Gulf of Maine Atlantic cod (*Gadus morhua*)

Figures

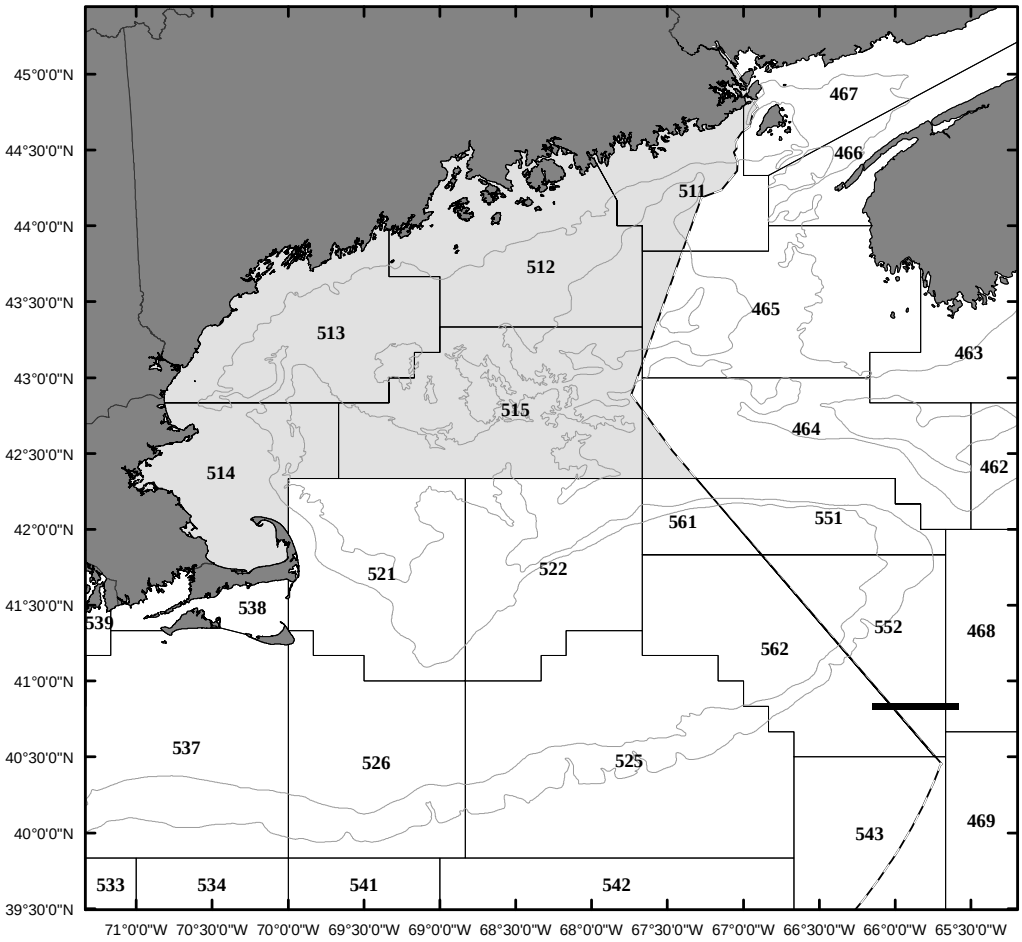


Figure A.1. Map of the Gulf of Maine Atlantic cod (*Gadus morhua*) management and assessment area (shaded grey). The United States exclusive econic zone (EEZ) is defined by the dashed line. Within the Gulf of Maine region, this line is informally referred to as the "Hague Line".

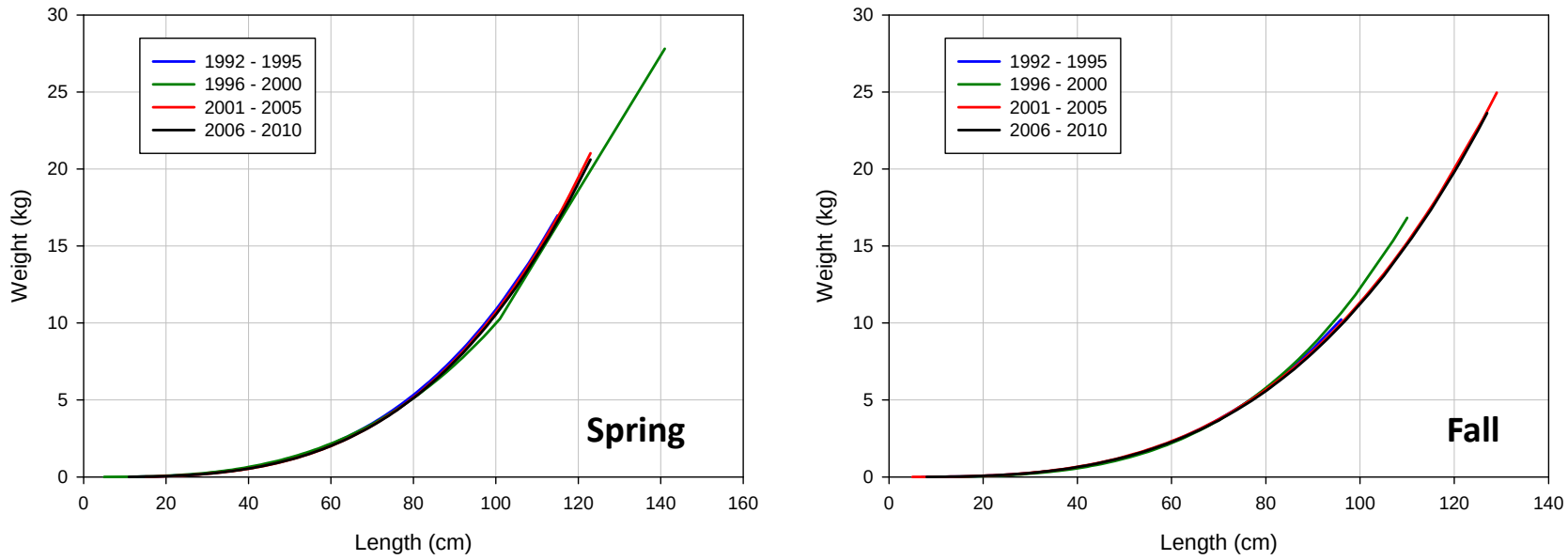


Figure A.2. Comparison of the seasonal length-weight equations estimated from NEFSC survey data relative to the length-weight equation used in previous Gulf of Maine Atlantic cod assessments.

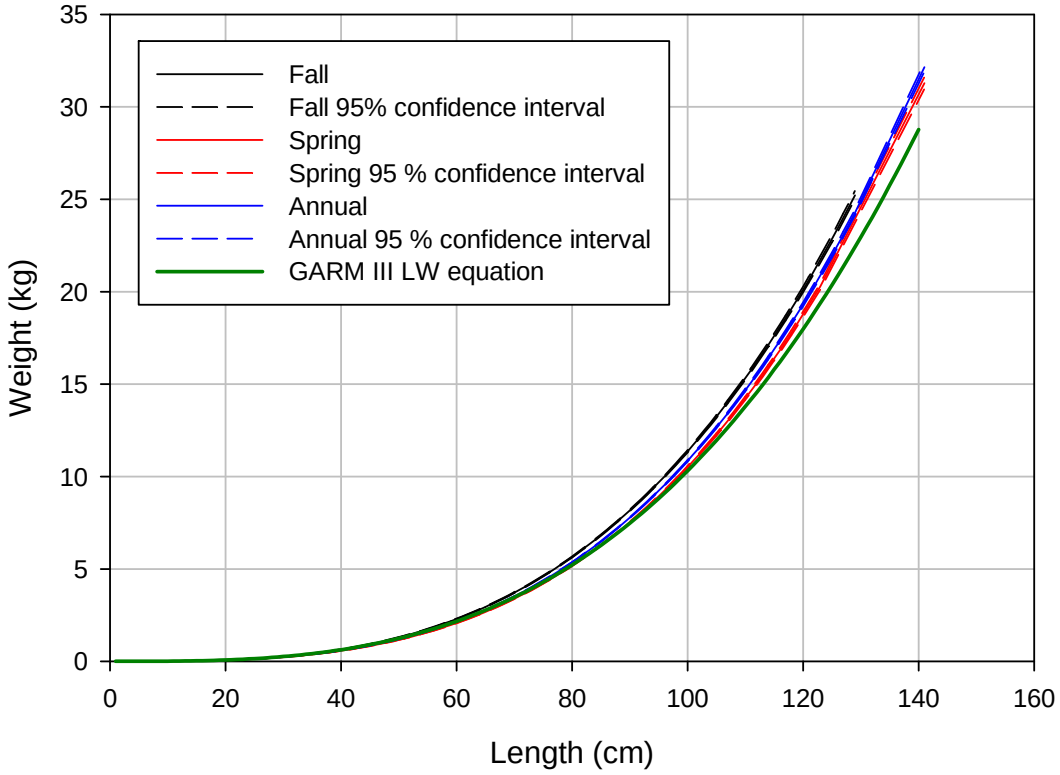


Figure A.3. Comparison of the seasonal length-weight equations estimated from NEFSC survey data relative to the length-weight equation used in previous Gulf of Maine Atlantic cod assessments.

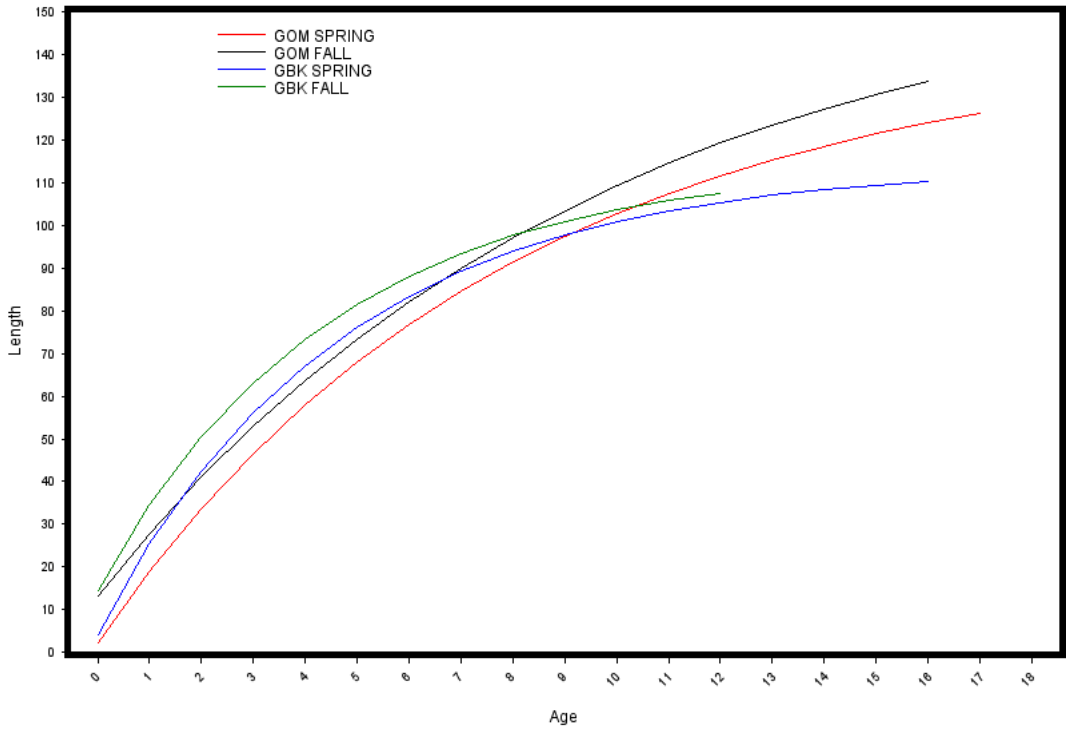


Figure A.4. Comparison of von Bertalanffy growth curves for the Gulf of Maine (GOM) and Georges Banks (GBK) Atlantic cod stocks as estimated from data collected from the Northeast Fisheries Science Center spring and fall bottom trawl survey s between 1970 and 2011. Growth paremeters estimated for the 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.

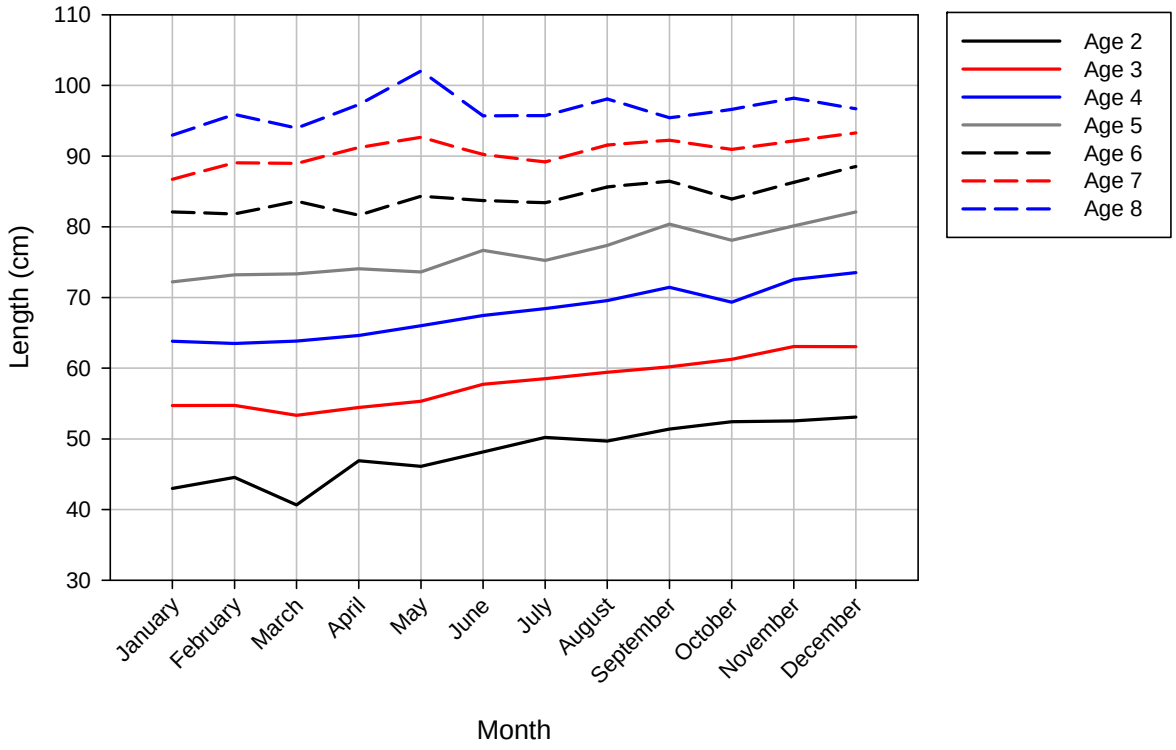


Figure A.5. Mean length-at-age of Altantic cod landed by the commercial fishery by month. Estimated from commercial port samples taken between 1981 and 2009.

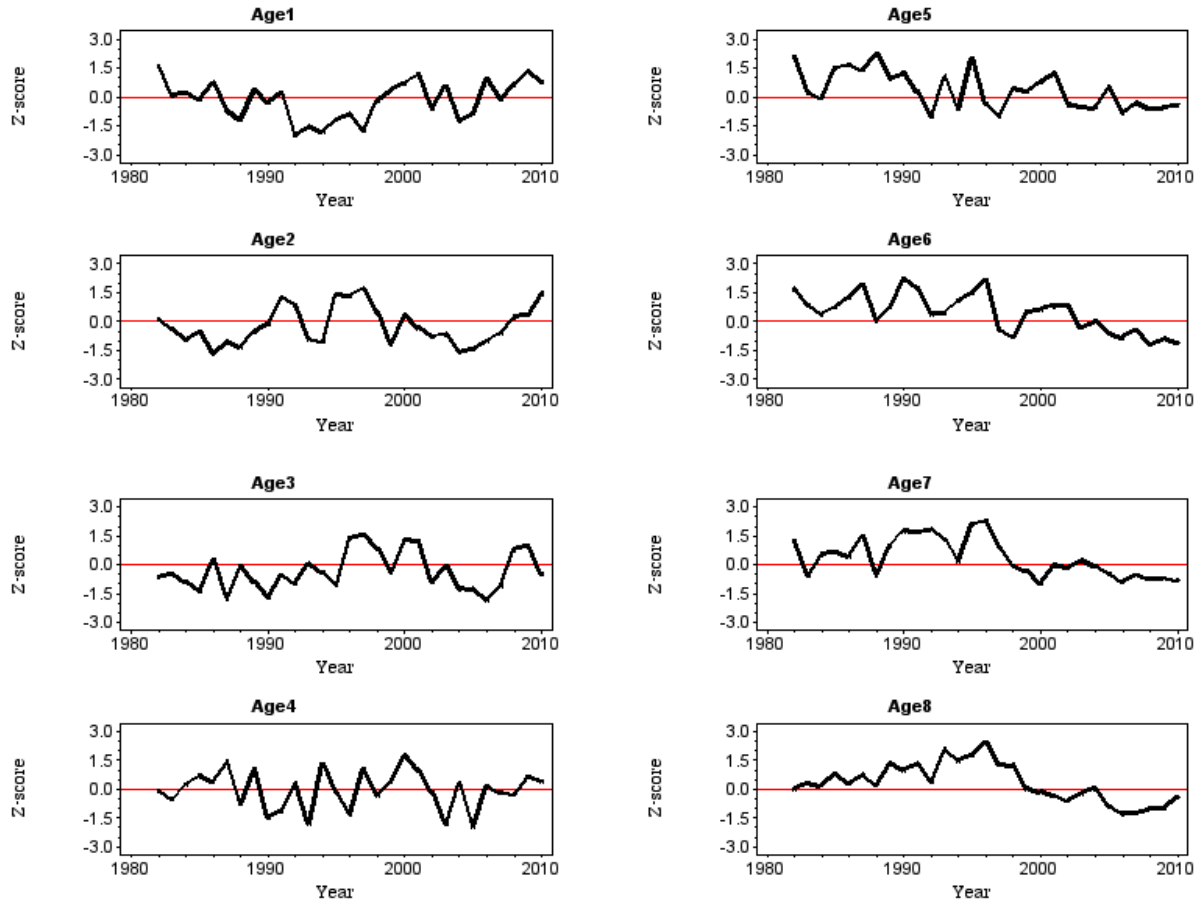


Figure A.6. Average catch weights-at-age of Age 1 through Age 8 Gulf of Maine Atlantic cod from 1982 to 2010. Weights-at-age were estimated using a number weighted average of commercial landing, commercial discard, recreational landings, and recreational discards weights-at-age. Average weights are presented as z-scores ($[x-\mu]/\sigma$).

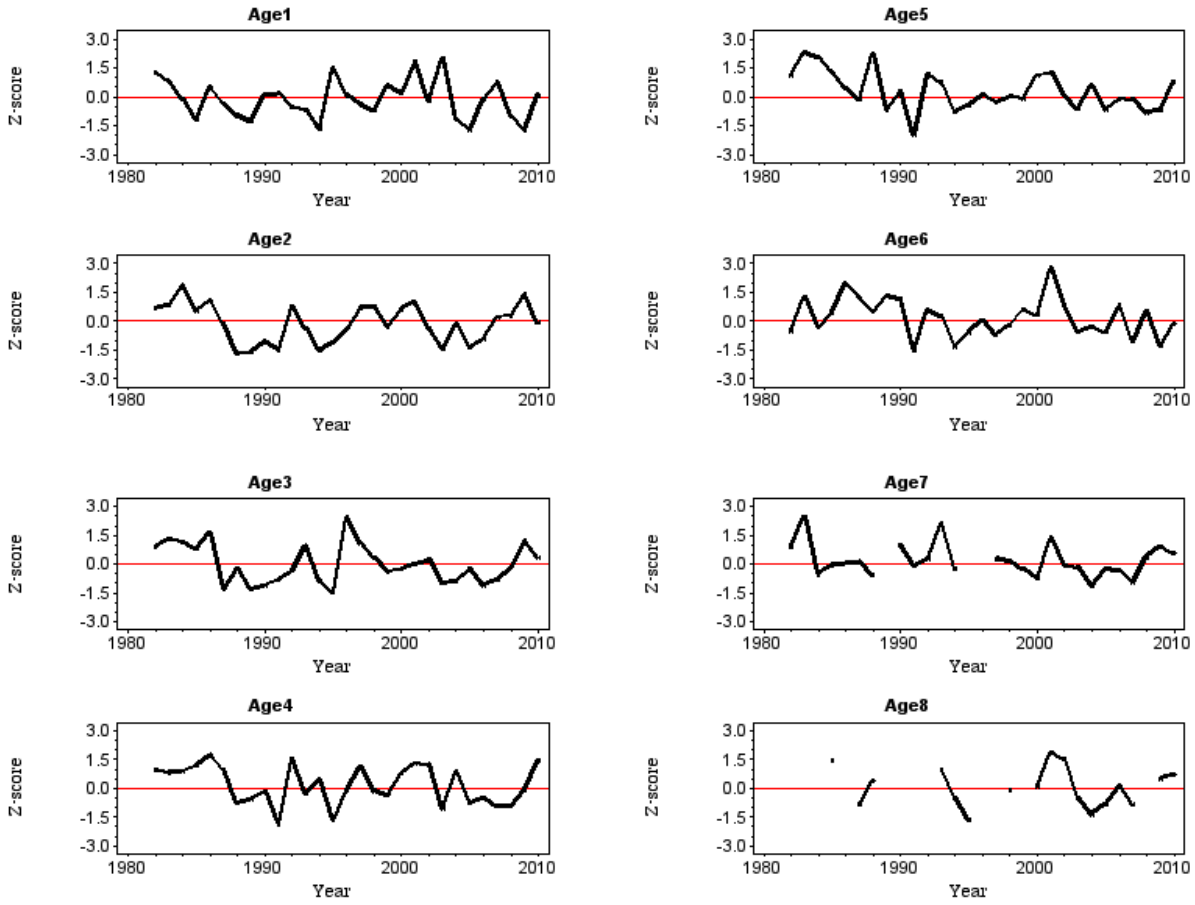


Figure A.7. Average survey weights-at-age of Age 1 through Age 8 Gulf of Maine Atlantic cod from 1982 to 2010. Survey weights are based on the average weight-at-age of cod sampled from the Northeast Fisheries Science Center spring bottom trawl survey . Average weights are presented as z-scores ($[x-\mu]/\sigma$).

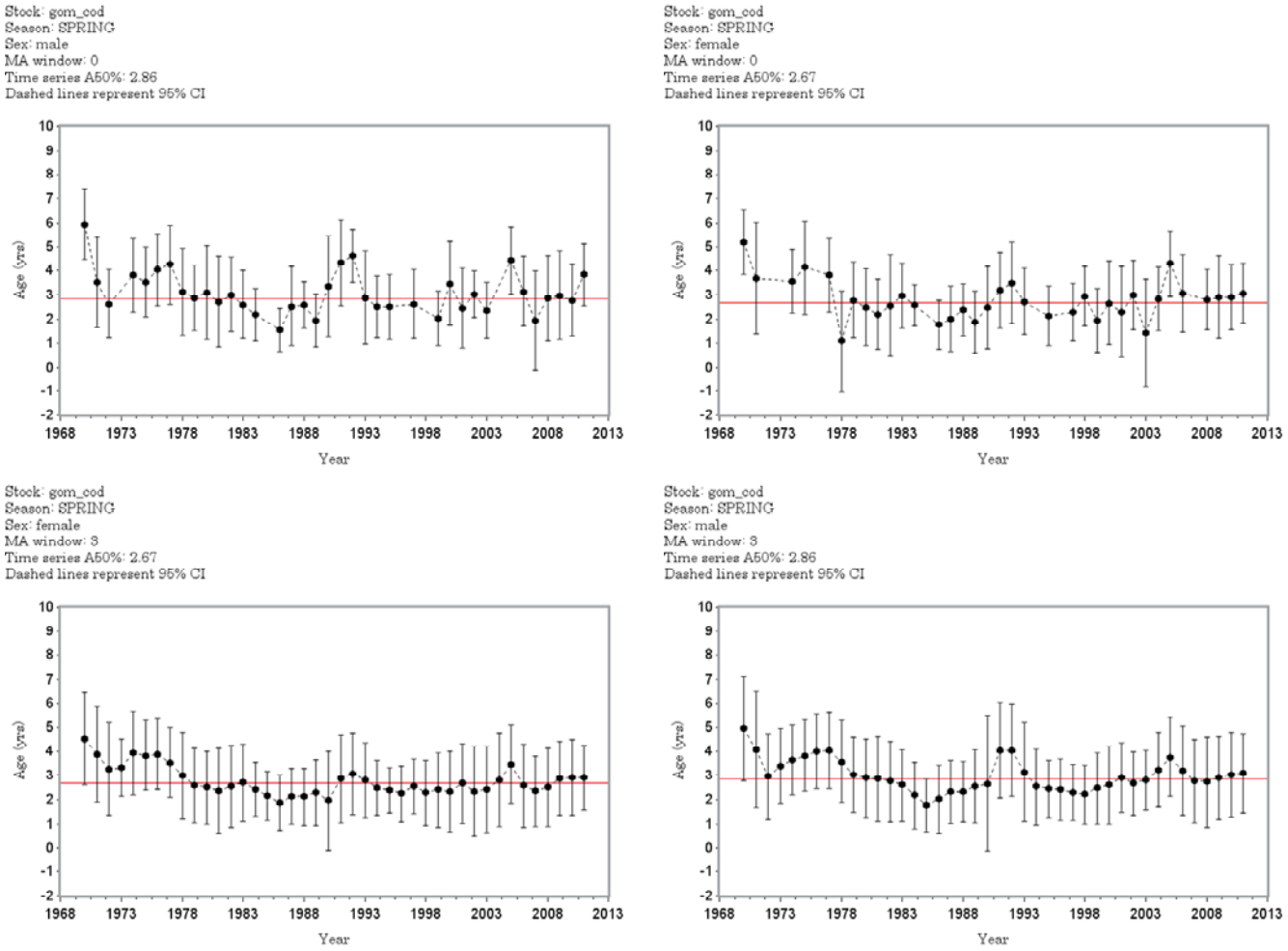


Figure A.8. Annual (top panels) and three-year moving averages (bottom panels) of the average age-at-50% maturity (A50) and corresponding 95% confidence intervals for male (left panels) and female (right panels) Gulf of Maine Atlantic cod from 1970 to 2011. Average maturity has been estimated from data 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.

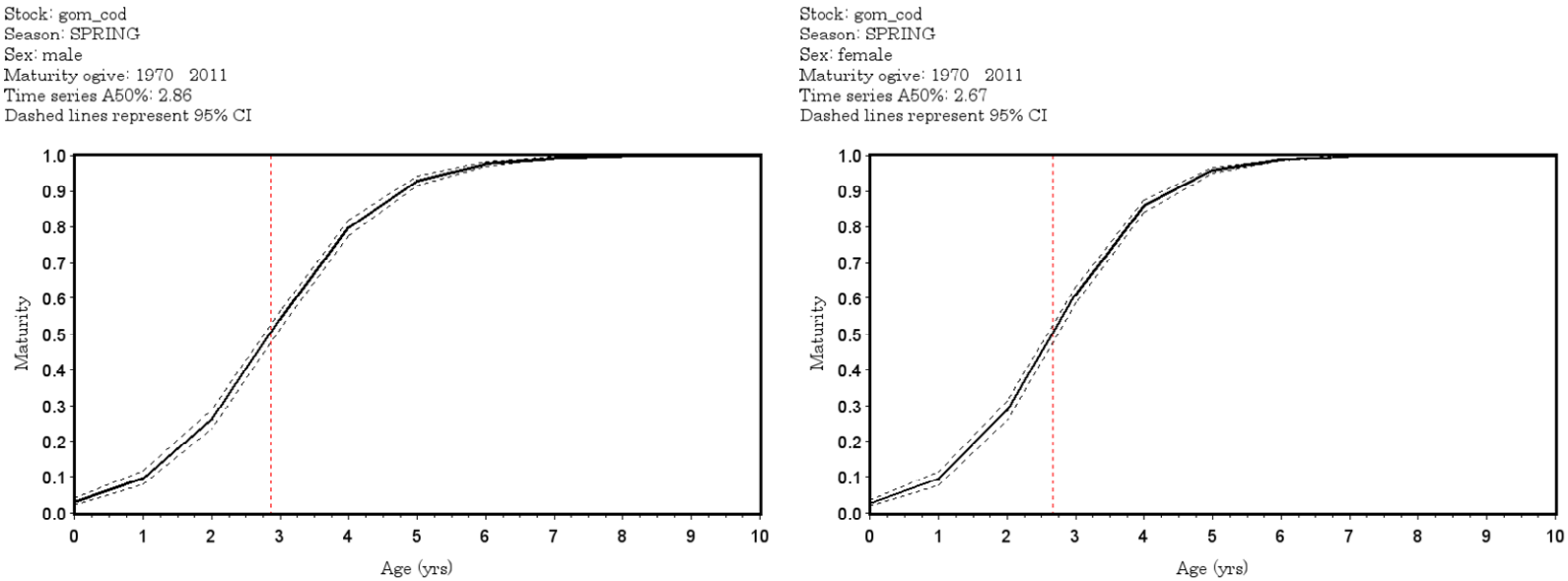


Figure A.9. Maturity ogives for male (left) and female (right) Gulf of Maine Atlantic cod based on time series averages of maturity and age information collected from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey from 1970 to 2011.

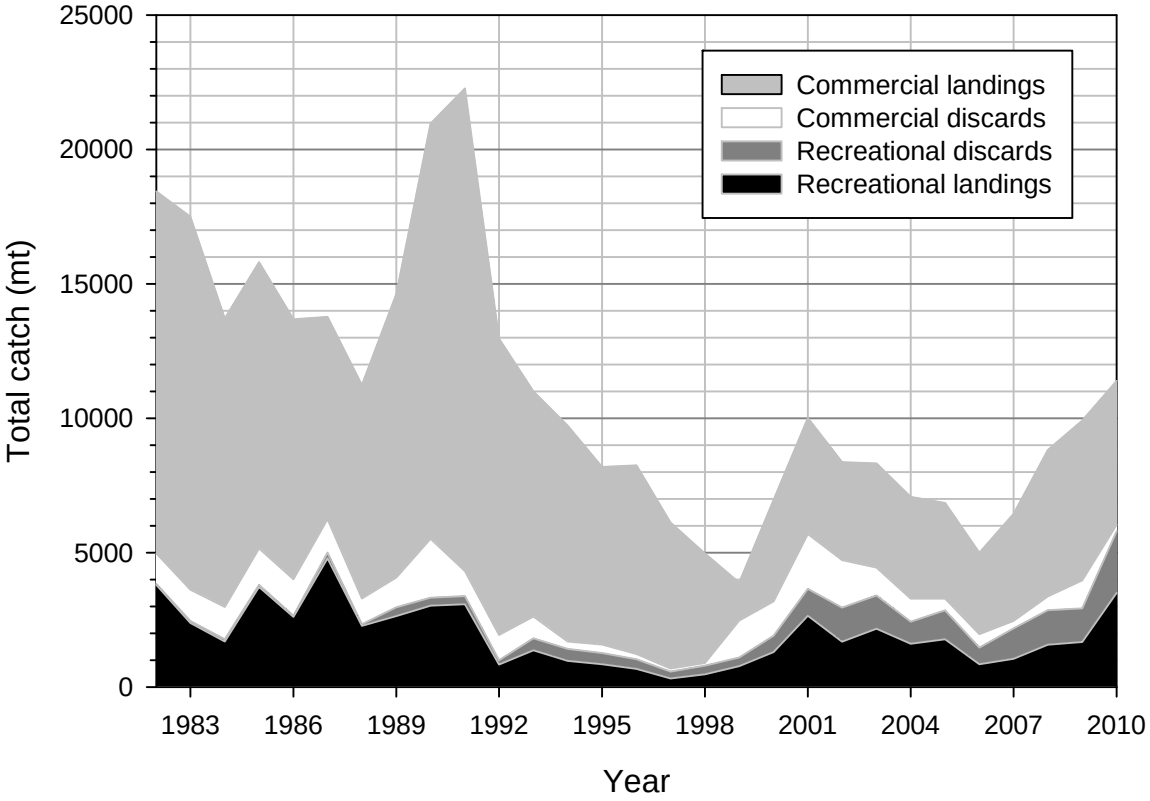


Figure A.10. Total catch of Gulf of Maine Atlantic cod from 1982 to 2010 by fleet (commercial and recreational) and disposition (landed, discarded).

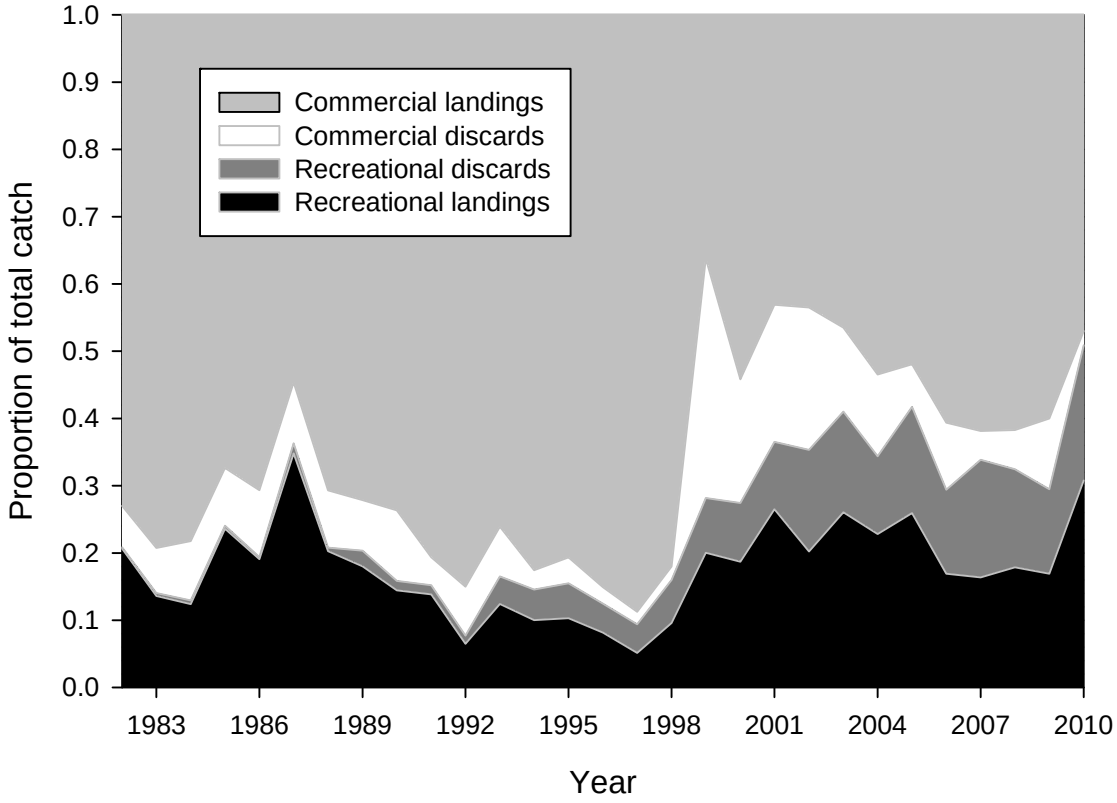


Figure A.11. Total catch of Gulf of Maine Atlantic cod of from 1982 to 2010 by fleet (commercial and recreational) and disposition (landed, discarded) expressed as proportions of the total catch.

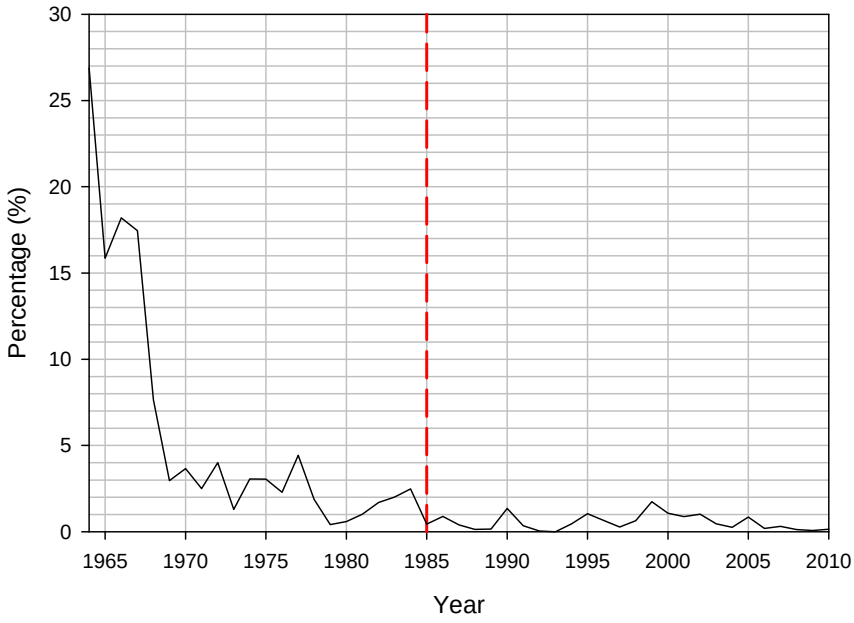


Figure A.12. Percentage of total commercial landings of Gulf of Maine Atlantic cod coming from statistical areas 464, 465 and 467 between 1964 and 2010. The Hague Line, which formaly defined the Exclusive Econonimic Zones of the Gulf of Maine into United States and Canada was adopted on October 12, 1984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

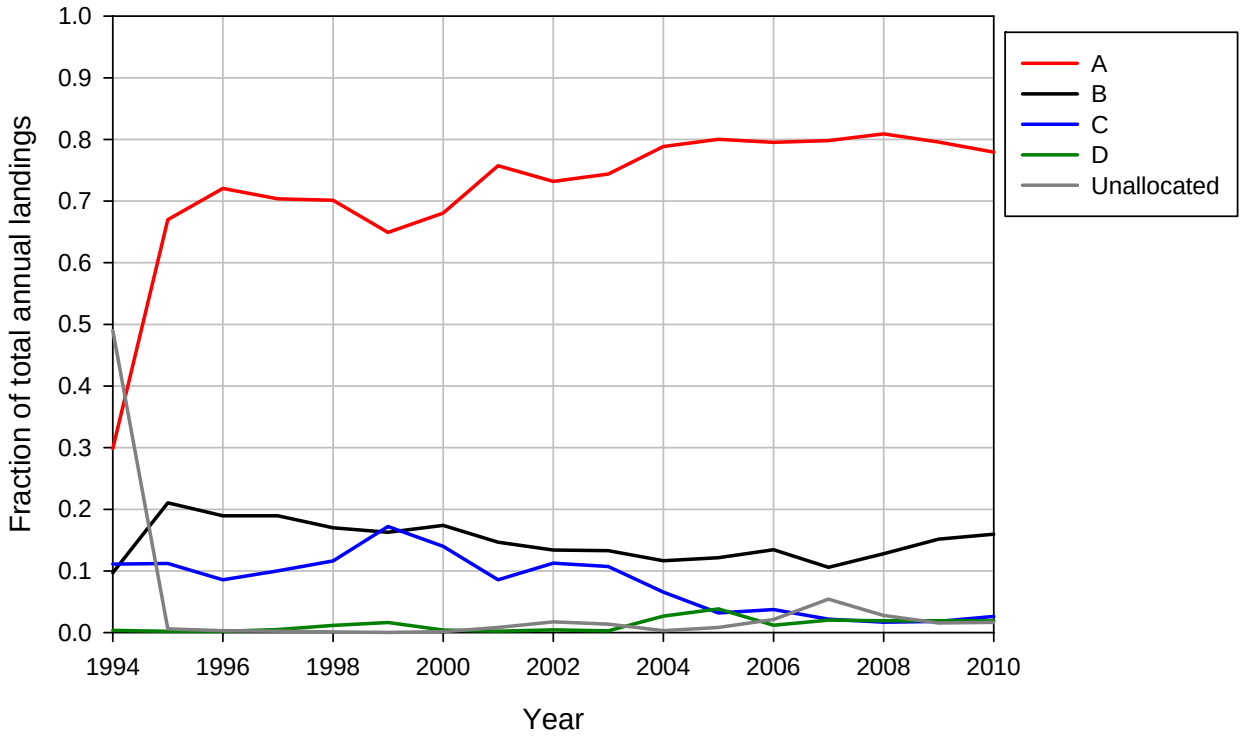


Figure A.13. Fraction of commercial landings by Area-Allocation level (AA, see Wigley et al. 2008) for Gulf of Maine Atlantic cod from 1994 to 2010. Certainty of the landings area allocation increases from level D to A. Unallocated landings do not enter the allocation procedure (e.g., state-reported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

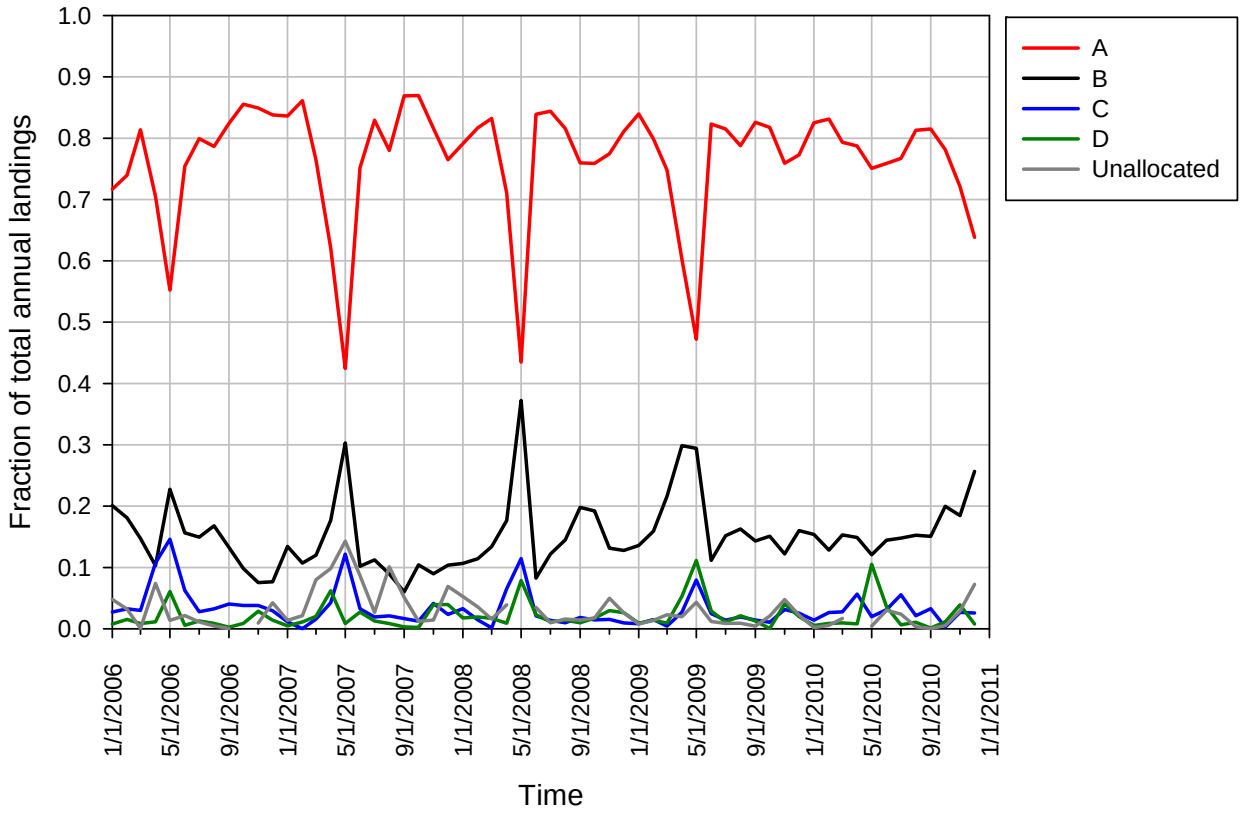


Figure A.14. Monthly commercial landing patterns (as a fraction of the total landings) by Area-Allocation level (AA, see Wigley et al. 2008) for Gulf of Maine Atlantic cod from 2006 to 2010. Certainty of the landings area allocation increases from level D to A. Unallocated landings do not enter the allocation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

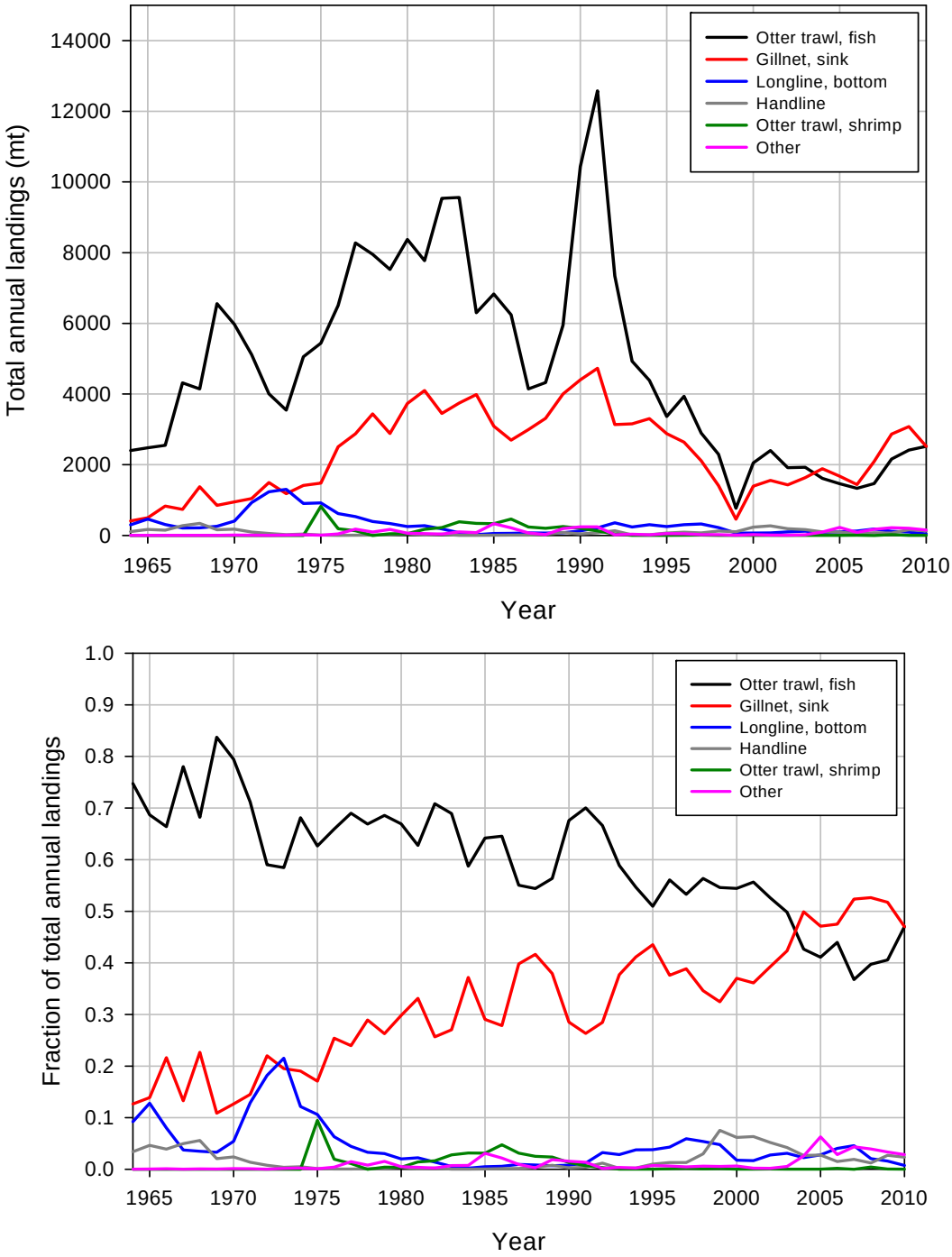


Figure A.15. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by gear from 1964 to 2010.

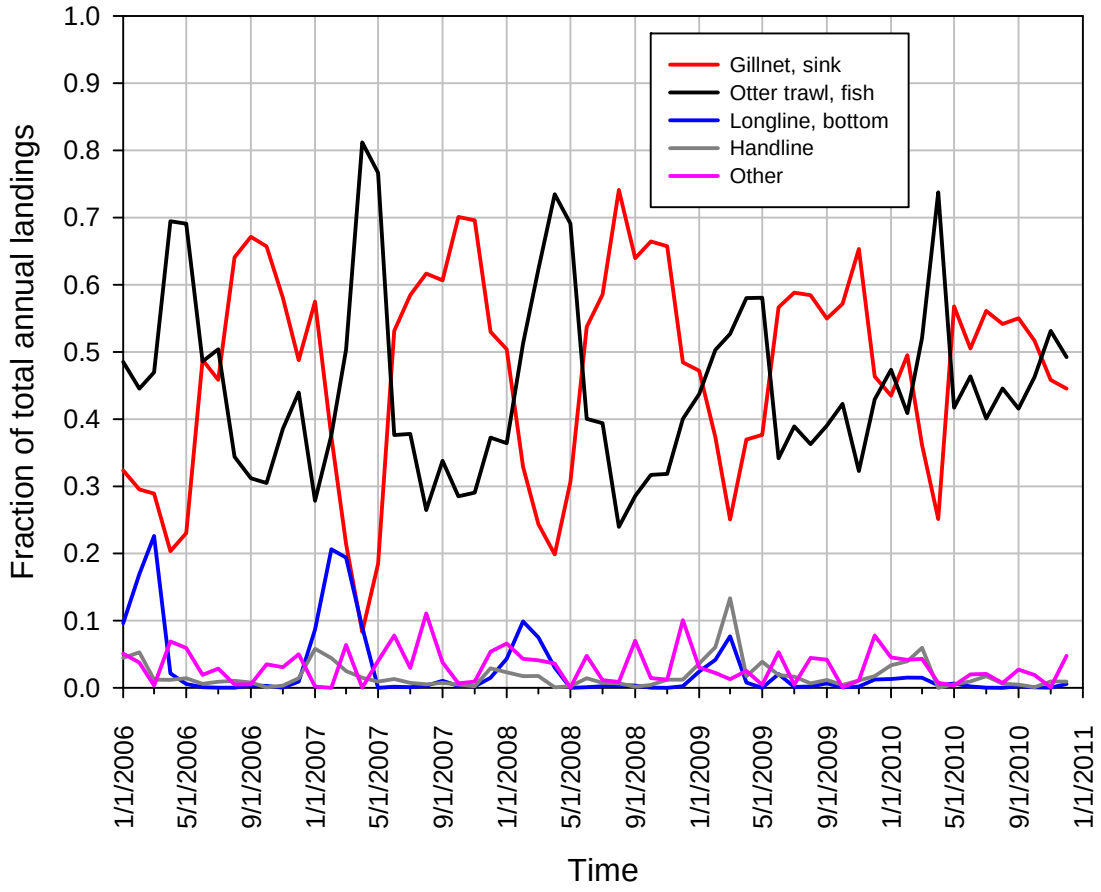


Figure A.16. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by gear from 2006 to 2010.

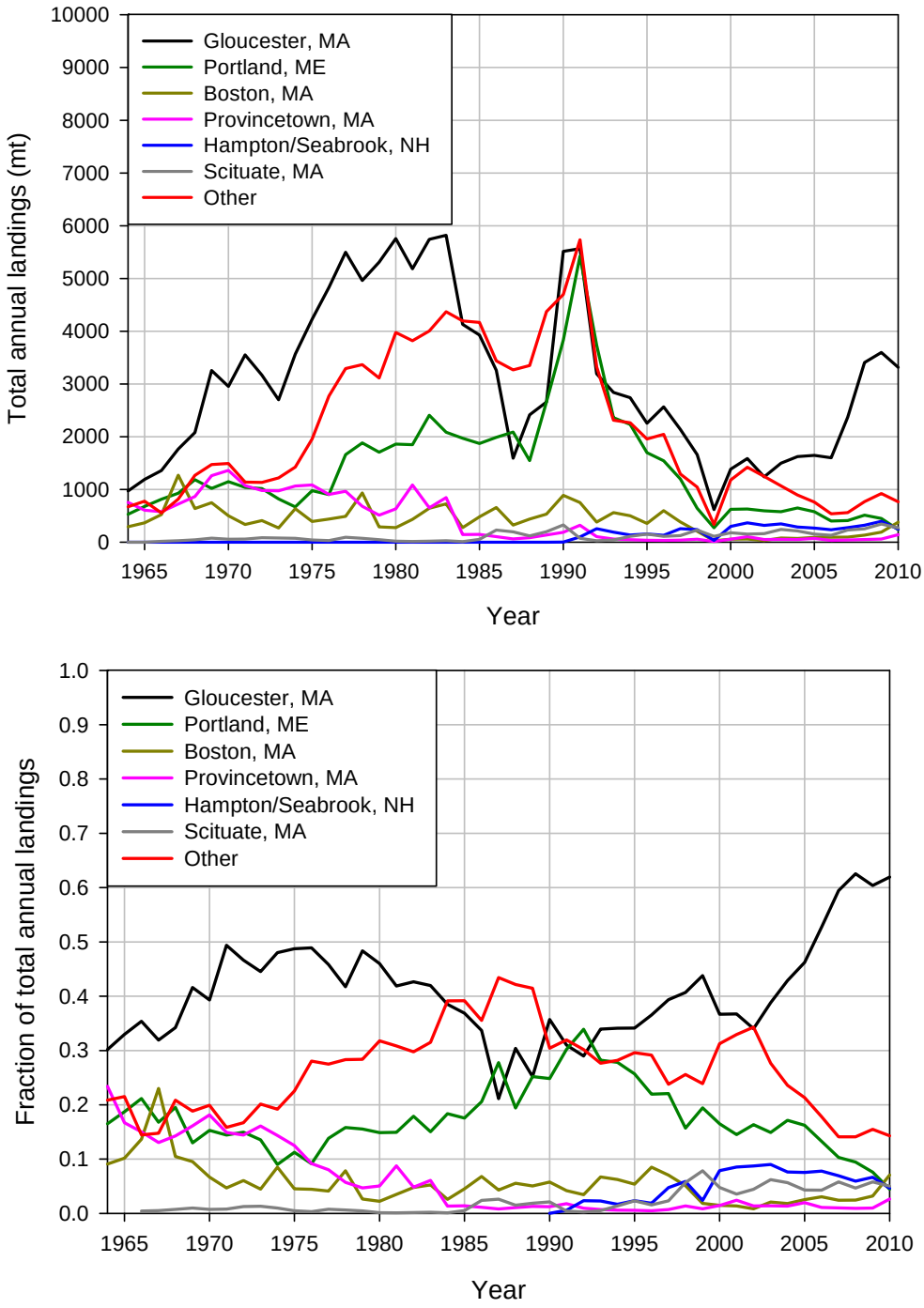


Figure A.17. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by port from 1964 to 2010.

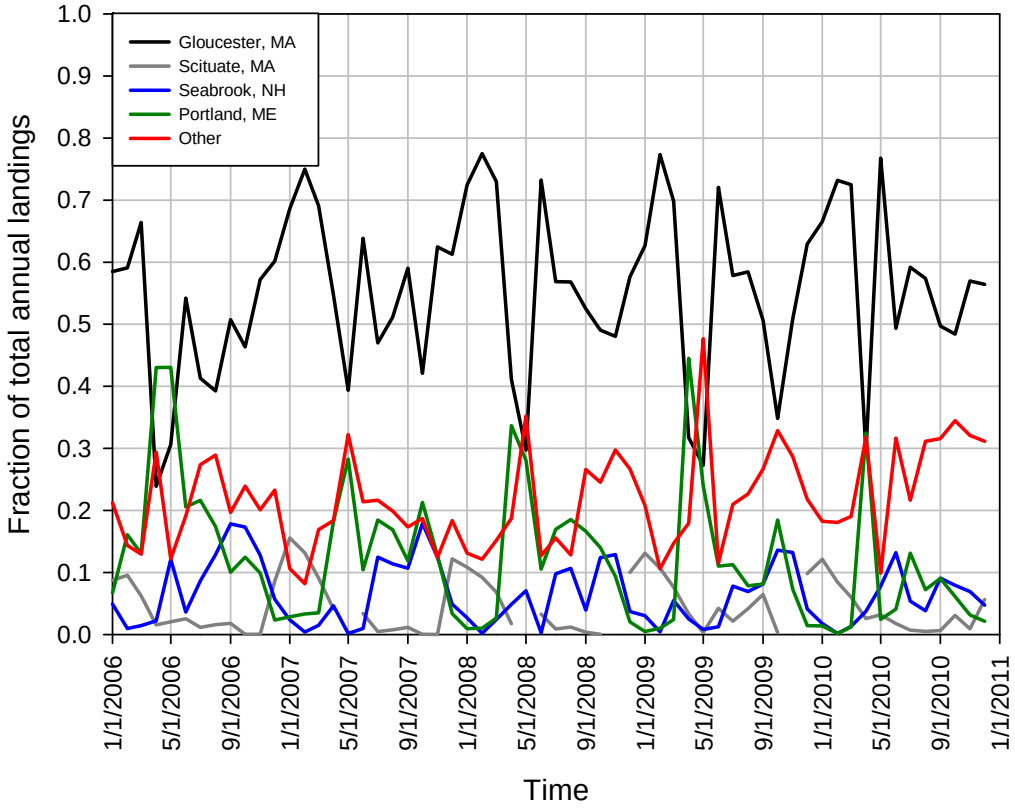


Figure A.18. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by port from 2006 to 2010.

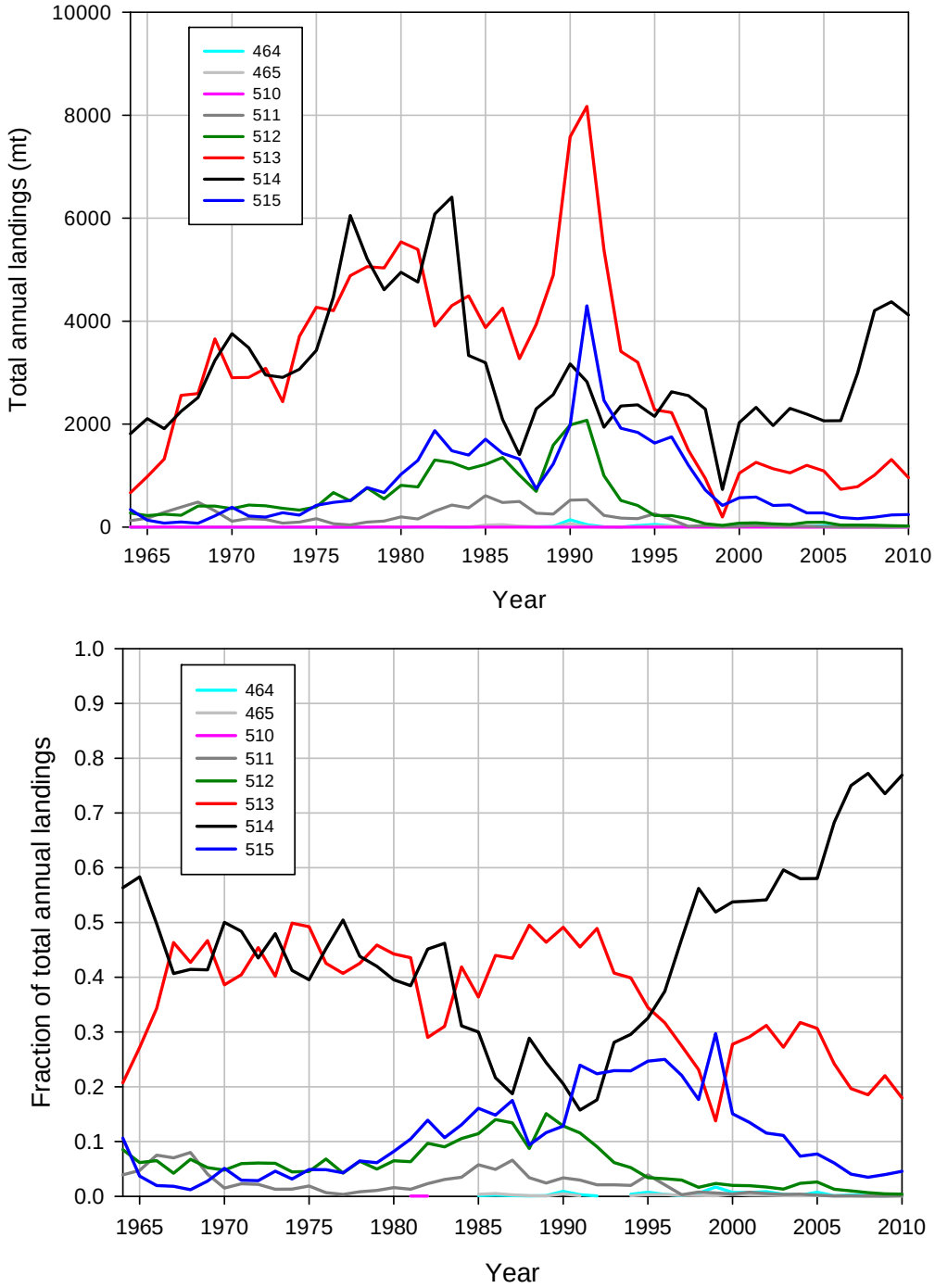


Figure A.19. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by statistical area from 1964 to 2010.

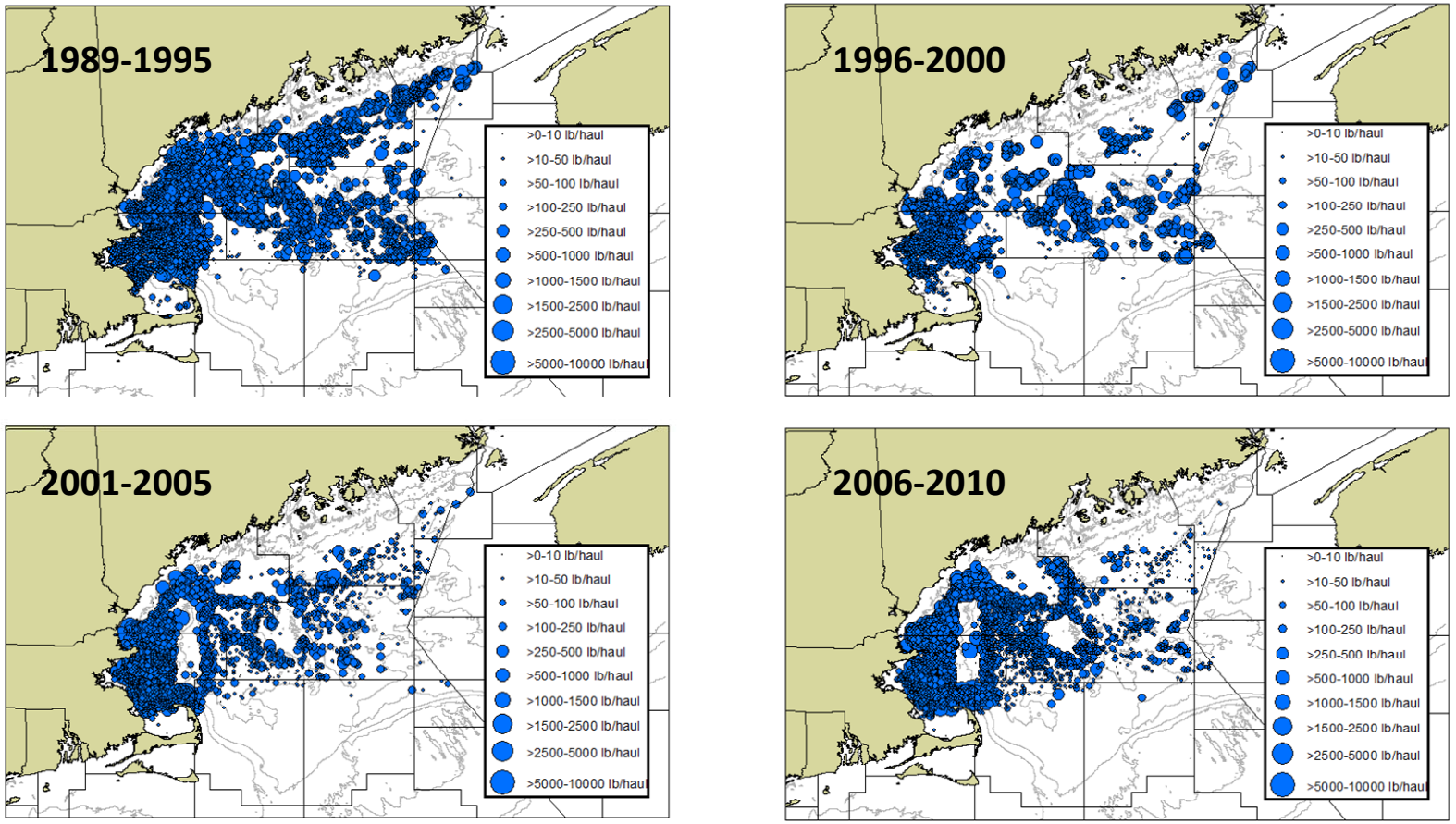


Figure A.20. Average Gulf of Maine Atlantic cod caught per haul (retained and discarded) by latitude and longitude position over approximately five year blocks from 1989 to 2010 (first block shown contains six years of data). Data come from data collected by the Northeast Fisheries Observer Program on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

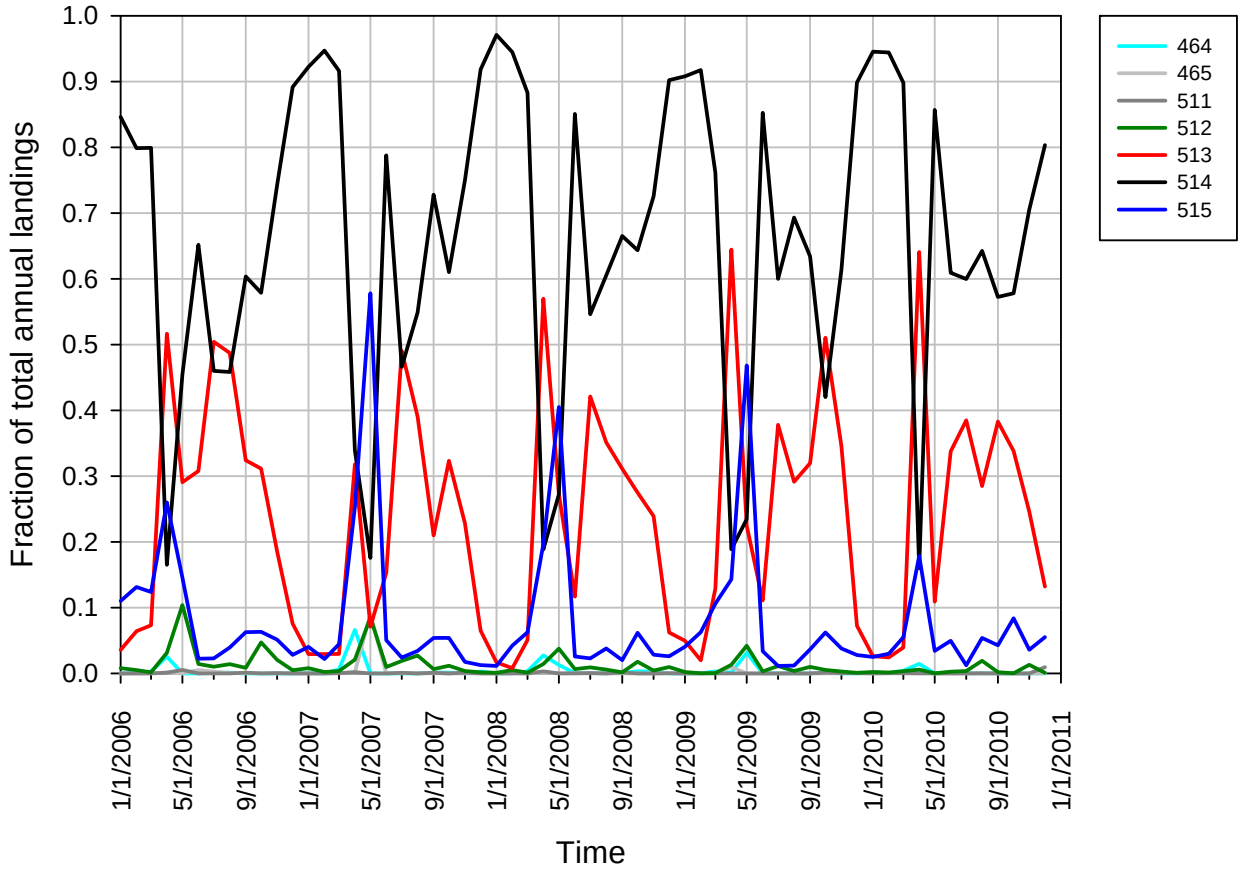


Figure A.21. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by statistical area from 2006 to 2010.

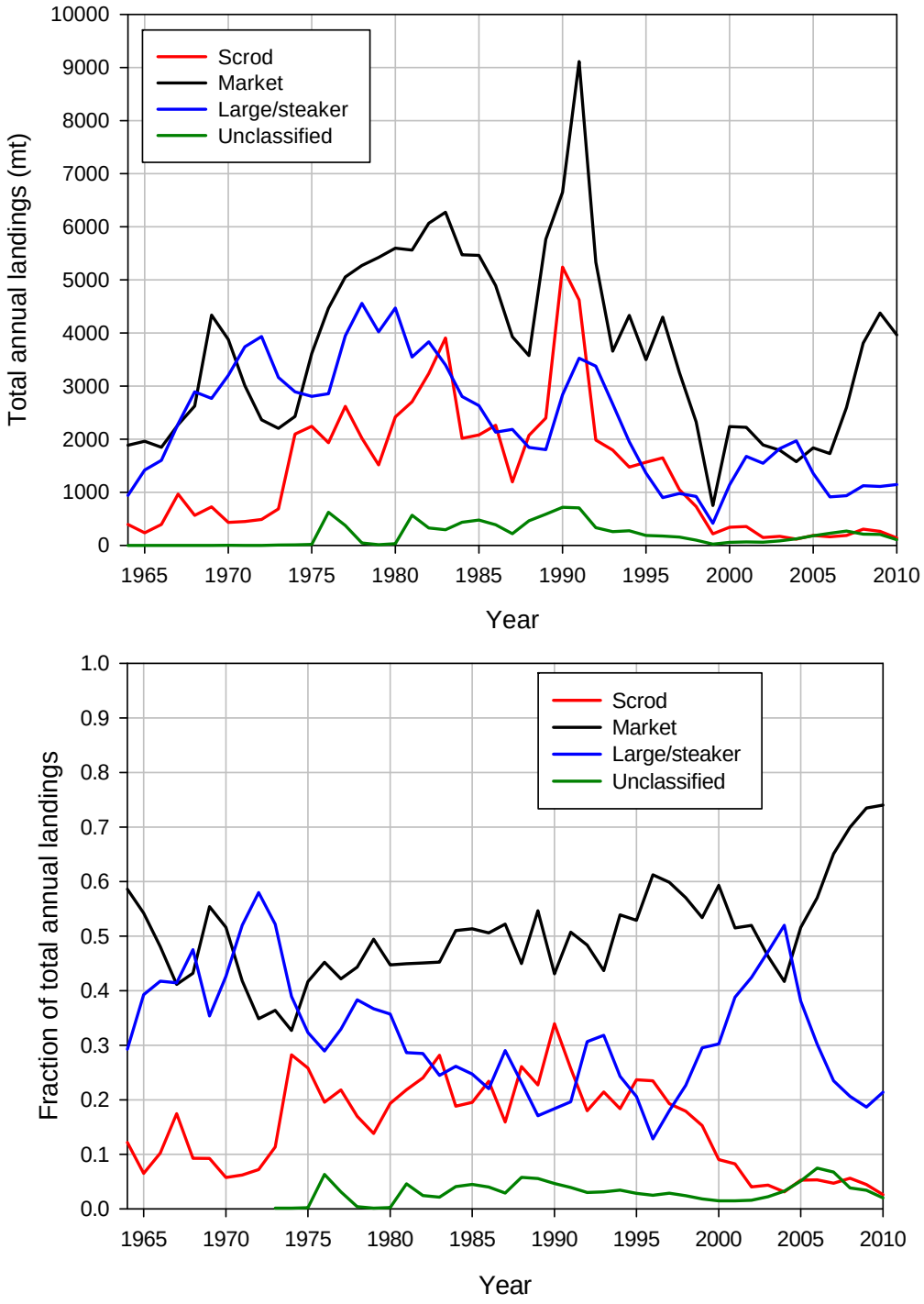


Figure A.22. Total (top) and fractional (as a fraction of the total, bottom) commercial landings of Gulf of Maine Atlantic cod by market category from 1964 to 2010.

