Northeast Fisheries Science Center Reference Document 12-18

54th Northeast Regional Stock Assessment Workshop (54th SAW)

Assessment Report

by the Northeast Fisheries Science Center

August 2012

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NOAA National Marine Fisheries Service
Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 2012

Northeast Fisheries Science Center Reference Documents

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Editorial Treatment: To distribute this report quickly, it has not undergone the normal technical and copy editing by the Northeast Fisheries Science Center's (NEFSC's) Editorial Office as have most other issues in the NOAA Technical Memorandum NMFS-NE series. Other than the four covers and first two preliminary pages, all writing and editing have been performed by the authors listed within.

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Foreword

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees / Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies.
Starting with SAW-39 (June 2004), the process was revised in two fundamental ways. First, the Stock Assessment Review Committee (SARC) became smaller panel with panelists provided by the Independent System for Peer Review (Center of Independent Experts, CIE). Second, the SARC provides little management advice. Instead, Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees, Science and Statistical Committee) formulate management advice, after an assessment has been accepted by the SARC. Starting with SAW-45 (June 2007) the SARC chairs were from external agencies, but not from the CIE. Starting with SAW-48 (June 2009), SARC chairs are from the Fishery Management Council's Science and Statistics Committee (SSC), and not from the CIE. Also at this time, some assessment Terms of Reference were revised to provide additional science support to the SSCs, as the SSC's are required to make annual ABC recommendations to the fishery management councils.

Reports that are produced following SAW/SARC meetings include: An *Assessment Summary Report* - a summary of the assessment results in a format useful to managers; an *Assessment Report* – a detailed account of the assessments for each stock; and the SARC panelist reports – a summary of the reviewer's opinions and recommendations as well as individual reports from each panelist. SAW/SARC assessment reports are available online at

http://www.nefsc.noaa.gov/nefsc/publications/series/crdlist.htm. The CIE review reports and assessment reports can be found at *http://www.nefsc.noaa.gov/nefsc/saw/*".
The 54th SARC was convened in Woods Hole at the Northeast Fisheries Science Center, June 5 -9, 2012 to review benchmark stock assessments of: Atlantic herring (*Clupea harengus*) and Southern New England Mid-Atlantic yellowtail flounder (*Pleuronectes ferrugineus*). CIE reviews for SARC54 were based on detailed reports produced by NEFSC Assessment Working Groups. This Introduction contains a brief summary of the SARC comments, a list of SARC panelists, the meeting agenda, and a list of attendees (Tables 1 – 3). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1 - 5).

Outcome of Stock Assessment Review Meeting:

Based on the Review Panel reports (at http://www.nefsc.noaa.gov/nefsc/saw/ under the heading "SARC 54 Panelist Reports"), the SARC review panel drew the following conclusions. For **Atlantic herring**, the Panel accepted the new ASAP assessment model. A feature of this new model is the 50% increase in natural mortality rate (M) during 1996-2011. This new M estimate is consistent with data on consumption of herring by predators and it largely resolves the retrospective pattern which has been a prominent feature of previous assessment models. The biological reference points were derived assuming that the 50% increase in M due to herring consumption will continue over the next 3 – 5 years. This assumption about the future is a source of uncertainty. The new biomass reference points (B_{TARGET} and MSY) are much lower than those from the previous assessment. A source of uncertainty in the stock projections is the size of the 2009 age-1 recruitment, which has been estimated to be almost twice as large as the next largest recruitment (1994). The 2009 age-1 fish contribute to the recent increase in stock biomass, and are a significant component of projected yield to the fishery in the future. It will be important to monitor the size of this year-class. Overall, the Panel concluded that the Atlantic herring stock is not overfished and that overfishing is not occurring.

For **Southern New England Mid-Atlantic yellowtail flounder** the Panel accepted a new stock assessment model (ASAP). There was a significant revision of most of the assessment's data sets. The new model assumed a higher natural mortality rate (M). There has been a marked decline in recruitment since 1990. Two stock–recruitment scenarios were developed which account for this decline, and the two scenarios lead to very different conclusions about biomass stock status. A "recent recruitment" scenario assumes that incoming year-classes since 1990 have been weak, perhaps due to a reduction in stock productivity, and not related to SSB. Alternatively, a "two-stanza" scenario assumes that recruitment over the entire time series is a function of spawning stock biomass (SSB) and that below about 4300 mt SSB average recruitment is very low. While neither scenario could be ruled out, the Panel concluded that the evidence was 60:40 in favor of the "recent recruitment" scenario (i.e., productivity change). Overall, the fishing mortality (F_{MSY}) reference point is relatively certain, and overfishing is likely not occurring. However, the reference points associated with biomass ($B_{MSY,}$ MSY) are uncertain due to the productivity change issue and require further exploration. There is considerable uncertainty as to whether or not the stock is overfished. Under the "recent recruitment" scenario the stock would not be considered overfished and it would be considered rebuilt to a new, much lower biomass target. In contrast, under the "two-stanza" scenario the stock would still be considered overfished.

CIE review reports can be found at http://www.nefsc.noaa.gov/nefsc/saw/ under the heading "SARC 54 Panelist Reports".

Table 1. 54th Stock Assessment Review Committee Panel.

SARC Chairman (NEFMC SSC):
Mr. Robert O'Boyle
Beta Scientific Consulting, Inc.
Bedford, Nova Scotia, Canada, B4A 2E5
E-mail: betasci@eastlink.ca

SARC Panelists (CIE):

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Dr. Norm Hall
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Dr. Neil Klaer
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Table 2. Agenda, 54th Stock Assessment Review Committee Meeting.

54th Northeast Regional Stock Assessment Workshop (SAW 54) Stock Assessment Review Committee (SARC) Meeting

June 5-9, 2012

Stephen H. Clark Conference Room – Northeast Fisheries Science Center
Woods Hole, Massachusetts

AGENDA* (version: 4 June 2012)

TOPIC PRESENTER(S) SARC LEADER RAPPORTEUR

Tuesday, June 5

1 – 1:30 PM
Welcome **James Weinberg**, SAW Chair
Introduction **Robert O'Boyle**, SARC Chair
Agenda
Conduct of Meeting

1:30 – 3:30 Assessment Presentation (A. Herring)
Jon Deroba, others **TBD** **Toni Chute**

3:30 – 3:45 Break

3:45 – 6 Assessment Presentation (A. Herring)
Jon Deroba, others **TBD** **Toni Chute**

Wednesday, June 6

9 – 11:45 SARC Discussion w/ presenters (A. Herring)
Robert O'Boyle, SARC Chair **Toni Chute**
11:45 – 1 Lunch

1:00 – 3:15 Assessment Presentation (B. SNE YT)
Larry Alade **TBD** **Jessica Blaylock**
3:15 – 3:30 Break

3:30 – 5:30 SARC Discussion w/ presenters (B. SNE YT)
Robert O'Boyle, SARC Chair **Jessica Blaylock**
(Mike Palmer)
7 social event --Coonamessett Inn, 311 Gifford St., Falmouth

Thursday, June 7

9 - 11	Revisit w/ presenters (A. herring)	**Robert O'Boyle**, SARC Chair	**T. Chute**
11 – 11:15	Break		
11:15 – 12:30	Revisit w/ presenters (B. SNE YT)	**Robert O'Boyle**, SARC Chair	**J. Blaylock**
12:30 – 1:45	Lunch		
1:45 – 2:15	(cont.) Revisit w/ presenters (B. SNE YT)	**Robert O'Boyle**, SARC Chair	**J. Blaylock**
2:15 -2:30	Break		
2:30 – 5:30	Review/edit Assessment Summary Report (A. herring)	**Robert O'Boyle**, SARC Chair	**T. Chute**

Friday, June 8

9 - 12	Review/edit Assessment Summary Report (B. SNE YT)	**Robert O'Boyle**, SARC Chair	**J. Blaylock**
12 – 1:15	**Lunch**		
1:15 – 5	SARC Report writing. (closed meeting)		

Saturday, June 9

9:00 - 3 PM (cont.) SARC Report writing. (closed meeting)

*All times are approximate, and may be changed at the discretion of the SARC chair. The meeting is open to the public, except where noted.

Table 3. 54th SAW/SARC, List of Attendees

Name	Affiliation	Email
James Weinberg	NEFSC	James.weinberg@noaa.gov
Paul Rago	NEFSC	Paul.Rago@noaa.gov
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Jud Crawford	PEW CT	jcrawford@pewtrusts.org
Steve Cadrin	SMAST/SSC	scadrin@umassd.edu
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John Hoey	NEFSC	John.hoey@noaa.gov
Dave McElroy	NEFSC	Dave.mcelroy@noaa.gov
Lori Steele	NEFMC	lsteele@nefmc.org

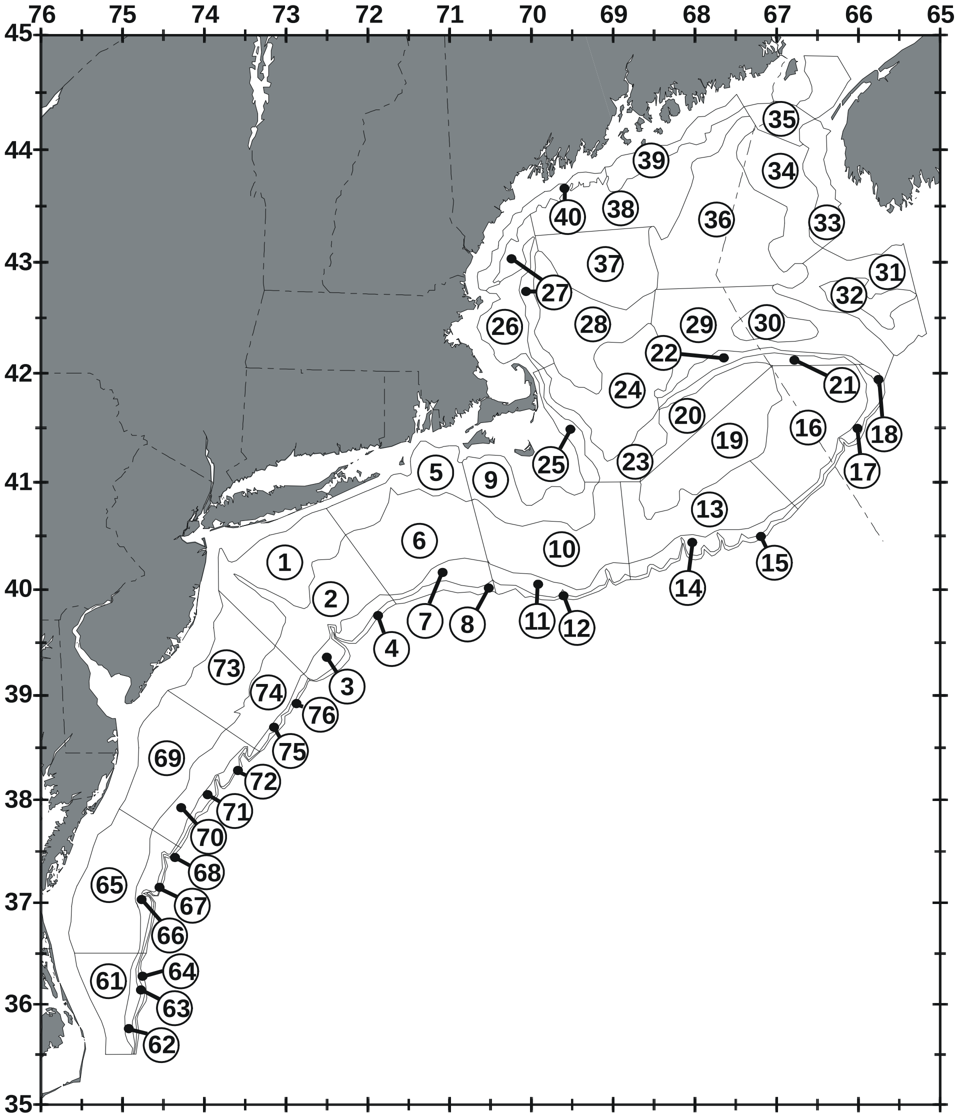


Figure 1. Offshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

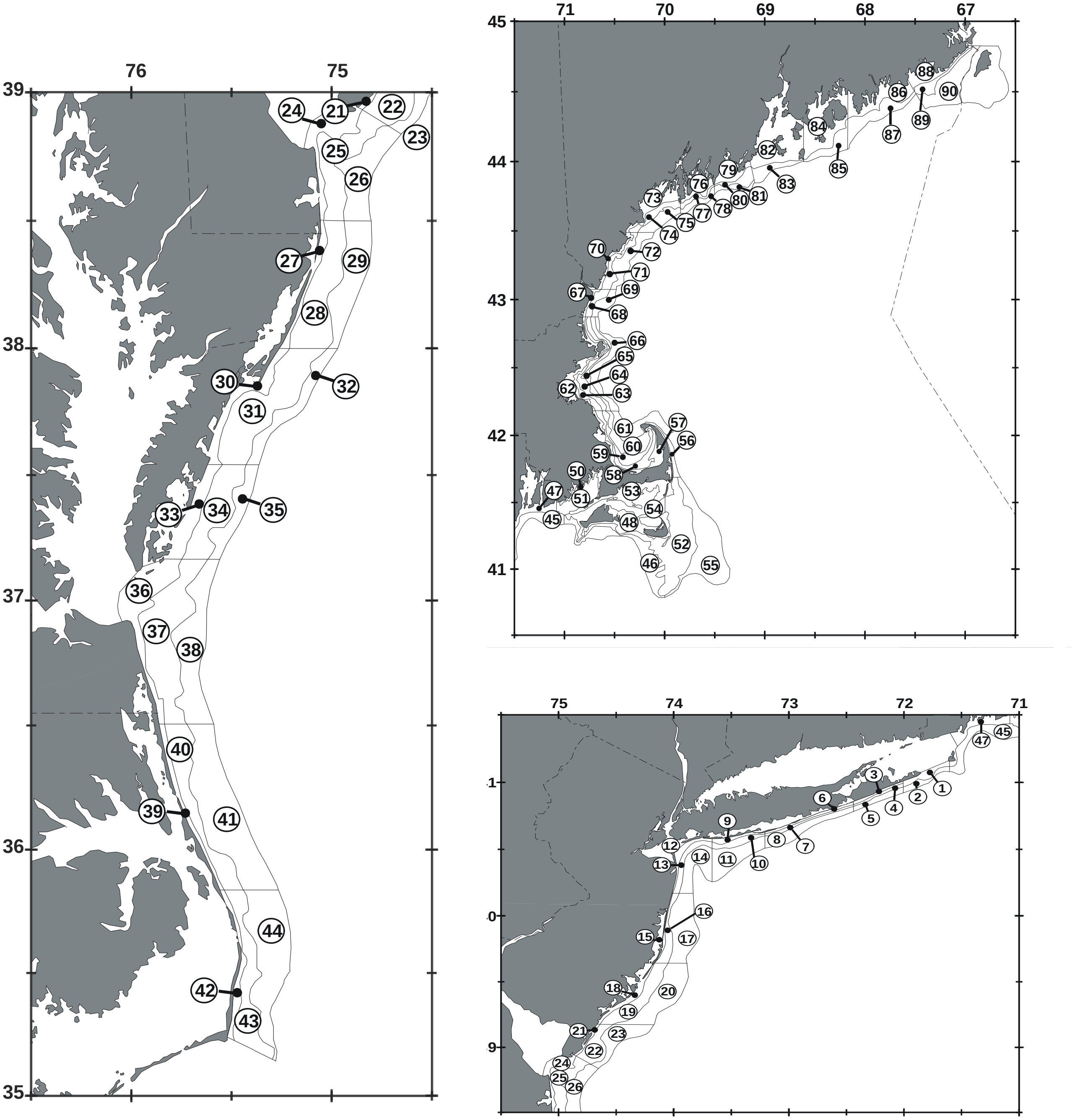


Figure 2. Inshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

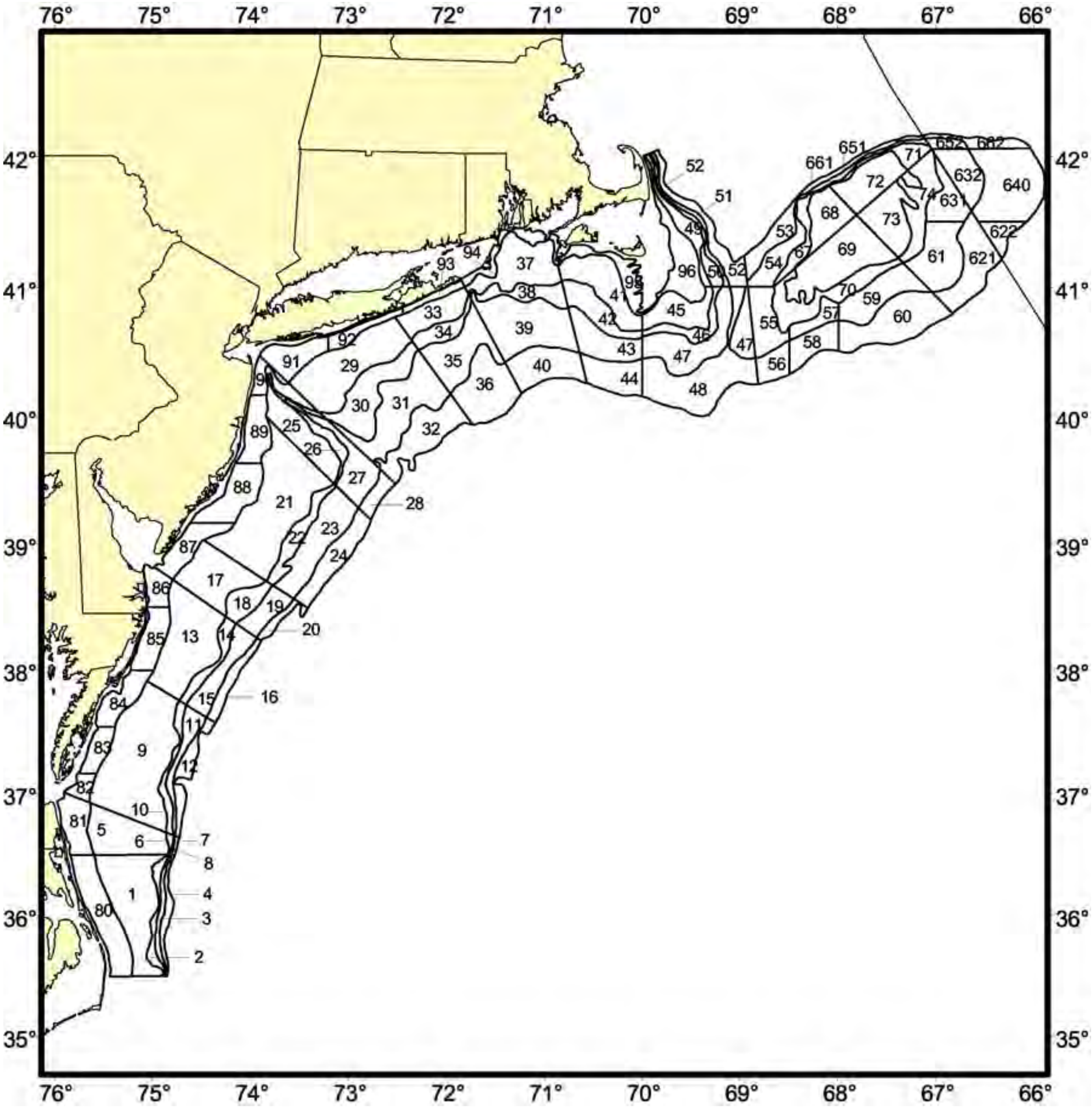


Figure 3. Depth strata sampled during Northeast Fisheries Science Center clam dredge research surveys.

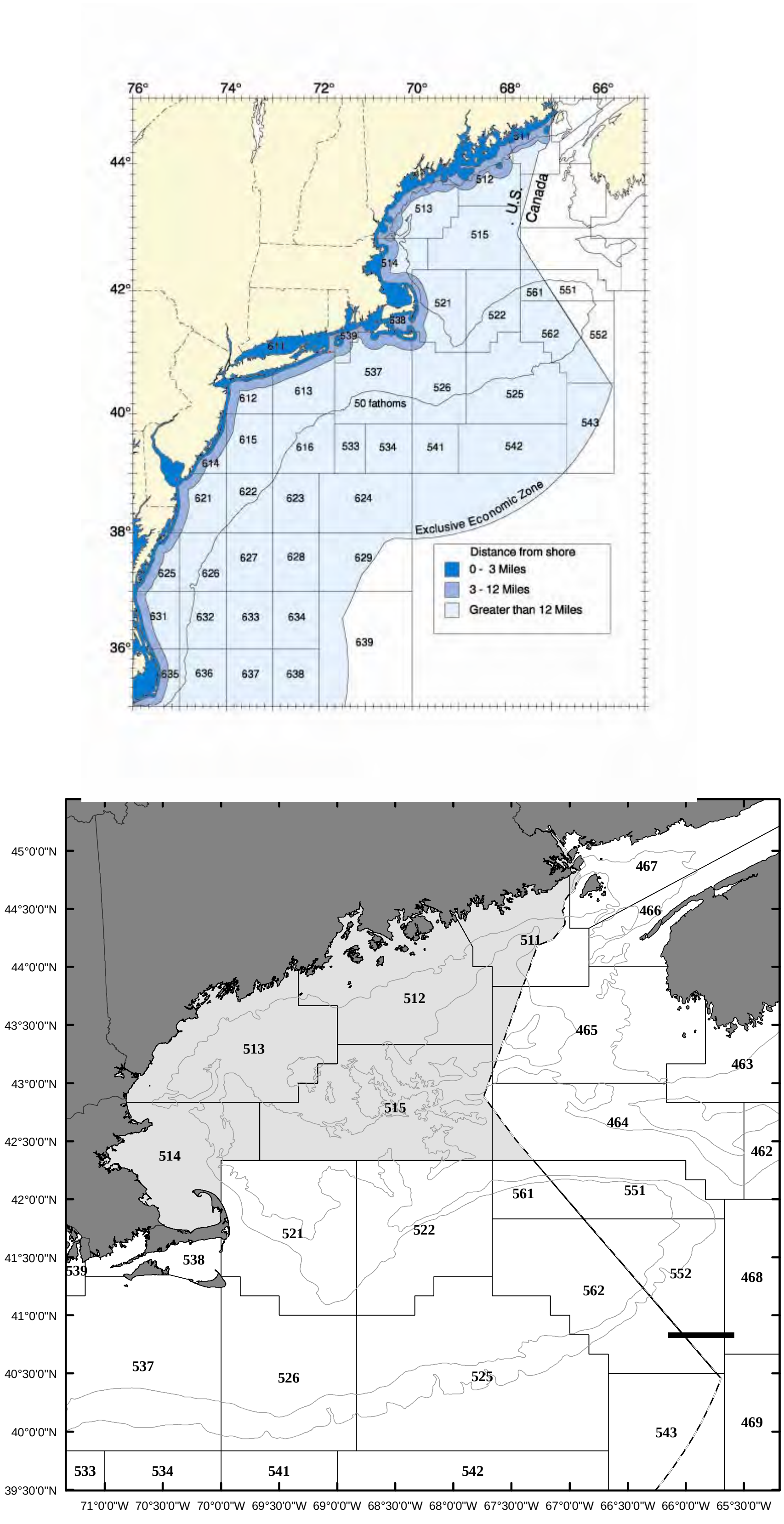


Figure 4. Statistical areas used for reporting commercial catches.

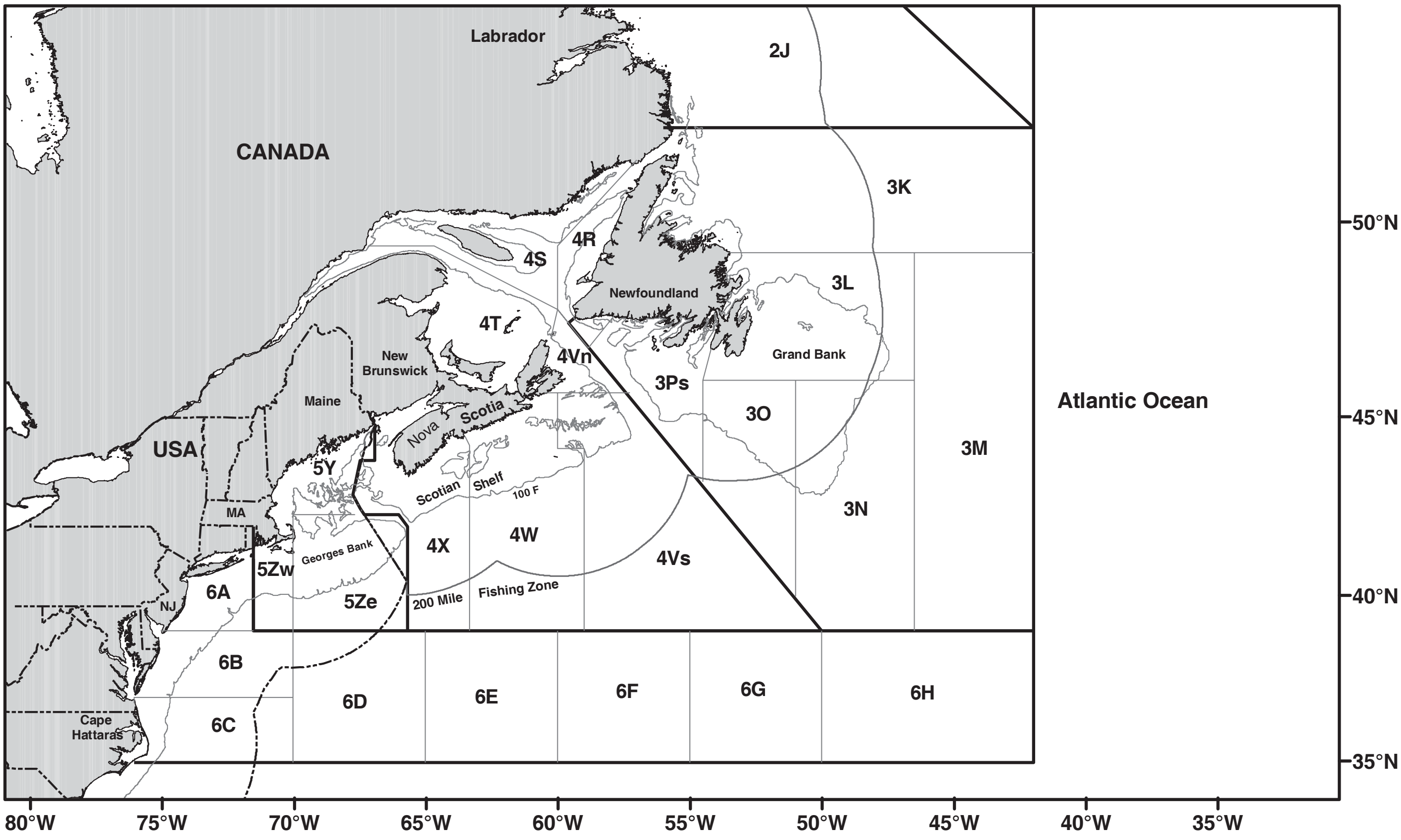


Figure 5. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

A. STOCK ASSESSMENT OF ATLANTIC HERRING – GULF OF MAINE/GEORGES BANK FOR 2012, UPDATEDTHROUGH 2011

Executive Summary

TOR 4. Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas (This term of reference is presented first because the conclusions of this term of reference had implications for how other terms of reference were addressed).

The Gulf of Maine/Georges Bank Atlantic herring complex is composed of several spawning aggregations. Fisheries and surveys, however, catch fish from a mix of the spawning aggregations and methods to distinguish fish from each aggregation are not yet well established. So, recent assessments have combined data from all areas and conducted a single assessment of the entire complex. Although this approach poses a challenge to optimally managing each stock component and can create retrospective patterns within an assessment, the mixing of the spawning components in the fishery and surveys precludes separate assessments. Atlantic herring caught in the New Brunswick, Canada, weir fishery were considered part of the Gulf of Maine/Georges Bank complex because tagging studies suggest mixing. Herring from the Canadian Scotian Shelf stock also likely mix with the Gulf of Maine/Georges Bank complex, but the degree of mixing is unknown and methods to distinguish fish from each stock are not fully developed. So, catches from the Scotian shelf were not considered part of the Gulf of Maine/Georges Bank complex.

TOR 1. Estimate catch from all sources including landings and discards. Describe the spatial distribution of fishing effort. Characterize uncertainty in these sources of data.

US catches were developed for the years 1964-2011 and were a sum of landings and self-reported discards. Discards have only been available since 1996, but were generally less than 1% of landings. Consequently, discards do not represent a significant source of mortality and a lack of historical discards is not considered problematic for the assessment. US catches were developed separately for fixed and mobile gear types. Catches from the New Brunswick, Canada, weir fishery were provided for the years 1965-2011 and were added to the US fixed gear catches for the purposes of assessment.

Total catches during 1964-2011 ranged from 44,613 mt in 1983 to 477,767 mt in 1968. Total catches during the past five years ranged from 79,413 mt in 2010 to 112,462 mt in 2007 and averaged 95,081 mt. Mobile gear catches have been the dominant gear type since about 1995, averaging of 87% of the total catch per year.

TOR 2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, larval surveys, age-length data, predator consumption rates, etc.). Investigate the utility of commercial LPUE as a measure of relative abundance, and characterize the uncertainty and any bias in these sources of data.

NMFS spring and fall bottom trawl surveys began in 1968 and 1963, respectively, and have continued uninterrupted through 2011. In 2009, the NMFS survey vessel was replaced so calibration coefficients were used to express the 2009-2011 data in units equivalent to that of years prior to 2009. Survey age data were collected since 1987. The practice of developing age composition information for these surveys by using data from commercial sources was discontinued for this assessment. The trawl doors used on the survey nets also changed in 1985 and likely altered the catchability of the survey gear. Consequently, each of these surveys are split into two time series in 1984-1985 and these were treated as separate indices in assessment models. The NMFS winter survey conducted during 1992-2007 provided indices of abundance at age. The utility of this survey was debated and it was not included in the base assessment model. A NMFS shrimp survey began in the summer of 1983. Although this survey had never been used in previous herring assessments, it was considered appropriate for inclusion in the 2012 base assessment model. Age data was not available from this survey.

An NMFS index of larval herring abundance was developed for the years 1978-1995, 1998, and 2000-2010. Following discussions about how the index might relate to spawning stock biomass or recruitment the survey was not included in the base assessment model.

Massachusetts Division of Marine Fisheries spring and fall bottom trawl surveys began in 1977, while joint Maine and New Hampshire spring and fall bottom trawl surveys began in 2001 and 2000, respectively. Results of these surveys were not used as tuning indices in the base assessment model, however they are likely useful indices of localized abundance and potentially useful for management.

Commercial landings per unit effort (LPUE) indices of abundance have not been used for previous Atlantic herring assessments. Based on a priori reasons, LPUE indices were not developed for this assessment.

TOR 3. Evaluate the utility of the NEFSC fall acoustic survey to the stock assessment of herring. Consider degree of spatial and temporal overlap between the survey and the stock. Compare acoustic survey results with measures derived from bottom trawl surveys.

An NMFS acoustics survey began in 1999, focusing on the Georges Bank area. Age data were collected during the survey using a mid-water trawl. The acoustic signal was converted to annual estimates of biomass and abundance. This survey declines sharply from 2000 to 2001, and although it has been considered, has not been included in previous herring assessments. Previous assessments have suggested that the sharp decline in 2000-2001 is inconsistent with other sources of data and may have been caused by a shift in the temporal or spatial overlap between the survey and spawning aggregations of herring. Annual distributions of the timing and spatial locations of spawning herring aggregations were developed from larval herring surveys. No clear evidence emerged to demonstrate a mismatch between the survey and spawning herring aggregations that might explain the trends in the annual acoustic signal. In the fall of 2006, an independent acoustic survey was conducted using a long range sonar system (OAWRS). Estimates of abundance from the OAWRS system were similar in scale to that from the NEFSC acoustic survey. In light of this information, the utility of this survey was discussed, and the survey was included in a sensitivity analysis, but was not included in the base assessment model.

TOR 5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-6), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

As in the last several herring assessments, a statistical catch-at-age model (ASAP) was used as the base model. The previous assessment in 2009, however, suffered from a severe retrospective pattern and so was not used as a basis for catch advice. The 2009 ASAP model configuration was updated using data through 2011 and the severe retrospective pattern persisted. Data inputs and model settings were reconsidered during the development of the 2012 assessment. The major changes to the data inputs include: age and time variable natural mortality, use of two fishing fleets with estimation of selectivity, time and age variable maturity, and the elimination of sharing age composition data among survey and commercial data sources.

The base ASAP model estimated SSB in 2011 to be 517,930 mt, with SSB ranging from a minimum of 53,349 mt (1978) to a maximum of 839,710 mt (1997) over the entire time series. The base ASAP model estimated total January 1 biomass in 2011 to be 1,322,446 mt, ranging from a minimum of 180,527 mt (1982) to a maximum of 1,936,769 mt (2009) over the entire time series. Fishing mortality at age 5 (F_5) in 2011 equaled 0.138 and was near the all-time low of 0.129 (1994). F_5 in 2011, however, was not representative of fishing mortality rates in recent years, which averaged 0.231 during 2000-2009 and also showed an increasing trend during those years. Fishing mortality rates in 2010 and 2011 were relatively low due to the presence of a strong 2009 age 1 cohort (2008 year class). The maximum F_5 over the time series equaled 0.798 (1980).

The internal retrospective error in SSB and F_5 during 2004-2011 was relatively minor in scale and was characterized by errors in both positive and negative directions. This result was expected because natural mortality was adjusted during 1996-2011 in part to alleviate a retrospective error in SSB. Despite these generally positive features of the retrospective error, some concerns still remained. The retrospective error suggested a tendency to overestimate SSB and underestimate F_5 during 2004-2007, but errors were in the opposite direction for both metrics during 2008-2011. Furthermore, retrospective errors suggested a tendency to underestimate recruitment (age 1 numbers). Recruitment relative retrospective error in the terminal years ranged from -0.92 in 2009 to -0.19 in 2006 and averaged (i.e., Mohn's Rho) -0.52.

TOR 6. Consider the implications of consumption of herring, at various life stages, for use in estimating herring natural mortality rate (M) and to inform the herring stock-recruitment relationship. Characterize the uncertainty of the consumption estimates. If possible integrate the results into the stock assessment.

Consumption of herring was addressed in one of two ways: 1) indirectly through the estimation of age and year specific Ms that were partially determined by using a Lorenzen curve, and 2) directly through estimation of annual consumption of herring by fish predators, which was treated as a fishing fleet in assessment modeling.

Based on the Lorenzen curve, natural mortality at ages 1 and 2 generally declined during 1964-2011. Average M at age 1 during 1964-1990 equaled 0.73, but equaled 0.48 during 1991-2011. Average M at age 2 during 1964-1990 equaled 0.57, but equaled 0.44 during 1991-2011. In contrast, the natural mortality at ages 3 and older generally remained stable or increased, especially since 1990. The maximum absolute change during the time series was about 0.02 for ages 3 and older, which suggested relatively minor biological significance. The average M at ages 3 and older during 1964-2011 ranged from 0.22 at age 14 to 0.35 at age 3. These Lorenzen estimates were used in the base ASAP assessment model.

Food habits data from NEFSC bottom trawl surveys were evaluated for 13 herring fish predators. The total amount and type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition of herring, per capita consumption, total consumption, and the amount of herring removed by the 13 predators were calculated. Combined with abundance estimates of these fish predators, herring consumption was summed across all predators as total herring consumption in each year during 1968-2010. Consumption ranged from 84 mt in 1983 to 542,233 mt in 1998 and averaged 161,305 mt over the entire time series. The consumption estimates were modeled directly as a fishing fleet in an ASAP model as a sensitivity analysis, but consumption estimates were not used directly in the base ASAP run. The estimates, however, did inform a change to the Lorenzen estimates of M used in the base ASAP model.

TOR 7. 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 scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.*

The existing MSY reference points are based on the fit of a Fox surplus production model. The overfishing definition is $F_{MSY} = 0.27$. The stock is considered overfished if SSB is less than half SSB_{MSY}. The existing overfished definition is ½ SSB_{MSY} = 0.5 x 670,600 mt = 335,300 mt. MSY = 178,374 mt.

Updated MSY reference points were estimated based on the fit to a Beverton-Holt stock-recruitment curve, which was estimated internally to the ASAP base run. Steepness of the Beverton-Holt curve = 0.53, F_{MSY} = 0.27, SSB_{MSY} = 157,000 mt (½ SSB_{MSY} = 78,500), and MSY = 53,000 mt.

TOR 8. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model, should one be developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).
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 model from the 2009 TRAC was updated using data through 2011. From this model, fully selected F in 2011 was estimated to be 0.07 and SSB in 2011 was 979,000 mt. A comparison of these values to the existing MSY reference points from the 2009 TRAC suggest that overfishing is not occurring and that the stock is not overfished.

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

The base ASAP run estimated fishing mortality at age 5 in 2011 to be 0.14 and SSB in 2011 was 517,930 mt. A comparison of these values to the new MSY reference points from the base ASAP run suggest that overfishing is not occurring and that the stock is not overfished.

TOR 9. Using simulation/estimation methods, evaluate consequences of alternative harvest policies in light of uncertainties in model formulation, presence of retrospective patterns, and incomplete information on magnitude and variability in M.

Several research projects have been undertaken to address this term of reference. Several projects from researchers at the University of Maine focused on causes and solutions of retrospective patterns. Another project from NMFS biologists in Woods Hole (J. Deroba) used simulation modeling to quantify the consequences (e.g., SSB, F, quotas) of either ignoring retrospective patterns or adjusting for retrospective patterns using Mohn's Rho. Some collaborative research is also underway by NMFS biologists (J. Deroba and A. Schueller) to quantify the extent of bias in stock assessment estimates when natural mortality varies among years and ages, but this variation is mis-specified in the assessment model. The working group did not discuss any of these projects in detail because they focus on more general topics that did not immediately inform decisions for this assessment. The details of some of the University of Maine project are provided in a working paper.

TOR 10. Develop approaches and apply them to conduct stock projections and to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

10.a. Provide numerical annual projections (3 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 (three year) stochastic projections of future stock status were conducted based on the results of the base ASAP run. Projections were conducted for a range of harvest scenarios, including F_{MSY}, 0.75 F_{MSY}, F_5 in 2011, MSY, and status quo catch (i.e., 2012 annual catch limit). Results suggested that none of the harvest scenarios will result in overfishing and the stock will not become overfished through 2015, with the exception of projections at status quo catch, which had relatively small probabilities for overfishing to occur.

10.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.

Natural mortality is an uncertainty in this assessment. Of particular importance is acceptance of the scale of the herring consumption estimates. A 50% increase in M from the original Lorenzen M values during 1996-2011 was used in the base ASAP run to reduce retrospective patterns in SSB and improve the consistency between implied amounts of biomass removals from M and the estimates of consumption. Furthermore, the reference points and projections were made under the assumption that prevailing conditions would persist. If life history traits such as M change rapidly, and prevailing conditions become altered, the associated biological reference points and projections would likewise need to be changed.

An ASAP assessment model using the original Lorenzen M values exhibited a retrospective pattern that the working group felt would not be acceptable to reviewers or managers (see TOR 5). Reference points and projection results from the ASAP run using the original Lorenzen M values also differ from the base ASAP model.

Stock structure is another uncertainty for this assessment. The working group acknowledged that a retrospective pattern in the Atlantic herring assessment may be inevitable as long as we are assessing a mixed stock complex. For example, varying contributions from the Scotian Shelf (4WX) stock can produce retrospective patterns.

The base ASAP model relies on bottom trawl surveys and fishery data. The differences between the trends in both the NEFSC acoustic survey and winter survey from the base ASAP model presents a potential source of uncertainty.

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

The unknown contributions of the Scotian Shelf (4WX), Gulf of Maine, and Georges Bank stocks can affect the stocks vulnerability to becoming overfished. For example, if the Scotian Shelf stock is contributing a significant amount of fish and that contribution decreases, the vulnerability to overfishing would increase.

In the short-term, the relatively large 2009 age 1 cohort (2008 year class) may reduce the vulnerability of this stock to overfishing. The size of this cohort, however, is uncertain and may be overestimated. An overestimate of the 2009 age 1 cohort would likely increase the vulnerability of this stock to overfishing.

Recent catches were generally greater than the estimate of MSY from the base ASAP run. This result suggests that in the long-term this stock may become more vulnerable to overfishing. The MSY reference points, however, are uncertain.

TOR A11. For any research recommendations listed in recent peer reviewed assessment and review panel reports, review, evaluate and report on the status of those research recommendations. Identify new research recommendations.

Research recommendations were not available from the previous assessment. Fifteen new research recommendations were developed.

TOR Links Index

Stock Assessment Terms of Reference for SAW/SARC-54 (June 4-8, 2012)

A. Atlantic herring

1. Estimate catch from all sources including landings and discards. Describe the spatial distribution of fishing effort. Characterize uncertainty in these sources of data.

2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, larval surveys, age-length data, predator consumption rates, etc.). Investigate the utility of commercial LPUE as a measure of relative abundance, and characterize the uncertainty and any bias in these sources of data.

3. Evaluate the utility of the NEFSC fall acoustic survey to the stock assessment of herring. Consider degree of spatial and temporal overlap between the survey and the stock. Compare acoustic survey results with measures derived from bottom trawl surveys.

4. Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas.

5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-6), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

6. Consider the implications of consumption of herring, at various life stages, for use in estimating herring natural mortality rate (M) and to inform the herring stock-recruitment relationship. Characterize the uncertainty of the consumption estimates. If possible integrate the results into the stock assessment.

7. 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}, $B_{THRESHOLD}$, $_{FMSY}$ 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 scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.

8. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model, should one be developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).
    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 and their estimates (from TOR-7).

9. Using simulation/estimation methods, evaluate consequences of alternative harvest policies in light of uncertainties in model formulation, presence of retrospective patterns, and incomplete information on magnitude and variability in M.

10. Develop approaches and apply them to conduct stock projections and 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 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.

11. For any research recommendations listed in recent peer reviewed assessment and review panel reports, review, evaluate and report on the status of those research recommendations. Identify new research recommendations.

Introduction

The fishery for Atlantic herring in the Gulf of Maine/Georges Bank stock has a long history dating to the colonial era. Although prosecution of the fishery has evolved, herring is still the focus of a significant fishery. Herring are targeted by trawls and purse seines as well as fixed gear in eastern Maine and New Brunswick, Canada. Additionally, herring are a key prey species in the Gulf of Maine/Georges Bank ecosystem.

Atlantic herring of the Gulf of Maine/Georges Bank stock was last assessed in the TRAC process (Transboundary Resources Assessment Committee) in June 2009 (TRAC 2009). Based on the results of a statistical catch at age model (ASAP), the TRAC concluded the stock was not overfished and overfishing was not occurring. The estimate of age 2+ biomass (652,000 mt) in 2008 was below B_{MSY} (670,600 mt) and fishing mortality in 2008 (0.14) was below F_{MSY} (0.27). However, a large retrospective bias in the results created a high degree of uncertainty and consequently the fishery quota resulting from the assessment was not used for management.

The intention of the SARC 54 stock assessment is to address the terms of reference and ultimately provide scientific information useful to the management process.

Although the terms of reference are numbered sequentially, the WG concluded that it was important to address terms of reference in the order necessary to complete subsequent TORs. Consequently term of reference A4 is addressed first and A6 precedes A5.

TOR A4: *Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas.*

Early assessments of Atlantic herring along the east coast of the United States divided the resource into separate Gulf of Maine/Nantucket Shoals and Georges Bank stocks based on known spawning aggregations (Figure A4-1). However, since the 1991 assessment herring from the two areas are combined into a single coastal stock complex, since there is evidence that fisheries and surveys include fish originating from all spawning areas (NEFSC 1998, Overholtz 2004). This approach poses a challenge for the conservation of individual spawning components. Catch limits for the stock complex are allocated to spatial management areas and catch allocations are based on estimates of stock composition and relative biomass among areas (Correia 2012). Recent simulations suggest that combining spawning components from the Gulf of Maine and Georges Bank into a single stock assessment can also produce retrospective patterns in stock assessment results (Guan et al. MS 2012). The intention of this term of reference is to re-examine the available information on stock identification information, including an update with recent information (Cadrin et al. 2005), and provide recommendations for the assessment. Literature was reviewed for information regarding stock structure with respect to geographic distribution, geographic variation and movement.

Geographic Distribution

Spatial patterns of abundance offer an indication of stock structure. Atlantic herring spawn on relatively shallow shoals, and bathymetric features like deep channels may form boundaries among spawning groups spawning areas. For pelagic species like herring, oceanographic features (e.g., temperature or density fronts) may also form boundaries among groups.

Resource distribution - Fishery independent surveys indicate two distinct spawning locations: 1) inshore waters of the Gulf of Maine (Figure A4-3; Clark et al. 1999, Power et al. 2002, Reid et al. 1999, Tupper et al. 1998) and on Georges Bank, including Nantucket Shoals and Cultivator Shoals (Figure A4-3; Melvin et al. 1996, Reid et al. 1999). Currently, spawning appears to be continuous from Massachusetts Bay into Great South Channel and along the northern fringe of Georges Bank to the Northeast Peak.

The distribution of juvenile and adult herring on Georges Bank and in adjacent areas changed since 1961. During the early and peak years of the Georges Bank fishery, 1961-1970, adult and juvenile herring were sparsely scattered throughout the Gulf of Maine and Georges Bank, with concentrations in the vicinity of known spawning areas (i.e., northern edge of Georges Bank, Nantucket Shoals and in Massachusetts Bay; Melvin et al. 1996).

Although survey coverage of the inshore waters of the Gulf of Maine is generally poor, increasing numbers of herring have been collected in the coastal areas of Maine since about 1990 (Figure 4a). Herring from the Gulf of Maine and Georges Bank overwinter between Cape Cod and Cape Hatteras, with major aggregations occurring in coastal and shelf waters off Long Island. Since 1990, herring have continued to broaden their winter distribution and increase in abundance in both coastal and offshore waters from Cape Cod to Cape Hatteras (Figure A4-4b).

Ichthyoplankton distribution - Information on distribution of early life history stages is pertinent to stock identification because it may indicate exchange between adjacent geographic groups, or alternatively the isolation of reproductive products (Hare 2005). Herring larvae produced by the major spawning stocks in the Gulf of Maine/Georges Bank region remain discrete during the early part of the larval stage (Sinclair and Iles 1985; Tupper et al. 1998). Therefore, the distribution pattern of young larvae (<10mm) provides information on stock structure. Based on the distribution of 4-9mm larvae, Tibbo et al. (1958) concluded that the largest herring spawning area in the Gulf of Maine occurred on the northern edge of Georges Bank (updated geographic distributions of <9mm larvae in Figure A4-5). Annual larval surveys were conducted throughout the 1960s in the Gulf of Maine (Boyar et al. 1973a, Boyar et al. 1973b; Tibbo and Legare, 1960). The largest herring spawning component occurred on the northeastern portion of Georges Bank.

Geographic Variation

Biochemistry - Genetics have provided little conclusive evidence of discrete stock structure of Atlantic herring (Tupper et al. 1998). Biochemical methods for distinguishing herring populations in the Northwest Atlantic have been conducted since the 1970s. The U.S. and U.S.S.R biochemical and serological studies of the 1970s were considered flawed and thus no conclusions could be reached based on their information (Anthony and Waring 1980). Kornfield and Bogdonowicz (1987) found no evidence of genetically distinct herring populations in the Gulf of Maine based on mitochondrial DNA analysis.

Growth - geographic patterns in size at age suggest sub-stock structure. The average length at age by station for the spring and fall trawl surveys shows that fish in the north are smaller at age (Figure A4-6). Older fish aren't located in this area during these surveys. There is approximately an 18% difference in length between the southern set of survey strata and the northern set of strata (Figure A4-7).

Morphology - Genetic or environmental differences among areas can produce geographic patterns in body form that are also important for identifying phenotypic stocks (Winans, 1987). Pectoral fin ray counts were used in the past to distinguish between herring from the Maine coast, Georges Bank and Nova Scotia (Anthony and Waring 1980). The number of pectoral fin rays is related to water temperature and is determined at an early age. Adult herring from Georges to Cape Cod are expected to have fewer fin rays than adults from further north since they inhabit warmer waters (Reid et al. 1999). Pectoral fin ray counts from juvenile fish from the Maine coast were found to be similar to adults from Georges Bank to Cape Cod (Anthony and Waring 1980).

Libby (cited in Tupper et al.1998) examined a number of otolith size and shape characteristics from recently hatched larvae from southwest Nova Scotia, western Georges Bank and mid-coast Maine. Eighty-four percent of 38 otoliths were classified to the correct spawning area.

Armstrong and Cadrin (2001) characterized morphometric variation between the two major spawning components in the Gulf of Maine-Georges Bank stock complex. Post-spawning herring were classified into their respective spawning groups using discriminant analysis of morphometric characters with 88% accuracy. Discrimination of mixed-stock samples from the winter fishery suggested that 70% were from Georges Bank and 30% were from the Gulf of

Maine. Bolles et al. (2005) refined the morphometric analysis and correctly classified herring to their stock of origin at 67 to 87% accuracy.

Movements and migrations

Ichthyoplankton dispersion - As mentioned above, information on distribution of early life history stages is pertinent to stock identification because it may indicate exchange between geographic groups or isolation of reproductive products. Understanding larval behavior and circulation patterns that may mix reproductive products from adjacent spawning areas or retain larvae within an area are also important for defining stocks (Sinclair 1988).

Herring larvae produced on spawning grounds in eastern Maine and New Brunswick are transported in a westerly direction and recruit to the juvenile herring population along the Maine coast (Tupper et al 1998). Larvae from spawning grounds in the western Gulf of Maine recruit to the juvenile herring populations along the coast of central and western Maine and along the coast of New Hampshire and Massachusetts (Lazzari and Stevenson 1992, Tupper et al. 1998). Larvae produced in the Jeffreys Ledge area move inshore and disperse in all directions (Tupper et al 1998).

Georges Bank larvae may be retained in a clockwise current gyre for several months (Boyar et al. 1973a, Reid et al 1999). However, larvae from Georges Bank and Nantucket Shoals may also migrate inshore (herring younger than two years of age are not usually found on Georges Bank; Anthony and Waring, 1980). This would most likely occur when the Georges Bank and Nantucket Shoals spawning populations are large (Tupper et al, 1998). Graham et al. (1972) report herring larvae entering the Sheepscot estuary of Western Maine in the early fall, soon after hatching. In the spring, additional larvae also entered the coastal area. The authors postulate that the spring larvae originated from Georges Bank, and the abundance of spring larvae along the coast coincided with the decline of the Georges Bank component.

Tagging observations - Movement of juveniles and adults among areas and fidelity to spawning groups is an essential element to stock identification (Harden Jones, 1968). Historical tagging studies and fisheries data provide the background source of information on seasonal movements of adult and juvenile herring from each of the three spawning components (Figure A4-8).

The annual life cycle of the herring can be divided into five seasonal phases: overwintering, spring migration, summer feeding, spawning and fall migration. Tagging of herring at each of these stages has previously been undertaken to characterize movements and identify stocks (Stobo 1983a,b, Tupper et al. 1998). Gulf of Maine and Georges Bank herring components are mixed to various degrees during all phases of their annual life cycle, except during spawning.

Herring tagged in the autumn in the Bay of Fundy and off Nova Scotia migrated north to Chedabucto Bay and south to Cape Cod Bay and Block Island Sound to overwinter (Stobo et al. 1975; Stobo 1976; 1982). During the feeding and pre-spawning period, the Bay of Fundy contained a large mixture of Gulf of Maine and Scotian Shelf stocks (Stobo 1982).

Age-1 Atlantic herring tagged in the western and central waters of Maine during the autumns and winters of 1982 and 1983 contributed to the commercial catch of age 2 fish east of the area where they were tagged during the 2nd and 3rd quarters of the following year, including easternmost Maine and western New Brunswick waters (Creaser and Libby 1986). Summer feeding adults and older juveniles (age 3) tagged in eastern Maine from 1976 to 1982 were recaptured on overwintering grounds in Massachusetts and Cape Cod Bays and in Southern New England (Creaser et al. 1984, Creaser and Libby 1988). Herring tagged in the summer and fall along the Maine coast tend to move southwest and overwinter in Massachusetts Bay, although a few move south of Cape Cod and some move across the Bay of Fundy to Nova Scotia (Stobo 1983a; b; Tupper et al. 1998).

Adult herring tagged off Cape Cod and the western Gulf of Maine move north and east from the central coast of Maine to southwest Nova Scotia during spring and summer (Grosslein 1986).

Herring tagged in 1977 in the Great South Channel and on Jeffreys Ledge were recovered all along the northeast coast from Ipswich Bay, Massachusetts into the Bay of Fundy and along southwest Nova Scotia in the summer and autumn herring fisheries. Tagged fish were also returned during the winter fisheries in Chedabucto Bay, Cape Cod Bay and Block Island Sound (Almeida and Burns 1978, Anthony and Waring, 1980).

From 1998 to 2002, herring tagged on spawning grounds and on the major Nova Scotia overwintering grounds were mostly recovered from the local tagging area (Waters and Cark 2005). However, recoveries were also found from the summer and fall weir fishery and the winter purse seine fishery around Grand Manan. In addition, there were recoveries from the eastern side of the Bay of Fundy, German Bank, the spawning grounds of Scots Bay and from USA waters as far south as Hudson Canyon. The 2006 Transboundary Assessment Review Committee considered this tagging information and concluded that there is a mix of Scotian Shelf and Gulf of Maine spawners in the New Brunswick weirs, but that there is no means to identify the exact proportion (TRAC 2006). The most recent tagging study of New England herring was by Kanwit and Libby (2009) to describe seasonal movements. Herring tagged in the Gulf of Maine during the summer feeding/spawning period were recaptured in the Gulf of Maine, on Georges Bank, on the Scotian Shelf and in the southern New England winter fishery (Figure A4-9). Herring tagged in Southern New England during the winter feeding period were recaptured in southern New England, the Gulf of Maine and the Scotian Shelf (Figure A4-10).

Conclusions

The Working Group (WG) examined a variety of factors related to stock structure, including geographic distribution, specifically resource and ichthyoplankton distribution, biochemistry, growth, morphology, ichthyoplankton dispersion and tagging studies. The WG agreed that the conclusions of previous Stock Assessment Workshops (Overholtz et al. 2004) and Transboundary Assessment Review Committees (TRAC 2006, 2009) are supported by historical and recent information on stock structure. Mixing of spawning components in the fishery and during resource surveys precludes separate assessment and management of the components. It is therefore necessary to continue to assess the entire Gulf of Maine-Georges Bank stock complex as a single unit. Subsequent consideration of the individual components will remain necessary but will not be supported by the assessment product. Herring in the New Brunswick weir fishery will continue to be included in the Gulf of Maine/Georges Bank stock whereas herring stocks associated with the Scotian Shelf will remain separate. The WG acknowledged some degree of mixing of Scotian shelf stocks with U.S. stocks but as noted, partitioning of stocks within fishery landings is not possible at this time.

Figure A4-1a. Atlantic herring management units in the northwest Atlantic (from www.clupea.net).

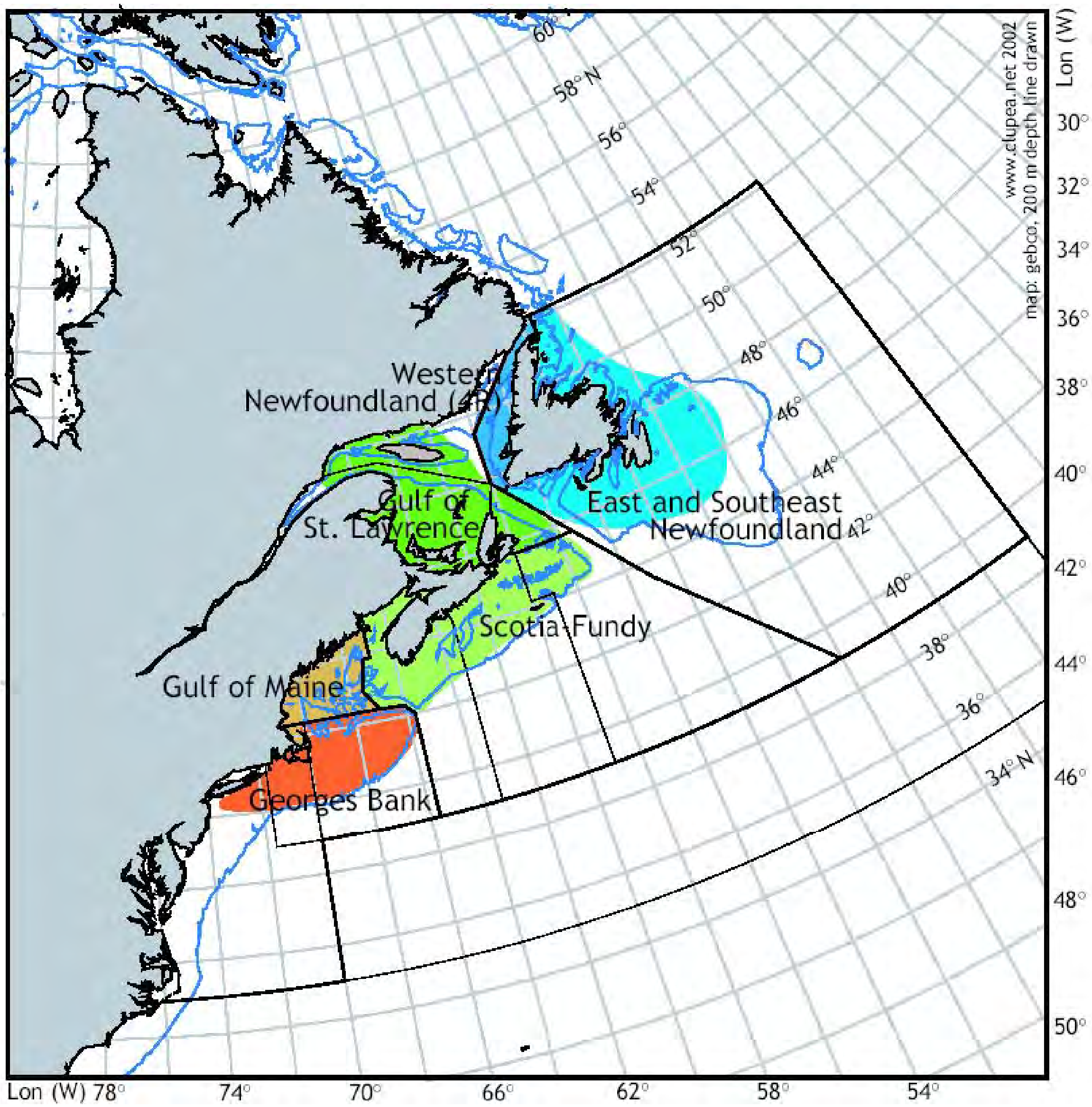


Figure A4-1b. ICNAF view of Atlantic herring stock structure (double lines indicate stock boundaries; from ICNAF 1972)

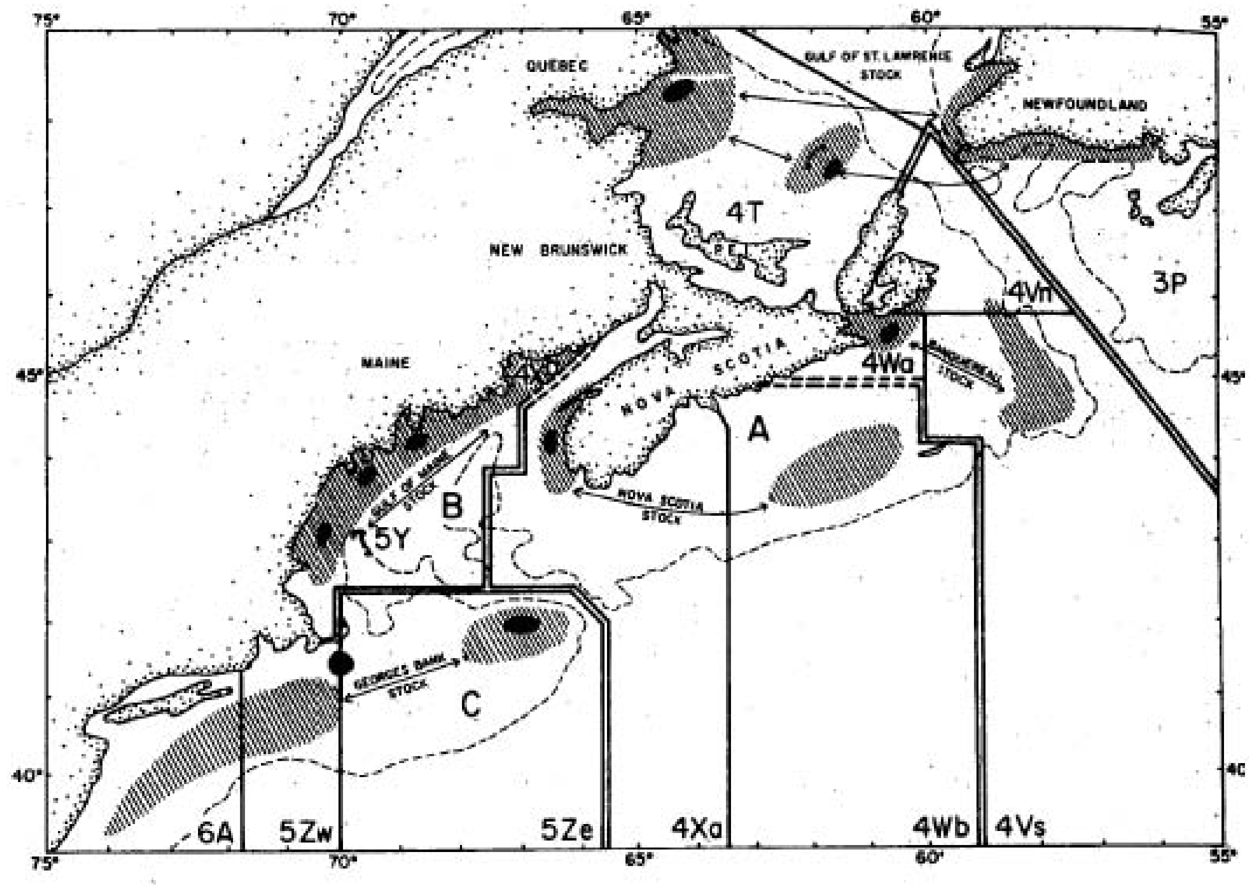


Figure A4-2. Management boundaries for Atlantic herring in the Gulf of Maine and on Georges Bank (lines indicate original boundaries, shaded area indicates 2006 revision to area 3 boundaries).

