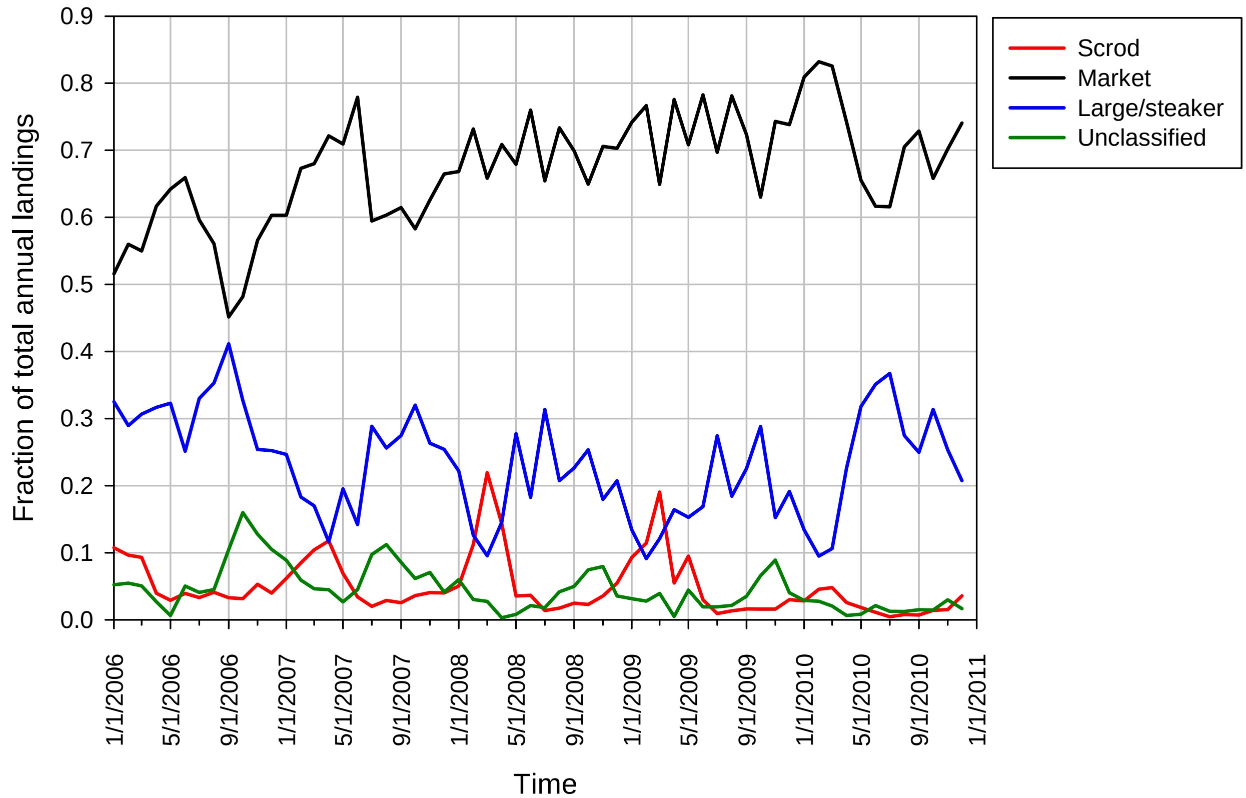


Figure A.23. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by market category from 2006 to 2010.

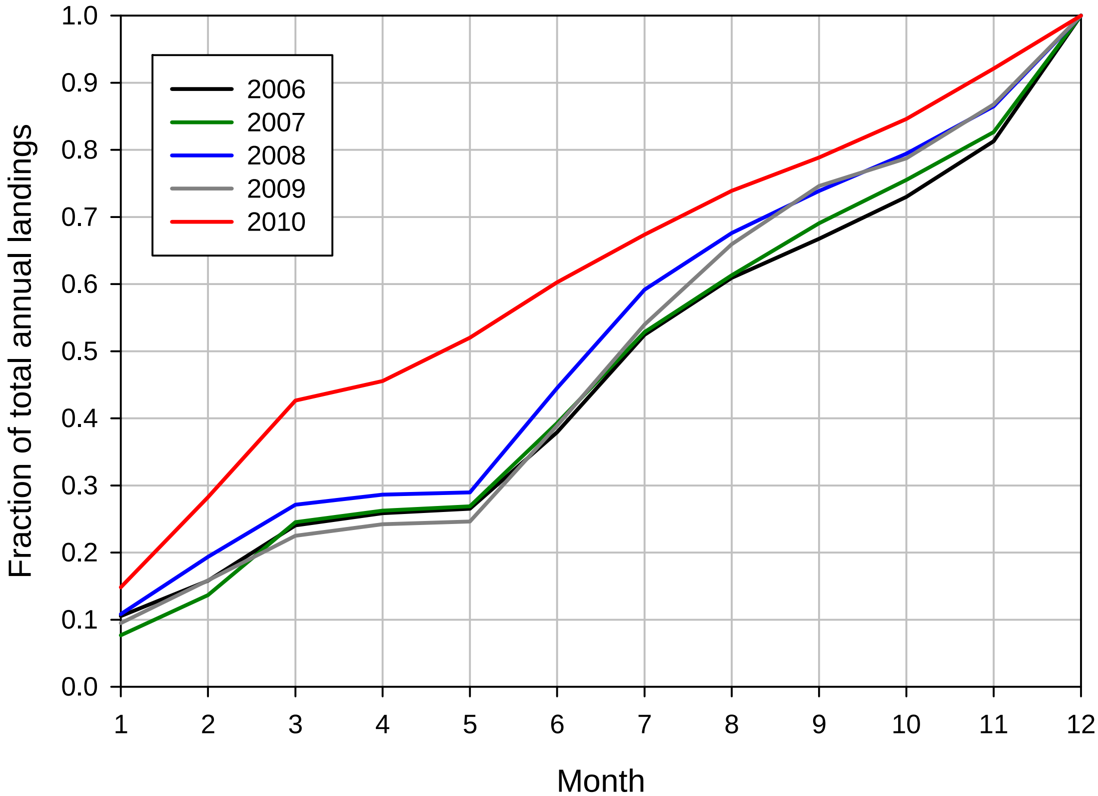


Figure A.24. Cumulative monthly commercial landings of Gulf of Maine Atlantic cod by year from 2006 to 2010.

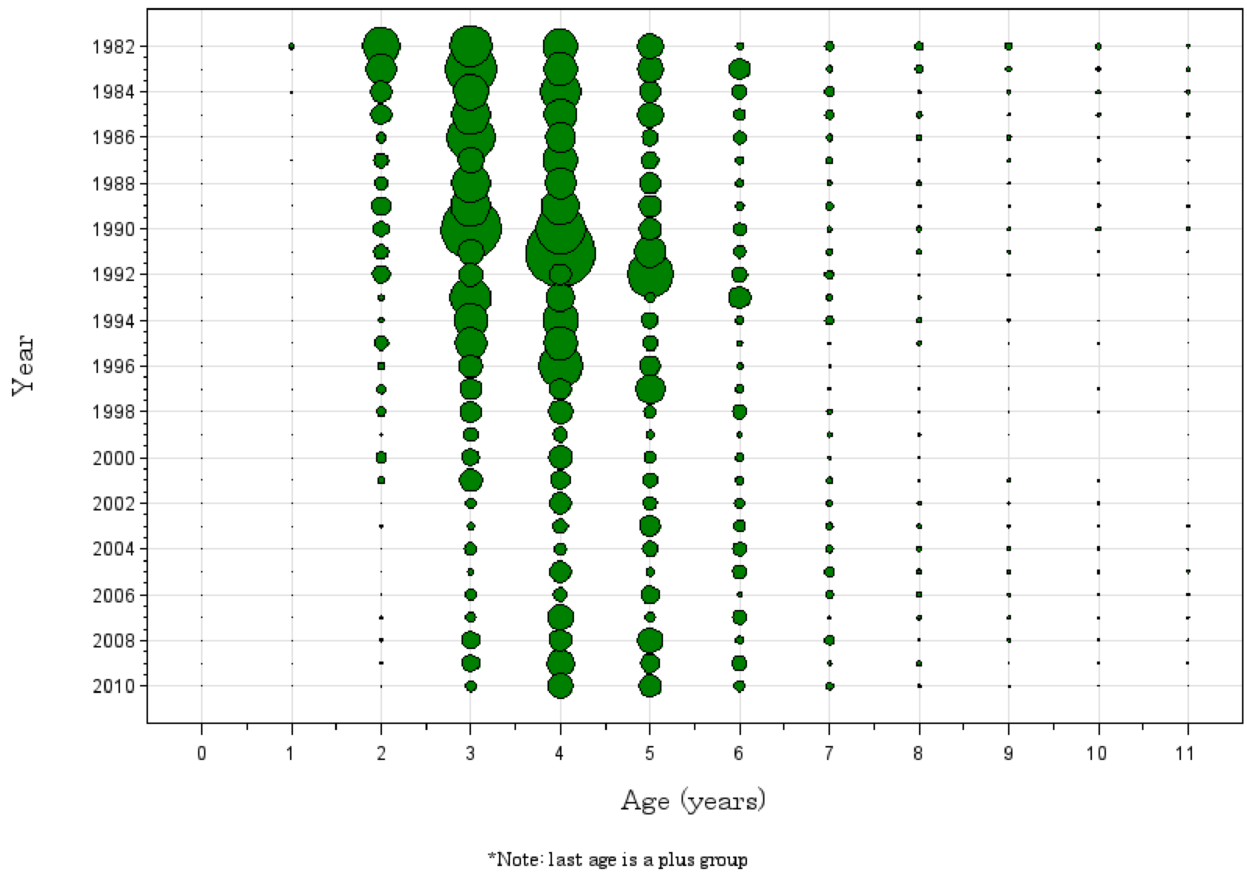


Figure A.25. Commercial landings-at-age of Gulf of Maine Atlantic cod from 1982 to 2010. **Note that age 11 is a plus group.*

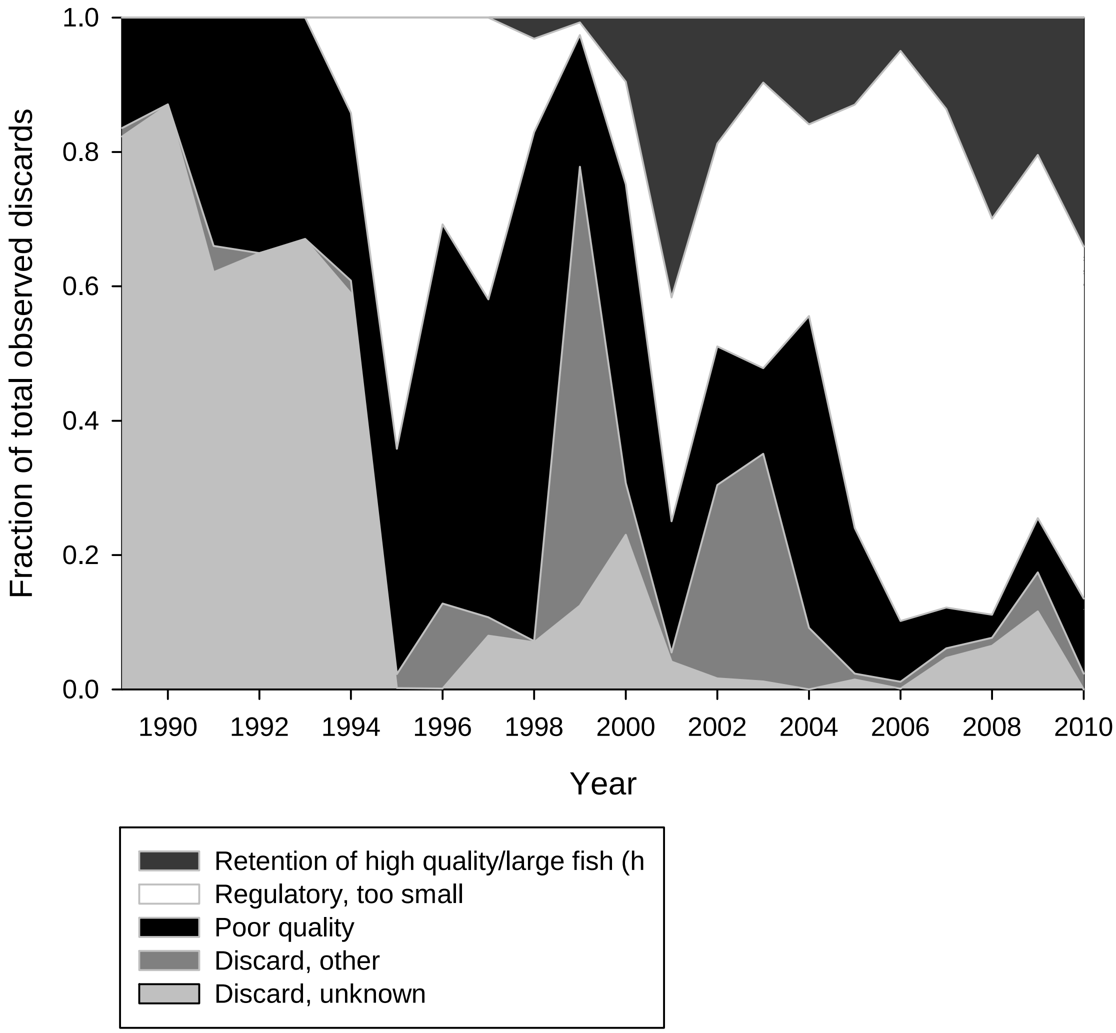


Figure A.26. Discard reasons for Gulf of Maine Atlantic cod as recorded by fisheries observers between 1989 and 2010.

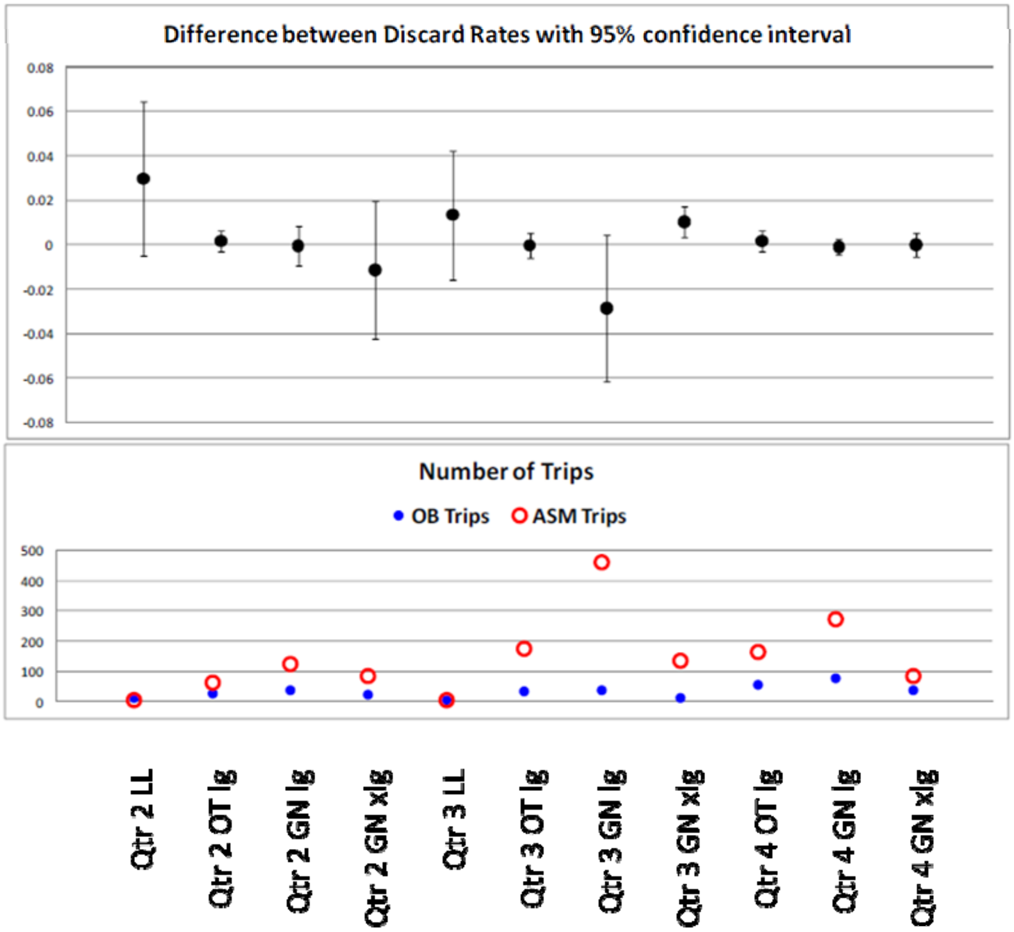


Figure A.27. Differences between the Gulf of Maine Atlantic cod discard rates estimated from data collected by groundfish At-Sea Monitors (ASMs) and certified Observers showing 95% confidence intervals (top panel) and the number of trips included in each analysis (bottom panel) broken down by gear-mesh combination and quarter (from Wigley et al. 2011). Gear categories are: longline (LL), large mesh otter trawl (OT lg), extra-large mesh sink gillnet (GN xlg) and large mesh sink gillnet (GN lg).

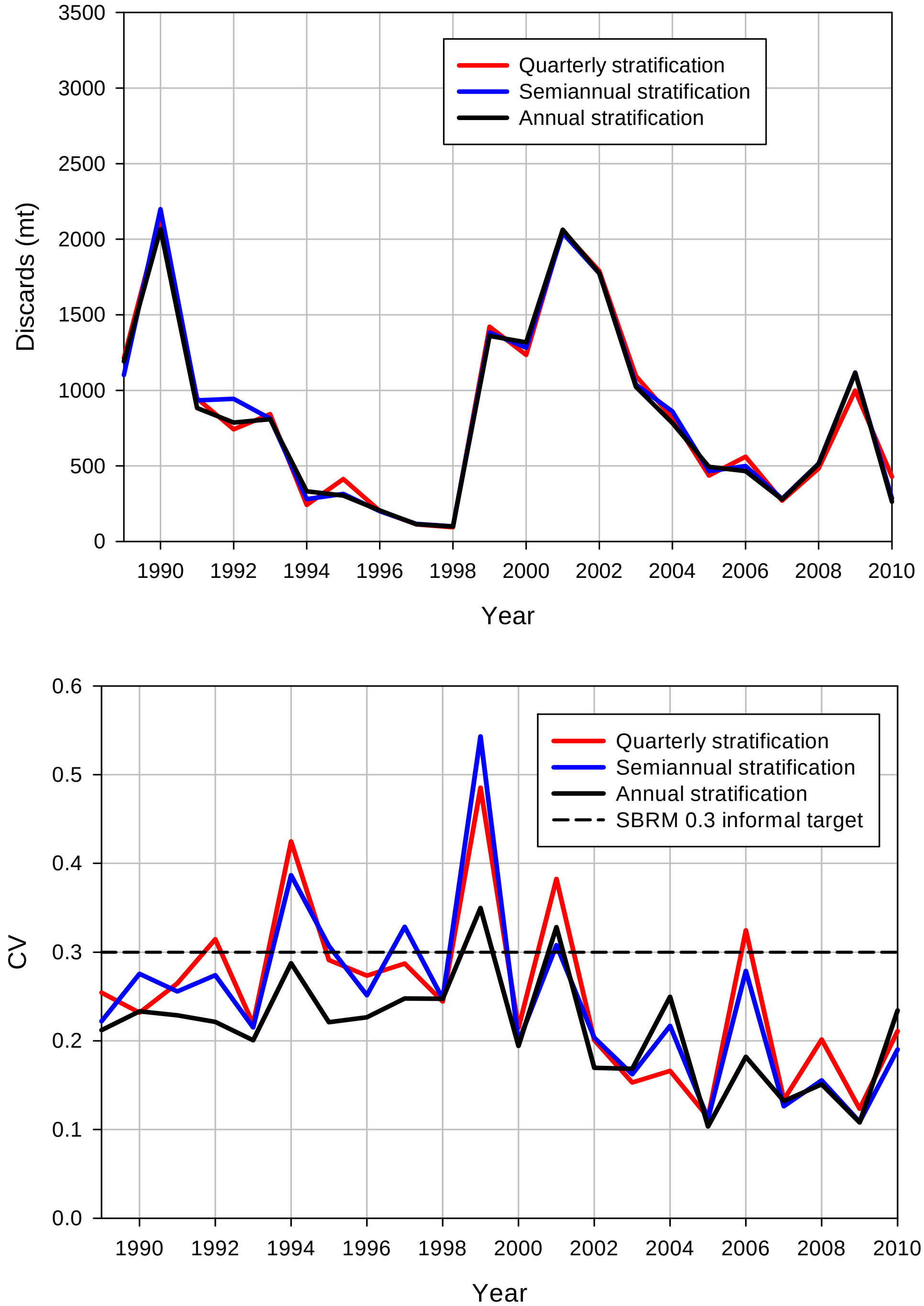


Figure A.28. Comparison of the annual discard estimates for Gulf of Maine Atlantic cod (top) and corresponding coefficients of variation (CV, bottom) using three different temporal stratification schemes: quarterly, annual and semiannual. The dashed black line represents the Standardized Bycatch Reporting Methodology (SBRM, Wigley et al. 2007) informal precision target. **Note that these comparisons were performed on a preliminary data set that included handline/jig gear, which was excluded from the final discard estimates, and may not match the final discard estimates exactly.*

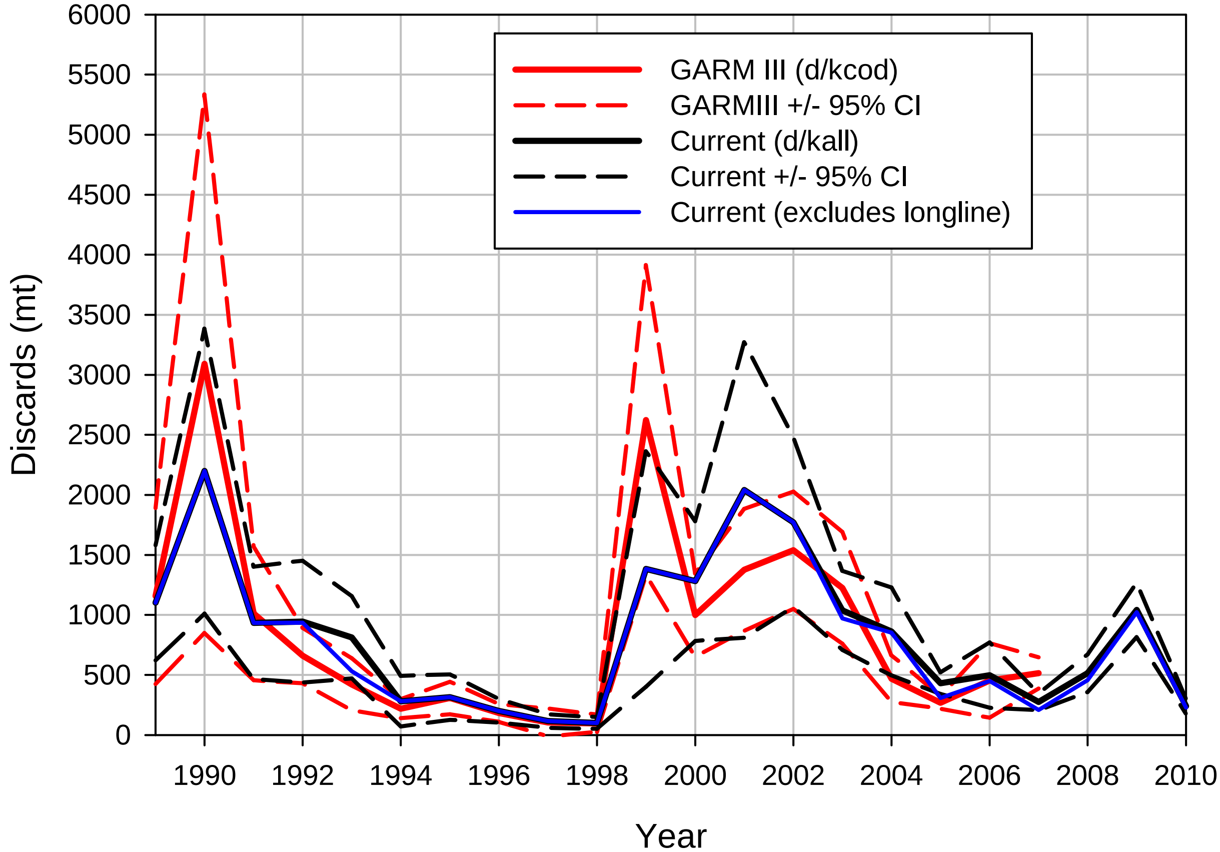


Figure A.29. Comparison of the updated discard estimates to the discard estimates used in the 2008 Groundfish Assessment Review Meeting (GARM III) for Gulf of Maine Atlantic cod. Both current and GARM III estimates are shown with their respective 95% confidence intervals (CI). The current estimate is shown both with, and without, longline gear since this gear type was not included in the GARM III discard estimate.

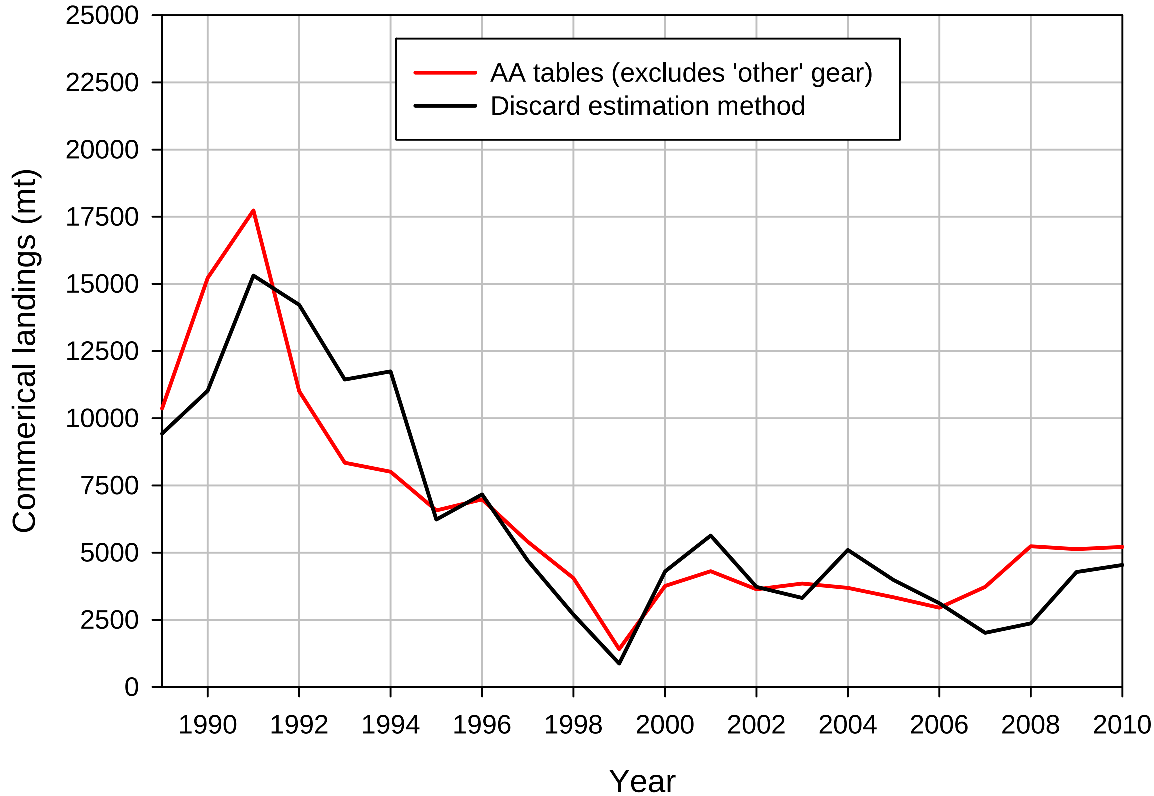


Figure A.30. Comparison of Gulf of Maine Atlantic cod landings estimates generated using the Standardized Bycatch Reporting Methodology (SBRM, Wigley et al. 2007) combined ratio approach to stock landings from the Commercial Fisheries Database (CFDBS). Landings are shown only for longline, handline, 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.**Note that these comparisons were performed on a preliminary data set that included handline/jig gear, which was excluded from the final discard estimates, and may not match the final discard estimates exactly.*

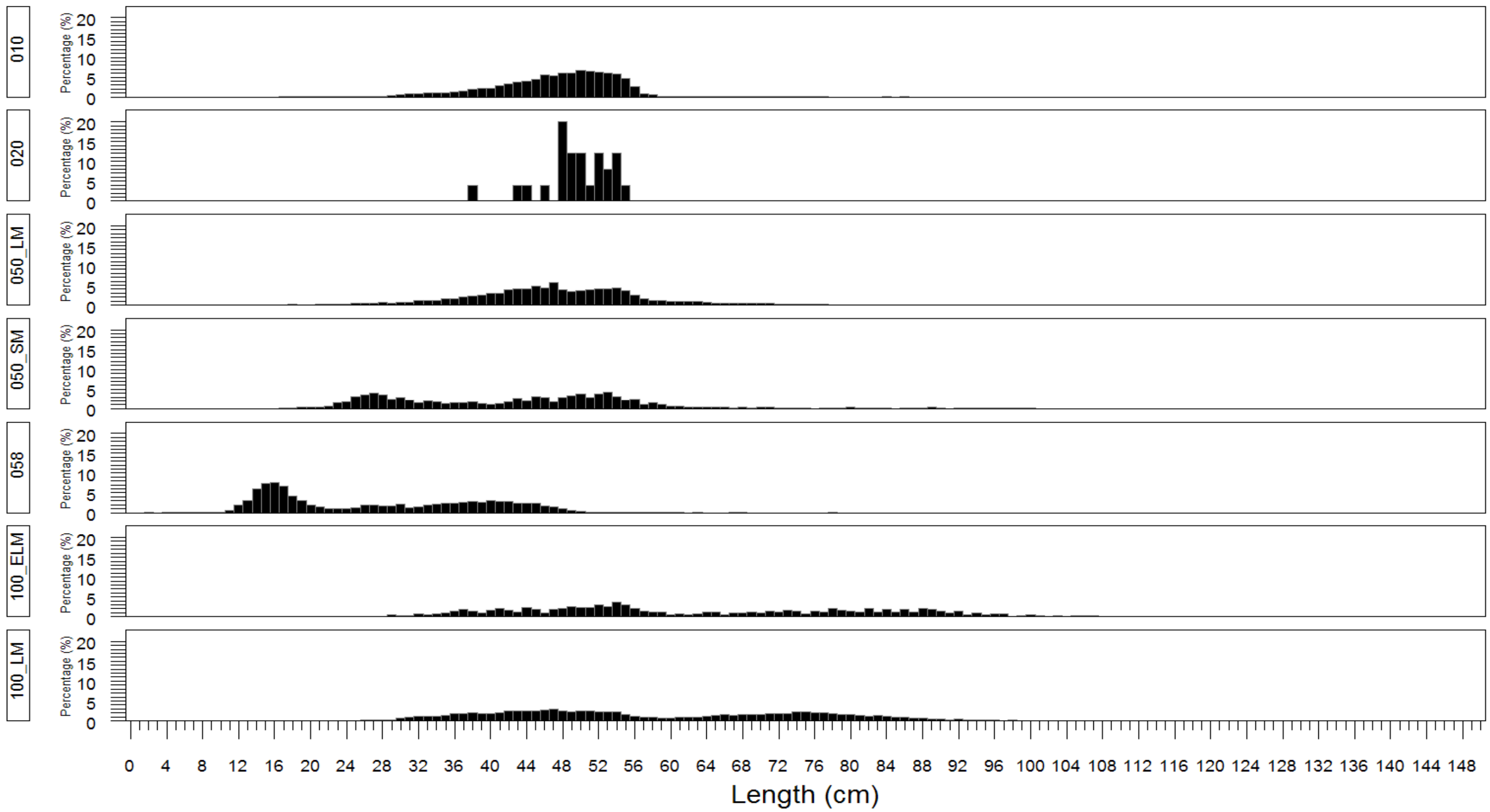


Figure A.31. Aggregate length frequency distributions, by gear type, of Gulf of Maine Atlantic cod discarded in the commercial fishery between 1989 and 2010. Gear types shown include: longline (010), handline/jig (020), large mesh otter trawl (050_LM), small mesh otter trawl (050_SM), shrimp trawl (058), extra-large mesh sink gillnet (100_ELM) and large mesh sink gillnet (100_LM).

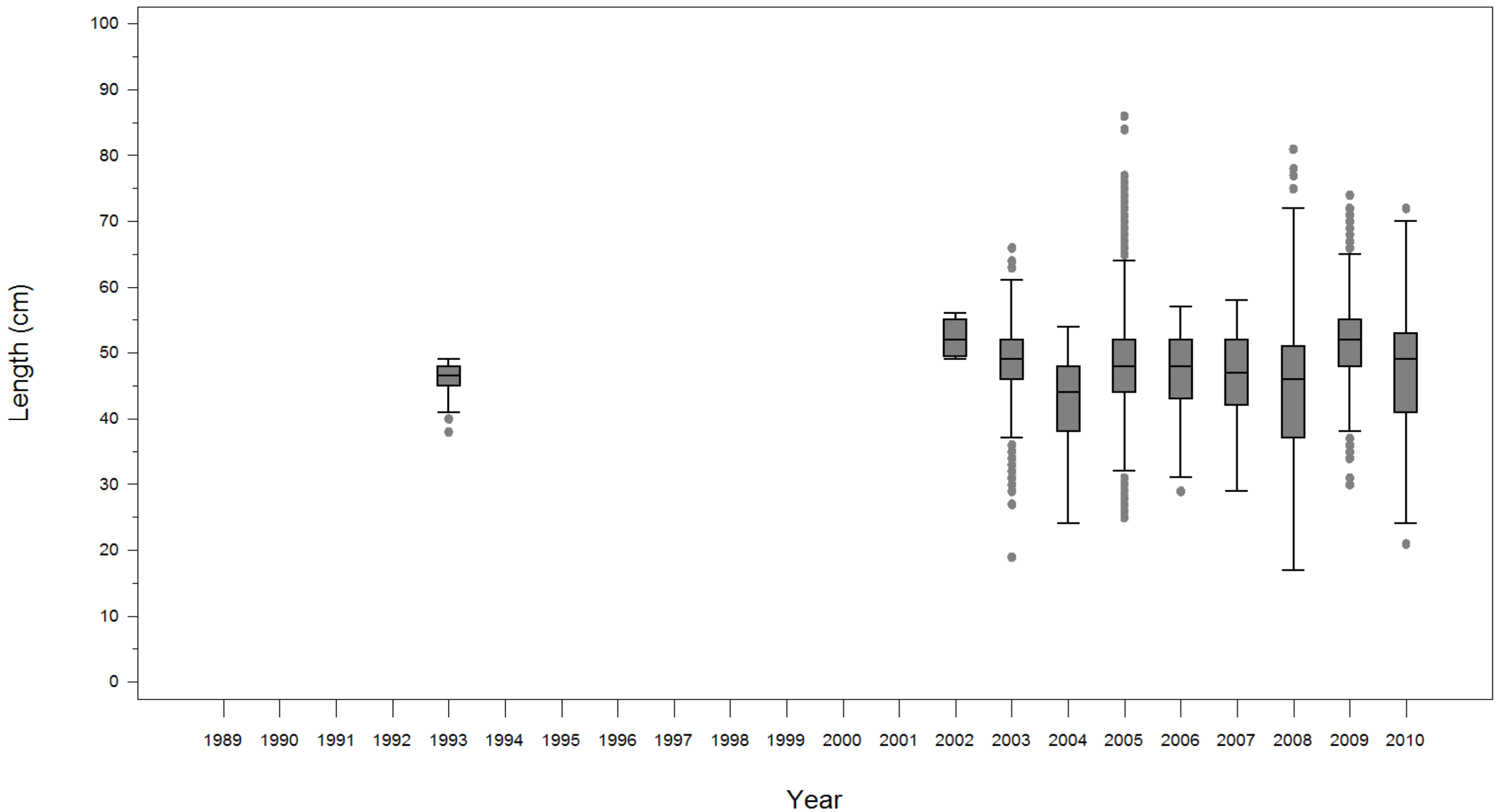


Figure A.32. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using benthic longline gear between 1989 and 2010. Missing years indicate that there were either no observed longline trips in the Gulf of Maine or no cod were observed to have been discarded.

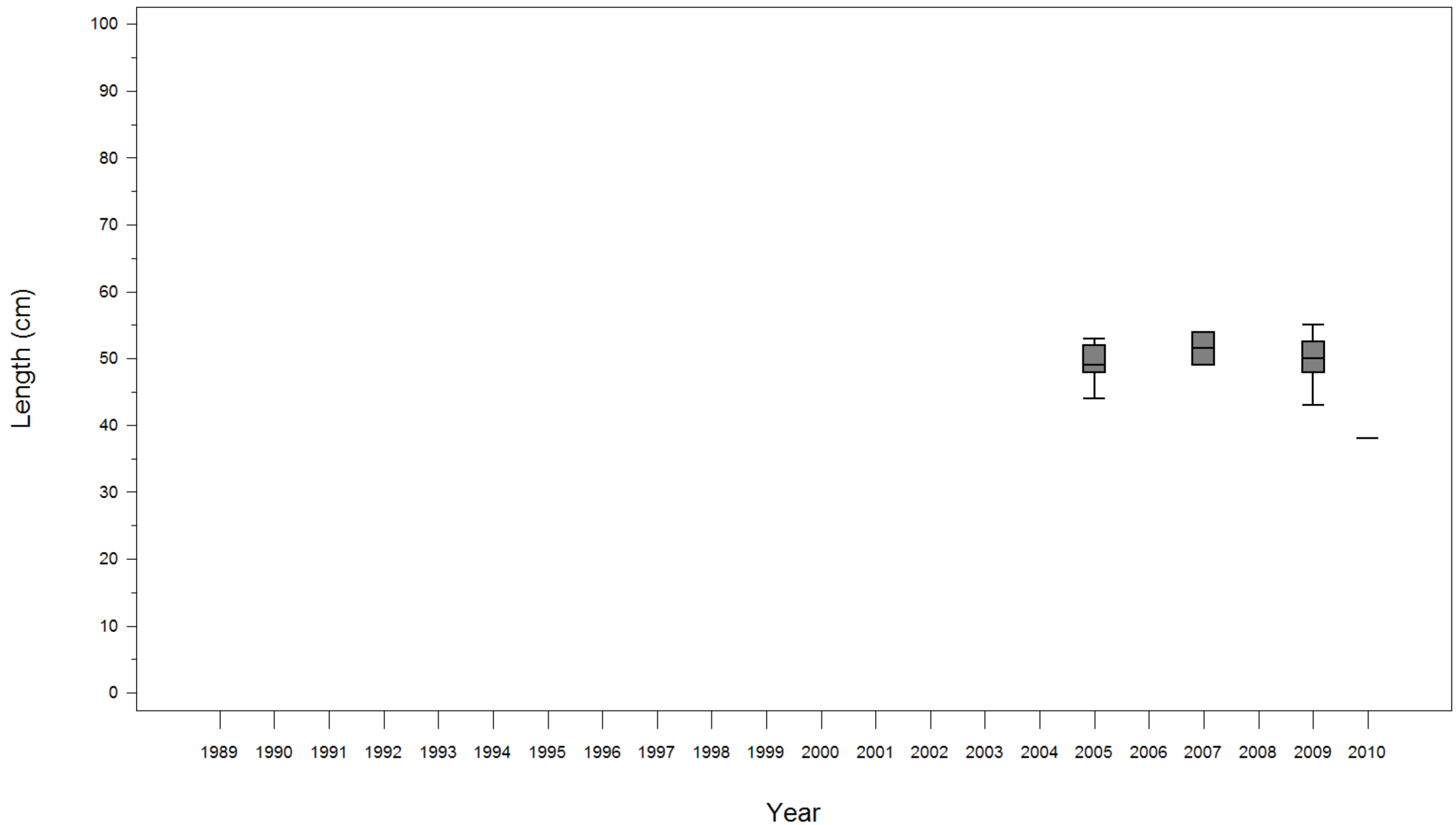


Figure A.33. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using handline (jig) gear between 1989 and 2010. Missing years indicate that there were either no observed handline trips in the Gulf of Maine or no cod were observed to have been discarded.

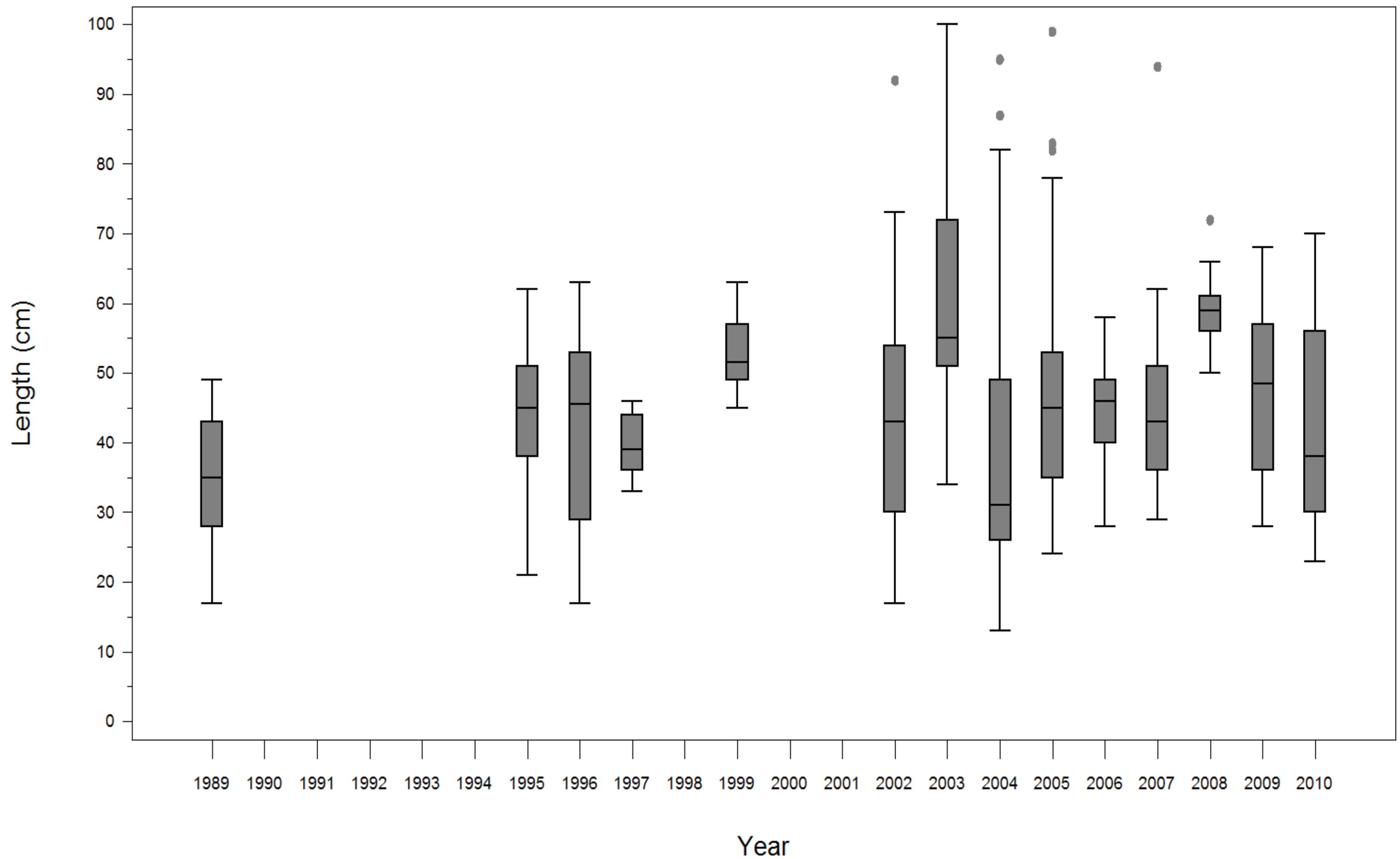


Figure A.34. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using small mesh otter trawl gear between 1989 and 2010. Missing years indicate that there were either no observed small mesh otter trawl trips in the Gulf of Maine or no cod were observed to have been discarded.

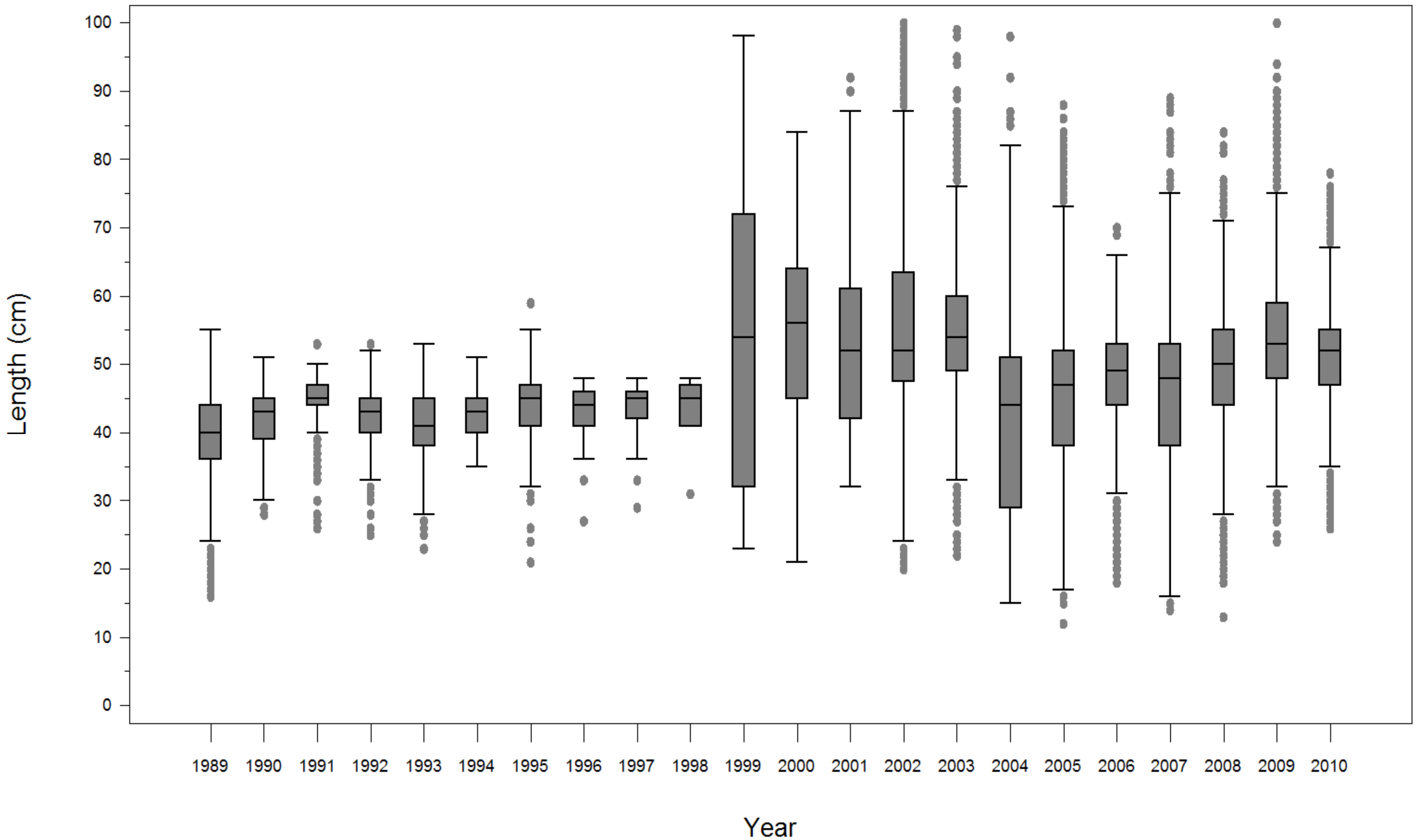


Figure A.35. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using large mesh otter trawl gear between 1989 and 2010. Missing years indicate that there were either no observed large mesh otter trawl trips in the Gulf of Maine or no cod were observed to have been discarded.

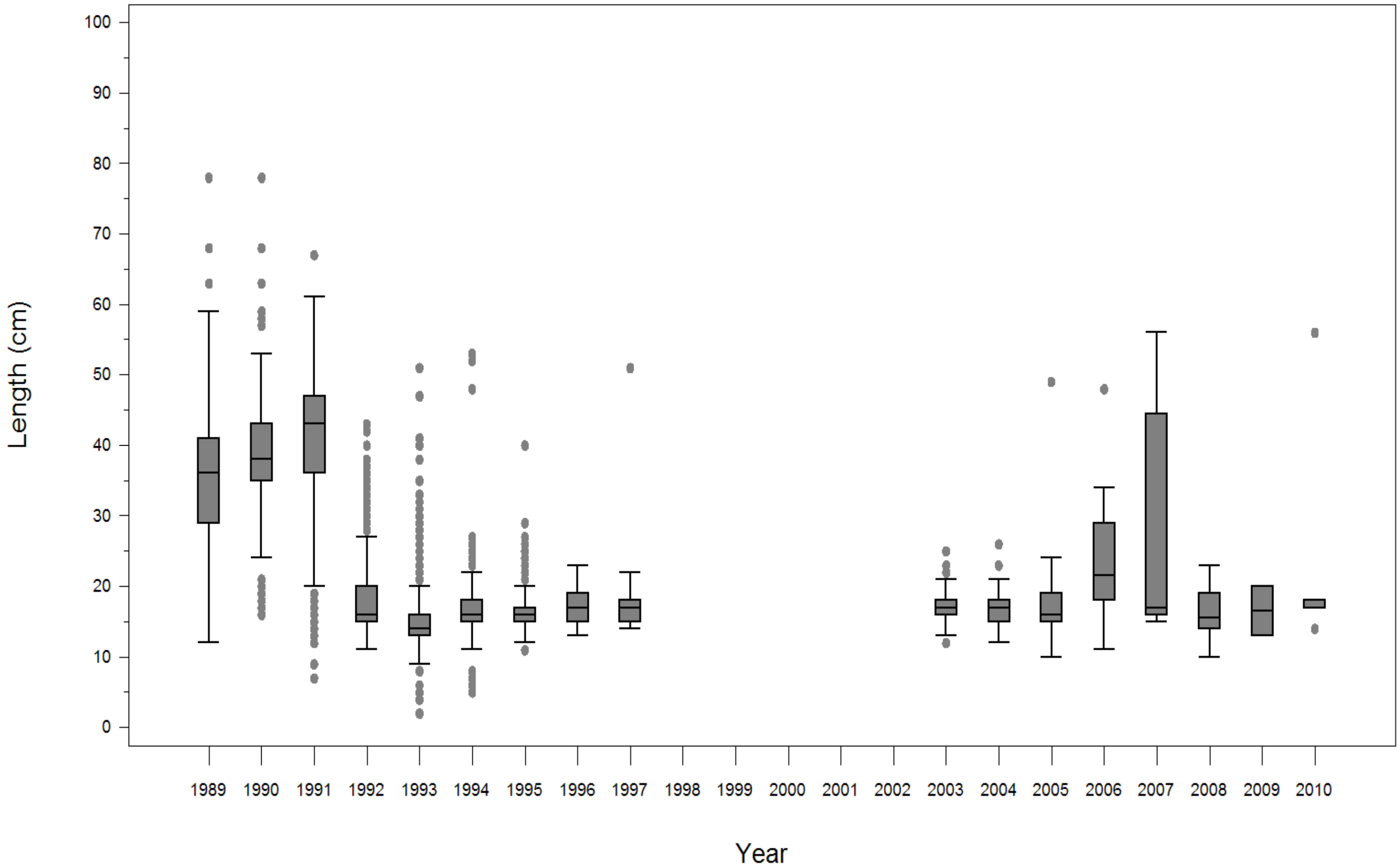


Figure A.36. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using shrimp trawl gear between 1989 and 2010. Missing years indicate that there were either no observed shrimp trawl trips in the Gulf of Maine or no cod were observed to have been discarded.

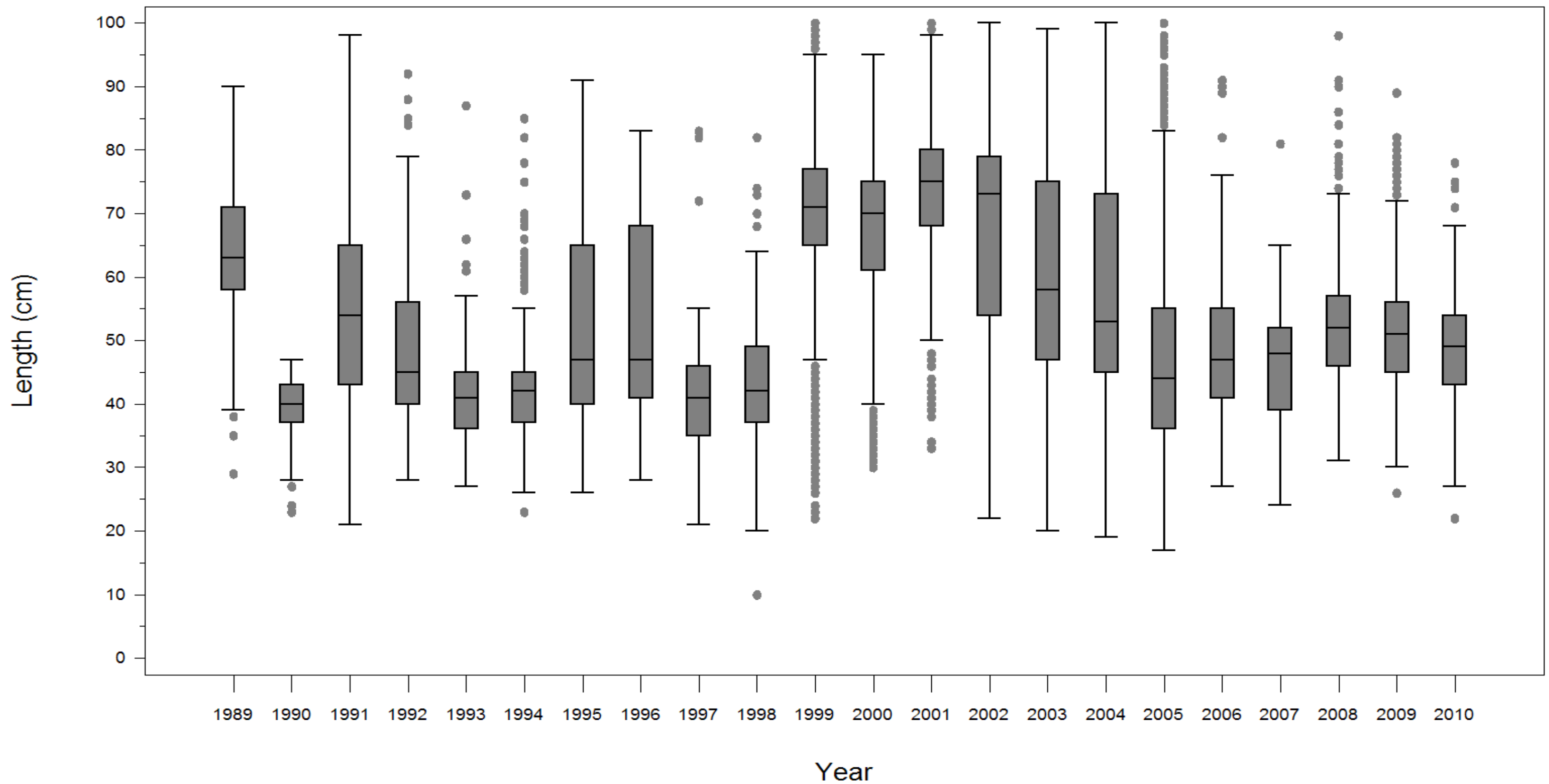


Figure A.37. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using large mesh sink gillnet gear between 1989 and 2010. Missing years indicate that there were either no observed large mesh sink gillnet trips in the Gulf of Maine or no cod were observed to have been discarded.

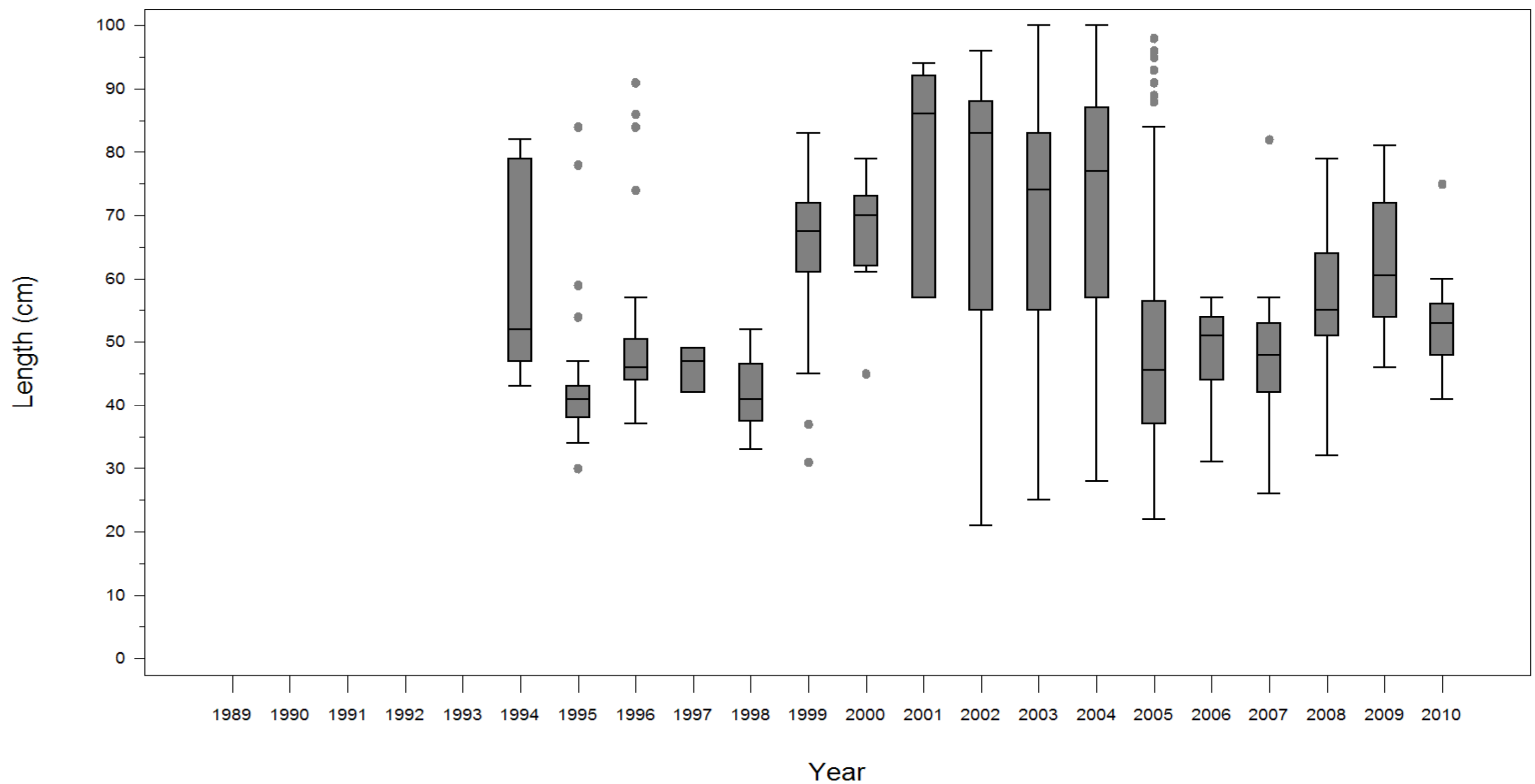


Figure A.38. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using extra large mesh sink gillnet gear between 1989 and 2010. Missing years indicate that there were either no observed extra-large mesh sink gillnet trips in the Gulf of Maine or no cod were observed to have been discarded.

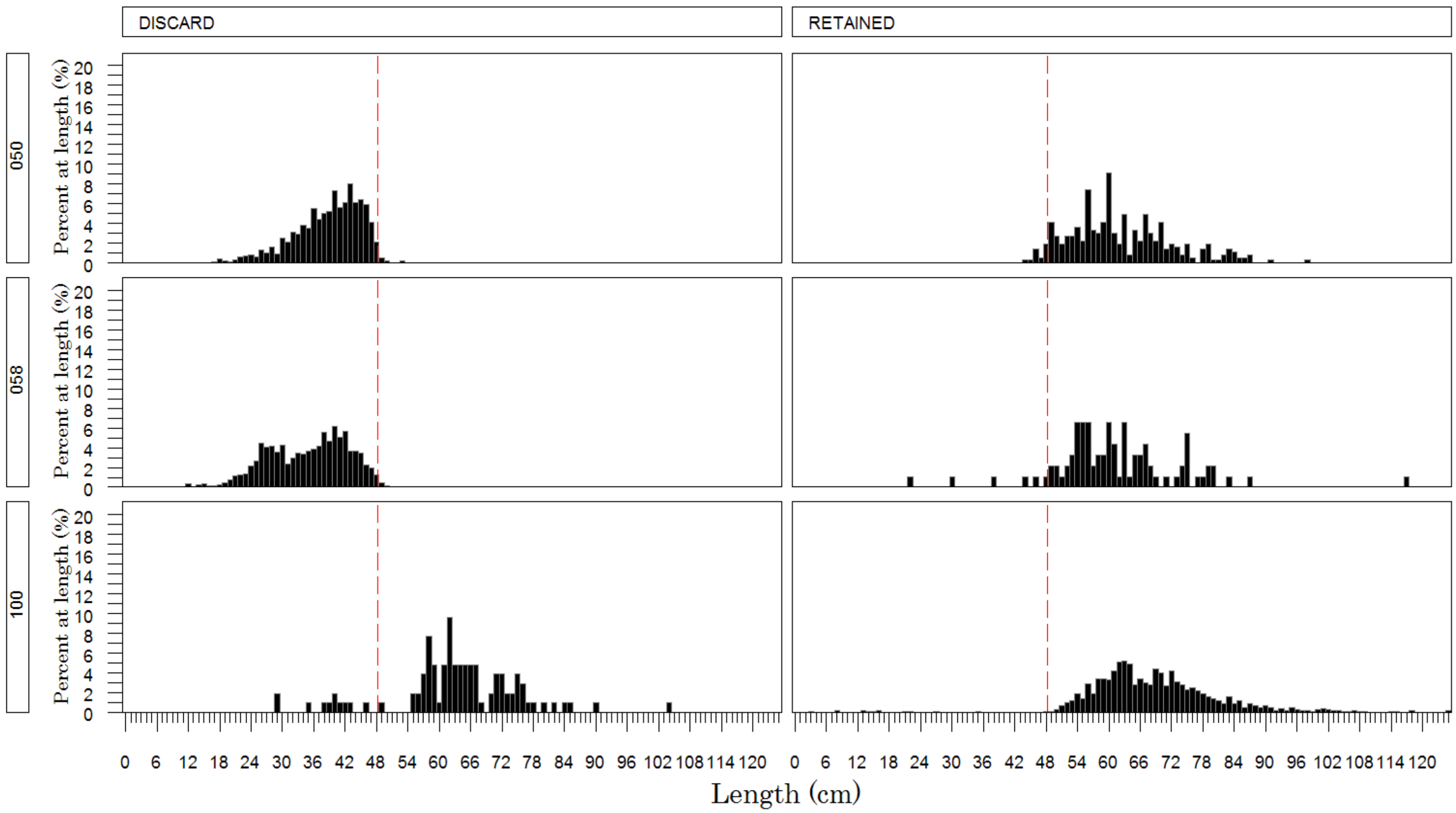


Figure A.39. Example of the length frequency distributions of Gulf of Maine Atlantic cod observed caught in the commercial fishery by large mesh otter trawl (050), shrimp trawl (058) and large mesh sink gillnet (100) gear in 1989. The 1989 – 1996 commercial minimum retention size of 19 inches (48.3 cm) is indicated by a dashed red line.

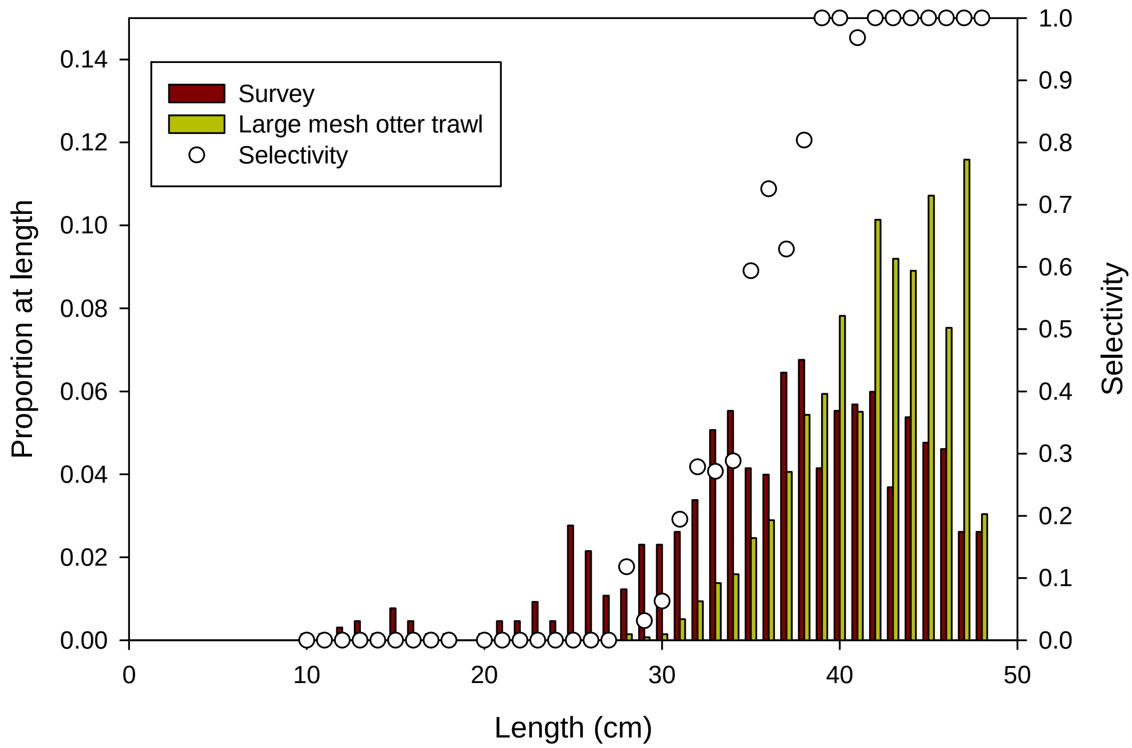


Figure A.40. Example of applying the survey-filter method to estimate the selectivity-at-length of fishing gears for Gulf of Maine Atlantic cod. In this example the proportion caught at length by large mesh otter trawl is compared to the proportion caught at-length in Northeast Fishery Science Center spring and fall surveys (combined) to estimate the selectivity-at-length of large mesh otter trawl.

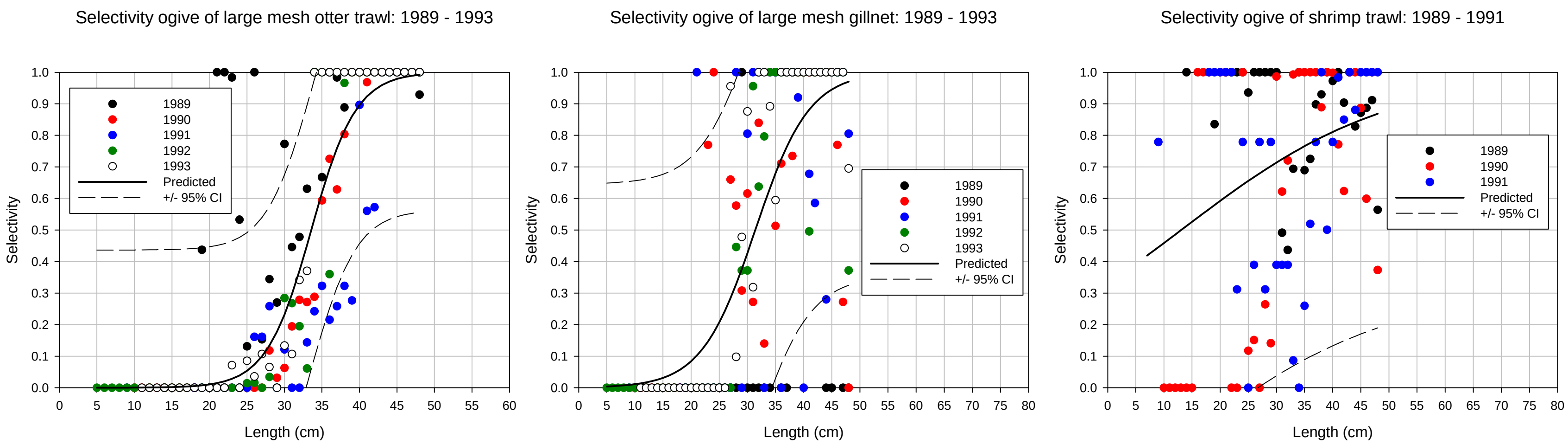
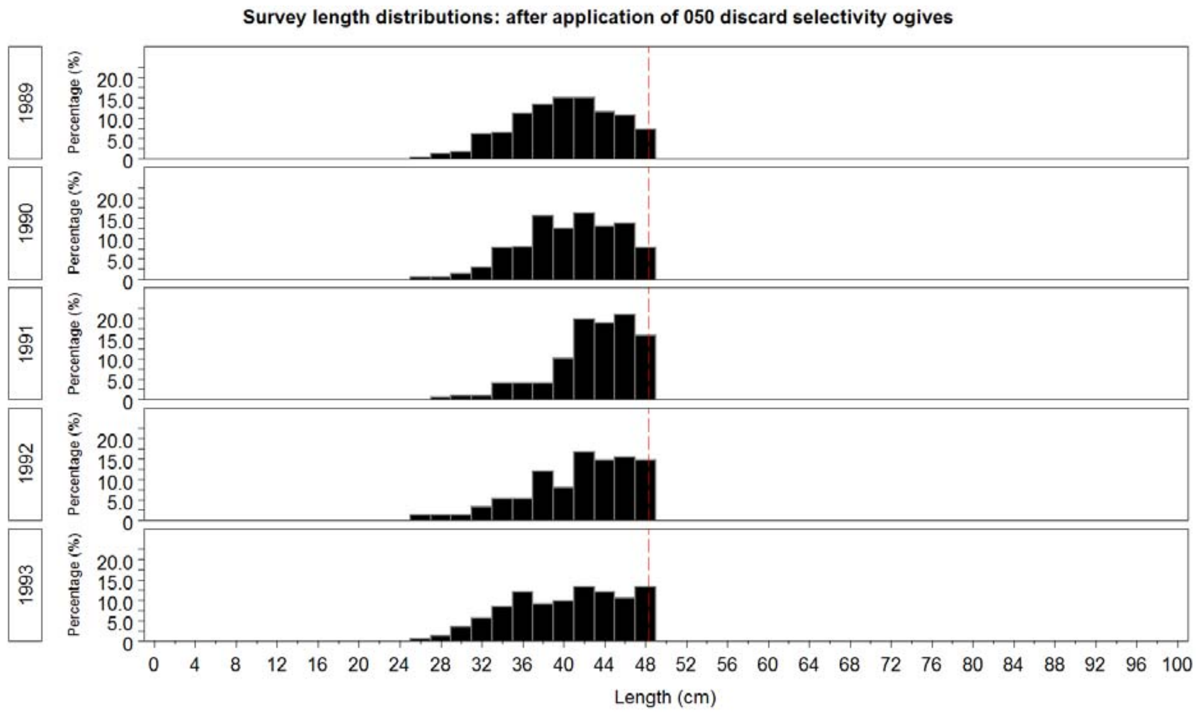


Figure A.41. Estimated selectivity ogives for large mesh otter trawl, large mesh sink gillnet and shrimp trawl and the corresponding 95% confidence intervals (CI) for Gulf of Maine Atlantic cod. Selectivity ogives were estimated from the logistic fits to the aggregated annual estimates of selectivity-at-length.



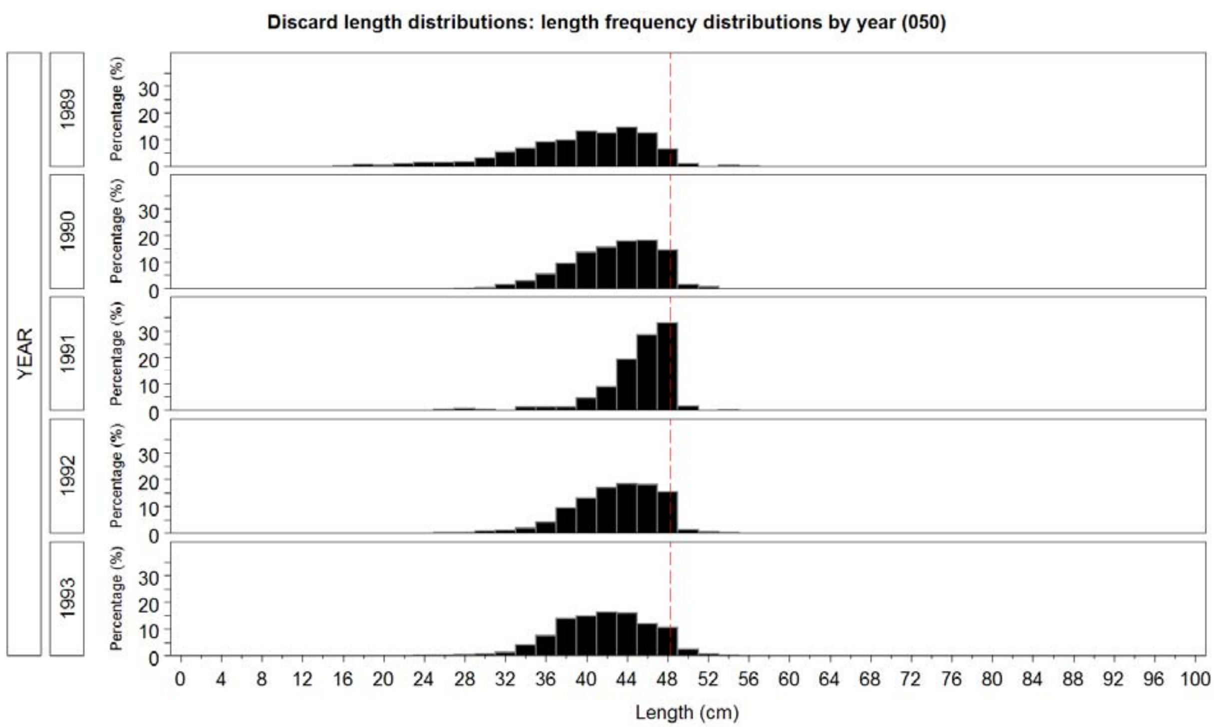


Figure A.42. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh otter trawl gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.

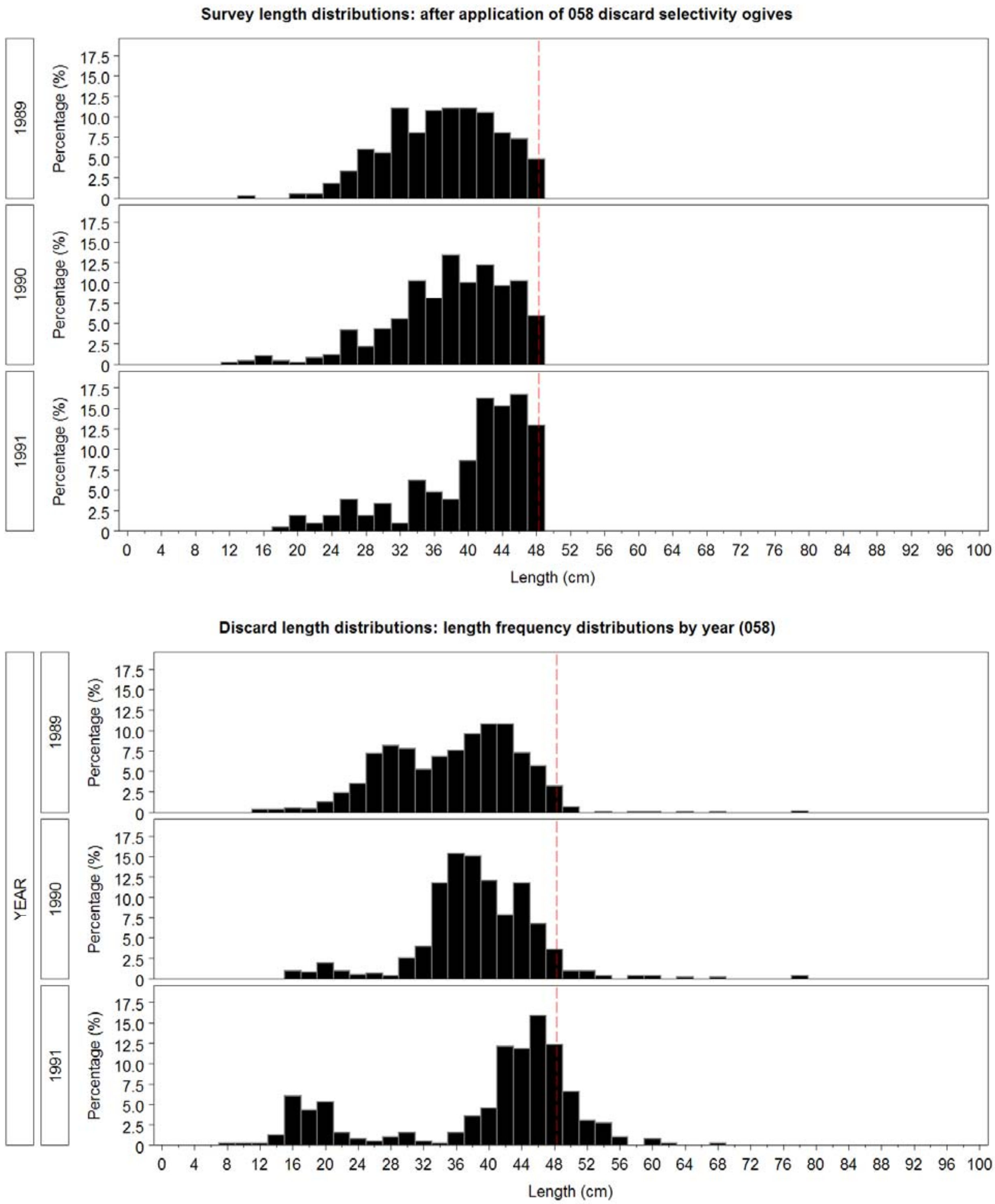
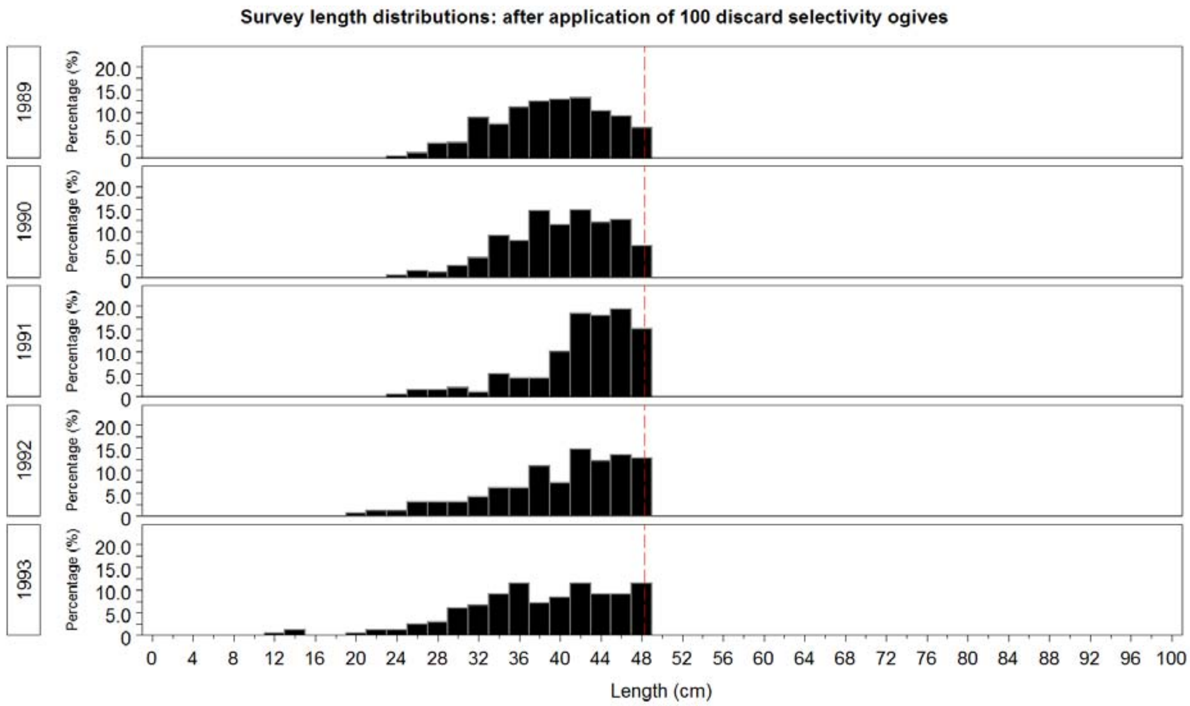


Figure A.43. Comparison of the survey filter-based estimates (top) of discards-at-length for shrimp trawl gear to the direct observer observations (bottom) from 1989 to 1991 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.



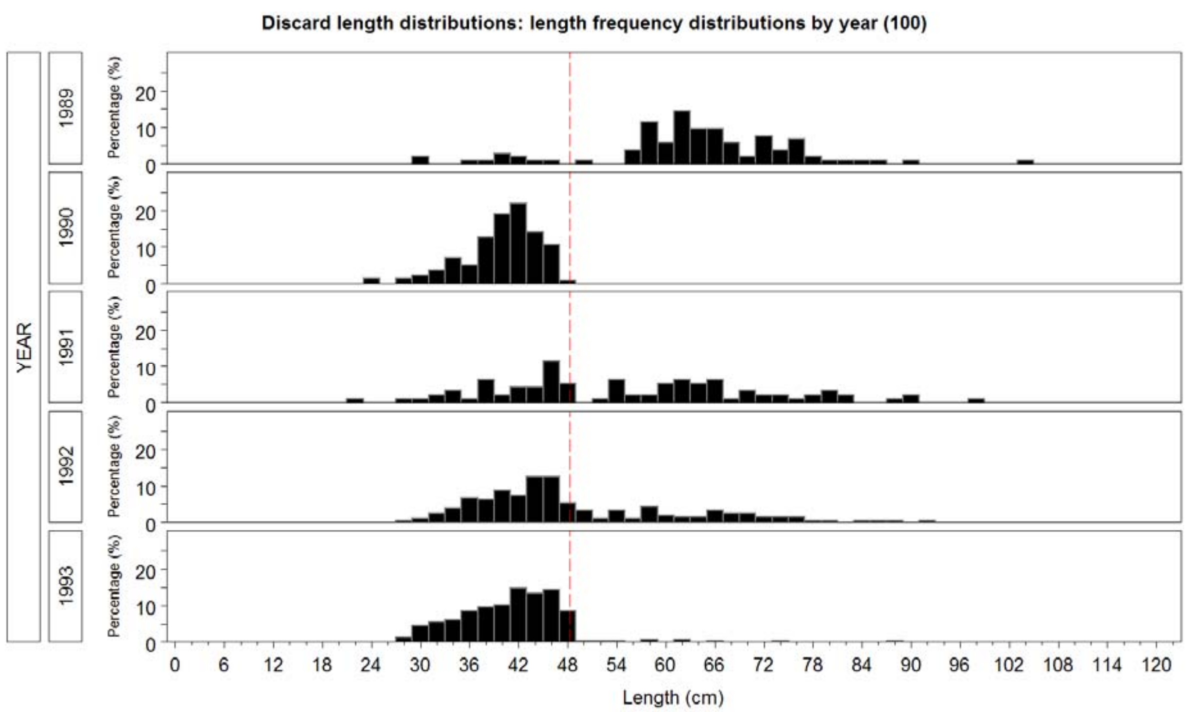


Figure A.44. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh sink gillnet gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from 1989 to 1996.

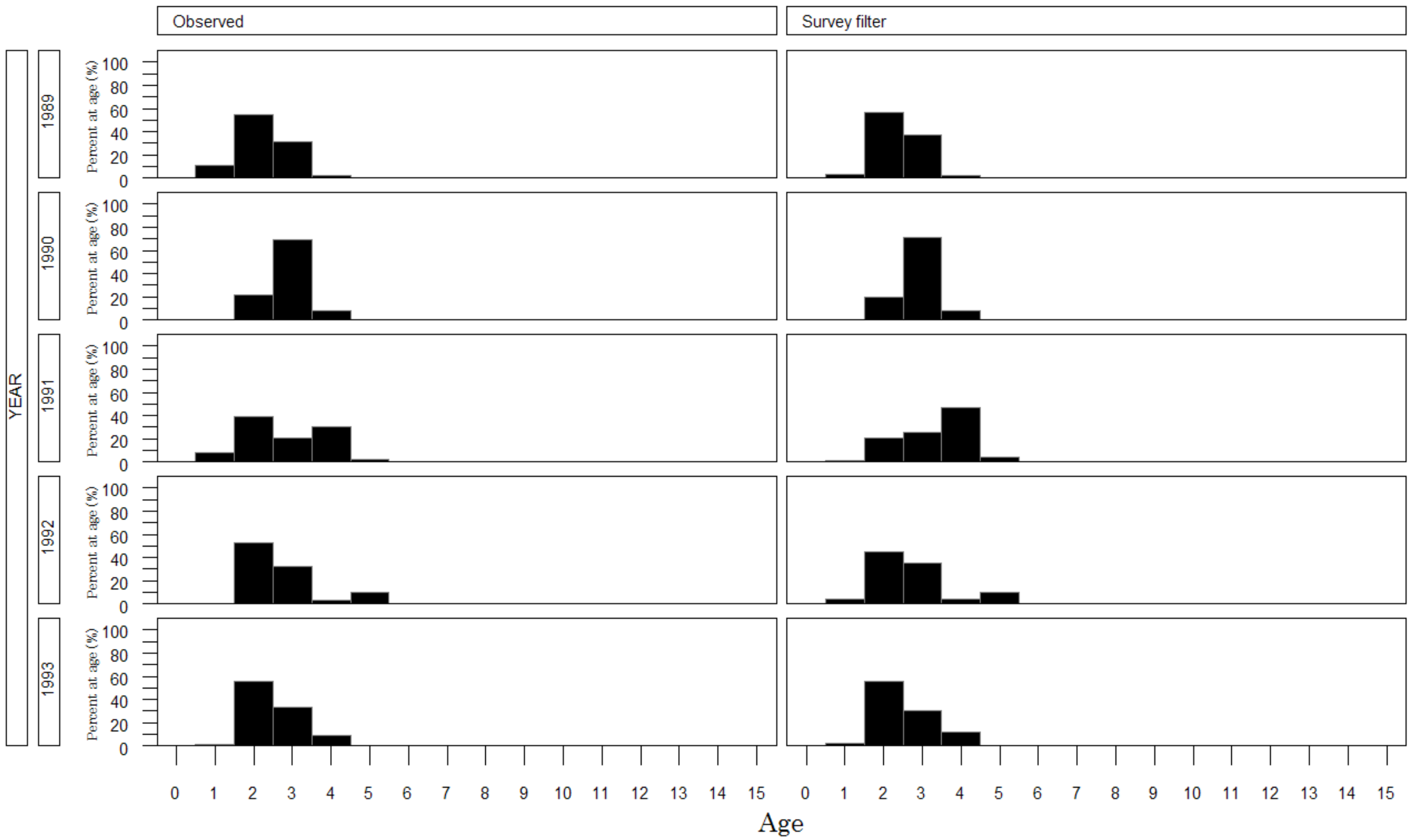


Figure A.45. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh otter trawl gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

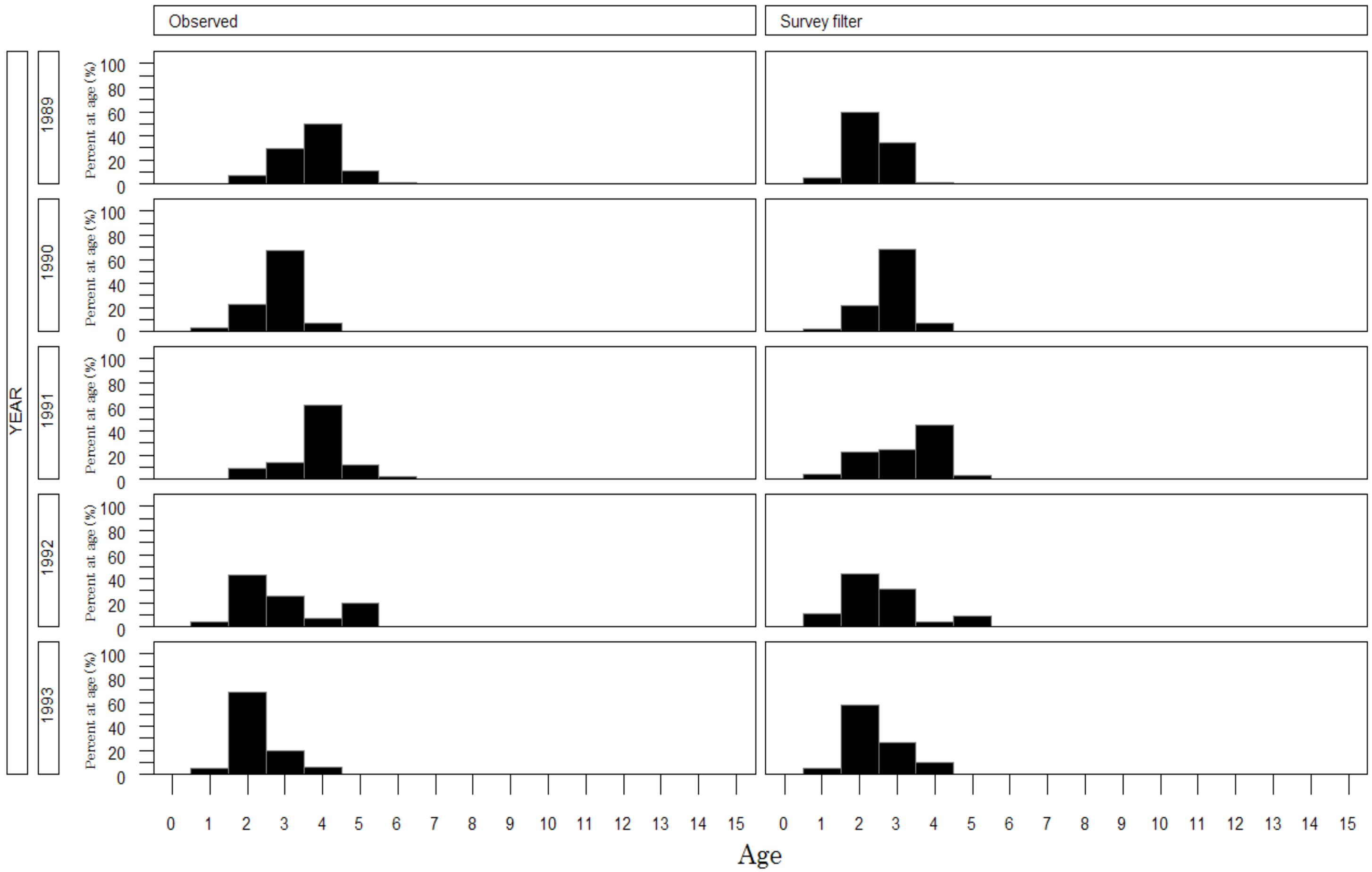


Figure A.46. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh sink gillnet gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

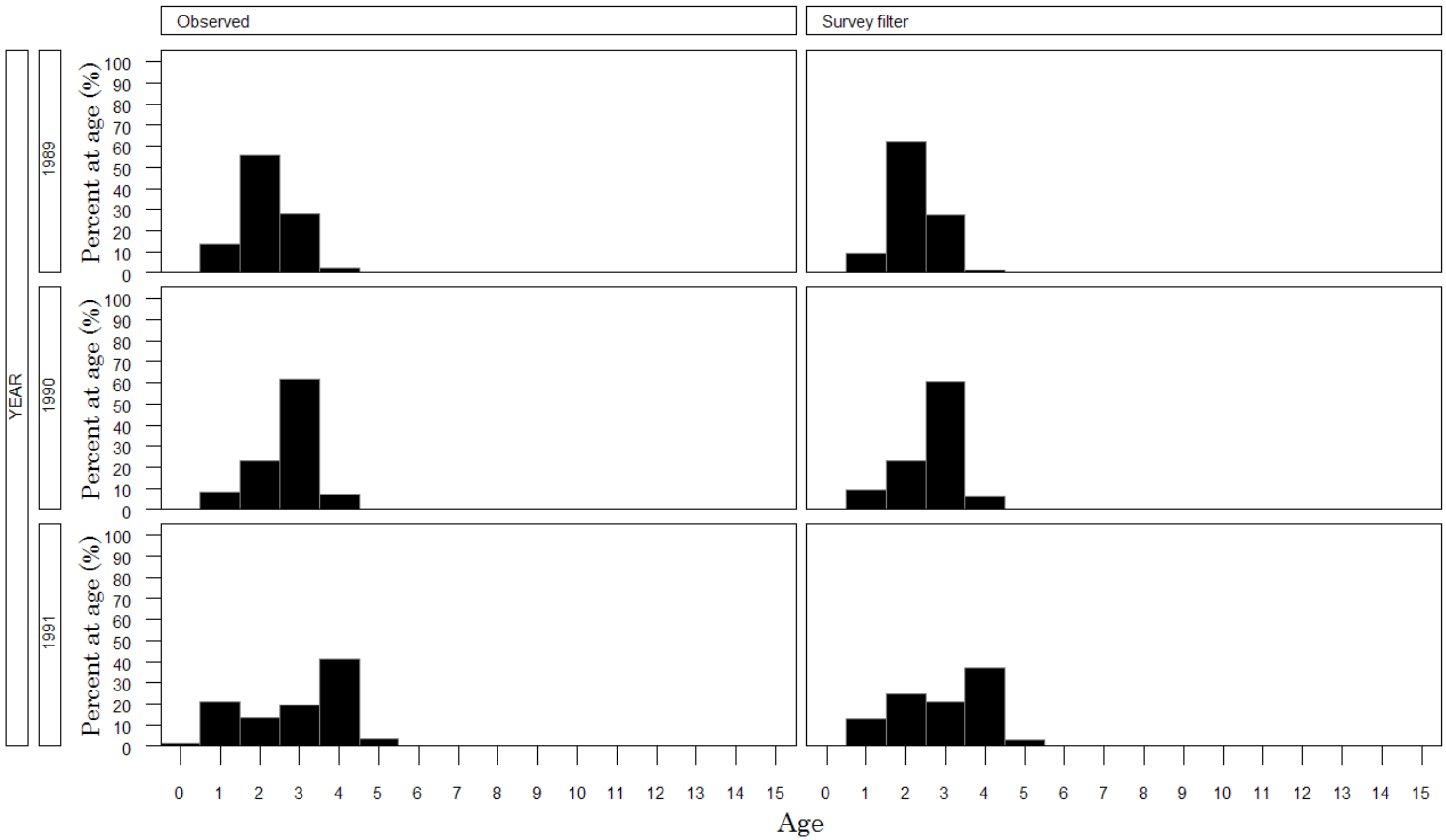


Figure A.47. Comparison of the survey filter-based estimates (right) of numbers-at-age for shrimp trawl gear to the direct observer observations (left) from 1989 to 1991 for Gulf of Maine Atlantic cod.