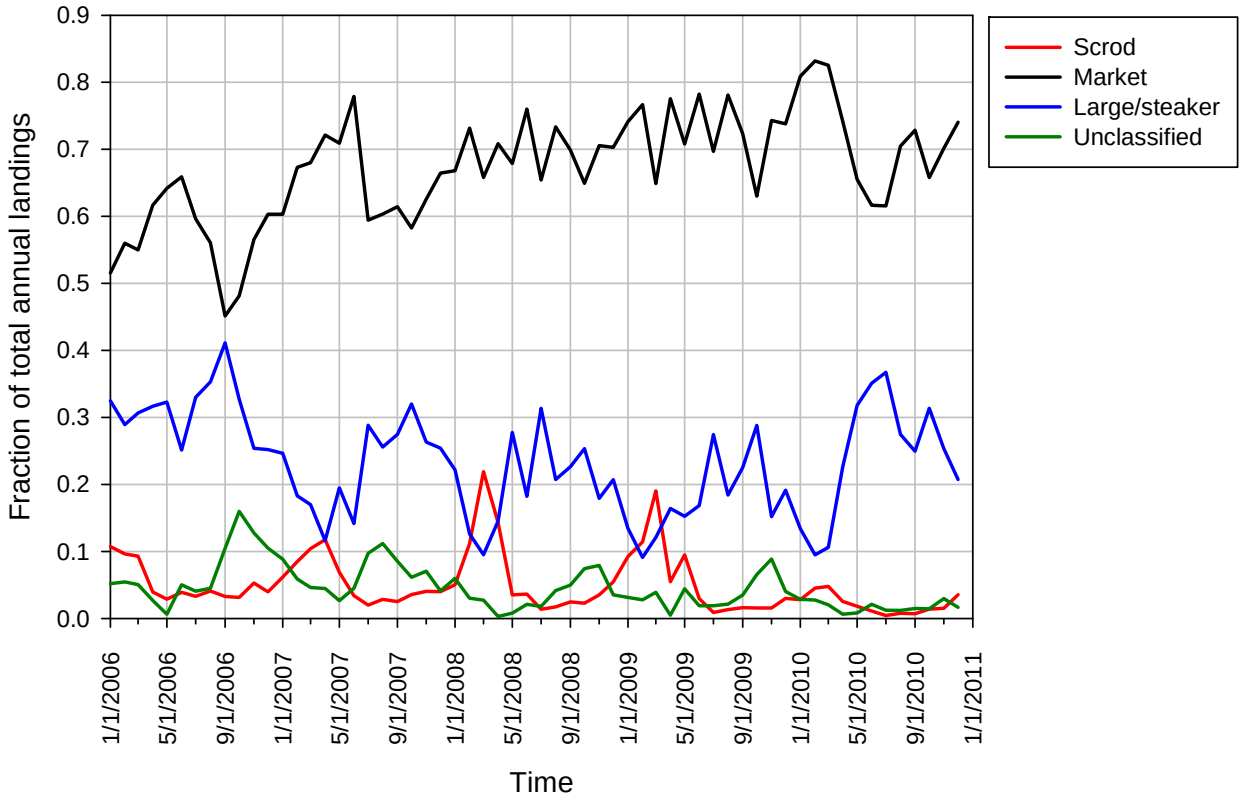


Figure A.23. Monthly commercial landing patterns (as a fraction of the total landings) of Gulf of Maine Atlantic cod by market category from 2006 to 2010.

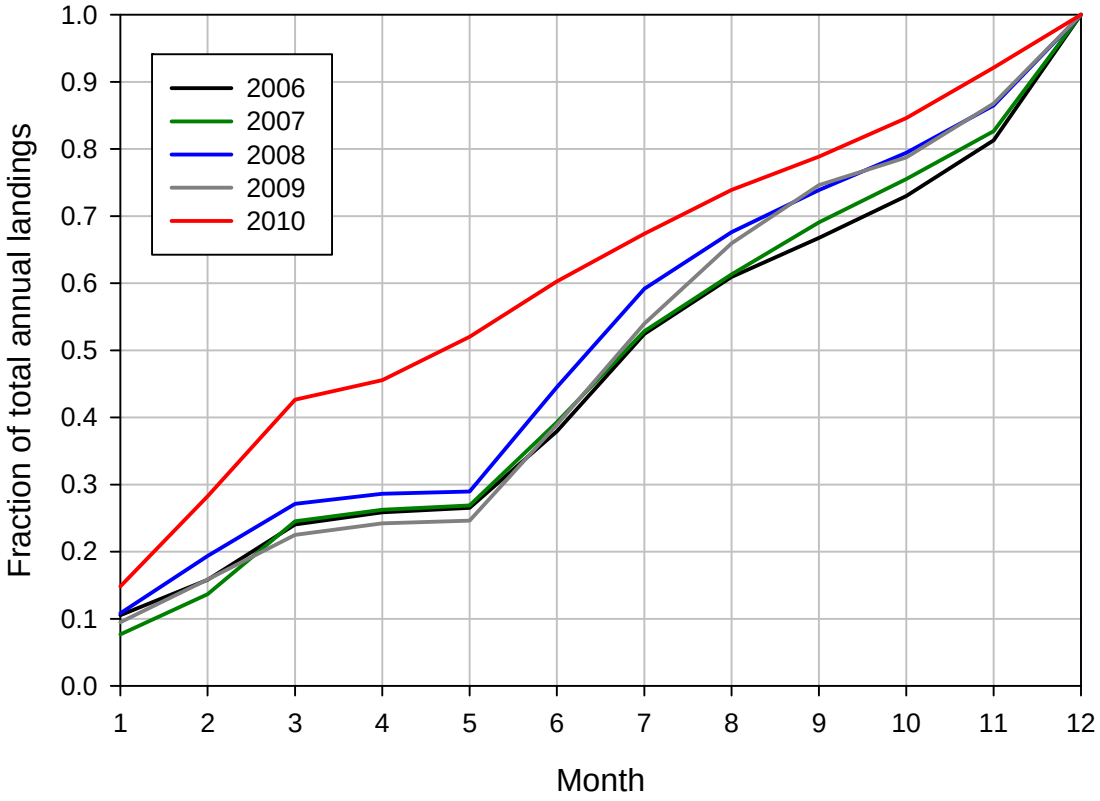


Figure A.24. Cumulative monthly commercial landings of Gulf of Maine Atlantic cod by year from 2006 to 2010.

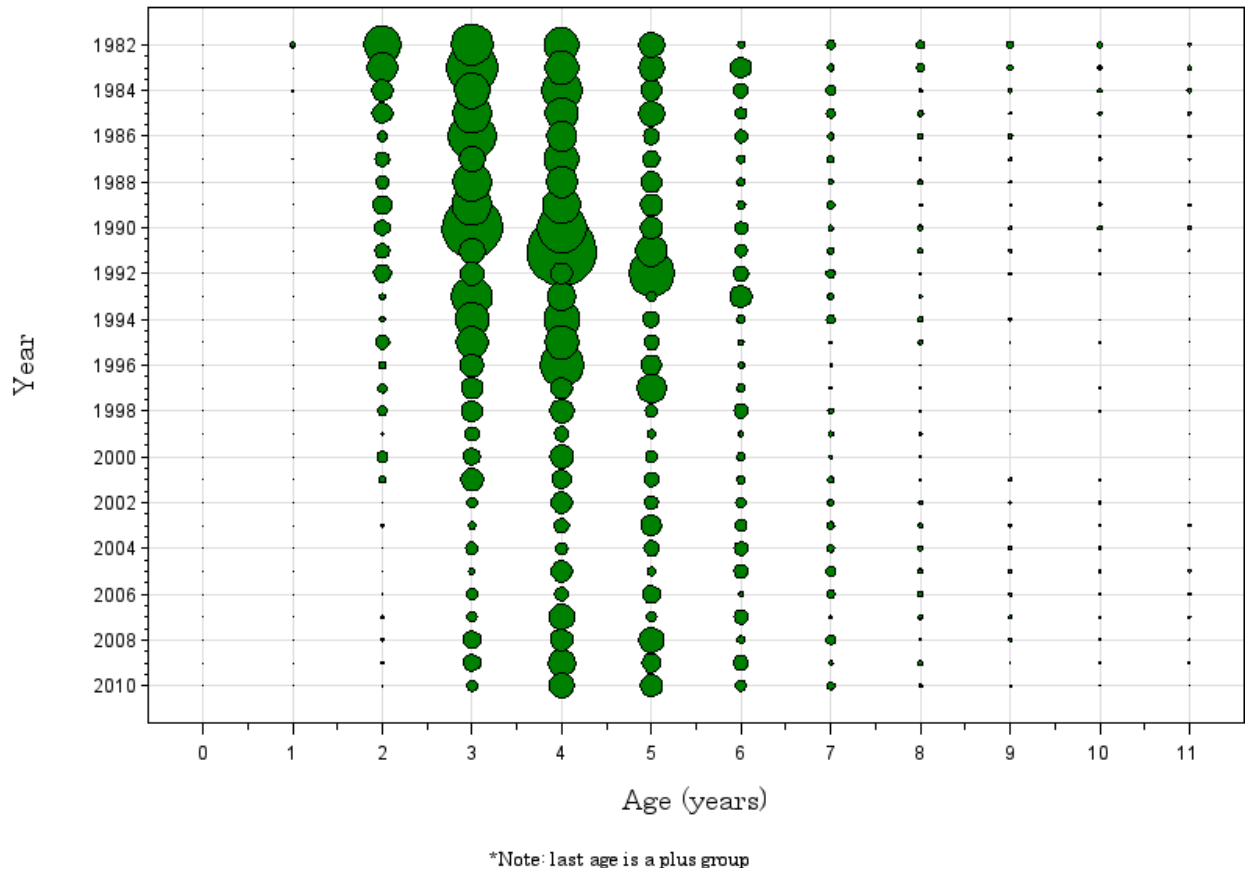


Figure A.25. Commercial landings-at-age of Gulf of Maine Atlantic cod from 1982 to 2010. **Note that age 11 is a plus group.*

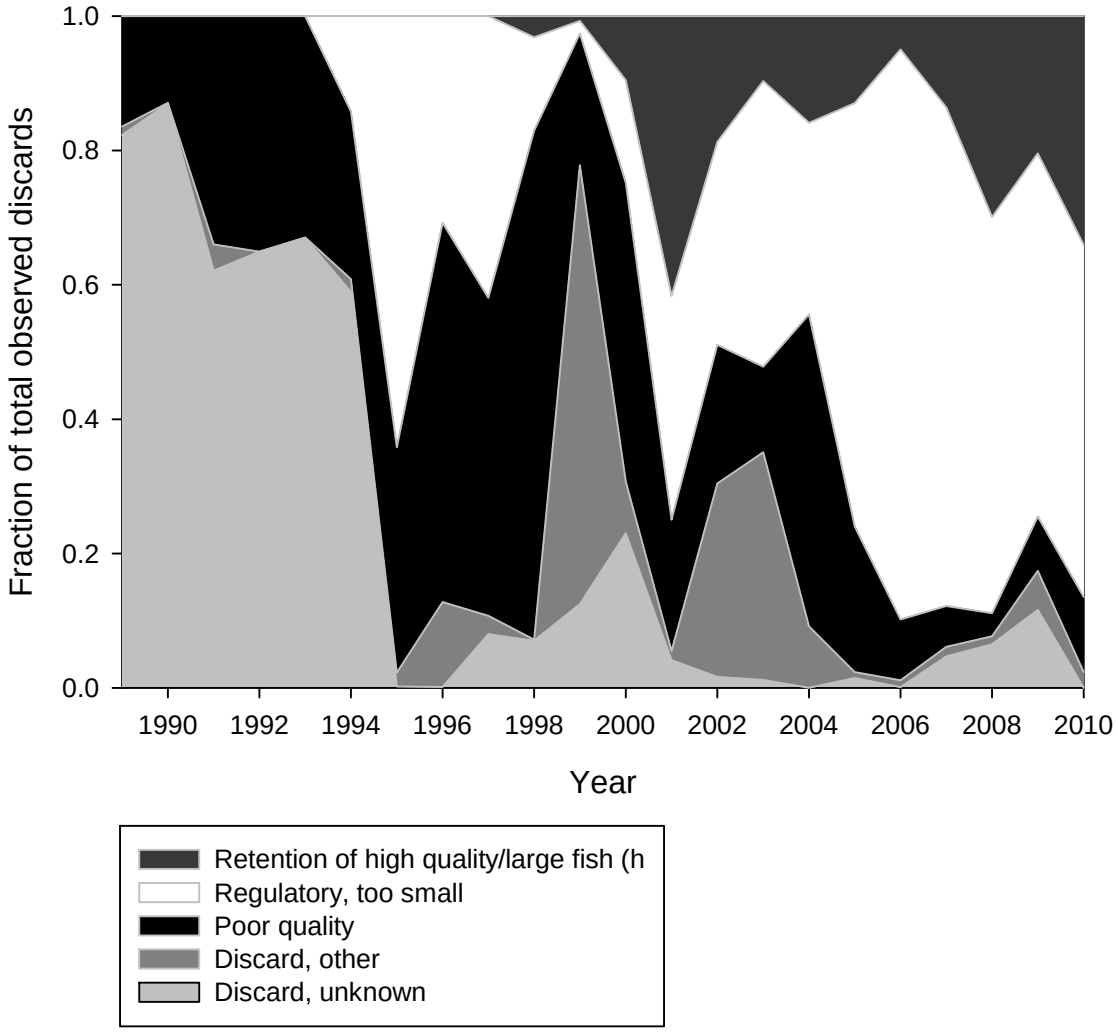


Figure A.26. Discard reasons for Gulf of Maine Atlantic cod as recorded by fisheries observers between 1989 and 2010.

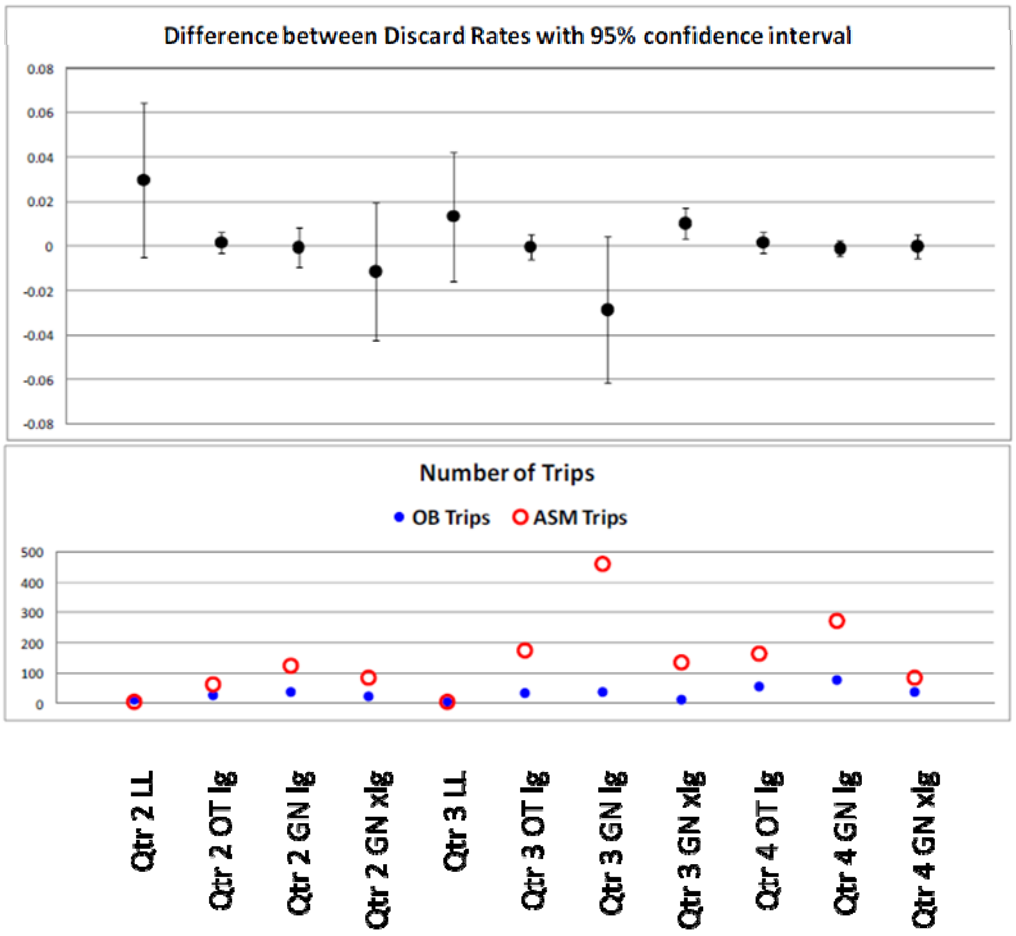


Figure A.27. Differences between the Gulf of Maine Atlantic cod discard rates estimated from data collected by groundfish At-Sea Monitors (ASMs) and certified Observers showing 95% confidence intervals (top panel) and the number of trips included in each analysis (bottom panel) broken down by gear-mesh 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).

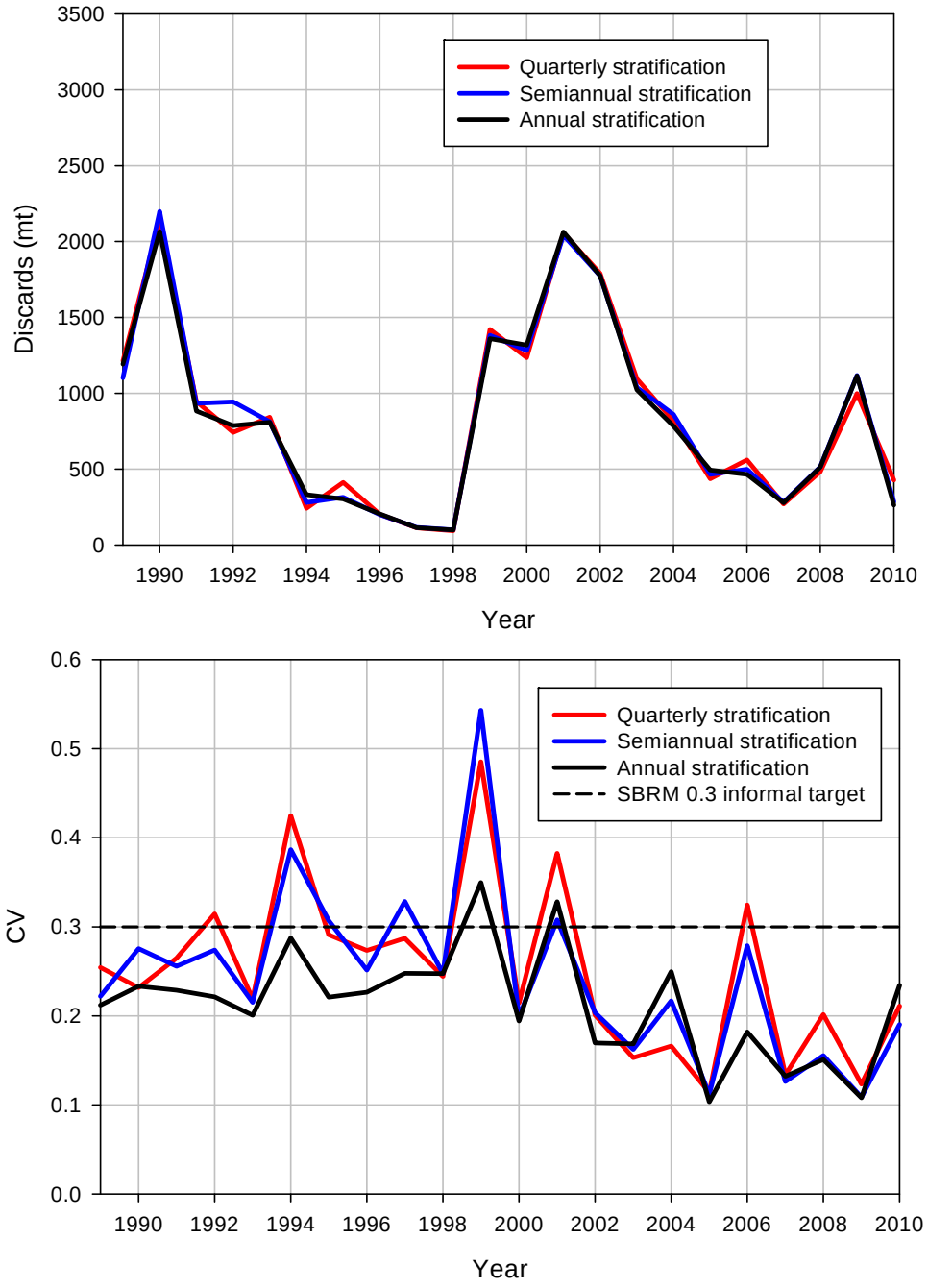


Figure A.28. Comparison of the annual discard estimates for Gulf of Maine Atlantic cod (top) and corresponding coefficients of variation (CV, bottom) using three different temporal stratification schemes: quarterly, annual and semiannual. The dashed black line represents the Standardized Bycatch Reporting 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.*

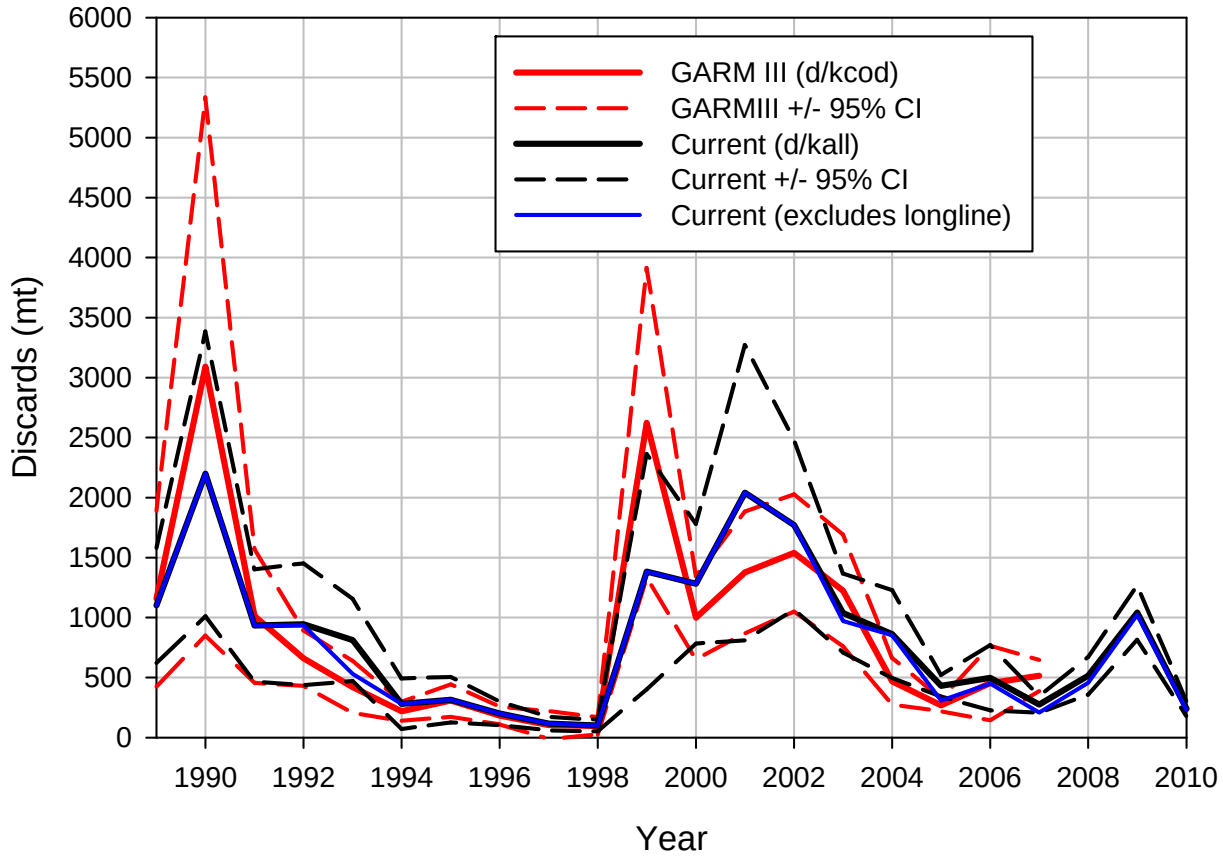


Figure A.29. Comparison of the updated discard estimates to the discard estimates used in the 2008 Groundfish Assessment Review Meeting (GARM III) for Gulf of Maine Atlantic cod. Both current and GARM III estimates are shown with their respective 95% confidence intervals (CI). The current estimate is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

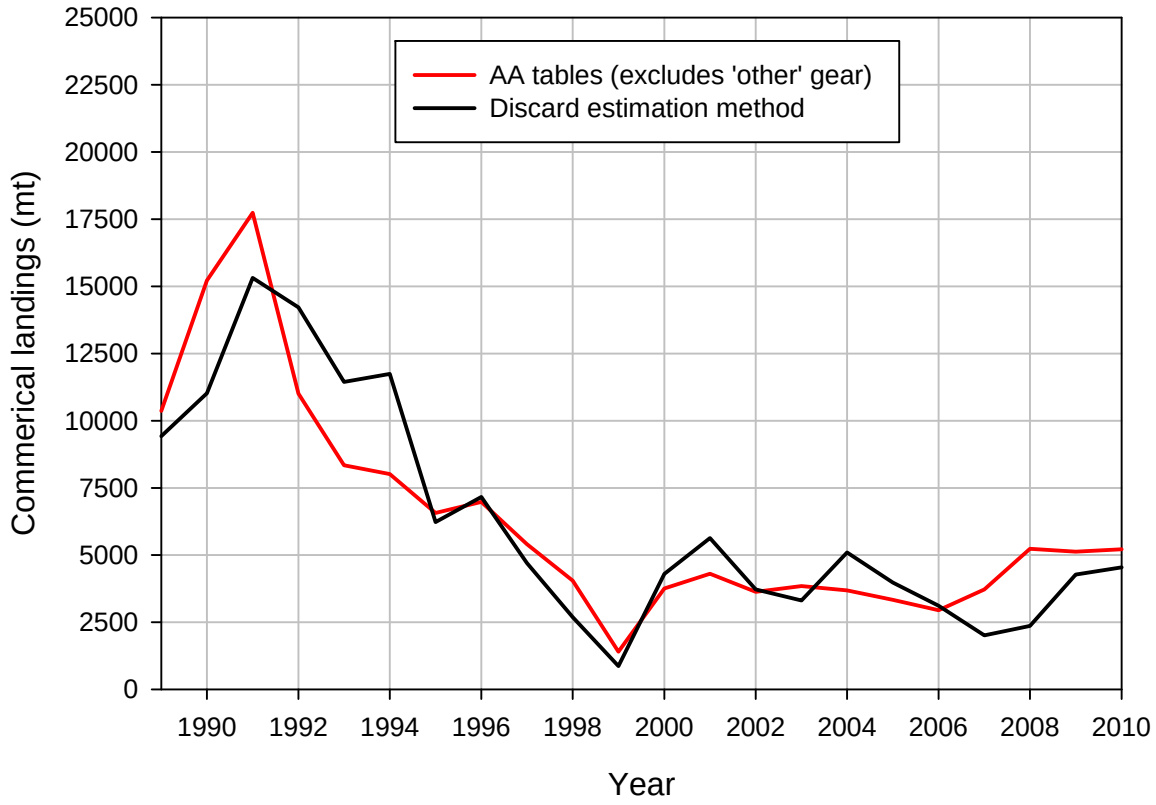


Figure A.30. Comparison of Gulf of Maine Atlantic cod landings estimates generated using the Standardized Bycatch Reporting Methodology (SBRM, Wigley et al. 2007) combined ratio approach to stock landings from the Commercial Fisheries Database AA tables. Landings are shown only for longline, handline, 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.*

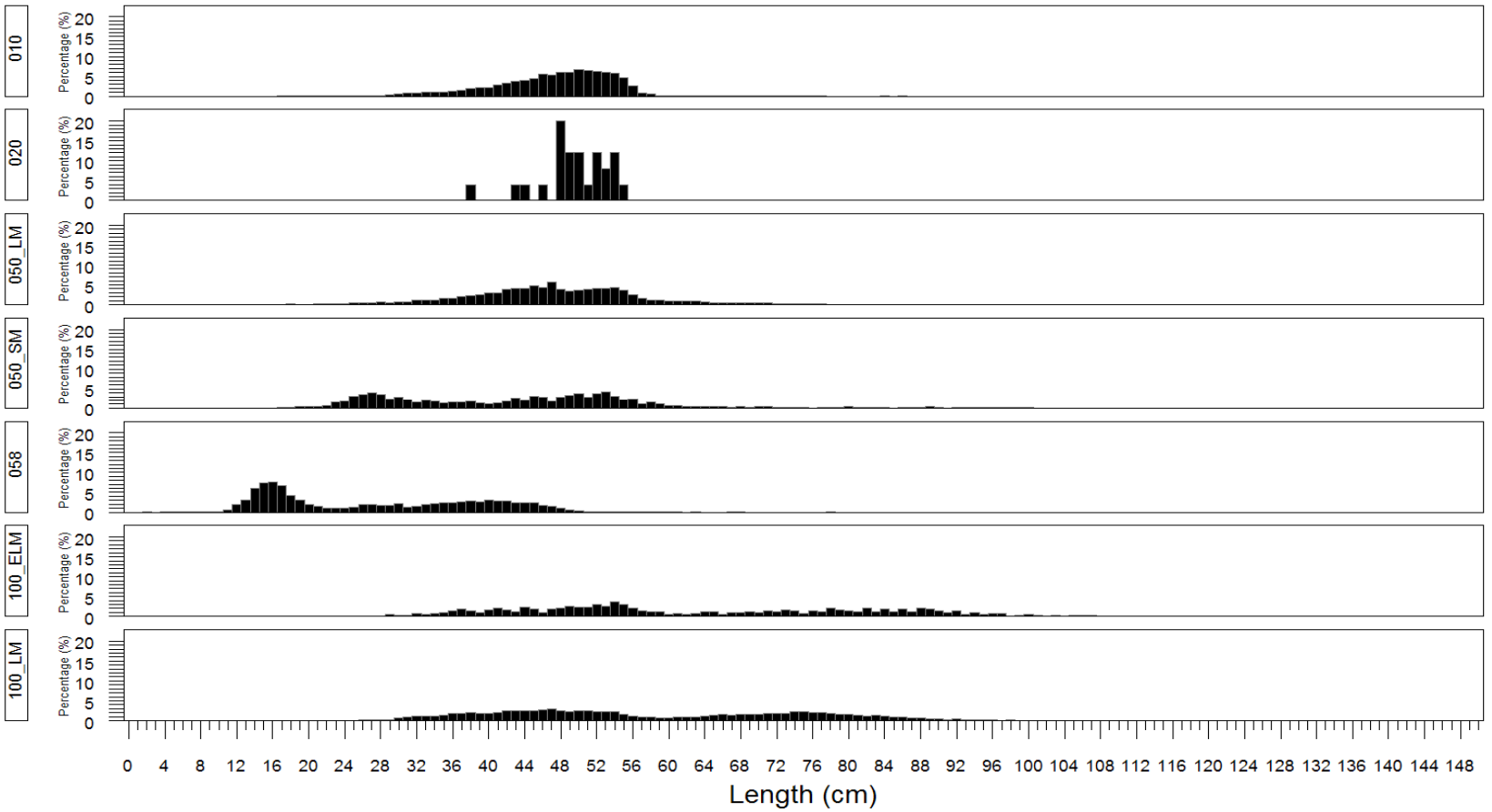


Figure A.31. Aggregate length frequency distributions, by gear type, of Gulf of Maine Atlantic cod discarded in the commercial fishery between 1989 and 2010. Gear types shown include: longline (010), handline/jig (020), large mesh otter trawl (050_LM), small mesh otter trawl (050_SM), shrimp trawl (058),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

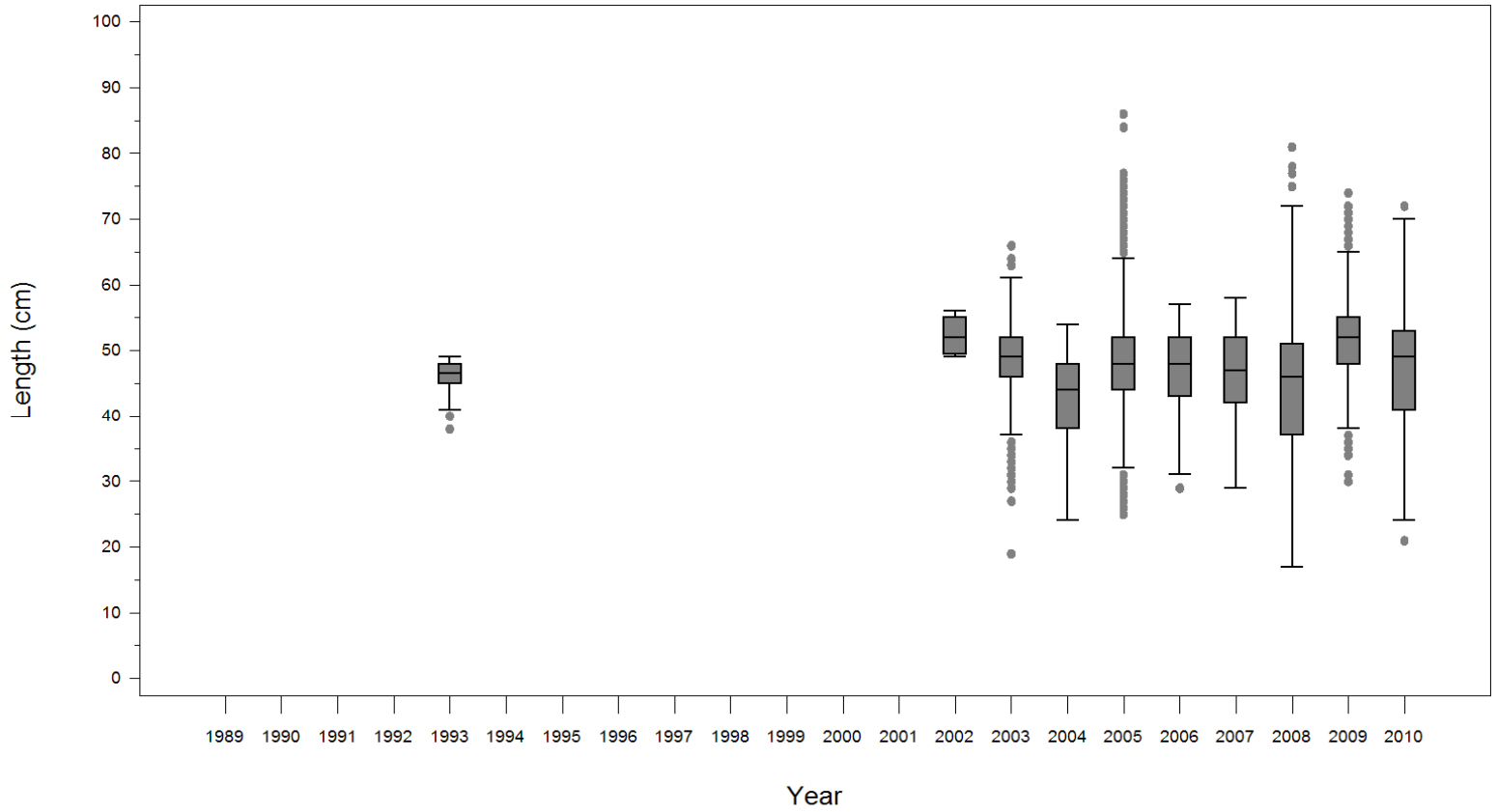


Figure A.32. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using benthic longline gear between 1989 and 2010. Missing years indicate that there were either no observed longline trips in the Gulf of Maine or no cod were observed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

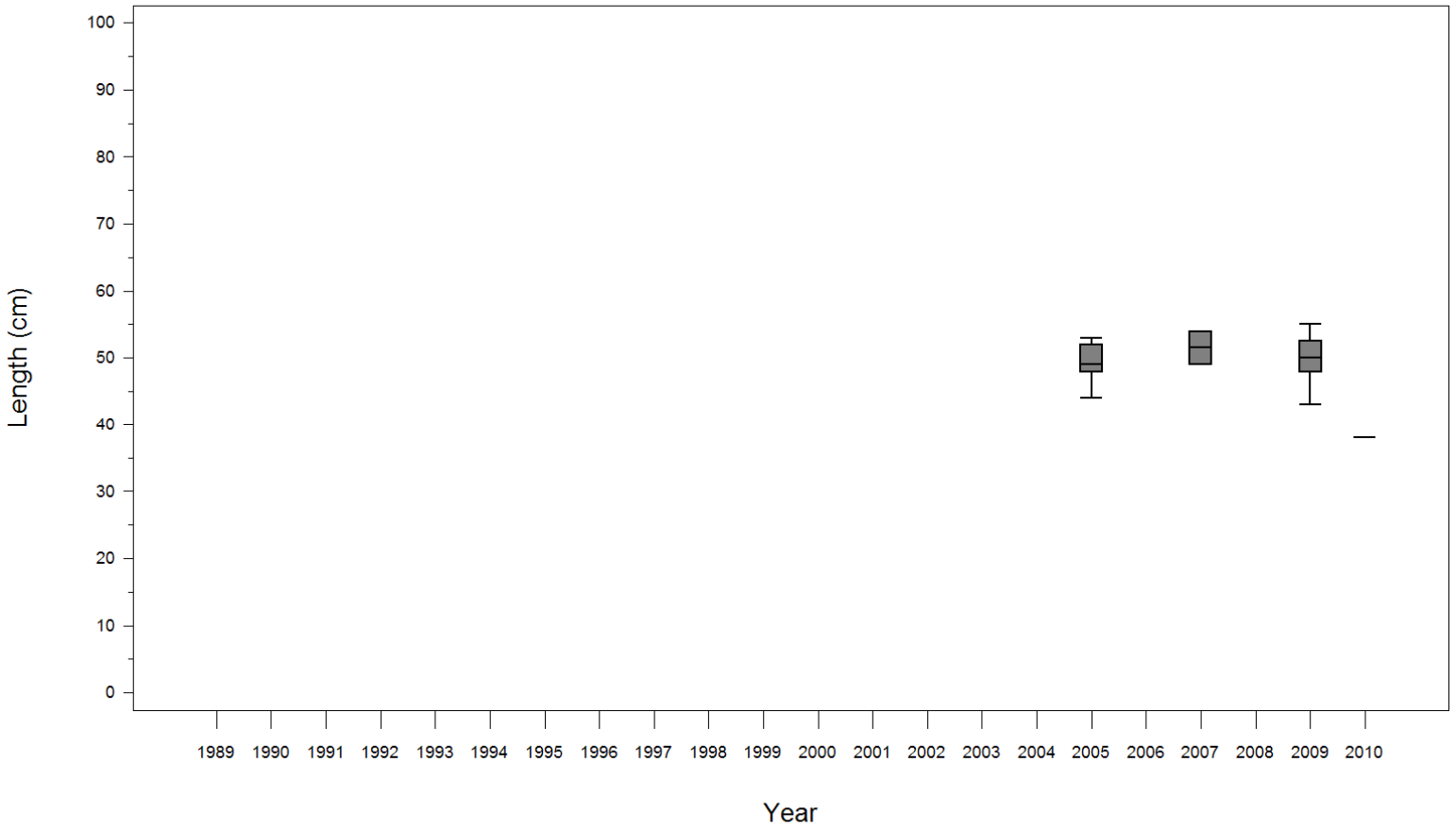


Figure A.33. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using handline (jig) gear between 1989 and 2010. Missing years indicate that there were either no observed handline trips in the Gulf of Maine or no cod were observed to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

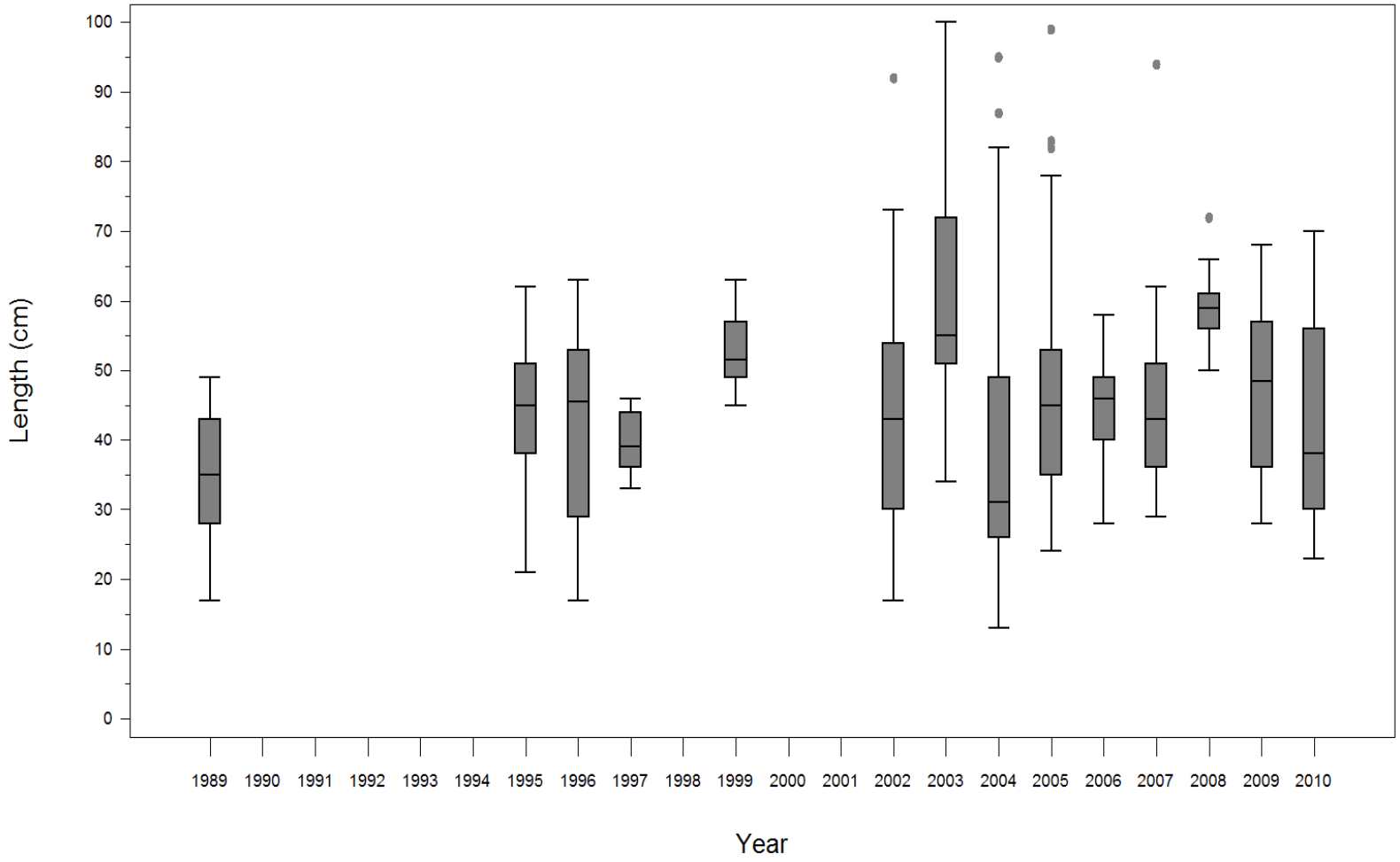


Figure A.34. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using small mesh otter trawl gear between 1989 and 2010. Missing years indicate that there were either no observed small mesh otter trawl trips in the Gulf of Maine or no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

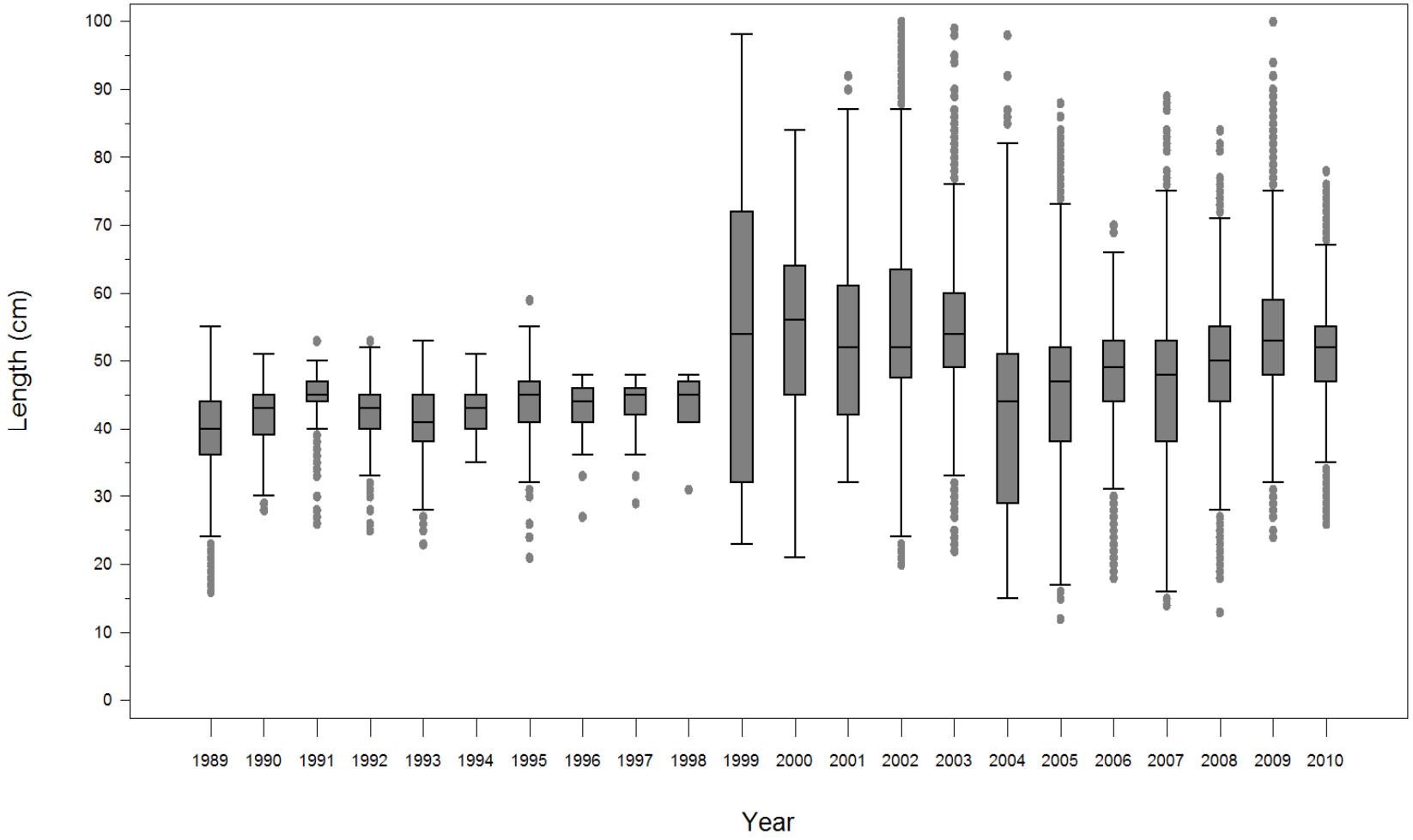


Figure A.35. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using large mesh otter trawl gear between 1989 and 2010. Missing years indicate that there were either no observed large mesh otter trawl trips in the Gulf of Maine or no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

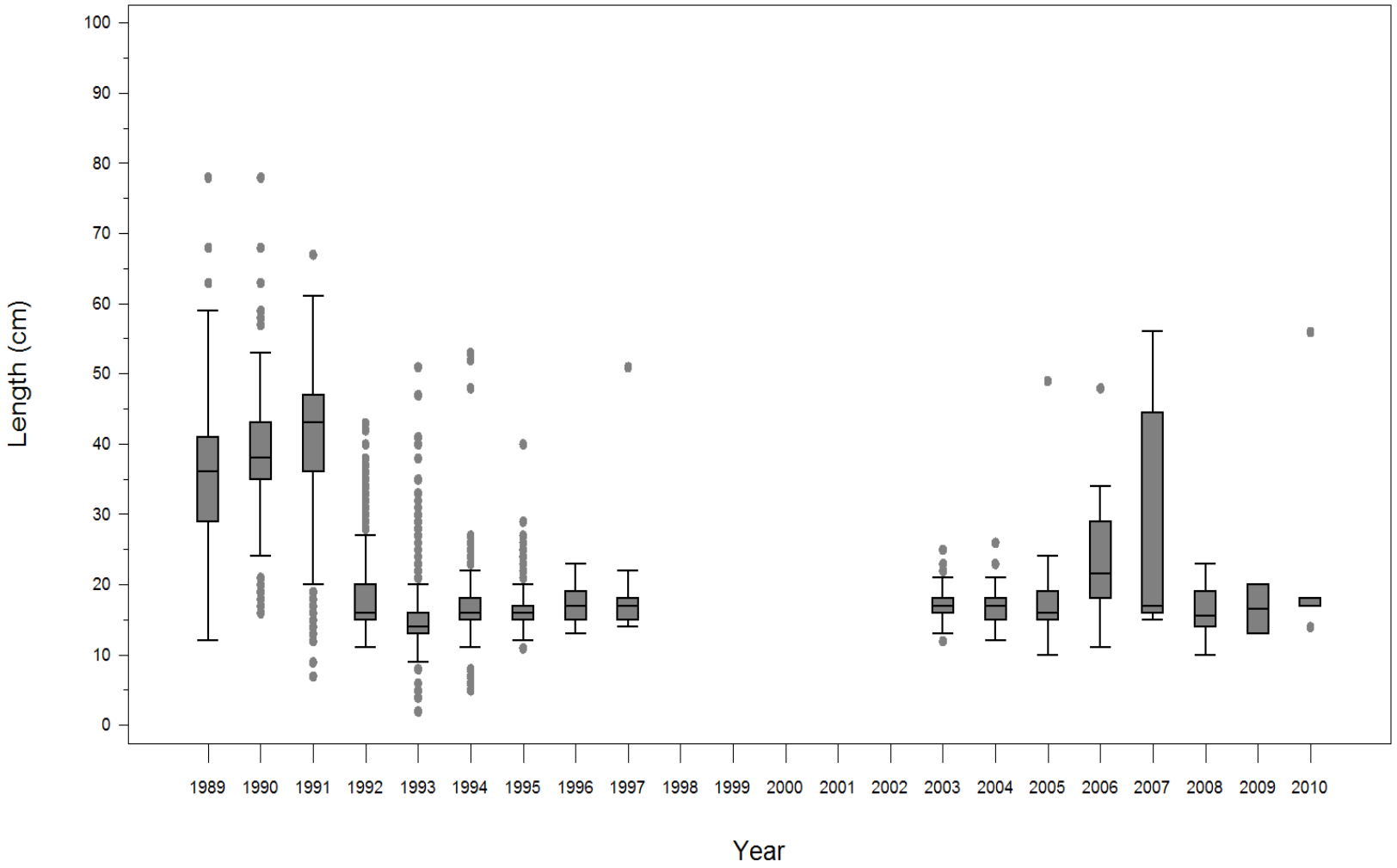


Figure A.36. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using shrimp trawl gear between 1989 and 2010. Missing years indicate that there were either no observed shrimp trawl trips in the Gulf of Maine or no cod were observed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

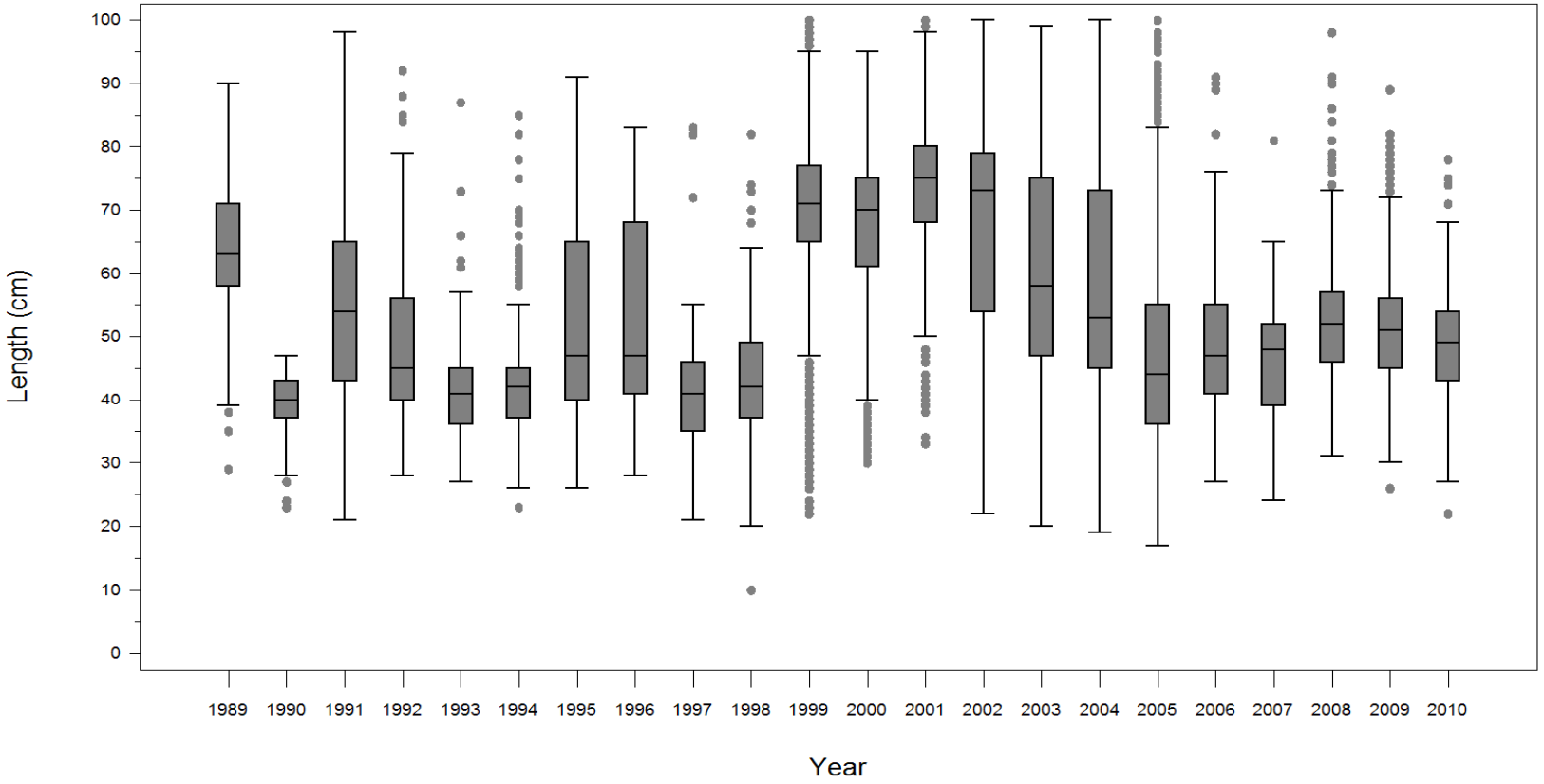


Figure A.37. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using large mesh sink gillnet gear between 1989 and 2010. Missing years indicate that there were either no observed large mesh sink gillnet trips in the Gulf of Maine or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

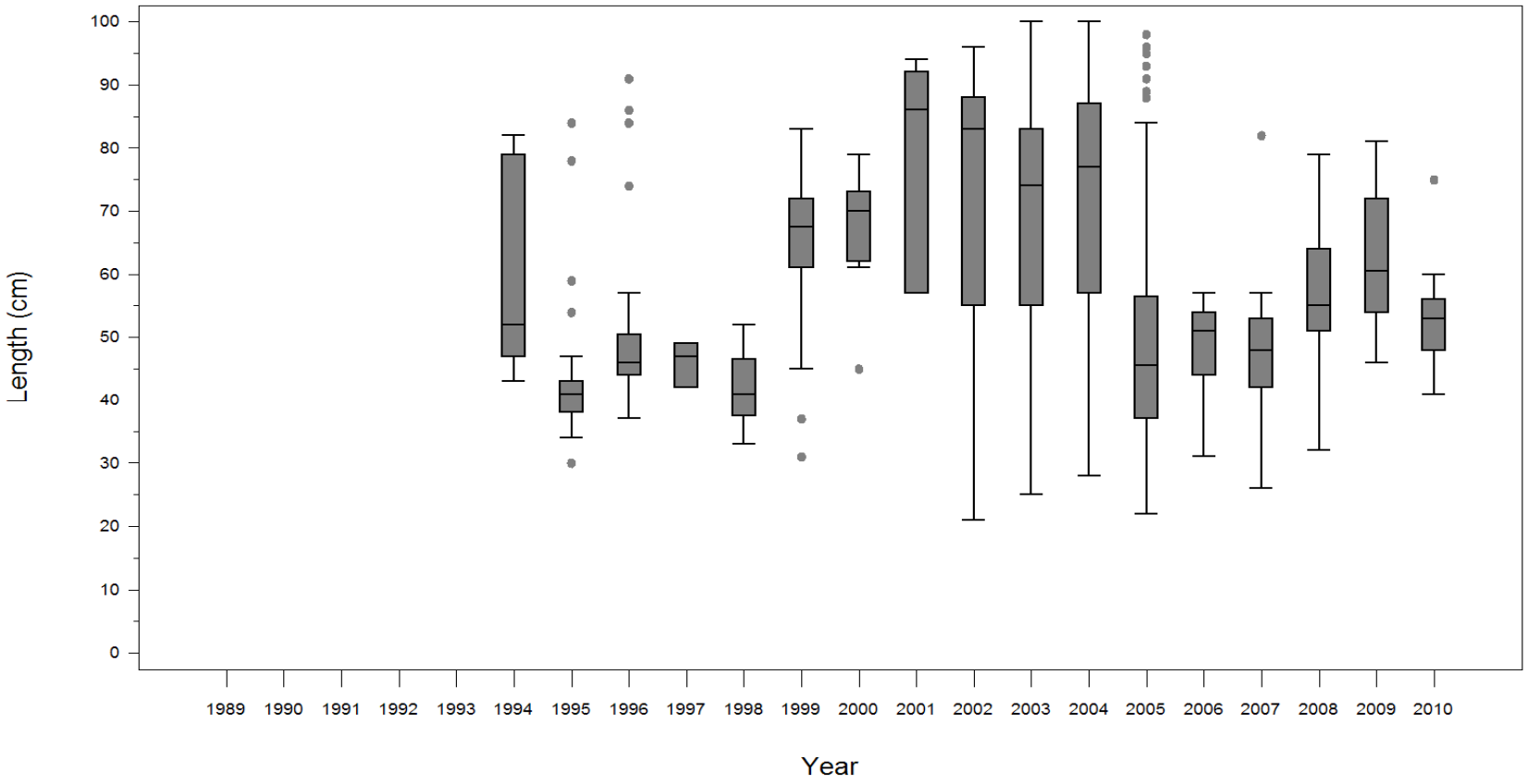


Figure A.38. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the commercial fishery by vessels using extra large mesh sink gillnet gear between 1989 and 2010. Missing years indicate that there were either no observed extra-large mesh sink gillnet trips in the Gulf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

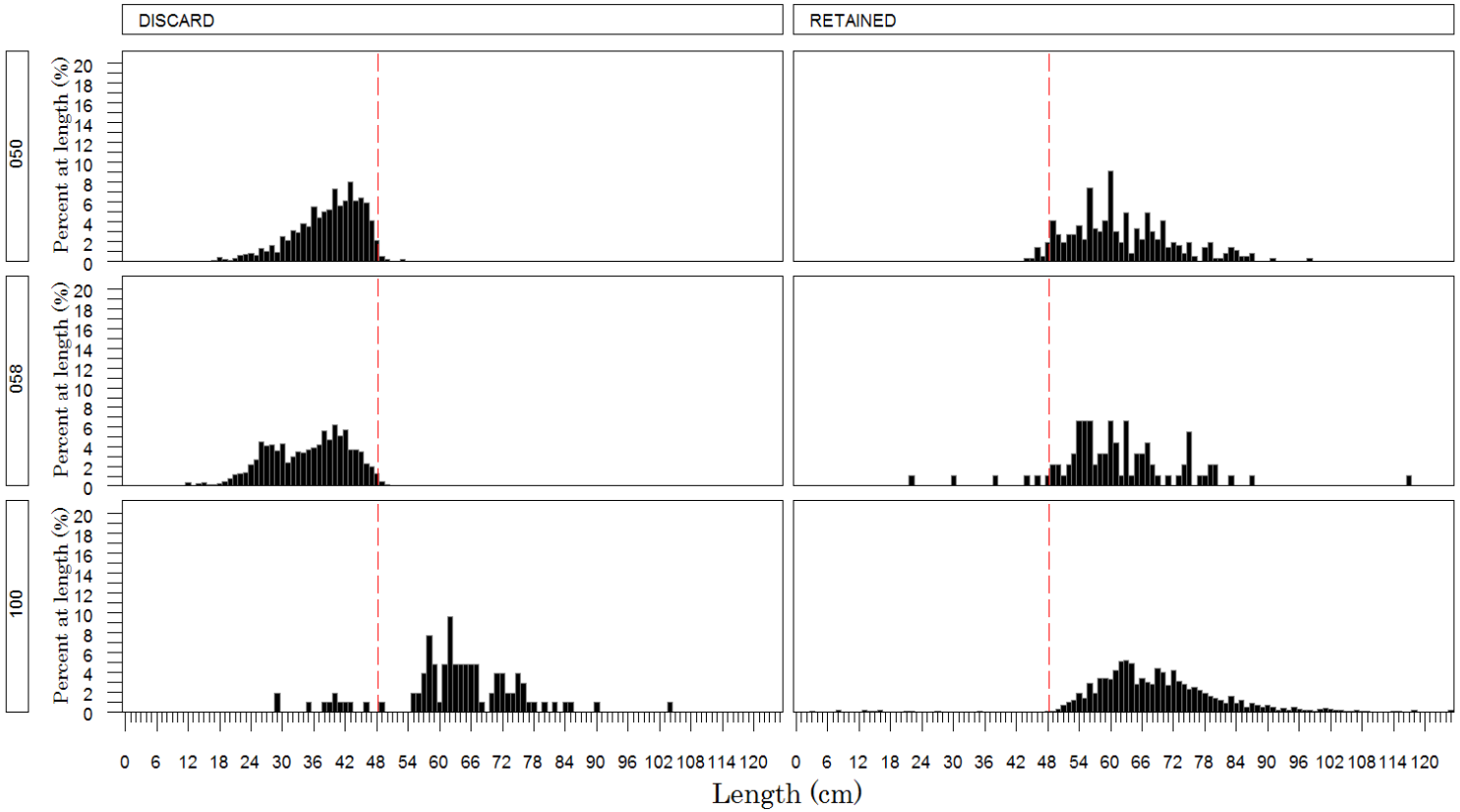


Figure A.39. Example of the length frequency distributions of Gulf of Maine Atlantic cod observed caught in the commercial fishery by large mesh otter trawl (050), shrimp trawl (058) and large mesh sink gillnet (100) gear in 1989. The 1989 – 1996 commercial minimum retention size of 19 inches (48.3 cm)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

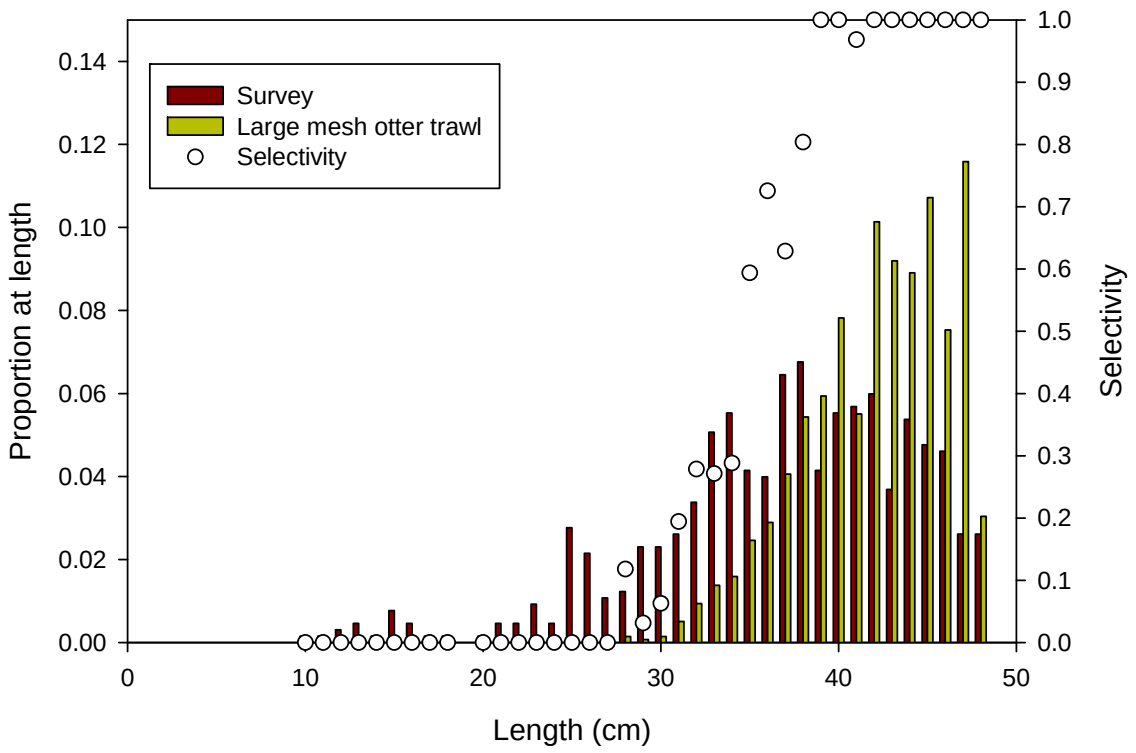


Figure A.40. Example of applying the survey-filter method to estimate the selectivity-at-length of fishing gears for Gulf of Maine Atlantic cod. In this example the proportion caught at length by large mesh otter trawl is compared to the proportion caught at-length in Northeast Fishery Science Center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

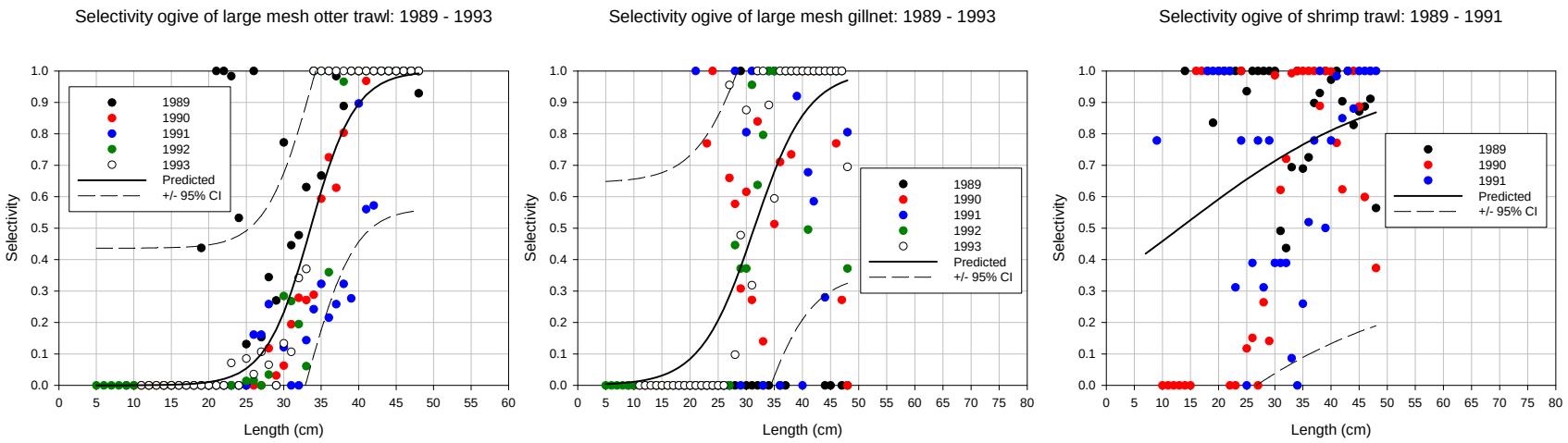


Figure A.41. Estimated selectivity ogives for large mesh otter trawl, large mesh sink gillnet and shrimp trawl and the corresponding 95% confidence intervals (CI) for Gulf of Maine Atlantic cod. Selectivity ogives were estimated from the logistic fits to the aggregated annual estimates of selectivity-at-length.