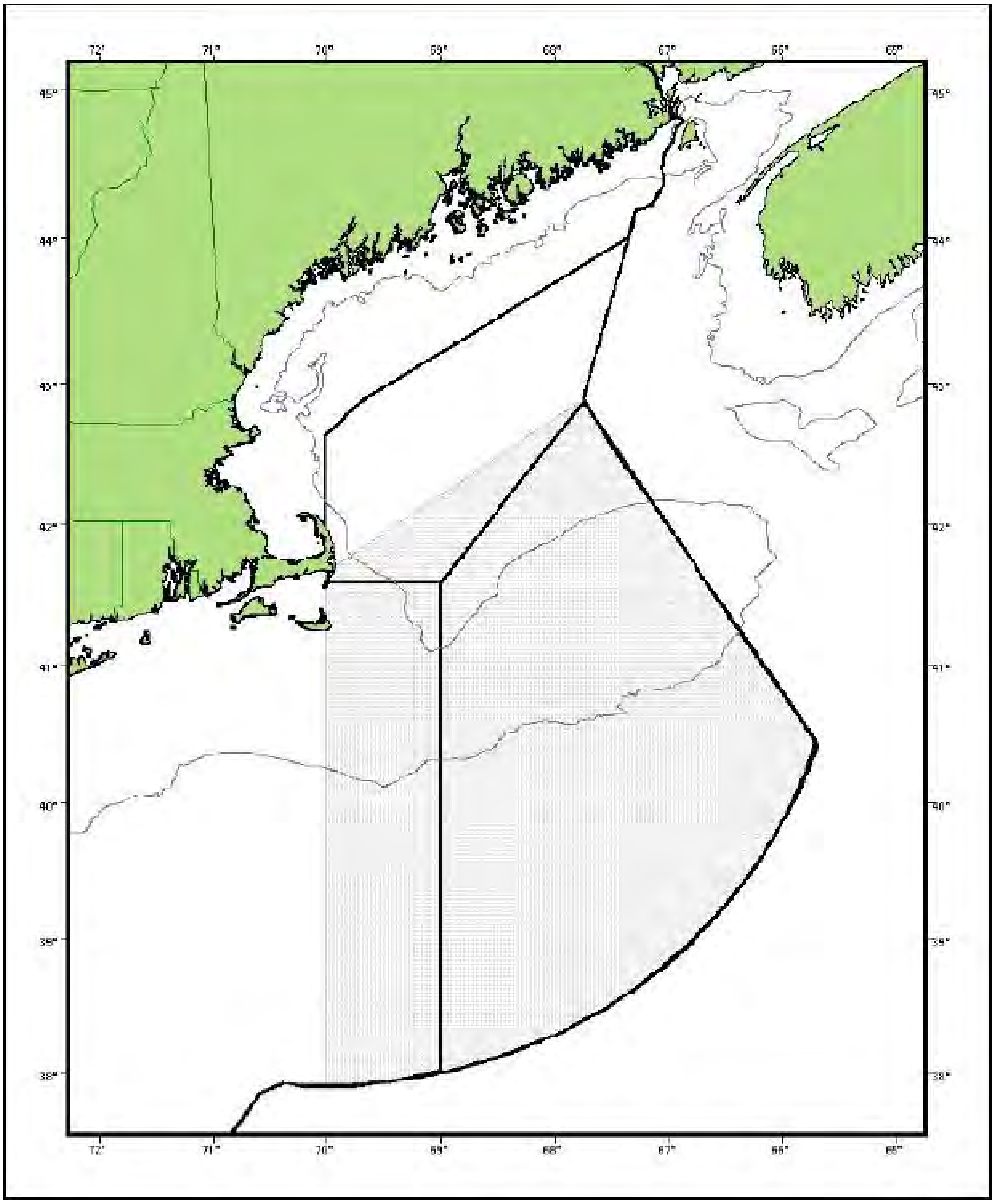


Figure A4- 3. Generalized view of the current major herring spawning areas in the Gulf of Maine and on George Bank (from Overholtz et al. 2004)

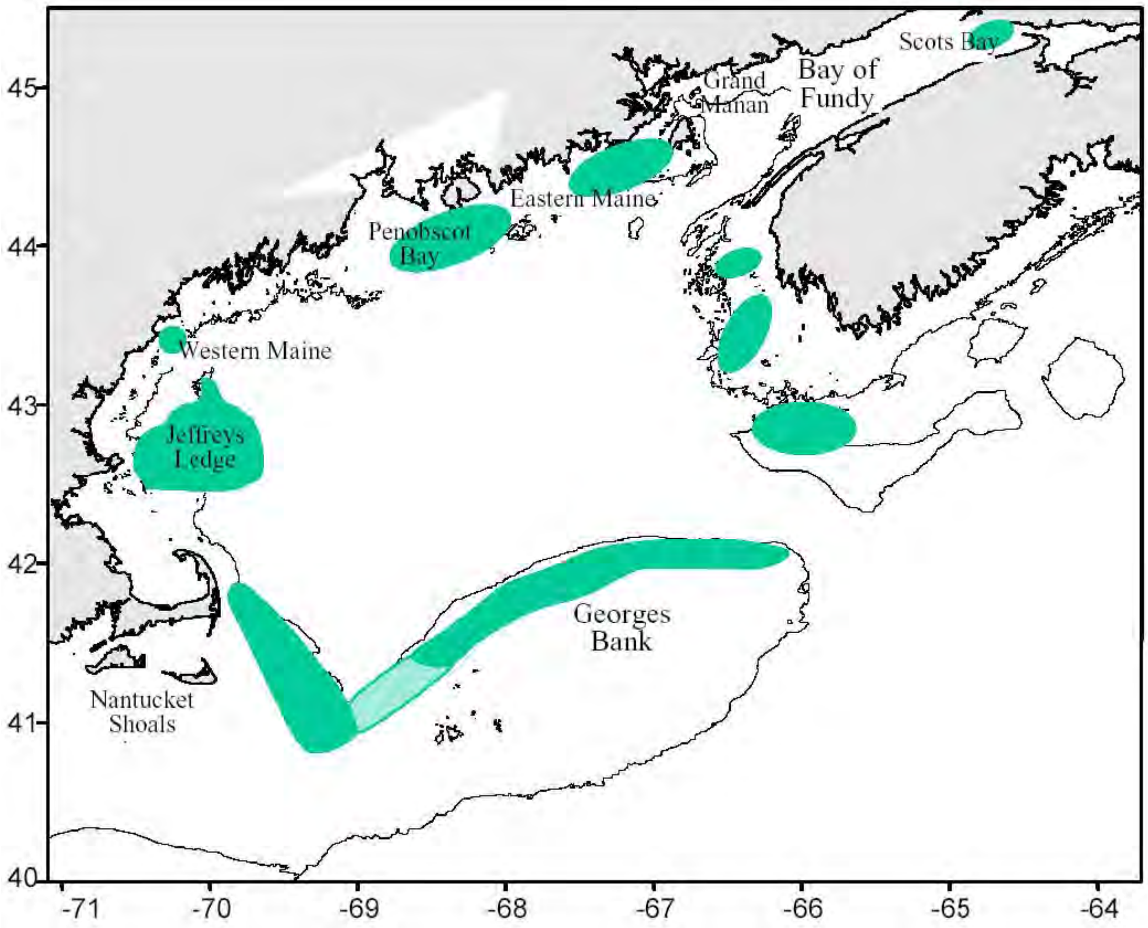


Figure A4-4. Distribution and abundance of Atlantic herring observed in the U.S. fall bottom trawl survey (A) and U.S. spring survey (B); from Overholtz et al.(2004).

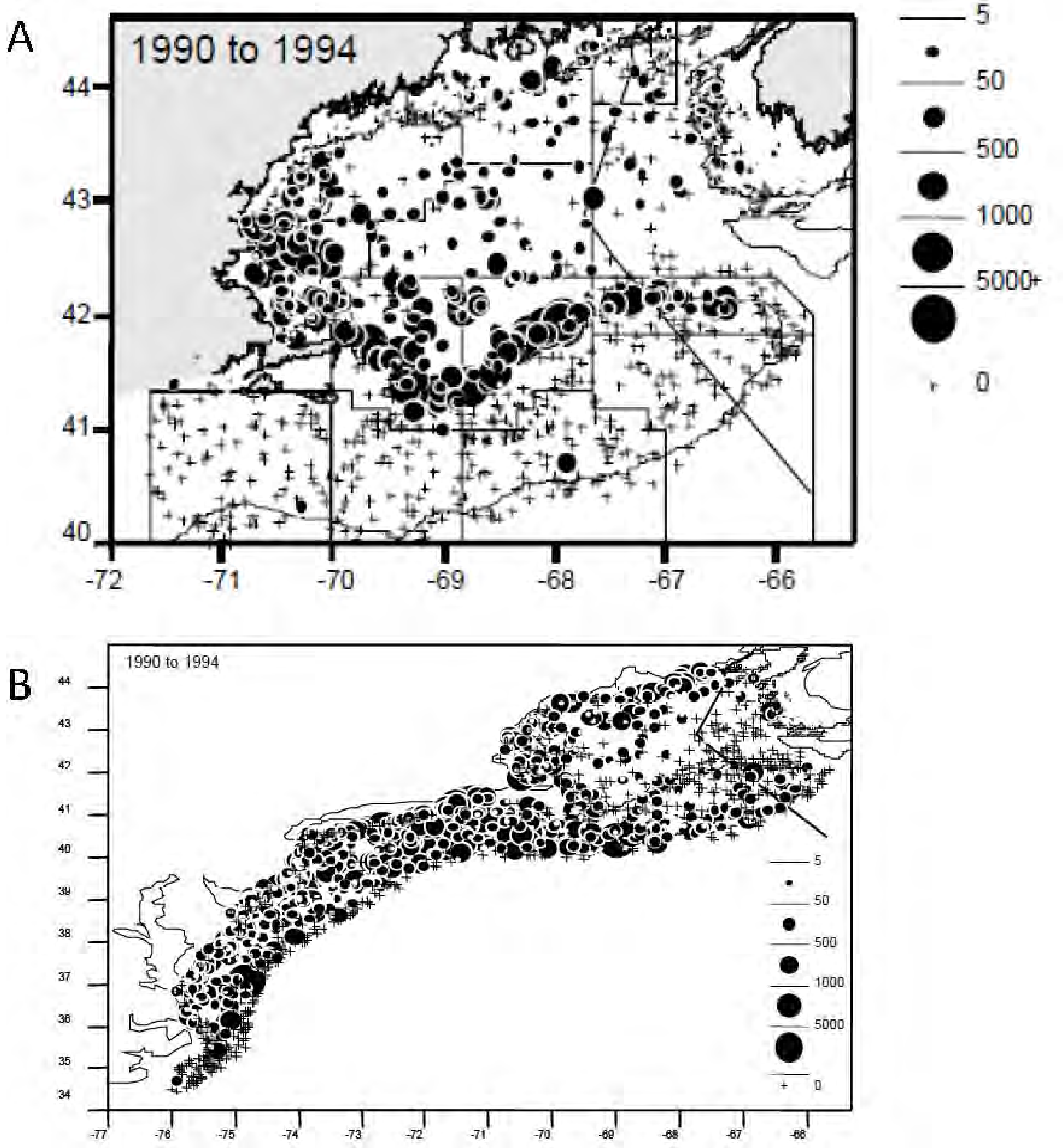
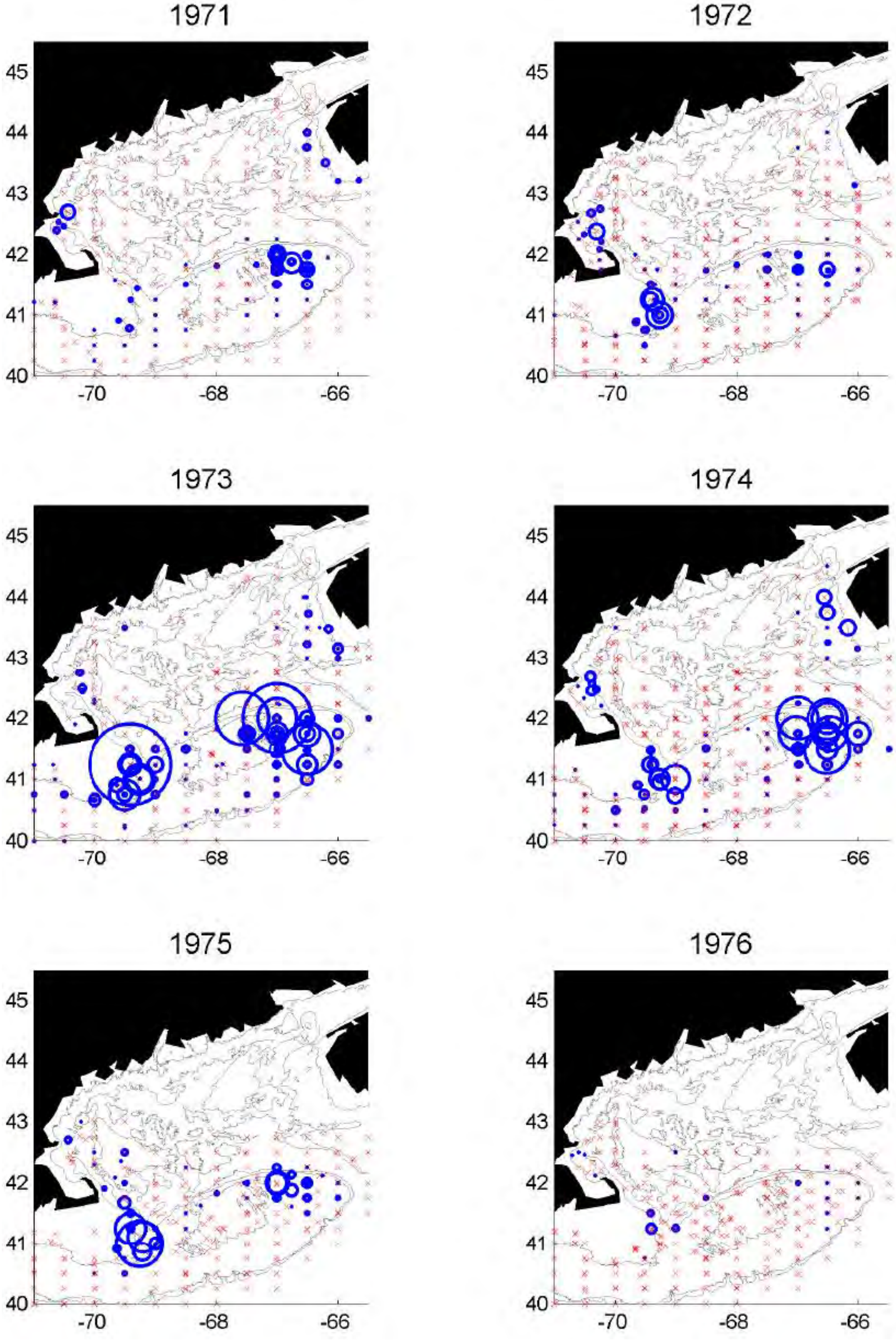
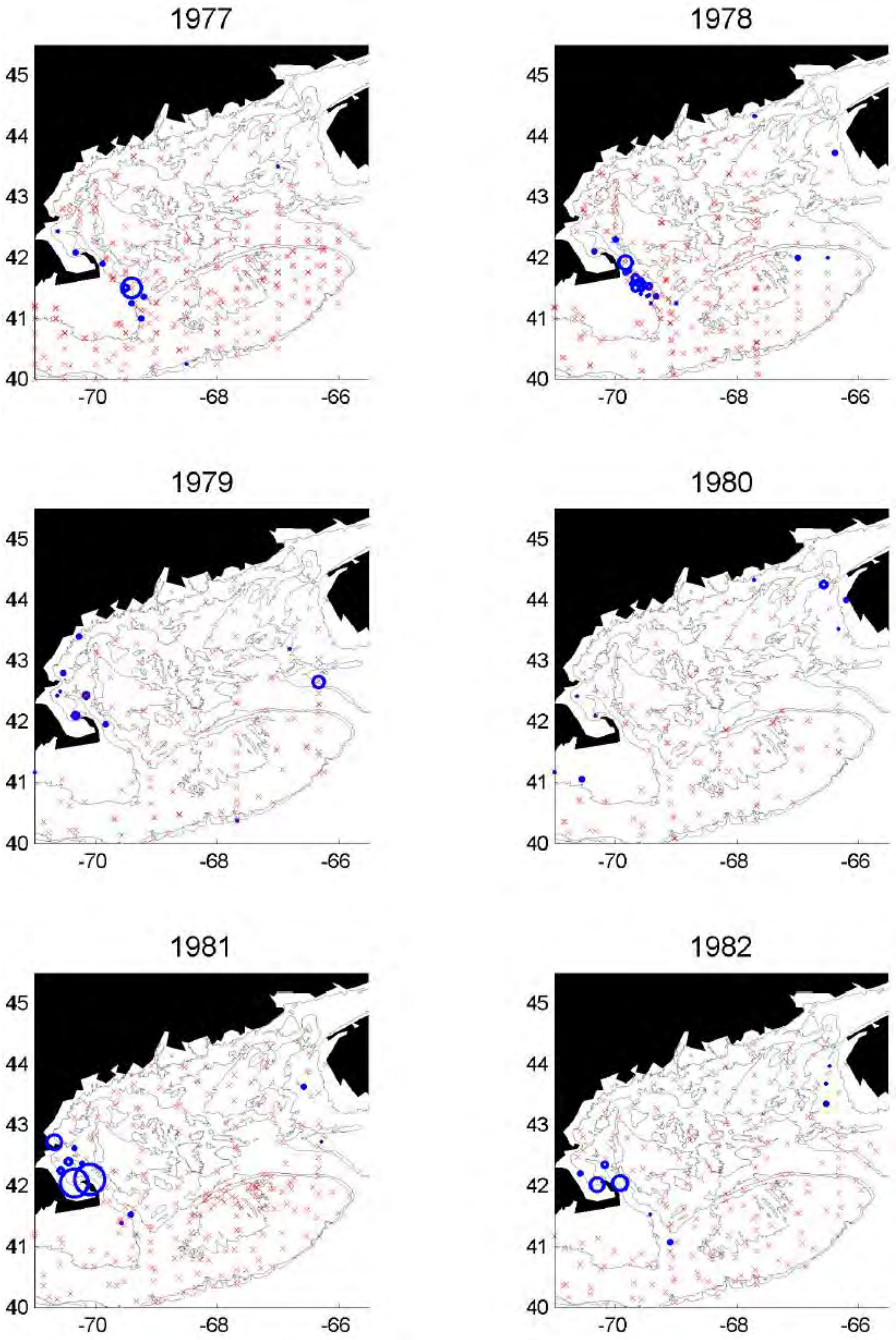


Figure A4-5. Annual distribution of small larvae (<9mm) during sampling in Oct-Dec. Red x's indicate samples with no larvae (continued on following pages).

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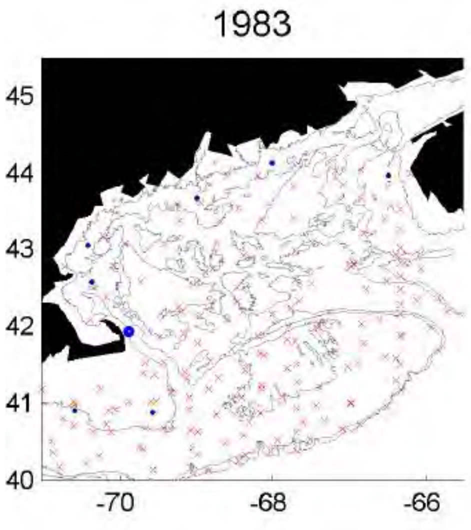
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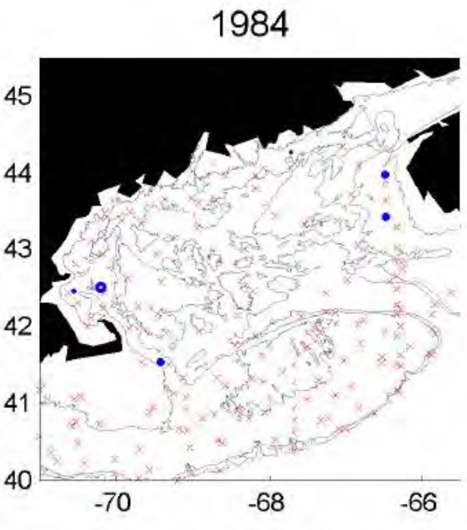
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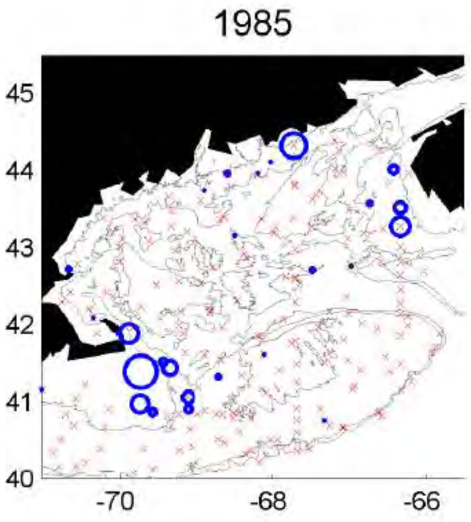
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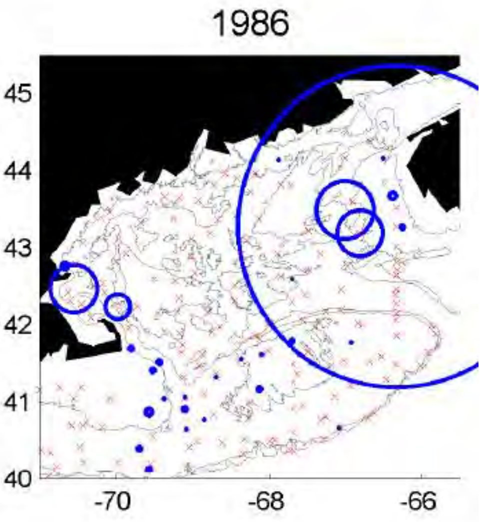
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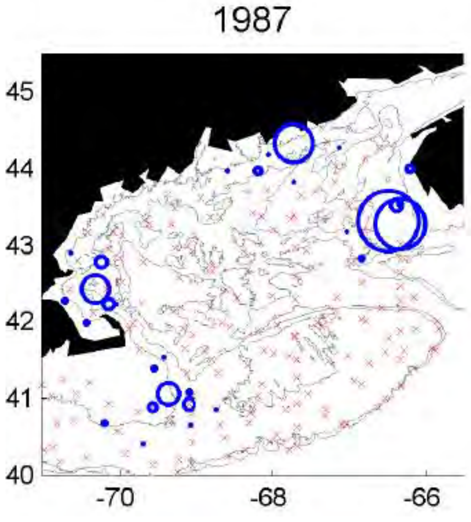
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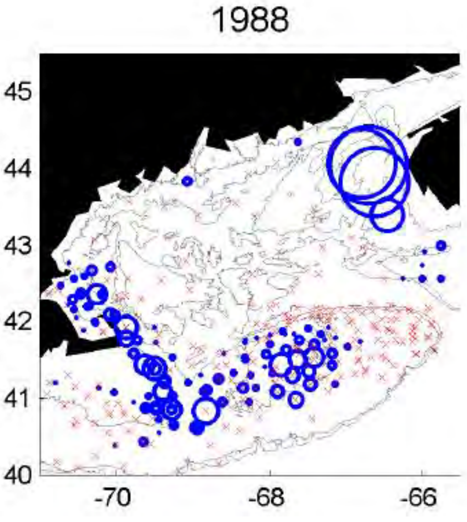
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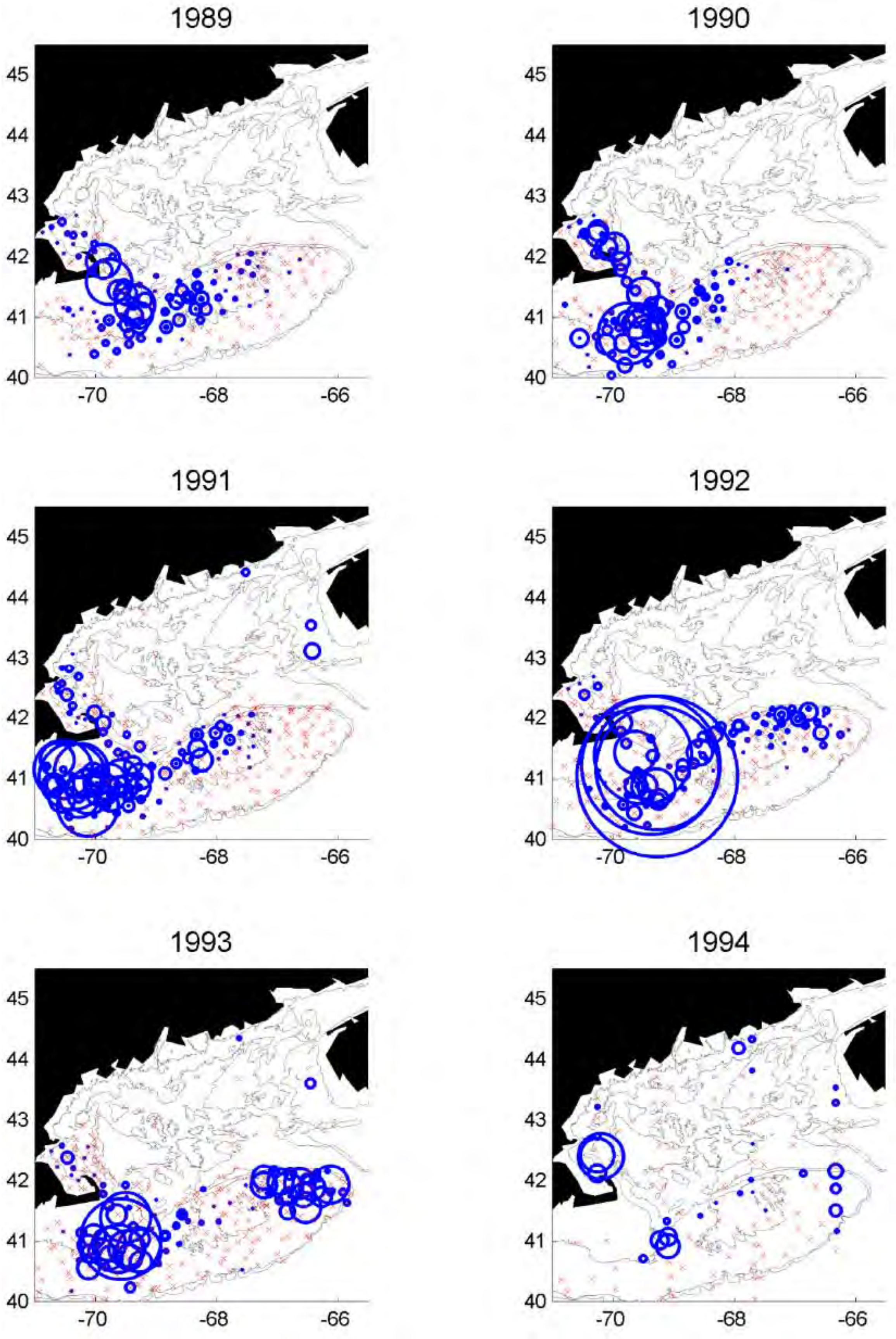
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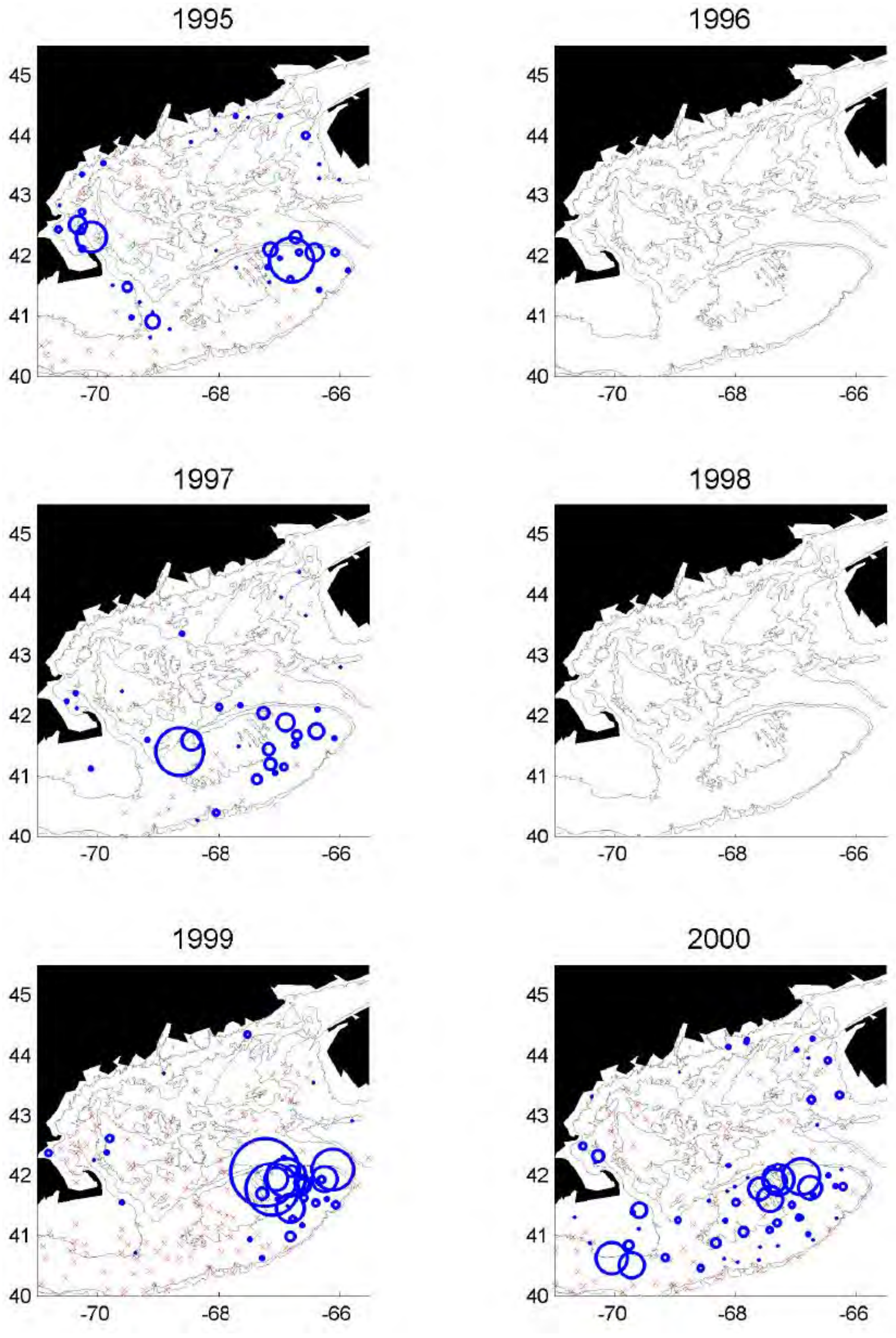
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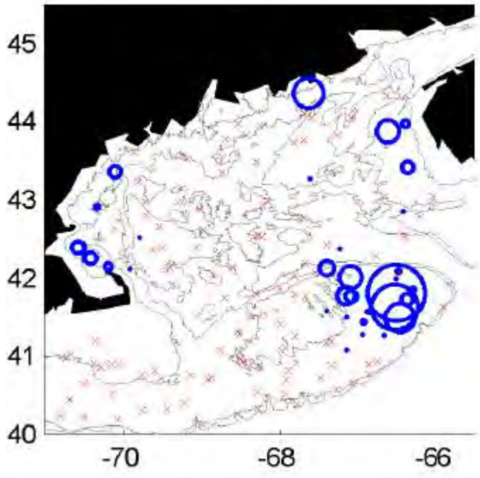

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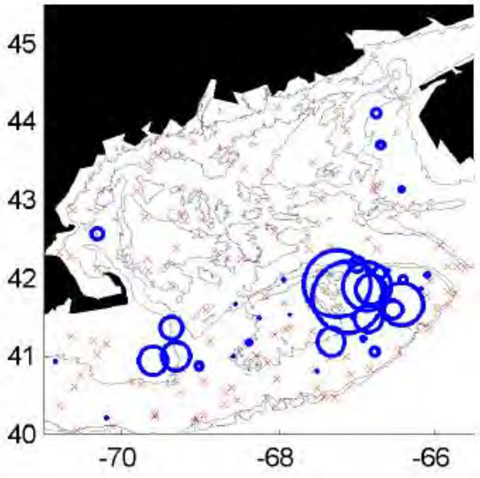

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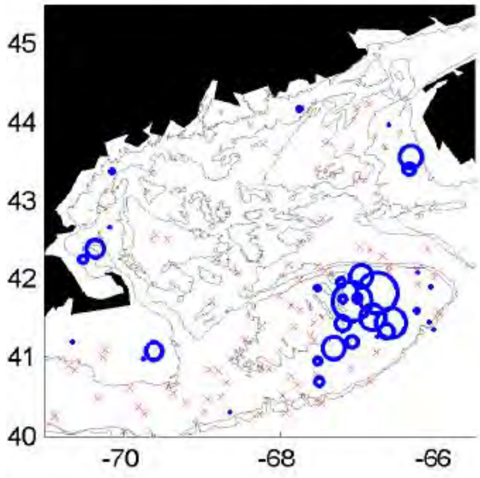

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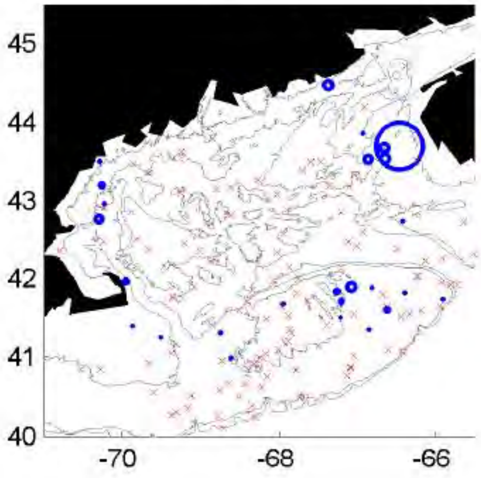

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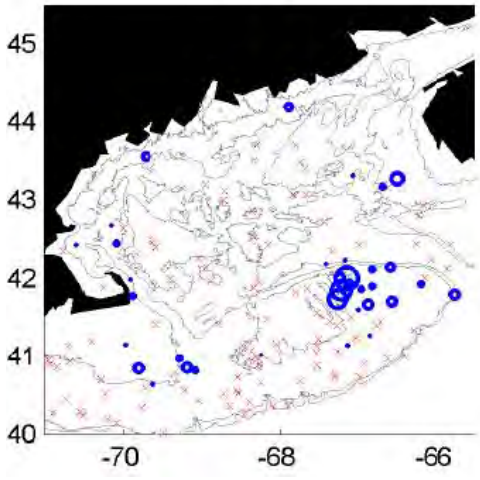

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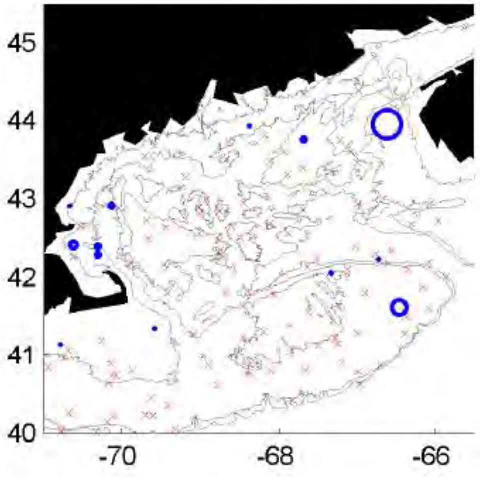

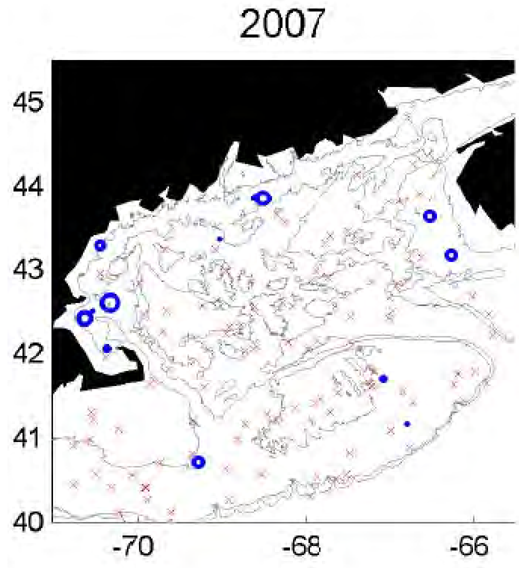
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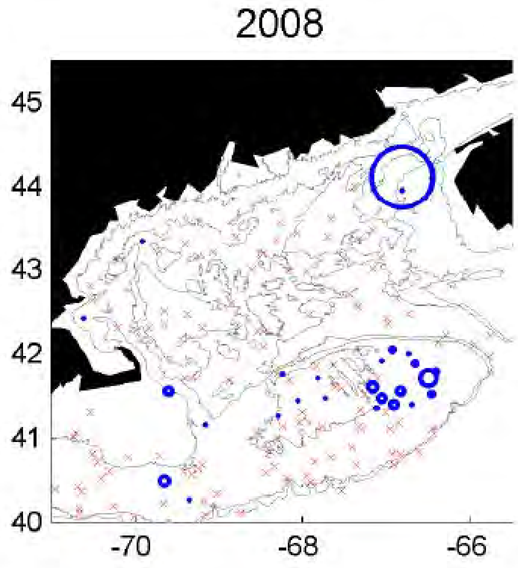
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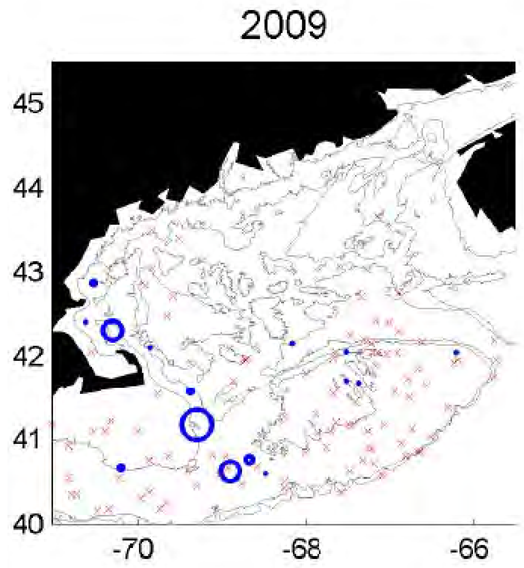
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Figure A4-6. Spatial patterns of length at age in the NEFSC spring and fall surveys, 2009 and 2010.

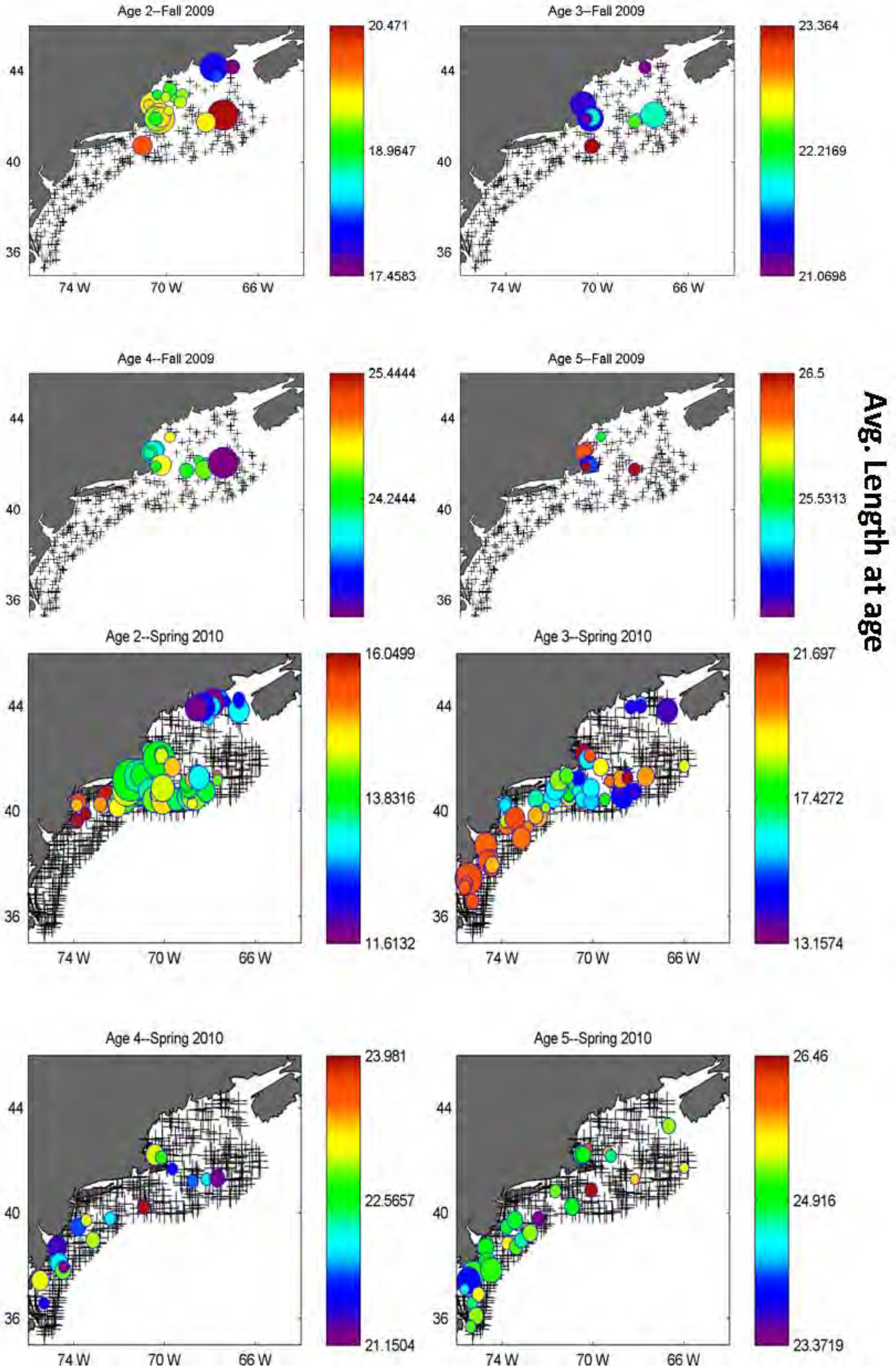


Figure A4-7. Average length calculated using SURVAN Southern Strata (1-25 and 69-76) and Northern Strata (33-40).

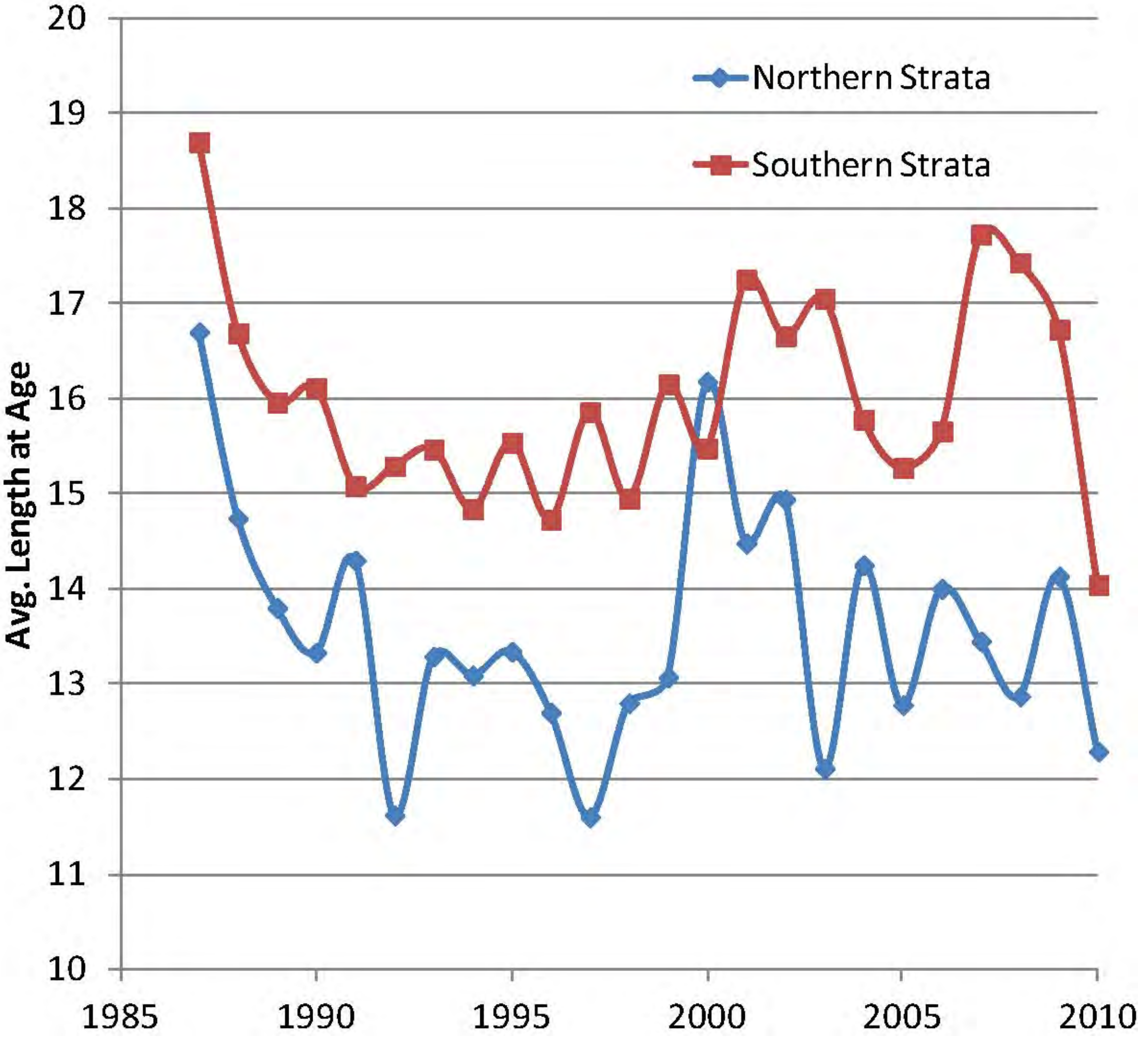


Figure A4-8. Hypothesized seasonal movements of three Atlantic herring spawning stocks inhabiting U.S. waters (from Reid et al. 1999).

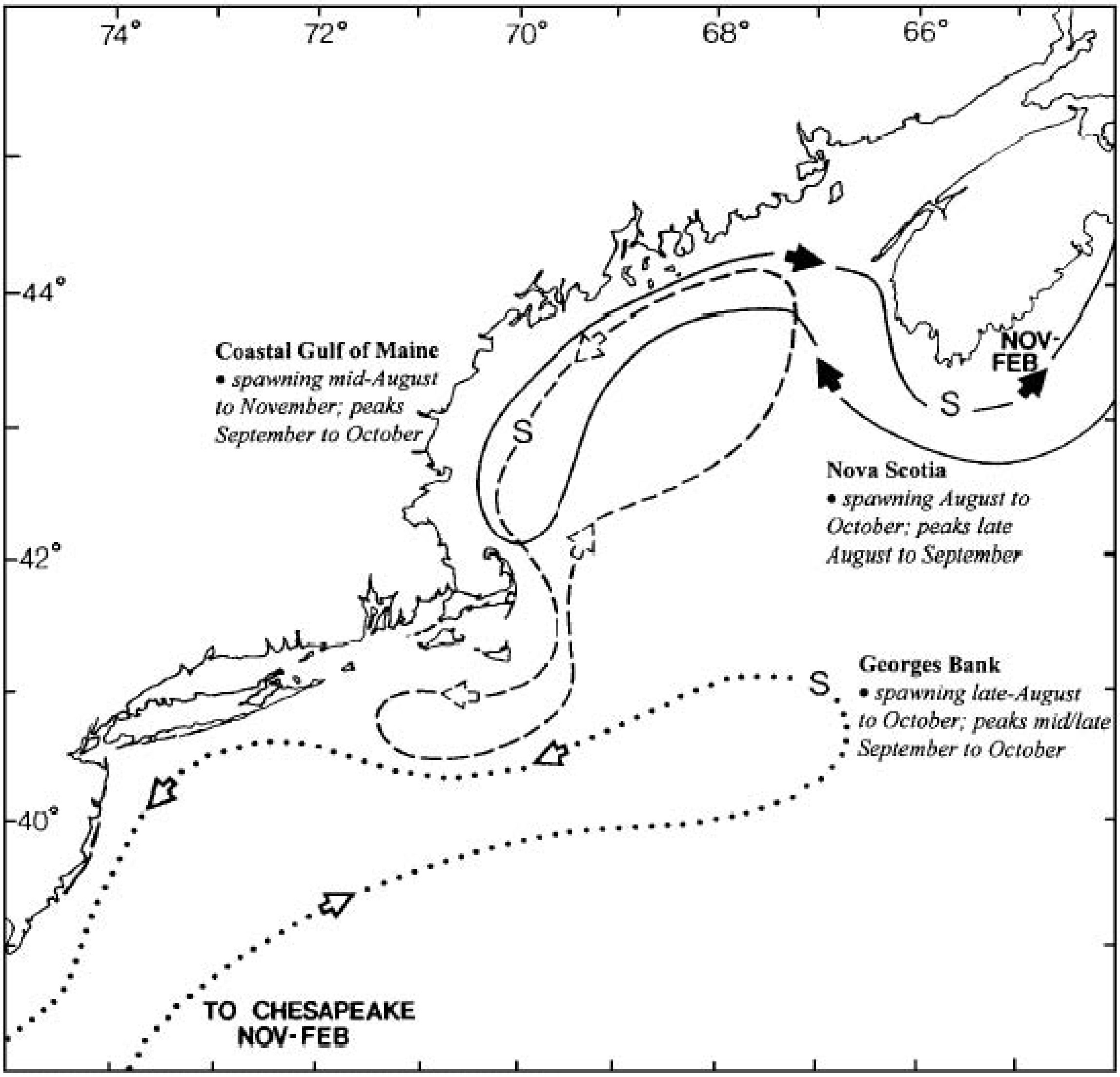
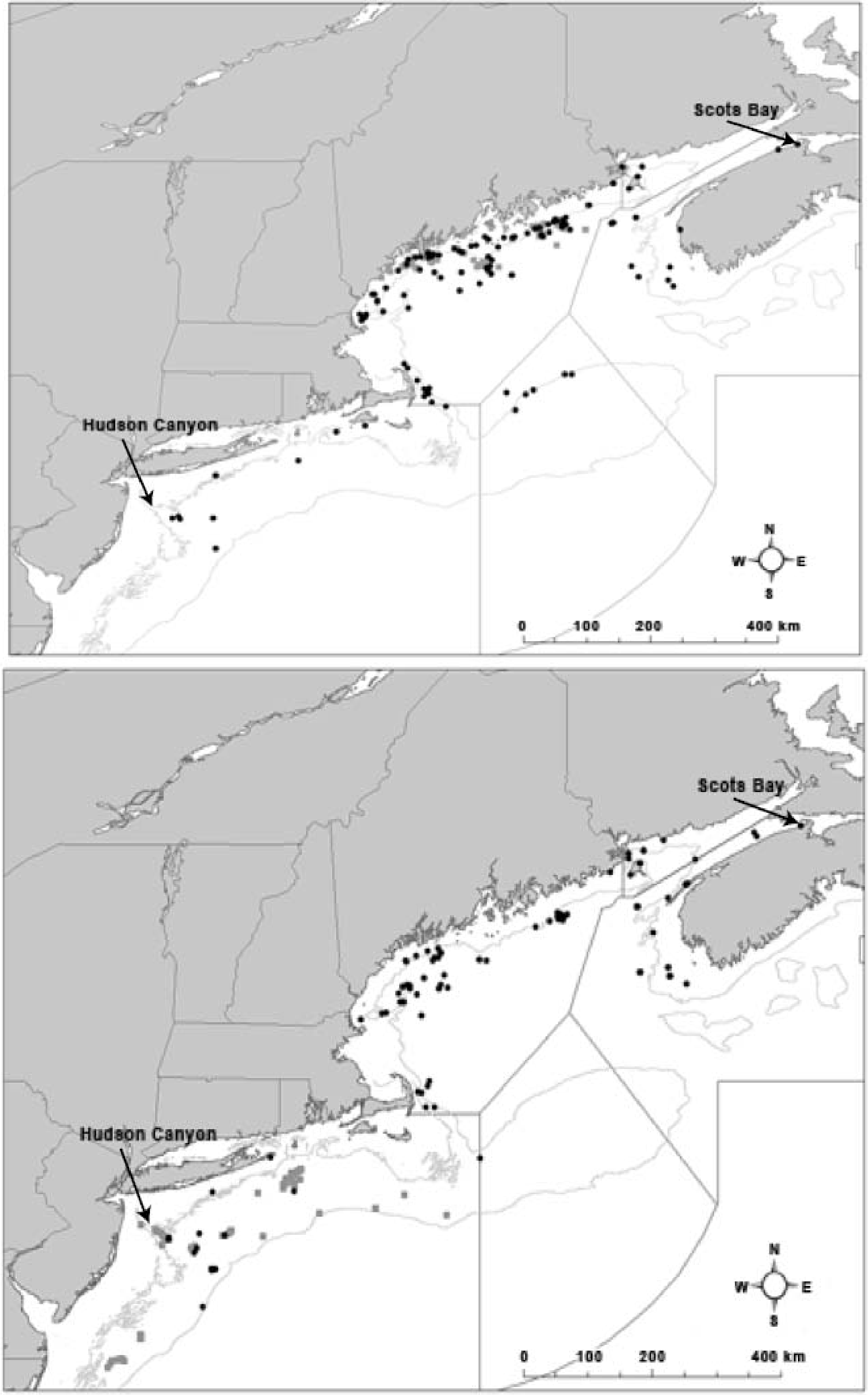


Figure A4-9. Tagging locations (gray dots) and returns (black dots) from Atlantic herring released in the Gulf of Maine during the spawning/feeding season (from Kanwit and Libby 2009).



***TOR A1**. Estimate catch from all sources including landings and discards. Describe the spatial distribution of fishing effort. Characterize uncertainty in these sources of data.*

Data from the United States

The catch data used to develop the US herring catch at age for 1964 to 2011 comes from a combination of NMFS Vessel Trip Reports (VTR), NAFO reports, Maine DMR, and other state landings reports. Landings from reports such as these were correlated to independent, scientifically derived estimates of landings (Rago et al. 2005 NEFSC Ref. Doc. 05-09; Wigley et al. 2007 NEFSC Ref. Doc. 07-09), and so are considered to be accurate. The reported catch here is a sum of landings and self-reported discards, but discard estimates were not available in all years (Table A1-1; Table A1-2). Observed discards, however, were generally less than 1% of landings and do not represent a significant source of mortality (Table A1-2; Wigley et al. 2011 NEFSC Ref. Doc. 11-09). Consequently, a lack of historical estimates of discards is not considered problematic for stock assessments. When data availability permitted, all the calculations used to produce the catch at age data below were done at the level of year, quarter, and gear type. Gear type was defined as either fixed or mobile gear. All trawl gears and purse seines were considered mobile, while all other gears (weirs, fyke nets, pound nets, etc.) were classified as fixed. These two aggregate gear types were used because biological data (e.g., lengths, ages, weights) were insufficient to do calculations on specific gear types. Weight-length relationships were similar between fixed and mobile gears, and so data were combined for the gear types to estimate the parameters of this relationship. When no weight-length or length frequency data existed for a unique combination of year, quarter, and gear type, the calculations were then done at the level of year, semester (January-June or July-December), and gear type. Similarly, when no weight-length or length frequency data existed for a unique combination of year, semester, and gear type, the calculations were done at the level of year and gear type. Aggregations to the level of year and gear type were only necessary for six years for the fixed gear type (none for mobile gear). For the fixed gear type, no biological data were available in nine years (1995, 1996, 2002-2005, 2008-2009, 2011). Catch at age for the fixed gear type was consequently not developed in these years. Age-length keys were developed at the level of year, semester, and gear type. When an observed length had no corresponding age data, age samples for that length from the alternative gear type were used or an age was imputed based on age samples at surrounding lengths. Data on sampling intensity is provided in Tables A1-3 –A1-6.

The catch at age was purposefully developed separately for the two aggregate gear types because they clearly have different selectivity patterns to support a statistical catch-at-age assessment model (Figure A1-1; Figure A1-2). Calculations did not include any spatial element because adding this to the stratification scheme resulted in a large number of combinations with little or no biological data (Table A1-4 – A1-6). The gear types are also confounded in space, with nearly all the fixed gear catch coming from the Gulf of Maine (Figure A1-3). Furthermore, the length frequencies of catches from different gears in the same area are clearly different, while length frequencies from the same gear in different areas are similar (Figure A1-2; Figure A1-4); suggesting that accounting for gear type was necessary while spatial differences were relatively inconsequential.

Data from New Brunswick, Canada

Department of Fisheries and Oceans, Canada, personnel (Michael Power) provided catch at age data for the New Brunswick (NB), Canada, weir fishery during 1965-2011 (Table A1-7). The NB weir fishery uses nearly the same gears as the US fixed gear fishery and have similar age compositions (Figures A1-5 - A1-6). Furthermore, some US weir operations are located in close geographic proximity to the NB weir fishery. Consequently, the working group agreed that data from the NB weir fishery and the US fixed gear fishery should be combined for the assessment.

Data summary and other assessment inputs

Catch in the US mobile gear fishery peaked in the late 1960s and early 70s, largely due to efforts from foreign fleets (Figure A1-7). Catch in this fishery has been relatively stable since about 2000 and has accounted for most of the Atlantic herring catches in recent years. Catch in the US fixed gear fishery has been variable, but has been relatively low since the mid-1980s (Figure A1-7). Catch in the NB weir fishery has also declined since the 1980s (Figure A1-7).

The US mobile gear fishery catches a relatively broad range of ages and some strong cohorts can be seen for several years (Figure A1-8; Tables A1-8 – A1-9). In contrast, the US fixed gear fishery and the NB weir fishery harvest almost exclusively age 2 herring (Figures A1-5 - A1-6; Tables A1-7, A1-10 - A1-11).

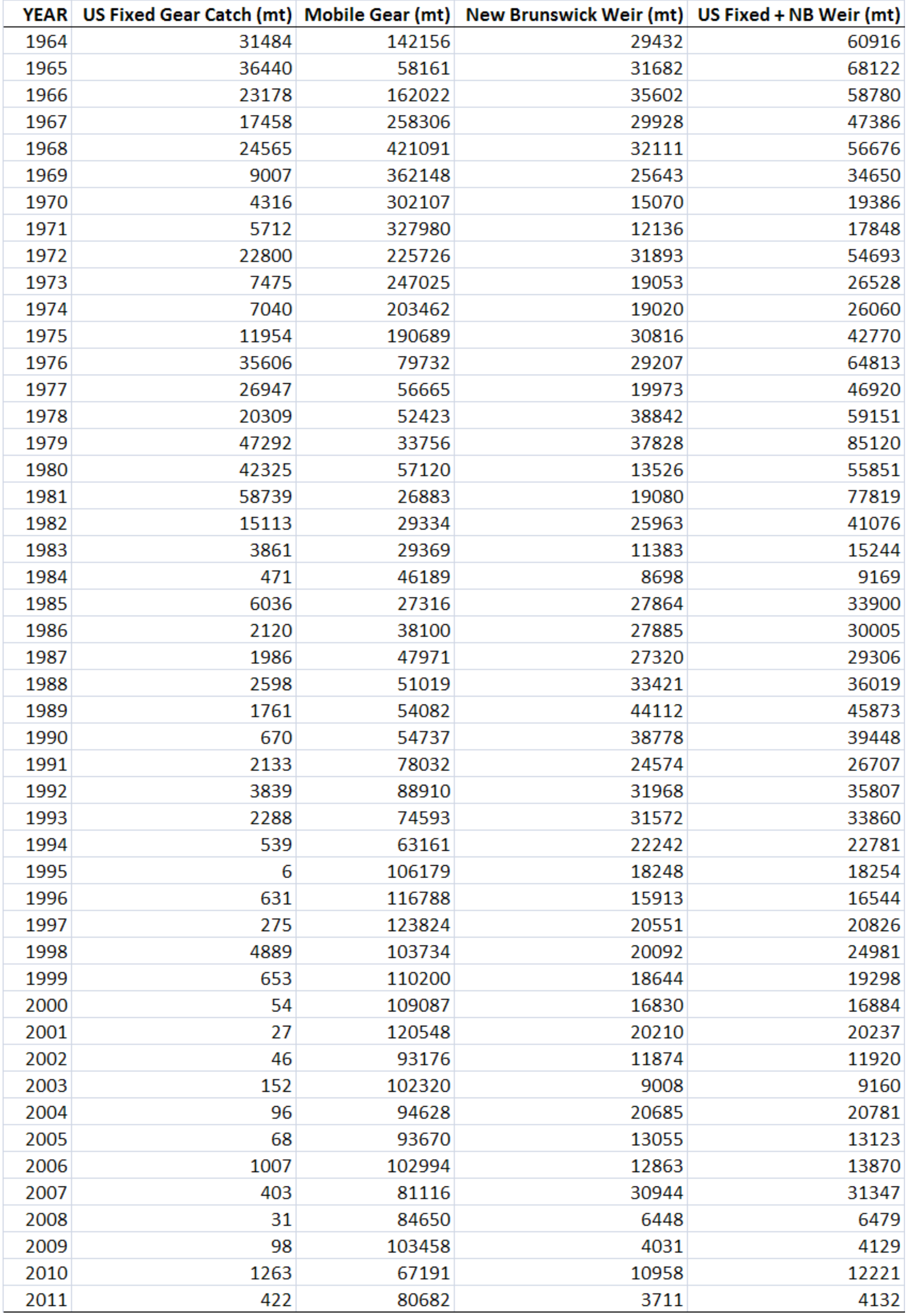
A single matrix of catch weights at age was estimated as the catch weighted mean weights at age among the strata used to develop the US catch at age matrices and ultimately among the mobile and fixed gear fisheries (Table A1-12). Weights at age for spawning stock biomass were estimated as the mean weights at age from the mobile gear fishery in quarter three (i.e., July-September; Table A1-13). This data was used because the mobile gear fishery is relatively well sampled in all years and quarter three is when herring typically begin spawning. January 1 weights at age were estimated by using a Rivard calculation of the SSB weights at age (Table A1-14). Any missing weights at age in each matrix were replaced by a time series average from one of three time stanzas: 1965-1985, 1986-1994, or 1995-2011. These three time stanzas were used to accommodate the temporal changes in herring growth, mostly evident for older aged herring (e.g., Figure A1-9). Since herring beyond age 8 experience relatively little growth, weight at age 8 was used to characterize fish in the plus group (age 8+) in the model.

Maturity at age was developed using samples from commercial catches during quarter three (July to September). Fish caught during this time of year were used because they reflect the maturity condition of herring just prior to or during spawning, and therefore are best for calculations related to spawning stock biomass. Fish of both sexes were included. Fish of unknown maturity were removed from the analysis (codes 0 and 9 in the dataset). Immature fish were defined as those classified as immature I or immature II (codes 1 and 2, respectively in dataset) while all other fish were considered mature (3=ripe, 4=eyed, 5=ripe and running, 6=spent, 7=resting). A general additive model with a logit link function (akin to a logistic regression) was fit to the proportion of mature fish at age in each year. The predicted maturity at age in each year from the general additive model was used in most stock assessment modeling (e.g., ASAP base run below; Figure A1-10; Table A1-15).

Spatial distribution of fishing effort

The fishery tends to operate as expected given what is known about Atlantic herring migration patterns. In the winter, fishery landings tend to be more southerly than other times of year. As warming occurs through the spring and summer and herring migrate to the north, fishery landings occur more frequently throughout the Gulf of Maine. As fish separate into components to spawn in the fall, fishery landings span the Gulf of Maine and Georges Bank. Example figures demonstrating these patterns are provided for 2006-2010 (Figures A1-11 - A1-15).

Table A1-1. Atlantic herring catch during 1964-2011. Discards were only included since 1996.



YEAR	US Fixed Gear Catch (mt)	Mobile Gear (mt)	New Brunswick Weir (mt)	US Fixed + NB Weir (mt)
1964	31484	142156	29432	60916
1965	36440	58161	31682	68122
1966	23178	162022	35602	58780
1967	17458	258306	29928	47386
1968	24565	421091	32111	56676
1969	9007	362148	25643	34650
1970	4316	302107	15070	19386
1971	5712	327980	12136	17848
1972	22800	225726	31893	54693
1973	7475	247025	19053	26528
1974	7040	203462	19020	26060
1975	11954	190689	30816	42770
1976	35606	79732	29207	64813
1977	26947	56665	19973	46920
1978	20309	52423	38842	59151
1979	47292	33756	37828	85120
1980	42325	57120	13526	55851
1981	58739	26883	19080	77819
1982	15113	29334	25963	41076
1983	3861	29369	11383	15244
1984	471	46189	8698	9169
1985	6036	27316	27864	33900
1986	2120	38100	27885	30005
1987	1986	47971	27320	29306
1988	2598	51019	33421	36019
1989	1761	54082	44112	45873
1990	670	54737	38778	39448
1991	2133	78032	24574	26707
1992	3839	88910	31968	35807
1993	2288	74593	31572	33860
1994	539	63161	22242	22781
1995	6	106179	18248	18254
1996	631	116788	15913	16544
1997	275	123824	20551	20826
1998	4889	103734	20092	24981
1999	653	110200	18644	19298
2000	54	109087	16830	16884
2001	27	120548	20210	20237
2002	46	93176	11874	11920
2003	152	102320	9008	9160
2004	96	94628	20685	20781
2005	68	93670	13055	13123
2006	1007	102994	12863	13870
2007	403	81116	30944	31347
2008	31	84650	6448	6479
2009	98	103458	4031	4129
2010	1263	67191	10958	12221
2011	422	80682	3711	4132

Table A1-2. Atlantic herring landing and discards during 1996-2011 for US fixed and mobile gears.

Year	Discards (mt)		Landings (mt)		D/L	
	Fixed	Mobile	Fixed	Mobile	Fixed	Mobile
1996	13	131	666	116609	0.02	0.00
1997	29	225	342	123504	0.08	0.00
1998	7	188	4925	103503	0.00	0.00
1999	5	48	704	110096	0.01	0.00
2000	6	317	62	108756	0.10	0.00
2001	11	539	54	119971	0.21	0.00
2002	3	38	52	93129	0.07	0.00
2003	8	22	159	102284	0.05	0.00
2004	9	477	103	94136	0.08	0.01
2005	3	299	76	93359	0.03	0.00
2006	1	199	1029	102772	0.00	0.00
2007	3	52	418	81045	0.01	0.00
2008	3	526	41	84111	0.07	0.01
2009	2	460	158	102928	0.01	0.00
2010	33	230	1511	66673	0.02	0.00

Table A1-3. Number of unique trips sampled for US fixed and mobile gears. 2011 is incomplete.

Year	Number of Trips Sampled		Total
	Fixed	Mobile	
1960	24	6	30
1961	34	8	42
1962	74	9	83
1963	308	27	335
1964	329	19	348
1965	353	13	366
1966	221	29	250
1967	241	66	307
1968	308	14	322
1969	300	25	325
1970	117	40	157
1971	103	91	194
1972	120	103	223
1973	95	69	164
1974	144	146	290
1975	154	131	285
1976	238	150	388
1977	248	106	354
1978	232	276	508
1979	559	121	680
1980	192	268	460
1981	352	100	452
1982	127	105	232
1983	62	134	196
1984	10	161	171
1985	54	88	142
1986	18	56	74
1987	21	79	100
1988	24	77	101
1989	29	68	97
1990	37	107	144
1991	24	99	123
1992	38	126	164
1993	32	125	157
1994	15	75	90
1995		124	124
1996	6	137	143
1997		213	213
1998	10	173	183
1999	3	206	209
2000		195	195
2001	2	214	216
2002		200	200
2003		155	155
2004		141	141
2005		186	186
2006	1	211	212
2007	1	147	148
2008		125	125
2009		123	123
2010	1	117	118
2011		74	74

Table A1-4. Number of unique trips sampled in the Gulf of Maine and other areas. 2011 is incomplete.