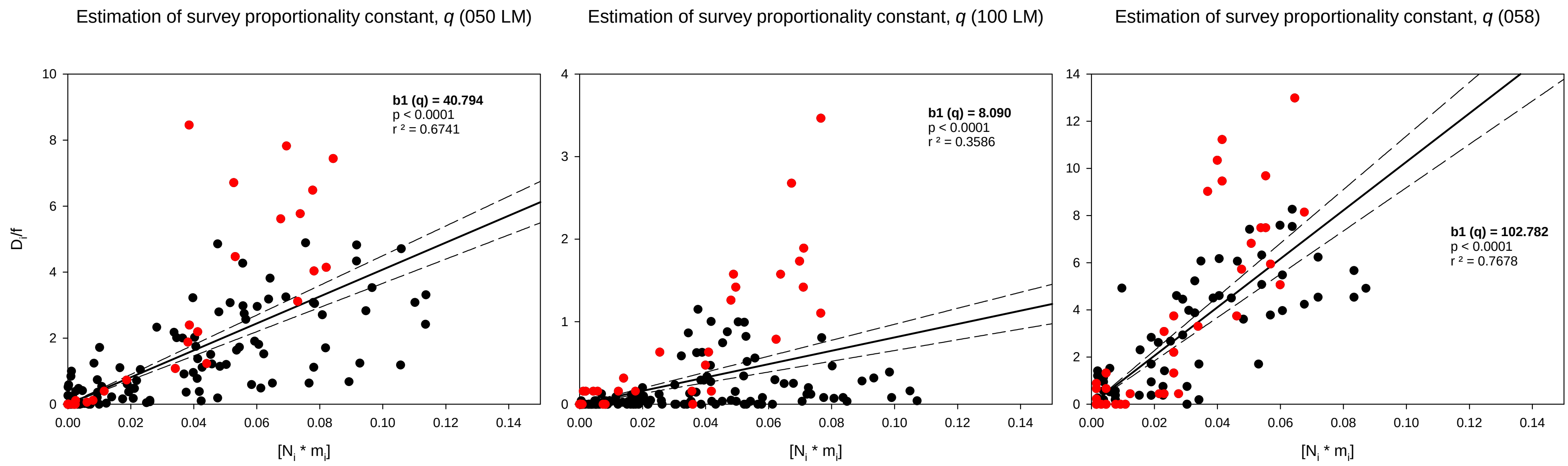


Figure A.48. Plots of the relationship by gear type between fraction of fish observed discarded-at-length (D_i/f) and the estimated number at length from the survey-filter method ($N_i \cdot m_i$) for Gulf of Maine Atlantic cod. Large mesh otter trawl (050 LM), large mesh sink gillnet (100 LM) and shrimp 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.

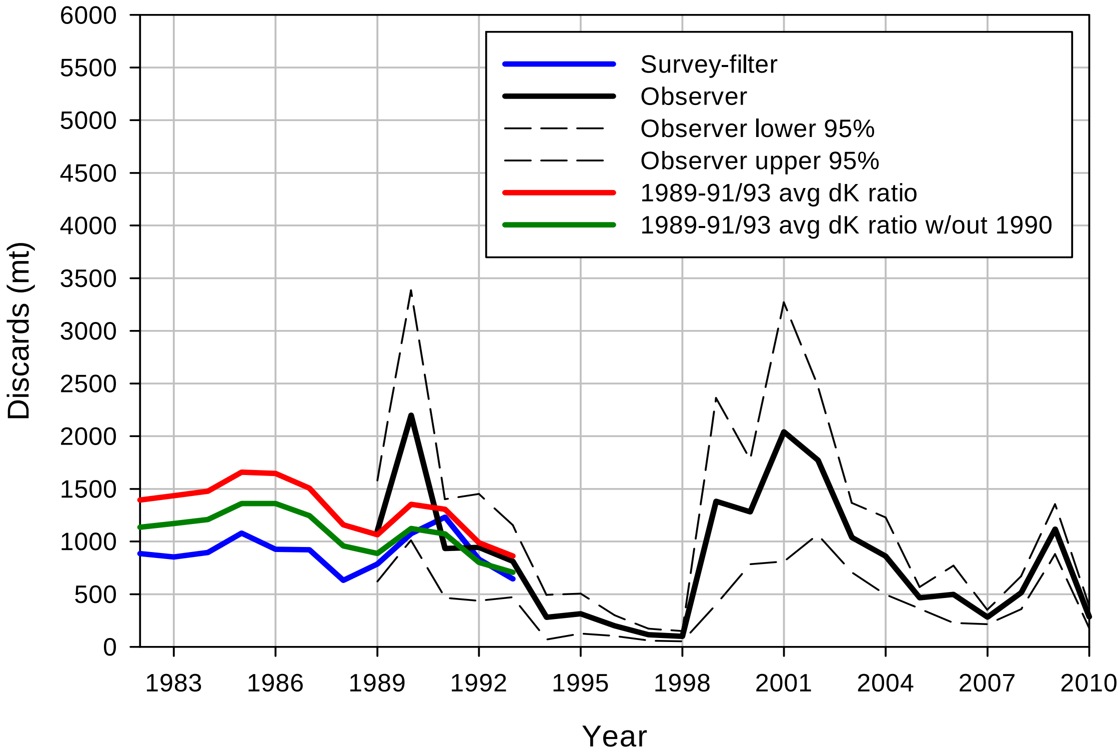


Figure A.49. Comparison of three different methods for achieving hindcasted estimates of Gulf of Maine Atlantic cod commercial discards from 1982 to 1988. (1) The survey-filter method uses the proportionality constant (q) multiplied by an index of fishing effort (total retained catch, K_{all}) to estimate 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.

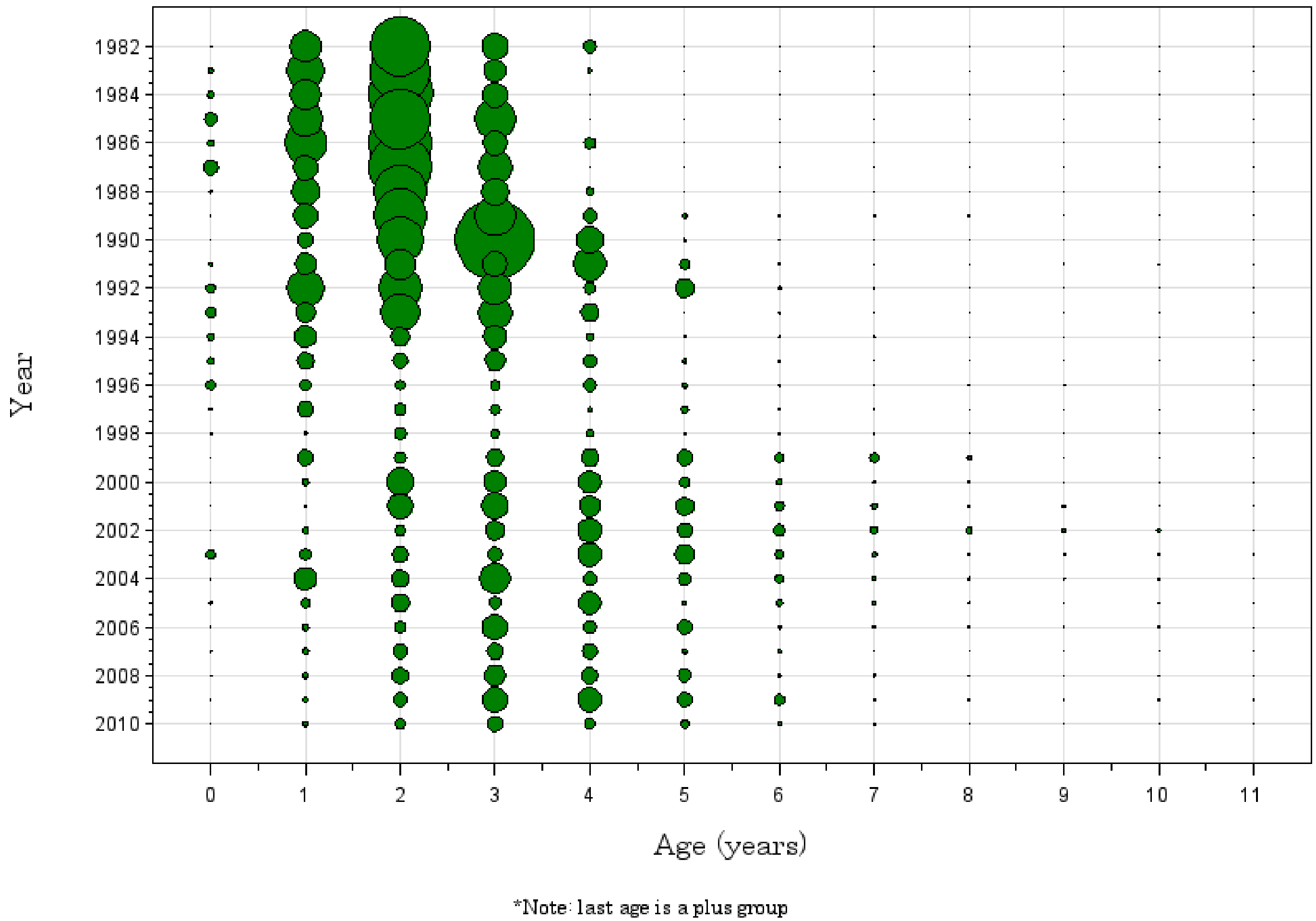


Figure A.50. Commercial discards-at-age of Gulf of Maine Atlantic cod from 1982 to 2010. **Note that age 11 is a plus group.*

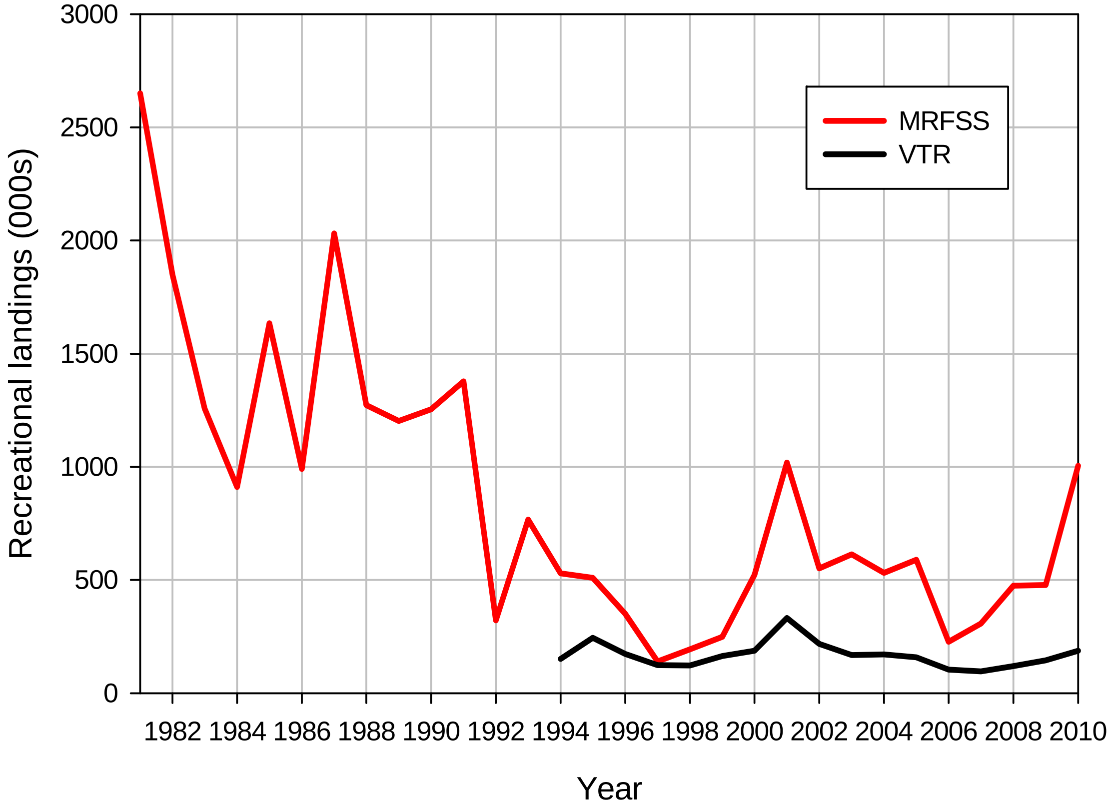


Figure A.51. Comparison of recreational landing estimates derived through the Marine Recreational Fishing Statistical Survey (MRFSS) to recreational landings reported on Vessel Trip Reports (VTRs) between 1994 and 2010 for Gulf of Maine Atlantic cod.

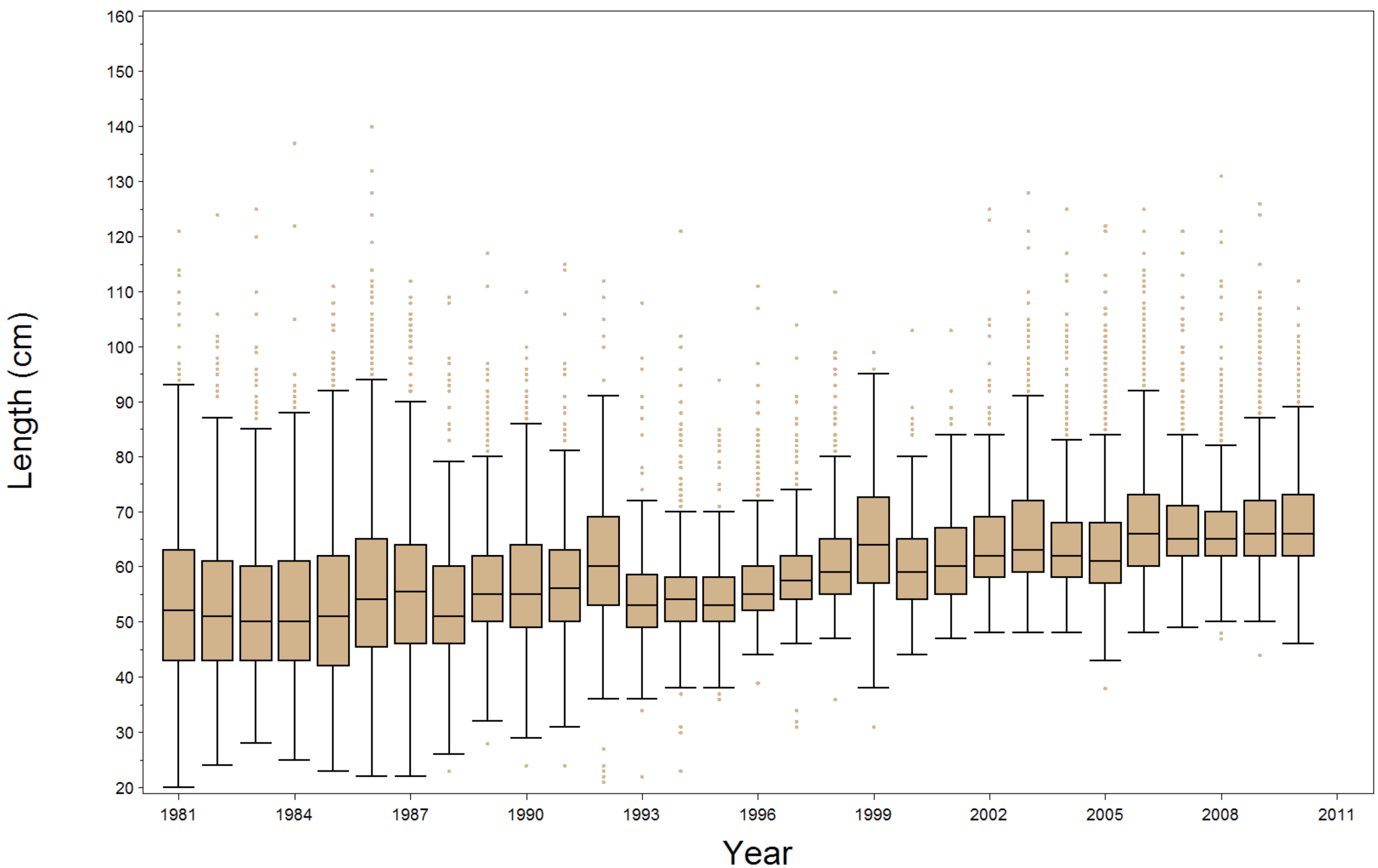


Figure A.52. Box plots showing the length distribution of Gulf of Maine Atlantic cod landed by the recreational fishery between 1981 and 2010.

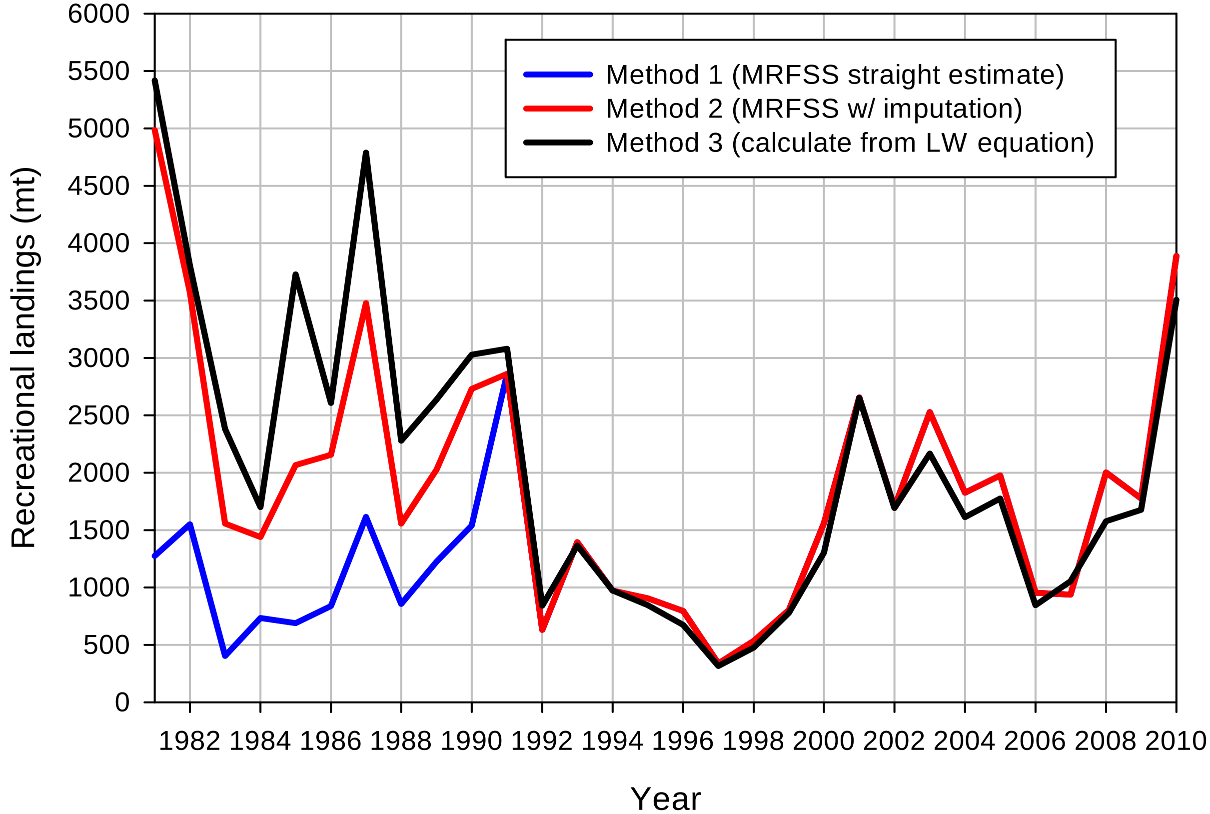


Figure A.53. Gulf of Maine Atlantic cod recreational landings in terms of weight (mt) estimated using three different methods. (1) Using the MRFSS provided weight estimates (does not account for state-semester cells without average weight estimates). (2) Using the MRFSS provided weight estimates but imputing missing cells with annual unweighted estimate of average weight. (3) Applying the annual length weight equation derived through survey data to the length frequency distribution of the recreational landings.

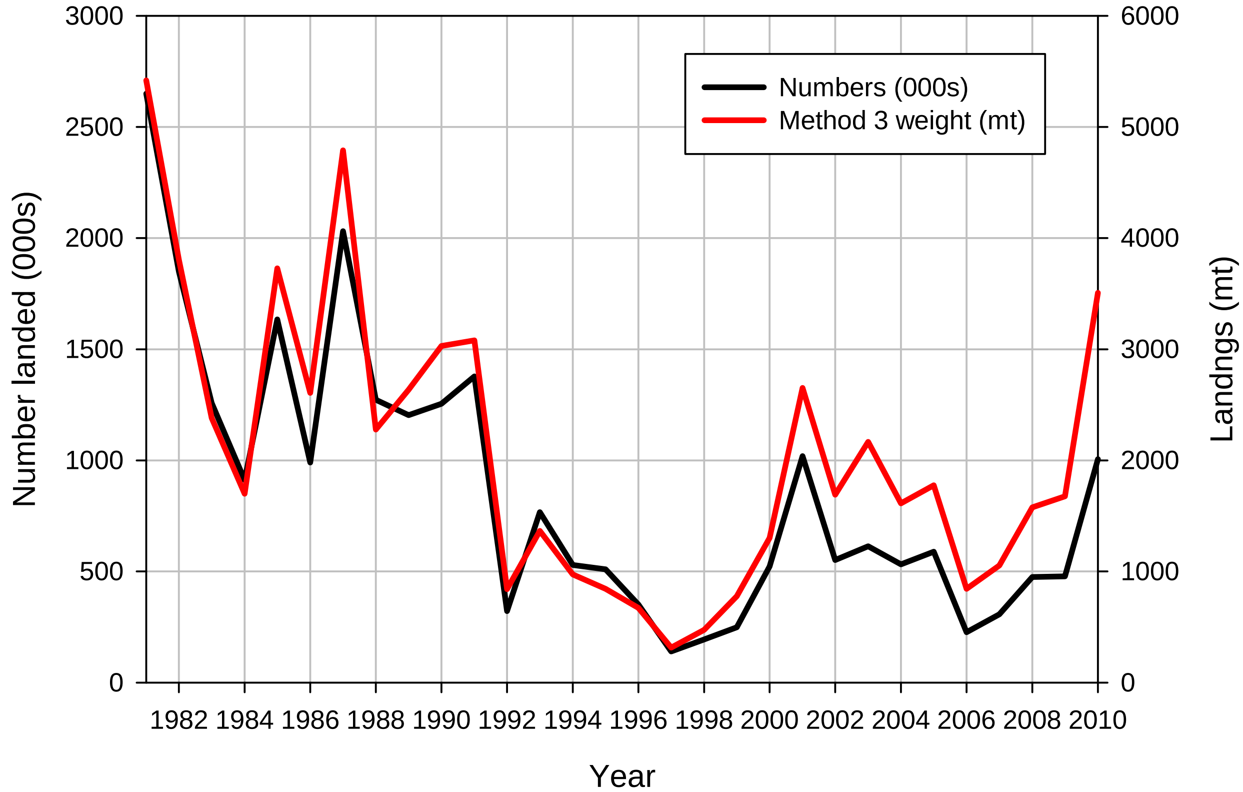


Figure A.54. Trends in Gulf of Maine Atlantic cod recreational landings between 1981 and 2010 in terms of weight (mt) and numbers (000's fish).

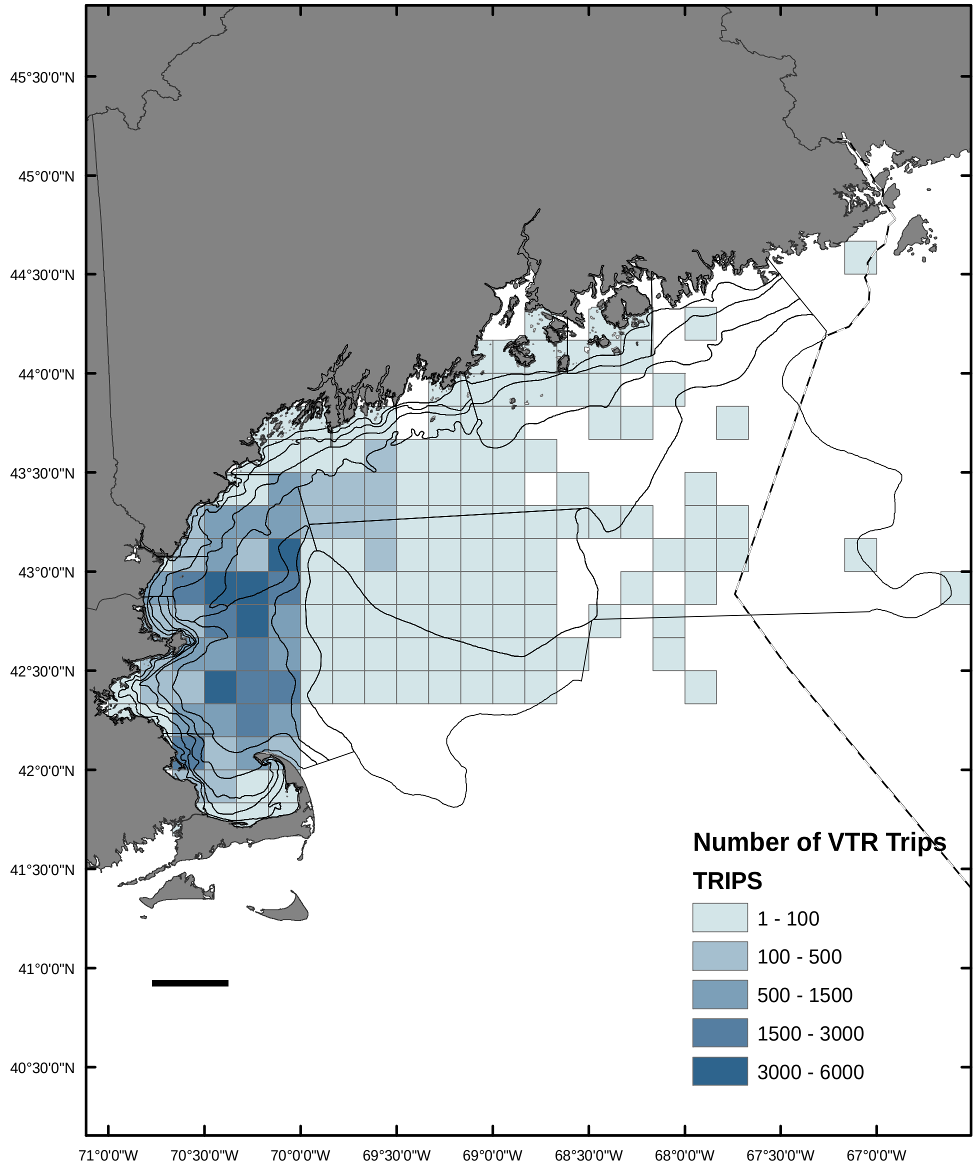


Figure A.55. Spatial distribution of recreational effort between 1994 and 2010 as determined from Vessel Trip Reports (VTRs) overlaid on the Northeast Fisheries Science Center bottom trawl survey sampling strata. VTR-based recreation effort has been binned to ten minute squares.

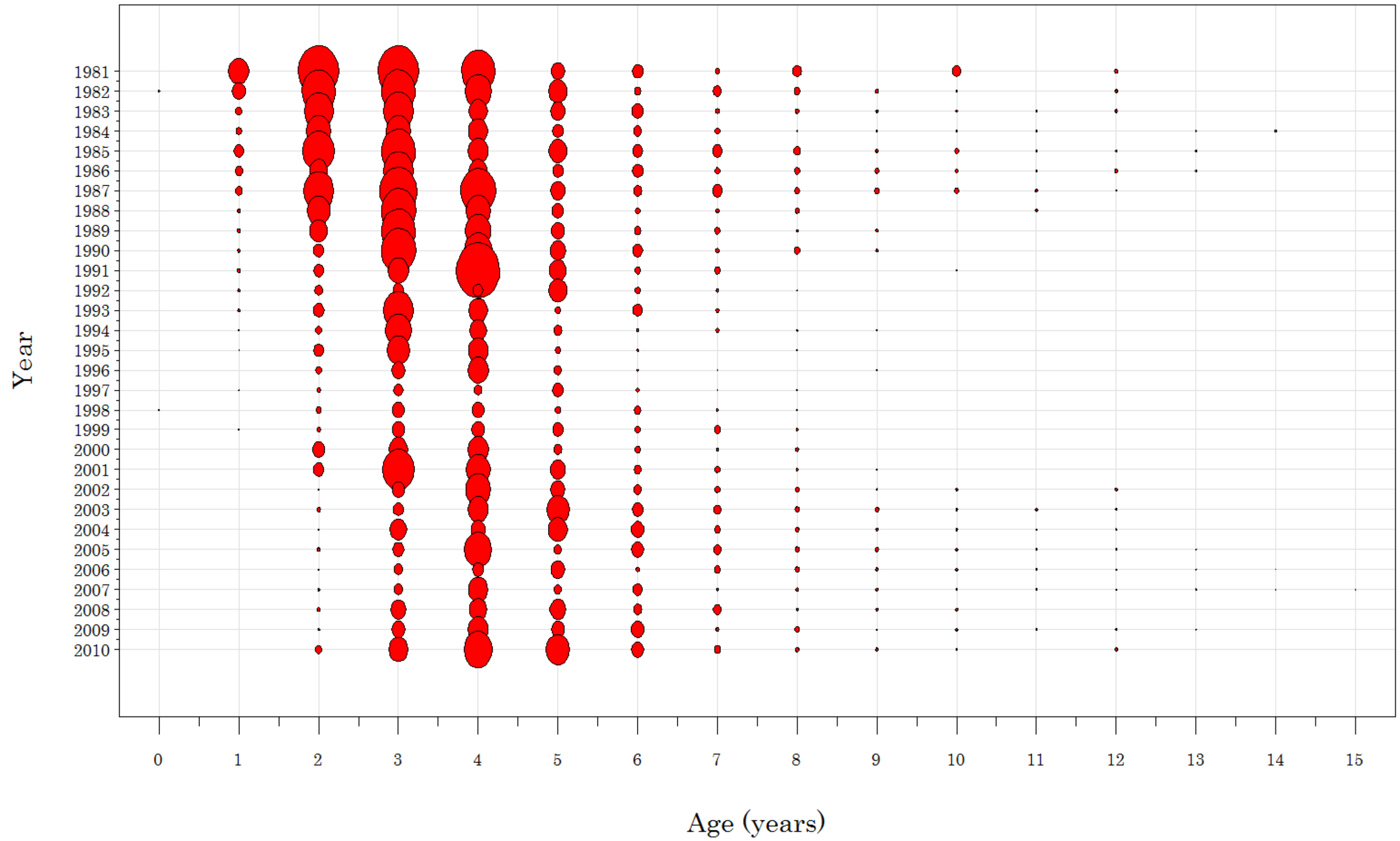


Figure A.56. Recreational landings-at-age of Gulf of Maine Atlantic cod from 1981 to 2010.

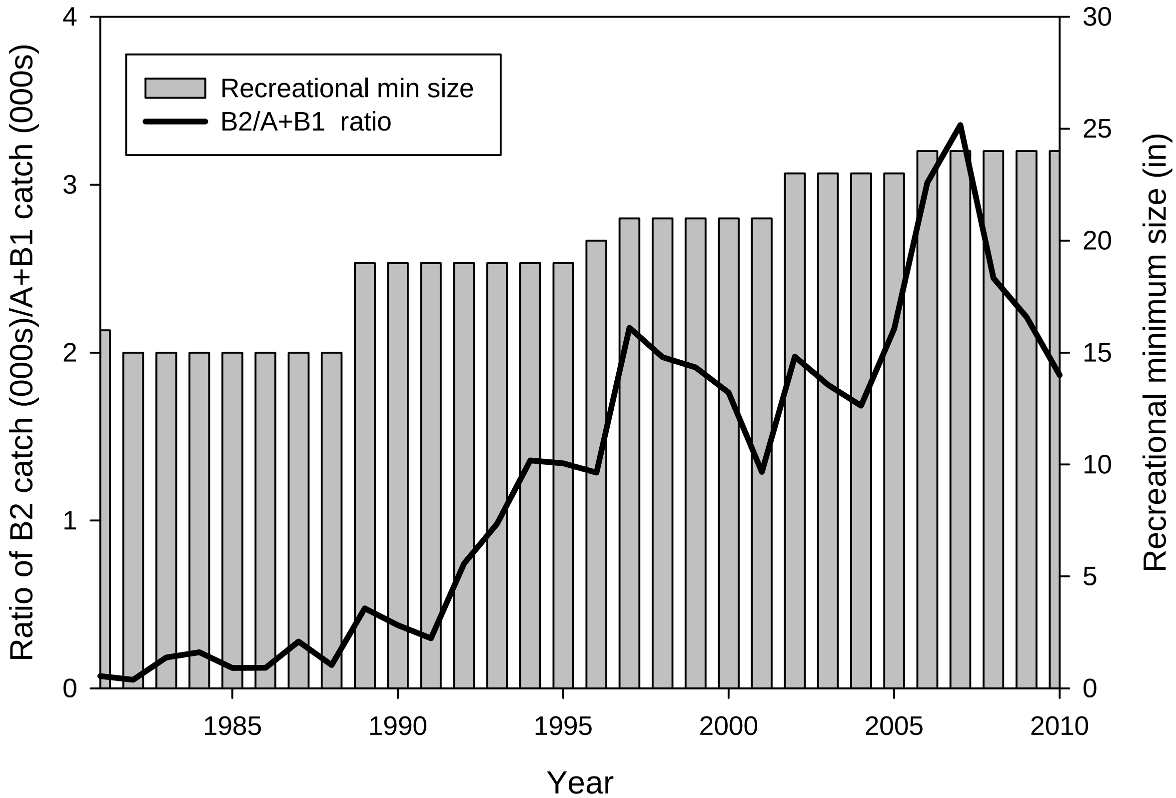


Figure A.57. Trends in the ratio of Gulf of Maine Atlantic cod recreational discards to recreational landings from 1981 to 2010 compared to increases in the recreational minimum retention size.

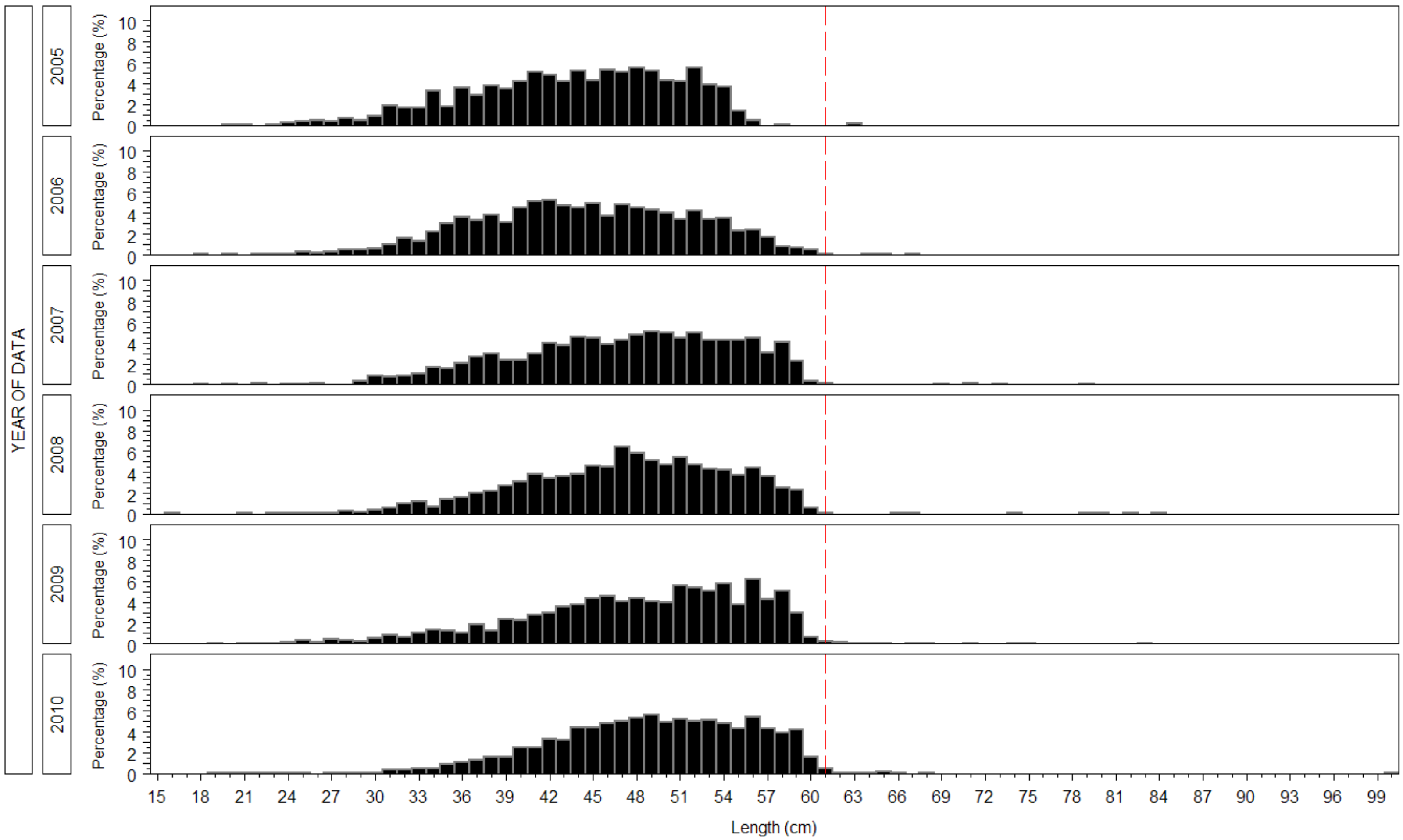


Figure A.58. Annual length frequency distributions of Gulf of Maine Atlantic cod discarded in the recreational fishery between 2005 and 2010. The dashed red line represents the recreational minimum retention size of 24 inches (61.0 cm) from May 1, 2006-2010. The minimum retention size from January 1, 2005 to May 1, 2006 was 23 inches (58.4cm). *No sampling of recreational discards occurred prior to 2005.*

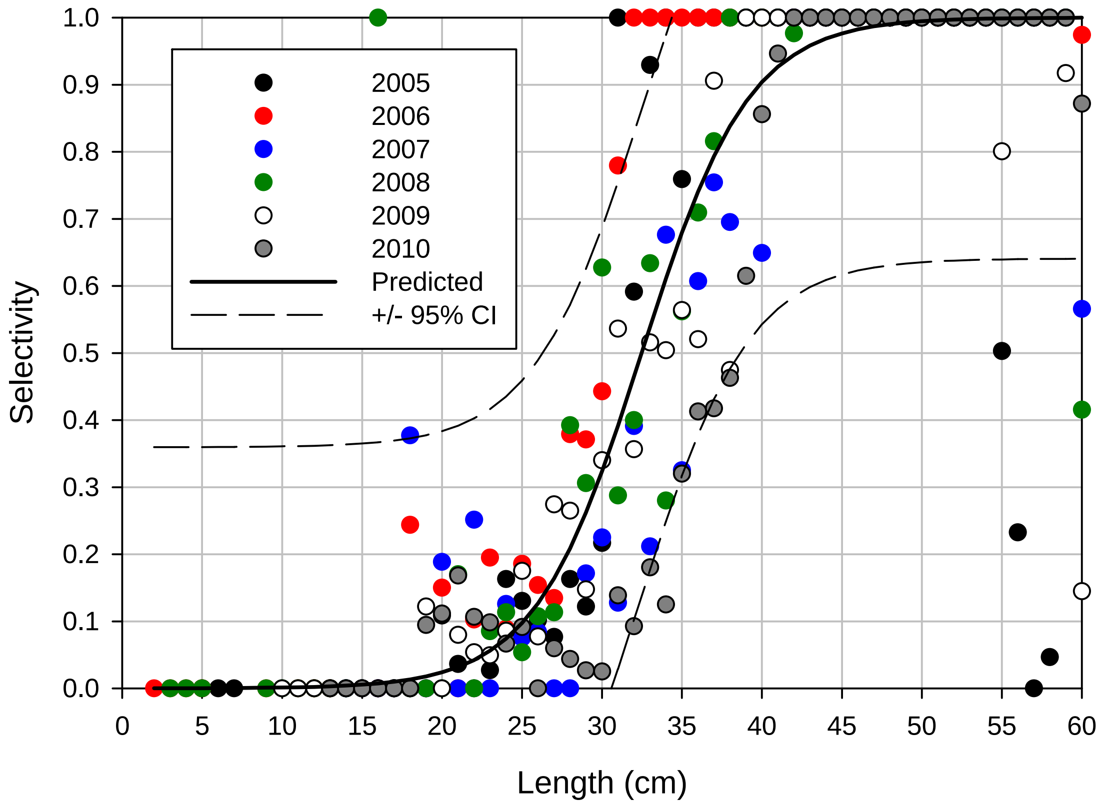
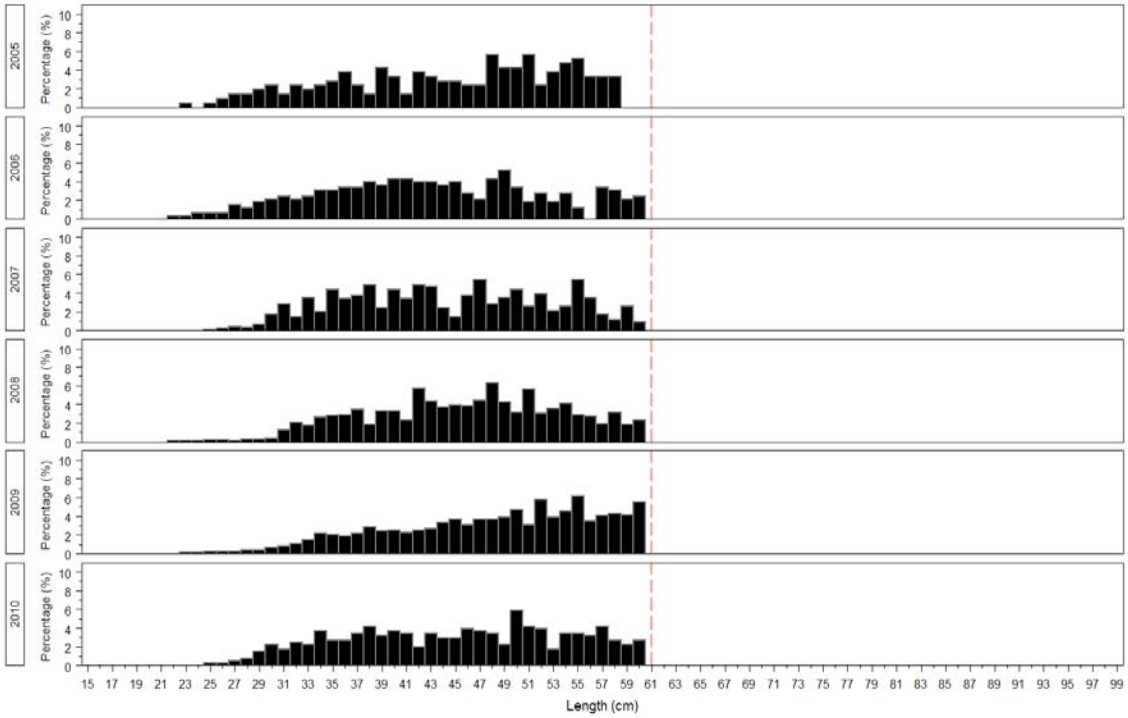
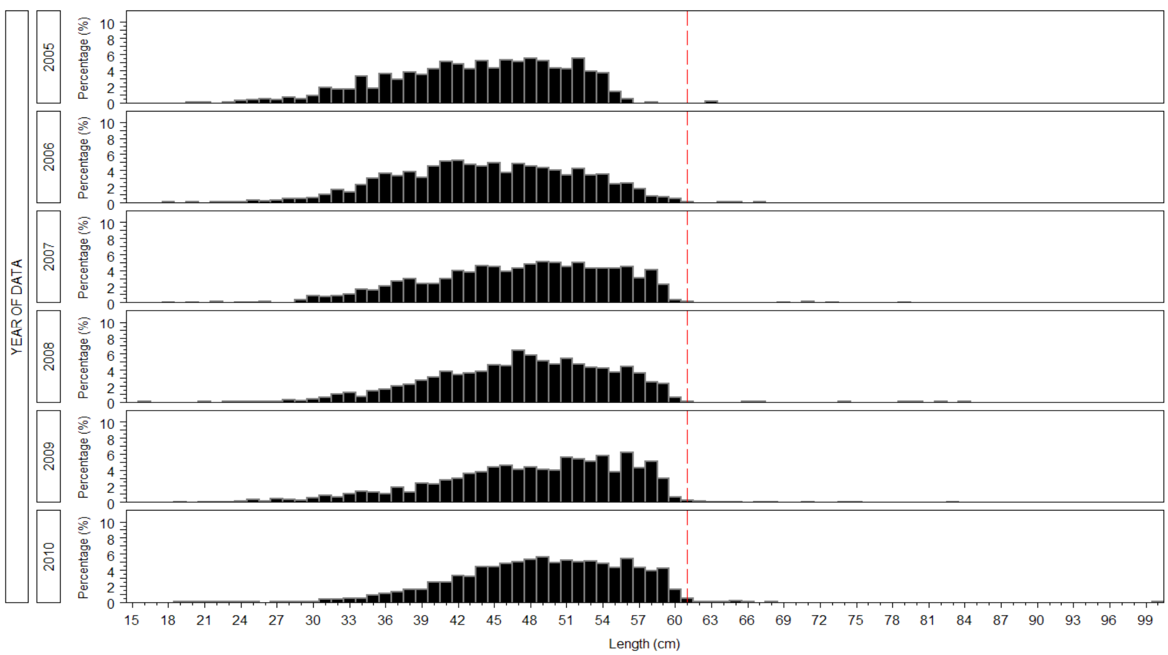


Figure A.59. Estimated selectivity ogive for the recreational fishery and the corresponding 95% confidence interval (CI) for Gulf of Maine Atlantic cod. The selectivity ogive was estimated from the logistic fits to the aggregated annual estimates of selectivity-at-length.





Figures A.60. 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).

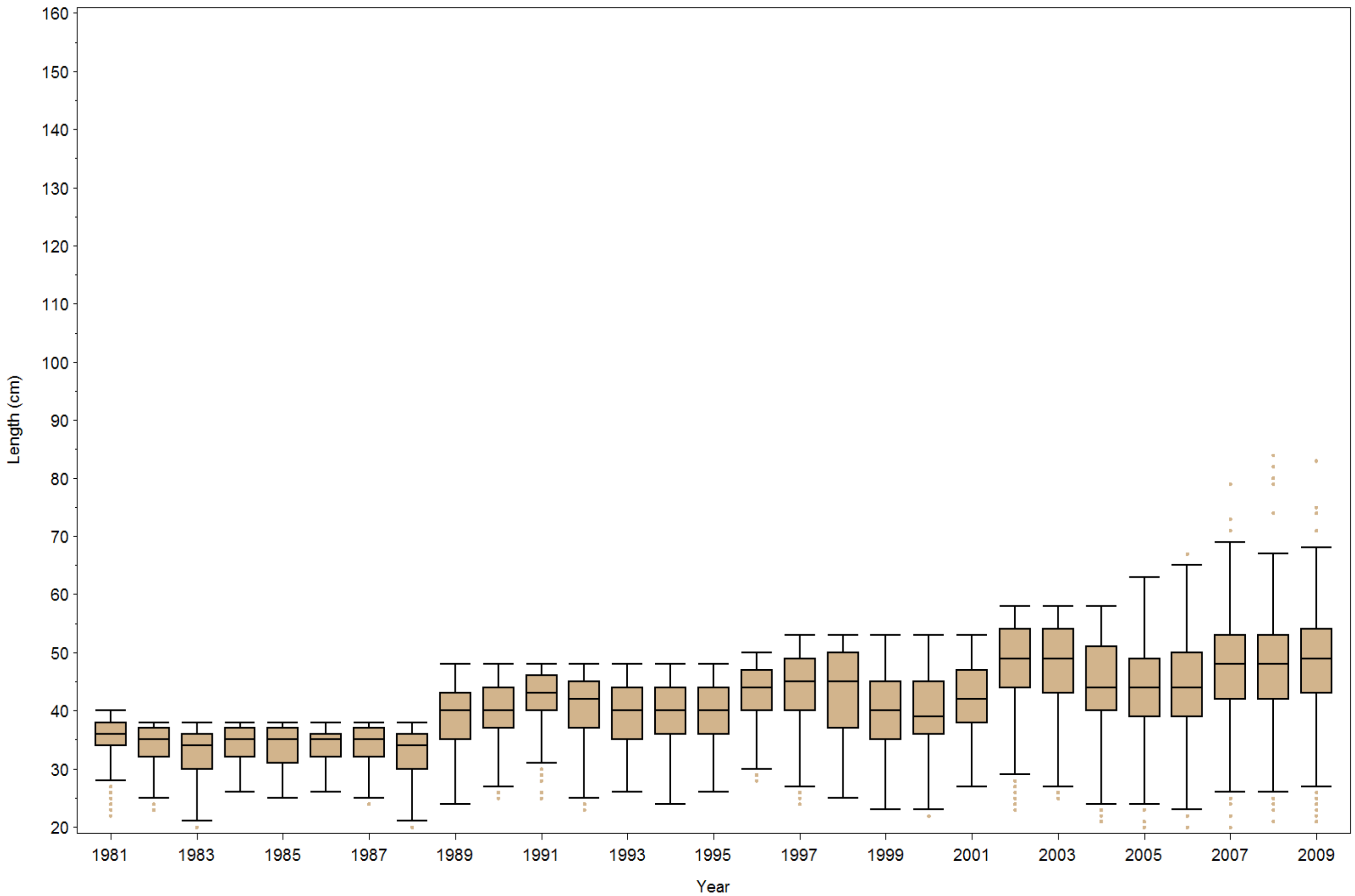


Figure A.61. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the recreational fishery between 1981 and 2010.

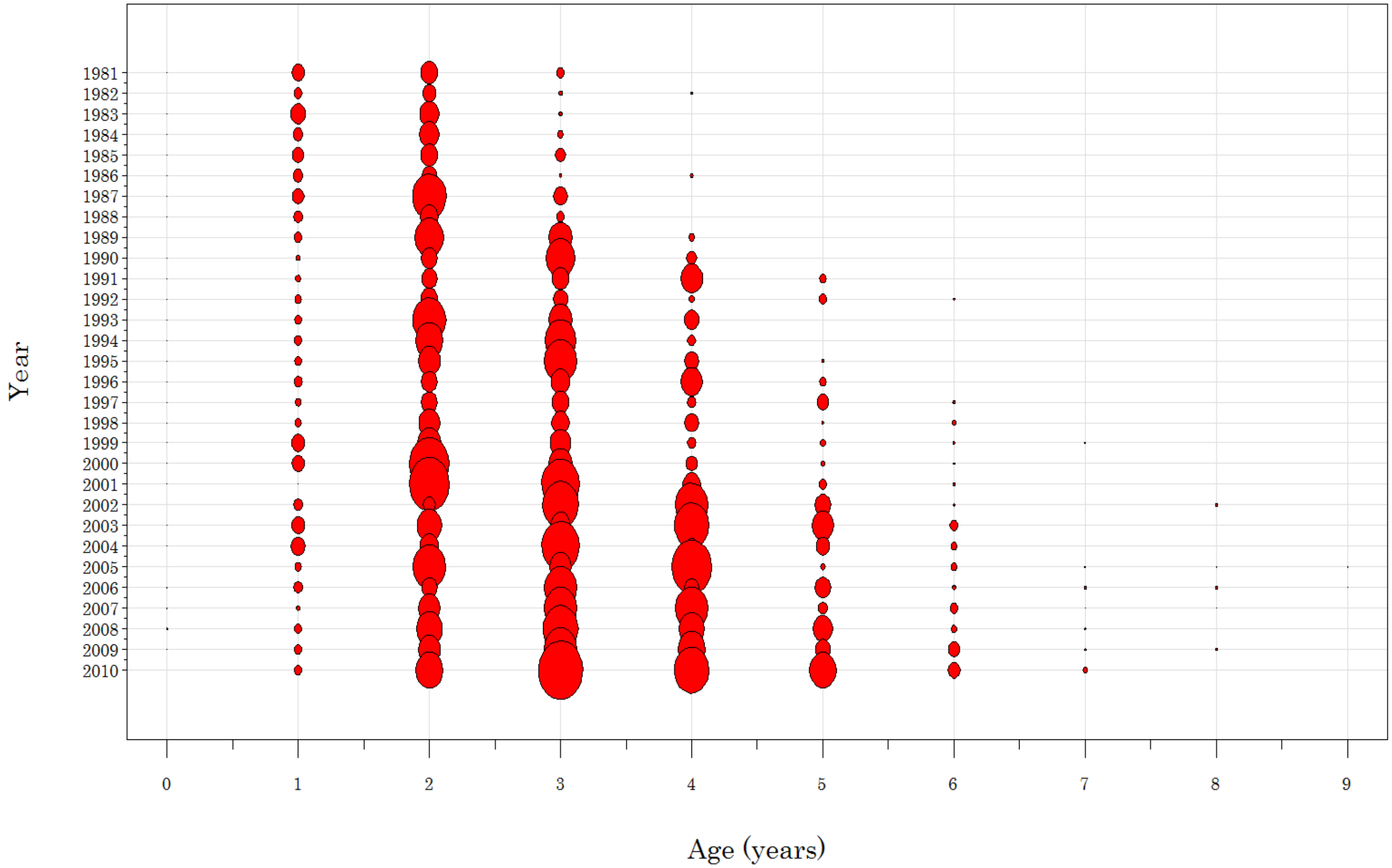
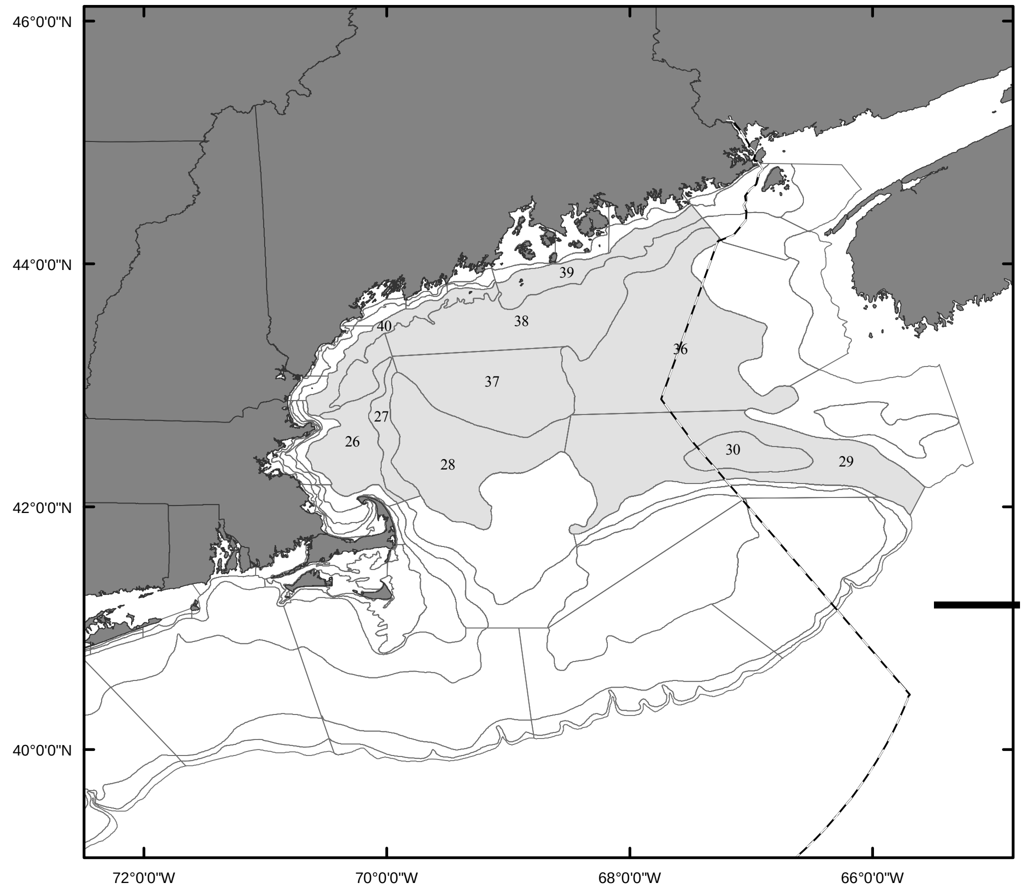


Figure A.62. Recreational discards-at-age of Gulf of Maine Atlantic cod from 1981 to 2010.



Figue A.63. Map of the Notheast Fisheries Science Center (NEFSC) bottom trawl offshore survey strat includedin the Gulf of Maine Atlantic cod stock assessment (shaded grey).

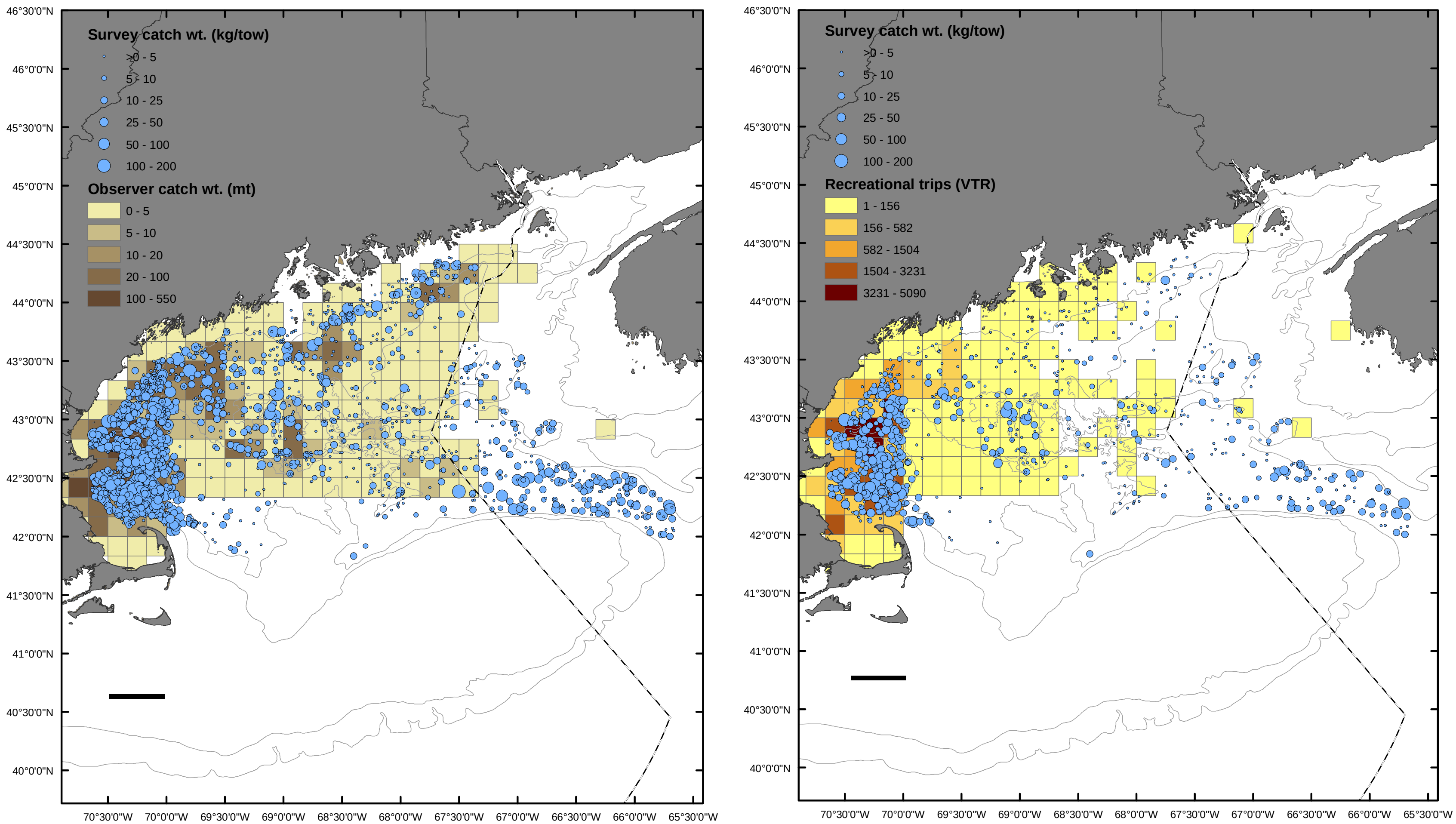


Figure A.64. Spatial overlap of survey catches (kg/tow) of Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey (spring and fall combined) and commercial and recreational fishing effort. On the left, NEFSC survey catches from 1989 – 2010 are overlayed on total observed 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 binned to ten minute squares. **Note the different time periods used in each plot.*

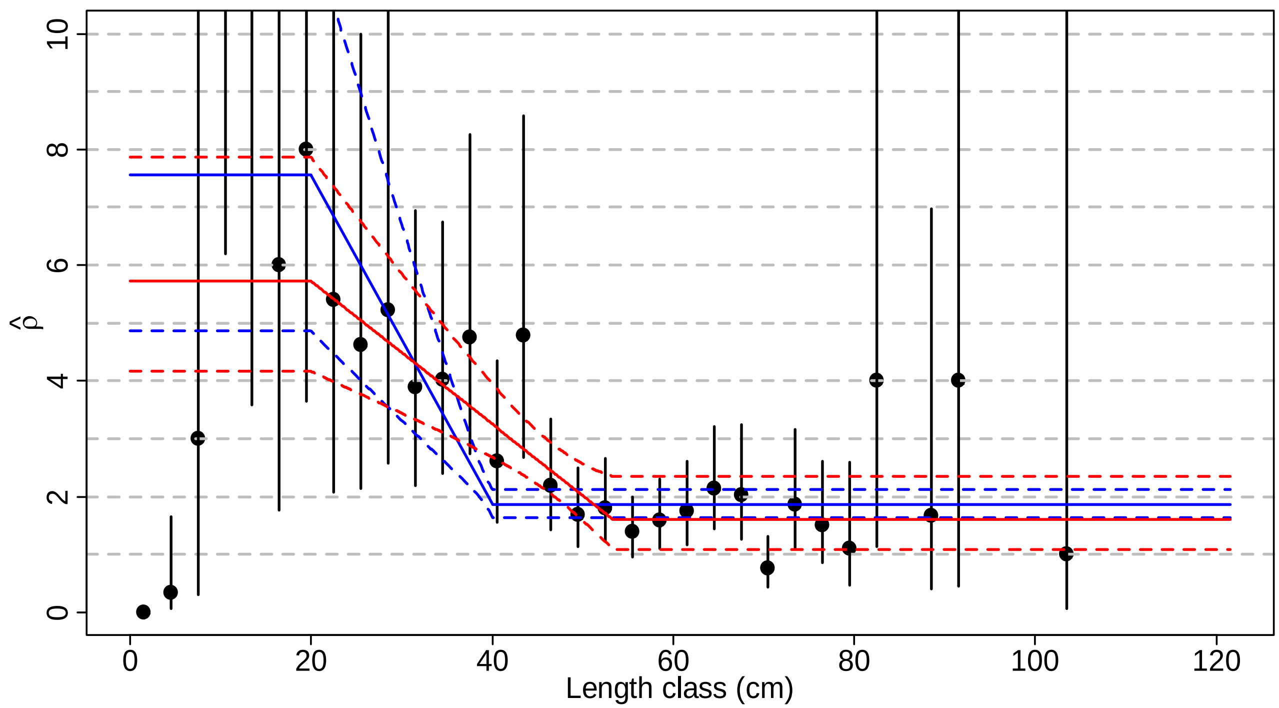


Figure A.65. Beta-binomial-based estimates of calibration factors and corresponding 95% confidence intervals by length class (3 cm bins) for Atlantic cod. The black points and vertical bars represent results where different calibration factors are estimated for each length class. The blue lines represent 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).

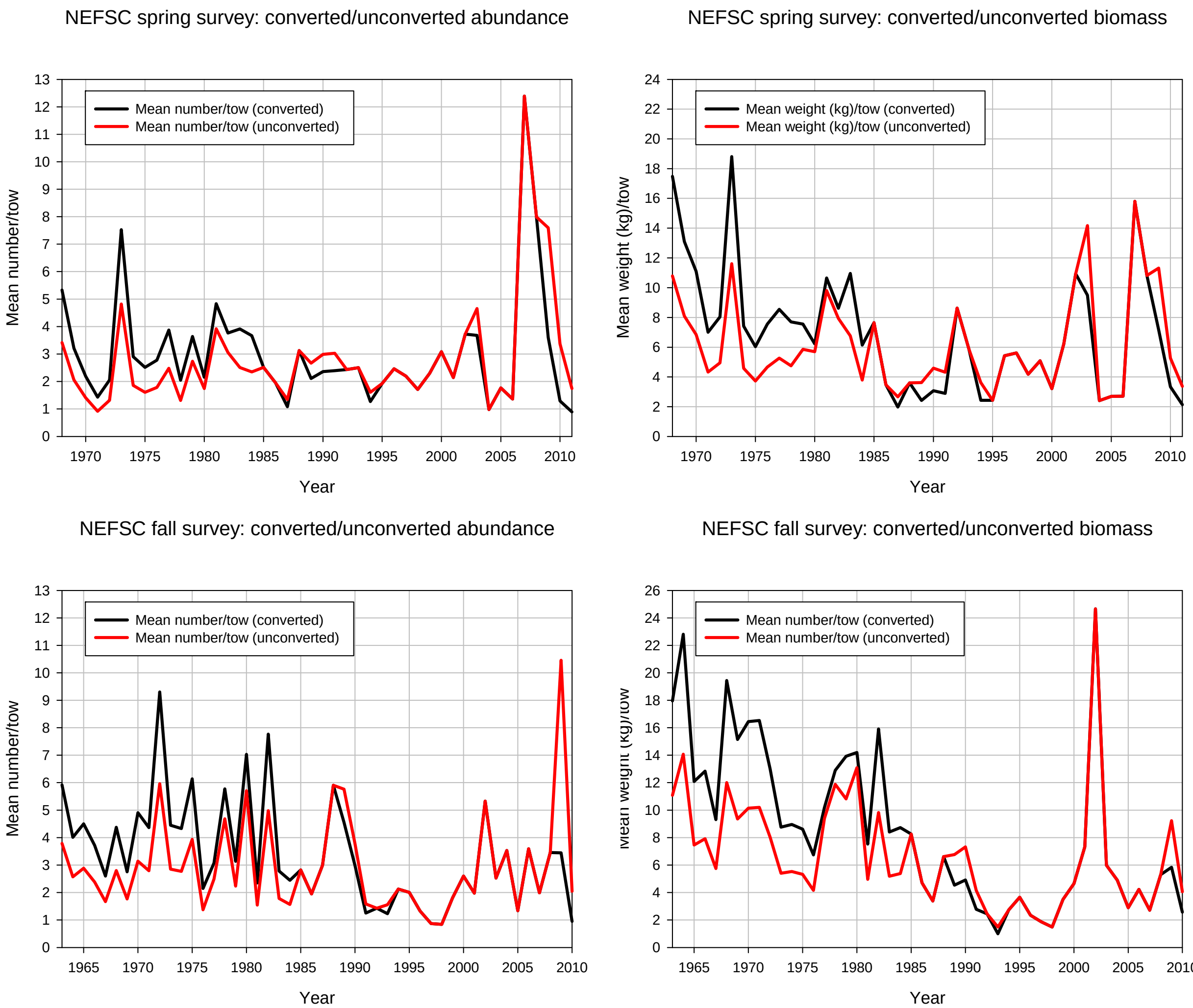


Figure A.66. Northeast Fisheries Science Center spring (top panels) and fall (bottom panels) survey indices of abundance (left panels) and biomass (right panels) showing both raw (unconverted) and vessel, door and survey converted indices over time for Gulf of Maine Atlantic cod.

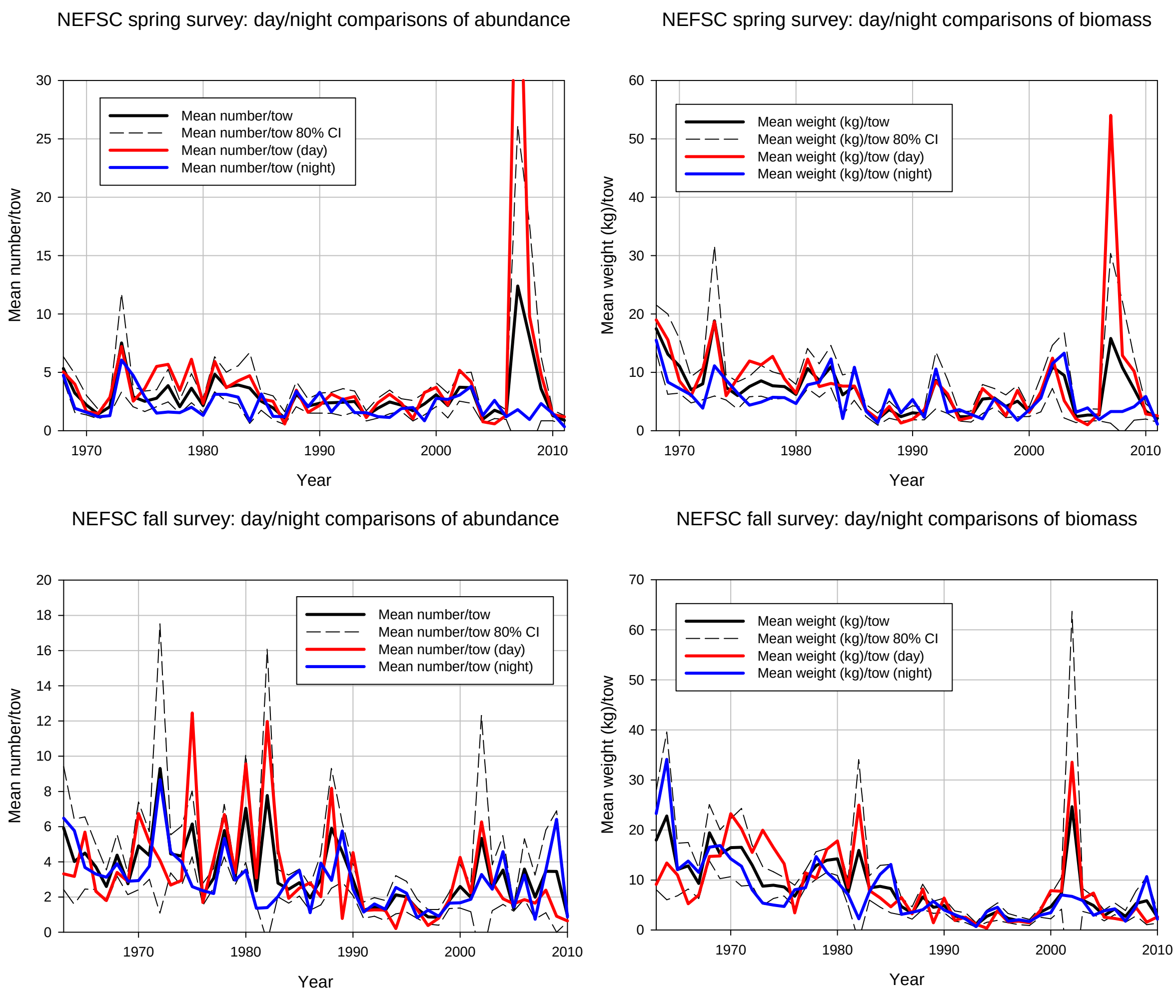
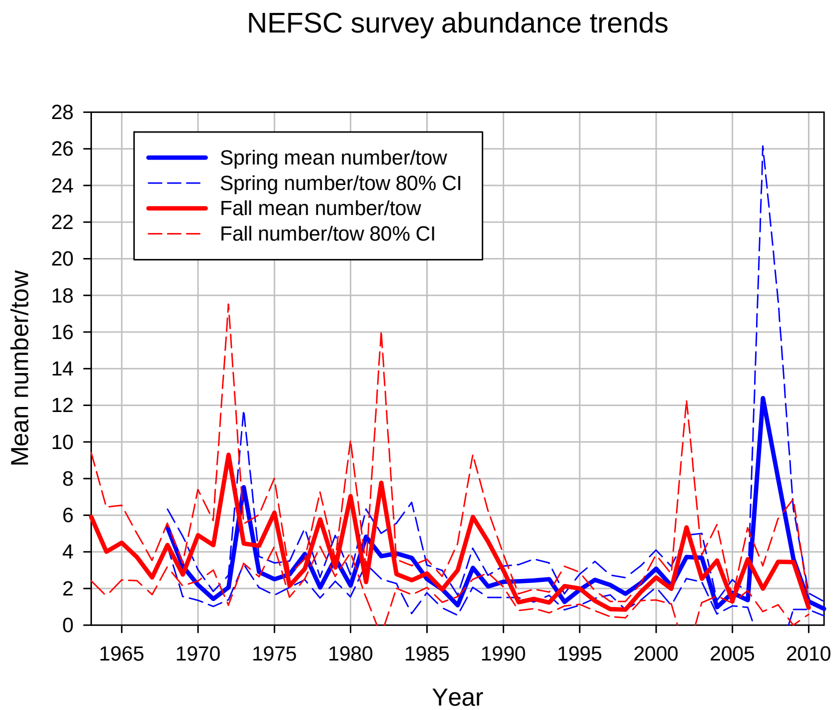


Figure A.67. Northeast Fisheries Science Center spring (top panels) and fall (bottom panels) survey indices of abundance (left panels) and biomass (right panels) broken down by day- and night-only tows compared to the aggregate index (day and night tows combined) and its associated 80% confidence interval (CI) for Gulf of Maine Atlantic cod.



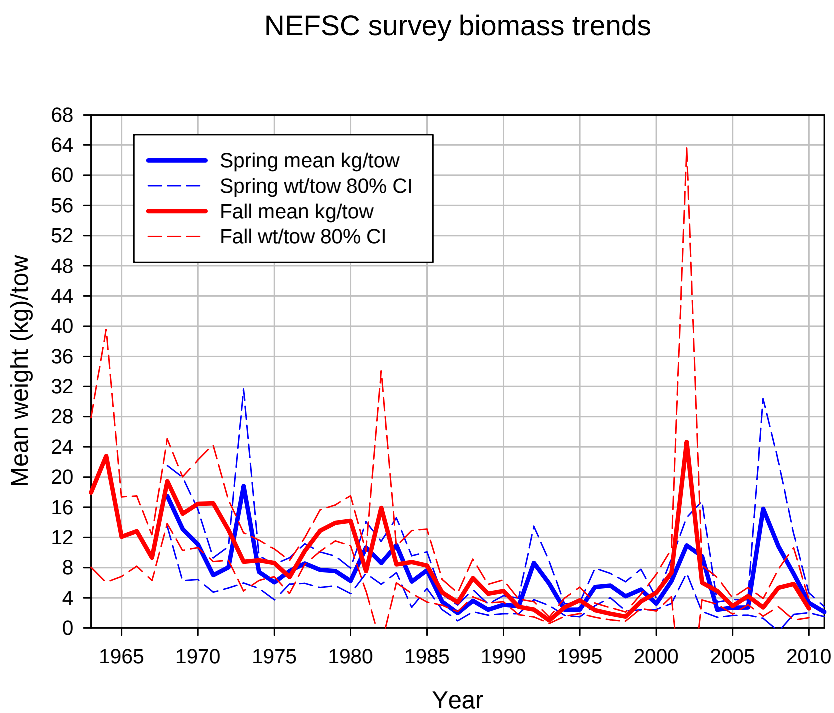


Figure A.68. Northeast Fisheries Science Center spring and fall bottom trawl survey abundance (top) and biomass (bottom) indices from 1963 to 2011 for Gulf of Maine Atlantic cod. **Spring survey did not begin until 1968, 2011 fall survey data not available at time of this report.*

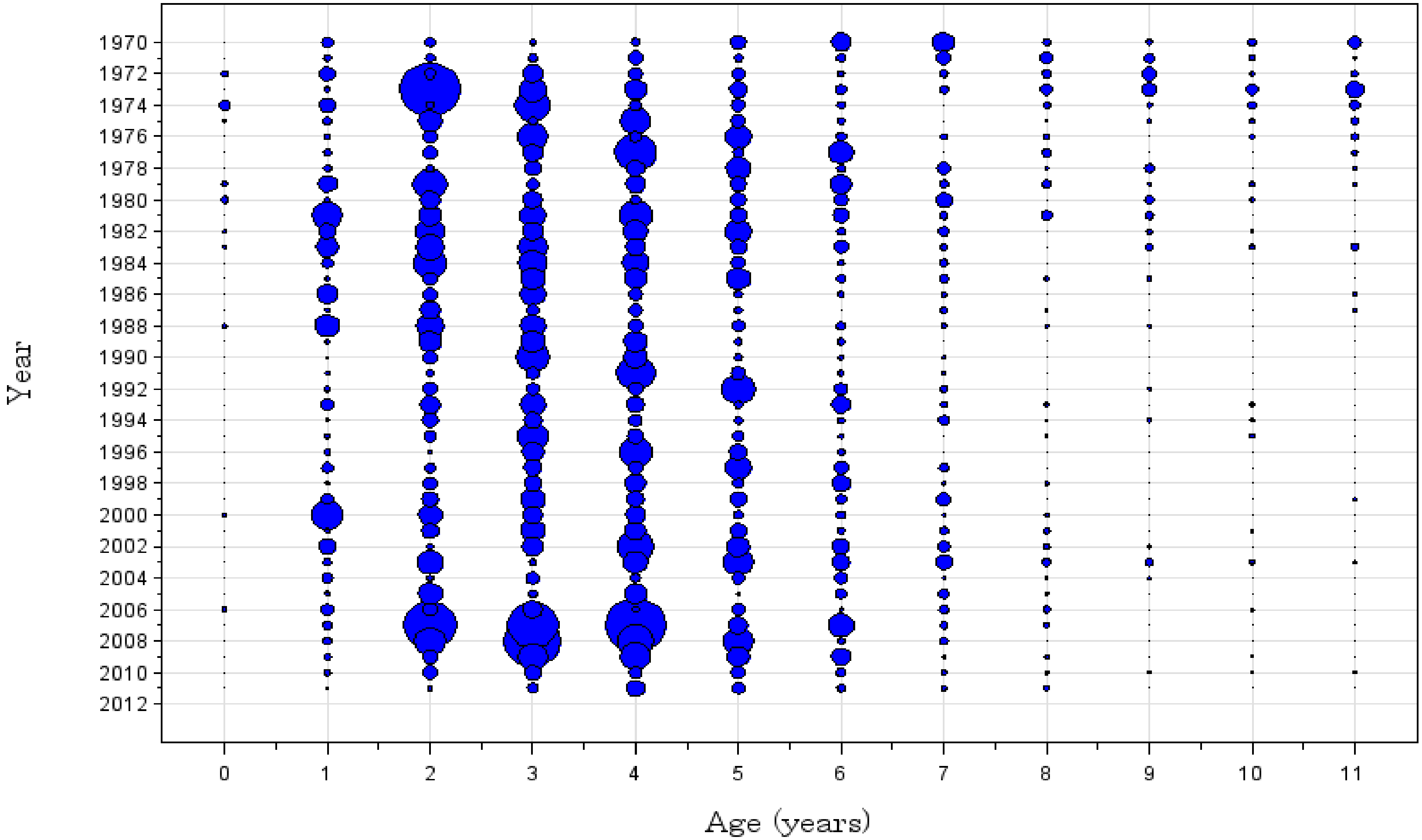


Figure A.69. Numbers-at-age from NEFSC spring bottom trawl survey, 1968 to 2011 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

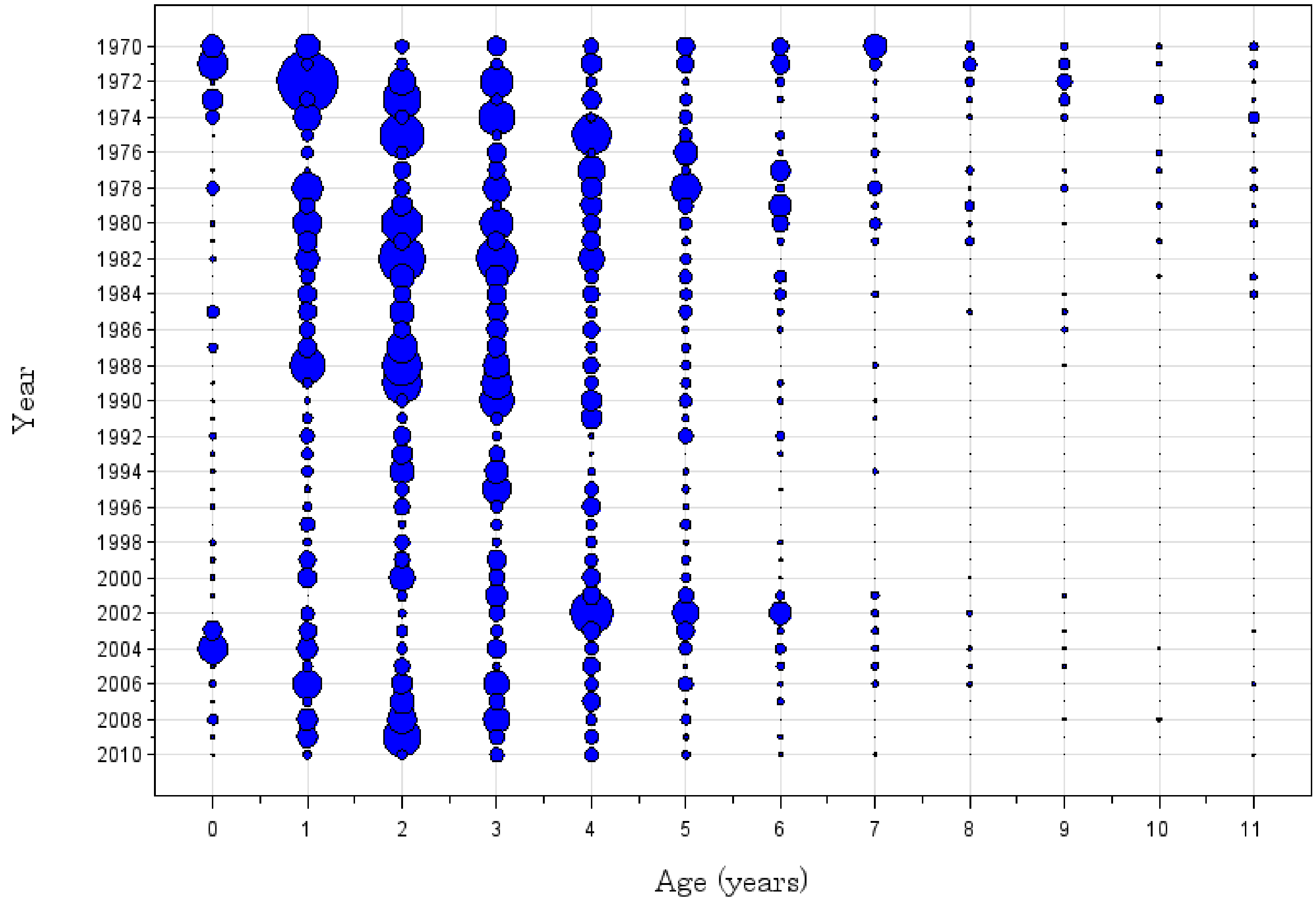


Figure A.70. Numbers-at-age from NEFSC fall bottom trawl survey, 1963 – 2010 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

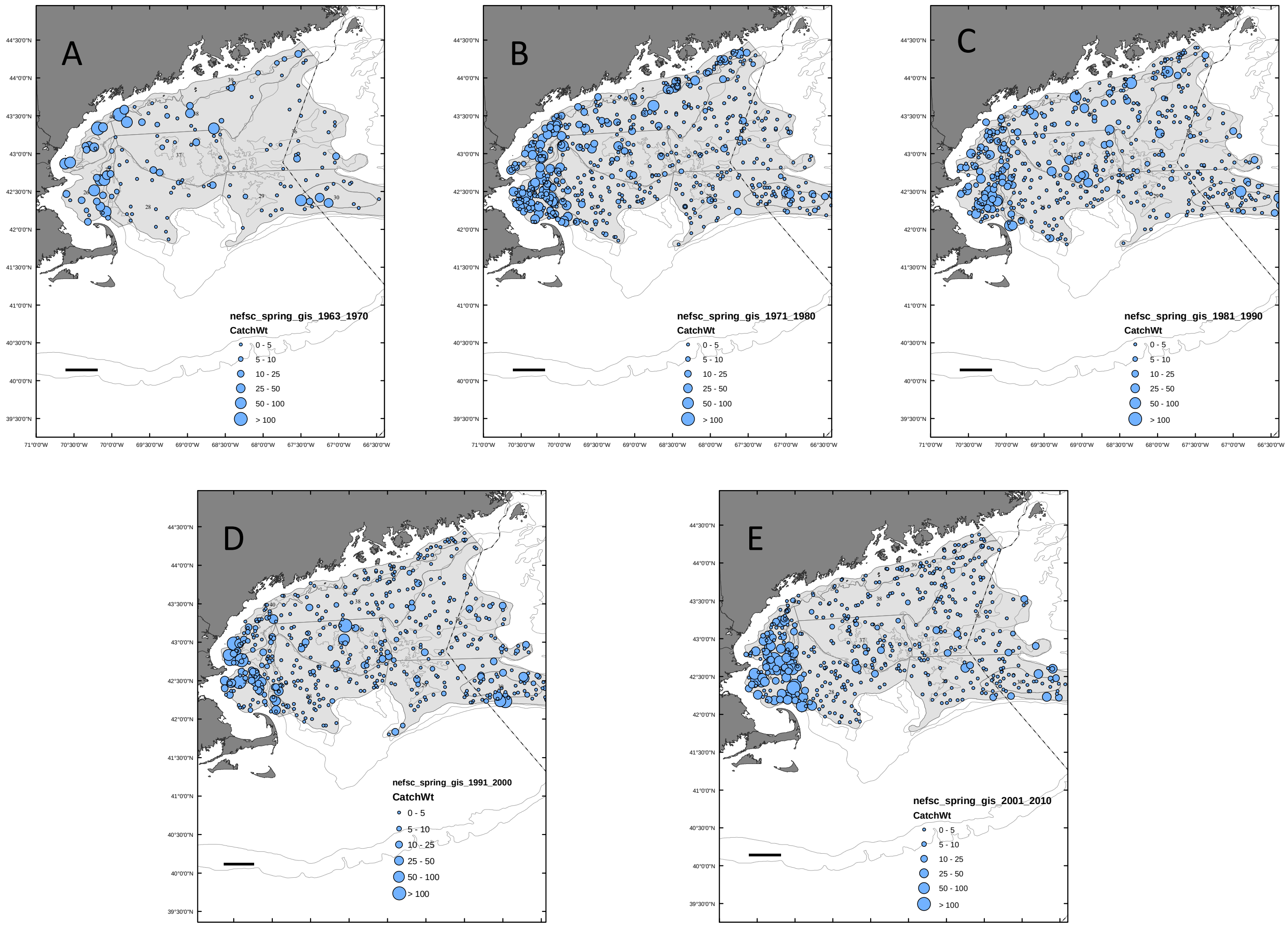


Figure A.71. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the Northeast Fisheries Science Center spring bottom trawl survey from 1968 – 2010. (A) 1963 – 1970 (*Note spring survey started in 1968), (B) 1971 – 1980, (C) 1981 – 1990, (D) 1991 – 2000, (E) 2001 – 2010. Bubble plot scale is identical in each plot.