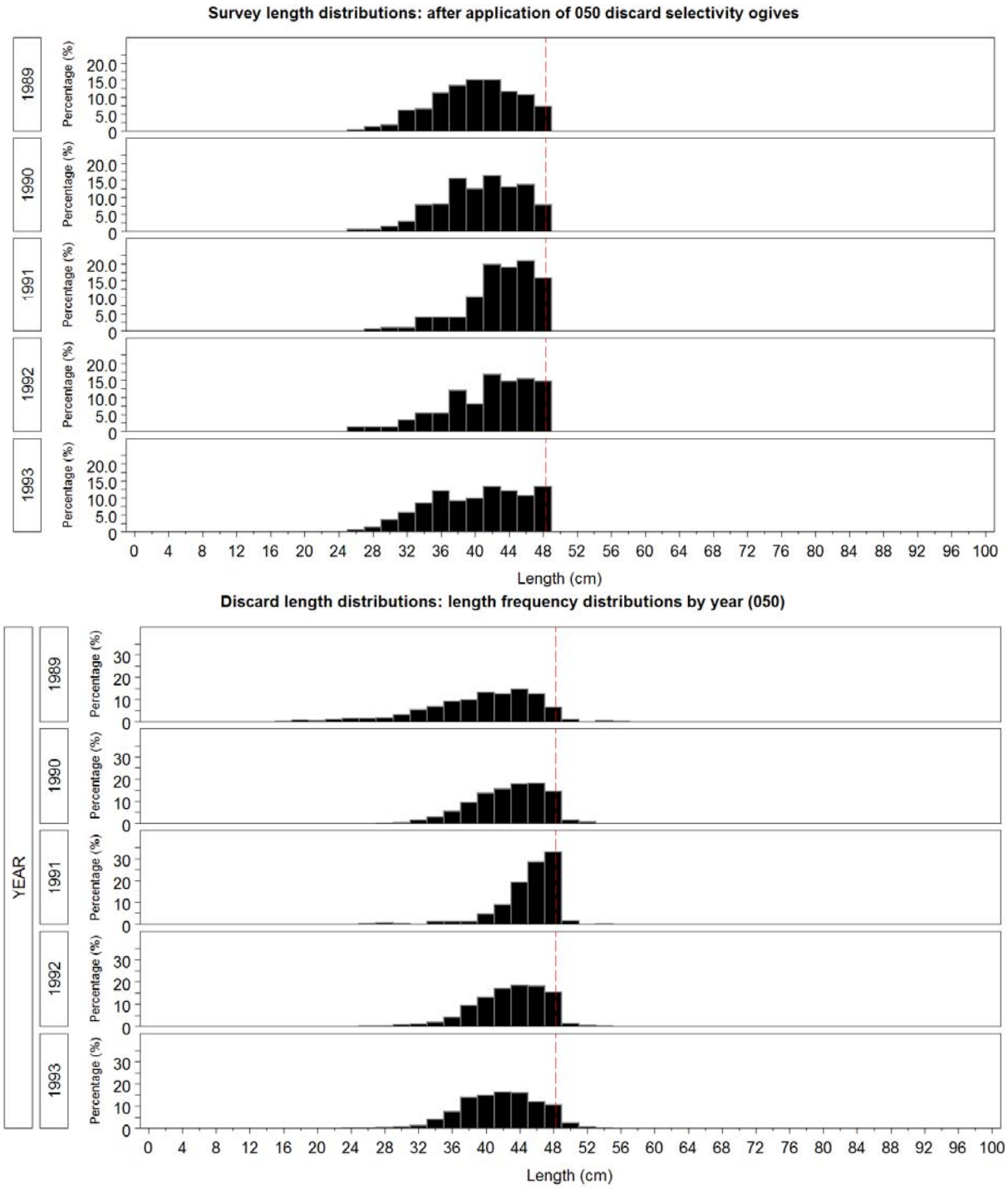


Figure A.42. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh otter trawl gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3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

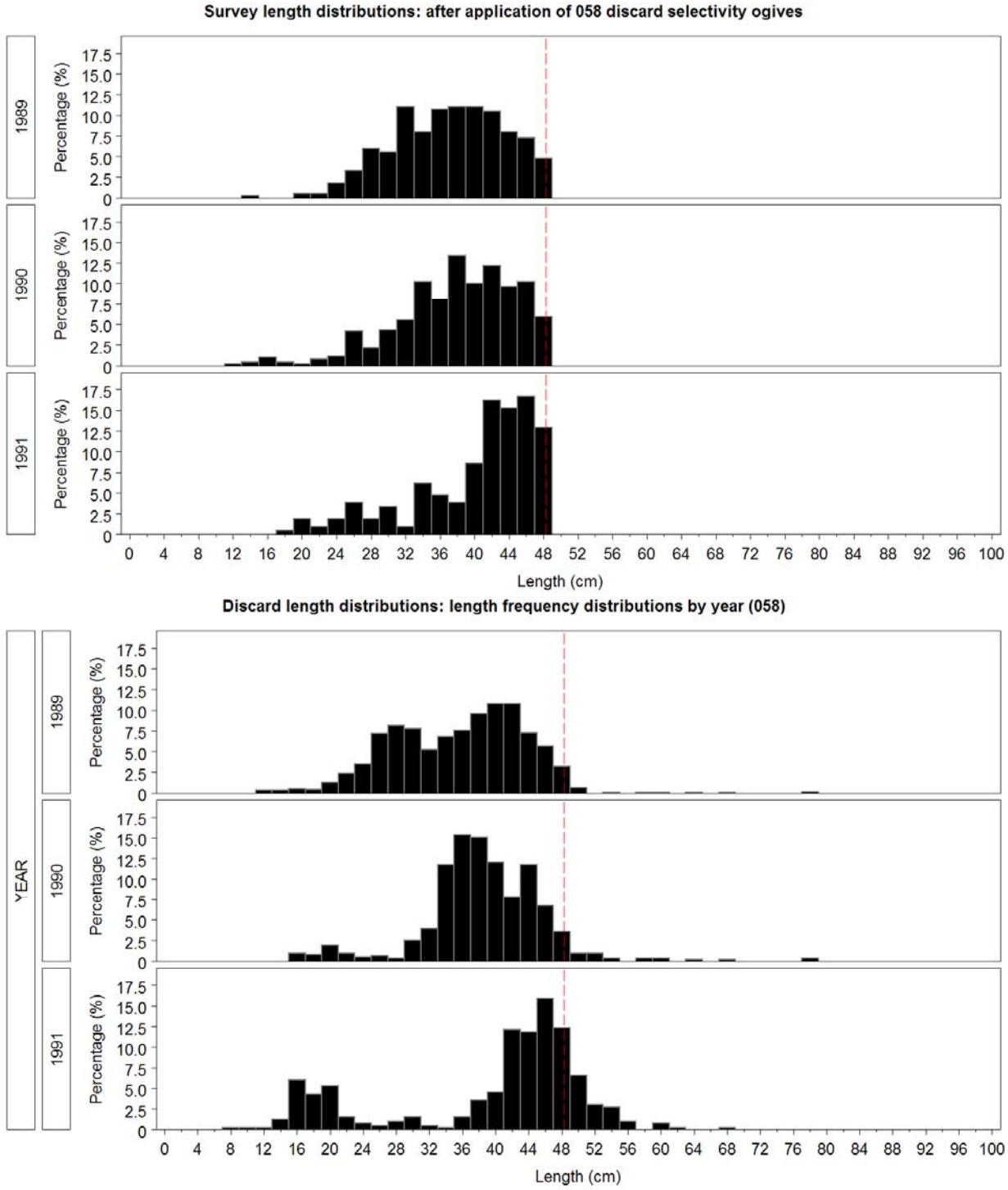


Figure A.43. Comparison of the survey filter-based estimates (top) of discards-at-length for shrimp trawl gear to the direct observer observations (bottom) from 1989 to 1991 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3 cm) from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

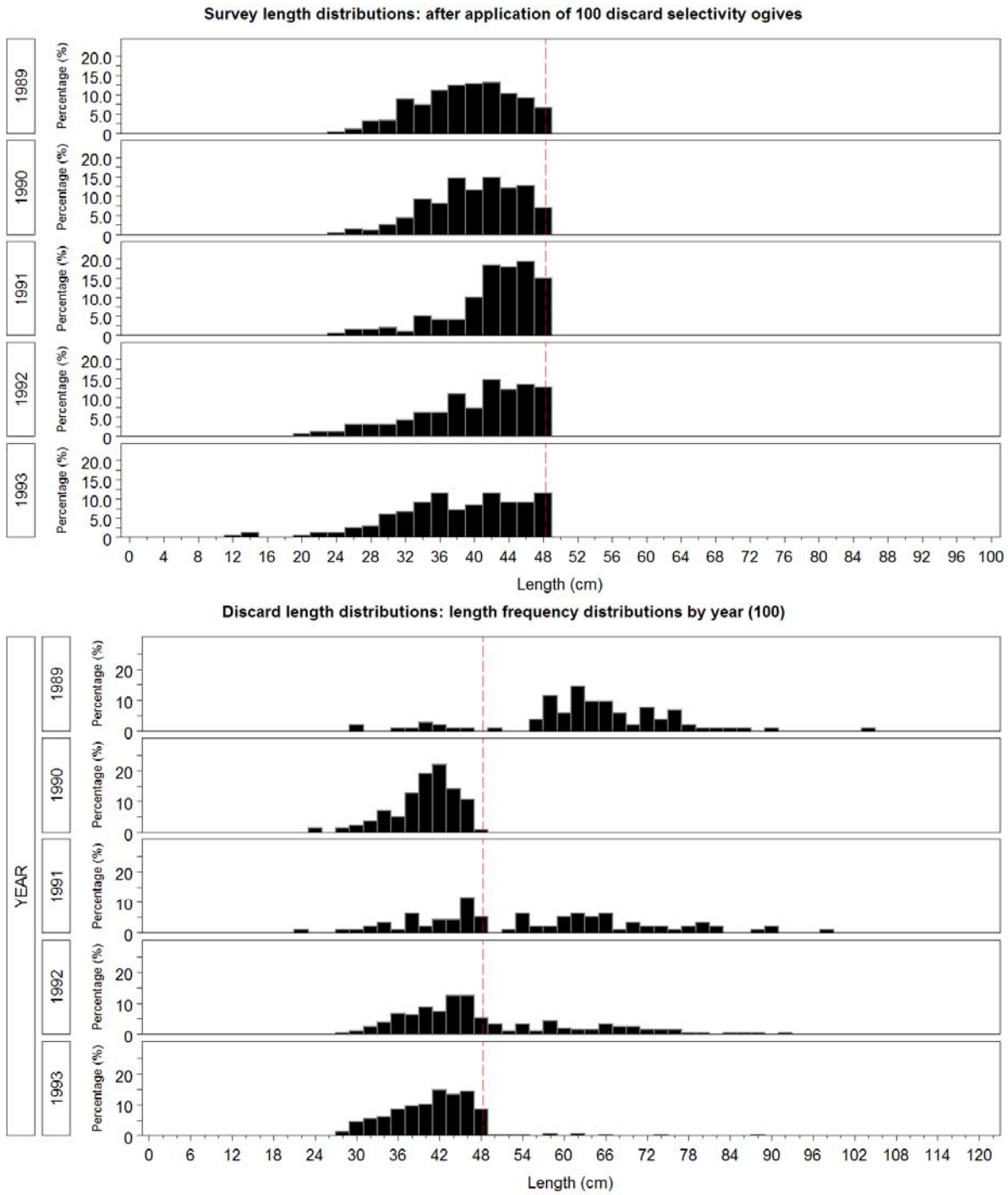


Figure A.44. Comparison of the survey filter-based estimates (top) of discards-at-length for large mesh sink gillnet gear to the direct observer observations (bottom) from 1989 to 1993 for Gulf of Maine Atlantic cod. The dashed red line represents the commercial minimum retention size of 19 inches (48.3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

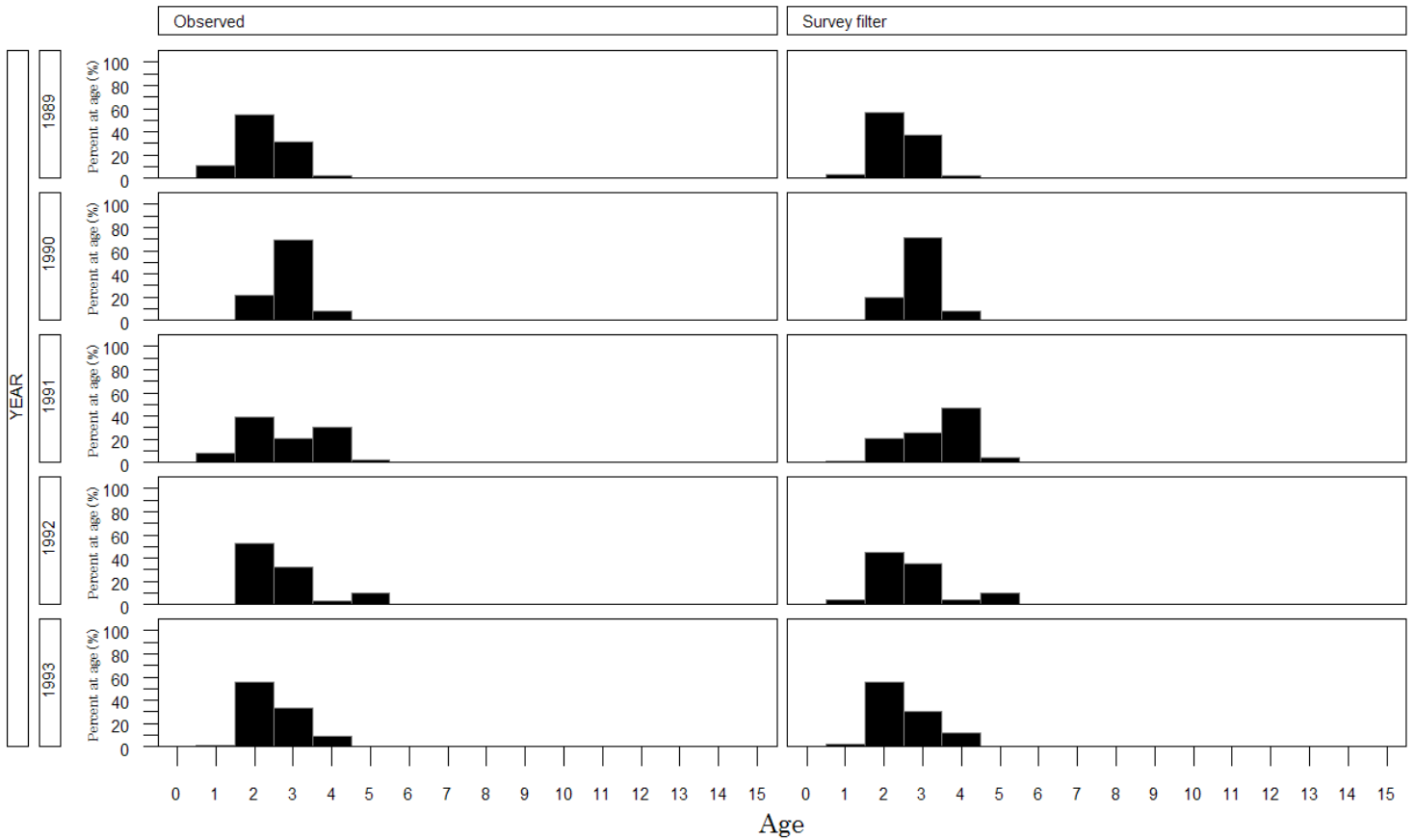


Figure A.45. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh otter trawl gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

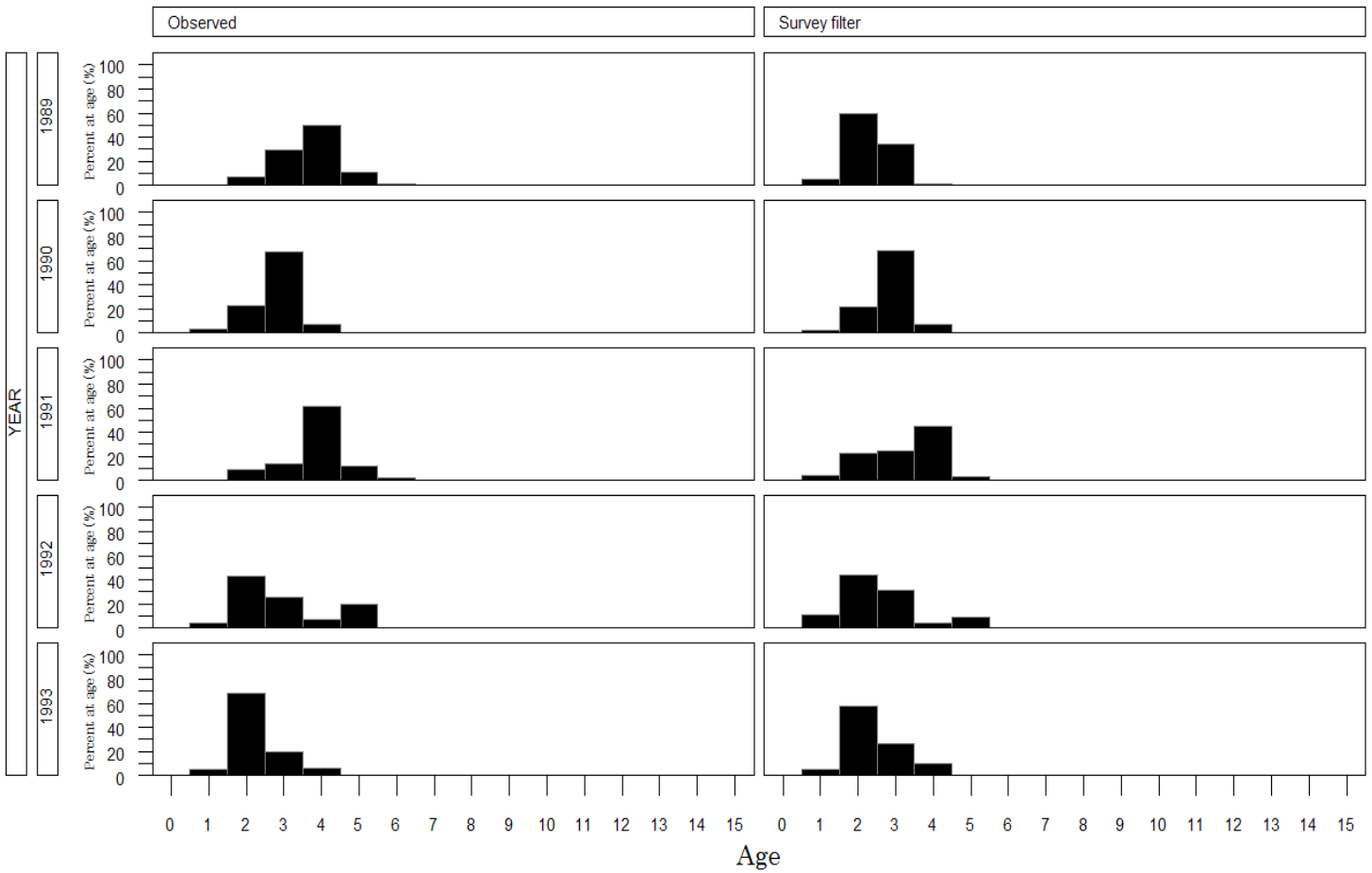


Figure A.46. Comparison of the survey filter-based estimates (right) of numbers-at-age for large mesh sink gillnet gear to the direct observer observations (left) from 1989 to 1993 for Gulf of Maine Atlantic cod.

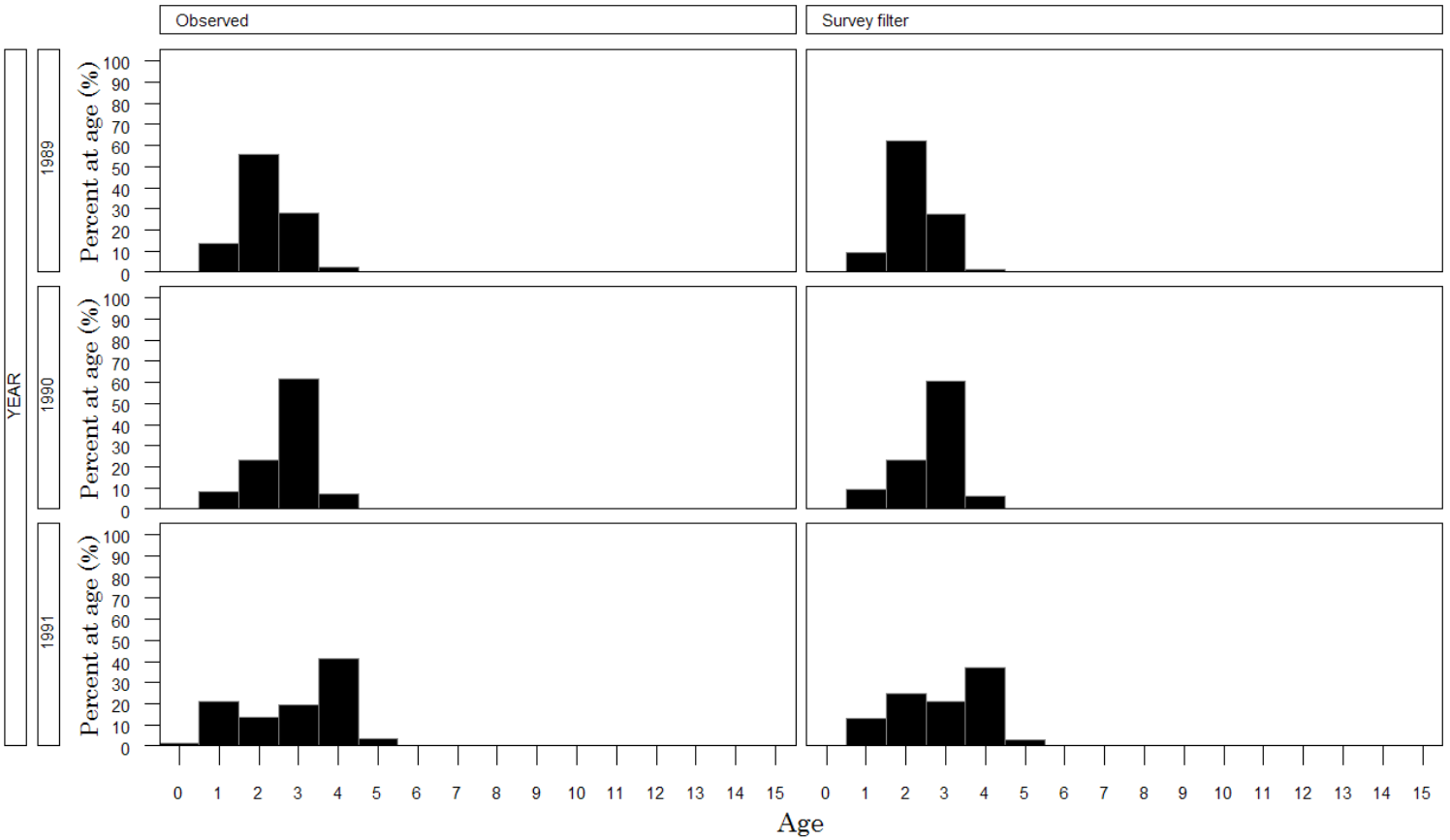


Figure A.47. Comparison of the survey filter-based estimates (right) of numbers-at-age for shrimp trawl gear to the direct observer observations (left) from 1989 to 1991 for Gulf of Maine Atlantic cod.

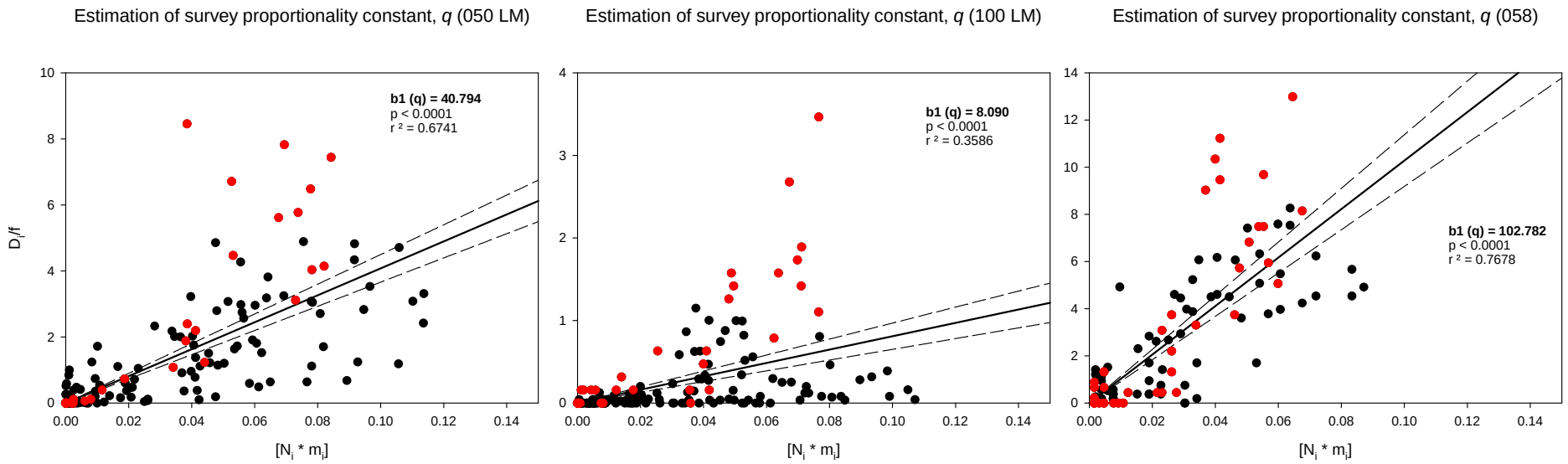


Figure A.48. Plots of the relationship by gear type between fraction of fish observed discarded-at-length (D_i/f) and the estimated number at length from the survey-filter method ($N_i \bullet m_i$) for Gulf of Maine Atlantic cod. Large mesh otter trawl (050 LM), large mesh sink gillnet (100 LM) and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

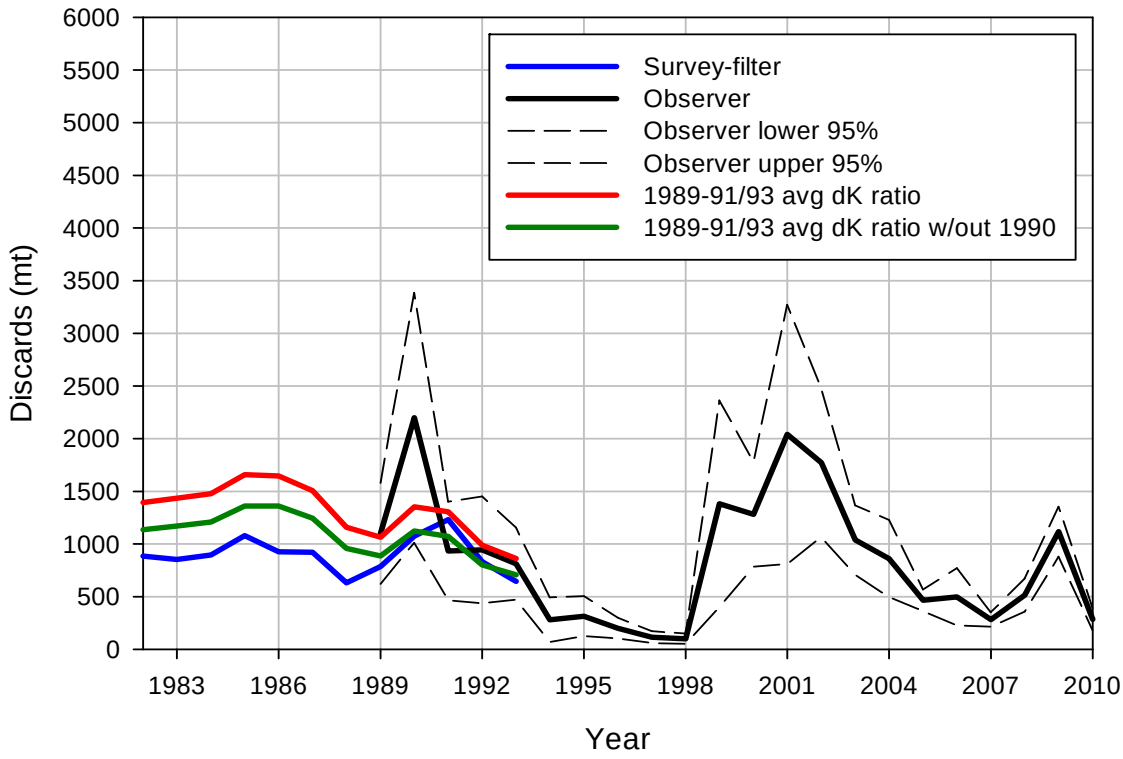


Figure A.49. Comparison of three different methods for achieving hindcasted estimates of Gulf of Maine Atlantic cod commercial discards from 1982 to 1988. (1) The survey-filter method uses the proportionality constant (q) multiplied by an index of fishing effort (total retained catch, K_{all}) to estimate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

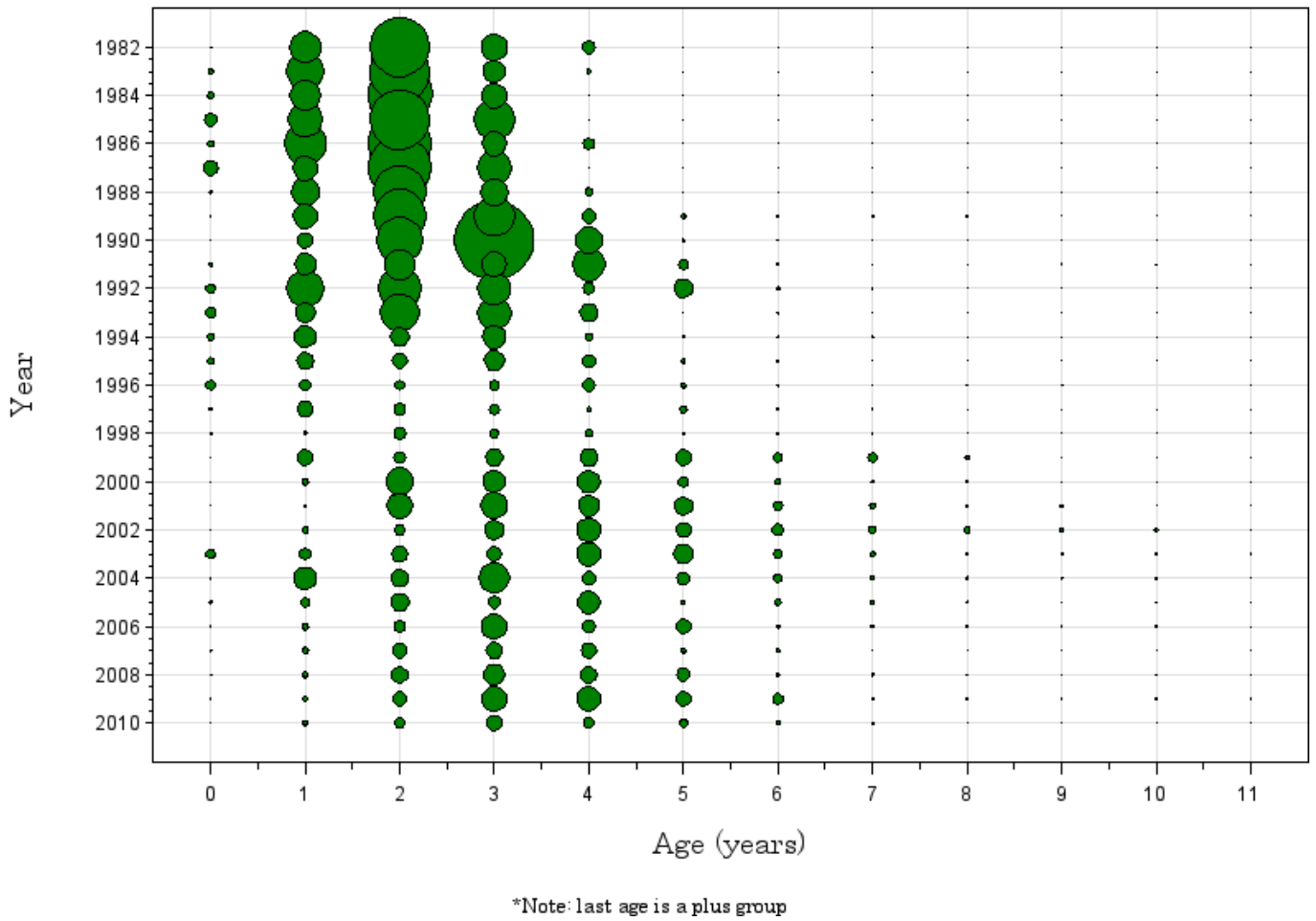


Figure A.50. Commercial discards-at-age of Gulf of Maine Atlantic cod from 1982 to 2010. **Note that age 11 is a plus group.*

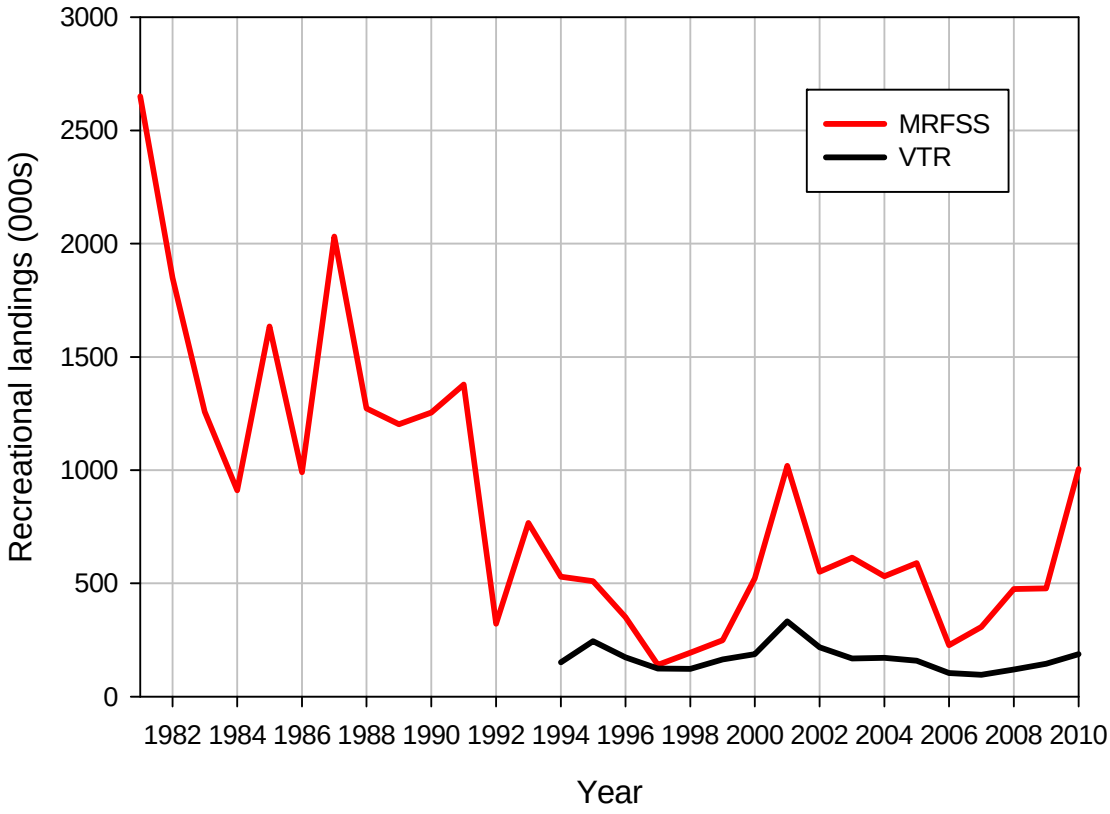


Figure A.51. Comparison of recreational landing estimates derived through the Marine Recreational Fishing Statistical Survey (MRFSS) to recreational landings reported on Vessel Trip Reports (VTRs) between 1994 and 2010 for Gulf of Maine Atlantic cod.

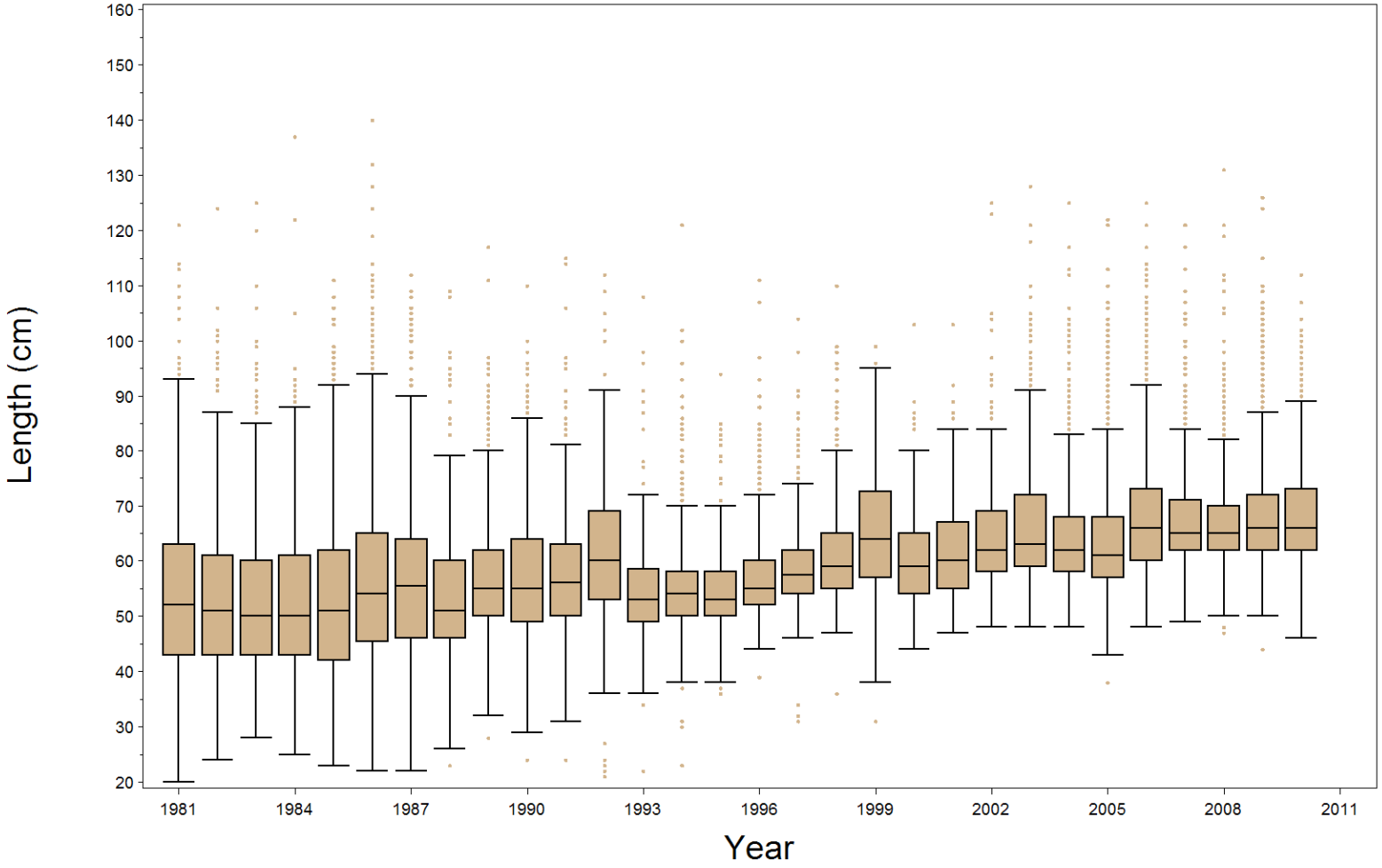


Figure A.52. Box plots showing the length distribution of Gulf of Maine Atlantic cod landed by the recreational fishery between 1981 and 2010.

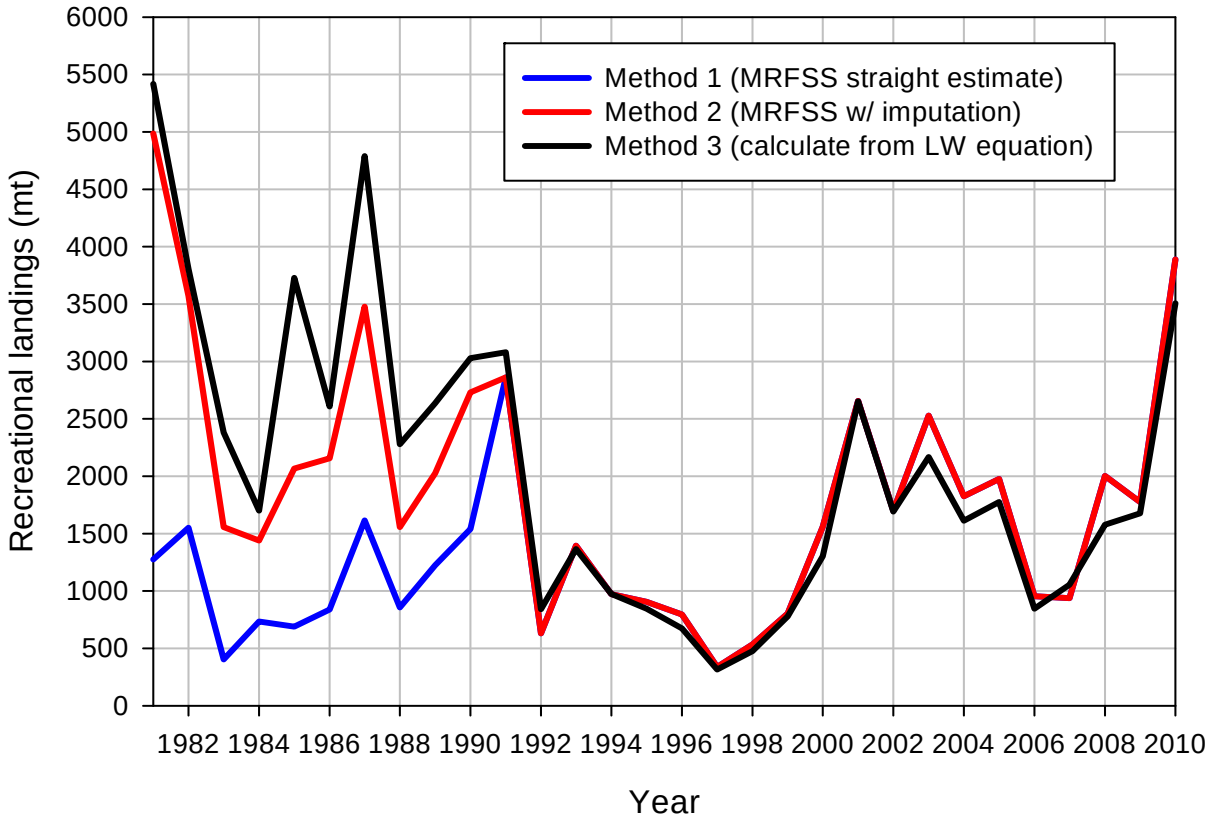


Figure A.53. Gulf of Maine Atlantic cod recreational landings in terms of weight (mt) estimated using three different methods. (1) Using the MRFSS provided weight estimates (does not account for state-semester cells without average weight estimates). (2) Using the MRFSS provided weight estimates but 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.

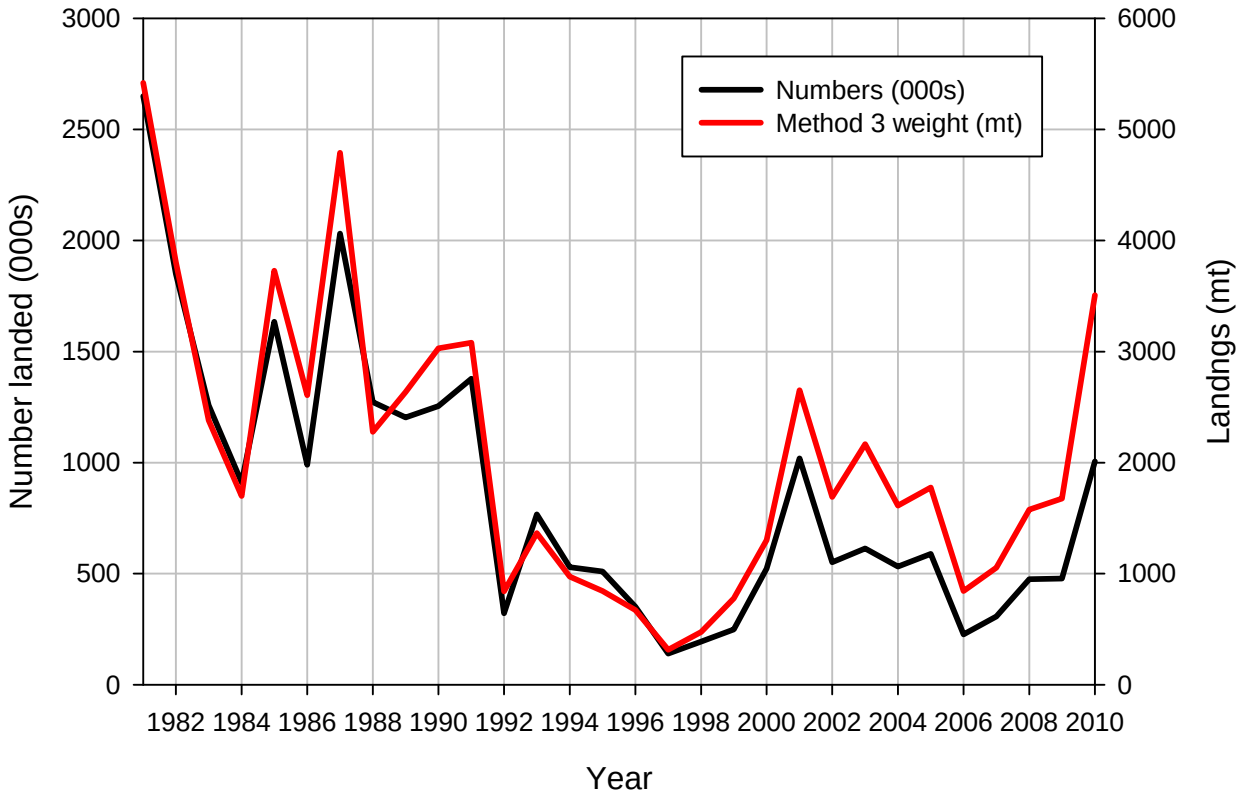


Figure A.54. Trends in Gulf of Maine Atlantic cod recreational landings between 1981 and 2010 in terms of weight (mt) and numbers (000's fish).

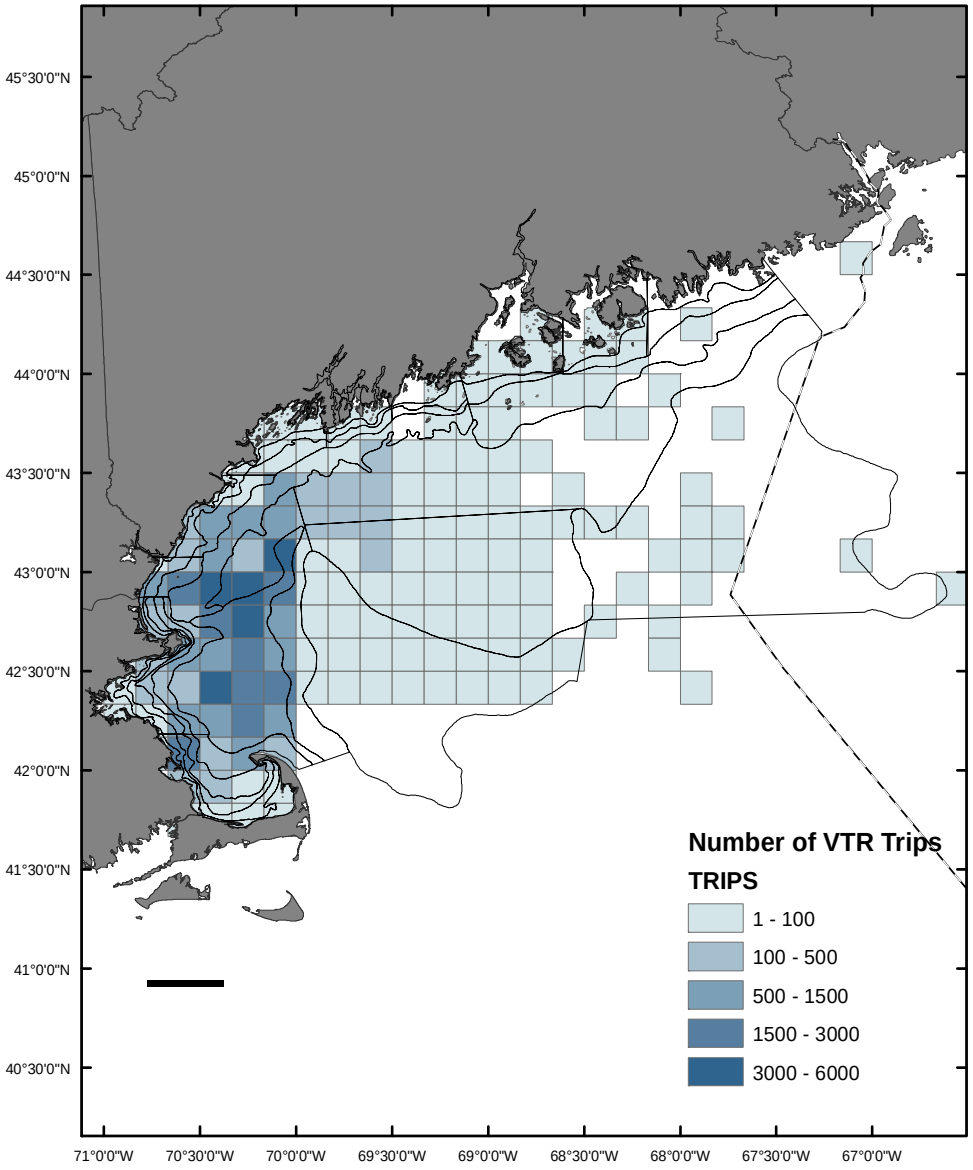


Figure A.55. Spatial distribution of recreational effort between 1994 and 2010 as determined from Vessel Trip Reports (VTRs) overlaid on the Northeast Fisheries Science Center bottom trawl survey sampling strata. VTR-based recreation effort has been binned to ten minute squares.

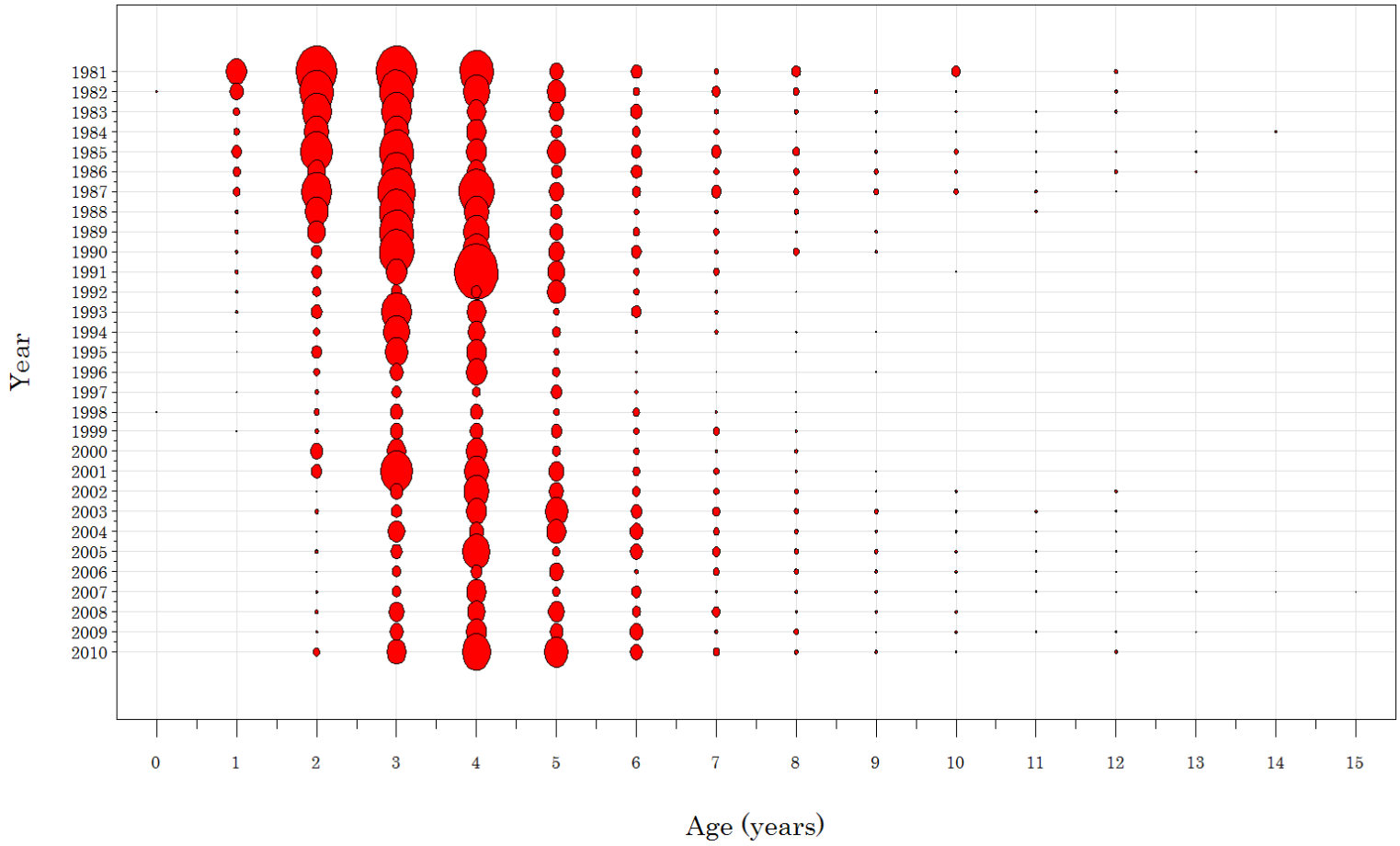


Figure A.56. Recreational landings-at-age of Gulf of Maine Atlantic cod from 1981 to 2010.

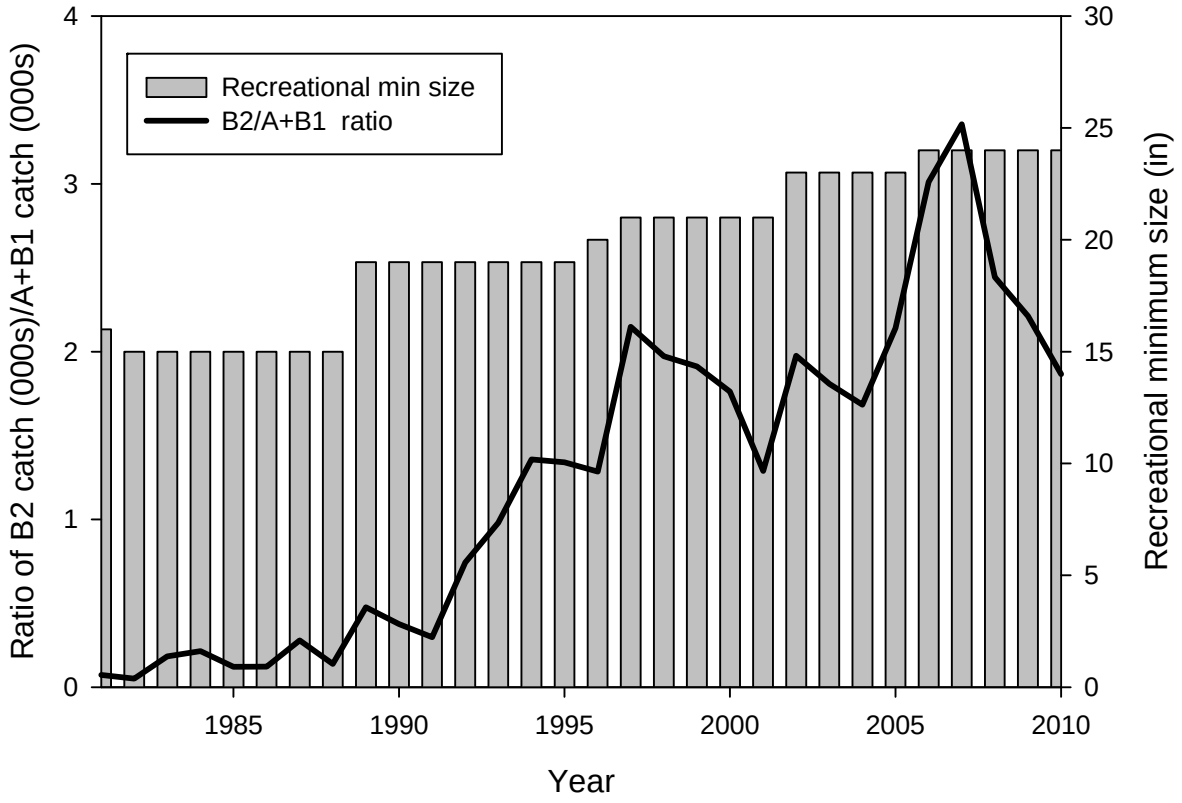


Figure A.57. Trends in the ratio of Gulf of Maine Atlantic cod recreational discards to recreational landings from 1981 to 2010 compared to increases in the recreational minimum retention size.

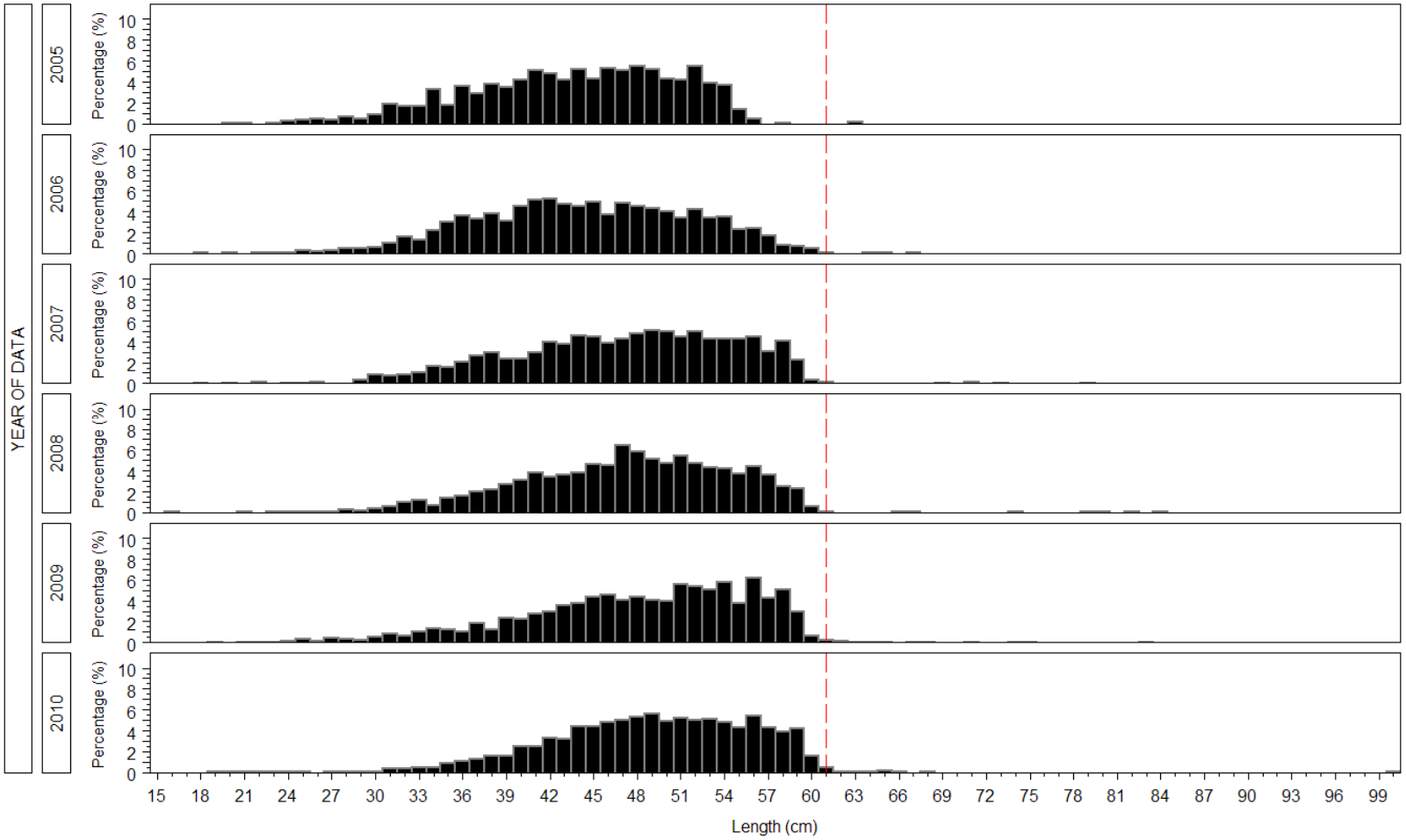


Figure A.58. Annual length frequency distributions of Gulf of Maine Atlantic cod discarded in the recreational fishery between 2005 and 2010. The dashed red line represent the recreational minimum retention size of 24 inches (61.0 cm) from May 1, 2006-2010. The minimum retention size from January 1,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

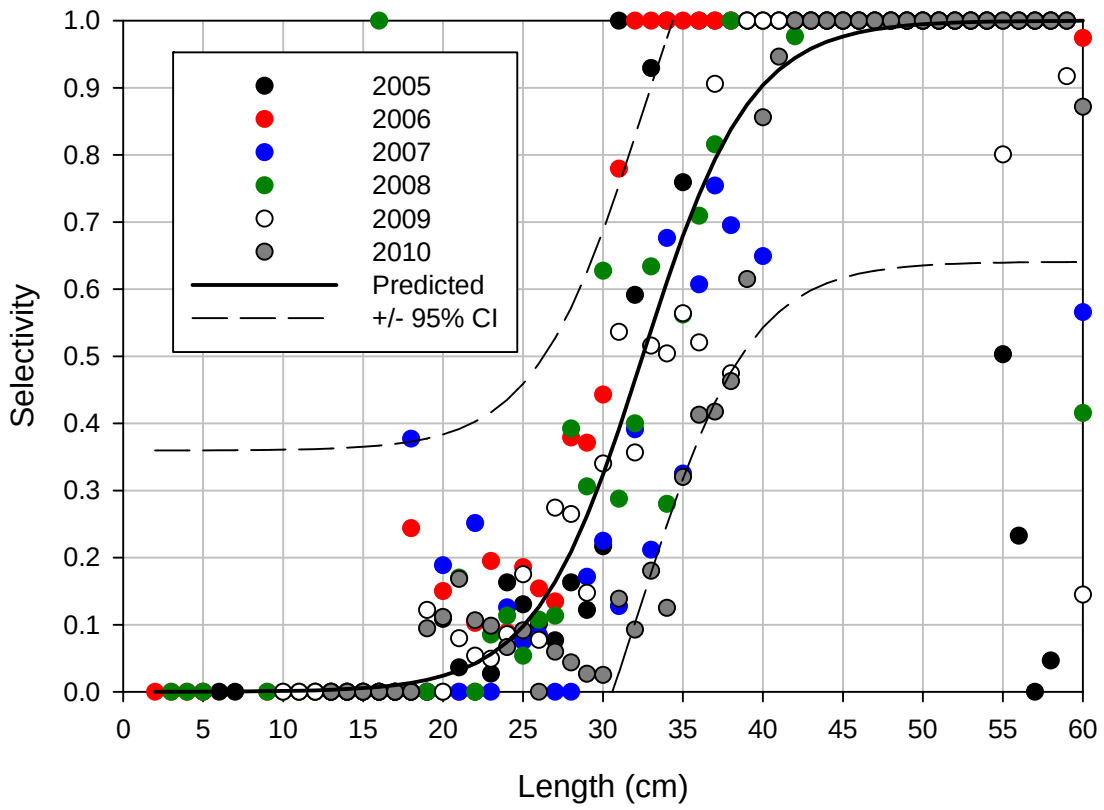
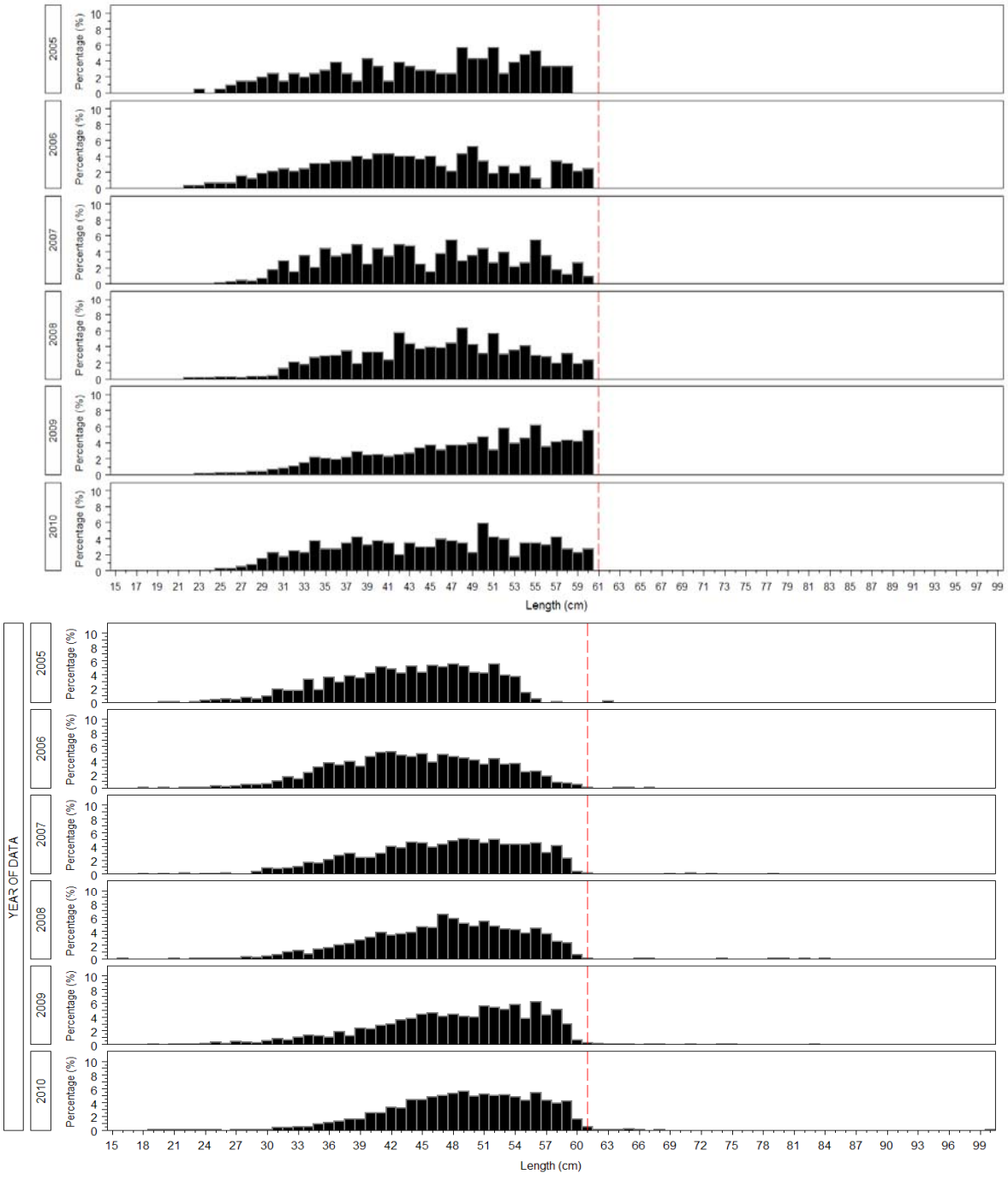


Figure A.59. Estimated selectivity ogive for the recreational fishery and the corresponding 95% confidence interval (CI) for Gulf of Maine Atlantic cod. The selectivity ogive was estimated from the logistic fits to the aggregated annual estimates of selectivity-at-length.



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).

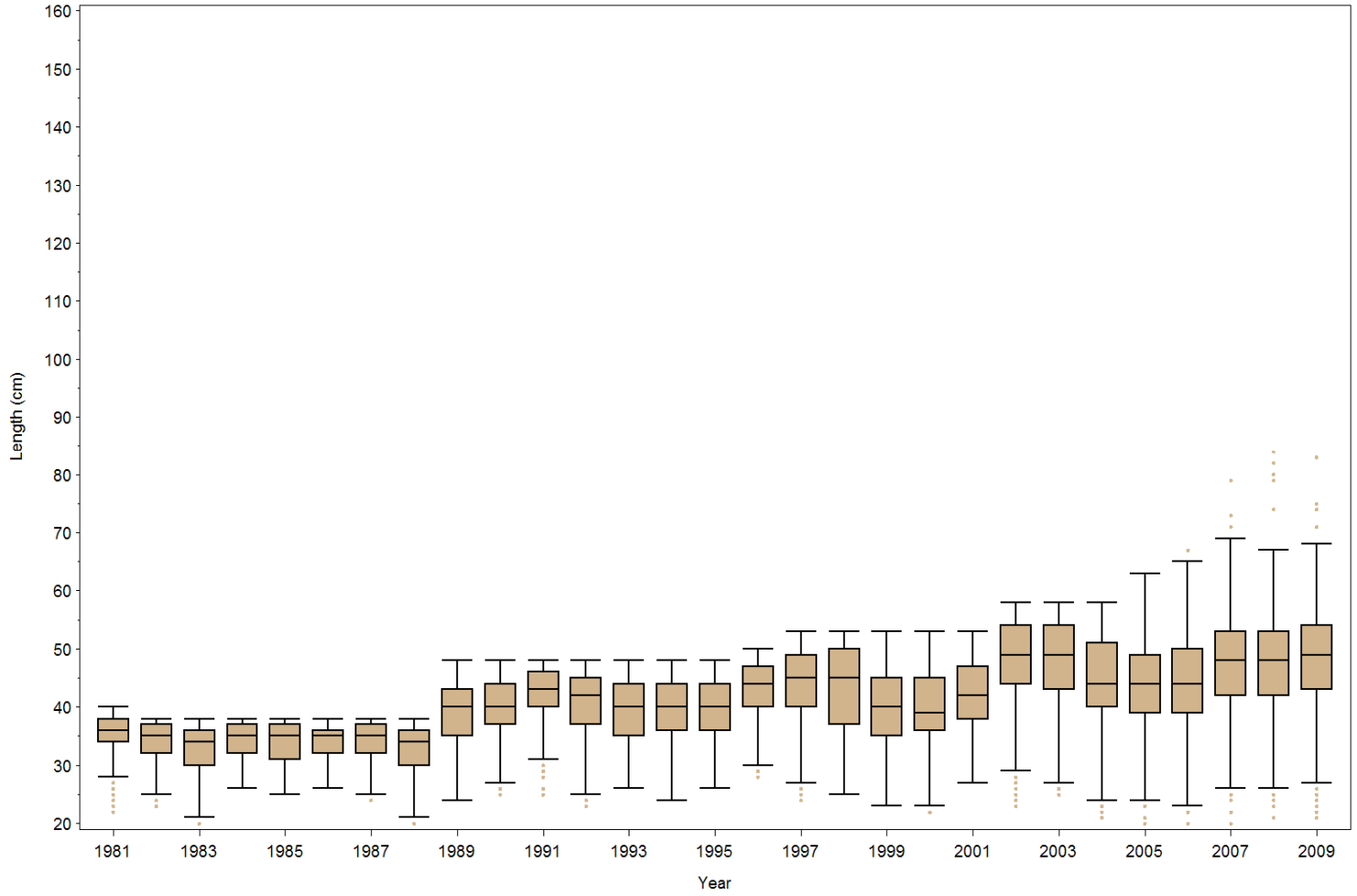


Figure A.61. Box plots showing the length distribution of Gulf of Maine Atlantic cod discarded by the recreational fishery between 1981 and 2010.

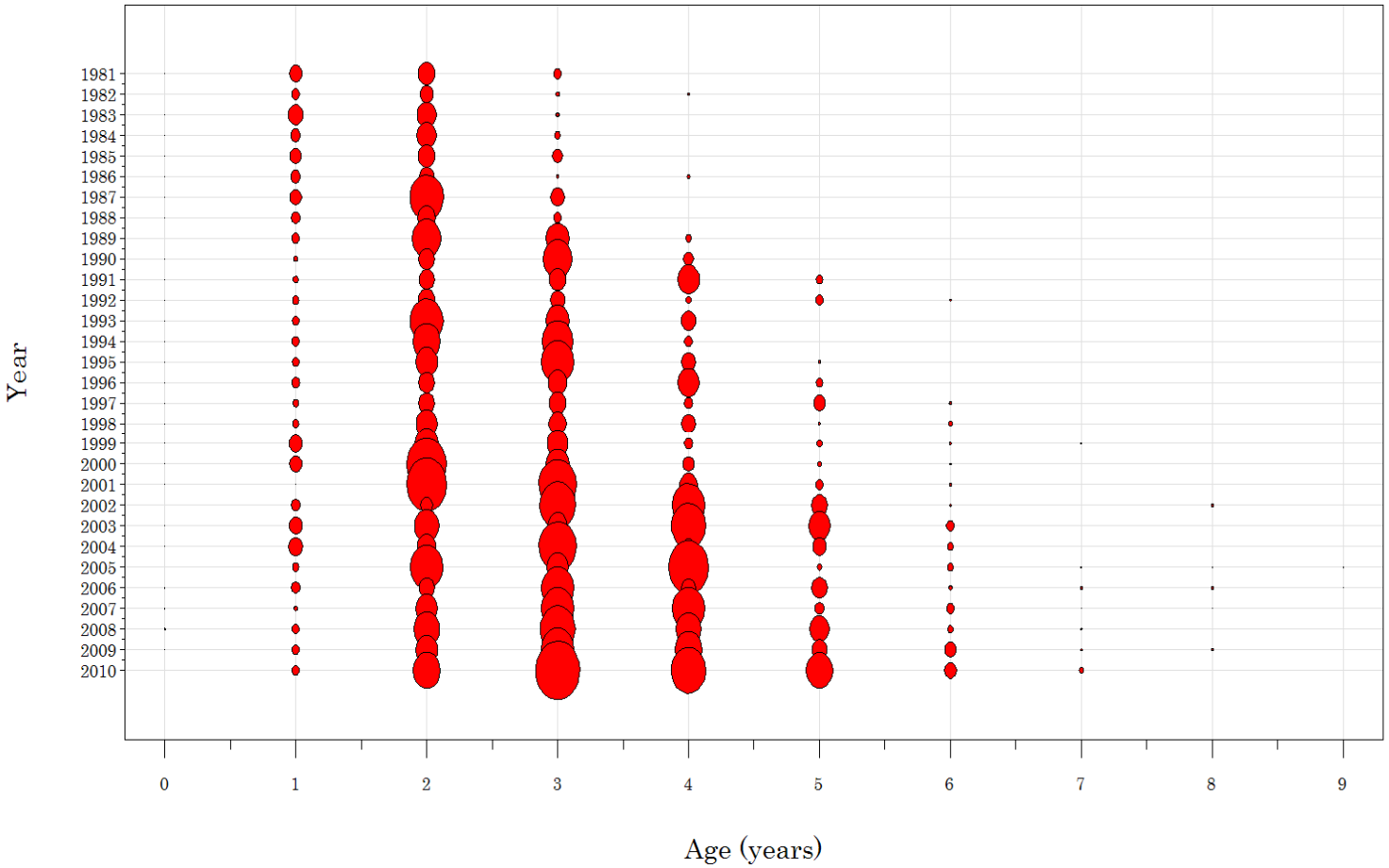


Figure A.62. Recreational discards-at-age of Gulf of Maine Atlantic cod from 1981 to 2010.

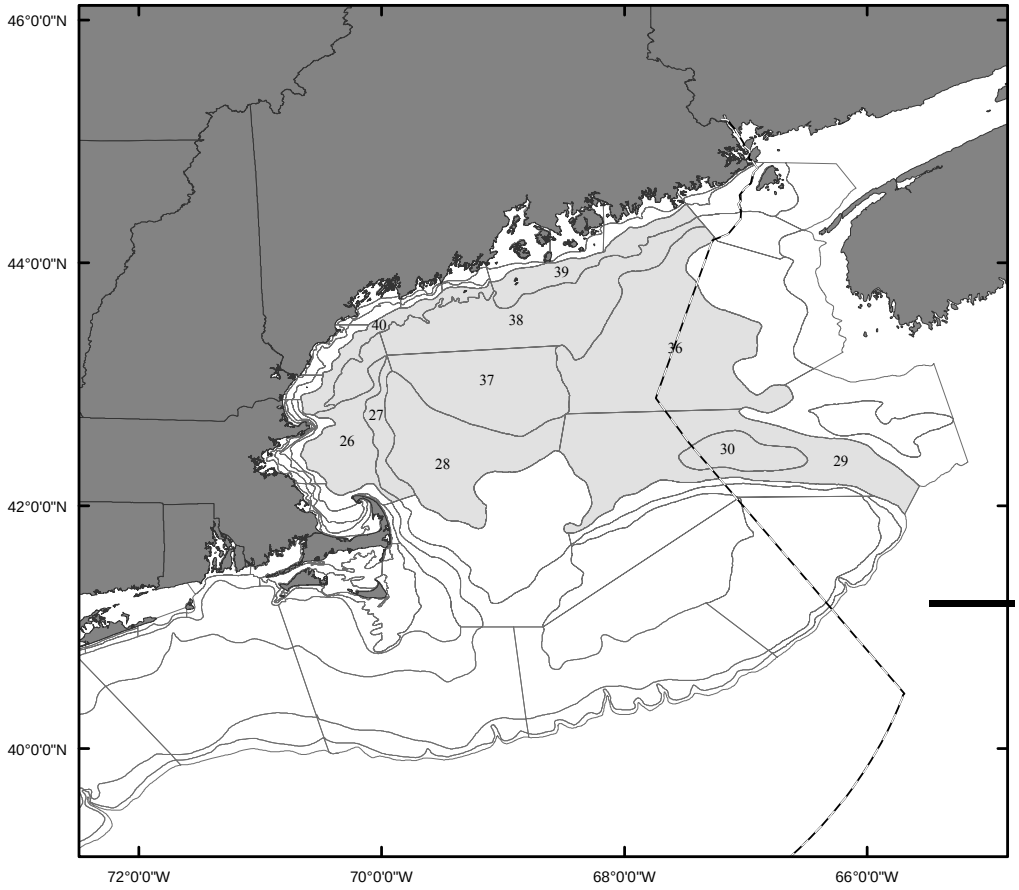


Figure A.63. Map of the Notheast Fisheries Science Center (NEFSC) bottom trawl offshore survey strat includedin the Gulf of Maine Atlantic cod stock assessment (shaded grey).