Year	Number of Trips Sampled		Total
	Gulf of Maine	Other	
1960	30		30
1961	42		42
1962	83		83
1963	332	3	335
1964	348		348
1965	366		366
1966	275	22	297
1967	305	35	340
1968	345	23	368
1969	359	33	392
1970	168	34	202
1971	136	76	212
1972	203	32	235
1973	151	30	181
1974	250	48	298
1975	246	53	299
1976	375	27	402
1977	343	25	368
1978	515	11	526
1979	677	3	680
1980	458	2	460
1981	450	2	452
1982	228	4	232
1983	196		196
1984	171		171
1985	141	1	142
1986	74		74
1987	100		100
1988	99	2	101
1989	97		97
1990	144		144
1991	122	1	123
1992	164		164
1993	155	2	157
1994	82	8	90
1995	118	6	124
1996	123	20	143
1997	171	42	213
1998	107	76	183
1999	181	28	209
2000	140	55	195
2001	130	86	216
2002	157	43	200
2003	93	62	155
2004	92	49	141
2005	113	73	186
2006	109	103	212
2007	92	56	148
2008	72	53	125
2009	68	55	123
2010	51	67	118
2011	36	38	74

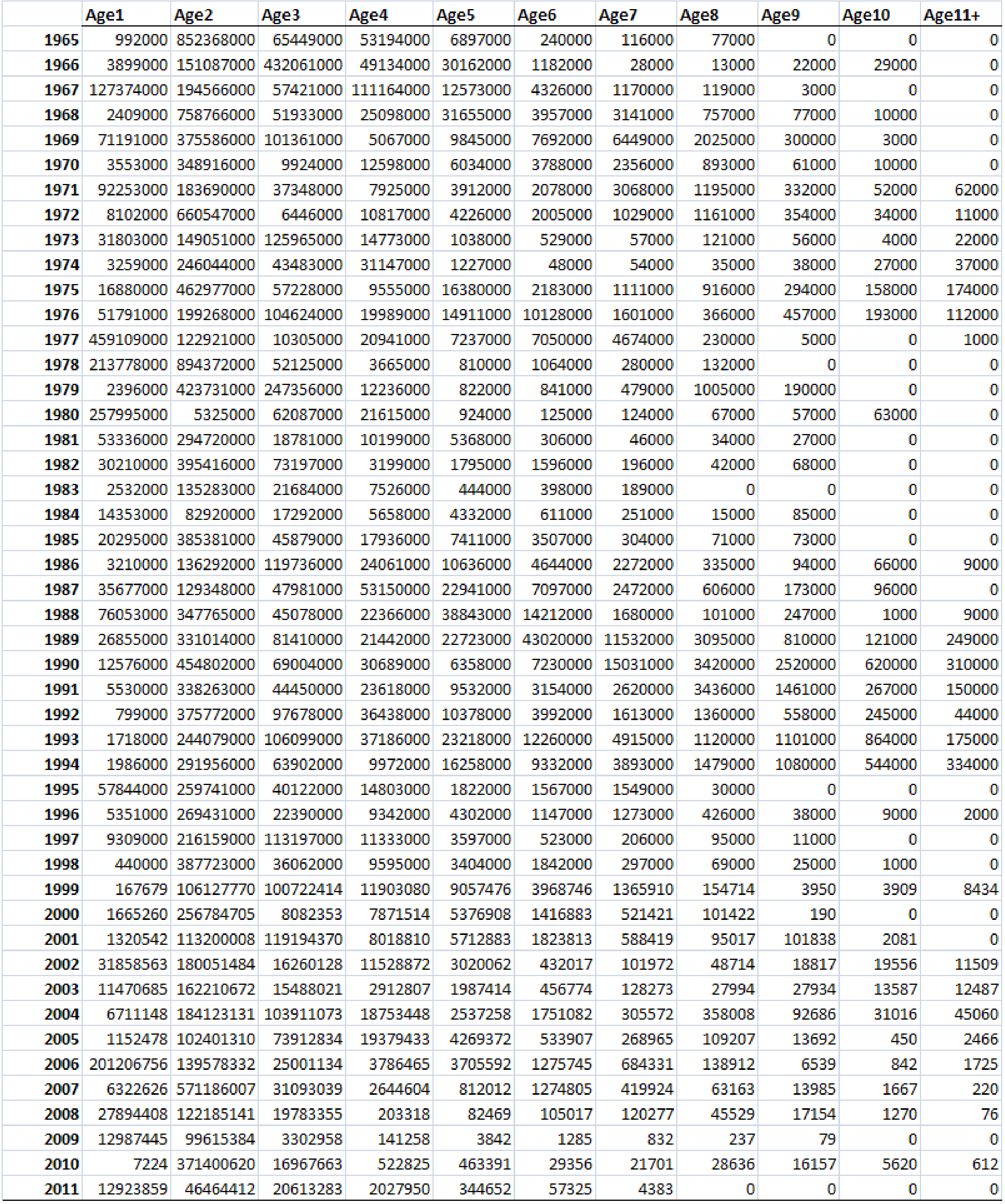
Table A1-5. Number of fish sampled for length for US fixed and mobile gears and in the Gulf of Maine and other areas. 2011 is incomplete.

Year	**# Length Samples**		**Total**	**# Length Samples**		**Total**
	Fixed	**Mobile**		**Gulf of Maine**	**Other**	
1960	2198	607	2805	2805		2805
1961	6185	1152	7337	7337		7337
1962	11796	1407	13203	13203		13203
1963	26465	2192	28657	28379	278	28657
1964	25802	1367	27169	27169		27169
1965	20671	715	21386	21386		21386
1966	11123	1401	12524	36766	19888	56654
1967	11410	12263	23673	27583	22156	49739
1968	16521	698	17219	36167	18944	55111
1969	14502	2910	17412	50050	30086	80136
1970	4171	20099	24270	34914	26580	61494
1971	7879	41157	49036	21537	44213	65750
1972	12945	33970	46915	35384	23685	59069
1973	4682	33633	38315	26913	27120	54033
1974	13340	45394	58734	37424	29368	66792
1975	14816	35026	49842	32797	31181	63978
1976	21267	31556	52823	43546	21457	65003
1977	23336	20257	43593	45443	11316	56759
1978	11574	15154	26728	44045	863	44908
1979	28815	8479	37294	37108	186	37294
1980	8867	19448	28315	28115	200	28315
1981	17433	6095	23528	23428	100	23528
1982	6327	6369	12696	12496	200	12696
1983	3100	7915	11015	11015		11015
1984	500	9595	10095	10095		10095
1985	2700	6288	8988	8888	100	8988
1986	896	3850	4746	4746		4746
1987	1050	5344	6394	6394		6394
1988	1200	5340	6540	6440	100	6540
1989	1450	4850	6300	6300		6300
1990	1847	6727	8574	8574		8574
1991	1200	6963	8163	8113	50	8163
1992	1900	9643	11543	11543		11543
1993	1671	6265	7936	7879	57	7936
1994	755	3717	4472	4072	400	4472
1995		6183	6183	5895	288	6183
1996	300	7181	7481	6483	998	7481
1997		10905	10905	8855	2050	10905
1998	500	8656	9156	5517	3639	9156
1999	150	10296	10446	9095	1351	10446
2000		9159	9159	6852	2307	9159
2001	100	10078	10178	6252	3926	10178
2002		9640	9640	7569	2071	9640
2003		7712	7712	4656	3056	7712
2004		7099	7099	4658	2441	7099
2005		9280	9280	5683	3597	9280
2006	50	11005	11055	5869	5186	11055
2007	45	7730	7775	4984	2791	7775
2008		6359	6359	3744	2615	6359
2009		6157	6157	3426	2731	6157
2010	50	6027	6077	2737	3340	6077
2011		3682	3682	1841	1841	3682

Table A1-6. Number of fish sampled for age for US fixed and mobile gears and in the Gulf of Maine and other areas. 2011 is incomplete.

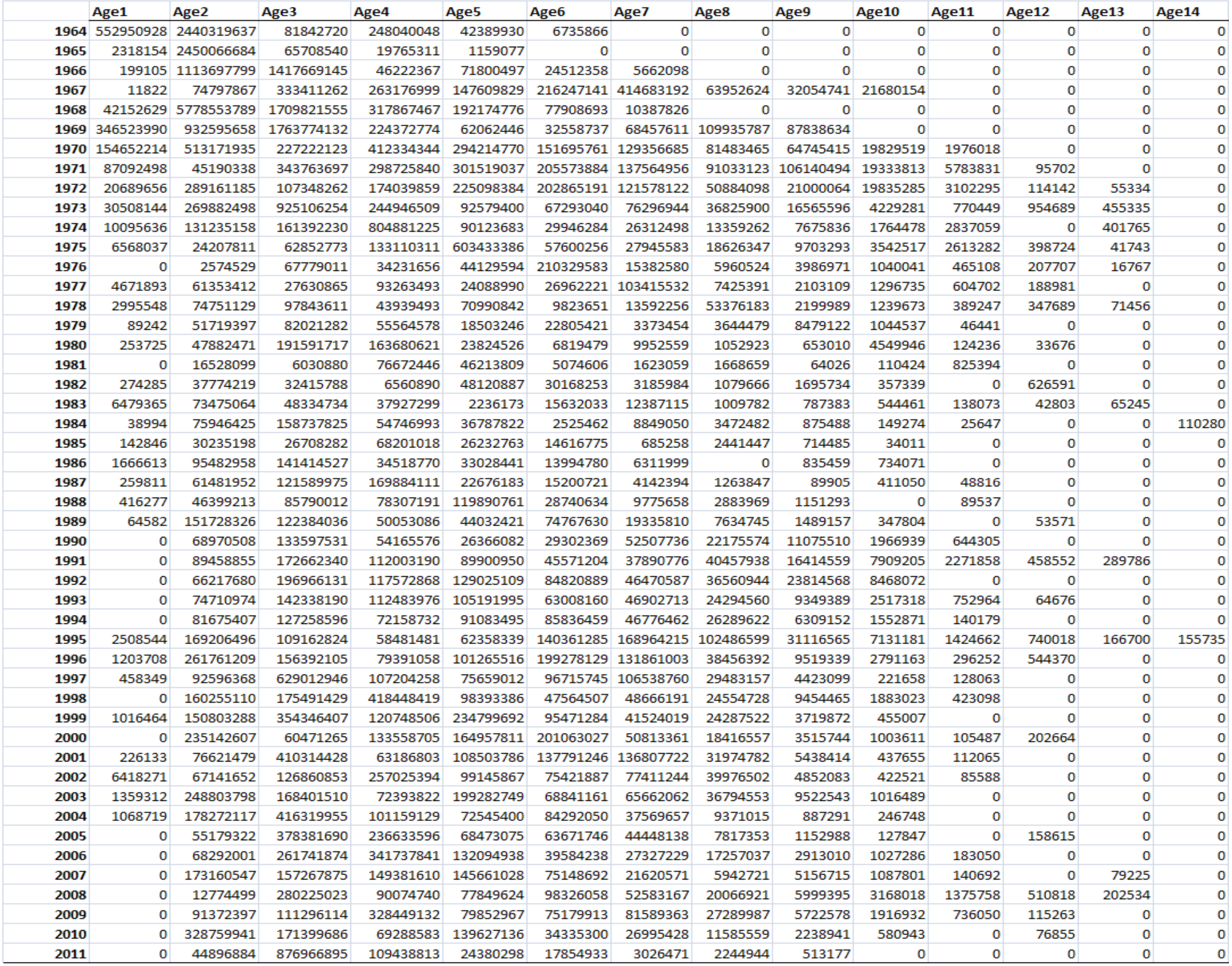
Year	# Age Samples		Total	# Age Samples		Total
	Fixed	Mobile		Gulf of Maine	Other	
1960	1156	317	1473	1473		1473
1961	3700	601	4301	4301		4301
1962	7452	879	8331	8331		8331
1963	13379	1317	14696	14546	150	14696
1964	12324	823	13147	13147		13147
1965	11463	516	11979	11979		11979
1966	4643	700	5343	29523	19802	49325
1967	4535	10774	15309	19205	21920	41125
1968	7012	275	7287	26090	18809	44899
1969	5380	2417	7797	40329	29948	70277
1970	1974	19812	21786	32426	26296	58722
1971	6788	41021	47809	20438	44013	64451
1972	6732	31137	37869	26693	23330	50023
1973	1467	32872	34339	22945	27034	49979
1974	1956	40313	42269	21728	28599	50327
1975	2658	29907	32565	16971	29730	46701
1976	3283	25233	28516	19414	21252	40666
1977	3584	13887	17471	20389	10226	30615
1978	2188	4019	6207	24038	339	24377
1979	4649	2077	6726	6636	90	6726
1980	1881	4165	6046	5984	62	6046
1981	2696	1789	4485	4425	60	4485
1982	1140	2007	3147	3027	120	3147
1983	500	1848	2348	2348		2348
1984	120	2793	2913	2913		2913
1985	480	2074	2554	2529	25	2554
1986	195	1324	1519	1519		1519
1987	265	2075	2340	2340		2340
1988	255	1819	2074	2014	60	2074
1989	255	1370	1625	1625		1625
1990	285	1903	2188	2188		2188
1991	240	1988	2228	2208	20	2228
1992	420	2541	2961	2961		2961
1993	365	2552	2917	2860	57	2917
1994	150	1582	1732	1547	185	1732
1995		2089	2089	1939	150	2089
1996	85	2217	2302	1842	460	2302
1997		3590	3590	2770	820	3590
1998	125	2544	2669	1511	1158	2669
1999	40	3040	3080	2633	447	3080
2000		2526	2526	1770	756	2526
2001	43	3034	3077	1794	1283	3077
2002		2986	2986	2394	592	2986
2003		2507	2507	1428	1079	2507
2004		2293	2293	1471	822	2293
2005		2998	2998	1759	1239	2998
2006	13	3063	3076	1587	1489	3076
2007	12	2124	2136	1284	852	2136
2008		2503	2503	1548	955	2503
2009		2532	2532	1285	1247	2532
2010	14	2569	2583	1008	1575	2583
2011		1371	1371	691	680	1371

Table A1-7. Catch at age (numbers) from the New Brunswick, Canada, weir fishery.



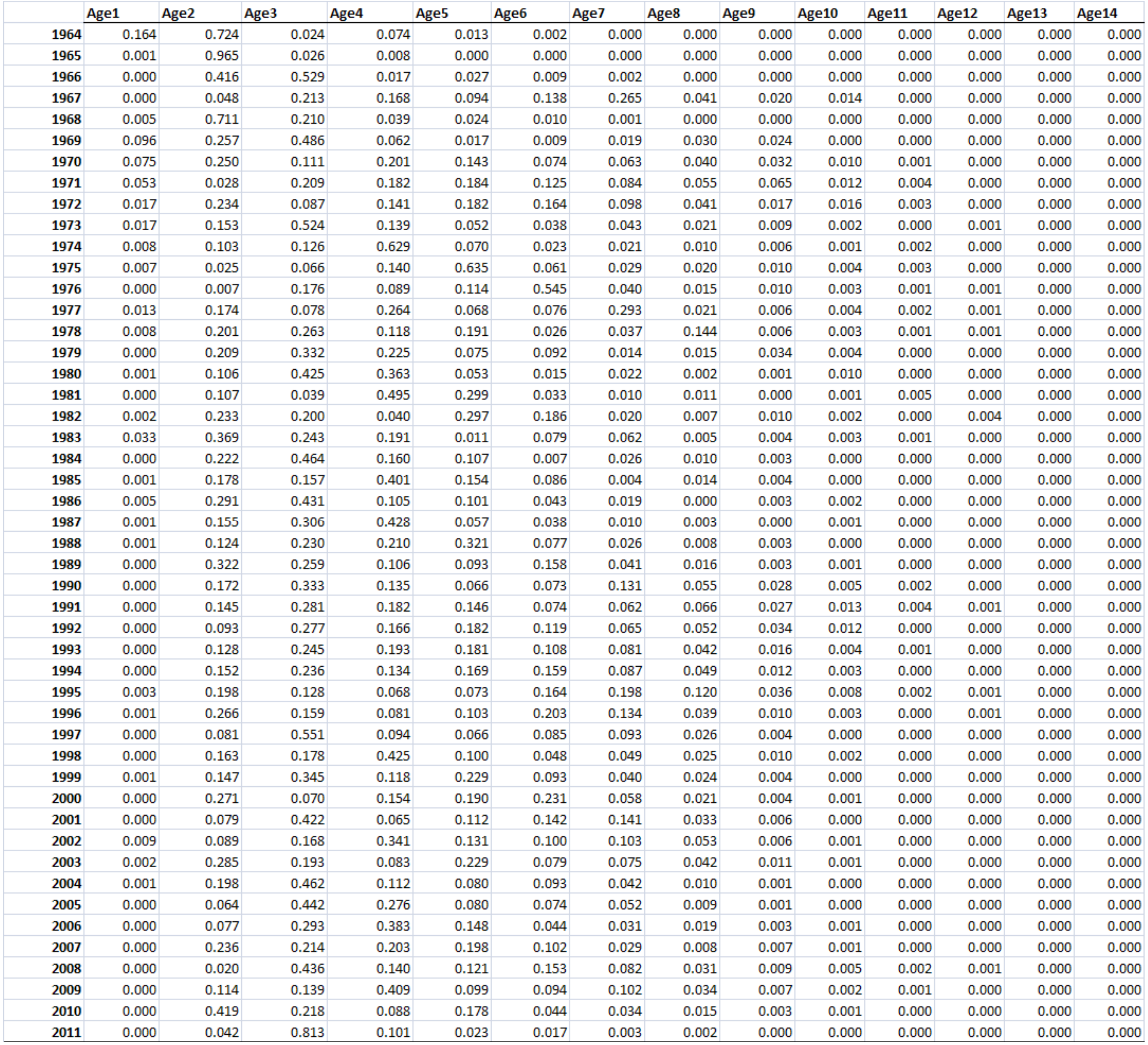
	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1965	992000	852368000	65449000	53194000	6897000	240000	116000	77000	0	0	0
1966	3899000	151087000	432061000	49134000	30162000	1182000	28000	13000	22000	29000	0
1967	127374000	194566000	57421000	111164000	12573000	4326000	1170000	119000	3000	0	0
1968	2409000	758766000	51933000	25098000	31655000	3957000	3141000	757000	77000	10000	0
1969	71191000	375586000	101361000	5067000	9845000	7692000	6449000	2025000	300000	3000	0
1970	3553000	348916000	9924000	12598000	6034000	3788000	2356000	893000	61000	10000	0
1971	92253000	183690000	37348000	7925000	3912000	2078000	3068000	1195000	332000	52000	62000
1972	8102000	660547000	6446000	10817000	4226000	2005000	1029000	1161000	354000	34000	11000
1973	31803000	149051000	125965000	14773000	1038000	529000	57000	121000	56000	4000	22000
1974	3259000	246044000	43483000	31147000	1227000	48000	54000	35000	38000	27000	37000
1975	16880000	462977000	57228000	9555000	16380000	2183000	1111000	916000	294000	158000	174000
1976	51791000	199268000	104624000	19989000	14911000	10128000	1601000	366000	457000	193000	112000
1977	459109000	122921000	10305000	20941000	7237000	7050000	4674000	230000	5000	0	1000
1978	213778000	894372000	52125000	3665000	810000	1064000	280000	132000	0	0	0
1979	2396000	423731000	247356000	12236000	822000	841000	479000	1005000	190000	0	0
1980	257995000	5325000	62087000	21615000	924000	125000	124000	67000	57000	63000	0
1981	53336000	294720000	18781000	10199000	5368000	306000	46000	34000	27000	0	0
1982	30210000	395416000	73197000	3199000	1795000	1596000	196000	42000	68000	0	0
1983	2532000	135283000	21684000	7526000	444000	398000	189000	0	0	0	0
1984	14353000	82920000	17292000	5658000	4332000	611000	251000	15000	85000	0	0
1985	20295000	385381000	45879000	17936000	7411000	3507000	304000	71000	73000	0	0
1986	3210000	136292000	119736000	24061000	10636000	4644000	2272000	335000	94000	66000	9000
1987	35677000	129348000	47981000	53150000	22941000	7097000	2472000	606000	173000	96000	0
1988	76053000	347765000	45078000	22366000	38843000	14212000	1680000	101000	247000	1000	9000
1989	26855000	331014000	81410000	21442000	22723000	43020000	11532000	3095000	810000	121000	249000
1990	12576000	454802000	69004000	30689000	6358000	7230000	15031000	3420000	2520000	620000	310000
1991	5530000	338263000	44450000	23618000	9532000	3154000	2620000	3436000	1461000	267000	150000
1992	799000	375772000	97678000	36438000	10378000	3992000	1613000	1360000	558000	245000	44000
1993	1718000	244079000	106099000	37186000	23218000	12260000	4915000	1120000	1101000	864000	175000
1994	1986000	291956000	63902000	9972000	16258000	9332000	3893000	1479000	1080000	544000	334000
1995	57844000	259741000	40122000	14803000	1822000	1567000	1549000	30000	0	0	0
1996	5351000	269431000	22390000	9342000	4302000	1147000	1273000	426000	38000	9000	2000
1997	9309000	216159000	113197000	11333000	3597000	523000	206000	95000	11000	0	0
1998	440000	387723000	36062000	9595000	3404000	1842000	297000	69000	25000	1000	0
1999	167679	106127770	100722414	11903080	9057476	3968746	1365910	154714	3950	3909	8434
2000	1665260	256784705	8082353	7871514	5376908	1416883	521421	101422	190	0	0
2001	1320542	113200008	119194370	8018810	5712883	1823813	588419	95017	101838	2081	0
2002	31858563	180051484	16260128	11528872	3020062	432017	101972	48714	18817	19556	11509
2003	11470685	162210672	15488021	2912807	1987414	456774	128273	27994	27934	13587	12487
2004	6711148	184123131	103911073	18753448	2537258	1751082	305572	358008	92686	31016	45060
2005	1152478	102401310	73912834	19379433	4269372	533907	268965	109207	13692	450	2466
2006	201206756	139578332	25001134	3786465	3705592	1275745	684331	138912	6539	842	1725
2007	6322626	571186007	31093039	2644604	812012	1274805	419924	63163	13985	1667	220
2008	27894408	122185141	19783355	203318	82469	105017	120277	45529	17154	1270	76
2009	12987445	99615384	3302958	141258	3842	1285	832	237	79	0	0
2010	7224	371400620	16967663	522825	463391	29356	21701	28636	16157	5620	612
2011	12923859	46464412	20613283	2027950	344652	57325	4383	0	0	0	0

Table A1-8. Catch at age (numbers) from the mobile gear fishery.



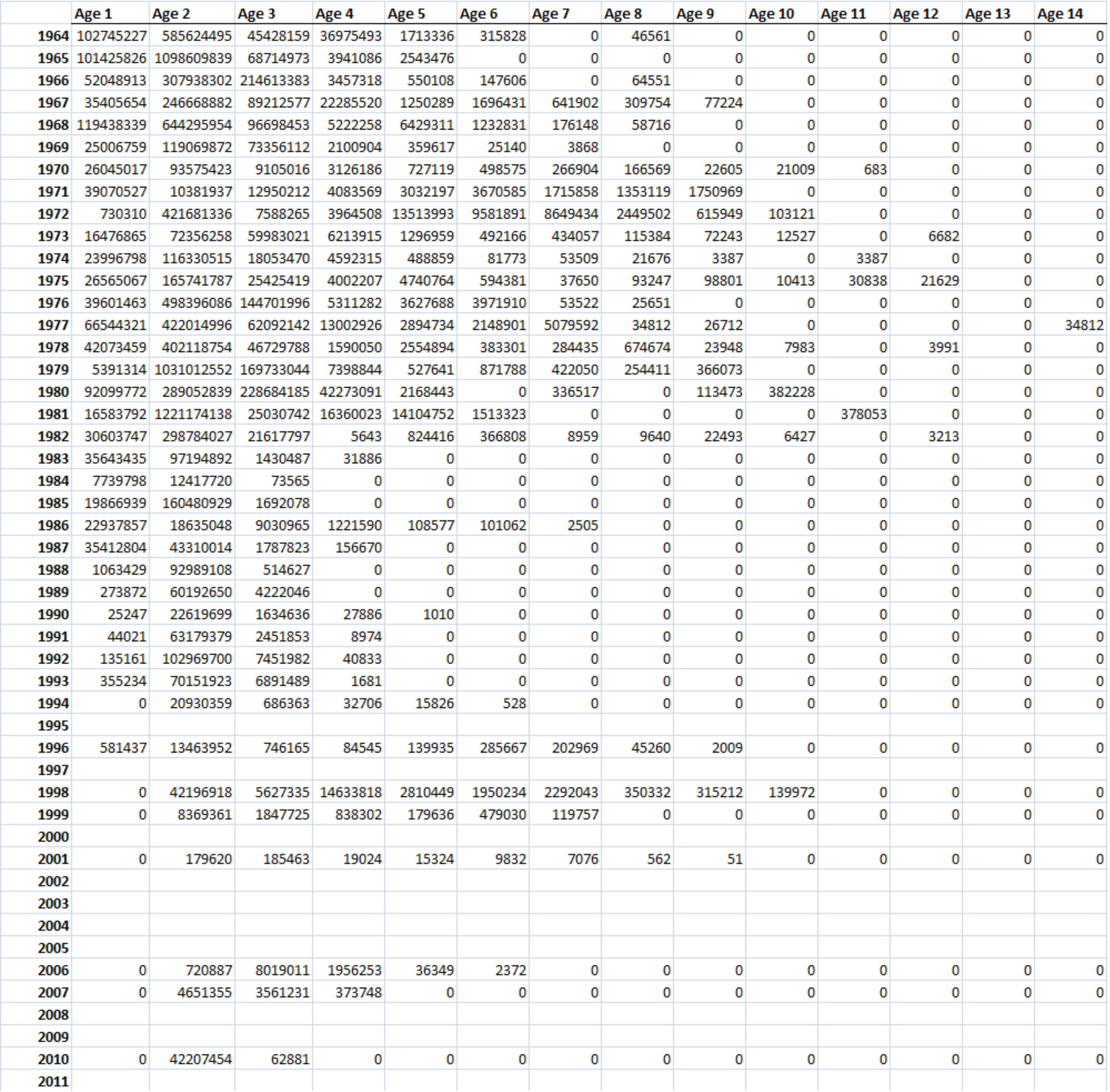
	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1964	552950928	2440319637	81842720	248040048	42389930	6735866	0	0	0	0	0	0	0	0
1965	2318154	2450066684	65708540	19765311	1159077	0	0	0	0	0	0	0	0	0
1966	199105	1113697799	1417669145	46222367	71800497	24512358	5662098	0	0	0	0	0	0	0
1967	11822	74797867	333411262	263176999	147609829	216247141	414683192	63952624	32054741	21680154	0	0	0	0
1968	42152629	5778553789	1709821555	317867467	192174776	77908693	10387826	0	0	0	0	0	0	0
1969	346523990	932595658	1763774132	224372774	62062446	32558737	68457611	109935787	87838634	0	0	0	0	0
1970	154652214	513171935	227222123	412334344	294214770	151695761	129356685	81483465	64745415	19829519	1976018	0	0	0
1971	87092498	45190338	343763697	298725840	301519037	205573884	137564956	91033123	106140494	19333813	5783831	95702	0	0
1972	20689656	289161185	107348262	174039859	225098384	202865191	121578122	50884098	21000064	19835285	3102295	114142	55334	0
1973	30508144	269882498	925106254	244946509	92579400	67293040	76296944	36825900	16565596	4229281	770449	954689	455335	0
1974	10095636	131235158	161392230	804881225	90123683	29946284	26312498	13359262	7675836	1764478	2837059	0	401765	0
1975	6568037	24207811	62852773	133110311	603433386	57600256	27945583	18626347	9703293	3542517	2613282	398724	41743	0
1976	0	2574529	67779011	34231656	44129594	210329583	15382580	5960524	3986971	1040041	465108	207707	16767	0
1977	4671893	61353412	27630865	93263493	24088990	26962221	103415532	7425391	2103109	1296735	604702	188981	0	0
1978	2995548	74751129	97843611	43939493	70990842	9823651	13592256	53376183	2199989	1239673	389247	347689	71456	0
1979	89242	51719397	82021282	55564578	18503246	22805421	3373454	3644479	8479122	1044537	46441	0	0	0
1980	253725	47882471	191591717	163680621	23824526	6819479	9952559	1052923	653010	4549946	124236	33676	0	0
1981	0	16528099	6030880	76672446	46213809	5074606	1623059	1668659	64026	110424	825394	0	0	0
1982	274285	37774219	32415788	6560890	48120887	30168253	3185984	1079666	1695734	357339	0	626591	0	0
1983	6479365	73475064	48334734	37927299	2236173	15632033	12387115	1009782	787383	544461	138073	42803	65245	0
1984	38994	75946425	158737825	54746993	36787822	2525462	8849050	3472482	875488	149274	25647	0	0	110280
1985	142846	30235198	26708282	68201018	26232763	14616775	685258	2441447	714485	34011	0	0	0	0
1986	1666613	95482958	141414527	34518770	33028441	13994780	6311999	0	835459	734071	0	0	0	0
1987	259811	61481952	121589975	169884111	22676183	15200721	4142394	1263847	89905	411050	48816	0	0	0
1988	416277	46399213	85790012	78307191	119890761	28740634	9775658	2883969	1151293	0	89537	0	0	0
1989	64582	151728326	122384036	50053086	44032421	74767630	19335810	7634745	1489157	347804	0	53571	0	0
1990	0	68970508	133597531	54165576	26366082	29302369	52507736	22175574	11075510	1966939	644305	0	0	0
1991	0	89458855	172662340	112003190	89900950	45571204	37890776	40457938	16414559	7909205	2271858	458552	289786	0
1992	0	66217680	196966131	117572868	129025109	84820889	46470587	36560944	23814568	8468072	0	0	0	0
1993	0	74710974	142338190	112483976	105191995	63008160	46902713	24294560	9349389	2517318	752964	64676	0	0
1994	0	81675407	127258596	72158732	91083495	85836459	46776462	26289622	6309152	1552871	140179	0	0	0
1995	2508544	169206496	109162824	58481481	62358339	140361285	168964215	102486599	31116565	7131181	1424662	740018	166700	155735
1996	1203708	261761209	156392105	79391058	101265516	199278129	131861003	38456392	9519339	2791163	296252	544370	0	0
1997	458349	92596368	629012946	107204258	75659012	96715745	106538760	29483157	4423099	221658	128063	0	0	0
1998	0	160255110	175491429	418448419	98393386	47564507	48666191	24554728	9454465	1883023	423098	0	0	0
1999	1016464	150803288	354346407	120748506	234799692	95471284	41524019	24287522	3719872	455007	0	0	0	0
2000	0	235142607	60471265	133558705	164957811	201063027	50813361	18416557	3515744	1003611	105487	202664	0	0
2001	226133	76621479	410314428	63186803	108503786	137791246	136807722	31974782	5438414	437655	112065	0	0	0
2002	6418271	67141652	126860853	257025394	99145867	75421887	77411244	39976502	4852083	422521	85588	0	0	0
2003	1359312	248803798	168401510	72393822	199282749	68841161	65662062	36794553	9522543	1016489	0	0	0	0
2004	1068719	178272117	416319955	101159129	72545400	84292050	37569657	9371015	887291	246748	0	0	0	0
2005	0	55179322	378381690	236633596	68473075	63671746	44448138	7817353	1152988	127847	0	158615	0	0
2006	0	68292001	261741874	341737841	132094938	39584238	27327229	17257037	2913010	1027286	183050	0	0	0
2007	0	173160547	157267875	149381610	145661028	75148692	21620571	5942721	5156715	1087801	140692	0	79225	0
2008	0	12774499	280225023	90074740	77849624	98326058	52583167	20066921	5999395	3168018	1375758	510818	202534	0
2009	0	91372397	111296114	328449132	79852967	75179913	81589363	27289987	5722578	1916932	736050	115263	0	0
2010	0	328759941	171399686	69288583	139627136	34335300	26995428	11585559	2238941	580943	0	76855	0	0
2011	0	44896884	876966895	109438813	24380298	17854933	3026471	2244944	513177	0	0	0	0	0

Table A1-9. Proportion of catch at age in each year for the mobile gear fishery (Table A1-8 converted to proportions at age in each year).



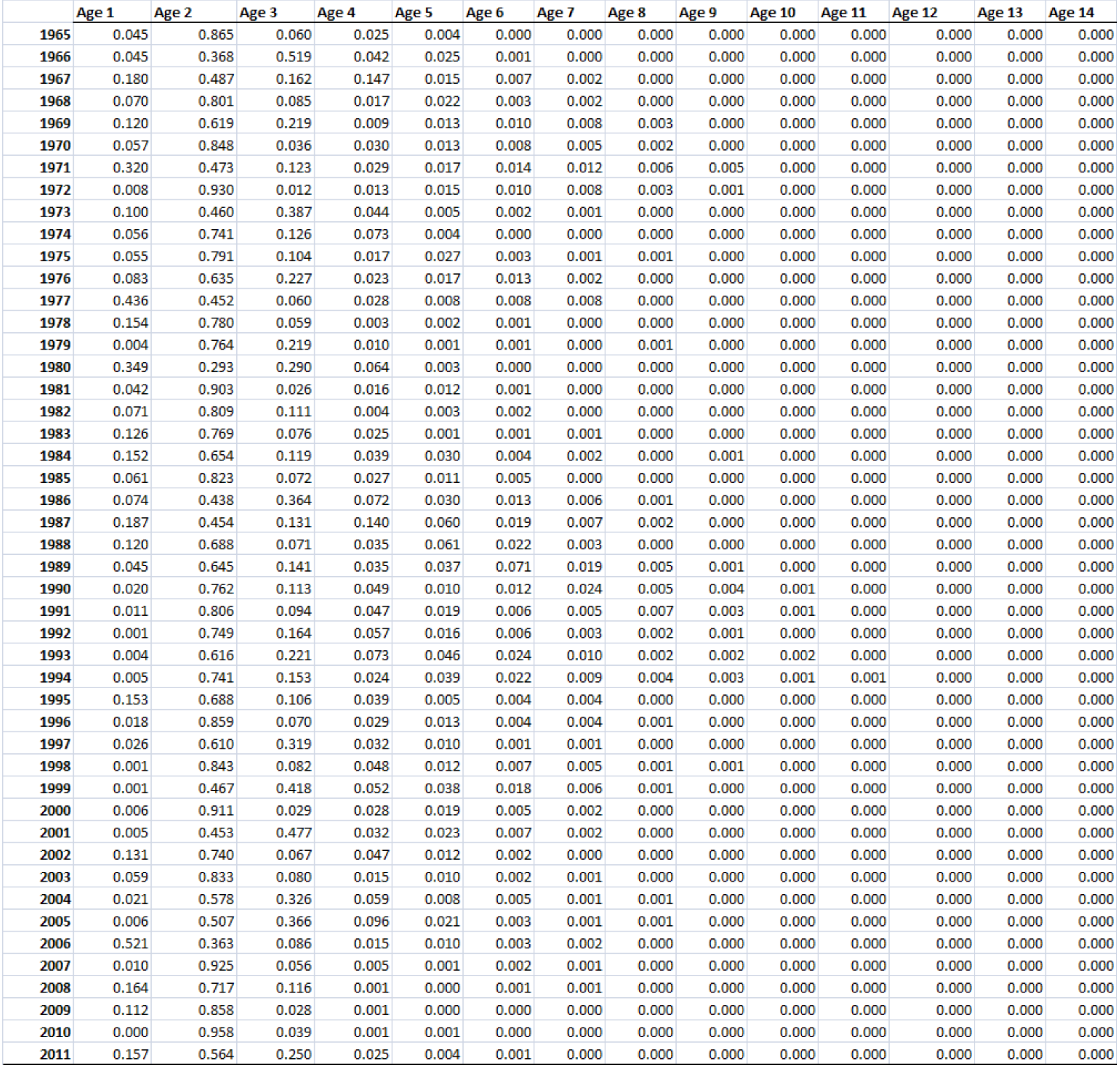
	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14
1964	0.164	0.724	0.024	0.074	0.013	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1965	0.001	0.965	0.026	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1966	0.000	0.416	0.529	0.017	0.027	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1967	0.000	0.048	0.213	0.168	0.094	0.138	0.265	0.041	0.020	0.014	0.000	0.000	0.000	0.000
1968	0.005	0.711	0.210	0.039	0.024	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1969	0.096	0.257	0.486	0.062	0.017	0.009	0.019	0.030	0.024	0.000	0.000	0.000	0.000	0.000
1970	0.075	0.250	0.111	0.201	0.143	0.074	0.063	0.040	0.032	0.010	0.001	0.000	0.000	0.000
1971	0.053	0.028	0.209	0.182	0.184	0.125	0.084	0.055	0.065	0.012	0.004	0.000	0.000	0.000
1972	0.017	0.234	0.087	0.141	0.182	0.164	0.098	0.041	0.017	0.016	0.003	0.000	0.000	0.000
1973	0.017	0.153	0.524	0.139	0.052	0.038	0.043	0.021	0.009	0.002	0.000	0.001	0.000	0.000
1974	0.008	0.103	0.126	0.629	0.070	0.023	0.021	0.010	0.006	0.001	0.002	0.000	0.000	0.000
1975	0.007	0.025	0.066	0.140	0.635	0.061	0.029	0.020	0.010	0.004	0.003	0.000	0.000	0.000
1976	0.000	0.007	0.176	0.089	0.114	0.545	0.040	0.015	0.010	0.003	0.001	0.001	0.000	0.000
1977	0.013	0.174	0.078	0.264	0.068	0.076	0.293	0.021	0.006	0.004	0.002	0.001	0.000	0.000
1978	0.008	0.201	0.263	0.118	0.191	0.026	0.037	0.144	0.006	0.003	0.001	0.001	0.000	0.000
1979	0.000	0.209	0.332	0.225	0.075	0.092	0.014	0.015	0.034	0.004	0.000	0.000	0.000	0.000
1980	0.001	0.106	0.425	0.363	0.053	0.015	0.022	0.002	0.001	0.010	0.000	0.000	0.000	0.000
1981	0.000	0.107	0.039	0.495	0.299	0.033	0.010	0.011	0.000	0.001	0.005	0.000	0.000	0.000
1982	0.002	0.233	0.200	0.040	0.297	0.186	0.020	0.007	0.010	0.002	0.000	0.004	0.000	0.000
1983	0.033	0.369	0.243	0.191	0.011	0.079	0.062	0.005	0.004	0.003	0.001	0.000	0.000	0.000
1984	0.000	0.222	0.464	0.160	0.107	0.007	0.026	0.010	0.003	0.000	0.000	0.000	0.000	0.000
1985	0.001	0.178	0.157	0.401	0.154	0.086	0.004	0.014	0.004	0.000	0.000	0.000	0.000	0.000
1986	0.005	0.291	0.431	0.105	0.101	0.043	0.019	0.000	0.003	0.002	0.000	0.000	0.000	0.000
1987	0.001	0.155	0.306	0.428	0.057	0.038	0.010	0.003	0.000	0.001	0.000	0.000	0.000	0.000
1988	0.001	0.124	0.230	0.210	0.321	0.077	0.026	0.008	0.003	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.322	0.259	0.106	0.093	0.158	0.041	0.016	0.003	0.001	0.000	0.000	0.000	0.000
1990	0.000	0.172	0.333	0.135	0.066	0.073	0.131	0.055	0.028	0.005	0.002	0.000	0.000	0.000
1991	0.000	0.145	0.281	0.182	0.146	0.074	0.062	0.066	0.027	0.013	0.004	0.001	0.000	0.000
1992	0.000	0.093	0.277	0.166	0.182	0.119	0.065	0.052	0.034	0.012	0.000	0.000	0.000	0.000
1993	0.000	0.128	0.245	0.193	0.181	0.108	0.081	0.042	0.016	0.004	0.001	0.000	0.000	0.000
1994	0.000	0.152	0.236	0.134	0.169	0.159	0.087	0.049	0.012	0.003	0.000	0.000	0.000	0.000
1995	0.003	0.198	0.128	0.068	0.073	0.164	0.198	0.120	0.036	0.008	0.002	0.001	0.000	0.000
1996	0.001	0.266	0.159	0.081	0.103	0.203	0.134	0.039	0.010	0.003	0.000	0.001	0.000	0.000
1997	0.000	0.081	0.551	0.094	0.066	0.085	0.093	0.026	0.004	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.163	0.178	0.425	0.100	0.048	0.049	0.025	0.010	0.002	0.000	0.000	0.000	0.000
1999	0.001	0.147	0.345	0.118	0.229	0.093	0.040	0.024	0.004	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.271	0.070	0.154	0.190	0.231	0.058	0.021	0.004	0.001	0.000	0.000	0.000	0.000
2001	0.000	0.079	0.422	0.065	0.112	0.142	0.141	0.033	0.006	0.000	0.000	0.000	0.000	0.000
2002	0.009	0.089	0.168	0.341	0.131	0.100	0.103	0.053	0.006	0.001	0.000	0.000	0.000	0.000
2003	0.002	0.285	0.193	0.083	0.229	0.079	0.075	0.042	0.011	0.001	0.000	0.000	0.000	0.000
2004	0.001	0.198	0.462	0.112	0.080	0.093	0.042	0.010	0.001	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.064	0.442	0.276	0.080	0.074	0.052	0.009	0.001	0.000	0.000	0.000	0.000	0.000
2006	0.000	0.077	0.293	0.383	0.148	0.044	0.031	0.019	0.003	0.001	0.000	0.000	0.000	0.000
2007	0.000	0.236	0.214	0.203	0.198	0.102	0.029	0.008	0.007	0.001	0.000	0.000	0.000	0.000
2008	0.000	0.020	0.436	0.140	0.121	0.153	0.082	0.031	0.009	0.005	0.002	0.001	0.000	0.000
2009	0.000	0.114	0.139	0.409	0.099	0.094	0.102	0.034	0.007	0.002	0.001	0.000	0.000	0.000
2010	0.000	0.419	0.218	0.088	0.178	0.044	0.034	0.015	0.003	0.001	0.000	0.000	0.000	0.000
2011	0.000	0.042	0.813	0.101	0.023	0.017	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000

Table A1-10. Catch at age (numbers) from the US fixed gear fishery. Landings occurred in blank years, but no biological samples were available.



	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
1964	102745227	585624495	45428159	36975493	1713336	315828	0	46561	0	0	0	0	0	0
1965	101425826	1098609839	68714973	3941086	2543476	0	0	0	0	0	0	0	0	0
1966	52048913	307938302	214613383	3457318	550108	147606	0	64551	0	0	0	0	0	0
1967	35405654	246668882	89212577	22285520	1250289	1696431	641902	309754	77224	0	0	0	0	0
1968	119438339	644295954	96698453	5222258	6429311	1232831	176148	58716	0	0	0	0	0	0
1969	25006759	119069872	73356112	2100904	359617	25140	3868	0	0	0	0	0	0	0
1970	26045017	93575423	9105016	3126186	727119	498575	266904	166569	22605	21009	683	0	0	0
1971	39070527	10381937	12950212	4083569	3032197	3670585	1715858	1353119	1750969	0	0	0	0	0
1972	730310	421681336	7588265	3964508	13513993	9581891	8649434	2449502	615949	103121	0	0	0	0
1973	16476865	72356258	59983021	6213915	1296959	492166	434057	115384	72243	12527	0	6682	0	0
1974	23996798	116330515	18053470	4592315	488859	81773	53509	21676	3387	0	3387	0	0	0
1975	26565067	165741787	25425419	4002207	4740764	594381	37650	93247	98801	10413	30838	21629	0	0
1976	39601463	498396086	144701996	5311282	3627688	3971910	53522	25651	0	0	0	0	0	0
1977	66544321	422014996	62092142	13002926	2894734	2148901	5079592	34812	26712	0	0	0	0	34812
1978	42073459	402118754	46729788	1590050	2554894	383301	284435	674674	23948	7983	0	3991	0	0
1979	5391314	1031012552	169733044	7398844	527641	871788	422050	254411	366073	0	0	0	0	0
1980	92099772	289052839	228684185	42273091	2168443	0	336517	0	113473	382228	0	0	0	0
1981	16583792	1221174138	25030742	16360023	14104752	1513323	0	0	0	0	378053	0	0	0
1982	30603747	298784027	21617797	5643	824416	366808	8959	9640	22493	6427	0	3213	0	0
1983	35643435	97194892	1430487	31886	0	0	0	0	0	0	0	0	0	0
1984	7739798	12417720	73565	0	0	0	0	0	0	0	0	0	0	0
1985	19866939	160480929	1692078	0	0	0	0	0	0	0	0	0	0	0
1986	22937857	18635048	9030965	1221590	108577	101062	2505	0	0	0	0	0	0	0
1987	35412804	43310014	1787823	156670	0	0	0	0	0	0	0	0	0	0
1988	1063429	92989108	514627	0	0	0	0	0	0	0	0	0	0	0
1989	273872	60192650	4222046	0	0	0	0	0	0	0	0	0	0	0
1990	25247	22619699	1634636	27886	1010	0	0	0	0	0	0	0	0	0
1991	44021	63179379	2451853	8974	0	0	0	0	0	0	0	0	0	0
1992	135161	102969700	7451982	40833	0	0	0	0	0	0	0	0	0	0
1993	355234	70151923	6891489	1681	0	0	0	0	0	0	0	0	0	0
1994	0	20930359	686363	32706	15826	528	0	0	0	0	0	0	0	0
1995														
1996	581437	13463952	746165	84545	139935	285667	202969	45260	2009	0	0	0	0	0
1997														
1998	0	42196918	5627335	14633818	2810449	1950234	2292043	350332	315212	139972	0	0	0	0
1999	0	8369361	1847725	838302	179636	479030	119757	0	0	0	0	0	0	0
2000														
2001	0	179620	185463	19024	15324	9832	7076	562	51	0	0	0	0	0
2002														
2003														
2004														
2005														
2006	0	720887	8019011	1956253	36349	2372	0	0	0	0	0	0	0	0
2007	0	4651355	3561231	373748	0	0	0	0	0	0	0	0	0	0
2008														
2009														
2010	0	42207454	62881	0	0	0	0	0	0	0	0	0	0	0
2011														

Table A1-11. Proportion of catch at age in each year for the fixed gear fishery (sum of table A1-7 and A1-10 converted to proportions).

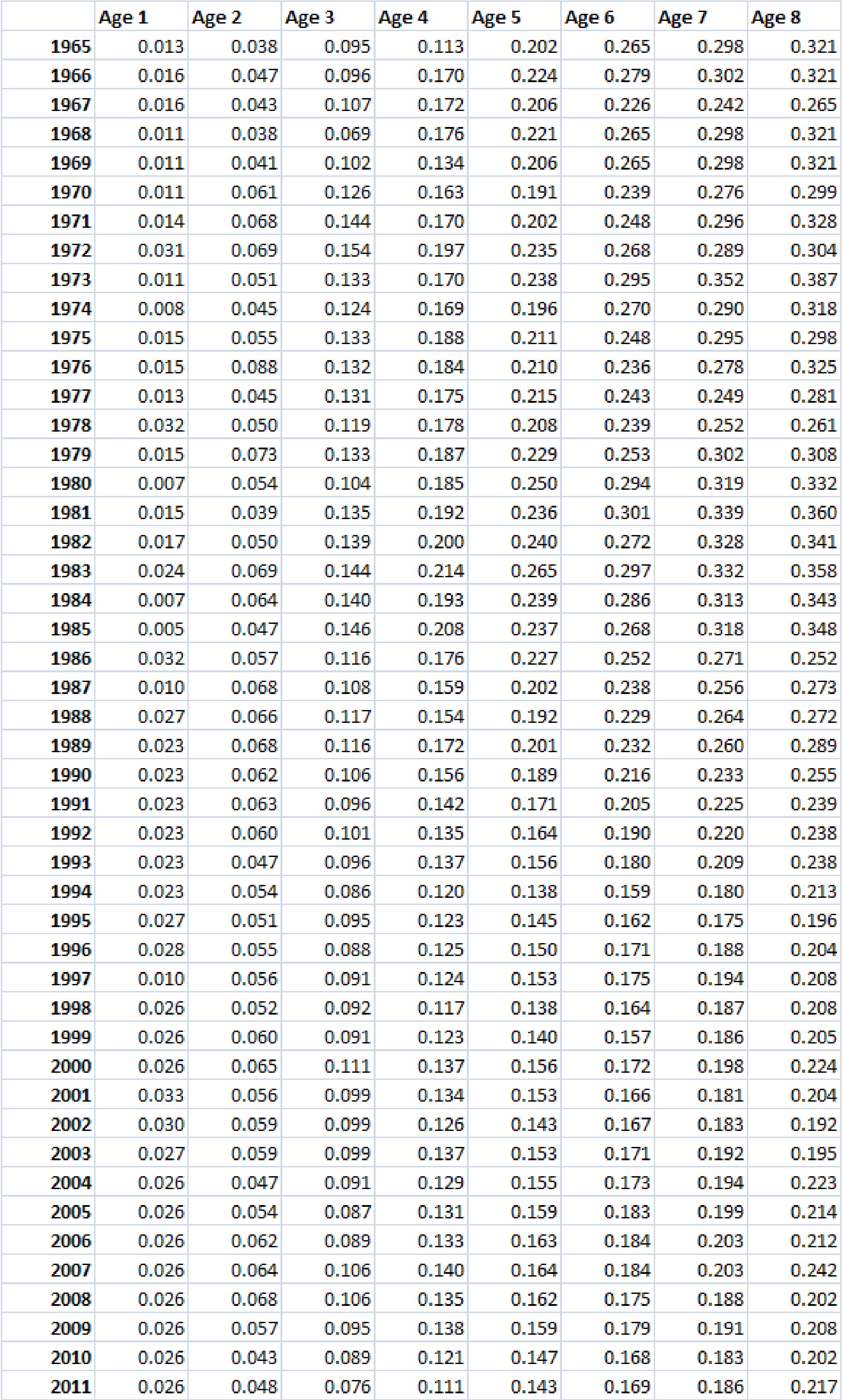


	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14
1965	0.045	0.865	0.060	0.025	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1966	0.045	0.368	0.519	0.042	0.025	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1967	0.180	0.487	0.162	0.147	0.015	0.007	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1968	0.070	0.801	0.085	0.017	0.022	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1969	0.120	0.619	0.219	0.009	0.013	0.010	0.008	0.003	0.000	0.000	0.000	0.000	0.000	0.000
1970	0.057	0.848	0.036	0.030	0.013	0.008	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000
1971	0.320	0.473	0.123	0.029	0.017	0.014	0.012	0.006	0.005	0.000	0.000	0.000	0.000	0.000
1972	0.008	0.930	0.012	0.013	0.015	0.010	0.008	0.003	0.001	0.000	0.000	0.000	0.000	0.000
1973	0.100	0.460	0.387	0.044	0.005	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1974	0.056	0.741	0.126	0.073	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1975	0.055	0.791	0.104	0.017	0.027	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1976	0.083	0.635	0.227	0.023	0.017	0.013	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.436	0.452	0.060	0.028	0.008	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.154	0.780	0.059	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.004	0.764	0.219	0.010	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1980	0.349	0.293	0.290	0.064	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1981	0.042	0.903	0.026	0.016	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.071	0.809	0.111	0.004	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.126	0.769	0.076	0.025	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.152	0.654	0.119	0.039	0.030	0.004	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000
1985	0.061	0.823	0.072	0.027	0.011	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.074	0.438	0.364	0.072	0.030	0.013	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.187	0.454	0.131	0.140	0.060	0.019	0.007	0.002	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.120	0.688	0.071	0.035	0.061	0.022	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.045	0.645	0.141	0.035	0.037	0.071	0.019	0.005	0.001	0.000	0.000	0.000	0.000	0.000
1990	0.020	0.762	0.113	0.049	0.010	0.012	0.024	0.005	0.004	0.001	0.000	0.000	0.000	0.000
1991	0.011	0.806	0.094	0.047	0.019	0.006	0.005	0.007	0.003	0.001	0.000	0.000	0.000	0.000
1992	0.001	0.749	0.164	0.057	0.016	0.006	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000
1993	0.004	0.616	0.221	0.073	0.046	0.024	0.010	0.002	0.002	0.002	0.000	0.000	0.000	0.000
1994	0.005	0.741	0.153	0.024	0.039	0.022	0.009	0.004	0.003	0.001	0.001	0.000	0.000	0.000
1995	0.153	0.688	0.106	0.039	0.005	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.018	0.859	0.070	0.029	0.013	0.004	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.026	0.610	0.319	0.032	0.010	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.001	0.843	0.082	0.048	0.012	0.007	0.005	0.001	0.001	0.000	0.000	0.000	0.000	0.000
1999	0.001	0.467	0.418	0.052	0.038	0.018	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.006	0.911	0.029	0.028	0.019	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.005	0.453	0.477	0.032	0.023	0.007	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.131	0.740	0.067	0.047	0.012	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.059	0.833	0.080	0.015	0.010	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.021	0.578	0.326	0.059	0.008	0.005	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.006	0.507	0.366	0.096	0.021	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.521	0.363	0.086	0.015	0.010	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.010	0.925	0.056	0.005	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.164	0.717	0.116	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.112	0.858	0.028	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.958	0.039	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	0.157	0.564	0.250	0.025	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A1-12. Catch weights at age (kg).

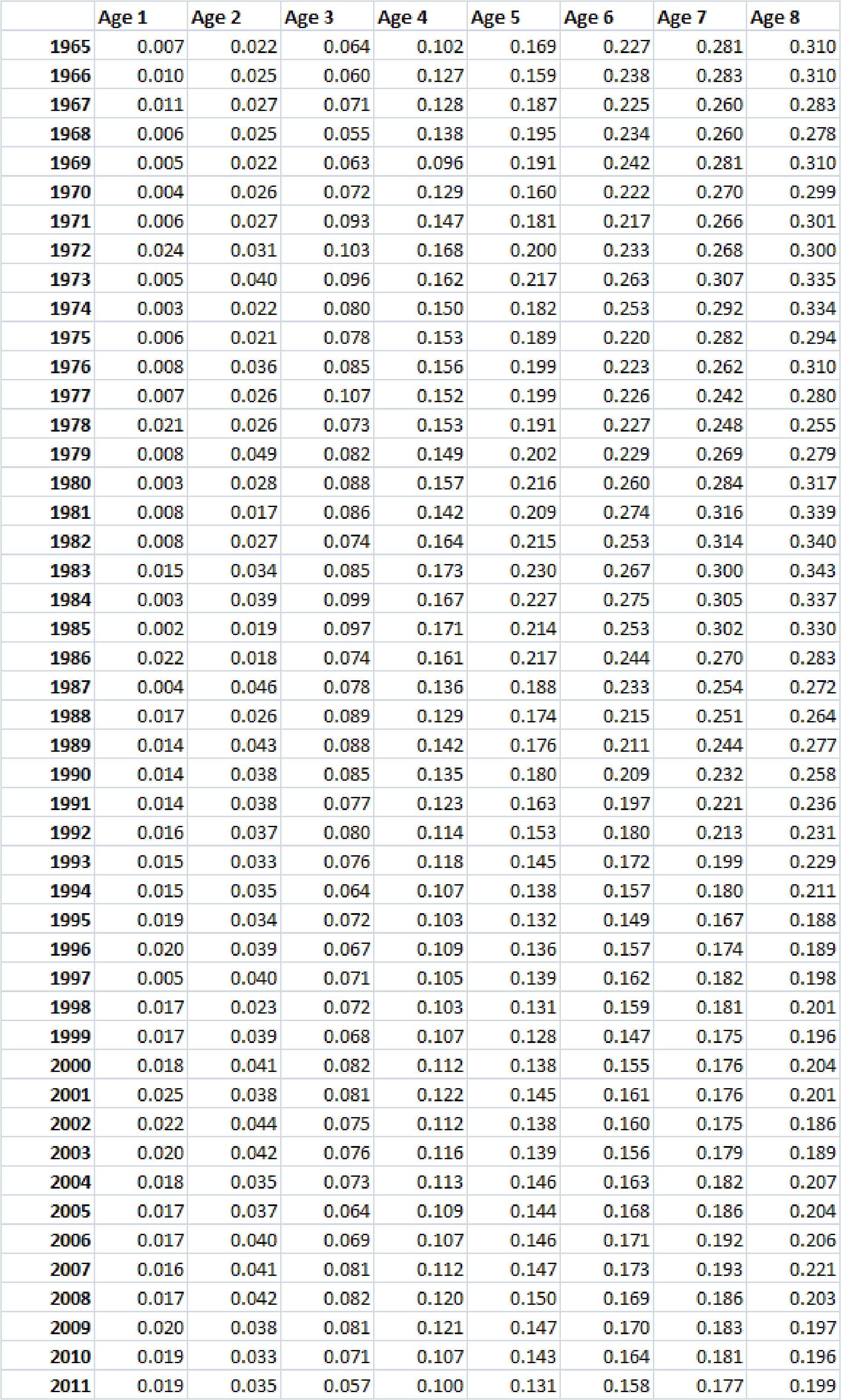
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1965	0.006	0.024	0.062	0.112	0.165	0.244	0.280	0.306
1966	0.009	0.027	0.069	0.142	0.219	0.272	0.300	0.280
1967	0.005	0.028	0.062	0.122	0.188	0.213	0.238	0.264
1968	0.005	0.033	0.068	0.143	0.186	0.237	0.276	0.305
1969	0.010	0.035	0.100	0.137	0.206	0.240	0.288	0.321
1970	0.010	0.044	0.121	0.159	0.186	0.232	0.269	0.292
1971	0.012	0.044	0.129	0.168	0.199	0.242	0.289	0.321
1972	0.026	0.039	0.113	0.175	0.212	0.260	0.292	0.307
1973	0.010	0.044	0.110	0.137	0.219	0.280	0.331	0.376
1974	0.010	0.038	0.103	0.167	0.203	0.271	0.294	0.332
1975	0.016	0.044	0.107	0.177	0.206	0.244	0.292	0.297
1976	0.014	0.036	0.106	0.174	0.205	0.229	0.263	0.289
1977	0.012	0.037	0.094	0.153	0.196	0.227	0.236	0.276
1978	0.011	0.036	0.096	0.158	0.196	0.220	0.239	0.251
1979	0.006	0.031	0.082	0.169	0.216	0.243	0.280	0.299
1980	0.012	0.041	0.097	0.150	0.229	0.265	0.291	0.290
1981	0.010	0.041	0.098	0.177	0.213	0.281	0.310	0.328
1982	0.019	0.041	0.104	0.204	0.229	0.253	0.305	0.334
1983	0.018	0.041	0.125	0.199	0.218	0.283	0.319	0.354
1984	0.014	0.041	0.117	0.154	0.195	0.209	0.291	0.326
1985	0.017	0.036	0.099	0.148	0.162	0.188	0.198	0.286
1986	0.018	0.042	0.101	0.159	0.210	0.236	0.247	0.205
1987	0.011	0.041	0.092	0.137	0.088	0.147	0.145	0.157
1988	0.009	0.031	0.091	0.106	0.121	0.129	0.190	0.230
1989	0.009	0.031	0.066	0.102	0.116	0.132	0.157	0.199
1990	0.006	0.029	0.080	0.138	0.174	0.167	0.177	0.220
1991	0.004	0.036	0.073	0.124	0.150	0.184	0.200	0.208
1992	0.009	0.035	0.073	0.124	0.138	0.164	0.191	0.208
1993	0.009	0.032	0.078	0.119	0.123	0.147	0.183	0.221
1994	0.009	0.029	0.070	0.118	0.134	0.152	0.162	0.196
1995	0.014	0.046	0.089	0.118	0.134	0.149	0.160	0.181
1996	0.024	0.043	0.083	0.120	0.146	0.164	0.179	0.194
1997	0.016	0.045	0.085	0.118	0.147	0.167	0.182	0.198
1998	0.016	0.037	0.080	0.112	0.132	0.158	0.178	0.194
1999	0.023	0.047	0.087	0.116	0.132	0.148	0.176	0.192
2000	0.018	0.060	0.101	0.127	0.147	0.159	0.182	0.202
2001	0.005	0.047	0.089	0.127	0.147	0.161	0.174	0.200
2002	0.020	0.045	0.093	0.121	0.138	0.158	0.169	0.179
2003	0.015	0.052	0.090	0.130	0.149	0.166	0.184	0.189
2004	0.011	0.043	0.092	0.125	0.152	0.166	0.186	0.193
2005	0.019	0.042	0.083	0.123	0.149	0.170	0.188	0.205
2006	0.016	0.066	0.085	0.120	0.147	0.172	0.188	0.204
2007	0.016	0.047	0.085	0.118	0.141	0.161	0.185	0.191
2008	0.016	0.041	0.100	0.131	0.152	0.169	0.180	0.193
2009	0.004	0.047	0.090	0.133	0.156	0.172	0.184	0.200
2010	0.016	0.037	0.072	0.113	0.142	0.162	0.174	0.183
2011	0.019	0.043	0.069	0.100	0.139	0.161	0.191	0.207

Table A1-13. Spawning stock biomass weights at age (kg).



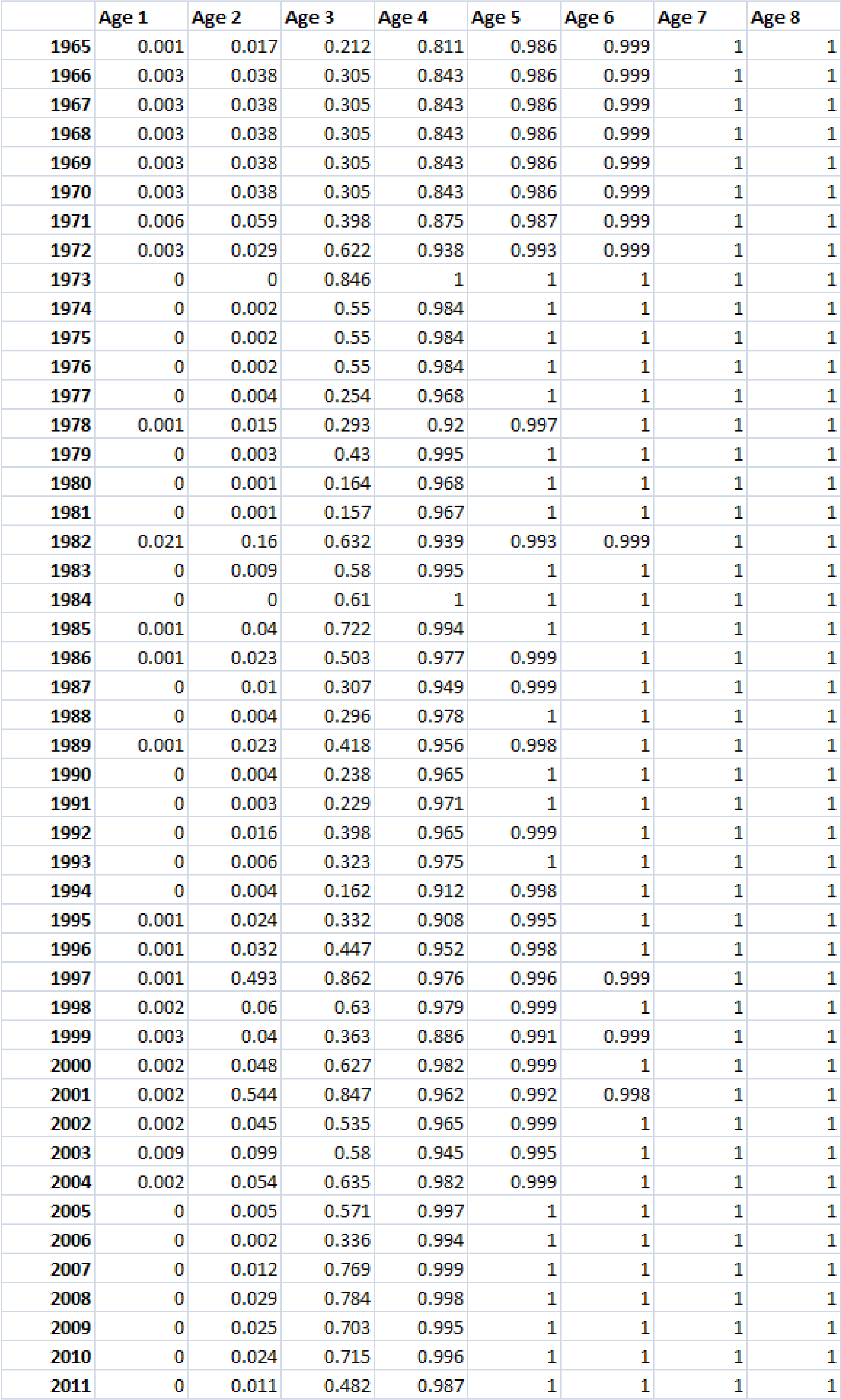
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1965	0.013	0.038	0.095	0.113	0.202	0.265	0.298	0.321
1966	0.016	0.047	0.096	0.170	0.224	0.279	0.302	0.321
1967	0.016	0.043	0.107	0.172	0.206	0.226	0.242	0.265
1968	0.011	0.038	0.069	0.176	0.221	0.265	0.298	0.321
1969	0.011	0.041	0.102	0.134	0.206	0.265	0.298	0.321
1970	0.011	0.061	0.126	0.163	0.191	0.239	0.276	0.299
1971	0.014	0.068	0.144	0.170	0.202	0.248	0.296	0.328
1972	0.031	0.069	0.154	0.197	0.235	0.268	0.289	0.304
1973	0.011	0.051	0.133	0.170	0.238	0.295	0.352	0.387
1974	0.008	0.045	0.124	0.169	0.196	0.270	0.290	0.318
1975	0.015	0.055	0.133	0.188	0.211	0.248	0.295	0.298
1976	0.015	0.088	0.132	0.184	0.210	0.236	0.278	0.325
1977	0.013	0.045	0.131	0.175	0.215	0.243	0.249	0.281
1978	0.032	0.050	0.119	0.178	0.208	0.239	0.252	0.261
1979	0.015	0.073	0.133	0.187	0.229	0.253	0.302	0.308
1980	0.007	0.054	0.104	0.185	0.250	0.294	0.319	0.332
1981	0.015	0.039	0.135	0.192	0.236	0.301	0.339	0.360
1982	0.017	0.050	0.139	0.200	0.240	0.272	0.328	0.341
1983	0.024	0.069	0.144	0.214	0.265	0.297	0.332	0.358
1984	0.007	0.064	0.140	0.193	0.239	0.286	0.313	0.343
1985	0.005	0.047	0.146	0.208	0.237	0.268	0.318	0.348
1986	0.032	0.057	0.116	0.176	0.227	0.252	0.271	0.252
1987	0.010	0.068	0.108	0.159	0.202	0.238	0.256	0.273
1988	0.027	0.066	0.117	0.154	0.192	0.229	0.264	0.272
1989	0.023	0.068	0.116	0.172	0.201	0.232	0.260	0.289
1990	0.023	0.062	0.106	0.156	0.189	0.216	0.233	0.255
1991	0.023	0.063	0.096	0.142	0.171	0.205	0.225	0.239
1992	0.023	0.060	0.101	0.135	0.164	0.190	0.220	0.238
1993	0.023	0.047	0.096	0.137	0.156	0.180	0.209	0.238
1994	0.023	0.054	0.086	0.120	0.138	0.159	0.180	0.213
1995	0.027	0.051	0.095	0.123	0.145	0.162	0.175	0.196
1996	0.028	0.055	0.088	0.125	0.150	0.171	0.188	0.204
1997	0.010	0.056	0.091	0.124	0.153	0.175	0.194	0.208
1998	0.026	0.052	0.092	0.117	0.138	0.164	0.187	0.208
1999	0.026	0.060	0.091	0.123	0.140	0.157	0.186	0.205
2000	0.026	0.065	0.111	0.137	0.156	0.172	0.198	0.224
2001	0.033	0.056	0.099	0.134	0.153	0.166	0.181	0.204
2002	0.030	0.059	0.099	0.126	0.143	0.167	0.183	0.192
2003	0.027	0.059	0.099	0.137	0.153	0.171	0.192	0.195
2004	0.026	0.047	0.091	0.129	0.155	0.173	0.194	0.223
2005	0.026	0.054	0.087	0.131	0.159	0.183	0.199	0.214
2006	0.026	0.062	0.089	0.133	0.163	0.184	0.203	0.212
2007	0.026	0.064	0.106	0.140	0.164	0.184	0.203	0.242
2008	0.026	0.068	0.106	0.135	0.162	0.175	0.188	0.202
2009	0.026	0.057	0.095	0.138	0.159	0.179	0.191	0.208
2010	0.026	0.043	0.089	0.121	0.147	0.168	0.183	0.202
2011	0.026	0.048	0.076	0.111	0.143	0.169	0.186	0.217

Table A1-14. January 1 weights at age (kg).