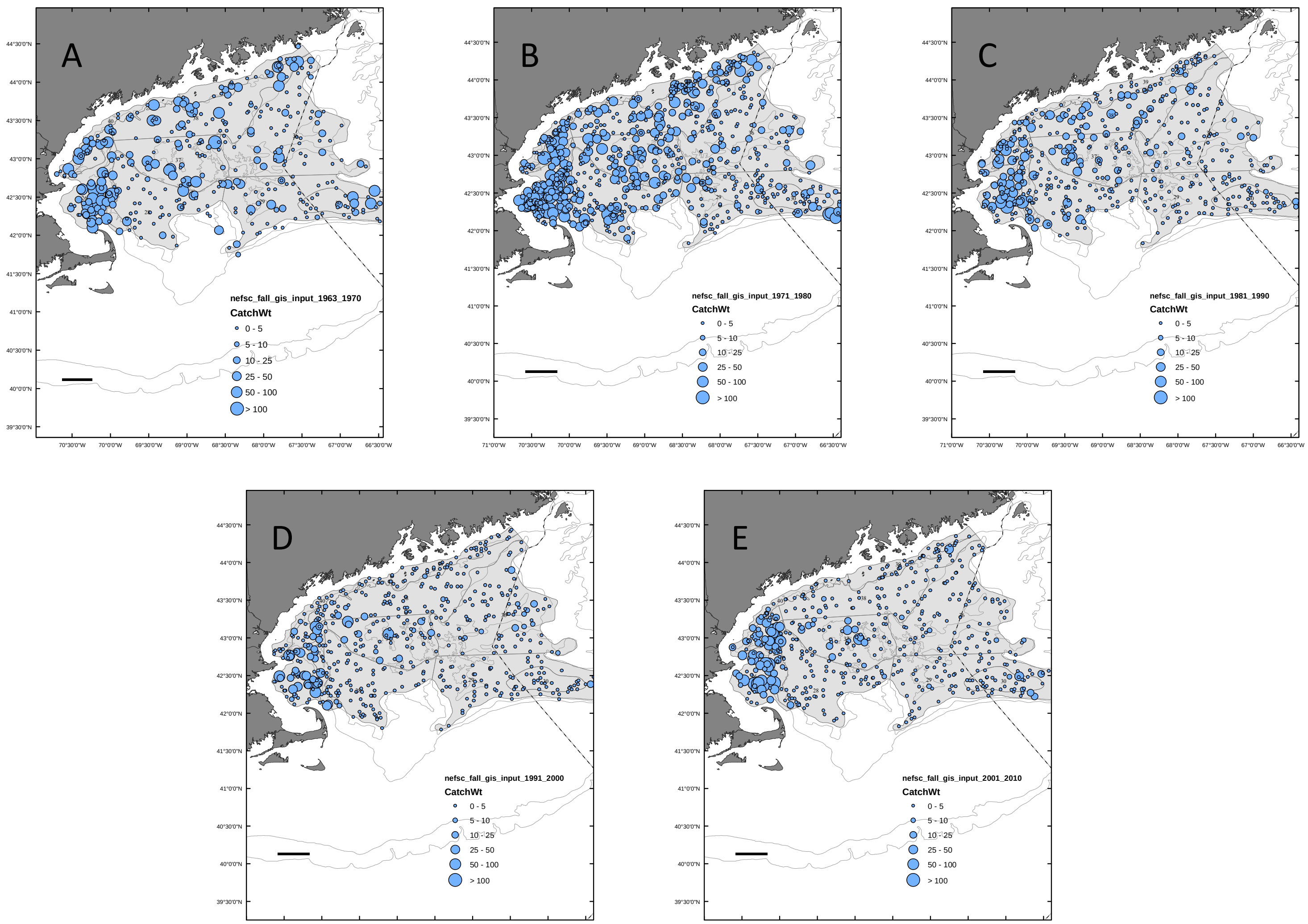


Figure A.72. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the Northeast Fisheries Science Center fall bottom trawl survey from 1963 – 2010. (A) 1963 – 1970, (B) 1971 – 1980, (C) 1981 – 1990, (D) 1991 – 2000, (E) 2001 – 2010. Bubble plot scale is identical in each plot.

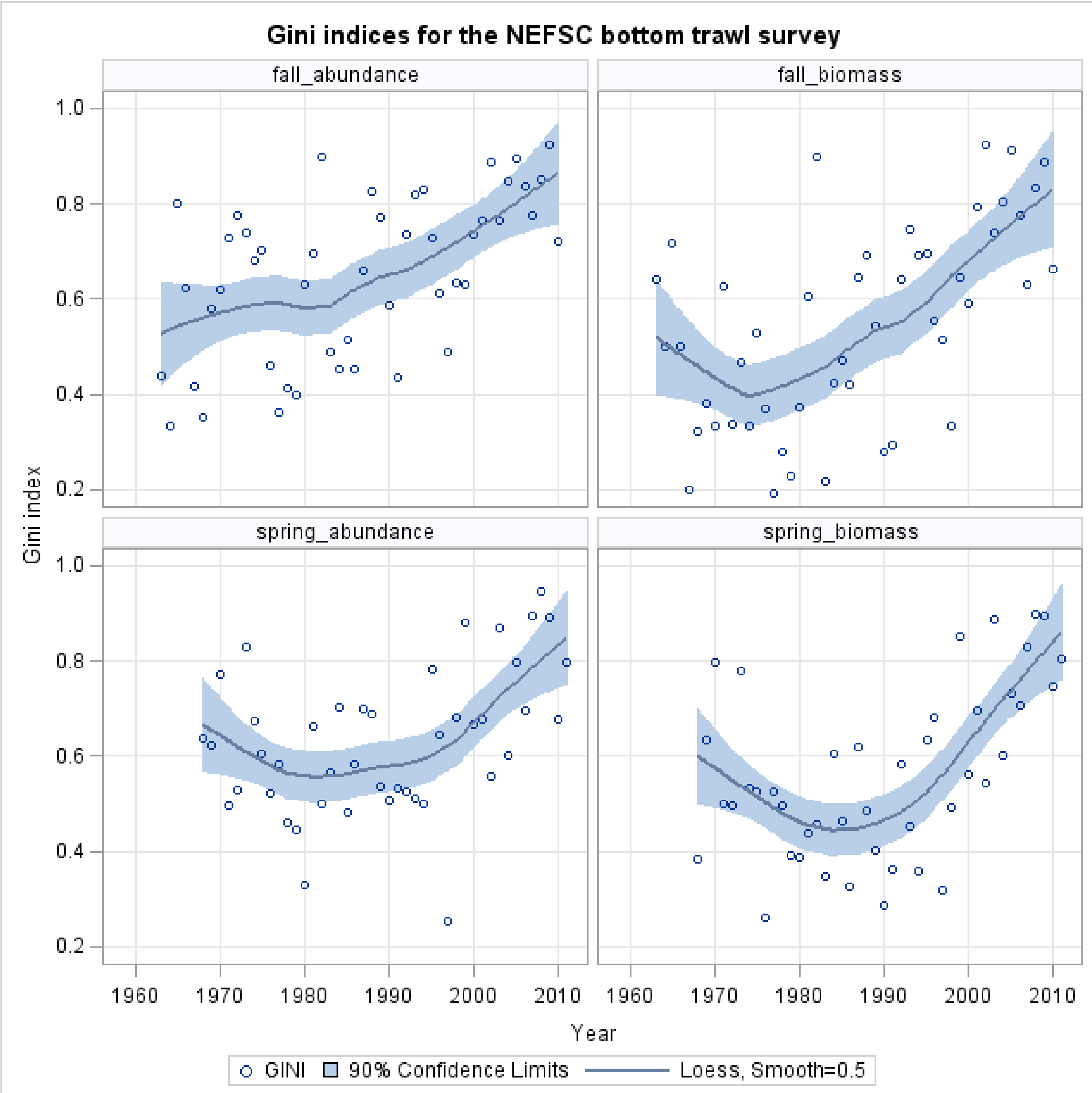
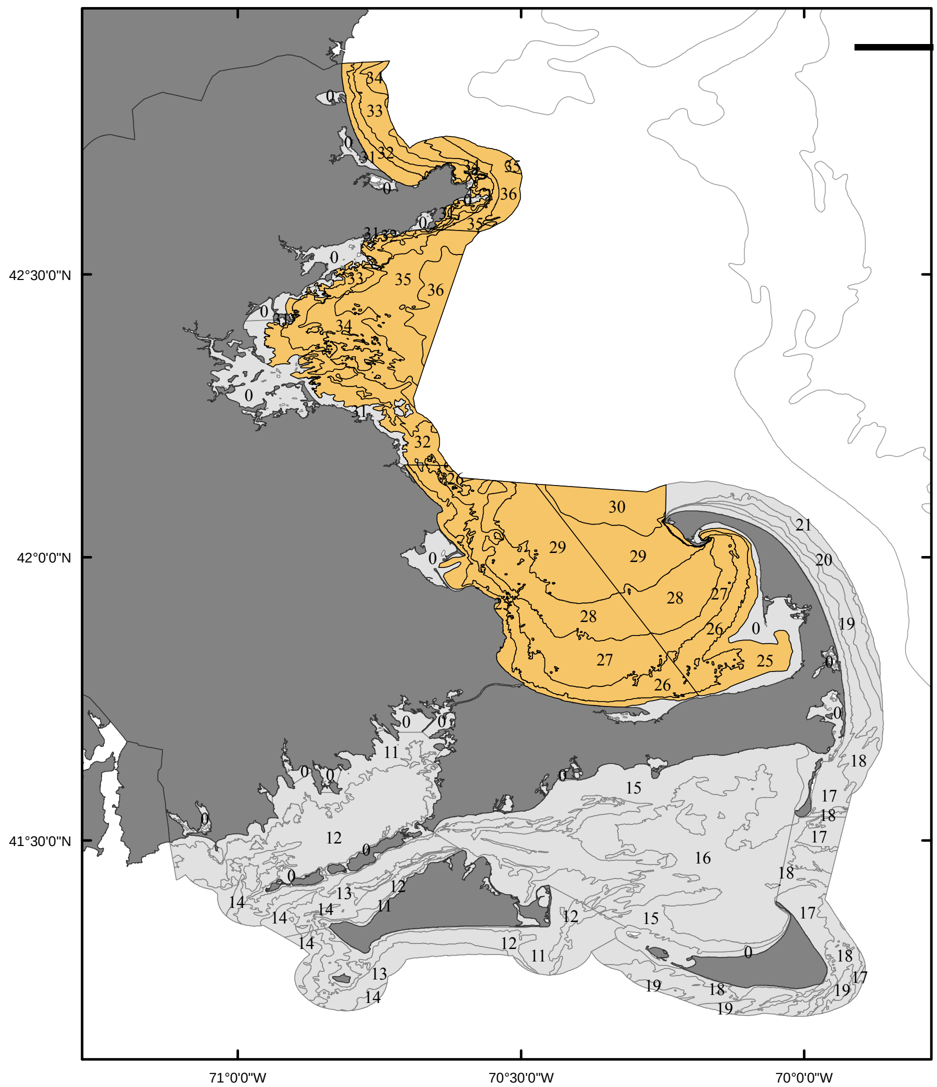
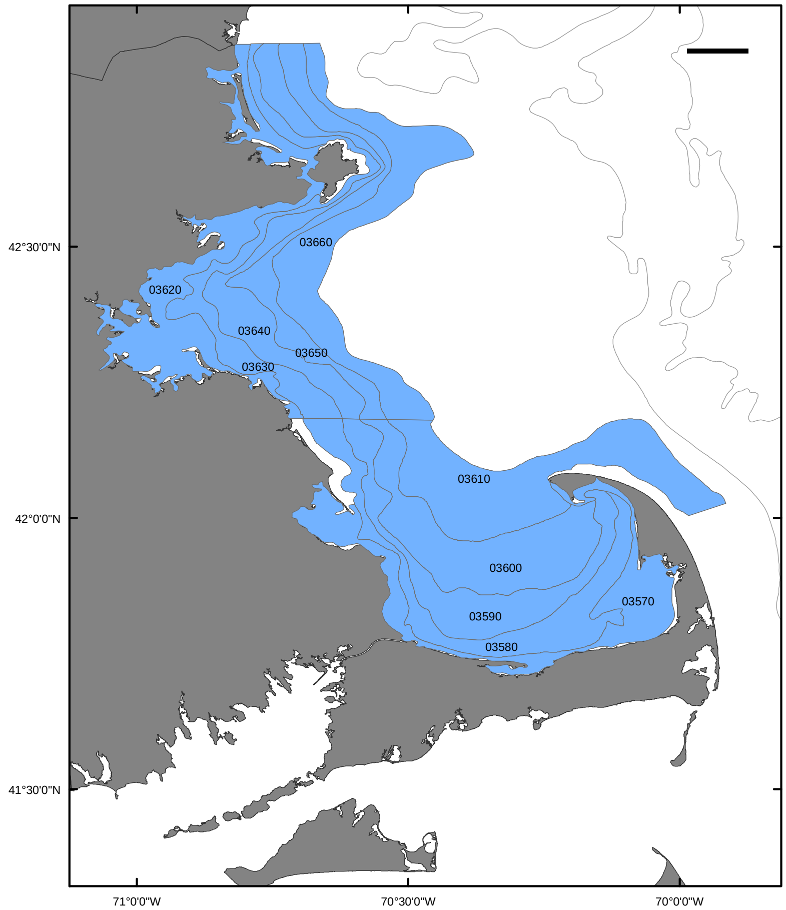


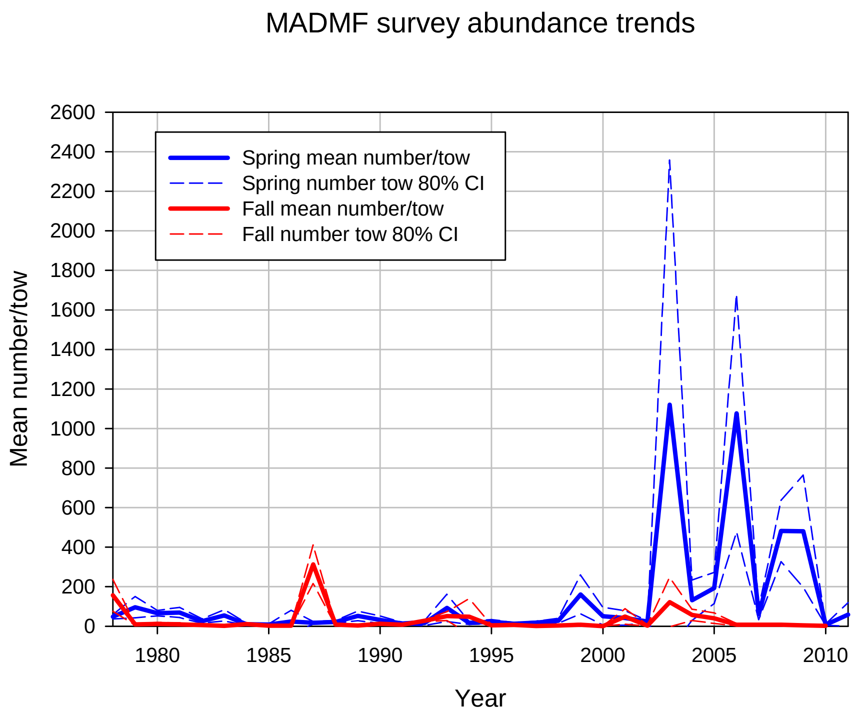
Figure A.73. Gini indices for Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) fall (top) and spring (bottom) bottom trawl surveys in terms of abundance (numbers/tow, left) and biomass (kg/tow, right). A loess smooth has been fit to the data with smoothing parameter of 0.5. The loess smooth is shown by the solid blue line along with the corresponding 90% confidence interval.



Figue A.74. 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).



Figue A.75. Map of the NEFSC inshore bottom trawl survey strata. Age length keys applied to MADMF surveys were augmented using age-length information collected from the NEFSC inshore strata when datat were available.



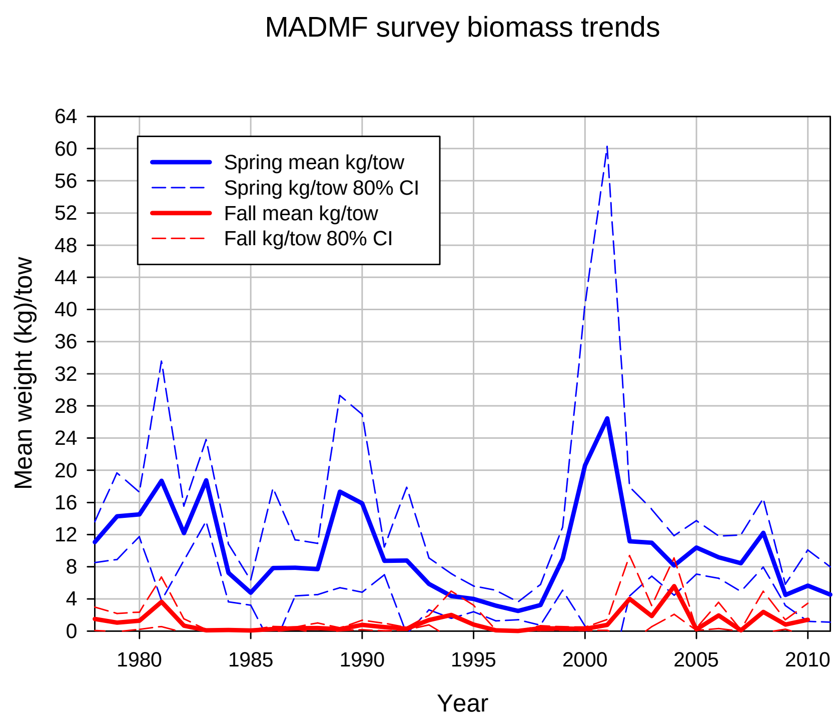


Figure A.76. Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey abundance (top) and biomass (bottom) indices from 1978 to 2011 for Gulf of Maine Atlantic cod. **2011 fall survey data not available at time of this report.*

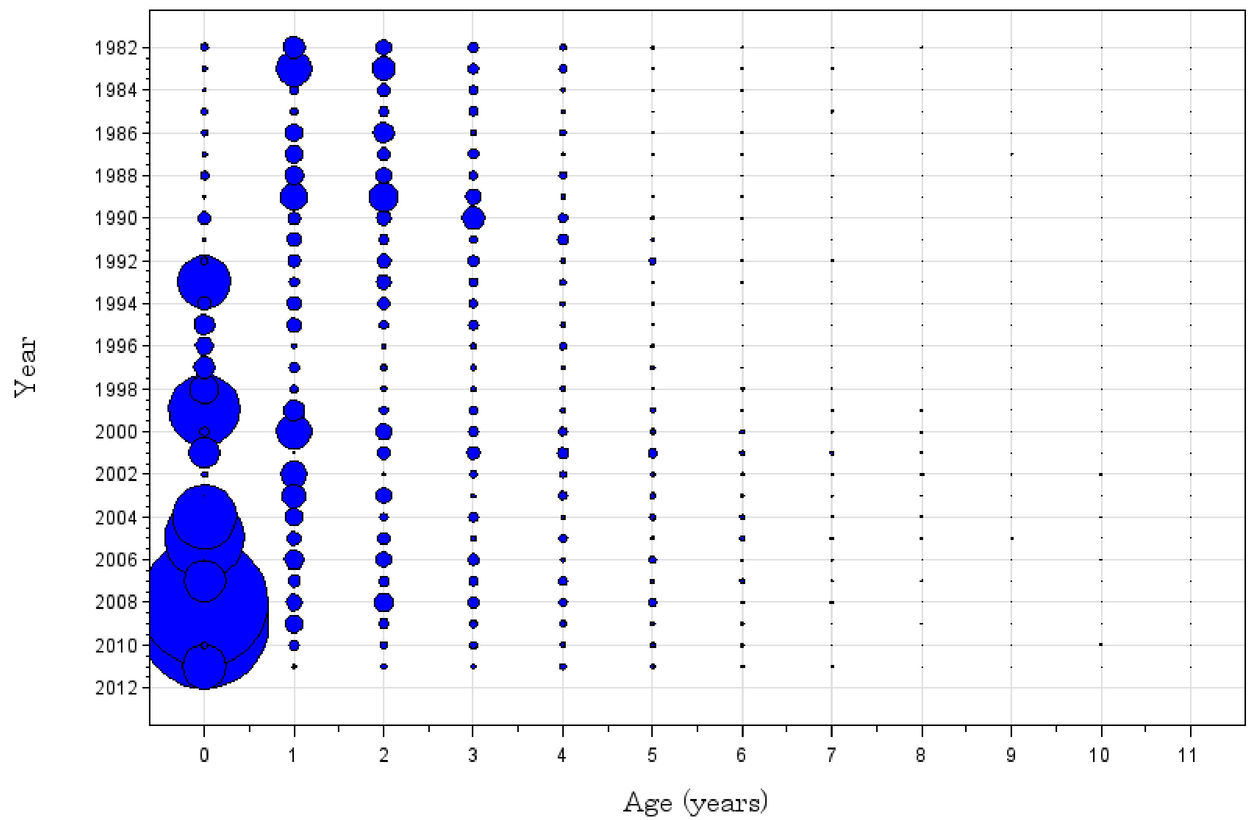


Figure A.77. Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey , 1982 – 2010 for Gulf of Maine Atlantic cod. There was insufficient age information available from the MADMF spring survey prior to 1982. **Note that age 11 is a plus group.*

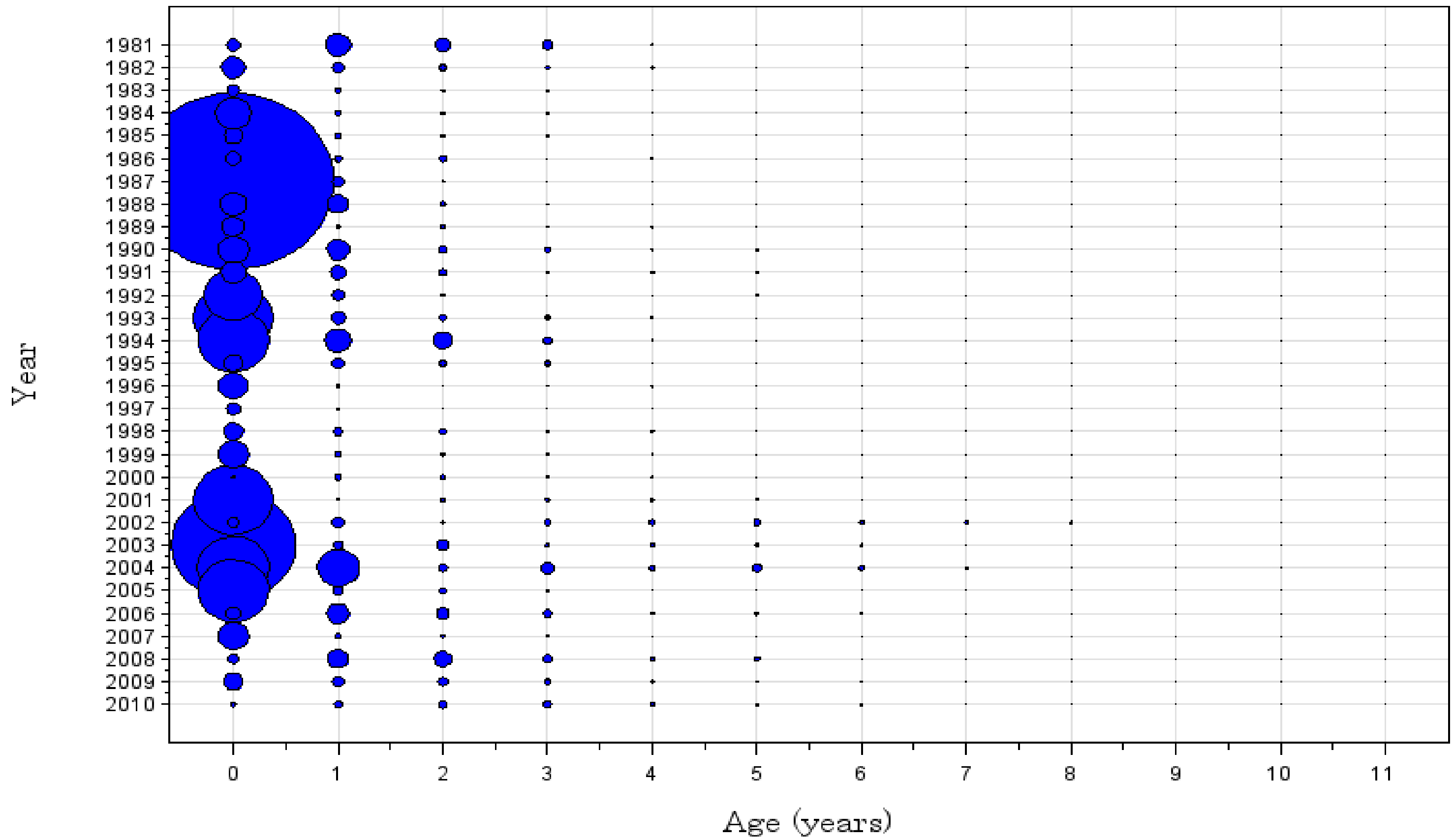


Figure A.78. Massachusetts Department of Marine Fisheries (MADMF) fall bottom trawl survey, 1981 – 2010 for Gulf of Maine Atlantic cod. There was insufficient age information available from the MADMF fall survey prior to 1981. **Note that age 11 is a plus group.*

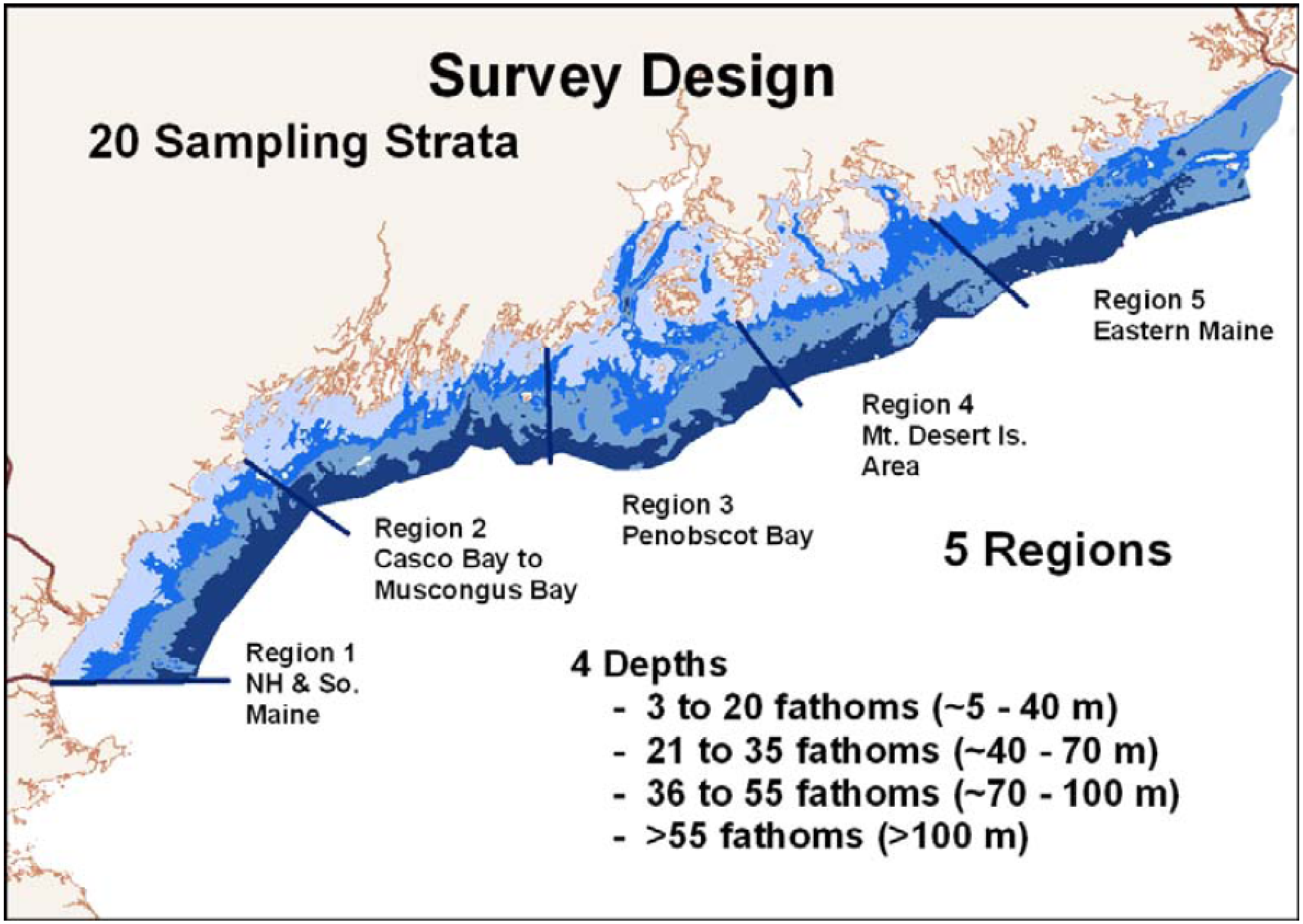
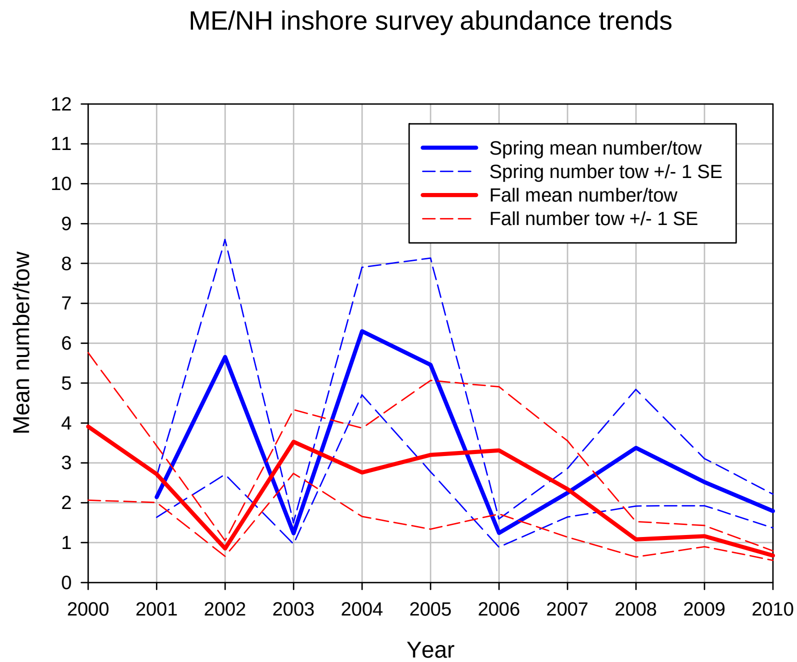


Figure 79. Map of the Maine – New Hampshire inshore groundfish trawl survey strata set (map from Sherman et al. 2005).



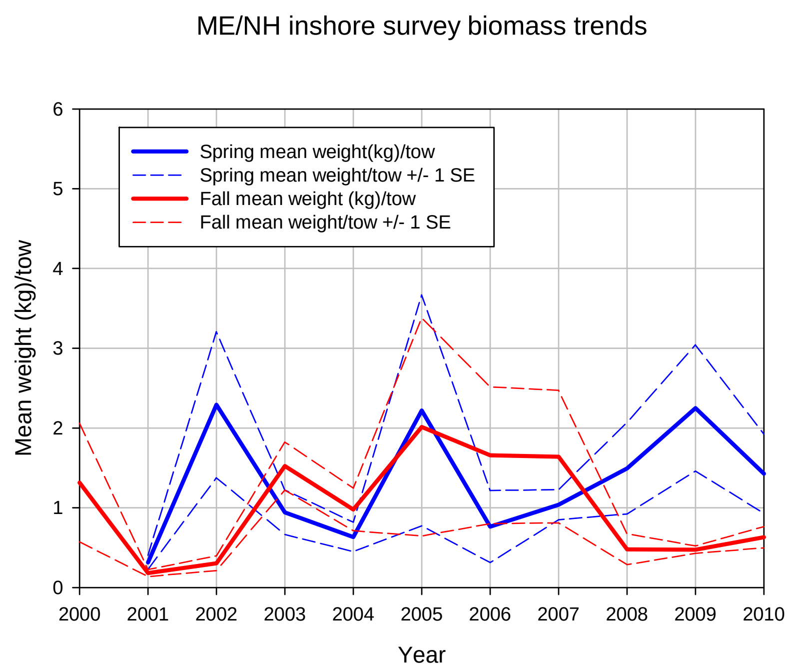


Figure A.80. Maine – New Hampshire inshore groundfish trawl survey spring and fall survey abundance (top) and biomass (bottom) indices from 1978 to 2011 for Gulf of Maine Atlantic cod. Dased lines indicate ± 1 standard error (SE). Data provided by S. Sherman (pers. comm.).

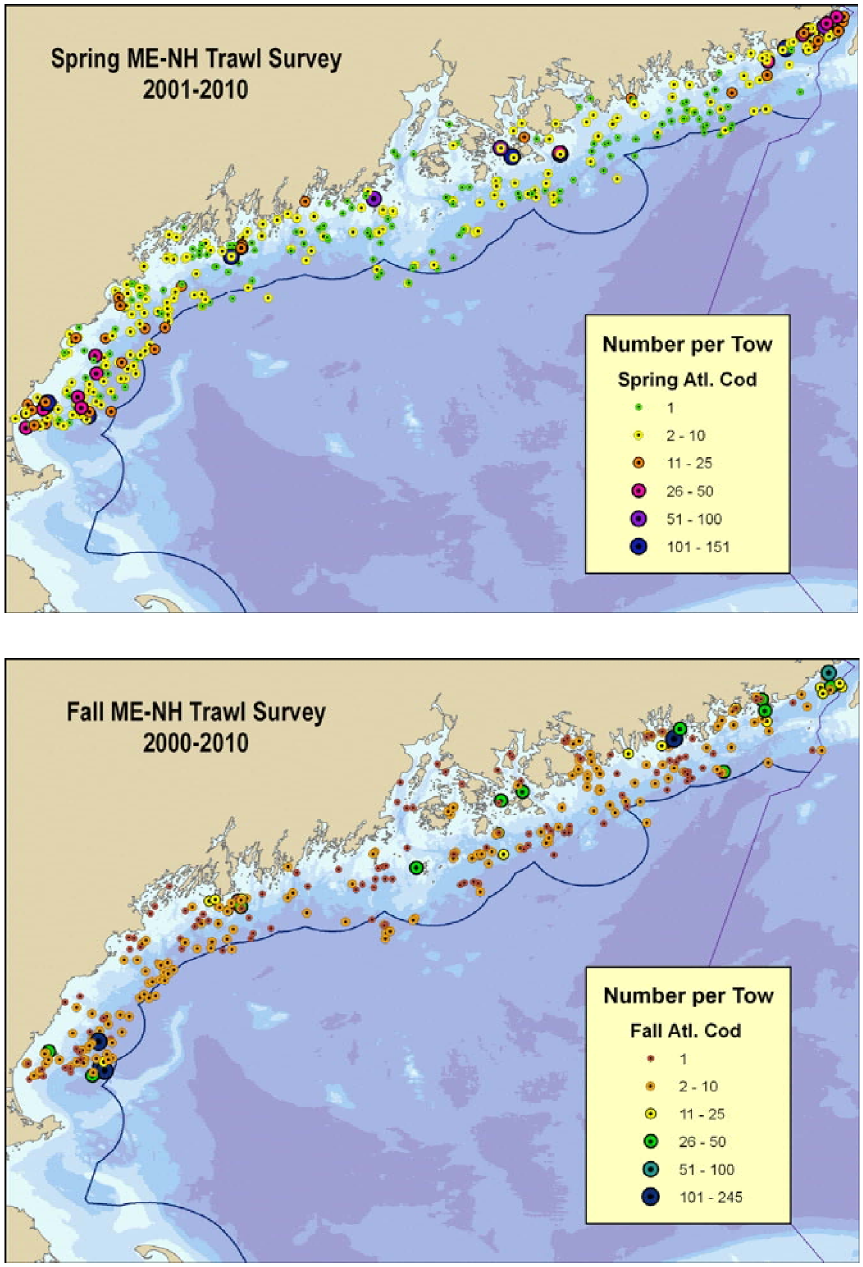


Figure A.81. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the spring (top) and fall (bottom) Maine – New Hampshire inshore groundfish trawl survey between 2001 and 2010. Map provided by S. Sherman (pers. comm.).

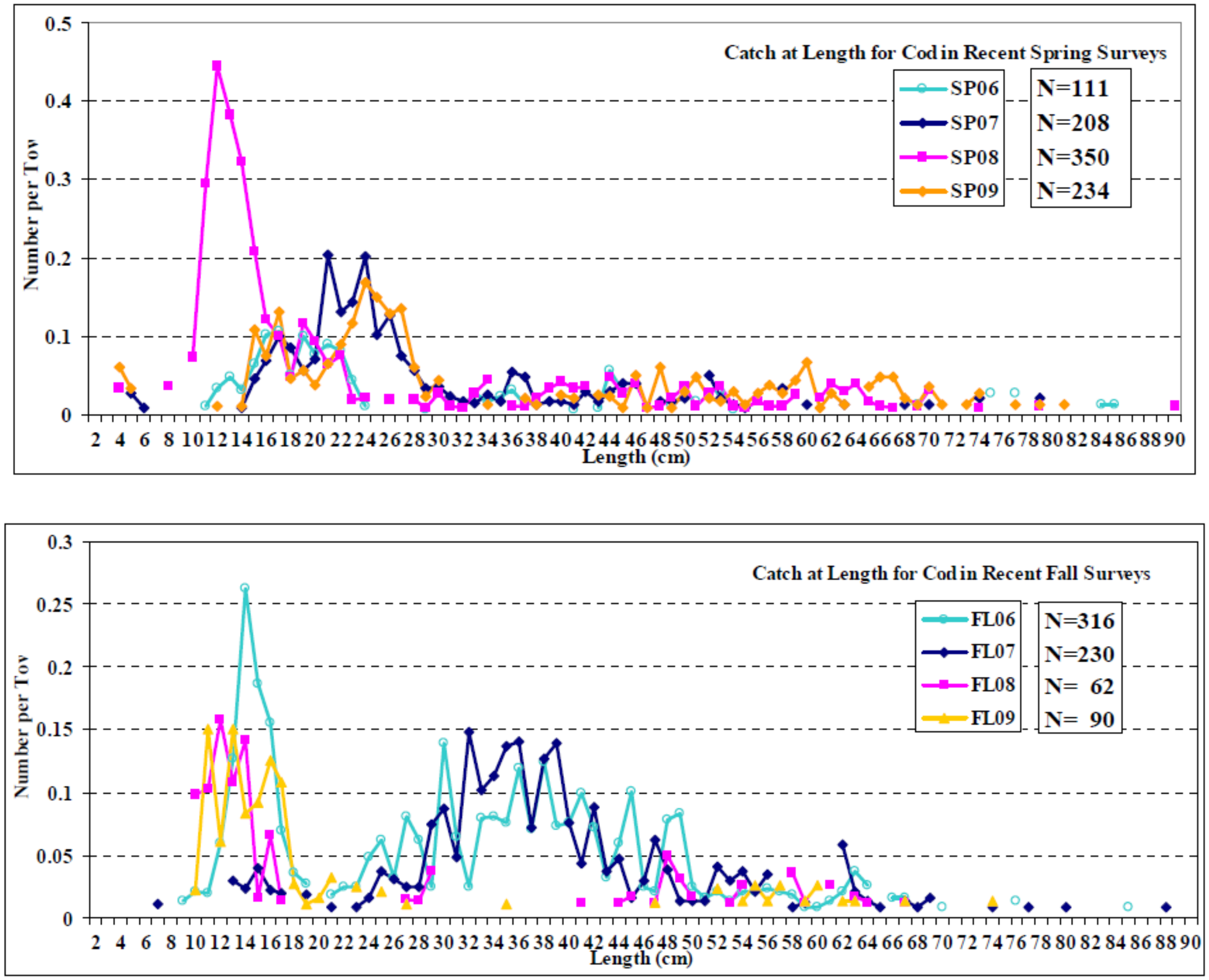


Figure A.82. Length distributions of Gulf of Maine Atlantic cod sampled in the Maine – New Hampshire inshore groundfish trawl spring (top) and fall (bottom) surveys from 2006 to 2009.

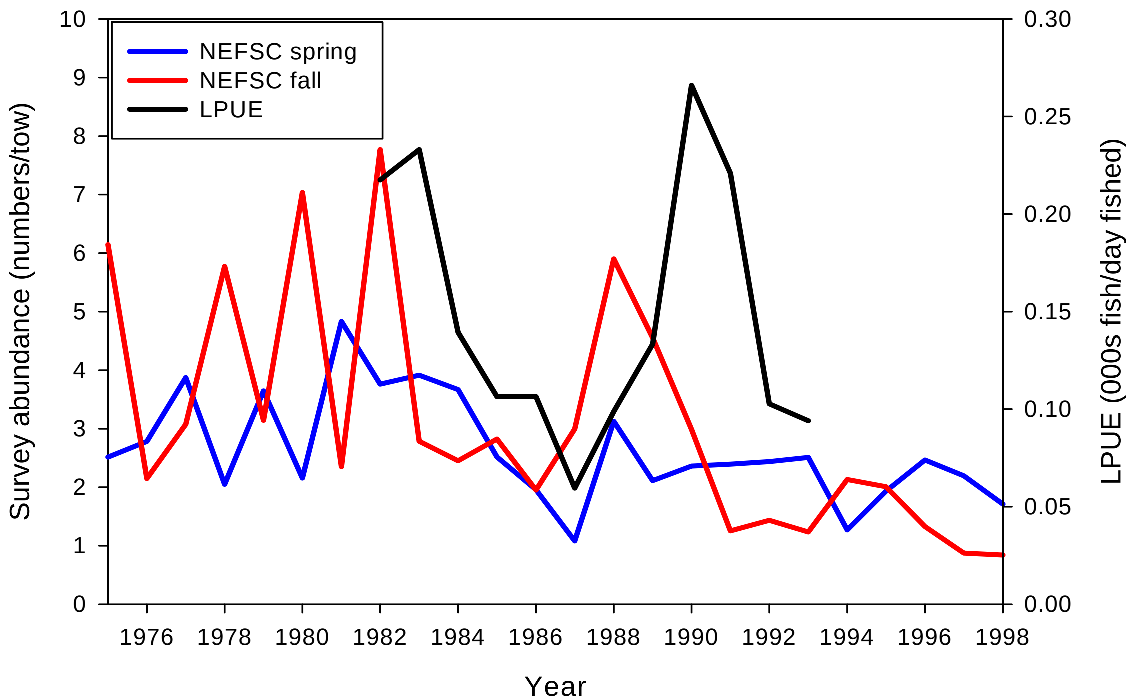


Figure A.83. Comparison of the Gulf of Maine Atlantic cod commercial landings per unit effort (LPUE) tuning index to the spring and fall Northeast Fisheries Science Center (NEFSC) bottom trawl survey abundance index.

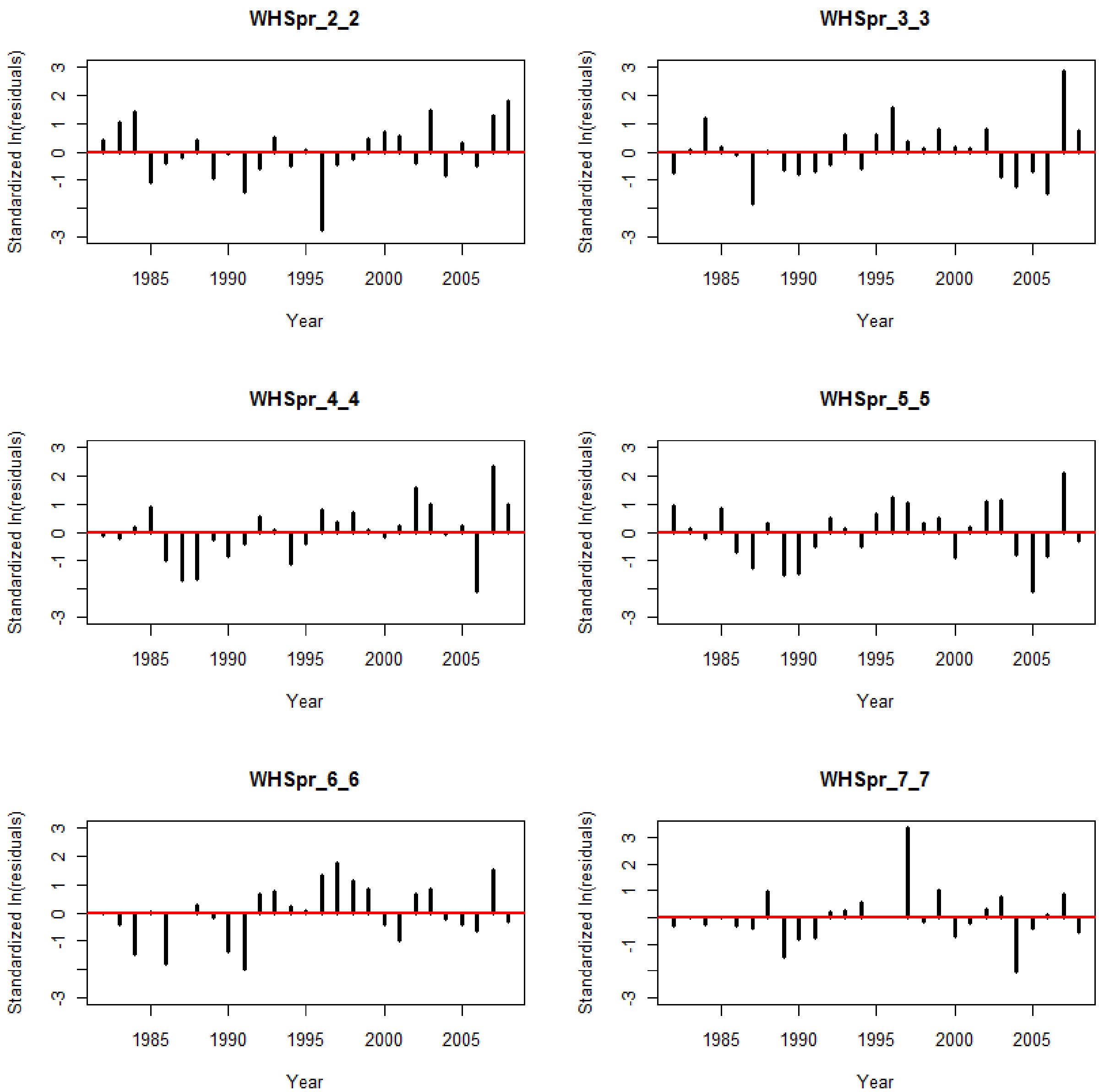


Figure A.84.a. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center spring Gulf of Maine Atlantic cod survey ages 2 (WHSpr_2_2) through 7 (WHSpr_7_7). **Note: fall surveys have been lagged forward a year and an age.*

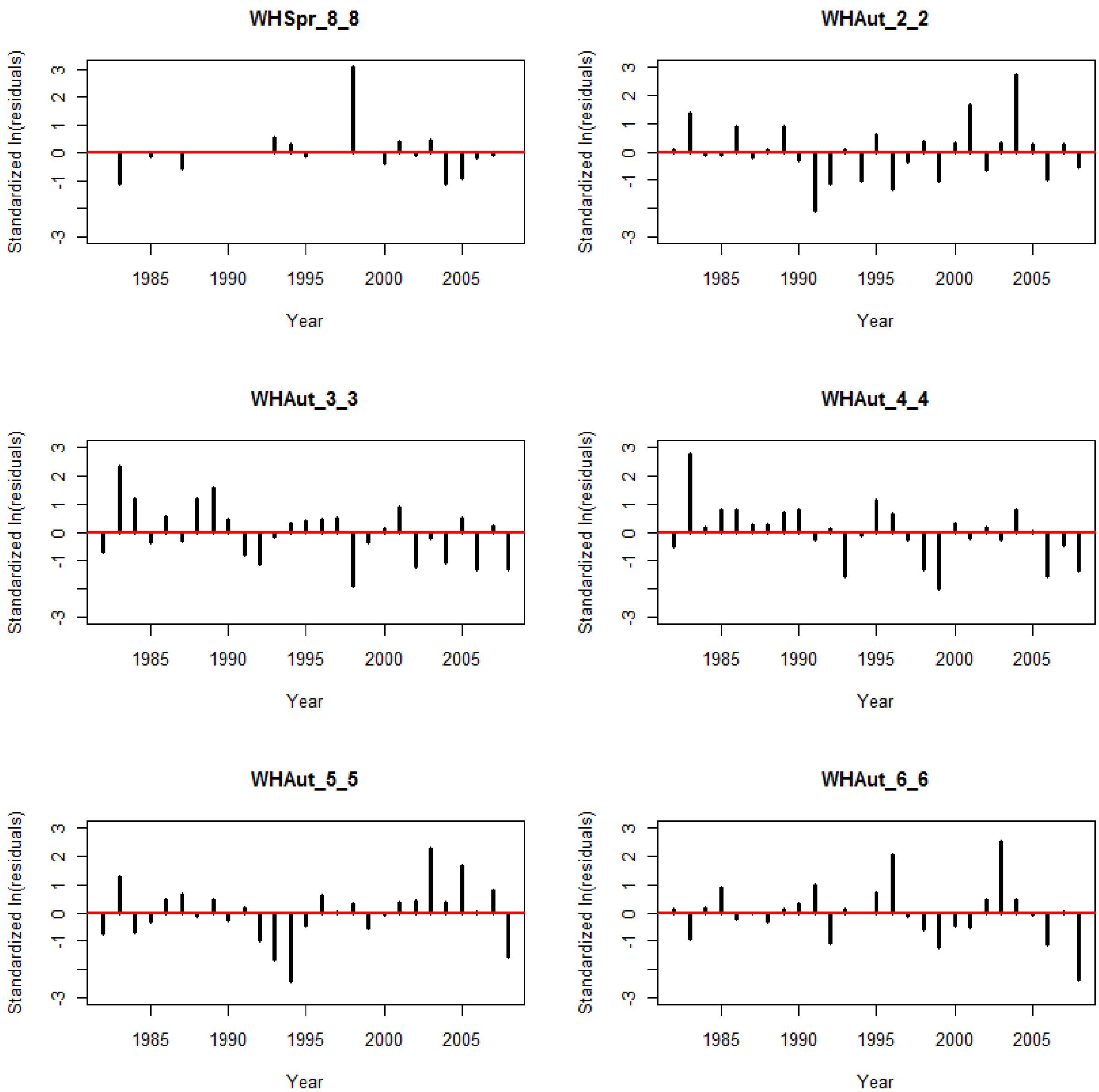


Figure A.84.b. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center spring Gulf of Maine Atlantic cod survey age 8 (WHSpr_8_8) and fall survey ages 1 (WHAut_1_1) through 5 (WHAut_6_6). **Note: fall surveys have been lagged forward a year and an age.*

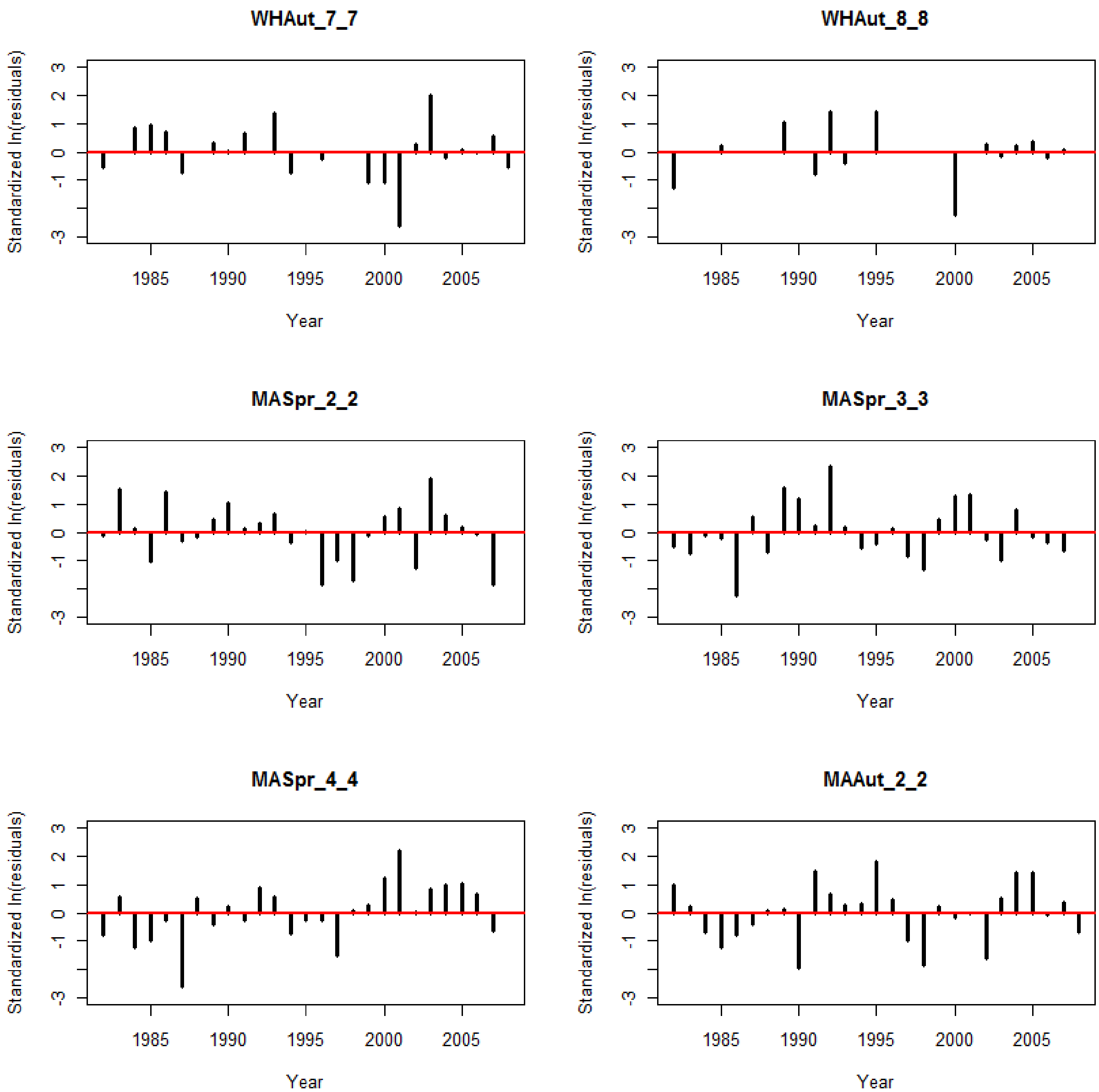


Figure A.84.c. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center fall Gulf of Maine Atlantic cod survey ages 6 (WHAut_7_7) through 7 (WHAut_8_8), Massachusetts Department of Marine Fisheries spring survey ages 2 (MASpr_2_2) through 4 (MASpr_4_4) and fall survey age 1 (MAAut_2_2). **Note: fall surveys have been lagged forward a year and an age.*

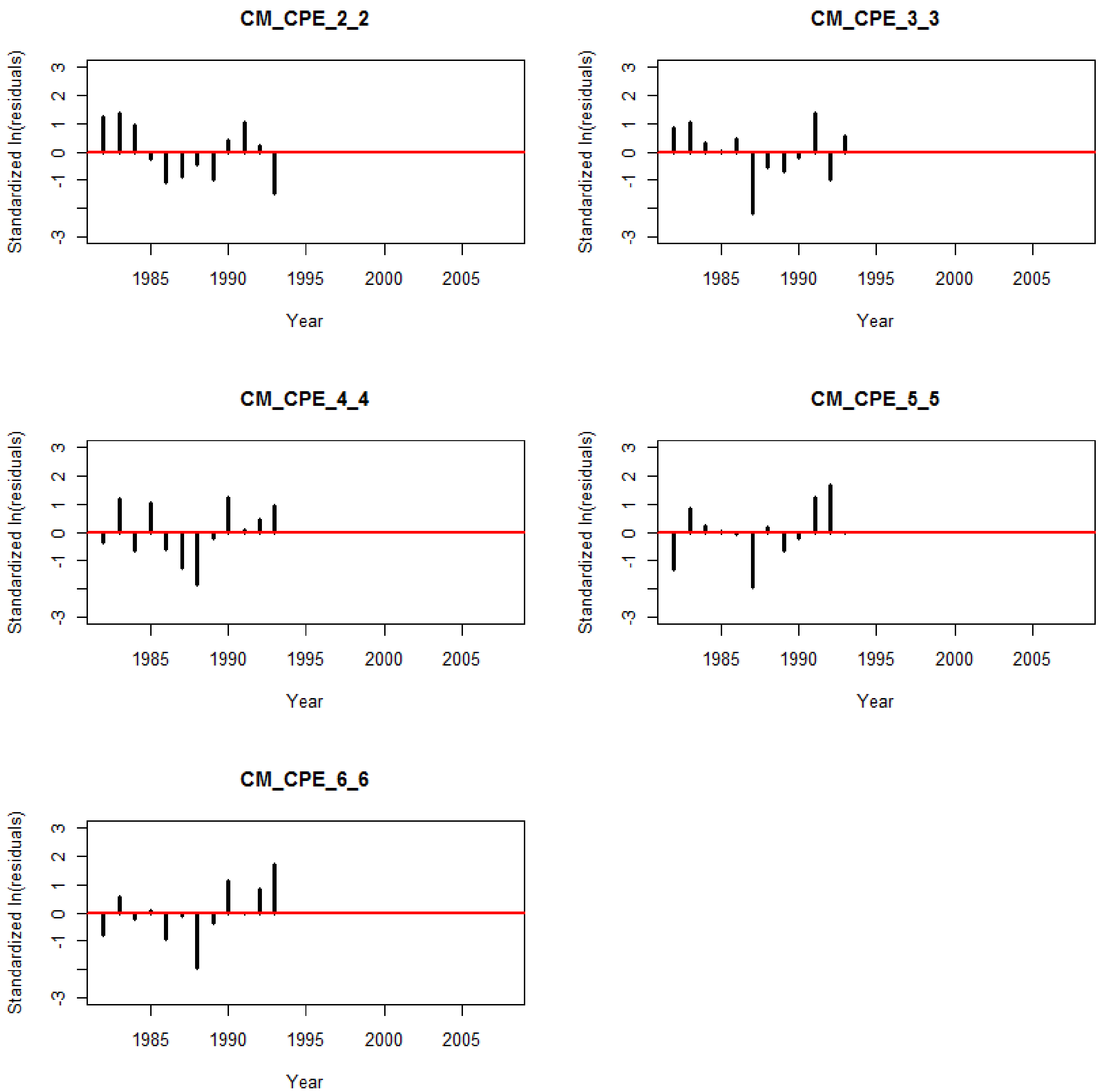


Figure A.84.d. ADAPT-VPA Model 2b residuals to the survey fits of the Gulf of Maine Atlantic cod commercial landings per unit effort tuning indices ages 2 (CM_CPE_2_2) through 6 (CM_CPE_6_6).

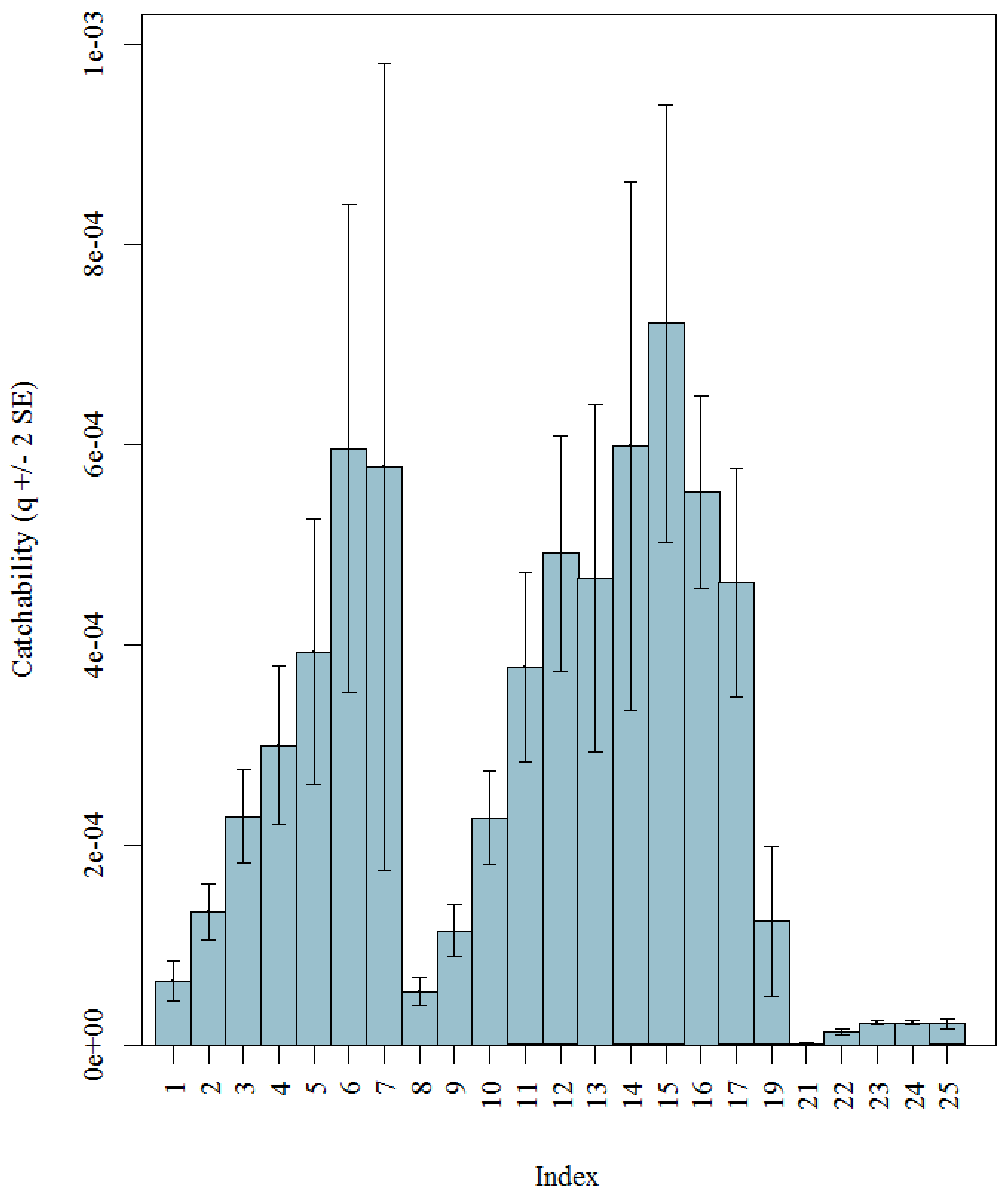


Figure A.85. ADAPT-VPA Model 2b patterns in survey catchability (q). Indices 1-7=NEFSC spring (ages 2-8), indices 8-14=NEFSC fall (ages 1-7), indices 15-17=MADMF spring (ages 2-4), index 19=MADMF fall (age 1), indices 21-25=commercial LPUE (ages 2-6).

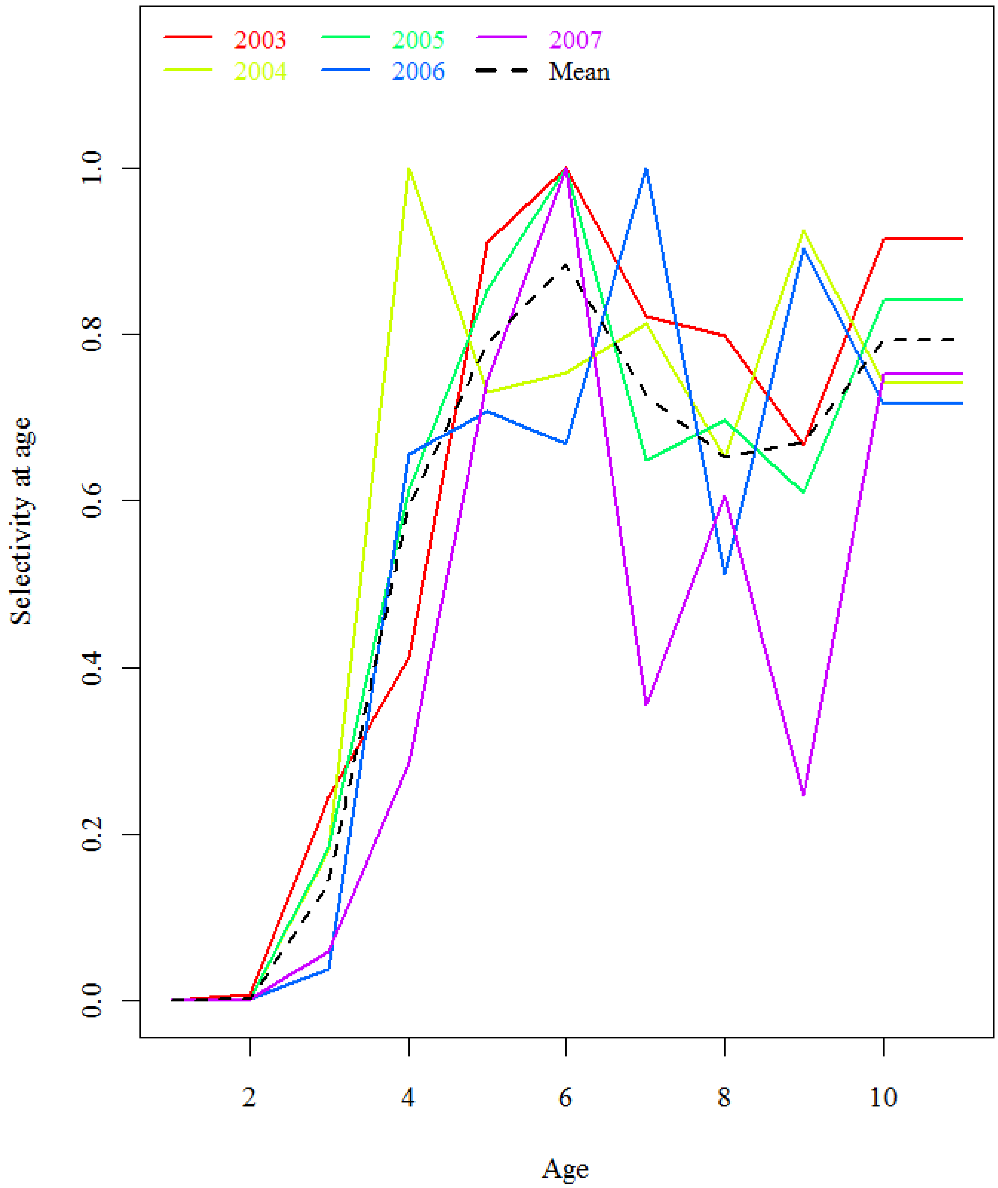
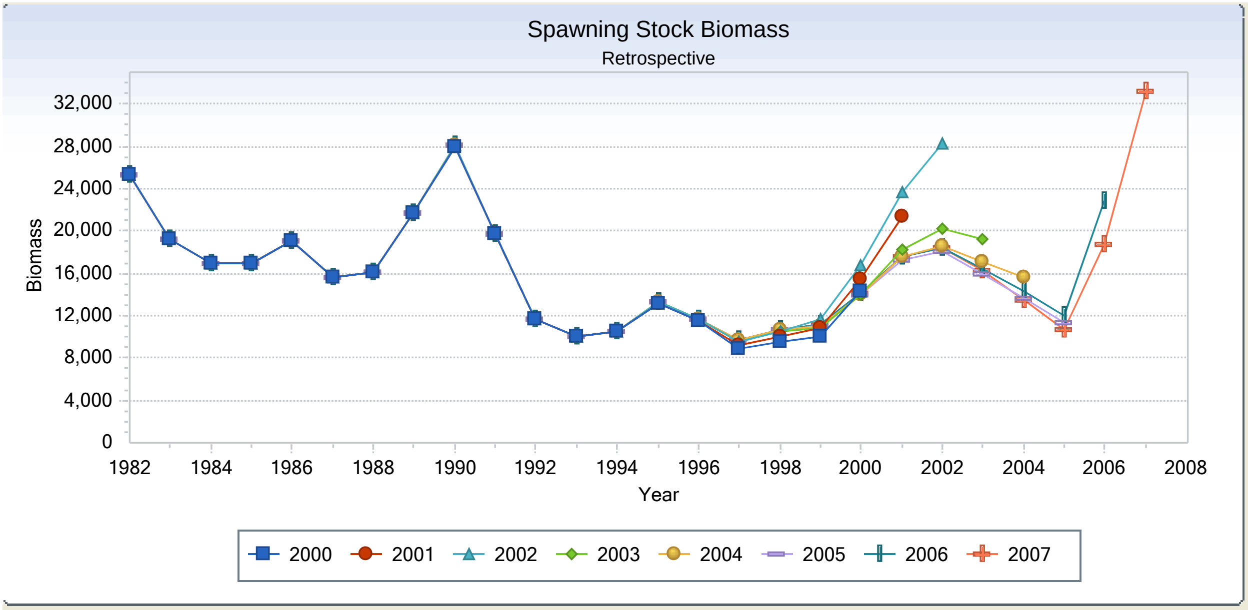


Figure A.86. ADAPT-VPA Model 2b catch selectivity patterns for Gulf of Maine Atlantic cod over the last five years of the model, 2003 through 2007.



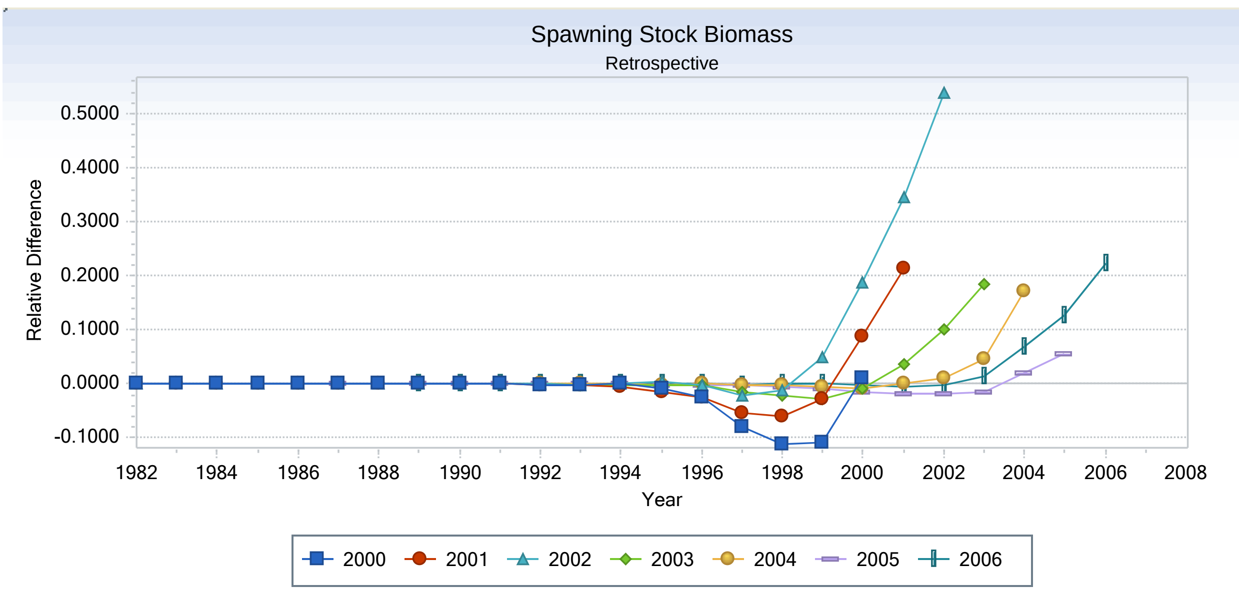
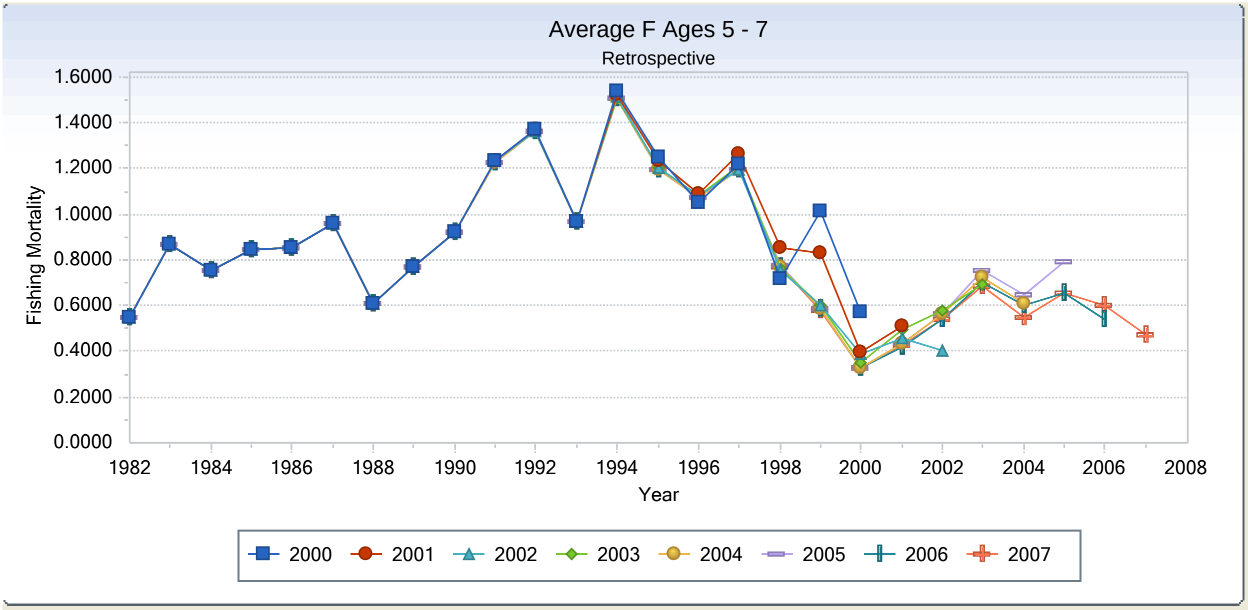


Figure A.87. ADAPT-VPA Model 2b retrospective patterns in Gulf of Maine Atlantic cod spawning stock biomass (mt) in absolute (top) and relative (bottom) terms.



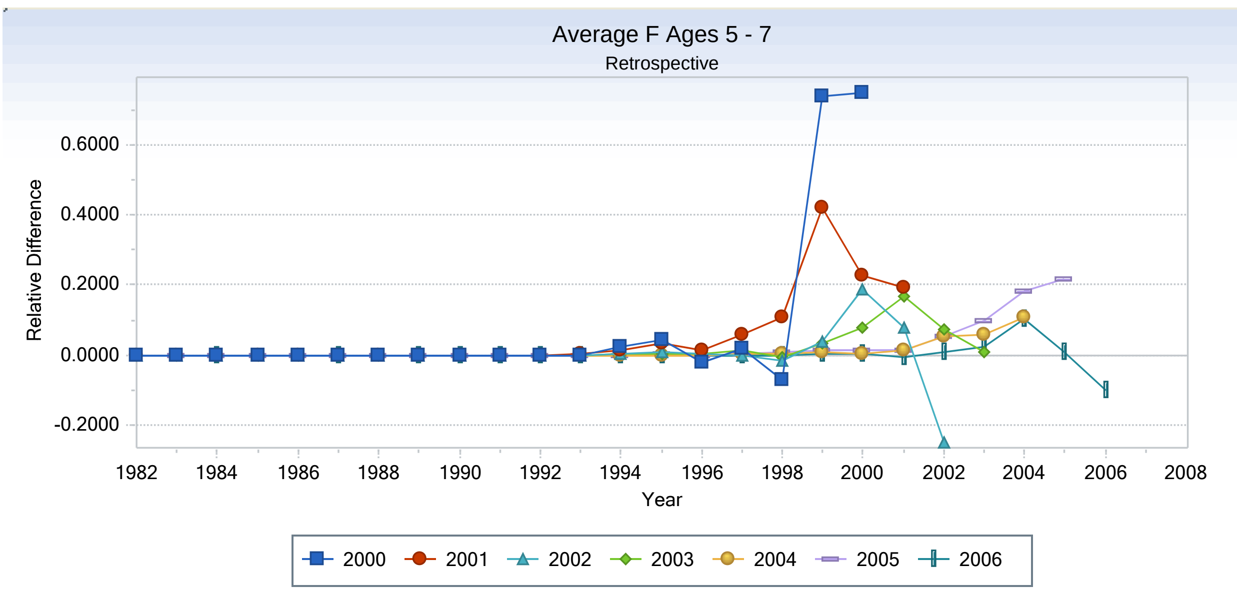
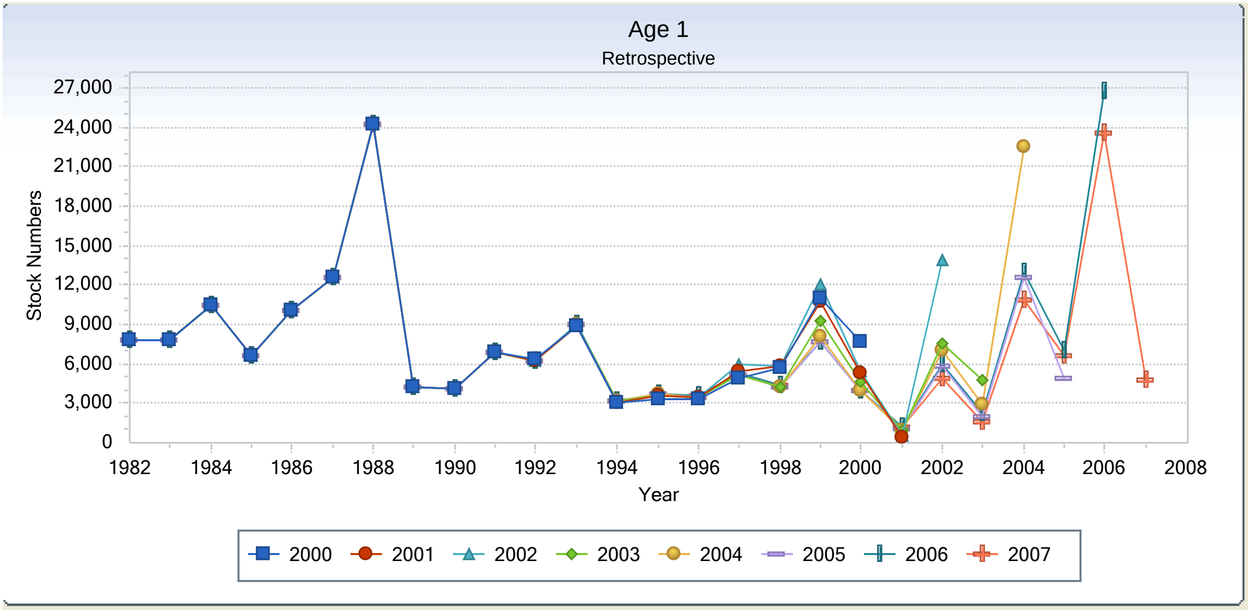


Figure A.88. ADAPT-VPA Model 2b retrospective patterns in Gulf of Maine Atlantic cod fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.



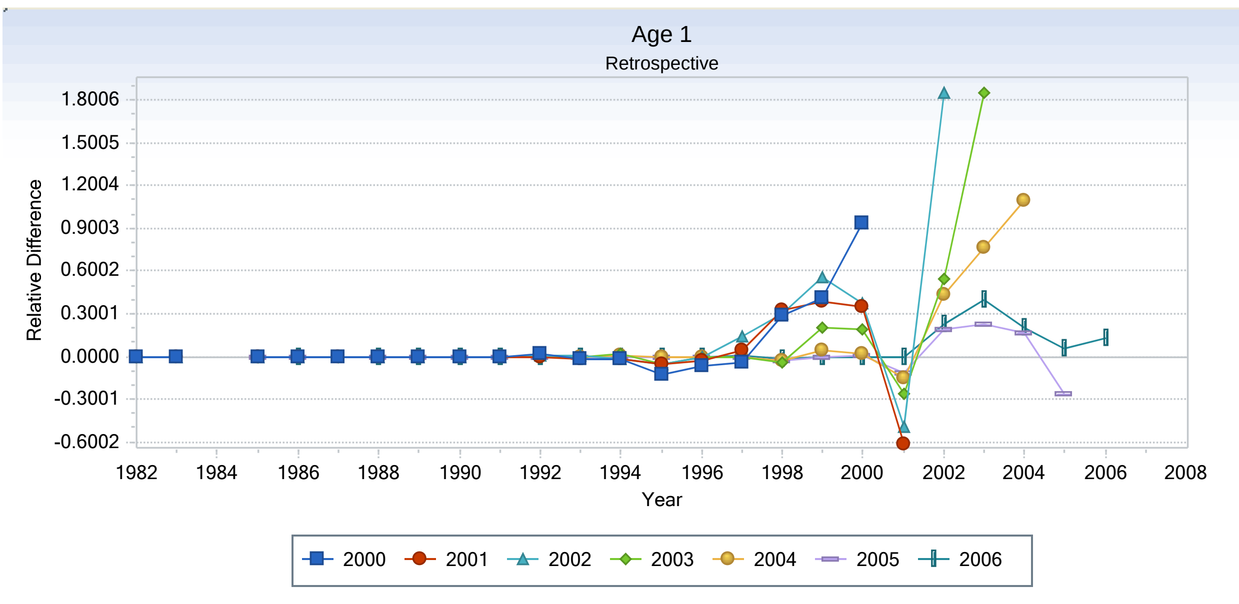


Figure A.89. ADAPT-VPA Model 2b retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.

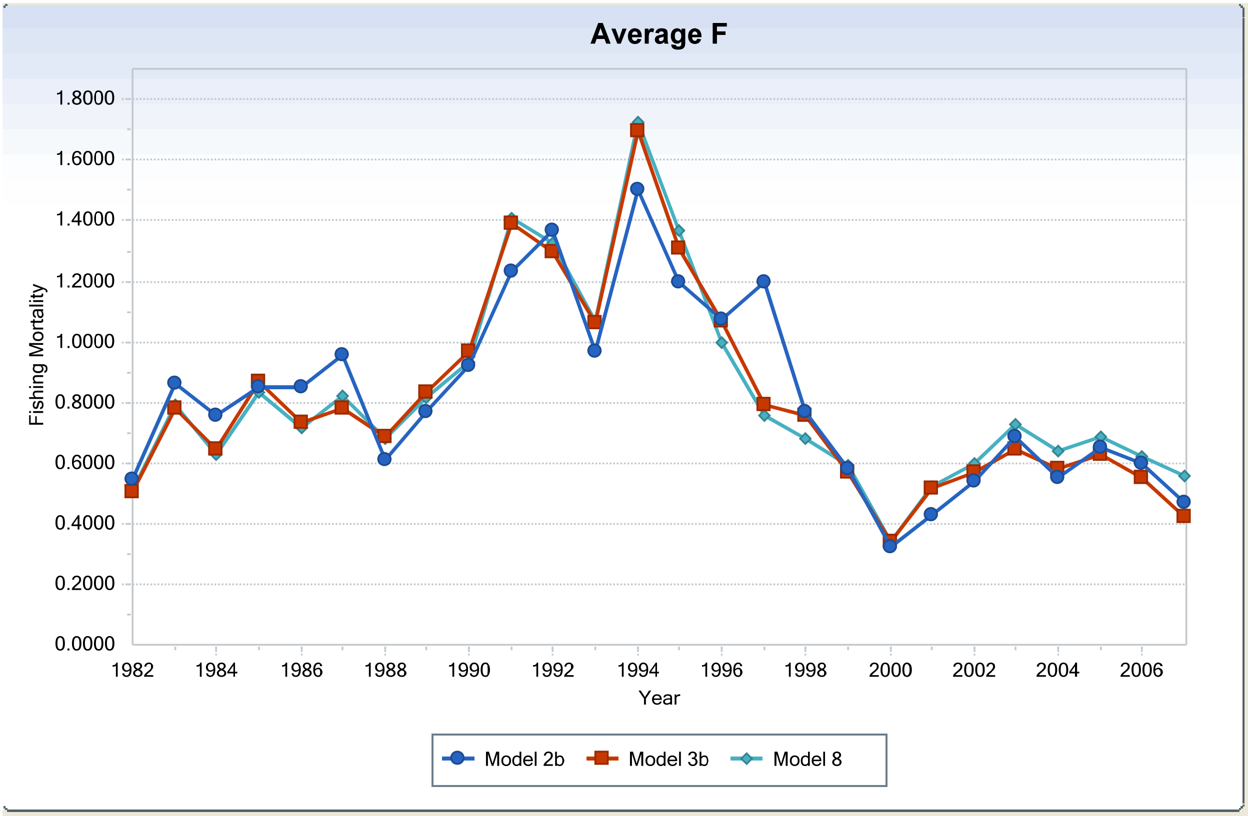


Figure A.90. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 2b, 3b and 8.

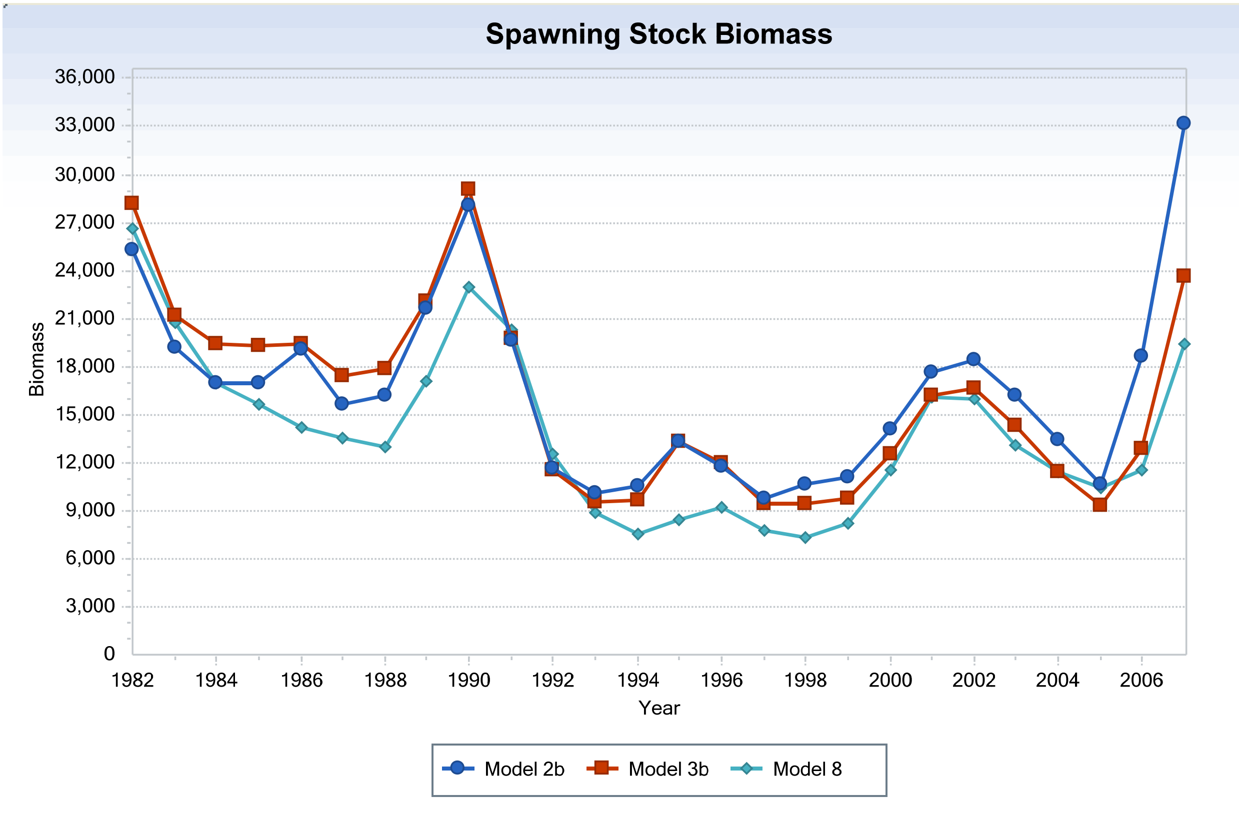


Figure A.91. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 2b, 3b and 8.

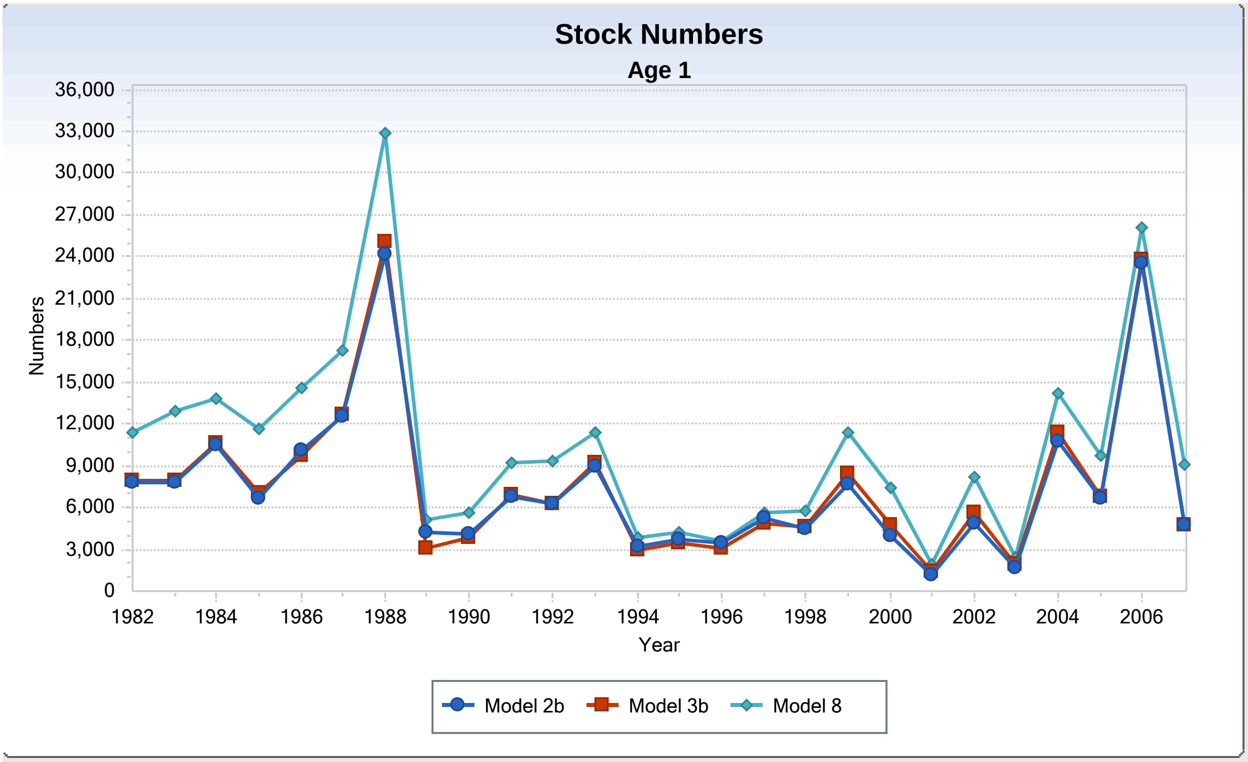


Figure A.92. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 2b, 3b and 8.