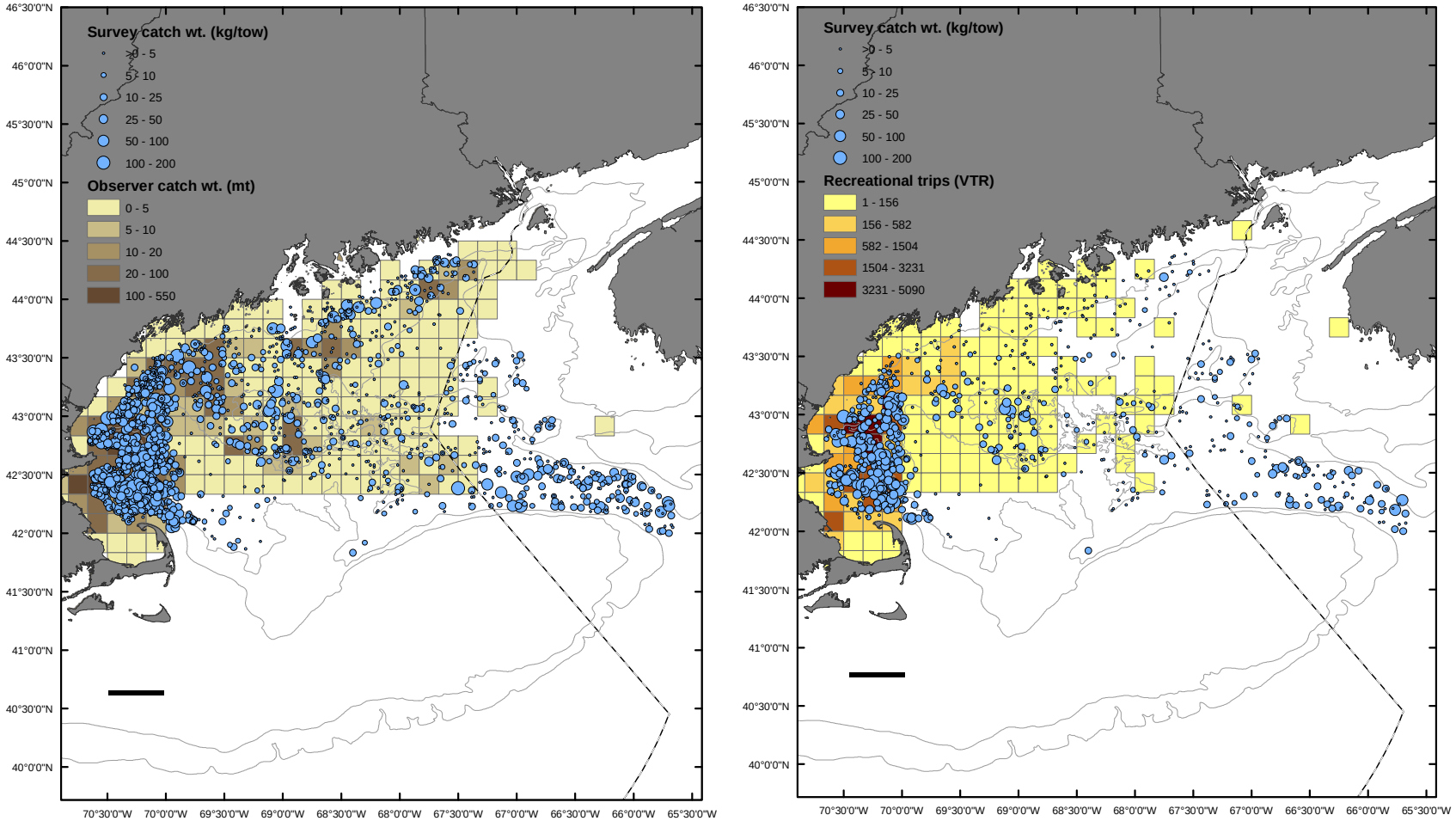


Figure A.64. Spatial overlap of survey catches (kg/tow) of Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey (spring and fall combined) and commercial and recreational fishing effort. On the left, NEFSC survey catches from 1989 – 2010 are overlayed on 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.*

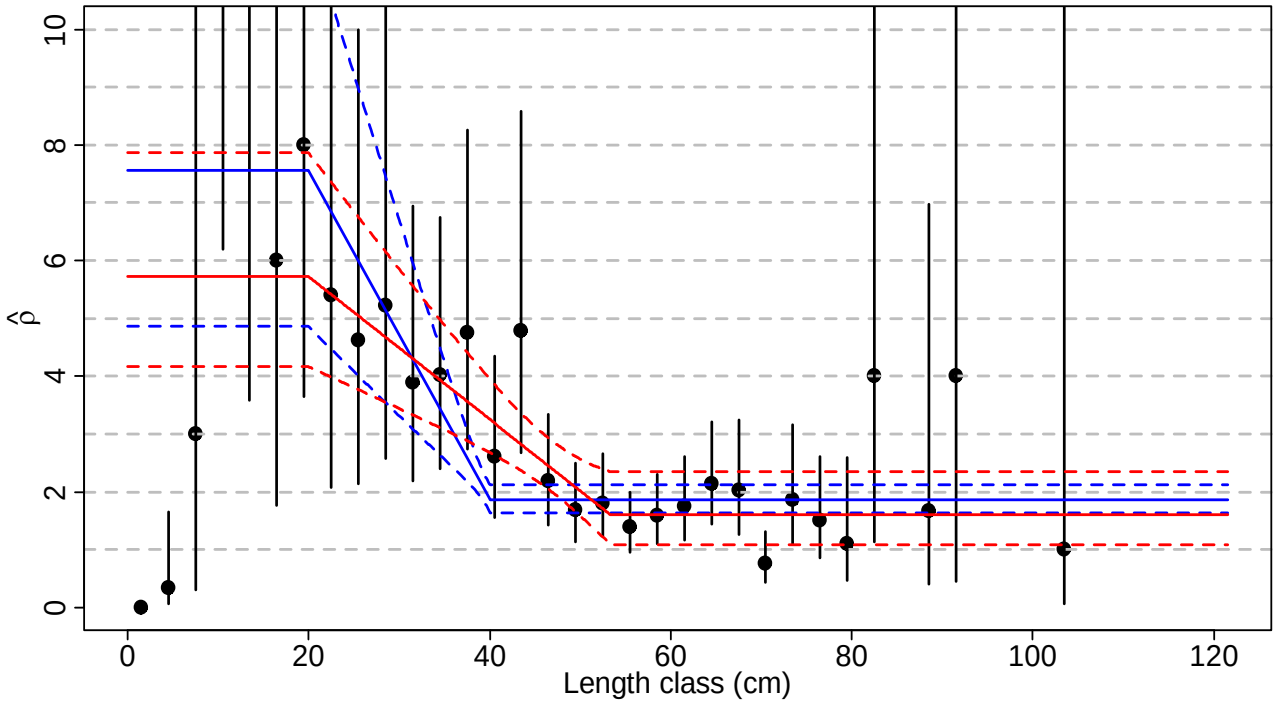


Figure A.65. Beta-binomial-based estimates of calibration factors and corresponding 95% confidence intervals by length class (3 cm bins) for Atlantic cod. The black points and vertical bars represent results where different calibration factors are estimated for each length class. The blue lines represent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

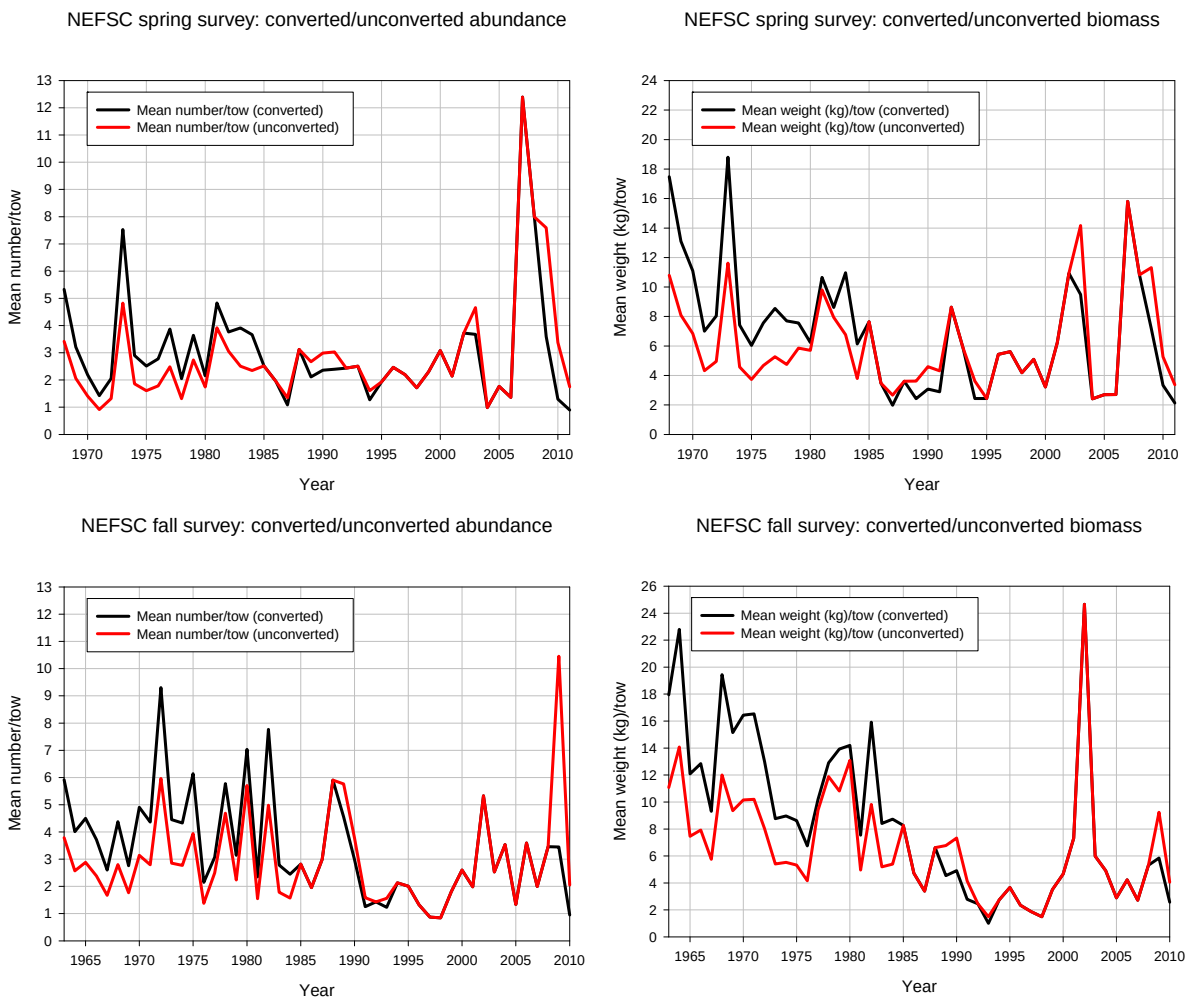


Figure A.66. Northeast Fisheries Science Center spring (top panels) and fall (bottom panels) survey indices of abundance (left panels) and biomass (right panels) showing both raw (unconverted) and vessel, door and survey converted indices over time for Gulf of Maine Atlantic cod.

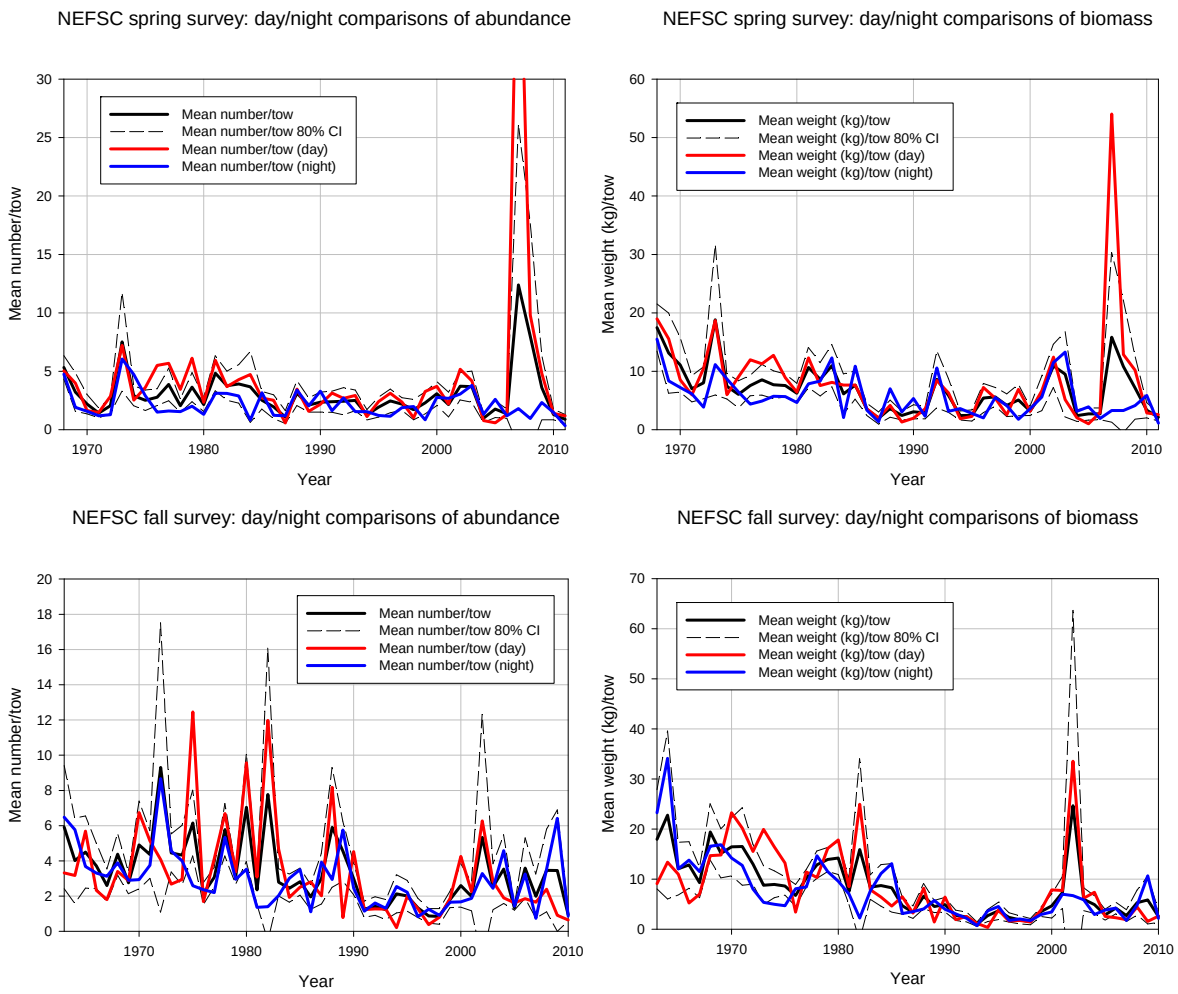
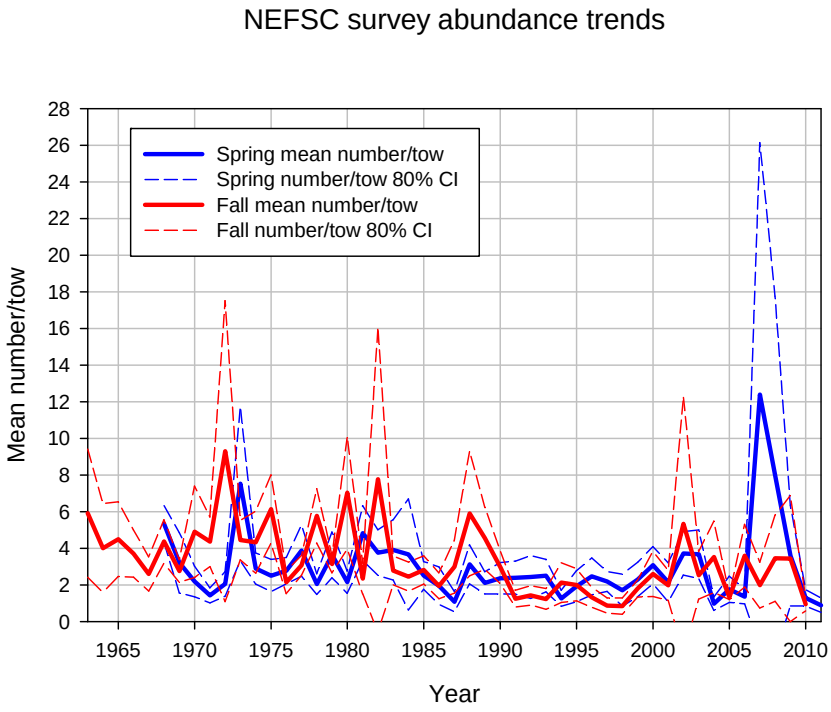


Figure A.67. Northeast Fisheries Science Center spring (top panels) and fall (bottom panels) survey indices of abundance (left panels) and biomass (right panels) broken down by day- and night-only tows compared to the aggregate index (day and night tows combined) and its associated 80% confidence interval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



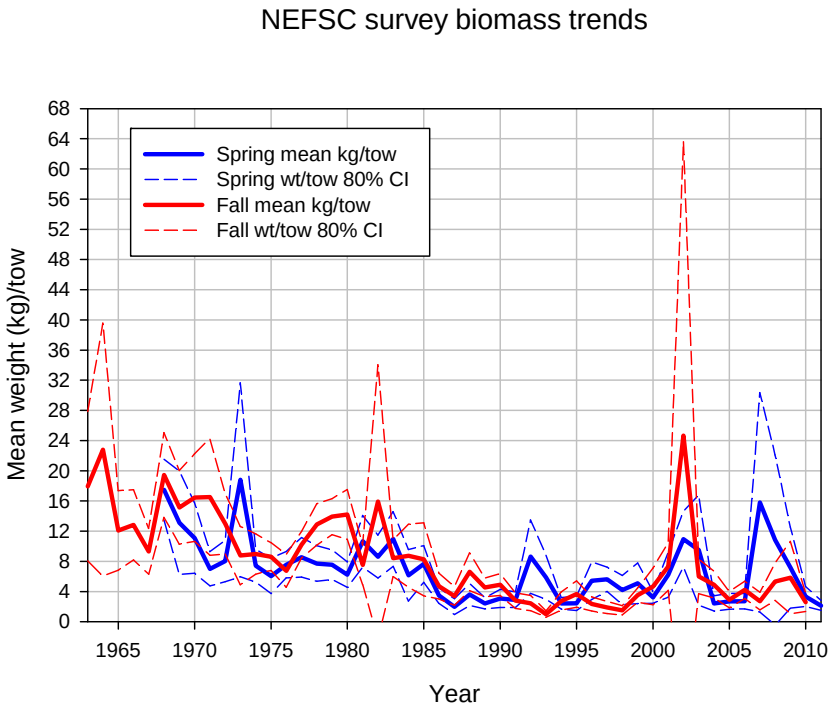


Figure A.68. Northeast Fisheries Science Center spring and fall bottom trawl survey abundance (top) and biomass (bottom) indices from 1963 to 2011 for Gulf of Maine Atlantic cod. **Spring survey did not begin until 1968, 2011 fall survey data not available at time of this report.*

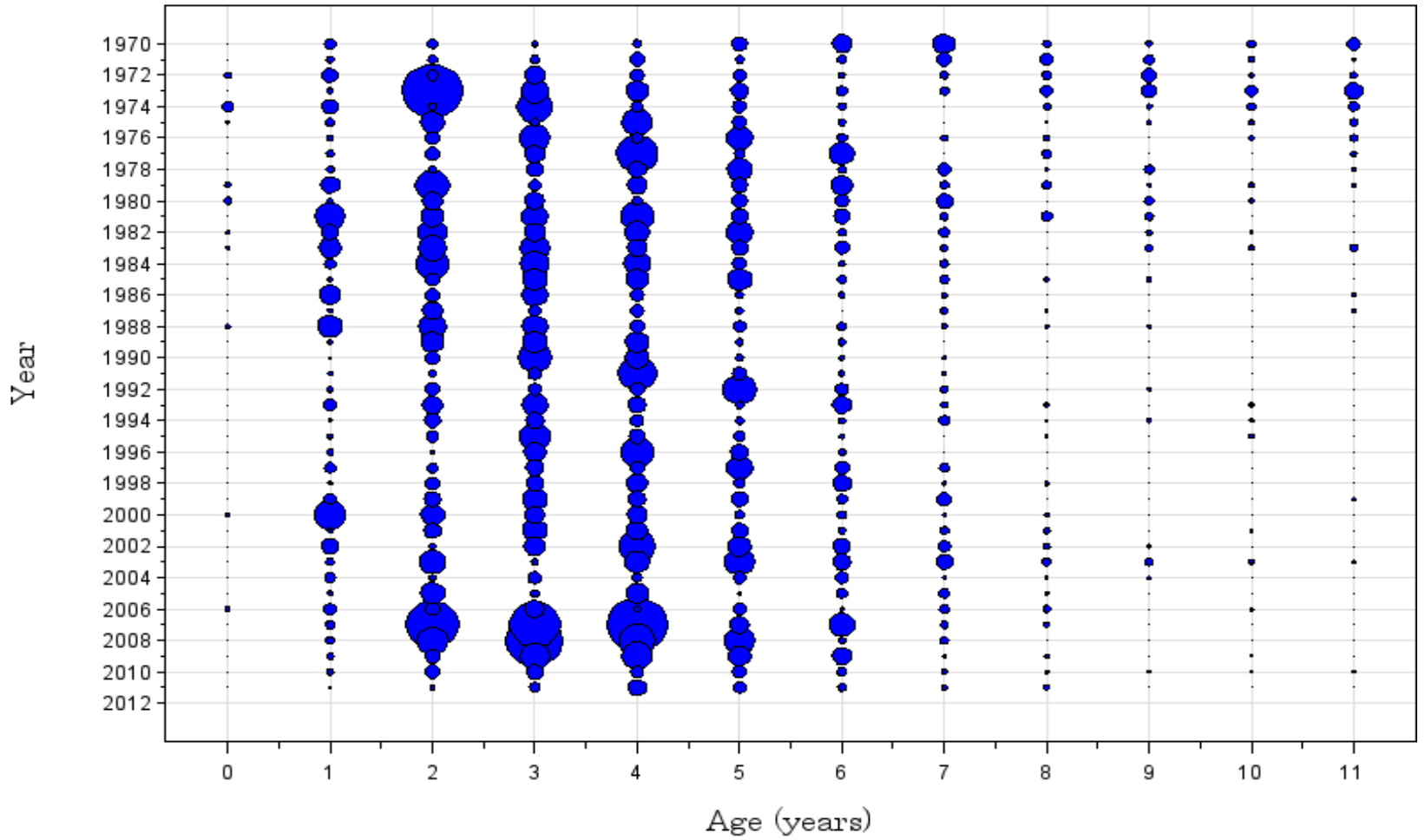


Figure A.69. Numbers-at-age from NEFSC spring bottom trawl survey, 1968 to 2011 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

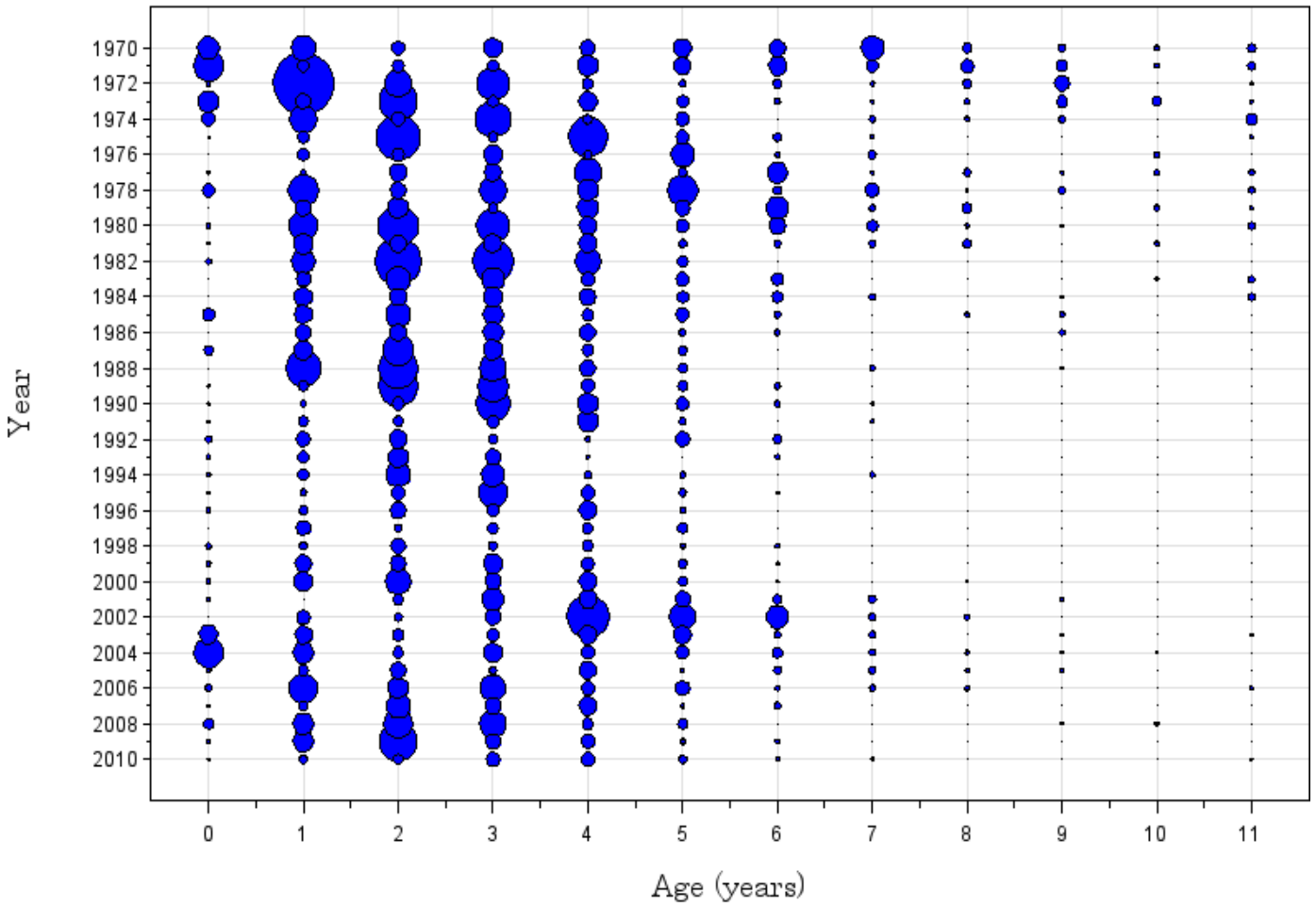


Figure A.70. Numbers-at-age from NEFSC fall bottom trawl survey , 1963 – 2010 for Gulf of Maine Atlantic cod. **Note that age 11 is a plus group.*

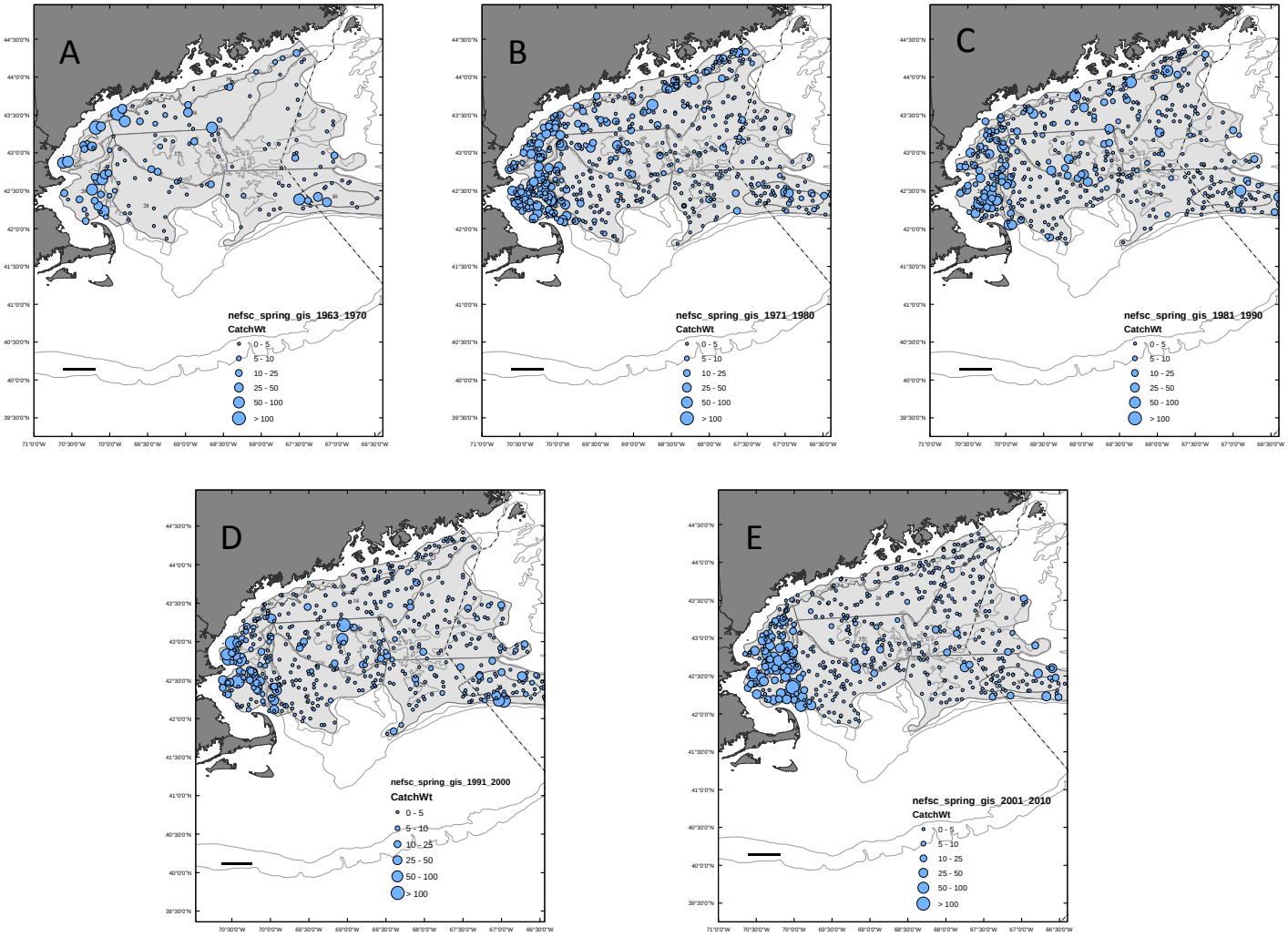


Figure A.71. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the Northeast Fisheries Science Center spring bottom trawl survey from 1968 – 2010. (A) 1963 – 1970 (*Note spring survey started in 1968), (B) 1971 – 1980, (C) 1981 – 1990, (D) 1991 – 2000, (E) 2001 – 2010. Bubble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

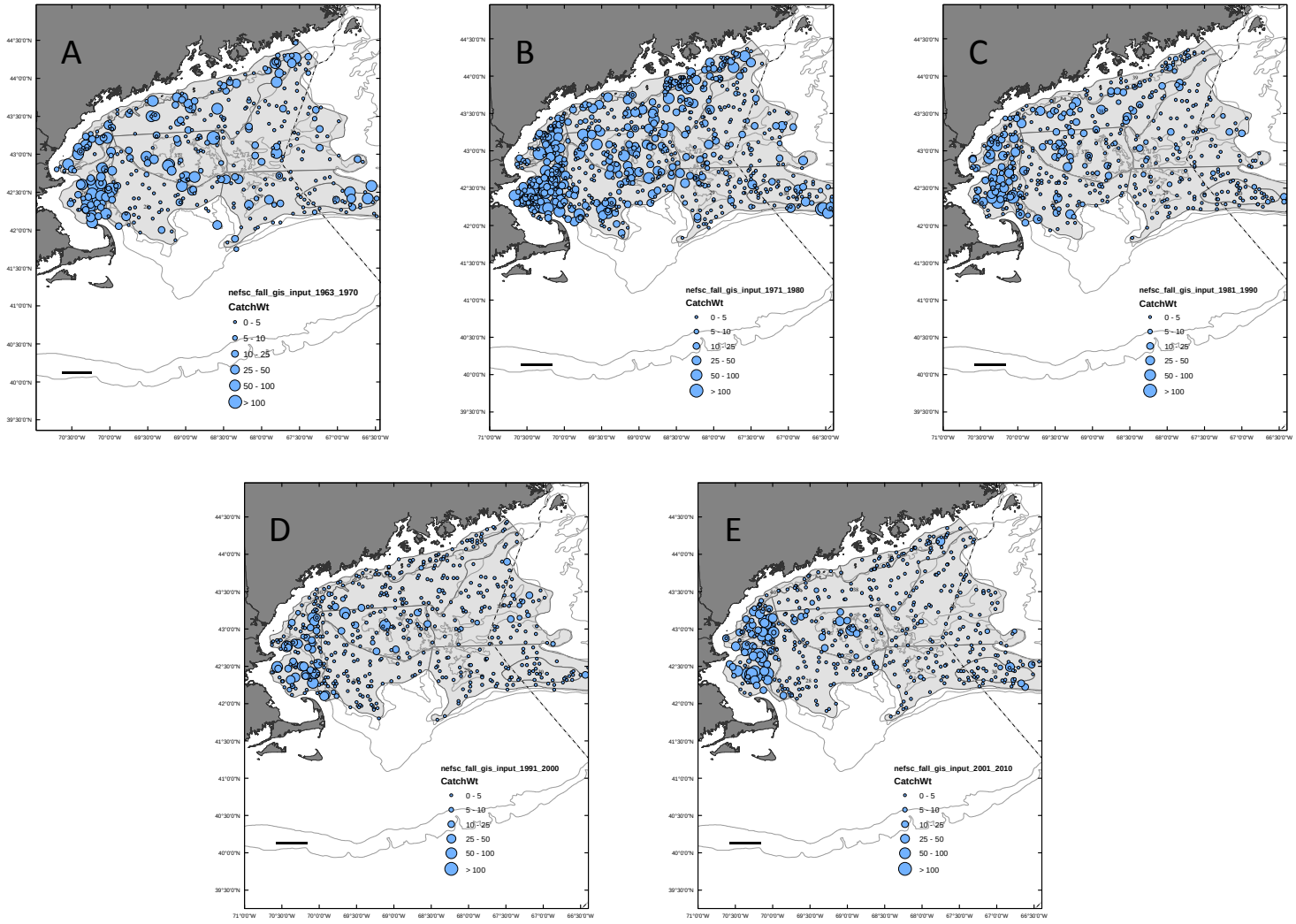


Figure A.72. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the Northeast Fisheries Science Center fall bottom trawl survey from 1963 – 2010. (A) 1963 – 1970, (B) 1971 – 1980, (C) 1981 – 1990, (D) 1991 – 2000, (E) 2001 – 2010. Bubble plot scale is identical in each plot.

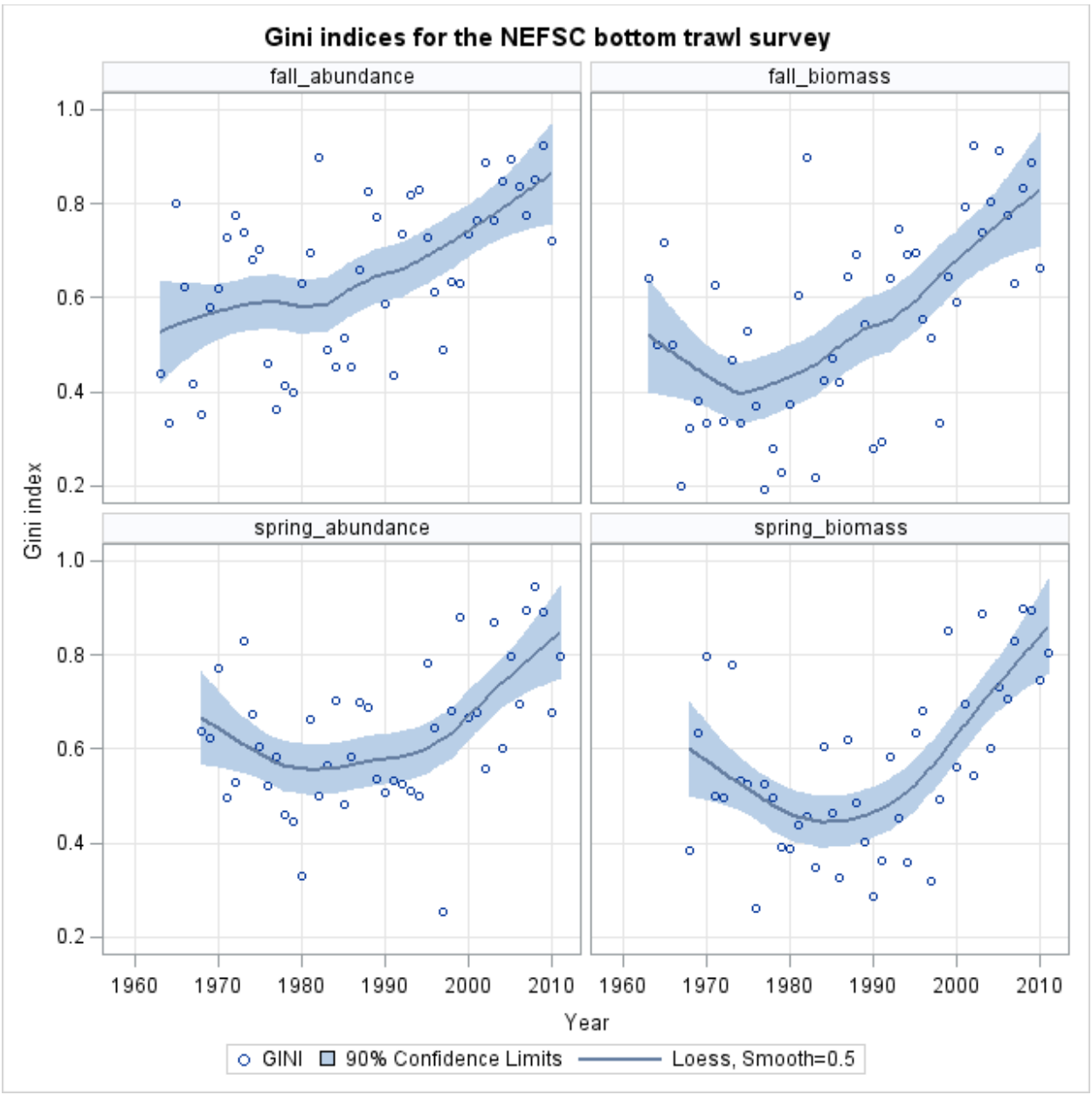


Figure A.73. Gini indices for Gulf of Maine Atlantic cod from the Northeast Fisheries Science Center (NEFSC) fall (top) and spring (bottom) bottom trawl surveys in terms of abundance (numbers/tow, left) and biomass (kg/tow, right). A loess smooth has been fit to the data with smoothing parameter of 0.5.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

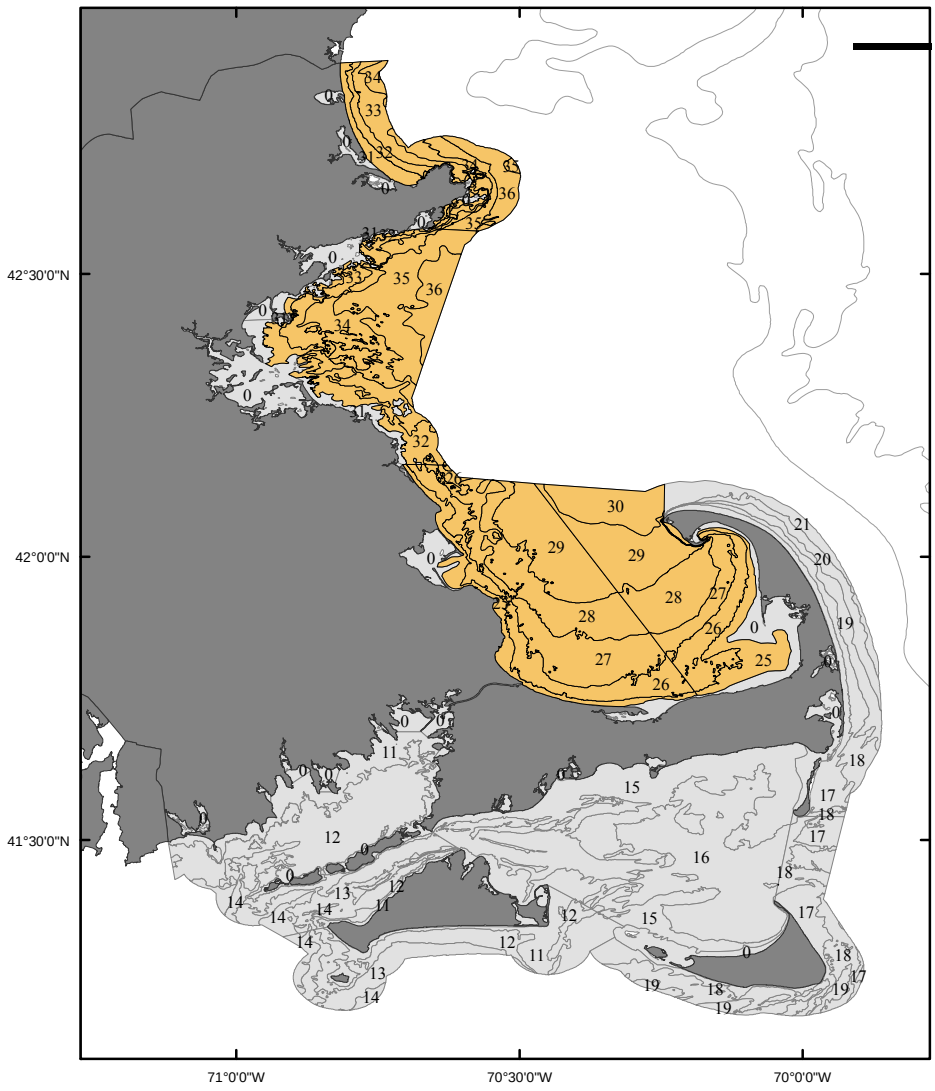


Figure A.74. Map of the Massachusetts Deparment of Marine Fisheries (MADMF) bottom trawl survey strata included in the Gulf of Maine Atlantic cod stock assessment (shaded orange).

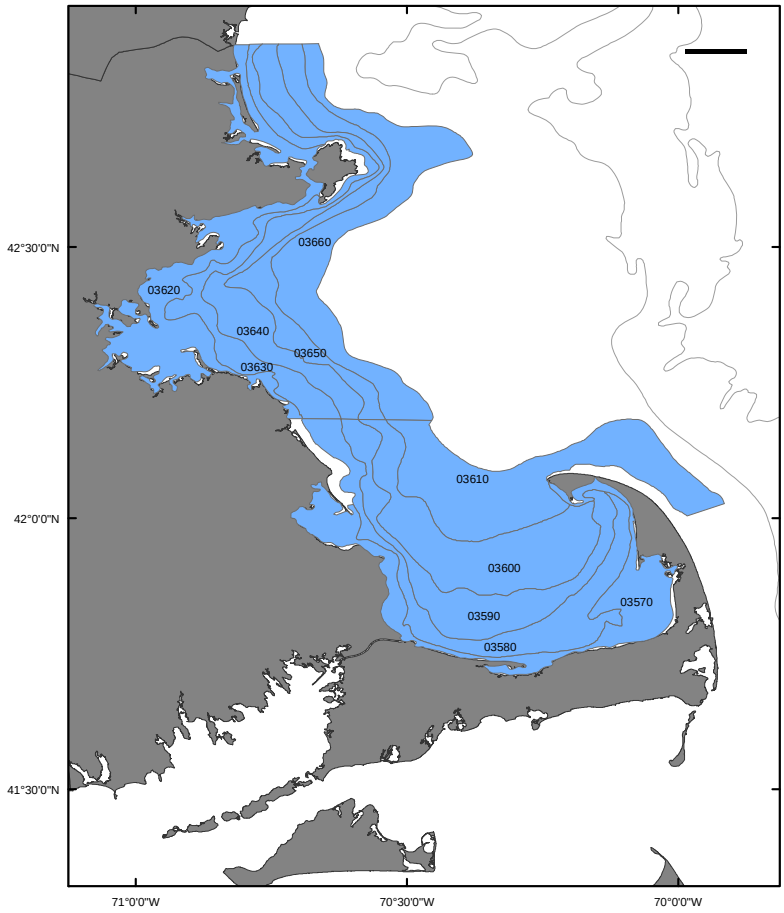


Figure A.75. Map of the NEFSC inshore bottom trawl survey strata. Age length keys applied to MADMF surveys were augmented using age-length information collected from the NEFSC inshore strata when datat were available.

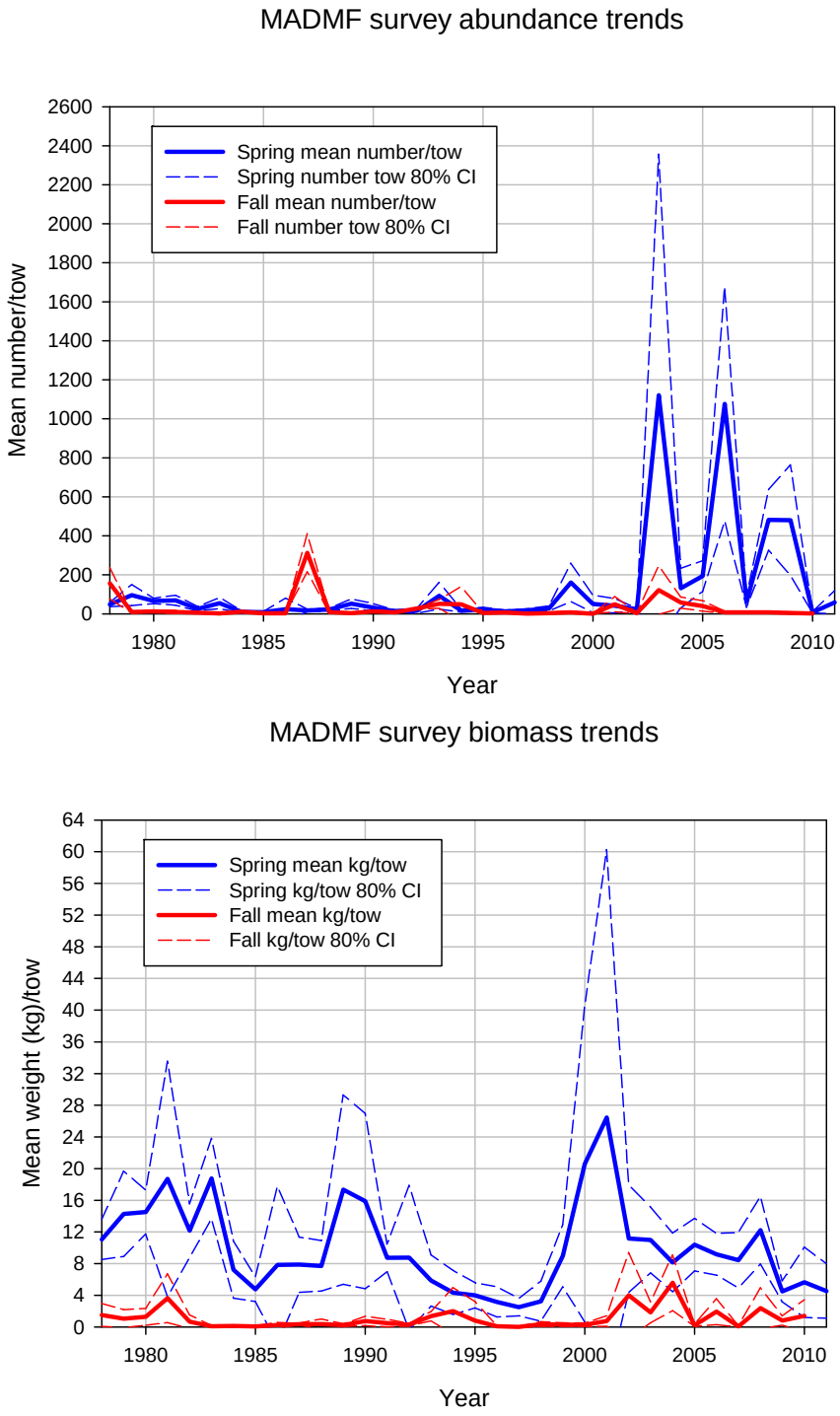


Figure A.76. Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey abundance (top) and biomass (bottom) indices from 1978 to 2011 for Gulf of Maine Atlantic cod. **2011 fall survey data not available at time of this report.*

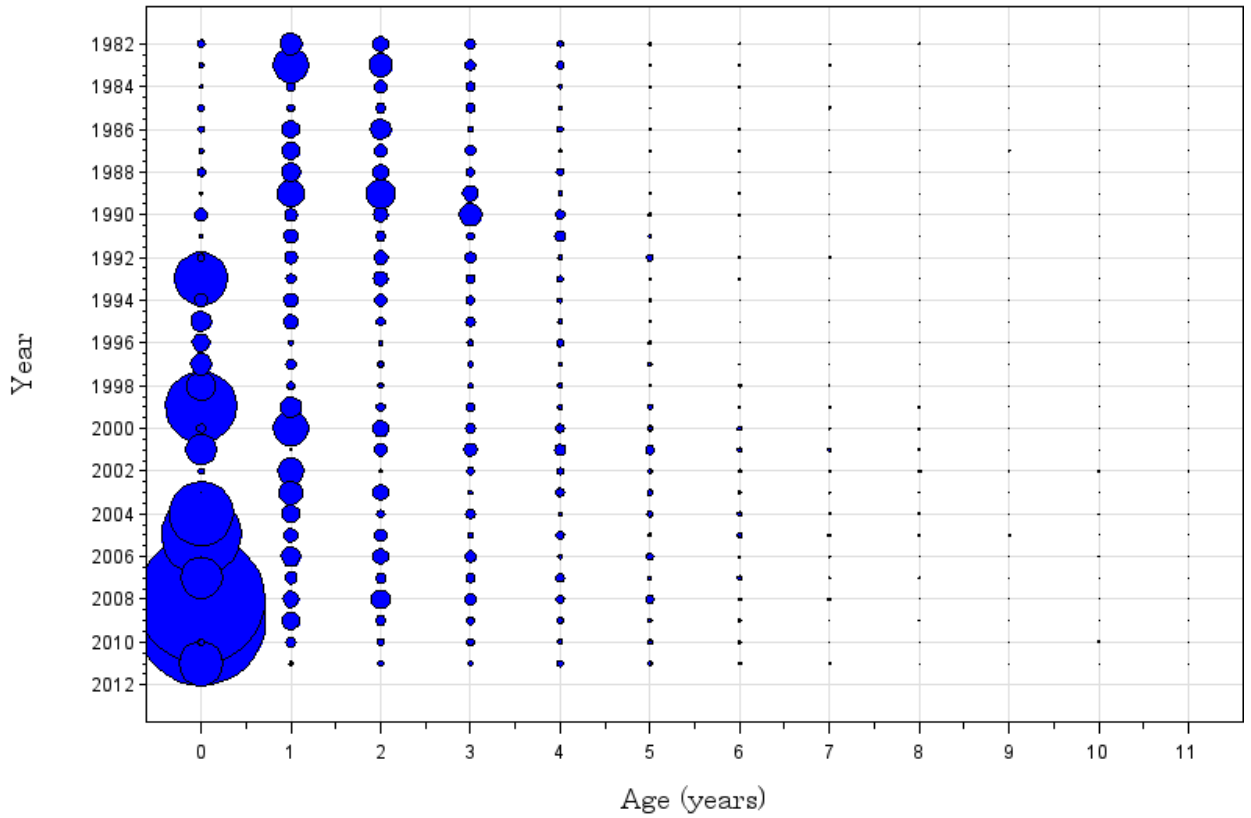


Figure A.77. Gulf of Maine cod numbers-at-age from the Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey, 1982 – 2010. There was insufficient age information available from the MADMF spring survey prior to 1982. **Note that age 11 is a plus group.*

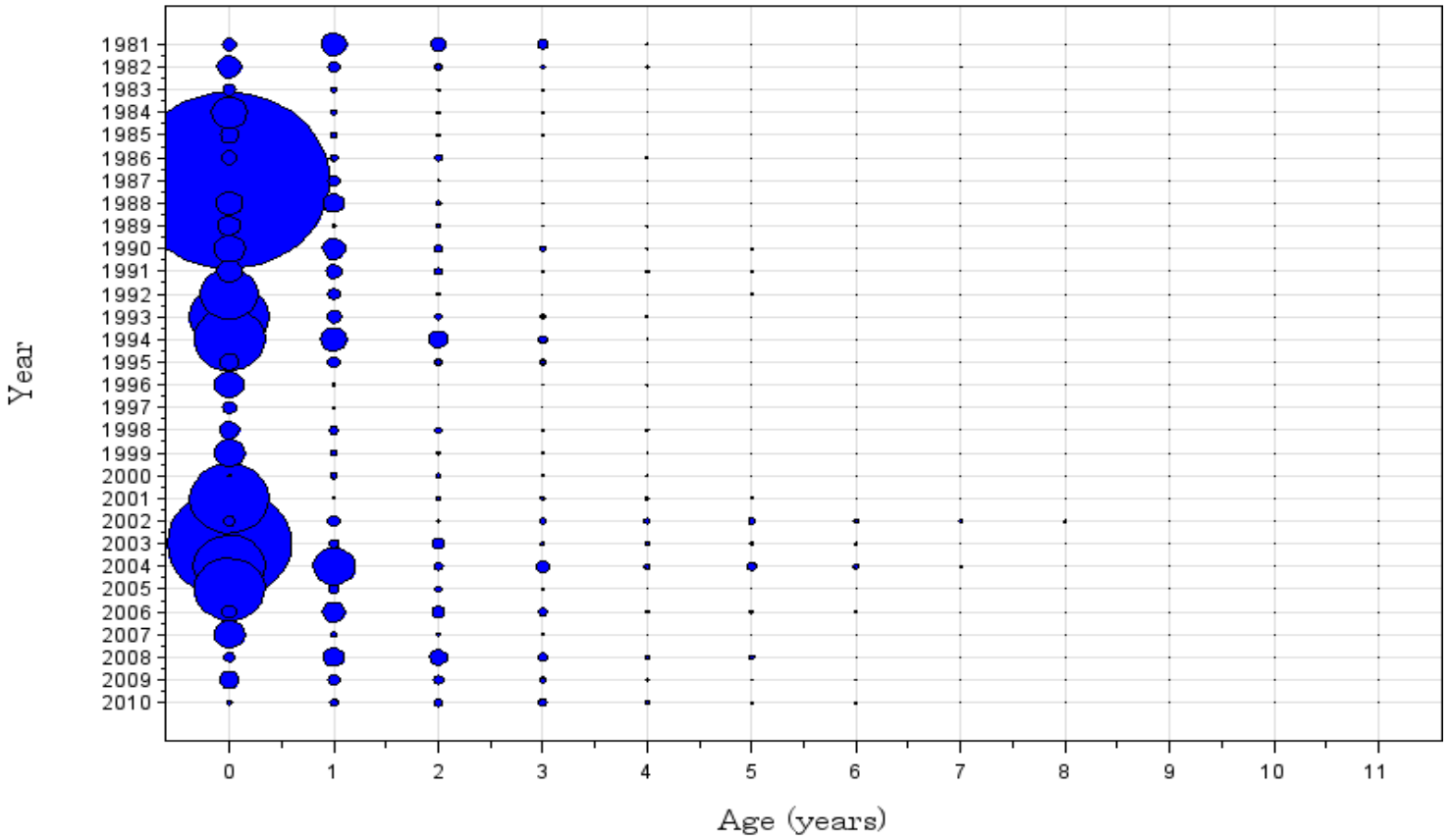


Figure A.78. Gulf of Maine cod numbers-at-age from the Massachusetts Department of Marine Fisheries (MADMF) fall bottom trawl survey, 1981 – 2010. There was insufficient age information available from the MADMF fall survey prior to 1981. **Note that age 11 is a plus group.*

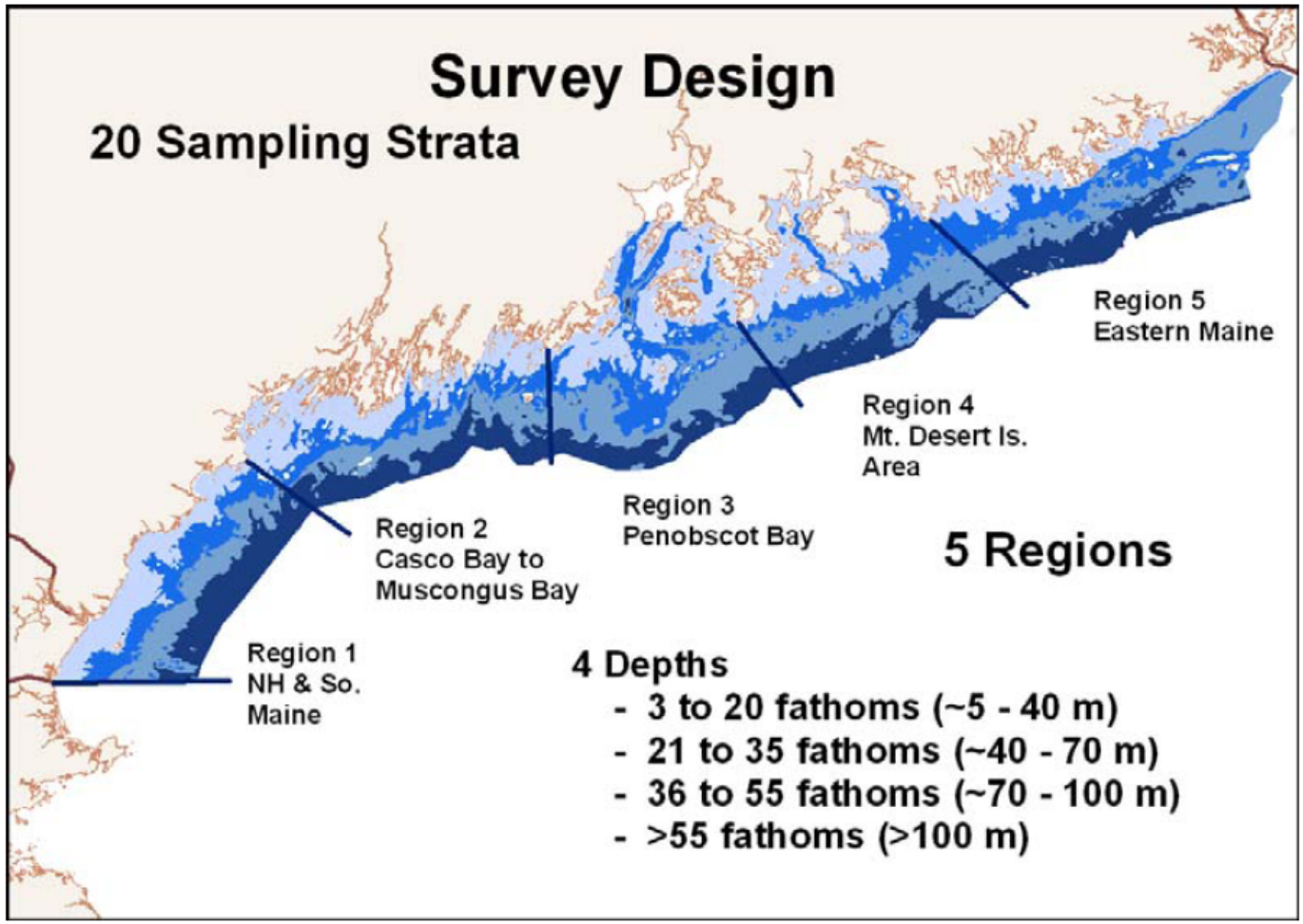


Figure 79. Map of the Maine – New Hamphire inshore groundfish trawl survey strata set (map from Sherman et al. 2005).

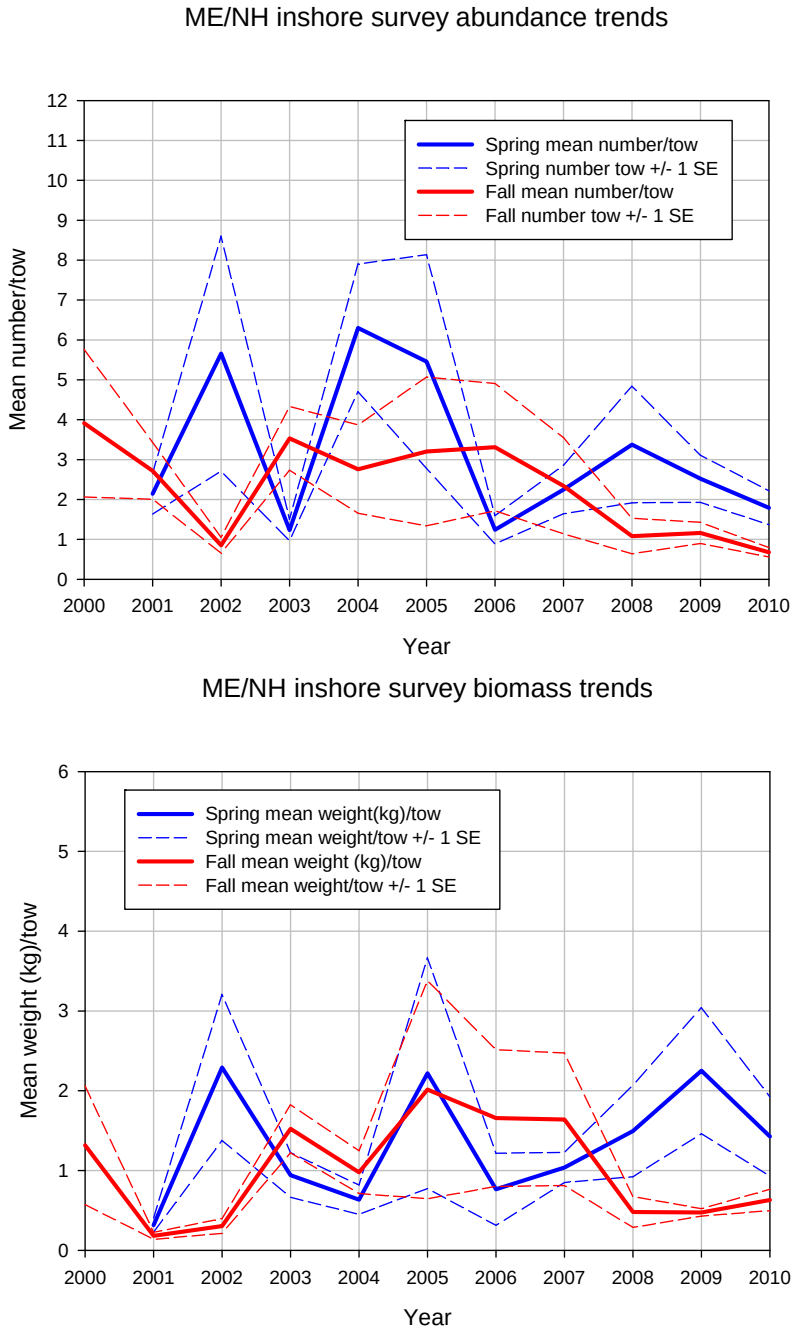


Figure A.80. Maine – New Hamphire inshore groundfish trawl survey spring and fall survey abundance (top) and biomass (bottom) indices from 1978 to 2011 for Gulf of Maine Atlantic cod. Dased lines indicate ± 1 standard error (SE). Data provided by S. Sherman (pers. comm.).

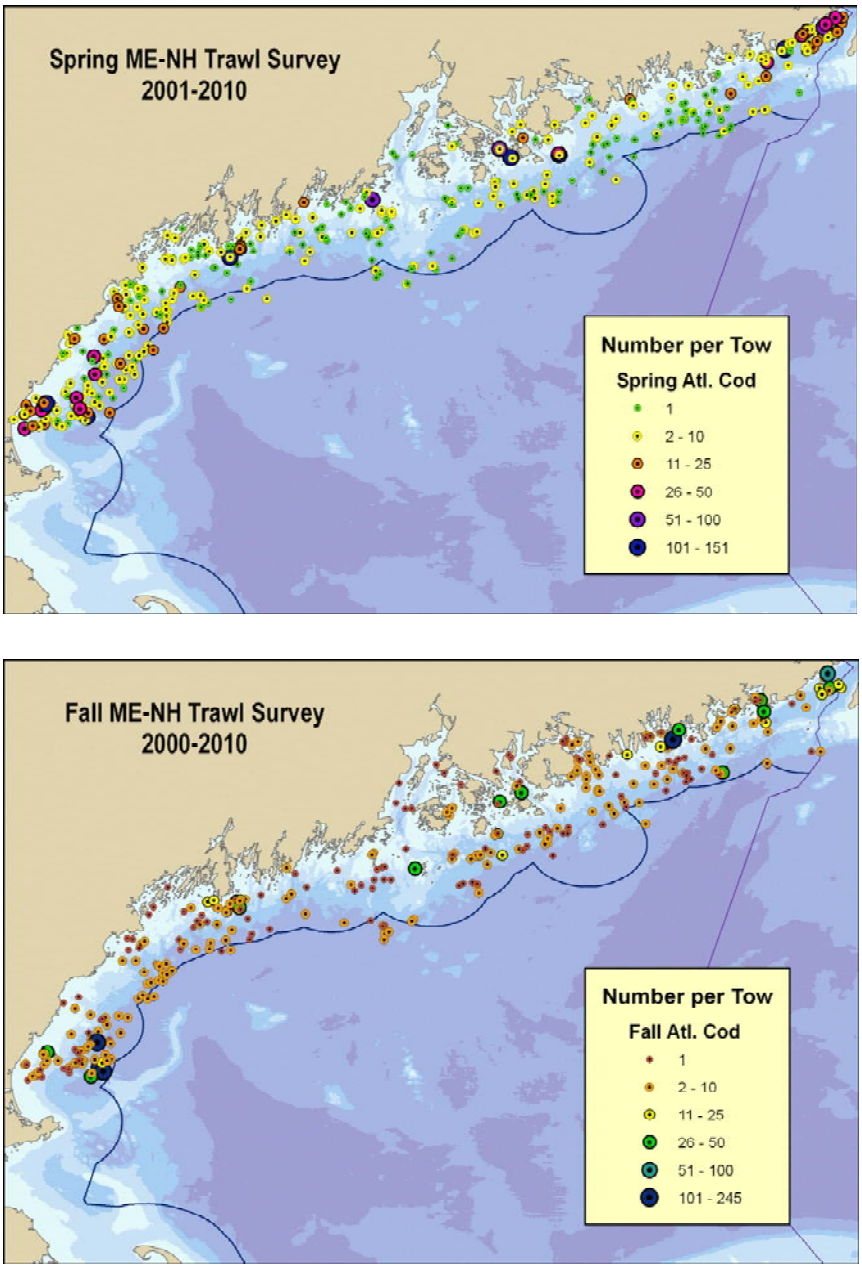


Figure A.81. Spatial distribution of Gulf of Maine Atlantic cod catches (numbers/tow) from the spring (top) and fall (bottom) Maine – New Hamphire inshore groundfish trawl survey between 2001 and 2010. Map provided by S. Sherman (pers. comm.).

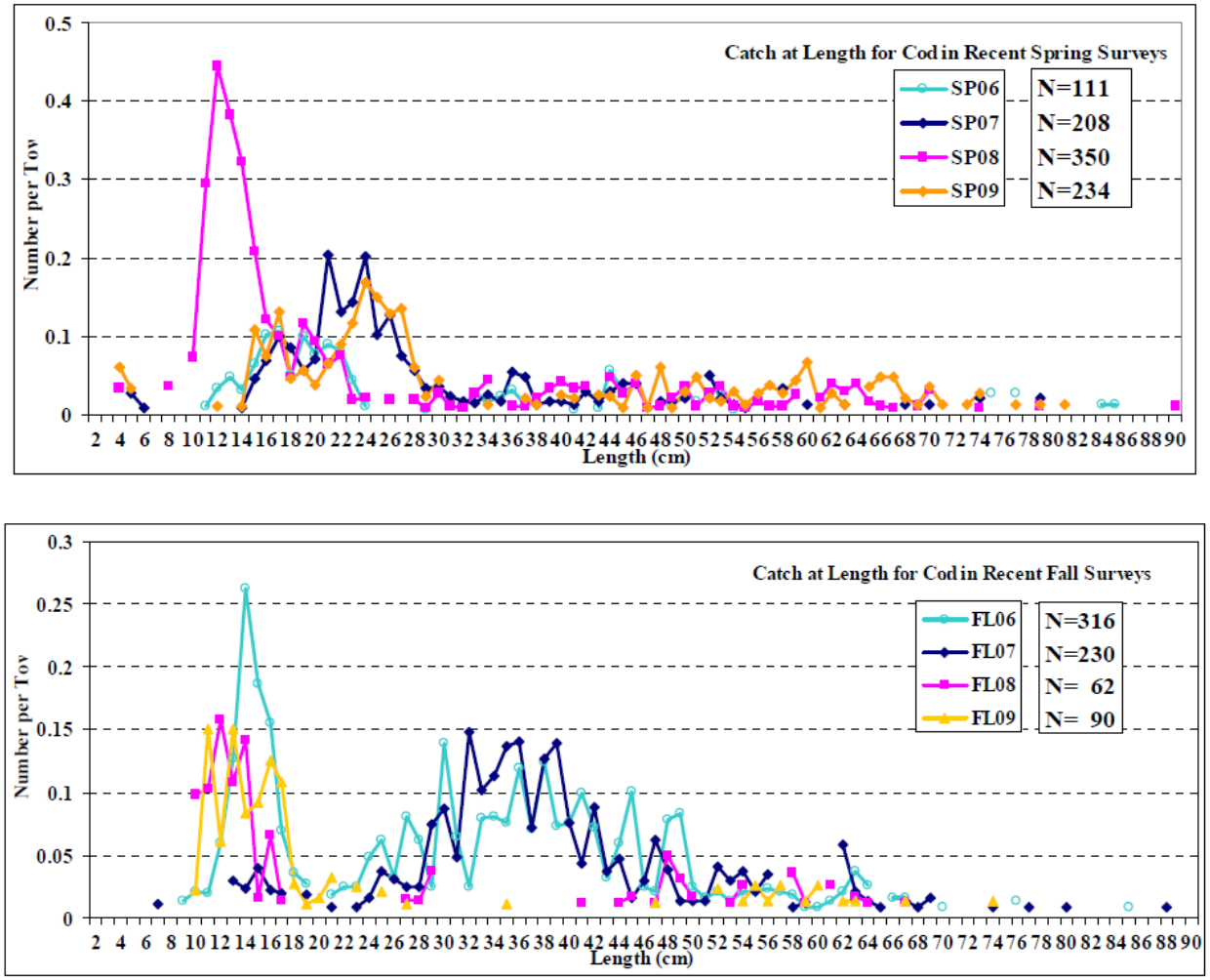


Figure A.82. Length distributions of Gulf of Maine Atlantic cod sampled in the Maine – New Hampshire inshore groundfish trawl spring (top) and fall (bottom) surveys from 2006 to 2009.