	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1965	0.007	0.022	0.064	0.102	0.169	0.227	0.281	0.310
1966	0.010	0.025	0.060	0.127	0.159	0.238	0.283	0.310
1967	0.011	0.027	0.071	0.128	0.187	0.225	0.260	0.283
1968	0.006	0.025	0.055	0.138	0.195	0.234	0.260	0.278
1969	0.005	0.022	0.063	0.096	0.191	0.242	0.281	0.310
1970	0.004	0.026	0.072	0.129	0.160	0.222	0.270	0.299
1971	0.006	0.027	0.093	0.147	0.181	0.217	0.266	0.301
1972	0.024	0.031	0.103	0.168	0.200	0.233	0.268	0.300
1973	0.005	0.040	0.096	0.162	0.217	0.263	0.307	0.335
1974	0.003	0.022	0.080	0.150	0.182	0.253	0.292	0.334
1975	0.006	0.021	0.078	0.153	0.189	0.220	0.282	0.294
1976	0.008	0.036	0.085	0.156	0.199	0.223	0.262	0.310
1977	0.007	0.026	0.107	0.152	0.199	0.226	0.242	0.280
1978	0.021	0.026	0.073	0.153	0.191	0.227	0.248	0.255
1979	0.008	0.049	0.082	0.149	0.202	0.229	0.269	0.279
1980	0.003	0.028	0.088	0.157	0.216	0.260	0.284	0.317
1981	0.008	0.017	0.086	0.142	0.209	0.274	0.316	0.339
1982	0.008	0.027	0.074	0.164	0.215	0.253	0.314	0.340
1983	0.015	0.034	0.085	0.173	0.230	0.267	0.300	0.343
1984	0.003	0.039	0.099	0.167	0.227	0.275	0.305	0.337
1985	0.002	0.019	0.097	0.171	0.214	0.253	0.302	0.330
1986	0.022	0.018	0.074	0.161	0.217	0.244	0.270	0.283
1987	0.004	0.046	0.078	0.136	0.188	0.233	0.254	0.272
1988	0.017	0.026	0.089	0.129	0.174	0.215	0.251	0.264
1989	0.014	0.043	0.088	0.142	0.176	0.211	0.244	0.277
1990	0.014	0.038	0.085	0.135	0.180	0.209	0.232	0.258
1991	0.014	0.038	0.077	0.123	0.163	0.197	0.221	0.236
1992	0.016	0.037	0.080	0.114	0.153	0.180	0.213	0.231
1993	0.015	0.033	0.076	0.118	0.145	0.172	0.199	0.229
1994	0.015	0.035	0.064	0.107	0.138	0.157	0.180	0.211
1995	0.019	0.034	0.072	0.103	0.132	0.149	0.167	0.188
1996	0.020	0.039	0.067	0.109	0.136	0.157	0.174	0.189
1997	0.005	0.040	0.071	0.105	0.139	0.162	0.182	0.198
1998	0.017	0.023	0.072	0.103	0.131	0.159	0.181	0.201
1999	0.017	0.039	0.068	0.107	0.128	0.147	0.175	0.196
2000	0.018	0.041	0.082	0.112	0.138	0.155	0.176	0.204
2001	0.025	0.038	0.081	0.122	0.145	0.161	0.176	0.201
2002	0.022	0.044	0.075	0.112	0.138	0.160	0.175	0.186
2003	0.020	0.042	0.076	0.116	0.139	0.156	0.179	0.189
2004	0.018	0.035	0.073	0.113	0.146	0.163	0.182	0.207
2005	0.017	0.037	0.064	0.109	0.144	0.168	0.186	0.204
2006	0.017	0.040	0.069	0.107	0.146	0.171	0.192	0.206
2007	0.016	0.041	0.081	0.112	0.147	0.173	0.193	0.221
2008	0.017	0.042	0.082	0.120	0.150	0.169	0.186	0.203
2009	0.020	0.038	0.081	0.121	0.147	0.170	0.183	0.197
2010	0.019	0.033	0.071	0.107	0.143	0.164	0.181	0.196
2011	0.019	0.035	0.057	0.100	0.131	0.158	0.177	0.199

Table A1-15. Proportion mature at age.



	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1965	0.001	0.017	0.212	0.811	0.986	0.999	1	1
1966	0.003	0.038	0.305	0.843	0.986	0.999	1	1
1967	0.003	0.038	0.305	0.843	0.986	0.999	1	1
1968	0.003	0.038	0.305	0.843	0.986	0.999	1	1
1969	0.003	0.038	0.305	0.843	0.986	0.999	1	1
1970	0.003	0.038	0.305	0.843	0.986	0.999	1	1
1971	0.006	0.059	0.398	0.875	0.987	0.999	1	1
1972	0.003	0.029	0.622	0.938	0.993	0.999	1	1
1973	0	0	0.846	1	1	1	1	1
1974	0	0.002	0.55	0.984	1	1	1	1
1975	0	0.002	0.55	0.984	1	1	1	1
1976	0	0.002	0.55	0.984	1	1	1	1
1977	0	0.004	0.254	0.968	1	1	1	1
1978	0.001	0.015	0.293	0.92	0.997	1	1	1
1979	0	0.003	0.43	0.995	1	1	1	1
1980	0	0.001	0.164	0.968	1	1	1	1
1981	0	0.001	0.157	0.967	1	1	1	1
1982	0.021	0.16	0.632	0.939	0.993	0.999	1	1
1983	0	0.009	0.58	0.995	1	1	1	1
1984	0	0	0.61	1	1	1	1	1
1985	0.001	0.04	0.722	0.994	1	1	1	1
1986	0.001	0.023	0.503	0.977	0.999	1	1	1
1987	0	0.01	0.307	0.949	0.999	1	1	1
1988	0	0.004	0.296	0.978	1	1	1	1
1989	0.001	0.023	0.418	0.956	0.998	1	1	1
1990	0	0.004	0.238	0.965	1	1	1	1
1991	0	0.003	0.229	0.971	1	1	1	1
1992	0	0.016	0.398	0.965	0.999	1	1	1
1993	0	0.006	0.323	0.975	1	1	1	1
1994	0	0.004	0.162	0.912	0.998	1	1	1
1995	0.001	0.024	0.332	0.908	0.995	1	1	1
1996	0.001	0.032	0.447	0.952	0.998	1	1	1
1997	0.001	0.493	0.862	0.976	0.996	0.999	1	1
1998	0.002	0.06	0.63	0.979	0.999	1	1	1
1999	0.003	0.04	0.363	0.886	0.991	0.999	1	1
2000	0.002	0.048	0.627	0.982	0.999	1	1	1
2001	0.002	0.544	0.847	0.962	0.992	0.998	1	1
2002	0.002	0.045	0.535	0.965	0.999	1	1	1
2003	0.009	0.099	0.58	0.945	0.995	1	1	1
2004	0.002	0.054	0.635	0.982	0.999	1	1	1
2005	0	0.005	0.571	0.997	1	1	1	1
2006	0	0.002	0.336	0.994	1	1	1	1
2007	0	0.012	0.769	0.999	1	1	1	1
2008	0	0.029	0.784	0.998	1	1	1	1
2009	0	0.025	0.703	0.995	1	1	1	1
2010	0	0.024	0.715	0.996	1	1	1	1
2011	0	0.011	0.482	0.987	1	1	1	1

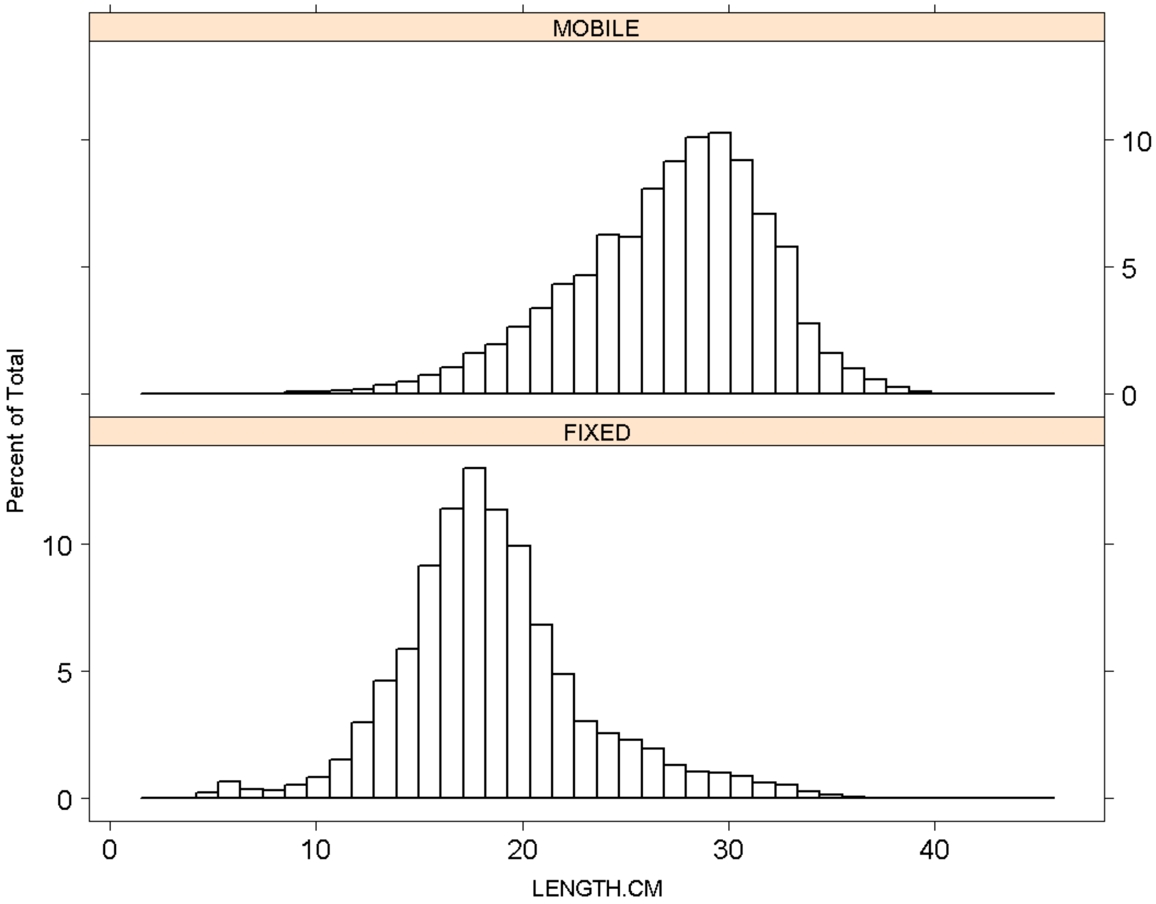


Figure A1-1. Length frequency of US commercial catches for fixed and mobile gear types during 1964-2011.

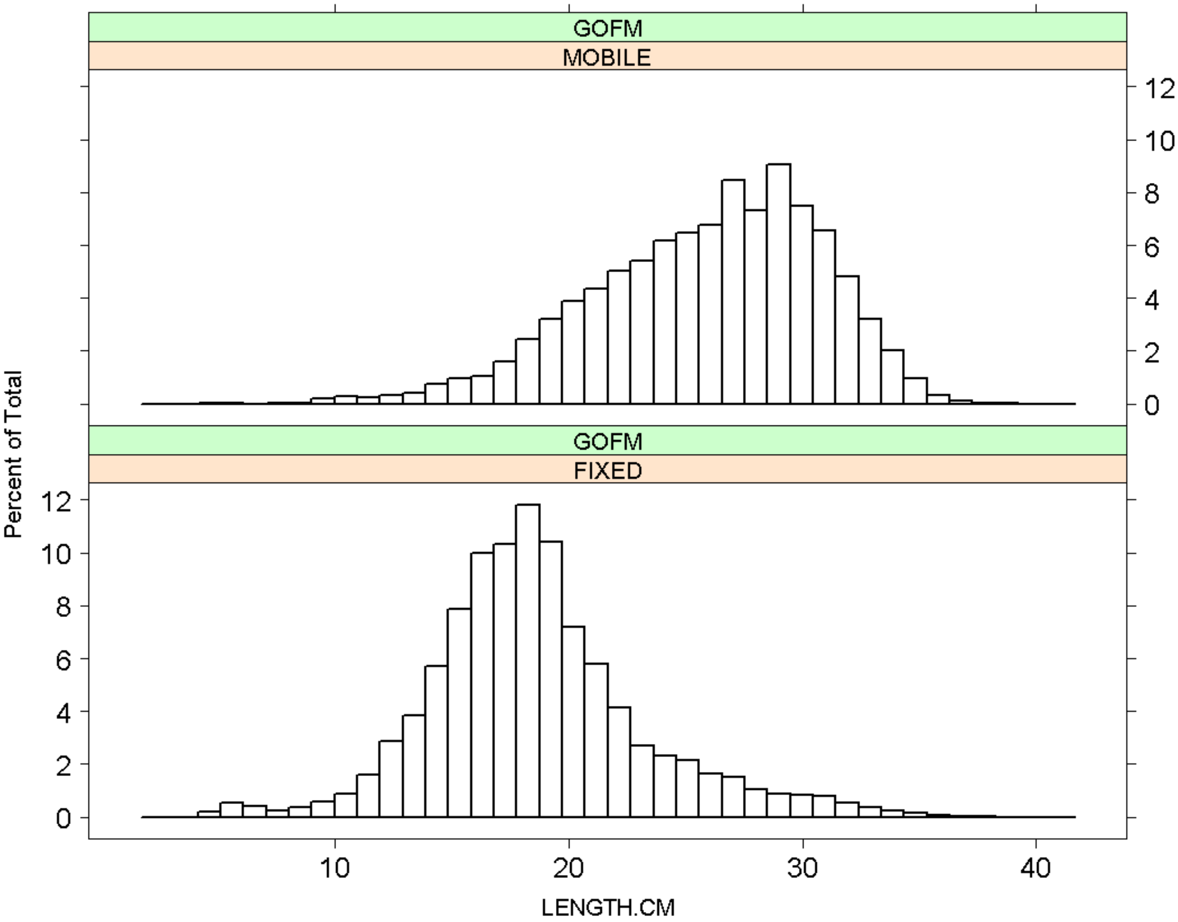


Figure A1-2. Length frequency of US commercial catches for fixed and mobile gear types in the Gulf of Maine during 1964-2011.

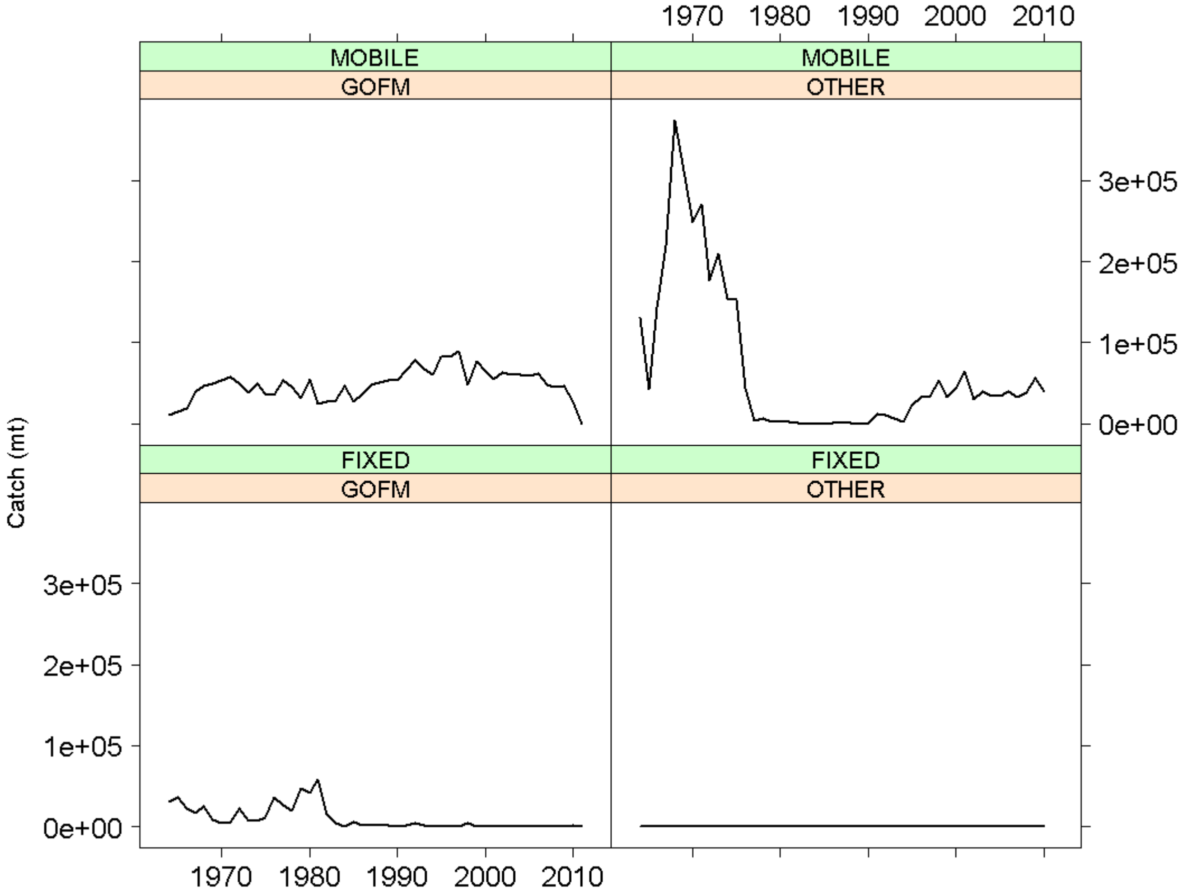


Figure A1-3. Atlantic herring catch during 1964-2011 for US mobile gears and US fixed gears in the Gulf of Maine and all other areas.

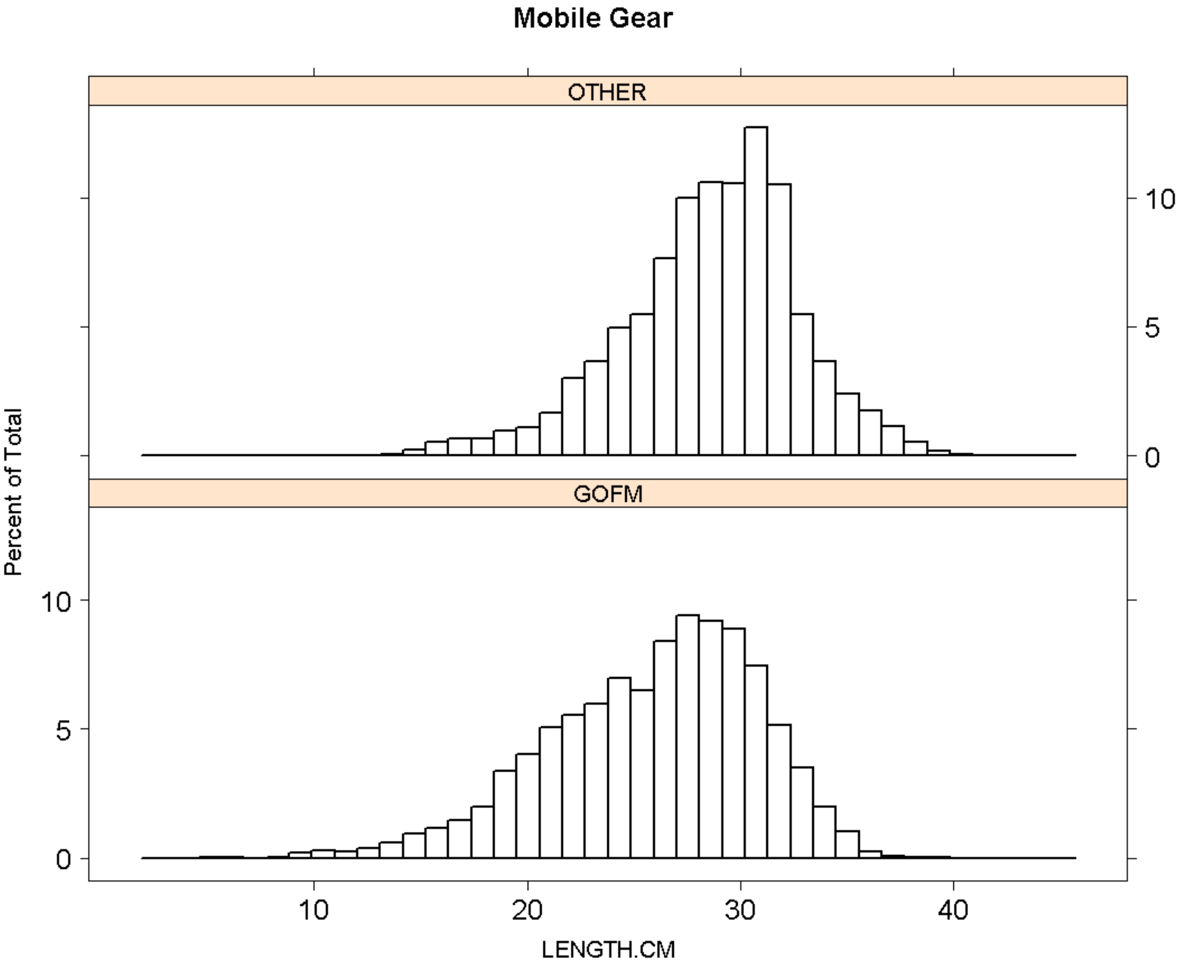


Figure A1-4. Length frequency of US commercial catches for mobile gears in the Gulf of Maine and other areas during 1964-2011. Only one fixed gear trip was sampled outside the Gulf of Maine during the entire time series, and so that data is not presented.

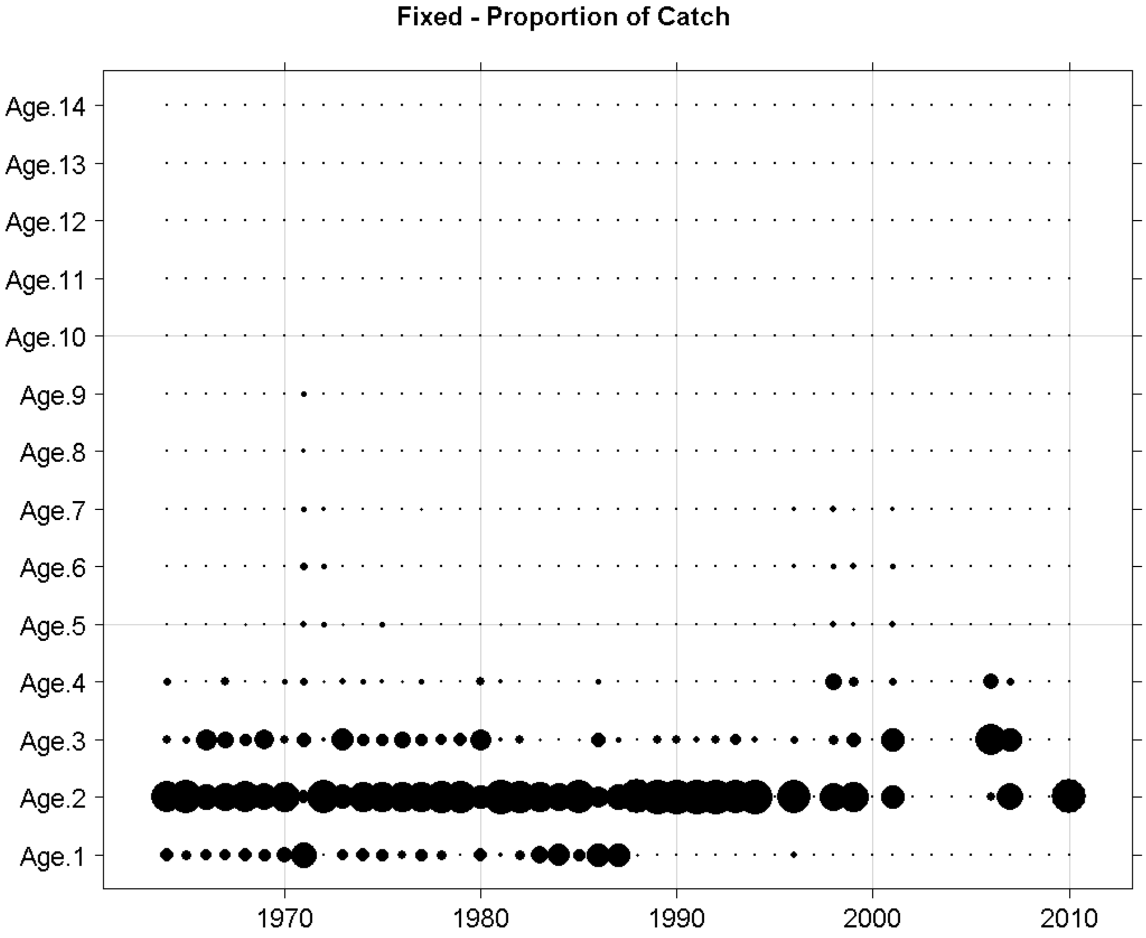


Figure A1-5. “Bubble plot” of the proportion of the catch in each year that is comprised of a given age for the US fixed gear category.

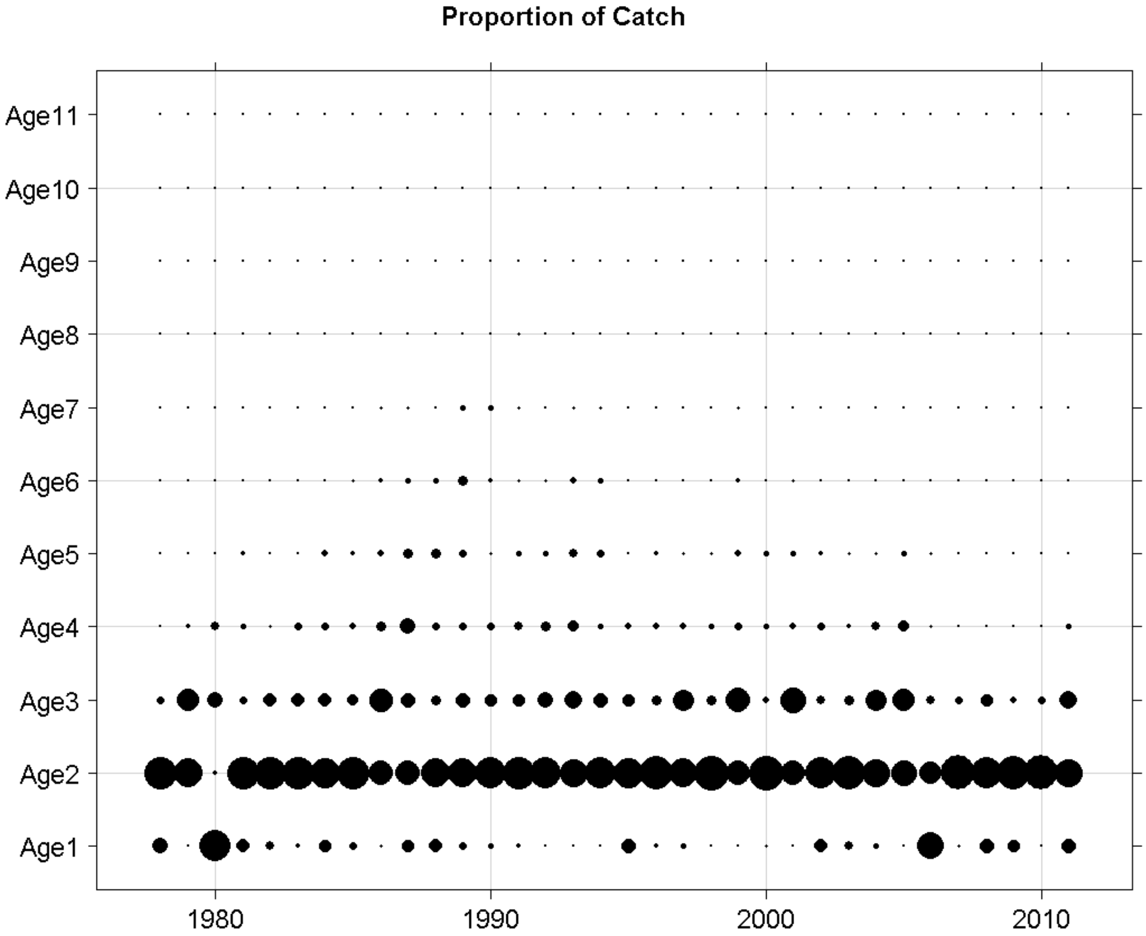


Figure A1-6. “Bubble plot” of the proportion of the catch in each year that is comprised of a given age for the New Brunswick, CA weir fishery.

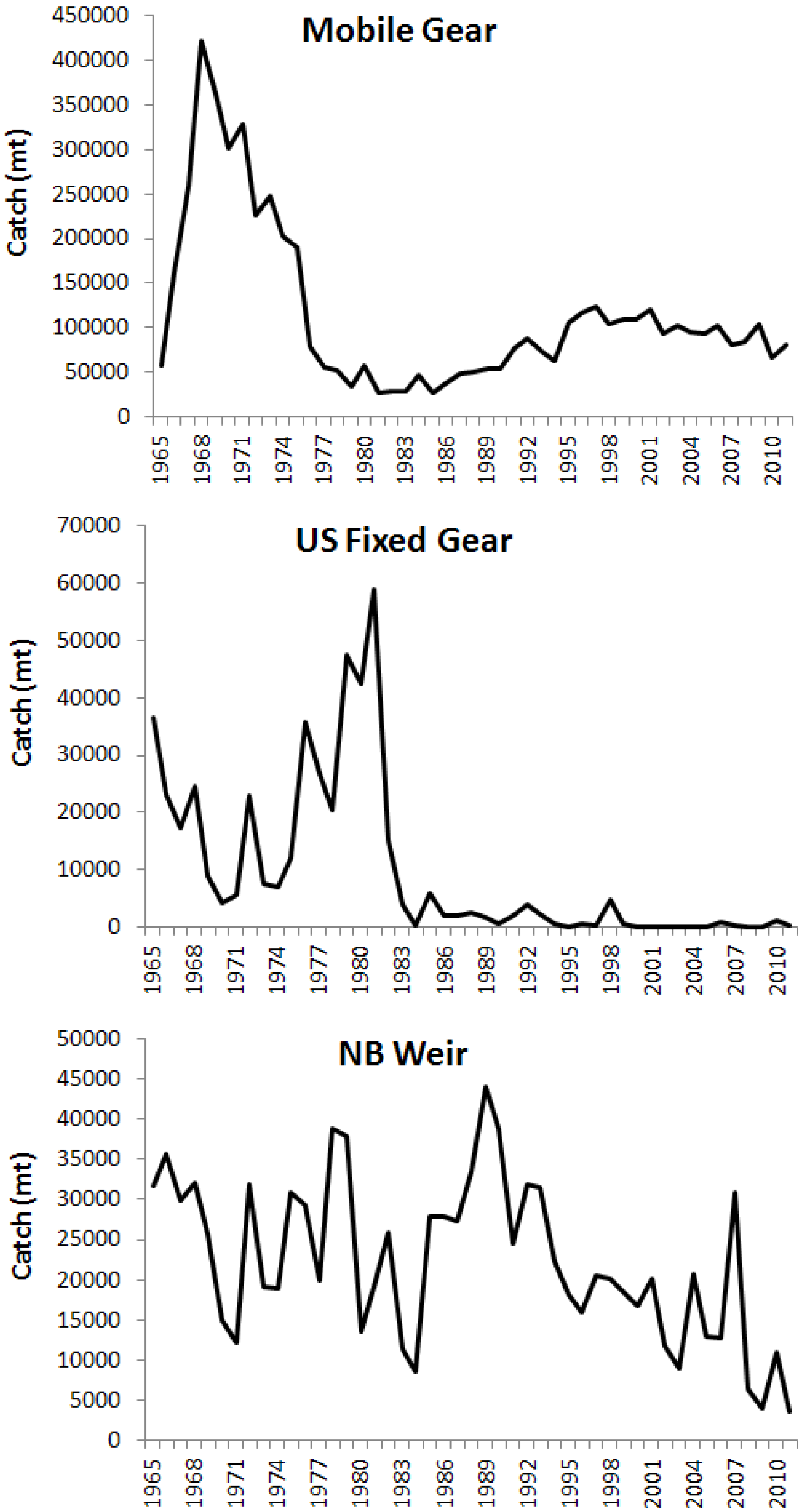


Figure A1-7. Atlantic herring catch during 1965-2011 for US mobile gears, US fixed gears, and NB weir fishery. Discards were only available since 1996.

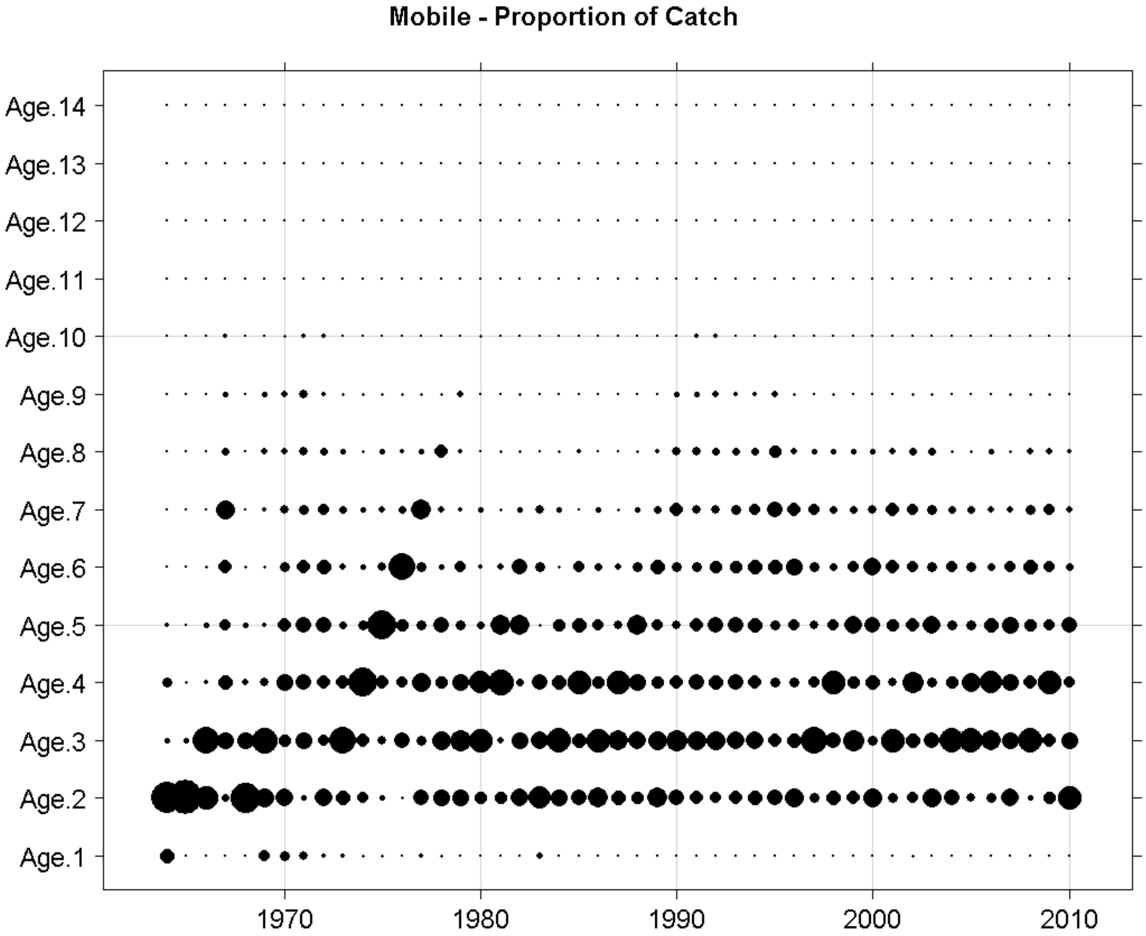


Figure A1-8. “Bubble plot” of the proportion of the catch in each year that is comprised of a given age for the US mobile gear category.

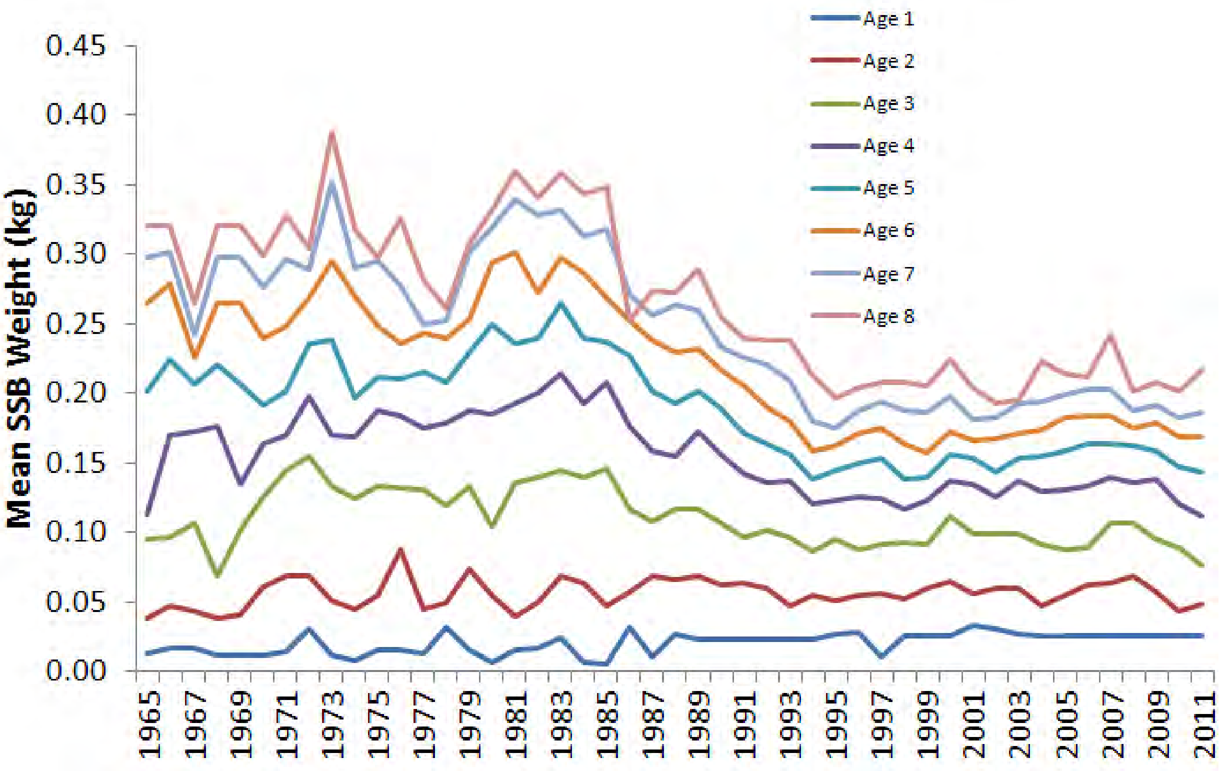


Figure A1-9. Mean spawning stock biomass (SSB) weights at age during 1965-2011.

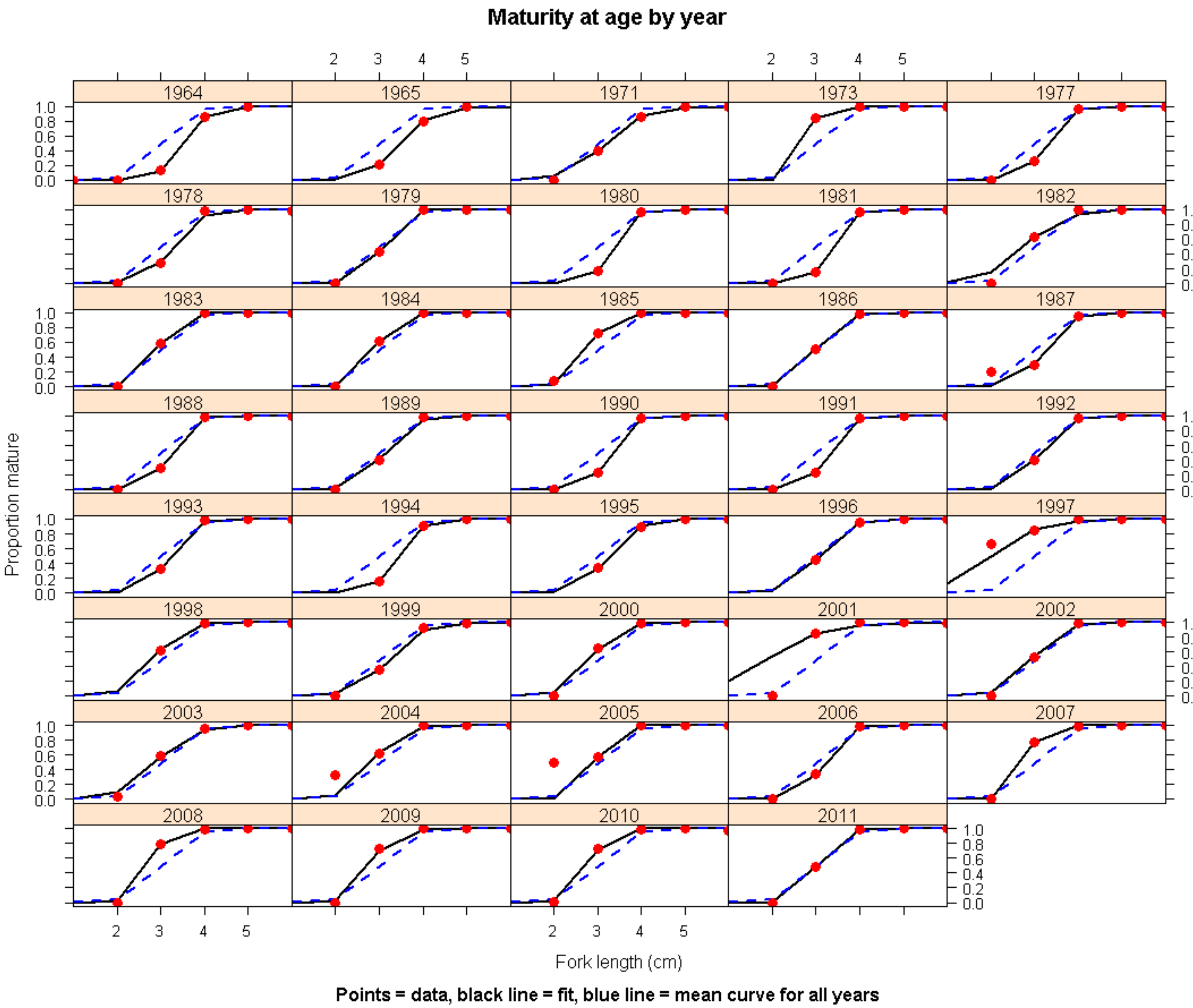


Figure A1-10. Maturity at age in each year, 1964-2011. Red dots are observed proportion mature, blue line is the mean among all years, and black line is the predicted maturity at age from a general additive model.

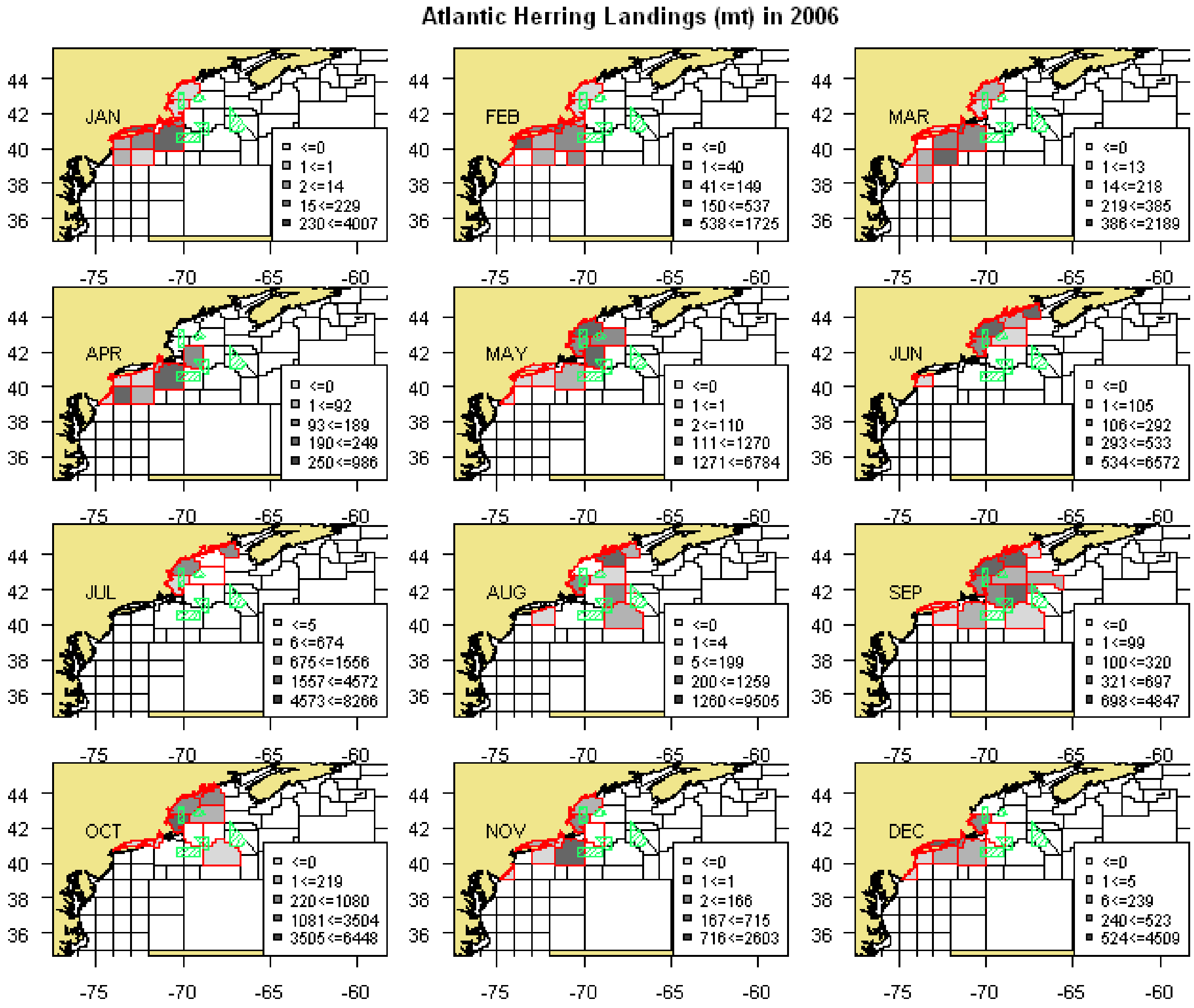


Figure A1-11. Distribution of Atlantic herring landings by month in 2006.

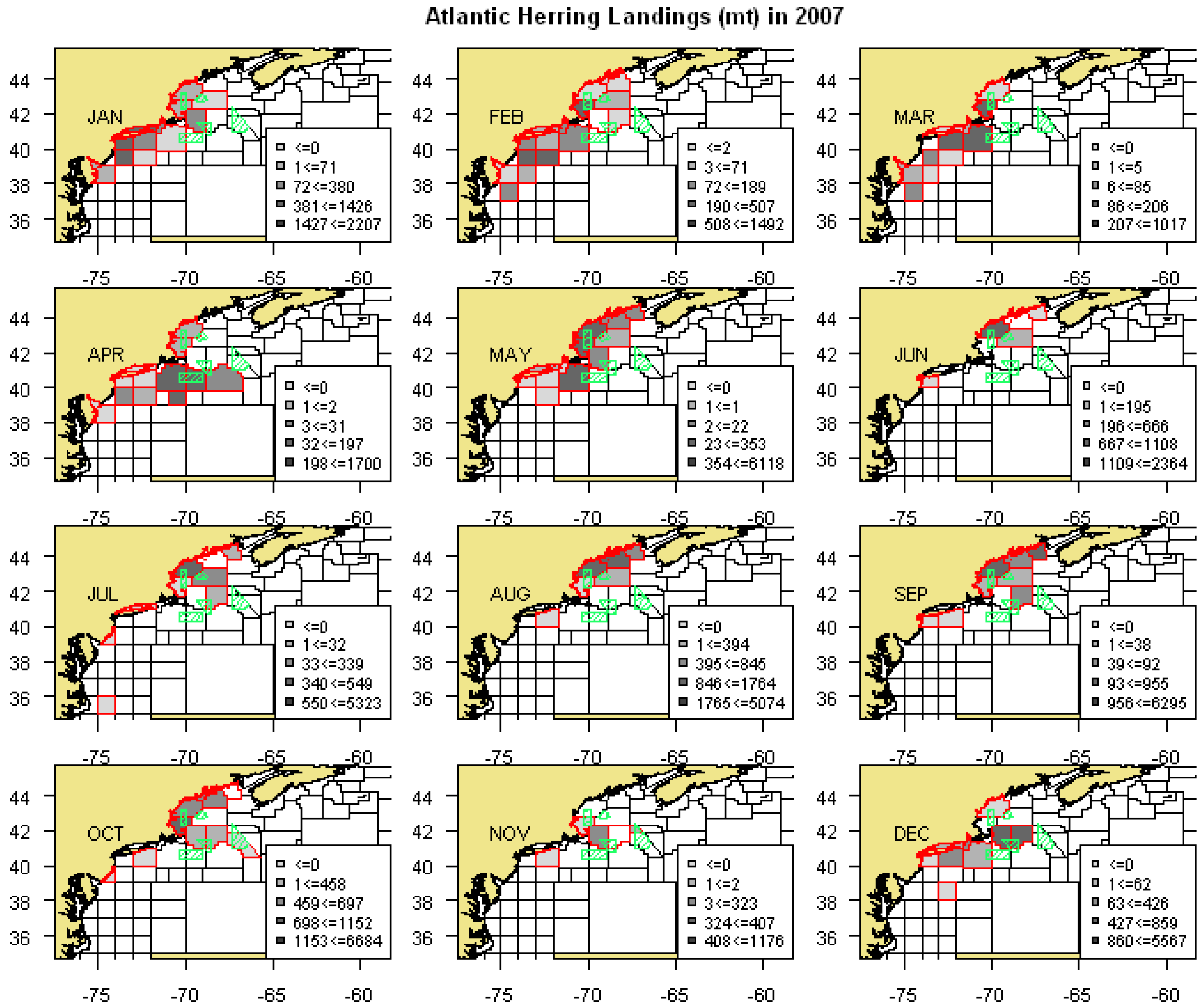


Figure A1-12. Distribution of Atlantic herring landings by month in 2007.

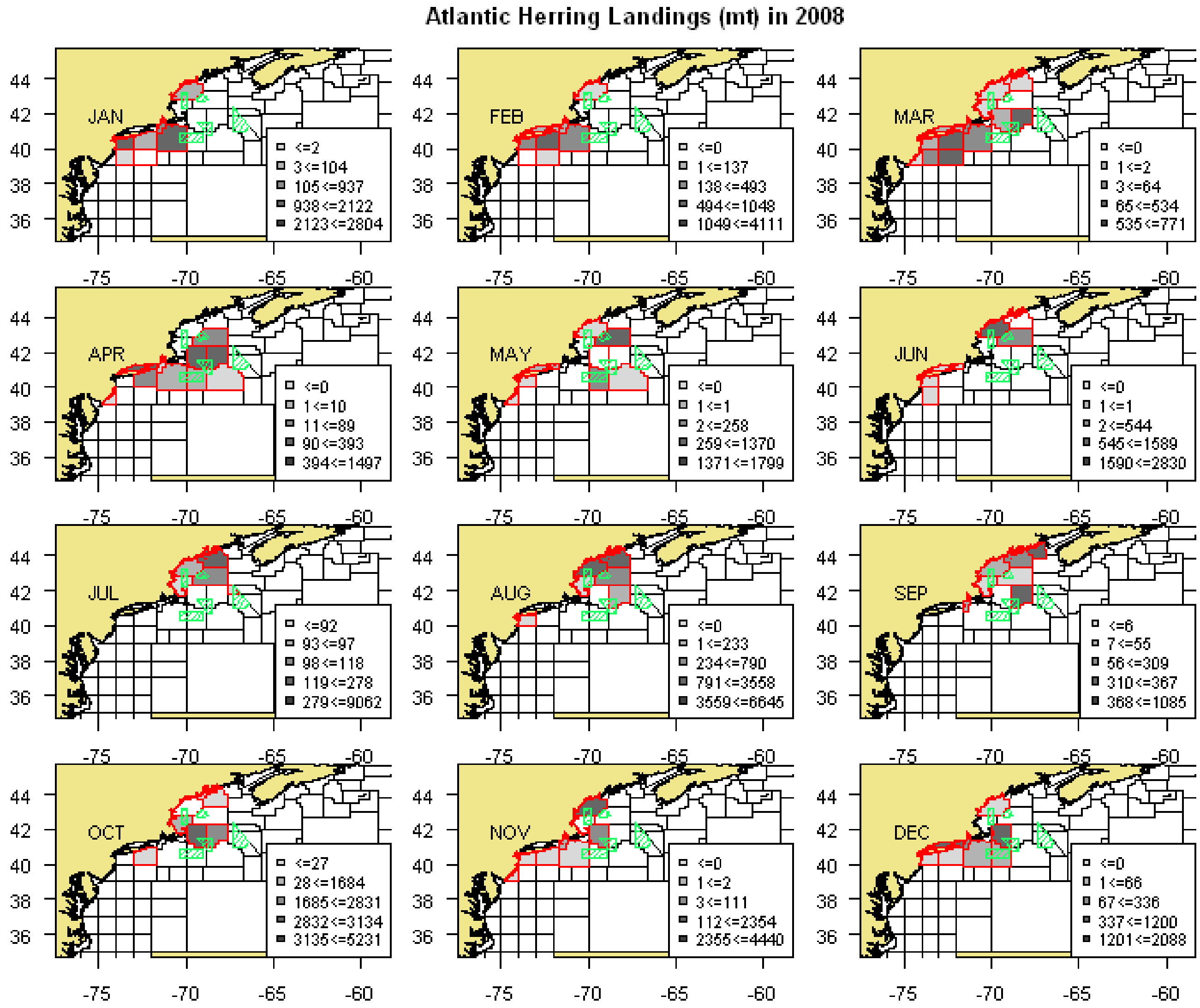


Figure A1-13. Distribution of Atlantic herring landings by month in 2008.

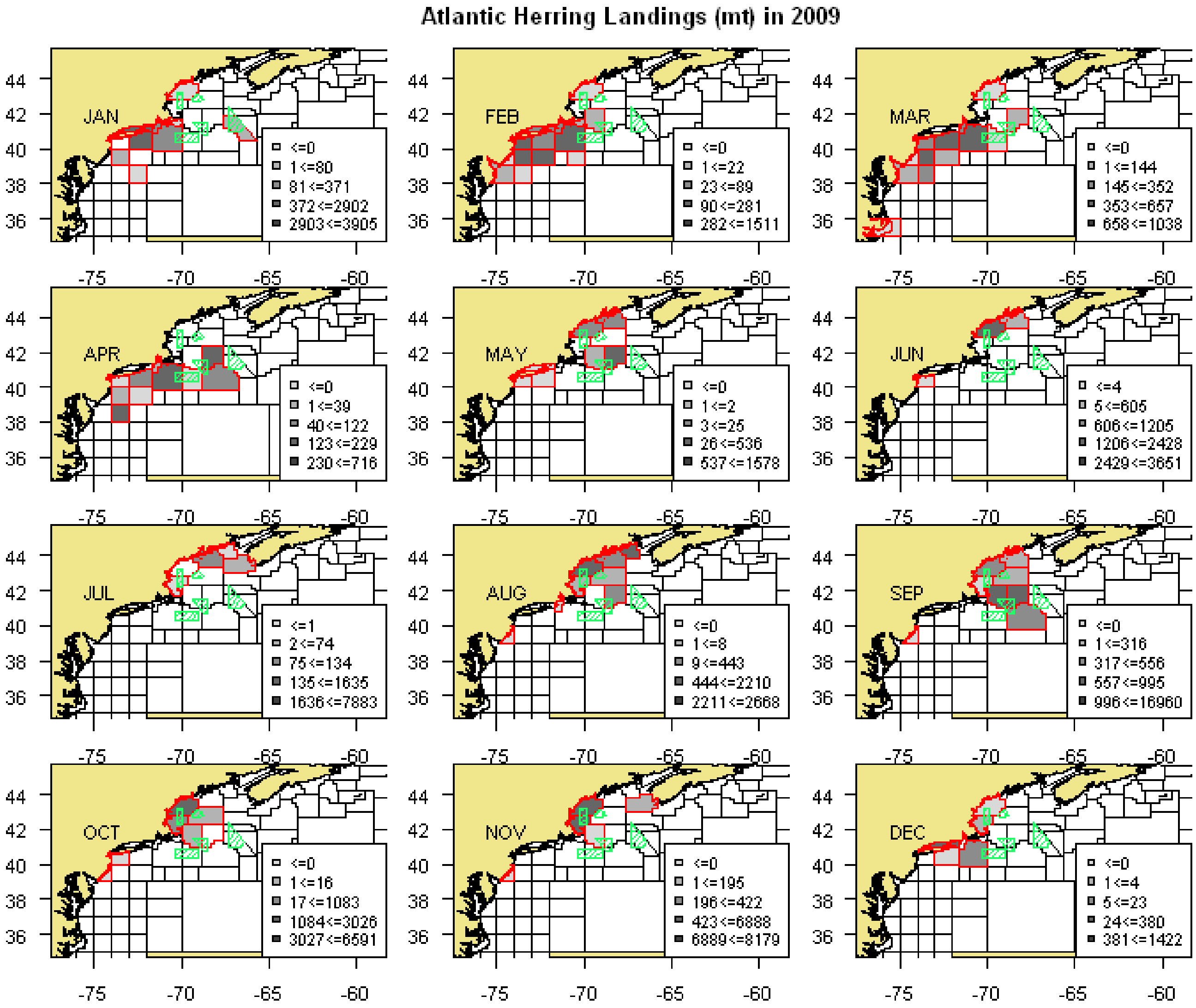


Figure A1-14. Distribution of Atlantic herring landings by month in 2009.

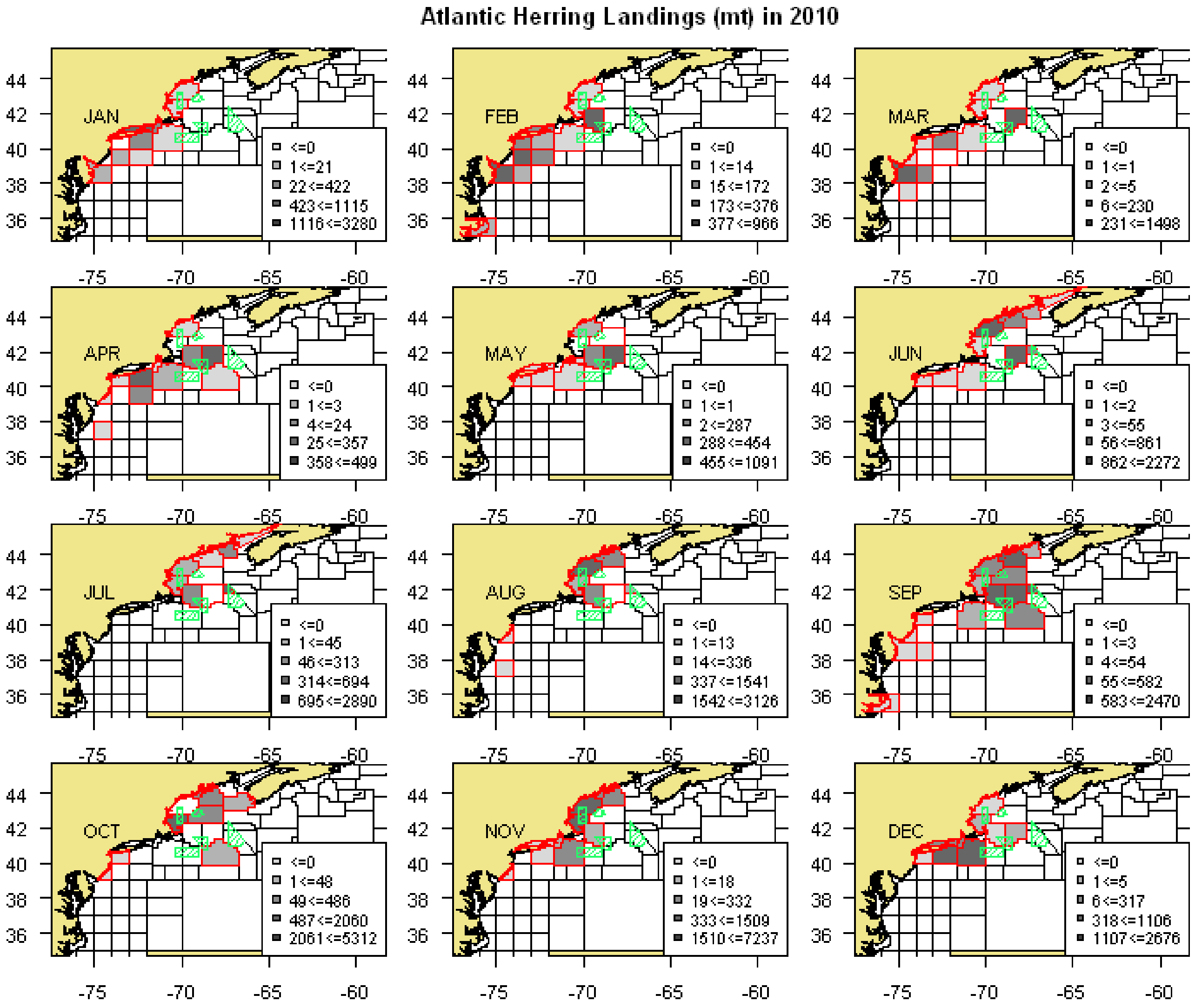


Figure A1-15. Distribution of Atlantic herring landings by month in 2010.

TOR A2. *Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, larval surveys, age-length data, predator consumption rates, etc.). Investigate the utility of commercial LPUE as a measure of relative abundance, and characterize the uncertainty and any bias in these sources of data.*

NMFS bottom trawl surveys

NMFS spring and fall bottom trawl surveys began in 1968 and 1963, respectively, and have continued uninterrupted through 2011. All survey tows in the spring and fall were conducted using the FRV Delaware II, FRV Albatross IV, or FSV Henry B. Bigelow. The Albatross IV was used for most tows in most years. In the spring, however, the Delaware II was responsible for most or all catches in 1973, 1979-1982, 1989-1991, 1994, and 2003. In the fall, the Delaware II was responsible for most or all of the catches in 1977-1978, 1980-1981, 1989-1991, and 1993. The Bigelow has been used exclusively since 2009. To ensure that changes in the indices were more reflective of changes in herring abundance and not due to differences in vessel catchability, all catches were calibrated to Albatross IV equivalents. Calibration coefficients were base on paired tow experiments (e.g., Byrne et al., 1991, Miller et al., 2010). Catch numbers from the Delaware II were multiplied by 0.59, and this value was constant among seasons and lengths (Byrne et al. 1991). A range of models used to develop the calibration coefficients for converting Bigelow catches to Albatross IV catches were explored (Miller et al. 2010; Appendix A3). Based on this analysis, catch numbers from the Bigelow in the spring survey were multiplied by 0.28, and this value was constant among lengths (Appendix A3). Calibration coefficients for catch numbers from the Bigelow in the fall were multiplied by length specific values (Table A2-1; Appendix A3). The conversion coefficients <20cm were constant and estimated based on pooled data for those lengths because sample sizes were too small to reliably estimate coefficients at individual lengths (Appendix A3). Herring age samples in the spring and fall surveys were collected beginning in 1987. In previous assessments for years prior to 1987, age specific indices were estimated by using age-length keys developed mostly from commercial catch data. Borrowing age-length keys among data sources, however, can potentially induce bias. For example, a comparison of age-length keys developed from mobile gear catches during January-June and the spring survey in 2006-2010 suggested significant differences (Figures A2-1:A2-5). Consequently, the practice of borrowing age-length keys to develop age composition information for NMFS surveys prior to 1987 was abandoned for this assessment. Arithmetic mean numbers per tow and associated coefficients of variation in each year were used as indices of Atlantic herring abundance, and age composition since 1987 data was used in assessments (Figures A2-6:A2-8; Tables A2-2:A2-4). Length frequencies were also provided (Figures A2-9, A2-10).