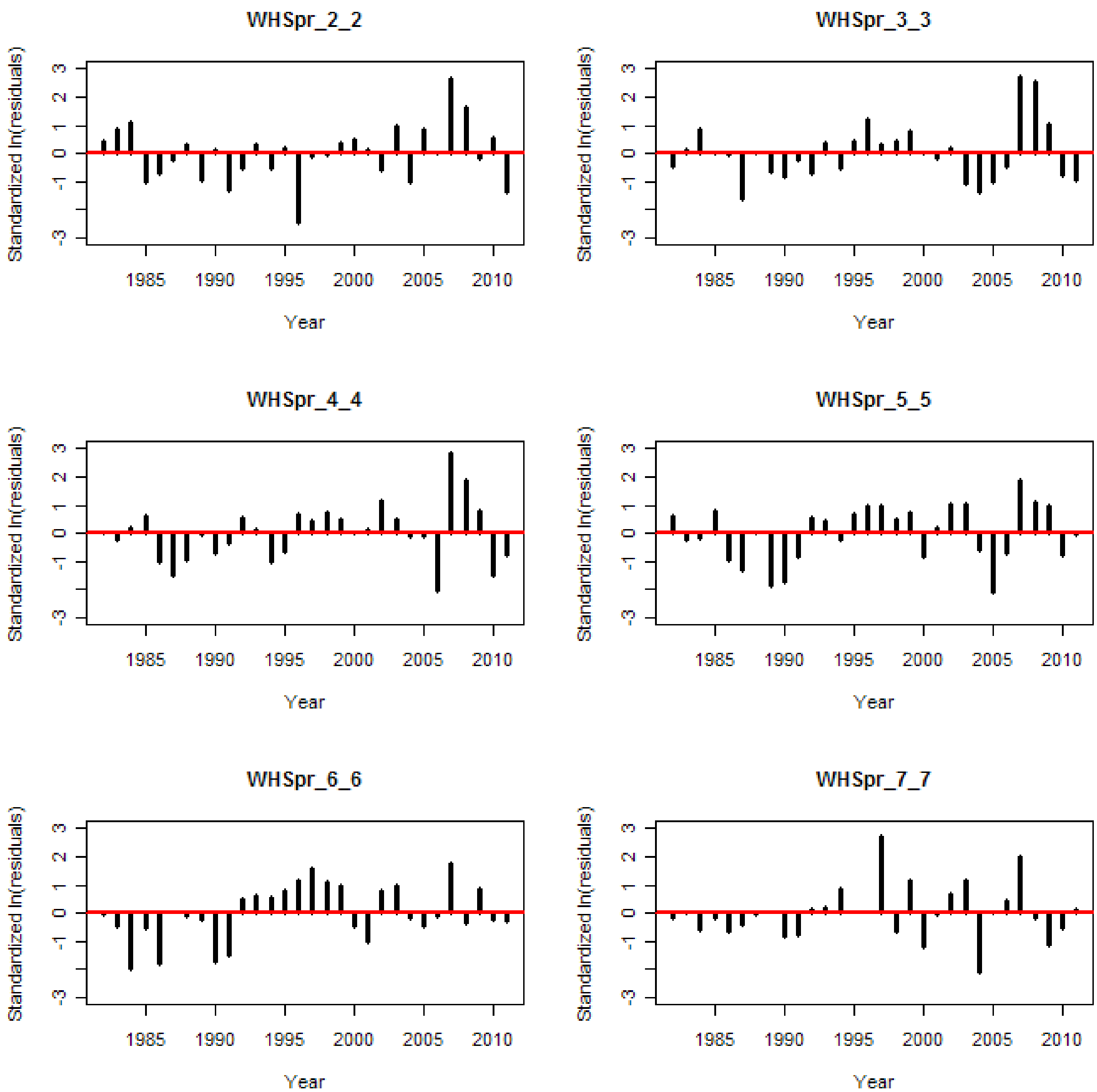


Figure A.93.a. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center spring survey Gulf of Maine Atlantic cod ages 2 (WHSpr_2_2) through 7 (WHSpr_7_7). **Note: fall surveys have been lagged forward a year and an age.*

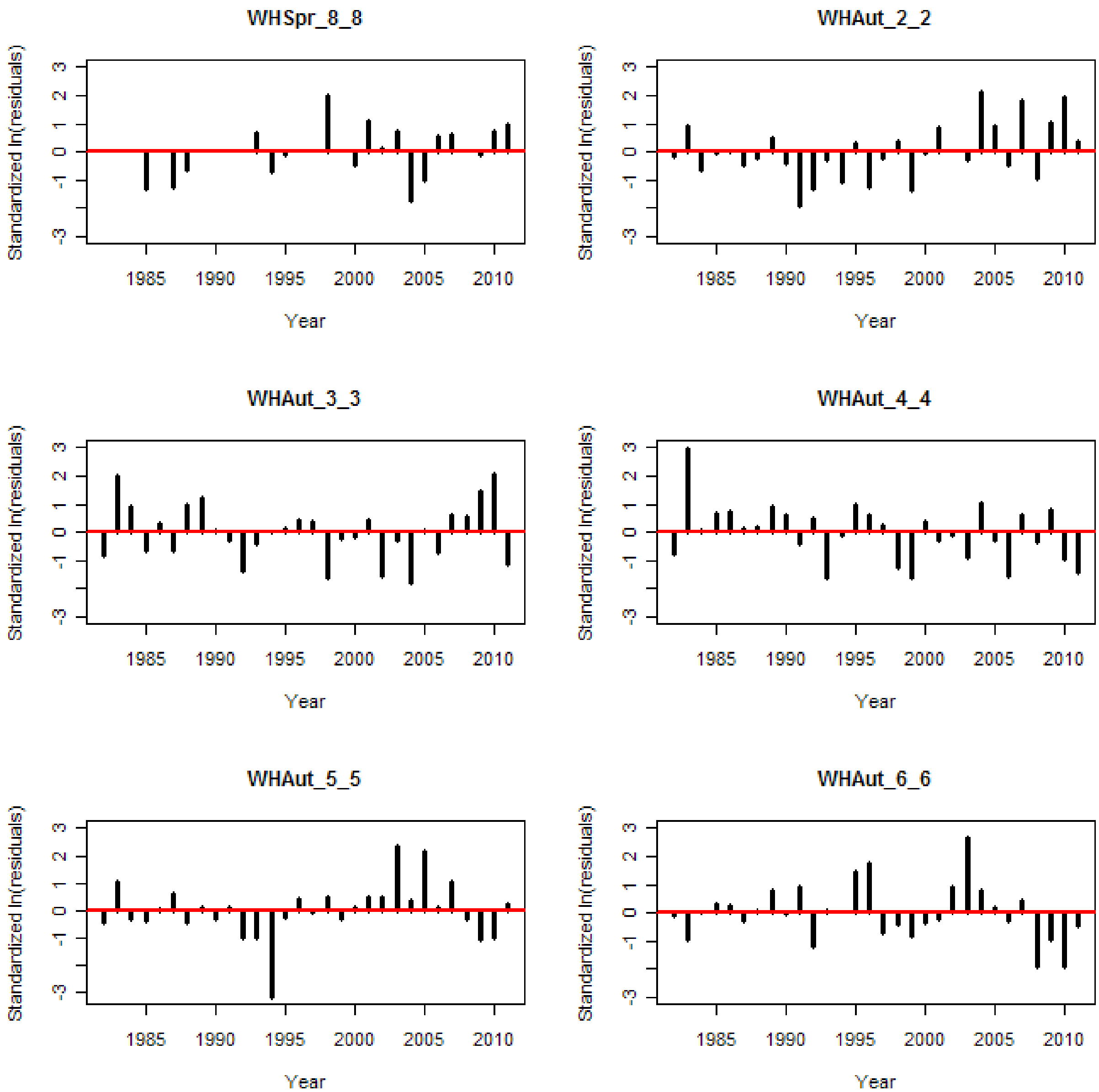


Figure A.93.b. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center spring survey Gulf of Maine Atlantic cod age 8 (WHSpr_8_8) and fall survey ages 1 (WHAut_1_1) through 5 (WHAut_6_6). **Note: fall surveys have been lagged forward a year and an age.*

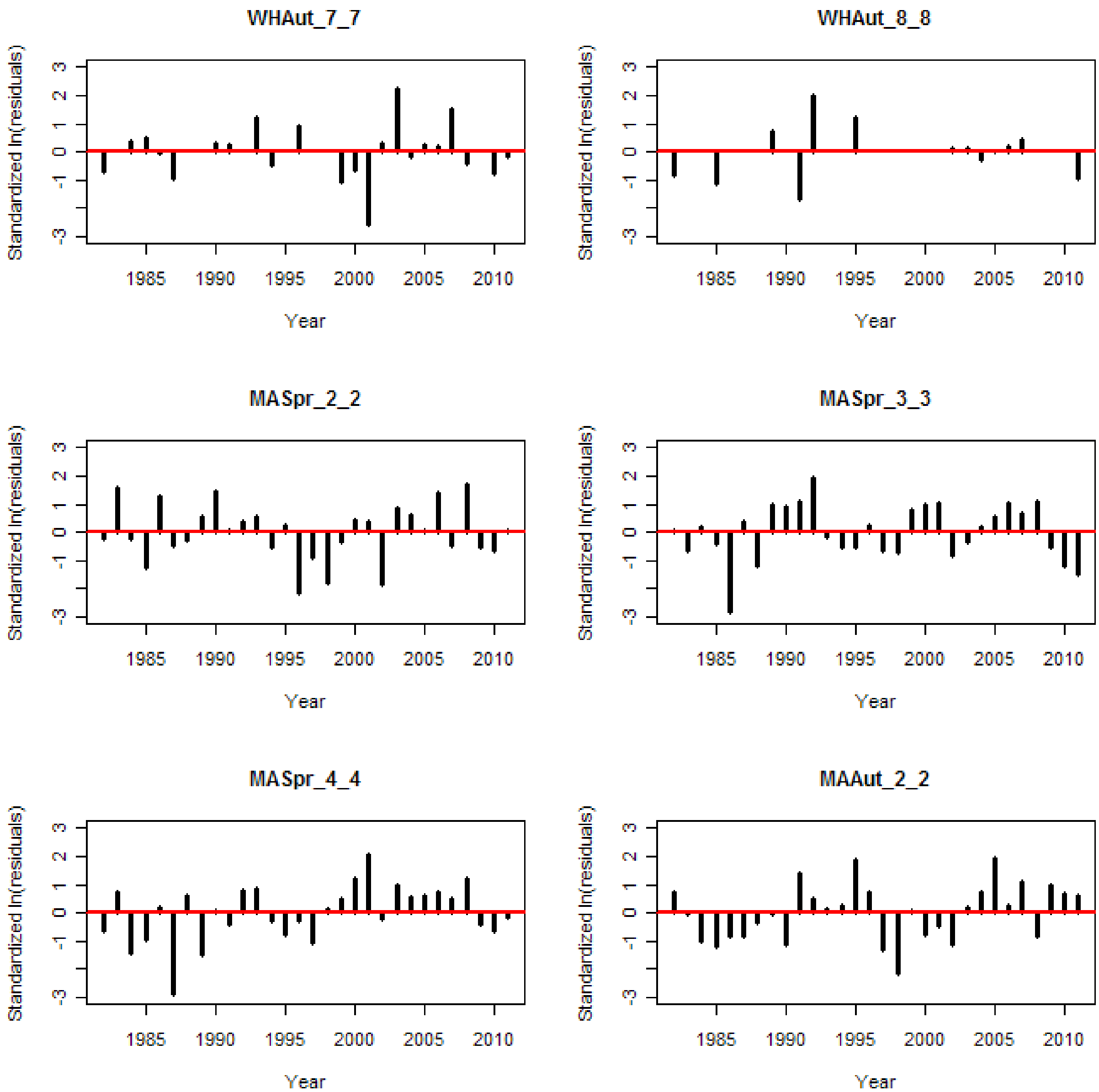


Figure A.93.c. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center fall survey ages 6 (WHAut_7_7) through 7 (WHAut_8_8), Massachusetts Department of Marine Fisheries spring survey Gulf of Maine Atlantic cod ages 2 (MASpr_2_2) through 4 (MASpr_4_4) and fall survey age 1 (MAAut_2_2). **Note: fall surveys have been lagged forward a year and an age.*

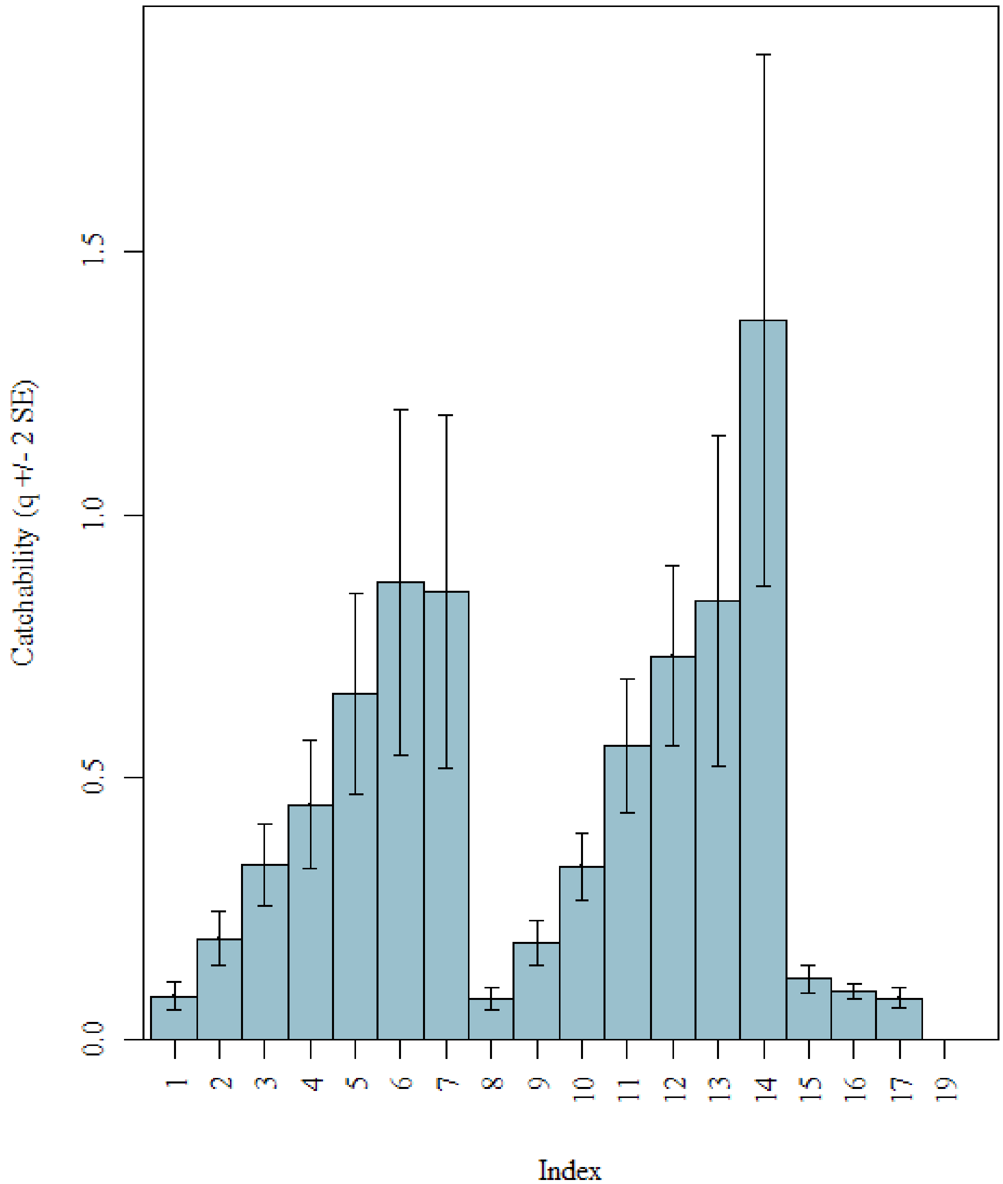


Figure A.94. ADAPT-VPA Model 10 patterns in survey catchability (q). Indices 1-7=NEFSC spring (ages 2-8), indices 8-14=NEFSC fall (ages 1-7), indices 15-17=MADMF spring (ages 2-4), index 19=MADMF fall (age 1). **Note: survey catchability is shown in terms of area swept biomass.*

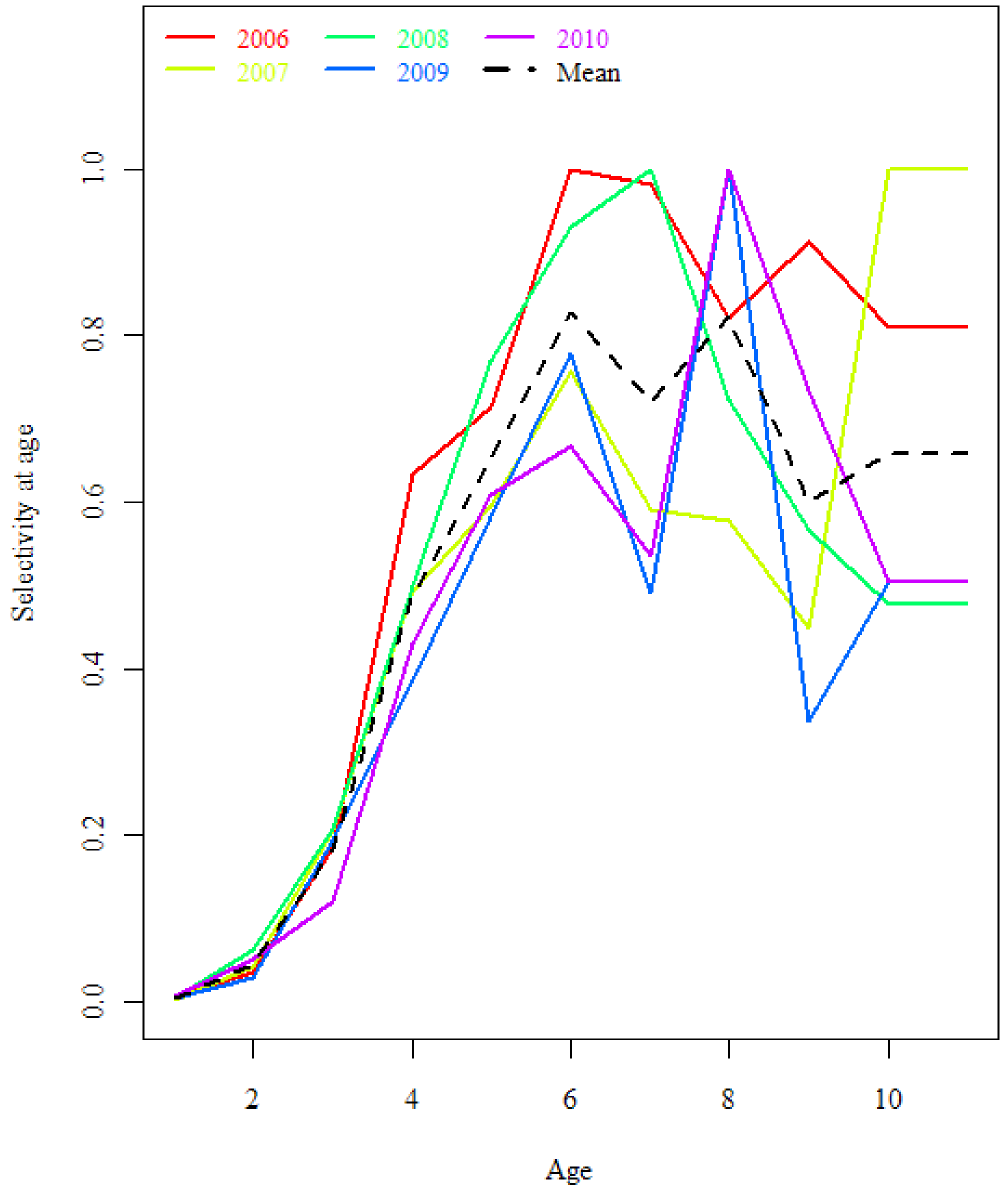
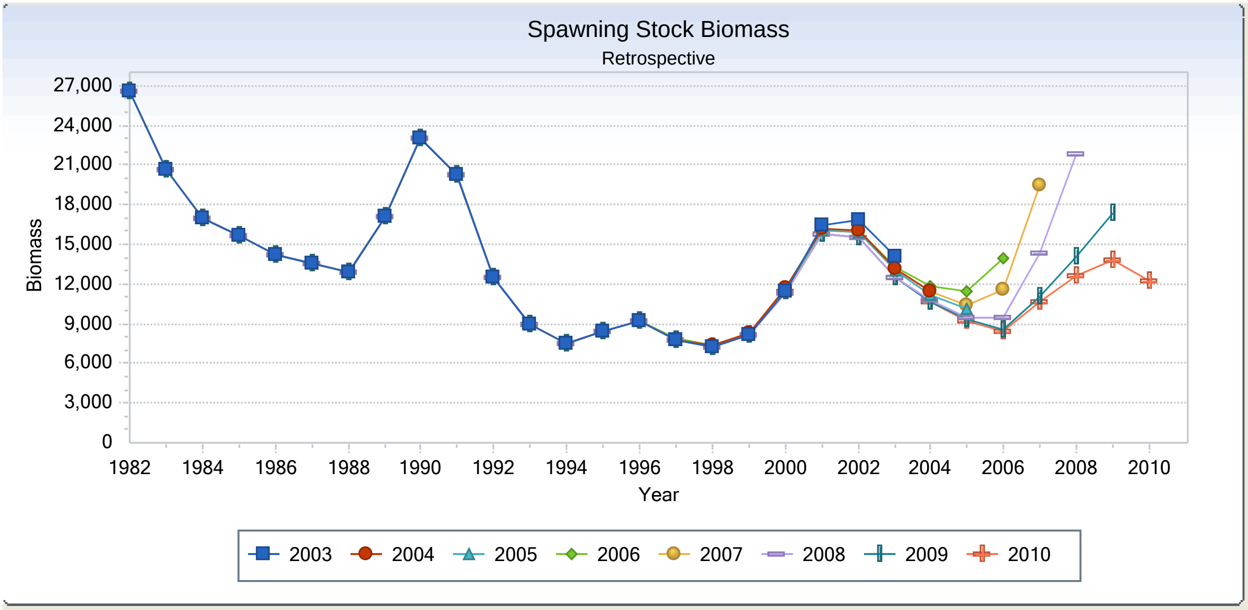


Figure A.95. ADAPT-VPA Model 10 catch selectivity patterns for Gulf of Maine Atlantic cod over the last five years of the model, 2006 through 2010.



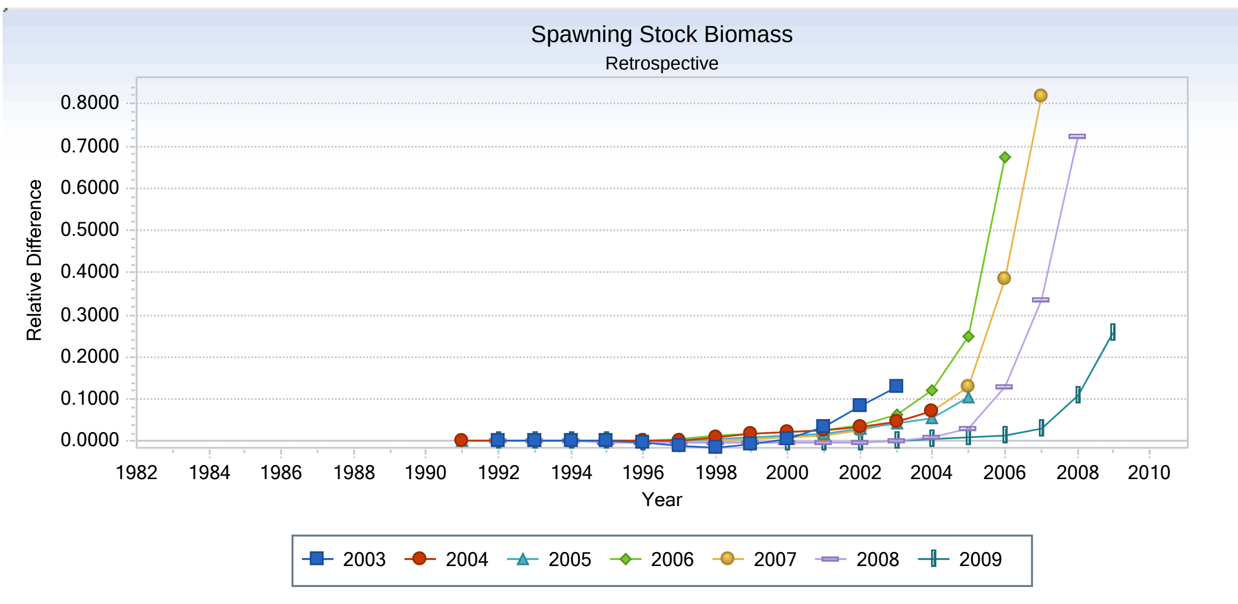
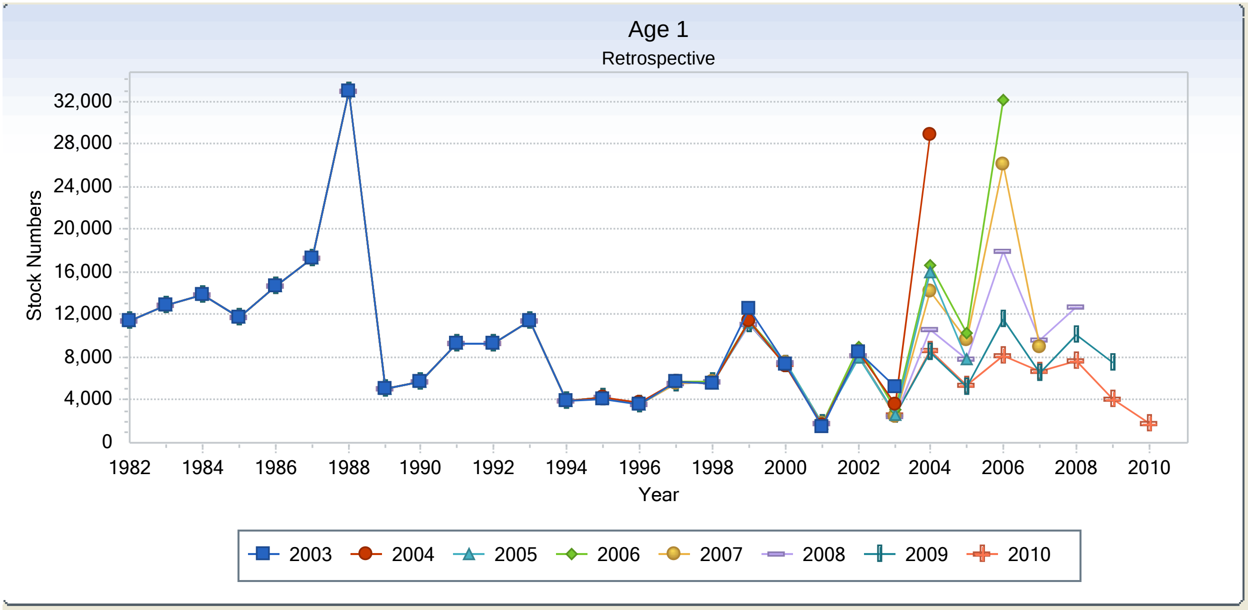


Figure A.96. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod spawning stock biomass (mt) in absolute (top) and relative (bottom) terms.



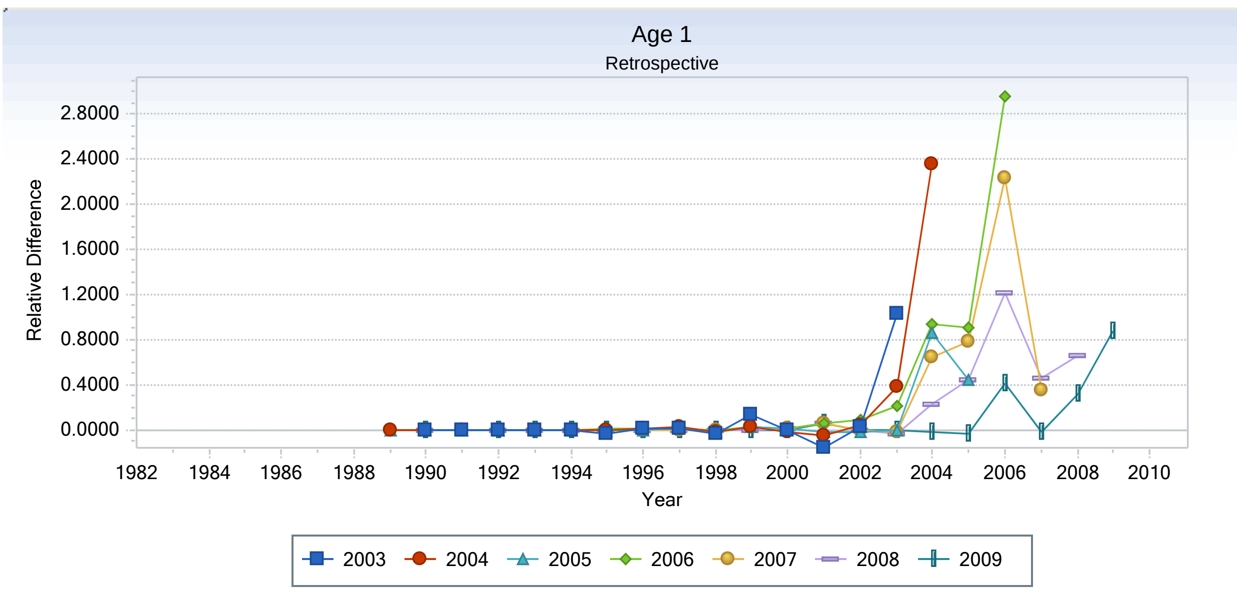
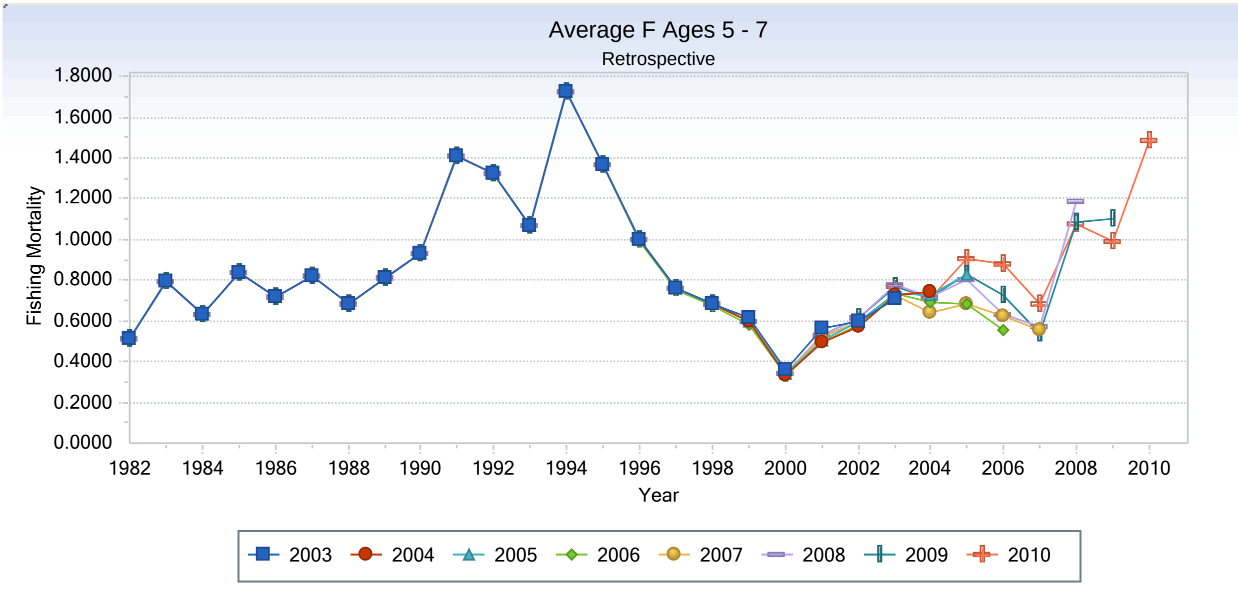


Figure A.97. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.



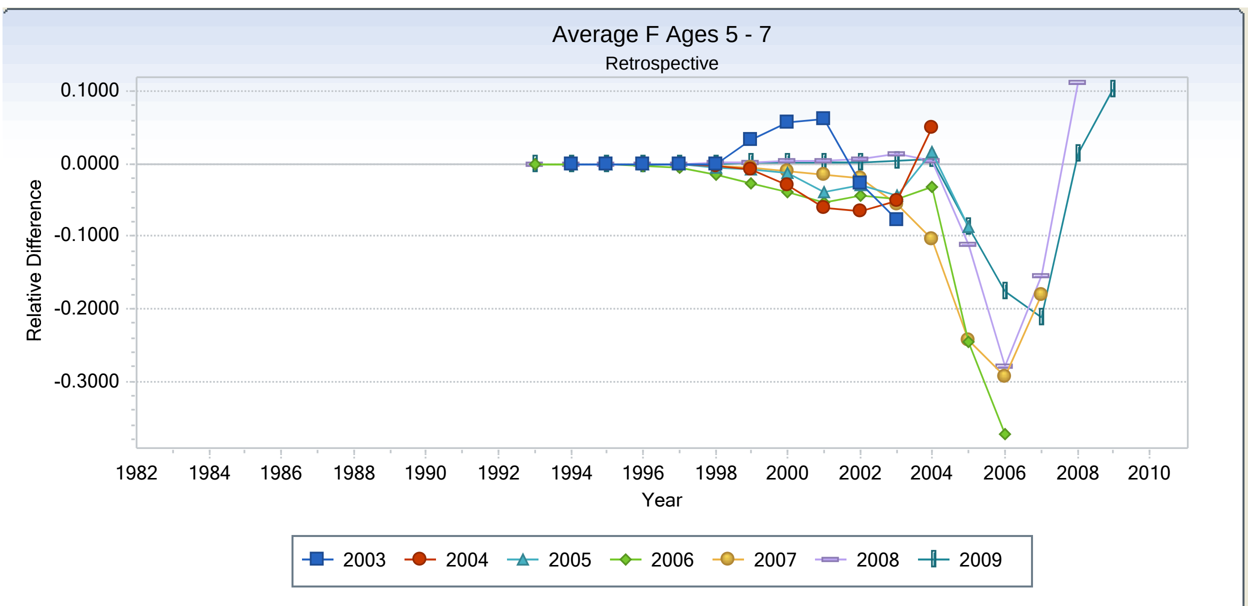


Figure A.98. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.

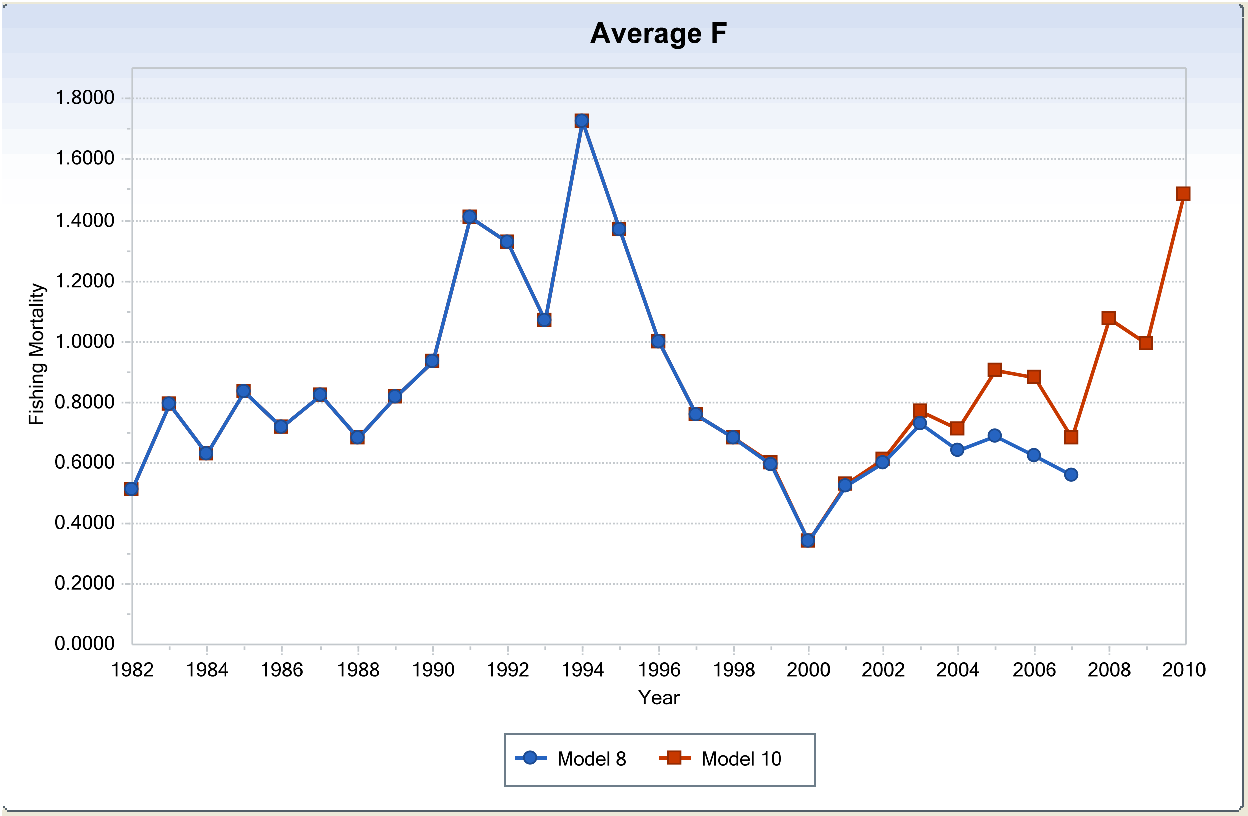


Figure A.99. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 8 and 10.

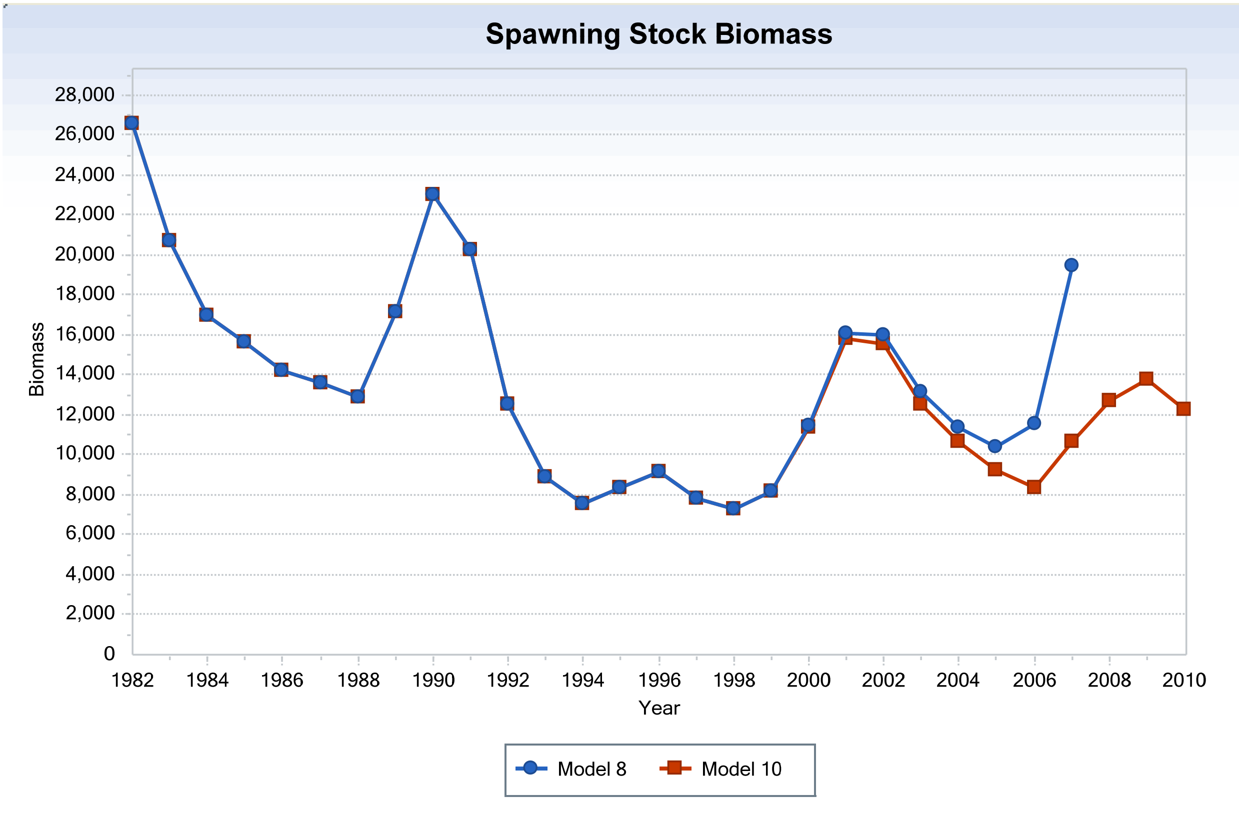


Figure A.100. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 8 and 10.

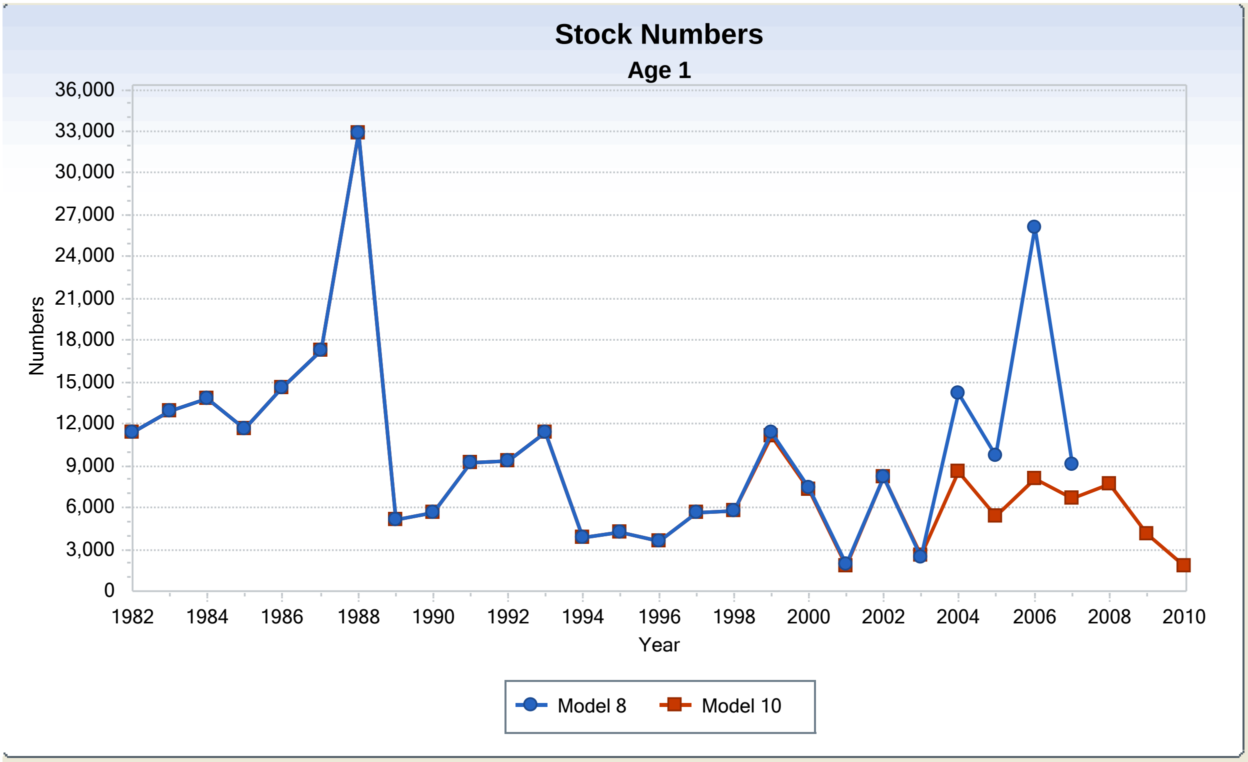


Figure A.101. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 8 and 10.

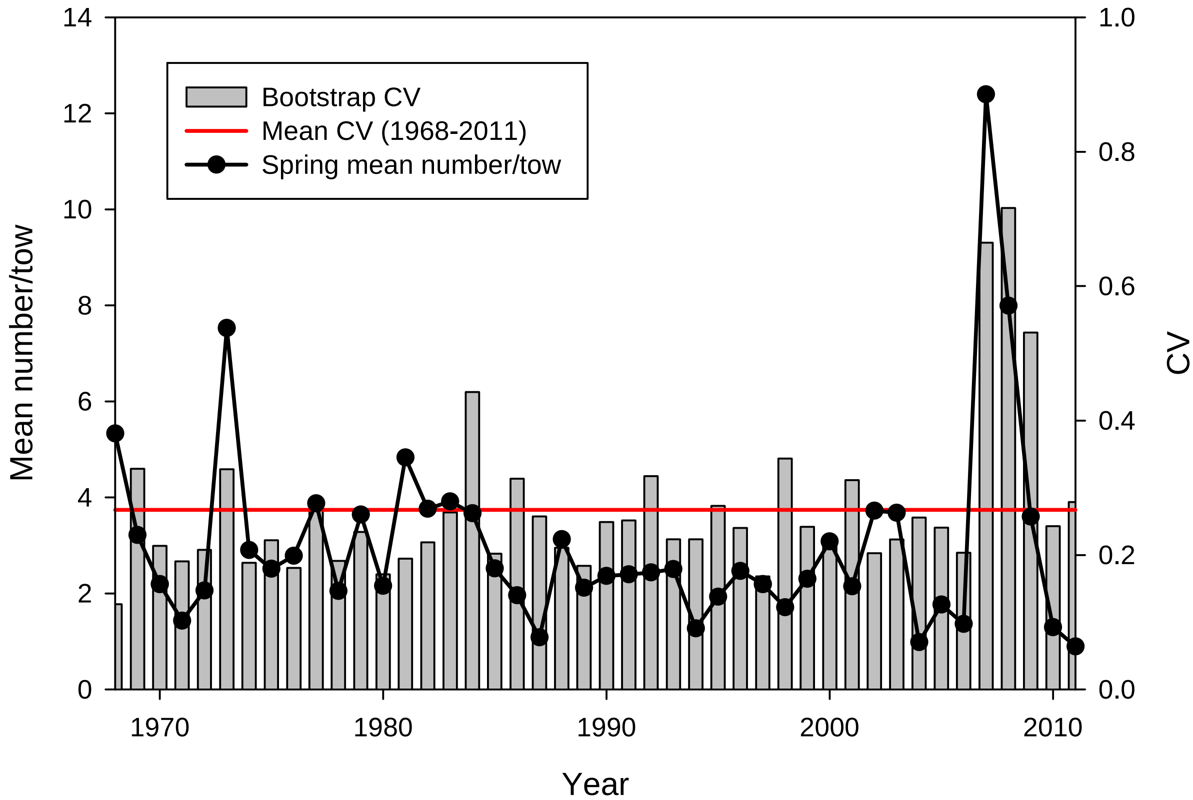


Figure A.102. Northeast Fisheries Science Center spring bottom trawl survey index of Gulf of Maine Atlantic cod abundance (mean number/tow) and the corresponding coefficient of variation (CV) from 1968 to 2011. The solid red line represents the time series average CV.

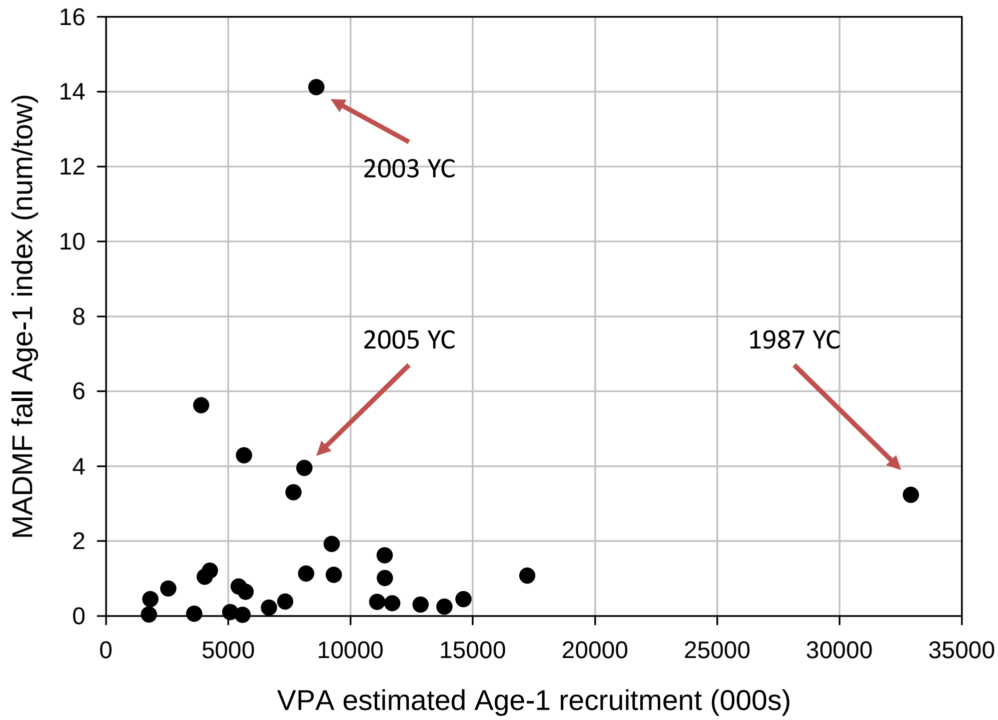


Figure A.103. Comparison of the Massachusetts Department of Marine Fisheries Gulf of Maine Atlantic cod age 1 survey index to the VPA Model run 10 estimated age 1 numbers. The three largest year classes estimated by the previous stock assessment (GARM III) are labeled.

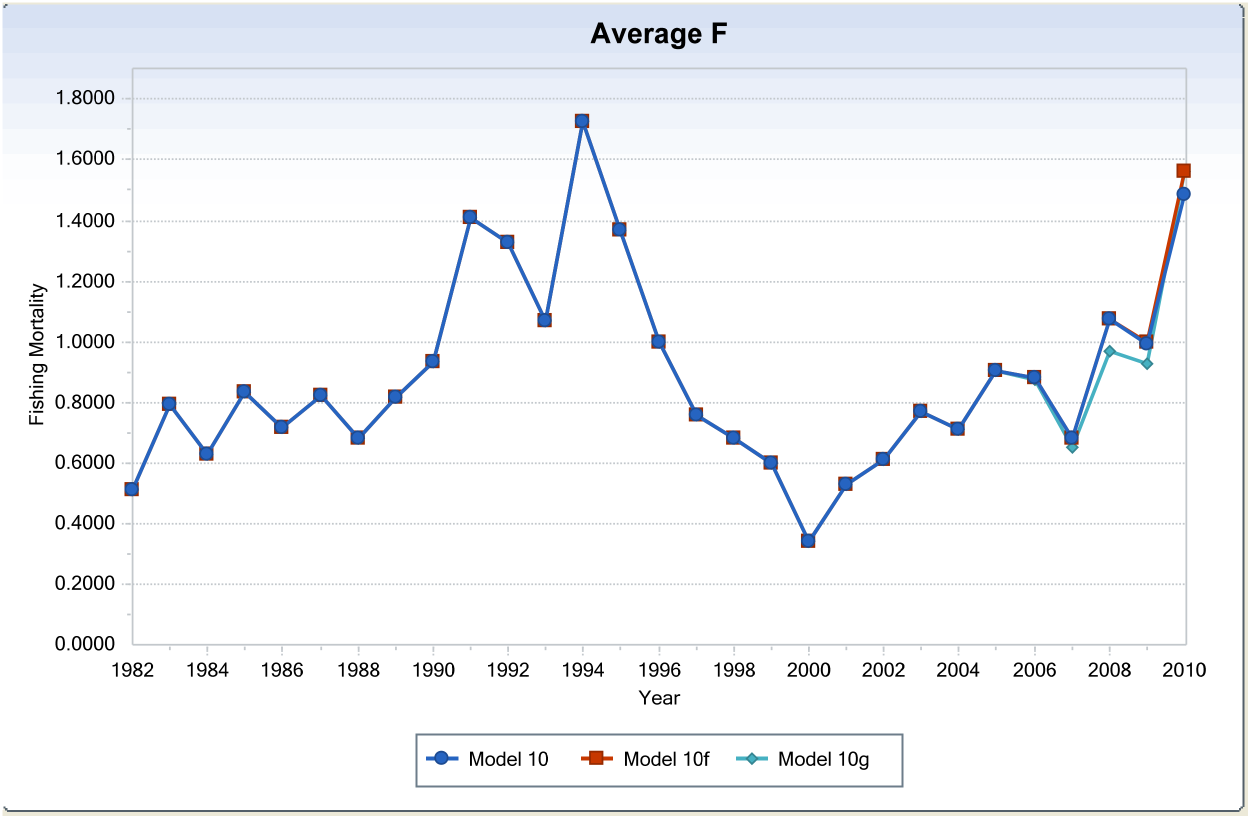


Figure A.104. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 10, 10f and 10g.

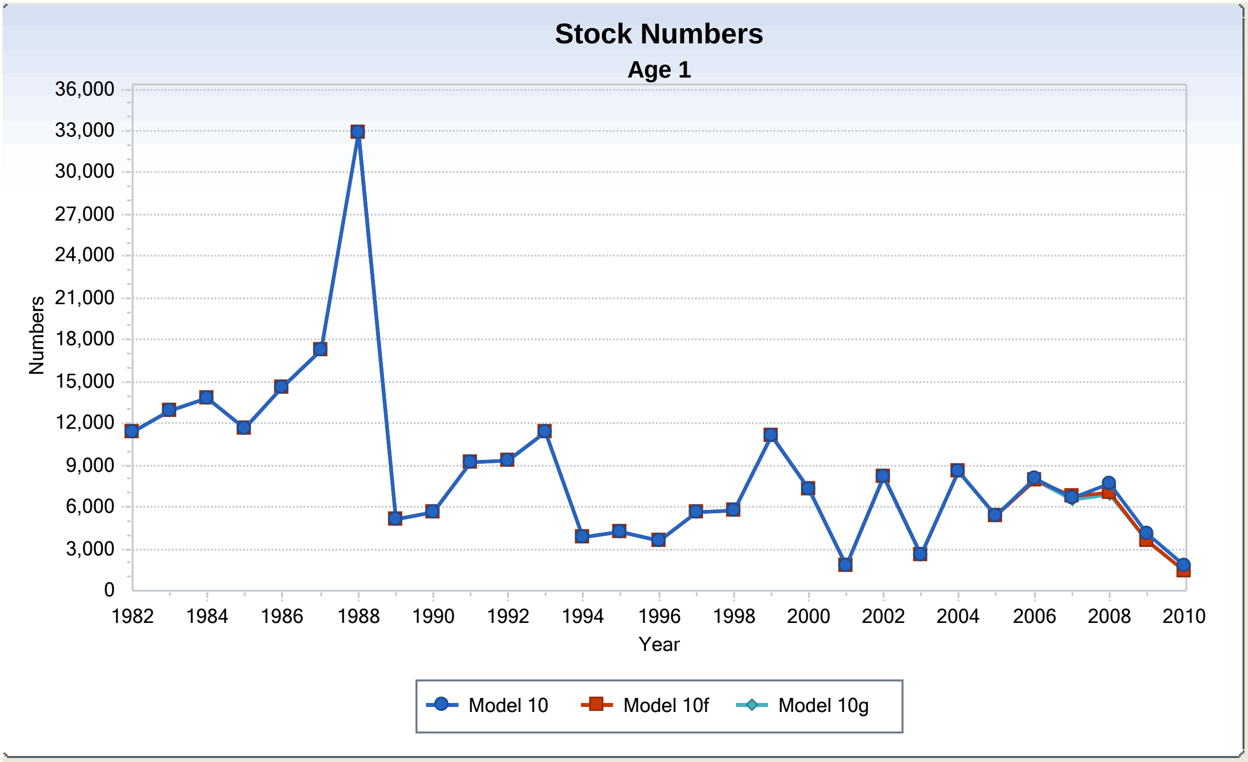


Figure A.105. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 10, 10f and 10g.

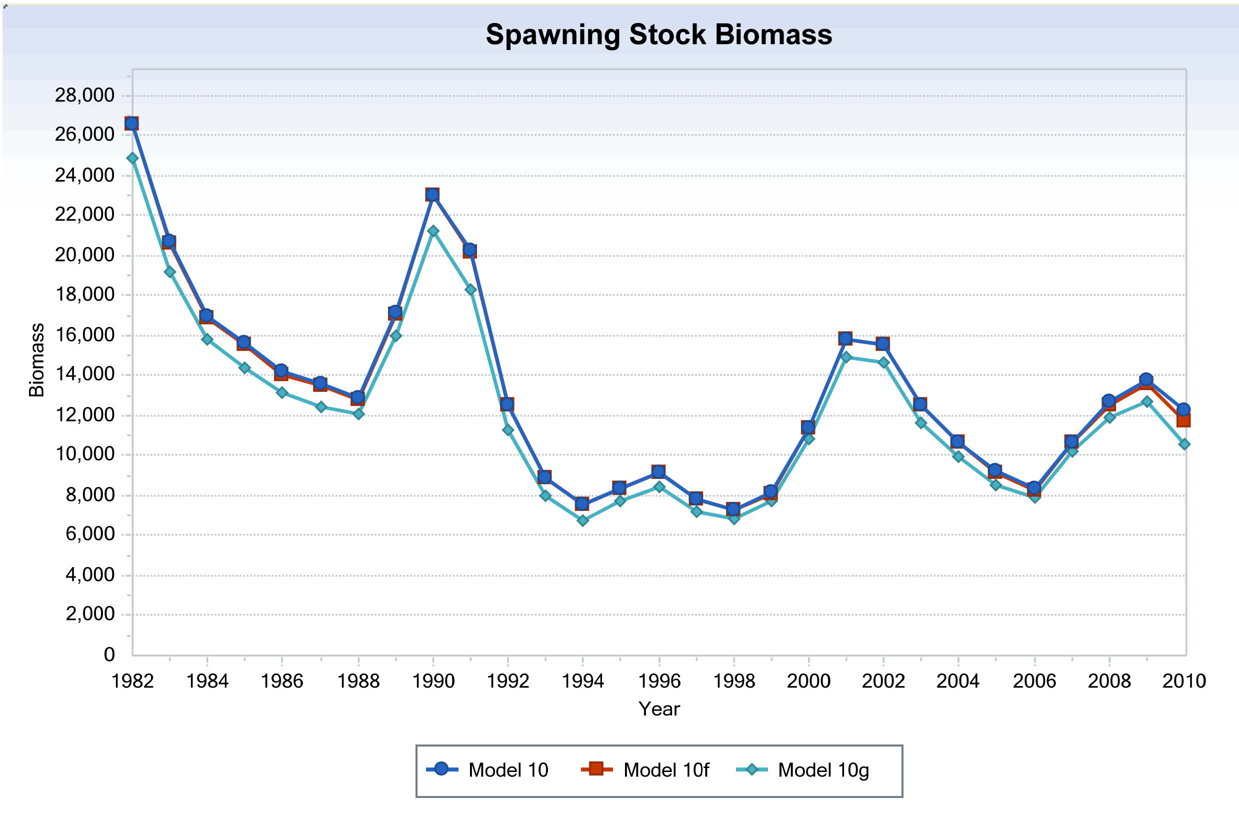
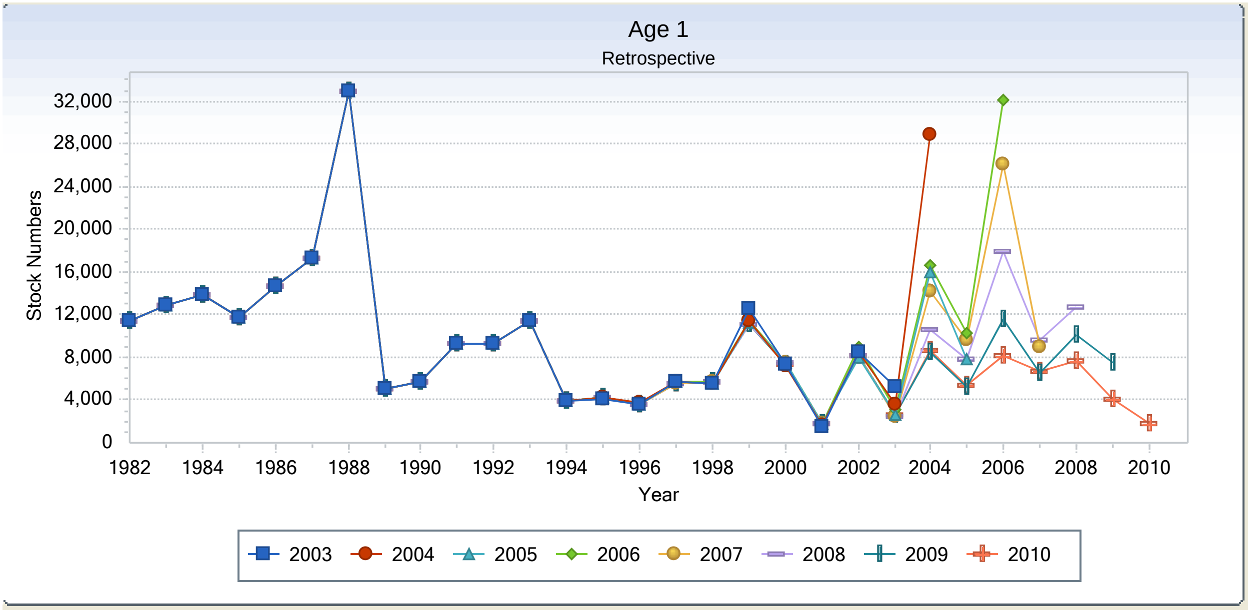


Figure A.106. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 10, 10f and 10g.



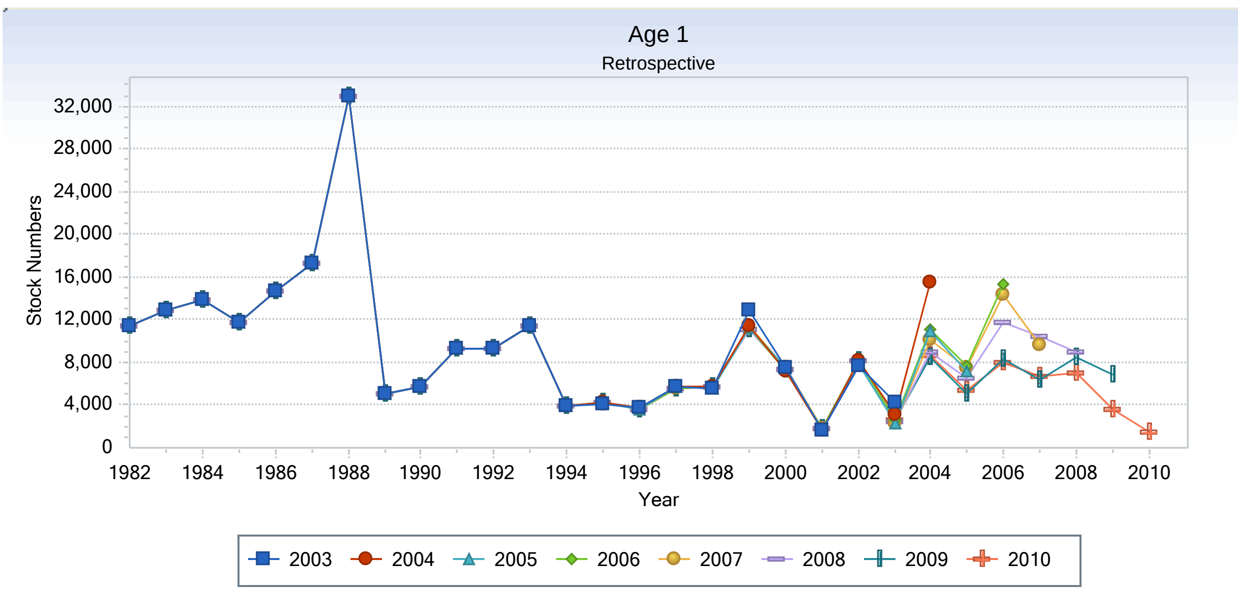
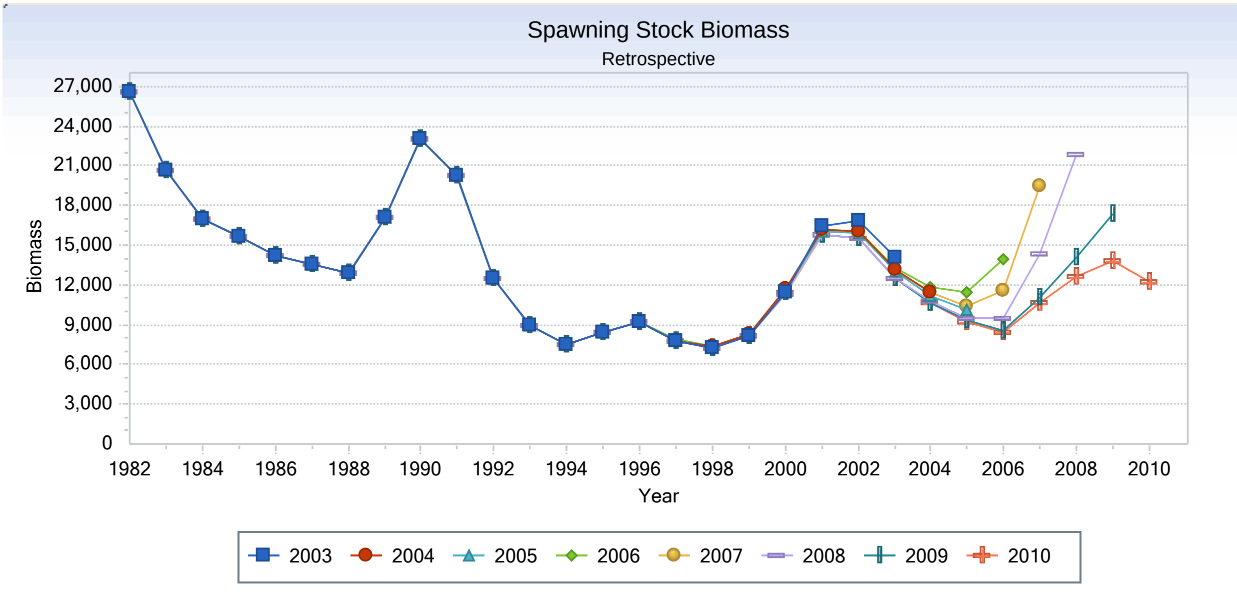


Figure A.107. Comparison of the retrospective patterns (absolute) of Gulf of Maine Atlantic cod age 1 recruitment between Model run 10 (top) and 10f (bottom).



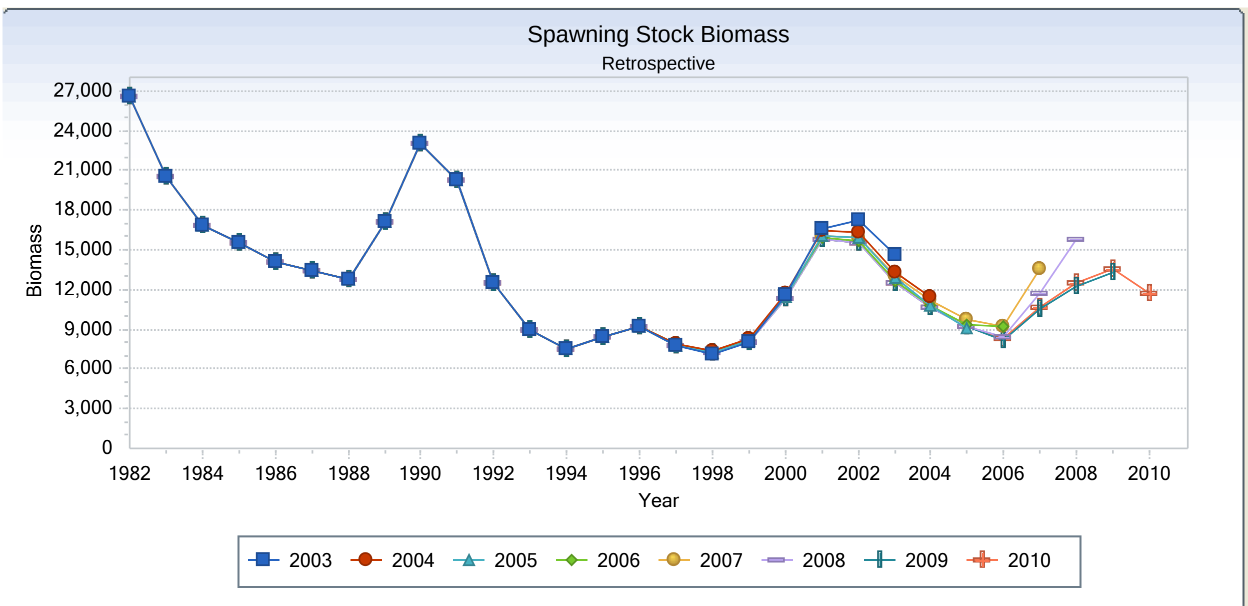


Figure A.108. Comparison of the retrospective patterns (absolute) of Gulf of Maine Atlantic cod spawning stock biomass between Model run 10 (top) and 10f (bottom).

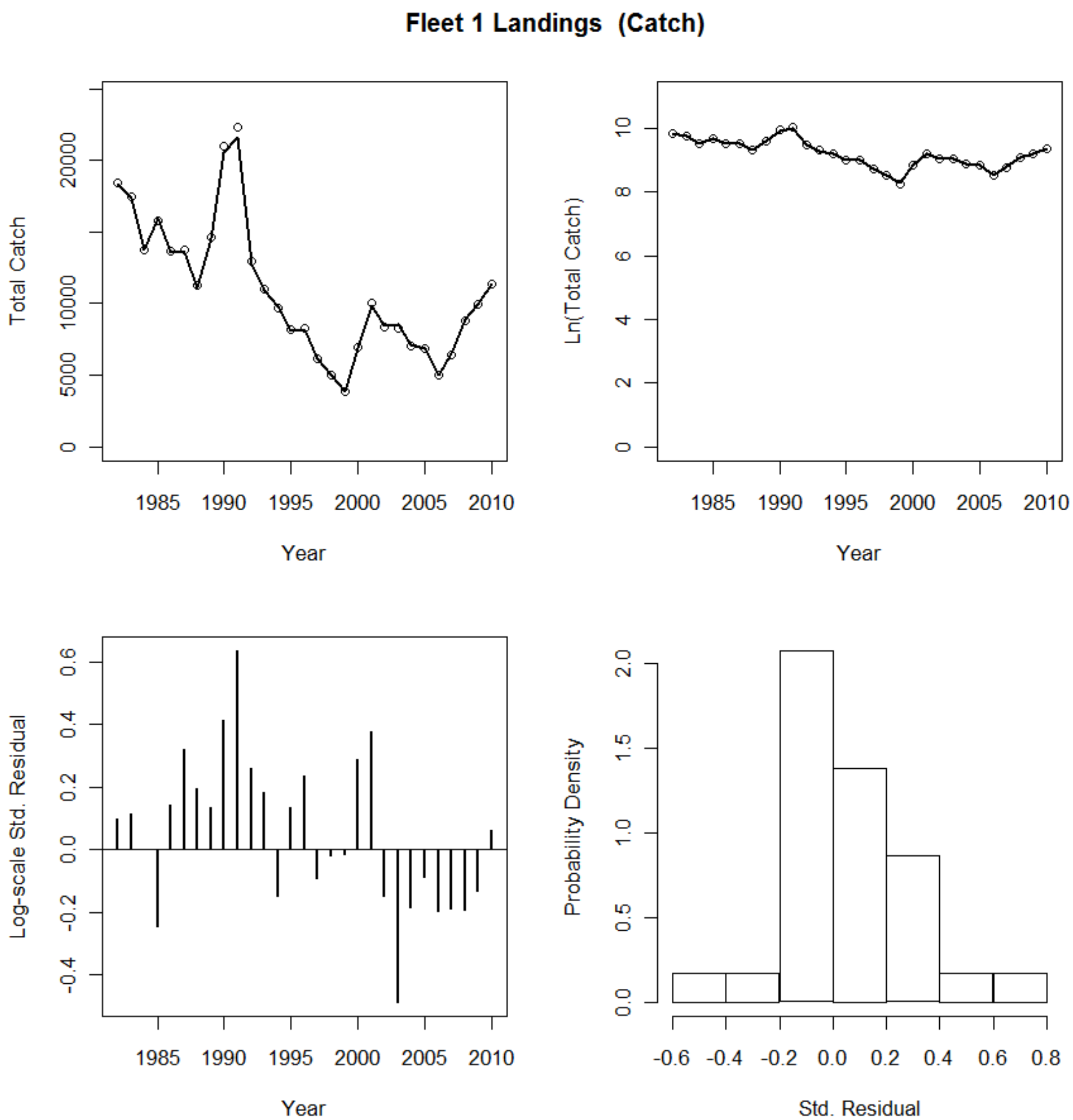


Figure A.109. ASAP BASE model fit to the total Gulf of Maine Atlantic cod fishery catch (Fleet 1).

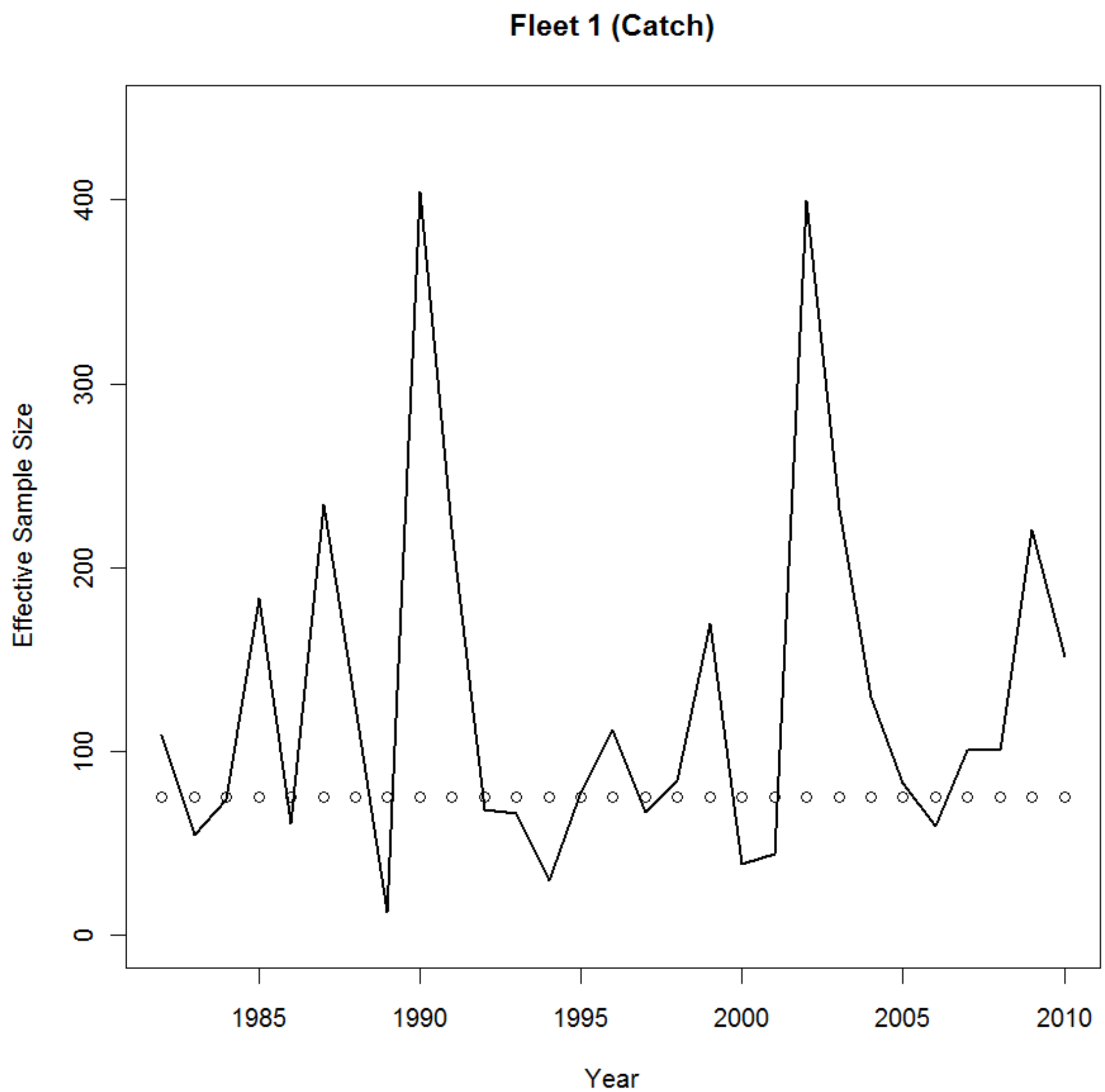


Figure A.110. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the Gulf of Maine Atlantic cod fishery catch.

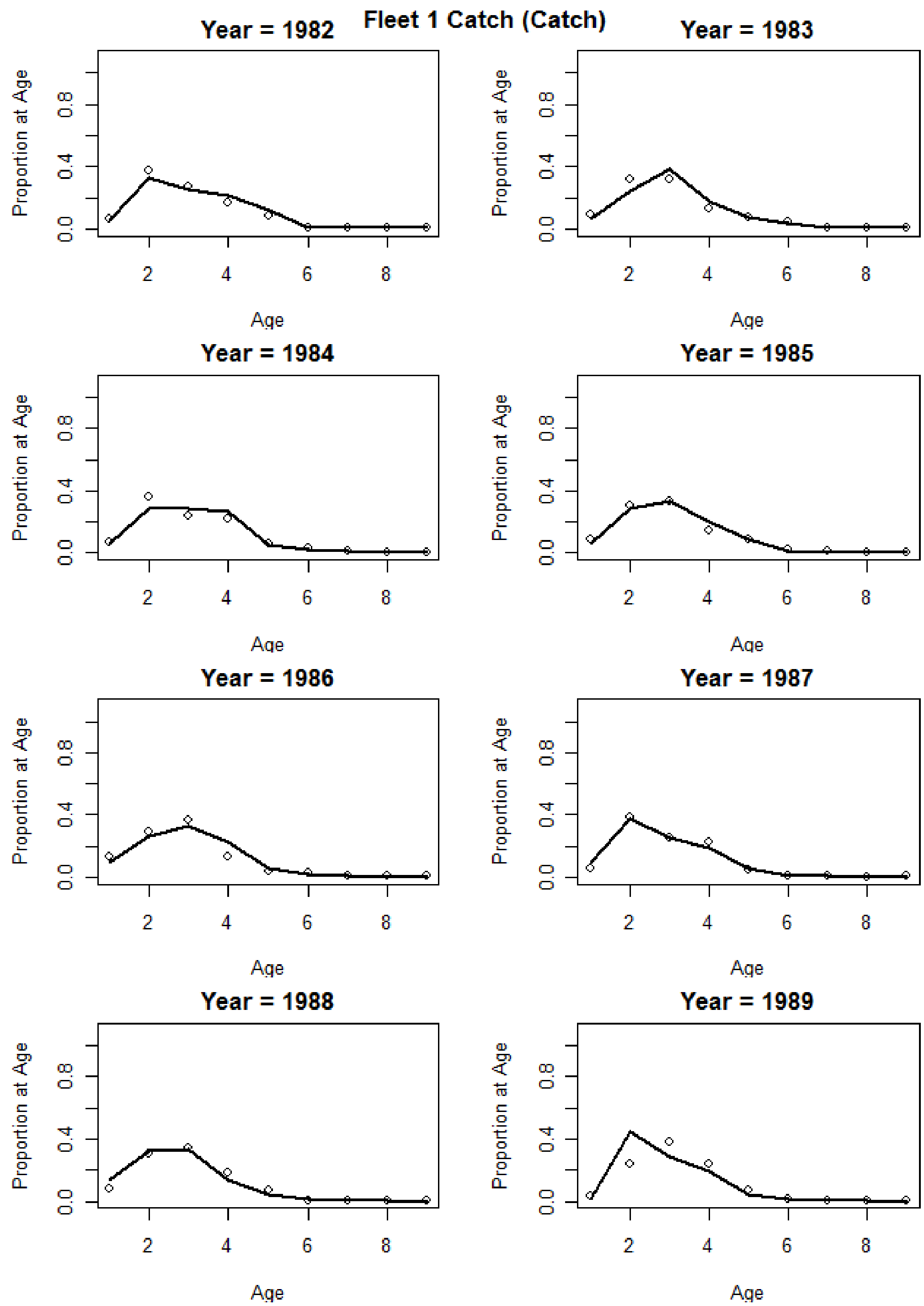


Figure A.111.a. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

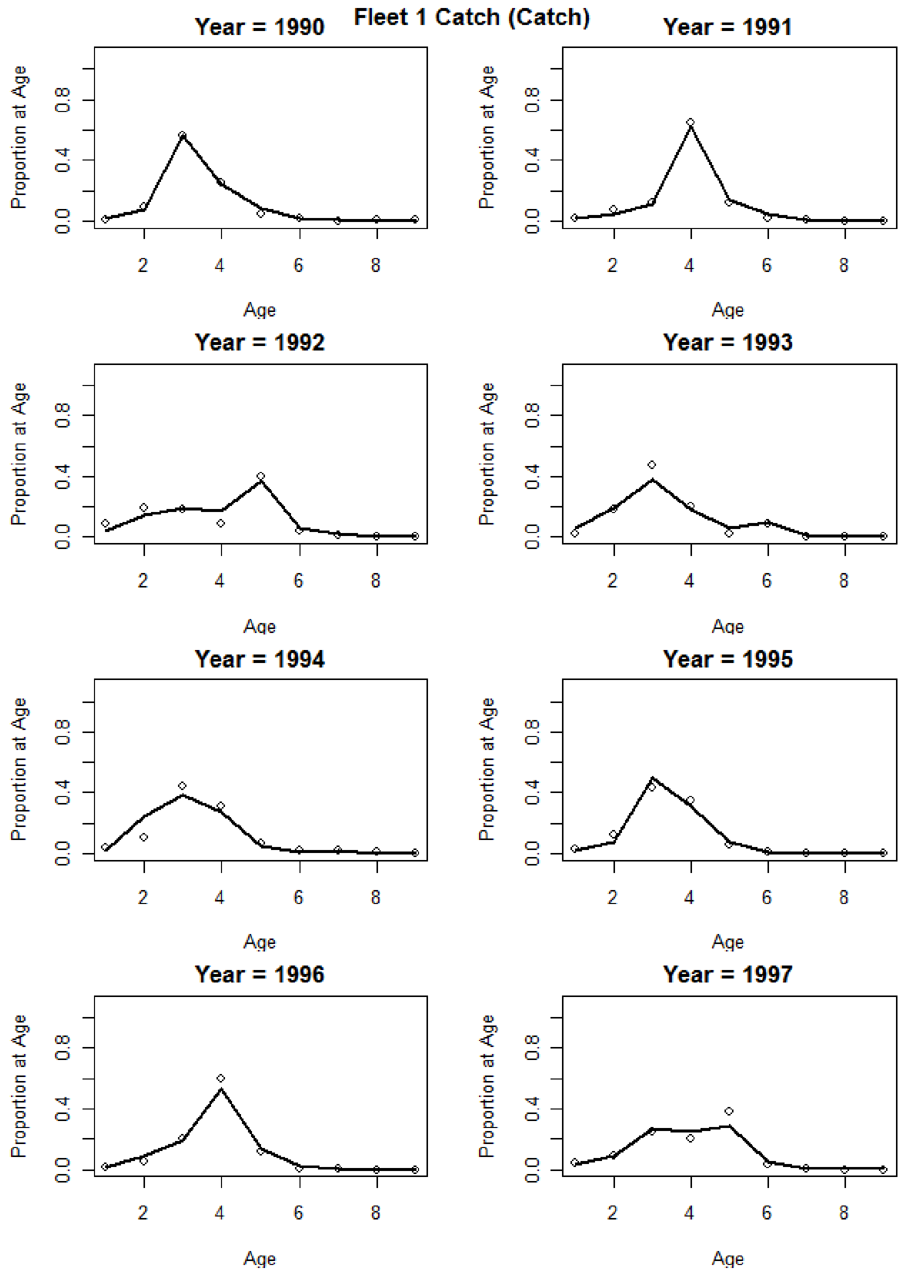


Figure A.111.b. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

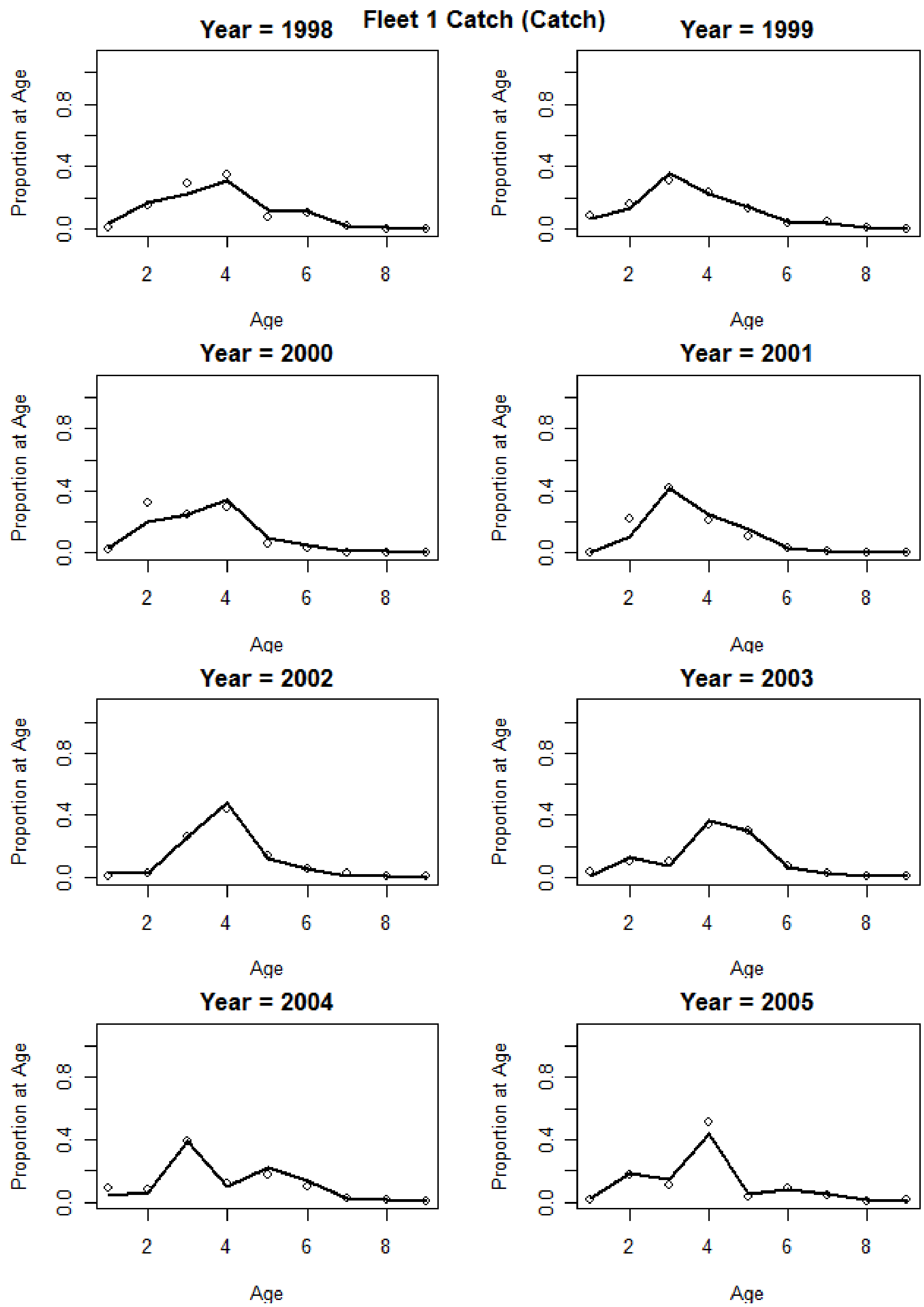


Figure A.111.c. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

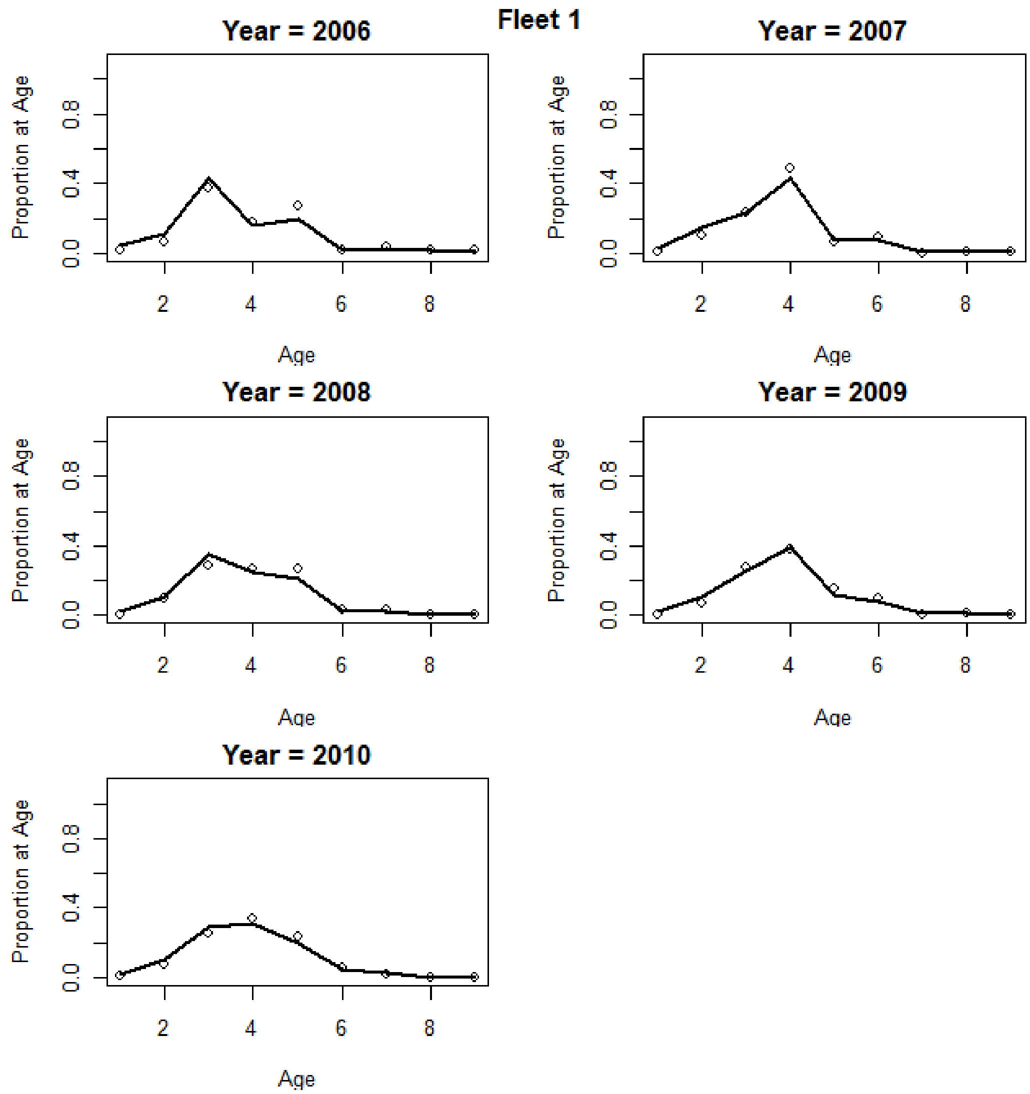


Figure A.111.d. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

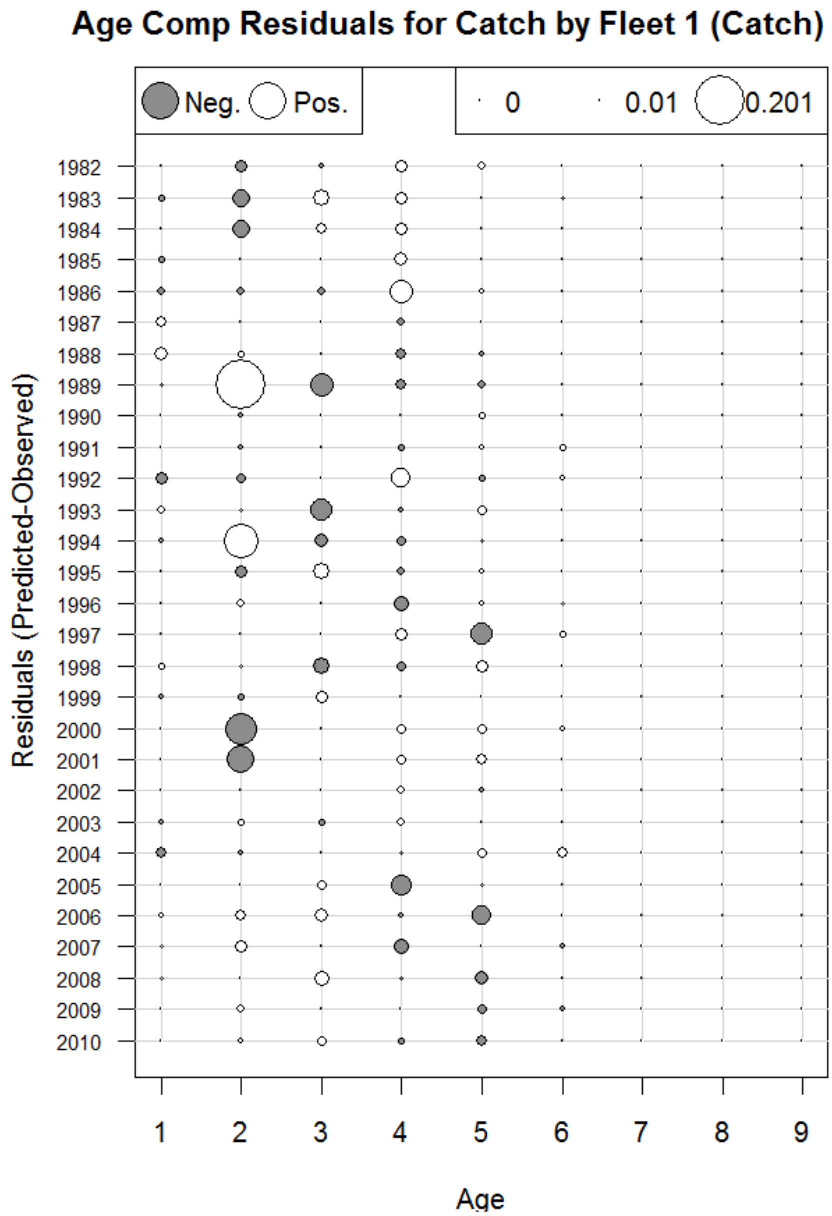


Figure A.112. ASAP BASE model fit residuals for the fishery (Fleet 1) catch-at-age of Gulf of Maine Atlantic cod.