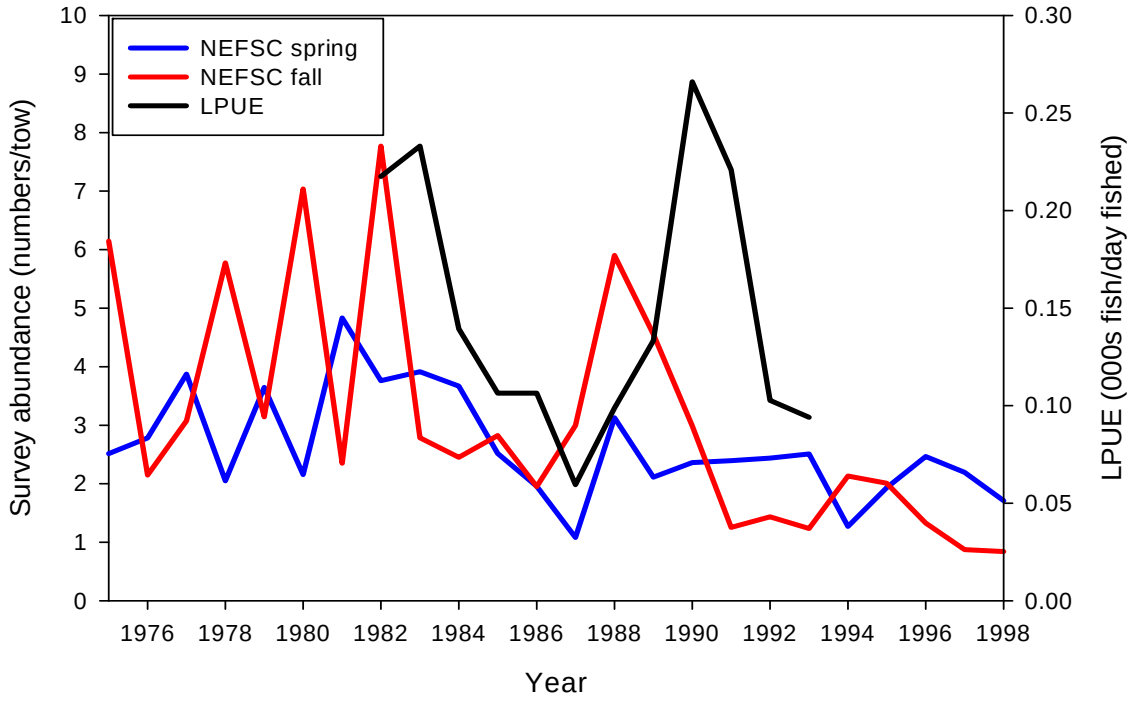


Figure A.83. Comparison of the Gulf of Maine Atlantic cod commercial landings per unit effort (LPUE) tuning index to the spring and fall Northeast Fisheries Science Center (NEFSC) bottom trawl survey abundance index.

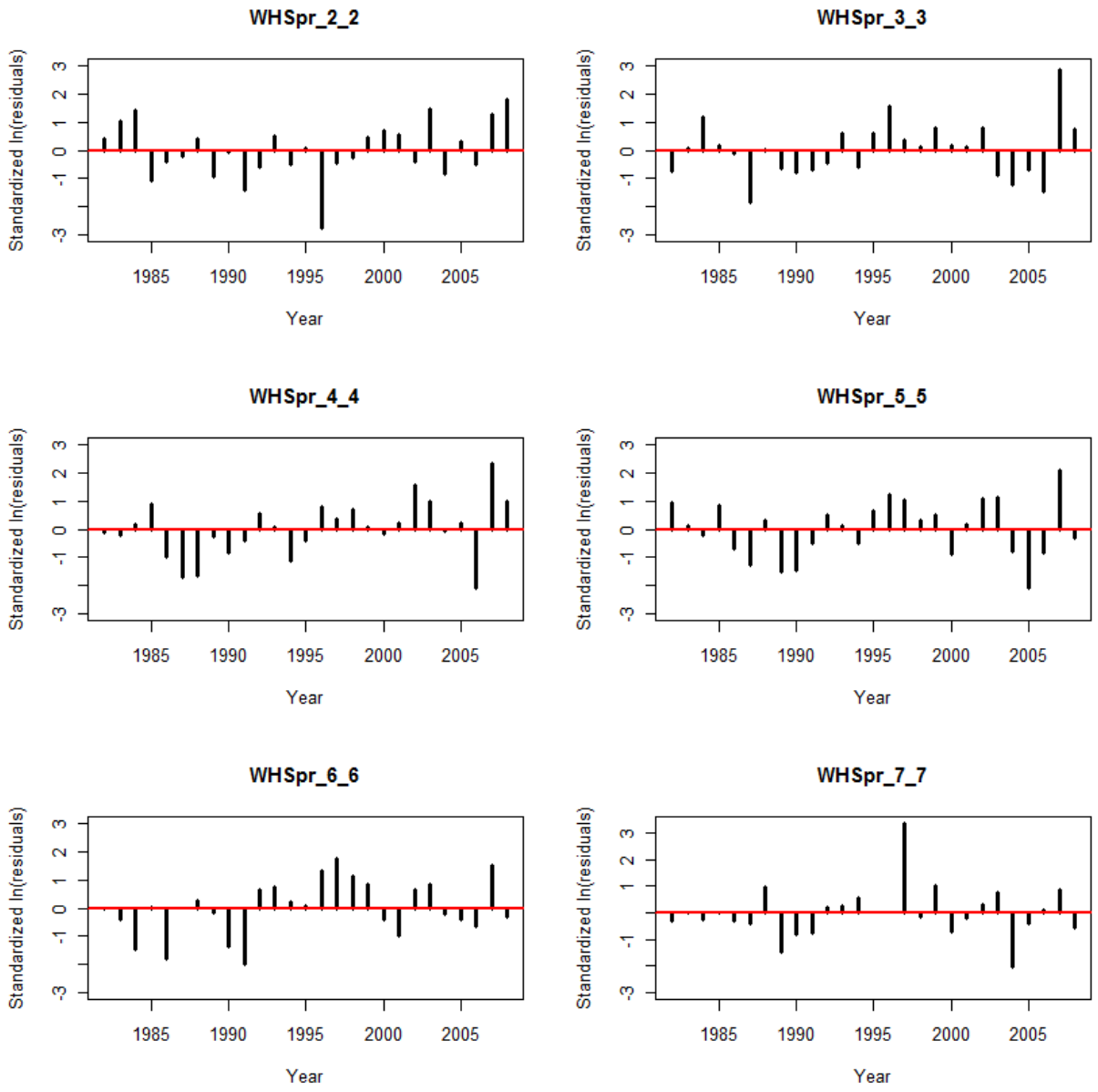


Figure A.84.a. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center spring Gulf of Maine Atlantic cod survey ages 2 (WHSpr_2_2) through 7 (WHSpr_7_7). **Note: fall surveys have been lagged forward a year and an age.*

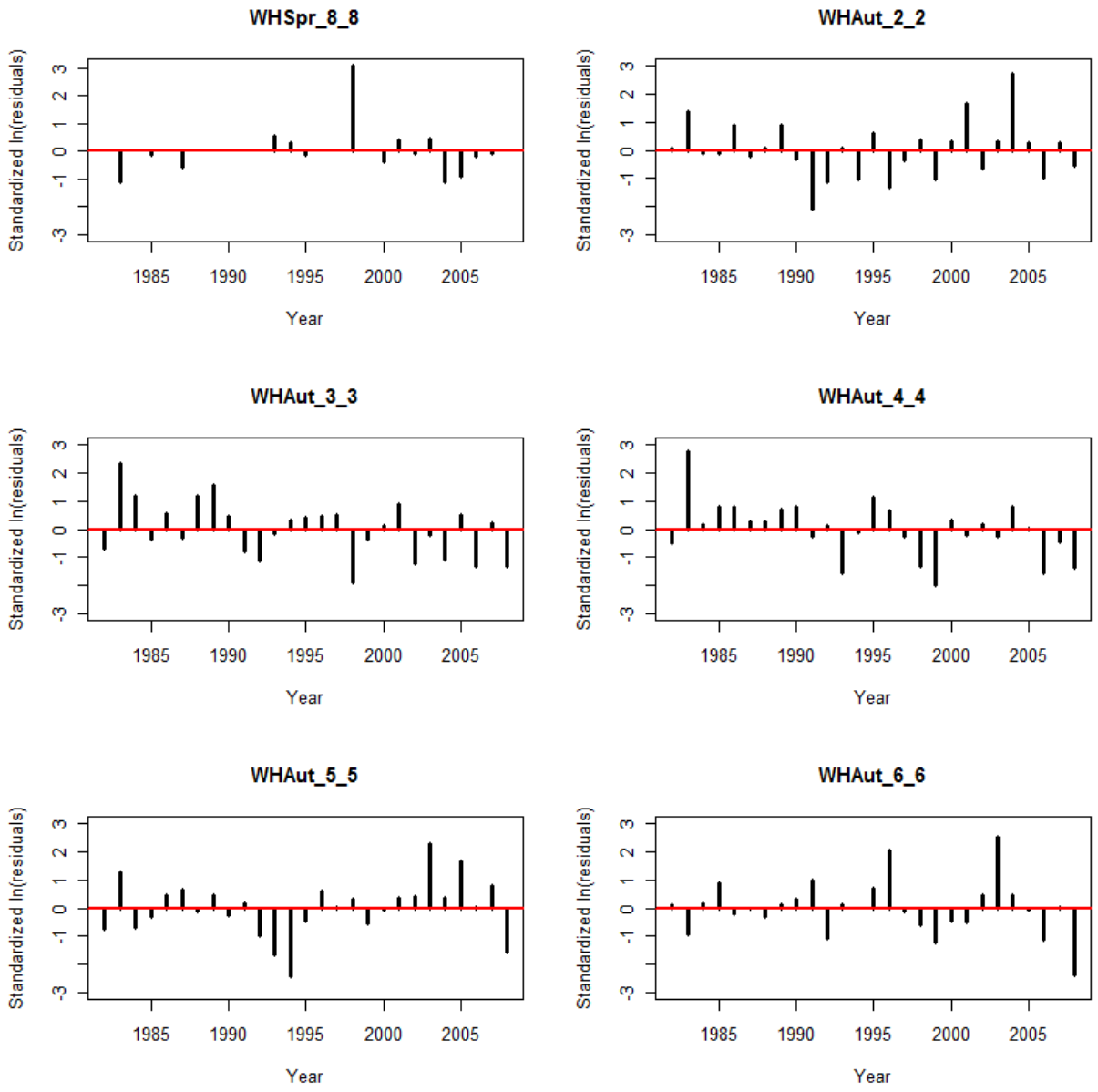


Figure A.84.b. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center spring Gulf of Maine Atlantic cod survey age 8 (WHSpr_8_8) and fall survey ages 1 (WHAut_1_1) through 5 (WHAut_6_6). **Note: fall surveys have been lagged forward a year and an age.*

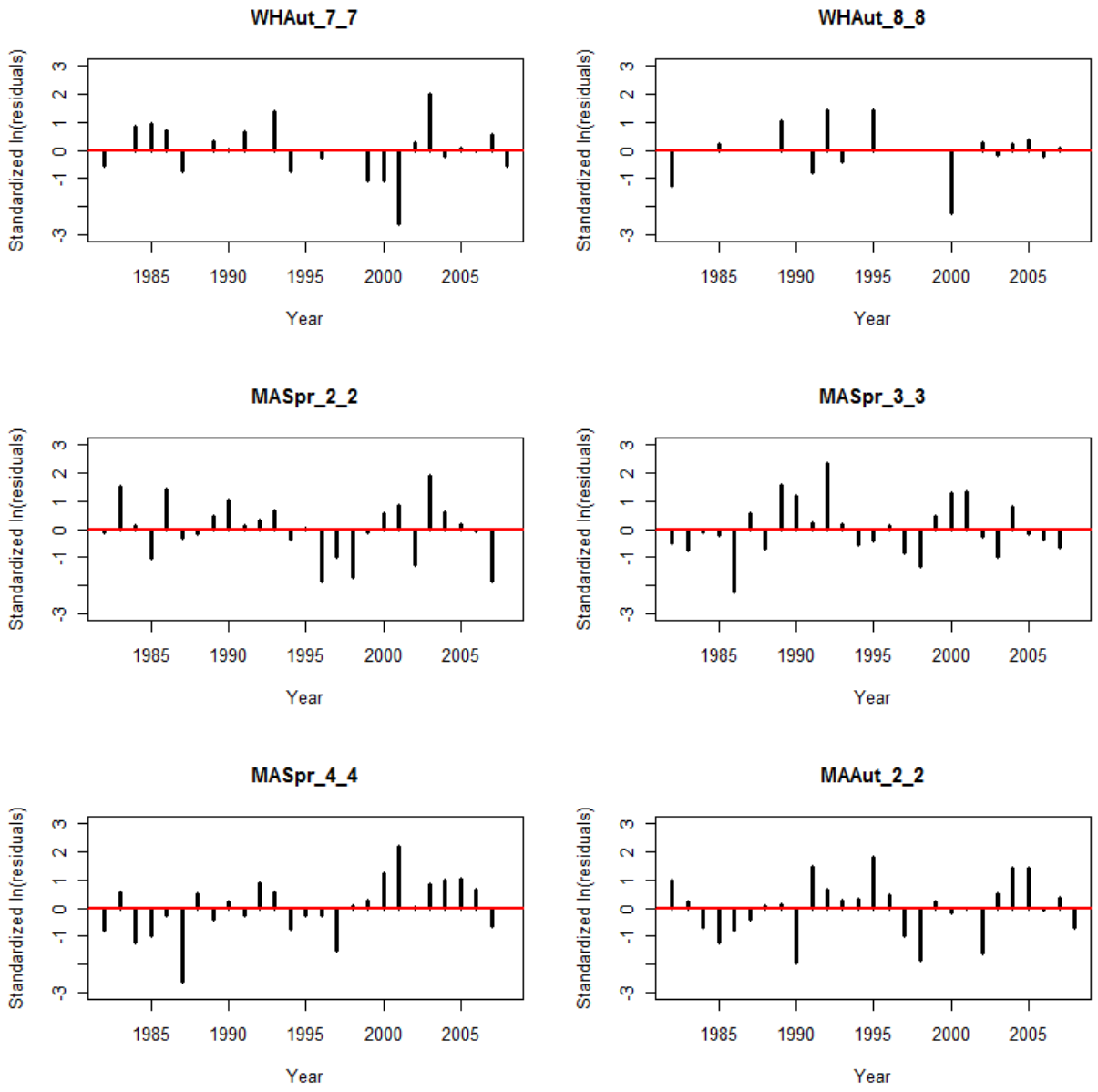


Figure A.84.c. ADAPT-VPA Model 2b residuals to the survey fits of the Northeast Fisheries Science Center fall Gulf of Maine Atlantic cod survey ages 6 (WHAut_7_7) through 7 (WHAut_8_8), Massachusetts Department of Marine Fisheries spring survey ages 2 (MASpr_2_2) through 4 (MASpr_4_4) and fall survey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

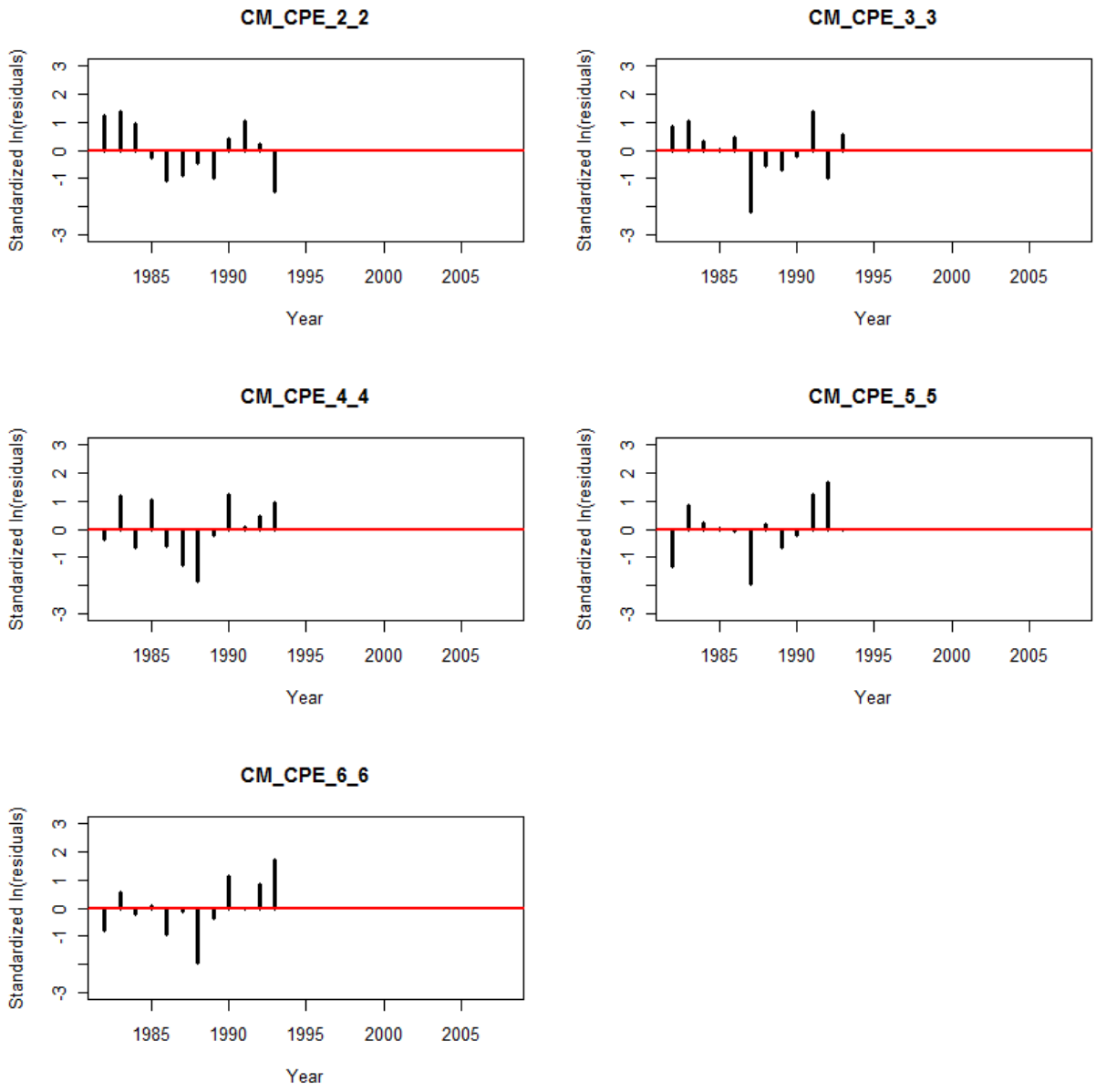


Figure A.84.d. ADAPT-VPA Model 2b residuals to the survey fits of the Gulf of Maine Atlantic cod commercial landings per unit effort tuning indices ages 2 (CM_CPE_2_2) through 6 (CM_CPE_6_6).

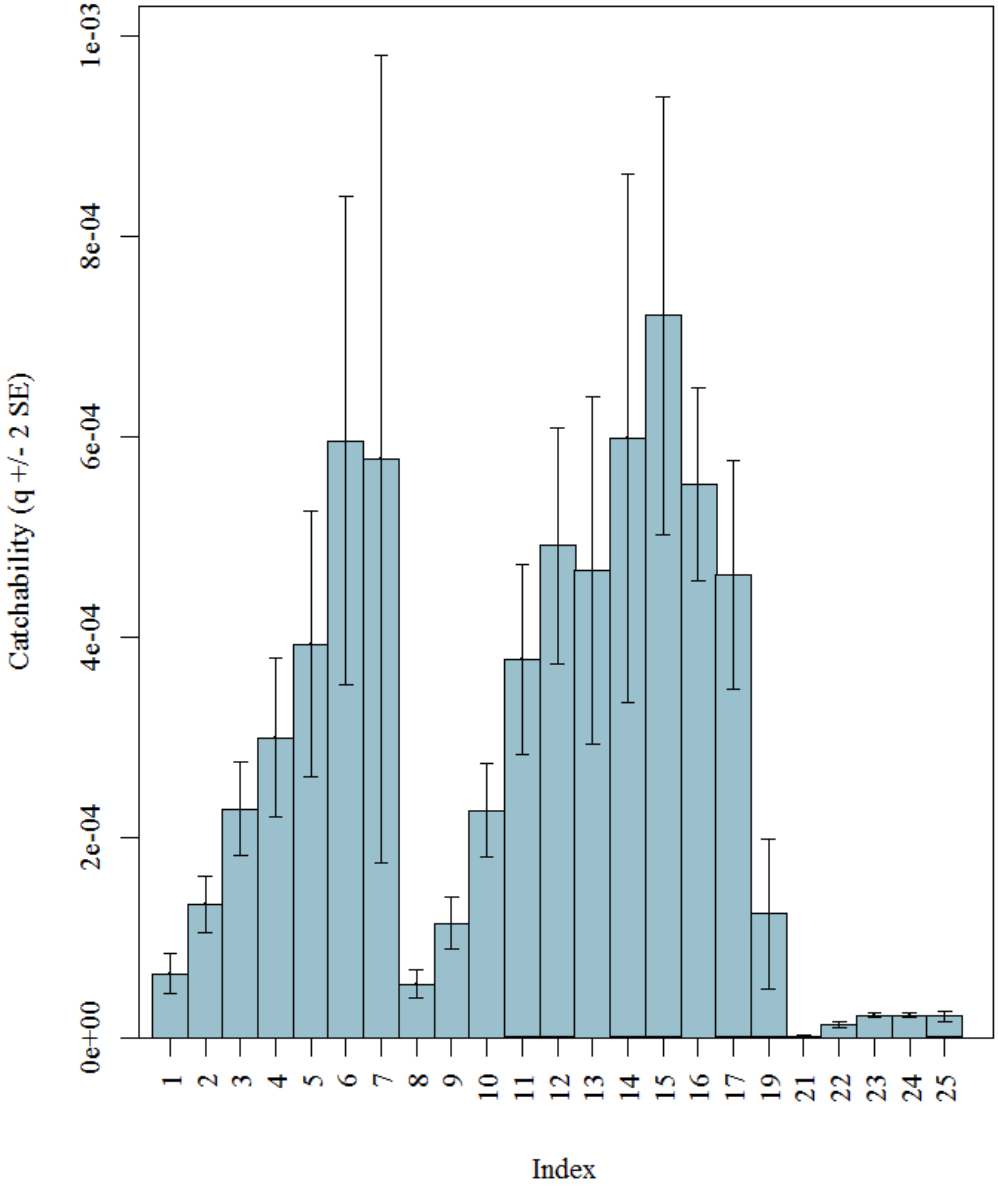


Figure A.85. ADAPT-VPA Model 2b patterns in survey catchability (q). Indices 1-7=NEFSC spring (ages 2-8), indices 8-14=NEFSC fall (ages 1-7), indices 15-17=MADMF spring (ages 2-4), index 19=MADMF fall (age 1), indices 21-25=commercial LPUE (ages 2-6).

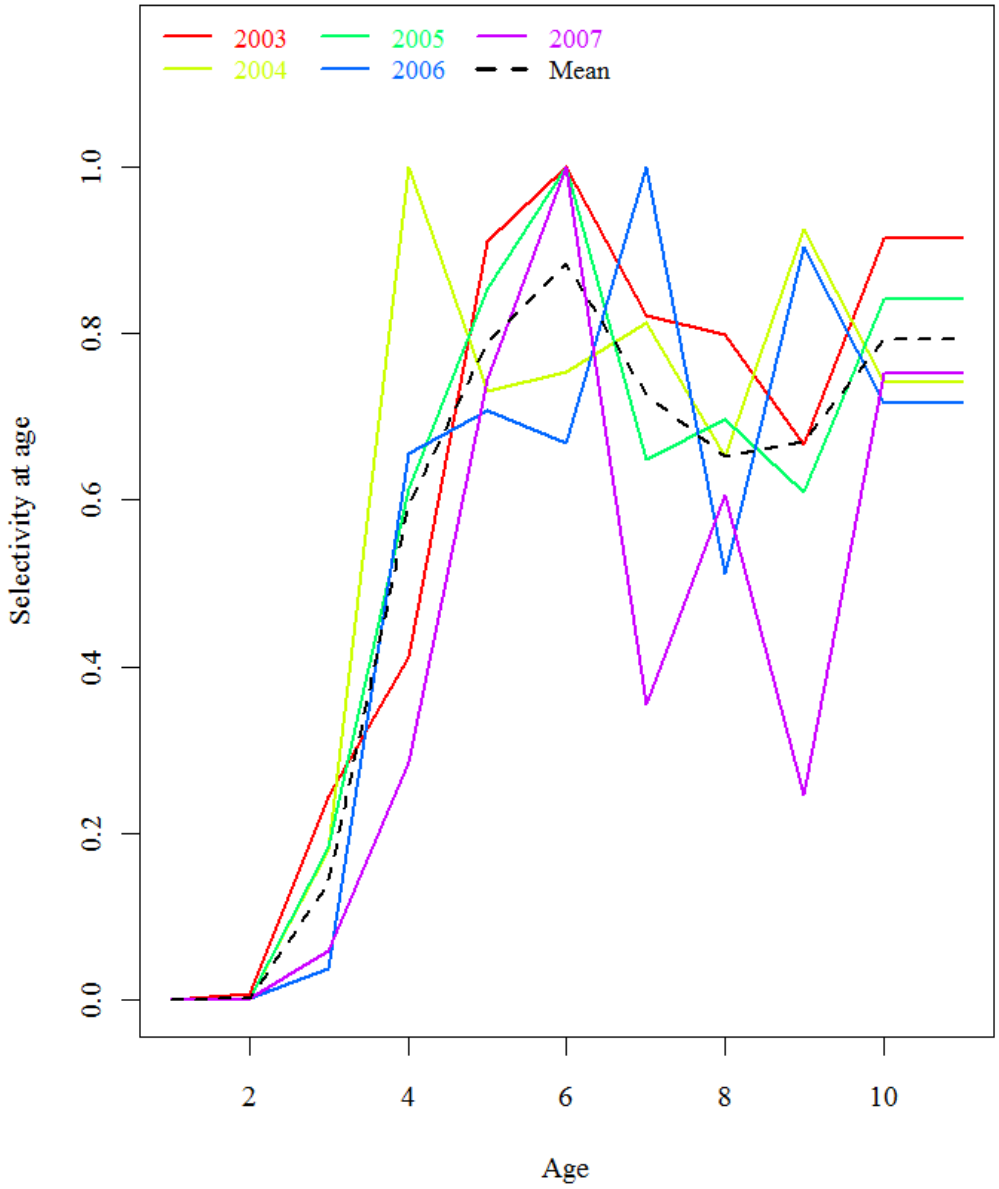


Figure A.86. ADAPT-VPA Model 2b catch selectivity patterns for Gulf of Maine Atlantic cod over the last five years of the model, 2003 through 2007.

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.

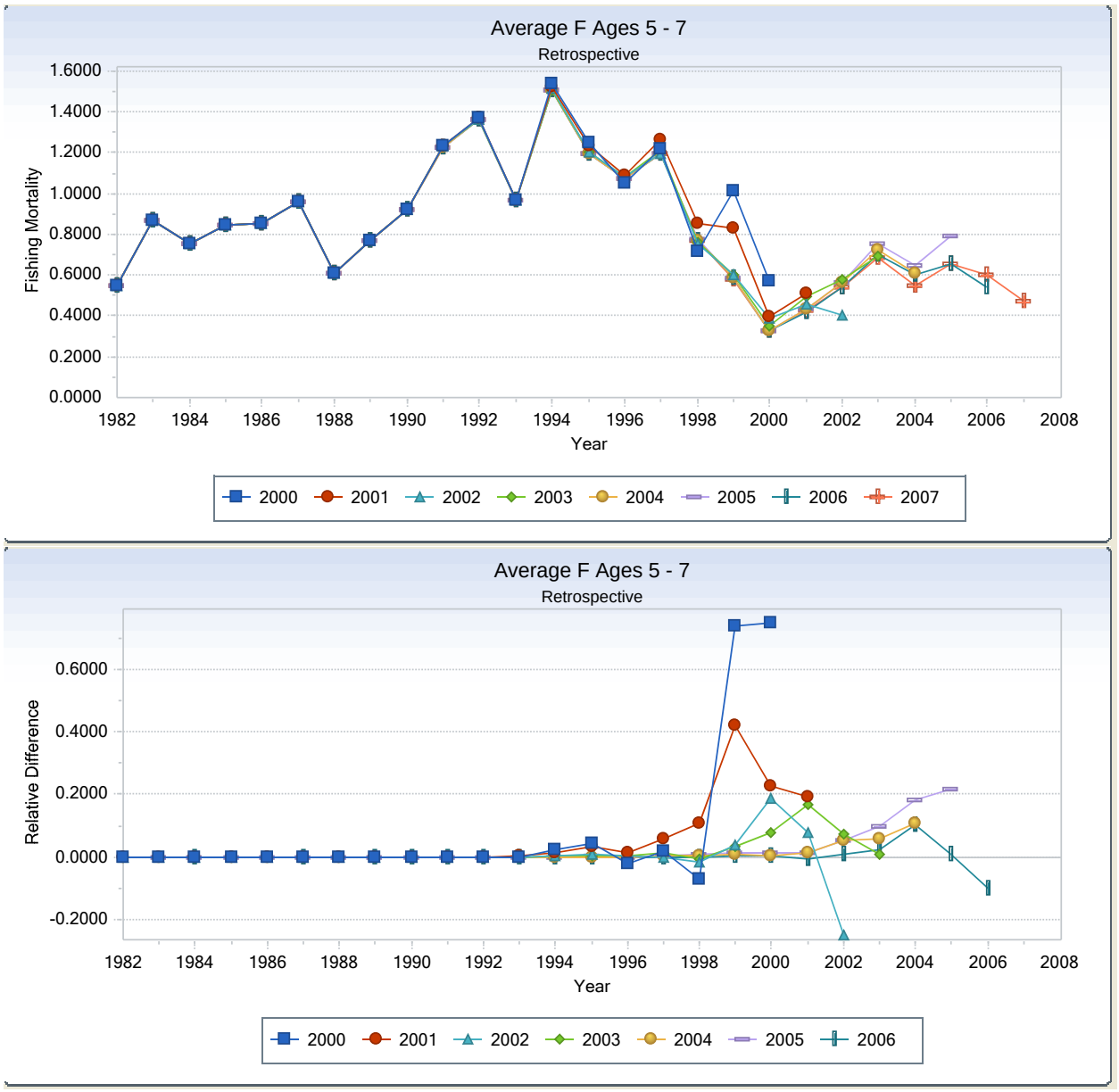


Figure A.88. ADAPT-VPA Model 2b retrospective patterns in Gulf of Maine Atlantic cod fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.

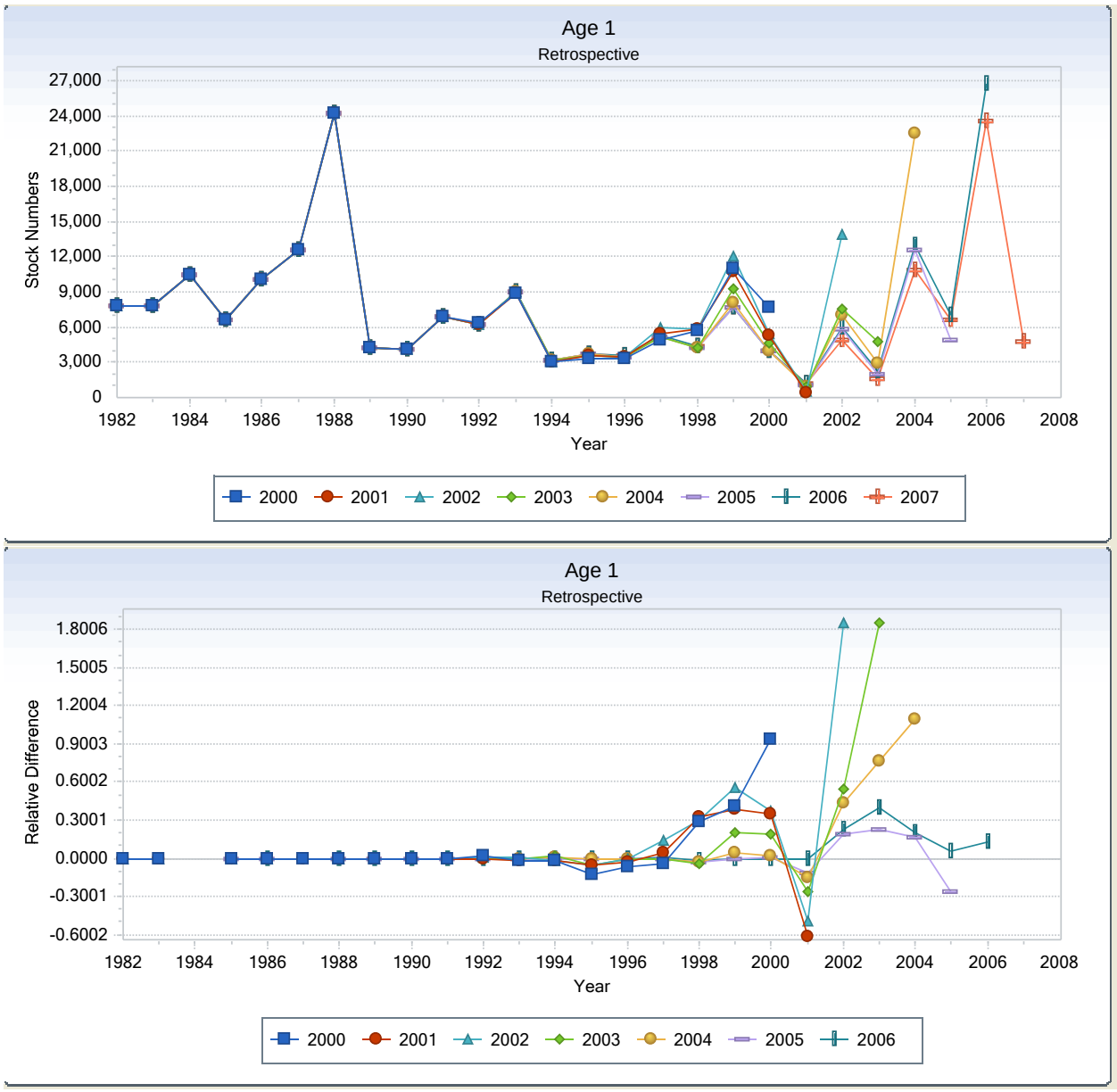


Figure A.89. ADAPT-VPA Model 2b retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.

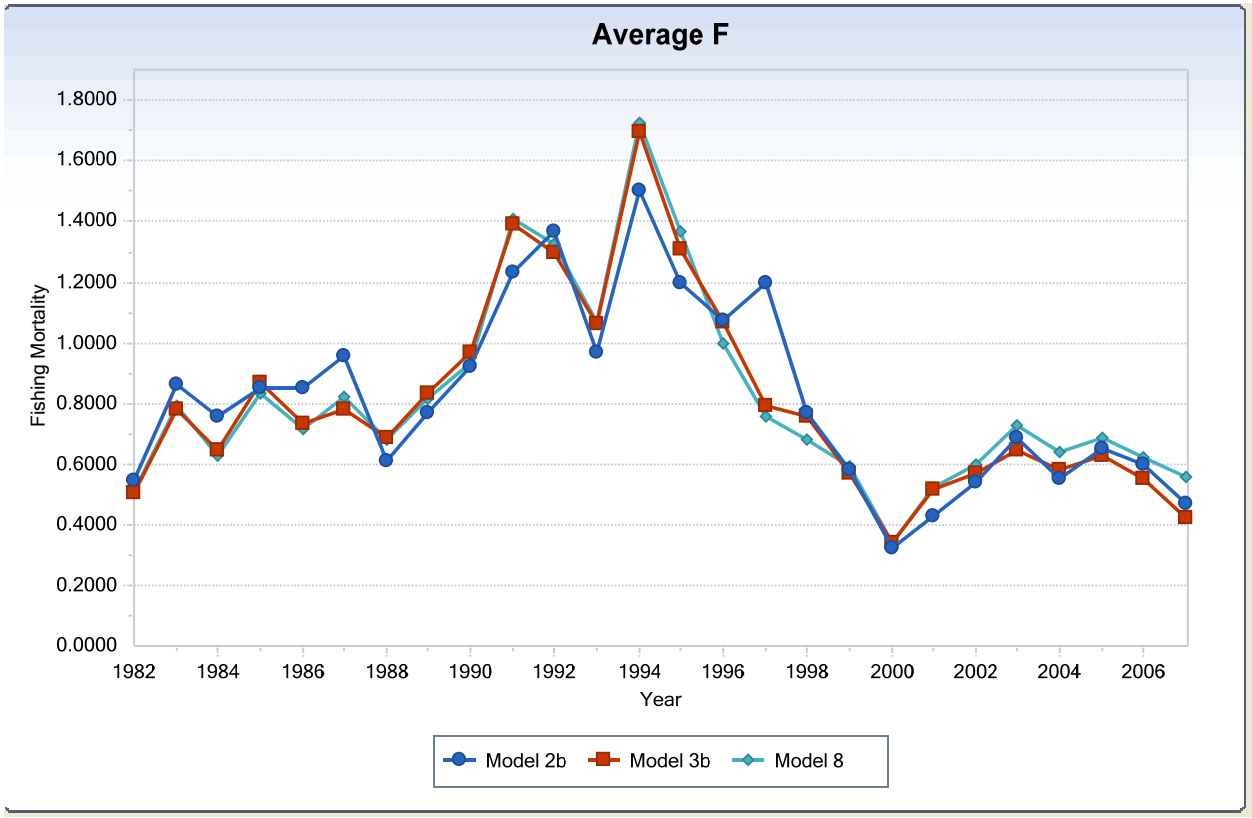


Figure A.90. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 2b, 3b and 8.

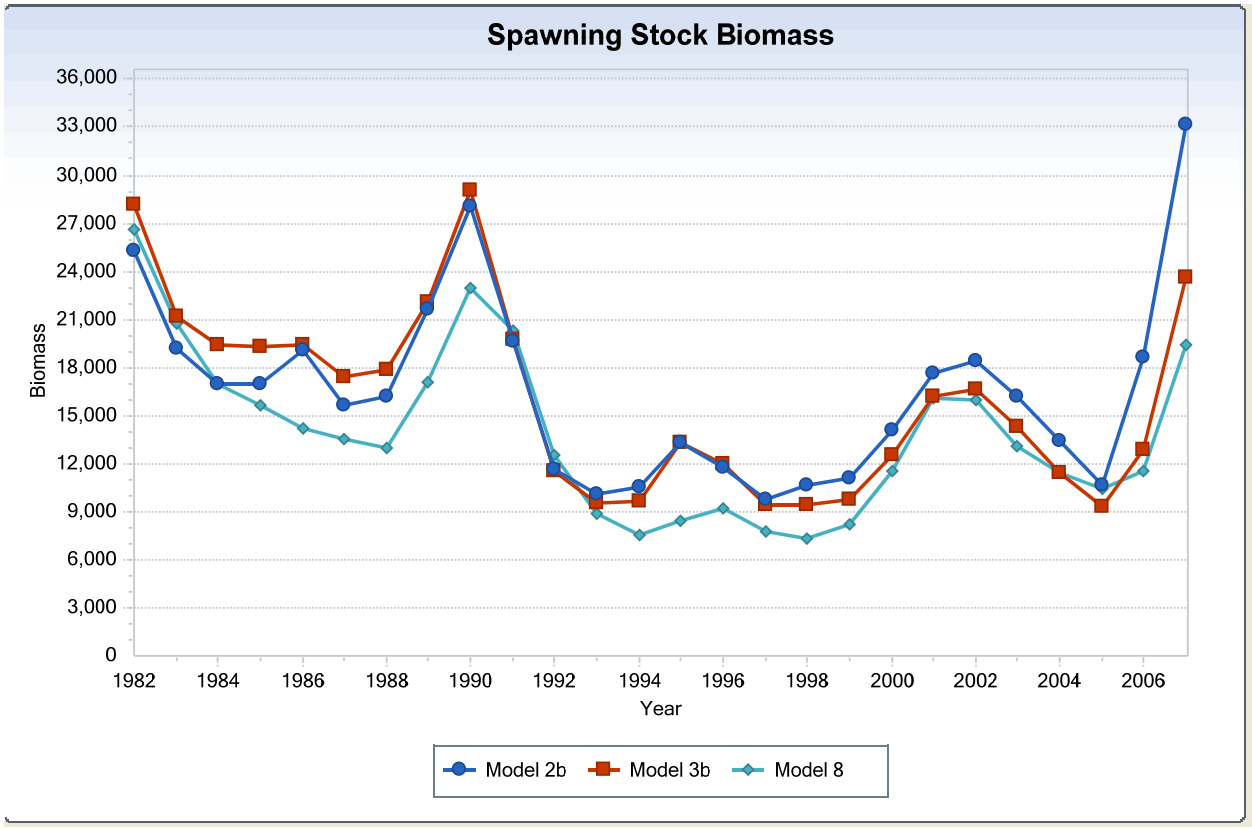


Figure A.91. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 2b, 3b and 8.

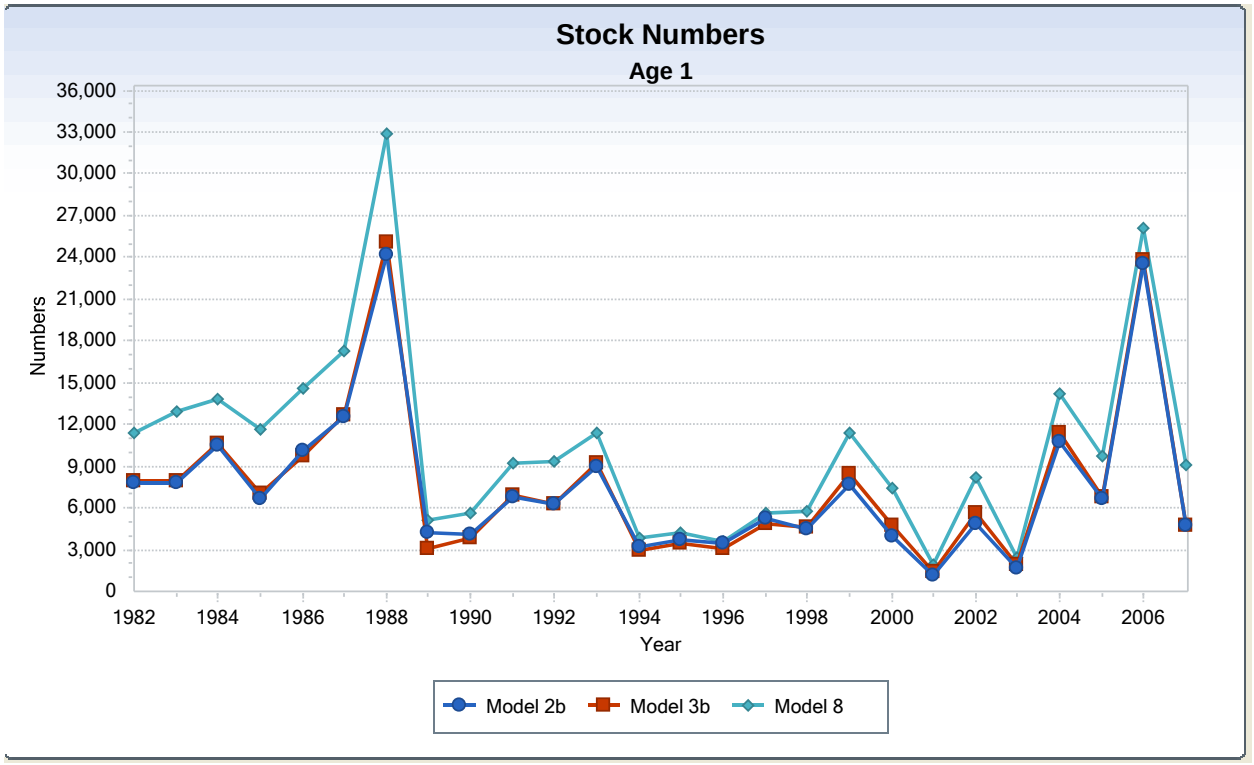


Figure A.92. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 2b, 3b and 8.

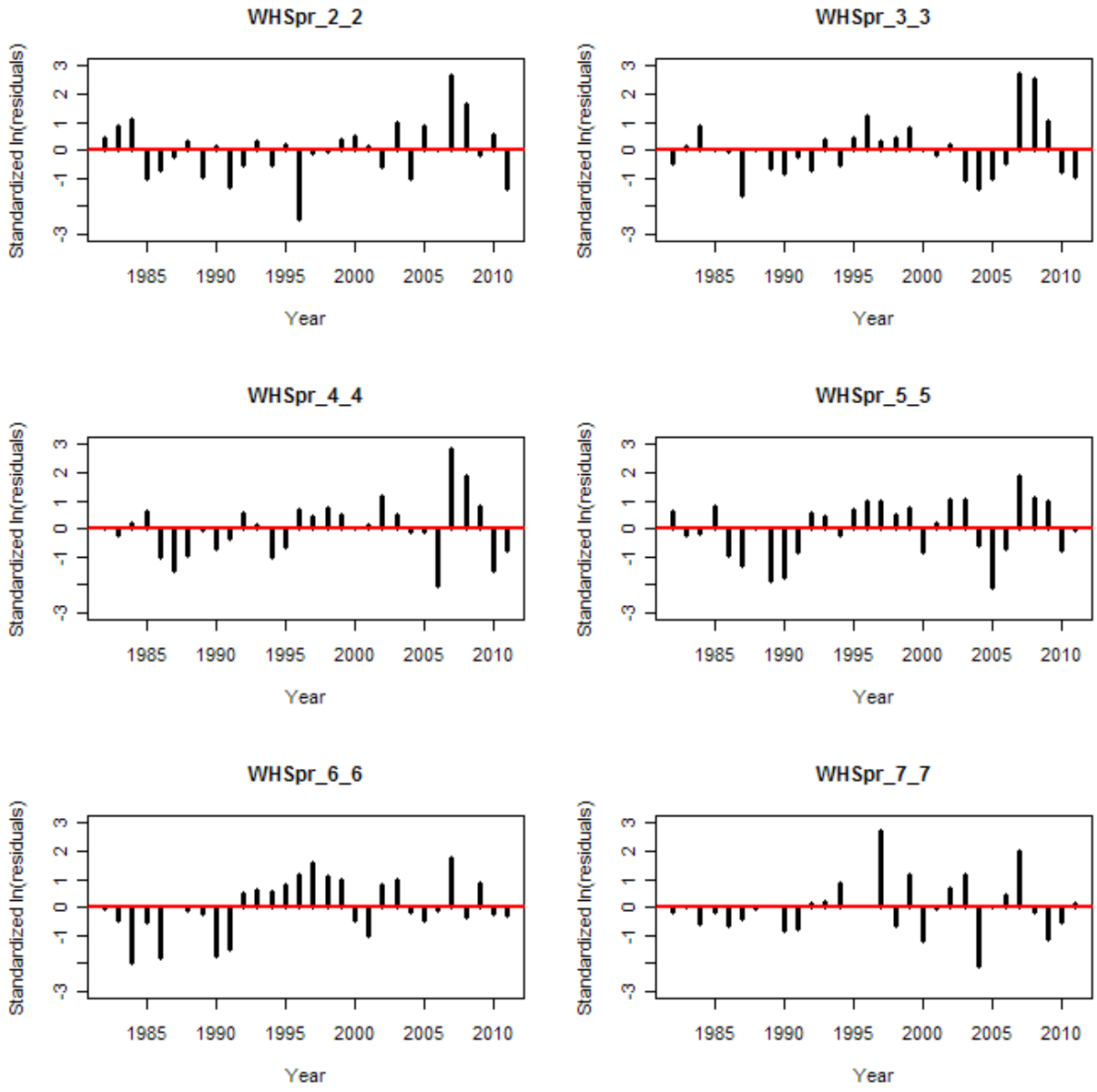


Figure A.93.a. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center spring survey Gulf of Maine Atlantic cod ages 2 (WHSpr_2_2) through 7 (WHSpr_7_7). **Note: fall surveys have been lagged forward a year and an age.*

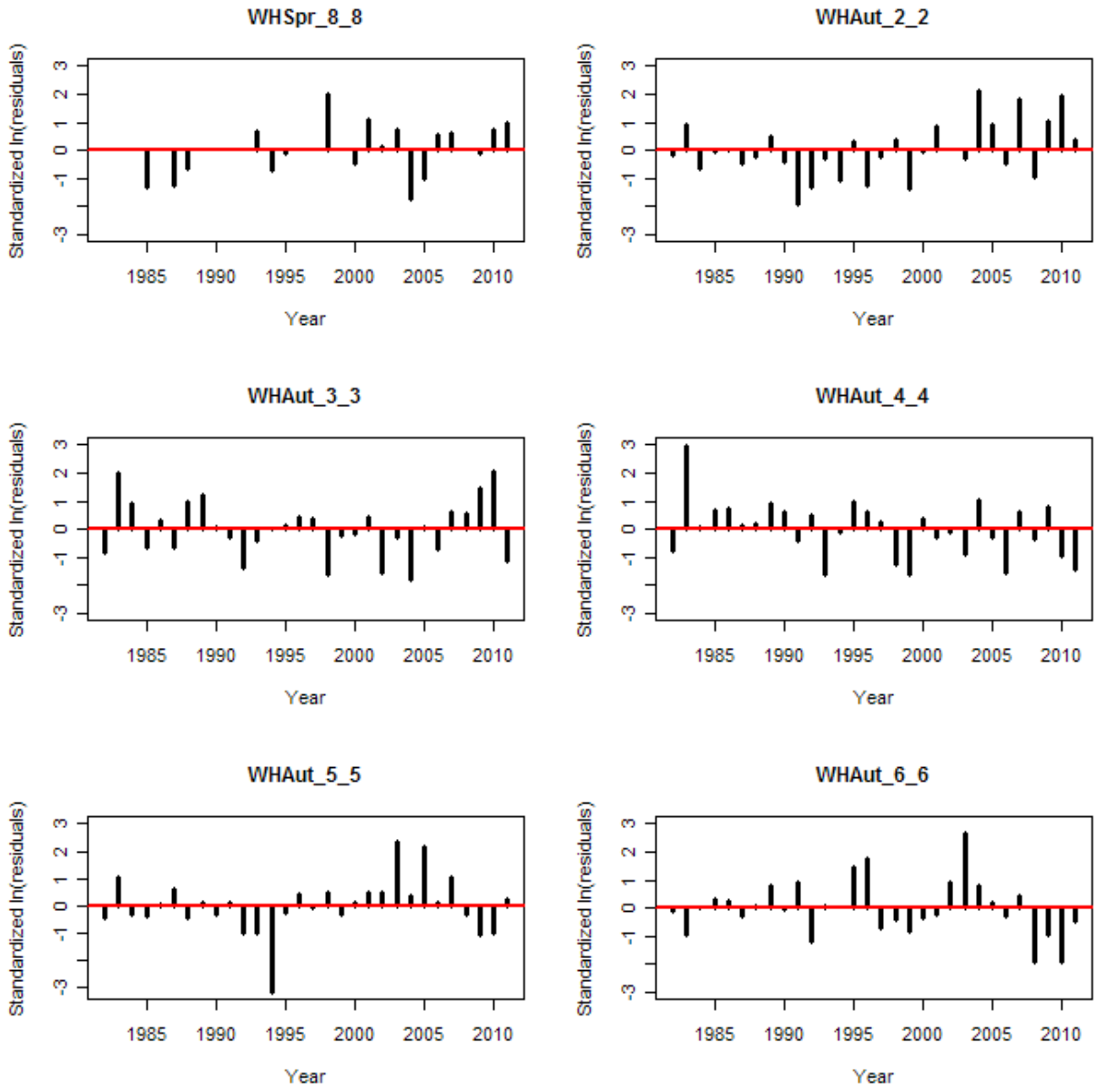


Figure A.93.b. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center spring survey Gulf of Maine Atlantic cod age 8 (WHSpr_8_8) and fall survey ages 1 (WHAut_1_1) through 5 (WHAut_6_6). **Note: fall surveys have been lagged forward a year and an age.*

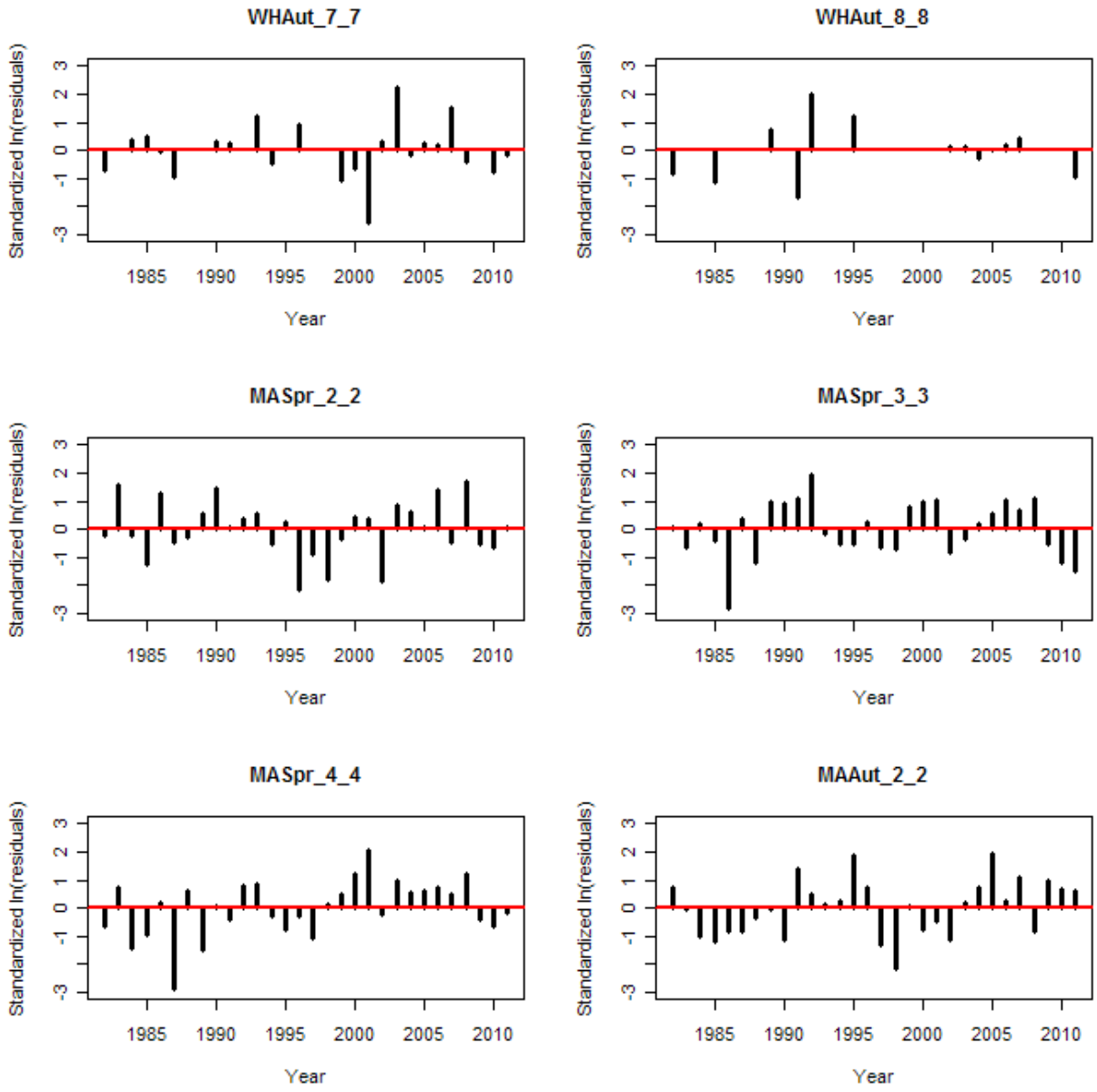


Figure A.93.c. ADAPT-VPA Model 10 residuals to the survey fits of the Northeast Fisheries Science Center fall survey ages 6 (WHAut_7_7) through 7 (WHAut_8_8), Massachusetts Department of Marine Fisheries spring survey Gulf of Maine Atlantic cod ages 2 (MASpr_2_2) through 4 (MASpr_4_4) and fall survey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

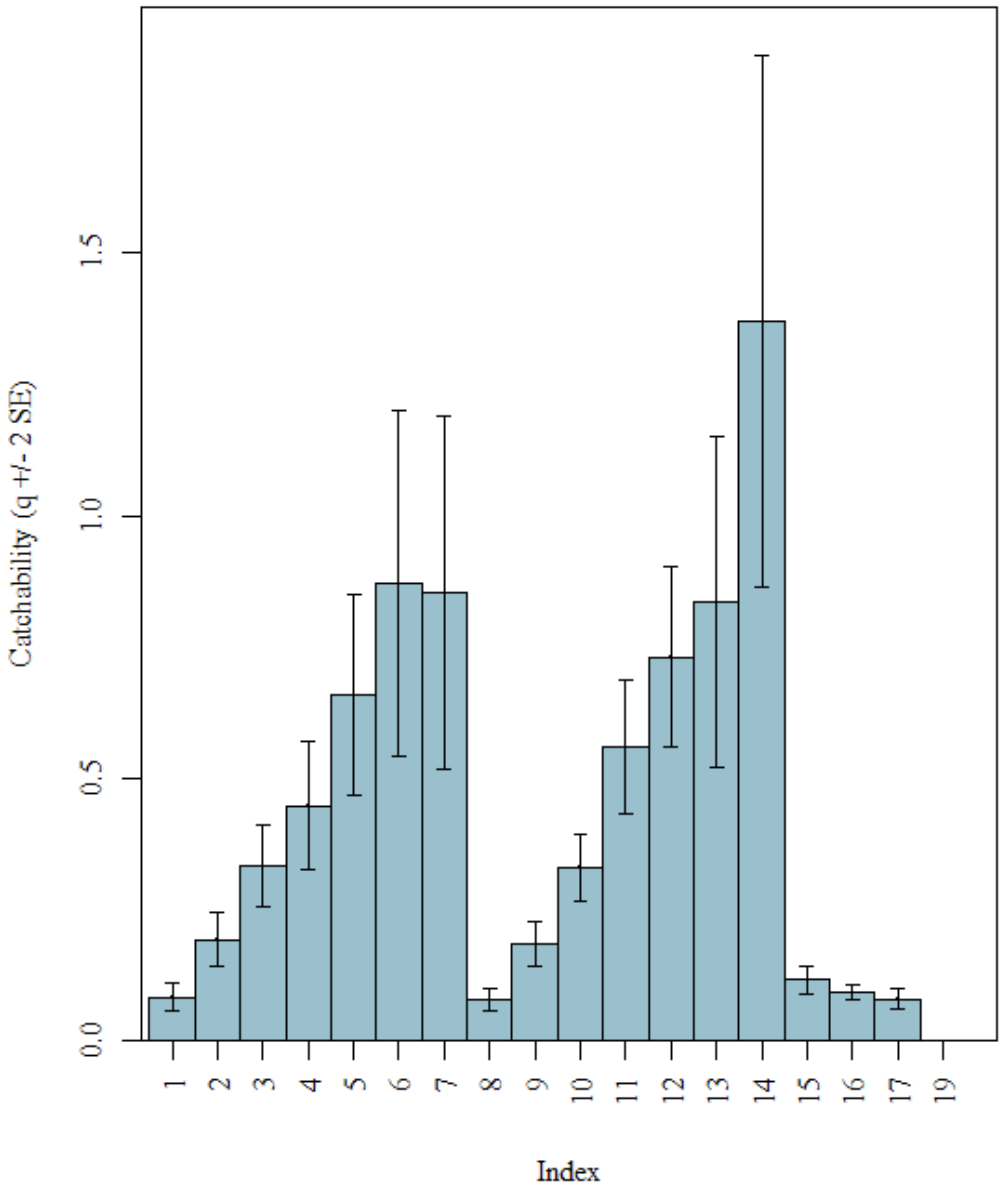


Figure A.94. ADAPT-VPA Model 10 patterns in survey catchability (q). Indices 1-7=NEFSC spring (ages 2-8), indices 8-14=NEFSC fall (ages 1-7), indices 15-17=MADMF spring (ages 2-4), index 19=MADMF fall (age 1). **Note: survey catchability is shown in terms of area swept biomass.*

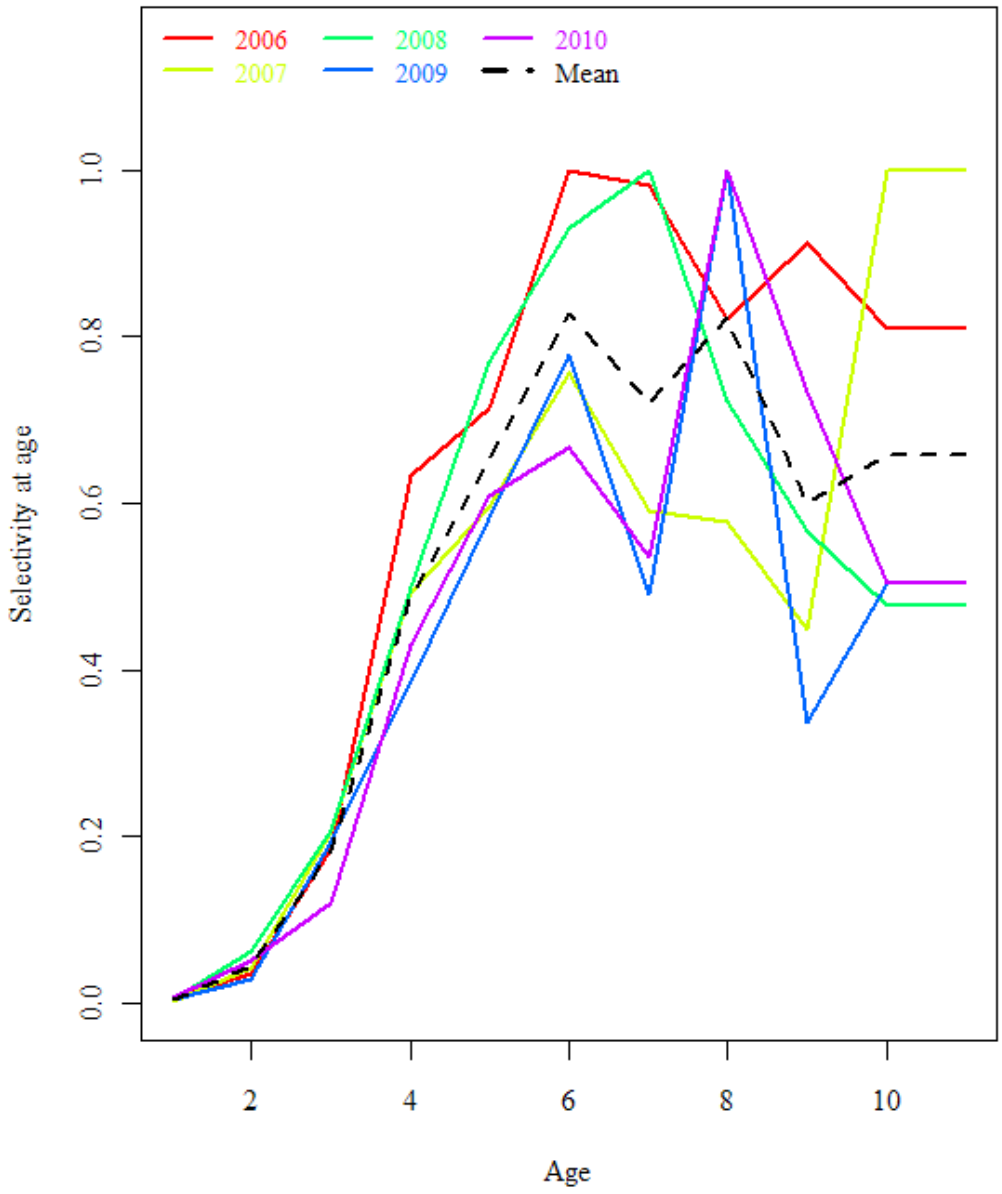


Figure A.95. ADAPT-VPA Model 10 catch selectivity patterns for Gulf of Maine Atlantic cod over the last five years of the model, 2006 through 2010.

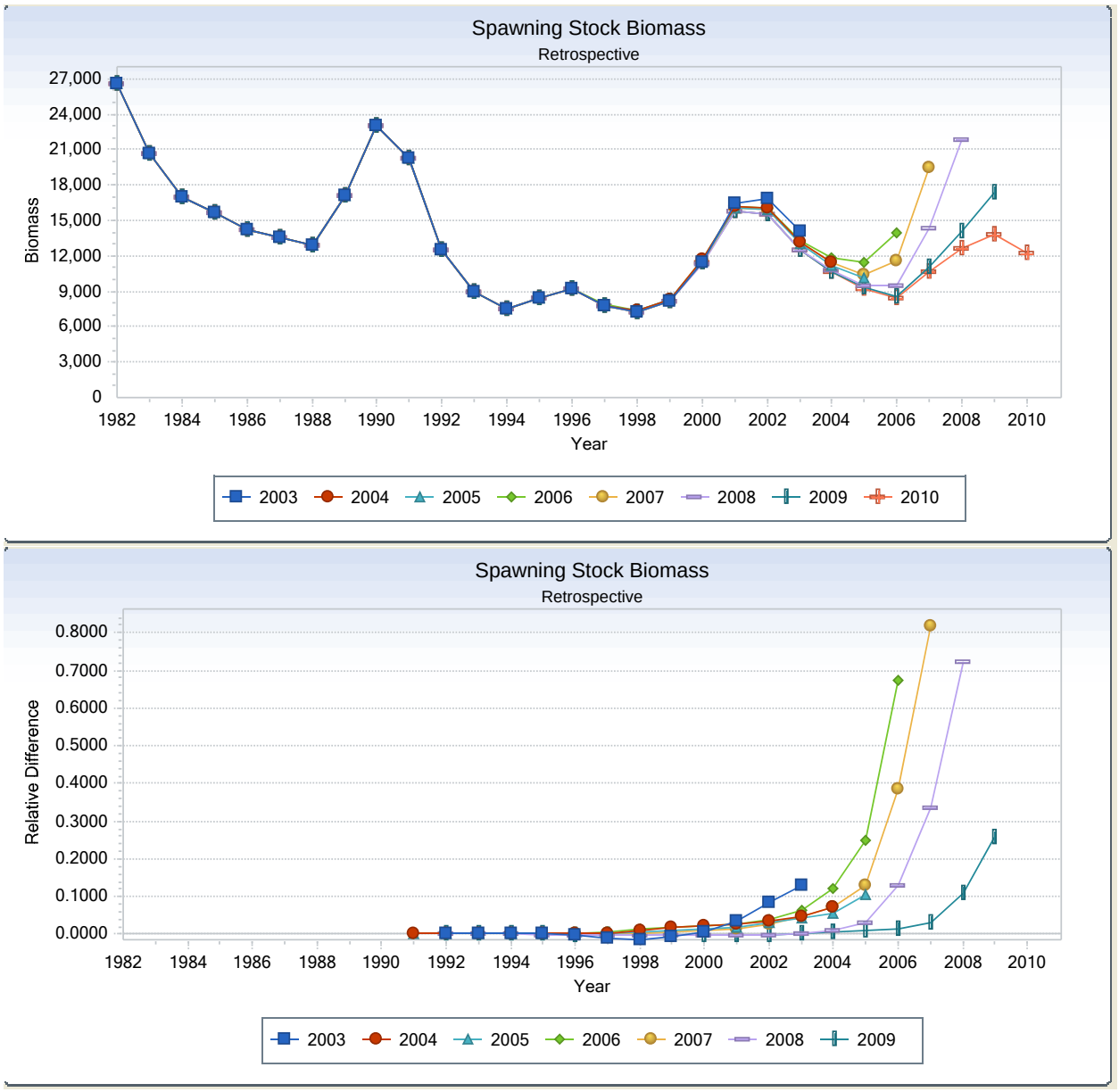


Figure A.96. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod spawning stock biomass (mt) in absolute (top) and relative (bottom) terms.

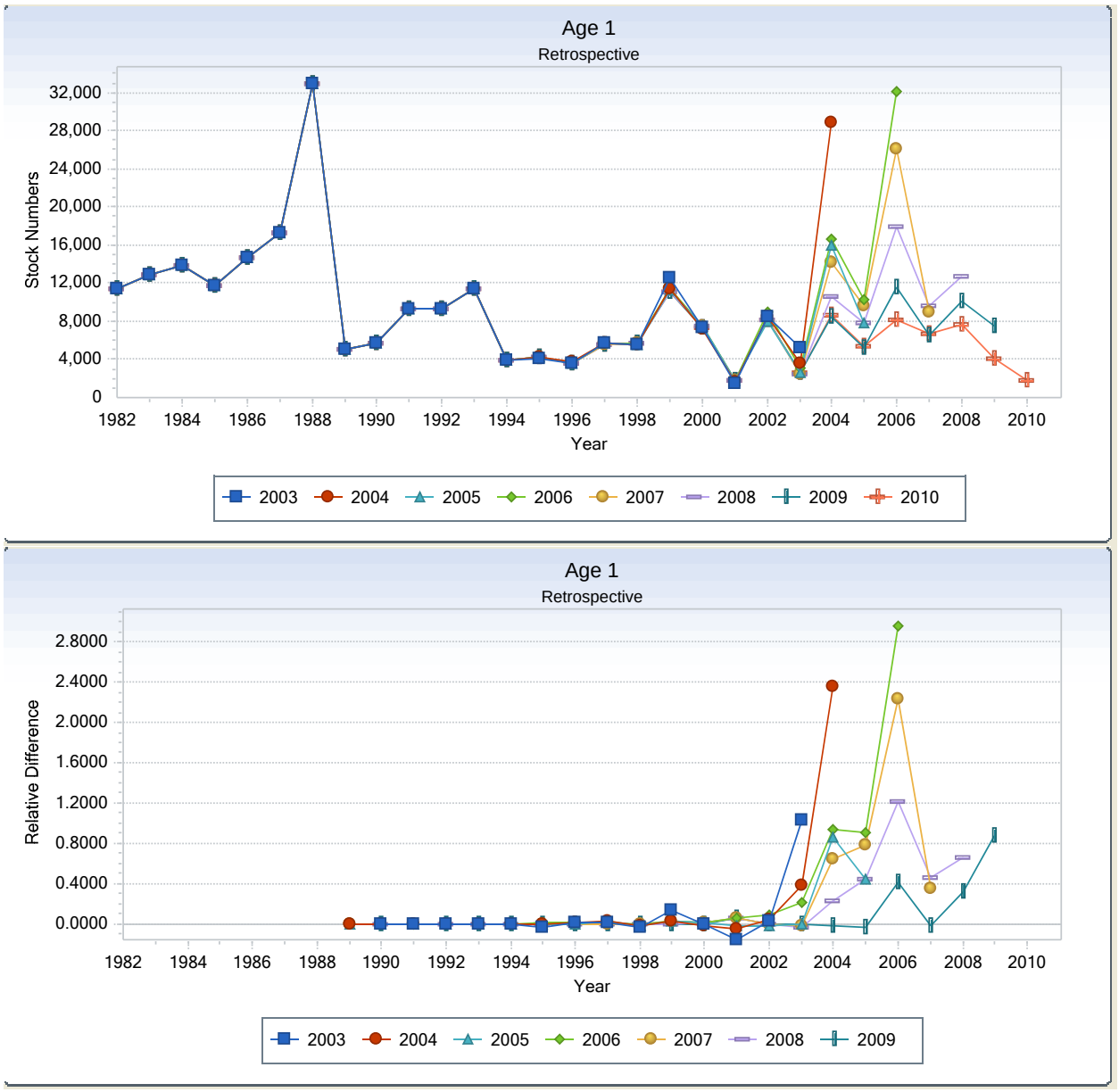


Figure A.97. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.