The trawl doors used on the NMFS spring and fall bottom trawl surveys changed in 1985. Preliminary assessment runs fit to the spring and fall surveys had all negative residuals followed by all positive residuals, with the change in direction approximately in 1984-1985 (Figure A2-11). Consequently, the spring and fall surveys were split into two time series (spring 1968-1984, 1985-2011; fall 1963-1984, 1985-2011) and these were treated as separate indices in assessment models. This split was used in previous herring assessments and resolved the issues of assessment fit (see TOR 5)

The NMFS winter survey was conducted during 1992-2007. Age samples were taken during this survey during the entire time series. Arithmetic mean numbers per tow and associated coefficients of variation in each year were proposed as indices of Atlantic herring abundance, and age composition was provided (Figures A2-12, A2-13; Tables A2-5, A2-6). Length frequencies were also provided (Figure A2-2:A2-14). As in previous assessments, the winter survey was eventually eliminated from consideration as an index of abundance because of concerns over inconsistent spatial coverage among years and lack of fit (see TOR 5).

A NMFS summer survey directed at shrimp began in 1983 and has continued uninterrupted through 2011, with the exception of 1984. The shrimp survey was not considered in previous Atlantic herring assessments. The spatial extent of this survey is limited to the Gulf of Maine (Figure A2-15). The working group agreed, however, that fish from the entire complex are mixed in the Gulf of Maine during the summer, and so this survey would be a valid index of the entire stock complex. Age data for Atlantic herring have never been collected on this survey. Arithmetic mean numbers per tow and associated coefficients of variation in each year were proposed as indices of Atlantic herring abundance (Figures A2-16; Table A2-7). Length frequencies were also provided (Figure A2-17).

General additive models (GAM) were used to evaluate the effects of environmental covariates and diel effects on spring, fall, and winter survey data (Jacobson, L. et al. 2012 working paper). A significant portion of survey stations, however, lacked environmental data and the general trends in the GAM fits were generally similar to arithmetic means. Consequently, the working group agreed that the arithmetic means based on the stratified random design of the bottom trawl surveys were sufficient.

Larval abundance index

An index of larval abundance was developed using maximum likelihood estimation with data from various ichthyoplankton surveys (Miller et al. 2012). This larval time series covered the years 1978-1995, 1998, and 2000-2010. Using this data as an index of spawning stock biomass, however, was argued to be inappropriate due to predation on herring eggs, especially by haddock, that creates nonlinearity in the relationship between the index and SSB (Richardson et al., 2011). Similarly, the shape of the relationship between the larval index and age 1 recruitment was unclear, but likely to be non-linear (Richardson et al., 2011). Because the utility of the larval index was not clear, the working group agreed not to use it for the assessment. None the less, some preliminary assessment runs were done using the larval data as an index of age 1 recruitment, and fits to the survey exhibited diagnostic problems (Figure A2-18).

Massachusetts Division of Marine Fisheries bottom trawl survey

Massachusetts Division of Marine Fisheries (MA DMF) spring and fall bottom trawl surveys began in 1977 and have continued uninterrupted through 2011. These surveys cover state waters ≤ 3 nm from shore to the north of Cape Cod. Because these surveys cover a relatively small proportion of the stock, in terms of both spatial coverage and size/age composition (Figures A2-19,A2-20), the working group agreed that they should not be used for the assessment. The surveys, however, were considered to be useful indices of localized abundance, and perhaps useful for management because they cover inshore areas that are not adequately sampled by NMFS surveys (Figures A2-21, A2-22).

Maine/New Hampshire bottom trawl survey

Joint Maine and New Hampshire spring and fall bottom trawl surveys began in 2001 and 2000, respectively, and have continued uninterrupted through 2011. As with the MA DMF surveys, these surveys occur in state waters and cover a relatively small proportion of the stock (Figures A2-23, A2-24). Consequently, the working group agreed that they should not be used for assessment. The surveys, however, were considered to be useful indices of localized age 1 abundance, and perhaps useful for management because they cover inshore areas that are not adequately sampled by NMFS surveys (Figure A2-25).

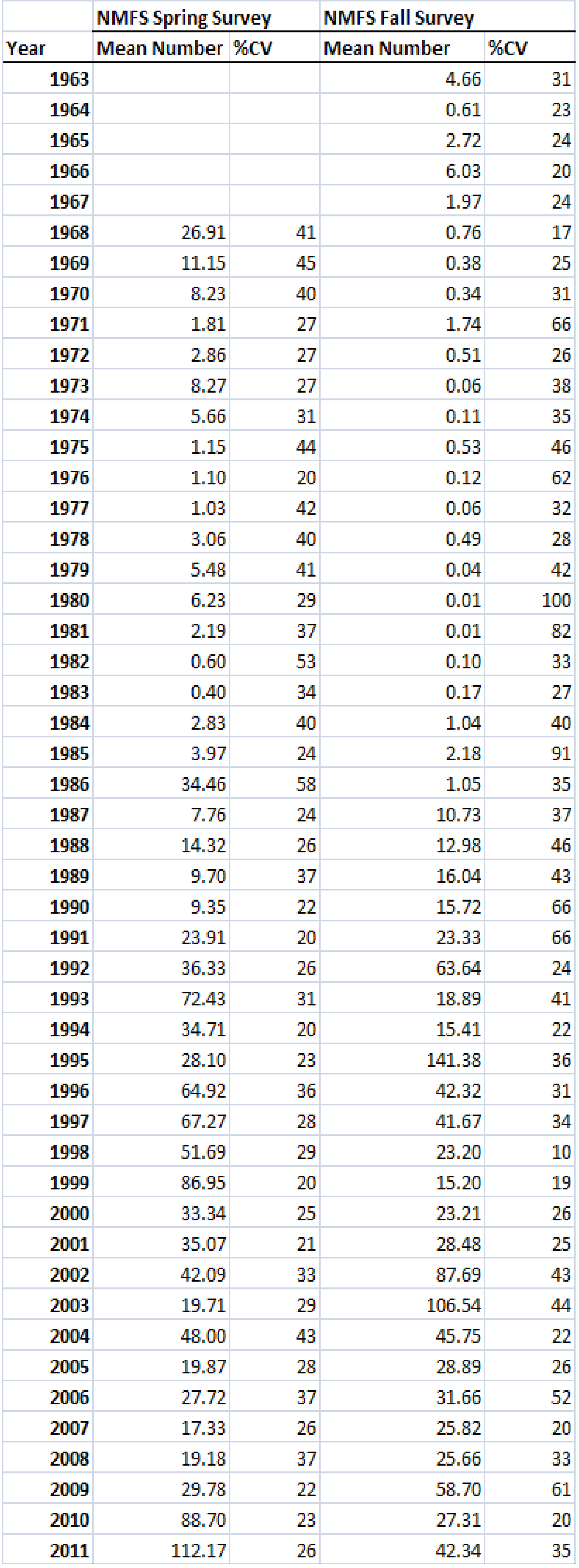
Commercial landings per unit effort

Commercial landings per unit effort (LPUE) were not developed for use as an index of abundance. The working group agreed, based on a priori reasons, that LPUE would not be a useful index of abundance. LPUE would likely be hyperstable given that much of the fishery uses sonar to track schools of fish and most of the landings in recent years come from relatively large scale pair trawls and purse seine gears. Identifying a "herring trip" for inclusion in an LPUE data set would also be difficult because the targeted species may change within a given trip depending on availability. Lastly, regulation changes have created temporal shifts in the spatial distribution of fishing effort that might obscure any herring abundance signal.

Table A2-1. Length specific coefficients for calibrating fall Bigelow catches to Albatross IV catches. Albatross IV catches were multiplied by these values.

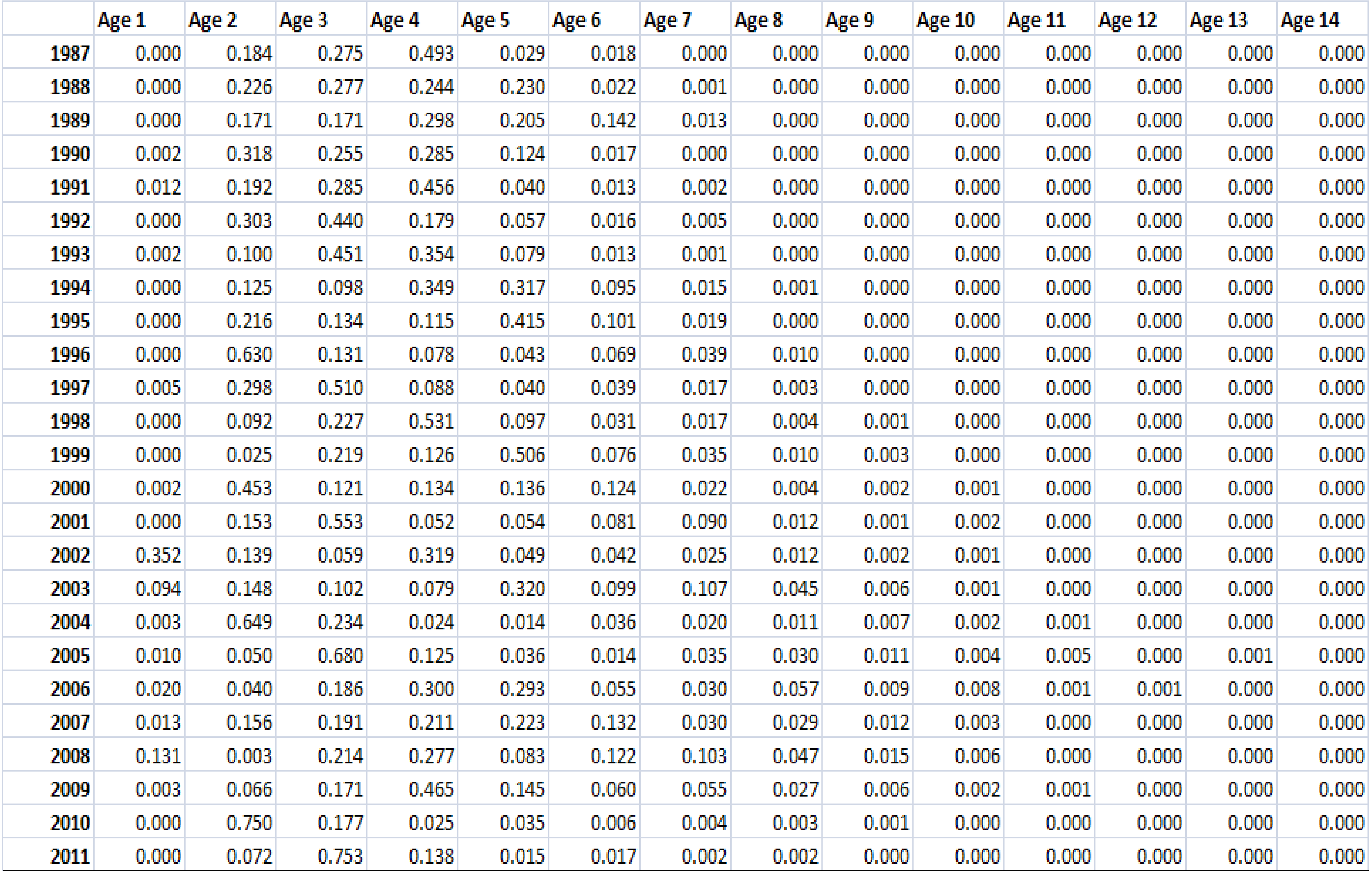
Length (cm)	Calibration Coefficient
4	0.33
5	0.33
6	0.33
7	0.33
8	0.33
9	0.33
10	0.33
11	0.33
12	0.33
13	0.33
14	0.33
15	0.33
16	0.33
17	0.33
18	0.33
19	0.33
20	0.33
21	0.89
22	0.73
23	0.50
24	0.44
25	0.54
26	0.75
27	0.90
28	0.75
29	0.44
30	0.27
31	0.43
32	0.43
33	0.43
34	0.43
35	0.43
36	0.43
37	0.43
38	0.43
39	0.43

Table A2-2. NMFS spring and fall survey time series with coefficients of variation.



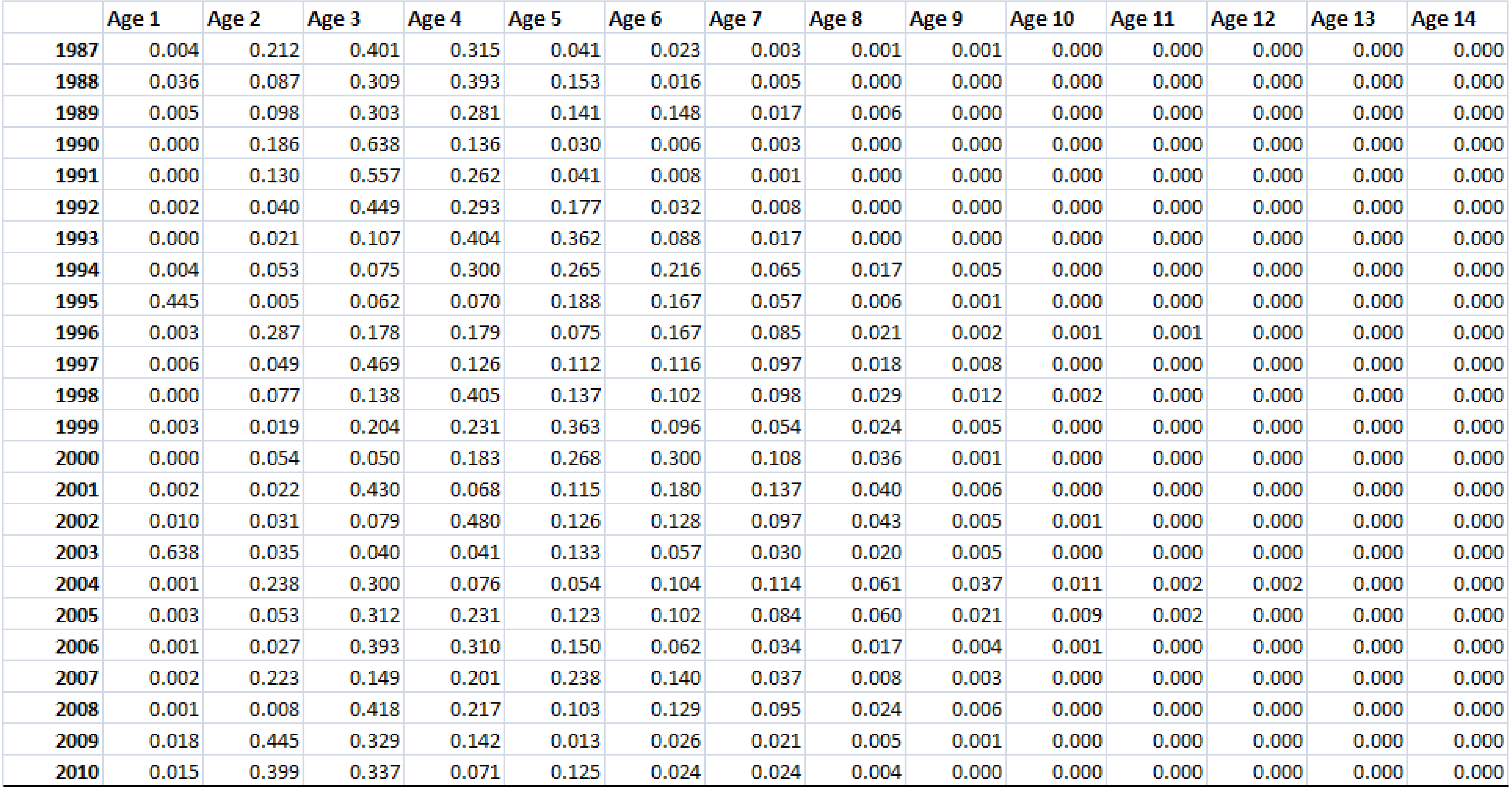
	NMFS Spring Survey		NMFS Fall Survey	
Year	Mean Number	%CV	Mean Number	%CV
1963			4.66	31
1964			0.61	23
1965			2.72	24
1966			6.03	20
1967			1.97	24
1968	26.91	41	0.76	17
1969	11.15	45	0.38	25
1970	8.23	40	0.34	31
1971	1.81	27	1.74	66
1972	2.86	27	0.51	26
1973	8.27	27	0.06	38
1974	5.66	31	0.11	35
1975	1.15	44	0.53	46
1976	1.10	20	0.12	62
1977	1.03	42	0.06	32
1978	3.06	40	0.49	28
1979	5.48	41	0.04	42
1980	6.23	29	0.01	100
1981	2.19	37	0.01	82
1982	0.60	53	0.10	33
1983	0.40	34	0.17	27
1984	2.83	40	1.04	40
1985	3.97	24	2.18	91
1986	34.46	58	1.05	35
1987	7.76	24	10.73	37
1988	14.32	26	12.98	46
1989	9.70	37	16.04	43
1990	9.35	22	15.72	66
1991	23.91	20	23.33	66
1992	36.33	26	63.64	24
1993	72.43	31	18.89	41
1994	34.71	20	15.41	22
1995	28.10	23	141.38	36
1996	64.92	36	42.32	31
1997	67.27	28	41.67	34
1998	51.69	29	23.20	10
1999	86.95	20	15.20	19
2000	33.34	25	23.21	26
2001	35.07	21	28.48	25
2002	42.09	33	87.69	43
2003	19.71	29	106.54	44
2004	48.00	43	45.75	22
2005	19.87	28	28.89	26
2006	27.72	37	31.66	52
2007	17.33	26	25.82	20
2008	19.18	37	25.66	33
2009	29.78	22	58.70	61
2010	88.70	23	27.31	20
2011	112.17	26	42.34	35

Table A2-3. NMFS spring survey age composition (annual proportions).



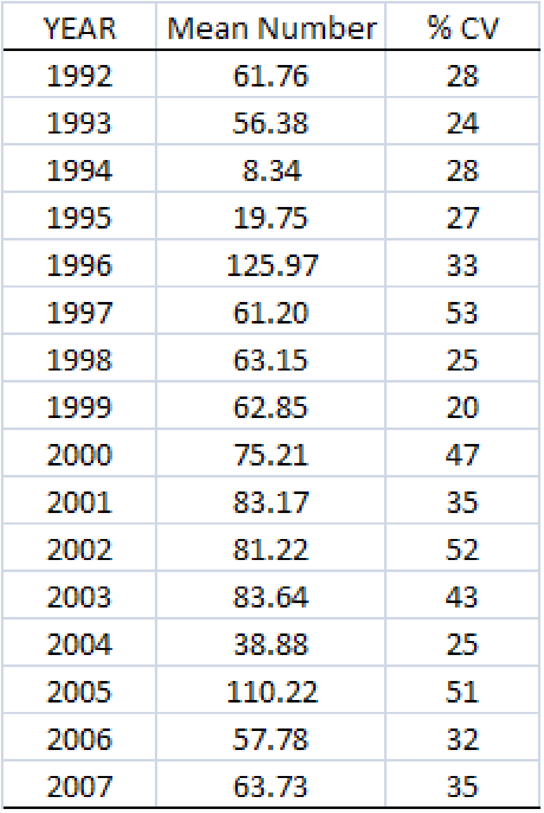
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14
1987	0.000	0.184	0.275	0.493	0.029	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.226	0.277	0.244	0.230	0.022	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.171	0.171	0.298	0.205	0.142	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.002	0.318	0.255	0.285	0.124	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.012	0.192	0.285	0.456	0.040	0.013	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.000	0.303	0.440	0.179	0.057	0.016	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.002	0.100	0.451	0.354	0.079	0.013	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.125	0.098	0.349	0.317	0.095	0.015	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.216	0.134	0.115	0.415	0.101	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.000	0.630	0.131	0.078	0.043	0.069	0.039	0.010	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.005	0.298	0.510	0.088	0.040	0.039	0.017	0.003	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.092	0.227	0.531	0.097	0.031	0.017	0.004	0.001	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.025	0.219	0.126	0.506	0.076	0.035	0.010	0.003	0.000	0.000	0.000	0.000	0.000
2000	0.002	0.453	0.121	0.134	0.136	0.124	0.022	0.004	0.002	0.001	0.000	0.000	0.000	0.000
2001	0.000	0.153	0.553	0.052	0.054	0.081	0.090	0.012	0.001	0.002	0.000	0.000	0.000	0.000
2002	0.352	0.139	0.059	0.319	0.049	0.042	0.025	0.012	0.002	0.001	0.000	0.000	0.000	0.000
2003	0.094	0.148	0.102	0.079	0.320	0.099	0.107	0.045	0.006	0.001	0.000	0.000	0.000	0.000
2004	0.003	0.649	0.234	0.024	0.014	0.036	0.020	0.011	0.007	0.002	0.001	0.000	0.000	0.000
2005	0.010	0.050	0.680	0.125	0.036	0.014	0.035	0.030	0.011	0.004	0.005	0.000	0.001	0.000
2006	0.020	0.040	0.186	0.300	0.293	0.055	0.030	0.057	0.009	0.008	0.001	0.001	0.000	0.000
2007	0.013	0.156	0.191	0.211	0.223	0.132	0.030	0.029	0.012	0.003	0.000	0.000	0.000	0.000
2008	0.131	0.003	0.214	0.277	0.083	0.122	0.103	0.047	0.015	0.006	0.000	0.000	0.000	0.000
2009	0.003	0.066	0.171	0.465	0.145	0.060	0.055	0.027	0.006	0.002	0.001	0.000	0.000	0.000
2010	0.000	0.750	0.177	0.025	0.035	0.006	0.004	0.003	0.001	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.072	0.753	0.138	0.015	0.017	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000

Table A2-4. NMFS fall survey age composition (annual proportions).



	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
1987	0.004	0.212	0.401	0.315	0.041	0.023	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000
1988	0.036	0.087	0.309	0.393	0.153	0.016	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.005	0.098	0.303	0.281	0.141	0.148	0.017	0.006	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.186	0.638	0.136	0.030	0.006	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.130	0.557	0.262	0.041	0.008	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.002	0.040	0.449	0.293	0.177	0.032	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.021	0.107	0.404	0.362	0.088	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.004	0.053	0.075	0.300	0.265	0.216	0.065	0.017	0.005	0.000	0.000	0.000	0.000	0.000
1995	0.445	0.005	0.062	0.070	0.188	0.167	0.057	0.006	0.001	0.000	0.000	0.000	0.000	0.000
1996	0.003	0.287	0.178	0.179	0.075	0.167	0.085	0.021	0.002	0.001	0.001	0.000	0.000	0.000
1997	0.006	0.049	0.469	0.126	0.112	0.116	0.097	0.018	0.008	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.077	0.138	0.405	0.137	0.102	0.098	0.029	0.012	0.002	0.000	0.000	0.000	0.000
1999	0.003	0.019	0.204	0.231	0.363	0.096	0.054	0.024	0.005	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.054	0.050	0.183	0.268	0.300	0.108	0.036	0.001	0.000	0.000	0.000	0.000	0.000
2001	0.002	0.022	0.430	0.068	0.115	0.180	0.137	0.040	0.006	0.000	0.000	0.000	0.000	0.000
2002	0.010	0.031	0.079	0.480	0.126	0.128	0.097	0.043	0.005	0.001	0.000	0.000	0.000	0.000
2003	0.638	0.035	0.040	0.041	0.133	0.057	0.030	0.020	0.005	0.000	0.000	0.000	0.000	0.000
2004	0.001	0.238	0.300	0.076	0.054	0.104	0.114	0.061	0.037	0.011	0.002	0.002	0.000	0.000
2005	0.003	0.053	0.312	0.231	0.123	0.102	0.084	0.060	0.021	0.009	0.002	0.000	0.000	0.000
2006	0.001	0.027	0.393	0.310	0.150	0.062	0.034	0.017	0.004	0.001	0.000	0.000	0.000	0.000
2007	0.002	0.223	0.149	0.201	0.238	0.140	0.037	0.008	0.003	0.000	0.000	0.000	0.000	0.000
2008	0.001	0.008	0.418	0.217	0.103	0.129	0.095	0.024	0.006	0.000	0.000	0.000	0.000	0.000
2009	0.018	0.445	0.329	0.142	0.013	0.026	0.021	0.005	0.001	0.000	0.000	0.000	0.000	0.000
2010	0.015	0.399	0.337	0.071	0.125	0.024	0.024	0.004	0.000	0.000	0.000	0.000	0.000	0.000

Table A2-5. NMFS winter survey time series with coefficients of variation.

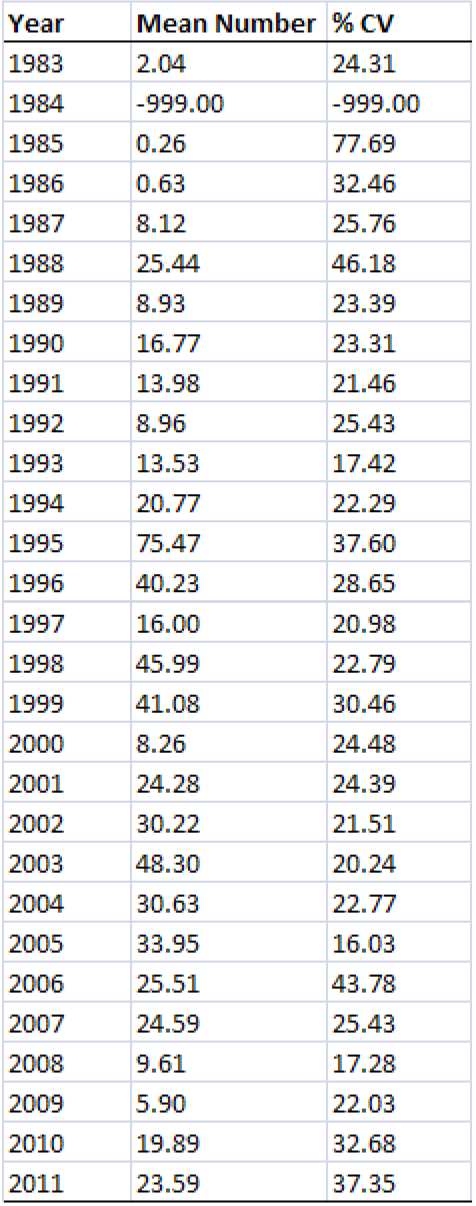


YEAR	Mean Number	% CV
1992	61.76	28
1993	56.38	24
1994	8.34	28
1995	19.75	27
1996	125.97	33
1997	61.20	53
1998	63.15	25
1999	62.85	20
2000	75.21	47
2001	83.17	35
2002	81.22	52
2003	83.64	43
2004	38.88	25
2005	110.22	51
2006	57.78	32
2007	63.73	35

Table A2-6. NMFS winter survey age composition (annual proportions).

	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
1992	0.000	0.234	0.373	0.218	0.120	0.039	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.006	0.325	0.342	0.197	0.116	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.018	0.119	0.266	0.280	0.230	0.055	0.026	0.005	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.004	0.048	0.056	0.278	0.346	0.214	0.049	0.001	0.004	0.000	0.000	0.000	0.000
1996	0.001	0.664	0.059	0.032	0.037	0.127	0.061	0.012	0.006	0.001	0.000	0.000	0.000	0.000
1997	0.000	0.016	0.140	0.025	0.116	0.280	0.282	0.128	0.011	0.001	0.000	0.000	0.000	0.000
1998	0.001	0.016	0.214	0.543	0.129	0.058	0.033	0.005	0.001	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.094	0.221	0.428	0.135	0.084	0.026	0.005	0.006	0.000	0.000	0.000	0.000
2000	0.000	0.724	0.043	0.083	0.077	0.063	0.007	0.002	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.000	0.074	0.497	0.053	0.153	0.123	0.078	0.019	0.002	0.000	0.000	0.000	0.000	0.000
2002	0.001	0.014	0.029	0.565	0.119	0.123	0.120	0.022	0.007	0.000	0.000	0.000	0.000	0.000
2003	0.001	0.195	0.102	0.069	0.344	0.103	0.112	0.064	0.007	0.002	0.001	0.000	0.000	0.000
2004	0.001	0.382	0.460	0.057	0.017	0.039	0.022	0.004	0.011	0.007	0.001	0.000	0.000	0.000
2005	0.001	0.015	0.482	0.253	0.096	0.046	0.048	0.032	0.016	0.006	0.003	0.000	0.000	0.000
2006	0.000	0.007	0.322	0.375	0.175	0.048	0.045	0.022	0.004	0.003	0.001	0.000	0.000	0.000
2007	0.000	0.008	0.105	0.294	0.404	0.140	0.024	0.018	0.006	0.000	0.000	0.000	0.000	0.000

Table A2-7. NMFS summer shrimp survey time series with coefficients of variation.



Year	Mean Number	% CV
1983	2.04	24.31
1984	-999.00	-999.00
1985	0.26	77.69
1986	0.63	32.46
1987	8.12	25.76
1988	25.44	46.18
1989	8.93	23.39
1990	16.77	23.31
1991	13.98	21.46
1992	8.96	25.43
1993	13.53	17.42
1994	20.77	22.29
1995	75.47	37.60
1996	40.23	28.65
1997	16.00	20.98
1998	45.99	22.79
1999	41.08	30.46
2000	8.26	24.48
2001	24.28	24.39
2002	30.22	21.51
2003	48.30	20.24
2004	30.63	22.77
2005	33.95	16.03
2006	25.51	43.78
2007	24.59	25.43
2008	9.61	17.28
2009	5.90	22.03
2010	19.89	32.68
2011	23.59	37.35

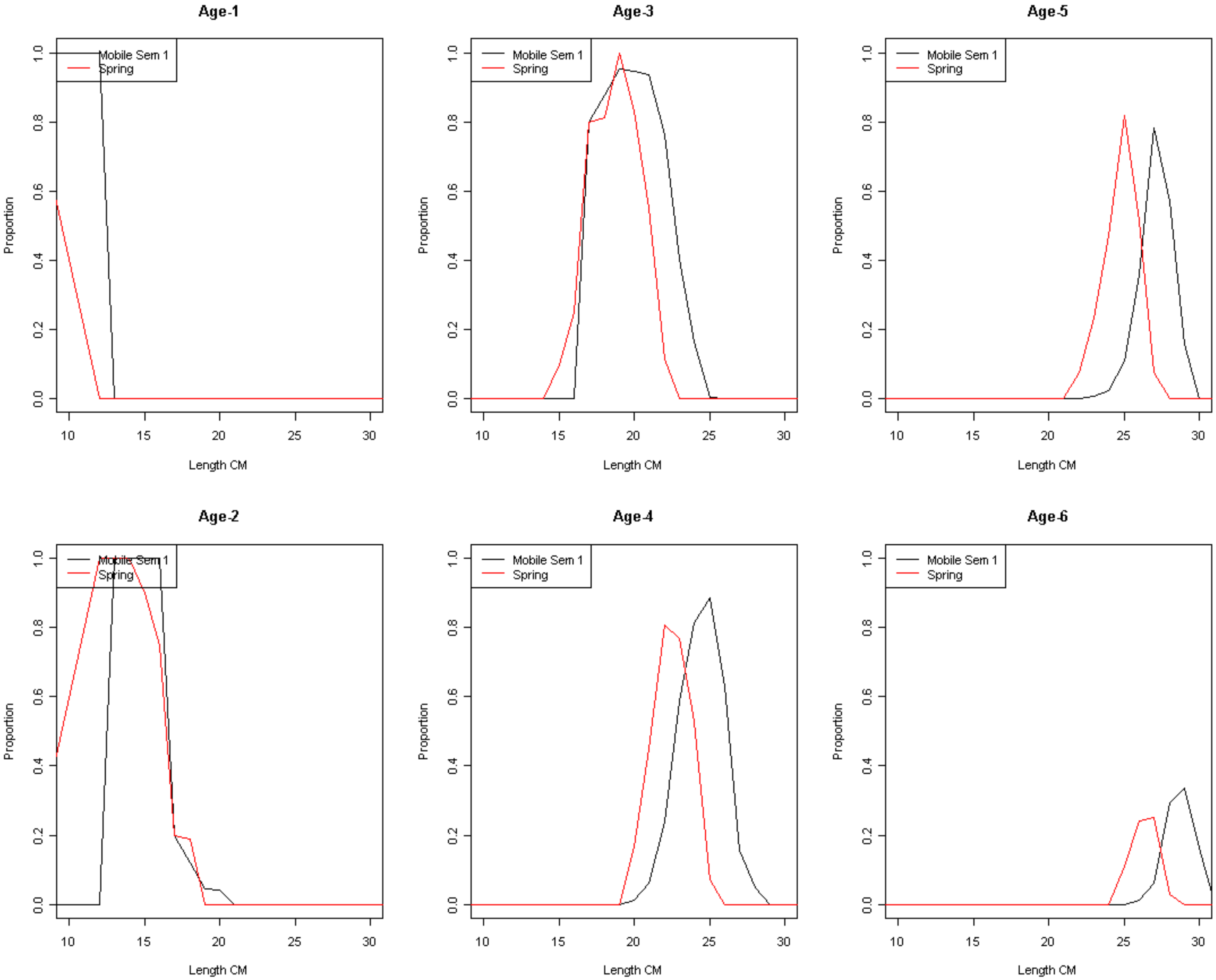


Figure A2-1. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2006.

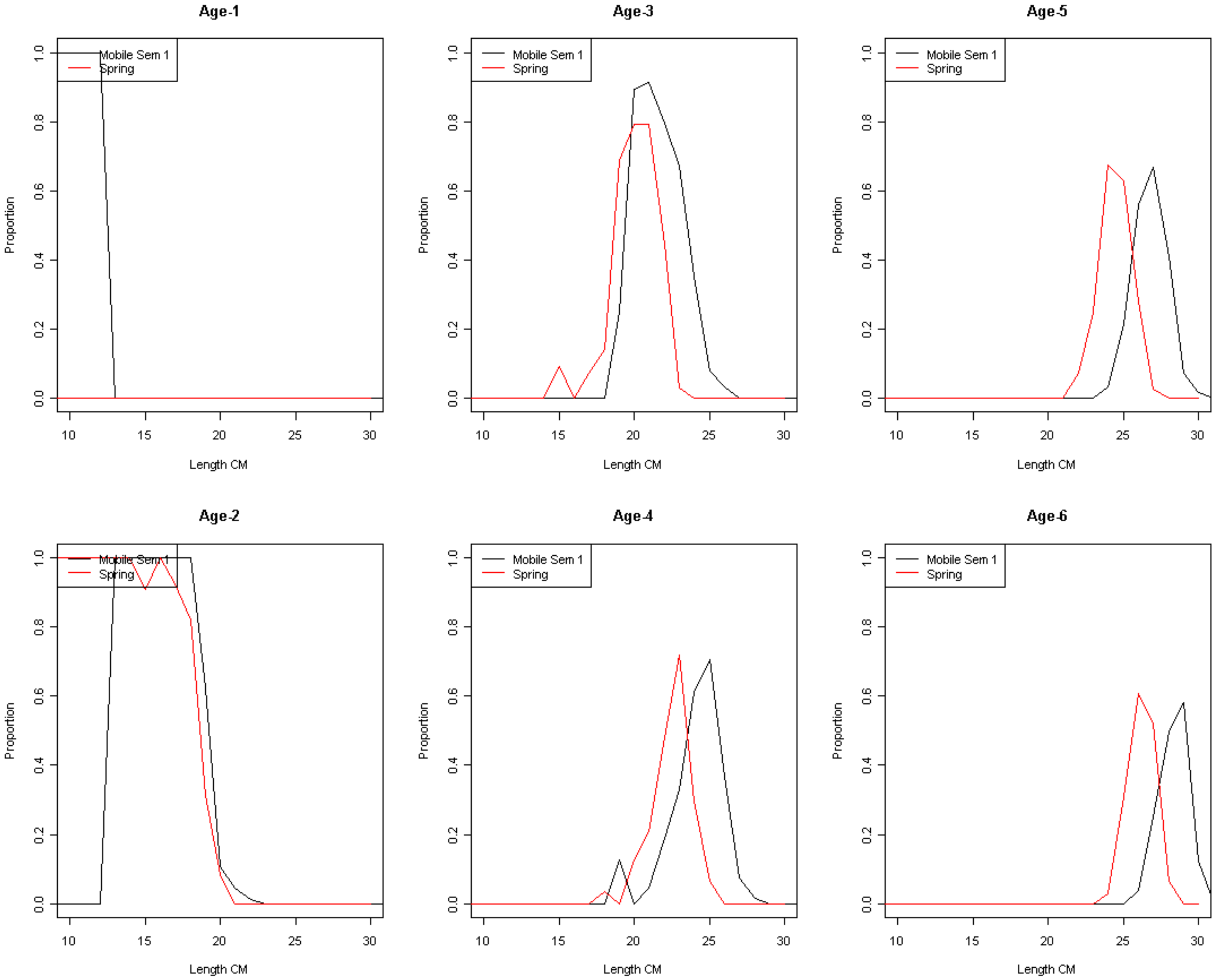


Figure A2-2. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2007.

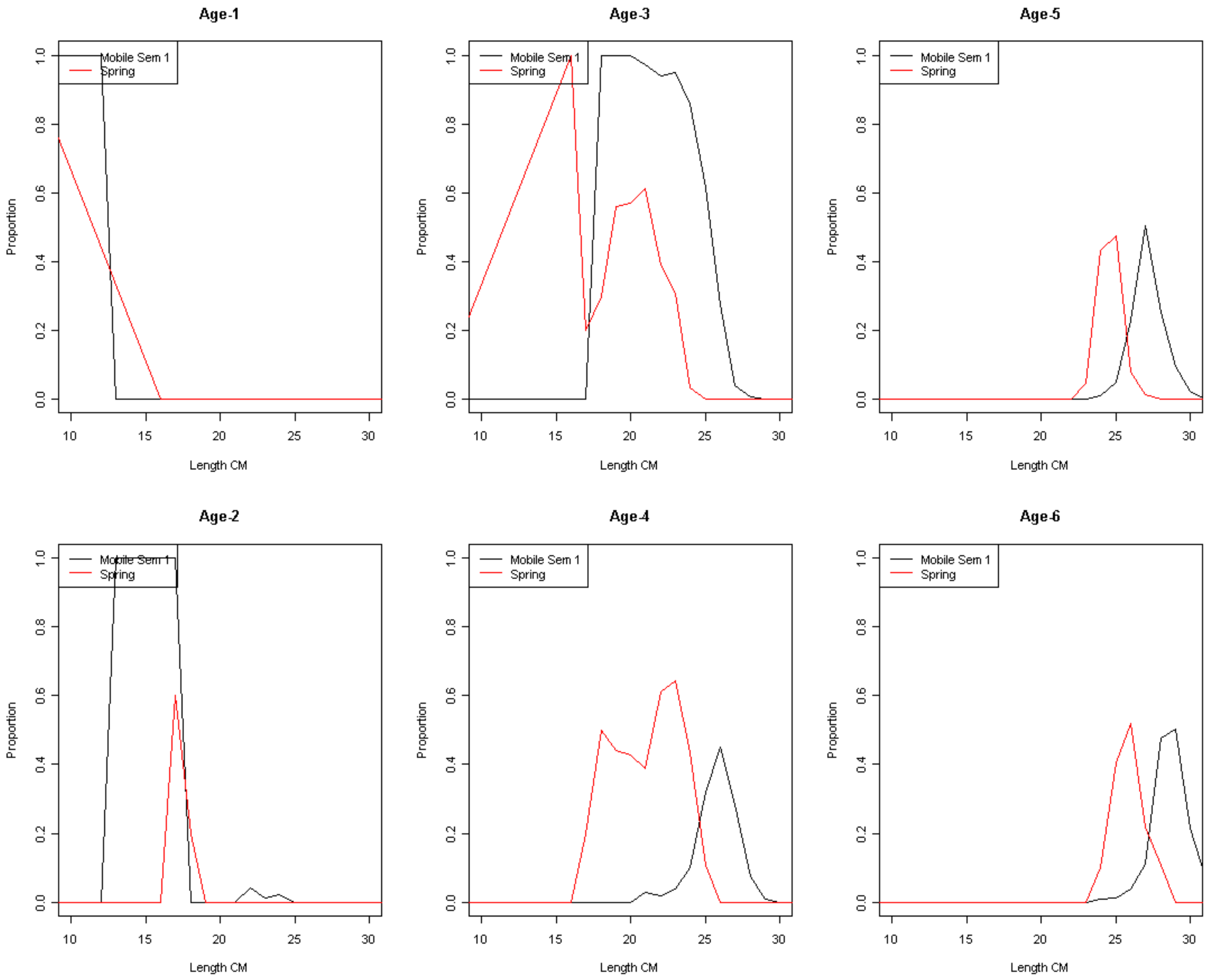


Figure A2-3. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2008.

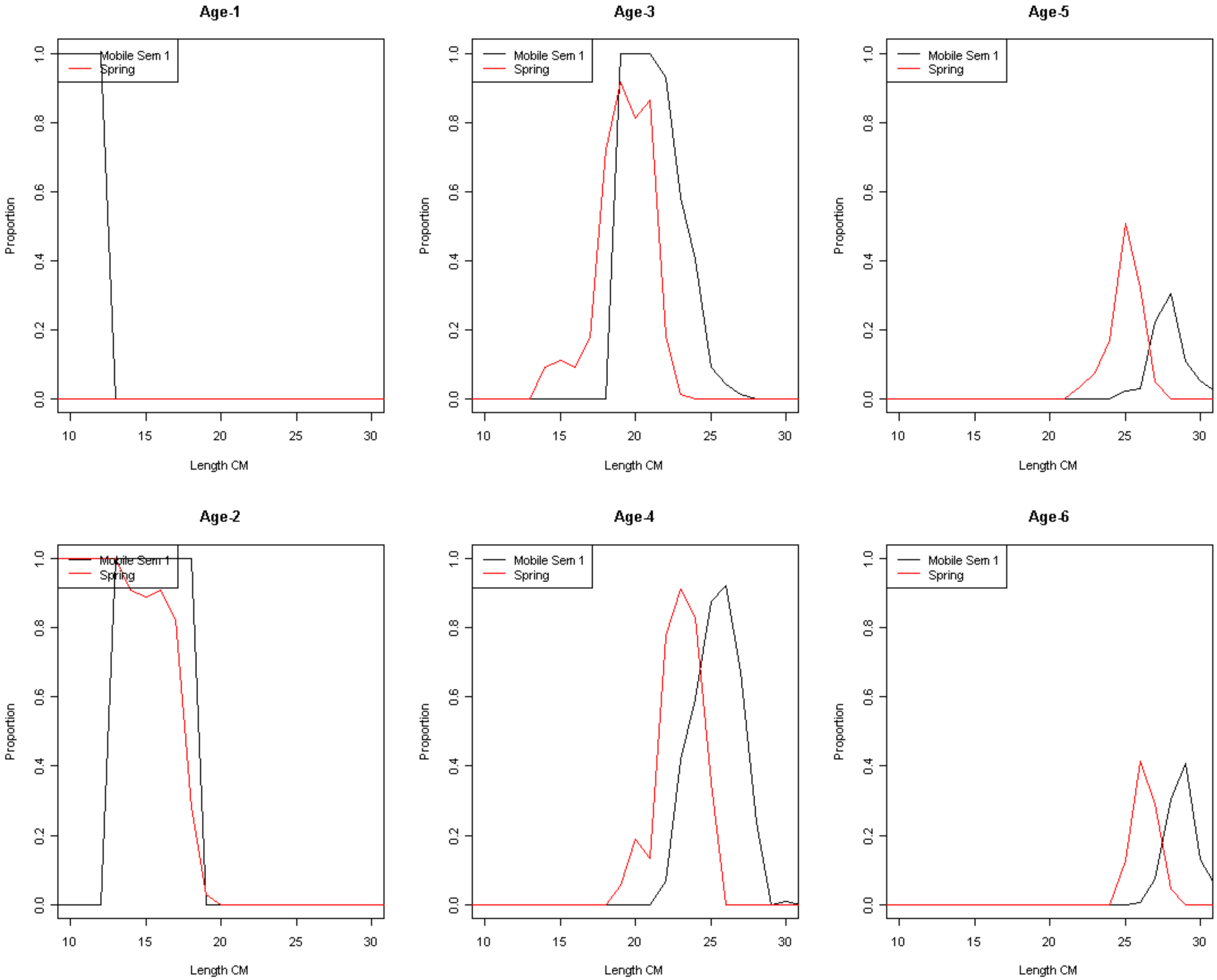


Figure A2-4. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2009.

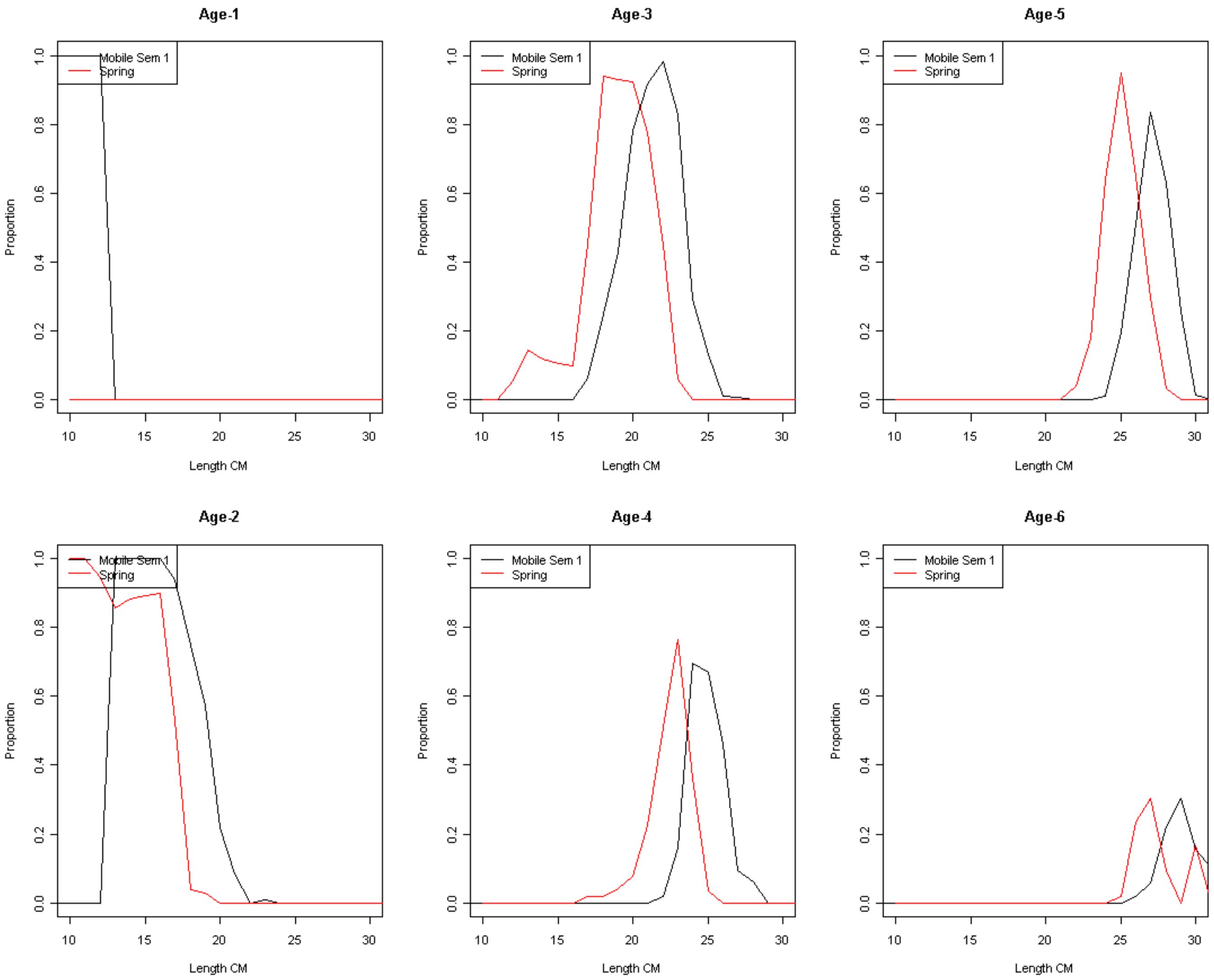


Figure A2-5. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2010.

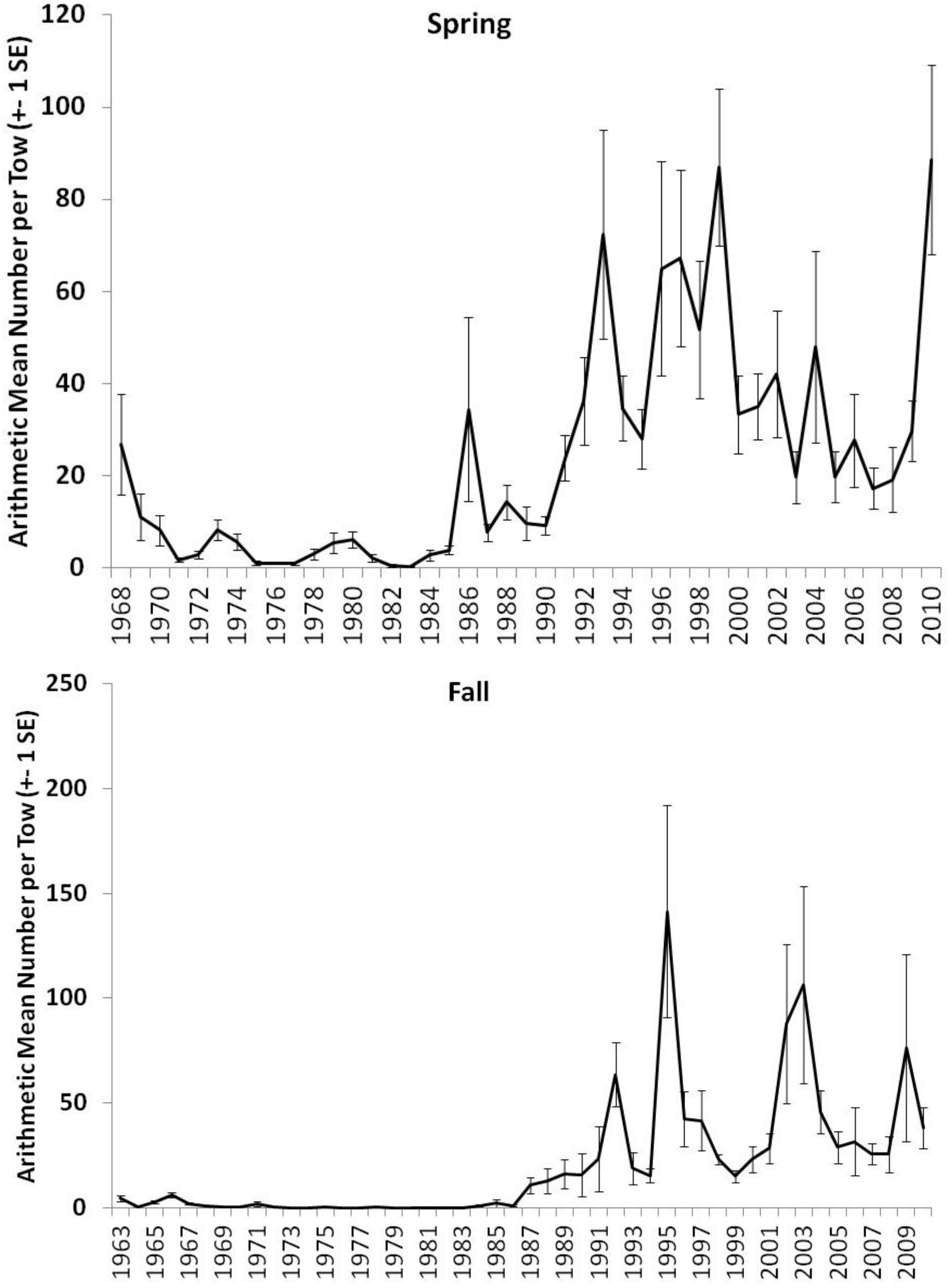


Figure A2-6. NMFS spring and fall bottom trawl survey time series, + one standard error.

NEFSC Spring Survey

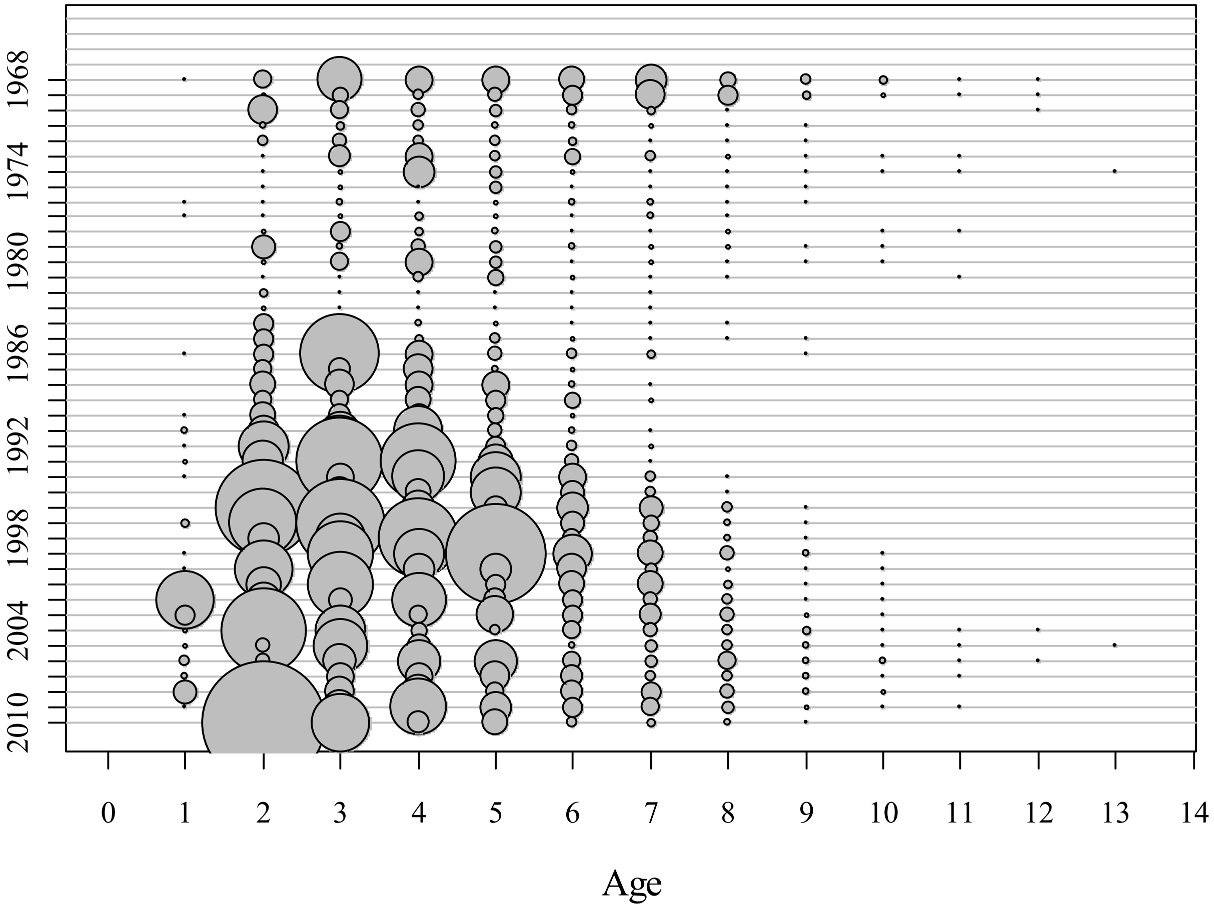


Figure A2-7. “Bubble” plot of NMFS spring survey age composition. Age data prior to 1987 was not used in the assessments (see TOR 2).

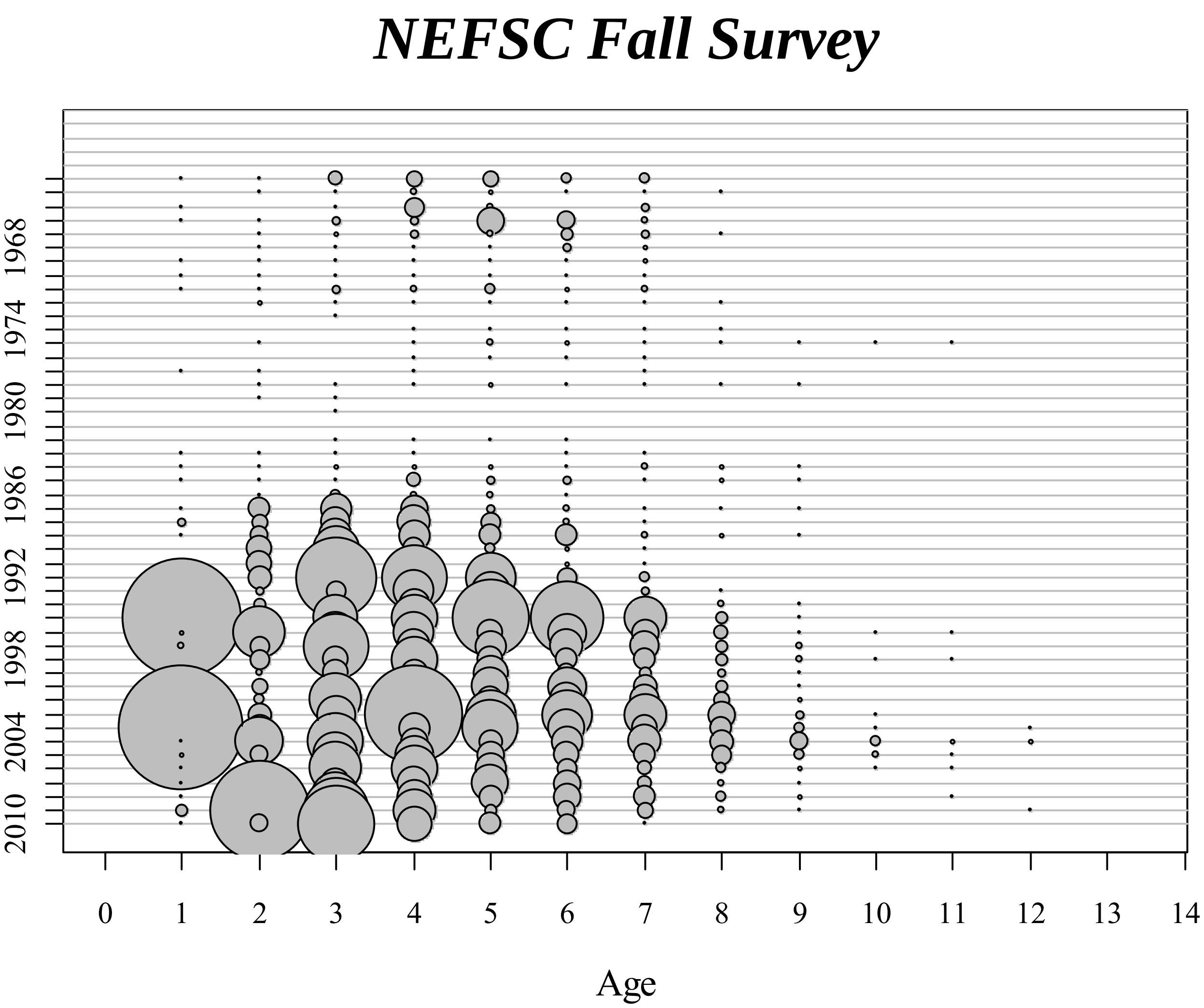


Figure A2-8. “Bubble” plot of NMFS fall survey age composition. Age data prior to 1987 was not used in the assessments (see TOR 2).

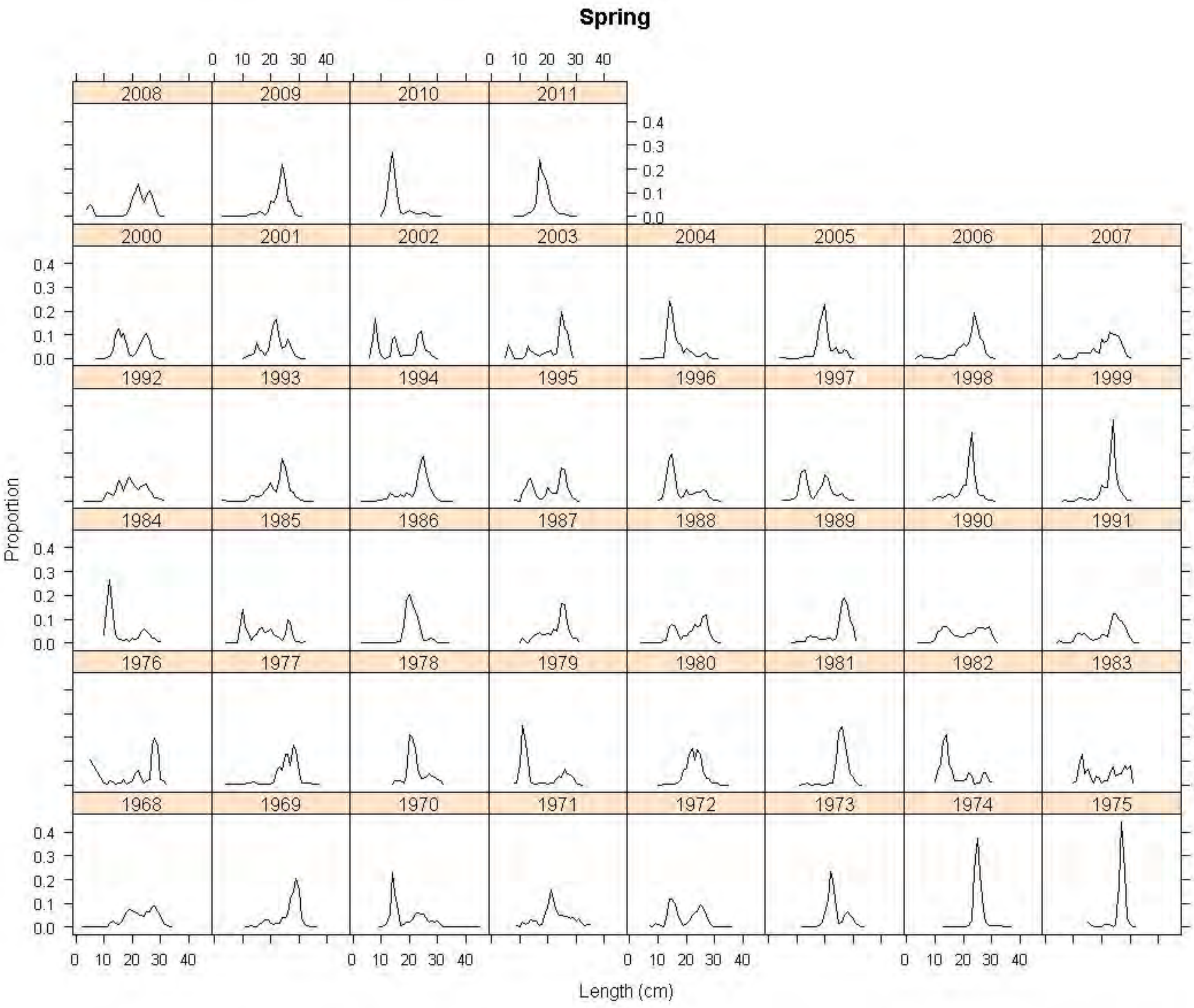


Figure A2-9. Annual length frequencies from the NMFS spring survey.