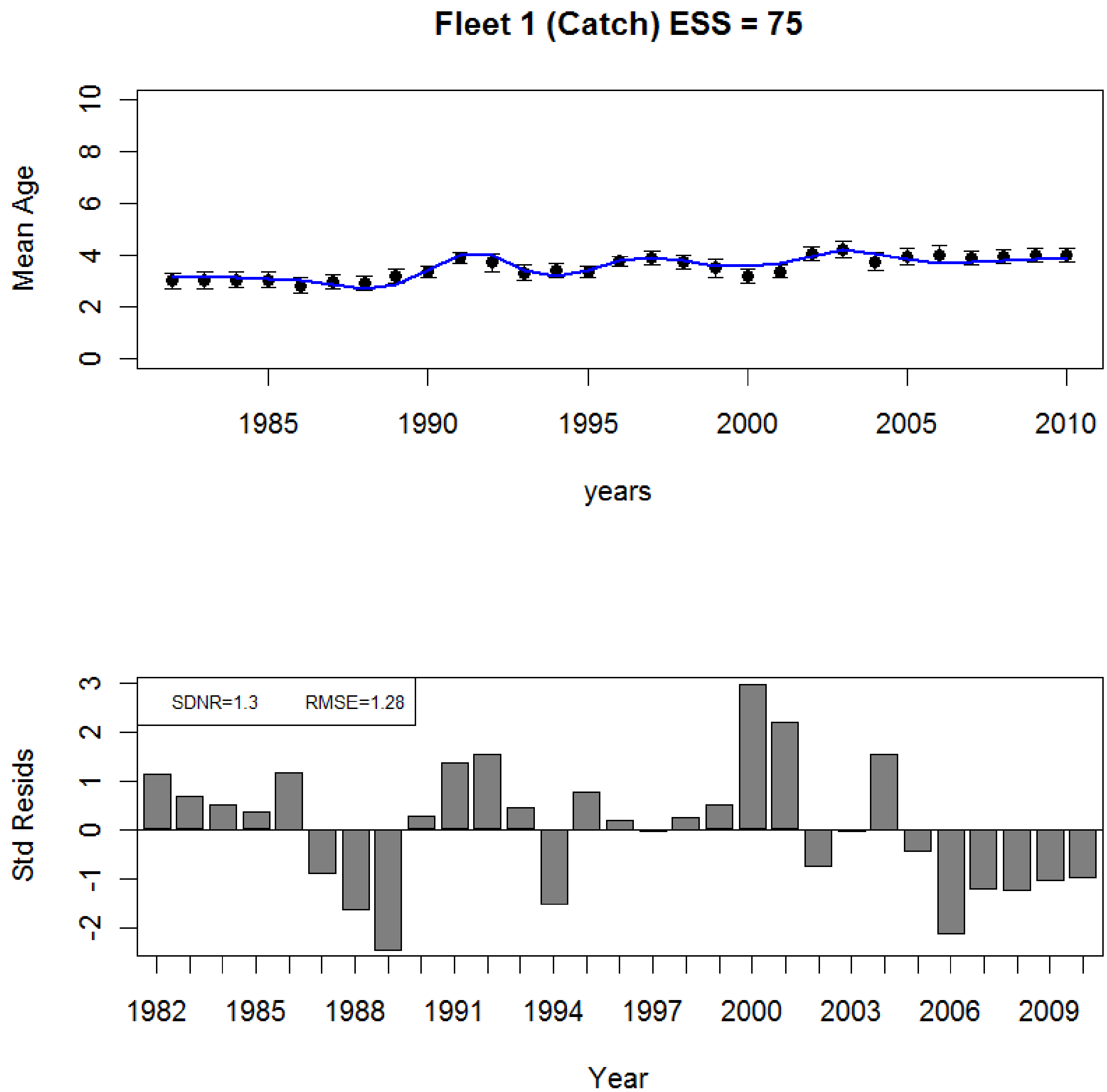


Figure A.113. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the fishery catch (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

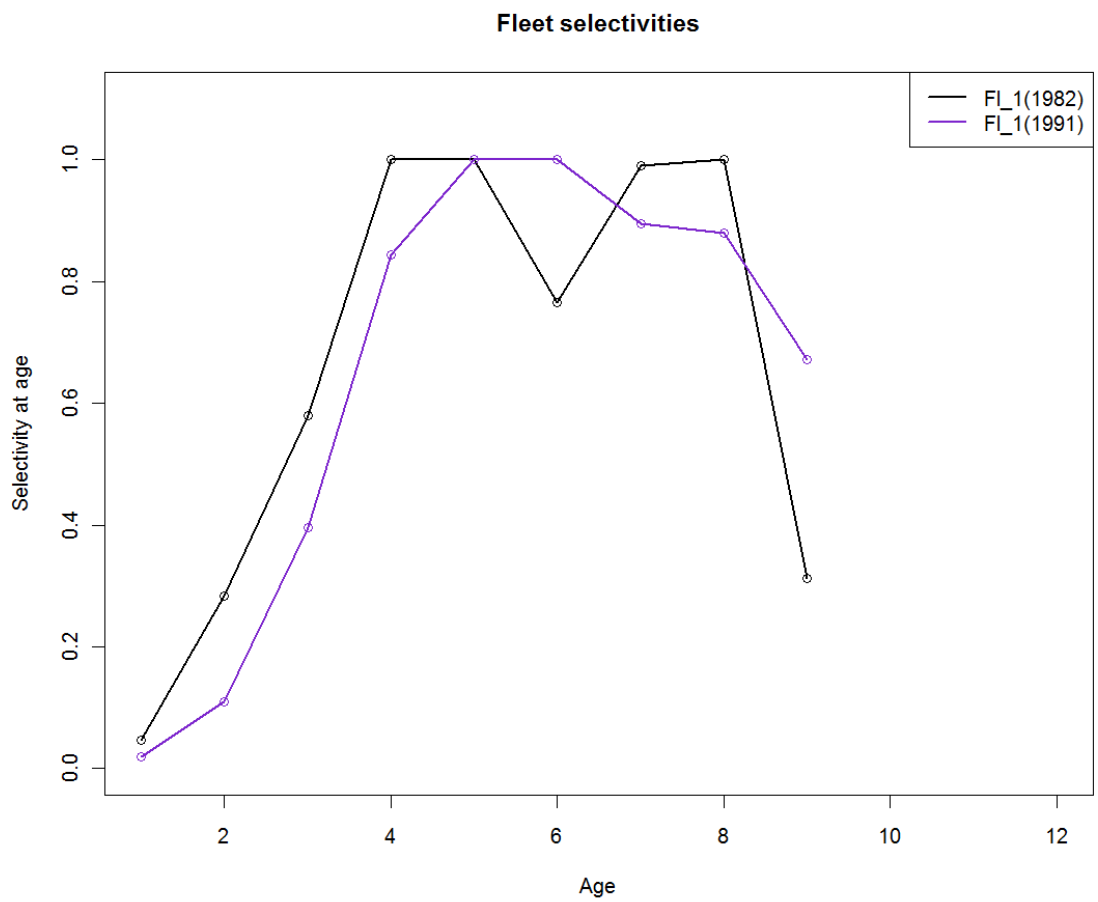


Figure A.114. ASAP BASE estimated Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1990) and block 2 (1991-2010).

Figure A.115. Scatter plot of observed Gulf of Maine Atlantic cod survey indices (obs) compared to the ASAP BASE model predicted survey indices (pred). The three survey indices shown are NEFSC spring (Index1), NEFSC fall (Index2), and MADMF spring (Index3). The 1:1equality line is indicated by a dashed red line.

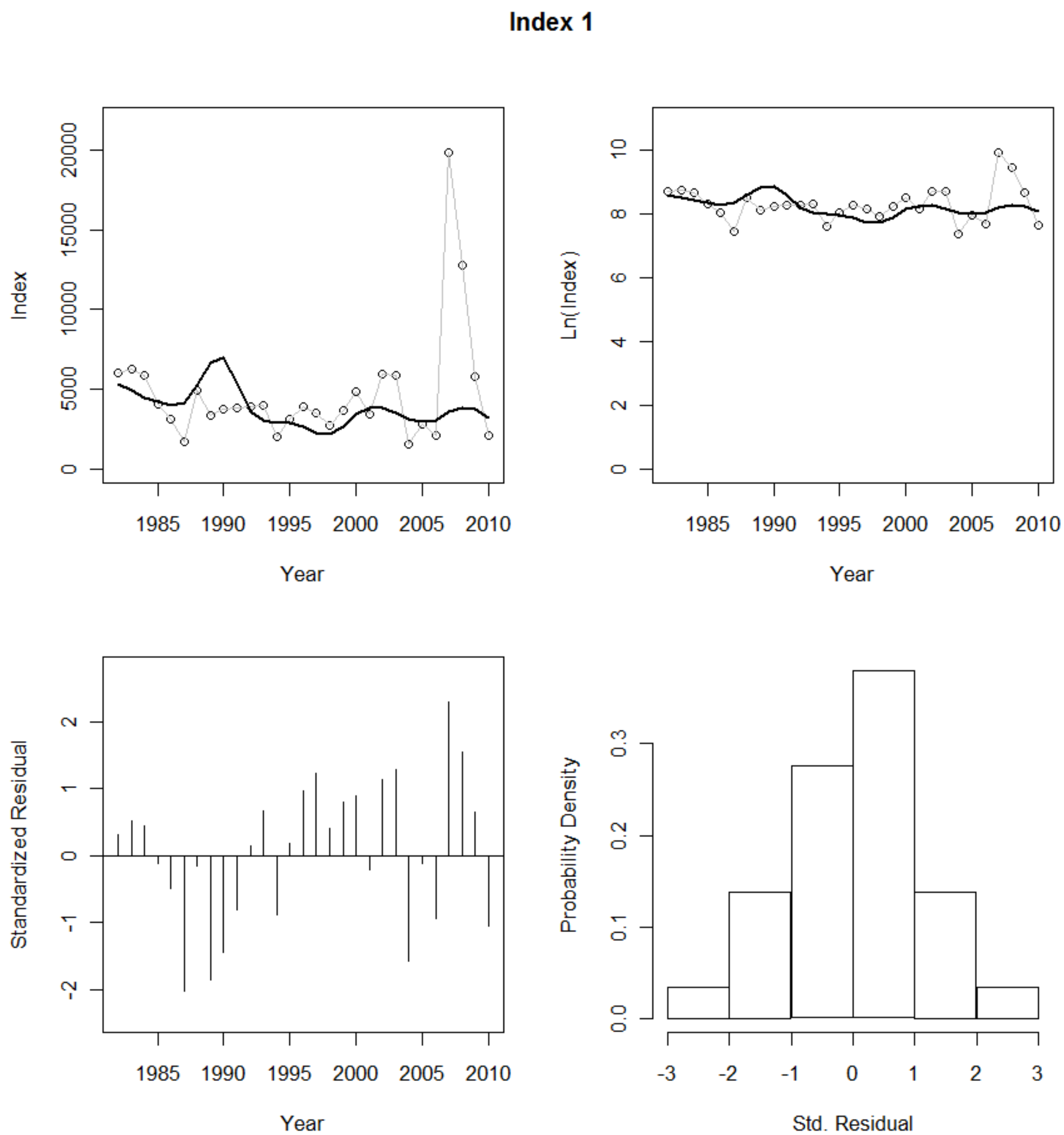


Figure A.116. ASAP BASE model fit to the NEFSC Gulf of Maine Atlantic cod spring (Index 1) survey.

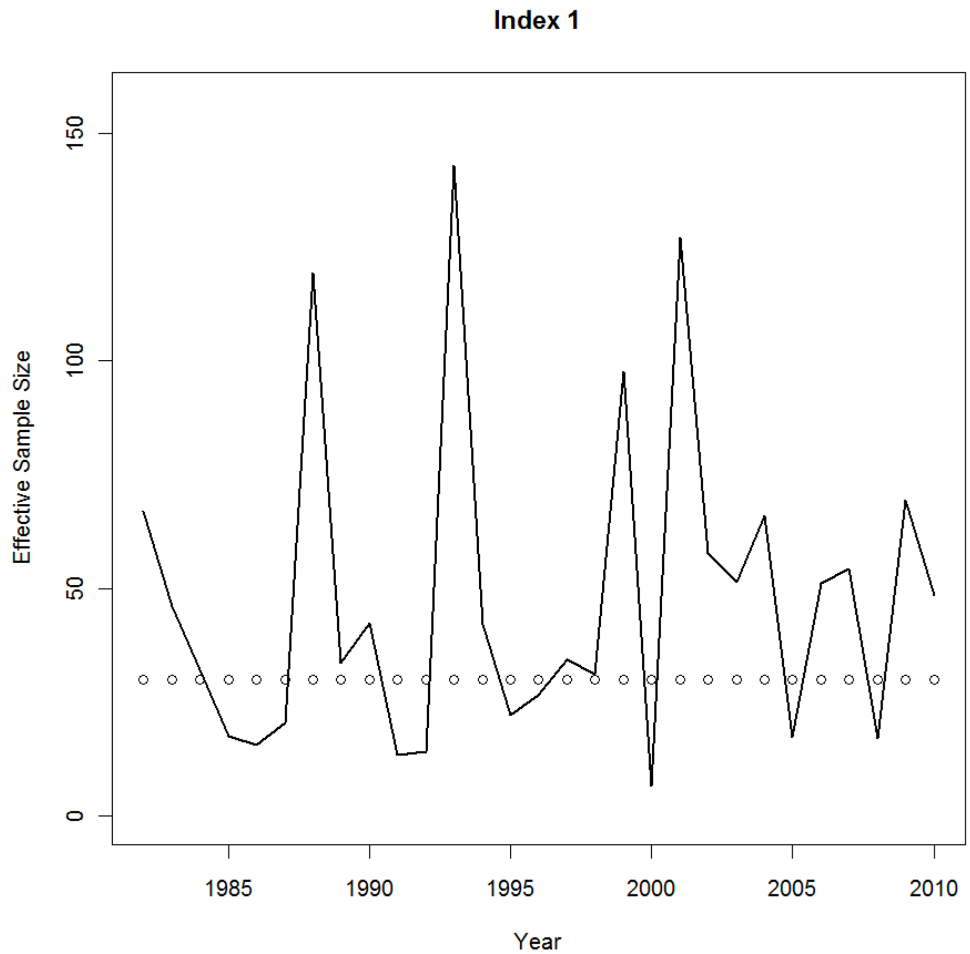


Figure A.117. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC spring (Index 1) Gulf of Maine Atlantic cod index.

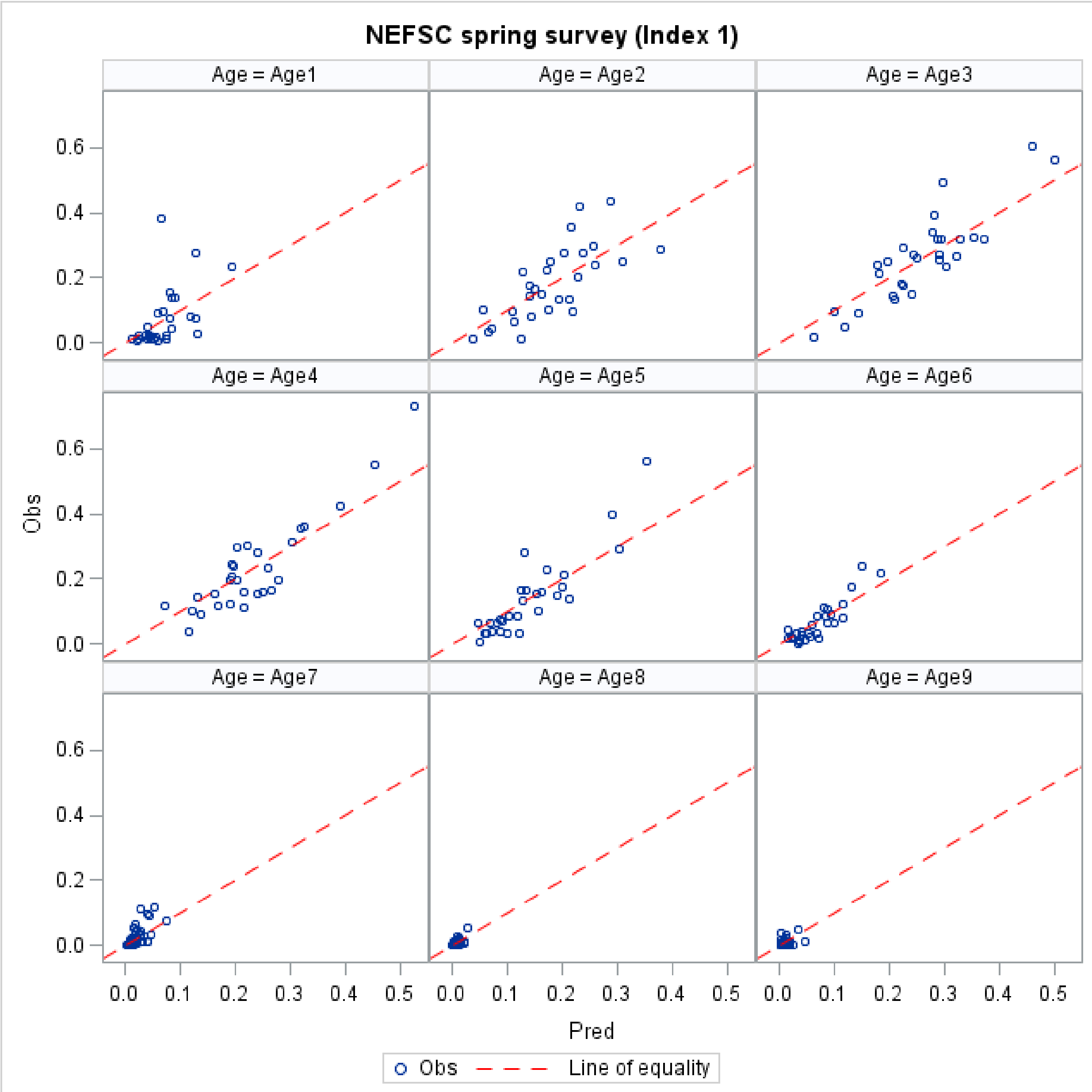


Figure A.118. Scatter plot of observed Gulf of Maine Atlantic cod NEFSC spring survey (Index1) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

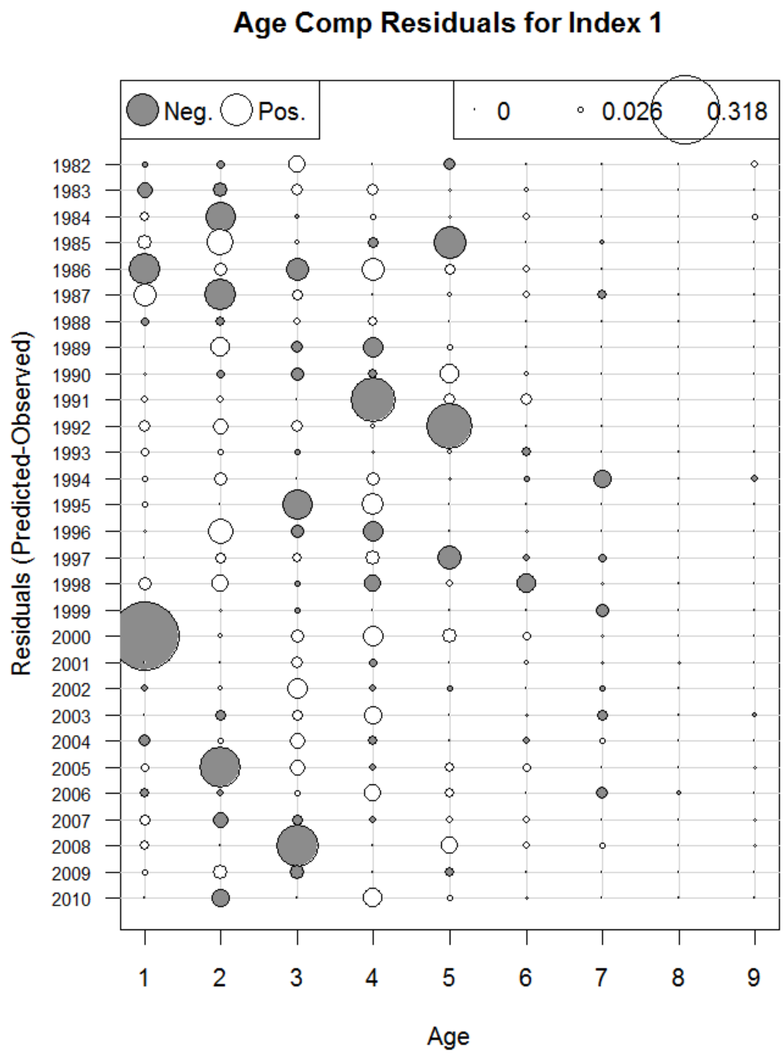


Figure A.119. ASAP BASE model fit residuals for the NEFSC spring survey (Index 1) Gulf of Maine Atlantic cod age composition.

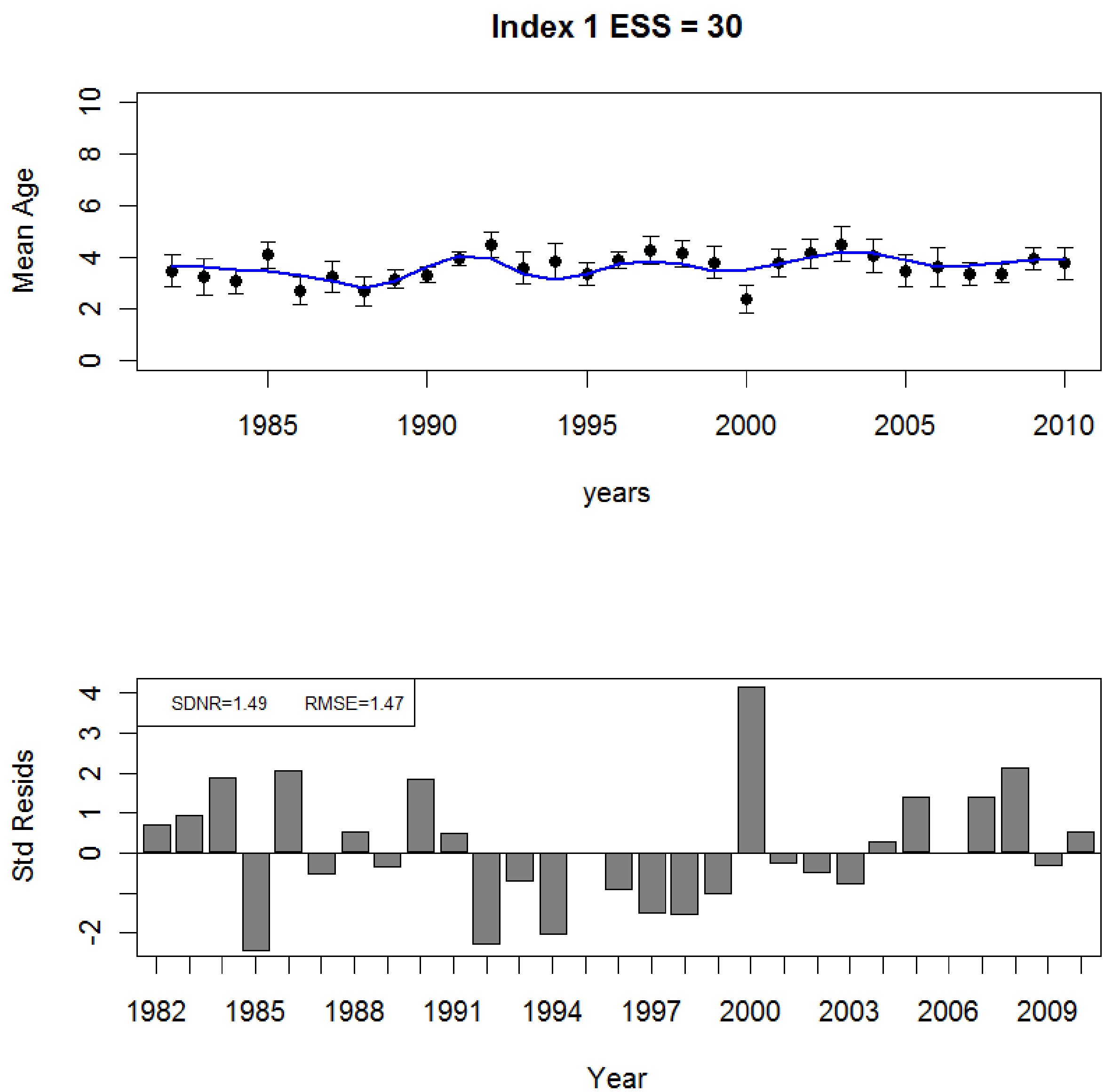


Figure A.120. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC spring (Index 1) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

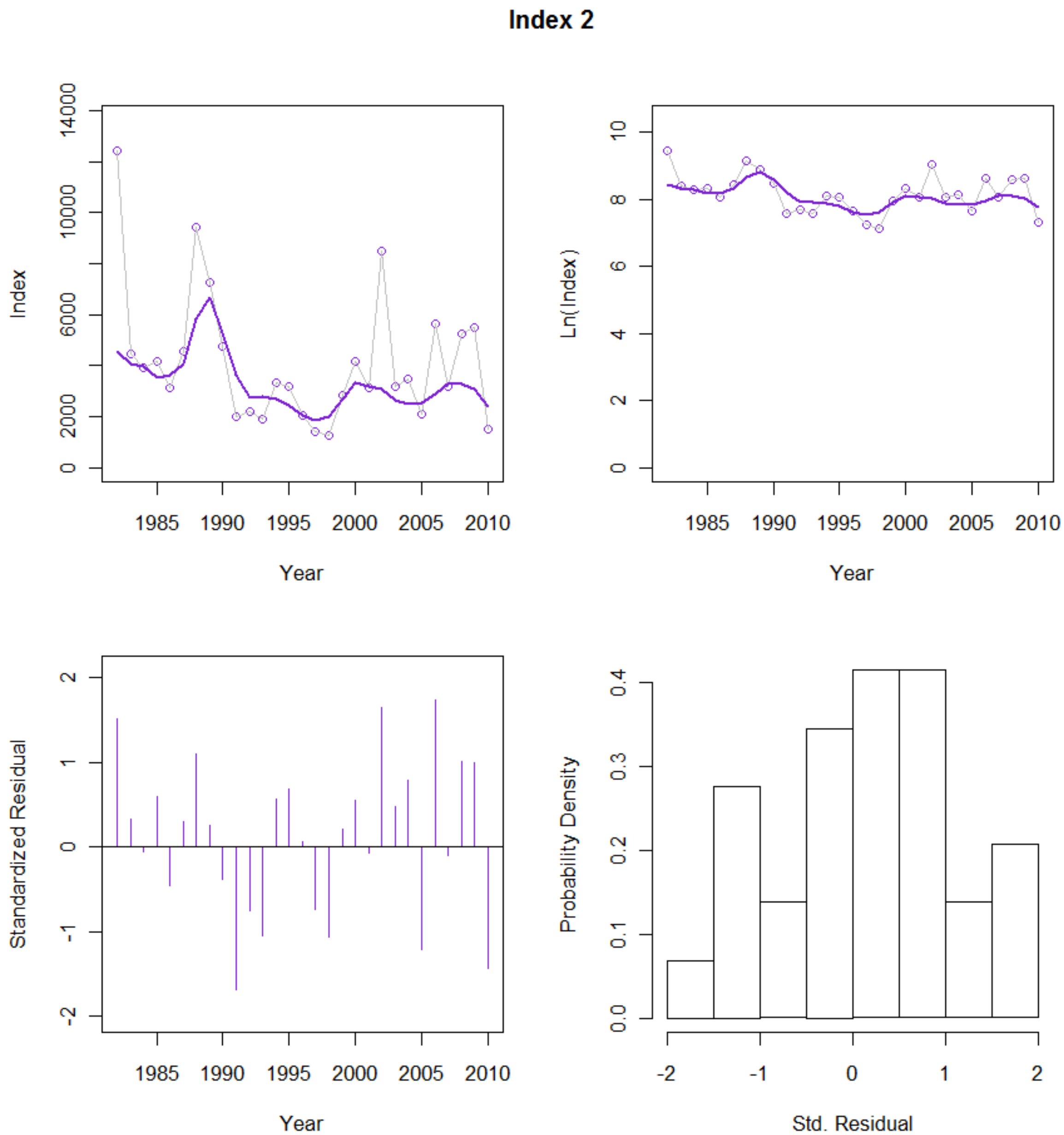


Figure A.121. ASAP BASE model fit to the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

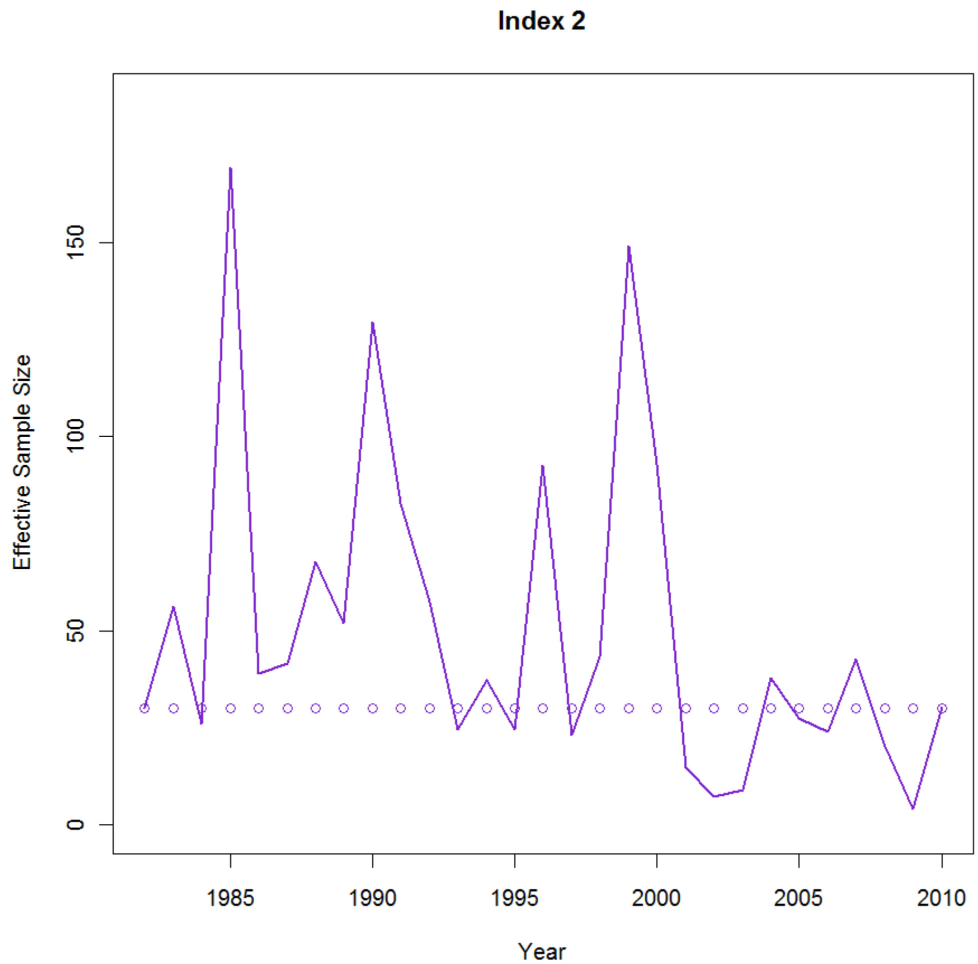


Figure A.122. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

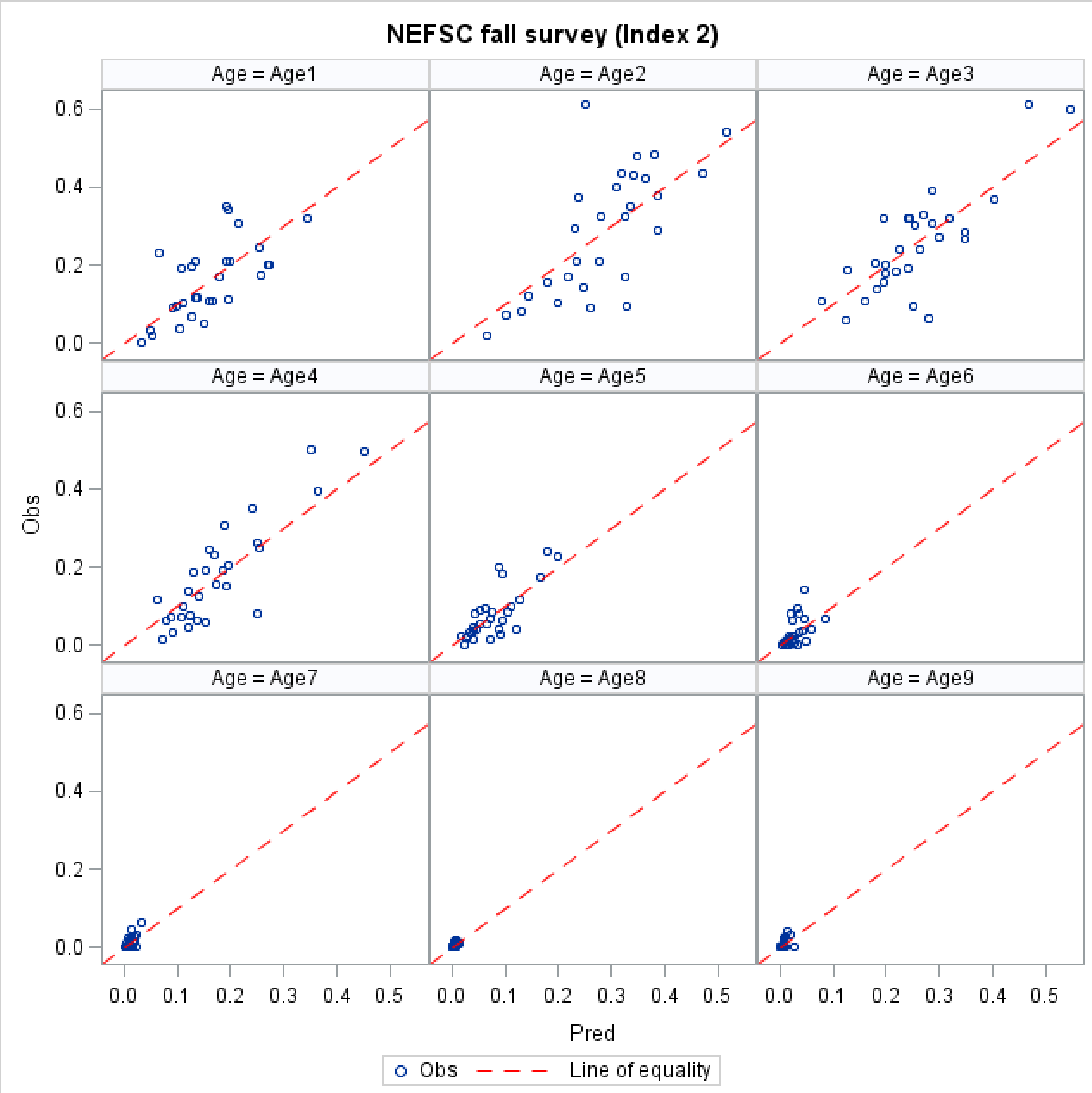


Figure A.123. Scatter plot of observed Gulf of Maine Atlantic cod NEFSC fall survey (Index2) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

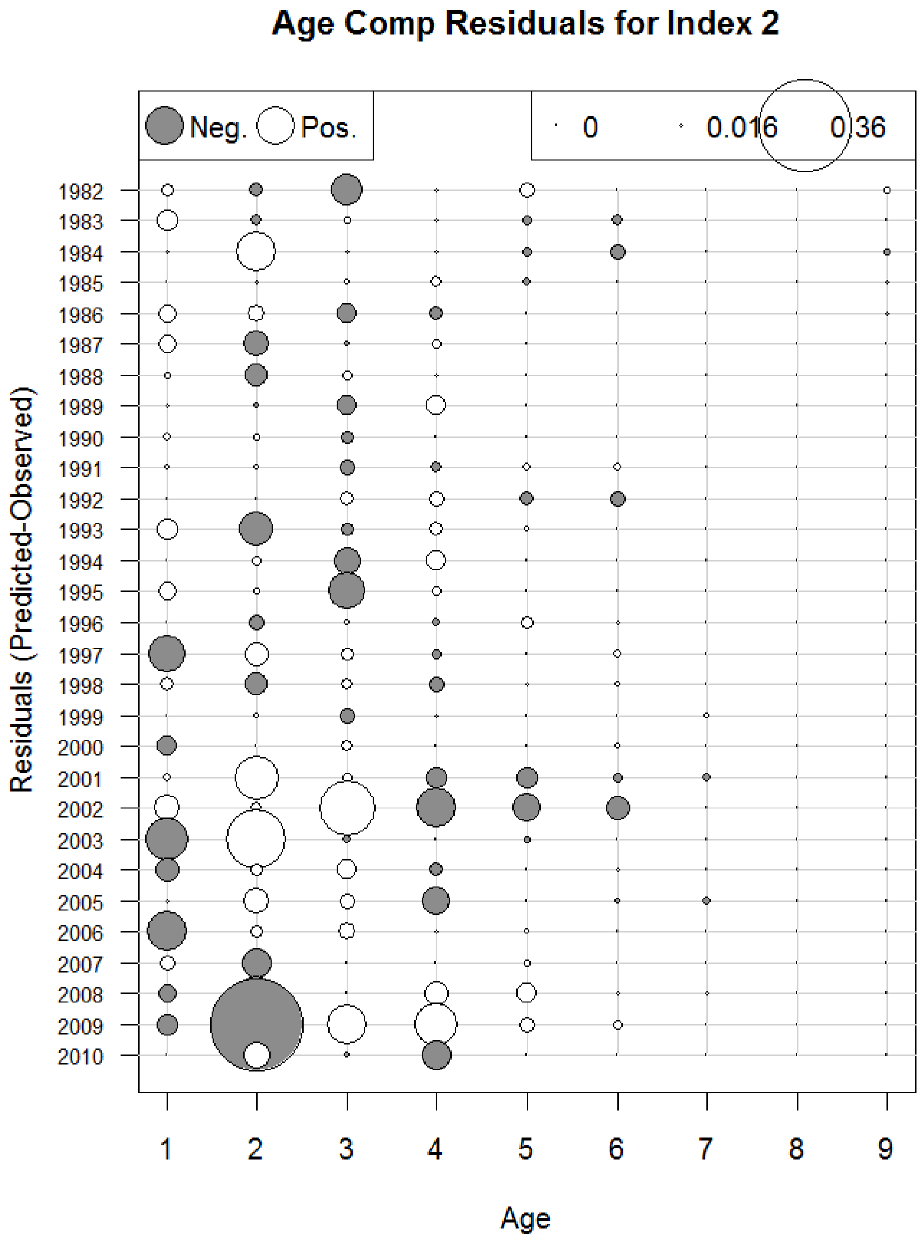


Figure A.124. ASAP BASE model fit residuals for the NEFSC fall survey (Index 2) Gulf of Maine Atlantic cod age composition.

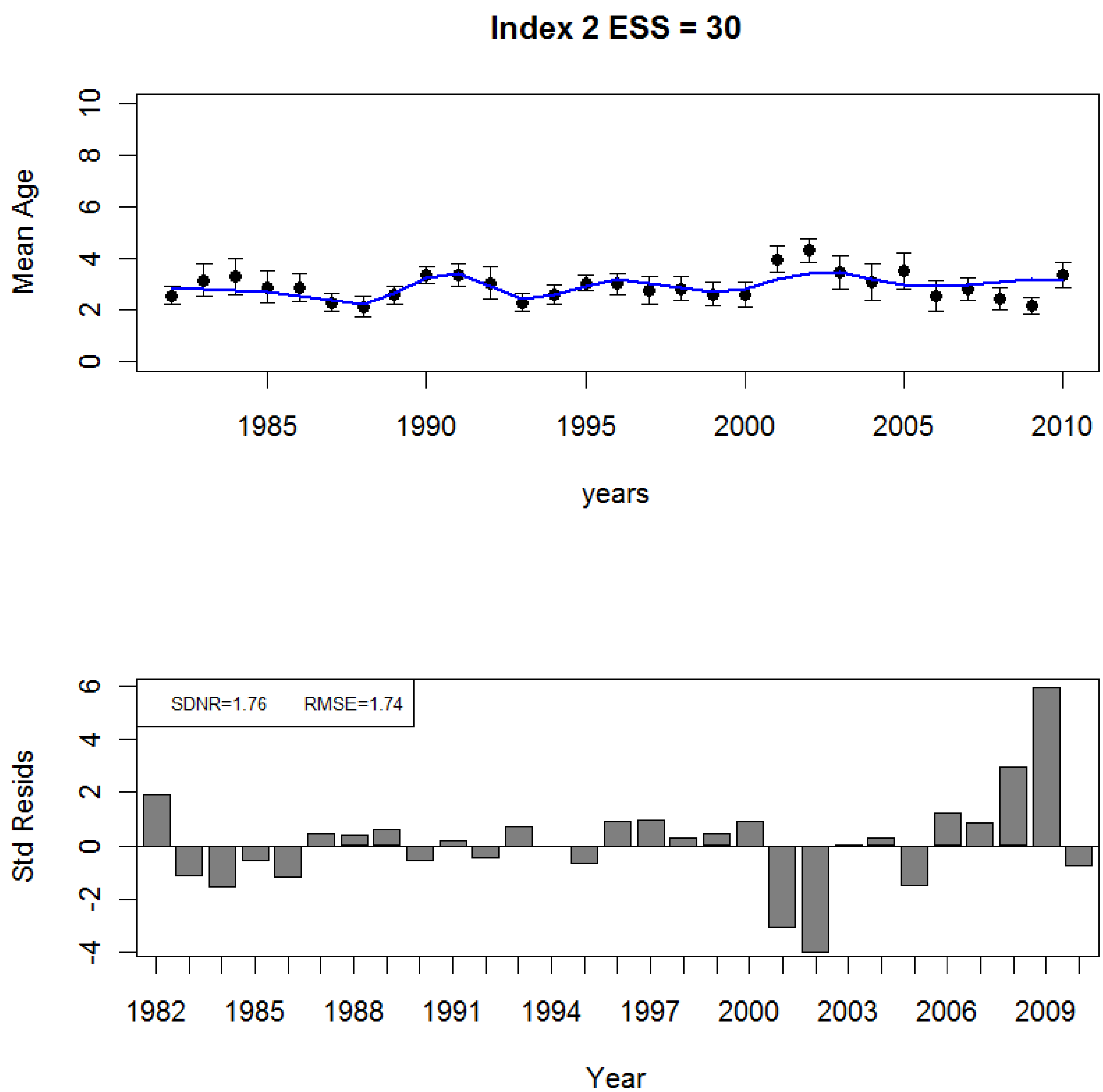


Figure A.125. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC fall (Index 2) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

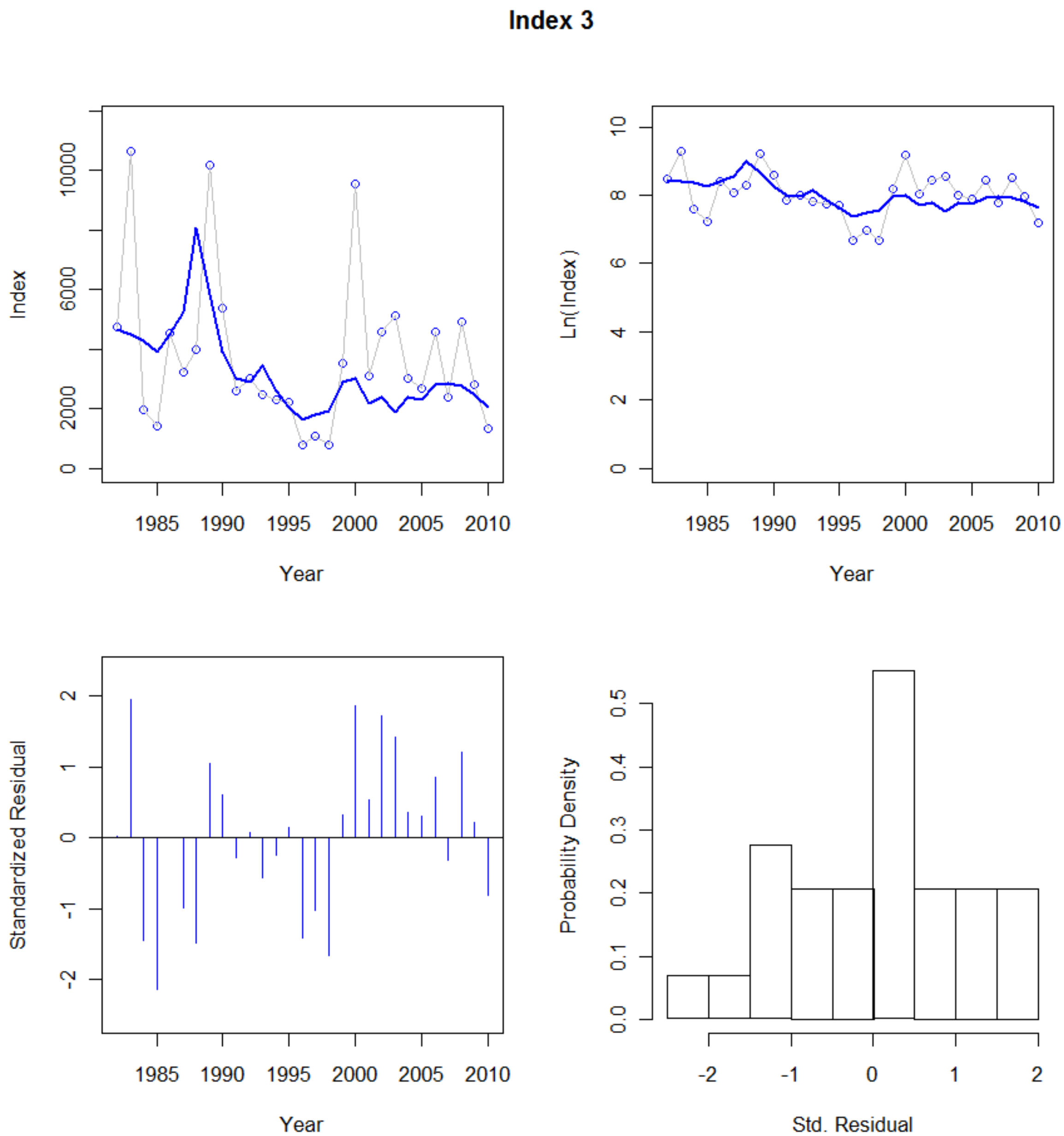


Figure A.126. ASAP BASE model fit to the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

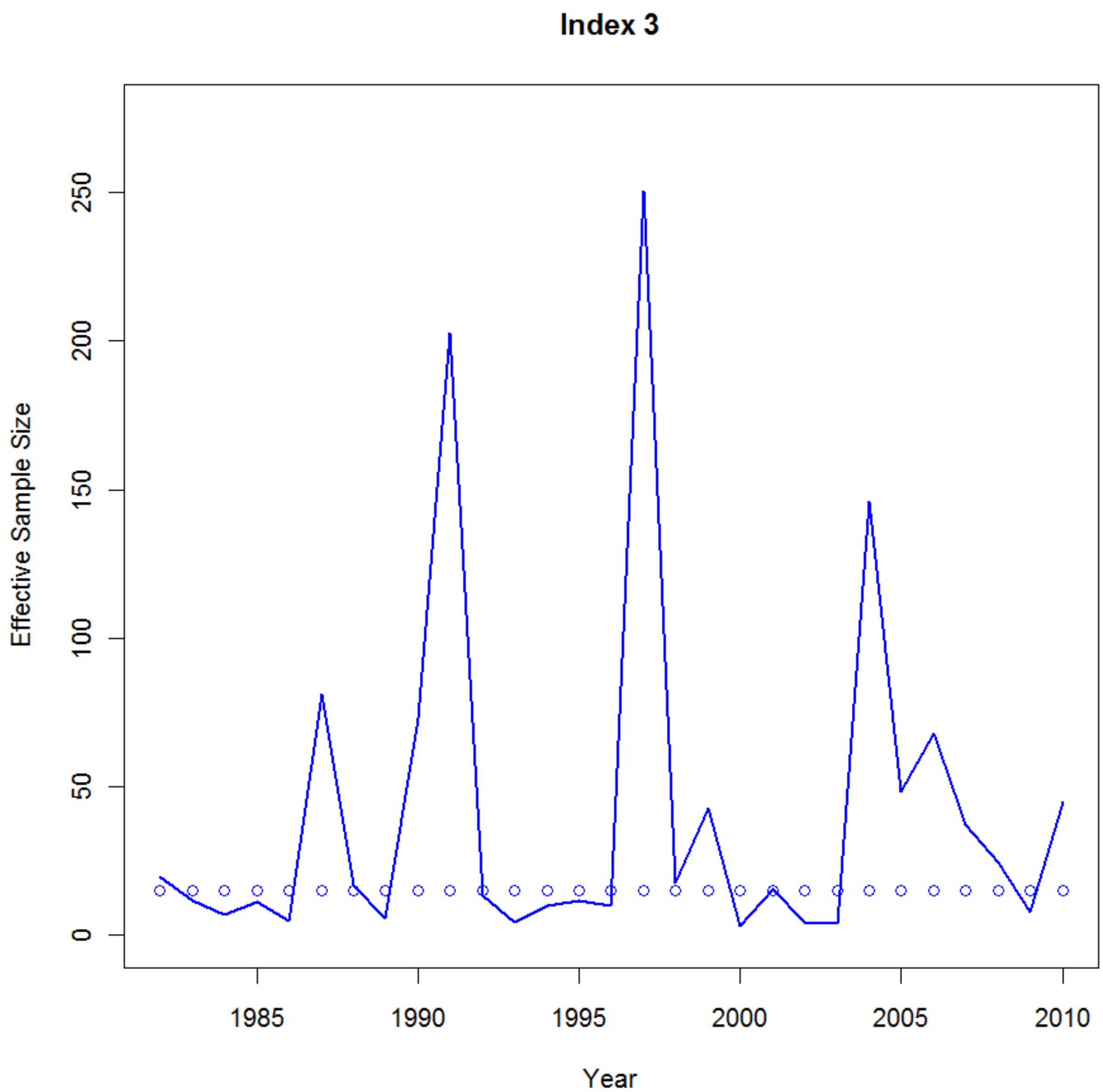


Figure A.127. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

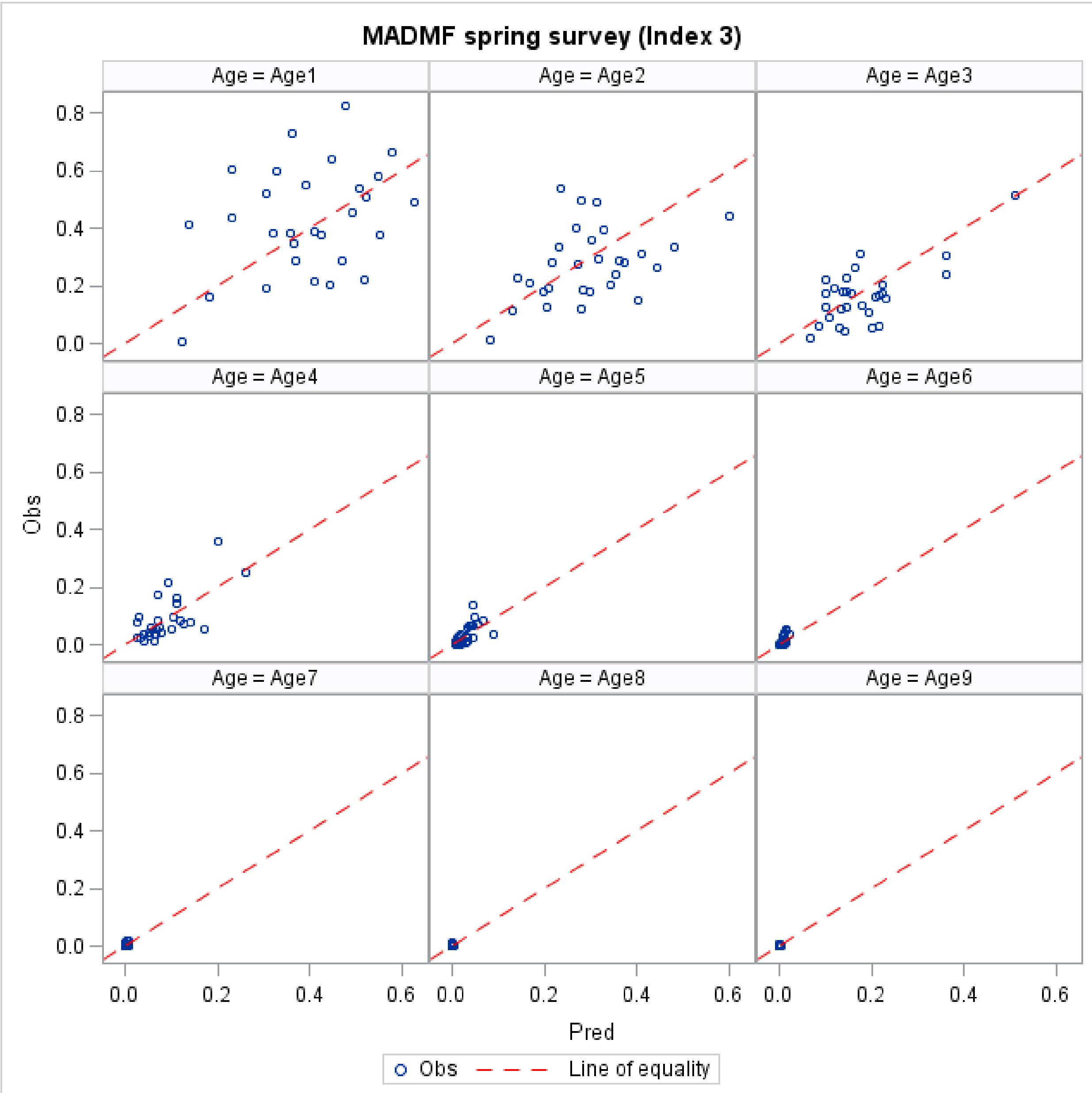


Figure A.128. Scatter plot of observed Gulf of Maine Atlantic cod MADMF spring survey (Index3) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

Figure A.129. ASAP BASE model fit residuals for the MADMF spring survey (Index 3) Gulf of Maine Atlantic cod age composition.

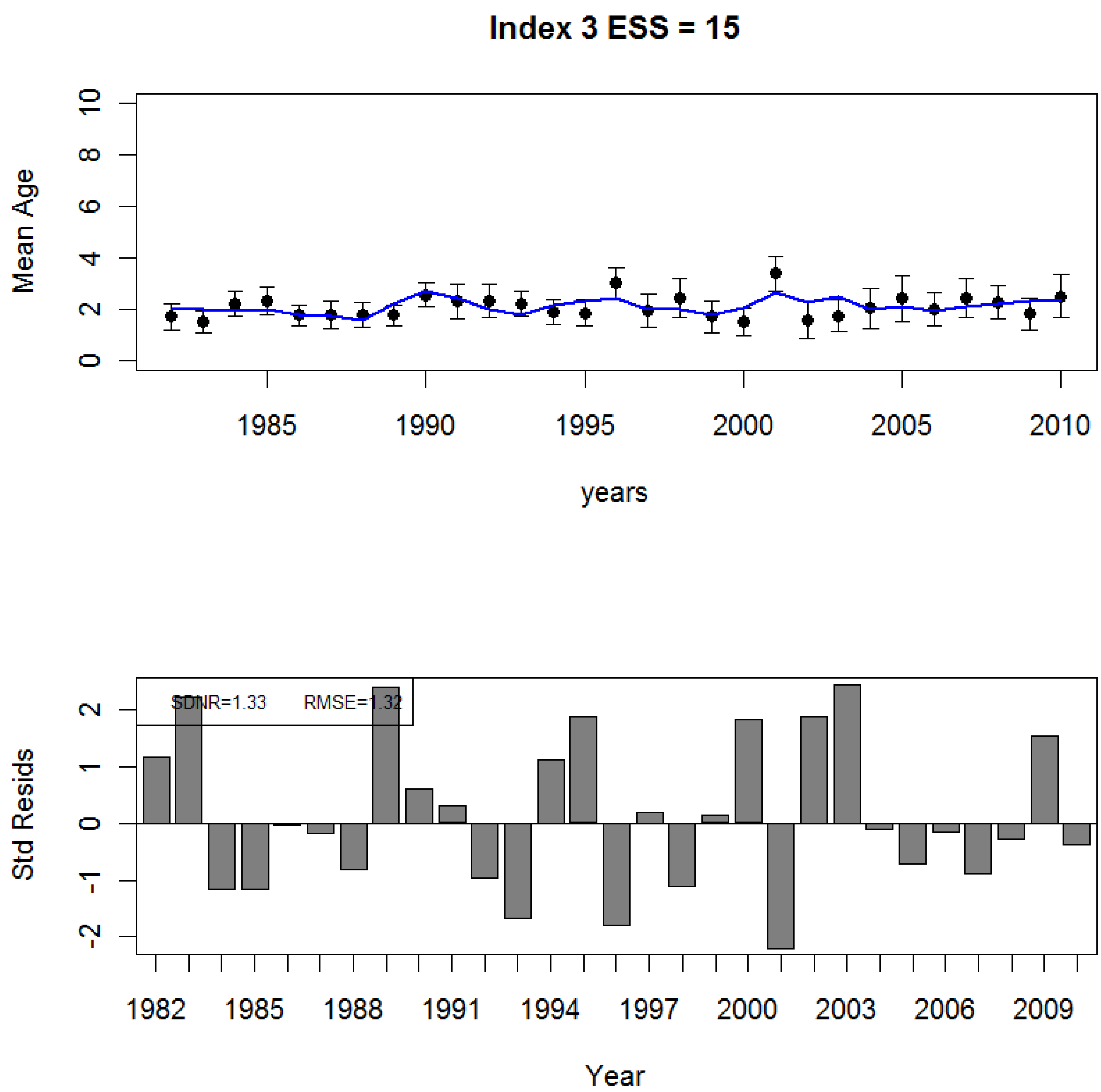


Figure A.130. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the MADMF spring (Index 3) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

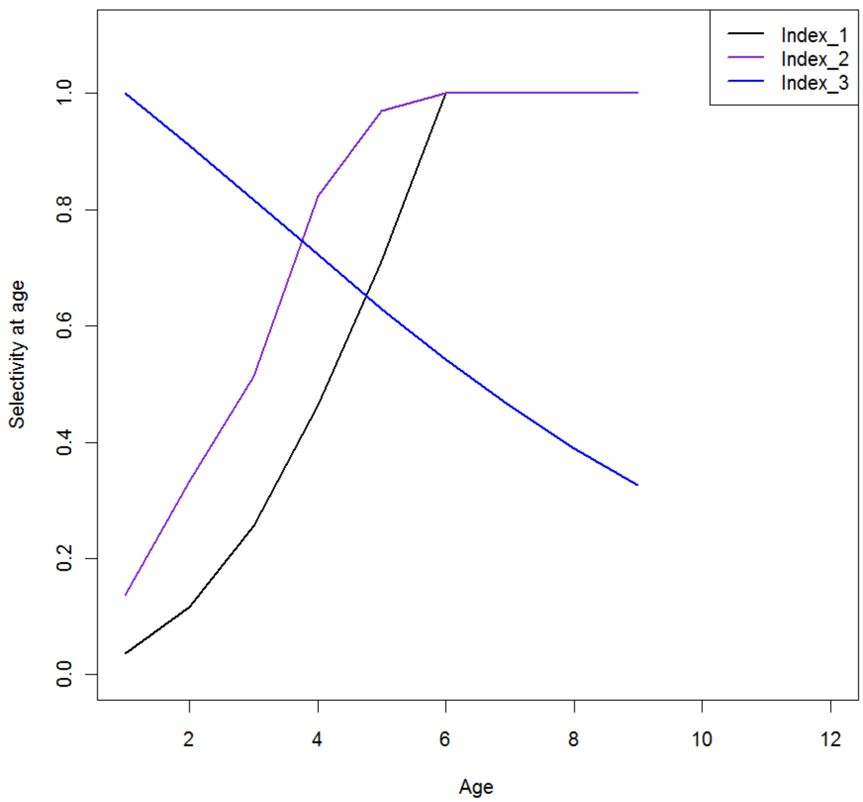


Figure A.131. Gulf of Maine Atlantic cod selectivity-at-age for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP BASE model.

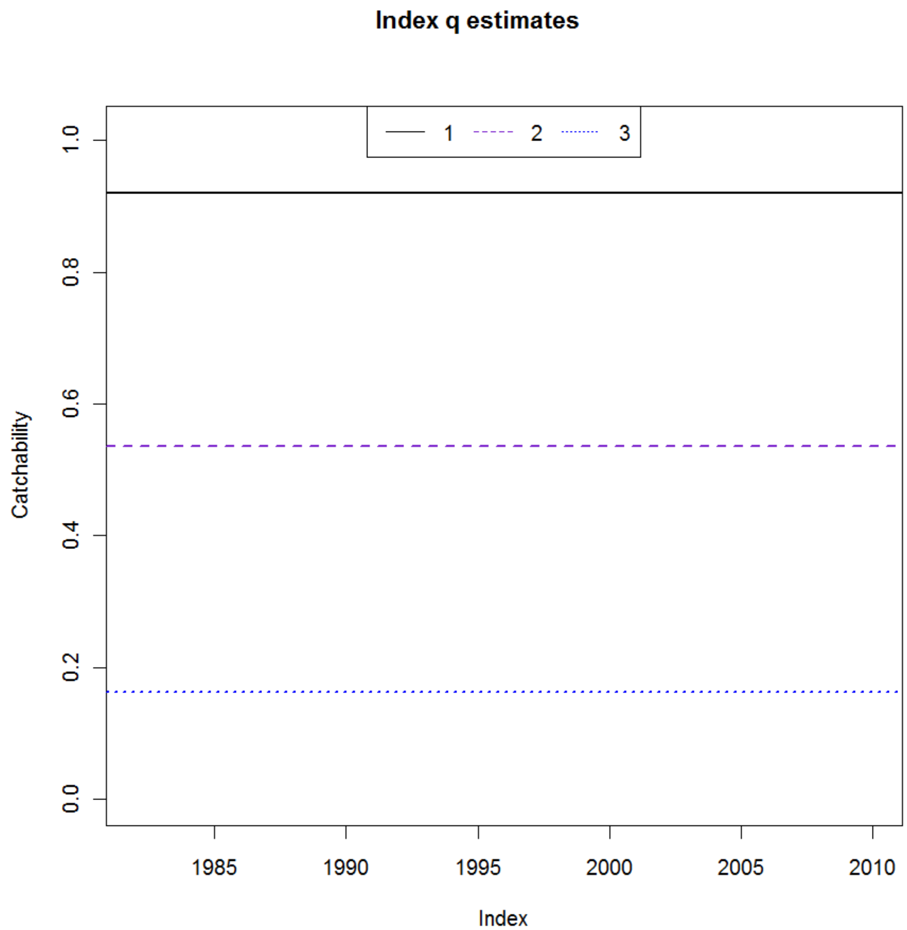


Figure A.132. Gulf of Maine Atlantic cod survey catchability (*q*) for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP BASE model.

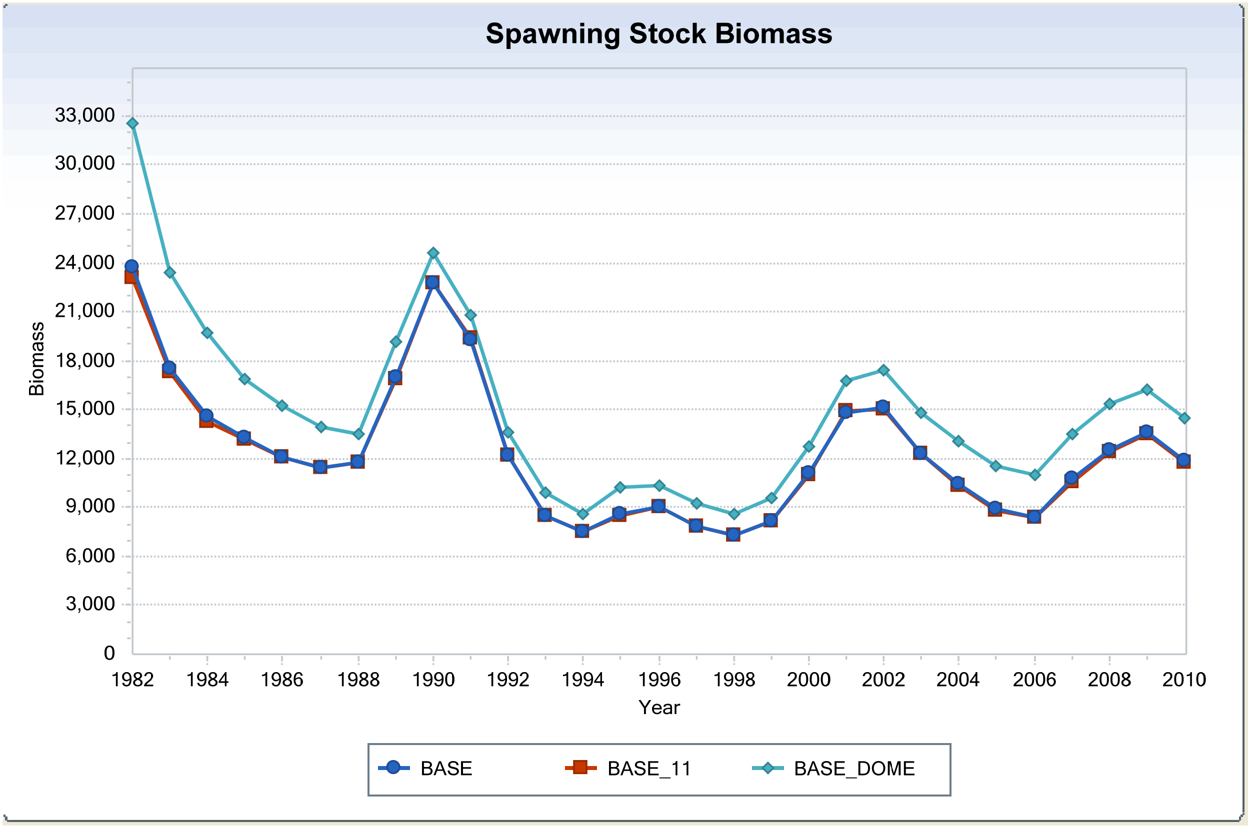


Figure A.133. Comparison of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

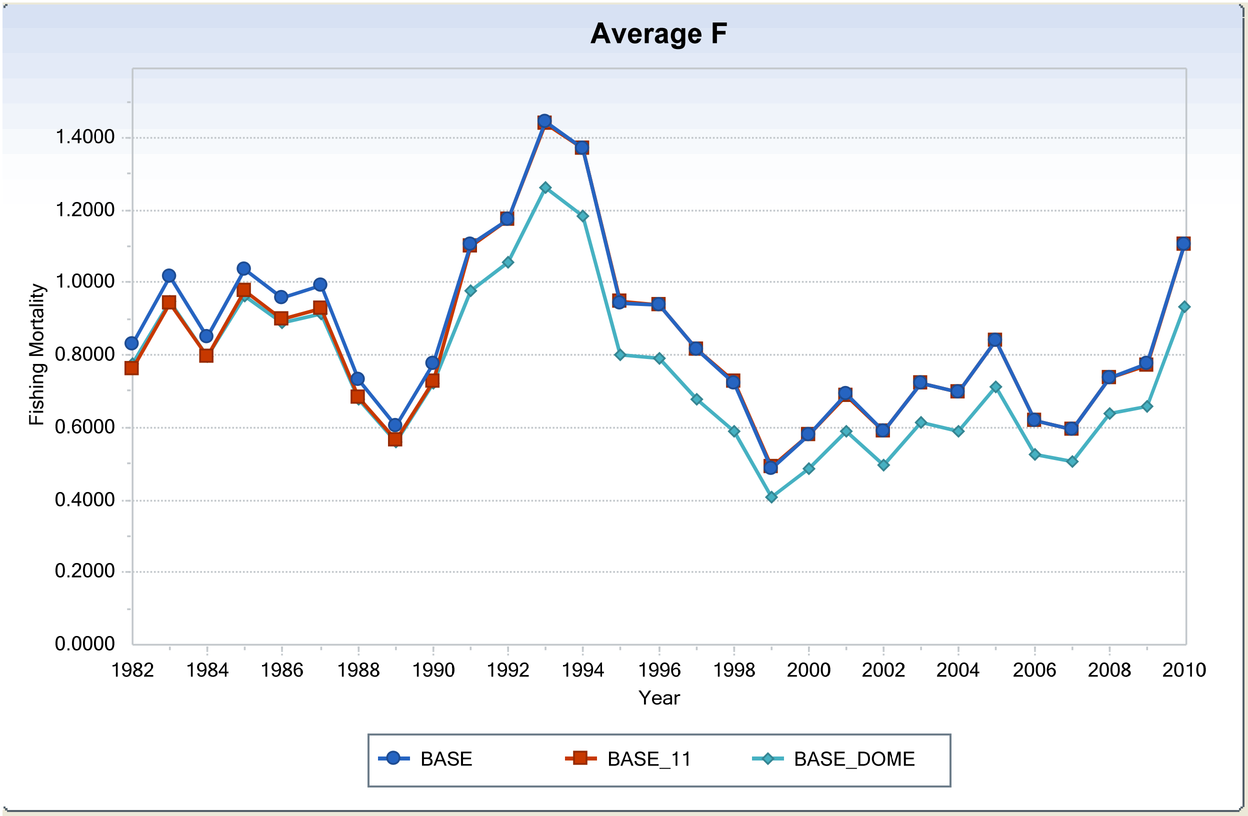


Figure A.134. Comparison of Gulf of Maine Atlantic cod fishing mortality (age 5 – 7) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

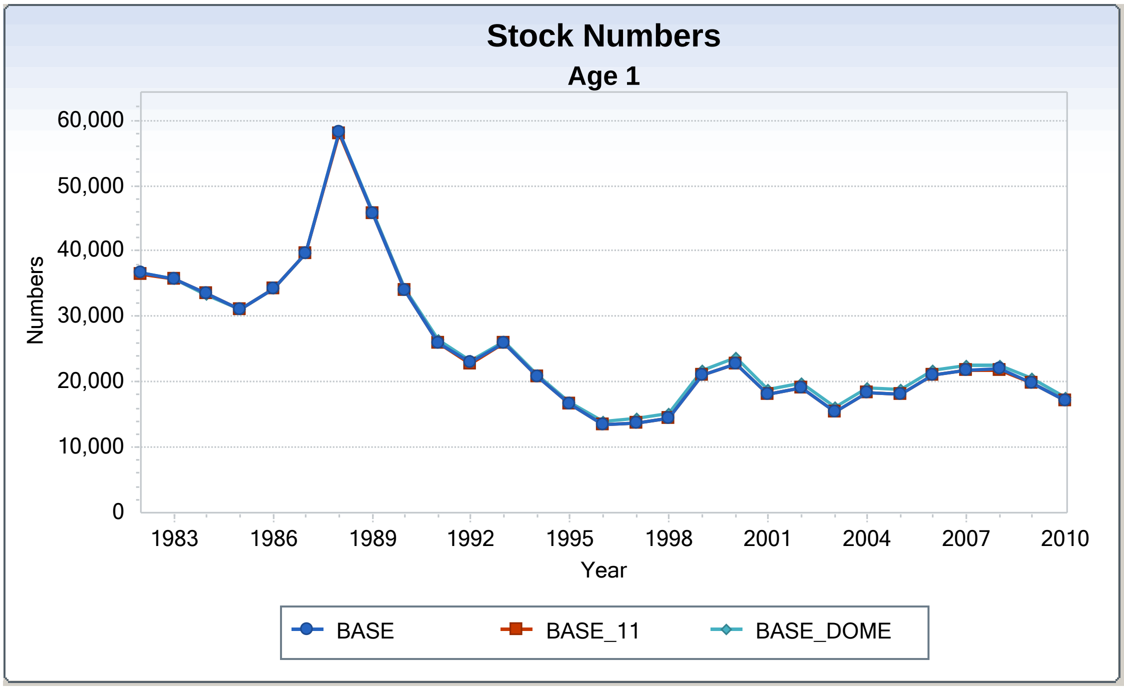


Figure A.135. Comparison of Gulf of Maine Atlantic cod age 1 recruitment (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

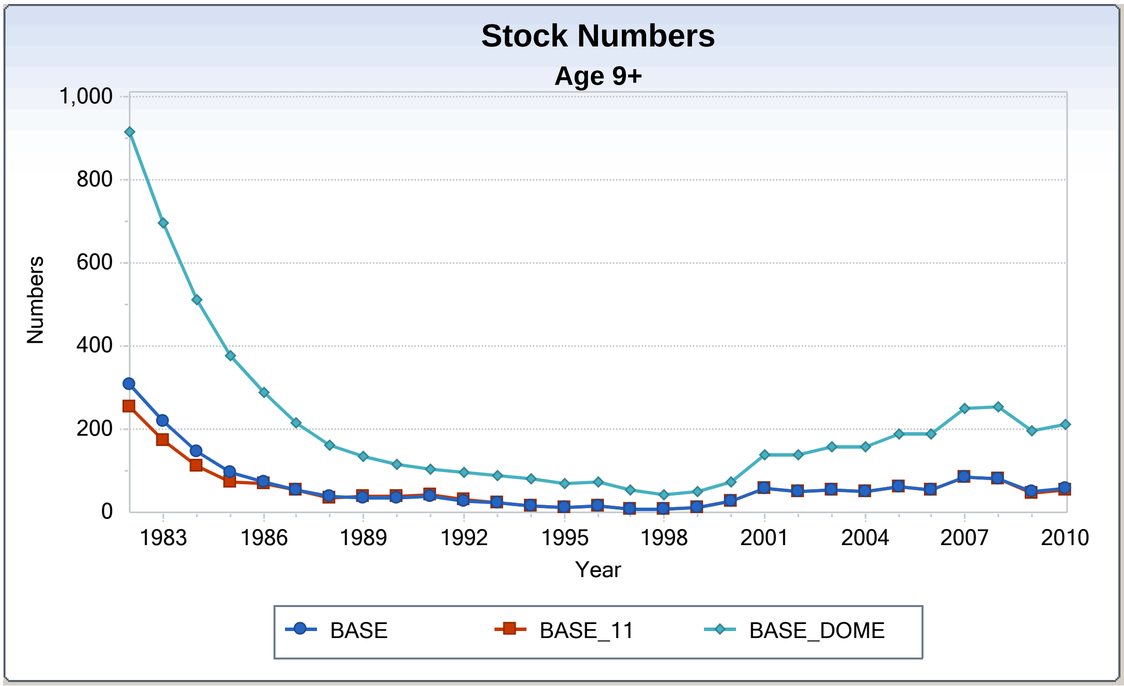


Figure A.136. Comparison of Gulf of Maine Atlantic cod age 9 numbers (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

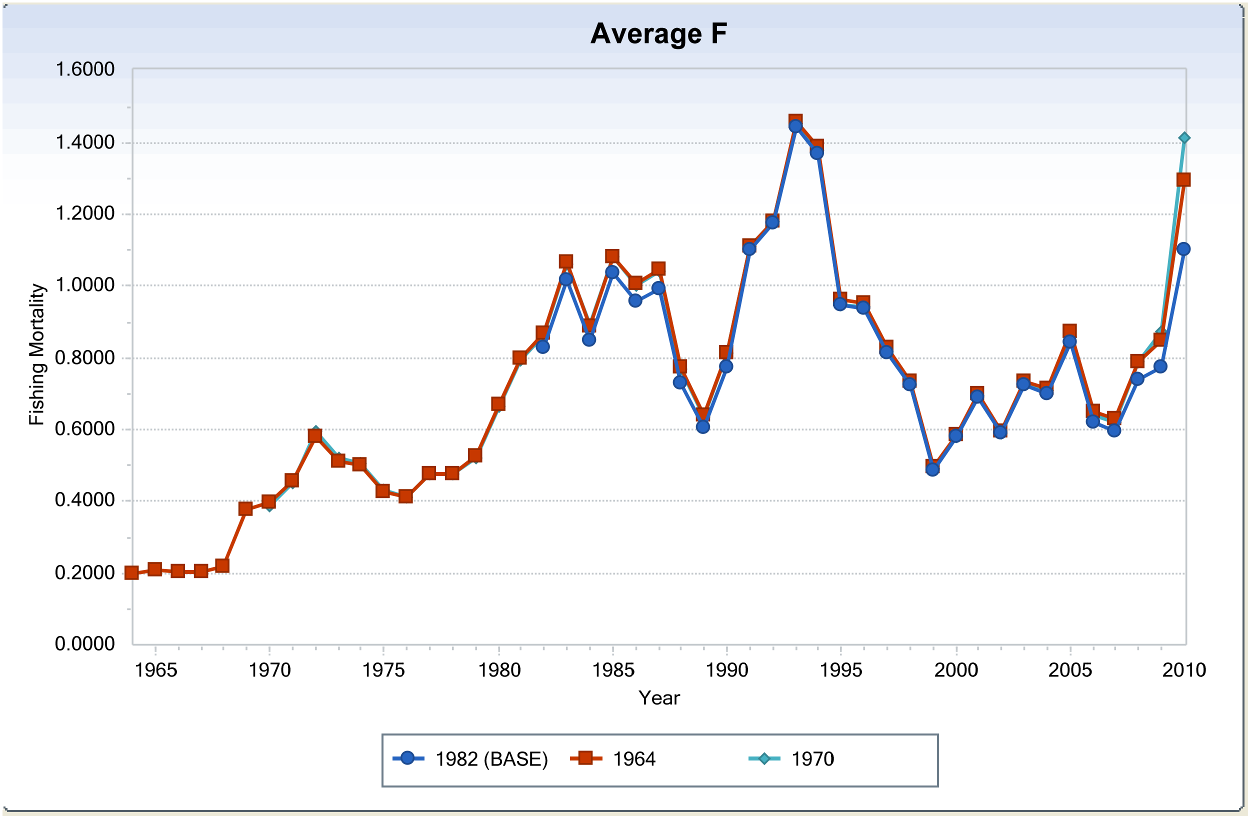


Figure A.137. Comparison of Gulf of Maine Atlantic cod fishing mortality (age 5 – 7) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

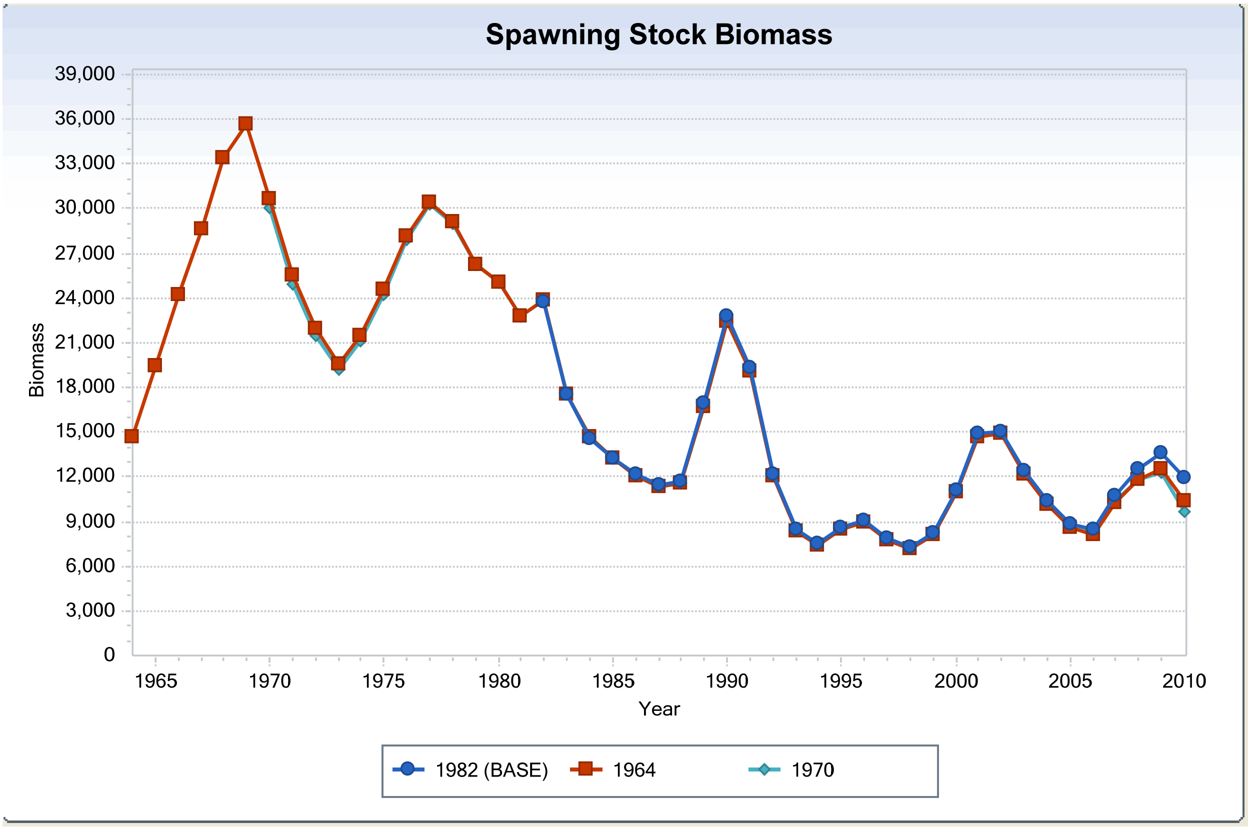


Figure A.138. Comparison of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

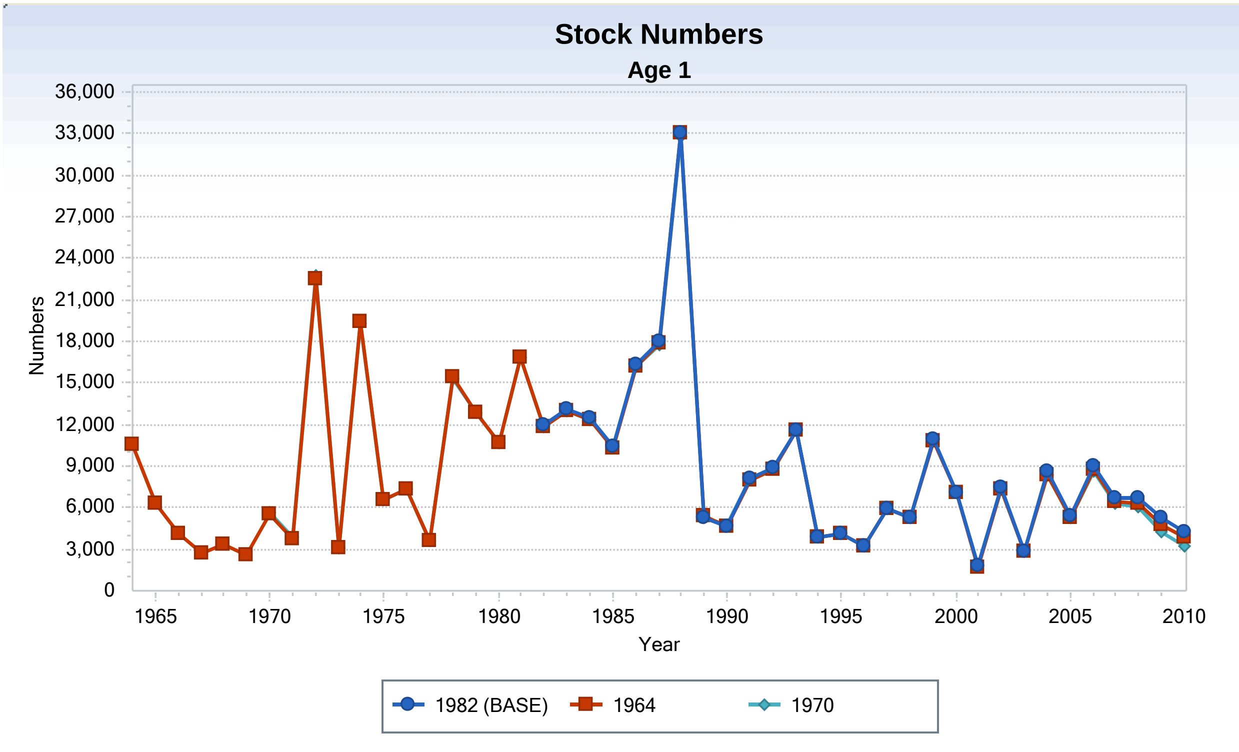


Figure A.139. Comparison of Gulf of Maine Atlantic cod age 1 recruitment (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

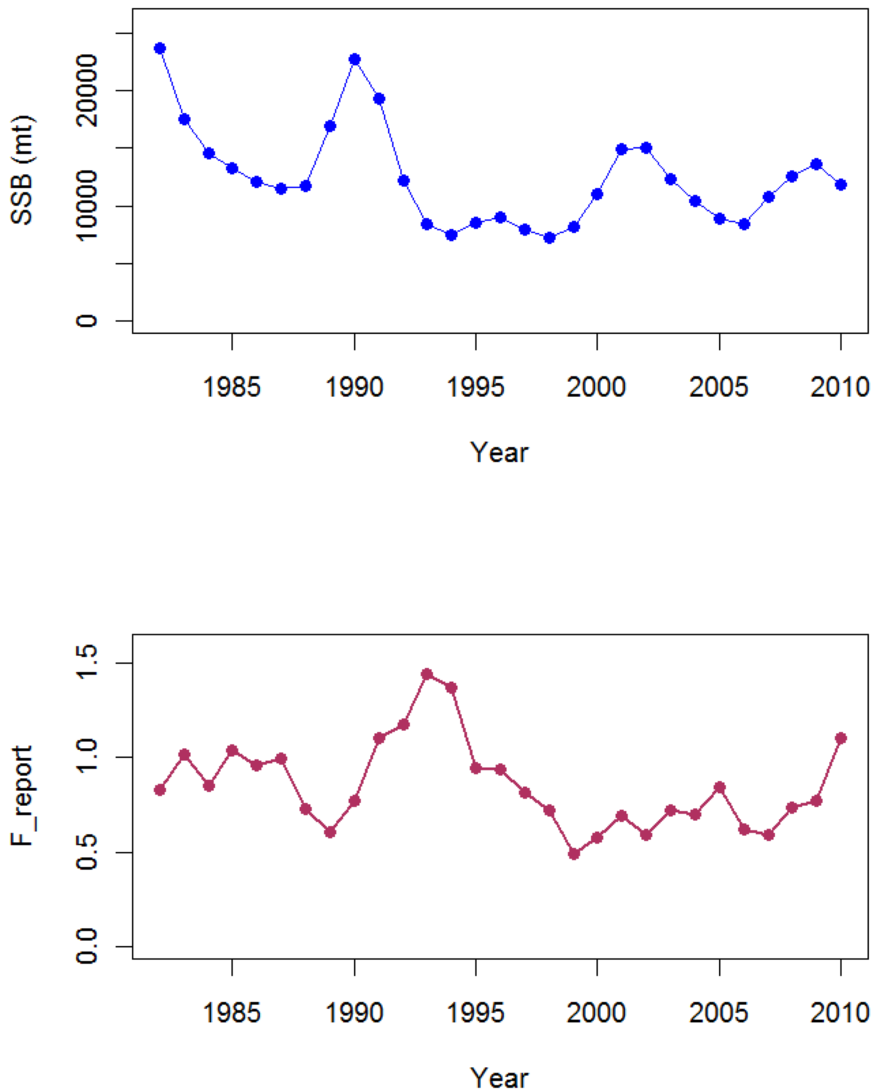
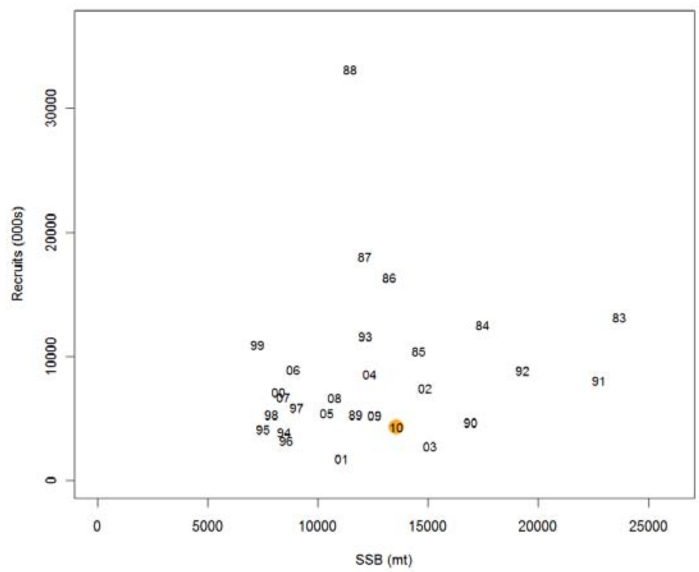


Figure A.140. ASAP BASE model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) and average fishing mortality ($F_{5\text{-}7}$ = F_report).



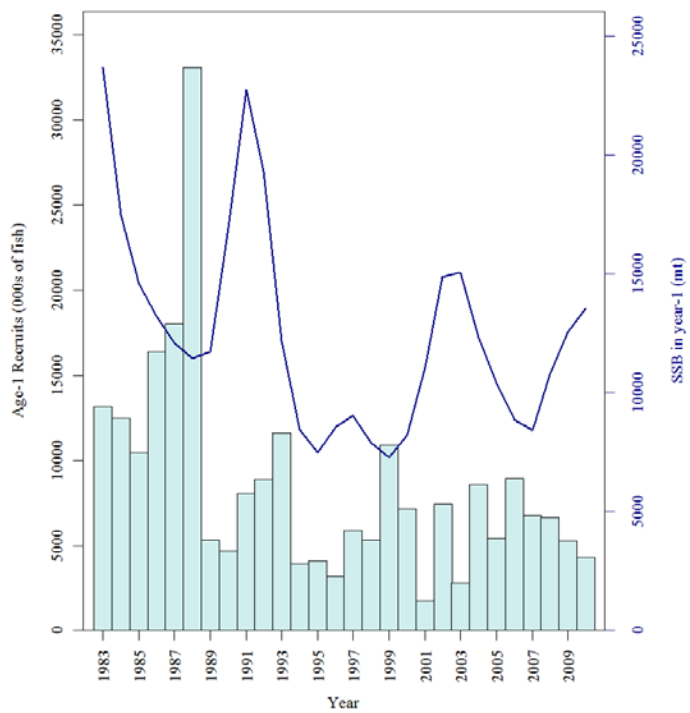


Figure A.141. Top: scatterplot of ASAP estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) versus recruitment at age 1 (000s). The symbol for each observation is the last two digits of the year (e.g., 88 indicated age 1 estimates of the 1987 year class). The most recent recruitment estimate is highlighted by an orange circle. Bottom: ASAP BASE time series of SSB (blue line) and age 1 recruitment (bars).