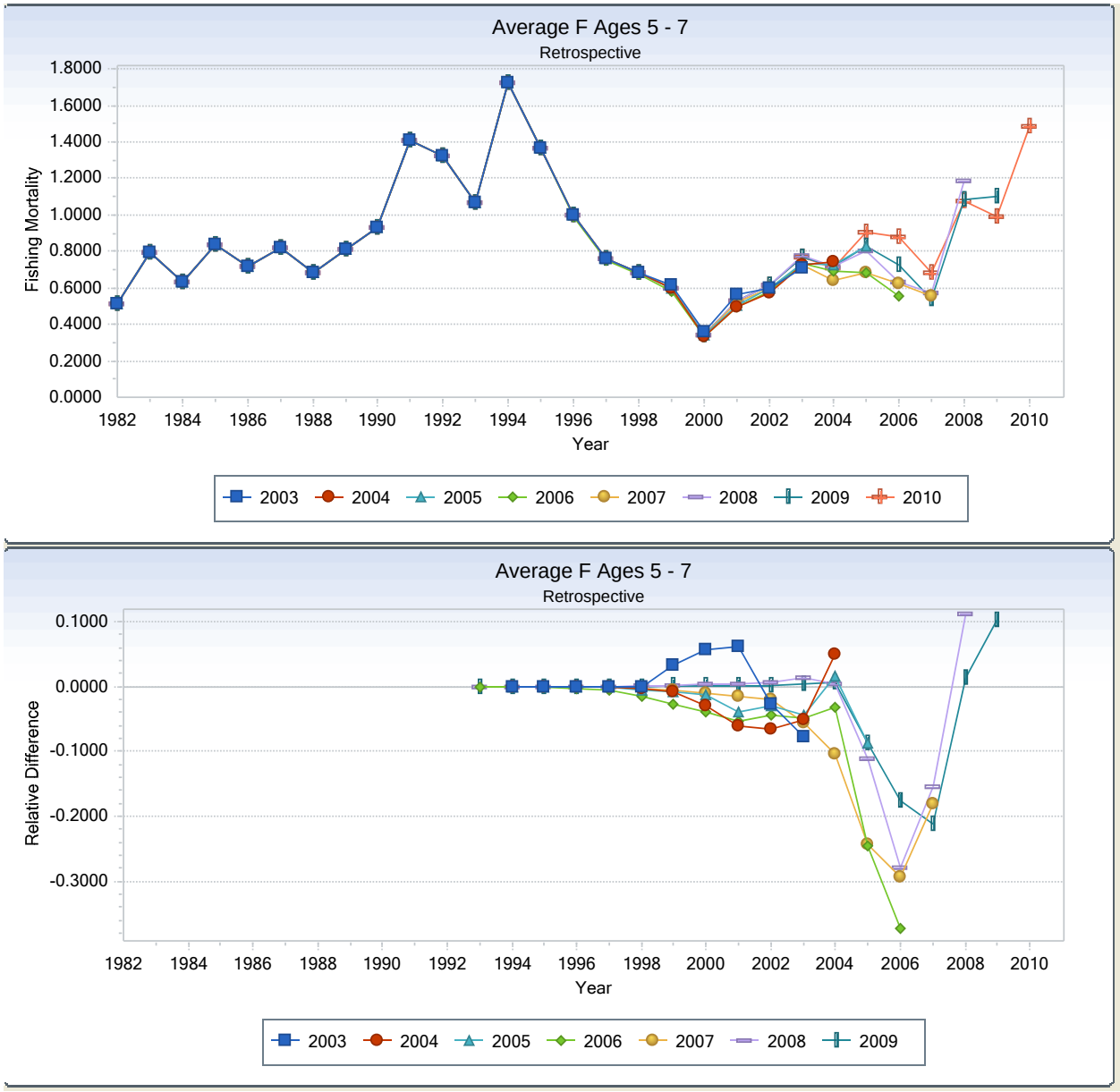


Figure A.98. ADAPT-VPA Model 10 retrospective patterns in Gulf of Maine Atlantic cod fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.

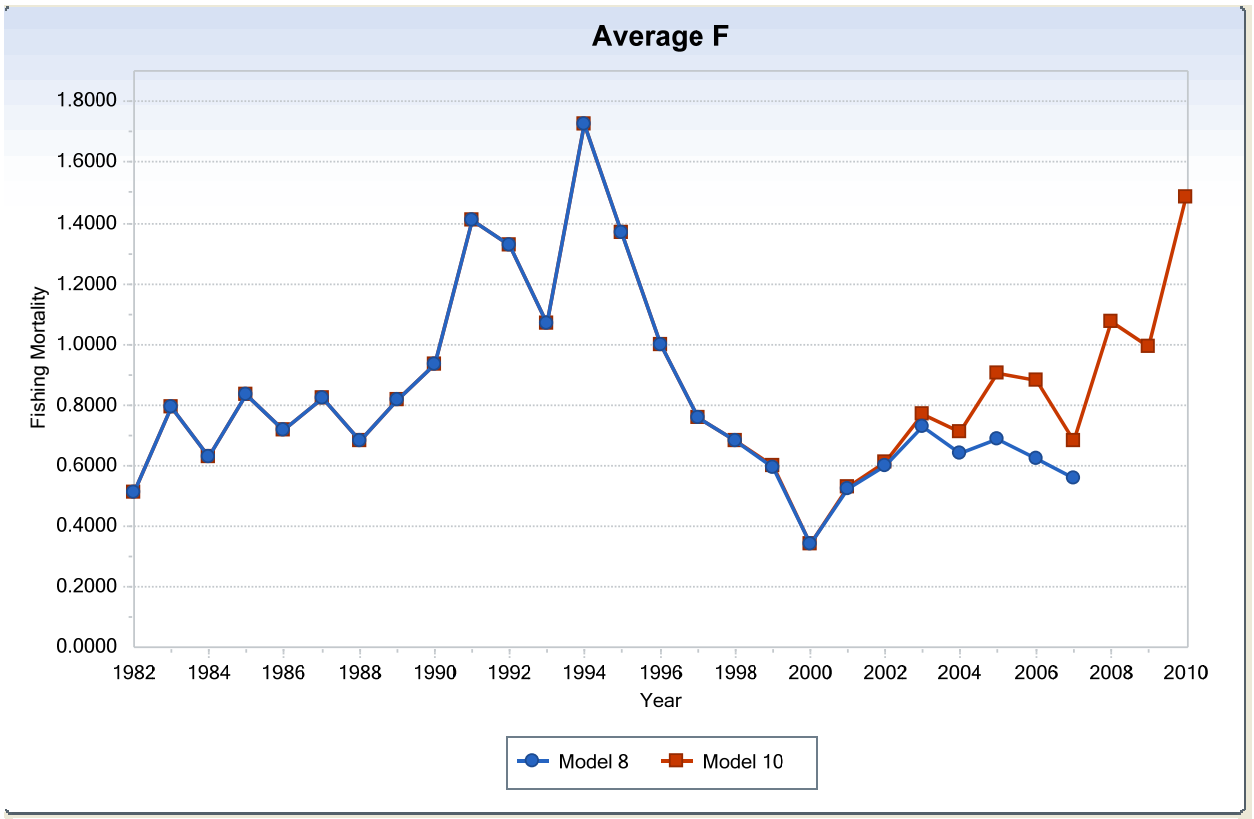


Figure A.99. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 8 and 10.

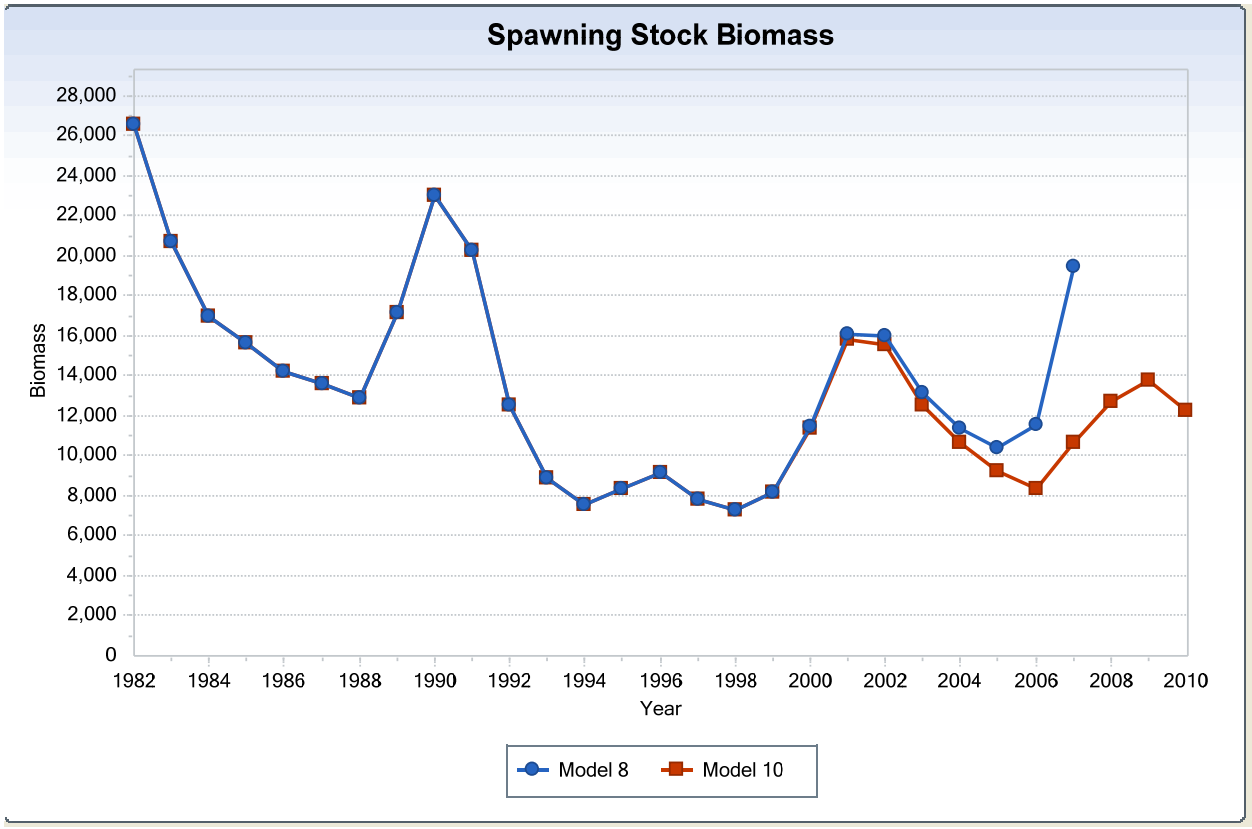


Figure A.100. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 8 and 10.

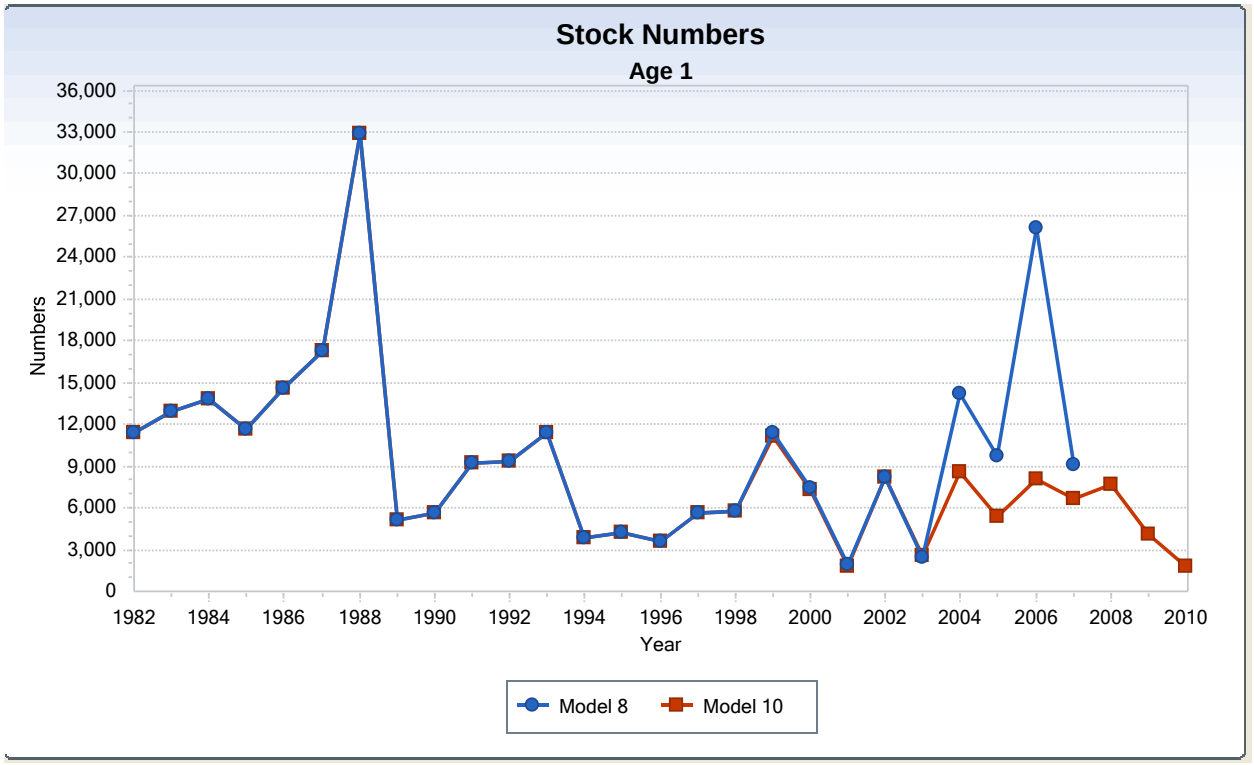


Figure A.101. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 8 and 10.

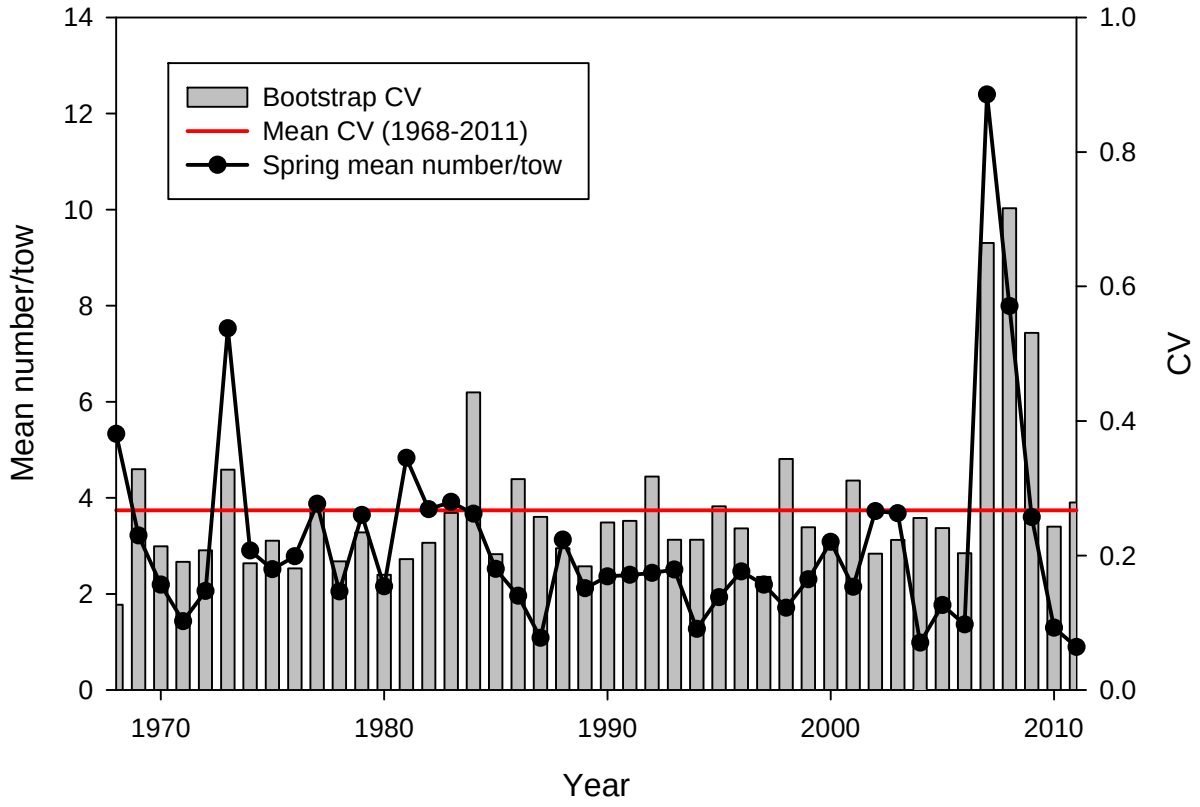


Figure A.102. Northeast Fisheries Science Center spring bottom trawl survey index of Gulf of Maine Atlantic cod abundance (mean number/tow) and the corresponding coefficient of variation (CV) from 1968 to 2011. The solid red line represents the time series average CV.

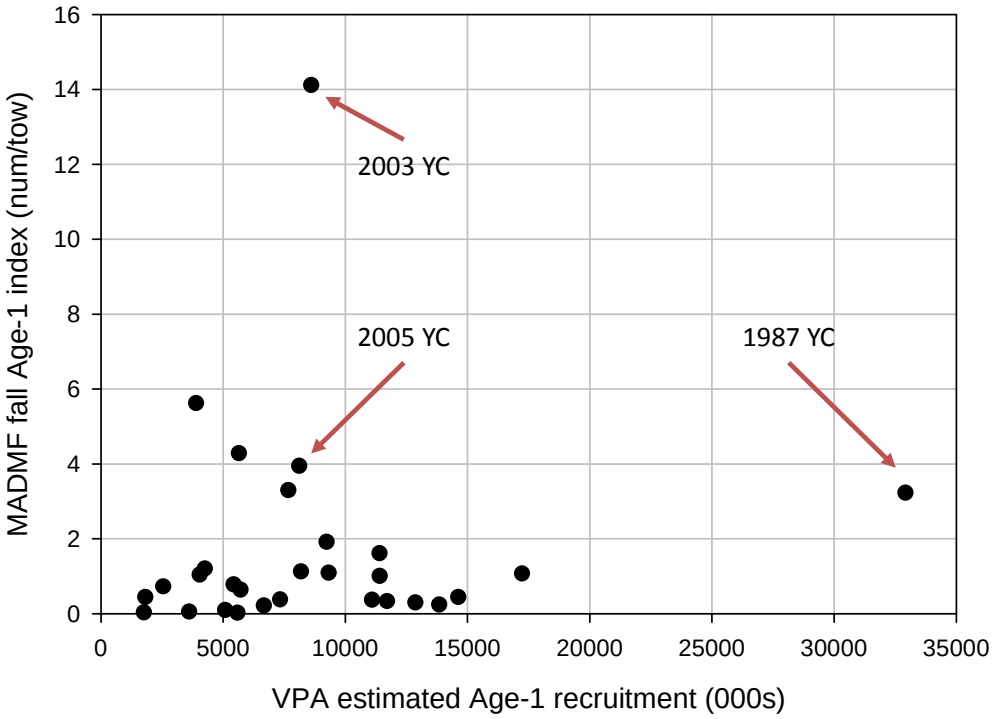


Figure A.103. Comparison of the Massachusetts Department of Marine Fisheries Gulf of Maine Atlantic cod age 1 survey index to the VPA Model run 10 estimated age 1 numbers. The three largest year classes estimated by the previous stock assessment (GARM III) are labeled.

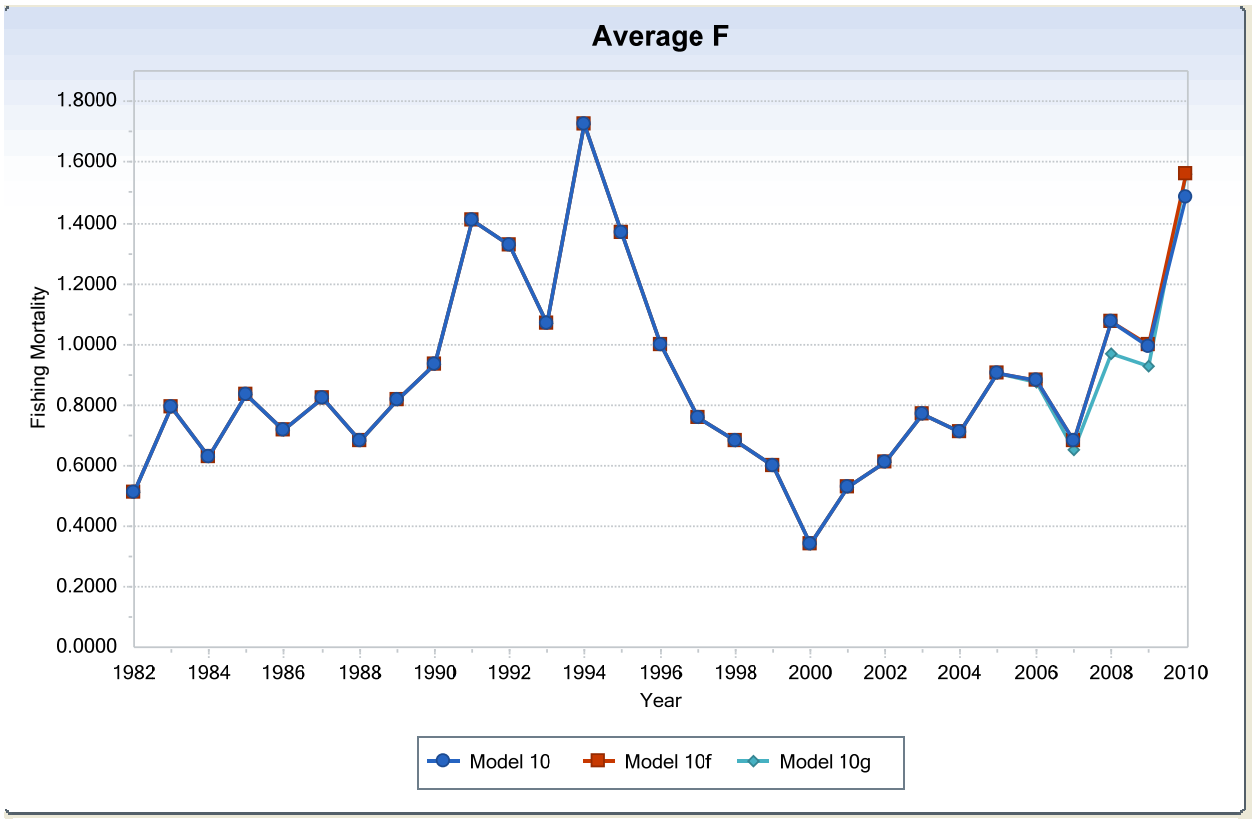


Figure A.104. Comparison of estimates of Gulf of Maine Atlantic cod fishing mortality (ages 5-7) from ADAPT-VPA Model runs 10, 10f and 10g.

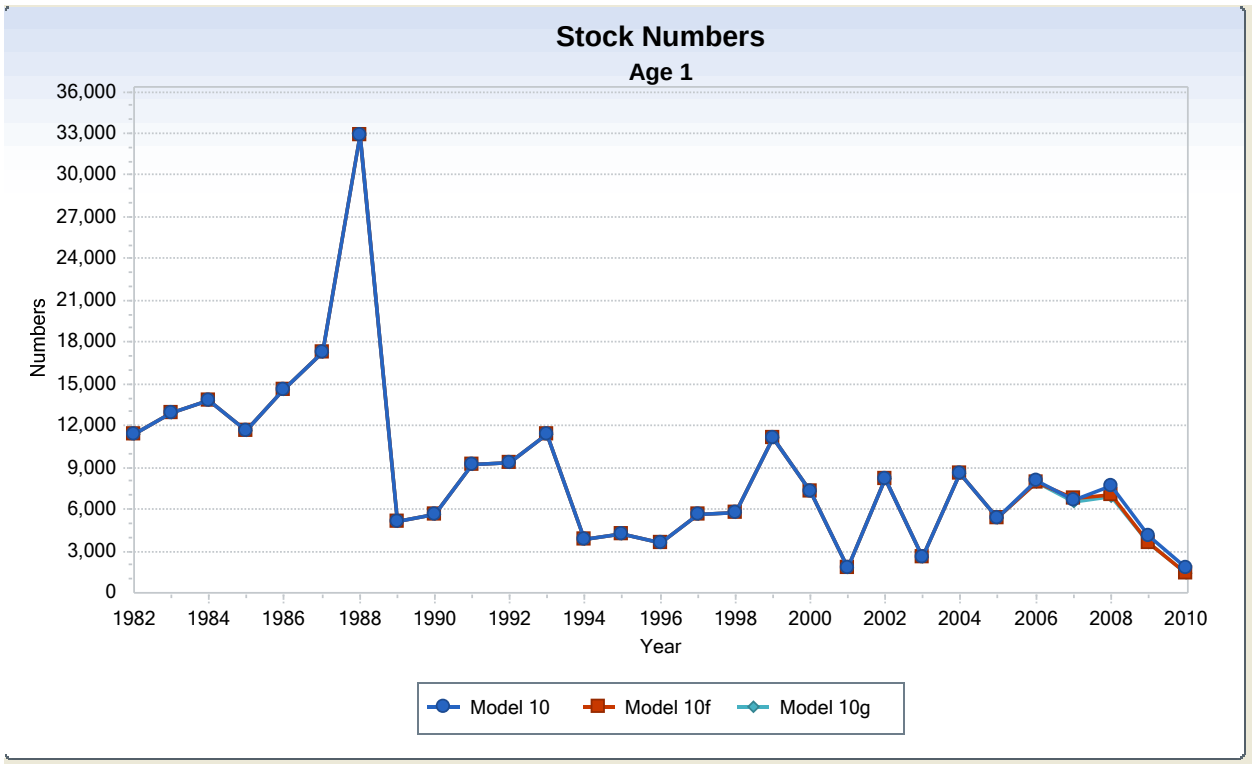


Figure A.105. Comparison of estimates of Gulf of Maine Atlantic cod age-1 recruitment (000s) from ADAPT-VPA Model runs 10, 10f and 10g.

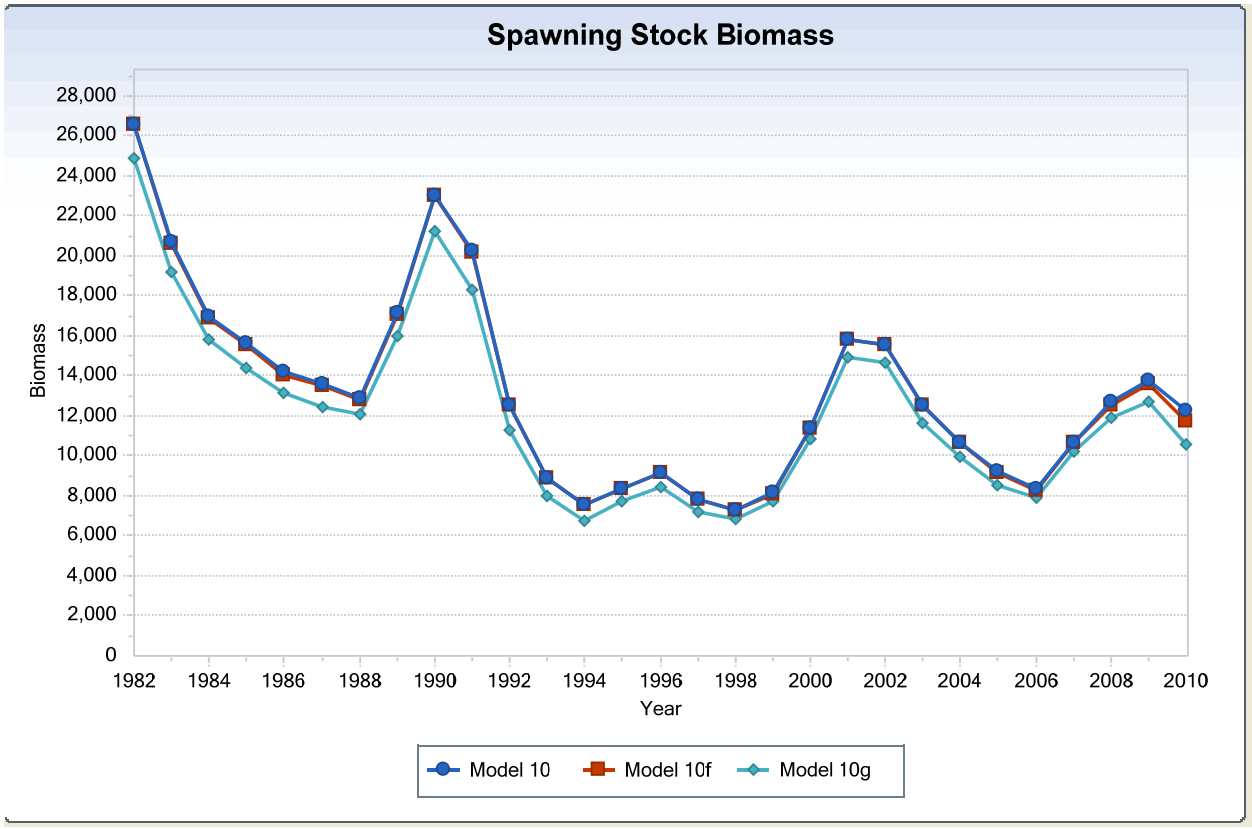


Figure A.106. Comparison of estimates of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ADAPT-VPA Model runs 10, 10f and 10g.

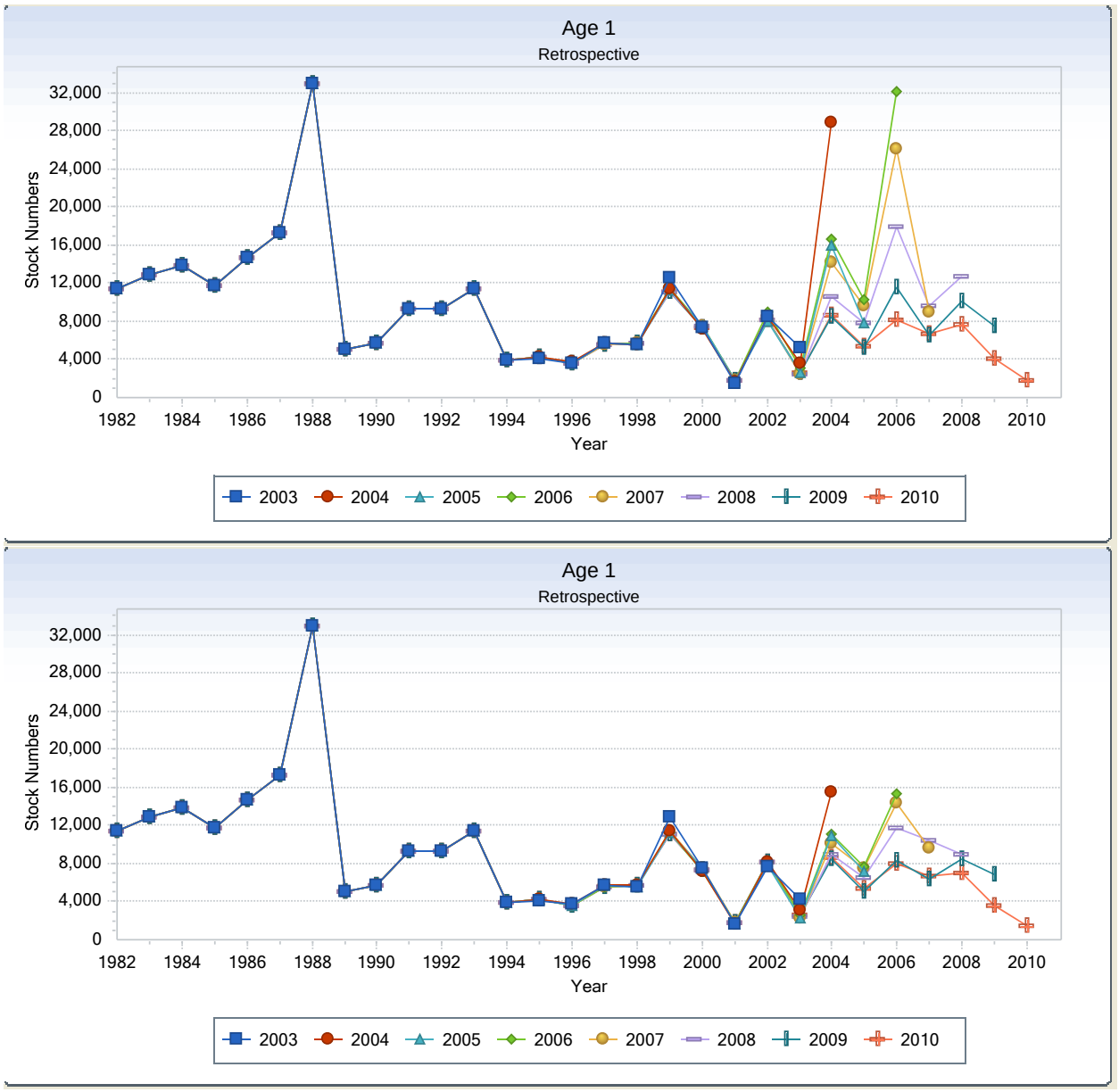


Figure A.107. Comparison of the retrospective patterns (absolute) of Gulf of Maine Atlantic cod age 1 recruitment between Model run 10 (top) and 10f (bottom).

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).

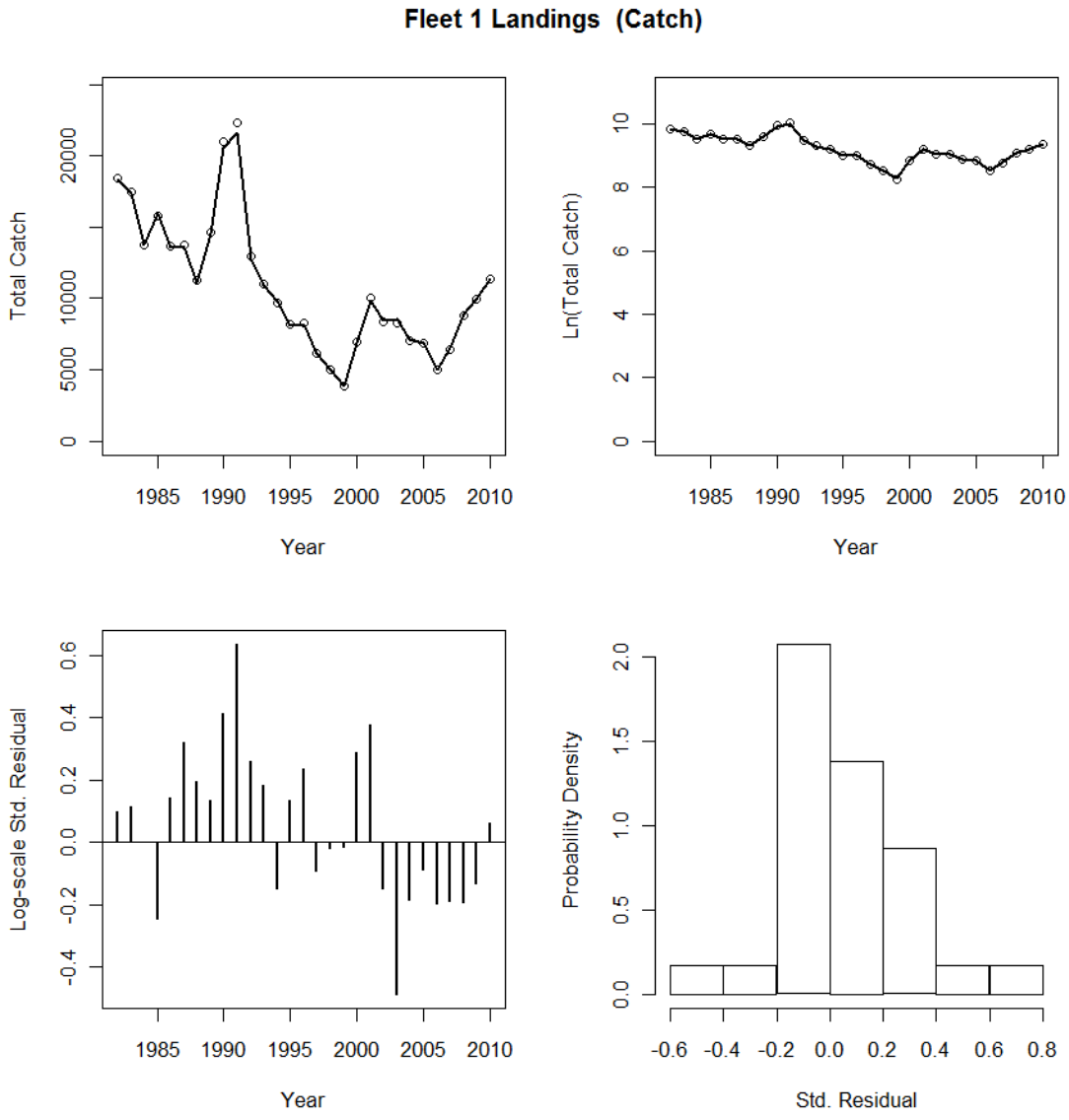


Figure A.109. ASAP BASE model fit to the total Gulf of Maine Atlantic cod fishery catch (Fleet 1).

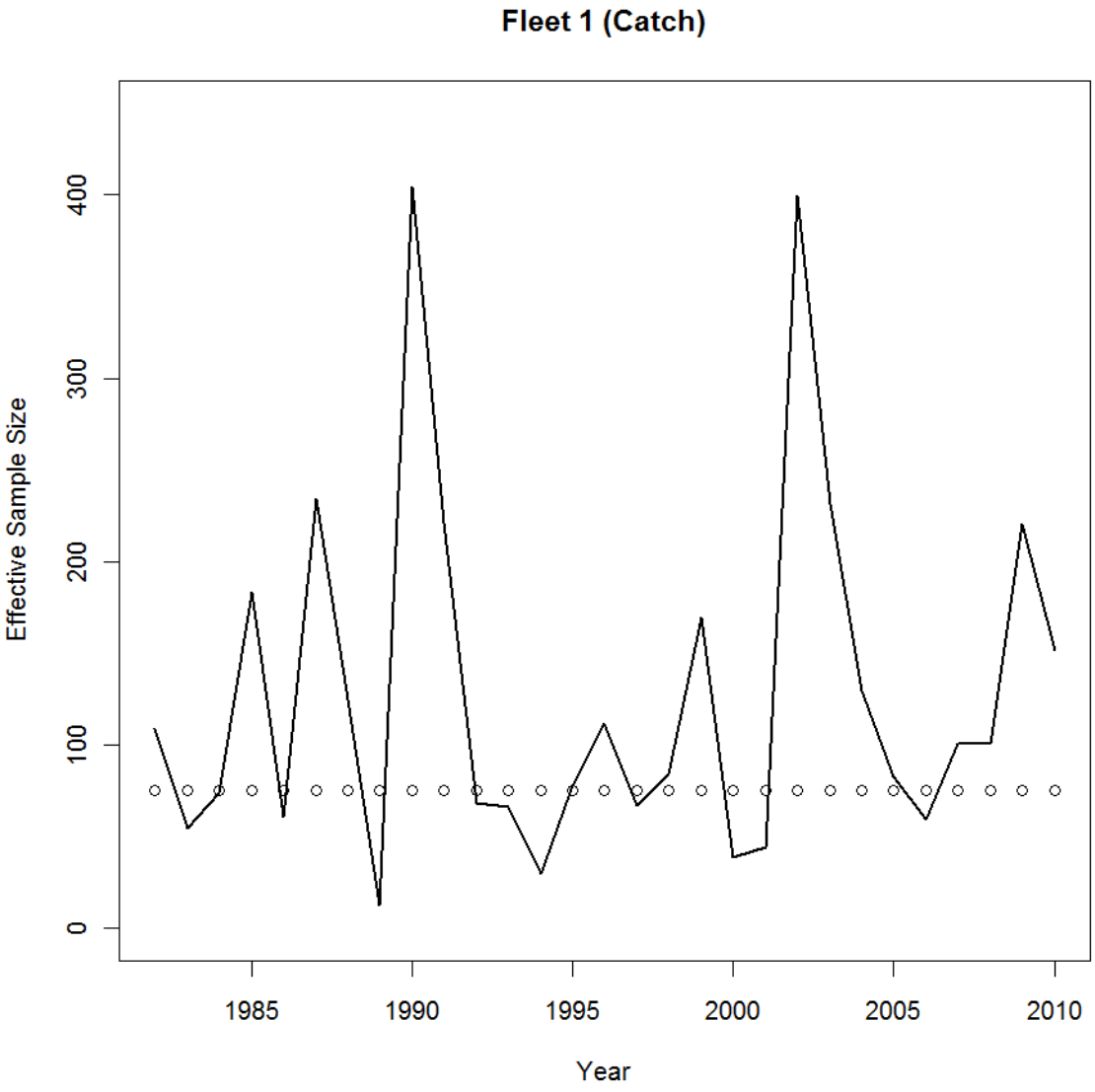


Figure A.110. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the Gulf of Maine Atlantic cod fishery catch.

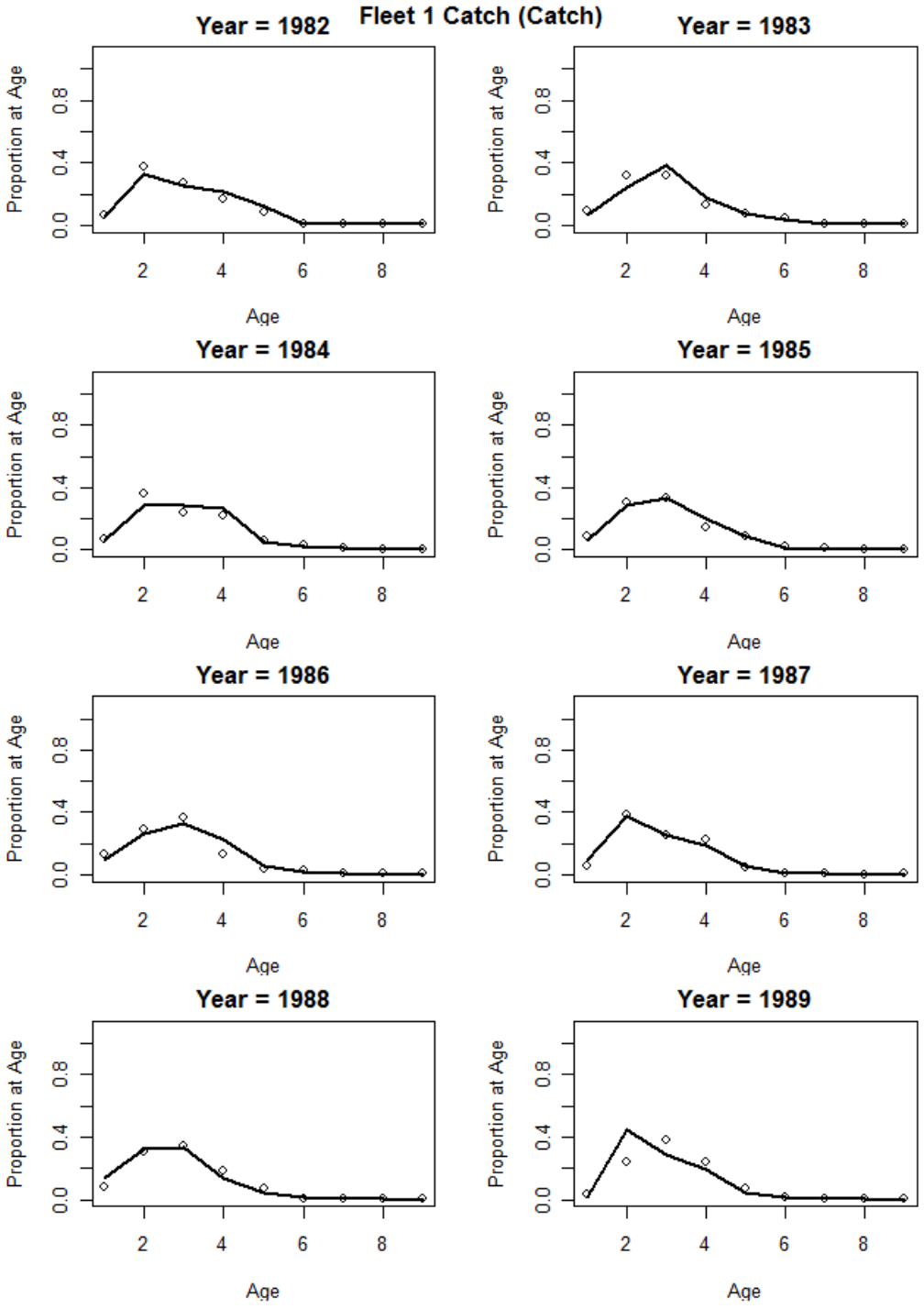


Figure A.111.a. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

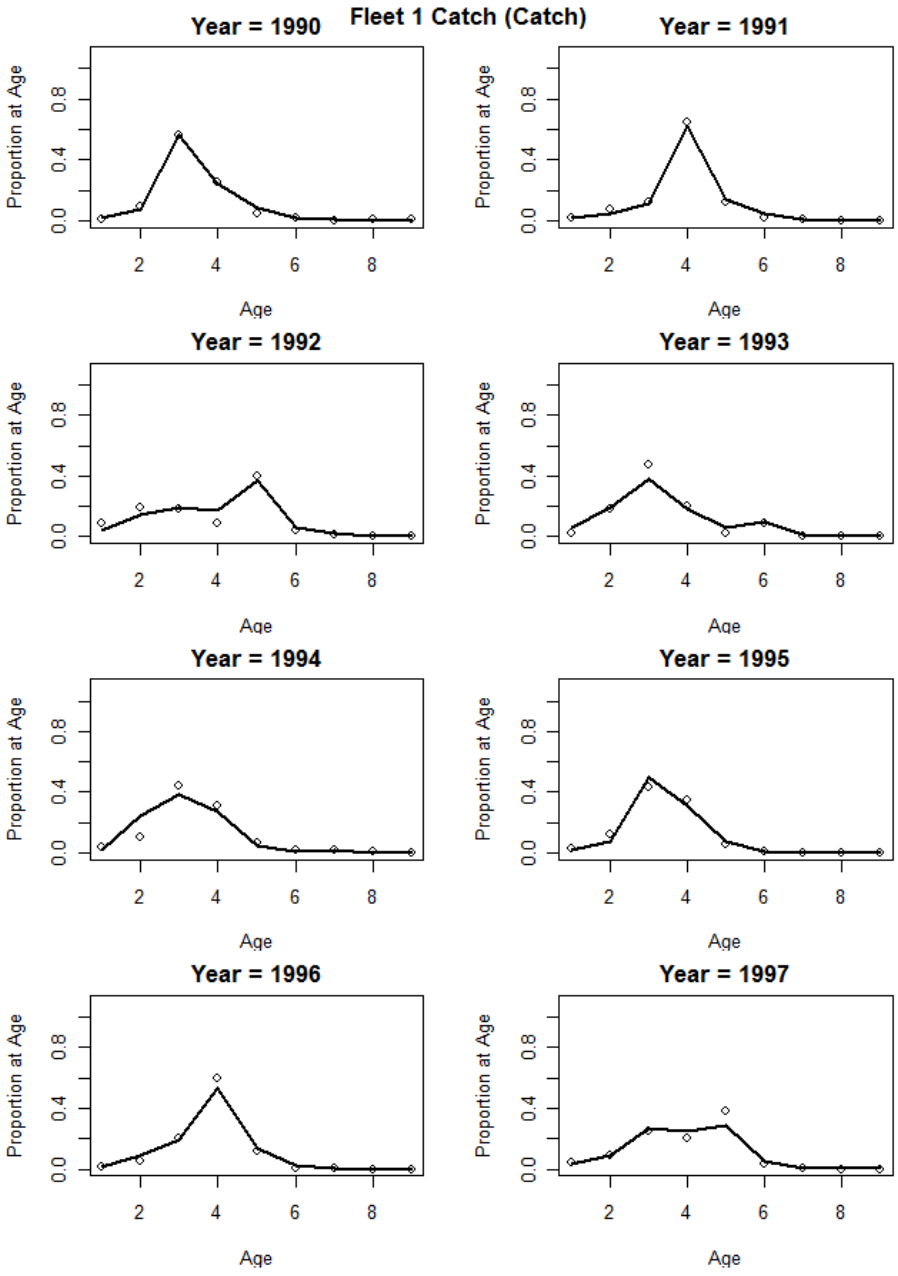


Figure A.111.b. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

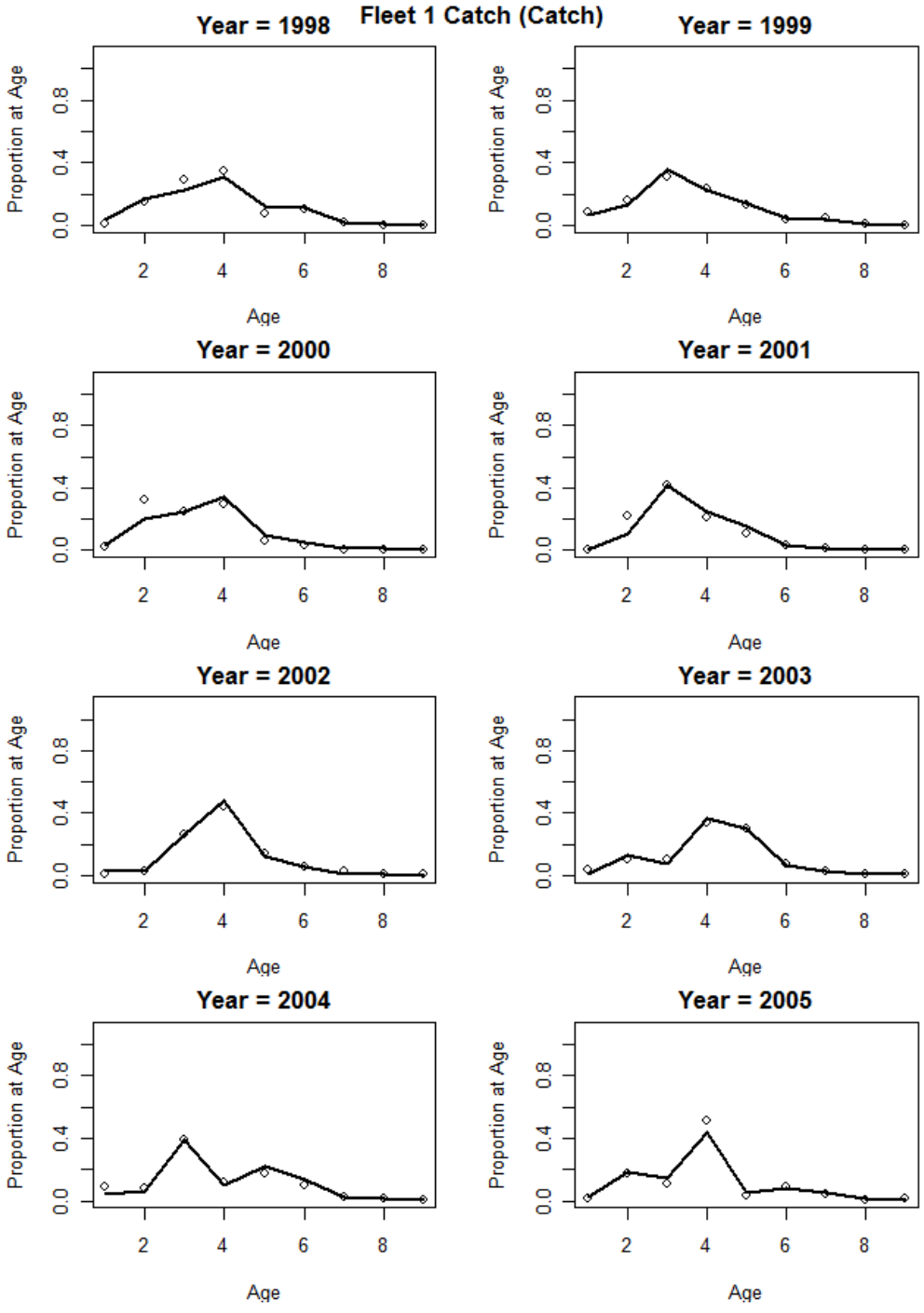


Figure A.111.c. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

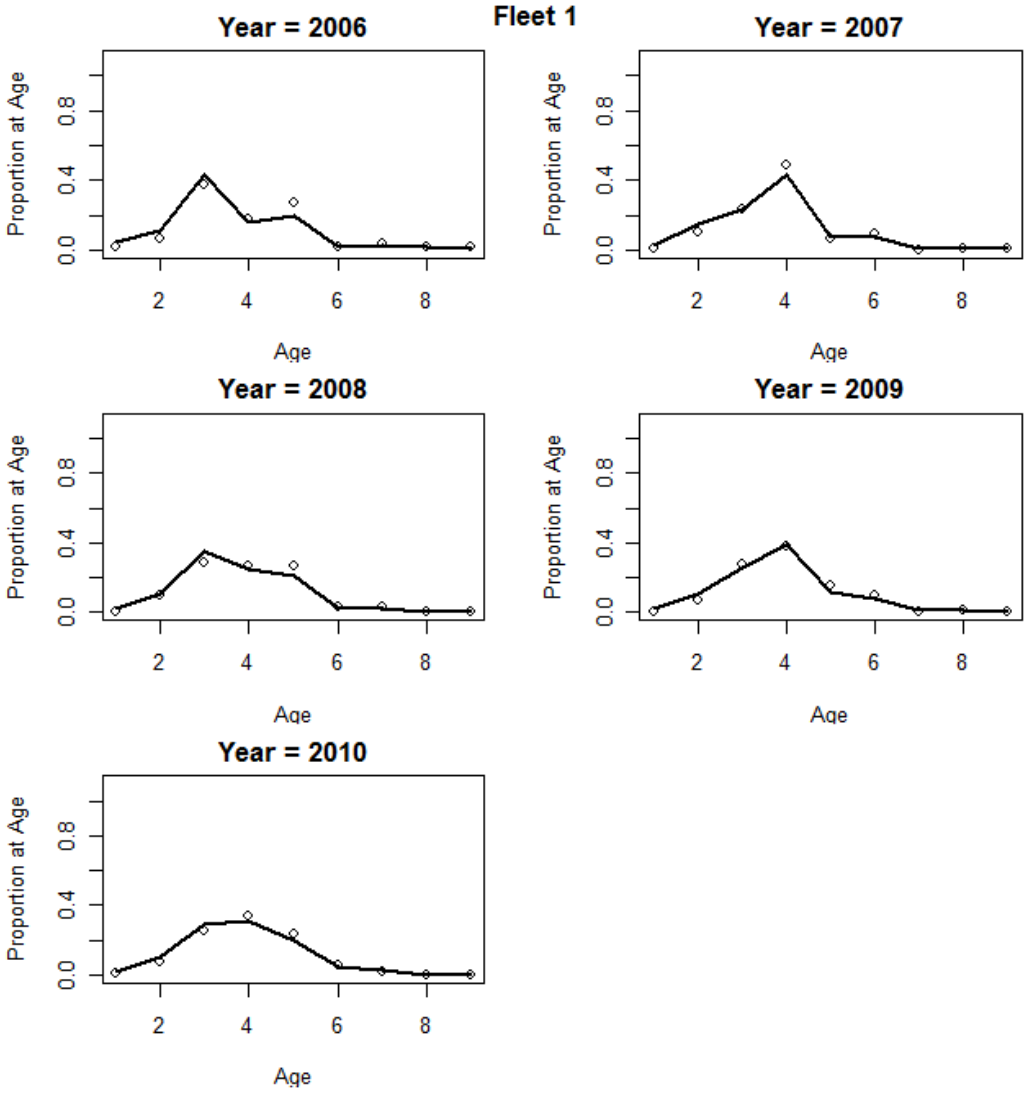


Figure A.111.d. Comparison of the ASAP BASE estimates of Gulf of Maine Atlantic cod proportion-at-age in the fishery to the data estimates.

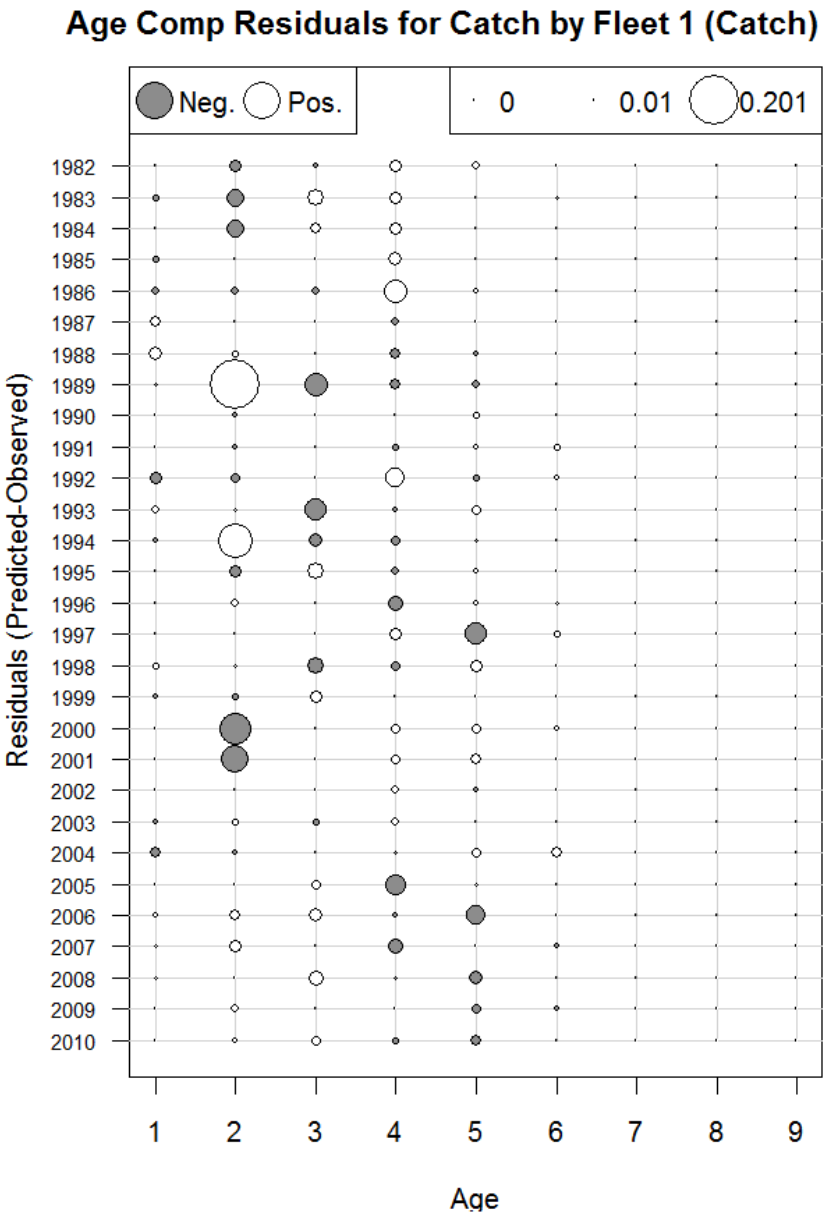


Figure A.112. ASAP BASE model fit residuals for the fishery (Fleet 1) catch-at-age of Gulf of Maine Atlantic cod.

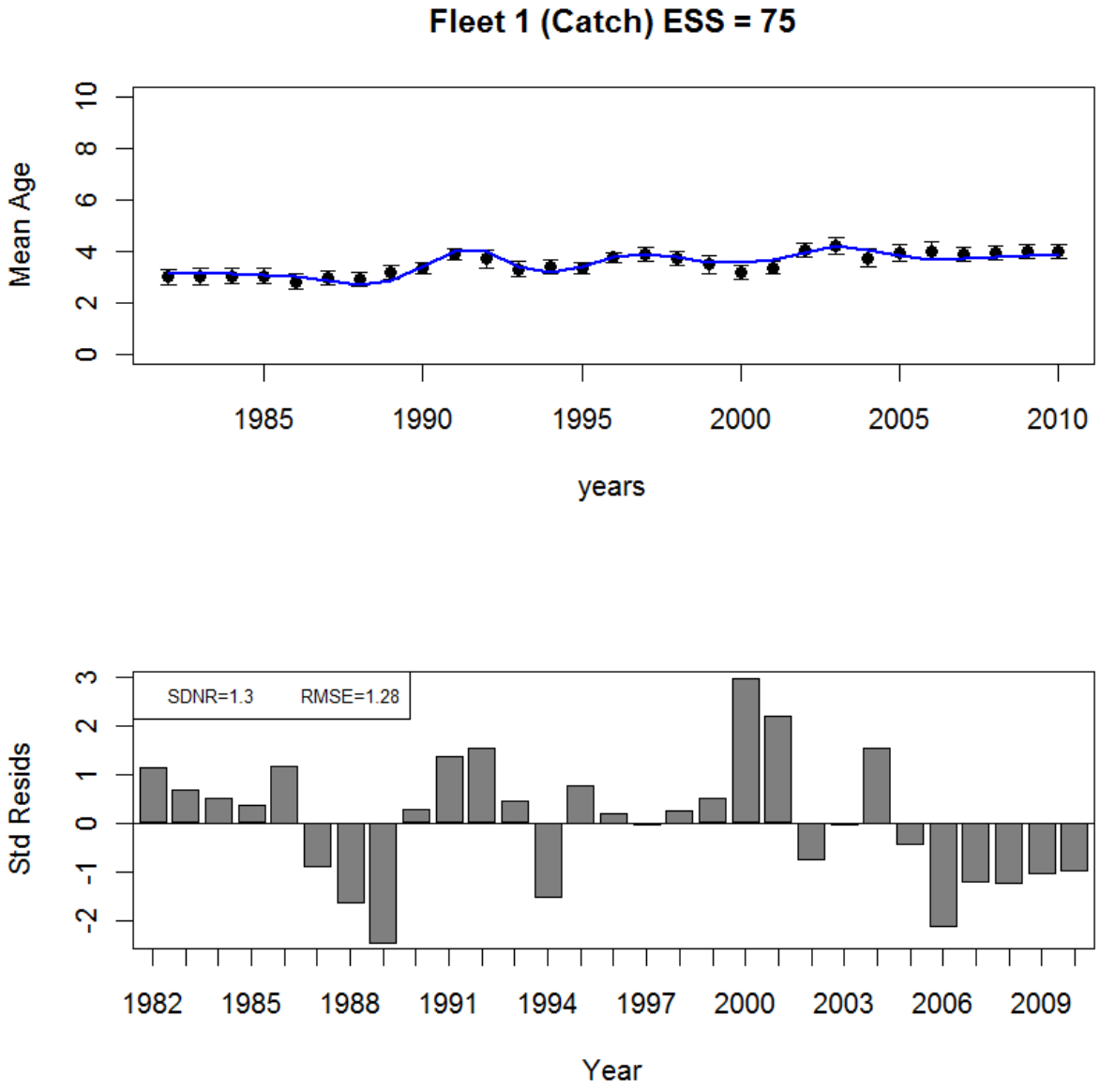


Figure A.113. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the fishery catch (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

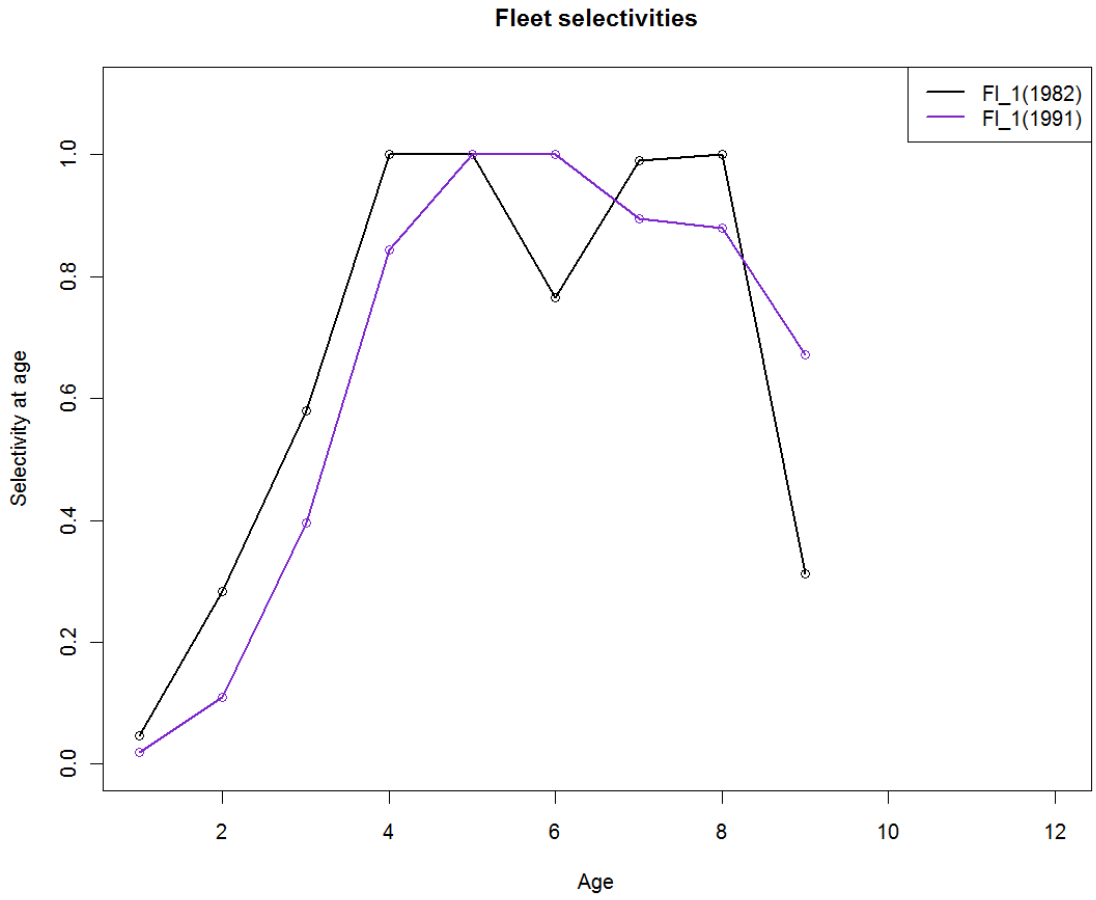


Figure A.114. ASAP BASE estimated Gulf of Maine Atlantic cod fishery selectivity blocks for block 1 (1982-1990) and block 2 (1991-2010).

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.

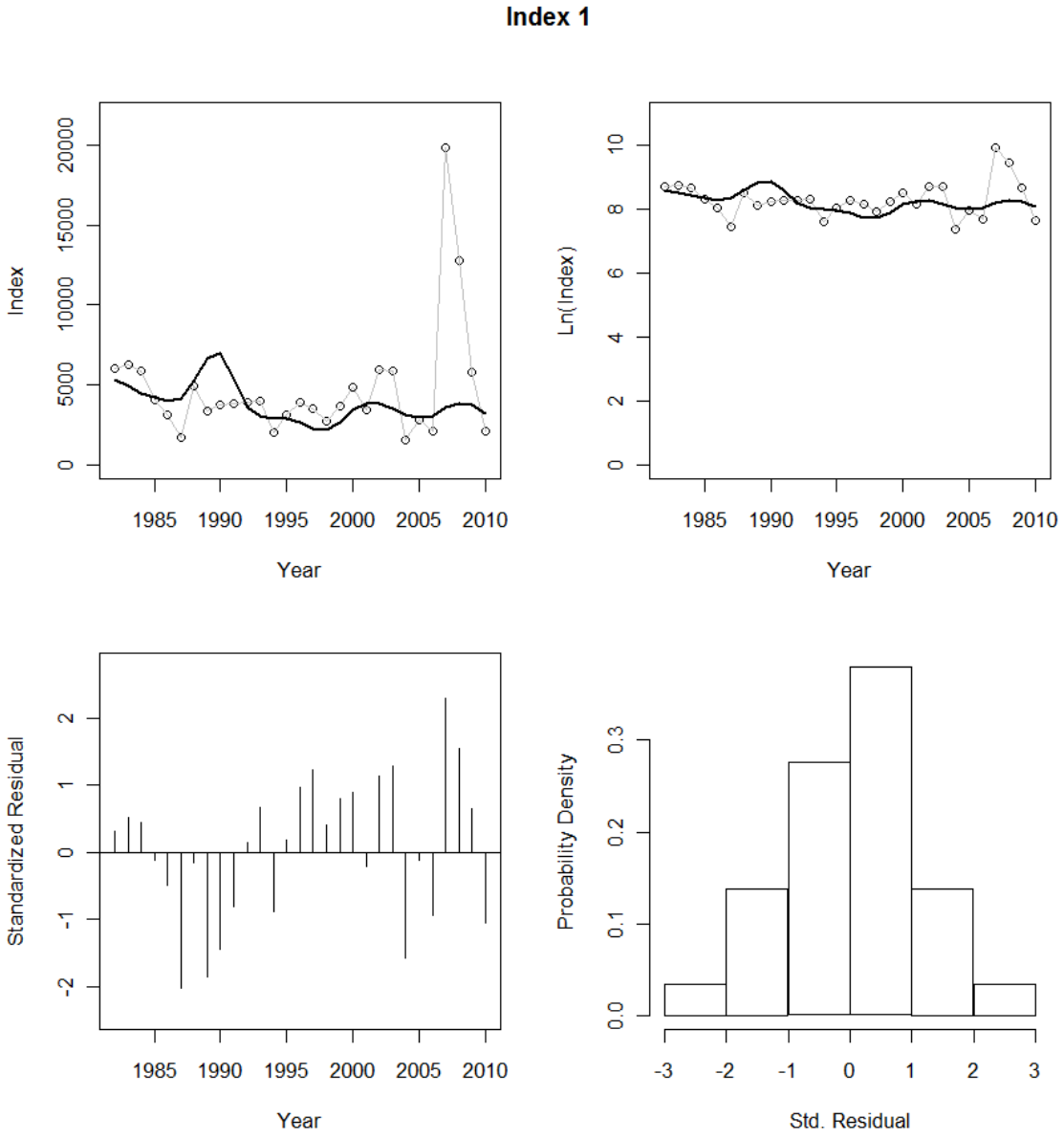


Figure A.116. ASAP BASE model fit to the NEFSC Gulf of Maine Atlantic cod spring (Index 1) survey.

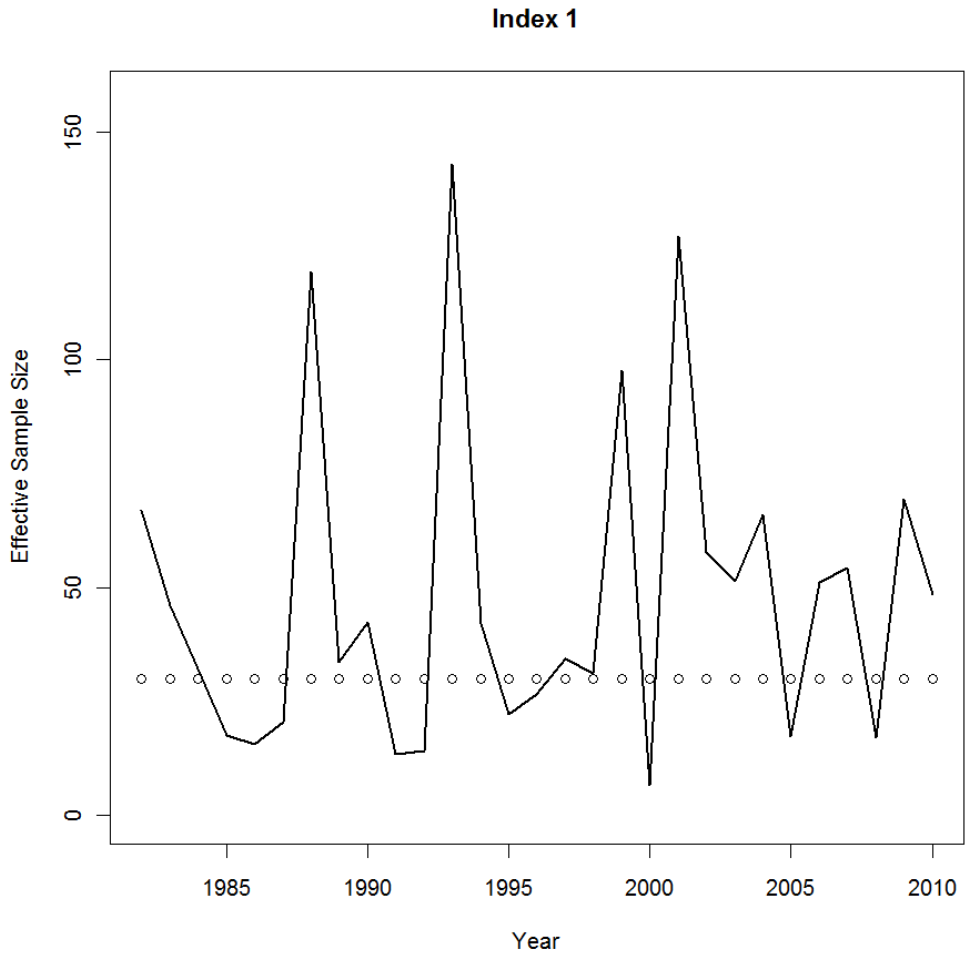


Figure A.117. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the NEFSC spring (Index 1) Gulf of Maine Atlantic cod index.