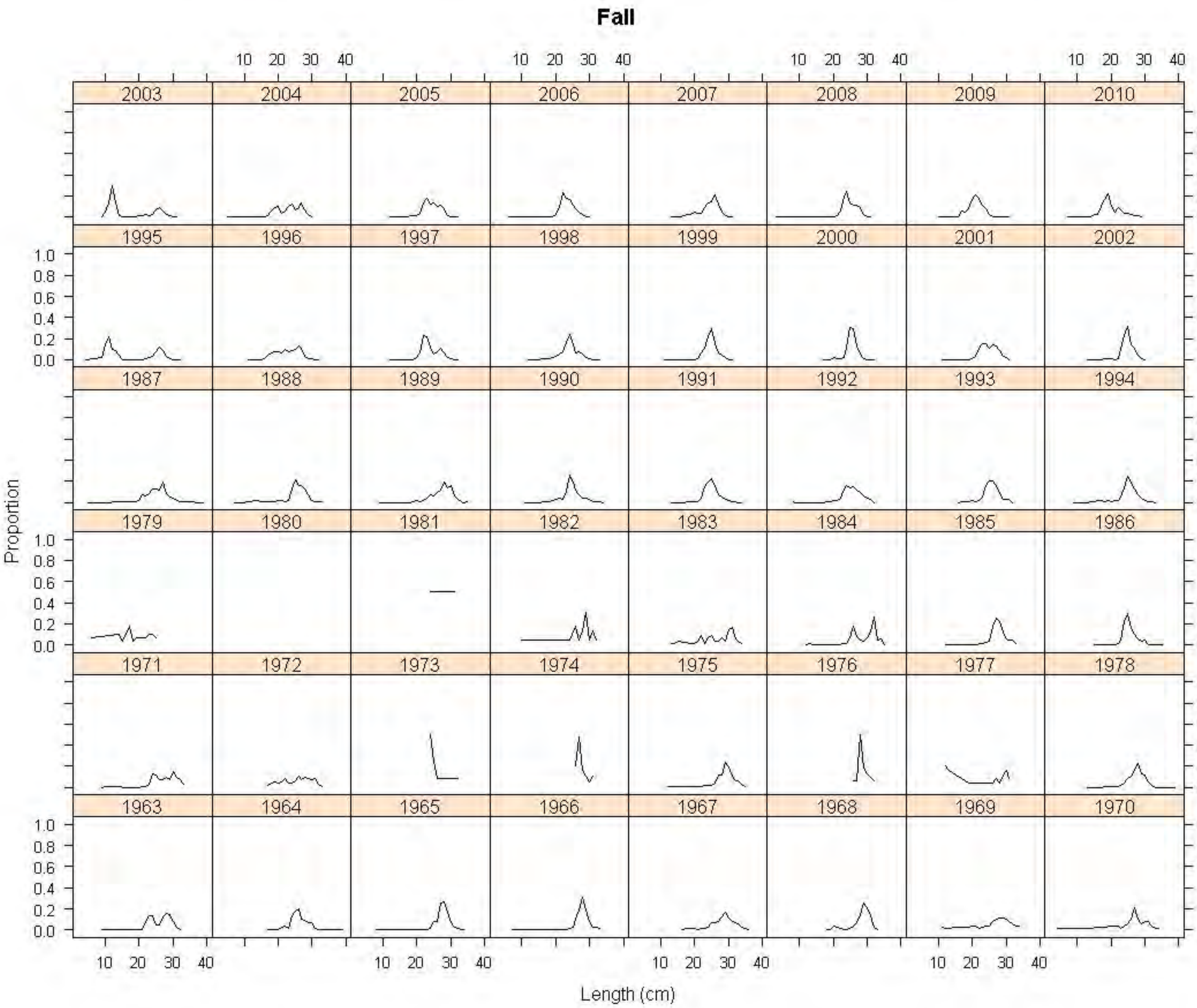


Figure A2-10. Annual length frequencies from the NMFS fall survey.

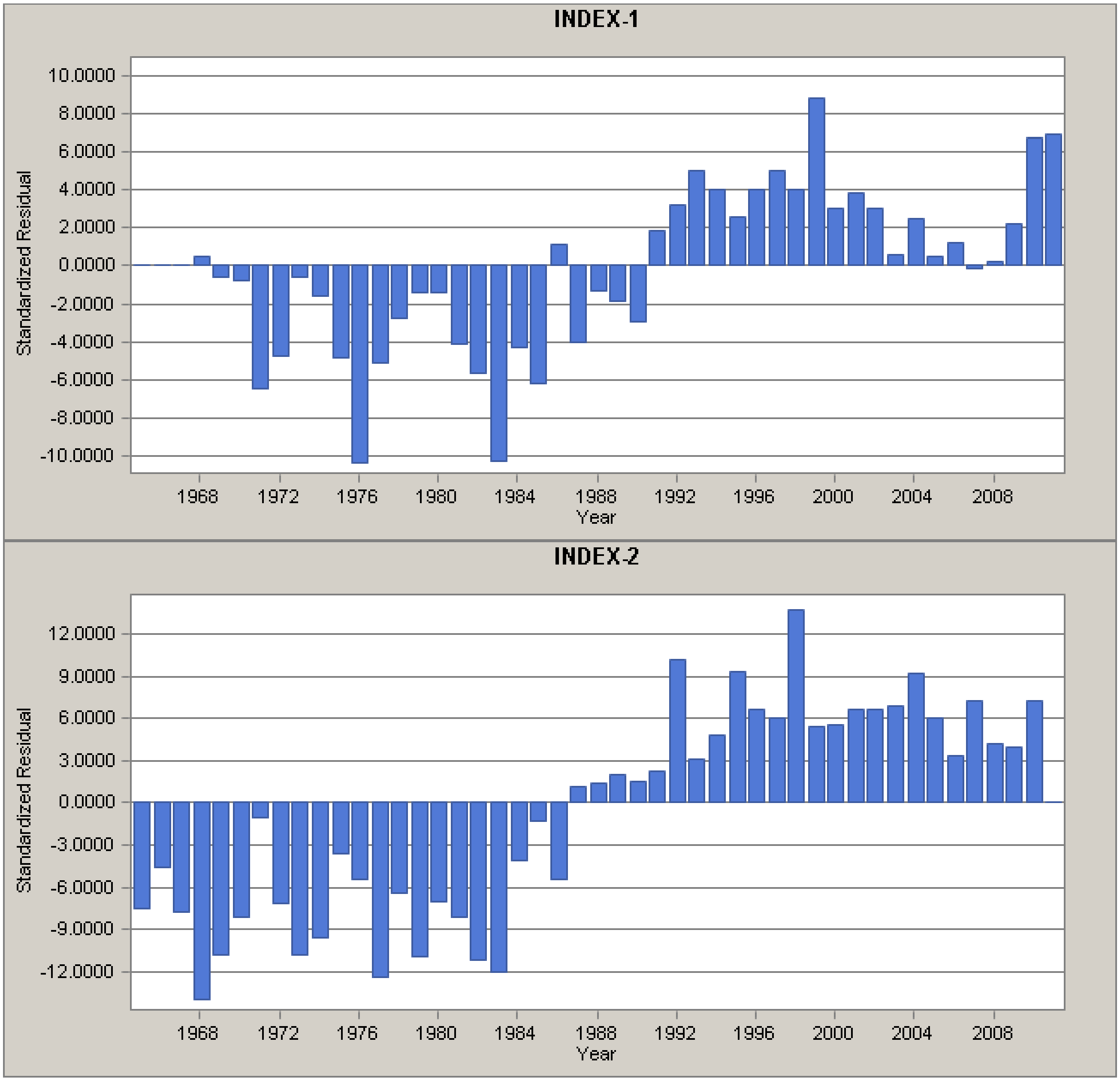


Figure A2-11. Standardized residuals of the fit to the NMFS spring survey (top panel) and fall survey (bottom panel) from a preliminary ASAP model run.

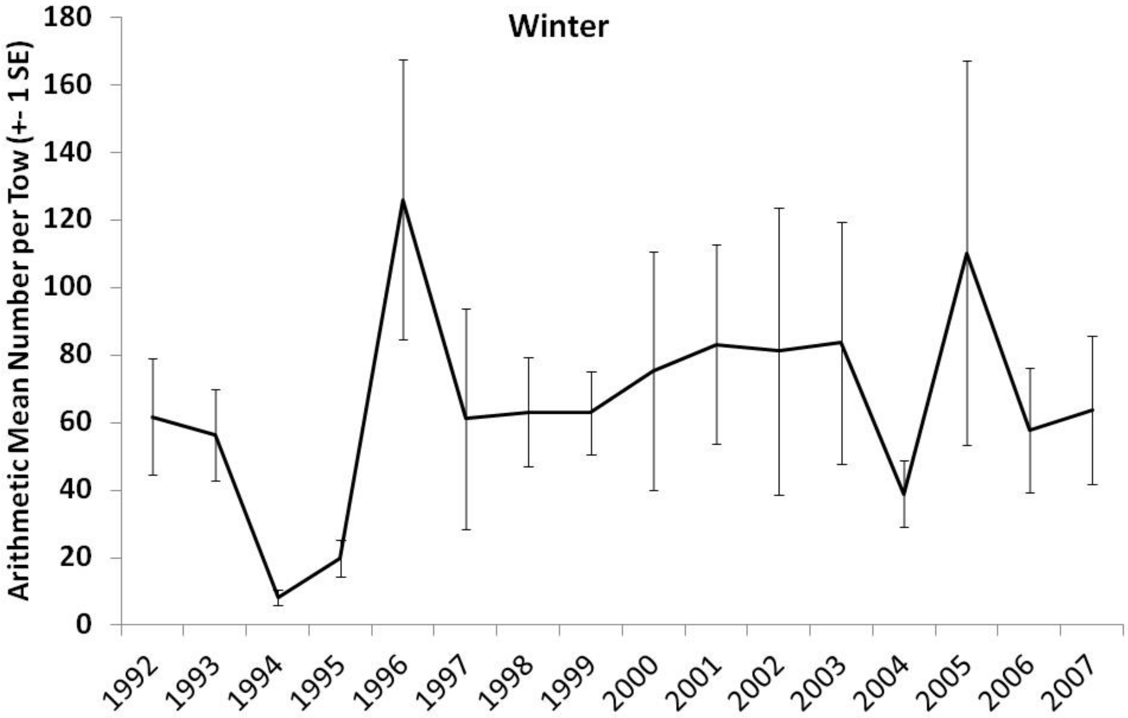


Figure A2-12. NMFS winter bottom trawl survey time series, ± one standard error.

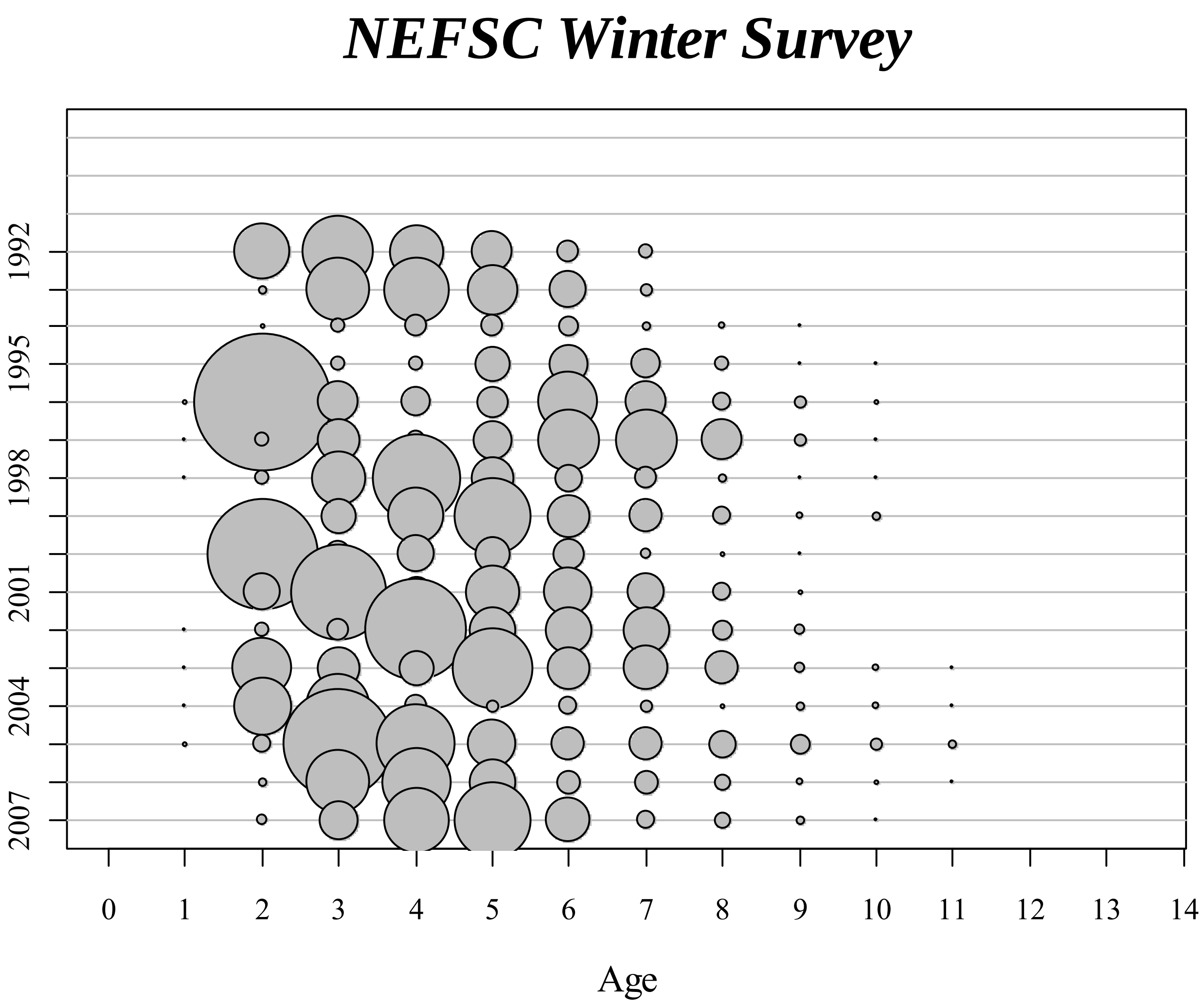


Figure A2-13. "Bubble" plot of NMFS winter survey age composition.

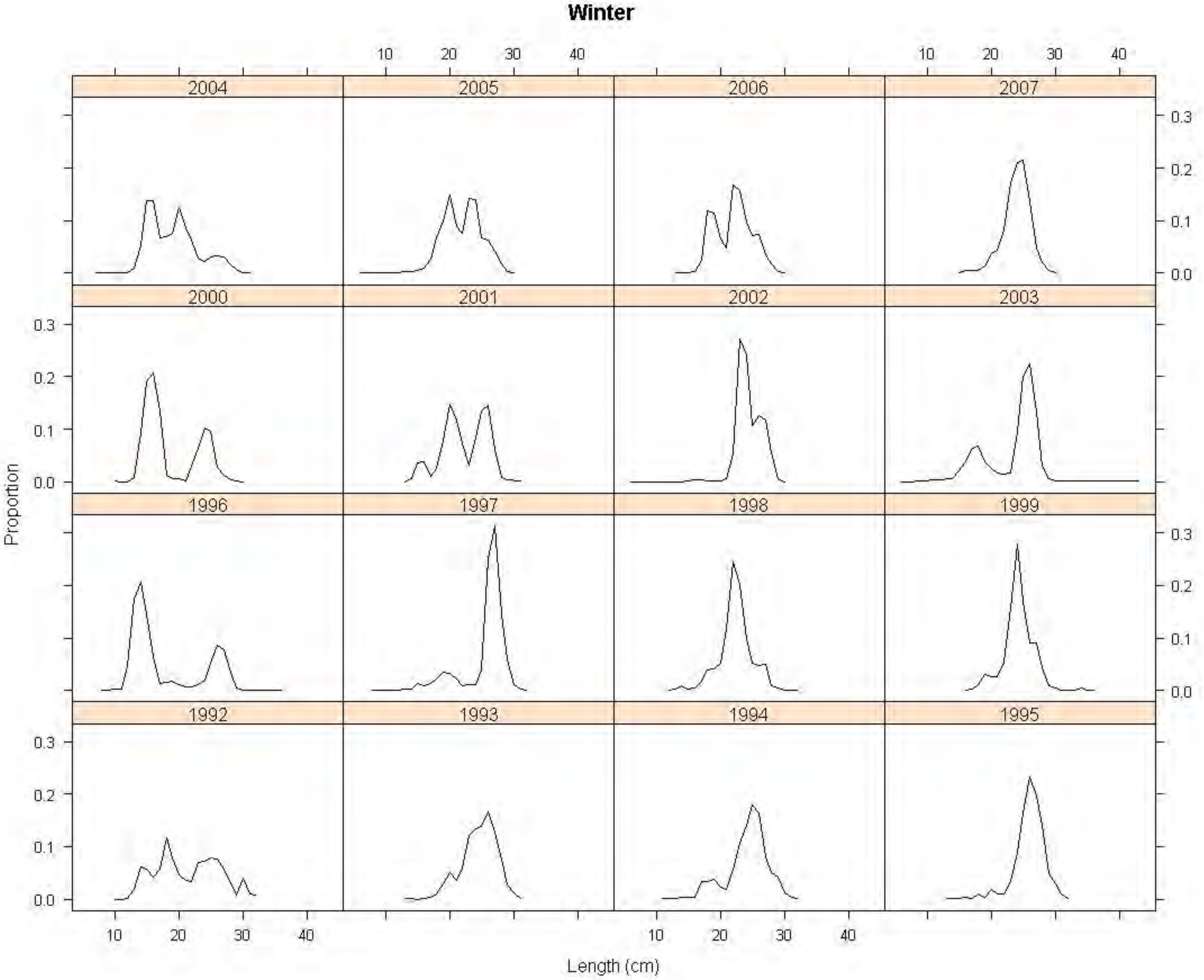


Figure A2-14. Annual length frequencies from the NMFS winter survey.

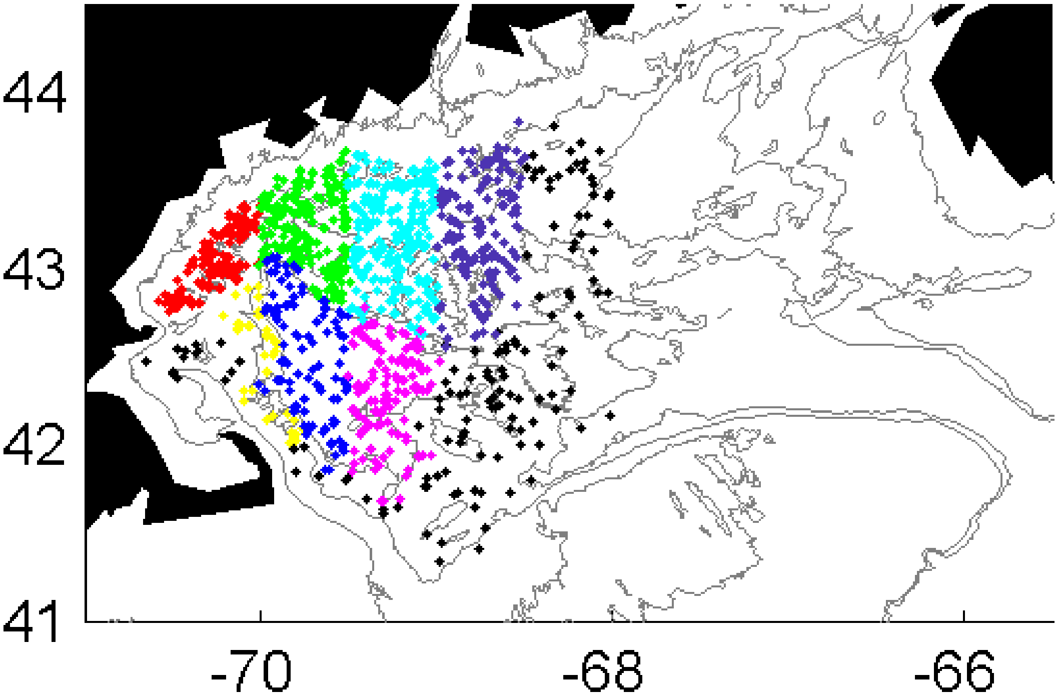


Figure A2-15. Location of tows taken during the NMFS shrimp survey that captured herring during 1983-2011. Different colors represent different survey strata.

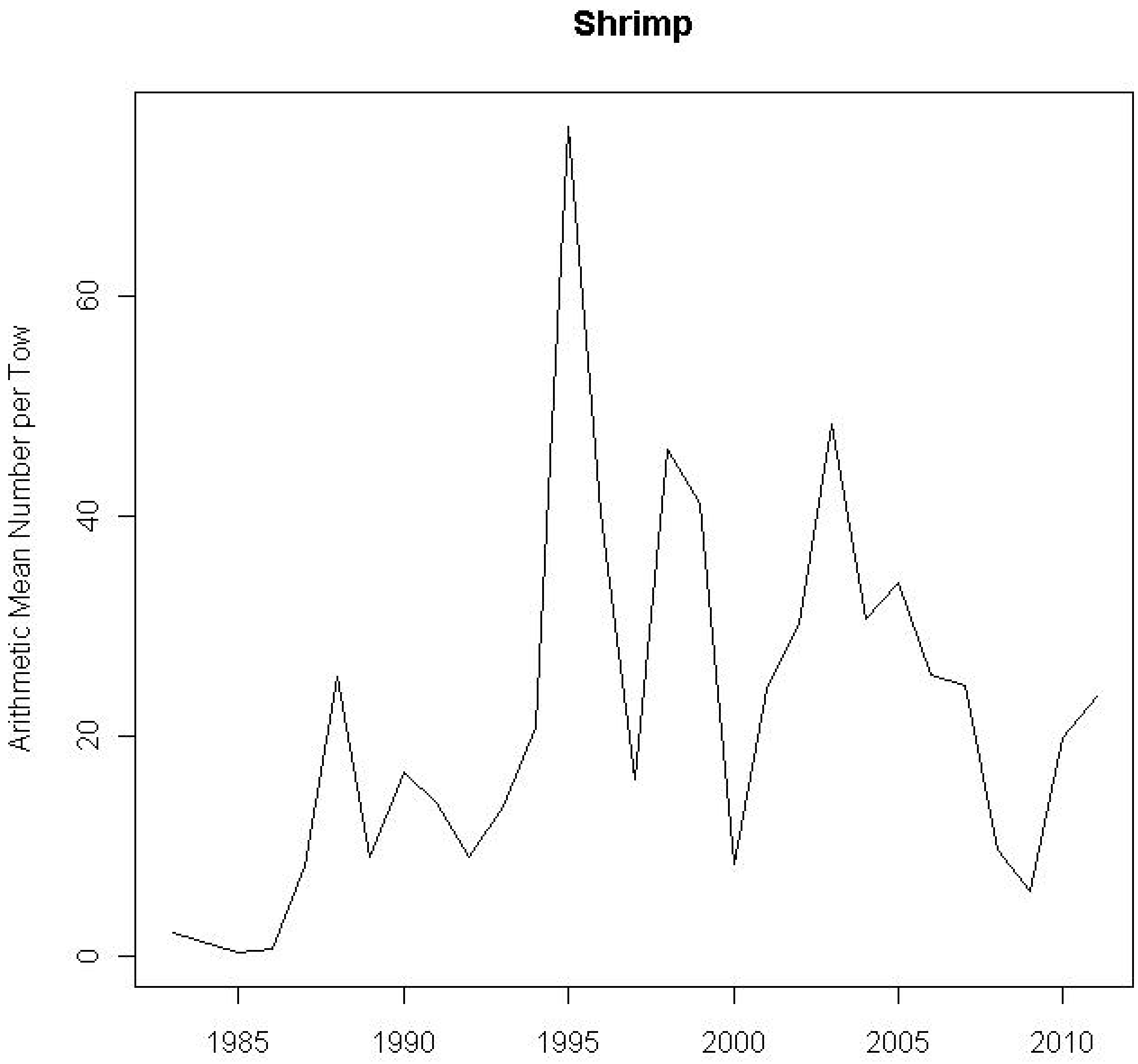


Figure A2-16. NMFS summer shrimp bottom trawl survey time series.

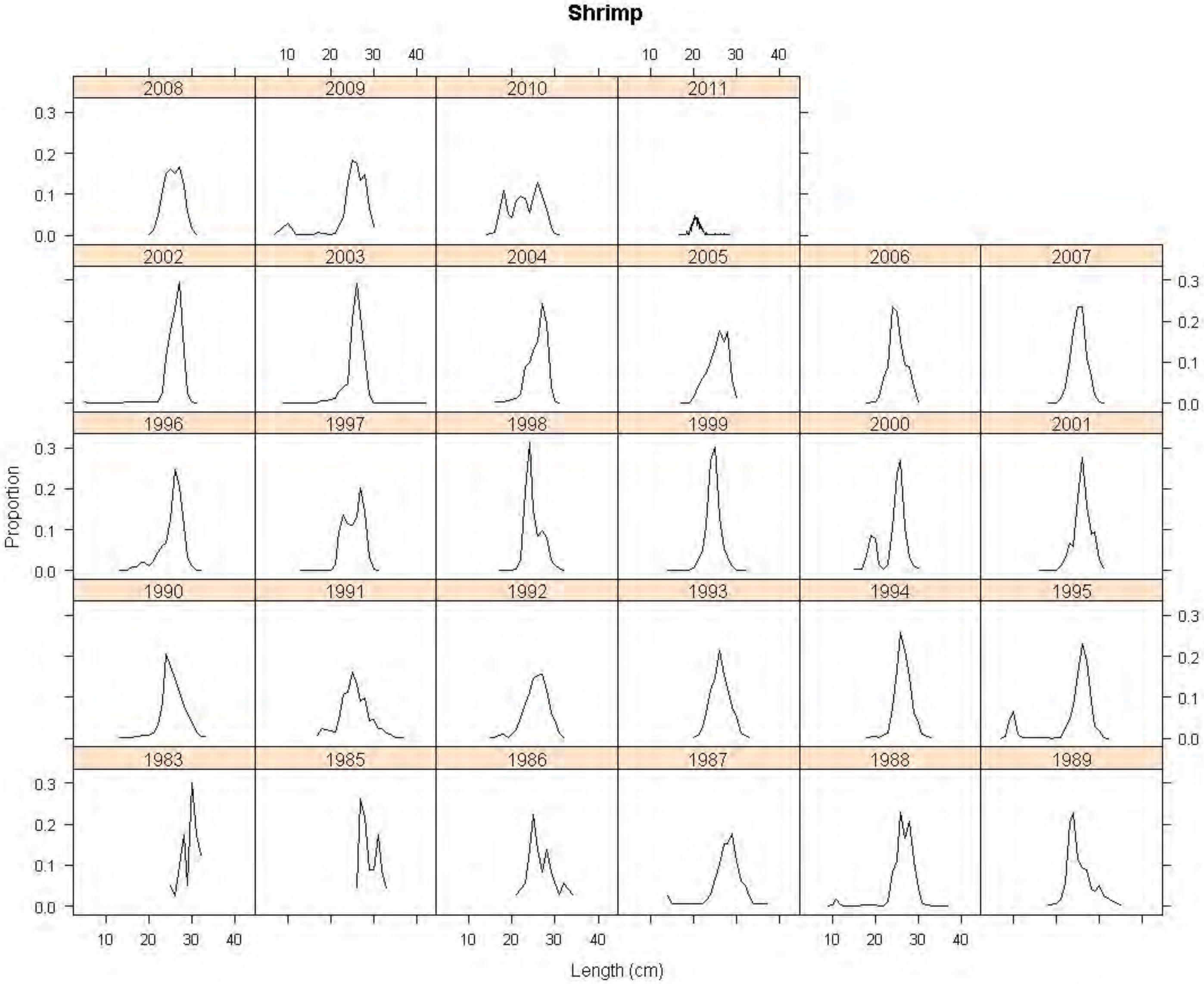


Figure A2-17. Annual length frequencies from the NMFS summer shrimp survey.

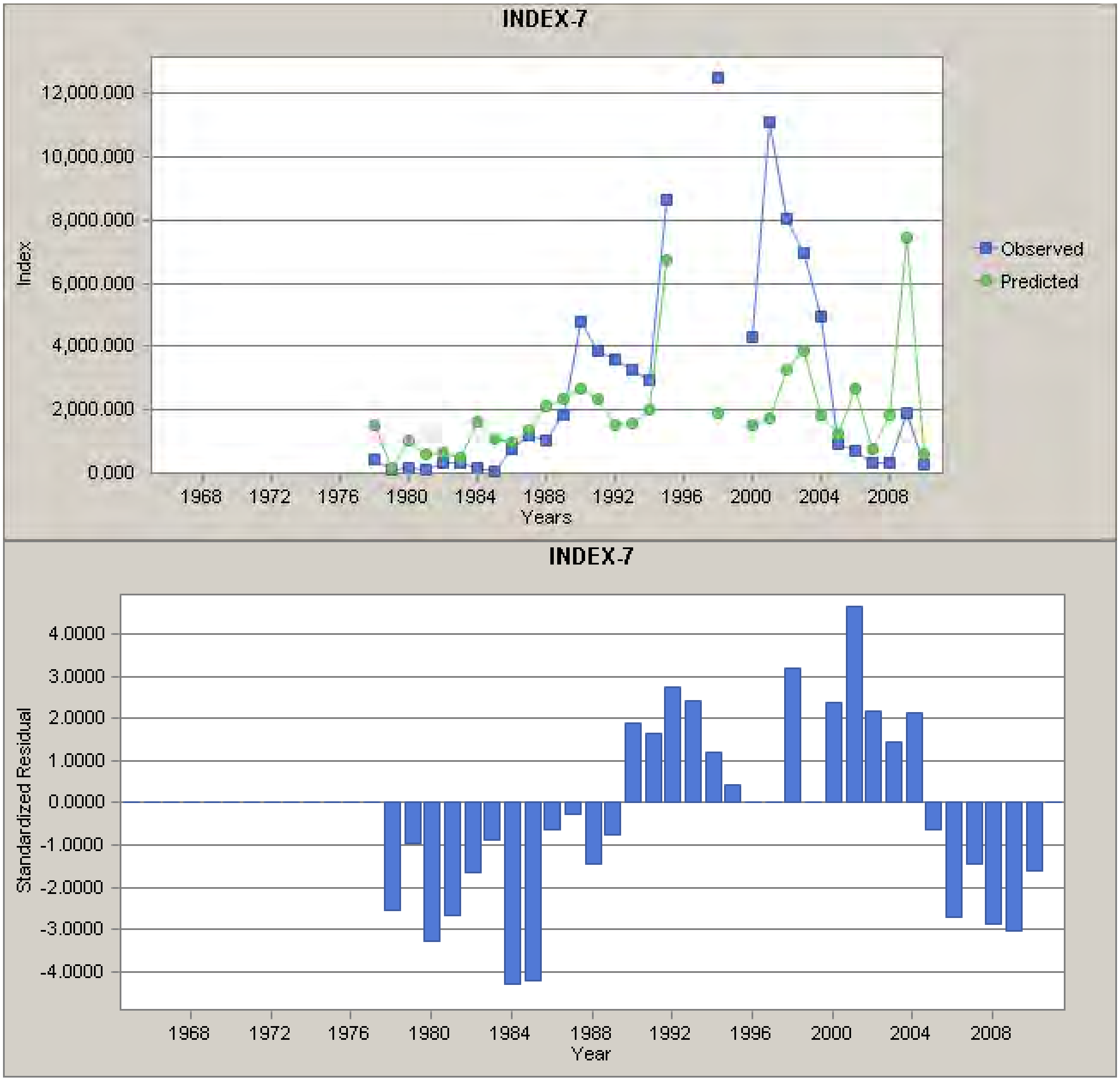


Figure A2-18. Time series (top panel) and standardized residuals (bottom panel) of the fit to the larval index from a preliminary ASAP model run.

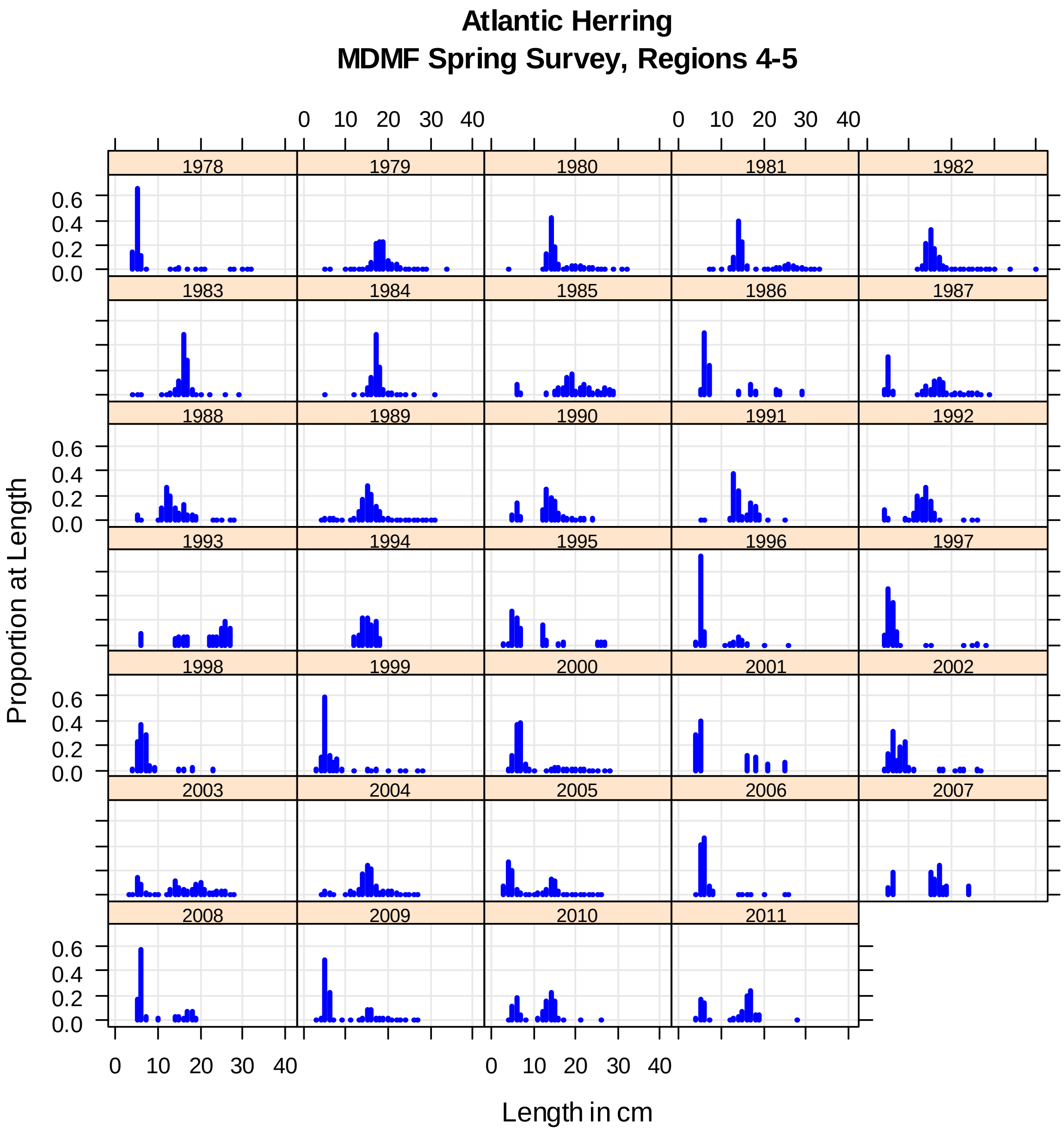


Figure A2-19. Proportion of mean number per tow at length for MA DMF spring survey.

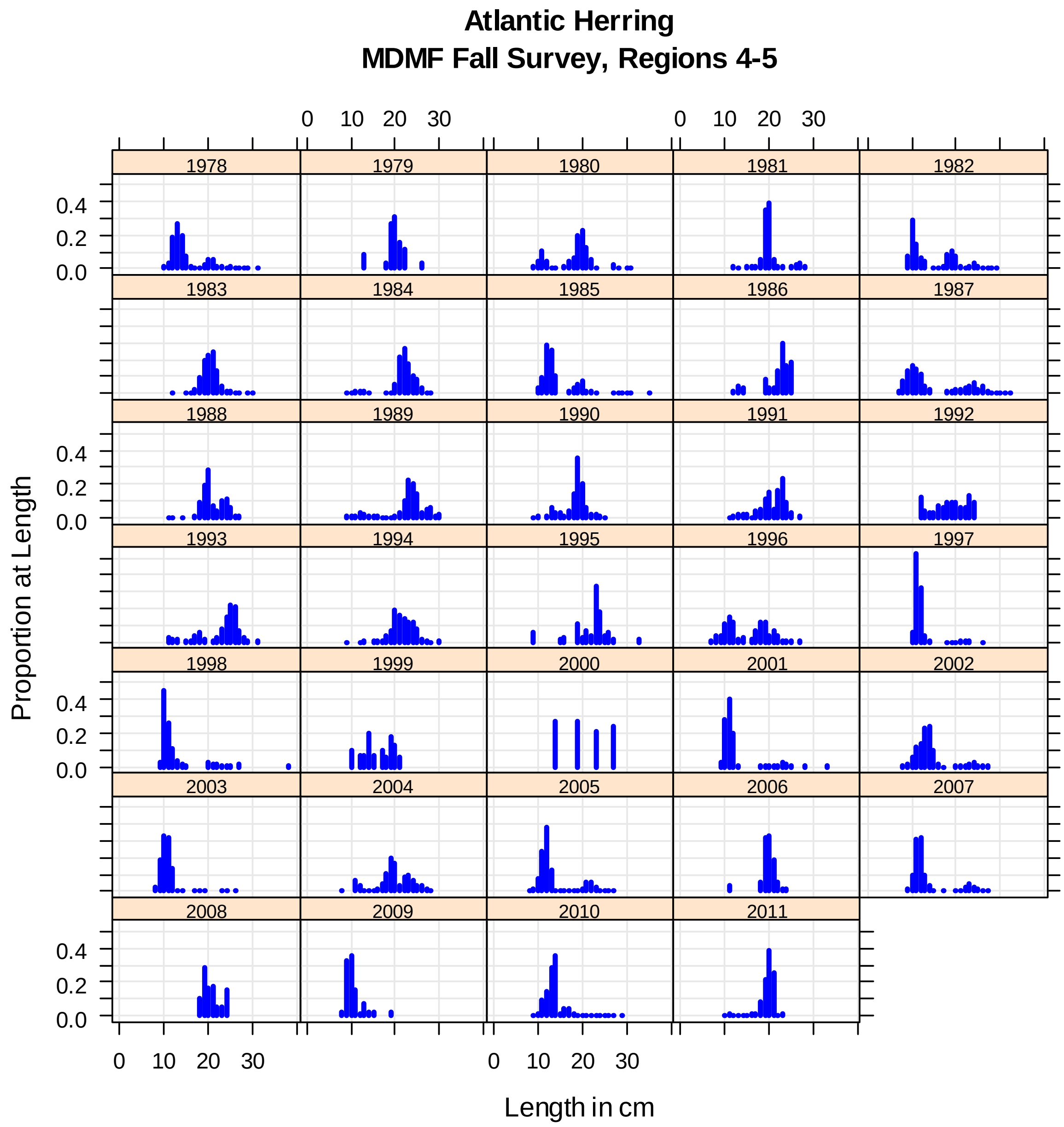


Figure A2-20. Proportion of mean number per tow at length for MA DMF fall survey.

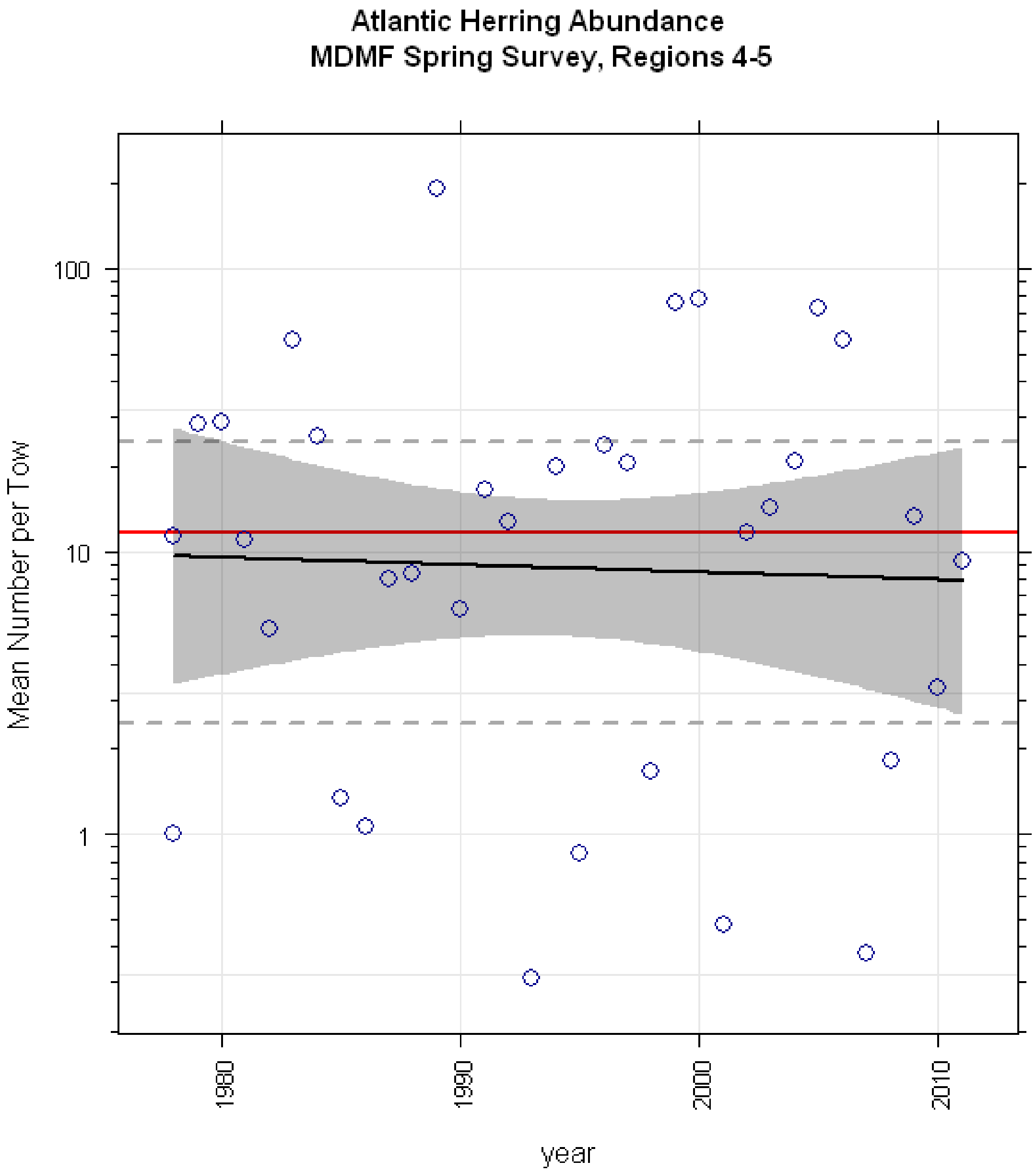


Figure A2-21. MA DMF spring survey abundance. Solid black line is a GAM fit. Solid red line is the time series median and dashed gray lines delimit inter-quartile range.

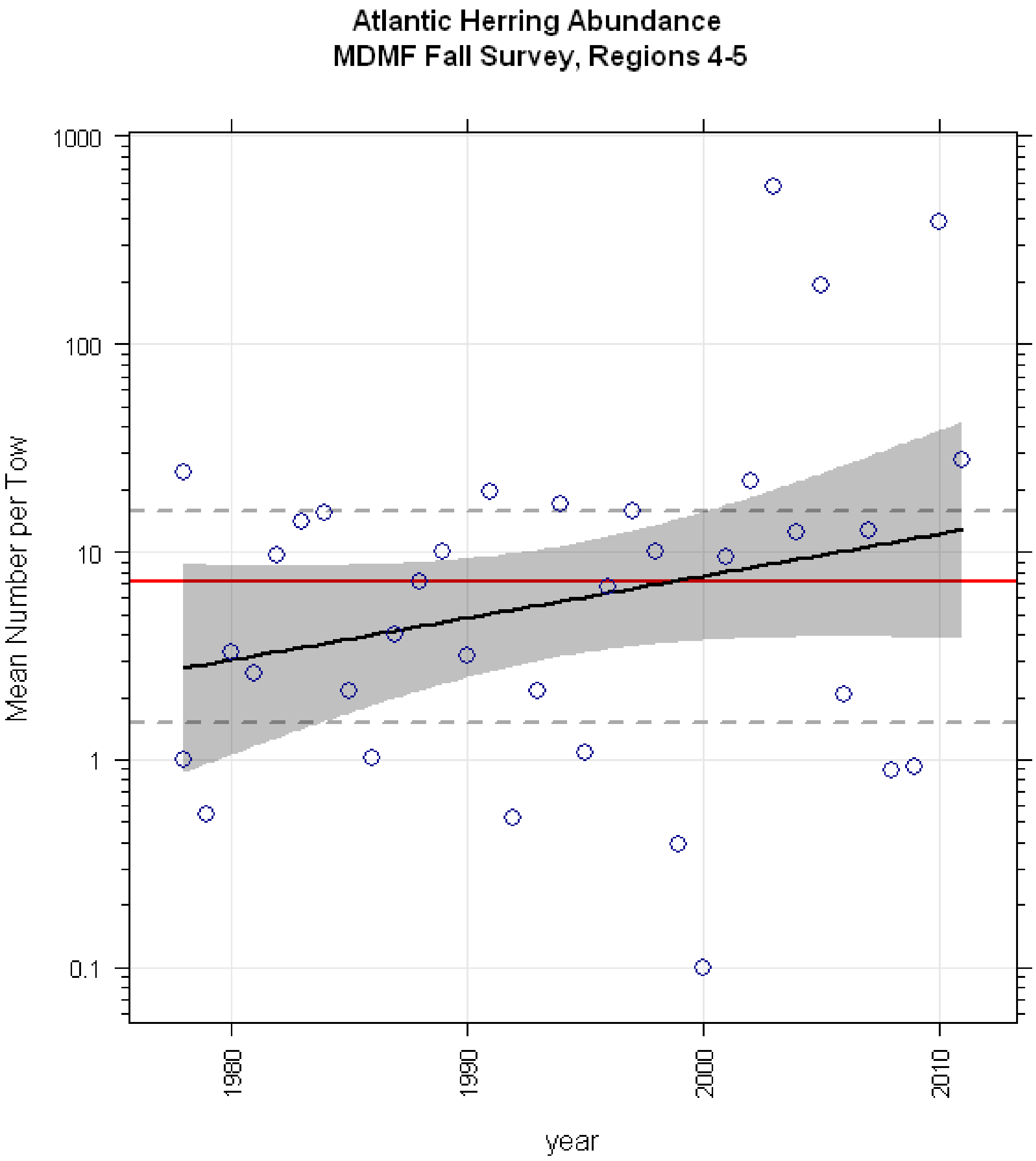


Figure A2-22. MA DMF fall survey abundance. Solid black line is a GAM fit. Solid red line is the time series median and dashed gray lines delimit inter-quartile range.

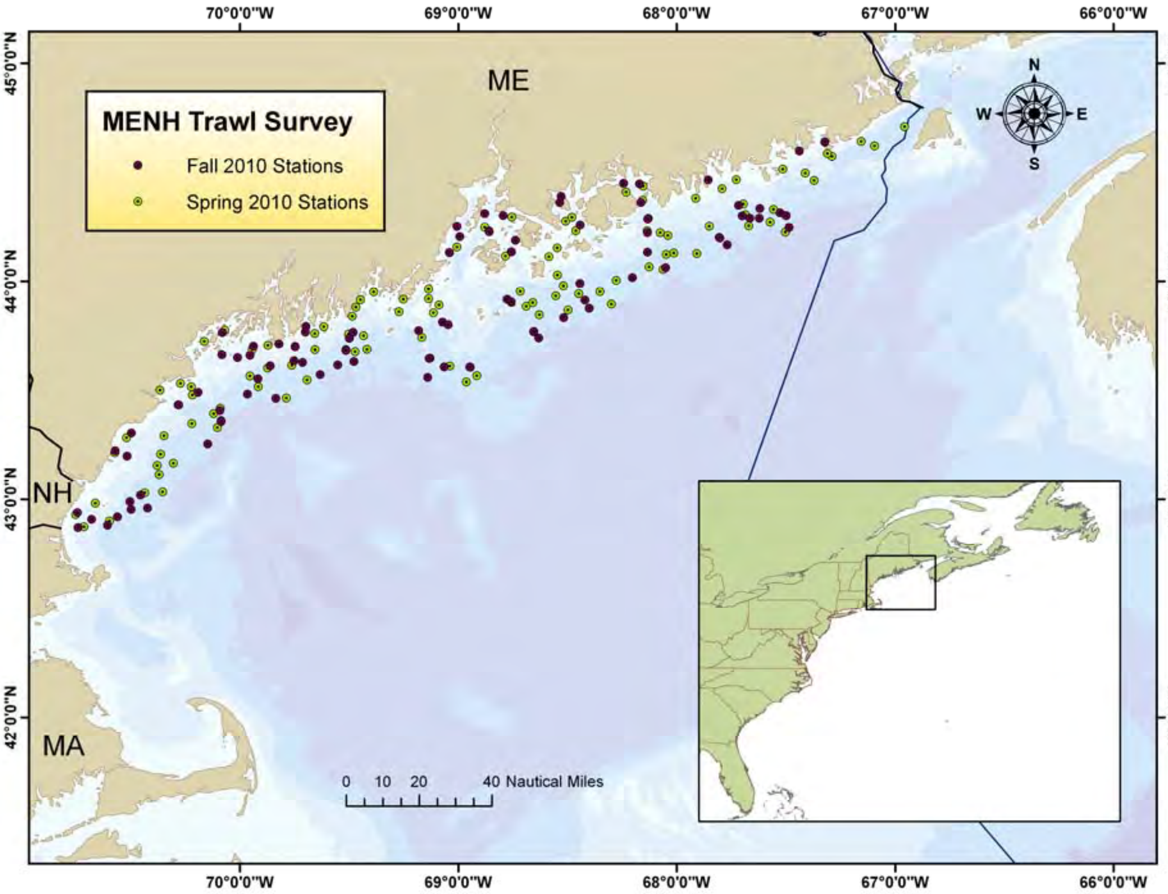
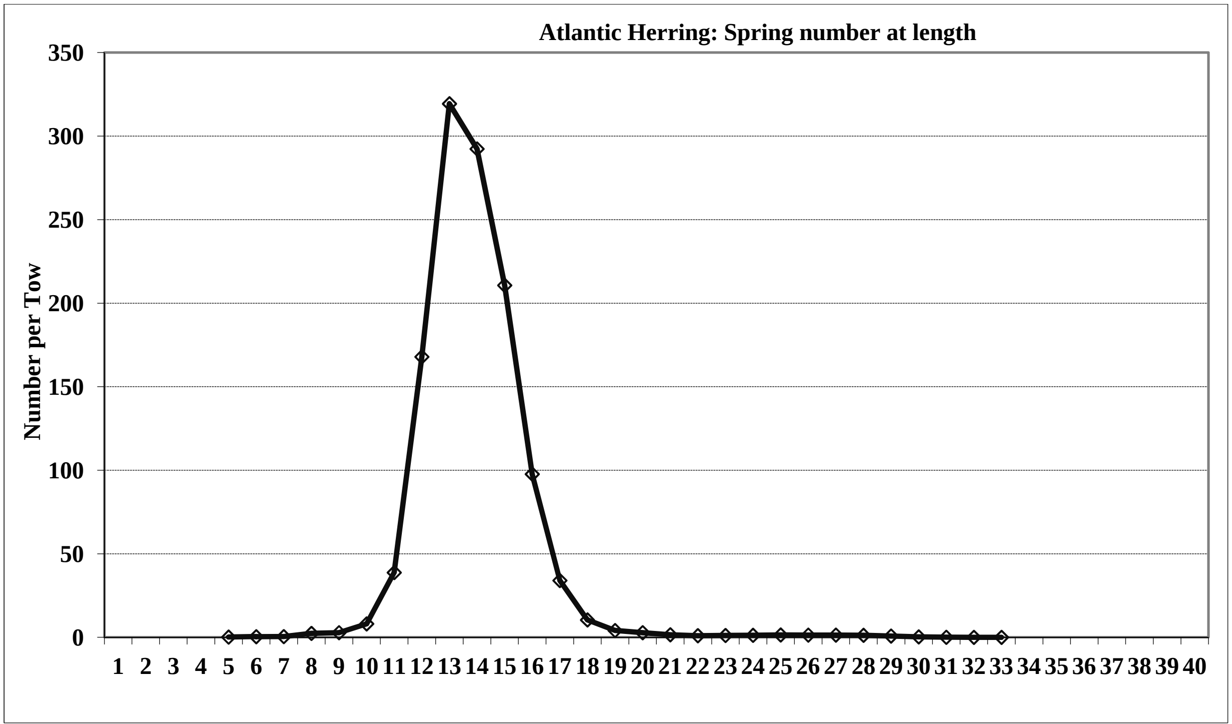


Figure A2-23. Location of tows during the Maine/New Hampshire survey in the spring and fall of 2010.



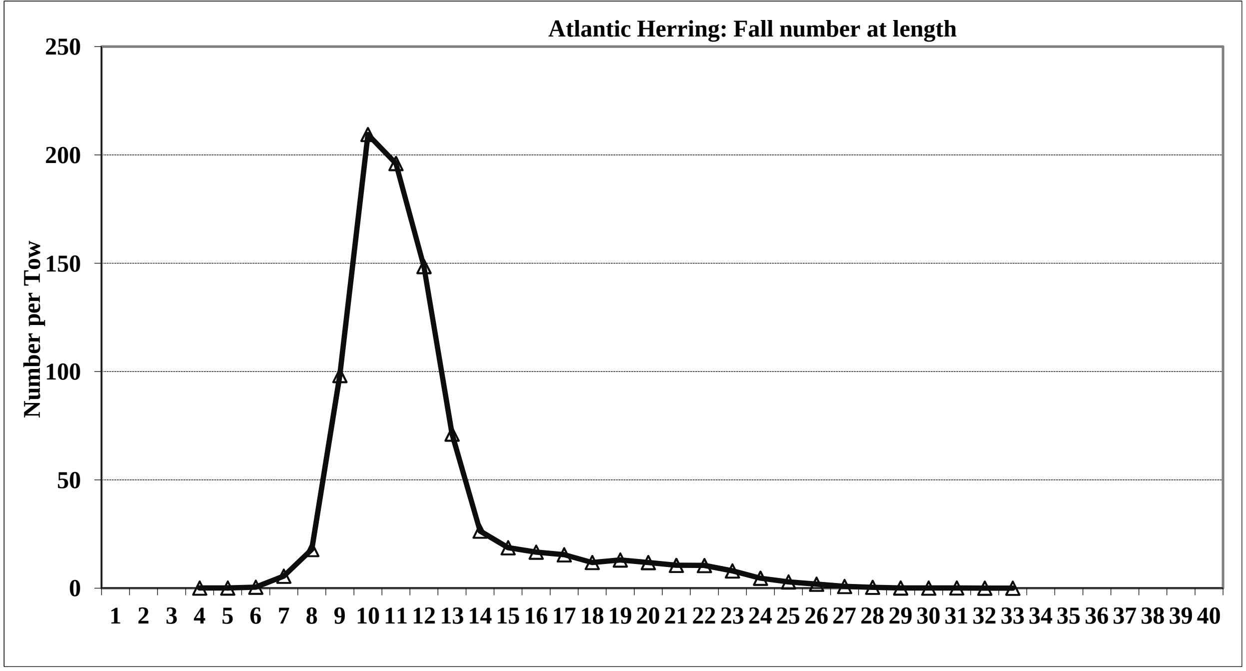


Figure A2-24. Example length frequency from the Maine/New Hampshire survey in the spring (top) and fall (bottom).

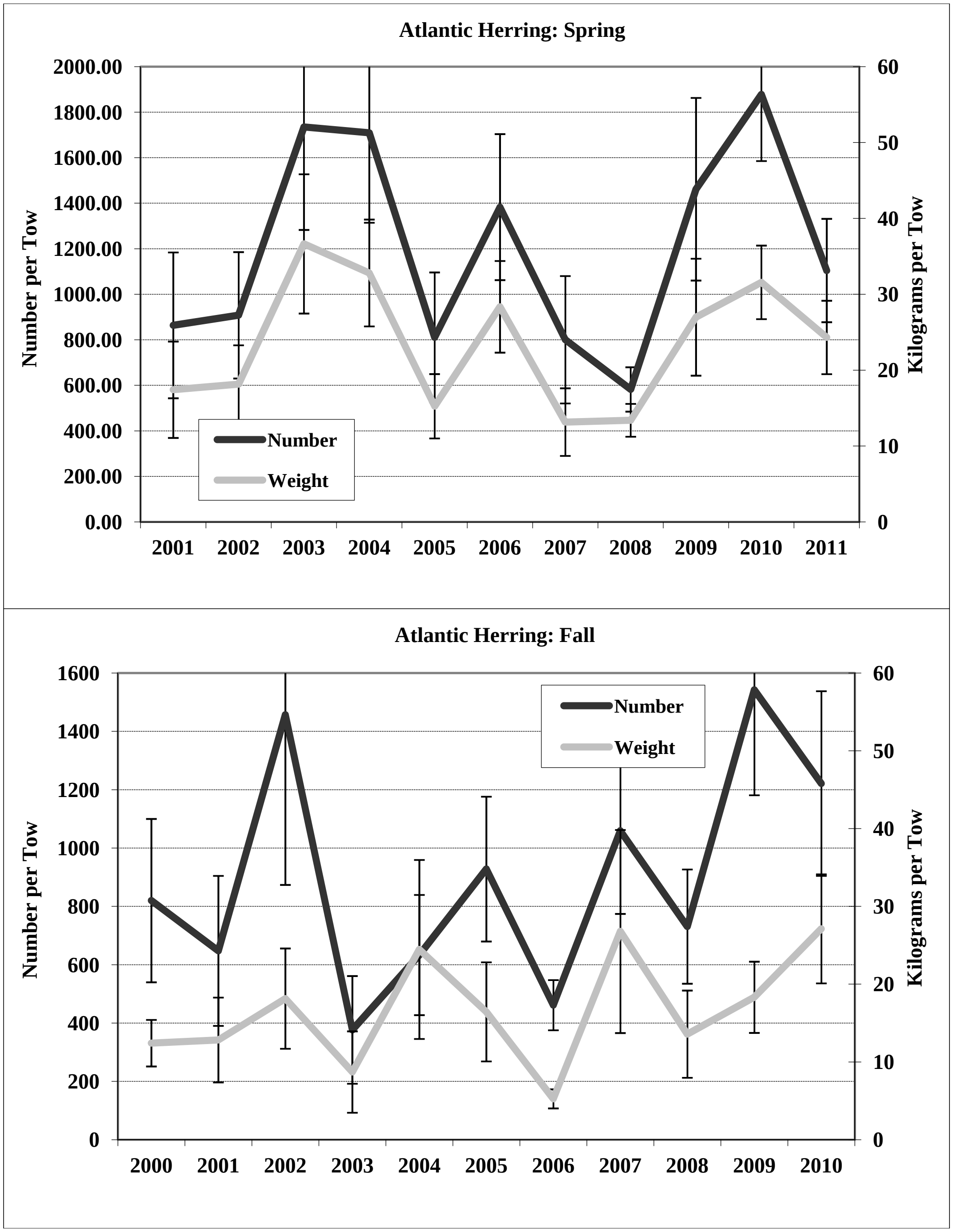


Figure A2-25. Maine/New Hampshire bottom trawl survey time series in numbers (black) and weight (grey).

TOR A3. *Evaluate the utility of the NEFSC fall acoustic survey to the stock assessment of herring. Consider degree of spatial and temporal overlap between the survey and the stock. Compare acoustic survey results with measures derived from bottom trawl surveys.*

Acoustic and midwater trawl data were collected during September - October from 1999 to present in the Georges Bank region to estimate Atlantic herring stock abundance and biomass. Data were collected along systematic parallel transects, oriented north-south (approximately perpendicular to the overall bathymetric contours) (Figure A3-1), with transect spacing of 8 or 10 nmi (Table A3-1). Midwater trawl hauls were conducted on an *ad hoc* basis to sample the species composition of the acoustic backscatter and to collect biological data (length, weight, maturity, sex, diet, and age) on Atlantic herring.

The steps for generating biomass estimates are detailed below and the results are in Table A3-2.

Biomass Estimates

1) Calculate the mean s_A (NASC, m^2 nmi^{-2}) (NASC = $s_A = 4\pi(1852^2)s_a$) for each transect (*Tr*) ($\overline{s_{A,Tr}}$) within the selected survey zone (*zone*):

$$\overline{s_{A,Tr}} = \frac{1}{N}\sum_{i=1}^{N} s_A(i)_{zone} \qquad (1),$$

where N is the number of sA values along each transect (including zeros). Then calculate the mean s_A among all transects within the survey zone ($\overline{s_{A,zone}}$):

$$\overline{s_{A,zone}} = \frac{1}{N_{Tr}}\sum_{j=1}^{N_{Tr}} \overline{s_{A,Tr(j)}} \qquad (2),$$

where N_{Tr} is the number of transects (Table A3-2). The survey area that was selected for the 2011 assessment is based on an analysis of Atlantic herring aggregations (Jech and Stroman, 2012), where over 90% of the aggregations were consistently found within 40 nmi to the north of and 10 nmi to the south of the 90-m bathymetric contour. This area is called the “common area” (Figure A3-1).

The standard error (SE) for the survey zone was calculated by:

$$SE_{zone} = \frac{SD\left(\overline{s_{A,Tr}}\right)}{\sqrt{N_{Tr}}} \qquad (3).$$

2) The mean fork length (cm) of Atlantic herring for each survey ($\overline{FL_{survey}}$) was calculated by selecting herring from trawls that were conducted during each survey (Figure A3-2). The target strength (TS) to length regression used in step X requires mean total length ($\overline{TL}$), The $\overline{TL}$ was calculated as:

$$\overline{TL_{survey}} = 1.0944 * \overline{FL_{survey}} + 0.4301 \qquad (4),$$

where the slope (1.0944) and intercept (0.4301) of the FL-to-TL regression were determined from data collected during 1999 (Table A3-2). The R^2 for this regression was 0.949 and the SE was 0.566.

3) The mean weight (W, kg) of Atlantic herring for each survey ($\overline{W_{survey}}$) was calculated by:

$$\overline{W_{survey}} = e^{LW_{int,year}} * \left(\overline{FL_{survey}}^{LW_{slope,year}}\right) \qquad (5),$$

where the length-weight coefficients LW_{int} and LW_{slope} were obtained from commercial catch data for each year (J. Deroba, pers. comm.) (Table A3-2).

4) The mean TS for each survey ($\overline{TS_{survey}}$) was calculated using a depth-dependent regression developed by Ona (2003):

$$\overline{TS_{survey}} = 20 * log_{10}\left(\overline{TL_{survey}}\right) - 2.3log_{10}\left(1 + \frac{\overline{Z_{survey}}}{10}\right) - 65.4 \qquad (6)$$

where the mean depth of Atlantic herring for each survey ($\overline{Z_{survey}}$) was obtained from an analysis of Atlantic herring aggregations (cf. Jech and Stroman, 2012). The mean depth for 2011 was estimated at 150 m (i.e., an analysis of aggregations during 2011 has not been completed yet) (Table A3-2).

5) The mean numerical areal density ($\overline{D_{\#,zone}}$, # nmi^{-2}) for each survey zone (Table A3-2) was calculated by:

$$\overline{D_{\#,zone}} = \frac{\overline{s_{A,zone}}}{4\pi 10^{\overline{TS_{survey}}/10}} \qquad (7).$$

6) The total abundance (P, #) for each survey zone (Table A3-2) was calculated by:

$$P_{zone} = \overline{D_{\#,zone}} * A_{zone} \qquad (8),$$

where the area of the “common area” (A_{zone}) was calculated in ArcGIS (v10) as 8745 nmi^2.

7) The mean biomass density for each survey ($\overline{D_{W,zone}}$, kg nmi^{-2}) (Table A3-2) was calculated as:

$$\overline{D_{W,zone}} = \overline{W_{survey}} * \overline{D_{\#,zone}} \qquad (9).$$

8) The total biomass for each survey zone (B_{zone}, kg) (Table A3-2) was calculated as:

$$B_{zone} = \overline{D_{W,zone}} * A_{zone} \qquad (10).$$

Error Propagation

1) One way to deal with error propagation is to multiply the standard error (SE) of the s_A values by the constant that was used to convert s_A to biomass (B_{zone}). The constant can be derived by combining Equations 7, 9 and 10:

$$B_{zone} = S_{A,zone} * C \qquad (11),$$

$$C = \frac{\overline{W_{survey}} * A_{zone}}{4 * \pi * \left(10^{\overline{TS_{survey}}/10}\right) 10^6} \qquad (12),$$

where 10^6 is the scaling factor to obtain million metric tons. The standard error of biomass is then $SE_{biomass} = C*SE_{zone}$ (Table A3-2; Fig. A3-3).
This is identical to converting each individual $s_A(i)$ to $B(i)$, then substitute biomass into equations 1 – 3 and estimate the biomass SE.

Age-based scaling

1) An age-length “key” was generated by partitioning the total number of sub-sampled herring for each length class by age. The trawl samples were pooled for all trawls within each survey. In the example table, the values are the total number of fish at a specific length and age.

   Fish 1 to 40 cm in length and 1 to 15 years were selected to fully encompass the Atlantic herring ranges in the midwater trawl data.

Length (cm)	Age 1	Age 2	Age … 15
1	0	0	0
2	1	0	0
…	0	5	1
40	0	0	0

2) The age-length "key" is converted to proportional values where the number of herring are summed over age classes (for each j^{th} length class) and then the number of herring in each age class is divided by the total number in that length class:

$$P_{AC_{i,j}} = \frac{n_{AC_{i,j}}}{\sum_{i=1}^{N_{AC}} n_{AC_{i,j}}} \qquad for\ j = (1,2,\dots,40) \qquad (13),$$

where $P_{AC_{i,j}}$ is the proportion (P) of the i^{th} age class (AC), N_{AC} is the number of age classes, and $n_{i,j}$ is the number of herring in the i^{th} age class and j^{th} length class.

3) The length-based age composition $\left(L_{AC_{i,j}}\right)$ is generated by multiplying the proportional age-length key by the length frequency distribution:

$$L_{AC_{i,j}} = P_{AC_{i,j}} * P_{FL_j} \qquad for\ i = (1,2,\dots 15)\ and\ j = (1,2,\dots 40) \qquad (14),$$

where P_{FL_j} is the proportion of herring in the j^{th} length (fork length, FL) class.

4) The final age-based composition $\left(P_{AC_i}\right)$is generated by summing over all length classes for each age class (Figure A3-4; Table A3-3):

$$P_{AC_i} = \sum_{j=1}^{N_L} L_{AC_{i,j}} \qquad for\ i = (1,2,\dots 15) \qquad (15).$$

5) The summation of $\left(P_{AC_i}\right)$ should equal 1. If not, it is most likely due to "round-off" errors. However, in the case of 1999 data, there is no age data for the 29-cm herring. This leads to about at 1% error.