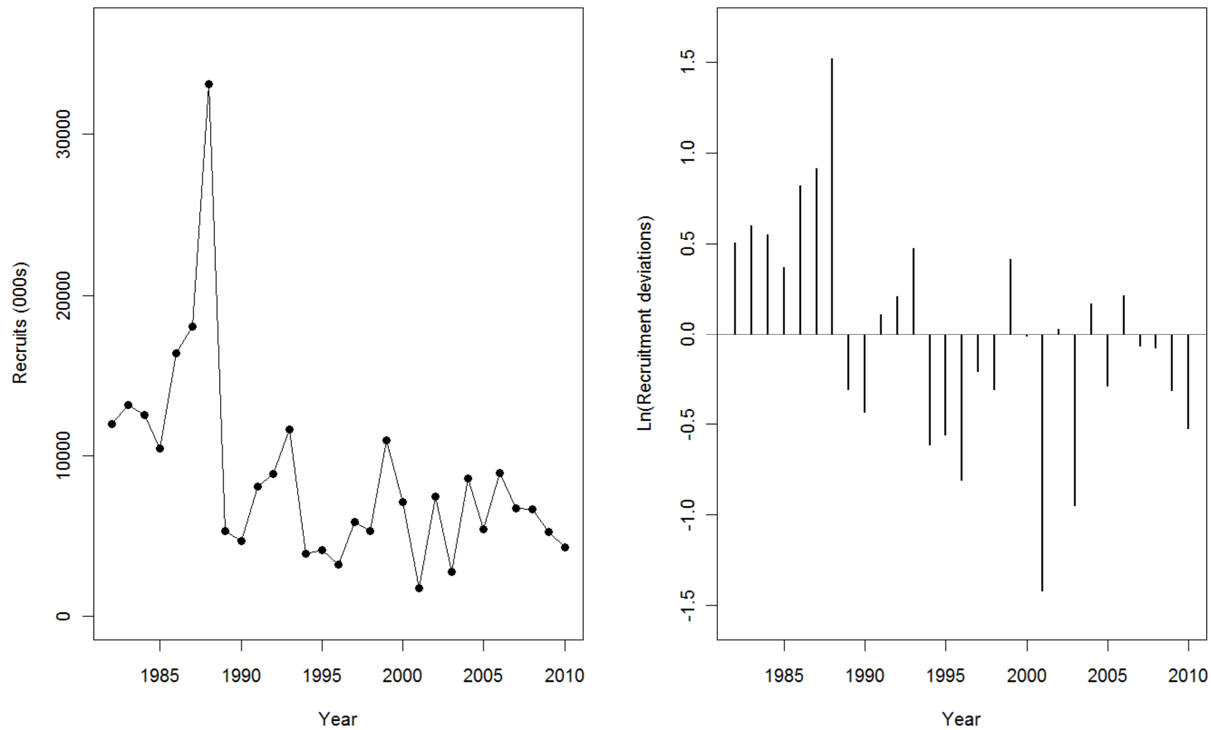
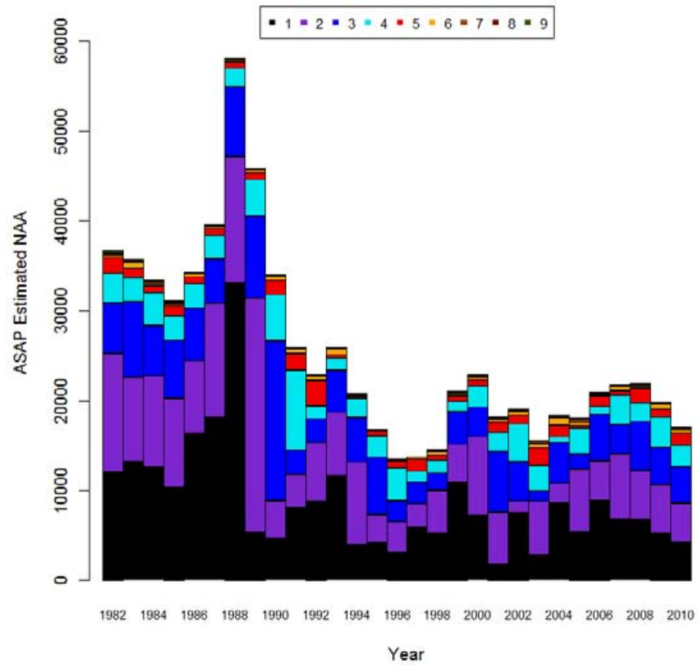


Figure A.142. ASAP BASE estimated Gulf of Maine Atlantic cod recruitment and recruitment residuals from the geometric mean.



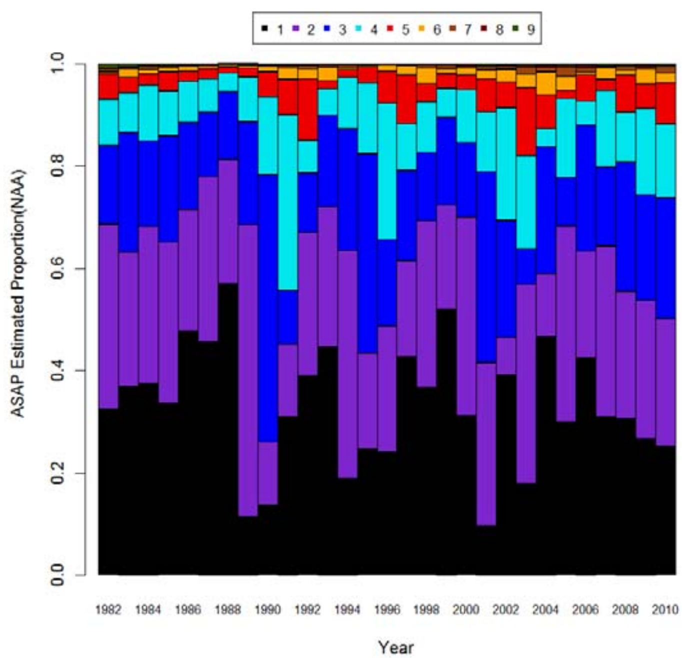


Figure A.143. ASAP BASE model estimates of Gulf of Maine Atlantic cod numbers-at-age in absolute (top) numbers (000s) and relative (bottom) terms.

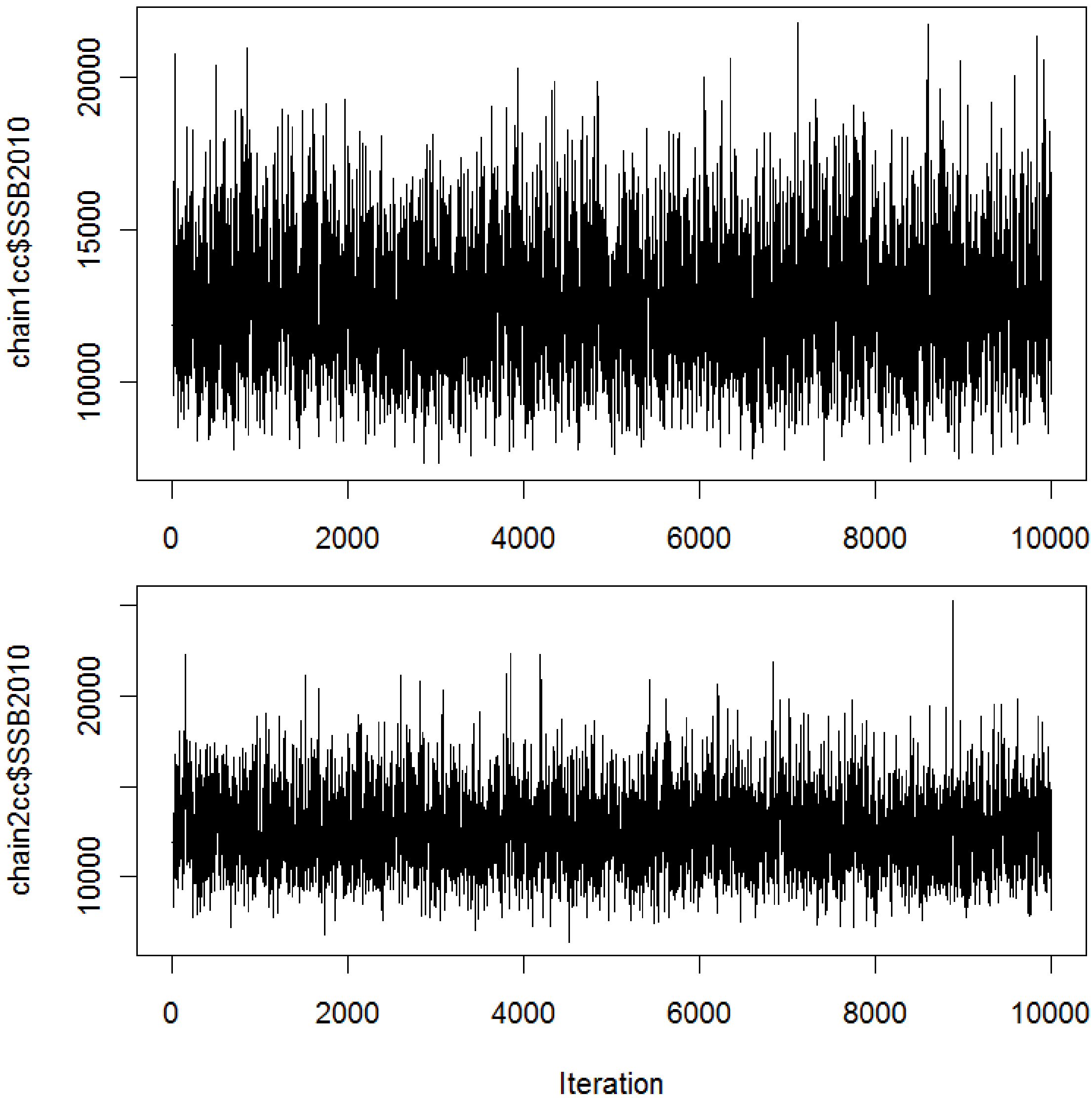
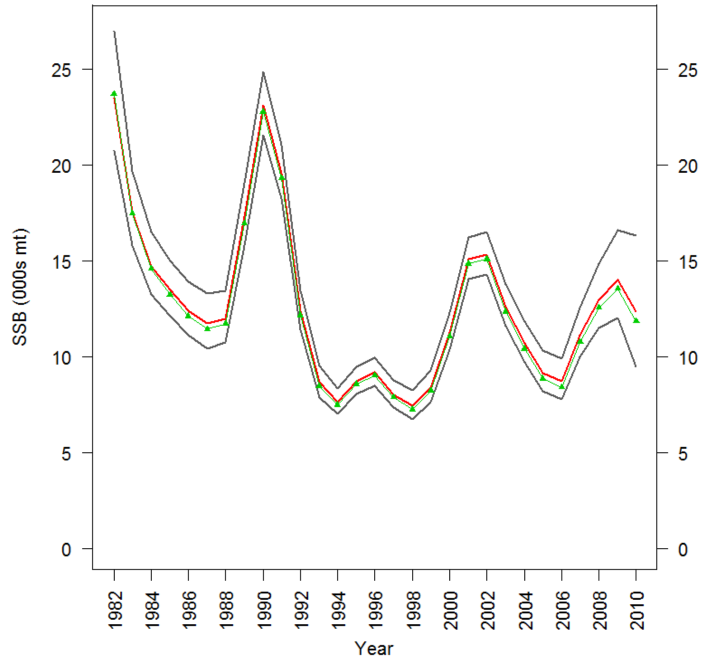


Figure A.144. Trace of MCMC chains for Gulf of Maine Atlantic cod SSB2010, showing good mixing (ASAP BASE model). Each chain had initial length of 1 million and was thinned at a rate of one out of every 100th. From the remaining 10,000 length chain (above), 1000 saved draws were extracted from every 10^{th} draw.



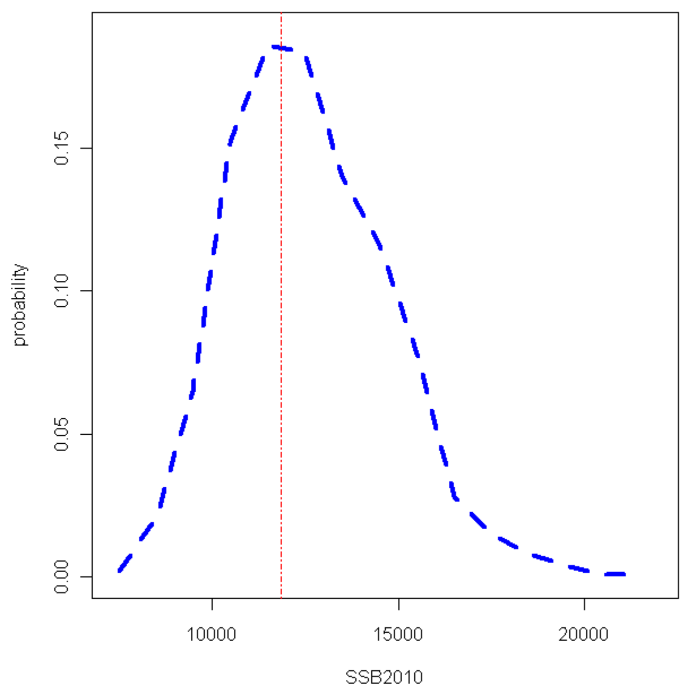


Figure A.145. Top: A 90% probability interval for Gulf of Maine Atlantic cod spawning stock biomass (SSB) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles. Bottom: MCMC distribution of spawning stock biomass in 2010, ASAP point estimate indicated by dashed red line.

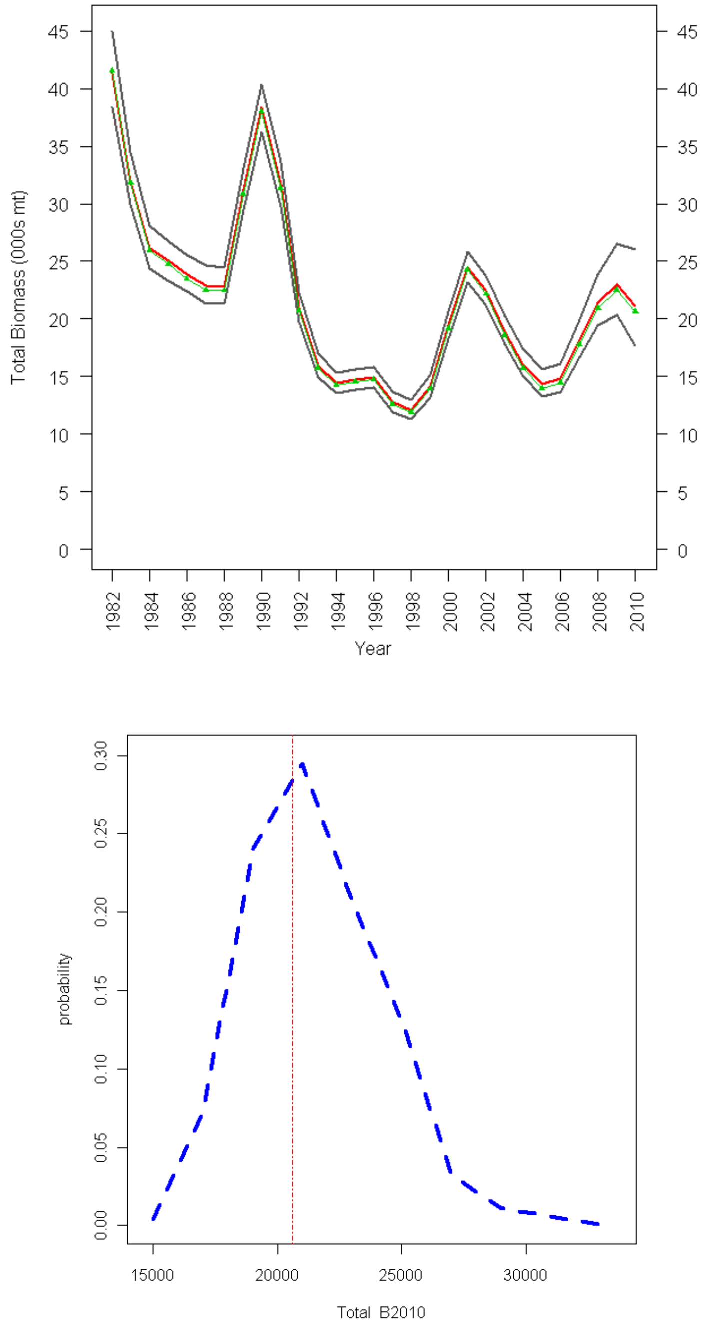


Figure A.146. Top: A 90% probability interval for Gulf of Maine Atlantic cod total stock biomass (B_{total}) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles. Bottom: MCMC distribution of total stock biomass in 2010 (B_{total}), ASAP point estimate indicated by dashed red line.

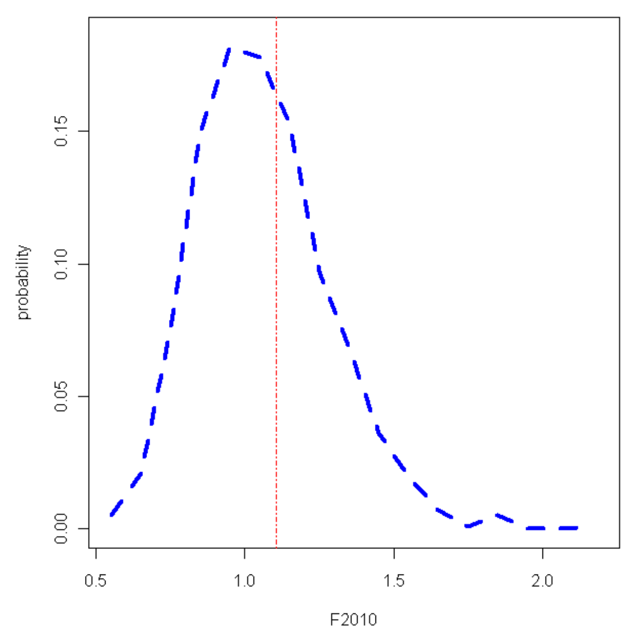
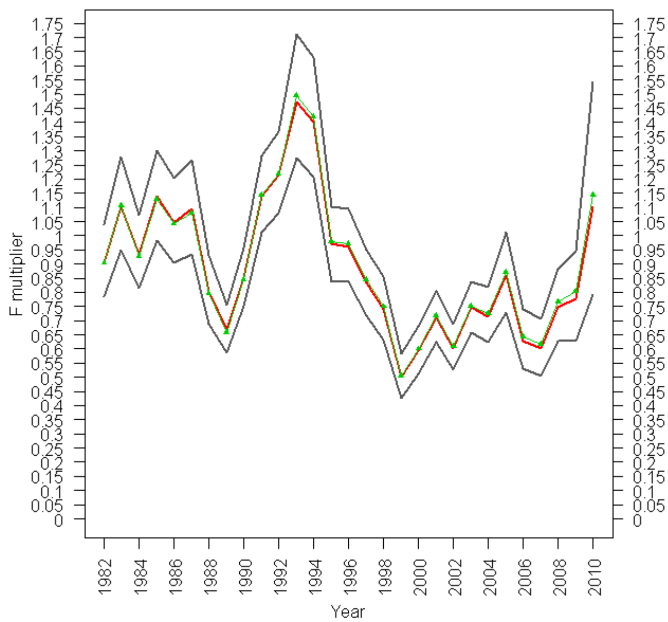


Figure A.147. Top: A 90% probability interval for Gulf of Maine Atlantic cod average fishing mortality from ages 5 to 7 (F_{5-7}) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles. Bottom: MCMC distribution of average fishing mortality from ages 5 to 7 (F_{5-7}) in 2010, ASAP point estimate indicated by dashed red line.



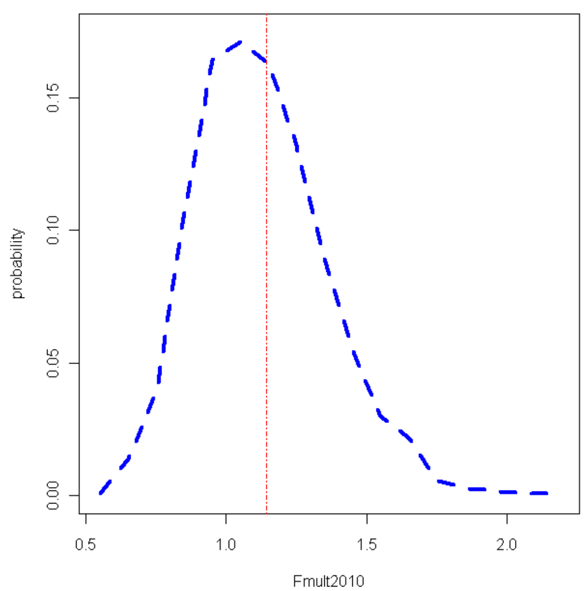
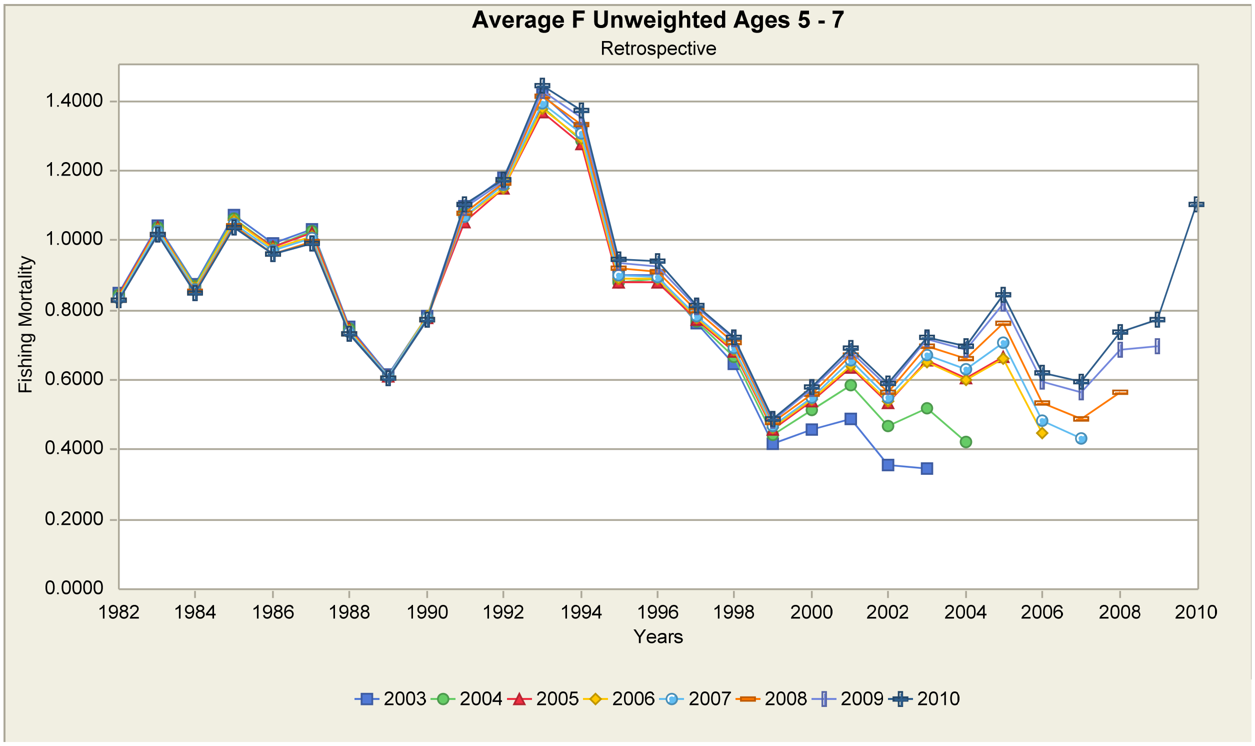


Figure A.148. Top: A 90% probability interval for Gulf of Maine Atlantic cod F_{mult}, total fishing mortality from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green line with filled triangles. Bottom: MCMC distribution of F_{mult}, total fishing mortality in 2010, ASAP point estimate indicated by dashed red line.



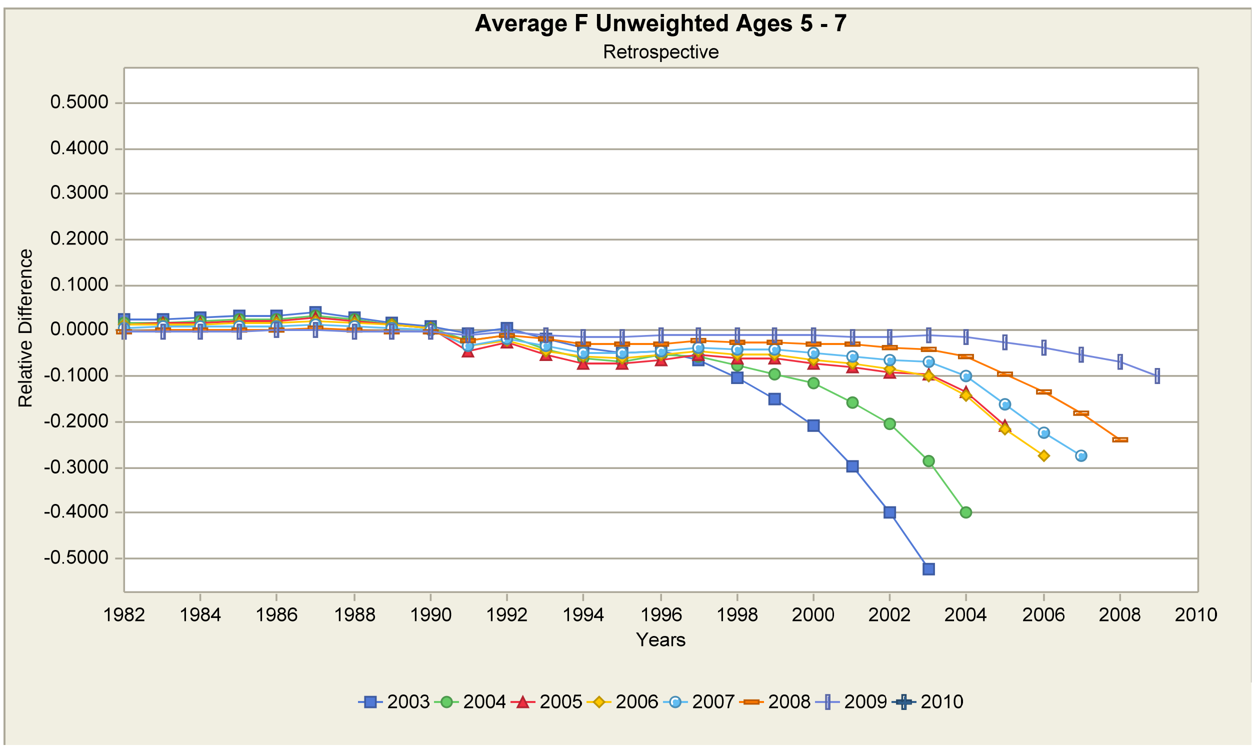
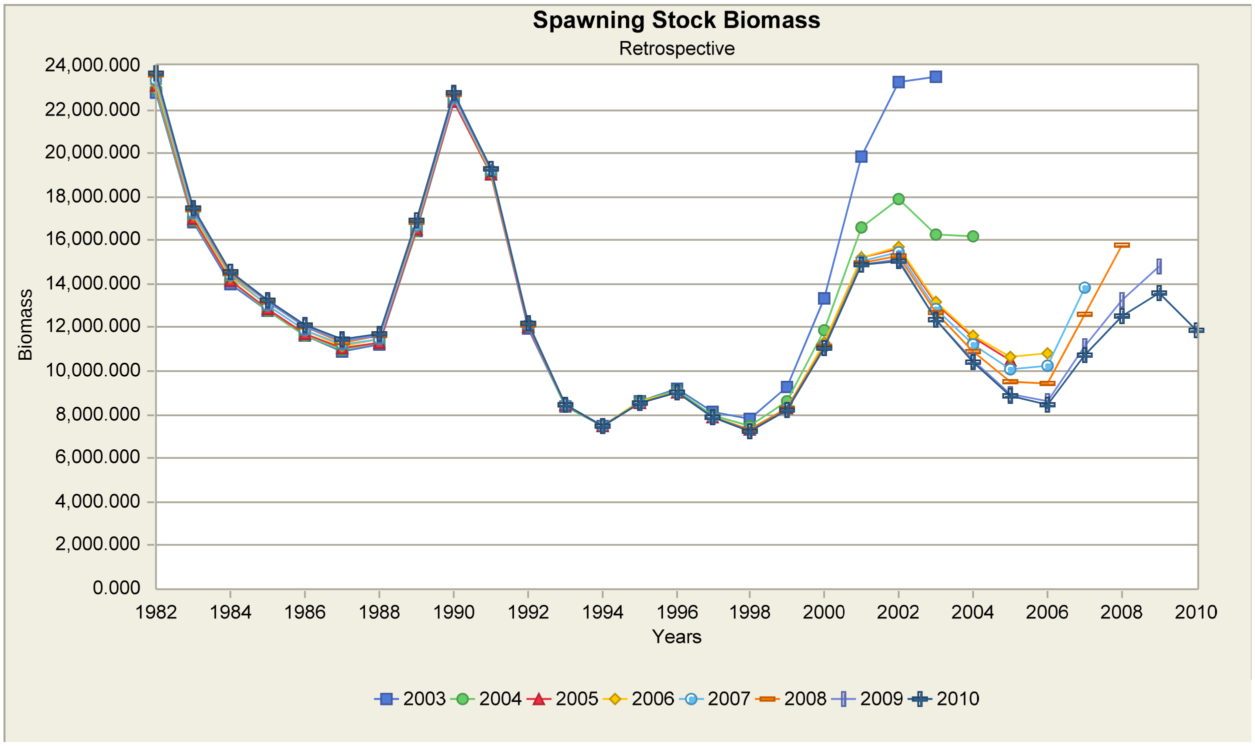


Figure A.149. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod average fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.



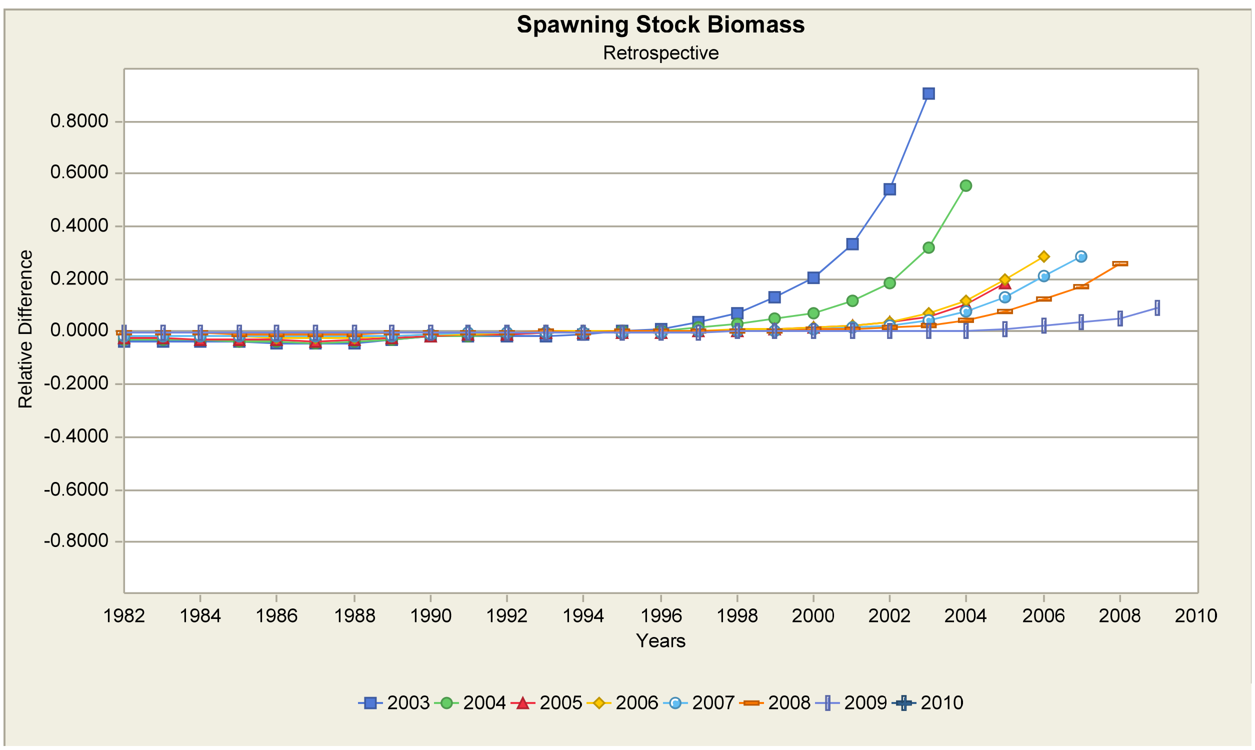
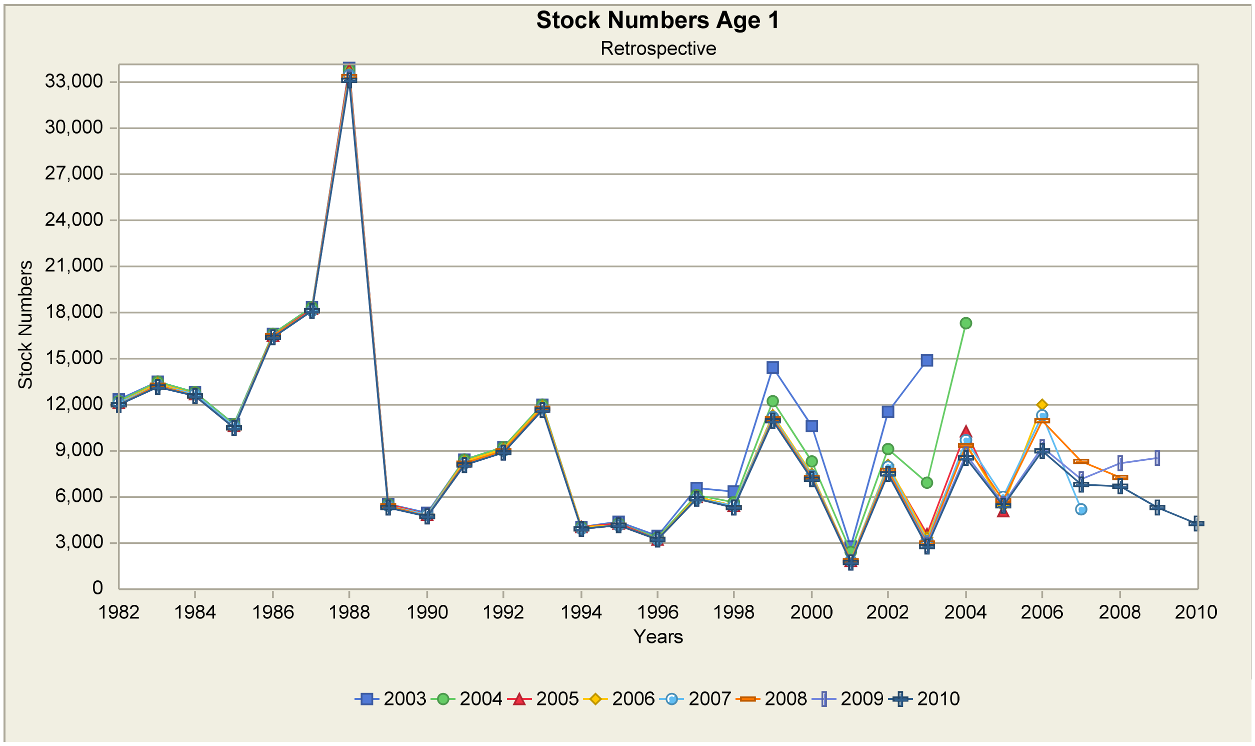


Figure A.150. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod spawning stock biomass (mt) in absolute (top) and relative (bottom) terms.



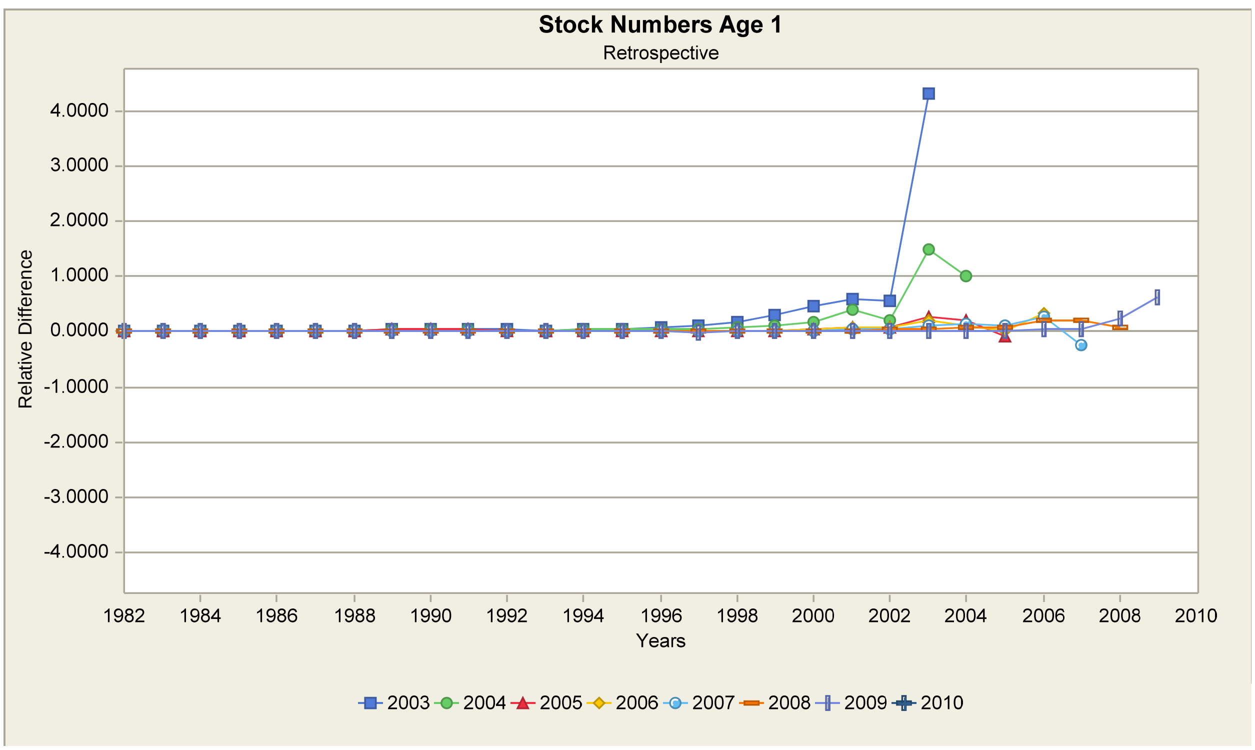


Figure A.151. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.

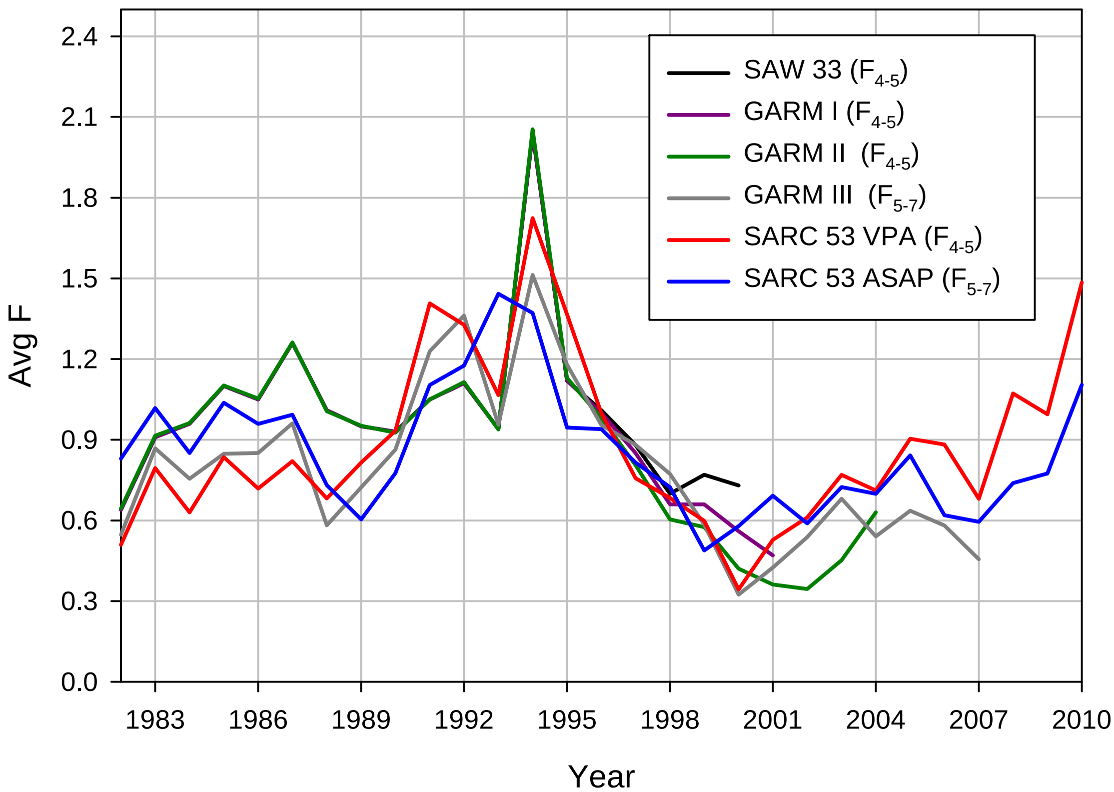


Figure A.152. Comparison of estimates of average fishing mortality from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates. **Note that the ages included in the average F calculation are not constant across assessments.*

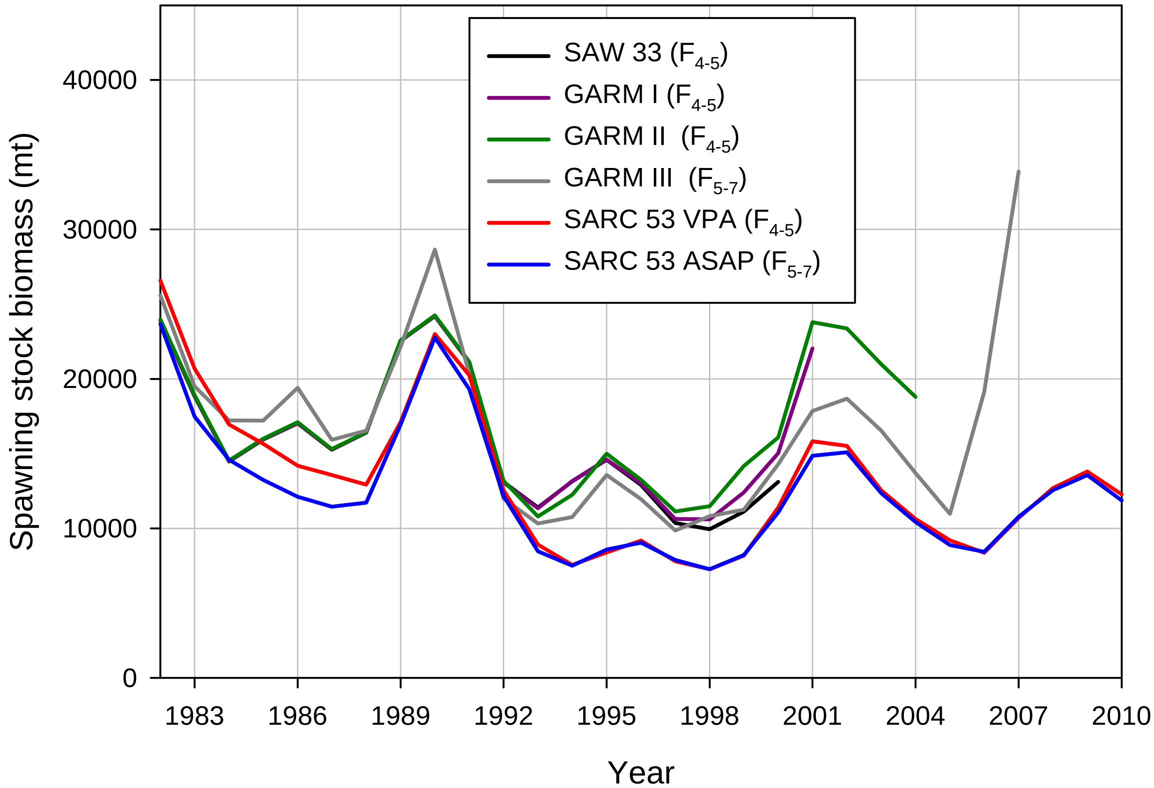


Figure A.153. Comparison of estimates of spawning stock biomass (mt) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

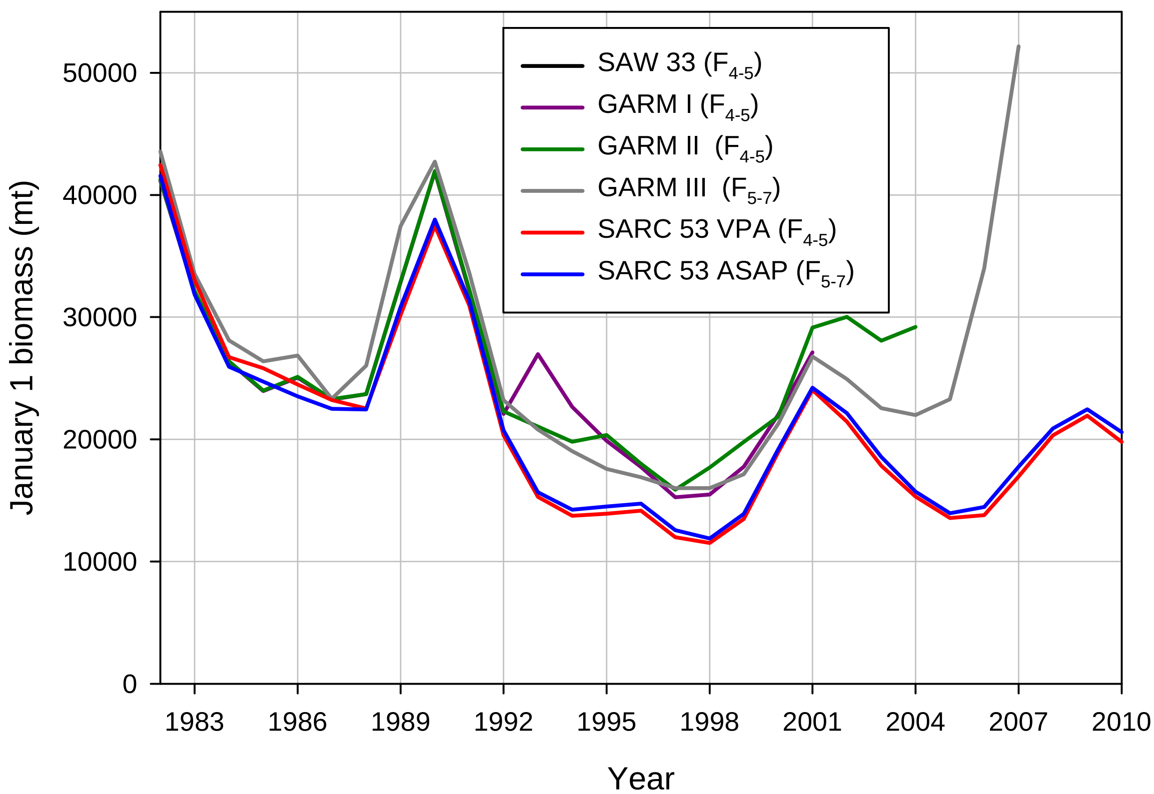


Figure A.154. Comparison of estimates of January 1 stock biomass (mt) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

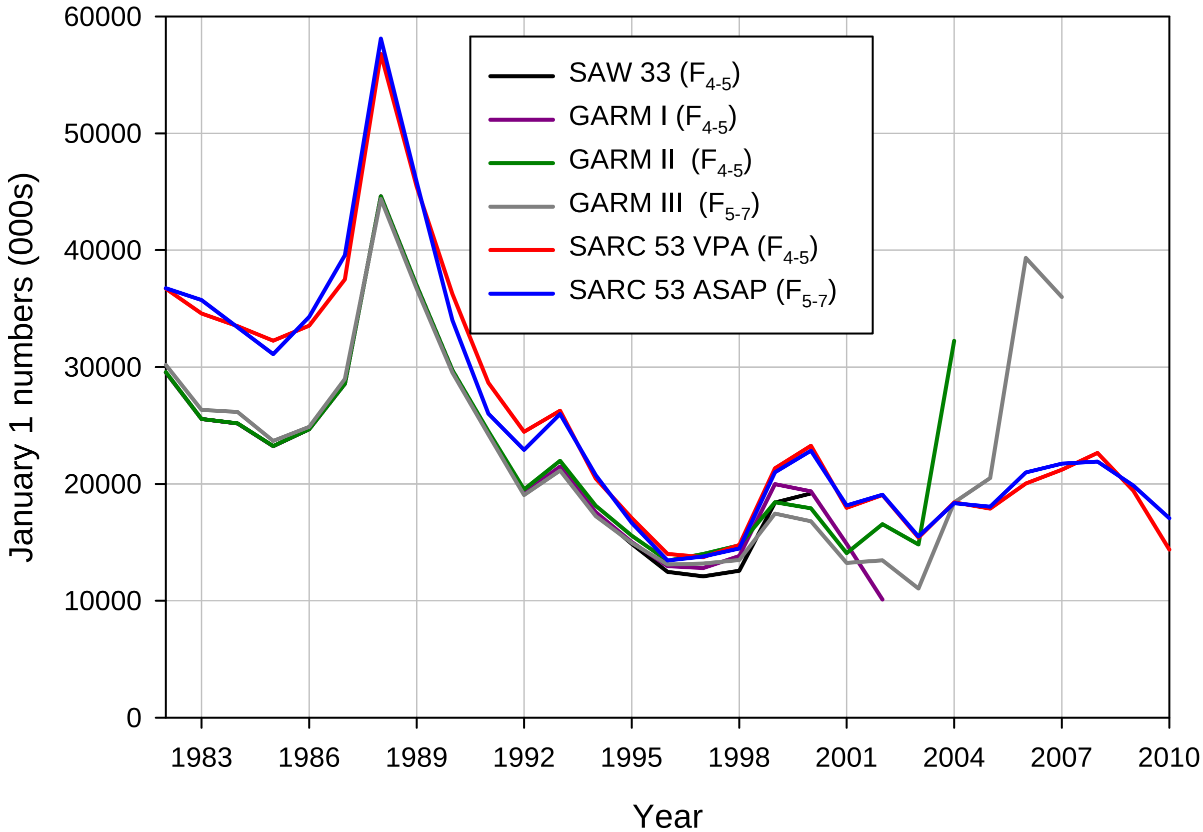


Figure A.155. Comparison of estimates of January 1 stock size (numbers, 000s) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

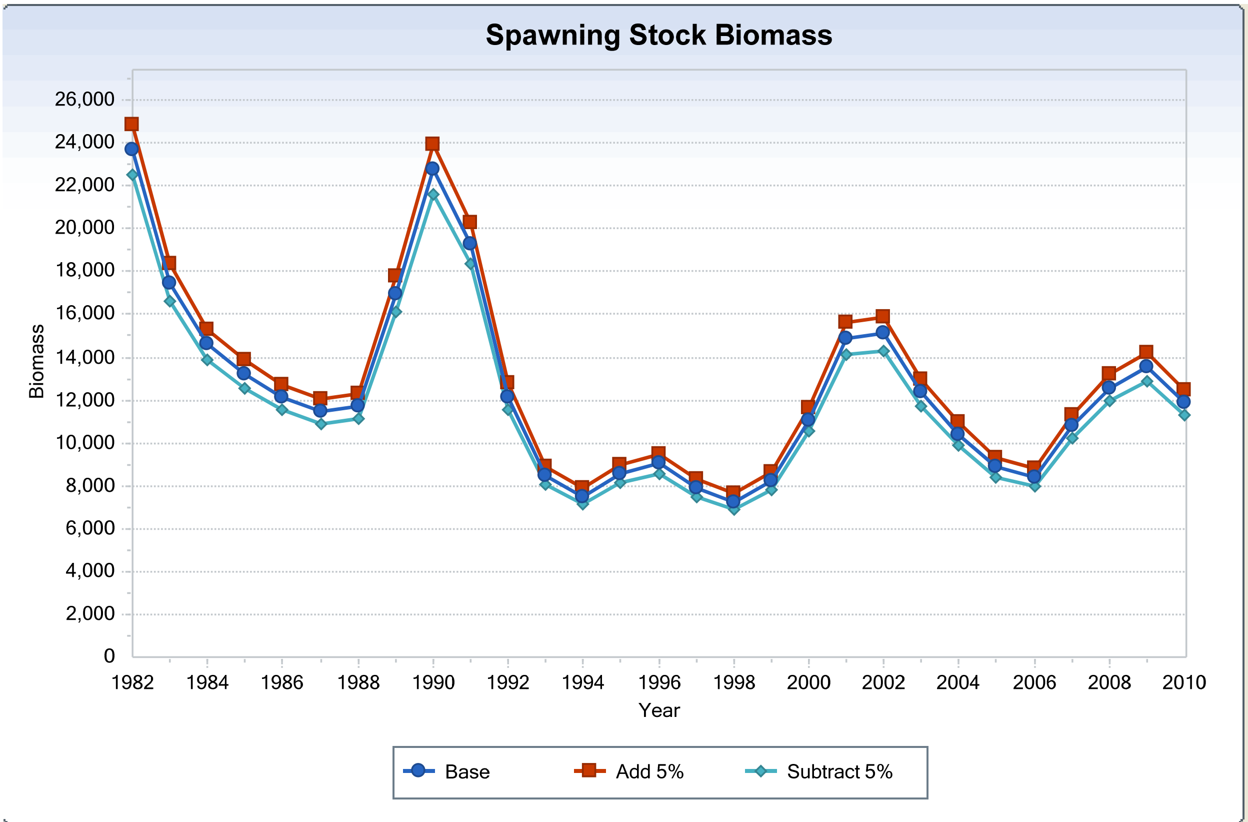
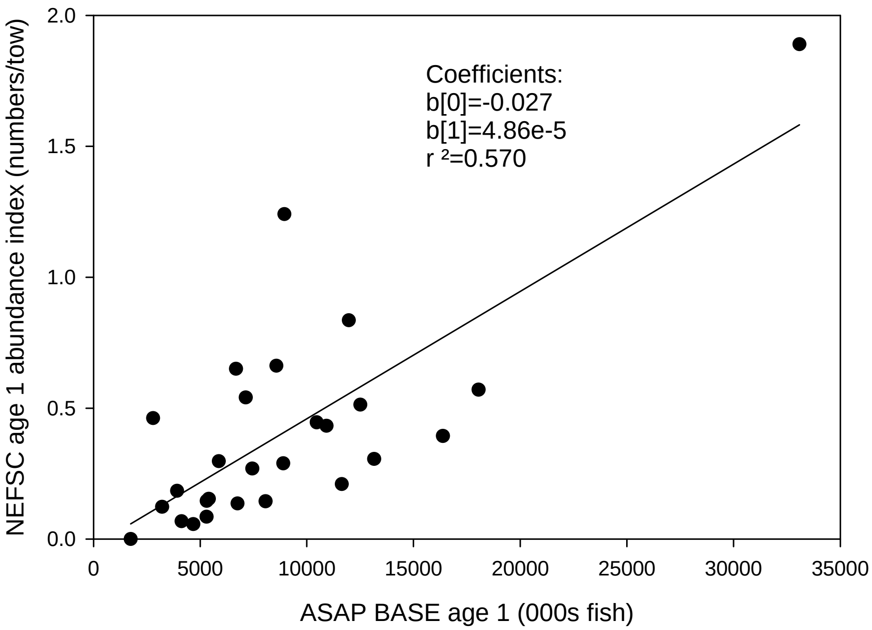


Figure A.156. Results of ASAP sensitivity runs exploring the impact of mis-allocation of Gulf of Maine Atlantic cod catch to stock areas on model performance. In each of the two sensitivity runs, the total catch was either increased or decreased by 5% commensurate with the likely scale of misallocation impacts on overall catch amounts.



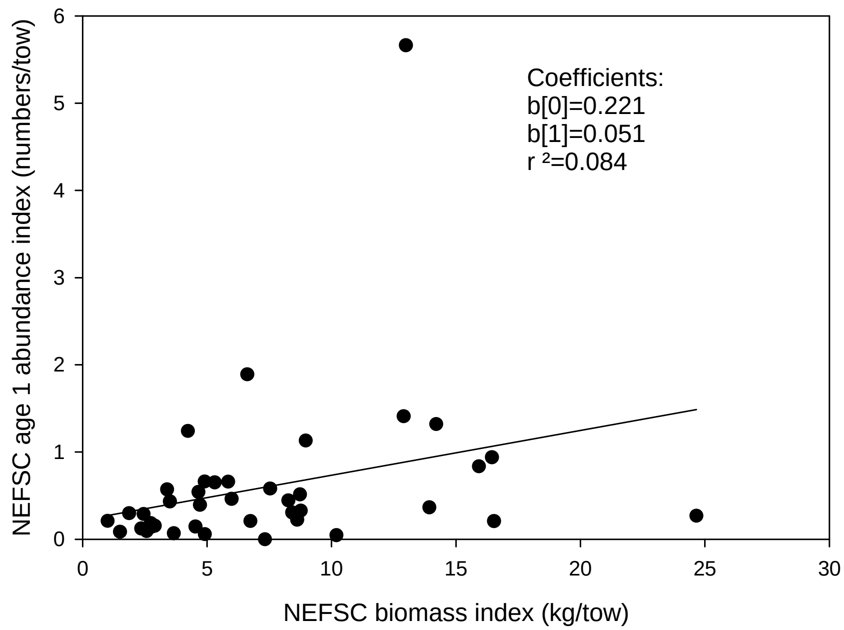


Figure A.157. Relationship of Gulf of Maine Atlantic cod age 1 estimated from the ASAP BASE model to the NEFSC fall survey age 1 abundance (numbers/tow) index from 1982 to 2008 (top). Relationship of he NEFSC fall sruvey age 1 abundance index to the NEFSC biomass (kg/tow) index from 1970 to 2010 (bottom).

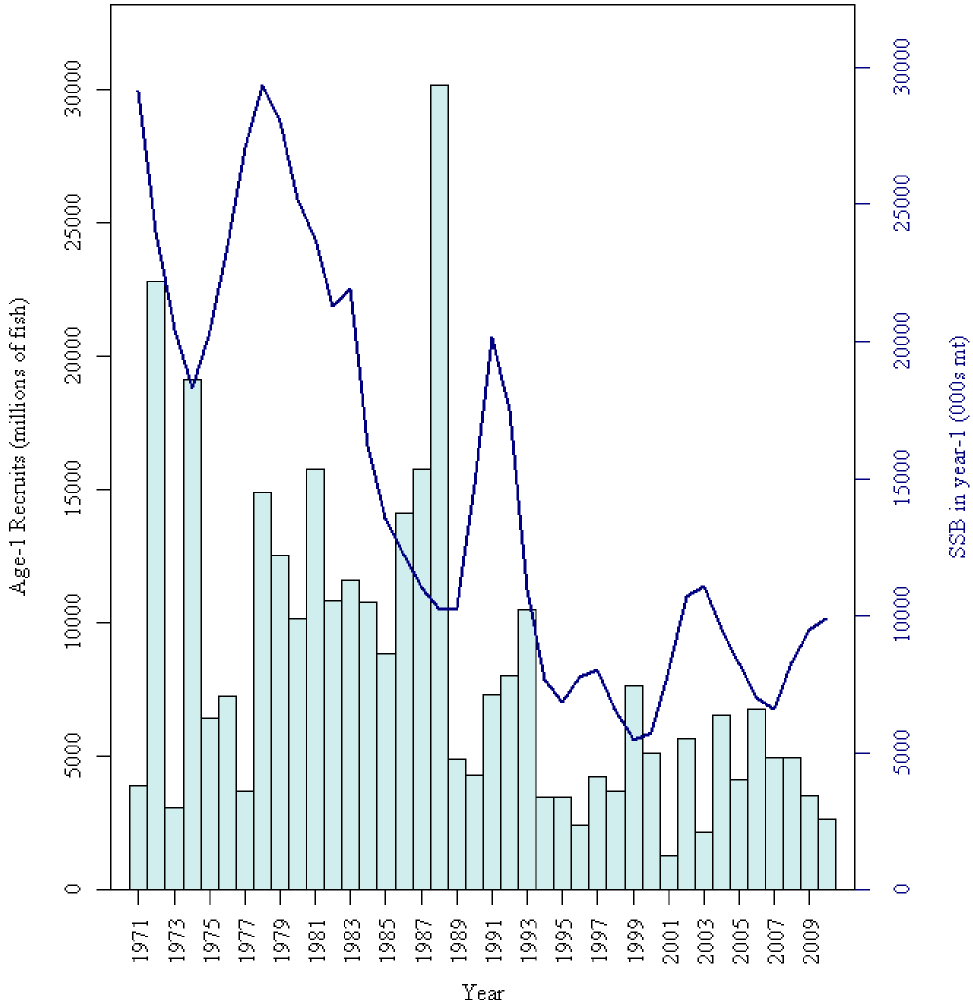


Figure A.158. Estimates of Gulf of Maine Atlantic cod age-1 recruits (solid bars) by year, and the spawning biomass (solid line, lagged 1 year) that produced that recruitment.

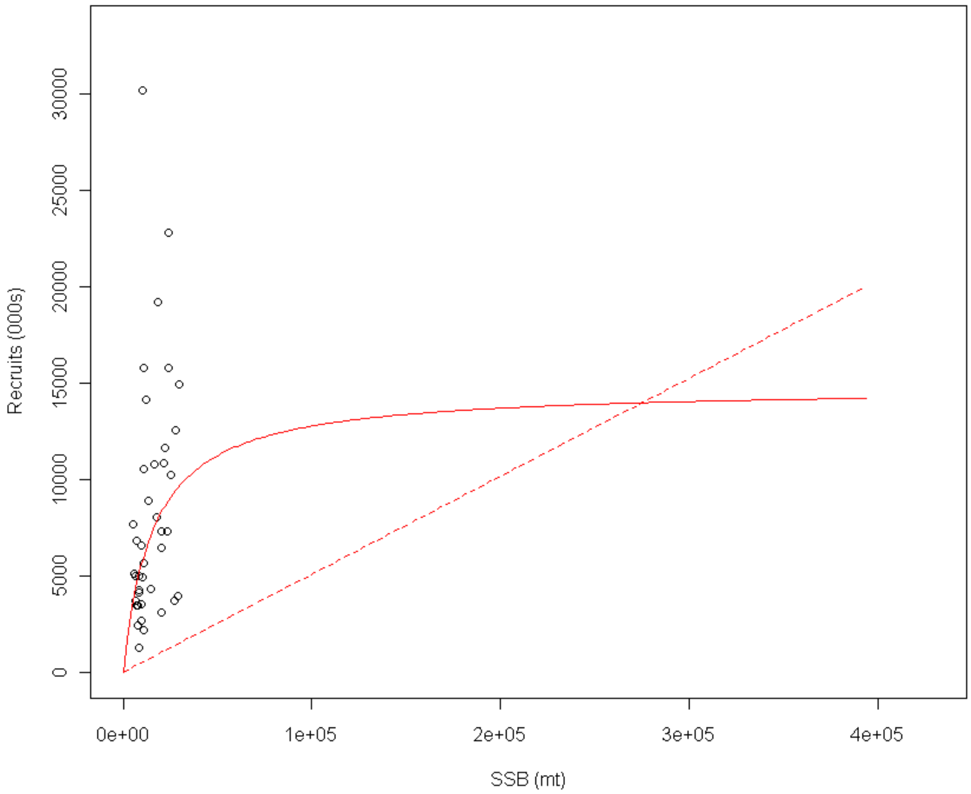


Figure A.159. Beverton-Holt fit (b) to Gulf of Maine Atlantic cod spawner-recruit relationship from the 1970 ASAP sensitivity model.

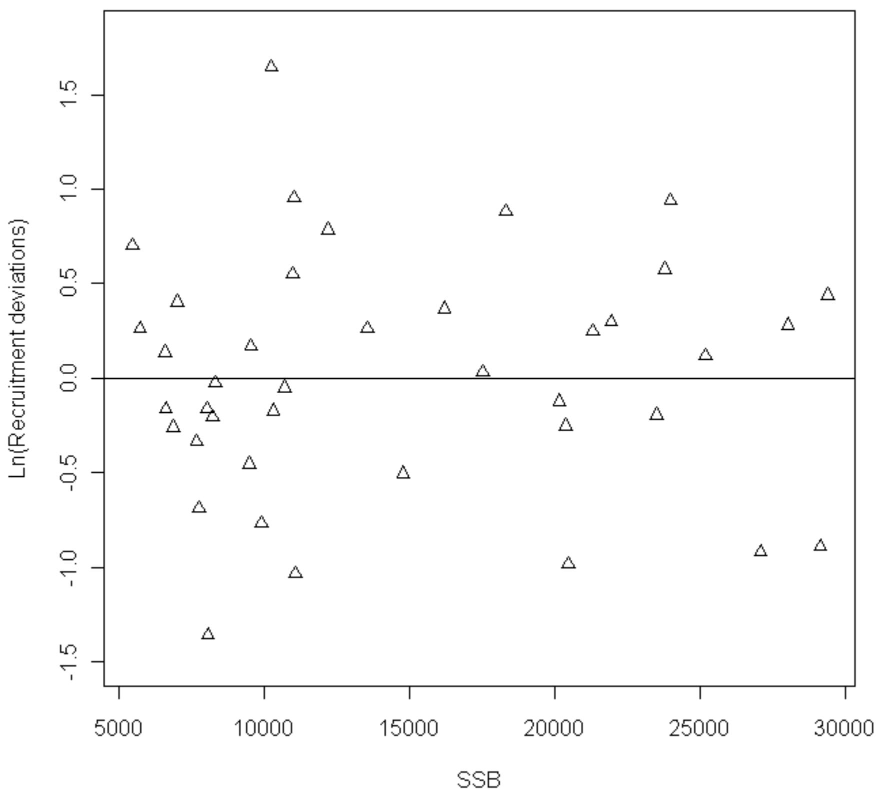


Figure A.160. Logscale residuals from the Beverton-Holt fit to Gulf of Maine Atlantic cod spawner-recruit relationship in the 1970 ASAP sensitivity model.

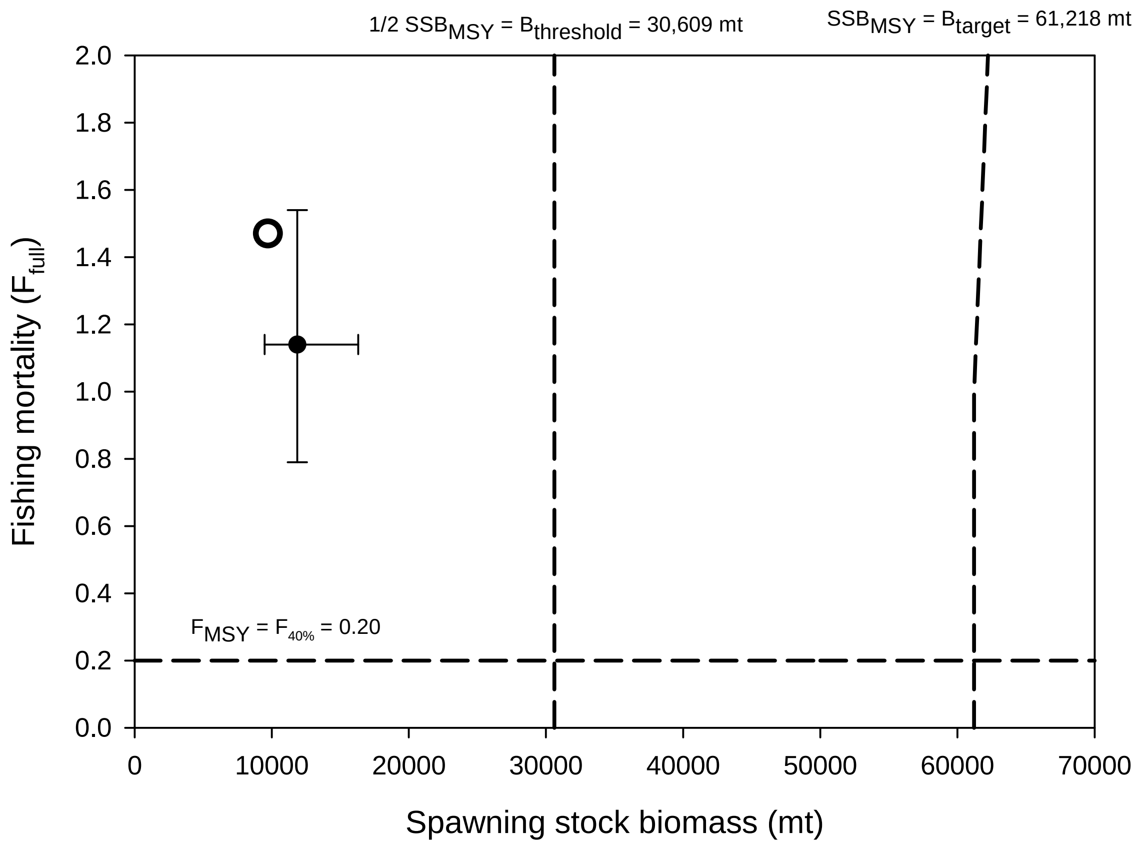


Figure A.161. Comparison of 2010 fishing mortality (F_{full}) and spawning stock biomass (SSB) of Gulf of Maine Atlantic cod relative to F_{MSY} proxy ($F_{40\%}$) and SSB_{MSY} both with (open circle) and without (solid black circle) accounting for retrospective pattern. The bias corrected point is based on a rho value determined from a 5-year peel. The unadjusted point is shown with the corresponding 90% confidence intervals.

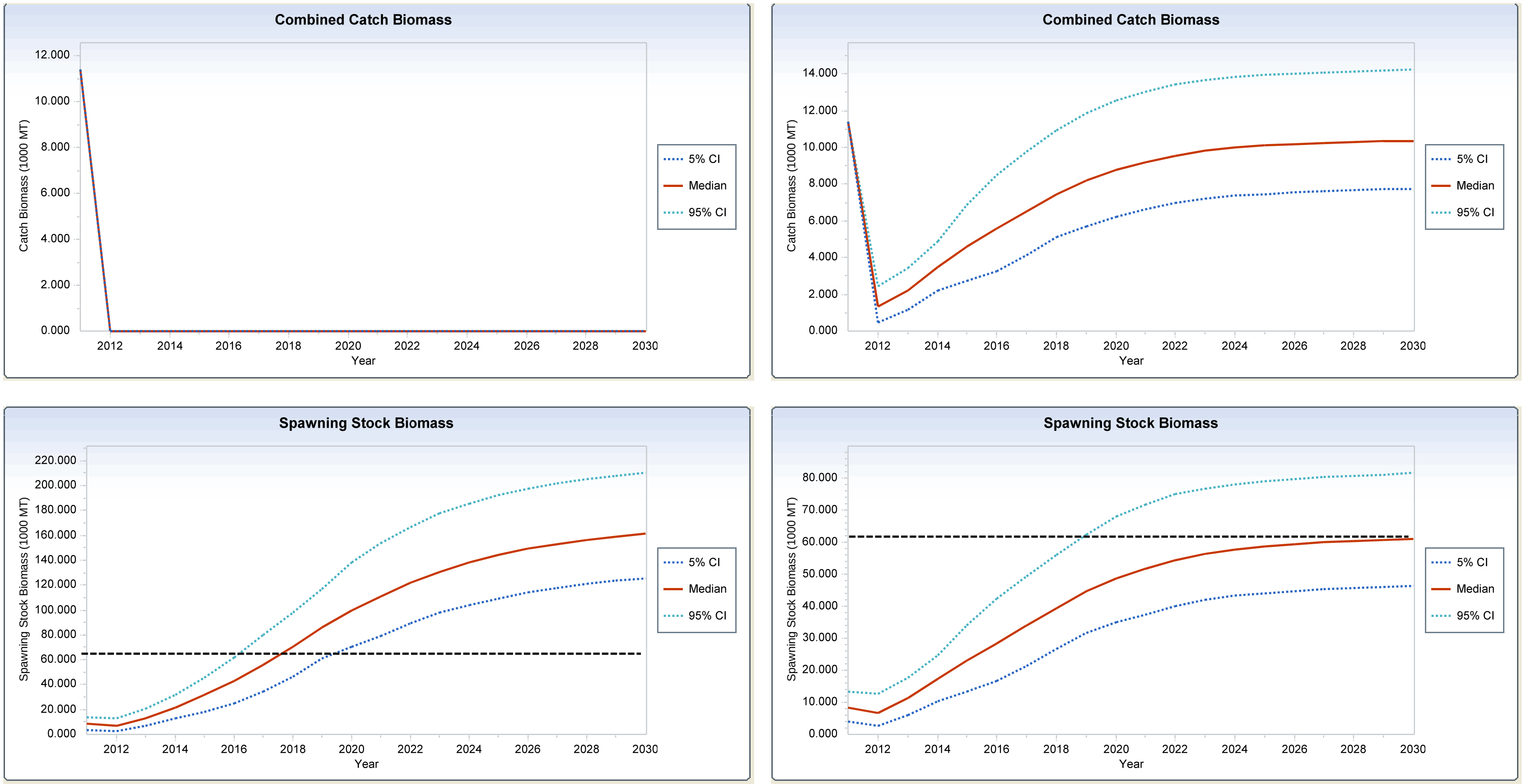


Figure A.162. Short-term projections for Gulf of Maine Atlantic cod in terms of fishery yield (catch, left) and spawning stock biomass (SSB, right) under two different harvest scenarios: zero fishing mortality (left) and fishing at the F_{MSY} proxy ($F_{40\%}$; right).

Appendix 1. List of meeting attendees and working group participants (black box indicates attendance on the specific meeting day)

Participant	Affiliation	Industry Meeting	Data Working Group Meeting			Models & Biological Reference Point Meeting				
		8/16/2011	9/7/2011	9/8/2011	9/9/2011	10/17/2011	10/18/2011	10/19/2011	10/20/2011	10/21/2011
Chris Legault	NOAA - NEFSC					■	■	■	■	
Dvora Hart	NOAA - NEFSC							■	■	
Eric Robillard	NOAA - NEFSC		■							
Henry Milliken	NOAA - NEFSC				■					
Jessica Blaylock	NOAA - NEFSC		■		■			■		
Jon Hare	NOAA - NEFSC						■			
Katherine Sosebee	NOAA - NEFSC		■	■	■	■	■	■	■	■
Liz Brooks	NOAA - NEFSC (Working Group Chair)	■	■	■	■	■	■	■	■	■
Loretta O'Brien	NOAA - NEFSC	■			■	■	■	■	■	■
Michele Traver	NOAA - NEFSC		■		■					
Mike Palmer	NOAA - NEFSC (Assessment Lead)	■	■	■	■	■	■	■	■	■
Paul Nitschke	NOAA - NEFSC		■	■	■	■	■	■	■	■
Paul Rago	NOAA - NEFSC			■	■	■				
Susan Wigley	NOAA - NEFSC					■	■	■	■	■
Tim Miller	NOAA - NEFSC								■	■
Don Frei	NOAA - NERO	■								
Sarah Heil	NOAA - NERO	■				■				■
Tom Warren	NOAA - NERO	■				■				■
Steven Correia	MADMF		■	■	■			■	■	■
Annie Hawkins	NEFMC	■								
Tom Nies	NEFMC				■	■	■	■	■	■
Dan Goethel	SMAST	■								
David Martins	SMAST		■	■	■					
Lisa Kerr	SMAST			■	■					
Steve Cadrin	SMAST					■			■	
Yong Chen	UMAINE				■		■	■		■
Jonathon Peros	GMRI	■								
Michelle Loquine	GMRI	■								
Maggie Raymond	Industry (AFM)					■	■		■	
Eric Brazer	Industry (CCCHFA)				■					
Melissa Sanderson	Industry (CCCHFA)				■					
Tom Dempsey	Industry (CCCHFA)				■					
Tom Rudolph	Industry (CCCHFA)				■					
Aaron Dority	Industry (NCCS)				■					
Joe Ravcazzo	Industry (NEFS I)	■								
Vencenso Toorman	Industry (NEFS I)	■								
Al Cottone	Industry (NEFS II)	■								
David Lefeile	Industry (NEFS II)	■								
Joseph Orlando	Industry (NEFS II)	■								
Mario Orlando	Industry (NEFS II)	■								
Paul Vitale	Industry (NEFS II)	■								
Russell Sherman	Industry (NEFS II)	■								
Nick Brancaleone	Industry (NEFS III)	■								
Mike Walsh	Industry (NEFS VI)	■								
Elizabeth Etrie	Industry (NESSN)	■								
Jackie Odell	Industry (NSC)	■	■			■	■			
Vito Giacalone	Industry (NSC)	■								■
Ben Martens	Industry (Port Clyde Sector Manager)	■								
Doug Butterworth	Industry consultant					■	■	■	■	■
Rebecca Rademeyer	Industry consultant					■	■	■	■	

Appendix 2. Additional material presented during SARC 53 including ASAP sensitivity runs and an evaluation of biomass scale and estimates of ASAP-estimated survey catchability.

A2.1 Additional ASAP sensitivity runs

During the SARC 53 meeting, the Panel requested several additional sensitivity runs of the ASAP model to a) better understand the development of the base assessment model, and b) to better characterize overall model uncertainty. The types of sensitivity runs requested included:

1. A better description of some of the preliminary Age Structured Assessment Program (ASAP) models that were explored when transitioning from the previous Virtual Population Assessment (ADAPT-VPA) base model to the ASAP model.
2. Accounting for greater uncertainty in total catch by increasing the coefficients of variation (CVs) inputs in the model.
3. Limiting the survey indices to only those age classes that exhibited internal consistency in terms of correlations between successive ages (ages 1-6).
4. Start the assessment in 2000 so that the assessment is not confounded by changes in fishery selectivity and/or biology that may have occurred earlier on in the assessment period.
5. Run the assessment with each survey index individually to better understand the influences of each survey on the assessment.

A2.1.1. Preliminary development of an ASAP model

There were well over 20 different preliminary ASAP model configurations that were explored prior to the development of the ASAP base model (BASE). Many of these preliminary models attempted to take advantage of the complexity and flexibility of ASAP by partitioning fishery catch into its various fleet (commercial, recreational) and disposition (retained, discarded) components. These preliminary explorations, while informative in broad terms for demonstrating the robustness of the base model results with respect to the trend and magnitude of the resource, were untenable for consideration as a base model. This is primarily because the more complex model configurations tended to be over-parameterized (and therefore unstable to even minor perturbations) or the model diagnostics were poor.

Although there were many different model configurations and parameterizations considered, they can be categorized into three main configurations. When viewed in this way, it is more straightforward to trace the transition from a VPA-based assessment to development of the statistical catch-at-age model, ASAP. The first formulation explored was similar to the VPA model formulation (BASE_VPA). Two additional configurations, PRELIM_2FLEET and PRELIM_4FLEET, explored the possibility of decomposing the single VPA catch-at-age matrix into two or four subcomponents, respectively. Details of these three broad categories are discussed below in more detail.

In the BASE_VPA formulation, a single catch-at-age matrix with an age 11+ group was considered, and survey indices were fit to individual indices-at-age rather than tuning to the aggregate indices with the age compositions fit separately. A single fishery selectivity ogive was assumed to operate for the period 1982 to 2010. This selectivity assumption differs from the VPA, where fishery selectivity can vary annually. To estimate the single fleet selectivity, age six was assumed to be fully selected, and the remaining ages were freely estimated. The coefficient of variation (CV) on the aggregate fishery catch was set at 0.05. All survey indices used in the base VPA model (run 10) were incorporated including the MADMF fall survey (which was later dropped in the final BASE model). Unlike in the VPA, where fall survey indices were lagged forward an age and a year, ASAP can account for survey timing within the year, so survey indices-at-age were entered as true ages and years. The CVs on all survey indices-at-age were fixed at 0.3. Recruitment steepness was fixed at 1, so recruitment was estimated as deviations about the geometric mean rather that attempting to fit to a stock-recruit function. Unlike the base VPA model (run 10), the time of spawning was updated to April 1 in the BASE_VPA model similar to VPA run 10g.

The time series of spawning stock biomass (SSB) and average fishing mortality on ages 5-7 ($F_{5\text{-}7}$) was similar between the BASE and BASE_VPA runs from approximately 1998 onward (Appendix Fig. A2.1). There were large differences in the SSB time series early on (1982 – 1988) that are primarily the result of differences in the model estimates of age 9^+ fish (Appendix Fig. A2.2). The large amount of age 9+ fish in the BASE_VPA model is an artifact of the ASAP burn in period where a large pulse of older fish is necessary to support the strong doming of the fishery selectivity estimated in the BASE_VPA model (Appendix Fig. A2.3). While the doming of the fishery selectivity is quite strong, the selectivity at age 9 and older is imprecisely estimated with CVs exceeding 0.50 (Appendix Table A2.1). The selectivity for ages 1 through 7 is similar, though not identical to the selectivity of the BASE model in the 1991 – 2010 time block. Overall, the current perception of the Gulf of Maine cod stock based on the BASE_VPA model is similar in terms of current stock biomass and fishing mortality rates.

Subsequent formulations of the ASAP model did not tune to the survey indices-at-age separately, rather they tuned to the aggregate survey indices with age compositions fit assuming a multinomial error distribution. All preliminary ASAP runs used three survey indices (NEFSC spring, NEFSC fall, MADMF spring) with age compositions fit to ages 1 through 11^+. Survey selectivities were estimated assuming a double logistic fit. All preliminary ASAP runs attempted to break the fishery catch into separate fleets (commercial and recreational). Selectivity was fit as a double logistic with three separate selectivity blocks per fleet. The timing of the selectivity block varied slightly by fleet, but generally, there was a single selectivity block per decade. Two main categories of the two fleet formulations were explored in the preliminary runs: 1) catch was divided into two fleets and within each fleet, discards are accounted for assuming a release mortality option. Release mortality was set at 100% (PRELIM_2FLEET); and 2) 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 (PRELIM_4FLEET).

The results from these preliminary runs were not substantially different than the BASE run in terms of SSB or $F_{5\text{-}7}$ (Appendix Fig. A2.4). The PRELIM_2FLEET had slightly higher estimates of SSB and F owing to greater doming of the fleet selectivities. The effects of the doming are evident in the number of fish surviving to the age 9^+ group (Appendix Fig. A2.5). Recruitment was nearly identical in the preliminary runs relative to the BASE run. While the results of these preliminary runs were similar to the BASE run, the preliminary runs suffered from diagnostic issues. Specifically, the PRELIM_2FLEET model suffered from strong residual patterning in the fits to catch combined with generally poor fits to the discard components. For both the commercial and recreational fleet the retained catch tended to have strong positive residuals while the discarded catch had strong negative residuals (see Appendix Fig. A2.6 for an example from the commercial fleet). Alternate configurations of the PRELIM_2FLEET model were attempted to address the residual patterning with limited success.

The development of the PRELIM_4FLEET model was an attempt to provide greater model flexibility and reduce the tension between landings and discards leading to the strong residual patterning. The PRELIM_4FLEET configuration was successful in this regard, but still resulted in poor overall fits to the discard fraction of the catch (Appendix Fig. A2.7). Subsequent attempts to improve the fit of the PRELIM_4FLEET were largely unsuccessful. Moreover, the model appeared to be highly unstable and many of subsequent model formulations failed to converge. Given the problems experienced with these complex ASAP formulations, a decisions was made to simplify the model formulation. Subsequent formulations fit to the aggregate catch as was done in the BASE run rather than attempting to treat fleet catches explicitly.

A2.1.2. Accounting for additional catch uncertainty

The SARC Panel expressed some 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.20) and recreational catch percent standard errors (PSE) around 20% (Table A.34). The Panel felt that CVs of 0.10 (BASE_CV10) or 0.15 (BASE_CV15) on the aggregate catch should be explored to examine the sensitivity of the BASE model to alternate assumptions. In these sensitivity runs only the CVs on the aggregate catch were adjusted; all model inputs and parameters were held constant.

The results of the sensitivity runs showed little impact on overall results in terms of SSB, F, age-1 recruitment and total stock size (Appendix Fig. A2.8 and A2.9). The largest impacts, while small, occurred during the late 1980s and early 1990s when large catches of Gulf of Maine cod occurred. Increasing the CVs on aggregate catch reduced the overall fit on catch; models with higher CVs were less inclined to fit to the high catch estimates during this period (Appendix Fig. A2.10). Lower catches lead to lower model estimates of recruitment and subsequent stock size, thus accounting for the small discrepancies observed in the late 1980s and early 1990s.

Increasing catch CVs lead to slight improvements in the model fits to the survey indices, but only marginally (Appendix Fig. A2.11). The root mean square error on the NEFSC spring survey went from 1.05 under the BASE model to 1.00 in the BASE_CV15 model. There was no noticeable change in the NESFC fall survey. The MADMF spring survey improved from a RMSE of 1.07 in the BASE model to 1.04 under the BASE_CV15 model. Overall, increasing CVs on the aggregate catch had negligible impacts on the assessment results.

A2.1.3. Restricting the age range in the survey to those ages that exhibit internal consistency

The SARC Panel was interested in examining the sensitivity of the BASE model to inclusion of only those survey ages that showed internal consistency across time (i.e., ages for which cohorts were traceable across years). An examination of cohort tracking within the survey suggested that in general, cohorts could be tracked from one age to the next at ages 1-6 on average across all surveys (Appendix Table A2.2). The division was not distinct, but does provide a basis for restricting surveys to an age range where there is sufficient information. Additionally, at survey ages greater than age 6, there is a notable increase in the number of zero indices-at-age (Tables A.48, A.49 and A.53).

The SSB and F trends of the survey, age-6 truncated run (BASE_AGE6) were identical to the BASE run, though the scale of the BASE_AGE6 run was scaled up in terms of SSB and down in terms of F (Appendix Fig. A2.12). The estimated recruitment in both runs were nearly identical, but there were large differences in the estimates of age 9^+ fish between the two runs (Appendix Fig. A2.13). The large increase in the numbers of age 9+ fish in the BASE_AGE6 run are the result of the strong doming in the fleet selectivity at older ages in the BASE_AGE6 run compared to the BASE run (Appendix Fig. A2.14). The large doming in the BASE_AGE6 run is a likely product of the absence of survey age composition out beyond age 6. With no information to anchor the catch at age, the model tends to fit a much stronger dome to the catch selectivities, leading to a buildup of older age fish and increase in SSB relative to the BASE run.

A2.1.4. Exploration of a shorter assessment time series

Over the course of the BASE assessment time series (1982 – 2010) there have been documented changes in fishery regulations, including increases in mesh size and minimum fish size and though less well documented, possible changes in fish biology (e.g., distribution and size at age). Both regulatory changes and biological changes can alter fishery and survey selectivity. The BASE model attempts to account for these changes by creating two discrete fishery selectivity blocks; the first between 1982-1990 and the second between 1991-2010. While the selectivity blocks represented a 'best' attempt to account for changes affecting fishery selectivity, they likely do not account for all changes. A sensitivity run starting in 2000 was conducted (BASE_2000) to give the model greater flexibility in the most recent period such that it is not confounded by changes to fishery and biology over the last two decades (i.e., block 2, 1991-2010).

The assessment results of the BASE_2000 are similar to the BASE run between 2000 and 2007, but become increasingly divergent from 2008 onward (Appendix Fig. A2.15). The BASE_2000 run estimated increasingly lower SSB and higher fishing mortality between 2008 and 2010 relative to the BASE model. The 2010 estimates of SSB and F fell outside of the 90% probability intervals (PI) of the BASE model (SSB PI = 9,479 – 16,301 mt, F_{full} 90% PI = 0.79 – 1.54), with SSB estimated at 8,815 mt and F estimated at 1.59. The CVs on the terminal estimates of the two model runs are identical (SSB = 0.16, F = 0.21). The differences between the two models are primarily the result of the differences in selectivity; with the BASE_2000 run having greater selectivity on the age 9^+ group relative to the BASE model (Appendix Fig. A2.16).

A2.1.5. Exploring the impacts of individual survey indices on model results

To better understand how the model results are being influenced by each of the survey indices the BASE model was run using only one index at a time. The three sensitivity runs were BASE_INDEX1 (NEFSC spring survey), BASE_INDEX2 (NEFSC fall survey) and BASE_INDEX3 (MADMF spring survey). In all three sensitivity runs all other model configurations were left unchanged.

There are minor differences between the BASE_INDEX1, BASE_INDEX2 and the BASE run, notably in the early 1990s, but over the most recent five year period the three runs are similar with respect to SSB and F (Appendix Fig. A2.17). There are minor differences in the recruitment estimates and age 9^+ population estimates but there are no major differences beyond the initial burn in period of 1982 to 1990 (Appendix Fig. A2.18). The BASE_INDEX3 which tunes only to the MADMF spring survey exhibits large differences in SSB and F over the last decade compared to the BASE model, with the BASE_INDEX3 model estimating higher terminal SSB and lower F relative (Appendix Fig. A2.19). The recruitment estimates between the two models are similar, but there are large differences in the estimates of age 9^+ fish. The increase in older age fish is a product of the sharp dome that exists in block 2 of the BASE_INDEX3 run, with selectivity on age 9+ fish near 0.19 compared to 0.67 in the BASE run (Appendix Fig. A2.20). The CVs on the selectivity estimates of age 8 and age 9+ in block2 of the BASE_INDEX3 run are nearly double those of the BASE run, additionally, the age9+ selectivity in block1 appears to be hitting a bound of 1.0 (Appendix Table A2.3). These results suggest that the BASE_INDEX3 model has difficulty estimating the fleet selectivity at older ages. This is consistent with the results of the BASE_AGE6 run which illustrated the sensitivity of model estimated selectivity curves when there was limited survey information for older age classes. The MADMF spring survey, which encompasses only nearshore waters, catches few old fish as indicated by the estimated survey selectivity in the BASE run (Fig. A.126).

A2.1.6. Summary of ASAP sensitivity runs and how the results inform the perception of model uncertainty

Including the 10 ASAP sensitivity runs explored in this Appendix, there are 14 sensitivity runs presented in this report. In 7 (50%) of the sensitivity runs, the 2010 SSB was above the 11,868 mt estimate of the BASE run (Appendix Table A2.4). Estimates of F_{full} exceeded the BASE estimate of 1.14 in 9 of the 14 runs (64.3%) 2010. All but two of the sensitivity runs had 2010 terminal SSB and F_{full} estimates that fell within the 90% PIs of the BASE run. The two exceptions were the BASE_INDEX3 run which estimated substantially higher SSB and lower F and the BASE_2000 run which estimated lower SSB and higher F. Over the assessment time series, the majority of sensitivity runs have fallen within the 90% PI of the BASE run both with respect to SSB (Appendix Fig A2.22) and to a greater extent, F_{full} (Appendix Fig. A2.23). While approximately 5 of the sensitivity runs fell outside the SSB 90% PI at some point in the time series, they all follow the same general trends of the BASE model, with the differences resulting primarily due to scale. The scaling issues are primarily related to the estimated fleet selectivity in each of the models. Given the robustness of the assessment results to different model formulations, there is a high degree of confidence that the 90% PI of the BASE model adequately characterizes the uncertainty in the assessment results.

A2.2. Exploration of survey catchability and its implications on estimated biomass

The scale of model estimates of biomass is sensitive to the estimated fleet (fishery) selectivity as illustrated by the sensitivity runs. In addition to fishery selectivity, the relative scale of the estimated biomass can be affected by assumptions of the estimated efficiency of the surveys. Further work was conducted to 1) evaluate the sensitivity of the BASE model results to alternate assumptions of survey catchability (*q*), and 2) generate model-independent estimate of total biomass and compare to the model estimates to determine whether the BASE results are reasonable.

A2.2.1.1. Model profiling across a range of NEFSC spring survey q values

The sensitivity of the BASE model to alternate assumptions of survey catchability was evaluated by profiling across a range of *q* values from 0.1 to 1.0. Priors were specified for catchability ranging from 0.1 to 1.0 in 0.1 increments. The input CV on catchability was set to 0.1 and given lambda values of 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 Appendix Fig. A2.24. On the basis of the objective function, the BASE model preferred *q* values in the range of 0.7 to 1.0. There was a general tendency for the model to estimate higher *q* values than inputted despite the low CV and a penalty was placed on deviations. Within the 0.7 to 1.0 range there was little impact in terms of SSB scaling (<5% difference from BASE run). Even when forcing *q* to a minimum believable range (≈0.4) the SSB scaling differences only amount to 10-20% differences from the base run *q* preference of 0.92. 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.

A2.2.1.2. 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 encompass 61.4 thousand km^2 which is 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 inside 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 (exclude 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 (Appendix Fig. A2.25). 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 (Appendix Fig. A2.26). 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 (BASE_revAS).

The BASE_revAS model is nearly identical to the BASE model with respect to the SSB, F and the age 1 recruitment time series (Appendix Fig. A2.27). There are small deviations early on in the time series, particularly in F, but over the last decade, the BASE and BASE_revAS are similar. 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 0.92 to 0.57, NEFSC fall from 0.53 to 0.42 and the MADMF spring survey was unchanged at 0.16. The 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.

A2.2.2. 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.

A2.2.2.1. 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 very 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 Equation 1.

(1) $B_{AW} = I/1000 \cdot A/f \cdot 1/q$

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. 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 BASE model (Fig. A.126). 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 (Appendix Fig. A2.28). 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 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; Appendix Fig. A2.29). 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 (Appendix Fig. A2.30). While the estimates are not exact, they are all of the same relative scale, suggesting that the BASE model estimates are realistic.

A2.2.2.2. 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 BASE model q estimates represent the q in terms of fully selected fish (i.e., after accounting for survey selectivity). To examine whether the

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 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 BASE model. 'Survey-able' biomass was estimated by decrementing the January 1 biomass (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 BASE-estimated 'surveyable' biomass generally fell within the 80% survey CI on total biomass for both the spring (Appendix Fig. A2.31) and fall (Appendix Fig. A2.32) surveys. How q is defined, whether in terms of absolute efficiency (as was done in section A2.2.2.1) or in terms of only fully selected ages, does impacts 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.