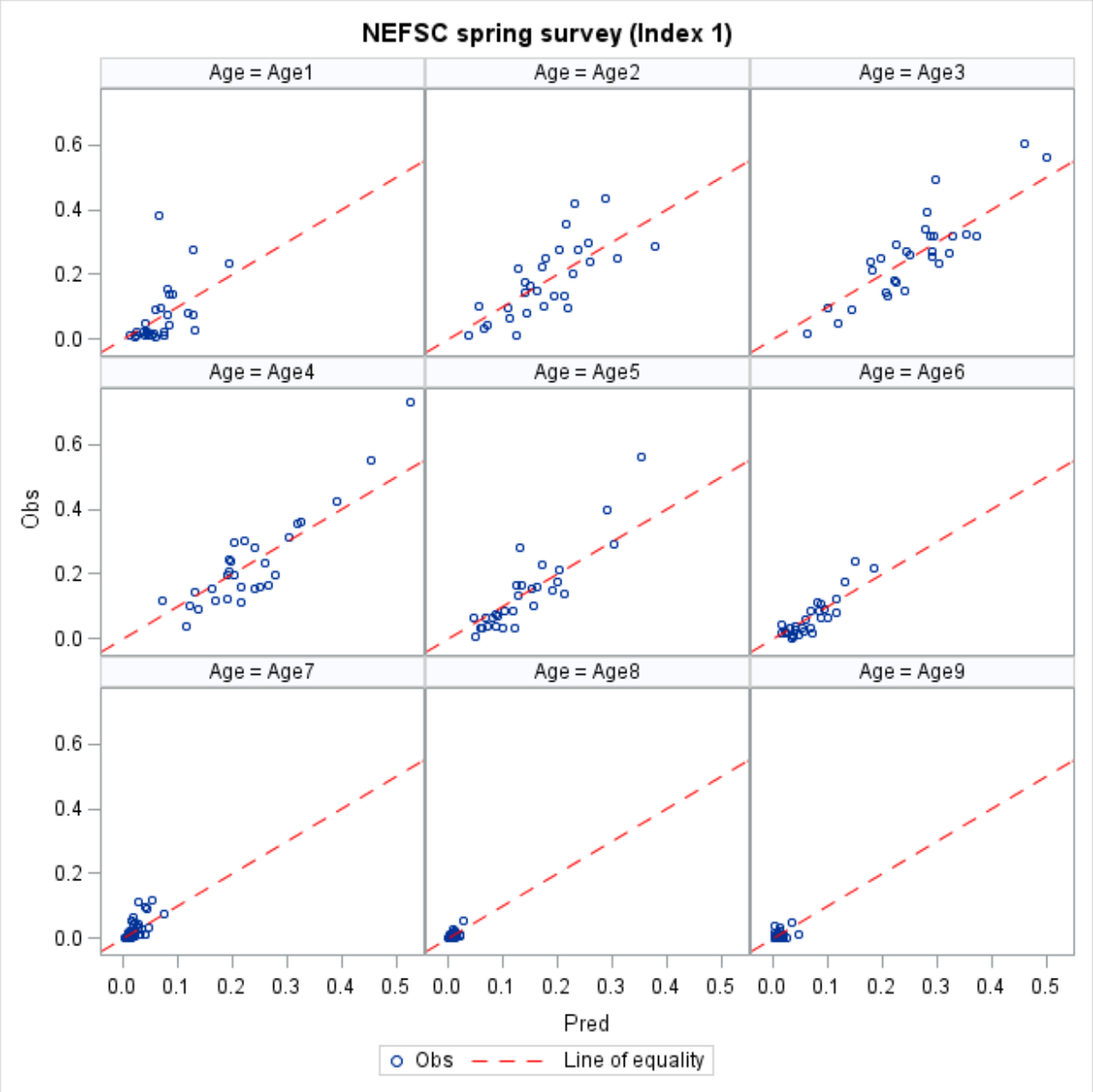


Figure A.118. Scatter plot of observed Gulf of Maine Atlantic cod NEFSC spring survey (Index1) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

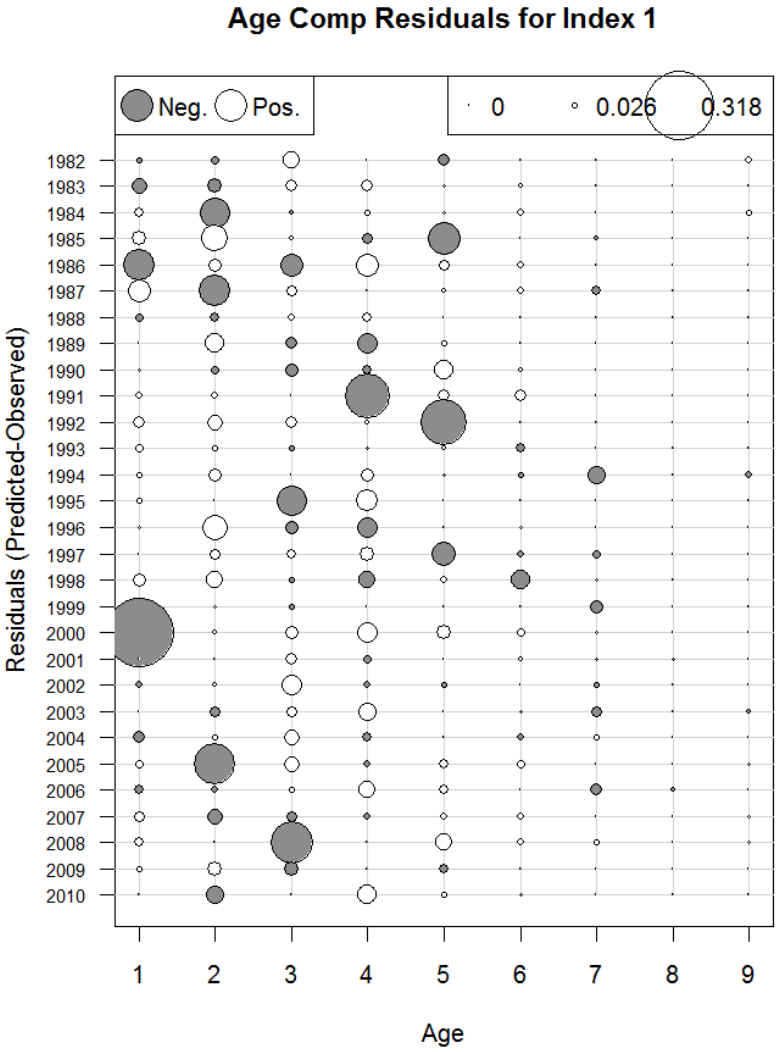


Figure A.119. ASAP BASE model fit residuals for the NEFSC spring survey (Index 1) Gulf of Maine Atlantic cod age composition.

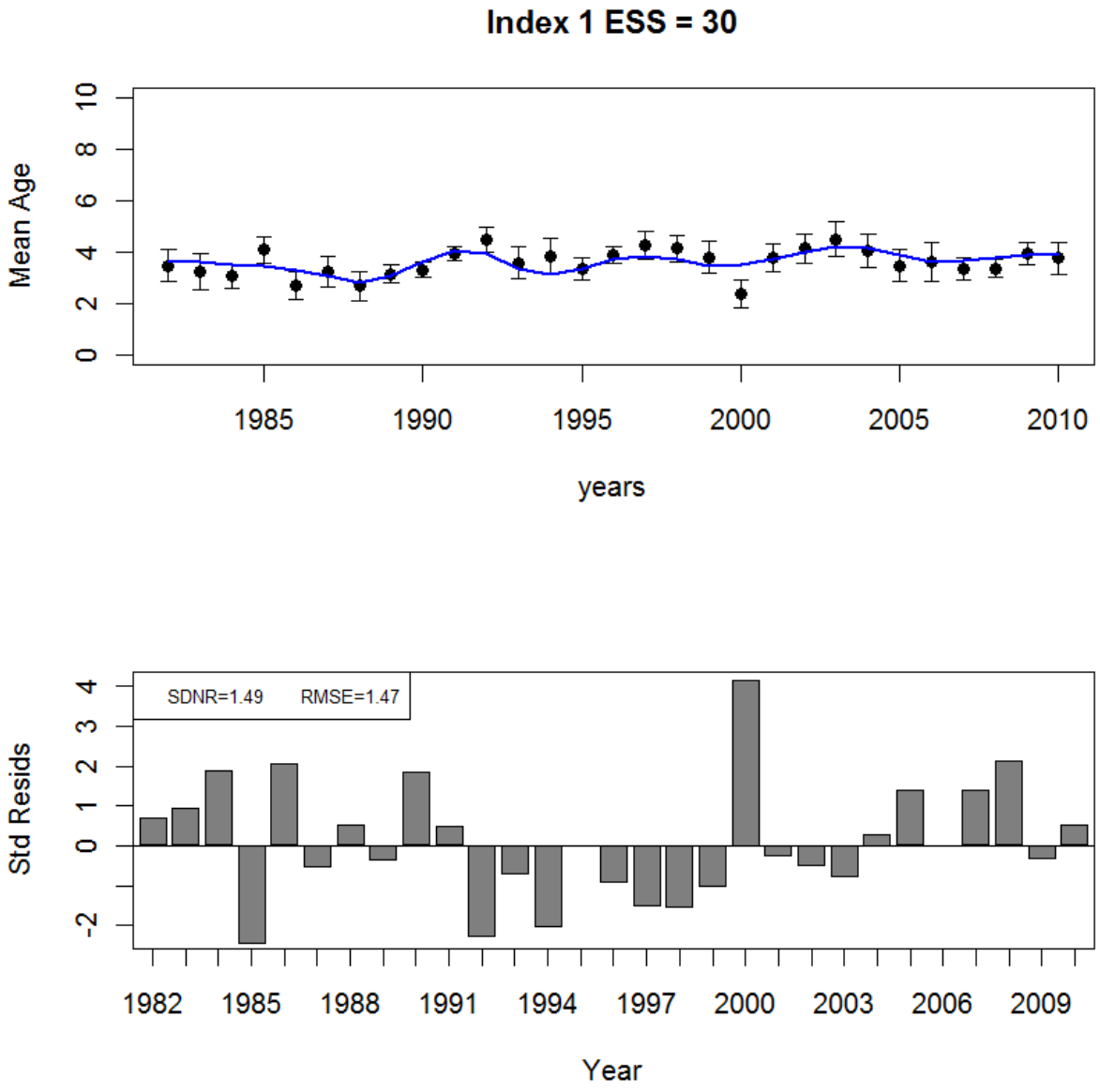


Figure A.120. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC spring (Index 1) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

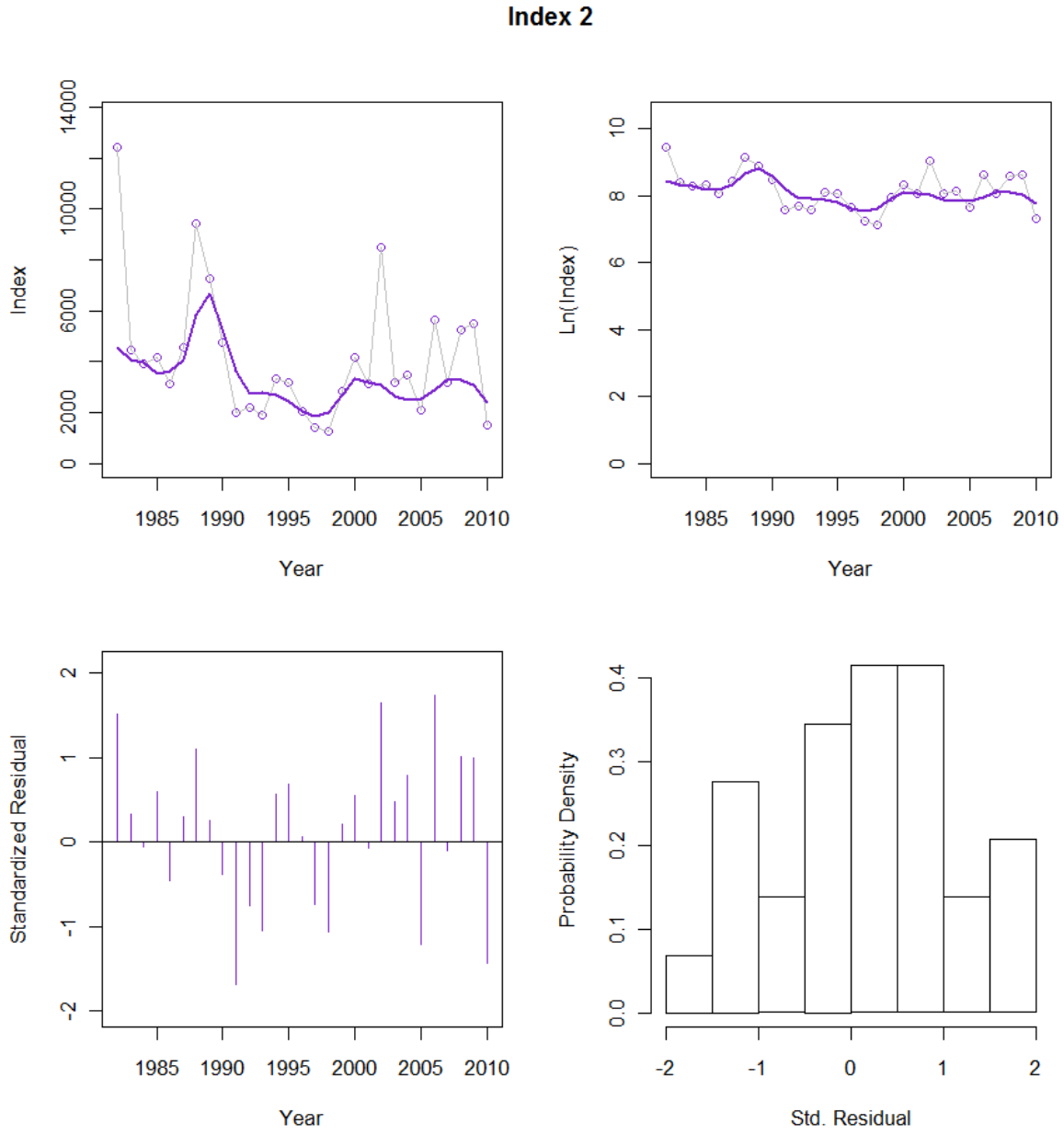


Figure A.121. ASAP BASE model fit to the NEFSC fall (Index 2) survey Gulf of Maine Atlantic cod index.

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.

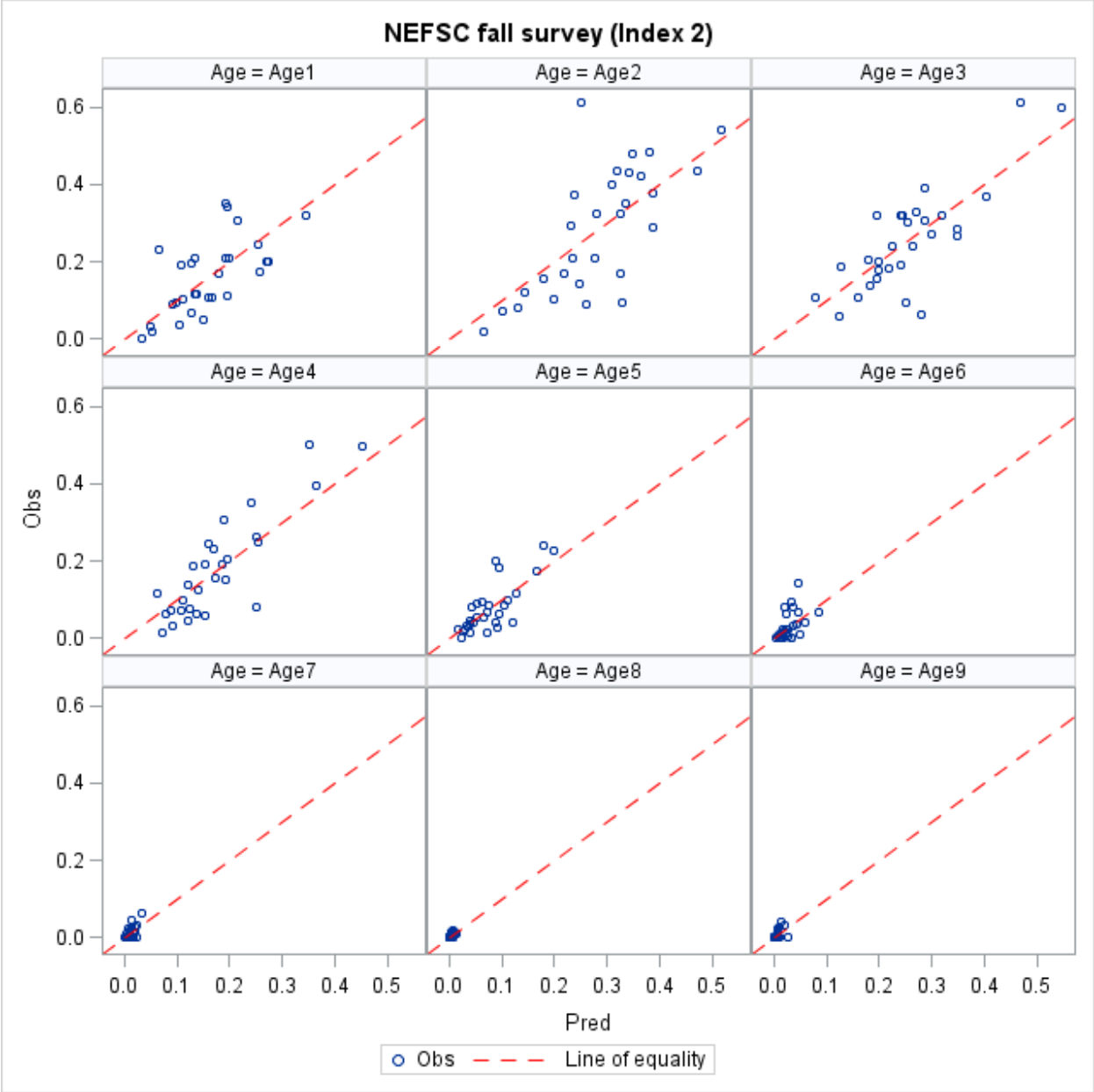


Figure A.123. Scatter plot of observed Gulf of Maine Atlantic cod NEFSC fall survey (Index2) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

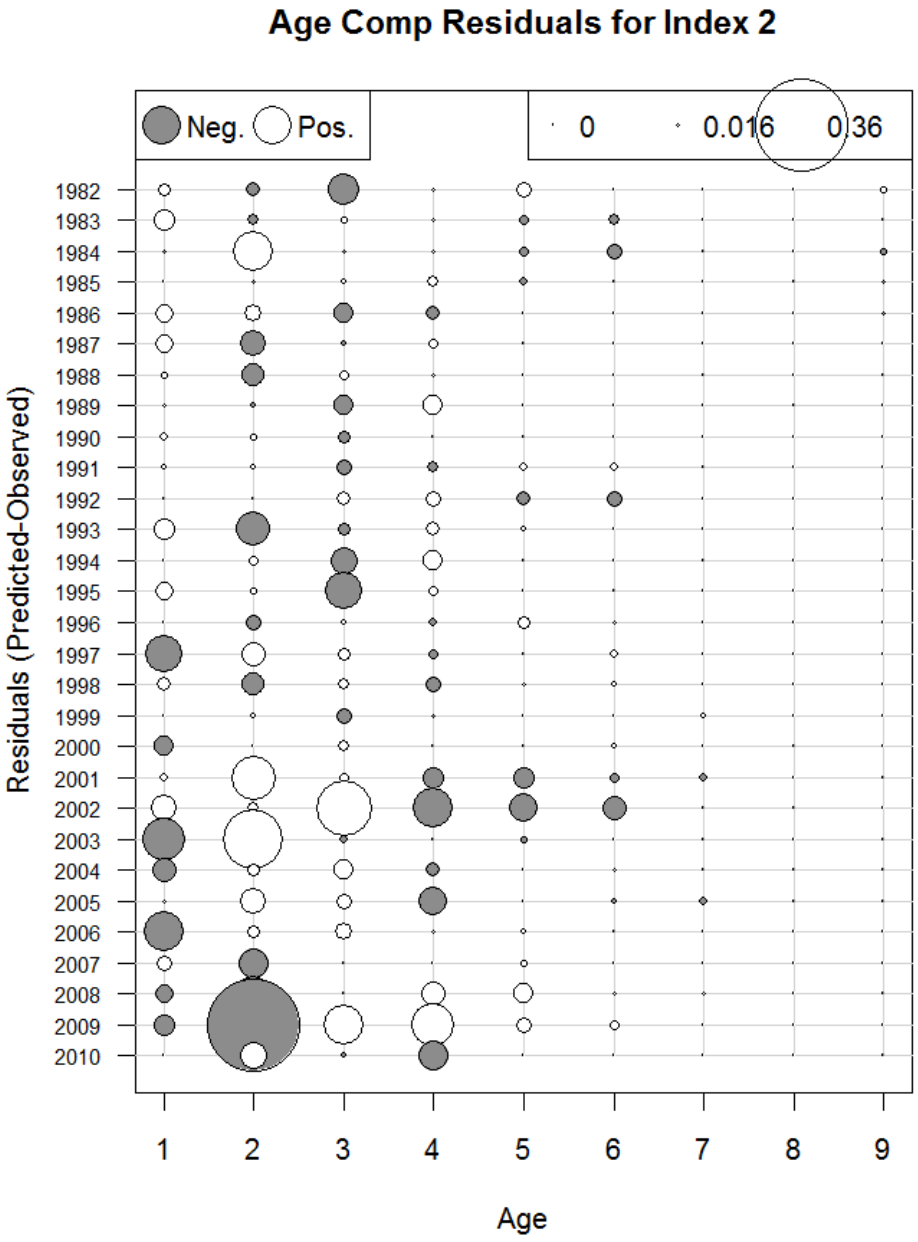


Figure A.124. ASAP BASE model fit residuals for the NEFSC fall survey (Index 2) Gulf of Maine Atlantic cod age composition.

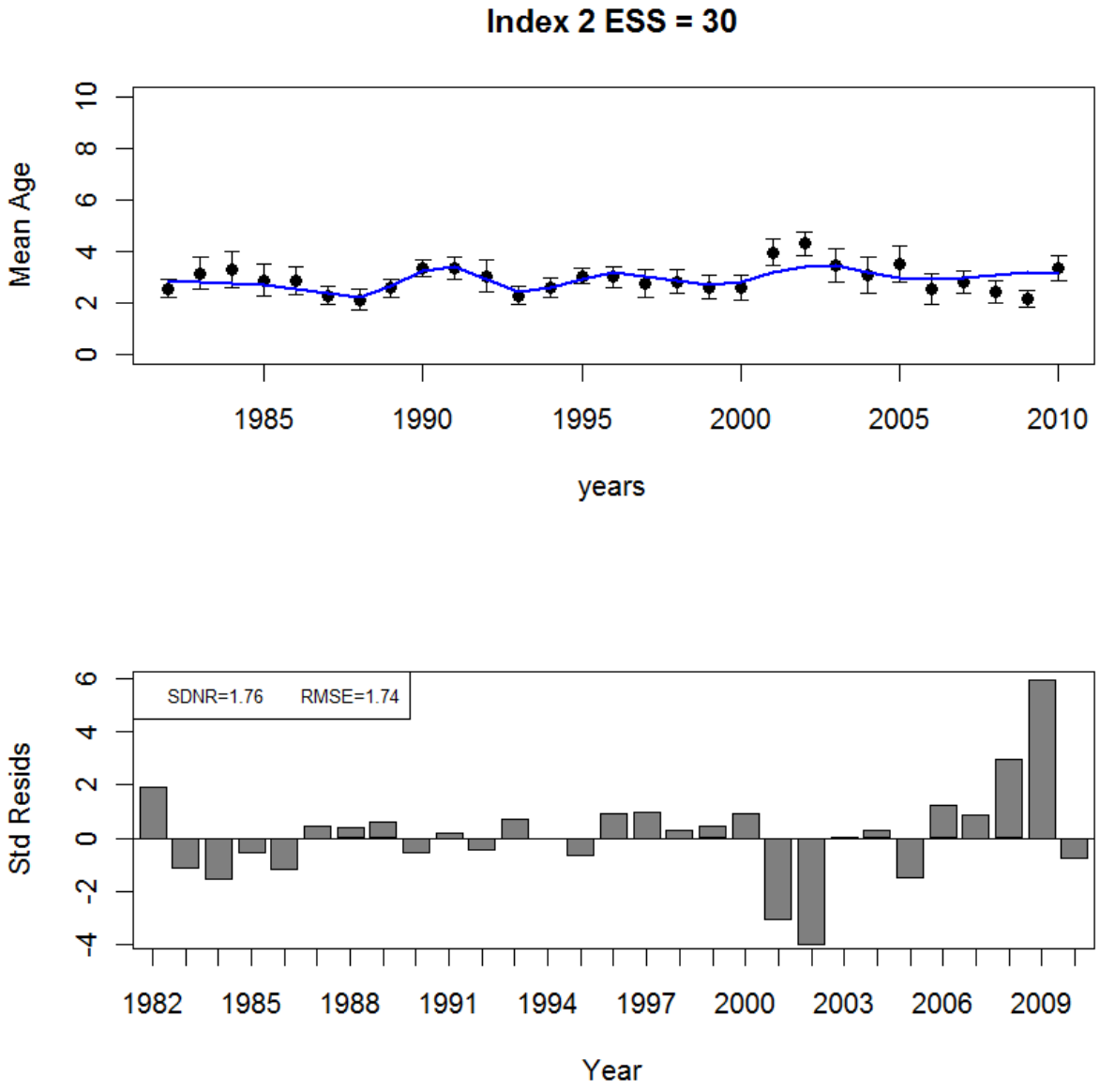


Figure A.125. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the NEFSC fall (Index 2) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

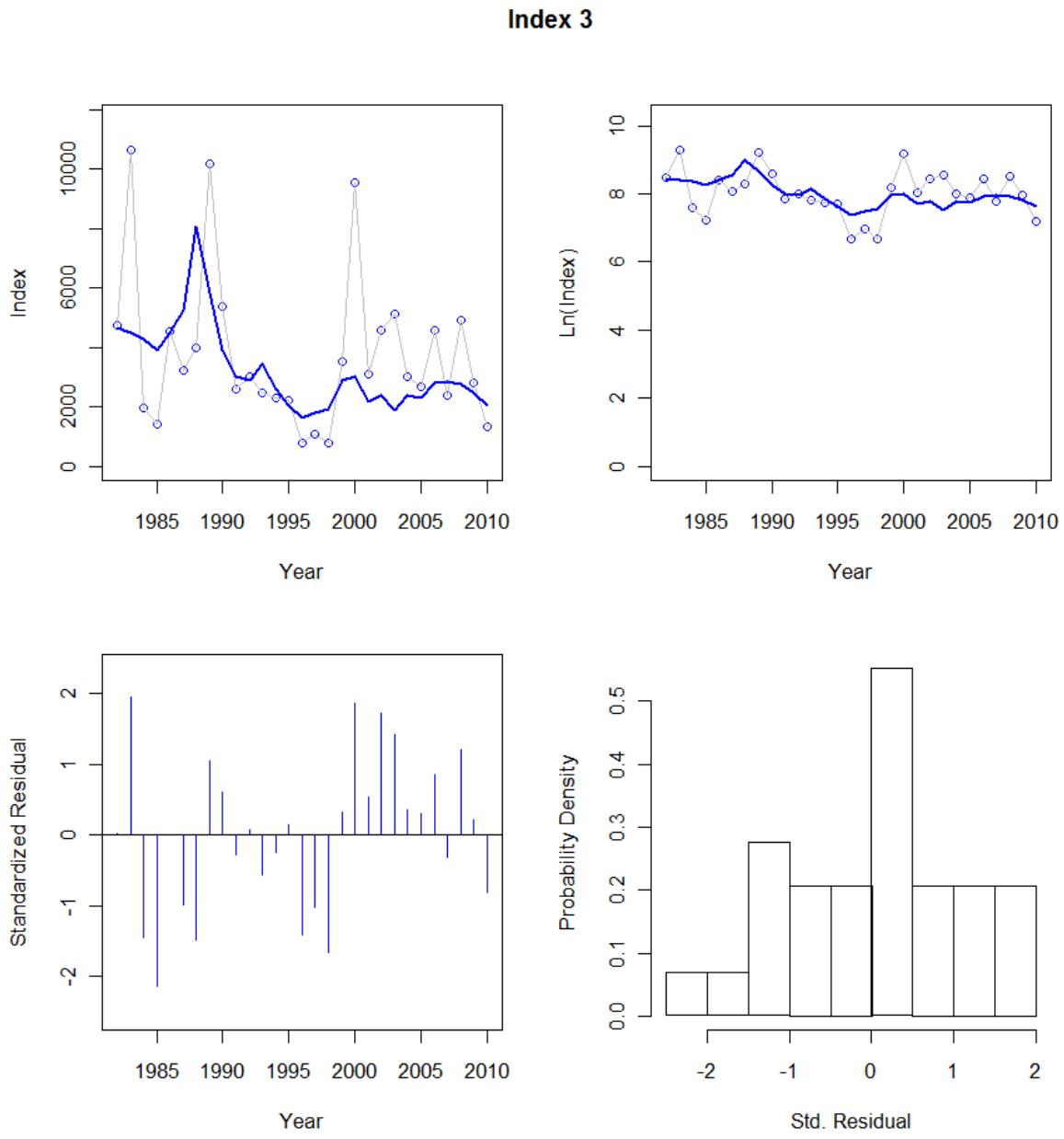


Figure A.126. ASAP BASE model fit to the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

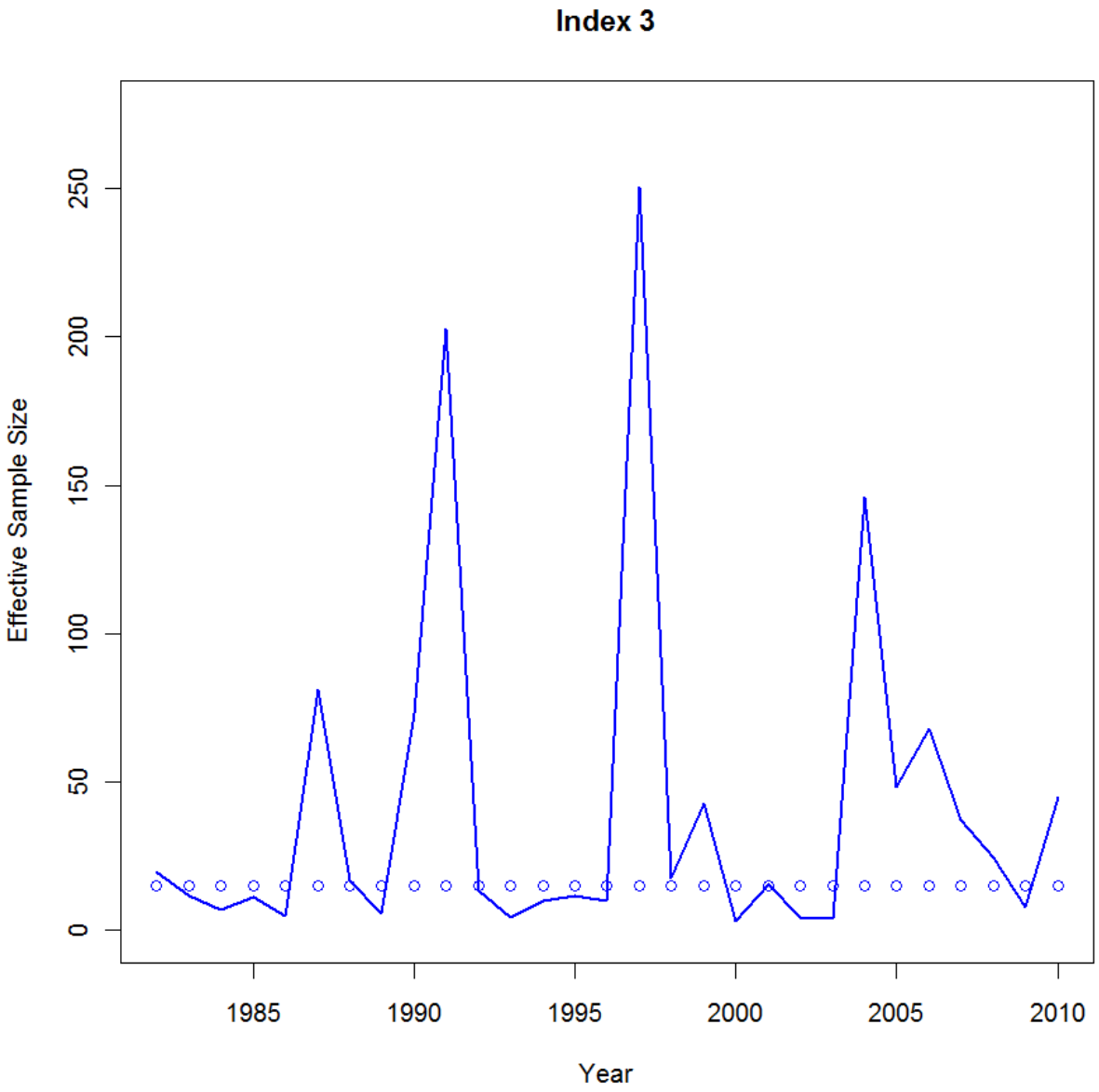


Figure A.127. ASAP base model comparison of input effective sample size versus the model estimated effective sample size for the MADMF spring (Index 3) survey Gulf of Maine Atlantic cod index.

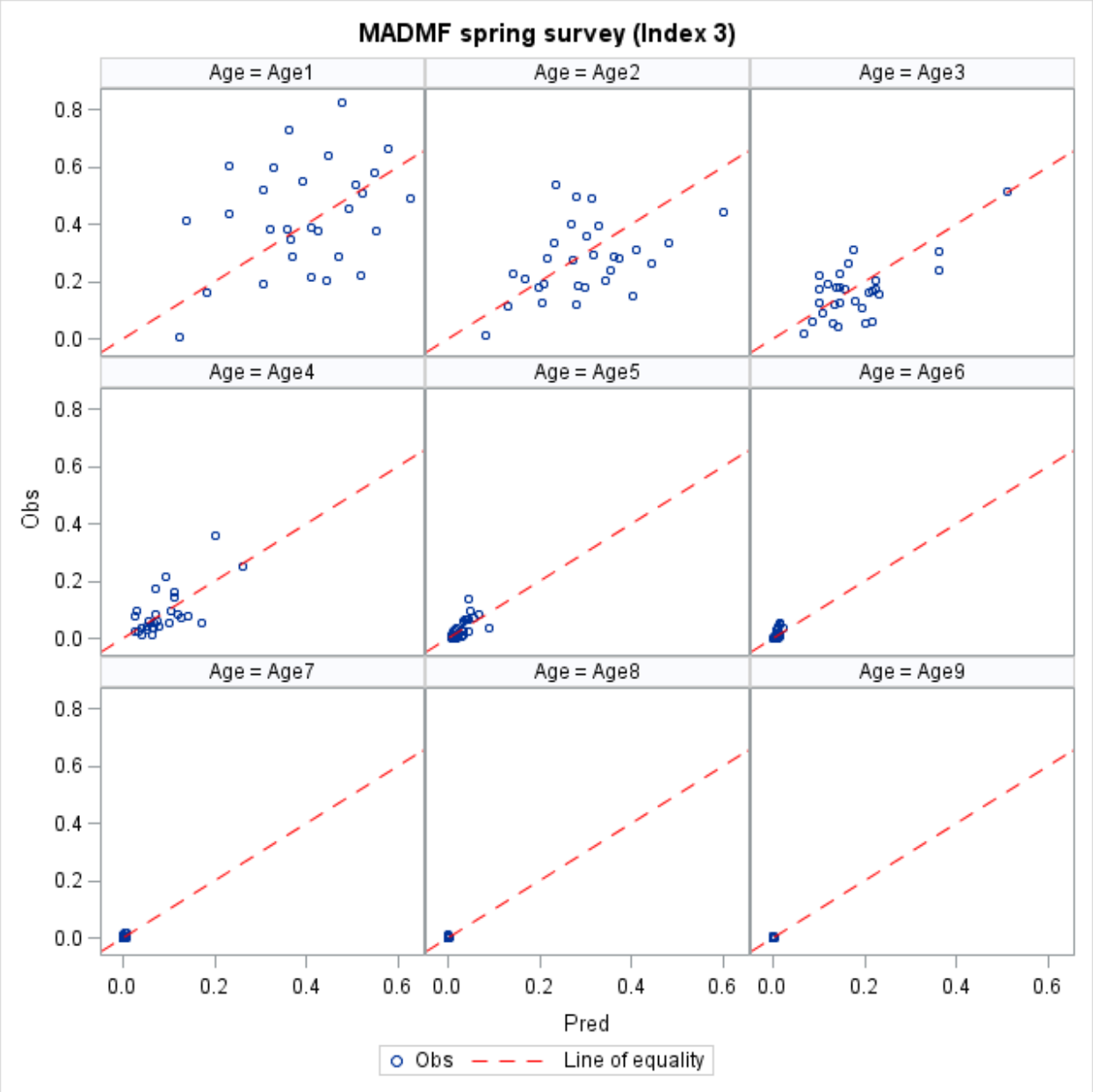


Figure A.128. Scatter plot of observed Gulf of Maine Atlantic cod MADMF spring survey (Index3) indices-at-age (obs) compared to the ASAP BASE model predicted survey indices (pred). The 1:1equality line is indicated by a dashed red line.

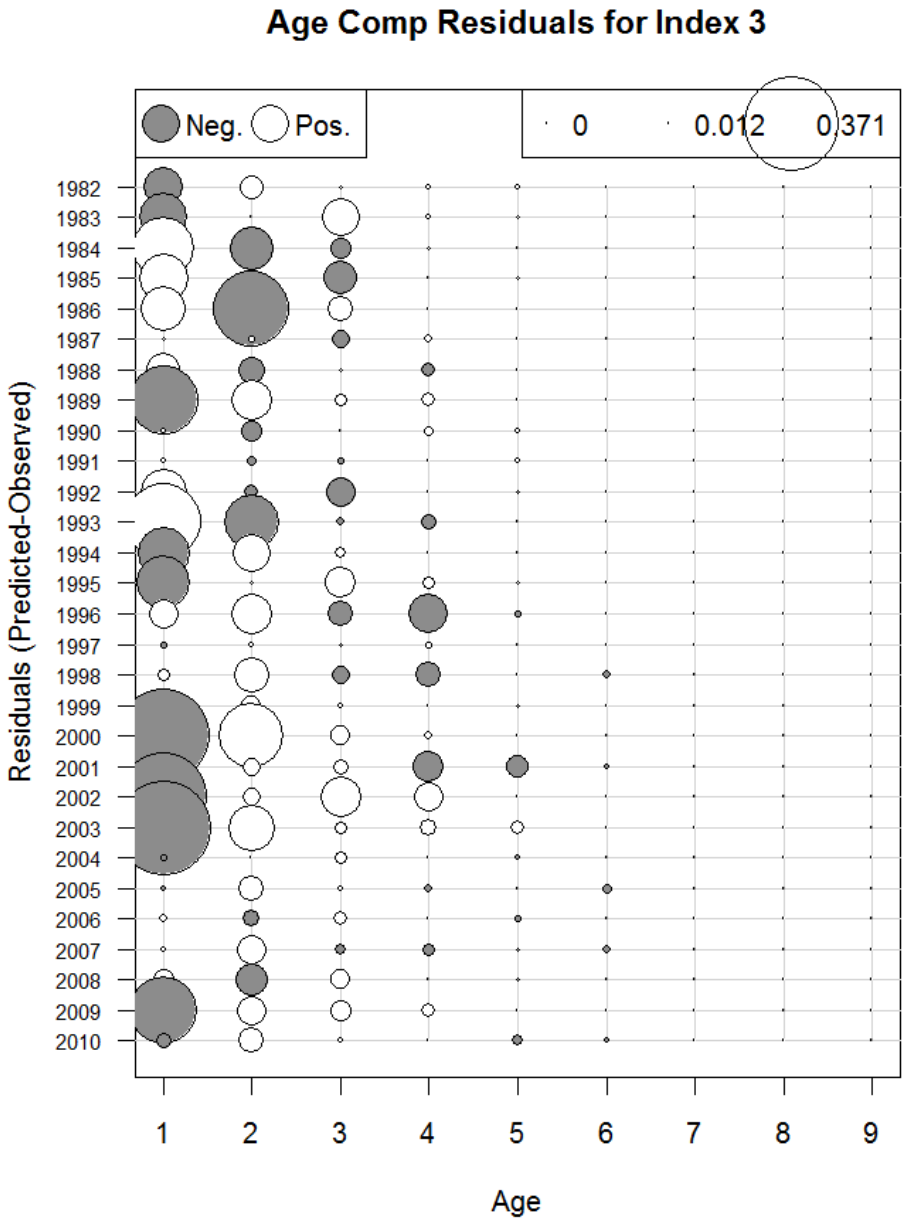


Figure A.129. ASAP BASE model fit residuals for the MADMF spring survey (Index 3) Gulf of Maine Atlantic cod age composition.

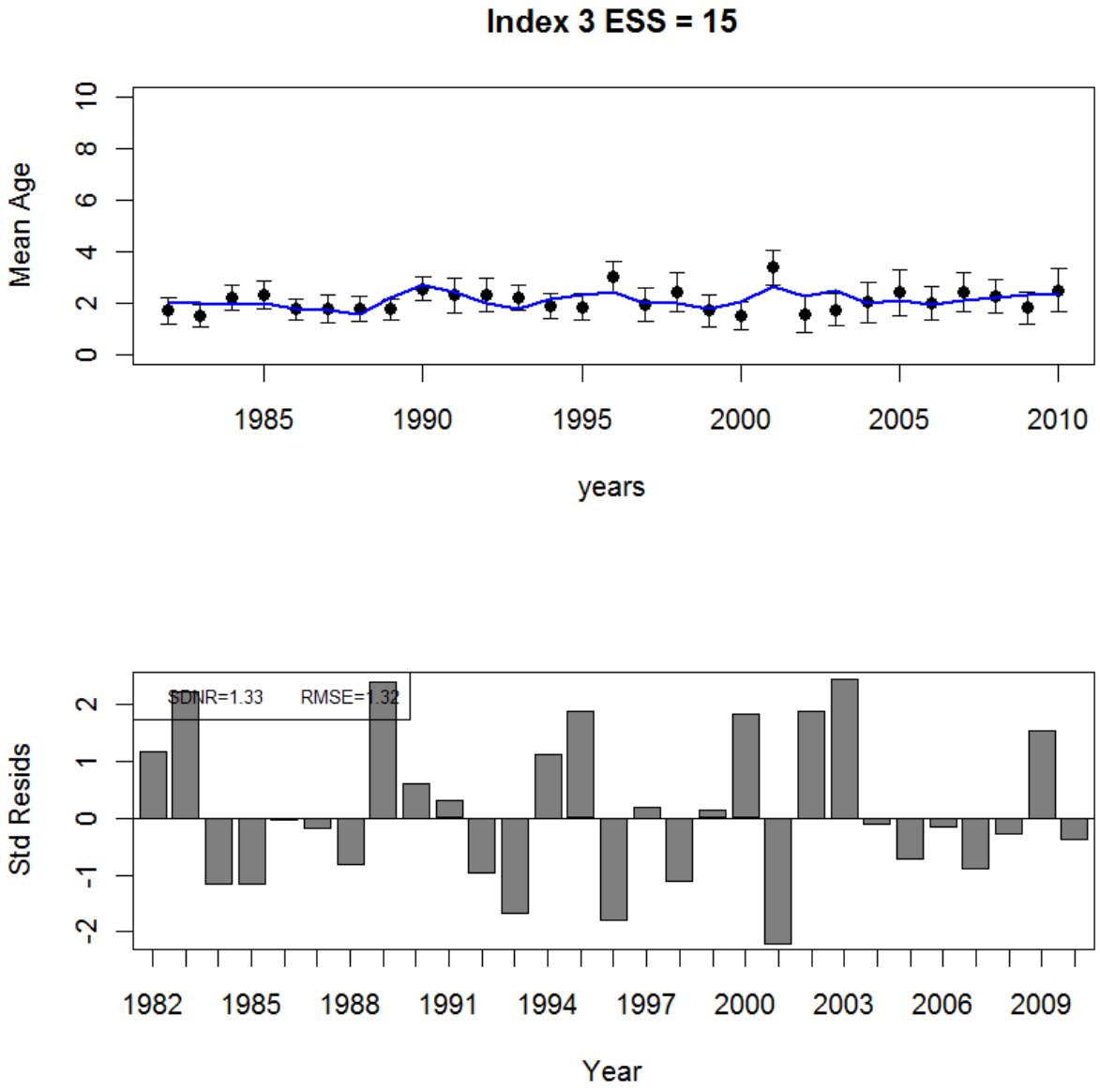


Figure A.130. ASAP BASE predicted mean age of Gulf of Maine Atlantic cod in the MADMF spring (Index 3) survey (blue line) compared to observed mean age (top plot) and the residuals about the mean (bottom plot).

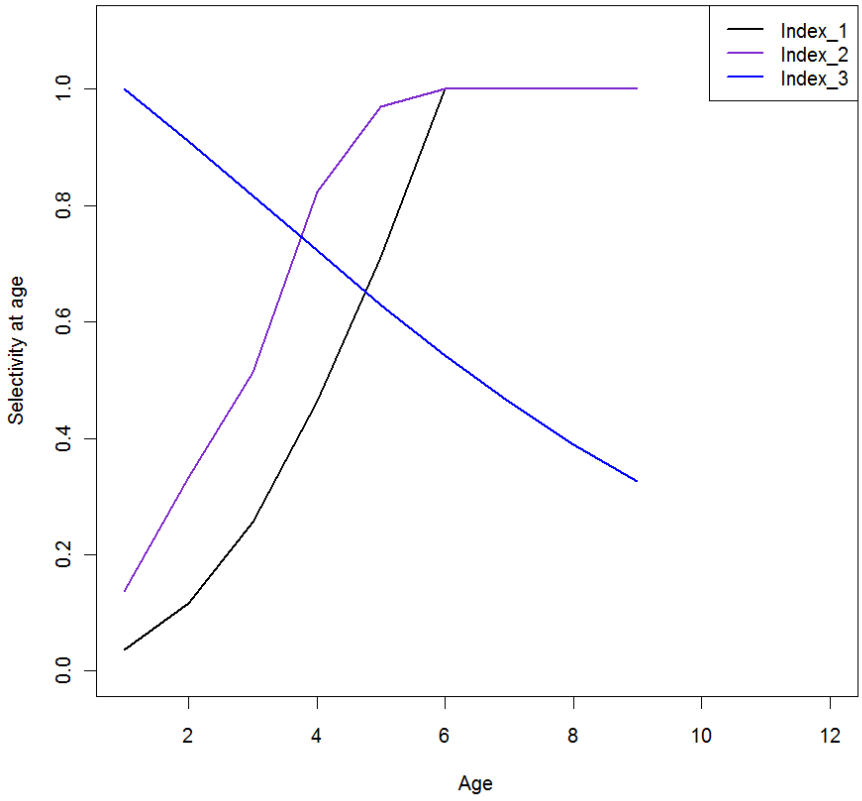


Figure A.131. Gulf of Maine Atlantic cod selectivity-at-age for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP BASE model.

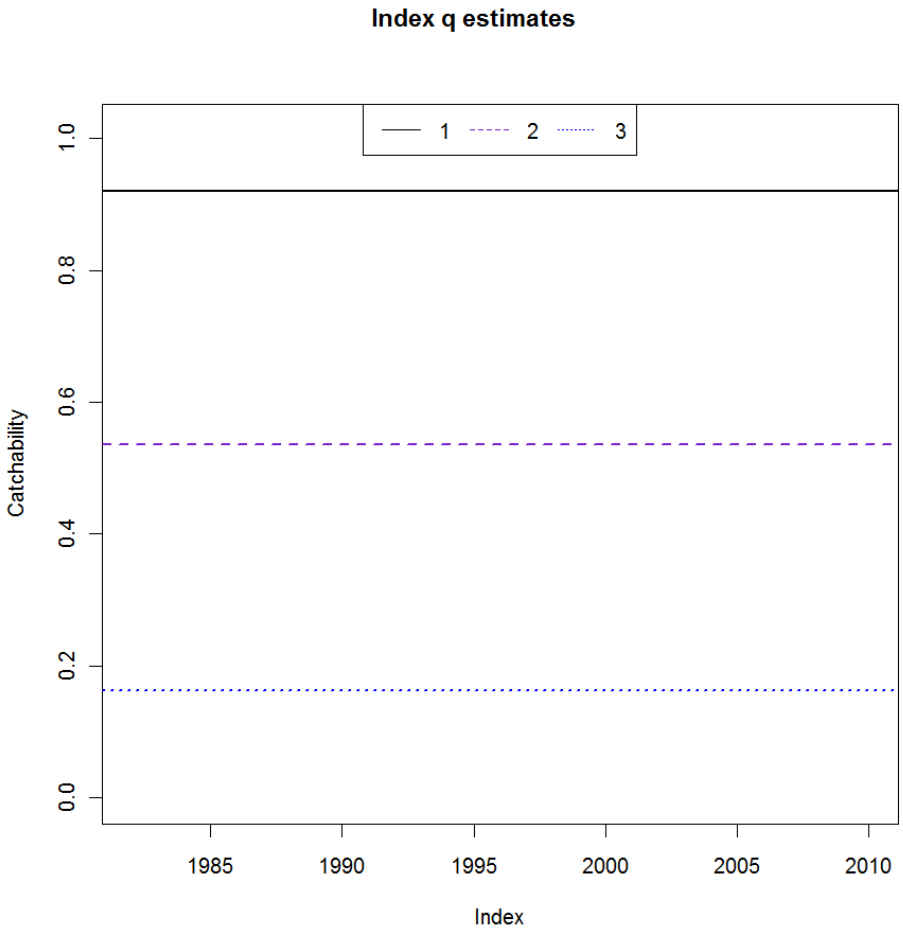


Figure A.132. Gulf of Maine Atlantic cod survey catchability (q) for the NEFSC spring (Index 1), fall (Index 2) and MADMF spring (Index 3) surveys from the ASAP BASE model.

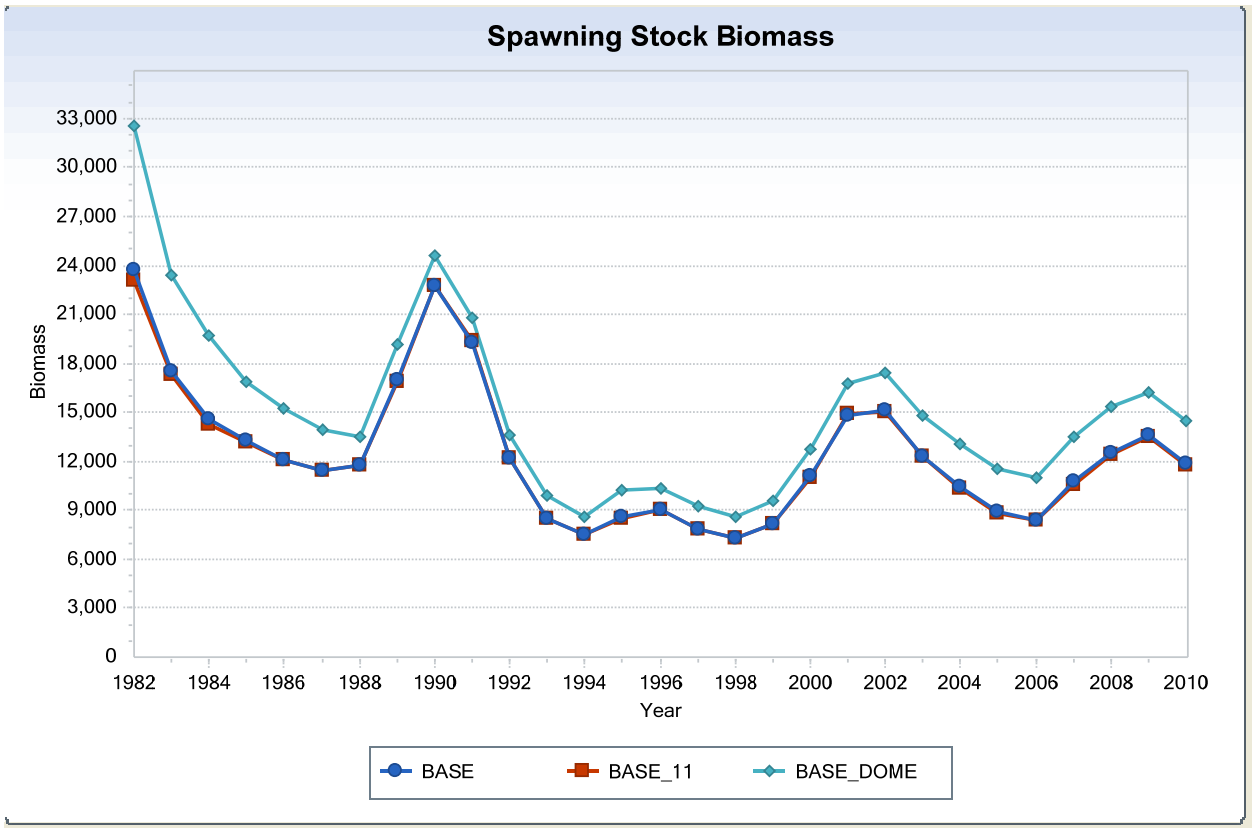


Figure A.133. Comparison of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

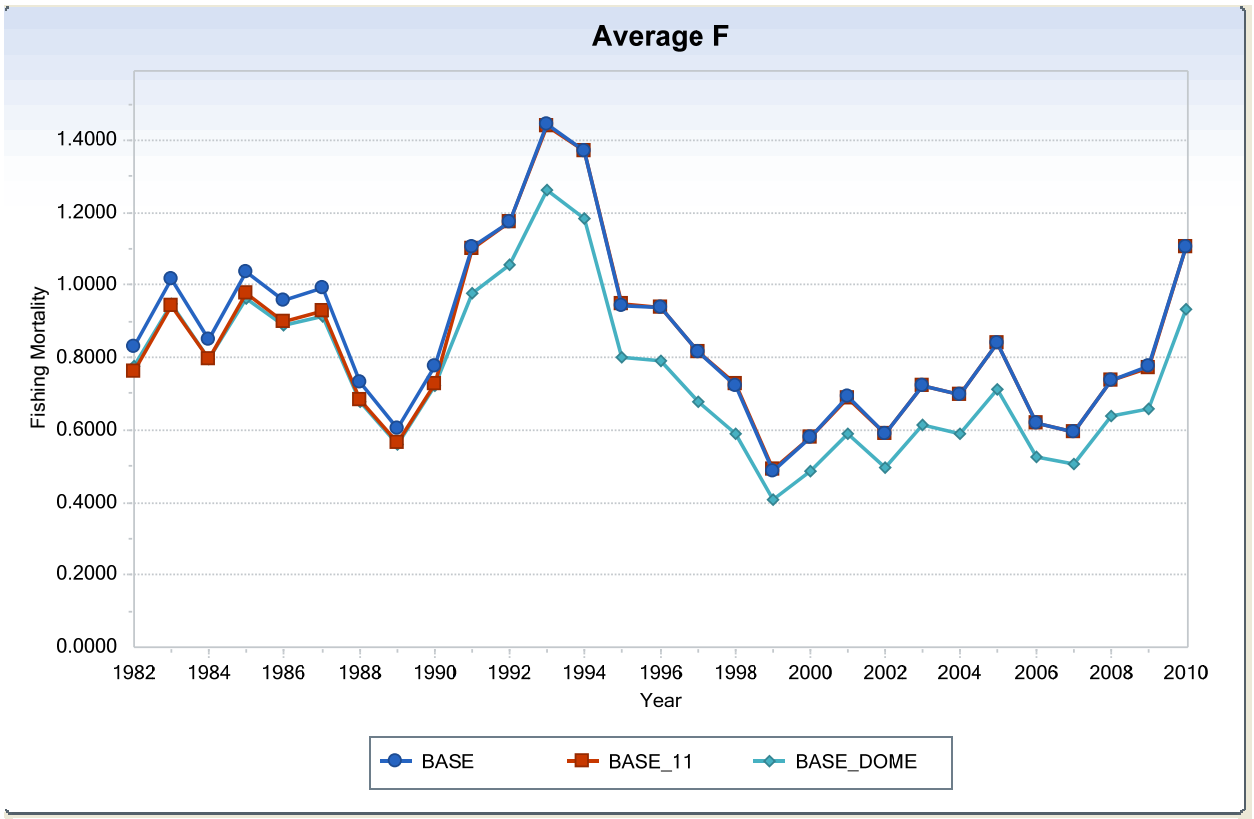


Figure A.134. Comparison of Gulf of Maine Atlantic cod fishing mortality (age 5 – 7) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

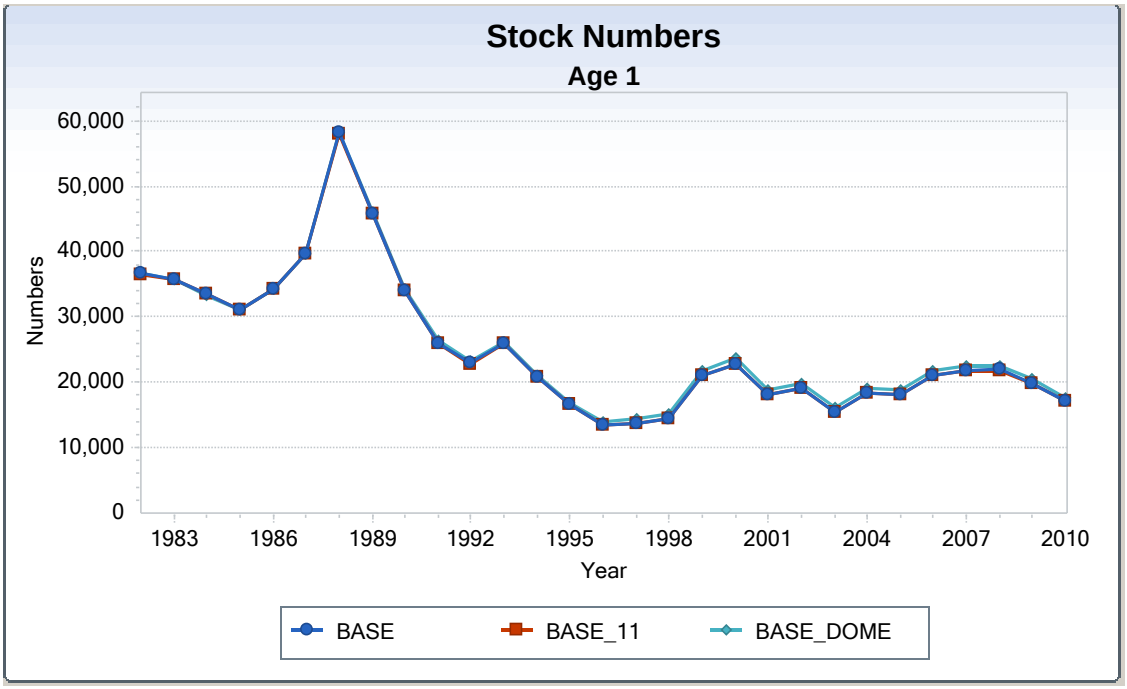


Figure A.135. Comparison of Gulf of Maine Atlantic cod age 1 recruitment (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

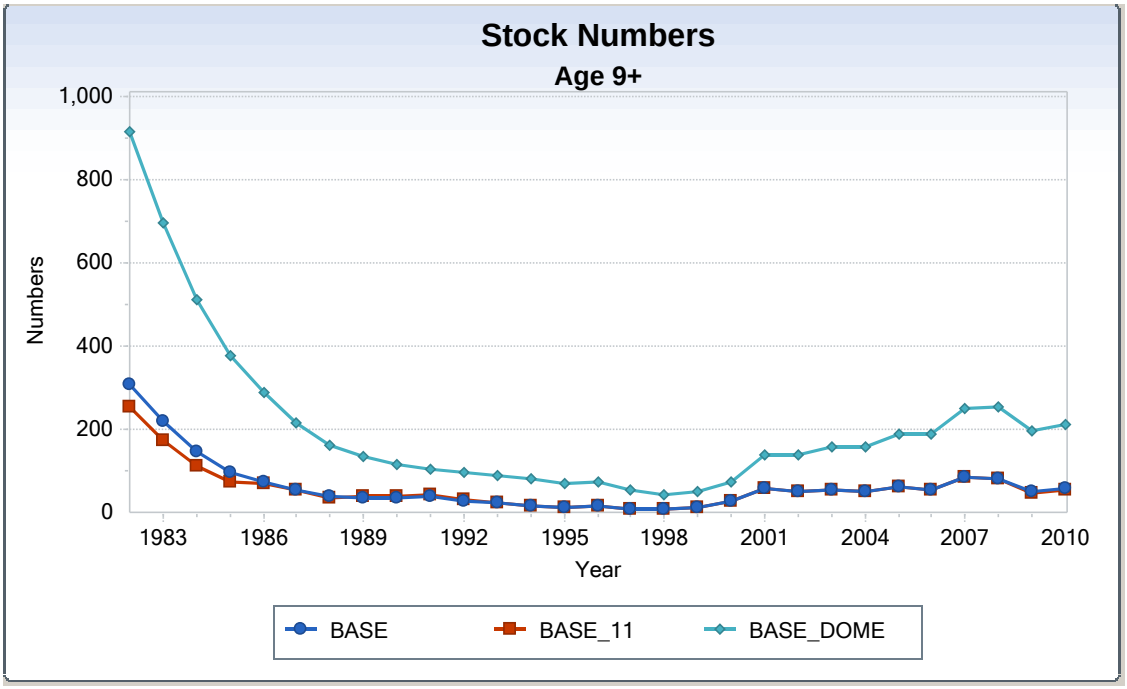


Figure A.136. Comparison of Gulf of Maine Atlantic cod age 9 numbers (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to an expanded age structure (out to age 11^{+}, BASE_11) and flexibility in the survey selectivity at older ages (BASE_DOME).

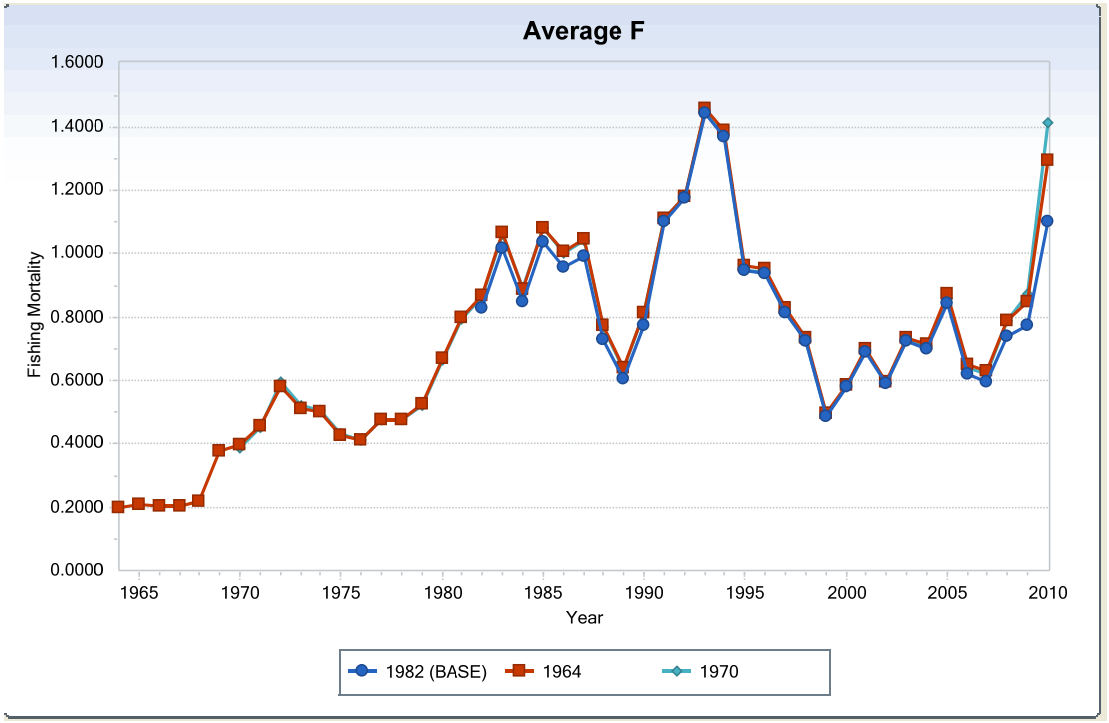


Figure A.137. Comparison of Gulf of Maine Atlantic cod fishing mortality (age 5 – 7) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

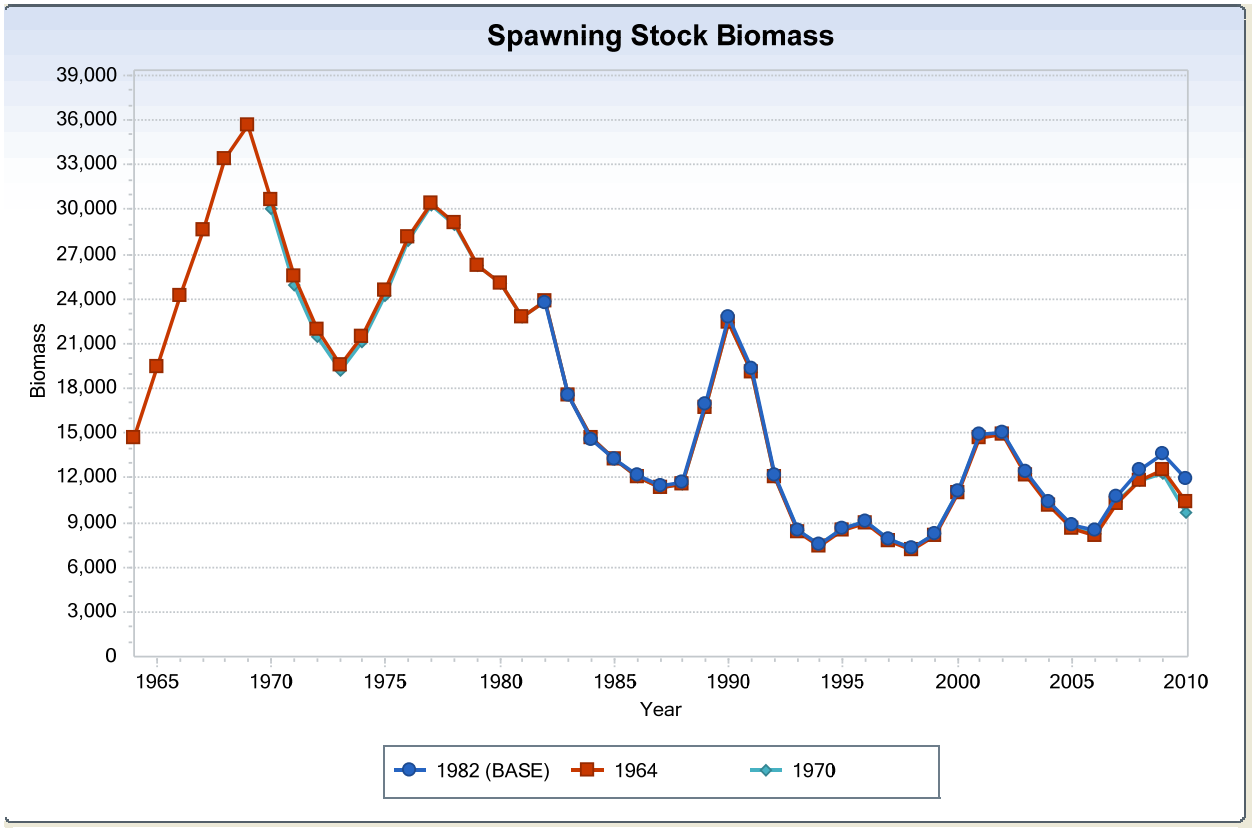


Figure A.138. Comparison of Gulf of Maine Atlantic cod spawning stock biomass (mt) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

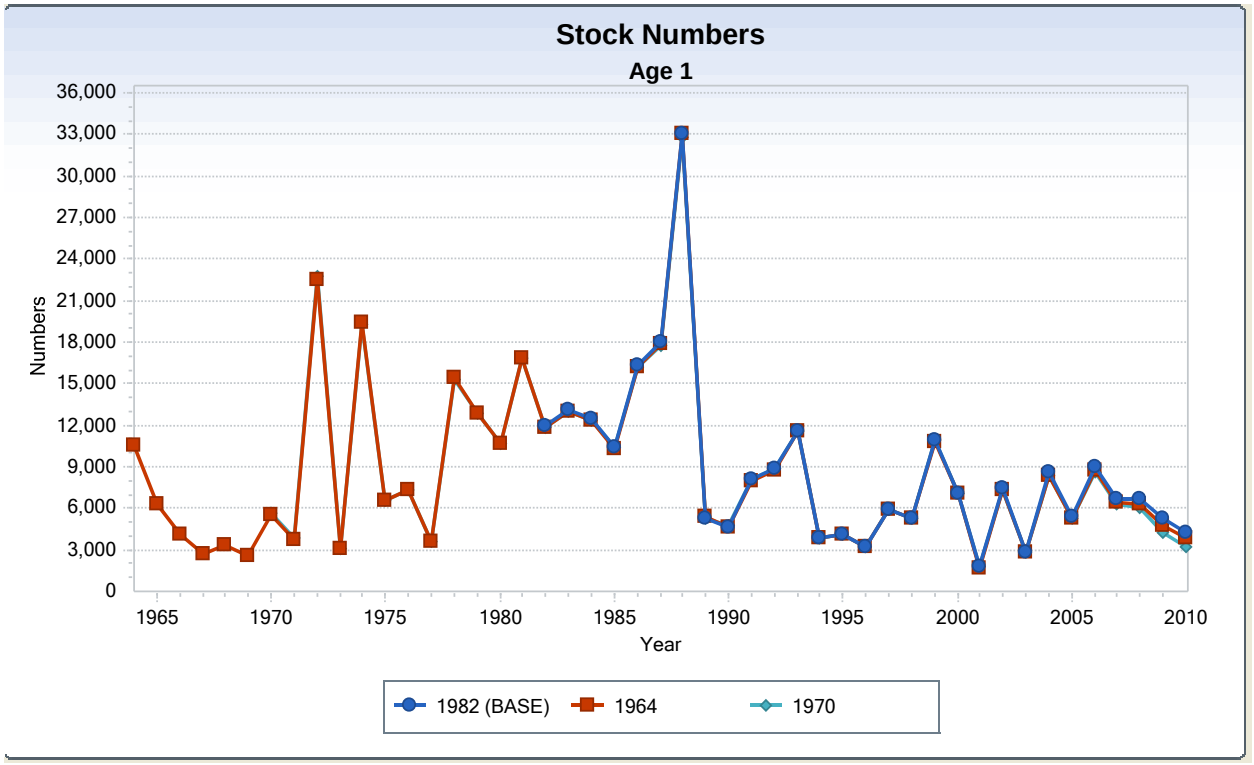


Figure A.139. Comparison of Gulf of Maine Atlantic cod age 1 recruitment (000s) from ASAP sensitivity runs exploring sensitivity of the BASE model to alternate starting years of 1964 and 1970 (relative to the BASE starting year of 1982).

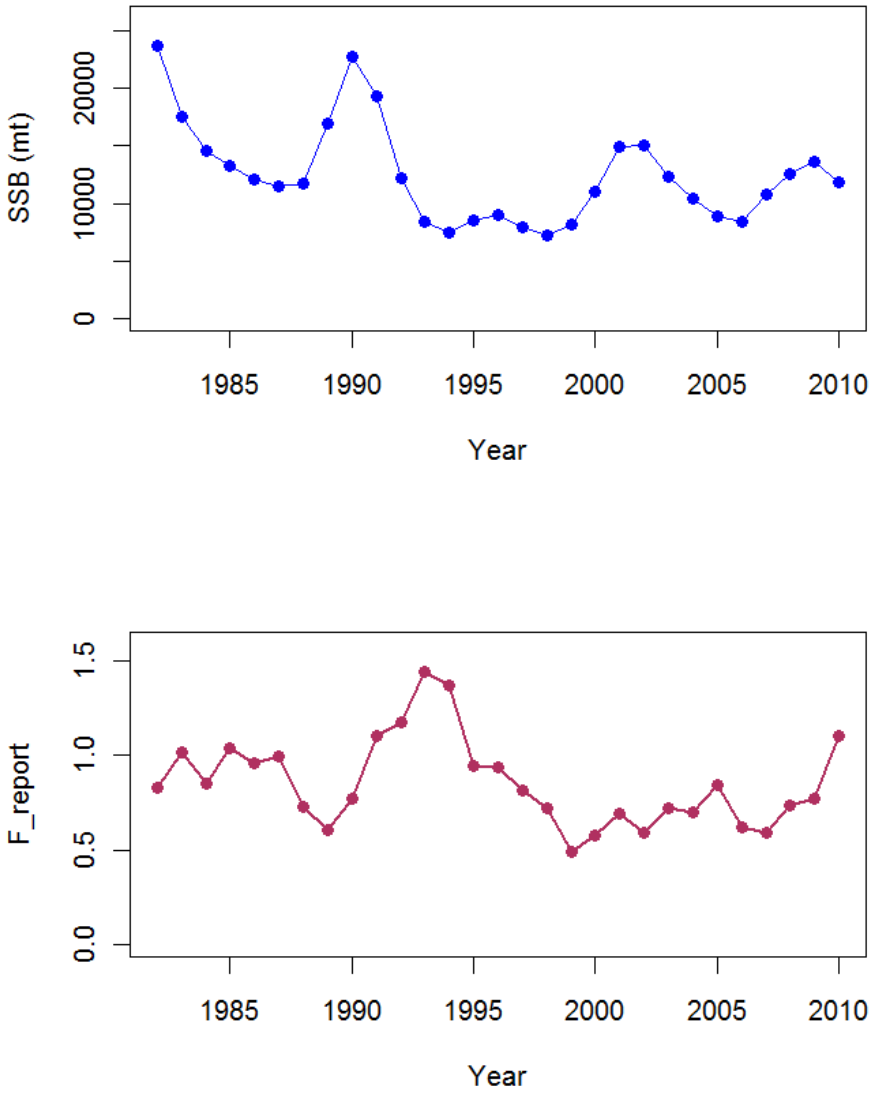


Figure A.140. ASAP BASE model estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) and average fishing mortality (F_{5-7} = F_report).