In addition to the NEFSC acoustic results, the WG examined additional acoustic information from a long range sonar system (OAWRS) (see WPs for details). Estimates on the northern flank of Georges Bank (same herring spawning grounds survey by NEFSC) were made daily over an 8 day period in the fall of 2006. The total herring population estimated as a synthesis of all 8 days.

These population estimates were made two ways. In the first method, the maximum population at any time over 8 days at each pixel was calculated and summed across all pixels. In the second method, the maximum population at each pixel was calculated for each day. Then maximum values at each pixel were summed over the 8 days, and then summed over all pixels. Consequently, the second method used 8 times as many data points. Two approaches for each method above were used. One included only pixels where shoals existed, and the other summed over all pixels, including those where no shoals were found but diffuse populations could have existed.

All approaches were consistent to within 20% or less, which seems to indicate that most herring passed through a large shoal on their way to spawn during this peak spawning period, and apparently there was not much spatial overlap of the shoal locations across days. One thing not examined was how much population flux there was through a given shoal in a day. The approaches assume a static population each day. If that is not true and there is a significant flux through the shoal, the total populations could increase. This is something that remains to be examined. Estimates for 2006 across the various acoustic methods are presented in Table A3-4.

At the 2009 TRAC assessment the sharp decline in the NEFSC herring acoustic index in 2001-2002 was evaluated. The group proposed the explanation that the acoustic survey may not be sampling a fixed proportion of the Atlantic herring population year-to-year, resulting in a biased index. Consequently the series was not included as a tuning index. During the 2012 assessment, the WG examined larval herring data collected by the NEFSC to evaluate changes in the timing and distribution of Atlantic herring egg hatching, which was used as a measure of spawning distributions (see Appendix A4). The group concluded that there was no evidence that herring spawning shifted from 2000 to 2003, the time period when the herring acoustic index declined substantially. Subsequently it was reconsidered as a tuning index.

As described below, the NMFS acoustic survey was excluded from the base assessment model. The acoustic index was excluded from the base model because it covers a variable proportion of the stock complex (Appendix 6) and so may not be a valid annual index of the entire complex. Furthermore, the sharp decline in the acoustic index between 2001 and 2002 remained unexplained. The trends from the acoustic survey also did not agree with information from bottom-trawl surveys or fishery monitoring data. This disagreement led to issues of fit when a sensitivity analysis was completed that included the acoustic survey.

Table A3-1. Survey timing. Each survey is listed for the week(s) that it occurred. “Prlll” denotes a systematic parallel-transect design. The number in parentheses is the transect spacing (8 or 10 nmi).

<table>
<tr><th>Year</th><th>Sept.
1st week</th><th>Sept.
2nd week</th><th>Sept.
3rd week</th><th>Sept.
4th week</th><th>Oct.
1st week</th><th>Oct.
2nd week</th><th>Oct.
3rd week</th><th>Oct.
4th week</th></tr>
<tr><td>1999</td><td></td><td></td><td></td><td></td><td colspan="2">Prlll (10)</td><td></td><td></td></tr>
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<tr><td>2007</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Prlll (10)</td></tr>
<tr><td>2008</td><td></td><td></td><td colspan="2">Prlll (10)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2009</td><td></td><td></td><td></td><td colspan="3">Prlll (8)</td><td></td><td></td></tr>
<tr><td>2010</td><td></td><td></td><td></td><td colspan="3">Prlll (8)</td><td></td><td></td></tr>
<tr><td>2011</td><td></td><td></td><td></td><td colspan="2">Prlll (8)</td><td></td><td></td><td></td></tr>
</table>

Table A3-2. Biomass estimates. “Mean TL” is the mean total length, “Mean W” is the mean weight (mass), “Mean TS” is the mean target strength, “Density” is the mean areal density, “Abundance” and “Biomass” are the total number and biomass, respectively, scaled to the common survey area, and “Std. Error” is the standard error of the biomass estimate.

year	Mean TL (cm)	Mean W (kg)	Mean TS (dB)	Density (# nmi^2)	Abundance (billion)	Biomass (1000mt)	Std. Error
1999	27.4	0.106	-39.5	704171.4	6.1581	652.13	320.12
2000	28.0	0.114	-39.2	601230.4	5.2579	599.91	228.79
2001	26.8	0.098	-39.7	703795.0	6.1548	604.24	246.63
2002	27.6	0.105	-39.5	224642.6	1.9645	206.93	55.10
2003	28.1	0.115	-39.2	239822.6	2.0973	240.61	132.40
2004	27.9	0.107	-39.2	73287.9	0.6409	68.36	22.15
2005	25.9	0.087	-40.0	140224.2	1.2263	106.55	34.13
2006	26.9	0.099	-39.5	79274.0	0.6933	68.51	24.74
2007	26.0	0.088	-39.9	91390.0	0.7992	70.13	41.77
2008	27.2	0.102	-39.5	85828.2	0.7506	76.42	27.94
2009	25.4	0.081	-39.8	100980.2	0.8831	71.48	29.00
2010	22.2	0.050	-41.3	234599.0	2.0516	102.09	25.08
2011	23.2	0.058	-40.9	225352.8	1.9708	114.77	45.23

Table A3-3. Age-based relative proportion of Atlantic herring from the annual surveys along the northern edge of Georges Bank.

Year	Age 01	Age 02	Age 03	Age 04	Age 05	Age 06	Age 07	Age 08	Age 09	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15	TOTAL
1999	0.000	0.000	0.159	0.100	0.604	0.098	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.989
2000	0.000	0.031	0.014	0.333	0.392	0.082	0.090	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.996
2001	0.002	0.002	0.568	0.040	0.091	0.070	0.171	0.033	0.010	0.009	0.002	0.000	0.000	0.000	0.000	0.997
2002	0.005	0.000	0.044	0.525	0.174	0.162	0.080	0.011	0.001	0.000	0.000	0.000	0.000	0.000	0.000	1.001
2003	0.000	0.050	0.038	0.342	0.404	0.099	0.062	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.001
2004	0.000	0.050	0.228	0.079	0.125	0.278	0.144	0.059	0.017	0.017	0.000	0.000	0.000	0.000	0.000	0.997
2005	0.000	0.000	0.518	0.255	0.058	0.063	0.055	0.038	0.010	0.005	0.000	0.000	0.000	0.000	0.000	1.001
2006	0.000	0.000	0.163	0.552	0.164	0.053	0.033	0.027	0.007	0.000	0.000	0.000	0.000	0.000	0.000	1.000
2007	0.000	0.245	0.154	0.207	0.236	0.112	0.020	0.021	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.999
2008	0.000	0.015	0.457	0.125	0.170	0.174	0.047	0.008	0.004	0.000	0.000	0.000	0.000	0.000	0.000	1.001
2009	0.159	0.003	0.075	0.423	0.163	0.111	0.055	0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.999
2010	0.000	0.617	0.247	0.054	0.045	0.014	0.018	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.999
2011	0.000	0.013	0.933	0.028	0.020	0.005	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.001

Table A3-4 . Comparison of 2006 estimate of herring number on Georges Bank northern spawning shoal from MIT OAWRS systems and NEFSC acoustic.

Number - 2006

	OAWRS daily
min	5.21E+07
avg	1.54E+08
max	3.25E+08

	OAWRS integrated
	method 1
min	1.68E+09
max	1.77E+09
	method 2
min	1.35E+09
max	1.45E+09

NEFSC acoustic
6.93E+08

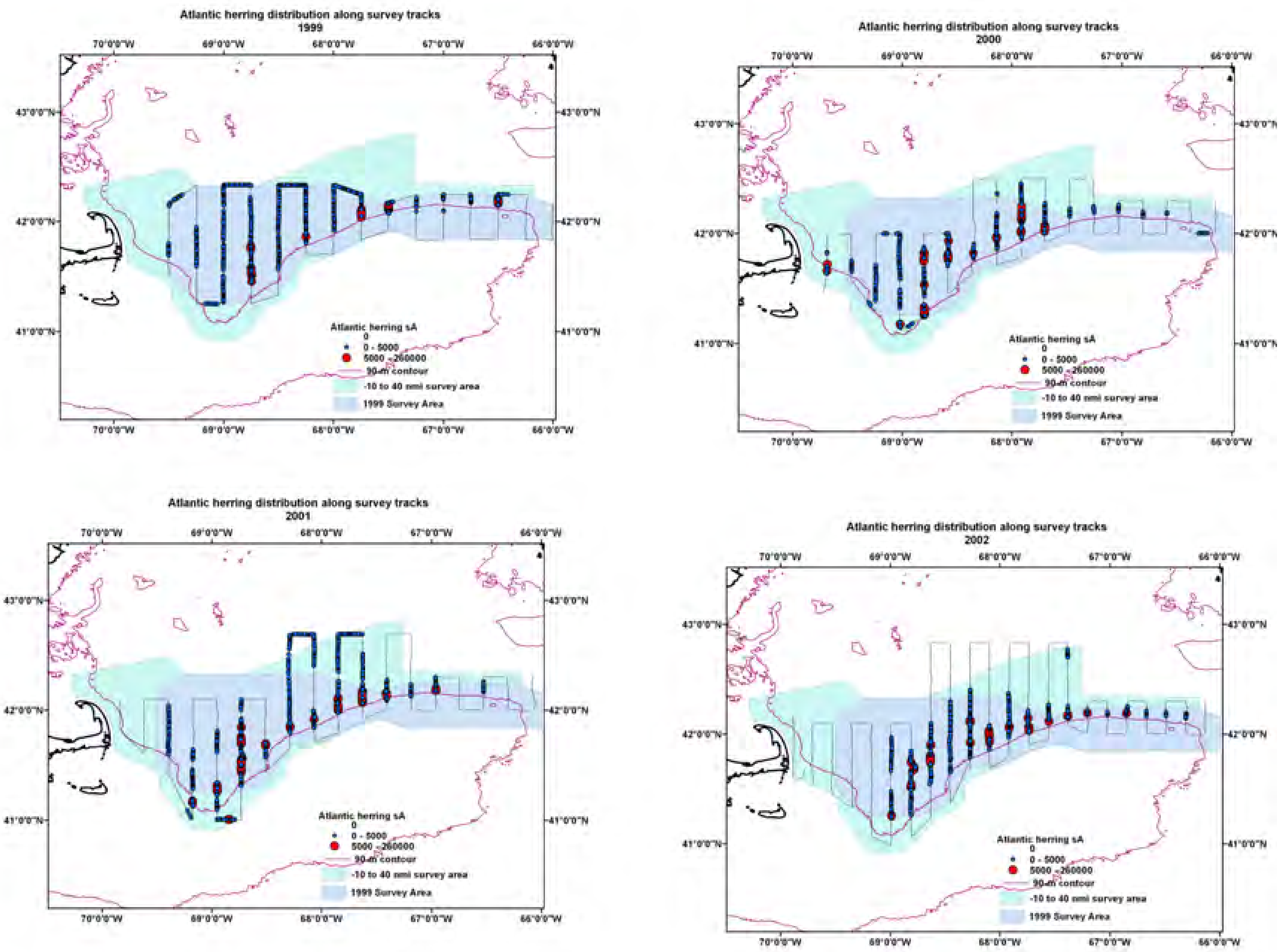


Figure A3-1. Acoustic s_A attributed to Atlantic herring along the systematic parallel transect surveys along the northern edge of Georges Bank for each year of the survey. The survey zone based on 40 nmi to the north of and 10 nmi to the south of the 90-m bathymetric contour (aka "common area") is displayed in green and the survey area of 1999 is shown in light purple.

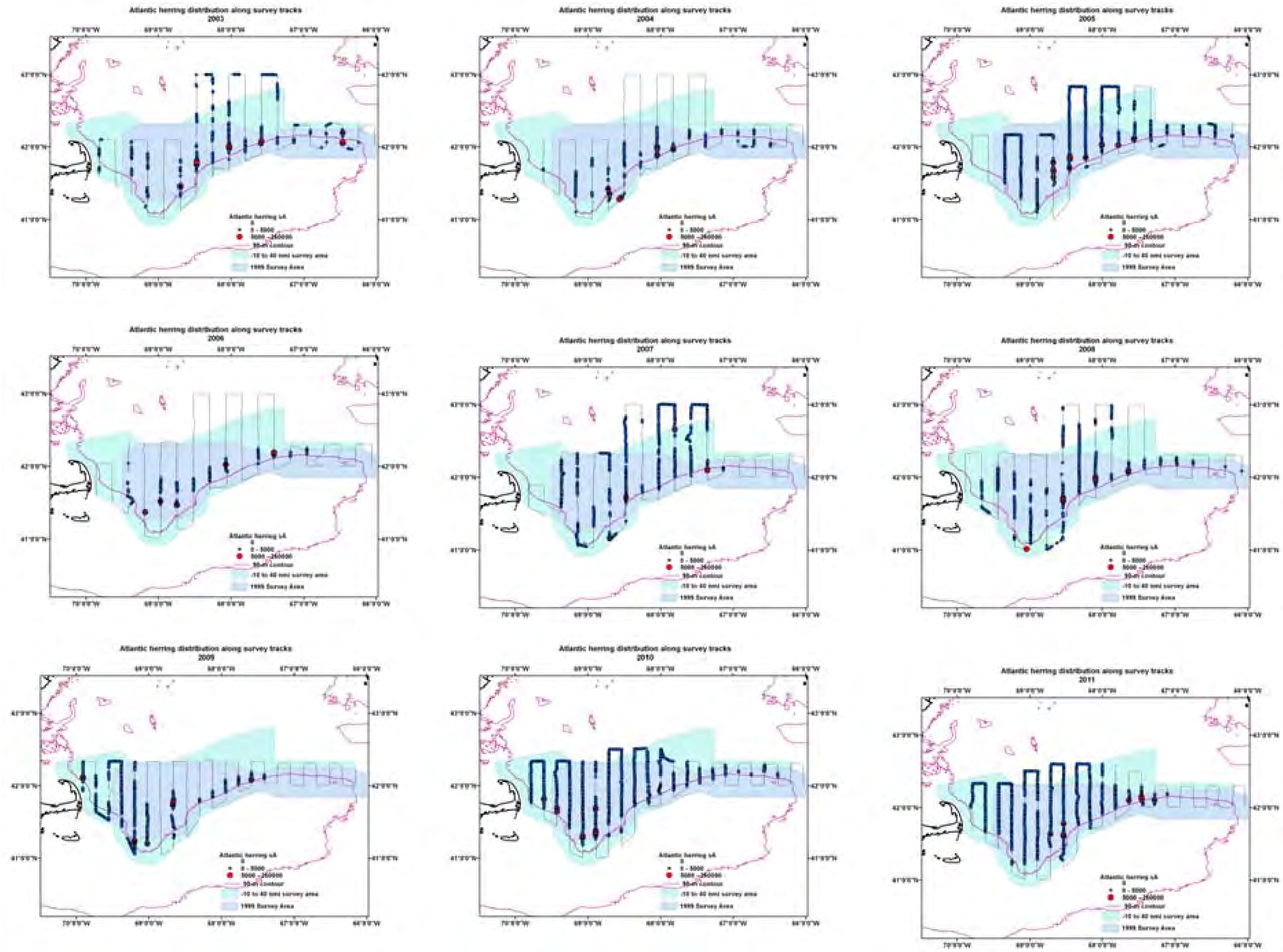


Figure A3-1 (cont'd). Acoustic s_A attributed to Atlantic herring along the systematic parallel transect surveys along the northern edge of Georges Bank for each year of the survey. The survey zone based on 40 nmi to the north of and 10 nmi to the south of the 90-m bathymetric contour (aka "common area") is displayed in green and the survey area of 1999 is shown in light purple.

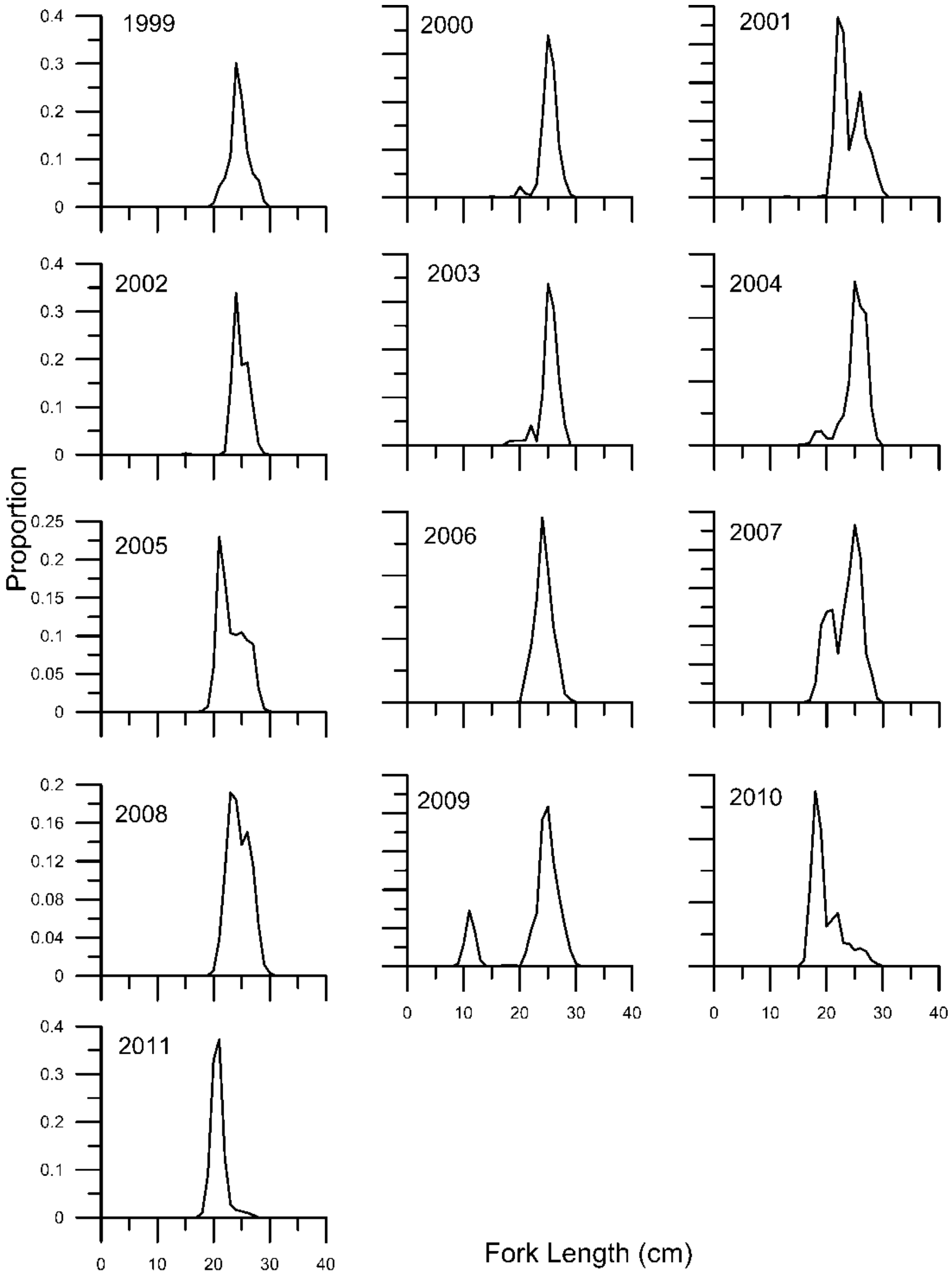


Figure A3-2. Atlantic herring length-frequency histograms for all midwater trawls conducted during each annual survey.

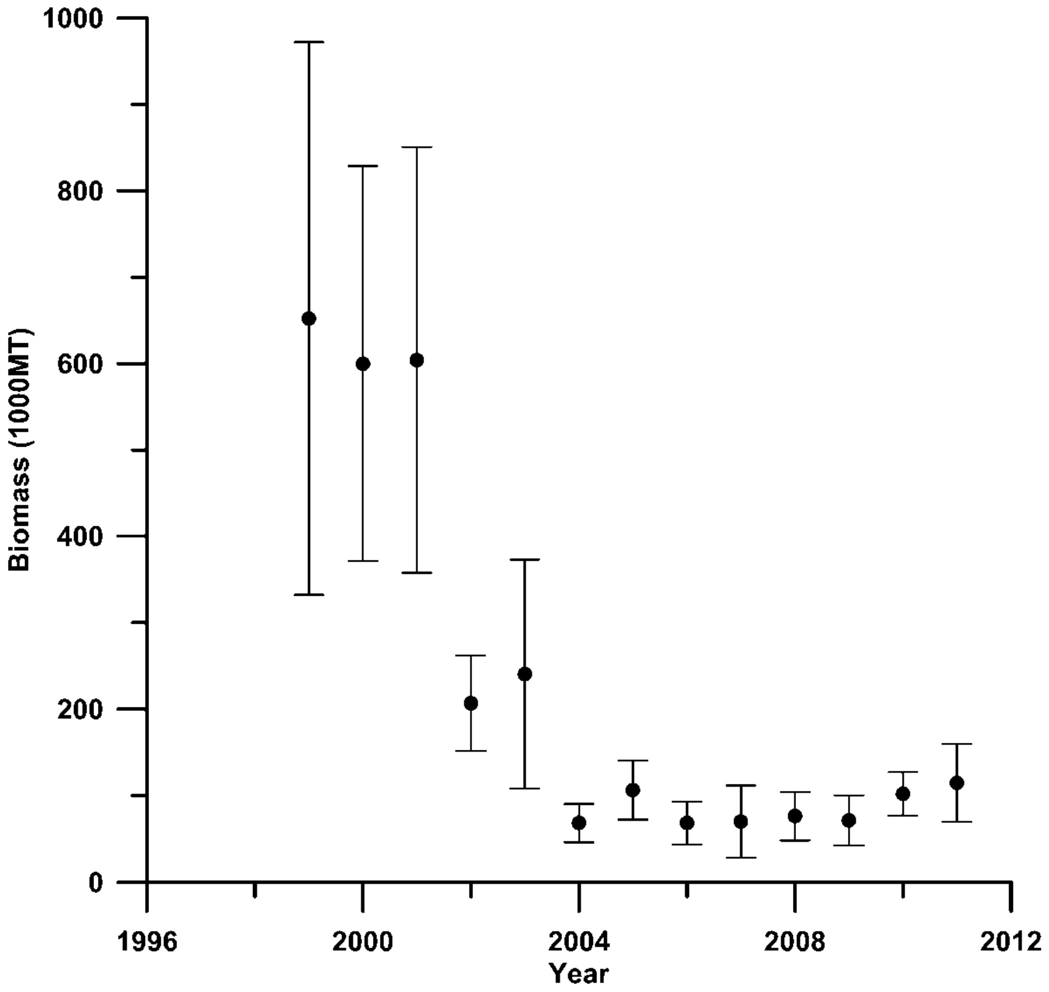


Figure A3-3. Biomass estimates and SE scaled to the ‘common area’ for each year.

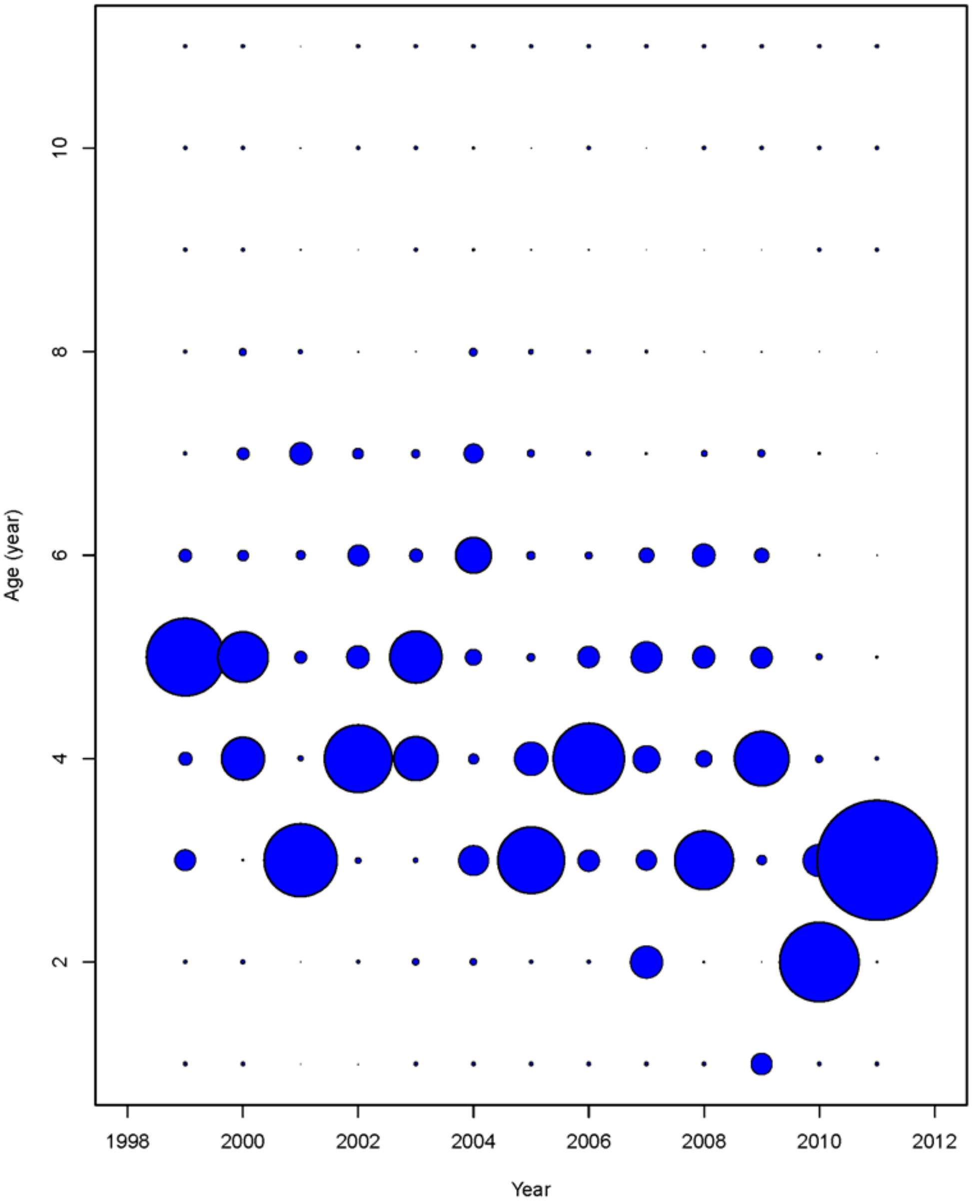


Figure A3-4. Age-based relative proportion of Atlantic herring from the annual surveys along the northern edge of Georges Bank.

TOR A6. *Consider the implications of consumption of herring, at various life stages, for use in estimating herring natural mortality rate (M) and to inform the herring stock-recruitment relationship. Characterize the uncertainty of the consumption estimates. If possible integrate the results into the stock assessment.*

Consumption of herring was addressed in one of two ways: 1) indirectly through the estimation of age and year specific Ms using a "Lorenzen" curve (see below), and 2) directly through estimation of annual consumption of herring by fish predators, which was treated as a fishing fleet in assessment modeling. The details of assessment models using each of these two approaches is discussed in TOR A5. The text below describes the methods used for each of the two approaches.

Lorenzen

Natural mortality (*M*) in fish likely varies with size (or age) and through time. Natural mortality is expected to decrease to an asymptote as fish grow larger and are better able to avoid predators; perhaps through improved mobility or due to predator gape limitations (e.g., Chen and Watanabe 1989; Lorenzen 1996; Chu et al. 2008). Natural mortality may also increase at the point of senescence, but this is usually irrelevant in exploited fish populations (Williams 1957; Chen and Watanabe 1989; Chu et al. 2008). Natural mortality can also vary through time due to factors such as changes in the predator field, prey switching, or prey growth.

Lorenzen (1996) developed an empirical relationship between fish body size and *M*, with *M* being a negative power function of fish weight. This relationship was not significantly different among lake, river, and ocean ecosystems, but the relationship among individual species within each ecosystem was significantly variable.

For application to ocean fishery stock assessments, the parameters of the power function developed by Lorenzen (1996) for the ocean ecosystem have been used to calculate age- and year-specific *M* values. For example, mean fish weights at age in each year have been input into the equation provided by Lorenzen (1996) to produce age- and time-varying *M* (e.g., Menhaden in the US, Sardine in the northeast Atlantic ICES). The *M* values produced by this method, however, can be inconsistent with what is known about a given specie's life history (e.g., the *M* values are too large), which is likely caused by the among species variation that is not accounted for by using the ecosystem level parameters provided by Lorenzen (1996). Consequently, the M values produced by Lorenzen's method are often rescaled to be more consistent with species life history.

Application to Atlantic herring

Age- and time-varying *M* values were developed for Atlantic herring using the relationship developed by Lorenzen (1996). Mean weights at age in each year were estimated using commercial samples from "mobile" gears (i.e., trawls and purse seines) during July to September. Missing values during 1964-1985, 1986-1994, and 1995-2011 were replaced by the time series averages during those ranges of years, respectively. This replacement was based on three time stanzas to account for temporal variation in herring growth. Missing values for ages 13 and 14 were replaced by the average weights at age among all years because observations were not available in each of the three previously defined time stanzas. These mean weights at age were then converted to January 1 weights at age using "Rivard" calculations. This conversion to January 1 weights was likely irrelevant, however, because the M values produced by Lorenzen's method were subsequently rescaled (see below).

The January 1 mean weights at age were converted to age- and year-specific M values using the relationship for the ocean ecosystem given by Lorenzen (1996):

$$M_{a,y} = 3.69\overline{W}_{a,y}{}^{-0.31};$$

where $\overline{W}_{a,y}$ was the January 1 mean weight at age a in year *y*.

These $M_{a,y}$ were perceived as being too high given what is known about Atlantic herring life history and longevity (Figure A6-1). So, the $M_{a,y}$ were rescaled so that the average M among ages for each year was the same, and was more consistent with Atlantic herring longevity:

$$\widehat{M}_{a,y} = M_{targ} M_{a,y} \frac{\delta}{\sum_{a=1}^{a=14} M_{a,y}} \;;$$

where δ was the number of exploited age classes and equaled 14 (Broadziak et al 2011). M_{targ} was the target level of average *M* among ages for each year and was specified using a relationship between *M* and the maximum age (A_{max}) in an unexploited population of fish (Hoenig 1983):

$$M_{targ} = \exp(1.46 - 1.01\ln(A_{max}));$$

where A_{max} was assumed to equal 14, which was the oldest age ever observed in commercial or survey gear catches and was consistent with maximum ages reported elsewhere (Collette and Klein-MacPhee 2002). Consequently, M_{targ} = 0.30. Because each $M_{a,y}$ was subject to measurement error that induced inter-annual changes in *M* that might be biological unrealistic (e.g., given a relatively static predator field), a smooth temporal trend was estimated for each age using a general additive model (Figure A6-2; Figure A6-3; Table A6-1). These smoothed values were used in the base ASAP assessment (see TOR A5).

Natural mortality at ages 1 and 2 generally declined during 1964-2011 (Figure A6-2; Table A6-1; Table A6-2). In contrast, the natural mortality at ages 3 and older generally remained stable or increased, especially since 1990 (Figure A6-2; Table A6-1; Table A6-2). Despite the appearance of strong temporal trends in *M* for ages 3 and older, the maximum absolute change during the time series was about 0.02 for those ages, which suggested relatively minor biological significance (Figure A6-3; Table A6-1; Table A6-2).

Fish Consumption of Herring

Food habits data from NEFSC bottom trawl surveys were evaluated for 13 herring predators (Table A6-3). The total amount and type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition of herring, per capita consumption, total consumption, and the amount of herring removed by the 13 predators were calculated. Combined with abundance estimates of these predators, herring consumption was summed across all predators as total herring consumption.

Methods

Every predator that contained Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) was identified. From that original list, a subset of the top 13 predators comprising 97% of the occurrences of all herring predation were included for estimating total herring consumption. Minimum sizes for herring predation were derived from the NEFSC Food Habits Database for each predator (Table A6-3). Diet data were not restricted by geographic area and were evaluated over the entire northeast U.S. shelf as one geographic unit to match the assessed herring stock structure (see above).

Estimates were calculated on a seasonal basis (two 6 month periods) for each predator and summed for each annum. Although food habits data collections for these predators started quantitatively in 1973 (Order Gadiformes only) and extends to the present (through 2010), not all herring predators were sampled during the full extent of this sampling program. Stomach sampling for the non-Gadiformes considered here began in 1977 and extends through 2010. For more details on the food habits sampling protocols and approaches, see Link and Almeida (2000) and Smith and Link (2010). This sampling program was part of the NEFSC bottom trawl survey program; further details of the survey program can be found in Azarovitz (1981), NEFC (1981), and Reid et al. (1999).

Basic Food Habits Data

To estimate mean stomach contents (S_i), each herring predator had the total amount of food eaten (as observed from food habits sampling) calculated for each temporal (t, fall or spring; year) scheme. The denominator in the mean stomach contents (i.e. number of stomach sampled) was inclusive of empty stomachs. These means were weighted by the number of fish at length per tow and the total number of fish per tow as part of a two-stage cluster design. Units for this estimate are in grams (g).

To estimate diet composition (D_{ij}), the amount of each prey item was summed across each predator's stomachs. These estimates were then divided by the total amount of food eaten in the temporal scheme, totaling 100%. These estimates were the proportions of data comprised by herring for each temporal scheme. Further particulars of these estimators can be found in Link and Almeida (2000).

Numbers of Stomachs

The adequacy of stomach sample sizes were assessed with trophic diversity curves by estimating the mean cumulative Shannon-Wiener diversity of stomach contents plotted as a function of stomach number. The order of stomachs sampled was randomized 100 times, and cumulative diversity curves were constructed for each species focusing on the early 1980s when stomach sampling effort was generally lowest for the entire time series. The criteria for asymptotic diversity was met when the slope of the three proceeding mean cumulative values was ≤ 0.1 which was similar to previous fish trophic studies (e.g. Koen Alonso et al. 2002; Belleggia et al. 2008; Braccini 2008). A minimum sample size approximately equal to 20 stomachs for each predator per year-season emerged as the general cutoff for these asymptotes. Additionally, total herring consumption was estimated with a minimum of 100 stomachs per predator-year-season to compare with the original approach; differences in total consumption estimates were minor.

Mean stomach contents (S_i) were averaged between years when stomach samples sizes were less than 20 (Tables A6-4–A6-6). With the exception of striped bass, annual estimates of mean stomach contents and herring diet compositions were estimated for each predator and season. Striped bass mean stomach contents and herring diet compositions were aggregated over 3-year bins from 1993-2010 given the numbers of stomachs sampled annually by season (Table A6-7). From 1977 to 1992, estimates of striped bass mean stomach contents were taken as an average for this time period including years 1993-1995 when numbers of striped bass stomachs were adequate. For all species, diet compositions (D_{ij}) were not averaged between years with zero stomachs containing herring (Tables A6-8 - A6-10). In the case of striped bass, herring were not observed in the fall diets until 1993 (spring: 1987); thus, the 1977 to 1992 fall time period had zero herring consumption.

Consumption Rates

To estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). There are several approaches for estimating consumption, but this approach was chosen as it was not overly simplistic (as compared to % body weight; Bajkov 1935) or overly complex (as compared to highly parameterized bioenergetics models; Kitchell et al. 1977). Additionally, there has been extensive use of these models (Durbin et al. 1983, Ursin et al 1985, Pennington 1985, Overholtz et al. 1991, 1999, 2000, Tsou and Collie 2001a, 2001b, Link and Garrison 2002, Link et al. 2002, Overholtz and Link 2007). Units are in g year^{-1}.

Using the evacuation rate model to calculate consumption requires two variables and two parameters. The per capita consumption rate, C_{it} is calculated as:

$$C_{it} = 24 \cdot E_{it} \cdot \overline{S_{it}}^{\gamma} \qquad ,$$

where 24 is the number of hours in a day. The evacuation rate E_{it} is:

$$E_{it} = \alpha e^{\beta T} \qquad ,$$

and is formulated such that estimates of mean stomach contents (S_i) and ambient temperature (T; here used as bottom temperature from the NEFSC bottom trawl surveys associated with the presence of each predator (Taylor and Bascuñán 2000, Taylor et al. 2005) are the only data required. The parameters α and β are set as values chosen from the literature (Tsou and Collie 2001a, 2001b, Overholtz et al. 1999, 2000). The parameter γ is a shape function and is typically set to 1 (Gerking 1994).

To evaluate the performance of the evacuation rate method for calculating consumption, a simple sensitivity analysis had been previously executed (NEFSC 2007). The results of that sensitivity analysis indicate singly the most sensitive factor when well within normal ranges is the mean stomach contents of a predator. The ranges of α and β within those reported for the literature do not appreciably impact consumption estimates (< half an order of magnitude), nor do ranges of T which were well within observed values (<< quarter an order of magnitude). An order of magnitude change in the amount of food eaten linearly results in an order of magnitude change in per capita consumption. Variance about any particular species of predator stomach contents has a CV of ~50%. Thus, within any given species for each temporal scheme, the variability of S_{it} is likely to only influence per capita consumption by half an order of magnitude or less. Estimates of abundance, and changes in estimates thereof, are likely going to dominate the scaling of total consumption by a broader range of magnitudes than the parameters and variables requisite for an evacuation method of estimating consumption. The parameters α and β were set as 0.002 and 0.115 for the elasmobranch predators respectively and 0.004 and 0.115 for the teleost predators respectively.

Fish Predator Abundance Estimation

The scaling of total consumption requires information on predator population abundance of sizes actively preying on herring (Table A6-3). Where age information was available, minimum size was converted to age using the average age at length from Table A6-3. Abundance estimates were either from assessment models or swept area biomass for each predator (Table A6-11). Predators with a short time series (post-1964 -2011) were extrapolated back using survey indices and their relationship with abundance estimates (Atlantic cod, pollock, summer flounder, striped bass, and goosefish) or landings using the relationship between landings and abundance (bluefish) (Figure A6-4). A predicted abundance for summer flounder in 1970 was not biologically possible and an average of the two surrounding years was substituted. In addition, summer flounder indices were not available prior to 1967, therefore 1964-1966 abundances were estimates from a 5-year average in the time series. Species estimated using swept area biomass (winter and thorny skate, silver and red hake, and sea raven) used an assumed q= 1.0. Survey indices, and consequently swept area biomass, were not available for some species prior to 1968 or in 2011. Annual predator abundances by species from survey swept area biomass and assessment model outputs used to estimate the scaled total amount of herring removed are provided in Tables A6-12 and A6-13.

Scaling Consumption

Following the estimation of per capita consumption rates for each predator and temporal (*t*) scheme, those estimates were scaled up to a seasonal estimate ($C'_{it} = C_{fall}$ or C_{spring}) by multiplying the number of days in each half year:

$$C'_{it} = C_{it} \cdot 182.5 \qquad .$$

Estimates of total per capita consumption (all prey) by season for each predator and year are available in Tables A6-14 and A6-15. These were then multiplied by the diet composition D_{ijt} that was herring (taken as a proportion), to estimate the seasonal per capita consumption of herring C_{ijt}:

$$C_{ijt} = C'_{it} \cdot D_{ijt} \qquad .$$

Estimates of per capita herring consumption are available by season for each predator in Tables A6-16 and A6-17. These were then summed to provide an annual estimate, C'_{ij}:

$$C'_{ij} = C_{ij,fall} + C_{ij,spring} \quad ,$$

and were then scaled by the stock abundance to estimate a total amount of herring (*j*) removed by any predator *i*, *Cij*:

$$C_{ij} = C'_{ij} \cdot N_i \quad ;$$

N_i is either the swept area estimate or model-based estimate of abundance for each predator according to Table A6-11, using the best available estimates of predator abundance described above. To complement the herring assessment time series prior to 1973, 5-yr averages of annual per capita consumption of herring (C'_{ij}) for the gadiform predators (1973-1977) and non-gadiform predators (1977-1981) were estimated and scaled for each predator by the available abundance data from 1968-1976. The final herring consumption time series was 1968-2010.

The total amount of herring removed (C_{ij}) were then summed across all *i* predators to estimate a total amount of herring removed by all consistent herring predators, C_j:

$$C_j = \sum_i C_{ij} \quad .$$

The total consumption of herring per predator and total amount of herring removed by all predators are presented as thousands of metric tons year^{-1}.

Marine Mammal Consumption

Marine mammal predation on Atlantic herring was recently estimated for the Northeast US continental shelf region (Col, 2012). Quantitative bounds on consumption estimates were determined using @Risk software for a suite of marine mammals (humpback, fin, minke, sei, right and pilot whales, bottlenose, Atlantic white-sided and common dolphin, harbor porpoise, and gray and harbor seals). Broad ranges of daily individual consumption rates were randomly sampled from compiled literature values based on taxonomic groupings of marine mammals. Daily individual consumption was expanded to annual population-level consumption based on abundance estimates of the marine mammals found on the NEUS continental shelf and annual residence of each species to the area. Uncertainty and time series trends in these estimates were incorporated to include plausible shifts in whale distribution and abundance over time. Diet compositions were summarized from published literature in order to determine clupeid consumption, of which Atlantic herring was by far the most common clupeid prey species. Bounds on consumption estimates of total marine mammal consumption of herring were determined using Monte Carlo re-sampling simulations. Results indicate that in recent years, marine mammal consumption of clupeids may be similar in magnitude to commercial fishery landings for Atlantic herring, averaging 105,000mt/year (12,000-250,000mt/year 80% CI) (Figure A6-6). Marine mammal consumption was likely lower during the early part of the time series due to lower mammal abundance, with a low of 65,000mt/year during the 1960s (4,200-160,000mt/year 80% CI). Further details on the methods used to estimate consumption by marine mammals on the Northeast US continental shelf can be found in Col's Master thesis (2012).

Highly Migratory Species

Among a suite of large pelagic species that are highly migratory (HMS) and seasonally important apex predators in the NES LME, bluefin tuna and blue shark are the primary large pelagic predators of herring in the region (Kohler and Stillwell, 1981; Stillwell and Kohler, 1982; Chase, 2002; ICCAT, 2003, Overholtz and Link 2007); thus we limit our treatment of HMS predation on herring to those two main species. We recognize that other methods have been adopted to incorporate a broader suite of predators, but they amount to a small amount of herring predation compared to these two species. The approach here is an extension of the Overholtz et al. (2008) and Overholtz and Link (2007) method. Because daily ration data were available as percentage body weight (%BW) consumed per day (Chase, 2002); therefore, biomass instead of numbers was used as an input variable. Input variables that were modeled for these large pelagic predatory species were therefore predator biomass, proportion of the population in the region, daily ration (%BW), and proportion of herring in the diet.

Bluefin tuna and blue shark biomasses were obtained from a VPA (ICCAT, 2010, 2008 respectively). Lacking any empirical information on the precision of abundance estimates for these three species, biomass estimates for the three large pelagic species were modeled using pert distributions and an assumed CV of 30%.

The residence period of large pelagic fish in the region varies among species, with bluefin tuna present from July to October, and blue shark more variably from May to October. We assumed that about 50% of the bluefin tuna and 10% of the blue shark biomass was resident during these times (Stillwell and Kohler, 1982; Kohler, 1987; Chase, 2002). A pert distribution was used to model the stock proportions for each species in the region, using an assumed 30% CV.

The estimated daily ration (%BW) for bluefin tuna (3.2% BW per day) was derived by averaging the published estimates that were available (Tiews, 1978; Young et al., 1997; Chase, 2002; ICCAT, 2003) and calculating a standard deviation (s.d. 1.4%). Blue shark estimates of daily ration (0.56 with CVs of 50%) were taken from the literature (Stillwell and Kohler, 1982; Kohler, 1987).

A spline-smoothed diet proportion approach was used for bluefin tuna and blue shark. Chase (2002) reported that herring accounted for 50% of the diet of bluefin tuna during the years 1988–1992. This value was used to centre a uniform distribution during the period 1988–1992 with a CV of 50%. During earlier years (1977–1987), herring were of lesser importance in the diet of bluefin, and values of 15–20% were used (Holliday, 1978; Eggleston and Bochenek, 1990). From 1993 to 2002, it was assumed that 60% of the bluefin tuna diet was herring (range 30–90%). For blue shark and shortfin mako shark, diet percentages during the years 1977–2002 were assumed to range from 10 to 20% with a CV of 50%, and from 5 to 10% with a CV of 50%, respectively (Kohler and Stillwell, 1981; Stillwell and Kohler, 1982; Kohler, 1987; Overholtz et al., 2004). A similar approach was undertaken for blue shark, but with a maximum of 30% of the diet being comprised by herring.

Results indicate that on average, these two HMS consume between and 15 and 25,000 mt per year, with 15-20,000 mt on average during the late 1970s to early 1990s, and 20-25,000 mt in later years (Figure A6-7).

Seabirds

Approximately 20 species of seabird are found in the Northeast Shelf ecosystem, and most are moderately abundant, especially over Georges Bank (Schneider and Heinemann, 1996). However, no large-scale surveys of seabird populations have been conducted in the area since 1988. The NES LME region is generally thought of as seasonal feeding areas, with few species actually nesting locally. Eight seabird species are important predators of herring: northern fulmar (*Fulmarus glacialis*), blacklegged kittiwake (*Rissa tridactyla*), northern gannet (*Morus bassanus*), herring gull (*Larus argentatus*), great black-backed gull (*L. marinus*), and shearwaters (greater shearwater *P. gravis*, sooty shearwater *P. griseus*, and Cory’s shearwater *Calonectris diomedae*). As the three species of shearwater are similar in size and greater shearwaters are by far the most abundant species in the region, their abundance was combined into one aggregate group. Quarterly estimates of seabird numbers, daily ration, and the proportion of herring in seabird diets were the variables that were estimated with an uncertainty framework. The approach here is an extension of the Overholtz et al. (2008) and Overholtz and Link (2007) method.

Schneider and Heinemann (1996) provide the mean and standard deviation in relative density for 18 species of seabird during the years 1978–1988 from annual surveys conducted by the Manomet Observatory. As seasonal abundance data are not available, the information in Powers (1983, Appendix 5) was used to derive quarterly abundance estimates for the seabird species. The Powers (1983) data were standardized to the highest quarterly value to obtain the seasonal scaler for the mean value provided in Schneider and Heinemann (1996). Then, standard and yearly deviations from the mean for each species were used to estimate the number of seabirds per square kilometer. This was then expanded to the total region to estimate the quarterly abundance of birds during the period 1978–1988 as:

N_{ij} ¼ ½D_{ij} _ SD_i þm_i_ _SC_{ij} _ A ;

where N_{ij} is the quarterly abundance, D_{ij} the annual deviation from the mean density mi, SD_i the standard deviation, SC_{ij} the quarterly scaler, A the total area for the northern Mid-Atlantic– Gulf of Maine region, i the species, and j is the quarter. It was assumed that the seasonal distribution of seabirds had not changed over time. As no estimates of abundance exist since 1988, the average abundance during the years 1984–1988 (the five most recent years of the series) was used for the balance of the study period. Anecdotal evidence suggests that seabird numbers have been stable (T. L. Evans, pers. comm.) recently but we have no data to confirm this.

Estimates of daily ration for each of the six seabird groups were obtained from Powers and Backus (1987). These are effectively metabolically derived demands per mass of each bird. These were used in pert distributions with CVs of 30%. Diets of seabirds are generally euryphagous, with numerous items and low frequencies of occurrence. Most seabird prey is generally unavailable except on occasion at the surface, when seabirds associate with marine mammals that are foraging, or from fishery discards (Powers and Backus, 1987; Pierotti, 1988). Available data from 1981 and 1982 indicate that herring were scarce in the diets of seabirds in the region then (Powers and Backus, 1987). The diet data for the six species-groups were examined, and percentages were used to centre uniform distributions with a CV of 50%. During the period 1977–2002, the percentage of herring in seabird diets ranged from a low of 2–5% for great black-backed gulls to a high of 5– 15% for northern gannets. A spline approach was used to estimate the proportion of herring in the seabird diets over time, with the lowest proportion applied during the late 1970s and early 1980s when herring were scarce, and higher proportions in the late 1990s when herring were more common.

Results indicate that on average these seabirds consume a relatively small amount herring per year, on the order 3-5 mt (Figure A6-8). This should be viewed as a lower bound estimate as several factors, namely seabird abundance, are understood to be conservative values.

An indirect approach was used to evaluate the hypothesis that egg mortality affects herring recruitment (Richardson et al. 2011). An index of larval abundance was developed (Miller et al 2012); this index is assumed to integrate the effects of inter-annual changes in egg production (i.e. spawning stock biomass) and predation-associated egg mortality. A new implementation of ASAP was run to evaluate whether larval abundance is a better predictor of recruitment than spawning stock biomass. The fit of the modified-ASAP model, incorporating a larval abundance to recruitment relationship, was not improved relative to the base model (Miller 2012).

Table A6-1.—Natural mortality for Atlantic herring estimated using a general additive model temporal smooth through rescaled Lorenzen estimates.

	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
1964	0.72	0.50	0.36	0.31	0.28	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1965	0.73	0.50	0.36	0.31	0.28	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1966	0.73	0.50	0.36	0.31	0.28	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1967	0.73	0.50	0.36	0.31	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1968	0.74	0.50	0.36	0.30	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1969	0.74	0.49	0.36	0.30	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1970	0.74	0.49	0.35	0.30	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1971	0.74	0.49	0.35	0.29	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1972	0.75	0.49	0.35	0.29	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.22
1973	0.75	0.49	0.35	0.29	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.22
1974	0.75	0.49	0.35	0.29	0.27	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.22
1975	0.75	0.49	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1976	0.75	0.48	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1977	0.75	0.48	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1978	0.75	0.48	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1979	0.74	0.48	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1980	0.74	0.48	0.35	0.29	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1981	0.74	0.48	0.35	0.29	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1982	0.73	0.47	0.35	0.29	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1983	0.73	0.47	0.35	0.28	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1984	0.72	0.47	0.35	0.28	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1985	0.71	0.47	0.35	0.28	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1986	0.70	0.47	0.35	0.29	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22
1987	0.69	0.47	0.35	0.29	0.27	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22
1988	0.68	0.46	0.35	0.30	0.27	0.26	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22
1989	0.67	0.46	0.35	0.30	0.28	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.22
1990	0.66	0.46	0.35	0.31	0.28	0.27	0.26	0.25	0.24	0.24	0.24	0.23	0.22	0.22
1991	0.65	0.46	0.35	0.31	0.29	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.22	0.22
1992	0.64	0.46	0.35	0.31	0.29	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1993	0.63	0.46	0.35	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1994	0.62	0.46	0.35	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1995	0.61	0.45	0.35	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1996	0.60	0.45	0.35	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.22
1997	0.59	0.45	0.35	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1998	0.58	0.45	0.36	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1999	0.57	0.45	0.36	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
2000	0.57	0.45	0.36	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.22
2001	0.56	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.23	0.22	0.22
2002	0.56	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.23	0.22	0.22
2003	0.55	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.23	0.22	0.22
2004	0.55	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2005	0.55	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2006	0.54	0.44	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2007	0.54	0.43	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2008	0.54	0.43	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2009	0.53	0.43	0.36	0.31	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.22	0.22
2010	0.53	0.43	0.36	0.32	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.22	0.22
2011	0.53	0.43	0.36	0.32	0.29	0.28	0.27	0.26	0.26	0.26	0.24	0.24	0.22	0.22

Table A6-2.—Rescaled Lorenzen natural mortality estimates for Atlantic herring.

	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
1964	0.73	0.48	0.35	0.31	0.28	0.25	0.24	0.23	0.23	0.23	0.22	0.21	0.22	0.22
1965	0.72	0.51	0.37	0.32	0.27	0.25	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21
1966	0.66	0.50	0.38	0.31	0.29	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.22
1967	0.65	0.50	0.37	0.31	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.22
1968	0.75	0.49	0.38	0.29	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.21
1969	0.79	0.50	0.36	0.32	0.26	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21
1970	0.82	0.47	0.35	0.29	0.27	0.25	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21
1971	0.76	0.48	0.33	0.29	0.27	0.26	0.24	0.23	0.22	0.23	0.22	0.22	0.21	0.22
1972	0.55	0.50	0.35	0.30	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.24
1973	0.81	0.44	0.34	0.29	0.26	0.25	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.22
1974	0.89	0.49	0.34	0.28	0.26	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.20	0.21
1975	0.76	0.52	0.35	0.28	0.27	0.25	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.22
1976	0.72	0.46	0.35	0.29	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.23
1977	0.75	0.50	0.32	0.29	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.22
1978	0.54	0.51	0.37	0.30	0.28	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23
1979	0.73	0.41	0.35	0.29	0.27	0.26	0.25	0.24	0.24	0.24	0.22	0.22	0.23	0.23
1980	0.90	0.47	0.33	0.28	0.25	0.24	0.23	0.22	0.22	0.22	0.22	0.21	0.21	0.21
1981	0.71	0.56	0.34	0.30	0.26	0.24	0.23	0.23	0.22	0.22	0.21	0.22	0.22	0.22
1982	0.72	0.50	0.37	0.29	0.27	0.25	0.24	0.23	0.23	0.22	0.23	0.21	0.22	0.22
1983	0.63	0.49	0.37	0.30	0.27	0.26	0.25	0.24	0.24	0.24	0.22	0.23	0.22	0.24
1984	0.95	0.43	0.33	0.28	0.25	0.24	0.23	0.22	0.22	0.21	0.22	0.21	0.21	0.21
1985	1.06	0.50	0.30	0.25	0.24	0.23	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20
1986	0.54	0.58	0.37	0.29	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.23
1987	0.86	0.40	0.34	0.29	0.26	0.24	0.24	0.23	0.24	0.23	0.22	0.22	0.21	0.21
1988	0.57	0.51	0.35	0.31	0.28	0.27	0.25	0.25	0.25	0.24	0.24	0.23	0.22	0.22
1989	0.62	0.44	0.35	0.30	0.29	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23
1990	0.61	0.45	0.35	0.31	0.28	0.27	0.26	0.25	0.24	0.25	0.24	0.23	0.22	0.23
1991	0.60	0.45	0.36	0.31	0.29	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1992	0.58	0.45	0.36	0.32	0.29	0.28	0.26	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1993	0.59	0.46	0.36	0.31	0.29	0.28	0.27	0.25	0.25	0.24	0.24	0.23	0.22	0.22
1994	0.58	0.45	0.37	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.22
1995	0.54	0.45	0.36	0.32	0.30	0.29	0.28	0.27	0.25	0.24	0.23	0.22	0.22	0.22
1996	0.53	0.43	0.37	0.32	0.30	0.28	0.27	0.27	0.26	0.25	0.24	0.23	0.22	0.23
1997	0.78	0.40	0.34	0.30	0.28	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.21	0.20
1998	0.55	0.50	0.35	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.21
1999	0.56	0.43	0.36	0.32	0.30	0.29	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22
2000	0.56	0.43	0.35	0.32	0.30	0.29	0.27	0.26	0.26	0.25	0.24	0.24	0.22	0.22
2001	0.51	0.44	0.35	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22
2002	0.52	0.42	0.36	0.32	0.30	0.28	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22
2003	0.53	0.43	0.36	0.31	0.30	0.29	0.27	0.27	0.26	0.25	0.24	0.24	0.23	0.22
2004	0.55	0.45	0.36	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.22	0.22
2005	0.56	0.44	0.37	0.32	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.24	0.22	0.22
2006	0.56	0.43	0.36	0.32	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2007	0.57	0.43	0.35	0.32	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.22	0.22
2008	0.56	0.43	0.35	0.31	0.29	0.28	0.27	0.26	0.26	0.26	0.24	0.24	0.23	0.22
2009	0.53	0.44	0.35	0.31	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.24	0.23	0.22
2010	0.54	0.45	0.36	0.32	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.22	0.22
2011	0.53	0.44	0.38	0.32	0.30	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.21

Table A6-3. Top 13 predators of Atlantic herring (*Clupea harengus* and unidentified clupeid remains) along with minimum sizes for herring predation from the NEFSC Food Habits Database and average age (where available).

Common Name	Scientific Name	Minimum Size (cm)	Avg. Age (years)
Spiny dogfish	*Squalus acanthias*	29	
Winter skate	*Leucoraja ocellata*	39	
Thorny skate	*Amblyraja radiata*	41	
Silver hake	*Merluccius bilinearis*	13	0.8
Atlantic cod	*Gadus morhua*	16	1.1
Pollock	*Pollachius virens*	19	1.4
White hake	*Urophycis tenuis*	21	0.4
Red hake	*Urophycis chuss*	24	1.3
Summer flounder	*Paralichthys dentatus*	23	0.9
Bluefish	*Pomatomus saltatrix*	17	0.0
Striped bass	*Morone saxatilis*	53	4.0
Sea raven	*Hemitripterus americanus*	13	
Goosefish	*Lophius americanus*	12	1.2

Table A6- 4. Number of stomachs examined for each predator in the fall and (spring), 1973-2010. Striped bass numbers aggregated over 3-year bins.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0 (0)	0 (0)	0 (0)	245 (149)	315 (136)	128 (73)	105 (45)	31 (24)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1974	0 (0)	0 (0)	0 (0)	158 (237)	149 (201)	50 (96)	81 (59)	47 (19)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1975	0 (0)	2 (0)	0 (0)	165 (85)	129 (10)	43 (4)	53 (0)	34 (11)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1976	0 (0)	0 (0)	0 (0)	200 (219)	169 (164)	63 (93)	59 (58)	75 (91)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1977	255 (369)	68 (59)	1 (30)	196 (295)	21 (67)	1 (24)	8 (7)	174 (130)	58 (39)	2 (0)	0 (0)	4 (3)	89 (79)
1978	413 (283)	65 (56)	63 (14)	307 (304)	123 (69)	7 (11)	100 (22)	293 (141)	100 (28)	142 (0)	1 (1)	29 (32)	139 (59)
1979	320 (262)	115 (81)	32 (19)	251 (188)	100 (77)	6 (2)	34 (24)	184 (128)	205 (50)	246 (7)	1 (1)	41 (3)	155 (56)
1980	281 (239)	168 (54)	9 (11)	153 (199)	31 (71)	0 (27)	29 (12)	146 (61)	82 (42)	114 (5)	1 (1)	15 (13)	124 (122)
1981	531 (1074)	13 (0)	0 (0)	197 (400)	151 (290)	19 (24)	76 (101)	55 (46)	101 (6)	176 (1)	0 (3)	0 (0)	69 (70)
1982	567 (1032)	41 (78)	0 (5)	52 (598)	0 (613)	85 (126)	180 (206)	351 (149)	40 (85)	127 (2)	0 (3)	0 (23)	68 (134)
1983	878 (1125)	20 (25)	0 (0)	13 (173)	1 (122)	79 (46)	226 (145)	301 (244)	5 (48)	17 (15)	0 (3)	0 (13)	59 (74)
1984	834 (1261)	132 (26)	16 (0)	185 (121)	180 (187)	62 (95)	280 (93)	313 (244)	20 (5)	83 (1)	0 (7)	36 (11)	46 (27)
1985	774 (1687)	18 (214)	80 (66)	1270 (1243)	272 (766)	68 (186)	268 (140)	351 (297)	127 (48)	196 (9)	0 (7)	41 (136)	60 (36)
1986	663 (1426)	109 (210)	21 (65)	1076 (1189)	314 (523)	48 (134)	369 (328)	201 (214)	37 (140)	112 (36)	0 (7)	70 (75)	45 (79)
1987	499 (1458)	126 (293)	12 (16)	772 (953)	302 (487)	55 (45)	279 (209)	171 (207)	125 (46)	226 (0)	2 (3)	34 (83)	61 (50)
1988	644 (1017)	169 (263)	28 (34)	929 (560)	392 (504)	71 (40)	340 (212)	249 (204)	111 (53)	83 (6)	2 (3)	62 (120)	42 (61)
1989	909 (1863)	287 (635)	65 (70)	1303 (926)	420 (555)	75 (139)	482 (185)	423 (242)	92 (34)	275 (1)	2 (3)	109 (216)	69 (76)
1990	815 (1747)	369 (441)	78 (70)	1214 (595)	526 (588)	112 (72)	634 (213)	463 (214)	131 (31)	232 (4)	0 (2)	120 (159)	71 (48)
1991	1270 (1805)	388 (406)	109 (64)	1397 (686)	370 (529)	72 (143)	1066 (227)	560 (166)	195 (98)	148 (1)	0 (2)	211 (230)	236 (88)
1992	2008 (2353)	318 (533)	103 (52)	1616 (828)	425 (447)	101 (91)	690 (213)	472 (219)	266 (523)	183 (10)	0 (2)	236 (222)	94 (233)
1993	1221 (2445)	238 (611)	119 (29)	1965 (1114)	326 (409)	117 (88)	886 (299)	565 (289)	218 (581)	128 (8)	37 (32)	183 (200)	200 (336)
1994	1103 (2095)	238 (581)	58 (33)	1638 (894)	91 (340)	58 (61)	830 (194)	509 (185)	15 (549)	2 (8)	37 (32)	145 (130)	144 (233)
1995	1482 (2722)	446 (631)	56 (29)	1879 (1038)	412 (506)	140 (103)	727 (188)	716 (263)	266 (612)	7 (0)	37 (32)	201 (195)	235 (407)
1996	786 (2429)	284 (627)	42 (7)	877 (942)	360 (357)	79 (41)	179 (145)	307 (193)	322 (1044)	236 (22)	34 (31)	193 (146)	85 (453)
1997	883 (2297)	194 (333)	34 (23)	810 (766)	277 (352)	110 (153)	221 (109)	309 (232)	360 (804)	125 (8)	34 (31)	144 (198)	74 (393)
1998	1177 (2499)	411 (609)	45 (42)	1090 (1103)	431 (514)	130 (111)	261 (137)	489 (315)	557 (807)	147 (30)	34 (31)	48 (373)	85 (311)
1999	617 (2289)	287 (382)	25 (24)	554 (854)	312 (377)	97 (69)	190 (155)	322 (312)	256 (932)	136 (23)	10 (122)	176 (199)	141 (445)
2000	444 (1201)	317 (349)	29 (28)	586 (622)	182 (223)	79 (52)	203 (154)	327 (187)	303 (684)	103 (13)	10 (122)	173 (157)	169 (418)
2001	457 (1157)	160 (347)	27 (24)	464 (633)	166 (268)	125 (64)	167 (137)	211 (215)	240 (717)	119 (8)	10 (122)	91 (217)	149 (539)
2002	374 (1063)	124 (265)	15 (21)	365 (655)	124 (225)	79 (54)	110 (97)	150 (179)	264 (794)	113 (18)	107 (193)	95 (172)	137 (439)
2003	285 (739)	113 (245)	38 (34)	460 (359)	135 (163)	76 (44)	93 (73)	162 (99)	192 (577)	134 (23)	107 (193)	86 (190)	122 (349)
2004	288 (807)	106 (317)	30 (23)	370 (467)	130 (163)	99 (24)	110 (89)	98 (111)	247 (625)	129 (4)	107 (193)	95 (155)	72 (428)
2005	336 (571)	119 (193)	19 (20)	268 (343)	138 (156)	82 (64)	85 (83)	174 (112)	209 (456)	133 (14)	44 (184)	114 (144)	85 (249)
2006	363 (699)	110 (196)	26 (11)	348 (453)	158 (150)	40 (39)	113 (81)	172 (156)	162 (377)	179 (24)	44 (184)	104 (189)	70 (217)
2007	272 (656)	108 (183)	10 (17)	358 (470)	107 (204)	32 (49)	121 (78)	142 (147)	181 (389)	112 (9)	44 (184)	119 (175)	59 (208)
2008	307 (412)	110 (126)	11 (17)	436 (370)	131 (159)	44 (54)	130 (71)	161 (119)	166 (113)	150 (4)	18 (210)	111 (155)	52 (53)
2009	306 (448)	103 (295)	32 (46)	531 (668)	124 (233)	16 (38)	167 (198)	175 (191)	186 (242)	103 (4)	18 (210)	78 (278)	232 (238)
2010	159 (427)	134 (256)	40 (38)	512 (595)	83 (234)	38 (40)	180 (127)	93 (135)	166 (257)	104 (8)	18 (210)	68 (184)	217 (204)

Table A6-5. Fall mean stomach contents (all prey) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	3.61	20.53	14.37	9.15	0.36	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.83	25.19	11.93	18.82	1.83	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	2.51	6.41	3.83	7.25	0.40	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.46	20.78	5.53	21.41	2.19	0.00	0.00	0.00	0.00	0.00
1977	5.69	2.26	4.62	3.02	10.98	5.86	14.06	0.76	2.12	8.30	152.25	29.86	77.02
1978	0.54	4.56	4.52	3.40	18.01	5.86	6.71	1.60	1.46	8.30	152.25	80.83	66.75
1979	1.03	19.47	38.87	0.91	9.32	5.86	4.53	1.64	4.58	8.54	152.25	1.10	62.19
1980	1.17	5.07	23.98	1.83	5.38	5.86	26.74	2.90	1.41	6.25	152.25	7.65	39.56
1981	1.50	17.38	23.98	3.27	53.35	5.86	13.62	1.18	8.74	5.43	152.25	7.65	92.93
1982	8.28	29.68	23.98	0.61	39.91	6.19	11.62	3.60	2.77	3.96	152.25	7.65	191.32
1983	13.23	10.24	23.98	2.00	39.91	9.98	79.60	4.16	3.61	6.49	152.25	7.65	5.76
1984	12.32	10.59	23.98	3.40	26.46	19.85	23.27	2.58	4.45	9.02	152.25	14.20	21.71
1985	5.33	14.38	9.08	1.86	14.32	16.57	17.19	4.86	3.57	6.82	152.25	10.97	59.76
1986	9.83	18.17	10.24	2.48	11.69	4.80	16.71	6.40	2.00	11.29	152.25	21.73	65.00
1987	3.74	10.39	21.34	4.18	14.49	27.10	26.46	3.43	3.15	17.65	152.25	1.73	22.39
1988	4.20	11.51	32.44	2.81	14.36	26.22	12.76	11.42	2.00	13.93	152.25	23.87	26.56
1989	6.70	5.41	5.82	1.57	17.86	3.57	9.90	1.71	1.81	3.63	152.25	4.58	11.96
1990	7.47	8.18	6.65	3.04	26.86	18.39	14.47	2.61	3.98	11.47	152.25	10.24	6.42
1991	8.02	5.86	25.11	2.54	33.53	11.61	12.59	2.39	0.87	4.89	152.25	9.22	22.29
1992	13.48	7.54	18.47	1.84	29.87	18.12	17.77	3.40	4.15	3.74	152.25	12.22	20.51
1993	5.99	5.26	16.74	1.17	22.94	14.93	13.03	1.69	4.29	10.87	23.94	19.97	21.16
1994	8.07	9.06	23.95	1.23	15.03	9.78	9.08	1.85	2.68	10.81	23.94	9.30	15.59
1995	4.11	4.96	14.65	2.50	21.10	13.60	15.85	3.01	1.07	10.81	23.94	6.69	17.62
1996	2.68	5.69	16.87	1.18	25.50	8.49	22.91	1.69	1.88	10.76	149.71	8.35	61.23
1997	6.44	5.36	26.04	2.37	22.13	10.85	12.14	4.85	1.17	18.11	149.71	7.63	44.77
1998	5.14	8.56	16.49	1.40	21.75	6.18	17.12	2.76	2.29	7.59	149.71	26.09	36.68
1999	6.11	14.20	16.64	1.59	19.86	30.84	10.29	3.12	2.09	6.98	113.21	15.56	16.47
2000	10.31	8.28	18.69	3.06	14.66	30.60	18.49	5.22	2.80	6.96	113.21	9.45	36.02
2001	4.86	6.90	11.31	1.62	25.88	19.96	37.54	2.82	3.83	7.69	113.21	11.92	26.39
2002	9.40	9.86	11.76	2.30	47.41	19.62	20.47	3.30	4.16	18.31	76.71	10.71	41.04
2003	11.44	11.50	12.21	1.24	42.35	2.13	11.21	3.71	4.72	4.50	76.71	15.21	34.10
2004	4.85	6.62	22.72	1.38	28.91	3.59	26.98	3.93	2.64	5.58	76.71	7.95	30.52
2005	2.73	6.40	21.61	1.30	15.32	3.54	13.19	2.11	7.40	4.03	87.75	10.81	41.34
2006	18.25	6.75	20.50	2.31	18.55	17.20	11.12	1.52	3.41	5.99	87.75	11.11	14.65
2007	4.15	24.15	14.35	0.77	17.55	5.56	35.32	2.82	3.46	6.40	87.75	10.47	72.45
2008	28.85	14.71	14.35	1.75	17.15	23.65	16.08	0.77	4.85	8.29	37.98	8.00	39.43
2009	5.75	10.73	8.19	1.36	11.62	22.71	22.00	1.44	2.40	12.70	37.98	4.32	31.45
2010	2.72	8.05	10.65	1.49	5.67	21.78	18.39	1.16	1.99	10.85	37.98	6.97	58.57

Table A6-6. Spring mean stomach contents (all prey) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	3.03	62.21	11.30	23.76	1.28	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	1.15	43.88	7.23	12.26	1.09	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	1.41	50.07	12.57	17.63	1.09	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	3.66	56.26	17.90	23.00	0.90	0.00	0.00	0.00	0.00	0.00
1977	5.22	5.61	1.76	1.30	12.76	1.73	12.93	0.54	0.29	21.08	117.65	9.42	37.81
1978	3.41	20.31	12.73	0.47	10.64	8.52	2.86	1.60	0.65	21.08	117.65	9.42	40.40
1979	2.40	7.79	12.73	0.93	56.47	8.52	1.82	4.42	1.70	21.08	117.65	11.80	12.17
1980	1.94	3.41	12.73	0.83	9.62	15.31	90.01	2.52	3.97	21.08	117.65	11.80	50.92
1981	5.46	9.49	12.73	3.84	45.60	53.42	178.20	3.13	3.12	21.08	117.65	11.80	46.07
1982	7.82	15.57	12.73	3.01	16.69	20.63	25.41	2.31	2.28	21.08	117.65	14.17	65.92
1983	6.89	6.46	12.73	4.94	16.24	24.97	10.69	26.77	0.55	21.08	117.65	16.92	66.45
1984	9.57	2.58	12.73	2.18	29.75	30.41	60.26	3.31	0.51	21.08	117.65	16.92	126.39
1985	6.30	8.62	23.70	1.54	19.61	8.01	8.55	2.03	0.47	21.08	117.65	19.66	16.33
1986	16.72	6.39	34.10	1.82	34.94	26.85	8.39	3.80	2.51	40.79	117.65	12.41	18.52
1987	18.35	8.42	20.32	1.27	29.64	14.34	20.95	4.10	6.34	22.54	117.65	11.65	33.78
1988	15.77	3.60	6.53	0.67	40.86	101.05	10.97	3.20	0.03	22.54	117.65	7.55	30.83
1989	7.88	7.90	5.87	0.77	22.05	5.23	8.40	3.09	1.08	22.54	117.65	10.30	3.78
1990	5.79	5.56	8.39	3.41	17.10	33.60	7.29	4.92	1.37	22.54	117.65	11.74	3.24
1991	9.84	9.31	14.15	1.18	21.95	4.05	5.09	1.61	0.89	22.54	117.65	8.81	17.08
1992	6.26	7.81	6.75	0.32	32.28	8.13	25.04	1.41	1.51	22.54	117.65	20.81	22.18
1993	6.39	10.68	13.57	0.60	32.21	9.72	8.09	0.79	1.95	22.54	98.68	16.72	19.58
1994	3.81	10.07	9.55	0.27	22.09	18.44	11.49	0.79	1.32	22.54	98.68	11.46	23.33
1995	6.09	8.78	18.09	0.48	24.65	3.55	6.63	1.46	0.94	22.54	98.68	12.32	24.08
1996	8.20	5.21	17.93	0.13	36.65	29.28	16.06	0.27	0.69	15.28	35.60	8.36	22.69
1997	6.59	9.78	17.77	1.24	37.94	26.46	14.10	1.65	0.88	10.29	35.60	6.71	19.19
1998	10.89	7.77	12.27	0.49	36.77	20.18	5.32	1.94	2.04	5.29	35.60	17.31	18.52
1999	7.06	8.83	10.42	0.44	25.66	5.58	10.32	4.35	1.90	5.26	65.02	12.83	19.96
2000	9.56	16.80	14.40	1.61	19.31	11.82	10.96	1.62	2.09	3.19	65.02	24.35	16.81
2001	3.75	7.70	13.74	0.92	48.96	10.71	12.67	9.87	2.45	3.19	65.02	13.86	19.07
2002	10.61	6.04	32.89	1.00	35.89	5.50	19.53	1.38	2.74	3.19	67.37	16.35	19.20
2003	6.11	7.42	12.55	0.40	21.33	3.88	14.13	1.66	4.35	1.11	67.37	13.05	23.12
2004	6.29	25.30	11.51	1.13	13.44	28.87	6.16	0.76	3.79	12.02	67.37	17.39	25.14
2005	8.01	7.30	9.97	0.85	20.54	34.86	2.68	0.40	4.02	12.02	89.13	20.38	28.48
2006	13.26	8.59	16.94	0.57	34.64	10.36	3.83	0.71	8.24	22.92	89.13	18.57	17.35
2007	5.94	7.92	16.94	0.58	19.75	12.20	3.27	0.44	3.85	16.03	89.13	16.25	11.52
2008	7.23	8.66	16.94	1.35	21.53	36.28	4.57	0.73	2.83	16.03	51.50	10.38	19.43
2009	20.89	6.28	23.91	1.11	18.77	13.56	6.06	1.05	1.44	16.03	51.50	14.62	33.90
2010	2.80	9.26	13.45	2.18	15.61	24.36	17.04	2.19	1.20	16.03	51.50	18.91	23.97

Table A6-7. Annual number of stomachs examined for striped bass in the fall and (spring), 1973-2010.