Tables

Appendix Table A2.1. Coefficients of variation associated with the estimates of Gulf of Maine cod selectivity-at-age between block 2 (1991-2010) of the ASAP base (BASE) model run and the sensitivity run BASE_VPA. **The BASE_VPA run includes catch out to age 11^{+} whereas the BASE run only includes catch out to age 9^{+}.*

AGE	BASE	BASE_VPA
AGE1	0.17	0.13
AGE2	0.10	0.09
AGE3	0.08	0.08
AGE4	0.08	0.08
AGE5	0.00	0.00
AGE6		
AGE7	0.20	0.20
AGE8	0.33	0.36
AGE9	0.54	0.65
AGE10		0.89
AGE11		1.41

Appendix Table A2.2. Significance (p-values) of Pearson correlation coefficients across survey cohorts for the NEFSC spring, fall and MADMF spring surveys. P-values > 0.05 are highlighted in bold.

NEFSC spring (Index 1)								
Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	0.37							
Age3	0.75	**0.00**						
Age4	0.58	0.35	0.20					
Age5	0.59	0.83	0.34	**0.00**				
Age6	0.49	0.21	0.95	**0.02**	**0.01**			
Age7	0.46	0.49	0.04	0.47	0.15	0.10		
Age8	0.90	0.42	0.97	0.22	0.34	0.68	0.11	
Age9	0.45	0.25	0.45	0.69	0.56	0.86	0.81	0.74

NEFSC fall (Index 2)								
Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	**0.00**							
Age3	**0.00**	**0.00**						
Age4	0.43	0.35	0.37					
Age5	0.90	0.64	0.63	**0.04**				
Age6	0.92	0.82	0.90	0.22	0.16			
Age7	0.58	0.60	0.35	0.05	**0.03**	**0.04**		
Age8	0.42	0.71	0.79	0.03	0.07	0.11	**0.00**	
Age9	0.39	0.15	0.77	0.74	0.35	0.35	0.63	0.68

MADMF spring (Index 3)								
Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	0.52							
Age3	0.91	**0.00**						
Age4	0.83	0.09	**0.00**					
Age5	0.68	0.87	0.12	**0.00**				
Age6	0.22	0.30	0.56	0.24	**0.00**			
Age7	0.85	0.26	0.53	0.75	0.08	**0.00**		
Age8	0.43	0.11	0.33	0.80	0.51	**0.04**	**0.00**	
Age9	0.45	0.11	0.38	0.69	0.04	0.26	0.06	0.02

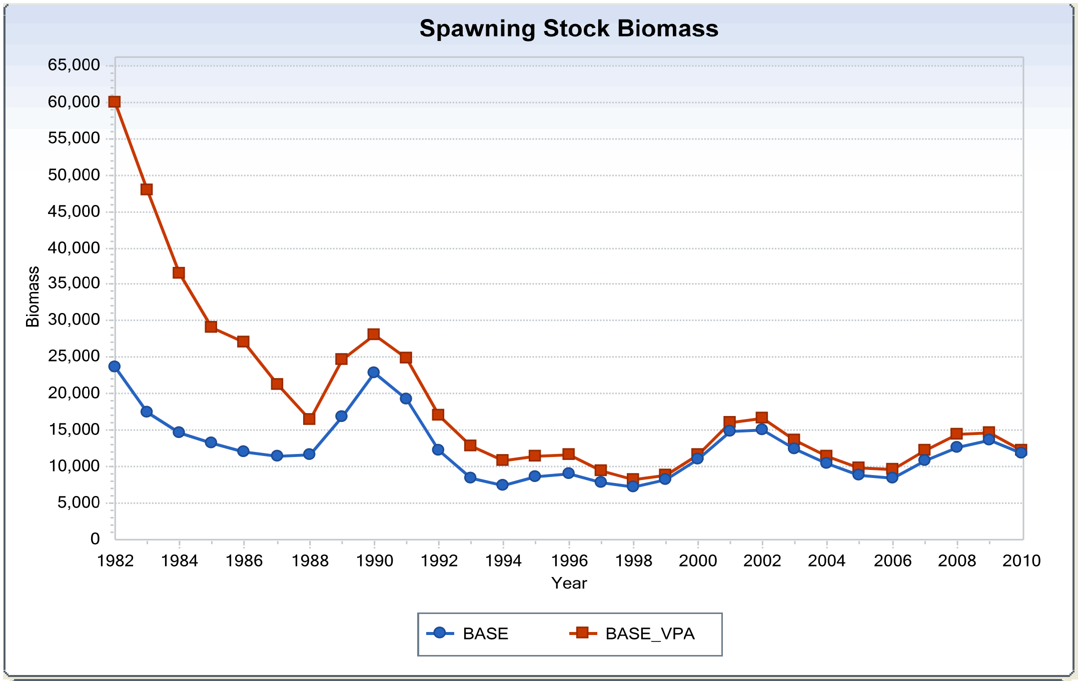
Appendix Table A2.3. Gulf of Maine cod fleet selectivities and coefficients of variation (CV) in blocks 1 (1982-1990) and block 2(1991-2010) for the sensitivity run tuned to only the MADMF spring survey index (BASE_INDEX3).

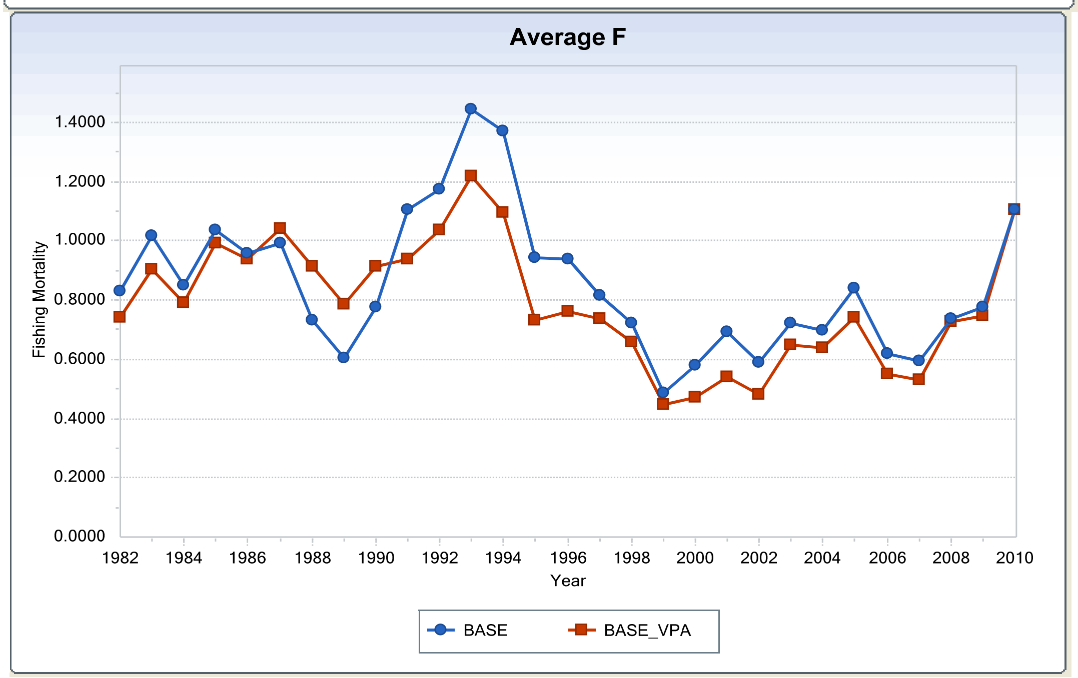
Block	Age	Selectivity	CV
1982-1990	Age1	0.05	0.18
	Age2	0.32	0.12
	Age3	0.64	0.11
	Age4	1.00	0.00
	Age5	1.00	
	Age6	0.83	0.30
	Age7	0.77	0.46
	Age8	0.70	0.66
	Age9	1.00	0.01
1991-2010	Age1	0.02	0.20
	Age2	0.12	0.15
	Age3	0.42	0.13
	Age4	0.89	0.11
	Age5	1.00	0.00
	Age6	1.00	
	Age7	0.66	0.32
	Age8	0.48	0.55
	Age9	0.19	0.95

Appendix Table A2.4. Summary of 2010 estimates of Gulf of Maine cod spawning stock biomass (SSB) and fully recruited fishing mortality (F_{full}) from 14 different ASAP sensitivity runs. Those runs that fell outside of the 90% probability intervals (PI) of the ASAP base run (BASE) are shown in bold; SSB 90% PI = 9,479 – 16,301 mt, F_{full} 90% PI = 0.79 – 1.54. **Note: PRELIM_2FLEET and PRELIM_4FLEET fishing mortalities are reported as the average fishing mortality on age 6, which is analogous to F_{full} for these two preliminary runs.*

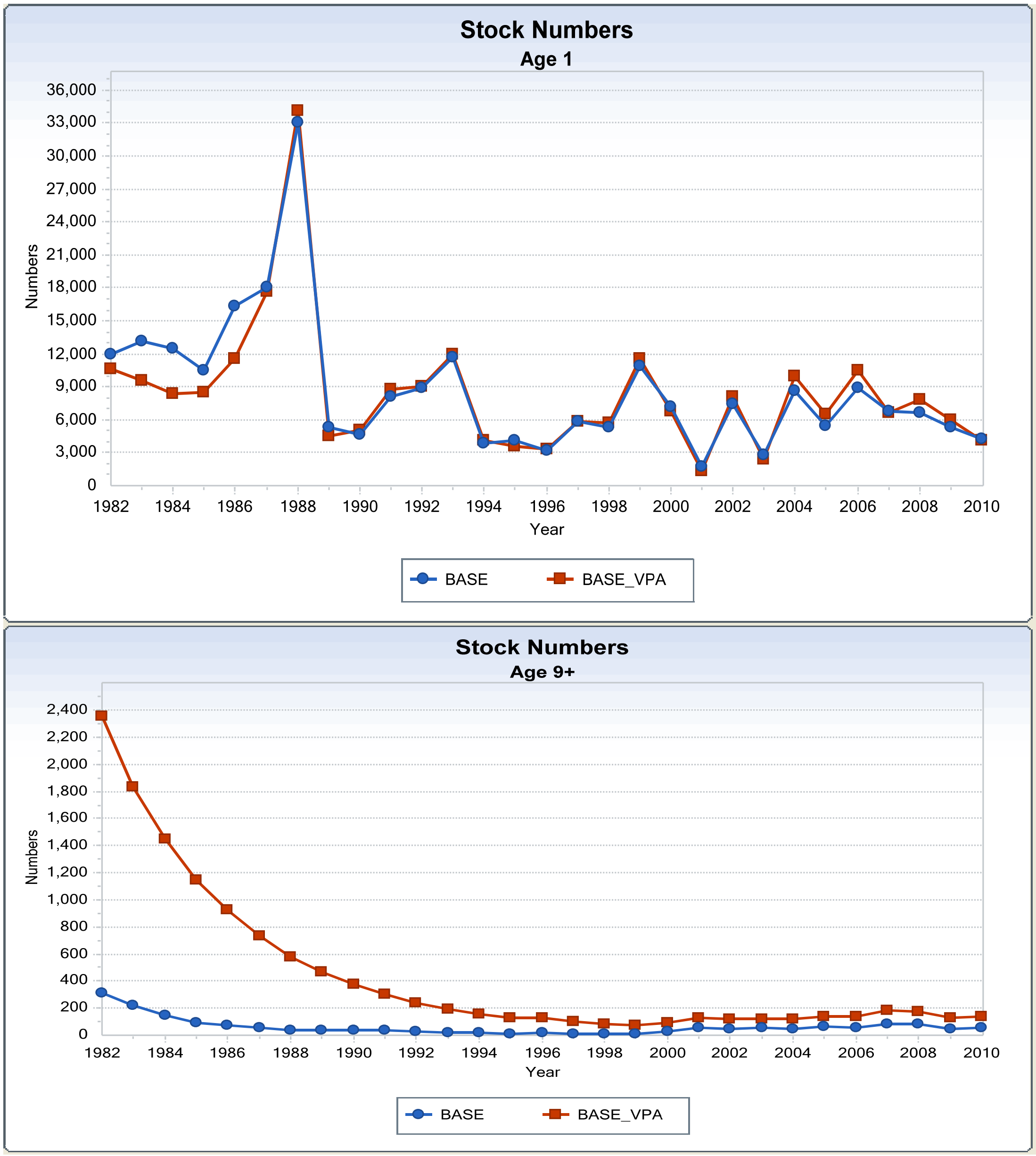
Model	2010 SSB (mt)	2010 F_{full}
BASE_11	11,777	1.15
BASE_DOME	14,476	1.04
BASE_1964	10,346	1.34
BASE_1970	9,664	1.46
BASE_VPA	12,318	1.21
PRELIM_2FLEET	15,488	*1.00*
PRELIM_4FLEET	12,134	*1.21*
BASE_CV10	11,635	1.16
BASE_CV15	11,347	1.16
BASE_AGE6	14,931	1.01
BASE_2000	**8,815**	**1.59**
BASE_INDEX1	10,726	1.28
BASE_INDEX2	12,144	1.13
BASE_INDEX3	**20,432**	**0.74**

Appendix A2 Figures

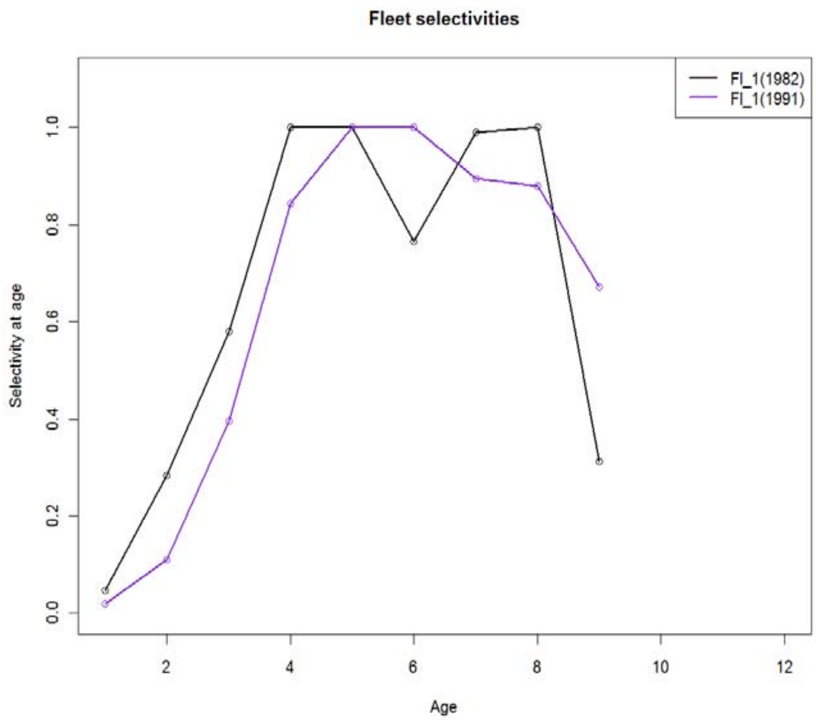


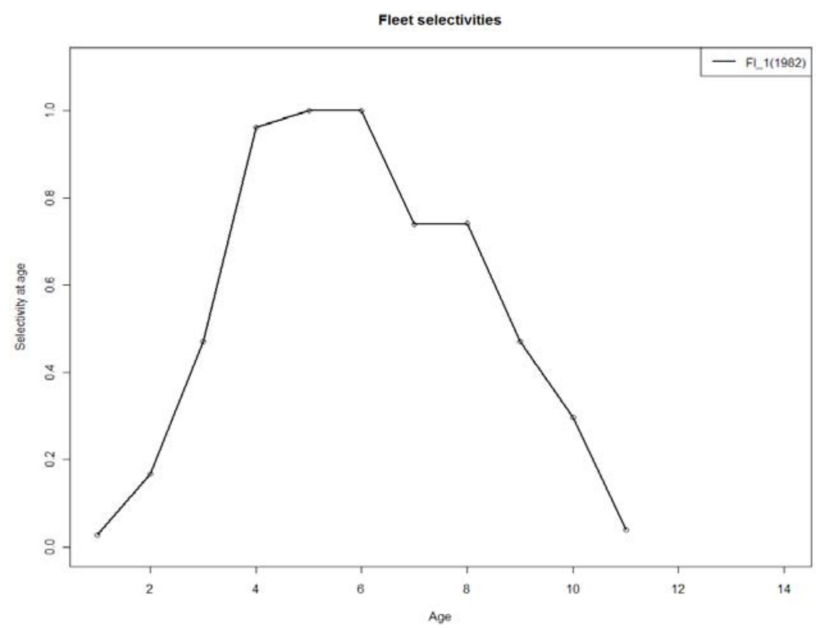


Appendix Figure A2.1. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA).

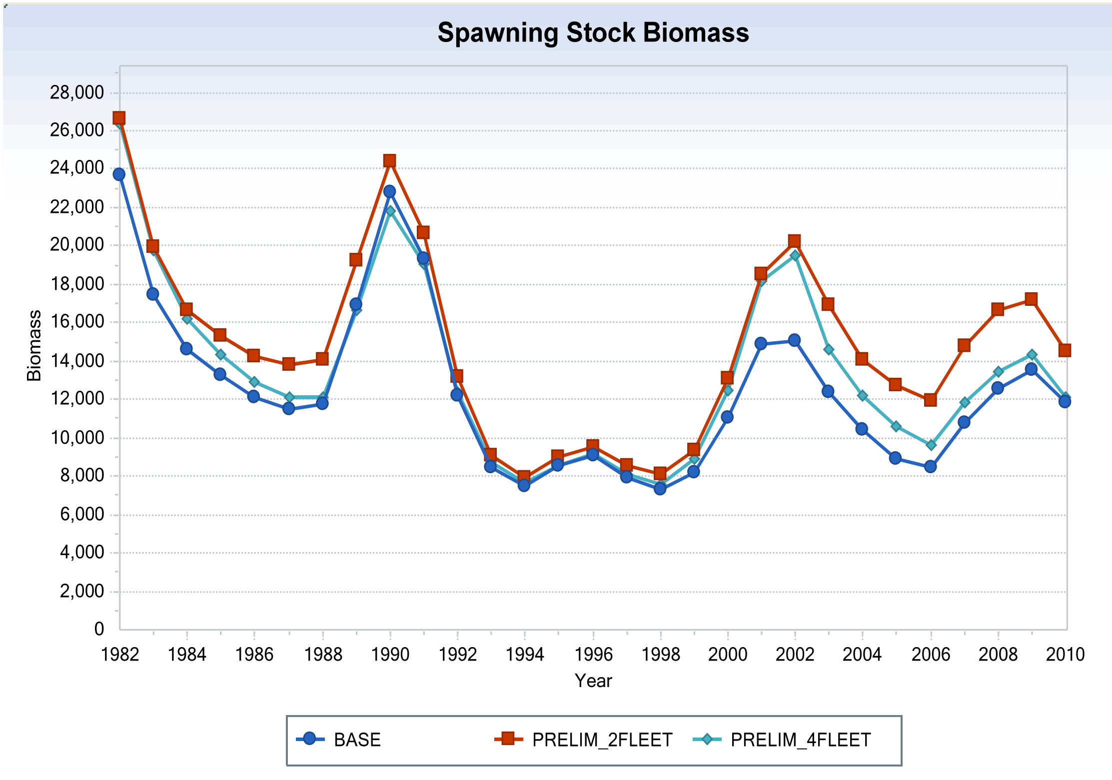


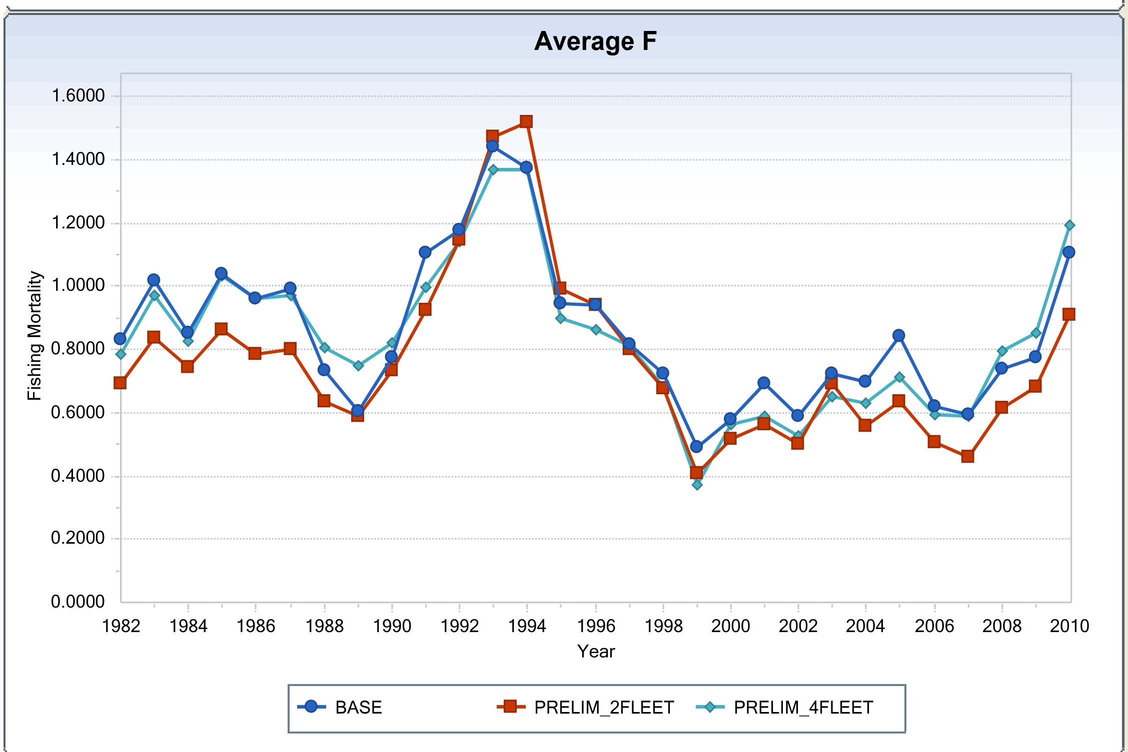
Appendix Figure A2.2. Comparison of the Gulf of Maine cod estimated age-1 recruitment in numbers (thousands of fish; top) and estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA).



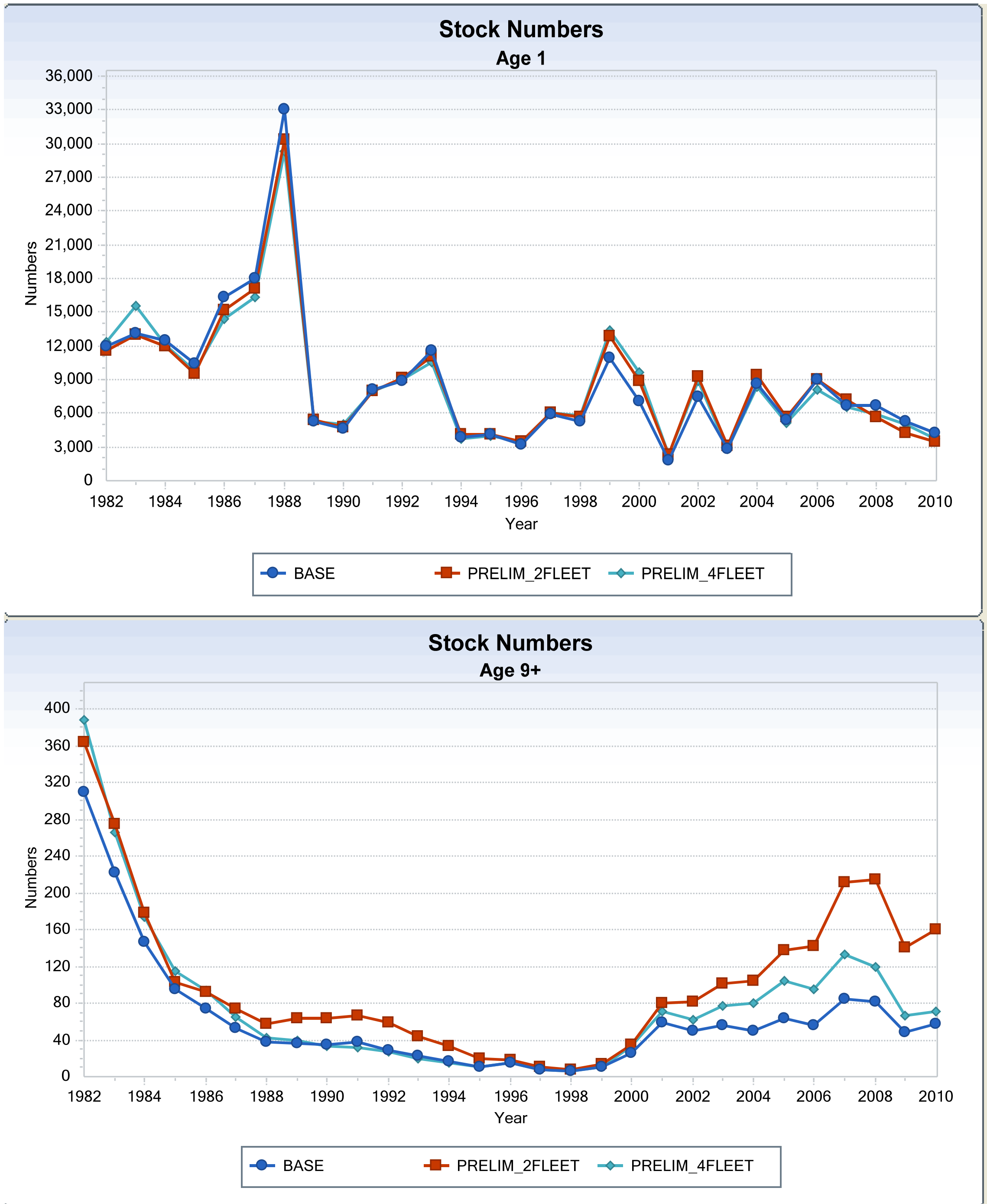


Appendix Figure A2.3. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA; bottom).

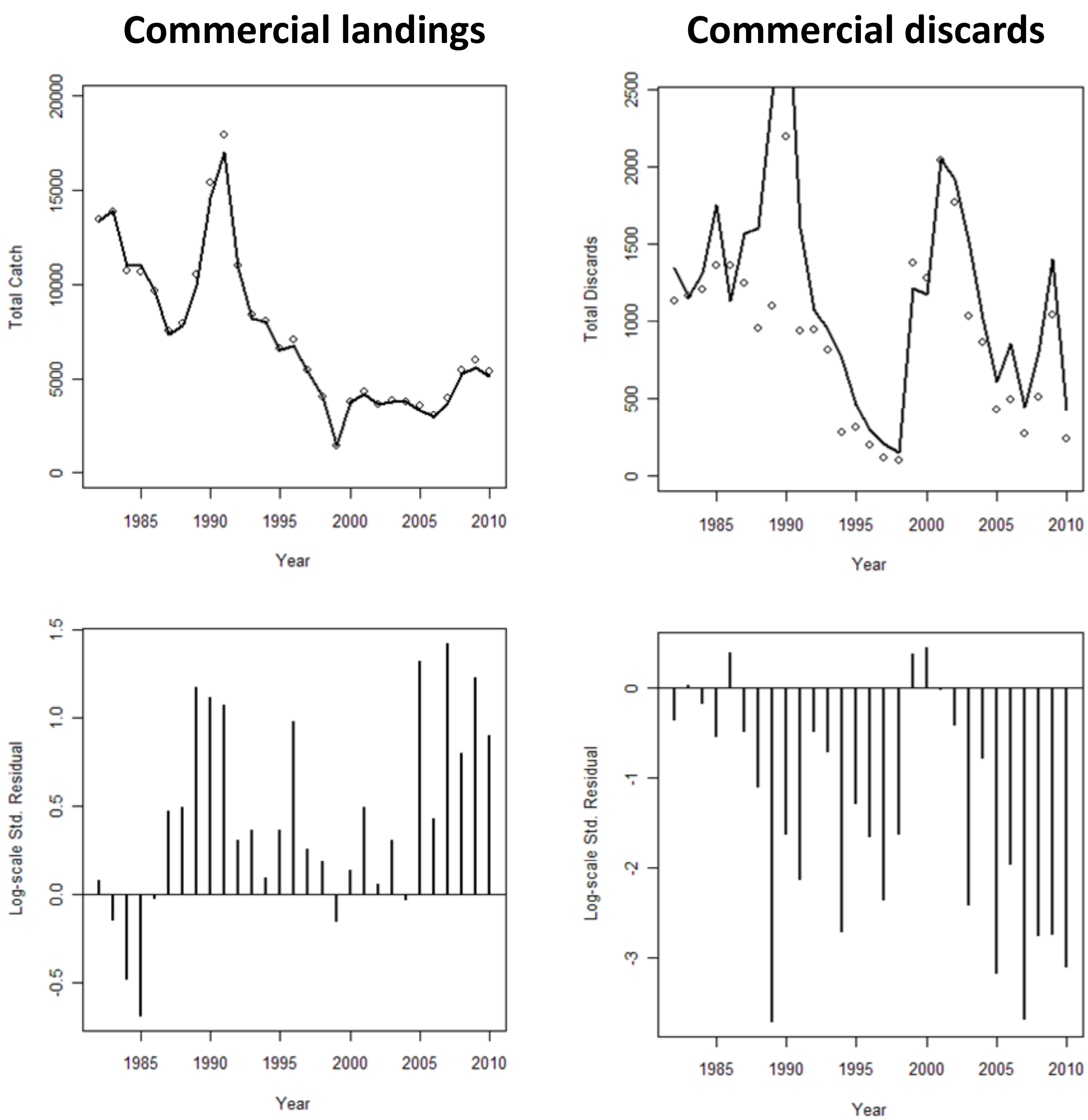




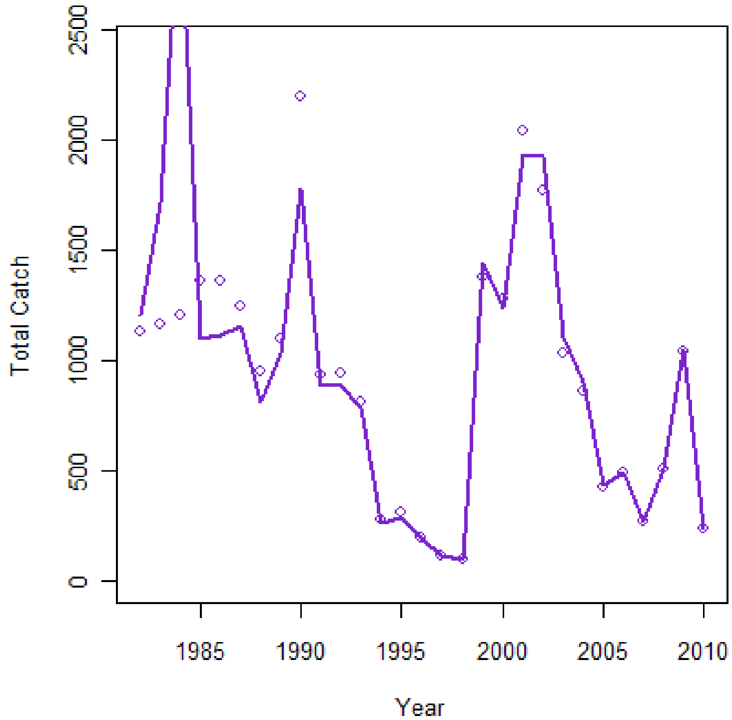
Appendix Figure A2.4. Comparison of Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) two preliminary configurations of the ASAP model, PRELIM_2FLEET and PRELIM_4FLEET.

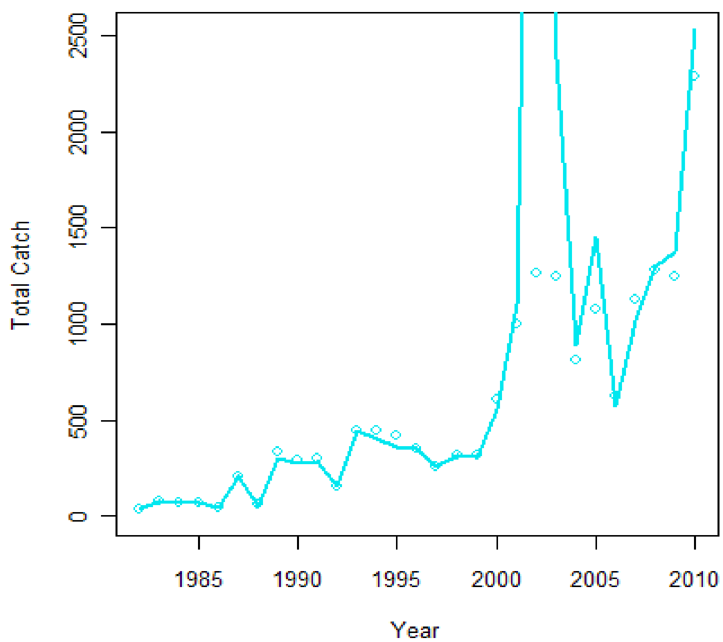


Appendix Figure A2.5. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) two preliminary configurations of the ASAP model, PRELIM_2FLEET and PRELIM_4FLEET.

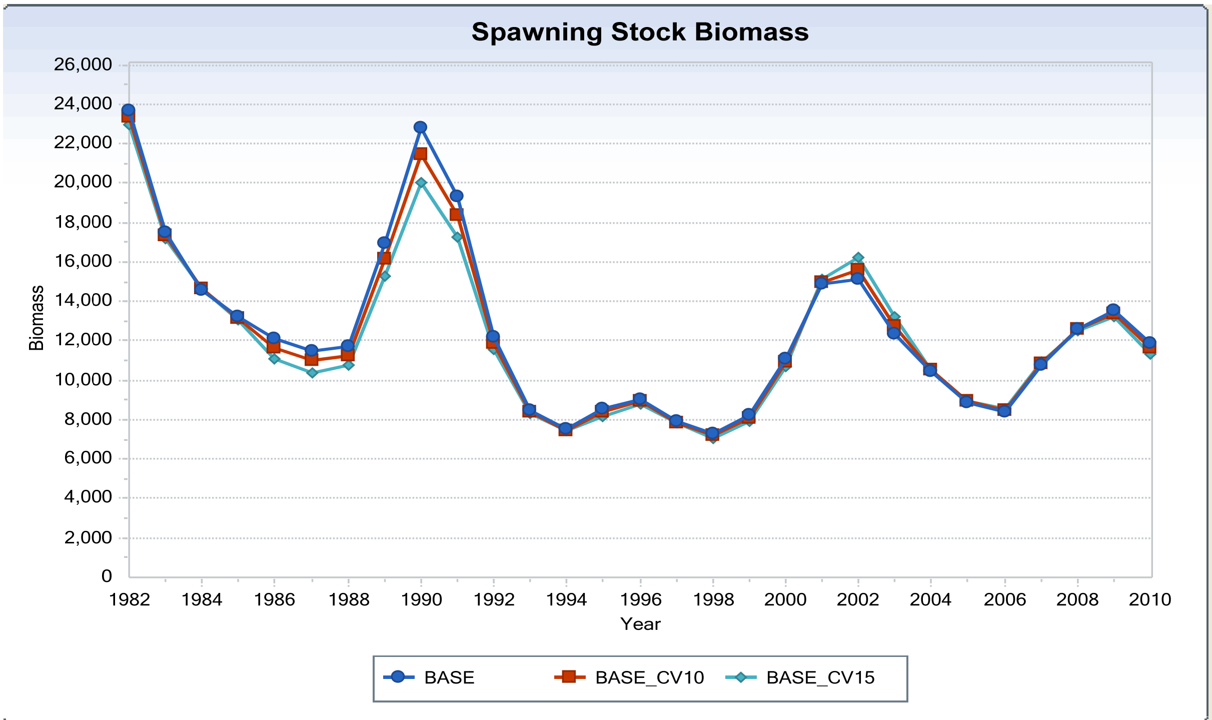


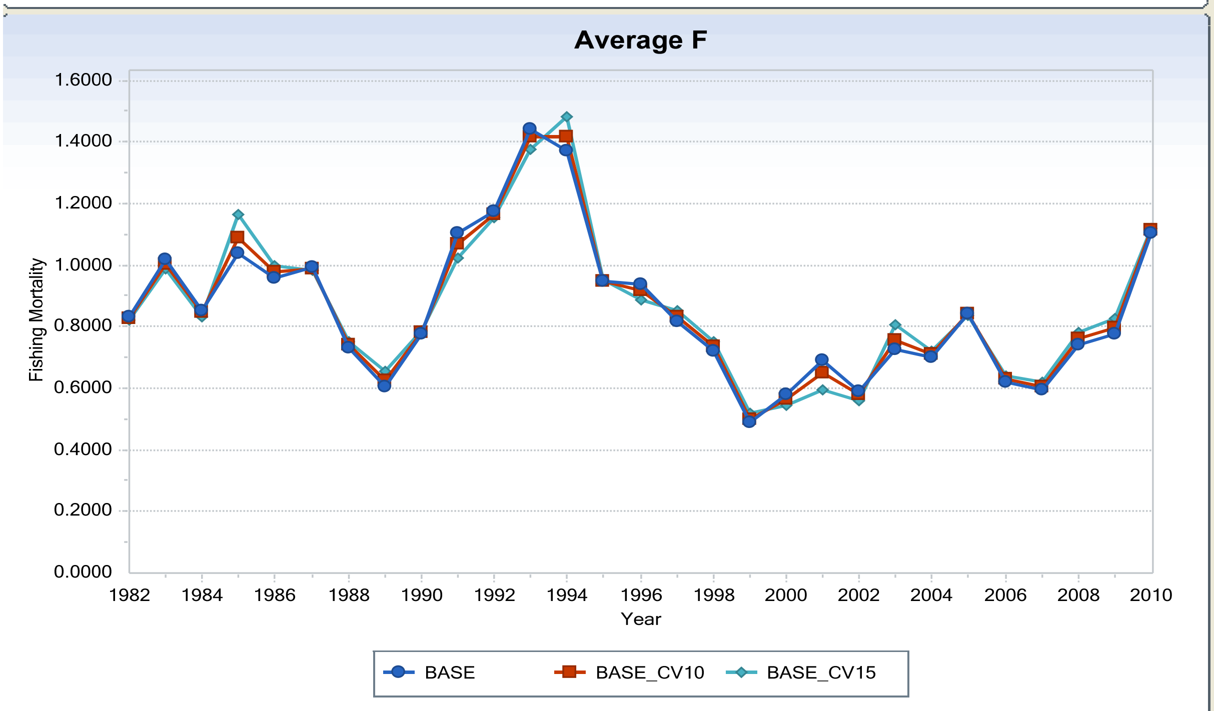
Appendix Figure A2.6. Example of the residual patterns observed in the model fits to Gulf of Maine cod commercial landings (left) and commercial discards (right) from the preliminary ASAP model, PRELIM_2FLEET.



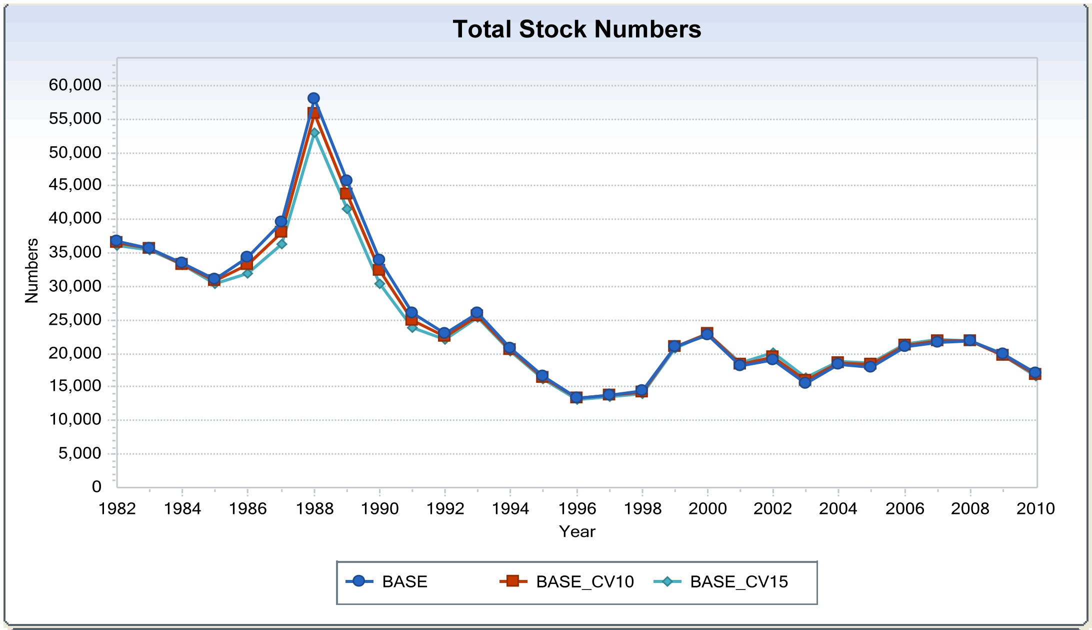


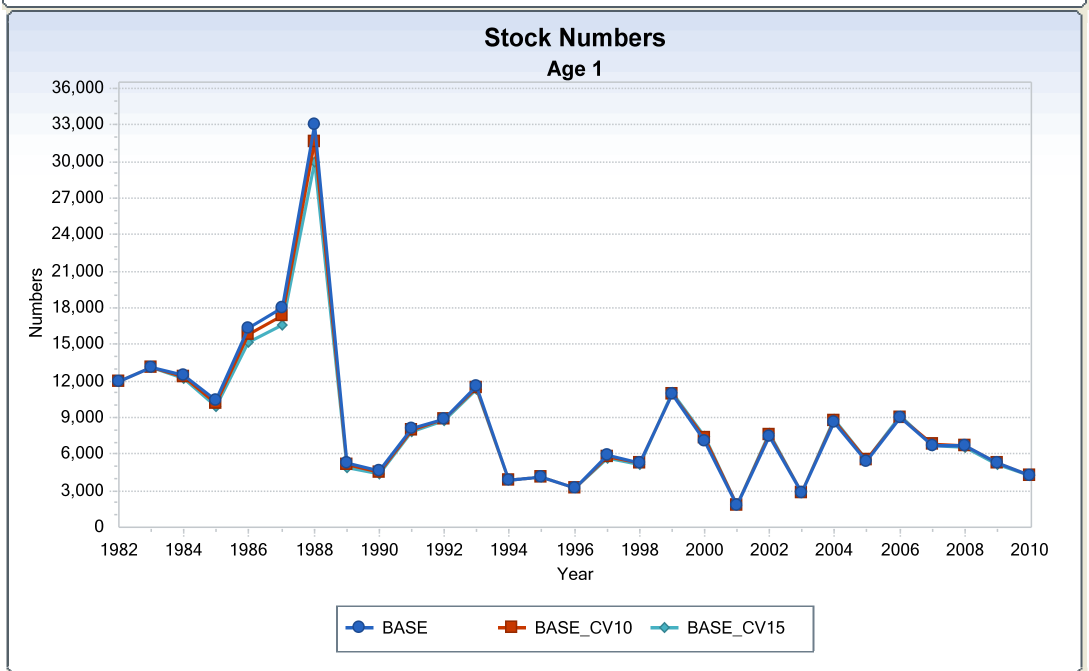
Appendix Figure A2.7. Example of poor model fits to Gulf of Maine cod commercial discards (top) and recreational discards (bottom) from a preliminary ASAP model run, PRELIM_4FLEET.



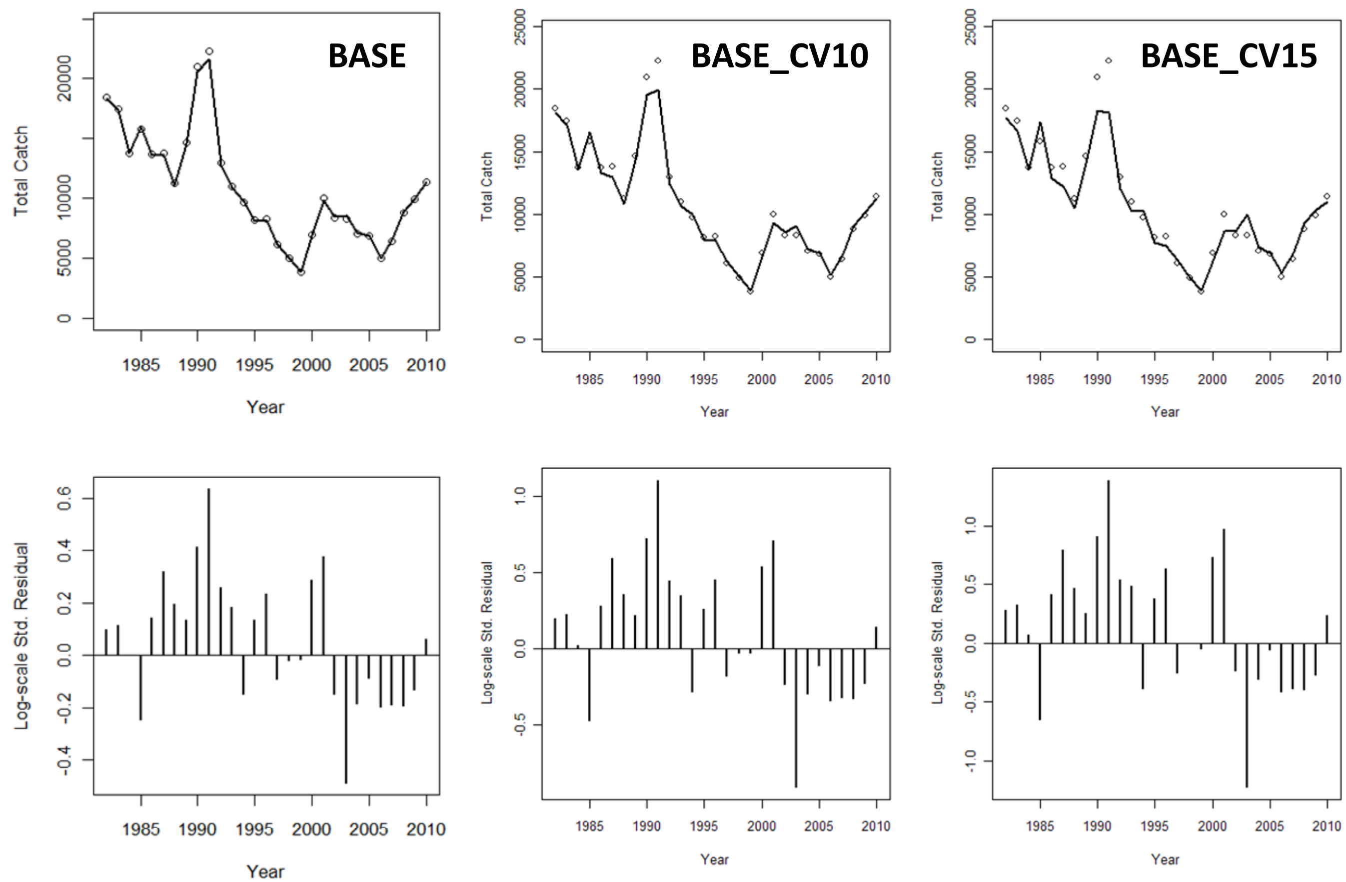


Appendix Figure A2.8. Comparison of Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and two ASAP sensitivity runs where the coefficient of variation (CV) on total catch was increased to 0.10 (BASE_CV10) and 0.15 (BASE_CV15). The CV of the BASE run was set at 0.05.

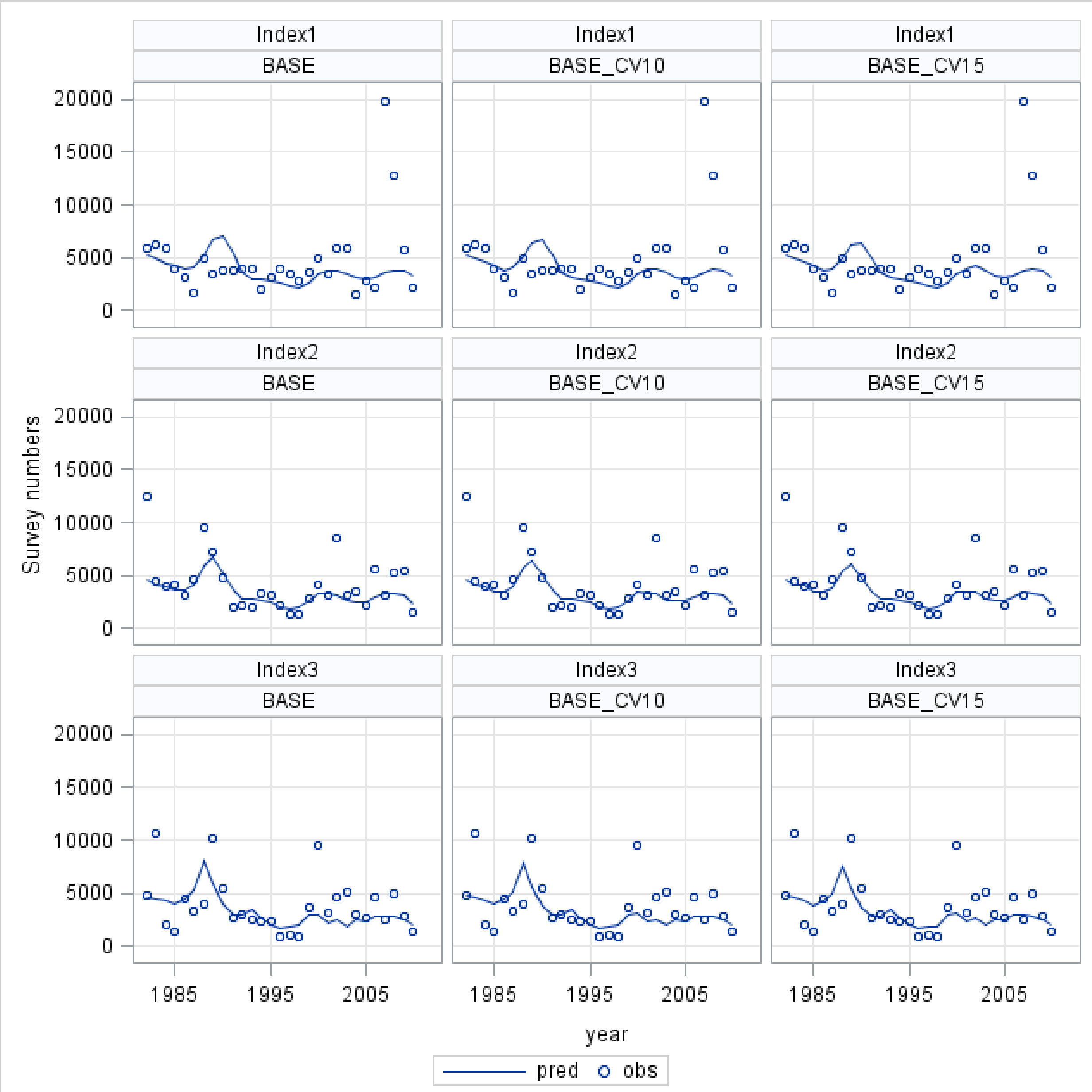




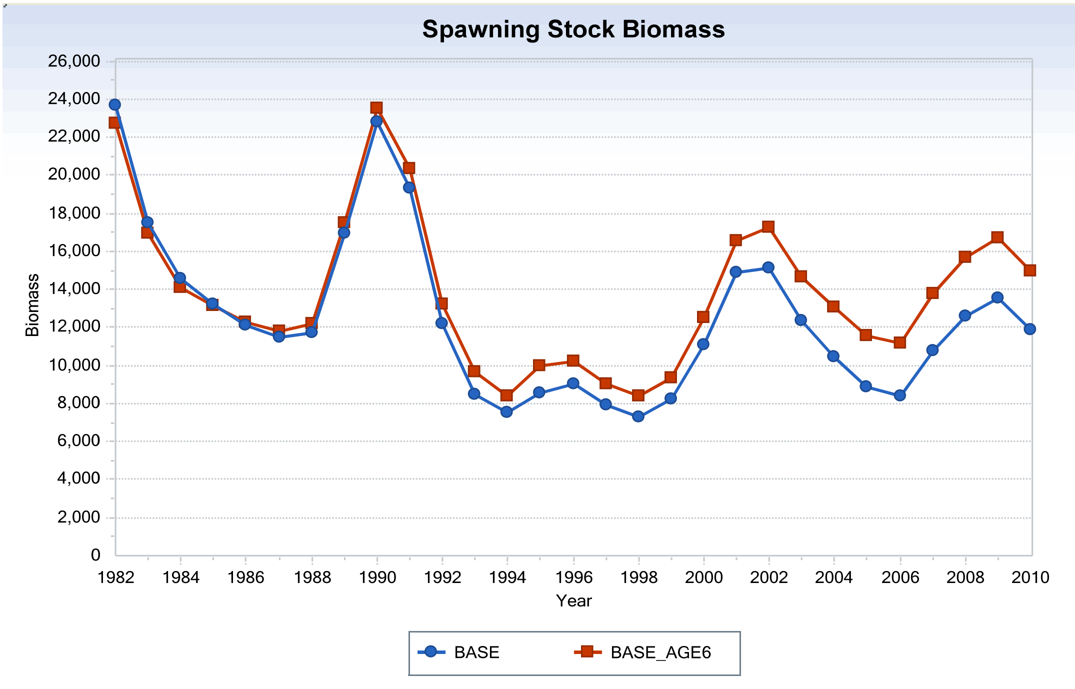
Appendix Figure A2.9. Comparison of Gulf of Maine cod total stock abundance (thousands of fish; top) and age-1 recruitment (thousands of fish; bottom) between the ASAP base run (BASE) and two ASAP sensitivity runs where the coefficient of variation on total catch was increased to 0.10 (BASE_CV10) and 0.15 (BASE_CV15). The CV of the BASE run was set at 0.05.

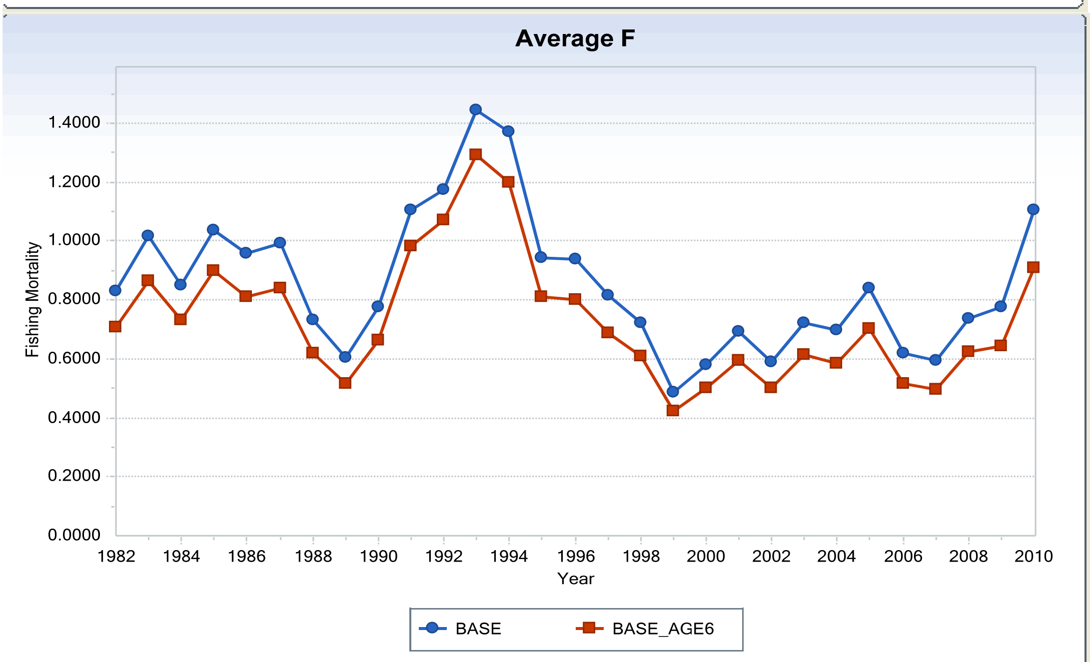


Appendix Figure A2.10. Model fits to the total catch of Gulf of Maine cod from three different ASAP model runs: BASE, BASE_CV10, and BASE_CV15. The differences in model runs are restricted to the inputted coefficient of variation on total catch; CVs were set at 0.05, 0.10 and 0.15, respectively, in each of the different model runs.

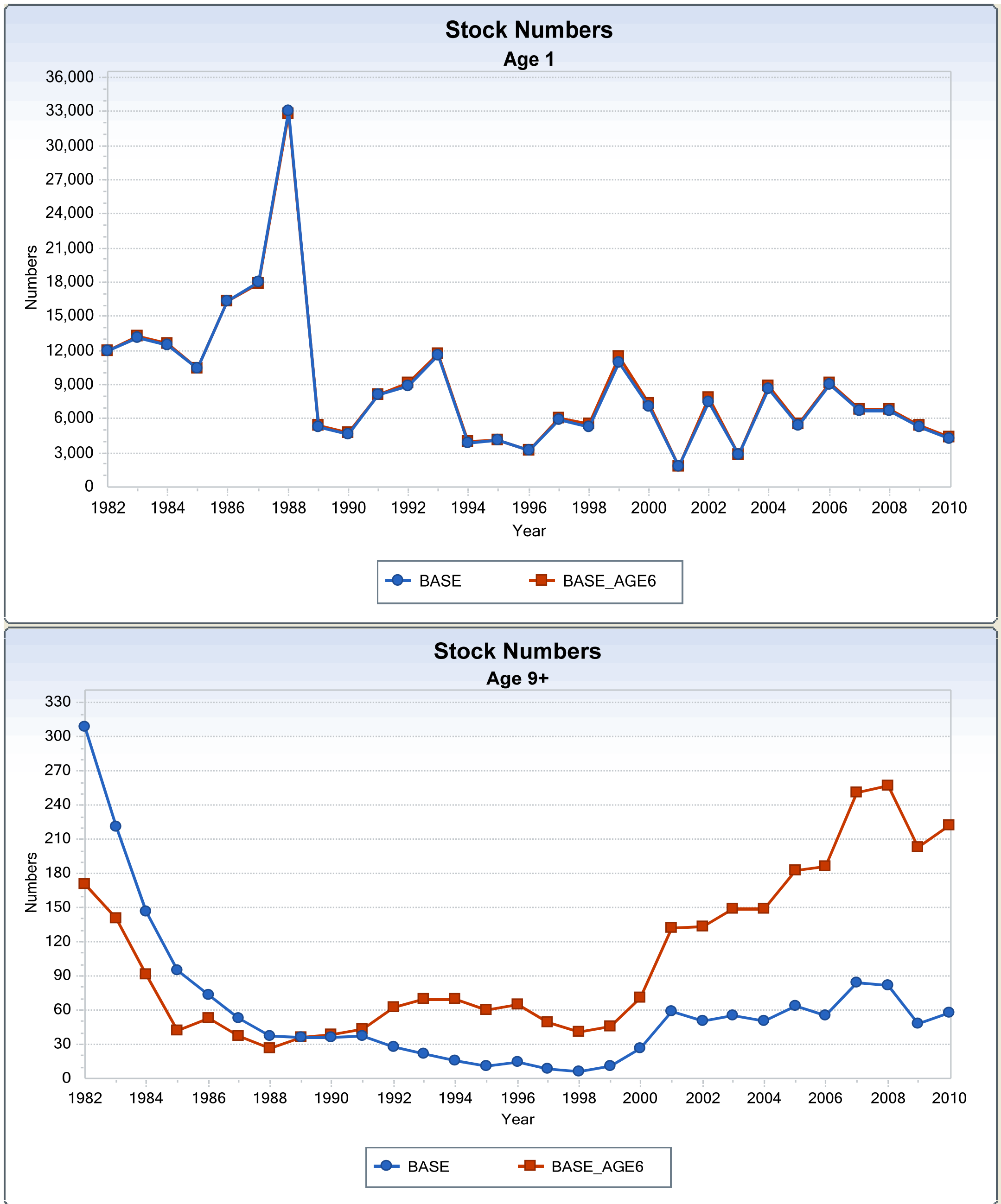


Appendix Figure A2.11. Model fits to the three Gulf of Maine cod survey indices from three different ASAP model runs: BASE, BASE_CV10, and BASE_CV15. The three survey indices are NEFSC spring (Index1), NEFSC fall (Index2) and MADMF spring (Index3). The differences in model runs are restricted to the inputted coefficient of variation on total catch; CVs were set at 0.05, 0.10 and 0.15, respectively, in each of the different model runs.

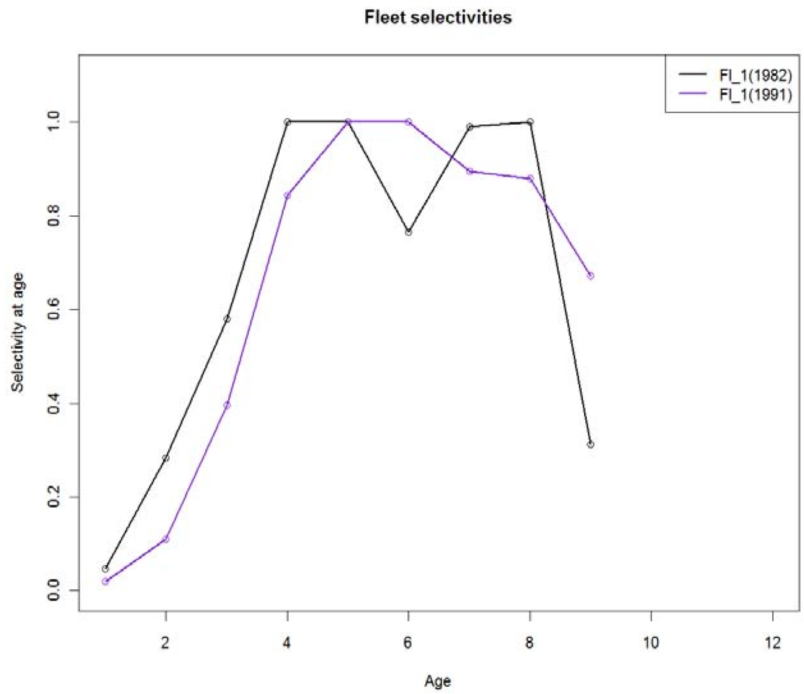


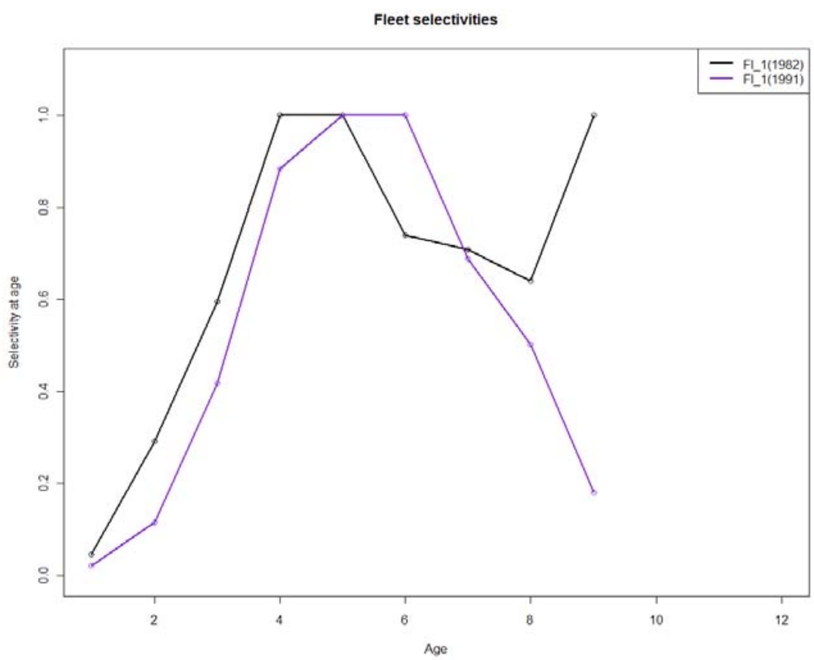


Appendix Figure A2.12. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6).

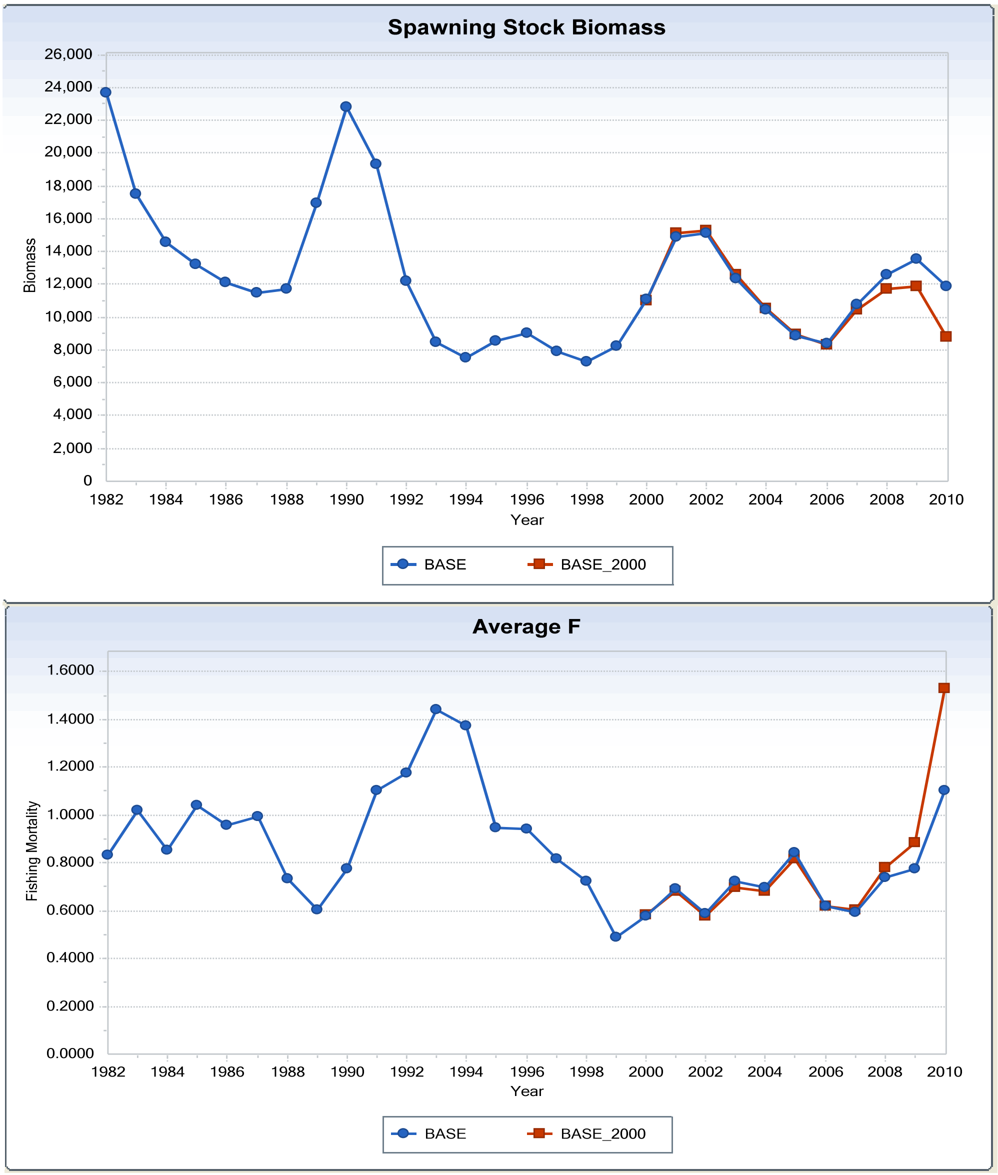


Appendix Figure A2.13. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6).

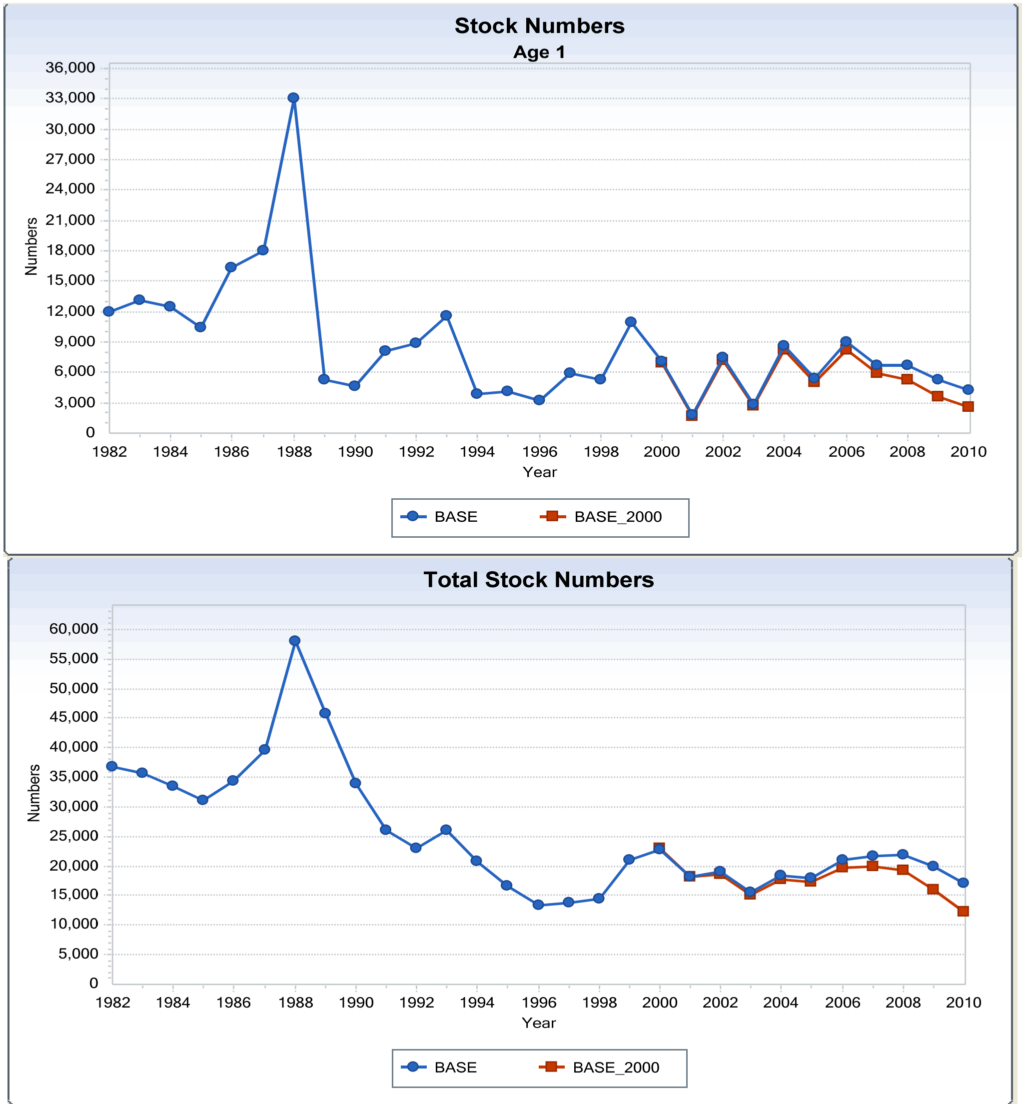




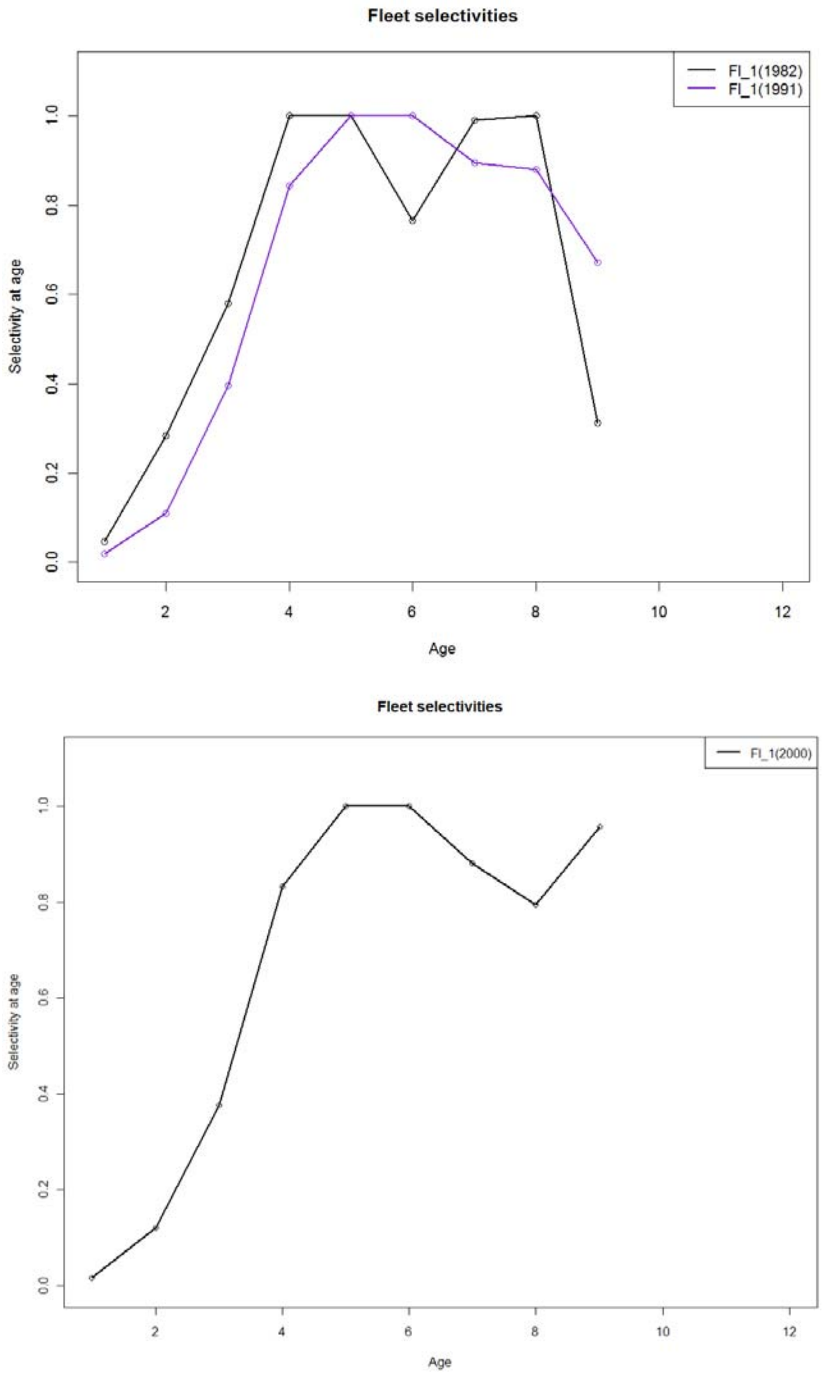
Appendix Figure A2.14. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6; bottom).



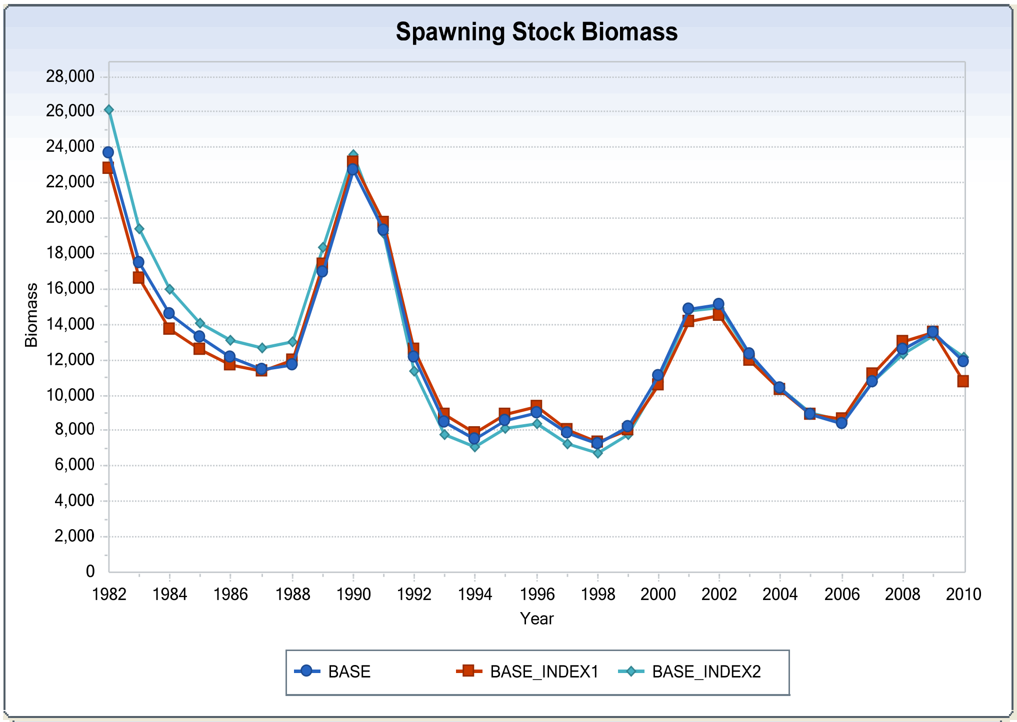
Appendix Figure A2.15. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).

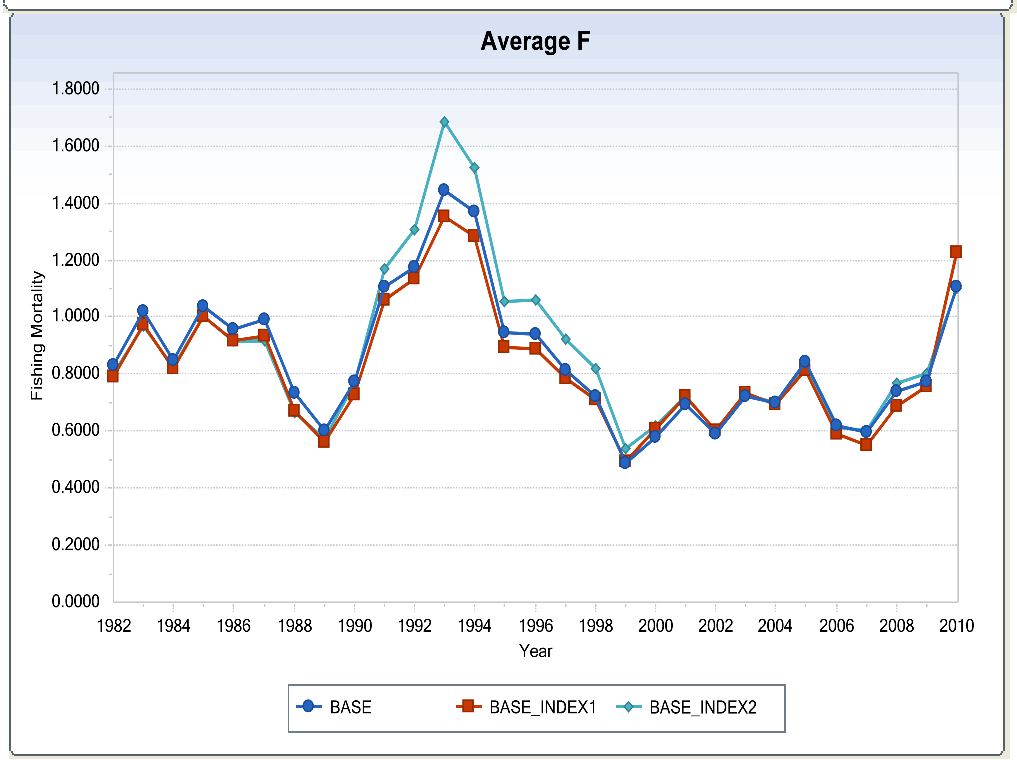


Appendix Figure A2.16. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and total population size (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).

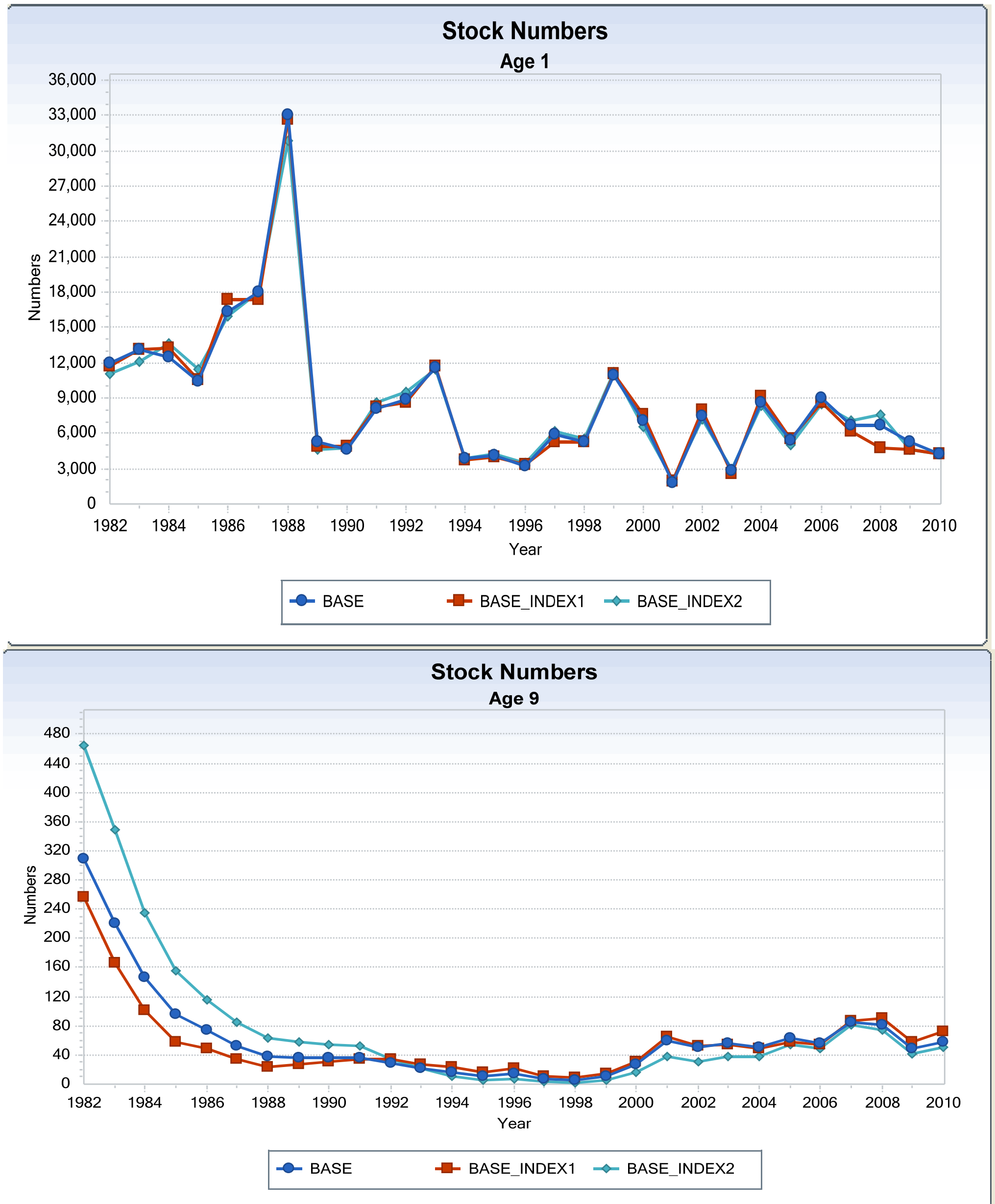


Appendix Figure A2.16. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).

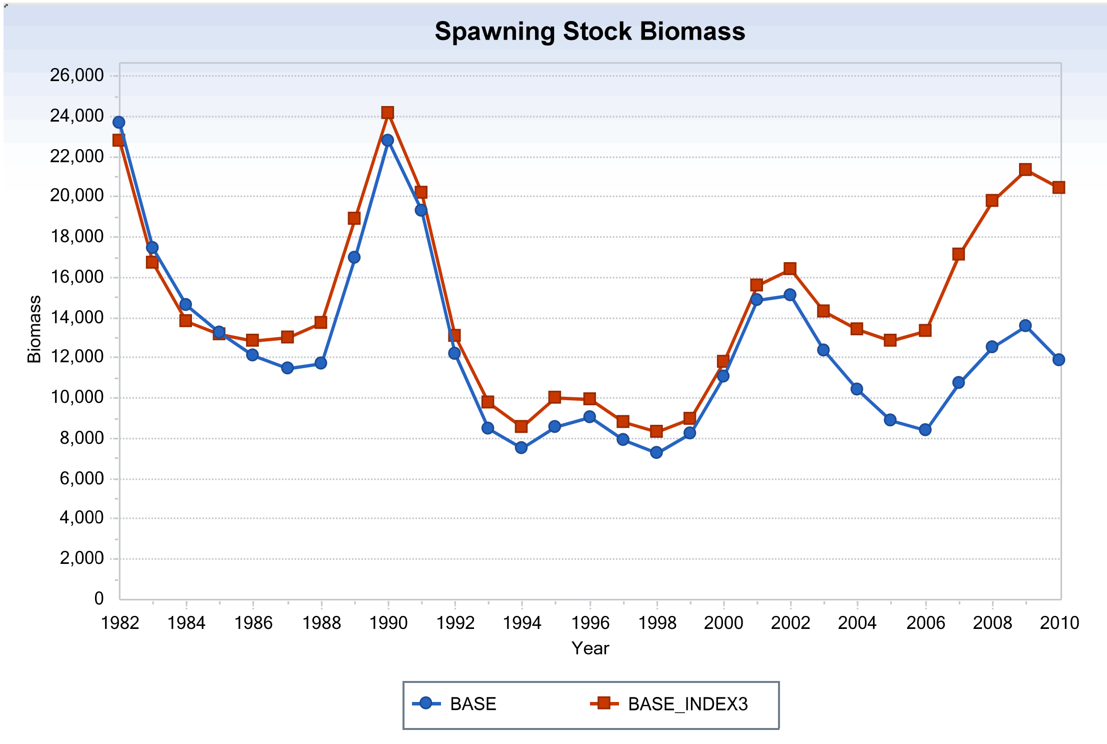


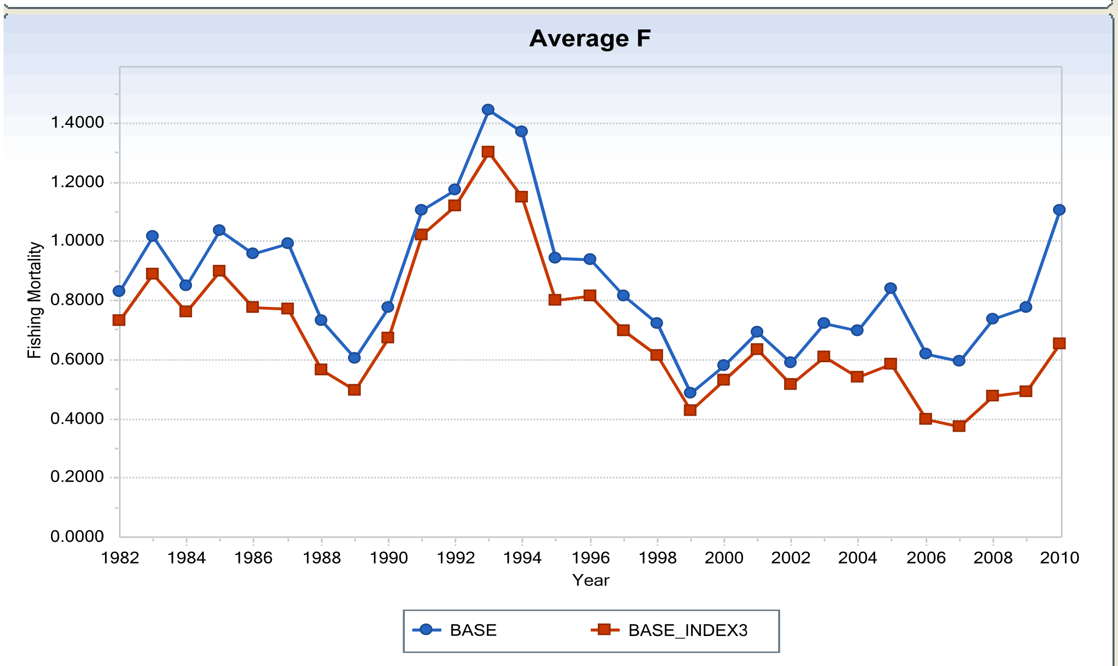


Appendix Figure A2.17. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1) or the NEFSC fall survey (BASE_INDEX2).

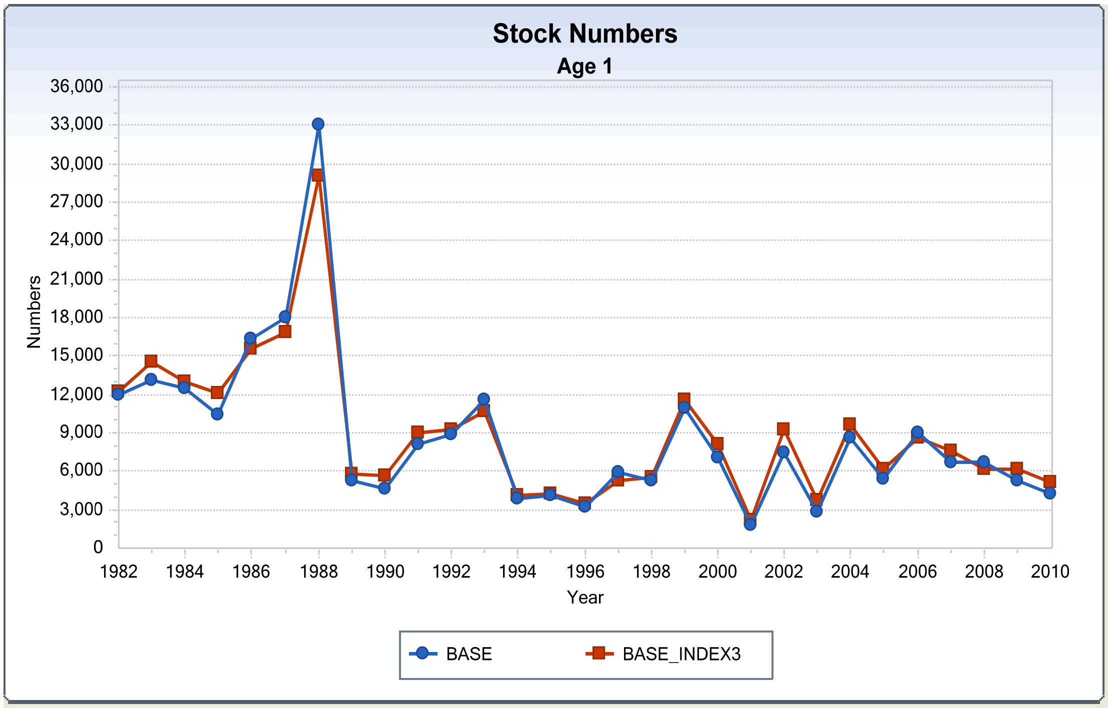


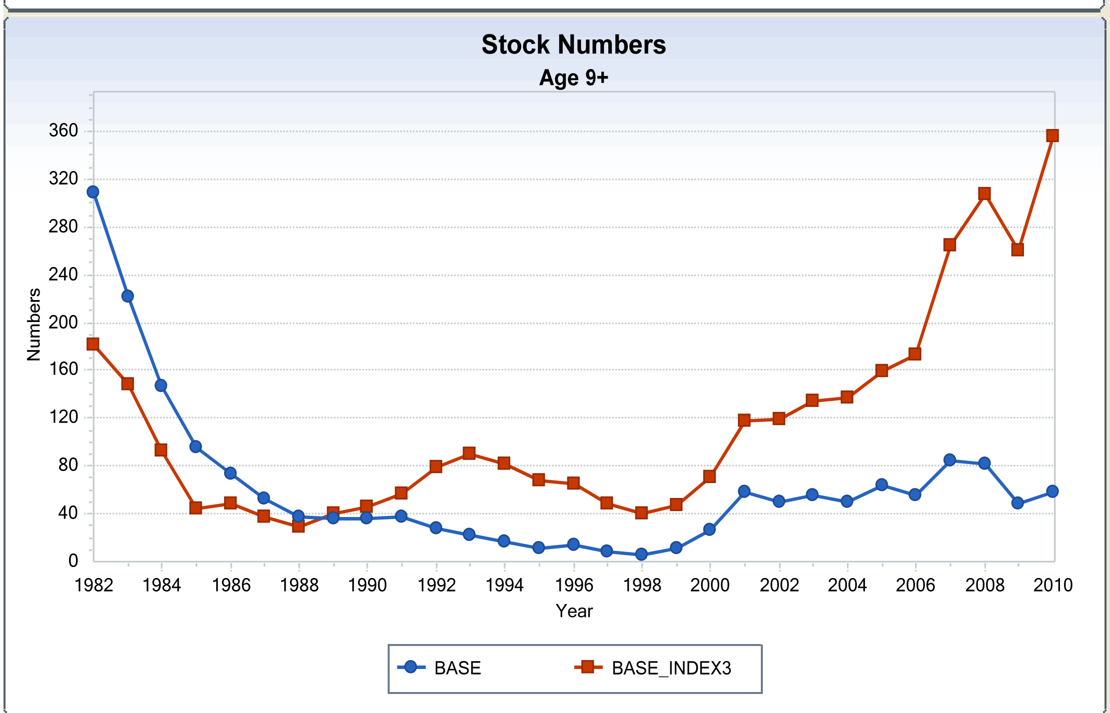
Appendix Figure A2.18. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1) or the NEFSC fall survey (BASE_INDEX2).