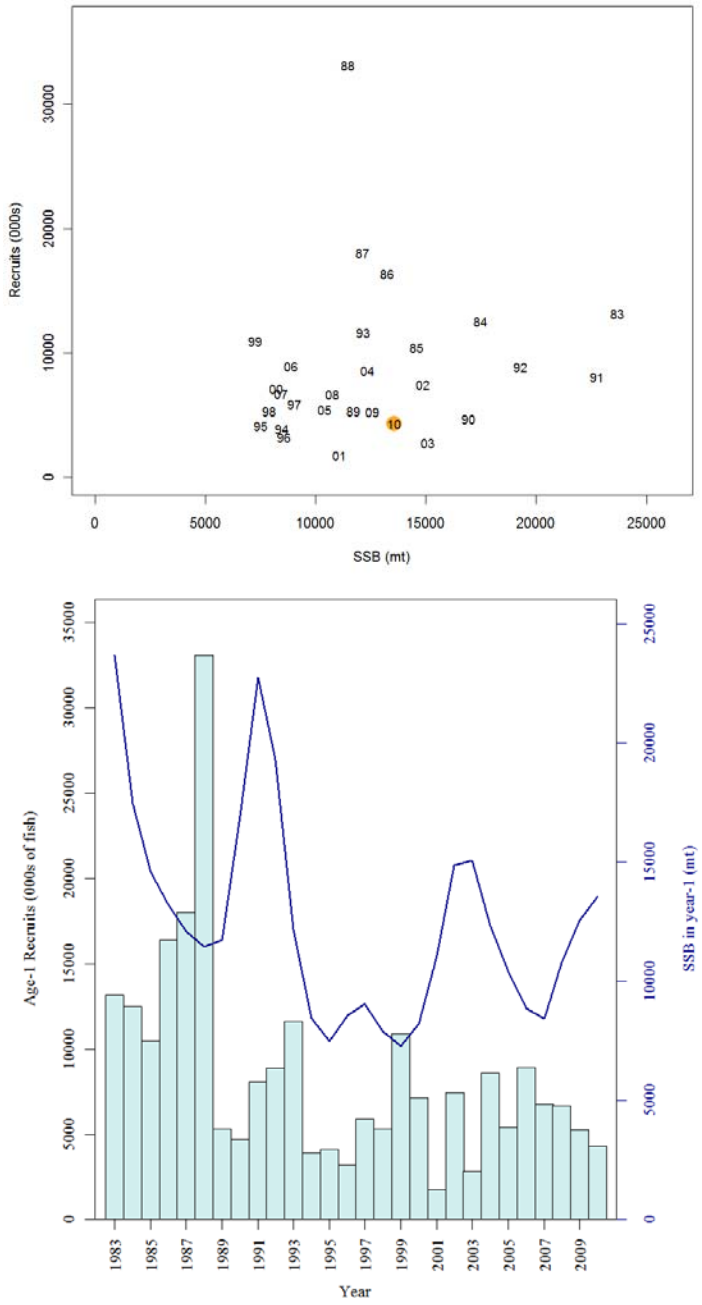


Figure A.141. Top: scatterplot of ASAP estimates of Gulf of Maine Atlantic cod spawning stock biomass (SSB) versus recruitment at age 1 (000s). The symbol for each observation is the last two digits of the year (e.g., 88 indicated age 1 estimates of the 1987 year class). The most recent recruitment estimate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

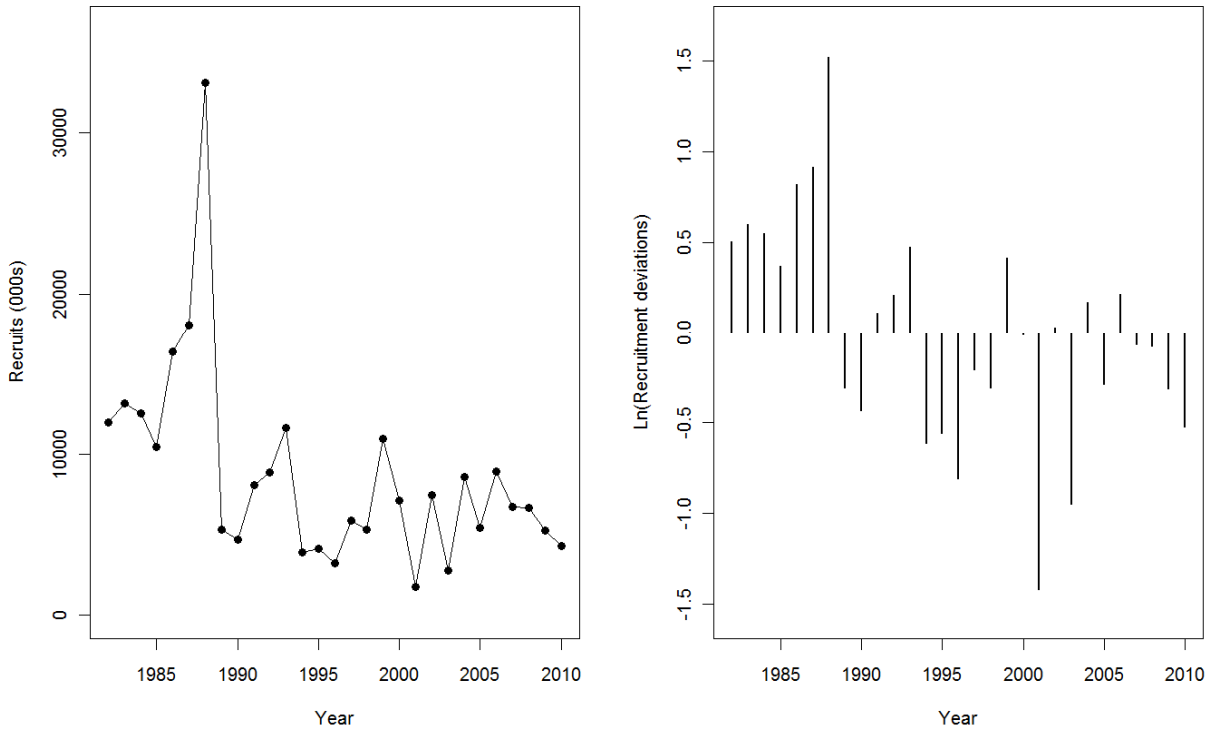


Figure A.142. ASAP BASE estimated Gulf of Maine Atlantic cod recruitment and recruitment residuals from the geometric mean.

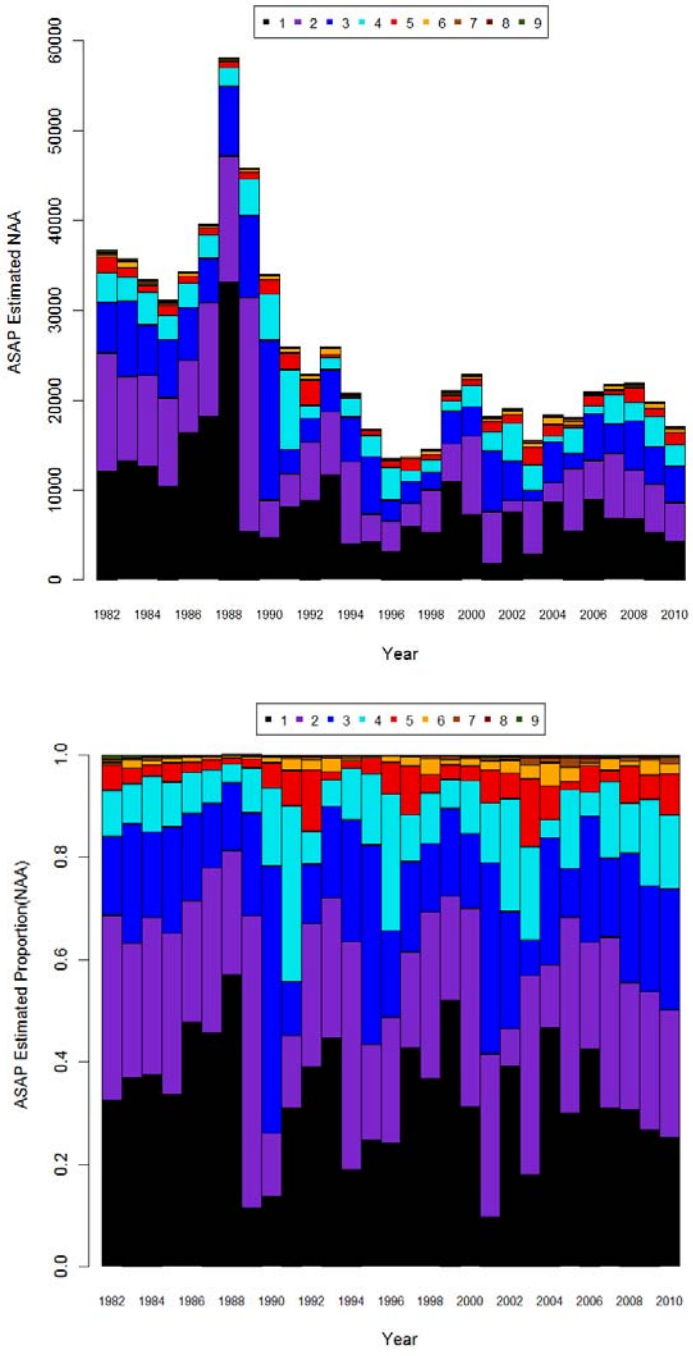


Figure A.143. ASAP BASE model estimates of Gulf of Maine Atlantic cod numbers-at-age in absolute (top) numbers (000s) and relative (bottom) terms.

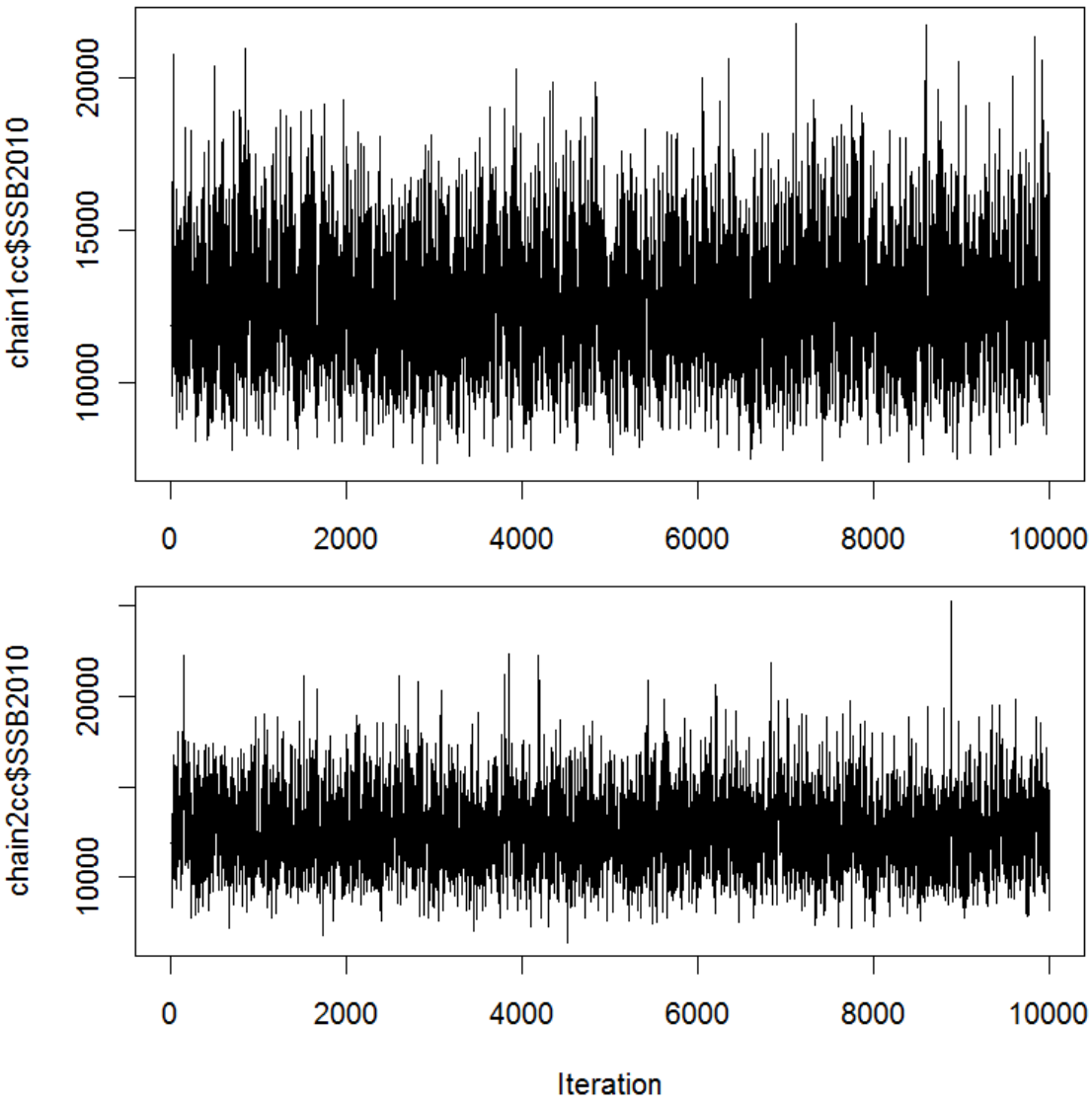


Figure A.144. Trace of MCMC chains for Gulf of Maine Atlantic cod SSB2010, showing good mixing (ASAP BASE model). Each chain had initial length of 1 million and was thinned at a rate of one out of every 100th. From the remaining 10,000 length chain (above), 1000 saved draws were extracted from every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

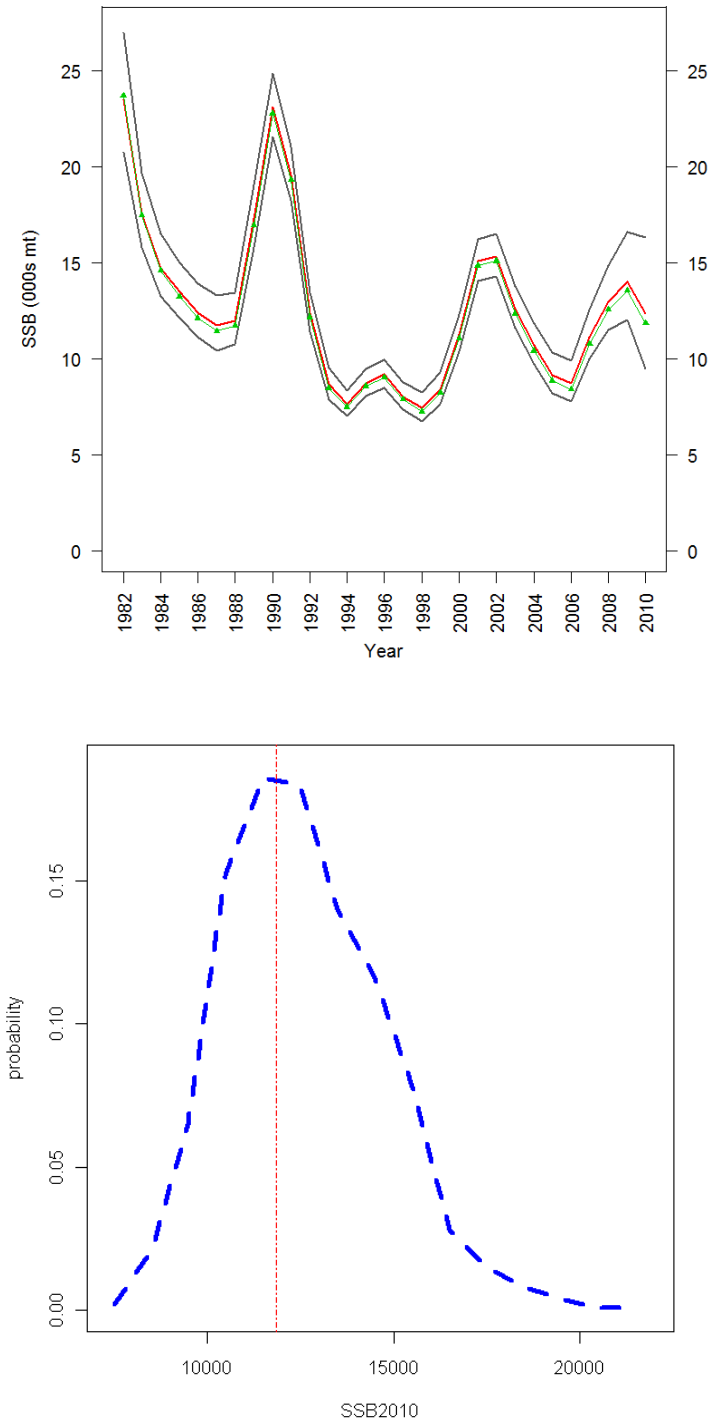


Figure A.145. Top: A 90% probability interval for Gulf of Maine Atlantic cod spawning stock biomass (SSB) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin green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

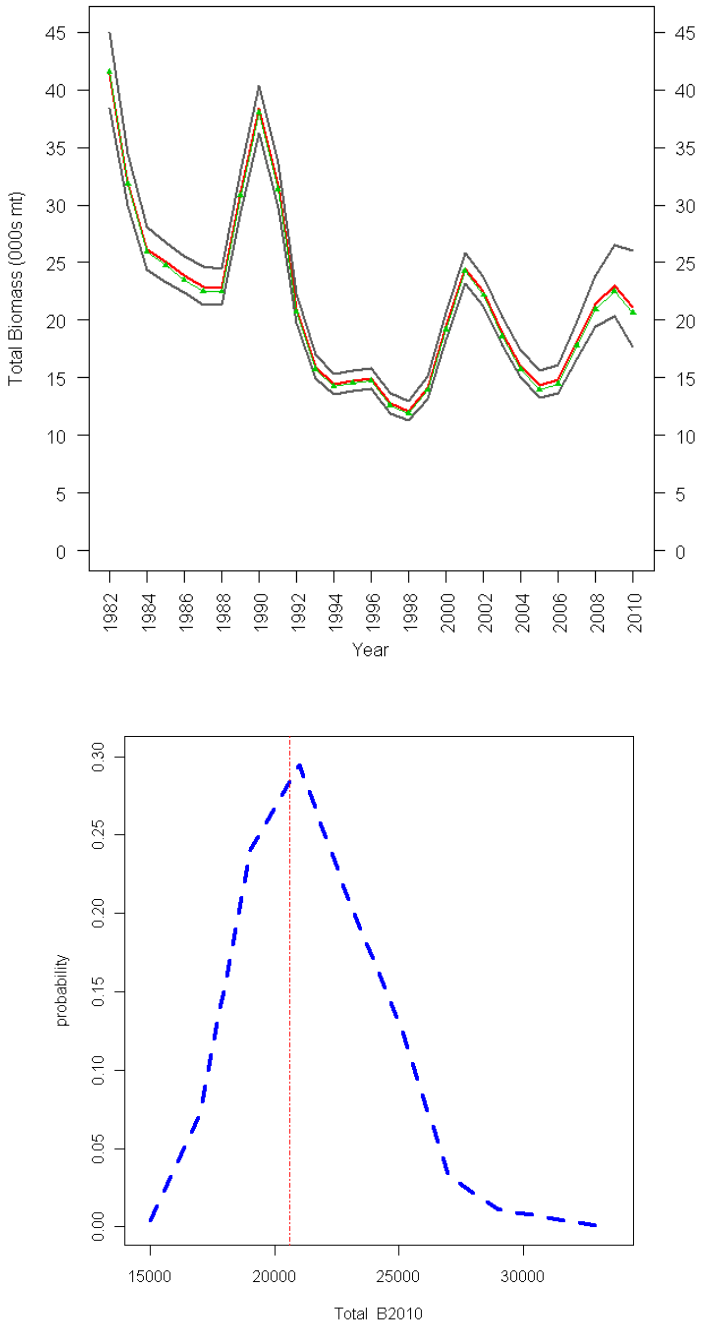


Figure A.146. Top: A 90% probability interval for Gulf of Maine Atlantic cod total stock biomass (B_{total}) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin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

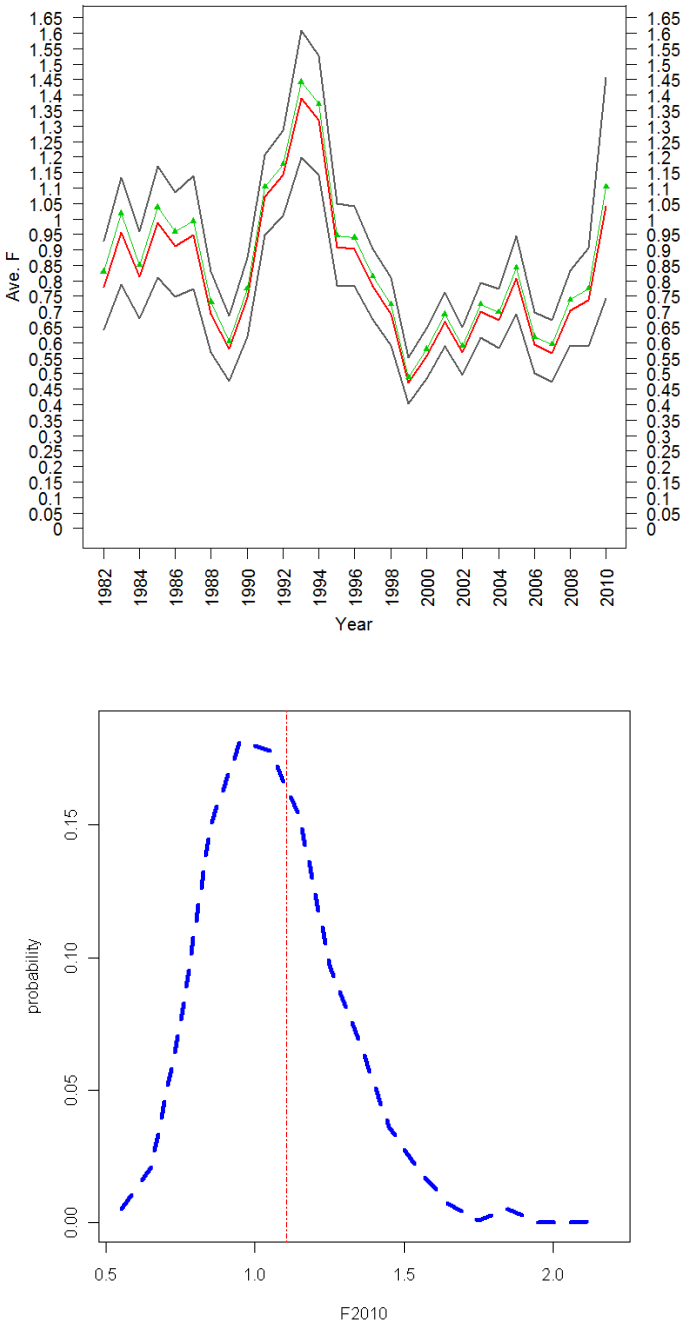


Figure A.147. Top: A 90% probability interval for Gulf of Maine Atlantic cod average fishing mortality from ages 5 to 7 (F_{5-7}) from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is 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.

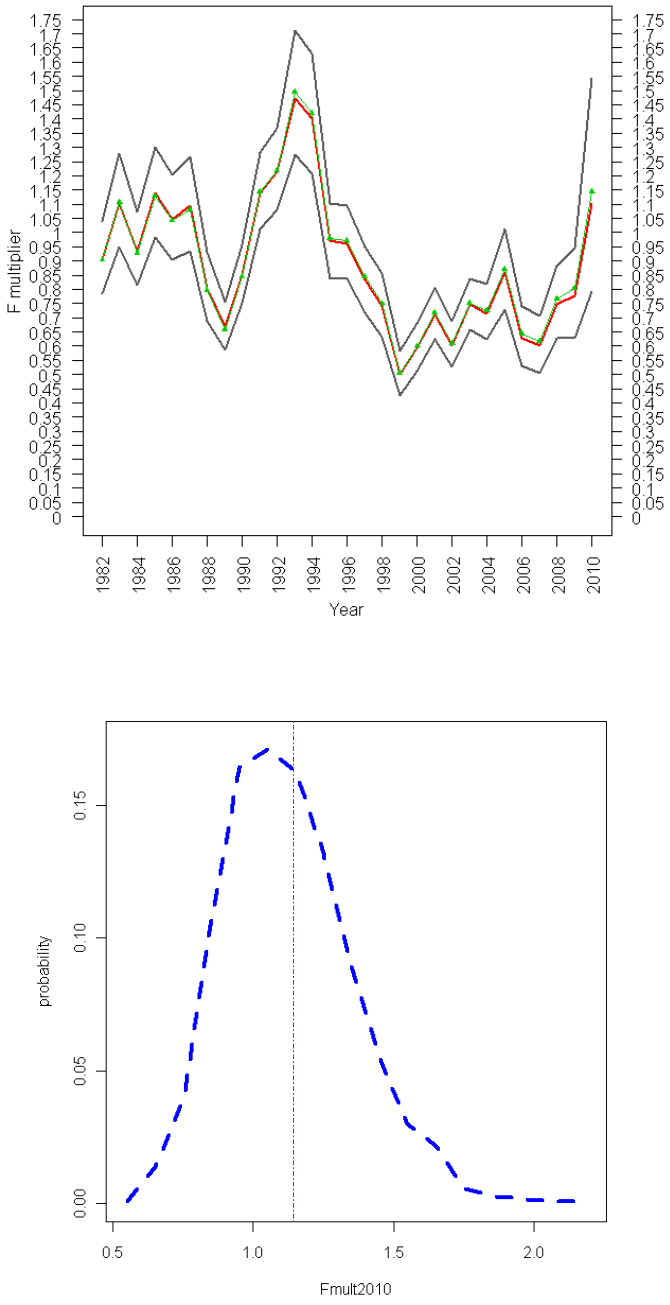


Figure A.148. Top: A 90% probability interval for Gulf of Maine Atlantic cod F_{mult}, total fishing mortality from the ASAP BASE model. The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model (joint posterior modes) is showin in the thin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

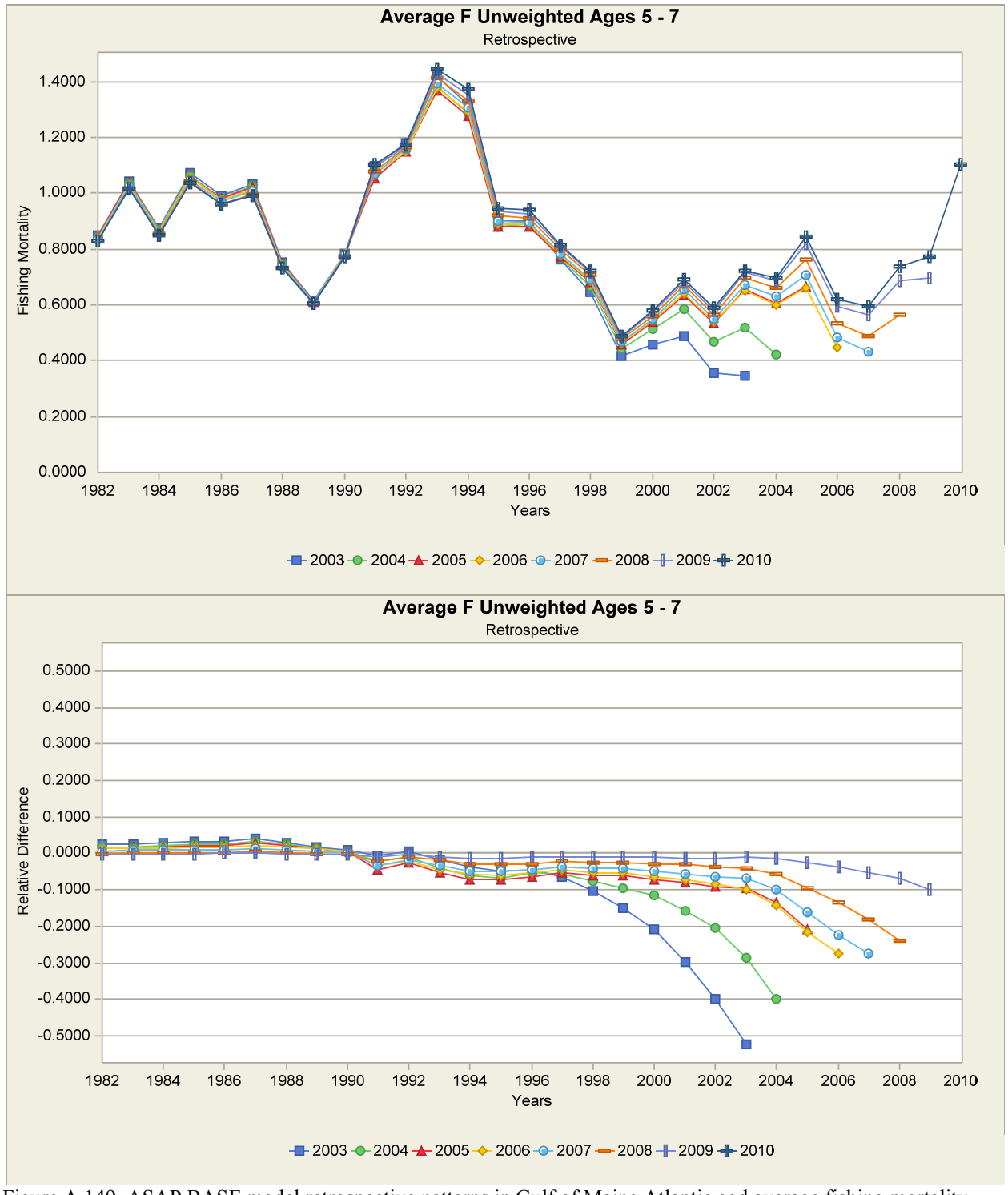


Figure A.149. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod average fishing mortality (ages 5-7) in absolute (top) and relative (bottom) terms.

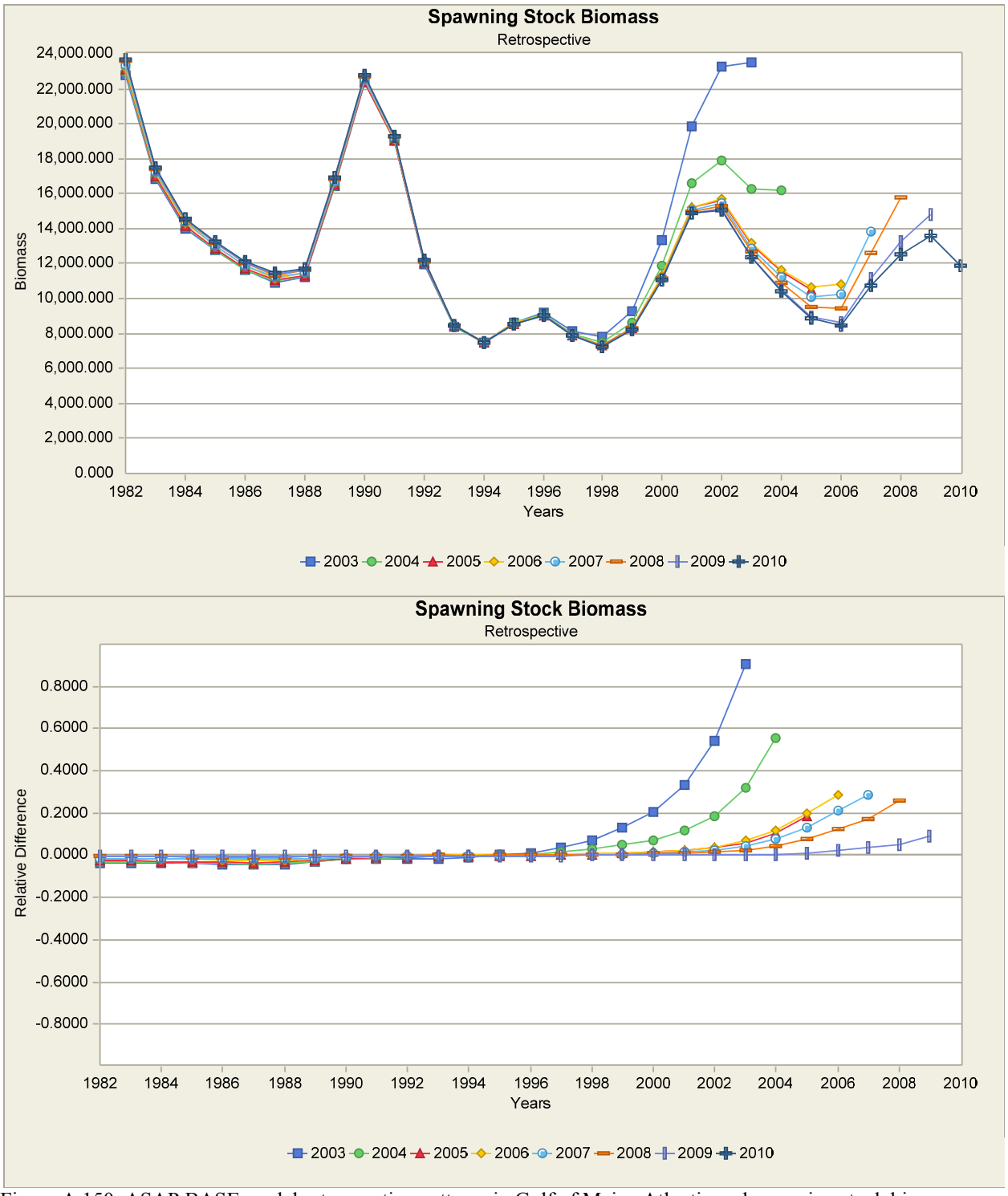


Figure A.150. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod spawning stock biomass (mt) in absolute (top) and relative (bottom) terms.

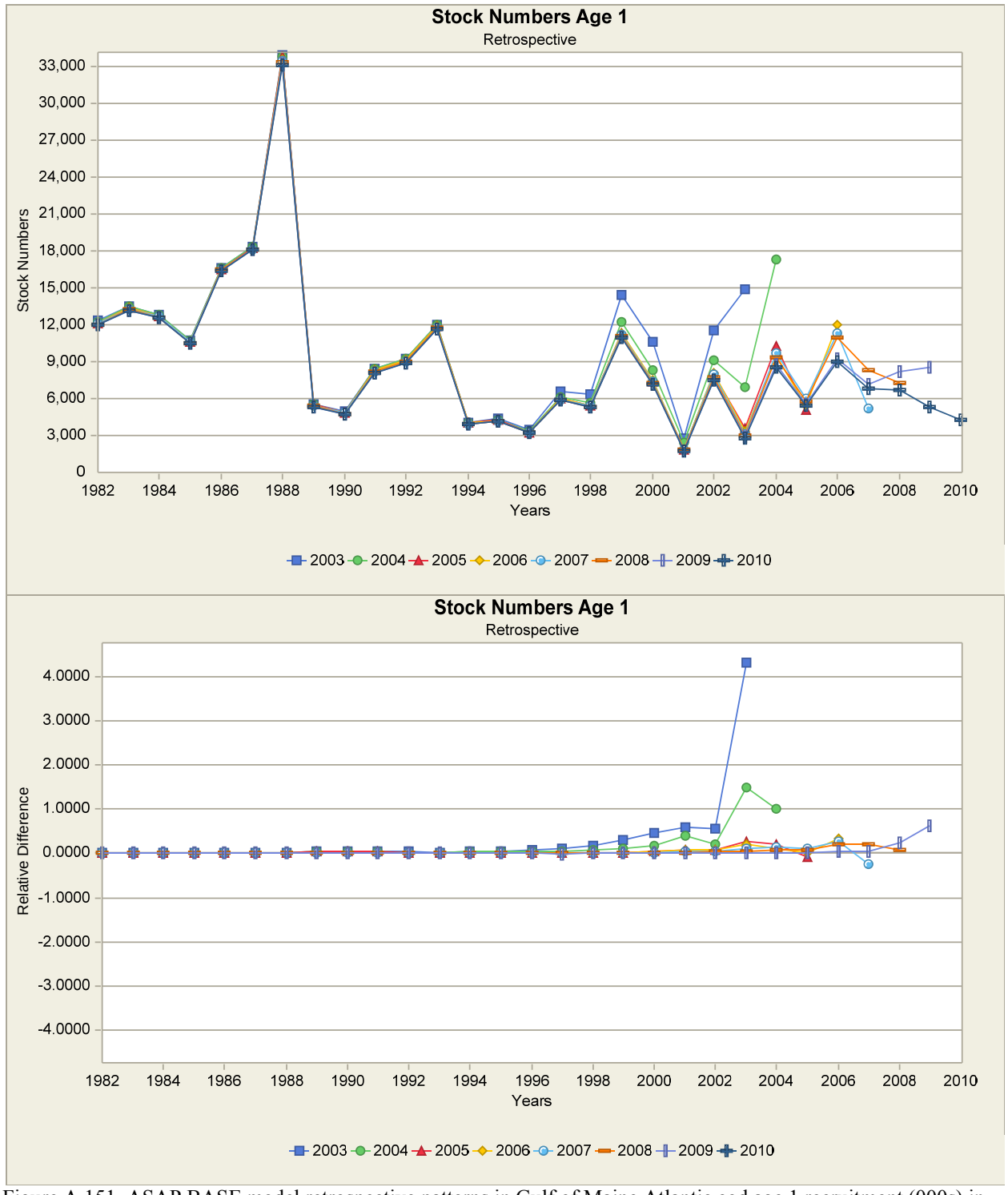


Figure A.151. ASAP BASE model retrospective patterns in Gulf of Maine Atlantic cod age 1 recruitment (000s) in absolute (top) and relative (bottom) terms.

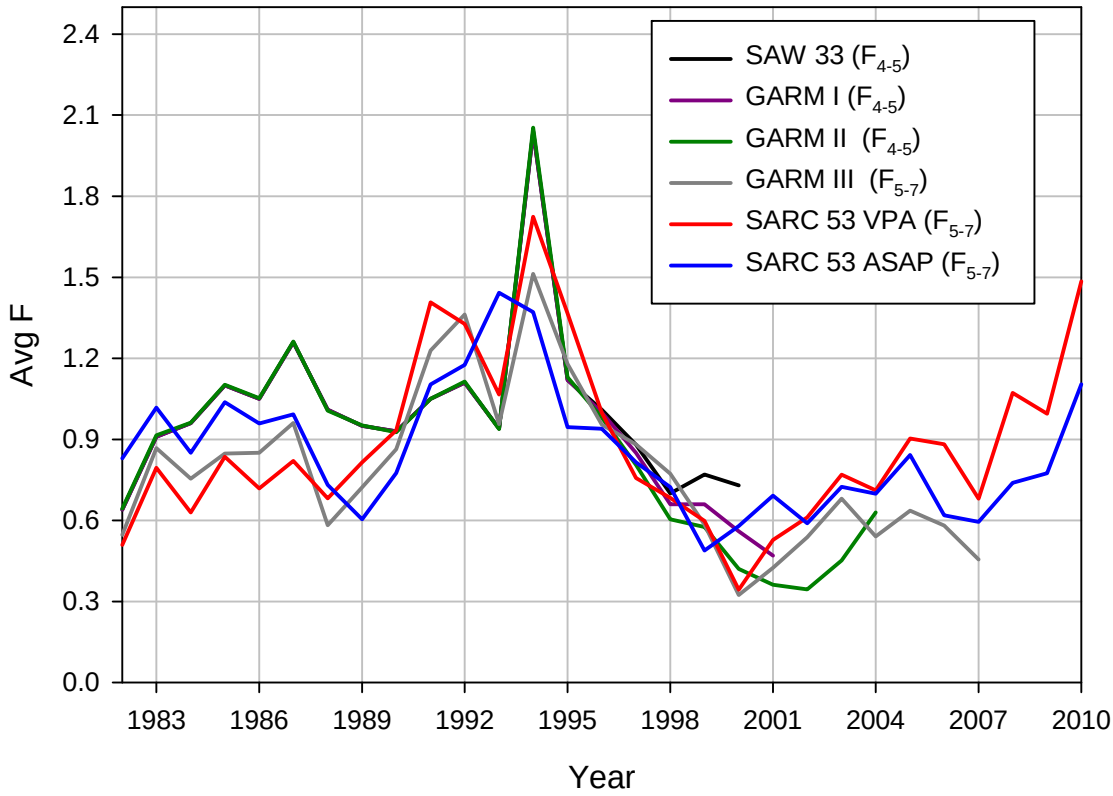


Figure A.152. Comparison of estimates of average fishing mortality from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates. **Note that the ages included in the average F calculation are not constant across assessments.*

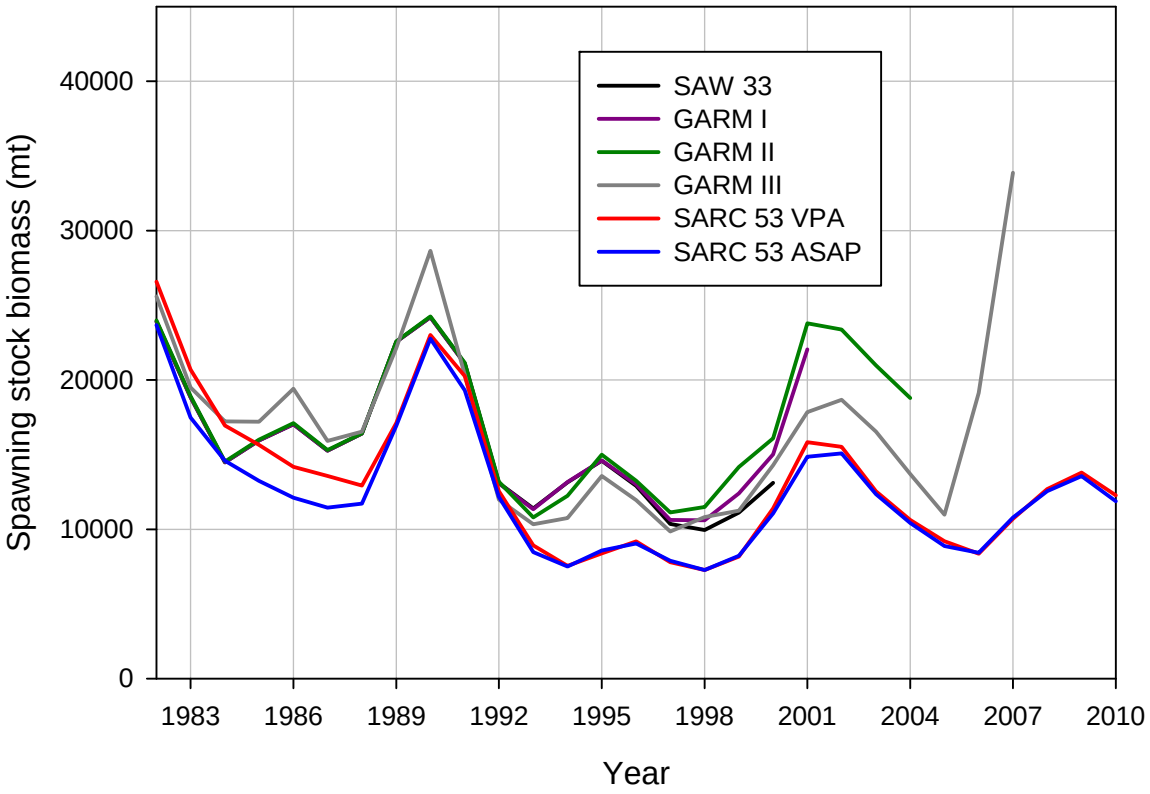


Figure A.153. Comparison of estimates of spawning stock biomass (mt) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

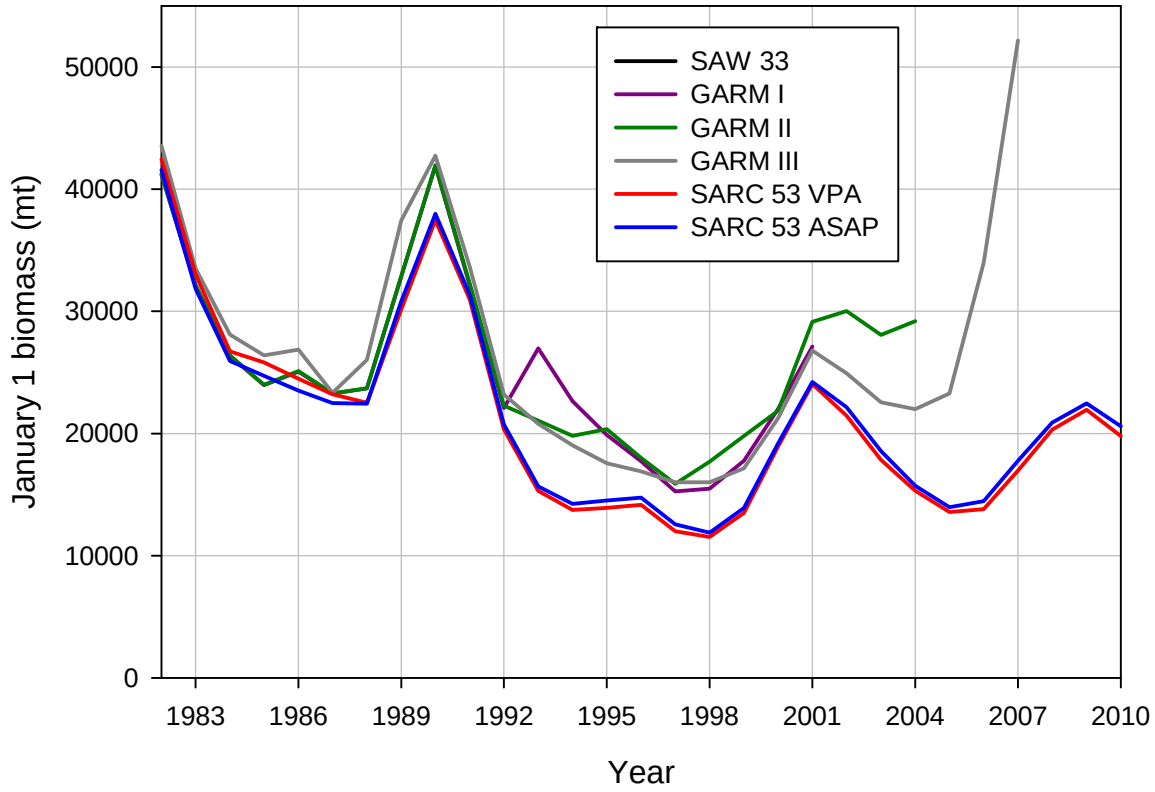


Figure A.154. Comparison of estimates of January 1 stock biomass (mt) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

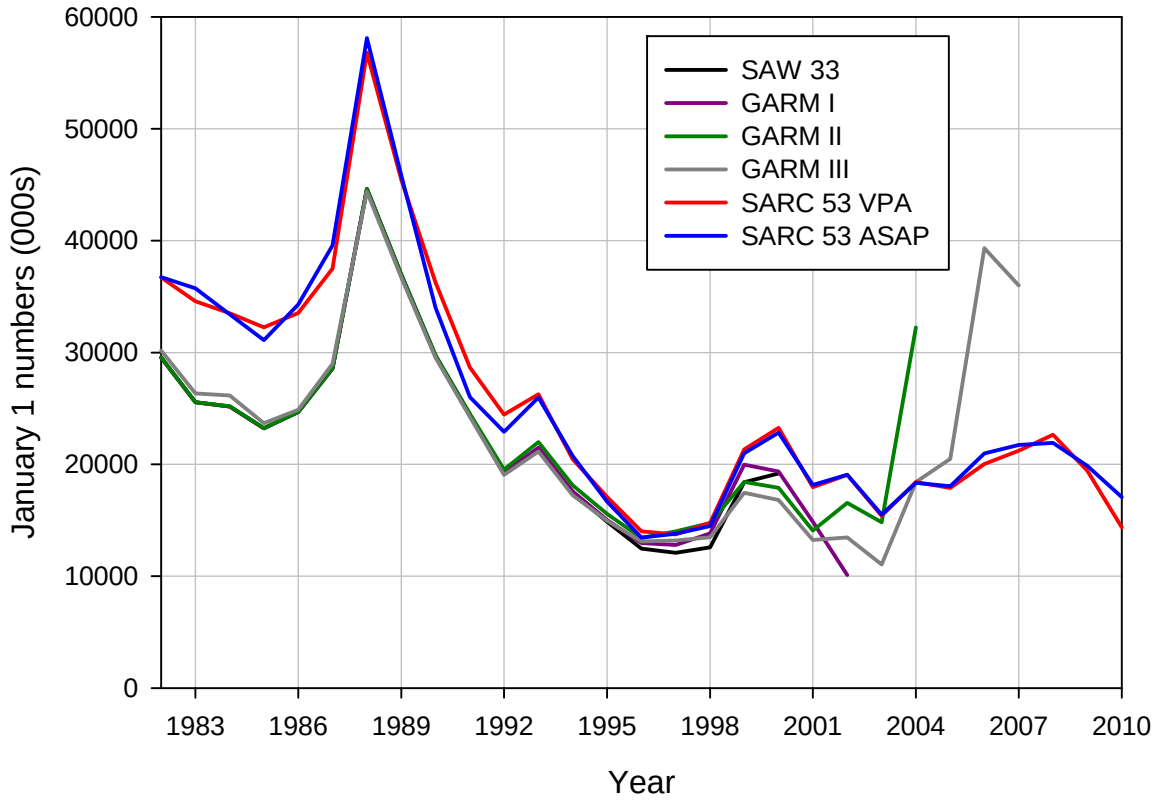


Figure A.155. Comparison of estimates of January 1 stock size (numbers, 000s) from previous Gulf of Maine Atlantic cod stock assessments including estimates from the 2011 VPA and ASAP base model assessment updates.

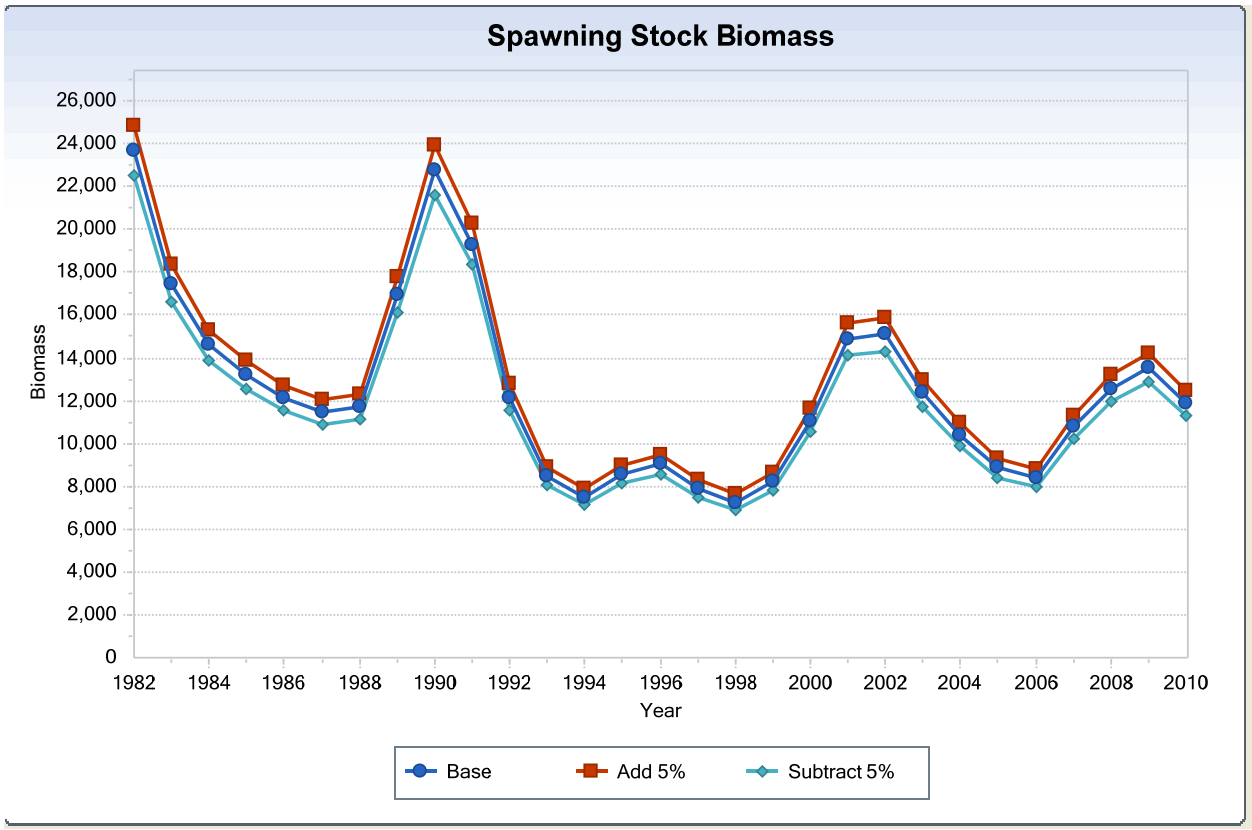


Figure A.156. Results of ASAP sensitivity runs exploring the impact of mis-allocation of Gulf of Maine Atlantic cod catch to stock areas on model performance. In each of the two sensitivity runs, the total catch was either increased or decreased by 5% commensurate with the likely scale of misallocation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

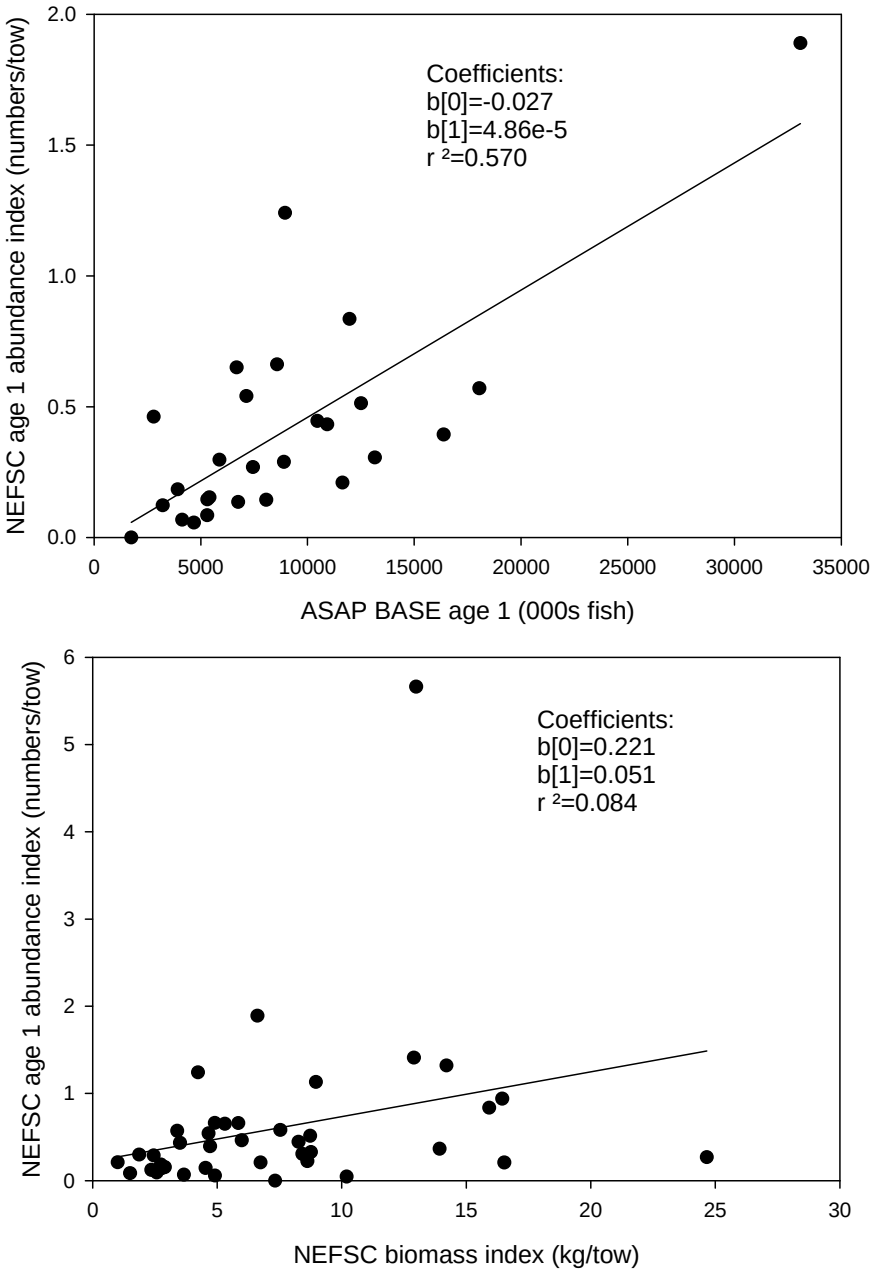


Figure A.157. Relationship of Gulf of Maine Atlantic cod age 1 estimated from the ASAP BASE model to the NEFSC fall survey age 1 abundance (numbers/tow) index from 1982 to 2008 (top). Relationship of he NEFSC fall sruvey age 1 abundance index to the NEFSC biomass (kg/tow) index from 1970 to 2010 (bottom).

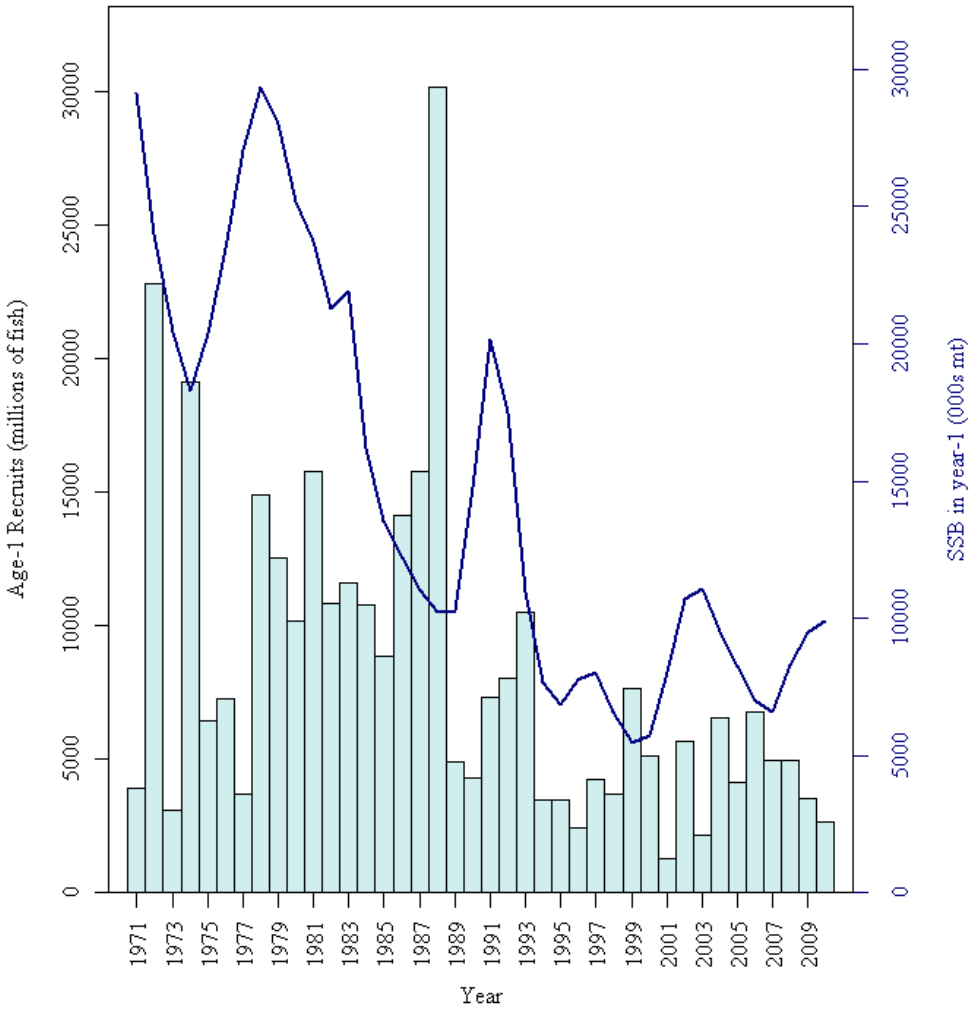


Figure A.158. Estimates of Gulf of Maine Atlantic cod age-1 recruits (solid bars) by year, and the spawning biomass (solid line, lagged 1 year) that produced that recruitment .

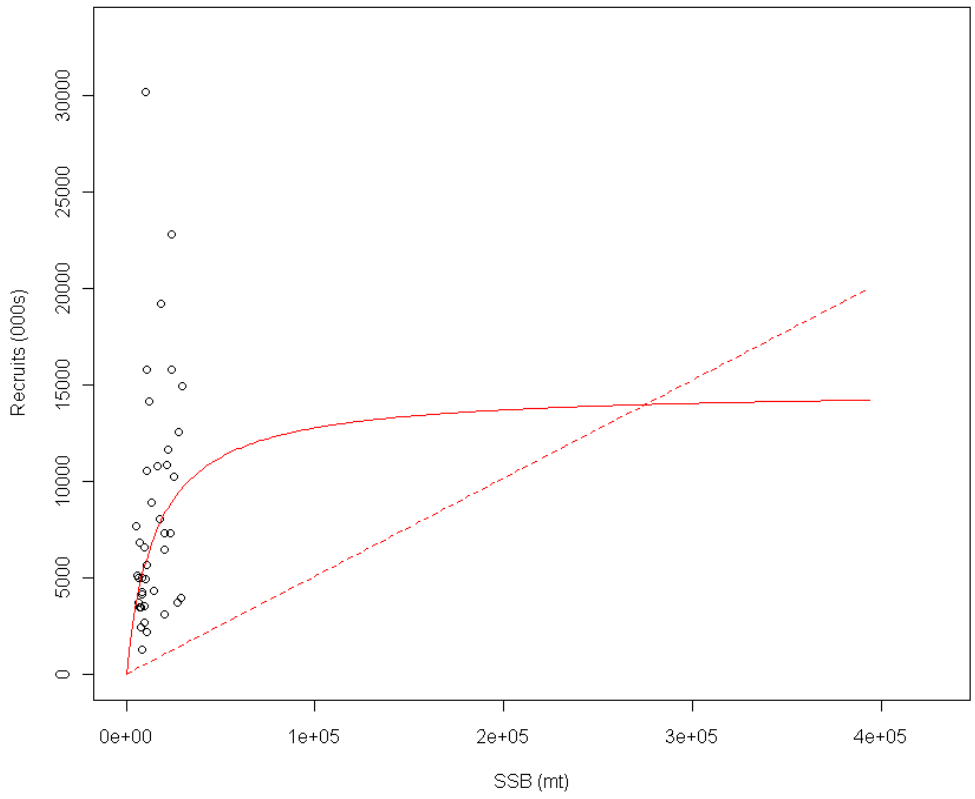


Figure A.159. Beverton-Holt fit (b) to Gulf of Maine Atlantic cod spawner-recruit relationship from the 1970 ASAP sensitivity model.

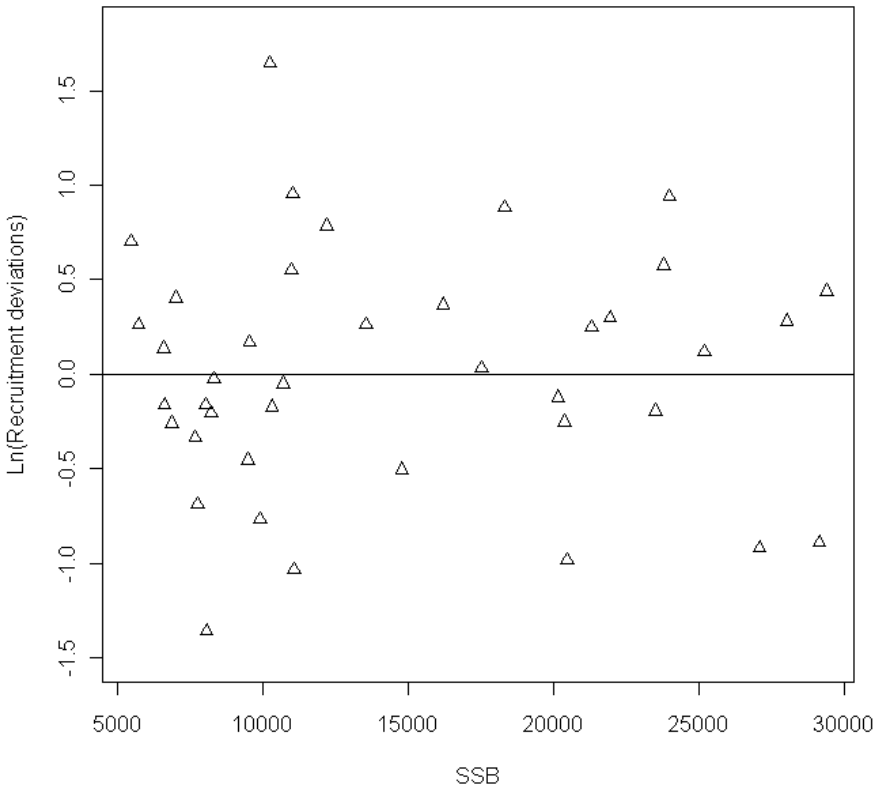


Figure A.160. Logscale residuals from the Beverton-Holt fit to Gulf of Maine Atlantic cod spawner-recruit relationship in the 1970 ASAP sensitivity model.

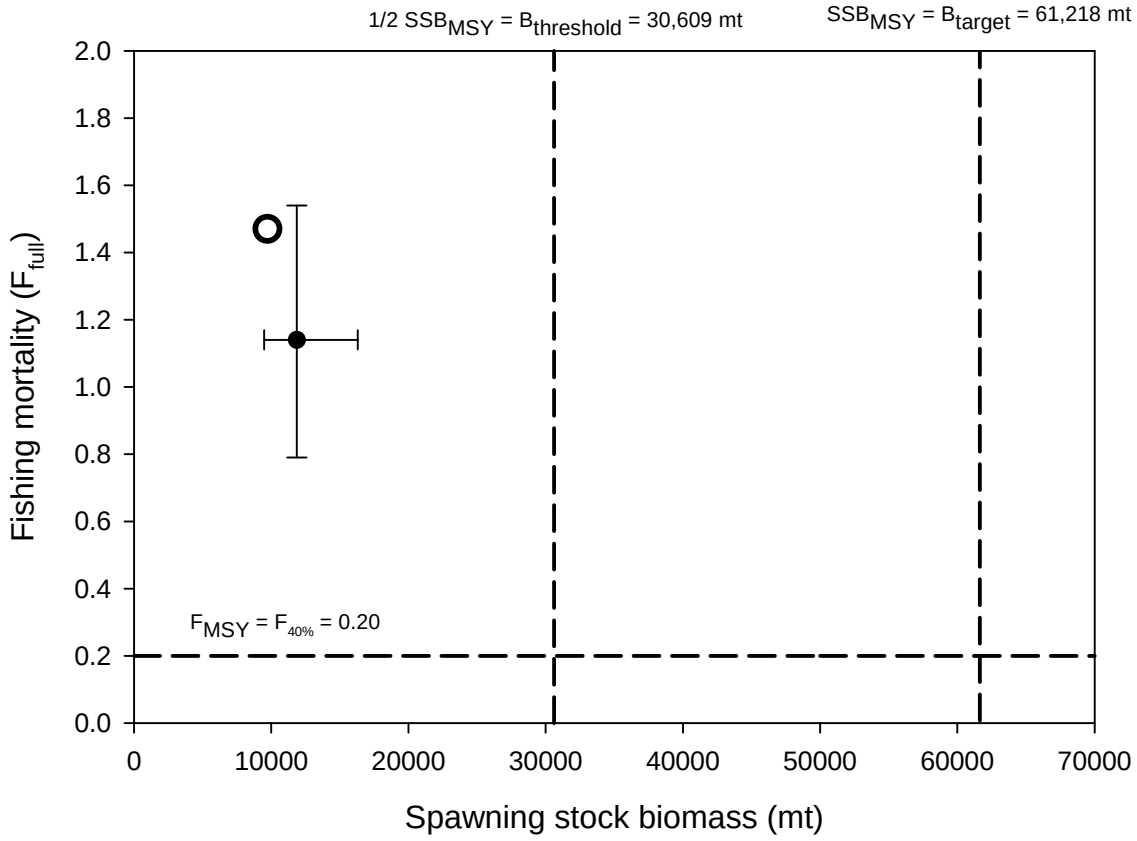


Figure A.161. Comparison of 2010 fishing mortality (F_{full}) and spawning stock biomass (SSB) of Gulf of Maine Atlantic cod relative to F_{MSY} proxy ($F_{40\%}$) and SSB_{MSY} both with (open circle) and without (solid black circle) accounting for retrospective bias. The bias corrected point is based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

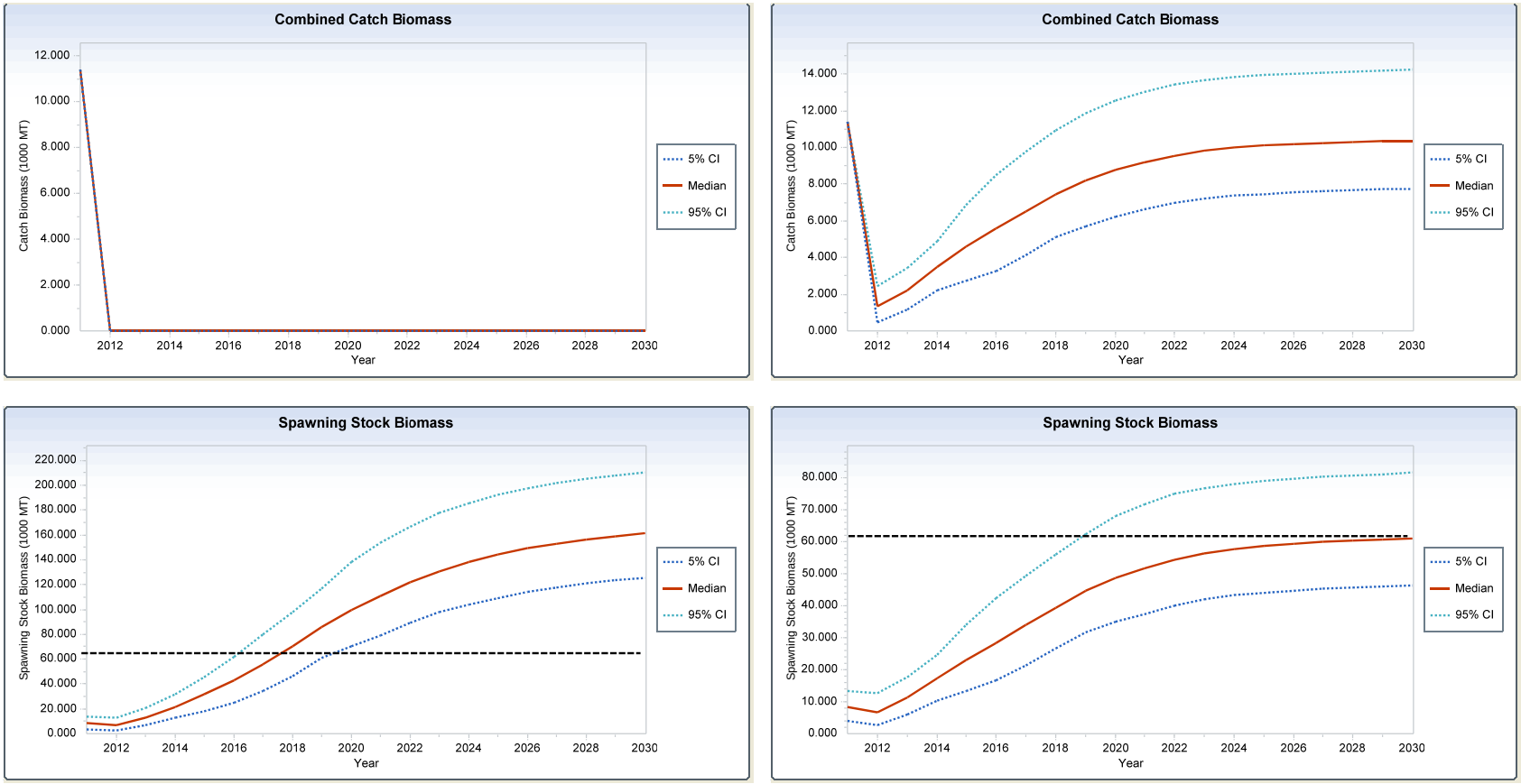


Figure A.162. Short-term projections for Gulf of Maine Atlantic cod in terms of fishery yield (catch, top) and spawning stock biomass (SSB, bottom) under two different harvest scenarios: zero fishing mortality (left) and fishing at the F_{MSY} proxy ($F_{40\%}$; right).