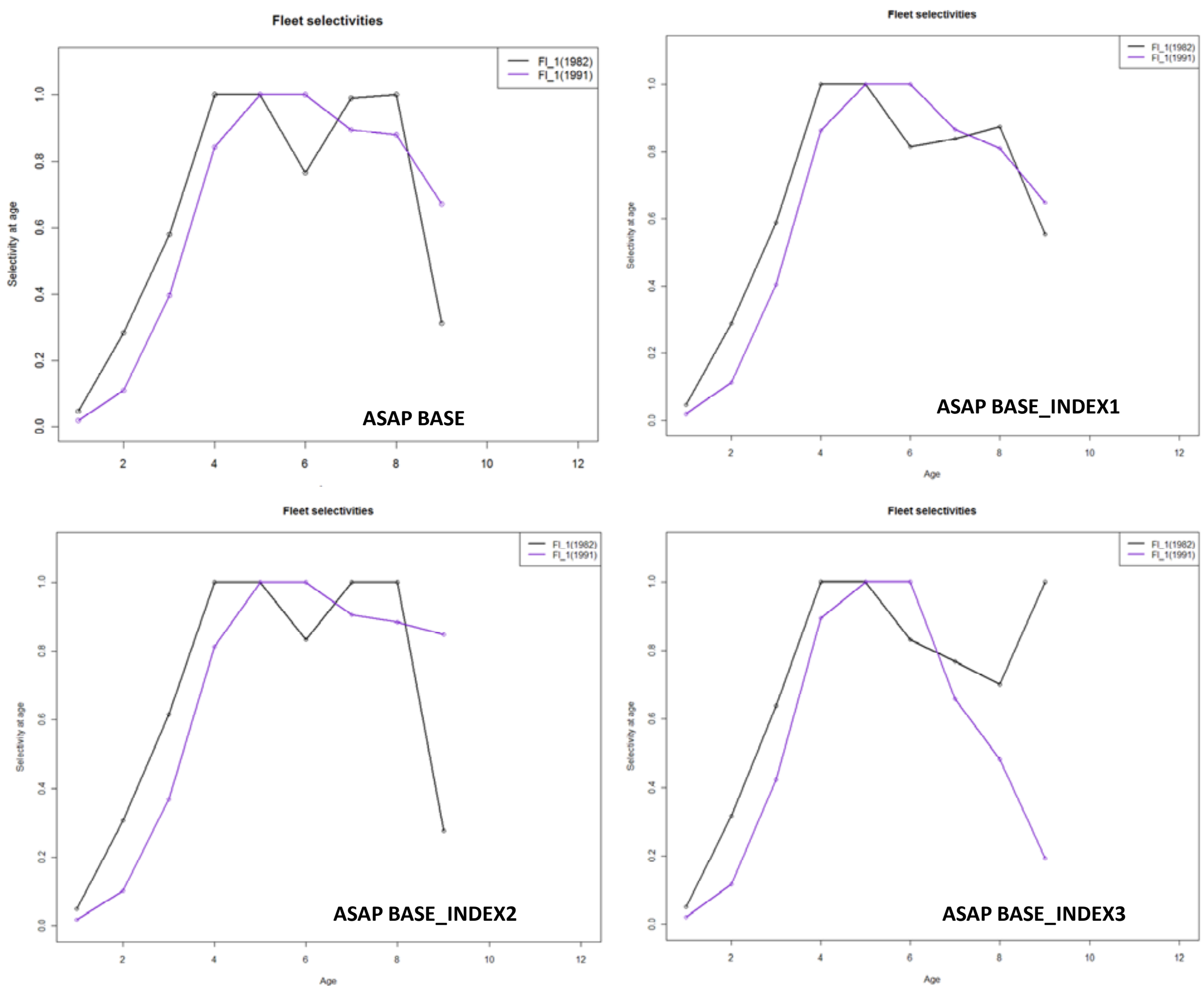


Appendix Figure A2.19. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run that includes only the MADMF spring survey (BASE_INDEX3).

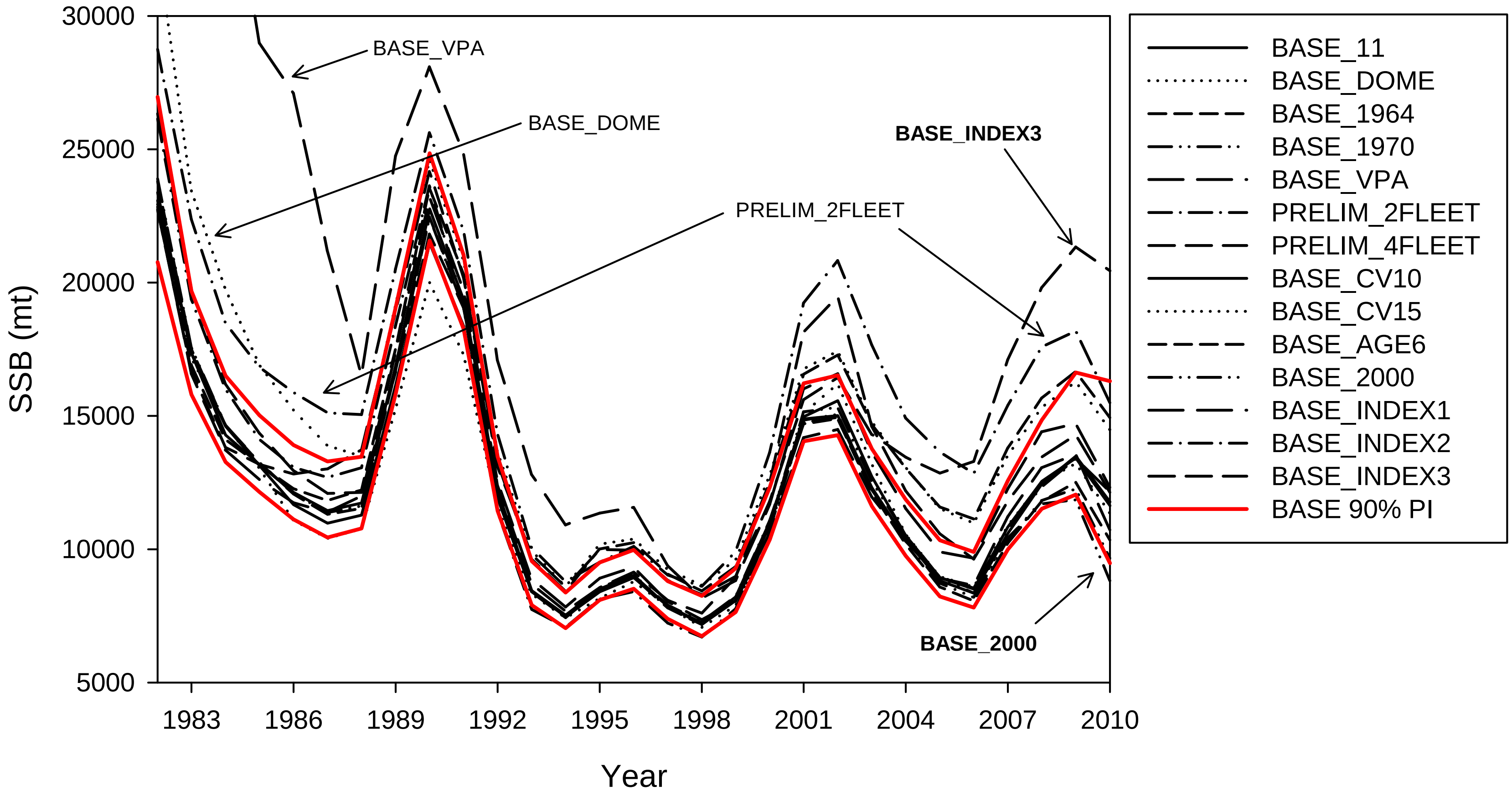




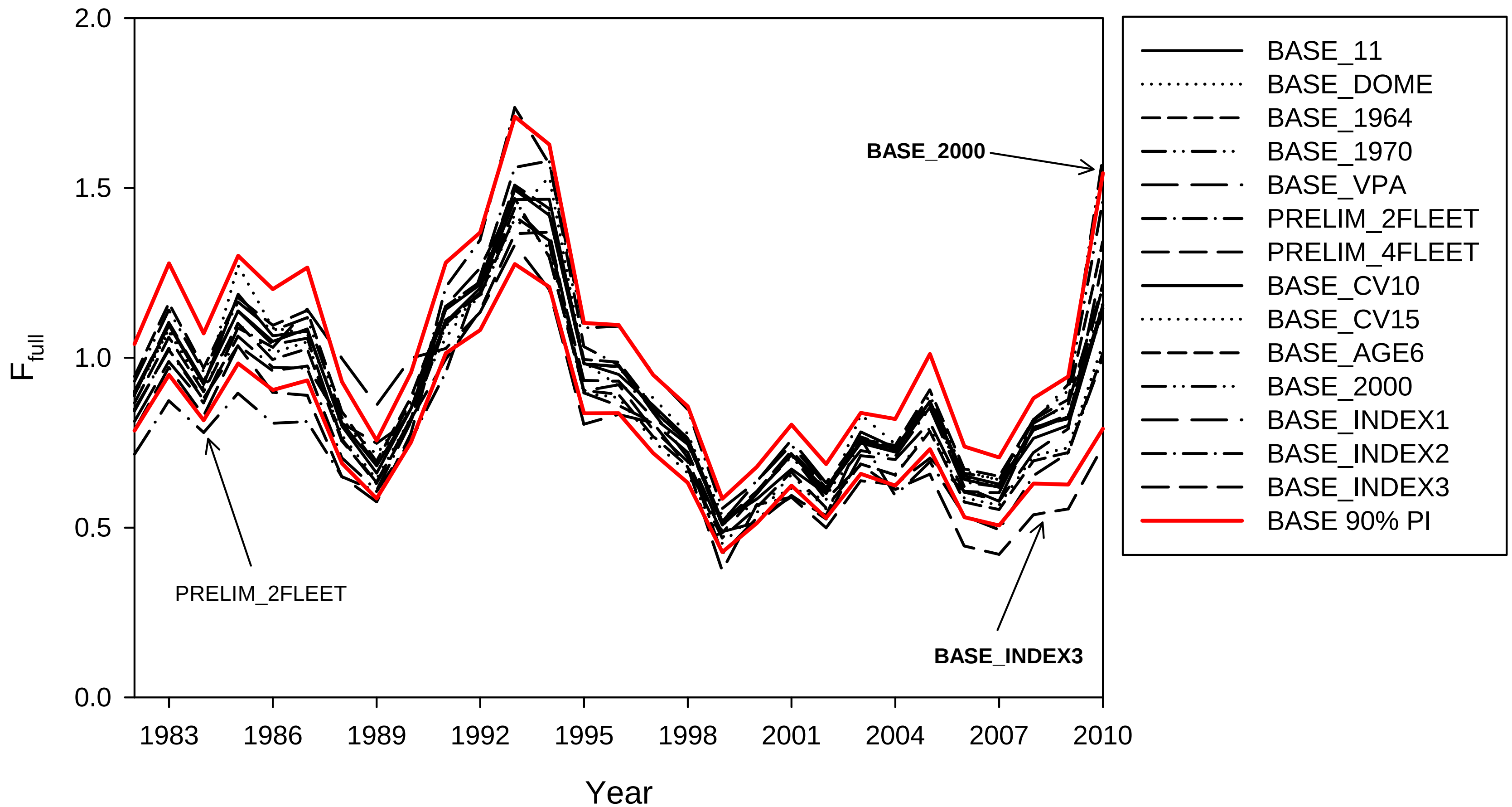
Appendix Figure A2.20. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run that includes only the MADMF spring survey (BASE_INDEX3).



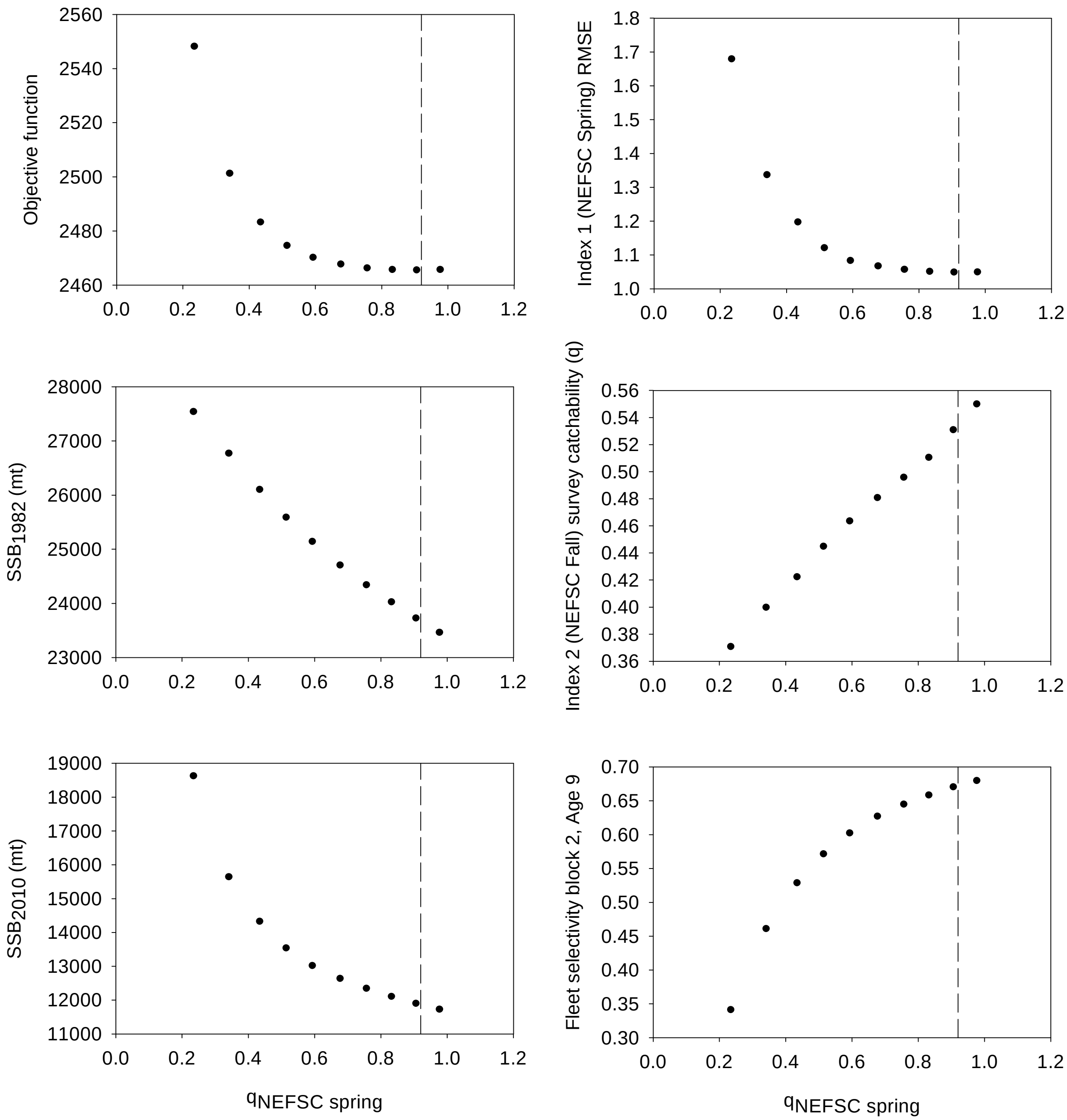
Appendix Figure A2.21. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1), the NEFSC fall survey (BASE_INDEX2), or the MADMF spring survey (BASE_INDEX3).



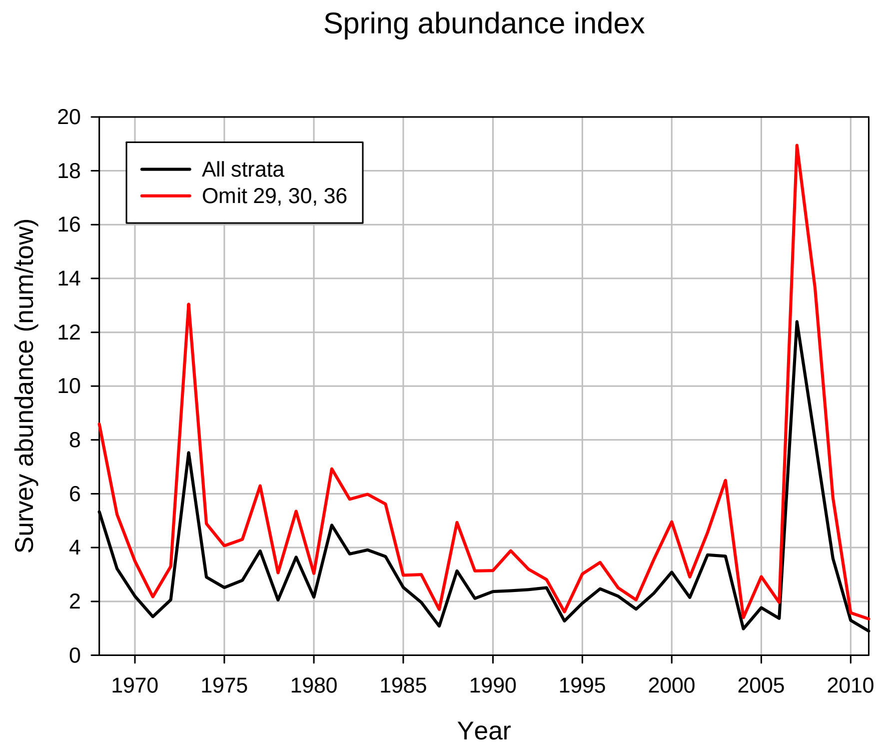
Appendix Figure A2.22. Estimates of Gulf of Maine cod spawning stock biomass (SSB) from 14 sensitivity runs of the ASAP model. The 90% probability intervals (PI) for the base ASAP model (BASE) are shown in red. The two sensitivity runs that fell outside the 90% PI in 2010 (BASE_INDEX3 and BASE_2000) are identified by bold text.

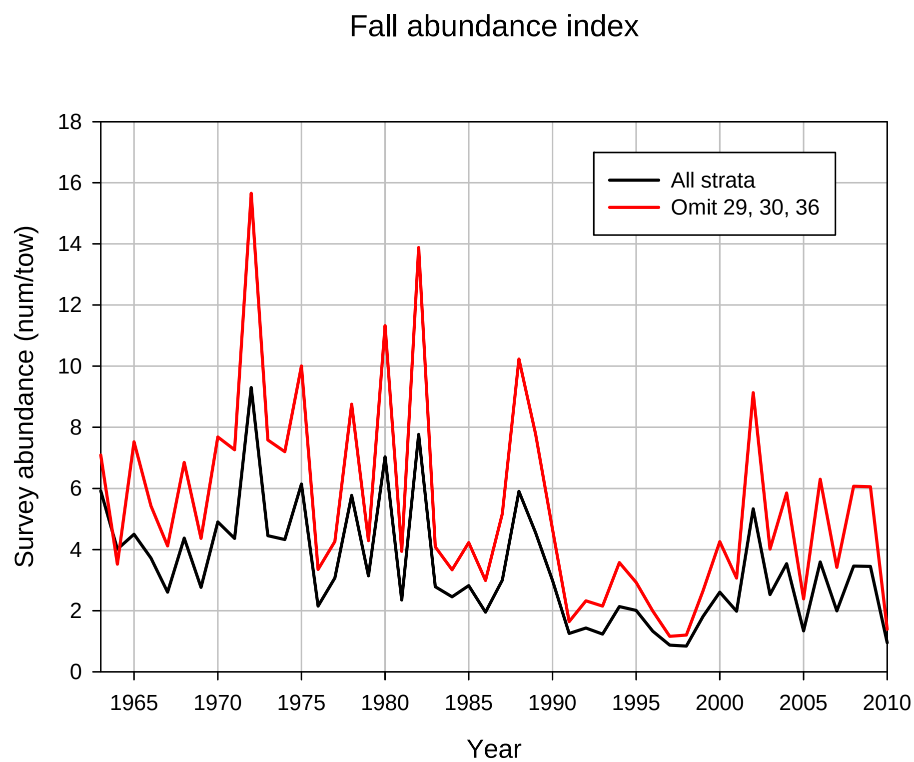


Appendix Figure A2.23. Estimates of Gulf of Maine cod fully recruited fishing mortality (F_{full}) from 14 sensitivity runs of the ASAP model. The 90% probability intervals (PI) for the base ASAP model (BASE) are shown in red. The two sensitivity runs that fell outside the 90% PI in 2010 (BASE_INDEX3 and BASE_2000) are identified by bold text.

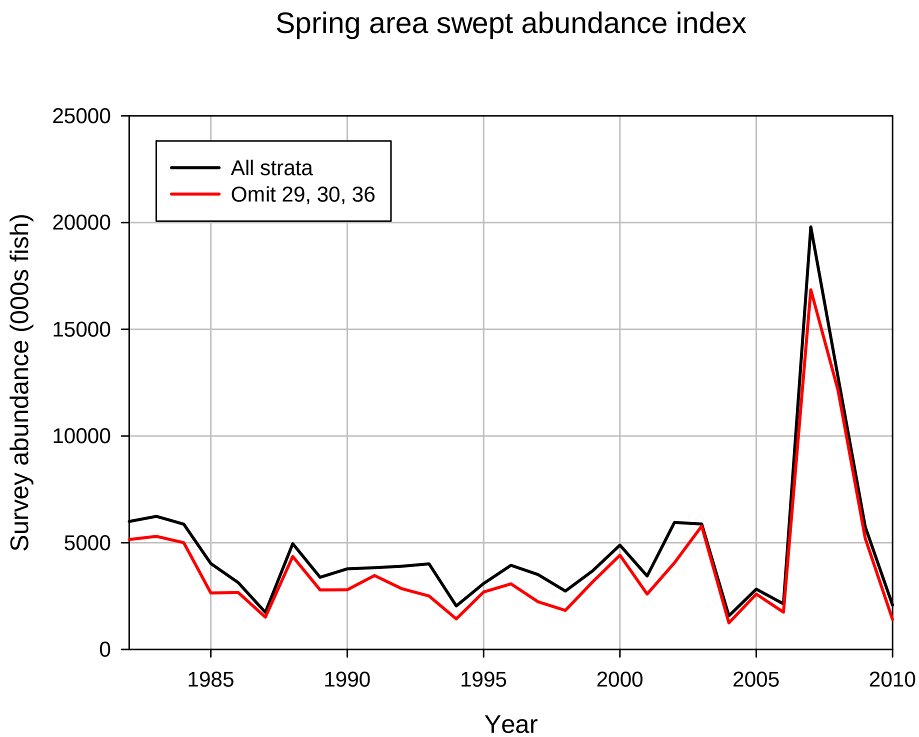


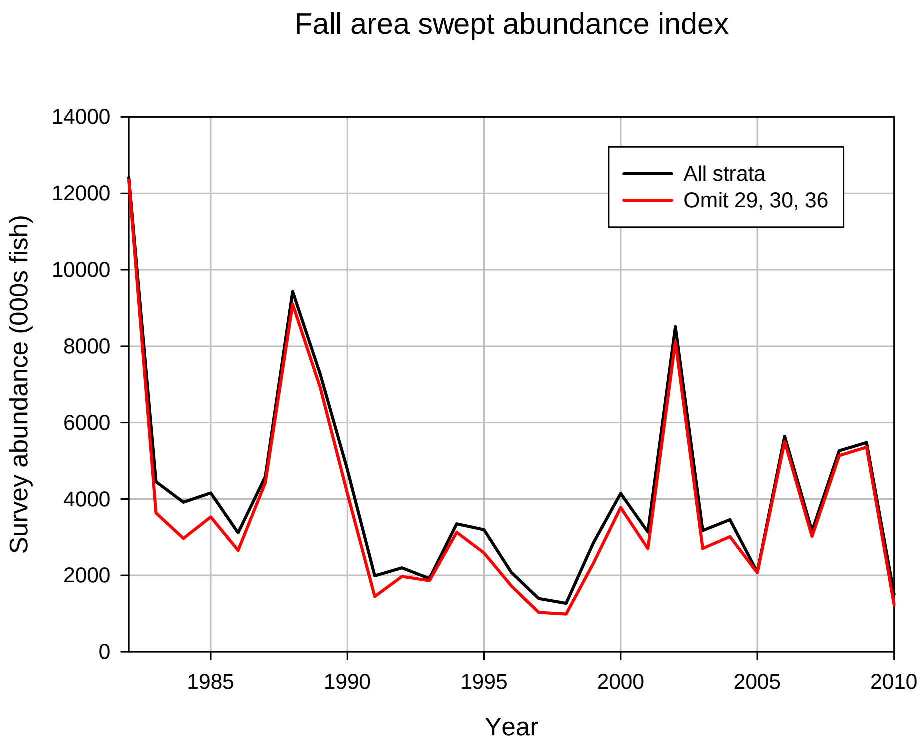
Appendix Figure A2.24. Sensitivity analysis showing the response of the ASAP base model (BASE) to different assumptions of Gulf of Maine Atlantic cod survey catchability (*q*) of the Northeast Fisheries Science Center spring survey.





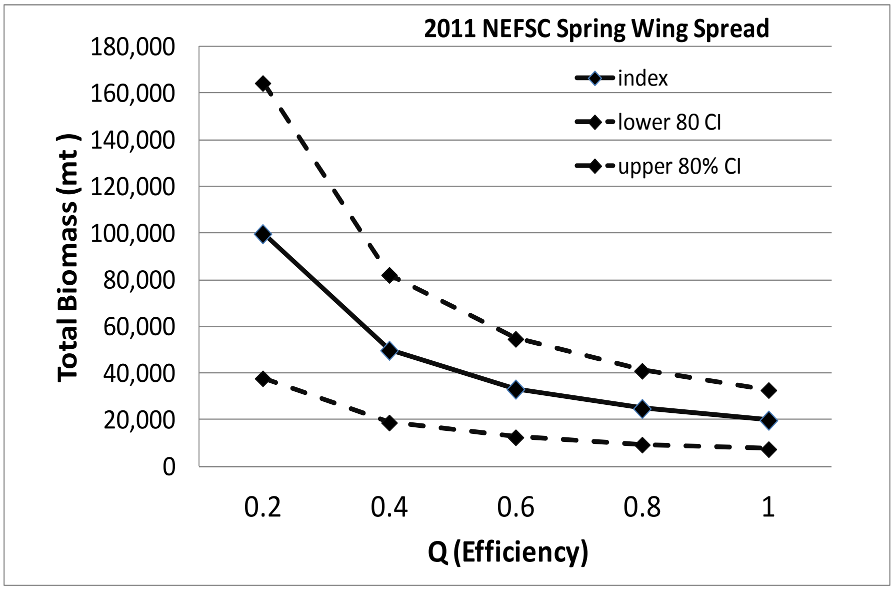
Appendix Figure A2.25. Gulf of Maine cod NEFSC spring (top) and fall (bottom) survey indices of abundance (numbers per tow) when estimated from all NEFSC offshore strata (26, 27, 28, 29, 30, 36, 37, 38, 39, 40; black line) and when strata 29, 30, and 36 are excluded (red line).

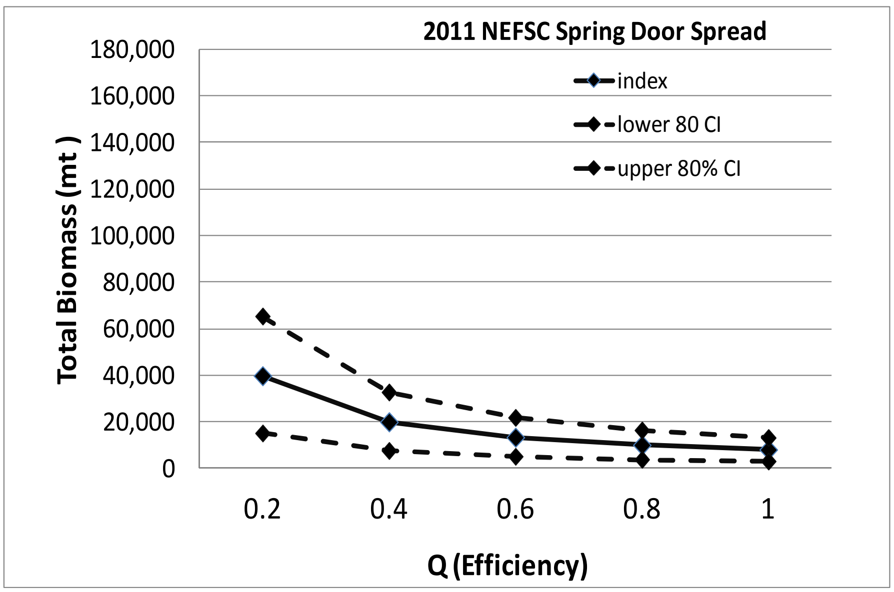




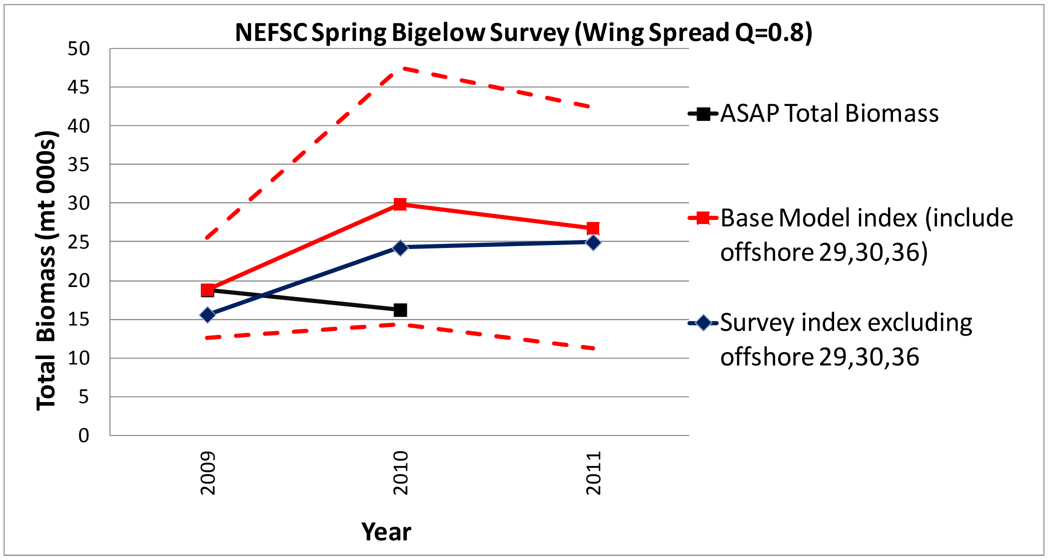
Appendix Figure A2.26. Gulf of Maine cod NEFSC spring (top) and fall (bottom) survey indices of abundance in terms of area swept abundance (thousands of fish) when estimated from all NEFSC offshore strata (26- 30 and 36- 40; black line) and when strata 29, 30, and 36 are excluded (red line).

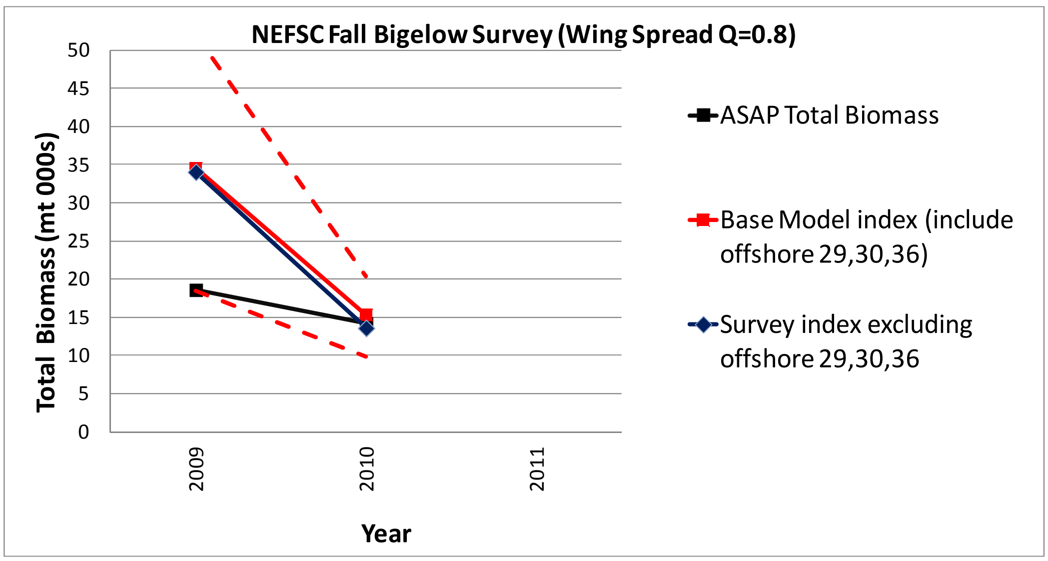
Appendix Figure A2.27. Comparison of Gulf of Maine cod spawning stock biomass (top), average fishing mortality (F) on ages 5-7 (middle) and age-1 recruitment (thousands of fish; bottom) between the ASAP base run (BASE) and a sensitivity run excluding NEFSC offshore survey strata 29, 30 and 36 (BASE_revAS).



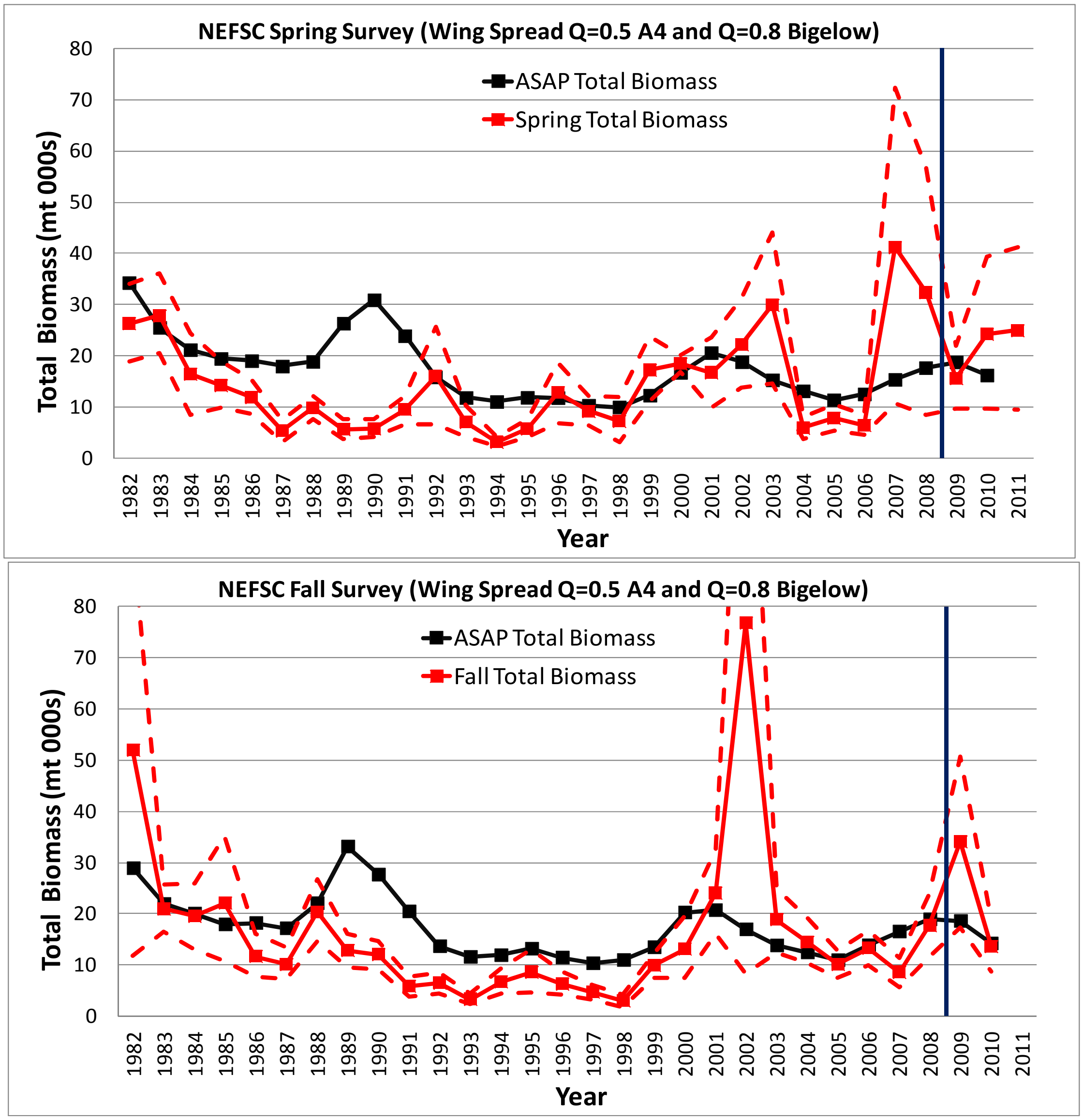


Appendix Figure A2.28. Area swept estimates of total Gulf of Maine cod biomass under different assumptions of NEFSC spring Bigelow survey catchability (*q*) and effective trawl area (wing spread vs. door spread). The 80% bootstrap confidence interval (CI) is shown by the dashed lines.

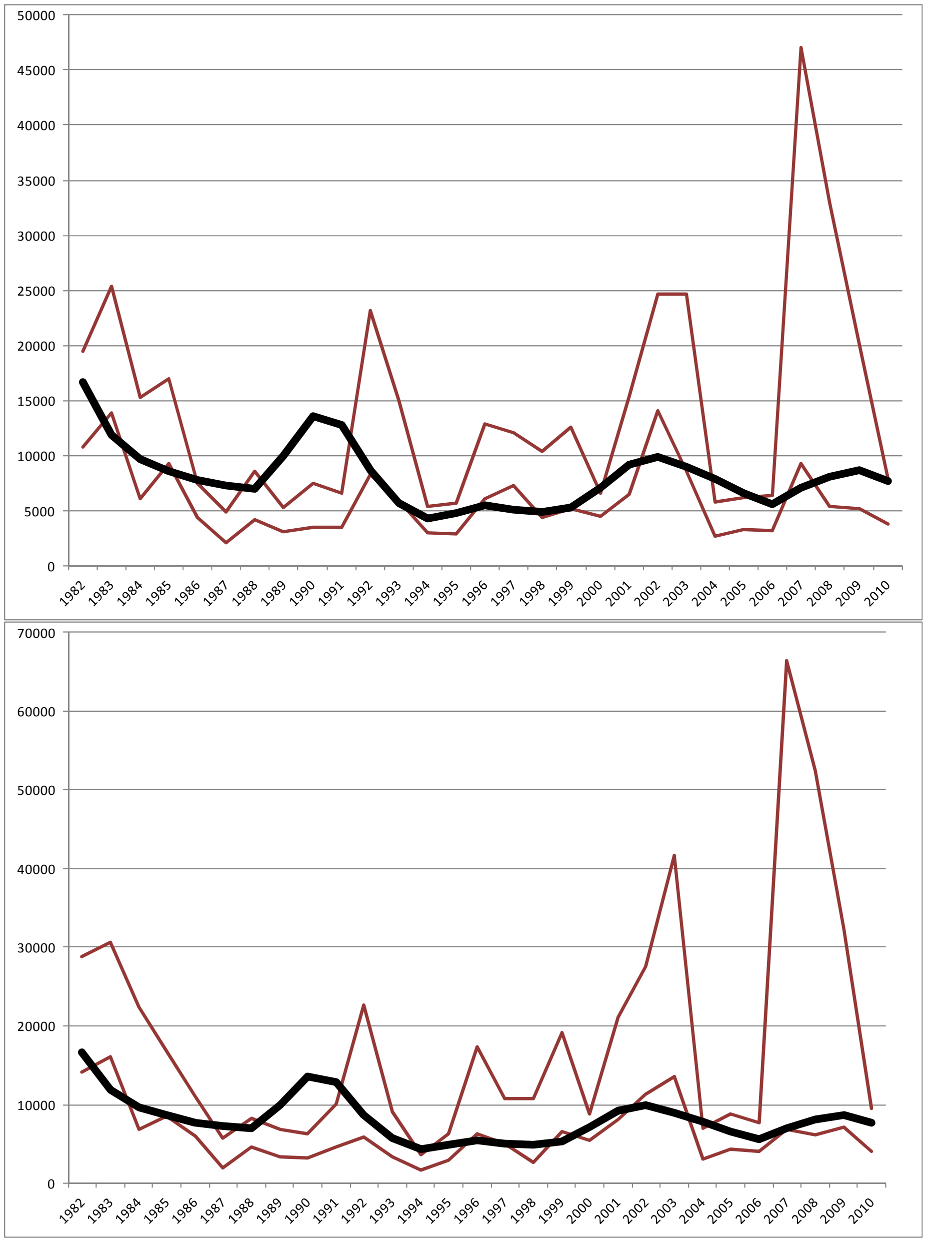




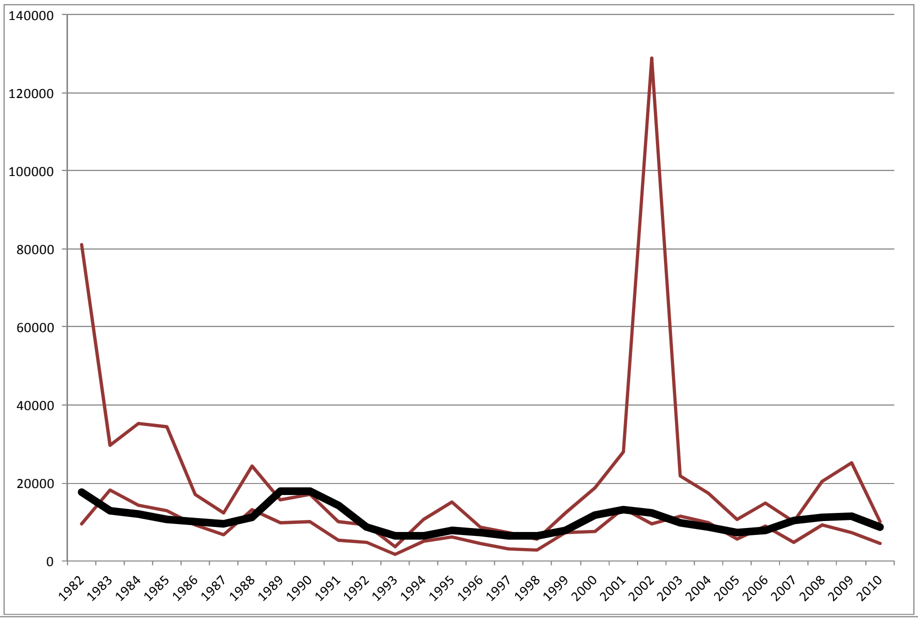
Appendix Figure A2.29. Area swept estimates of total Gulf of Maine cod biomass from 2009 to 2011 based on the NEFSC spring (top) and fall (bottom) Bigelow survey when the effective area is set equal to the wing spread and the survey is assumed to be 80% efficient (q=0.8). Biomass has been estimated using 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.*

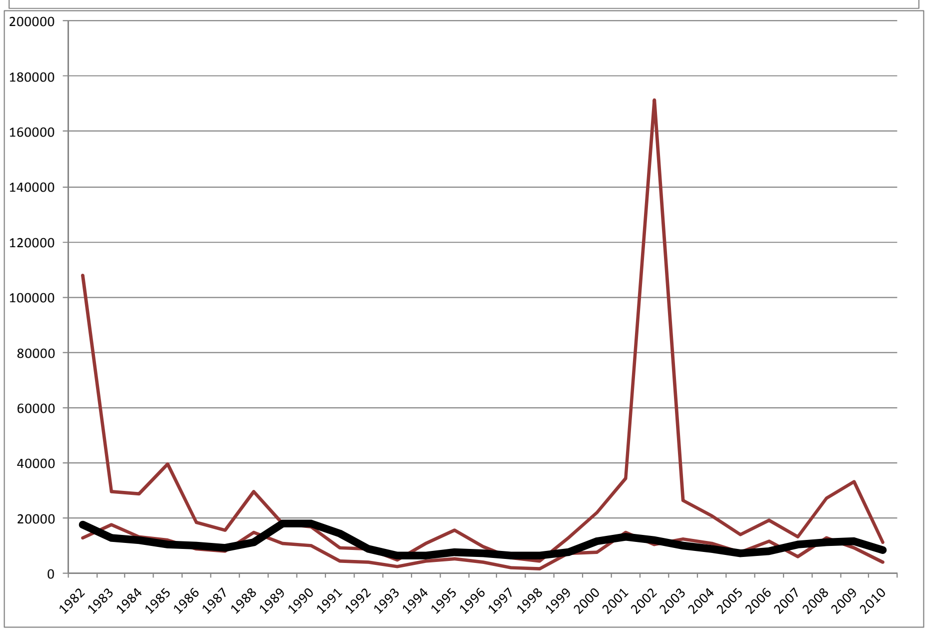


Appendix Figure A2.30. Area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC spring (top) and fall (bottom) survey when a the effective trawl area is set equal to the wing spread and strata set 29, 30 and 36 are excluded from the indices calculation. In these analyses, 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.*



Appendix Figure A2.31. Comparison of the 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.





Appendix Figure A2.32. Comparison of the 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.

Appendix 3. ASAP BASE model input file.

```
# ASAP VERSION 2.0
# ASAP GoM cod 1982 start flat survey selectivity (no LPUE)
#
# ASAP GUI - 15 JAN 2008
#
# Number of Years
29
# First Year
1982
# Number of Ages
9
# Number of Fleets
1
# Number of Selectivity Blocks (sum over all fleets)
2
# Number of Available Indices
5
# Fleet Names
#$Catch
# Index Names
#$NEFSCspring
#$NEFSCfall
#$MAspring
#$MAfall
#$ComLPUE
#
# Natural Mortality Rate Matrix
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
```

0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
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0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
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0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
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0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
Fecundity Option
0
Fraction of year that elapses prior to SSB calculation (0=Jan-1)
0.25
Maturity Matrix
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000

0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
0.094 0.287 0.610 0.859 0.959 0.989 0.997 0.999 1.000
Weight at Age for Catch Matrix
0.347 0.813 1.480 2.560 5.084 7.058 9.630 9.724 15.637
0.226 0.720 1.520 2.415 3.806 6.055 6.097 10.268 13.399
0.236 0.617 1.434 2.678 3.621 5.533 8.315 10.087 14.898
0.210 0.694 1.336 2.818 4.694 5.951 8.517 11.245 13.476
0.278 0.488 1.668 2.736 4.803 6.565 8.139 10.295 14.686
0.160 0.600 1.257 3.054 4.634 7.340 10.159 11.136 14.354
0.124 0.550 1.606 2.339 5.182 5.166 6.142 10.141 12.818
0.248 0.689 1.433 2.925 4.294 5.990 9.247 12.272 20.776
0.195 0.766 1.271 2.104 4.500 7.697 10.705 11.641 18.635
0.236 1.020 1.506 2.216 3.825 7.138 10.613 12.261 14.028
0.058 0.949 1.416 2.679 2.935 5.541 10.900 10.389 14.483
0.095 0.624 1.625 2.001 4.367 5.628 9.869 13.673 15.661
0.074 0.601 1.536 3.023 3.221 6.328 7.650 12.583 11.691
0.123 1.048 1.404 2.535 5.028 6.806 11.466 13.096 22.443

0.146 1.038 1.902 2.164 3.374 7.572 11.717 14.388 16.225
0.076 1.103 1.941 2.928 2.973 4.570 8.993 12.150 16.938
0.203 0.881 1.790 2.491 3.941 4.163 7.086 12.118 16.676
0.247 0.577 1.532 2.733 3.845 5.671 6.593 9.736 12.279
0.278 0.853 1.882 3.181 4.192 5.821 5.302 9.409 12.704
0.316 0.733 1.866 2.919 4.482 6.014 7.193 9.066 9.488
0.171 0.652 1.433 2.535 3.366 6.078 6.948 8.542 12.374
0.263 0.671 1.600 1.994 3.273 4.745 7.666 9.252 12.116
0.117 0.498 1.357 2.696 3.262 5.094 7.118 9.729 13.320
0.148 0.531 1.356 1.955 3.984 4.337 6.319 7.983 12.490
0.295 0.611 1.243 2.639 3.062 4.125 5.493 7.226 12.131
0.211 0.685 1.389 2.531 3.424 4.535 6.153 7.295 12.400
0.272 0.833 1.779 2.496 3.219 3.710 5.780 7.723 12.267
0.326 0.854 1.823 2.804 3.266 4.027 5.852 7.760 12.895
0.281 1.057 1.521 2.730 3.354 3.828 5.687 8.876 11.865
Weight at Age for Spawning Stock Biomass Matrix
0.2409 0.5946 1.1586 2.0995 4.6586 7.5939 9.3260 9.6769 15.6370
0.1368 0.4998 1.1116 1.8906 3.1214 5.5483 6.5599 9.9439 13.3990
0.1376 0.3734 1.0161 2.0176 2.9571 4.5890 7.0956 7.8422 14.8980
0.1378 0.4047 0.9079 2.0102 3.5455 4.6420 6.8647 9.6697 13.4760
0.1892 0.3201 1.0759 1.9119 3.6790 5.5512 6.9595 9.3639 14.6860
0.0863 0.4084 0.7832 2.2570 3.5607 5.9375 8.1666 9.5203 14.3540
0.0526 0.2966 0.9816 1.7147 3.9782 4.8928 6.7143 10.1500 12.8180
0.1411 0.2923 0.8878 2.1674 3.1692 5.5714 6.9116 8.6819 20.7760
0.0853 0.4359 0.9358 1.7364 3.6280 5.7490 8.0077 10.3752 18.6350
0.1177 0.4460 1.0741 1.6783 2.8369 5.6675 9.0382 11.4566 14.0280
0.0177 0.4732 1.2018 2.0086 2.5503 4.6037 8.8207 10.5004 14.4830
0.0378 0.1902 1.2418 1.6833 3.4204 4.0643 7.3949 12.2080 15.6610
0.0197 0.2389 0.9790 2.2164 2.5387 5.2568 6.5616 11.1437 11.6910
0.0423 0.2785 0.9186 1.9733 3.8987 4.6821 8.5180 10.0092 22.4430
0.0531 0.3573 1.4118 1.7431 2.9246 6.1703 8.9301 12.8442 16.2250
0.0223 0.4013 1.4194 2.3599 2.5364 3.9267 8.2520 11.9315 16.9380
0.1204 0.2588 1.4051 2.1989 3.3969 3.5180 5.6906 10.4392 16.6760
0.1329 0.3422 1.1618 2.2118 3.0948 4.7275 5.2390 8.3060 12.2790
0.1712 0.4590 1.0421 2.2076 3.3848 4.7309 5.4834 7.8761 12.7040
0.2200 0.4514 1.2616 2.3438 3.7759 5.0210 6.4707 6.9331 9.4880

0.0863 0.4539 1.0249 2.1749 3.1345 5.2193 6.4642 7.8385 12.3740
0.1911 0.3387 1.0214 1.6904 2.8805 3.9965 6.8260 8.0177 12.1160
0.0549 0.3619 0.9542 2.0769 2.5504 4.0832 5.8116 8.6361 13.3200
0.0728 0.2493 0.8218 1.6288 3.2773 3.7613 5.6735 7.5381 12.4900
0.1936 0.3007 0.8124 1.8917 2.4467 4.0539 4.8809 6.7573 12.1310
0.1062 0.4495 0.9212 1.7737 3.0060 3.7264 5.0380 6.3302 12.4000
0.1535 0.4192 1.1039 1.8620 2.8543 3.5641 5.1198 6.8934 12.2670
0.1810 0.4820 1.2323 2.2335 2.8552 3.6004 4.6595 6.6972 12.8950
0.1345 0.5870 1.1397 2.2309 3.0667 3.5359 4.7856 7.2071 11.8650
Weight at Age for Jan-1 Biomass Matrix
0.2409 0.5946 1.1586 2.0995 4.6586 7.5939 9.3260 9.6769 15.6370
0.1368 0.4998 1.1116 1.8906 3.1214 5.5483 6.5599 9.9439 13.3990
0.1376 0.3734 1.0161 2.0176 2.9571 4.5890 7.0956 7.8422 14.8980
0.1378 0.4047 0.9079 2.0102 3.5455 4.6420 6.8647 9.6697 13.4760
0.1892 0.3201 1.0759 1.9119 3.6790 5.5512 6.9595 9.3639 14.6860
0.0863 0.4084 0.7832 2.2570 3.5607 5.9375 8.1666 9.5203 14.3540
0.0526 0.2966 0.9816 1.7147 3.9782 4.8928 6.7143 10.1500 12.8180
0.1411 0.2923 0.8878 2.1674 3.1692 5.5714 6.9116 8.6819 20.7760
0.0853 0.4359 0.9358 1.7364 3.6280 5.7490 8.0077 10.3752 18.6350
0.1177 0.4460 1.0741 1.6783 2.8369 5.6675 9.0382 11.4566 14.0280
0.0177 0.4732 1.2018 2.0086 2.5503 4.6037 8.8207 10.5004 14.4830
0.0378 0.1902 1.2418 1.6833 3.4204 4.0643 7.3949 12.2080 15.6610
0.0197 0.2389 0.9790 2.2164 2.5387 5.2568 6.5616 11.1437 11.6910
0.0423 0.2785 0.9186 1.9733 3.8987 4.6821 8.5180 10.0092 22.4430
0.0531 0.3573 1.4118 1.7431 2.9246 6.1703 8.9301 12.8442 16.2250
0.0223 0.4013 1.4194 2.3599 2.5364 3.9267 8.2520 11.9315 16.9380
0.1204 0.2588 1.4051 2.1989 3.3969 3.5180 5.6906 10.4392 16.6760
0.1329 0.3422 1.1618 2.2118 3.0948 4.7275 5.2390 8.3060 12.2790
0.1712 0.4590 1.0421 2.2076 3.3848 4.7309 5.4834 7.8761 12.7040
0.2200 0.4514 1.2616 2.3438 3.7759 5.0210 6.4707 6.9331 9.4880
0.0863 0.4539 1.0249 2.1749 3.1345 5.2193 6.4642 7.8385 12.3740
0.1911 0.3387 1.0214 1.6904 2.8805 3.9965 6.8260 8.0177 12.1160
0.0549 0.3619 0.9542 2.0769 2.5504 4.0832 5.8116 8.6361 13.3200
0.0728 0.2493 0.8218 1.6288 3.2773 3.7613 5.6735 7.5381 12.4900
0.1936 0.3007 0.8124 1.8917 2.4467 4.0539 4.8809 6.7573 12.1310
0.1062 0.4495 0.9212 1.7737 3.0060 3.7264 5.0380 6.3302 12.4000

0.1535 0.4192 1.1039 1.8620 2.8543 3.5641 5.1198 6.8934 12.2670
0.1810 0.4820 1.2323 2.2335 2.8552 3.6004 4.6595 6.6972 12.8950
0.1345 0.5870 1.1397 2.2309 3.0667 3.5359 4.7856 7.2071 11.8650
Selectivity Blocks (fleet outer loop, year inner loop)
Sel block for fleet 1
1
1
1
1
1
1
1
1
1
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
2
Selectivity Options for each block 1=by age, 2=logisitic, 3=double logistic
1 1

Selectivity initial guess, phase, lambda, and CV
(have to enter values for nages + 6 parameters for each block)
Sel Block 1

0.1	1	0	1
0.3	1	0	1
0.5	1	0	1
0.8	1	0	1
1	-1	0	1
1	2	0	1
0.9	2	0	1
0.8	2	0	1
0.8	2	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

Sel Block 2

0.1	1	0	1
0.3	1	0	1
0.5	1	0	1
0.8	1	0	1
0.9	1	0	1
1	-2	0	1
0.9	2	0	1
0.8	2	0	1
0.8	2	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

Selectivity Start Age by fleet
1

Selectivity End Age by fleet
9
Age range for average F
5 7
Average F report option (1=unweighted, 2=Nweighted, 3=Bweighted)
1
Use likelihood constants? (1=yes)
1
Release Mortality by fleet
1
Fleet 1 Catch at Age - Last Column is Total Weight
604.400 3499.200 2513.900 1540.700 794.100 71.000 102.800 77.200 92.400 18442.6
853.200 3093.900 3084.300 1247.300 730.300 468.200 52.000 64.200 58.200 17493.8
514.700 2790.000 1834.200 1691.100 451.400 227.700 108.800 9.600 54.400 13707.7
705.400 2538.200 2757.300 1203.800 780.900 174.600 119.000 53.900 36.500 15807.1
1032.900 2345.800 2941.200 1053.800 293.200 217.200 51.300 42.000 52.700 13681.0
411.900 2927.100 1937.500 1734.700 372.500 98.100 93.300 17.600 43.500 13771.5
570.500 2076.600 2350.100 1243.200 464.100 70.400 26.900 28.300 9.900 11242.8
238.800 1787.400 2833.000 1760.400 544.700 92.800 74.200 9.900 20.300 14623.1
90.600 1076.500 6483.100 2910.300 572.100 202.000 31.300 40.500 44.000 20959.4
169.300 663.300 1128.200 6040.000 1094.500 154.800 59.900 26.000 16.000 22272.7
504.100 1081.500 1038.100 533.500 2281.400 231.300 81.100 6.100 5.500 12960.8
152.100 1009.100 2601.400 1106.400 107.000 508.500 42.900 11.300 0.000 10993.4
178.200 459.800 1949.800 1354.700 275.000 67.100 75.600 28.900 8.000 9727.3
116.800 495.200 1729.700 1379.400 228.100 30.400 6.500 18.300 2.800 8189.9
67.800 195.000 763.500 2207.600 427.000 37.100 4.100 0.500 1.800 8249.8
100.800 220.700 624.900 497.400 927.500 76.100 5.600 2.300 1.000 6120.9
18.100 312.500 606.500 710.800 158.200 216.500 29.100 5.300 2.300 4967.9
143.700 265.100 517.200 401.600 213.200 64.200 71.700 13.900 1.100 3883.1
75.400 1033.700 795.600 949.400 196.900 91.500 13.600 11.900 0.000 6961.4
0.800 946.000 1778.300 882.300 457.000 120.300 63.100 9.100 12.100 10009.8
42.200 95.100 801.000 1359.500 440.700 182.700 74.100 34.500 24.200 8366.5
105.300 330.100 318.600 1041.100 946.900 226.100 83.500 32.400 30.300 8314.4
250.300 233.600 1136.700 347.000 522.600 290.900 74.300 35.400 29.200 7072.0
41.500 526.900 335.400 1568.500 103.300 278.500 117.700 30.700 34.500 6845.4
42.400 134.100 768.500 364.600 562.400 35.400 84.400 42.400 28.600 4996.5

19.400	262.900	615.200	1289.400	161.300	249.100	8.000	19.300	22.100	6447.8
31.300	358.000	1028.000	942.800	937.000	102.400	117.800	4.400	17.700	8817.5
28.300	263.900	1012.800	1400.100	581.100	367.900	22.500	33.900	10.600	9918.2
29.000	344.700	1138.800	1488.900	1046.800	249.100	88.200	14.300	11.000	11392.4

Fleet 1 Discards at Age - Last Column is Total Weight

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	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	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	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	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
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	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	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	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	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
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	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	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	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	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
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	0.0	0.0

Fleet 1 Release Proportion at Age

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
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
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
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
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
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
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
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
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
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
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
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
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
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
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
# Index Units
2  2  2  2  2
# Index Month
4  10  4  9  6
# Index Selectivity Choice
-1  -1  -1  -1  1
# Index Selectivity Option for each Index 1=by age, 2=logisitic, 3=double logistic
1  1  3  3  2
```

Index Start Age
1 1 1 1 2
Index End Age
9 9 9 9 6
Use Index? 1=yes
1 1 1 0 0
Index Selectivity initial guess, phase, lambda, and CV
(have to enter values for nages + 6 parameters for each block)
Index-1

0.05	1	0	1
0.2	1	0	1
0.4	1	0	1
0.79	1	0	1
0.9	1	0	1
1	-2	0	1
1	-2	0	1
1	-2	0	1
1	-2	0	1
1.5	1	0	1
1	2	0	1
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Index-2

0.05	1	0	1
0.2	1	0	1
0.4	1	0	1
0.79	1	0	1
0.9	1	0	1
1	-2	0	1
1	-2	0	1
1	-2	0	1
1	-2	0	1
1.5	1	0	1
1	2	0	1

0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
Index-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
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
0.25 1 0 1
10 -1 0 1
2 2 0 1
1 3 0 1
Index-4
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
0 0 0 0
0 0 0 0
11 -1 0 1
11 -1 0 1
2 2 0 1
0.1 3 0 1

Index-5

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
1	-1	0	1
2	-3	0	1
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Index Data - Year, Index Value, CV, proportions at age and input effective sample size (only used if estimating parameters)
Index-1

1982	5988.4	0.419	570.8000	1661.4000	794.8000	1177.7000	1355.0000	132.9000	215.8000	0.0000	80.0000	30
1983	6229.8	0.463	974.2000	1546.4000	1664.4000	723.2000	537.2000	399.1000	95.9000	0.0000	289.5000	30
1984	5858.4	0.643	241.2000	2091.3000	1576.9000	1363.0000	366.5000	75.2000	144.3000	0.0000	0.0000	30
1985	4020.7	0.402	45.7000	379.9000	1079.4000	978.3000	1129.4000	150.6000	174.6000	41.4000	41.4000	30
1986	3126.1	0.514	857.2000	413.1000	1224.8000	348.3000	120.3000	73.8000	59.9000	0.0000	28.8000	30
1987	1729.1	0.457	47.6000	752.1000	304.5000	354.6000	120.1000	0.0000	108.3000	18.1000	23.8000	30
1988	4949.9	0.411	1148.8000	1479.0000	1263.1000	452.7000	326.7000	157.8000	57.2000	32.3000	32.3000	30
1989	3374.2	0.384	39.8000	972.7000	1136.9000	1005.6000	110.7000	108.5000	0.0000	0.0000	0.0000	30
1990	3773	0.449	14.4000	371.9000	2116.4000	1068.4000	122.0000	51.3000	28.6000	0.0000	0.0000	30
1991	3823	0.451	45.0000	123.0000	371.6000	2796.3000	393.8000	64.7000	28.6000	0.0000	0.0000	30
1992	3889.6	0.517	80.2000	395.2000	355.9000	396.8000	2185.1000	340.7000	117.3000	0.0000	18.4000	30
1993	4004.8	0.423	321.3000	810.6000	1284.2000	581.5000	134.5000	711.7000	88.5000	36.3000	36.3000	30
1994	2030.6	0.423	24.6000	504.2000	649.4000	321.7000	133.1000	83.9000	227.2000	14.5000	72.0000	30
1995	3083.7	0.473	58.3000	298.7000	1860.6000	513.4000	234.8000	54.3000	0.0000	18.1000	45.4000	30
1996	3937	0.44	91.4000	34.3000	936.3000	2164.1000	614.9000	96.0000	0.0000	0.0000	0.0000	30
1997	3501.1	0.368	253.4000	222.5000	623.5000	432.1000	1395.6000	390.1000	183.9000	0.0000	0.0000	30
1998	2732.5	0.544	28.9000	364.9000	573.7000	819.2000	229.1000	651.1000	33.4000	32.3000	0.0000	30
1999	3675.5	0.442	264.5000	546.2000	1160.1000	560.1000	487.2000	214.5000	424.8000	0.0000	18.1000	30

2000	4883.9	0.421	1873.9000	1176.9000	700.0000	774.9000	158.2000	146.7000	18.1000	35.3000	0.0000	30
2001	3429	0.511	45.7000	566.8000	1091.1000	814.2000	547.0000	103.7000	155.0000	87.5000	18.1000	30
2002	5948.9	0.403	543.6000	72.4000	875.9000	2530.4000	967.8000	545.9000	295.7000	90.6000	26.7000	30
2003	5874.6	0.423	119.3000	1317.3000	93.8000	1147.5000	1711.7000	618.2000	542.4000	128.9000	195.5000	30
2004	1567.6	0.456	217.6000	71.1000	368.1000	185.2000	332.9000	340.6000	18.1000	18.1000	16.1000	30
2005	2818.6	0.441	45.7000	1181.0000	129.9000	995.9000	18.1000	220.3000	204.5000	23.3000	0.0000	30
2006	2131.5	0.403	293.5000	378.6000	693.6000	77.6000	314.5000	37.4000	201.4000	110.2000	24.6000	30
2007	19797.7	0.865	159.3000	5467.0000	4915.3000	7102.5000	698.4000	1271.1000	119.0000	65.0000	0.0000	30
2008	12763.4	0.916	126.7000	1860.6000	6278.5000	2527.1000	1755.0000	85.1000	130.4000	0.0000	0.0000	30
2009	5749.6	0.731	100.3000	446.2000	1677.4000	1813.2000	958.2000	700.0000	12.8000	35.8000	5.8000	30
2010	2070.2	0.443	94.9000	445.1000	534.4000	313.9000	365.8000	181.2000	69.3000	25.4000	40.3000	30

Index-2

1982	12410.2	0.736	1333.9000	5214.6000	3955.6000	1551.7000	354.5000	0.0000	0.0000	0.0000	0.0000	30
1983	4450.2	0.27	487.9000	1445.1000	1208.5000	426.7000	400.0000	350.2000	0.0000	0.0000	131.7940	30
1984	3912.1	0.32	819.4000	668.4000	936.5000	612.8000	313.1000	309.9000	99.2000	0.0000	152.8810	30
1985	4159.3	0.276	711.2000	1465.4000	1000.8000	321.3000	392.7000	101.9000	0.0000	54.3000	111.6650	30
1986	3115.6	0.33	628.8000	644.8000	999.7000	588.0000	116.1000	66.1000	0.0000	0.0000	72.0470	30
1987	4581.3	0.408	910.7000	2217.3000	936.6000	316.9000	199.7000	0.0000	0.0000	0.0000	0.0000	30
1988	9429.6	0.449	3018.2000	3778.9000	1707.4000	586.0000	233.1000	0.0000	70.0000	0.0000	36.1040	30
1989	7272.8	0.323	232.0000	3941.8000	2329.3000	451.3000	219.8000	84.2000	0.0000	14.4000	0.0000	30
1990	4770.5	0.29	90.9000	348.3000	2856.0000	975.6000	407.5000	77.0000	15.2000	0.0000	0.0000	30
1991	1985.7	0.367	229.2000	241.4000	367.4000	991.2000	120.3000	0.0000	36.1000	0.0000	0.0000	30
1992	2196.1	0.313	461.7000	716.3000	229.9000	64.7000	522.4000	201.1000	0.0000	0.0000	0.0000	30
1993	1919.1	0.359	334.8000	918.4000	577.2000	27.6000	0.0000	61.0000	0.0000	0.0000	0.0000	30
1994	3351.4	0.409	293.1000	1452.0000	1303.7000	148.6000	81.6000	0.0000	72.4000	0.0000	0.0000	30
1995	3194.2	0.401	108.6000	492.5000	1958.7000	485.2000	131.2000	18.1000	0.0000	0.0000	0.0000	30
1996	2074.7	0.354	195.4000	605.3000	369.7000	824.5000	79.9000	0.0000	0.0000	0.0000	0.0000	30
1997	1393.2	0.399	474.1000	145.7000	263.9000	268.5000	240.9000	0.0000	0.0000	0.0000	0.0000	30
1998	1267.1	0.446	135.8000	545.5000	176.4000	295.1000	65.3000	49.0000	0.0000	0.0000	0.0000	30
1999	2845.9	0.281	690.3000	599.4000	942.0000	389.0000	195.1000	30.2000	0.0000	0.0000	0.0000	30
2000	4146.5	0.406	862.8000	1566.8000	636.8000	786.6000	223.0000	16.1000	0.0000	54.3000	0.0000	30
2001	3135.3	0.371	0.0000	273.0000	1150.4000	763.8000	568.1000	197.5000	146.3000	0.0000	36.2630	30
2002	8511.8	0.678	429.9000	165.8000	531.6000	4286.1000	1709.8000	1197.5000	122.2000	68.9000	0.0000	30
2003	3175.2	0.407	737.1000	297.0000	344.4000	827.0000	721.0000	113.1000	99.5000	0.0000	36.1040	30
2004	3458.3	0.427	1056.3000	275.4000	922.1000	406.2000	399.4000	237.9000	90.6000	36.3000	34.1870	30
2005	2082.8	0.165	244.9000	604.3000	124.0000	728.0000	36.3000	143.8000	131.2000	36.3000	34.1870	30

2006	5640	0.401	1982.3000	956.6000	1609.2000	402.6000	467.4000	59.3000	83.9000	57.2000	21.5660	30
2007	3163.8	0.468	217.3000	1378.2000	631.7000	793.0000	36.6000	107.2000	0.0000	0.0000	0.0000	30
2008	5263.9	0.489	1038.1000	1960.3000	1693.0000	301.1000	222.1000	0.0000	0.0000	0.0000	49.3630	30
2009	5475.1	0.635	1053.9000	3348.5000	501.6000	442.0000	72.5000	56.6000	0.0000	0.0000	0.0000	30
2010	1501	0.333	150.5000	211.5000	463.4000	460.2000	147.1000	37.1000	21.1000	0.0000	10.0640	30

Index-3

1982	4734.4	0.52	2599.6000	1326.1000	554.7000	184.8000	43.4000	9.1000	6.8000	9.8000	0.0000	15
1983	10611.8	0.46	6757.6000	2928.7000	544.0000	321.6000	29.6000	15.9000	14.3000	0.0000	0.0000	15
1984	1974.7	0.58	399.5000	963.6000	451.7000	114.1000	28.8000	16.9000	0.0000	0.0000	0.0000	15
1985	1399	0.51	297.4000	554.4000	432.2000	87.9000	7.5000	0.0000	19.6000	0.0000	0.0000	15
1986	4511.7	0.85	1704.3000	2414.3000	185.7000	183.3000	19.4000	4.5000	0.0000	0.0000	0.0000	15
1987	3230.8	0.52	1631.9000	940.1000	569.0000	35.6000	30.1000	10.4000	0.0000	0.0000	13.7420	15
1988	3991.5	0.5	1959.8000	1346.1000	363.1000	308.6000	0.0000	7.4000	6.4000	0.0000	0.0000	15
1989	10189.9	0.57	4214.0000	4498.4000	1348.4000	97.5000	22.1000	9.4000	0.0000	0.0000	0.0000	15
1990	5384.5	0.58	879.3000	1216.6000	2775.8000	443.5000	55.2000	14.1000	0.0000	0.0000	0.0000	15
1991	2615.9	0.52	1020.9000	544.5000	336.5000	651.4000	60.2000	2.4000	0.0000	0.0000	0.0000	15
1992	3022.4	0.57	874.5000	1083.2000	670.3000	113.0000	252.8000	20.0000	8.6000	0.0000	0.0000	15
1993	2459	0.65	537.0000	1214.8000	440.7000	229.6000	19.9000	17.1000	0.0000	0.0000	0.0000	15
1994	2299.7	0.53	1008.0000	765.9000	372.7000	123.8000	29.3000	0.0000	0.0000	0.0000	0.0000	15
1995	2228	0.56	1154.7000	422.1000	527.1000	114.2000	9.9000	0.0000	0.0000	0.0000	0.0000	15
1996	807.5	0.52	152.2000	97.5000	214.0000	290.5000	53.3000	0.0000	0.0000	0.0000	0.0000	15
1997	1066.8	0.54	571.9000	189.5000	185.8000	39.2000	74.5000	5.9000	0.0000	0.0000	0.0000	15
1998	801.6	0.56	300.2000	161.3000	151.2000	138.5000	6.7000	40.2000	3.4000	0.0000	0.0000	15
1999	3540	0.67	2346.0000	440.7000	446.7000	138.5000	126.3000	14.7000	24.6000	2.5000	0.0000	15
2000	9531.4	0.68	6940.1000	1410.9000	508.1000	401.5000	139.6000	102.5000	11.5000	17.1000	0.0000	15
2001	3108.4	0.73	16.5000	893.9000	943.3000	661.7000	420.5000	101.2000	50.6000	20.8000	0.0000	15
2002	4590	0.39	3783.3000	50.0000	265.1000	252.3000	103.2000	52.9000	20.4000	46.0000	16.8200	15
2003	5141.8	0.81	3090.9000	1339.8000	87.0000	385.8000	178.2000	36.3000	13.3000	2.8000	7.6260	15
2004	3026.9	0.75	1755.5000	352.6000	521.6000	68.9000	196.0000	104.7000	19.2000	5.6000	2.8030	15
2005	2701.9	0.53	1034.0000	831.8000	169.4000	384.8000	59.2000	138.4000	49.3000	18.3000	16.7220	15
2006	4573.2	0.63	2084.6000	1294.1000	753.6000	111.0000	287.0000	20.7000	15.2000	0.0000	7.1160	15
2007	2402	0.57	825.4000	569.9000	435.2000	388.1000	67.5000	103.4000	6.5000	6.0000	0.0000	15
2008	4929.5	0.5	1407.6000	1963.9000	768.4000	411.1000	311.4000	36.7000	30.4000	0.0000	0.0000	15
2009	2826.3	0.67	1683.6000	511.7000	305.5000	207.0000	80.2000	32.8000	0.0000	5.5000	0.0000	15
2010	1354.6	0.54	514.8000	247.2000	274.0000	133.3000	128.5000	45.3000	1.4000	0.0000	10.0960	15

Index-4

1982	300.2	0.32	197.8000	65.5000	25.8000	9.1000	0.0000	0.0000	2.1000	0.0000	0.0000	10
1983	70.5	0.34	58.8000	8.4000	3.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1984	62.8	0.19	47.8000	11.8000	3.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1985	76.7	0.3	66.1000	8.2000	2.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1986	170.1	0.3	87.6000	76.9000	0.0000	5.6000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1987	215.2	0.18	210.2000	5.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1988	681.5	0.24	633.2000	46.2000	2.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1989	53.5	0.06	19.3000	27.1000	1.6000	5.5000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1990	989.7	0.27	840.3000	86.7000	52.6000	4.6000	5.4000	0.0000	0.0000	0.0000	0.0000	10
1991	483.1	0.27	375.7000	90.6000	2.6000	11.7000	2.6000	0.0000	0.0000	0.0000	0.0000	10
1992	232.4	0.08	214.3000	10.6000	0.0000	0.0000	7.4000	0.0000	0.0000	0.0000	0.0000	10
1993	427	0.25	317.1000	75.8000	29.0000	5.1000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1994	1787.9	0.49	1102.4000	583.7000	99.4000	2.4000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1995	362.3	0.3	235.9000	68.7000	56.4000	1.4000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1996	16.8	0.37	11.5000	0.5000	1.2000	3.6000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1997	5.2	0.24	5.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1998	213	0.26	126.3000	65.1000	13.9000	7.7000	0.0000	0.0000	0.0000	0.0000	0.0000	10
1999	96.1	0.55	72.9000	20.0000	1.6000	1.6000	0.0000	0.0000	0.0000	0.0000	0.0000	10
2000	124	0.36	75.0000	38.7000	7.1000	3.2000	0.0000	0.0000	0.0000	0.0000	0.0000	10
2001	75.2	0.46	6.8000	26.4000	24.4000	12.4000	5.2000	0.0000	0.0000	0.0000	0.0000	10
2002	467.7	0.57	220.7000	9.0000	63.8000	52.7000	65.6000	32.5000	16.8000	6.7000	0.0000	10
2003	453.5	0.48	143.3000	229.0000	21.6000	32.1000	18.1000	9.3000	0.0000	0.0000	0.0000	10
2004	3390.9	0.29	2768.3000	127.4000	279.9000	48.5000	122.2000	41.3000	3.2000	0.0000	0.0000	10
2005	227.5	0.41	153.8000	69.7000	4.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
2006	1155.8	0.39	773.8000	238.5000	100.8000	14.4000	19.8000	8.4000	0.0000	0.0000	0.0000	10
2007	67.6	0.27	42.5000	18.9000	6.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
2008	1303.7	0.41	647.0000	466.9000	126.4000	29.6000	33.8000	0.0000	0.0000	0.0000	0.0000	10
2009	418.3	0.43	205.0000	143.6000	58.3000	8.1000	1.6000	1.7000	0.0000	0.0000	0.0000	10
2010	355.4	0.44	87.5000	125.3000	95.3000	33.4000	6.6000	7.3000	0.0000	0.0000	0.0000	10

Index-5

1982	0.218	0.3	-999.0000	0.0740	0.0740	0.0450	0.0220	0.0030	-999.0000	-999.0000	-999.0000	-999
1983	0.233	0.3	-999.0000	0.0480	0.1100	0.0420	0.0210	0.0120	-999.0000	-999.0000	-999.0000	-999
1984	0.139	0.3	-999.0000	0.0330	0.0450	0.0440	0.0120	0.0060	-999.0000	-999.0000	-999.0000	-999
1985	0.106	0.3	-999.0000	0.0140	0.0420	0.0290	0.0180	0.0040	-999.0000	-999.0000	-999.0000	-999
1986	0.106	0.3	-999.0000	0.0040	0.0690	0.0230	0.0070	0.0040	-999.0000	-999.0000	-999.0000	-999
1987	0.06	0.3	-999.0000	0.0070	0.0190	0.0260	0.0060	0.0020	-999.0000	-999.0000	-999.0000	-999

1988	0.099	0.3	-999.0000	0.0150	0.0490	0.0240	0.0090	0.0020	-999.0000	-999.0000	-999.0000	-999
1989	0.133	0.3	-999.0000	0.0170	0.0640	0.0400	0.0110	0.0020	-999.0000	-999.0000	-999.0000	-999
1990	0.266	0.3	-999.0000	0.0110	0.1600	0.0780	0.0120	0.0050	-999.0000	-999.0000	-999.0000	-999
1991	0.221	0.3	-999.0000	0.0190	0.0400	0.1360	0.0220	0.0040	-999.0000	-999.0000	-999.0000	-999
1992	0.103	0.3	-999.0000	0.0150	0.0170	0.0140	0.0520	0.0050	-999.0000	-999.0000	-999.0000	-999
1993	0.094	0.3	-999.0000	0.0030	0.0500	0.0230	0.0040	0.0140	-999.0000	-999.0000	-999.0000	-999
1994	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
1995	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
1996	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
1997	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
1998	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
1999	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2000	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2001	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2002	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2003	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2004	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2005	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2006	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2007	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999
2008	-999	1	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999.0000	-999

2009 -999 1 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999
2010 -999 1 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999.0000 -999
Phase Control Data
Phase for F mult in 1st Year
3
Phase for F mult Deviations
3
Phase for Recruitment Deviations
4
Phase for N in 1st Year
1
Phase for Catchability in 1st Year
1
Phase for Catchability Deviations
-3
Phase for Stock Recruitment Relationship
2
Phase for Steepness
-3
Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5

0.5
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0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
#Lambda for Each Index
1 1 1 1 1
Lambda for Total Catch in Weight by Fleet
1
Lambda for Total Discards at Age by Fleet
0
Catch Total CV by Year and Fleet
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
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0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
Discard Total CV by Year and Fleet
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
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0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
Input Effective Sample Size for Catch at Age by Year & Fleet
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75

75
75
75
Input Effective Sample Size for Discards at Age by Year & Fleet
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
Lambda for F mult in first year by fleet
0
CV for F mult in first year by fleet

1
Lambda for F mult Deviations by Fleet
0
CV for F mult deviations by Fleet
1
Lambda for N in 1st Year Deviations
0
CV for N in 1st Year Deviations
1
Lambda for Recruitment Deviations
1
Lambda for Catchability in first year by index
0 0 0 0 0
CV for Catchability in first year by index
1 1 1 1 1
Lambda for Catchability Deviations by Index
0 0 0 0 0
CV for Catchability Deviations by Index
1 1 1 1 1
Lambda for Deviation from Initial Steepness
0
CV for Deviation from Initial Steepness
1
Lambda for Deviation from Initial unexploited Stock Size
0
CV for Deviation from Initial unexploited Stock Size
1
NAA for Year 1
11397 13272 5773 3454 1941 212 296 163 103
F mult in 1st year by Fleet
0.05
Catchability in 1st year by index
0.3 0.3 0.1 0.05 0.0001
Initial unexploited Stock Size
200000
Initial Steepness

```
1.00
# Maximum F
3
# Ignore Guesses
0
# Projection Control Data
# Do Projections? (1=yes, 0=no), still need to enter values even if not doing projections
0
# Fleet Directed Flag
1
# Final Year of Projections
2011
# Year Projected Recruits, What Projected, Target, non- directed F mult
2011    0    0    0    0
# MCMC info
# doMCMC (1=yes)
0
# MCMCnyear option (0=use final year values of NAA, 1=use final year + 1 values of NAA)
1
# MCMCnboot
10000
# MCMCnthin
10
# MCMCseed
548623
# R in agepro.bsn file (enter 0 to use NAA, 1 to use stock-recruit relationship, 2 to used geometric mean of previous years)
2
# Starting year for calculation of R
1982
# Starting year for calculation of R
2008
# Test Value
-23456
#####
# ---- FINIS ----
```

Appendix 4. The Statistical Catch-at-Age Model (SCAA)

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).

4.1. Population dynamics

4.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \tag{4.1}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 0 \le a \le m-2 \tag{4.2}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - C_{y,m-1}\right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - C_{y,m}\right) e^{-M_m/2} \tag{4.3}$$

where

$N_{y,a}$ is the number of fish of age a at the start of year y (which refers to a calendar year),

R_y is the recruitment (number of 0-year-old fish) at the start of year y,

M_a denotes the natural mortality rate for fish of age a,

$C_{y,a}$ is the predicted number of fish of age a caught in year y, and

m is the maximum age considered (taken to be a plus-group).

These equations reflect Pope's form of the catch equation (Pope, 1972) (the catches are assumed to be taken as a pulse in the middle of the year) rather than the more customary Baranov form (Baranov, 1918) (for which catches are incorporated under the assumption of steady continuous fishing mortality). Pope's form has been used in order to simplify computations. As long as mortality rates are not too high, the differences between the Baranov and Pope formulations will be minimal.

4.1.2. 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 Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship:

for the modified Ricker:

$$R_y = \alpha B_y^{\mathrm{sp}} \exp\left[-\beta\left(B_y^{\mathrm{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_{\mathrm{R}})^2/2)} \tag{4.4}$$

where

and for Beverton-Holt:

$$R_y = \frac{\alpha B_y^{\mathrm{sp}}}{\beta + B_y^{\mathrm{sp}}} e^{(\varsigma_y - (\sigma_{\mathrm{R}})^2/2)} \tag{4.5}$$

where

α, β and γ 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:

$$B_y^{\mathrm{sp}} = \sum_{a=0}^{m} f_{y,a} w_{y,a}^{\mathrm{strt}} \left[N_{y,a} e^{-M_a/12} - C_{y,a} \big/ 6 \right] e^{-M_a/12} \tag{4.6}$$

because spawning for the cod stocks under consideration is taken to occur two months after the start of the year and some mortality (natural and fishing) has therefore occurred,
where

$w_{y,a}^{\mathrm{strt}}$ is the mass of fish of age a during spawning, and

$f_{y,a}$ is the proportion of fish of age a that are mature.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", h, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass. In the fitting procedure, both h and K^{sp} are estimated with γ being either fixed on input or estimated as well.

4.1.3. Total catch and catches-at-age

The total catch by mass in year y is given by:

$$C_y = \sum_{a=0}^{m} w_{y,a}^{\mathrm{mid}} C_{y,a} = \sum_{a=0}^{m} w_{y,a}^{\mathrm{mid}} N_{y,a} e^{-M_a/2} S_{y,a} F_y^* \tag{4.7}$$

where

$w_{y,a}^{\mathrm{mid}}$ 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,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear)-at-age a for year y; when $S_{y,a} = 1$, the age-class a is said to be fully selected, and

F_y^* is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mid-year mass-at-age (using the individual weights of the landed fish) and applying natural and fishing mortality for half the year:

$$B_y^{\mathrm{ex}} = \sum_{a=0}^{m} w_{y,a}^{\mathrm{mid}} S_{y,a} N_{y,a} e^{-M_a/2} (1 - S_{y,a} F_y^* / 2) \tag{4.8}$$

whereas for survey estimates of biomass in the beginning of the year (for simplicity spring and autumn surveys are treated as mid-year surveys):

$$B_y^{\mathrm{surv}} = \sum_{a=0}^{m} w_{y,a}^{\mathrm{strt}} S_a^{\mathrm{surv}} N_{y,a} e^{-M_a/2} (1 - S_{y,a} F_y^* / 2) \tag{4.9}$$

where

S_a^{surv} is the survey selectivity for age a, which is taken to be year-independent.

4.1.4. Initial conditions

As the first year for which data (even annual catch data) are available for the cod stock considered clearly does not correspond to the first year of (appreciable) exploitation, one cannot necessarily make the conventional assumption in the application of ASPM's that this initial year reflects a population (and its age-structure) at pre-exploitation equilibrium. For the first year (y_0) considered in the model therefore, the stock is assumed to be at a fraction (θ) of its pre-exploitation biomass, i.e.:

$$B_{y_0}^{\mathrm{sp}} = \theta \cdot K^{\mathrm{sp}} \tag{4.10}$$

with the starting age structure:

$$N_{y_0,a} = R_{\text{start}} N_{\text{start},a} \qquad \text{for } 1 \le a \le m \qquad (4.11)$$

where

$$N_{\text{start},1} = 1 \qquad (4.12)$$

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } 2 \le a \le m-1 \qquad (4.13)$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \qquad (4.14)$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

4.2. 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 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 (- $\ell\text{n}L$) are as follows.

4.2.1 LPUE relative abundance data

The likelihood is calculated assuming that an observed CPUE abundance index for a particular fishing fleet is log-normally distributed about its expected value:

$$I_y = \hat{I}_y \exp(\varepsilon_y) \quad \text{or} \quad \varepsilon_y = \ell\text{n}(I_y) - \ell\text{n}(\hat{I}_y) \qquad (4.15)$$

where

I_y is the LPUE abundance index for year y for ages 2 to 6,

$\hat{I}_y = \hat{q}\ \widehat{N}_y^{\text{ex}}$ is the corresponding model estimate, where $\widehat{N}_y^{\text{ex}}$ is the model estimate of exploitable resource numbers for ages 2 to 6, given by

$$N_y^{\text{ex}} = \sum_{a=2}^{6} S_{y,a} N_{y,a} e^{-M_a/2} (1 - S_{y,a} F_y^* / 2) \qquad (4.16)$$

$\hat{q}$ is the constant of proportionality (catchability) for the LPUE abundance series, and

ε_y from $N\left(0, (\sigma_y)^2\right)$.

The contribution of the LPUE data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{\text{LPUE}} = \sum_y \left\{ \ell\text{n}\left(\sqrt{(\sigma_y^2 + \sigma_{Add}^2)}\right) + (\varepsilon_y)^2 / \left[2(\sigma_y^2 + \sigma_{Add}^2)\right] \right\} \qquad (4.17)$$

where

σ_y is the standard deviation of the residuals for the logarithm of index i in year y (which is input), and

σ_{Add} is the square root of the additional variance for the LPUE abundance series, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^i for CPUE abundance index i is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln \hat{B}_y^{\text{ex}}\right) \qquad (4.18)$$

D2.2. Survey abundance data

In general, data from the surveys are treated as relative abundance indices in exactly the same manner to the CPUE series above, with survey selectivity function S_a^{surv} replacing the commercial selectivity $S_{y,a}$. Account is also taken of the time of year when the survey is held. For these analyses, selectivities are estimated as detailed in section 4.4.2 below.

4.2.3. 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:

$$-\ell\mathrm{n}\,L^{\mathrm{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_{\mathrm{com}} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{\mathrm{com}}\right)^2 \right] \tag{4.19}$$

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

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_a/2}\, S_{y,a}\, F_y \tag{4.20}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{\mathrm{com}} = \sqrt{\sum_y \sum_a p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \tag{4.21}$$

The log-normal error distribution underlying equation (4.19) is chosen on the grounds that (assuming no ageing error) variability is likely dominated by a combination of interannual variation in the distribution of fishing effort, and fluctuations (partly as a consequence of such variations) in selectivity-at-age, which suggests that the assumption of a constant coefficient of variation is appropriate. However, for ages poorly represented in the sample, sampling variability considerations must at some stage start to dominate the variance. To take this into account in a simple manner, motivated by binomial distribution properties, the observed proportions are used for weighting so that undue importance is not attached to data based upon a few samples only.

Commercial catches-at-age are incorporated in the likelihood function using equation (4.19), for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

4.2.4. 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 log-normal error distribution (equation (4.19)) where:

$p_{y,a} = C_{y,a}^{\mathrm{surv}} / \sum_{a'} C_{y,a'}^{\mathrm{surv}}$ is the observed proportion of fish of age a in year y,

$\hat{p}_{y,a}$ is the expected proportion of fish of age a in year y in the survey, given by:

$$\hat{p}_{y,a} = S_a^{\mathrm{surv}} N_{y,a} \Big/ \sum_{a'=0}^{m} S_a^{\mathrm{surv}} N_{y,a} \qquad \text{for begin-year surveys.} \tag{4.22}$$

4.2.5. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{\mathrm{pen}} = \sum_{y=y_1+1}^{y_2} \left[\left(\frac{\lambda_y - \rho\lambda_{y-1}}{\sqrt{1-\rho^2}} \right)^2 \Big/ 2\sigma_{\mathrm{R}}^2 \right] \qquad (4.23)$$

where

$\lambda_y = \rho\lambda_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y$ is the recruitment residual for year y, which is estimated for year y_1 to y_2 (see equation (4.4)),

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_{R} is the standard deviation of the log-residuals, which is input, and

ρ is the serial correlation coefficient, which is input.

In the interest of simplicity, equation (4.23) omits a term in λ_{y_1} for the sensitivity when serial correlation is assumed ($\rho \neq 0$), which is generally of little quantitative consequence to values estimated.

The analyses conducted in this paper have however all assumed $\rho = 0$.

4.3. Estimation of precision

Where quoted, 95% probability interval estimates are based on the Hessian.

4.4. Model parameters

4.4.1. Fishing selectivity-at-age:

The commercial fishing selectivity, S_a , as well as the fishing selectivities for the NEFSC offshore and Massachusetts inshore spring and autumn surveys, are estimated separately for ages a_{minus} to a_{plus}. The estimated decrease from ages a_{plus}-1 to a_{plus}. is assumed to continue exponentially to age 11+ if otherwise not specified (see Table below for a_{minus} to a_{plus}.).

The commercial selectivity is taken to differ over the 1893-1991 and 1992+ periods. The decrease from ages a_{plus}-1 to a_{plus}. however is taken to be the same throughout the period. 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.

Selectivity is taken to differ for the surveys, but the decrease from ages a_{plus}-1 to a_{plus}. is taken to be the same for both spring and autumn surveys.

4.4.2. Other parameters

Model plus group				
m	11			
Commercial CAA				
a_{minus}	1			
a_{plus}	9			
Survey CAA	NEFSC spr	NEFSC fall	MASS spr	MASS fall
a_{minus}	1	1	0	0
a_{plus}	9	9	4	3
Natural mortality:				
M	age independent or not, fixed			
Proportion mature-at-age:				
$f_{y,a}$	input, see Table A10			
Weight-at-age:				
w_y^{strt}	input, see Table A2			
w_y^{mid}	input, see Table A3			
Initial conditions (unless otherwise specified):				
θ	estimated (with upper bound of 0.95)			
ϕ	0.1			