Year	Striped Bass
1973	0 (0)
1974	0 (0)
1975	0 (0)
1976	0 (0)
1977	0 (0)
1978	0 (1)
1979	0 (0)
1980	1 (0)
1981	0 (1)
1982	0 (0)
1983	0 (2)
1984	0 (0)
1985	0 (7)
1986	0 (0)
1987	0 (0)
1988	0 (1)
1989	2 (2)
1990	0 (2)
1991	0 (0)
1992	0 (0)
1993	1 (0)
1994	0 (14)
1995	36 (18)
1996	0 (2)
1997	0 (0)
1998	34 (29)
1999	4 (22)
2000	6 (53)
2001	0 (47)
2002	38 (79)
2003	46 (73)
2004	23 (41)
2005	7 (67)
2006	21 (52)
2007	16 (65)
2008	7 (58)
2009	0 (99)
2010	11 (53)

Table A6-8. Annual number of stomachs containing Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) for all predators in the fall and (spring), 1973-2010.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0 (0)	0 (0)	0 (0)	0 (0)	6 (4)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1974	0 (0)	0 (0)	0 (0)	1 (0)	5 (4)	1 (2)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1975	0 (0)	0 (0)	0 (0)	2 (0)	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1976	0 (0)	0 (0)	0 (0)	0 (0)	0 (2)	0 (0)	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1977	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
1978	4 (0)	0 (0)	1 (0)	8 (0)	1 (0)	0 (0)	0 (0)	1 (0)	0 (0)	6 (0)	0 (0)	0 (0)	0 (1)
1979	10 (1)	0 (0)	1 (0)	2 (1)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (2)
1980	0 (0)	0 (0)	1 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)	0 (0)	0 (0)	0 (1)
1981	0 (1)	0 (0)	0 (0)	1 (0)	0 (2)	0 (0)	1 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (2)
1982	1 (2)	0 (0)	0 (0)	0 (3)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1983	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1984	11 (1)	0 (0)	1 (0)	0 (0)	0 (8)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1985	3 (9)	0 (1)	1 (0)	0 (0)	3 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)
1986	5 (9)	1 (0)	0 (0)	7 (3)	2 (3)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)
1987	4 (16)	0 (1)	0 (0)	16 (1)	3 (3)	2 (0)	6 (1)	0 (0)	0 (0)	3 (0)	0 (0)	0 (0)	1 (0)
1988	12 (9)	1 (1)	0 (1)	11 (0)	4 (11)	1 (0)	6 (0)	3 (0)	1 (0)	3 (0)	0 (1)	0 (1)	2 (1)
1989	11 (14)	0 (3)	0 (1)	6 (1)	11 (7)	2 (0)	6 (0)	1 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
1990	28 (9)	1 (6)	0 (0)	22 (2)	31 (1)	7 (0)	14 (0)	5 (0)	1 (0)	3 (0)	0 (0)	0 (1)	0 (1)
1991	50 (31)	2 (4)	3 (0)	36 (1)	18 (7)	2 (3)	34 (0)	2 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (2)
1992	91 (36)	2 (5)	3 (0)	17 (10)	25 (18)	3 (2)	29 (0)	2 (0)	1 (2)	4 (0)	0 (0)	1 (1)	0 (6)
1993	53 (41)	2 (3)	2 (0)	39 (9)	18 (8)	3 (0)	57 (2)	0 (0)	0 (2)	3 (0)	1 (0)	1 (0)	4 (15)
1994	36 (49)	0 (2)	7 (0)	20 (1)	9 (7)	1 (1)	16 (0)	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (7)
1995	44 (58)	1 (2)	0 (0)	57 (4)	24 (15)	32 (0)	21 (0)	5 (0)	1 (0)	2 (0)	2 (3)	0 (0)	4 (4)
1996	17 (34)	1 (2)	2 (0)	9 (3)	19 (44)	0 (0)	3 (0)	1 (0)	1 (3)	6 (0)	0 (2)	3 (0)	3 (6)
1997	25 (68)	0 (1)	0 (0)	9 (4)	9 (20)	0 (0)	12 (1)	2 (0)	0 (2)	5 (0)	0 (0)	0 (0)	3 (11)
1998	29 (48)	4 (1)	1 (0)	9 (11)	9 (24)	0 (5)	7 (0)	2 (0)	0 (3)	8 (0)	10 (3)	0 (1)	3 (3)
1999	19 (80)	14 (0)	0 (0)	7 (2)	7 (11)	0 (1)	6 (1)	0 (1)	0 (9)	4 (0)	0 (1)	3 (1)	2 (17)
2000	17 (45)	6 (6)	0 (0)	13 (7)	5 (9)	1 (0)	8 (0)	3 (0)	0 (1)	0 (0)	1 (6)	2 (0)	2 (1)
2001	10 (50)	1 (2)	3 (0)	11 (6)	5 (20)	6 (0)	11 (0)	2 (0)	0 (3)	0 (1)	0 (5)	0 (1)	2 (8)
2002	6 (36)	3 (1)	0 (0)	7 (4)	7 (7)	0 (1)	7 (1)	1 (0)	0 (2)	1 (0)	7 (4)	0 (1)	3 (7)
2003	7 (14)	0 (1)	0 (0)	3 (1)	7 (6)	3 (0)	5 (0)	2 (0)	0 (3)	1 (0)	0 (3)	0 (0)	1 (5)
2004	7 (27)	1 (1)	1 (0)	5 (1)	6 (6)	1 (0)	6 (1)	0 (0)	0 (1)	2 (0)	1 (1)	1 (0)	1 (12)
2005	9 (13)	0 (1)	0 (0)	2 (1)	6 (0)	3 (0)	2 (0)	0 (0)	3 (1)	1 (1)	0 (1)	0 (0)	2 (2)
2006	7 (18)	0 (0)	1 (0)	0 (2)	7 (4)	2 (1)	4 (0)	0 (0)	0 (3)	1 (0)	0 (3)	0 (0)	0 (3)
2007	6 (10)	0 (1)	1 (0)	1 (1)	4 (3)	1 (0)	14 (0)	0 (0)	0 (2)	0 (0)	0 (1)	0 (0)	1 (1)
2008	10 (8)	1 (0)	0 (0)	5 (1)	4 (2)	3 (0)	9 (0)	0 (0)	0 (1)	2 (0)	1 (3)	0 (0)	3 (1)
2009	7 (6)	1 (0)	1 (0)	10 (0)	2 (4)	0 (0)	3 (0)	0 (0)	0 (1)	1 (0)	0 (1)	0 (3)	10 (4)
2010	1 (7)	0 (1)	0 (0)	9 (6)	3 (4)	1 (0)	6 (2)	0 (0)	0 (0)	0 (0)	0 (11)	0 (0)	2 (1)

Table A6-9. Fall percent diet composition of Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) for each predator by year

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	0.00	5.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	23.50	52.63	26.12	0.27	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	70.81	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	49.63	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00
1978	17.01	0.00	0.00	14.90	6.78	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00
1979	1.35	0.00	28.33	33.05	0.00	0.00	0.00	0.00	2.50	0.00	0.00	0.00	22.68
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00
1981	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
1982	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.80	0.00	69.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	2.91	0.00	15.42	0.00	5.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.69	1.56	0.00	12.23	4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	1.72	0.00	0.00	22.13	6.07	17.82	10.47	0.00	0.00	9.20	0.00	0.00	11.17
1988	4.81	0.00	0.00	11.28	1.96	0.95	12.06	5.59	0.00	1.55	0.00	0.00	41.84
1989	5.98	0.00	0.00	1.52	58.30	39.91	27.17	0.00	0.00	1.73	0.00	0.00	0.00
1990	30.88	0.00	0.00	23.61	31.86	23.78	4.69	2.14	4.16	38.88	0.00	0.00	0.00
1991	21.52	4.72	41.27	18.50	39.82	12.95	34.64	1.36	0.00	0.00	0.00	12.30	0.00
1992	38.75	4.42	5.05	14.75	34.51	52.06	33.52	12.85	0.77	3.64	0.00	0.73	0.00
1993	31.93	1.46	23.42	22.32	27.65	41.90	34.38	0.00	0.00	17.91	30.79	4.14	27.23
1994	21.19	0.00	27.83	17.74	53.40	0.90	19.57	0.36	0.00	0.00	30.79	0.00	2.57
1995	15.56	4.15	0.00	4.69	31.30	49.70	22.80	4.87	4.00	28.05	30.79	0.00	11.78
1996	6.55	1.46	43.98	7.56	23.26	0.00	13.88	10.55	2.20	38.20	71.59	33.16	30.77
1997	6.42	0.00	0.00	8.62	18.42	0.00	35.76	7.68	0.00	28.56	71.59	0.00	21.08
1998	5.24	5.68	4.85	6.84	17.35	0.00	9.00	18.06	0.00	35.58	71.59	0.00	39.76
1999	14.19	18.67	0.00	10.63	32.93	0.00	19.87	0.00	0.00	9.98	67.73	10.77	15.43
2000	16.29	8.60	0.00	6.08	14.00	1.70	24.92	10.87	0.00	0.00	67.73	13.60	25.97
2001	29.60	2.58	48.41	18.11	21.75	28.83	22.36	30.35	0.00	0.00	67.73	0.00	12.30
2002	2.65	14.47	0.00	10.84	53.73	0.00	20.30	2.24	0.00	0.28	22.08	0.00	10.53
2003	1.73	0.00	0.00	14.20	36.76	7.25	12.14	45.29	0.00	0.78	22.08	0.00	10.67
2004	11.79	8.80	12.46	11.65	53.46	8.30	20.82	0.00	0.00	6.17	22.08	9.09	2.52
2005	4.86	0.00	0.00	7.25	49.00	18.19	18.32	0.00	4.40	2.24	0.00	0.00	7.11
2006	22.51	0.00	14.94	0.00	50.02	39.40	17.06	0.00	0.00	0.94	0.00	0.00	0.00
2007	1.03	0.00	6.87	1.14	17.40	13.03	28.29	0.00	0.00	0.00	0.00	0.00	61.35
2008	81.95	9.38	0.00	14.22	48.13	67.15	45.63	0.00	0.00	3.70	9.17	0.00	13.70
2009	6.88	16.93	1.41	15.32	8.66	0.00	9.68	0.00	0.00	1.05	9.17	0.00	9.48
2010	16.19	0.00	0.00	3.74	5.90	4.80	12.33	0.00	0.00	0.00	9.17	0.00	3.18

Table A6-10. Spring percent diet composition of Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) for each predator by year.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	0.00	2.31	0.00	0.00	25.81	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	11.65	10.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	80.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.27
1979	9.29	0.00	0.00	0.00	13.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.58
1982	0.03	0.00	0.00	21.10	1.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.14	0.00	0.00	0.00	38.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	1.88	9.78	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	2.59	0.00	0.00	2.22	0.00	2.08	0.00	0.00	0.00	0.00	0.00	0.13	0.00
1987	0.04	7.85	0.00	0.47	5.71	0.00	0.15	0.00	0.00	0.00	16.06	0.00	0.00
1988	1.07	0.00	0.00	0.00	8.84	0.00	0.00	0.00	0.00	0.00	16.06	0.00	5.64
1989	7.33	2.43	0.00	0.28	5.50	0.00	0.00	0.00	0.00	0.00	16.06	0.00	0.00
1990	1.32	6.62	0.00	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	10.98	5.10	0.00	0.10	2.82	7.76	0.00	0.00	0.00	0.00	0.00	0.48	1.76
1992	20.35	10.00	0.00	18.40	23.35	2.82	0.00	0.00	5.30	0.00	0.00	0.93	18.71
1993	17.77	1.21	0.00	30.21	24.12	0.00	6.54	0.00	7.48	0.00	0.54	0.00	28.16
1994	15.59	0.82	0.00	1.41	7.31	3.94	0.00	0.00	0.00	0.00	0.54	0.00	18.08
1995	16.56	0.87	0.00	4.90	16.94	0.00	0.00	0.00	0.00	0.00	0.54	0.00	7.30
1996	8.38	0.41	0.00	2.95	30.45	0.00	0.00	0.00	3.03	0.00	39.41	0.00	5.30
1997	9.58	0.77	0.00	6.49	34.55	0.00	23.17	0.00	10.17	0.00	39.41	0.00	19.05
1998	7.40	1.55	0.00	16.27	22.76	31.25	0.00	0.00	6.86	0.00	39.41	1.02	10.42
1999	25.98	0.00	0.00	1.71	10.72	5.04	5.85	0.35	20.22	0.00	26.70	8.61	20.61
2000	8.71	4.34	0.00	37.66	18.47	0.00	0.00	0.00	2.22	0.00	26.70	0.00	0.90
2001	16.43	1.09	0.00	8.02	27.07	0.00	0.00	0.00	7.75	4.93	26.70	3.37	1.95
2002	19.83	0.34	0.00	8.79	17.75	2.35	1.56	0.00	4.72	0.00	10.98	1.07	9.16
2003	7.45	0.52	0.00	0.95	5.69	0.00	0.00	0.00	9.77	0.00	10.98	0.00	3.53
2004	11.57	0.01	0.00	0.99	8.12	0.00	1.90	0.00	6.70	0.00	10.98	0.00	9.33
2005	3.85	2.90	0.00	0.01	0.00	0.00	0.00	0.00	4.34	10.99	7.27	0.00	0.82
2006	24.71	0.00	0.00	0.25	3.23	49.37	0.00	0.00	2.34	0.00	7.27	0.00	7.18
2007	10.95	0.97	0.00	7.15	2.51	0.00	0.00	0.00	11.59	0.00	7.27	0.00	1.56
2008	2.63	0.00	0.00	1.32	2.67	0.00	0.00	0.00	18.84	0.00	11.45	0.00	4.40
2009	1.44	0.00	0.00	0.00	2.90	0.00	0.00	0.00	30.83	0.00	11.45	3.07	6.45
2010	0.46	0.13	0.00	0.27	4.14	0.00	0.57	0.00	0.00	0.00	11.45	0.00	0.15

Table A6-11. Summary of methods used for estimating predator abundances.

Species	Method
Spiny dogfish	Model based estimate
Winter skate	Swept area biomass-fall offshore
Thorny skate	Swept area biomass-fall offshore
Silver hake	Swept area biomass-fall offshore
Atlantic cod	ASAP model- two stocks combined - linear extrapolation
Pollock	ASAP model and ln curve extrapolation
White hake	Model based estimate with fall q 2008-10
Red hake	Swept area biomass - fall offshore
Summer flounder	ASAP model and ln curve extrapolation
Bluefish	ASAP model and power curve extrapolation
Striped bass	SCA model and hindcast based on SSB model
Sea raven	Swept area biomass - fall offshore
Goosefish	SCALE model and linear extrapolation

Table A6-12. Predator abundance estimates (000s) from survey swept area biomass.

Year	Winter skate	Thorny skate	Silver hake	Red hake	Sea raven
1964		46,821			1,489
1965		44,644			2,209
1966		79,324			2,419
1967	42,174	27,002	70,922		2,182
1968	39,170	46,564	89,512	25,440	2,151
1969	31,235	57,670	47,974	20,843	1,198
1970	66,461	76,762	80,958	25,719	2,507
1971	26,039	51,378	68,236	82,647	1,106
1972	77,881	51,003	146,397	69,310	2,769
1973	109,651	58,009	68,810	97,211	1,804
1974	48,083	38,349	56,575	54,537	686
1975	22,112	26,105	154,983	62,377	1,810
1976	31,998	20,433	132,479	100,195	1,558
1977	59,419	45,394	80,063	54,397	2,286
1978	56,714	66,053	101,838	123,425	2,494
1979	60,063	46,974	124,690	50,975	2,738
1980	84,277	59,154	102,275	65,831	4,239
1981	68,178	46,464	70,898	134,357	5,390
1982	97,257	8,080	100,328	72,854	4,683
1983	129,380	29,930	195,977	64,361	3,547
1984	152,920	33,818	67,919	38,820	2,474
1985	131,940	42,286	218,501	43,429	3,823
1986	225,983	21,122	277,507	52,831	3,899
1987	190,116	17,228	167,007	38,928	4,333
1988	128,761	20,419	151,751	32,559	4,018
1989	95,683	26,401	217,644	25,238	4,992
1990	122,490	28,165	244,773	28,057	3,239
1991	118,152	27,450	186,210	28,427	5,136
1992	94,087	15,488	213,884	27,619	3,892
1993	68,745	25,649	223,078	35,129	2,502
1994	79,682	29,149	156,010	36,201	2,310
1995	80,828	15,025	321,267	25,686	2,552
1996	74,511	12,811	141,012	28,315	3,288
1997	79,262	11,965	100,096	47,178	4,471
1998	104,887	9,428	549,251	27,741	4,898
1999	131,546	8,673	300,018	31,756	3,596
2000	112,495	10,564	337,965	36,740	4,383
2001	108,547	8,065	233,894	49,928	4,118
2002	121,734	4,612	168,910	56,142	4,284
2003	79,712	15,444	250,294	16,140	2,512
2004	101,184	10,082	143,085	23,628	3,936
2005	81,522	4,132	59,146	21,023	4,245
2006	81,682	7,585	114,492	19,065	3,294
2007	114,327	4,242	203,444	49,628	3,745
2008	183,027	2,018	160,614	55,629	4,829
2009	197,860	4,105	155,190	48,697	5,575
2010	189,704	4,254	473,475	50,094	3,629

Table A6-13. Predator abundance estimates (000s) using assessment model results.

Year	Spiny dogfish	Atlantic cod	Pollock	White hake	Summer flounder	Bluefish	Striped bass	Goosefish
1964		70,685	113,317	15,880	48,738	31,524	18,536	184,825
1965		82,011	96,093	15,430	48,251	32,186	19,199	161,216
1966		76,424	99,688	16,597	50,480	34,344	19,164	195,715
1967		107,183	87,802	20,685	61,441	31,073	18,920	134,569
1968	415,937	75,965	86,536	24,855	57,575	34,261	19,233	132,827
1969	231,597	59,530	114,753	27,932	46,349	36,276	19,094	143,292
1970	167,804	88,103	118,616	30,515	41,558	40,139	20,000	134,308
1971	193,286	72,875	120,863	31,790	36,767	37,604	20,662	133,530
1972	258,667	160,946	152,730	31,721	59,003	41,477	19,547	158,374
1973	190,396	129,509	142,834	31,812	68,722	55,435	18,536	183,219
1974	202,545	74,028	134,403	32,611	73,912	55,130	14,772	127,306
1975	165,977	91,719	128,427	33,091	83,649	53,647	14,528	150,605
1976	122,110	105,129	126,674	32,900	70,072	55,224	14,041	133,467
1977	71,582	88,431	123,446	33,144	73,729	58,115	12,577	152,691
1978	119,940	121,917	104,080	35,087	45,769	60,294	11,287	144,870
1979	42,871	106,393	94,966	32,038	59,996	69,456	10,904	166,162
1980	285,013	129,916	107,928	34,416	67,397	87,661	8,011	147,923
1981	384,743	118,992	106,067	34,738	59,847	98,996	7,175	146,605
1982	529,924	119,207	89,300	35,429	71,452	132,124	2,838	141,247
1983	430,983	94,362	90,378	31,857	82,679	127,531	2,558	134,347
1984	274,145	94,300	76,840	30,514	87,883	113,935	1,964	127,648
1985	1,470,054	80,814	66,837	34,778	61,895	114,740	2,038	119,834
1986	226,592	107,050	66,826	30,741	61,200	100,043	4,115	118,762
1987	725,666	109,175	59,559	32,039	63,678	79,072	5,817	128,369
1988	635,207	128,763	61,832	30,610	56,997	60,748	7,370	118,376
1989	589,119	108,693	53,705	34,126	23,034	54,736	7,932	123,805
1990	1,020,672	85,387	46,849	37,400	26,291	70,732	9,355	137,938
1991	665,308	74,097	46,723	34,031	36,716	61,432	10,761	151,414
1992	823,870	58,973	54,610	30,180	33,632	56,205	12,619	156,931
1993	665,057	55,354	64,637	24,583	36,738	46,018	16,014	176,611
1994	990,496	43,048	64,680	20,102	39,950	41,134	17,479	183,636
1995	563,687	34,280	66,954	17,039	45,713	43,521	18,627	171,610
1996	1,064,681	31,651	77,702	16,160	61,927	43,178	20,299	155,606
1997	656,308	36,619	78,396	19,675	60,488	43,251	27,815	153,438
1998	604,336	34,625	95,931	23,685	60,488	42,217	28,561	173,841
1999	705,764	46,682	118,261	27,497	62,719	46,082	30,759	197,928
2000	464,396	46,347	145,747	21,254	60,015	52,584	34,146	214,052
2001	293,022	36,325	140,080	16,678	65,292	50,318	31,861	200,570
2002	469,755	33,071	147,204	15,775	68,520	57,325	30,249	187,477
2003	462,958	24,935	132,979	14,761	76,963	59,246	27,949	185,457
2004	231,786	30,822	125,334	13,343	75,105	63,015	28,143	169,394
2005	478,234	28,427	113,029	16,044	88,758	57,439	29,405	147,606
2006	730,044	31,912	104,769	19,484	79,235	60,699	26,345	138,368
2007	408,974	34,025	100,560	21,336	78,564	73,848	29,896	128,969
2008	544,182	33,412	101,099	16,963	79,907	70,980	27,115	125,146
2009	595,382	35,086	100,842	12,510	86,208	74,915	24,110	123,294
2010	498,688	31,267	100,842	16,276	104,579	65,653	20,337	136,400

Table A6-14. Fall total per capita consumption (all prey) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	263.62	1088.20	643.97	421.77	25.17	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	54.58	1506.72	569.92	900.07	127.72	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	166.22	294.77	166.77	338.48	25.97	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	33.48	1200.02	270.16	1019.02	154.28	0.00	0.00	0.00	0.00	0.00
1977	164.59	86.10	124.35	149.16	1034.63	245.12	959.07	44.55	186.56	836.94	15527.61	1498.30	4146.37
1978	14.10	151.50	109.82	139.53	1049.32	301.13	417.40	72.12	151.01	1544.88	15527.61	4055.89	3288.68
1979	32.66	758.45	854.49	41.68	440.83	369.94	349.23	90.87	507.05	827.00	15527.61	70.60	3476.44
1980	40.05	201.66	583.24	90.24	260.99	324.32	1535.03	166.93	245.85	852.46	15527.61	134.02	2263.44
1981	44.09	612.00	583.24	162.48	2505.25	284.32	583.05	60.48	911.39	682.61	15527.61	134.02	4946.84
1982	222.47	1087.77	583.24	34.95	2185.02	269.33	577.86	189.88	452.55	618.21	15527.61	134.02	10332.11
1983	367.28	469.80	583.24	160.86	2547.74	502.54	3903.23	212.63	554.17	585.91	15527.61	134.02	303.61
1984	375.02	292.33	645.47	202.06	1562.53	1081.40	1304.93	146.84	641.76	787.03	15527.61	825.00	1201.66
1985	163.71	389.72	224.84	120.59	762.59	871.42	890.24	276.92	491.78	847.10	15527.61	670.58	3498.02
1986	274.97	568.32	255.48	155.21	633.16	226.12	869.52	344.77	201.03	997.49	15527.61	1357.01	3334.06
1987	97.62	346.30	426.96	208.69	667.59	1150.81	1126.09	173.05	292.64	1562.11	15527.61	100.35	1163.31
1988	111.41	361.53	724.23	146.89	683.03	1110.73	577.88	550.60	179.58	1125.08	15527.61	1257.79	1323.97
1989	192.52	175.76	125.28	87.37	885.80	170.10	488.16	80.23	189.22	386.52	15527.61	262.57	618.36
1990	170.26	347.97	140.37	167.46	1139.05	785.93	627.60	141.01	609.97	1880.24	15527.61	583.37	322.93
1991	219.10	190.11	573.21	142.97	1822.26	542.97	665.21	123.66	128.45	534.43	15527.61	493.70	1222.44
1992	368.03	253.46	418.82	106.77	1495.25	772.25	901.43	185.03	503.33	357.40	15527.61	650.35	1067.25
1993	167.15	174.67	385.10	66.03	1240.46	701.94	640.65	92.08	464.44	1049.97	2441.89	1113.68	1054.07
1994	255.00	379.96	627.17	79.42	855.00	502.41	485.37	114.82	430.66	1163.59	2441.89	615.09	1137.05
1995	134.65	224.11	370.03	162.01	1262.83	720.00	831.08	192.26	157.82	901.41	2145.45	443.18	1039.63
1996	77.25	193.06	398.61	64.75	1331.05	422.89	1142.91	85.41	276.25	1479.25	14539.73	464.99	3232.45
1997	197.21	191.34	588.62	140.37	1281.76	498.36	633.75	272.04	133.23	2060.81	14539.73	500.96	2498.74
1998	137.10	259.48	348.84	71.27	1062.75	258.00	792.49	139.39	224.65	743.79	15758.57	1554.72	1773.54
1999	196.85	574.36	405.56	103.87	1083.18	1492.07	524.90	186.44	268.30	907.28	15855.08	907.87	1058.18
2000	343.85	299.96	465.31	191.40	770.84	1417.42	882.42	308.61	335.21	916.94	9523.95	578.55	2071.57
2001	145.56	273.32	240.21	95.99	1320.18	875.73	1651.61	144.00	447.55	884.68	10775.37	729.54	1401.16
2002	307.32	395.03	305.99	151.21	3079.68	1077.78	1044.90	209.31	520.15	2541.21	8260.91	692.63	2544.34
2003	358.49	418.93	256.39	71.33	2134.63	93.75	558.26	216.74	588.73	618.37	9791.40	868.44	1942.85
2004	140.42	210.76	445.74	76.30	1341.59	154.17	1233.24	187.55	288.89	704.15	7680.92	428.29	1402.93
2005	83.29	219.16	578.51	74.31	805.50	161.59	688.72	120.92	834.46	495.50	8355.57	589.86	2293.72
2006	598.47	284.16	520.81	149.27	1011.79	797.21	585.13	85.72	384.72	699.84	10200.67	700.29	866.44
2007	109.83	856.68	321.66	39.10	846.08	222.95	1755.63	137.71	374.82	788.15	8109.44	578.31	3604.43
2008	749.97	484.49	326.76	92.01	817.99	1038.79	707.69	36.00	590.78	887.36	2973.18	410.83	1818.92
2009	185.56	420.24	192.07	89.41	628.75	1058.78	1175.44	90.43	282.73	1579.86	3417.65	260.28	1976.63
2010	91.37	298.07	275.24	100.52	308.09	1093.56	1094.66	70.82	217.51	1112.44	3928.57	413.18	3718.30

Table A6-15. Spring total per capita consumption (all prey) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	120.53	2217.65	444.51	973.92	48.74	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	53.33	1624.27	276.46	504.34	69.68	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	57.36	1614.24	367.38	705.90	47.38	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	146.51	2032.86	688.05	896.38	38.87	0.00	0.00	0.00	0.00	0.00
1977	93.73	97.30	29.23	44.49	410.89	56.30	413.31	18.09	11.70	1346.69	7387.43	289.22	1297.25
1978	55.76	303.02	212.99	16.44	318.47	290.80	94.34	53.99	26.68	1346.69	7387.43	290.92	1295.55
1979	41.21	123.16	195.23	30.99	1713.37	299.18	57.20	153.73	85.98	1346.69	5686.84	347.67	403.85
1980	38.72	60.54	229.36	28.23	324.43	595.18	3266.40	79.30	185.46	1670.17	5686.84	425.37	1798.20
1981	106.15	155.51	207.18	149.33	1515.92	1867.59	6284.84	108.13	179.75	1496.46	5686.84	407.30	1788.94
1982	149.72	235.76	187.14	111.81	527.75	695.55	988.08	87.26	135.81	1166.37	5686.84	468.61	2677.29
1983	148.02	113.31	204.92	179.62	478.37	886.00	401.80	1032.62	26.49	1366.18	4377.73	510.58	2791.14
1984	205.40	44.86	204.92	81.16	816.15	1012.97	2262.08	126.56	20.03	1308.52	3694.72	694.16	4634.28
1985	129.82	136.12	417.70	58.63	644.64	281.40	318.16	78.82	26.48	1490.62	3694.72	606.98	703.75
1986	351.06	119.23	700.43	76.30	1358.69	1109.56	357.08	159.20	109.07	2656.27	3694.72	460.27	800.27
1987	358.01	142.67	331.65	47.36	987.45	474.26	737.68	153.02	248.90	1467.84	3694.72	382.05	1455.98
1988	310.33	56.14	115.69	26.04	1303.24	3621.92	403.22	127.74	1.44	1351.74	3694.72	249.48	1270.83
1989	160.60	121.50	90.47	29.92	682.78	175.57	302.57	116.88	44.81	1892.26	3118.27	316.84	147.48
1990	113.28	93.19	133.50	132.77	555.47	1130.95	281.15	190.09	61.80	1892.26	5322.96	376.08	132.37
1991	193.71	163.13	246.26	43.79	736.87	141.70	192.39	59.46	47.16	2648.90	4278.19	286.39	701.57
1992	119.69	122.19	119.10	11.91	1033.68	277.92	932.02	53.85	64.07	2017.43	4278.19	642.43	842.61
1993	114.49	156.48	213.41	20.21	954.20	299.73	286.32	27.03	73.46	1497.77	3588.62	489.32	674.48
1994	73.79	143.88	177.15	10.48	768.85	701.04	459.64	33.12	49.62	1055.64	2884.26	373.71	925.36
1995	123.55	154.00	349.13	19.15	863.08	136.36	260.19	60.30	43.21	1175.00	3420.59	439.58	987.55
1996	153.09	78.11	313.90	4.99	1266.48	1044.91	622.18	10.13	25.89	886.70	1026.70	262.83	951.27
1997	133.26	166.67	331.75	50.16	1278.59	941.11	524.68	63.05	44.29	671.72	1196.65	219.94	790.97
1998	199.30	130.65	208.97	17.59	1210.85	692.72	184.31	66.03	80.55	302.54	1394.74	560.56	646.33
1999	137.72	149.43	190.23	16.86	914.64	204.75	379.92	164.55	89.71	495.64	2310.82	438.28	767.34
2000	201.56	318.94	265.34	64.02	728.00	452.99	422.21	64.70	99.28	194.95	2475.90	930.27	696.71
2001	73.05	124.76	233.48	33.53	1665.96	377.87	457.15	361.62	104.28	191.37	2183.46	443.42	720.44
2002	234.41	115.32	606.75	41.12	1345.31	208.48	746.49	57.22	137.37	221.80	2925.95	599.95	816.29
2003	105.95	110.83	208.38	13.35	644.78	127.20	491.73	56.07	164.83	75.87	2196.88	378.72	837.85
2004	103.42	367.61	177.44	36.28	396.86	916.30	196.46	23.46	141.63	1435.42	2225.62	495.00	787.95
2005	144.39	109.60	176.10	29.83	620.69	1175.76	96.16	14.40	154.42	666.58	2689.54	608.08	1037.23
2006	270.06	161.61	345.86	22.87	1216.23	397.22	149.30	27.97	415.41	1869.52	3863.68	650.46	713.14
2007	111.68	128.82	276.13	21.53	635.28	431.56	113.84	15.72	160.76	1059.62	2810.97	523.13	439.05
2008	136.92	160.33	292.77	50.10	718.06	1227.36	164.08	26.85	125.17	992.62	1975.35	333.96	738.02
2009	395.04	107.99	399.02	41.19	622.46	463.86	221.41	38.00	58.37	1444.11	1648.66	476.91	1294.75
2010	55.93	166.84	254.64	84.36	565.94	947.96	669.85	86.86	48.21	1309.18	1774.17	688.58	1020.94

Table A6-16. Fall per capita consumption of Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	0.00	64.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	12.83	793.04	148.89	2.46	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	117.70	24.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	505.72	0.00	0.00	0.00	0.00	0.00	0.00
1977	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.87	0.00	0.00	0.00
1978	2.40	0.00	0.00	20.79	71.19	0.00	0.00	0.00	0.00	11.37	0.00	0.00	0.00
1979	0.44	0.00	242.08	13.77	0.00	0.00	0.00	0.00	12.67	0.00	0.00	0.00	788.63
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.65	0.00	0.00	0.00
1981	0.00	0.00	0.00	4.06	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00
1982	3.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	3.01	0.00	448.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	4.77	0.00	34.68	0.00	41.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	1.90	8.85	0.00	18.98	28.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	1.67	0.00	0.00	46.17	40.55	205.04	117.90	0.00	0.00	143.71	0.00	0.00	129.90
1988	5.36	0.00	0.00	16.57	13.40	10.54	69.69	30.75	0.00	17.40	0.00	0.00	553.96
1989	11.51	0.00	0.00	1.33	516.46	67.88	132.63	0.00	0.00	6.67	0.00	0.00	0.00
1990	52.57	0.00	0.00	39.55	362.87	186.88	29.43	3.02	25.40	731.06	0.00	0.00	0.00
1991	47.14	8.97	236.54	26.45	725.65	70.33	230.40	1.68	0.00	0.00	0.00	60.74	0.00
1992	142.61	11.21	21.16	15.75	515.97	402.06	302.12	23.77	3.90	13.00	0.00	4.75	0.00
1993	53.37	2.56	90.20	14.74	342.99	294.12	220.27	0.00	0.00	188.05	751.83	46.09	287.00
1994	54.04	0.00	174.55	14.09	456.58	4.53	95.01	0.42	0.00	0.00	751.83	0.00	29.17
1995	20.96	9.30	0.00	7.59	395.26	357.83	189.51	9.37	6.30	252.87	660.56	0.00	122.42
1996	5.06	2.81	175.33	4.90	309.56	0.00	158.63	9.01	6.07	565.01	10409.07	154.17	994.50
1997	12.67	0.00	0.00	12.09	236.09	0.00	226.60	20.89	0.00	588.60	10409.07	0.00	526.76
1998	7.19	14.75	16.92	4.87	184.42	0.00	71.33	25.17	0.00	264.65	11281.65	0.00	705.09
1999	27.92	107.24	0.00	11.04	356.68	0.00	104.30	0.00	0.00	90.52	10738.85	97.75	163.23
2000	56.01	25.79	0.00	11.65	107.90	24.12	219.89	33.55	0.00	0.00	6450.70	78.67	537.92
2001	43.09	7.06	116.29	17.38	287.15	252.46	369.25	43.70	0.00	0.00	7298.29	0.00	172.32
2002	8.14	57.17	0.00	16.39	1654.77	0.00	212.11	4.70	0.00	7.08	1824.14	0.00	267.85
2003	6.20	0.00	0.00	10.13	784.59	6.79	67.77	98.17	0.00	4.80	2162.10	0.00	207.32
2004	16.56	18.54	55.53	8.89	717.23	12.80	256.82	0.00	0.00	43.46	1696.07	38.93	35.36
2005	4.04	0.00	0.00	5.38	394.73	29.40	126.17	0.00	36.71	11.11	0.00	0.00	163.19
2006	134.72	0.00	77.80	0.00	506.12	314.06	99.82	0.00	0.00	6.58	0.00	0.00	0.00
2007	1.13	0.00	22.11	0.44	147.18	29.05	496.67	0.00	0.00	0.00	0.00	0.00	2211.27
2008	614.64	45.42	0.00	13.08	393.71	697.55	322.94	0.00	0.00	32.87	272.76	0.00	249.21
2009	12.76	71.15	2.71	13.70	54.46	0.00	113.84	0.00	0.00	16.53	313.54	0.00	187.30
2010	14.79	0.00	0.00	3.75	18.17	52.50	134.92	0.00	0.00	0.00	360.41	0.00	118.15

Table A6-17. Spring per capita consumption of Atlantic herring (*Clupea harengus*, and unidentified clupeid remains) for each predator by year. Units: grams per individual.

Year	Spiny dogfish	Winter skate	Thorny skate	Silver hake	Atlantic cod	Pollock	White hake	Red hake	Summer flounder	Bluefish	Striped bass	Sea raven	Goosefish
1973	0.00	0.00	0.00	0.00	51.25	0.00	0.00	12.58	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	189.15	28.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	1638.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	107.10
1979	3.83	0.00	0.00	0.00	227.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	26.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	153.52
1982	0.05	0.00	0.00	23.59	6.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.29	0.00	0.00	0.00	316.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	2.44	13.31	0.00	0.00	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	9.09	0.00	0.00	1.69	0.04	23.06	0.00	0.00	0.00	0.00	0.00	0.58	0.00
1987	0.13	11.20	0.00	0.22	56.41	0.00	1.11	0.00	0.00	0.00	593.30	0.00	0.00
1988	3.31	0.00	0.00	0.00	115.26	0.00	0.00	0.00	0.00	0.00	593.30	0.00	71.68
1989	11.77	2.95	0.00	0.08	37.52	0.00	0.00	0.00	0.00	0.00	500.74	0.00	0.00
1990	1.49	6.17	0.00	2.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	21.27	8.32	0.00	0.04	20.80	11.00	0.00	0.00	0.00	0.00	0.00	1.38	12.36
1992	24.36	12.21	0.00	2.19	241.38	7.83	0.00	0.00	3.39	0.00	0.00	5.96	157.68
1993	20.35	1.89	0.00	6.10	230.16	0.00	18.72	0.00	5.50	0.00	19.43	0.00	189.95
1994	11.51	1.18	0.00	0.15	56.17	27.60	0.00	0.00	0.00	0.00	15.61	0.00	167.34
1995	20.47	1.34	0.00	0.94	146.23	0.00	0.00	0.00	0.00	0.00	18.52	0.00	72.10
1996	12.82	0.32	0.00	0.15	385.62	0.00	0.00	0.00	0.78	0.00	404.62	0.00	50.41
1997	12.77	1.29	0.00	3.25	441.76	0.00	121.55	0.00	4.50	0.00	471.59	0.00	150.66
1998	14.75	2.03	0.00	2.86	275.58	216.45	0.00	0.00	5.53	0.00	549.66	5.73	67.33
1999	35.79	0.00	0.00	0.29	98.07	10.31	22.22	0.57	18.14	0.00	616.99	37.74	158.17
2000	17.55	13.83	0.00	24.11	134.44	0.00	0.00	0.00	2.20	0.00	661.06	0.00	6.26
2001	12.01	1.36	0.00	2.69	450.90	0.00	0.00	0.00	8.08	9.43	582.98	14.96	14.03
2002	46.47	0.39	0.00	3.62	238.75	4.91	11.63	0.00	6.49	0.00	321.27	6.44	74.75
2003	7.89	0.58	0.00	0.13	36.68	0.00	0.00	0.00	16.10	0.00	241.22	0.00	29.58
2004	11.97	0.04	0.00	0.36	32.21	0.00	3.73	0.00	9.49	0.00	244.37	0.00	73.50
2005	5.57	3.18	0.00	0.00	0.00	0.00	0.00	0.00	6.71	73.27	195.47	0.00	8.54
2006	66.73	0.00	0.00	0.06	39.25	196.11	0.00	0.00	9.72	0.00	280.80	0.00	51.17
2007	12.23	1.25	0.00	1.54	15.96	0.00	0.00	0.00	18.63	0.00	204.29	0.00	6.86
2008	3.60	0.00	0.00	0.66	19.14	0.00	0.00	0.00	23.58	0.00	226.19	0.00	32.44
2009	5.67	0.00	0.00	0.00	18.03	0.00	0.00	0.00	18.00	0.00	188.78	14.64	83.51
2010	0.26	0.21	0.00	0.23	23.42	0.00	3.79	0.00	0.00	0.00	203.15	0.00	1.57

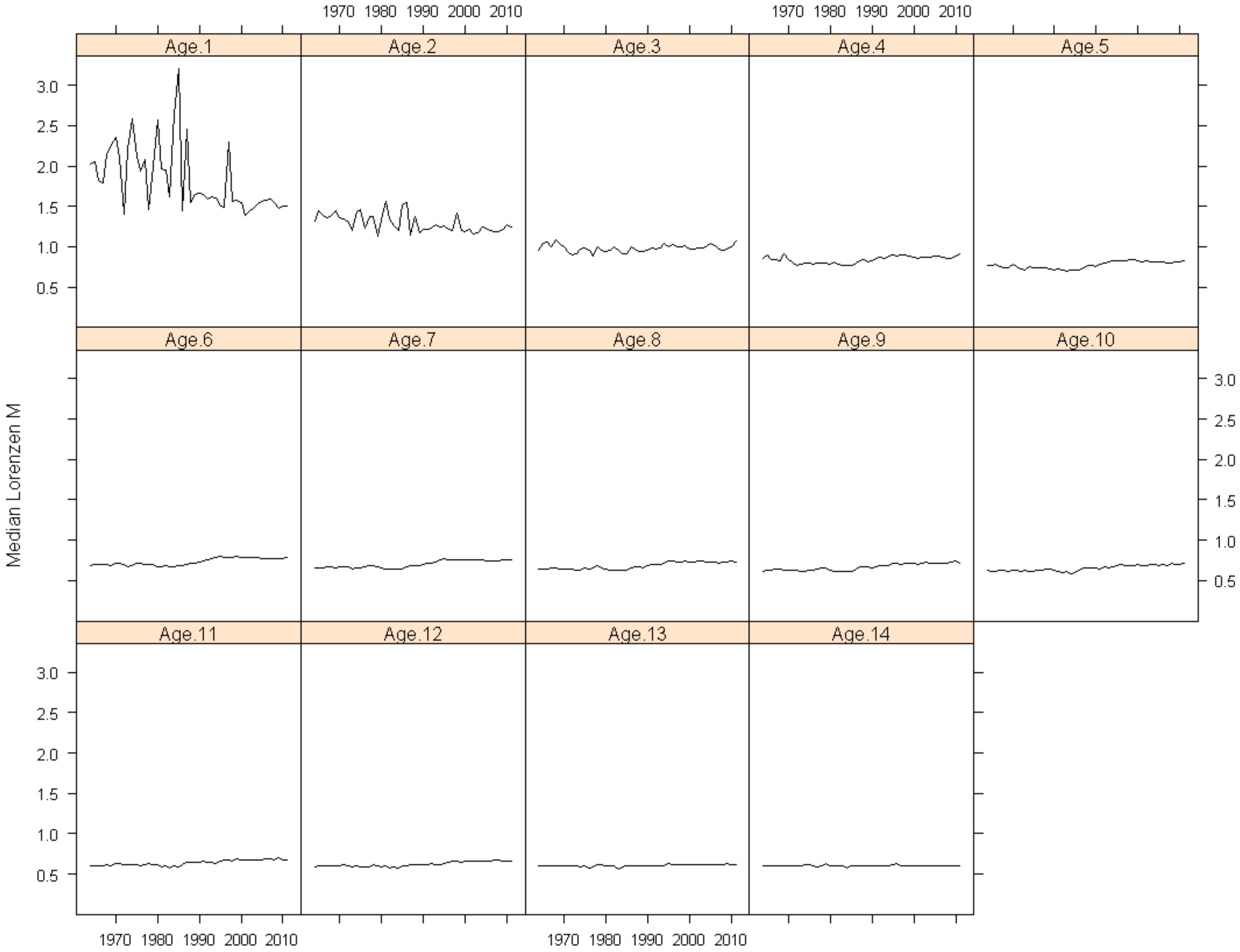


Figure A6-1. Lorenzen natural mortality (*M*) estimates for Atlantic herring during 1964-2011.

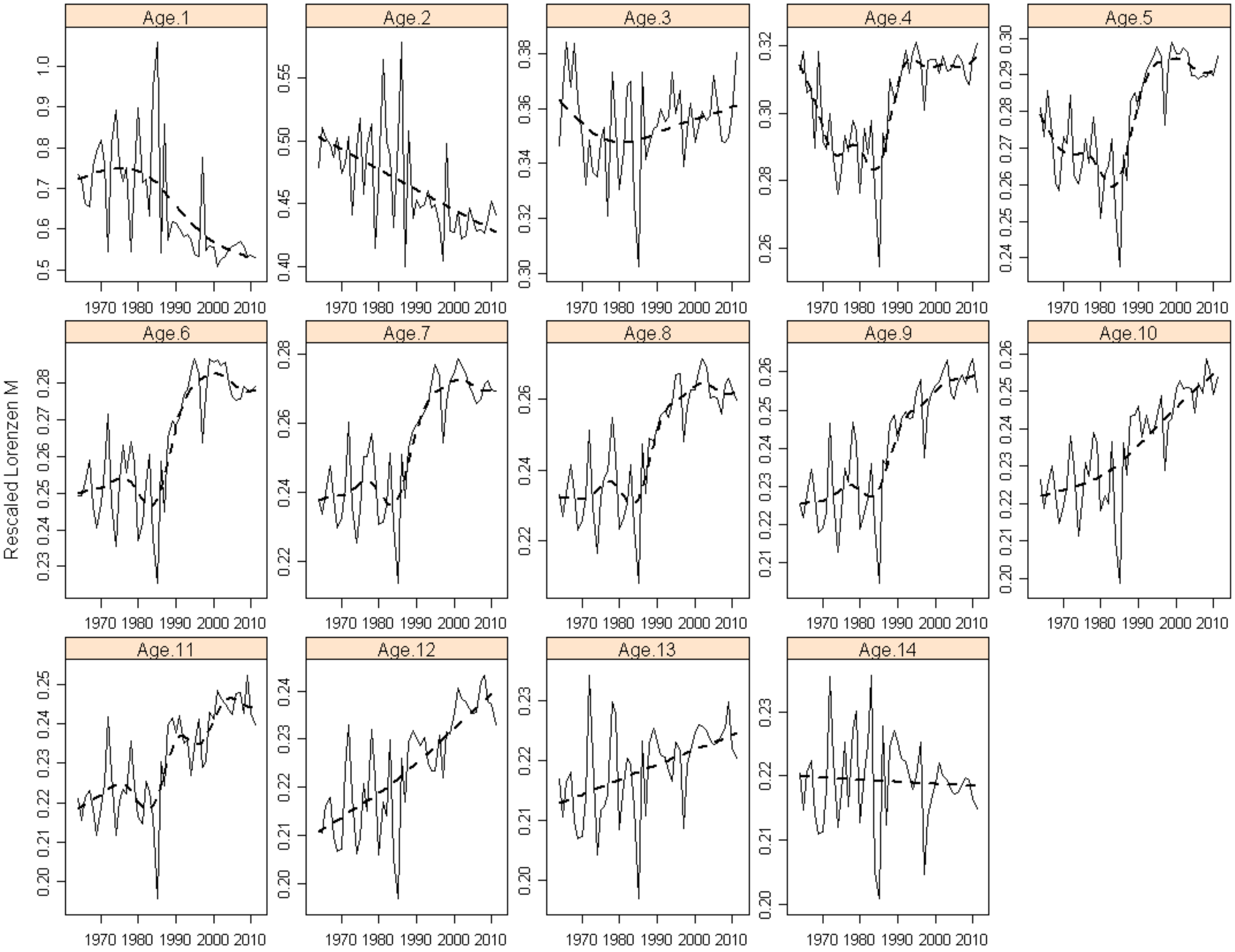


Figure A6-2.—Rescaled Lorenzen natural mortality (*M*) estimates for Atlantic herring during 1964-2011 (solid line). The dashed line is a smoothed temporal trend estimated using a general additive model. Note each panel has a unique scale.

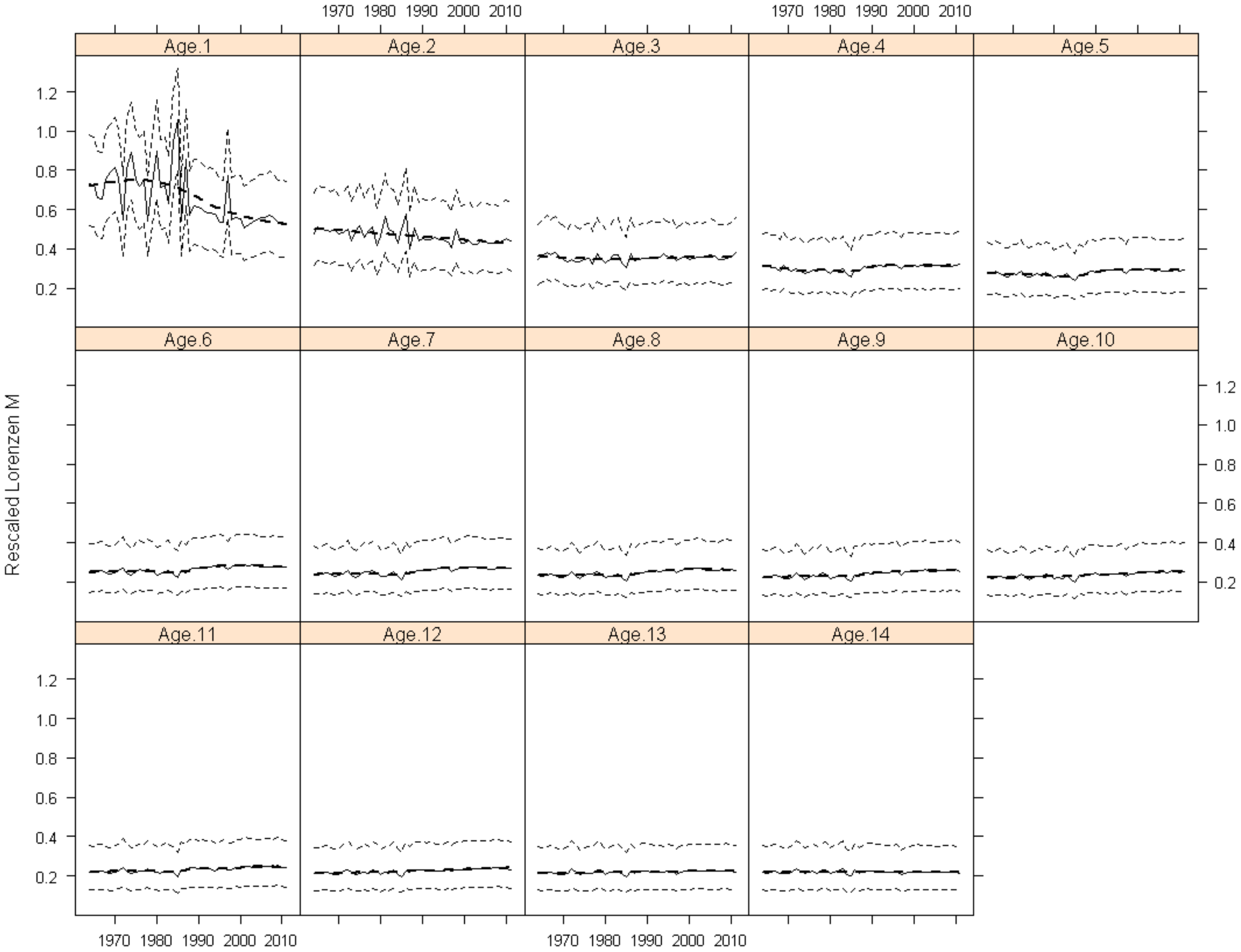


Figure A6-3.—As in Figure A2 except each panel has a standardized y-axis scale and the thin dashed lines are 90% confidence intervals. The confidence intervals only represent the uncertainty in the Lorenzen parameters, and so do not fully quantify the uncertainty.

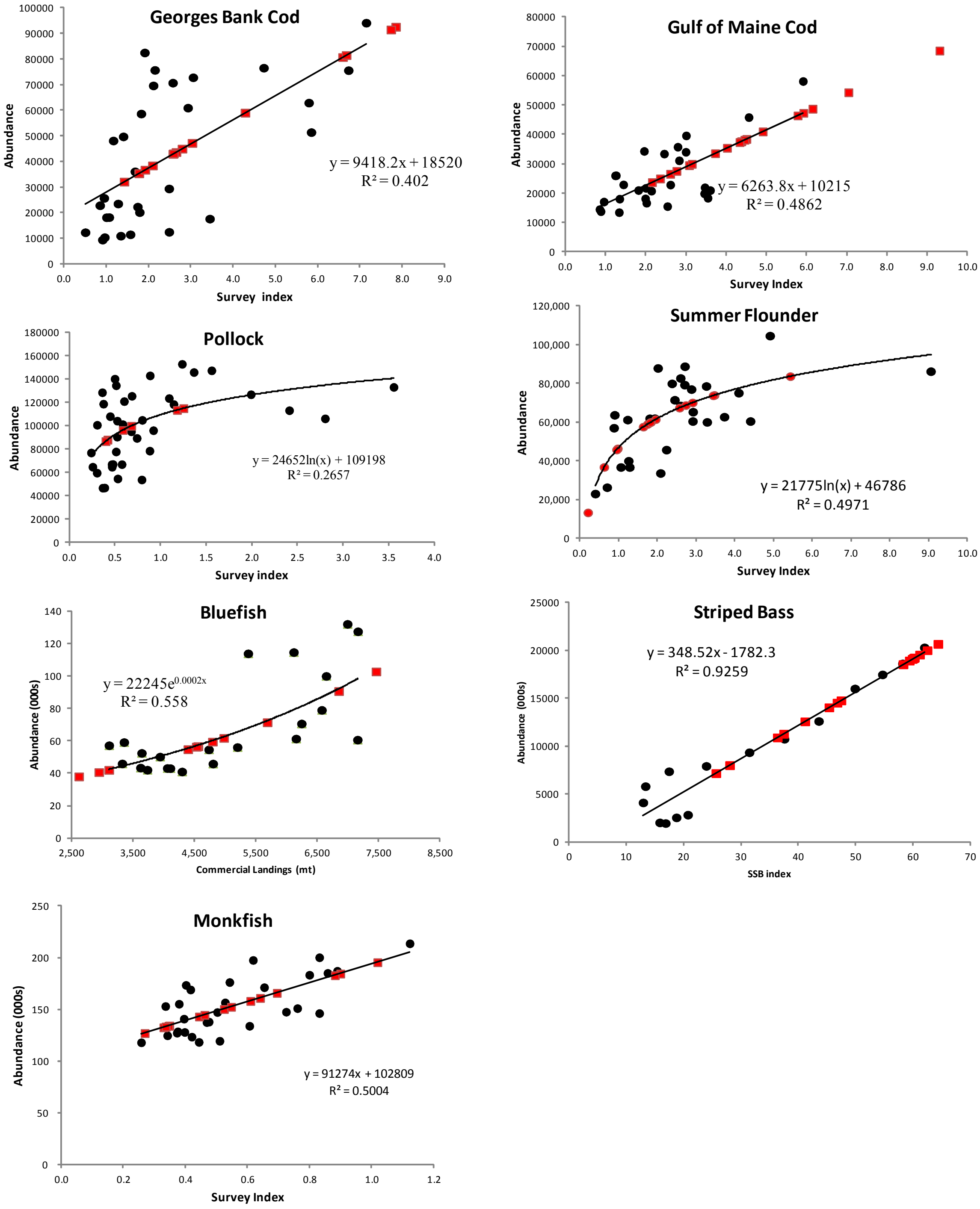


Figure A6-4. Relationships between indices and abundance estimates from assessment results.

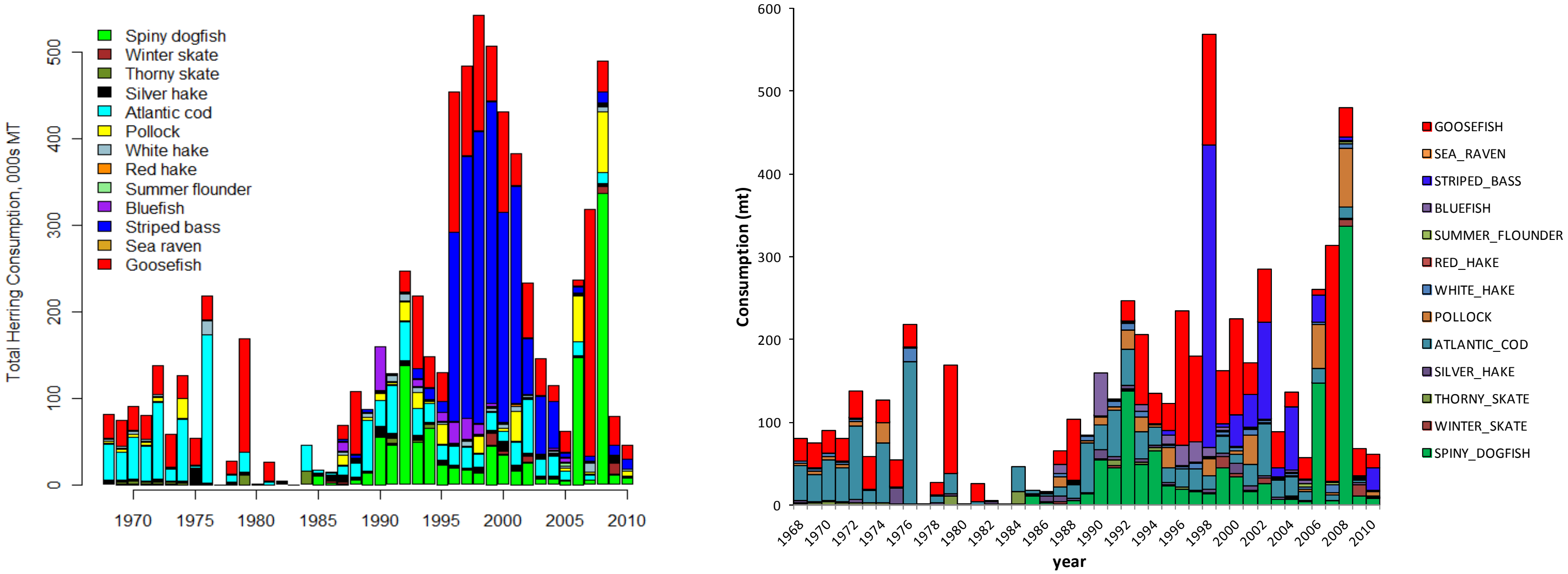


Figure A6-5. Total herring consumption by fish predator (non-HMS predators) using a moving average for striped bass for some years (left) and without using a moving average for striped bass (right). The left panel was used to inform the assessment.

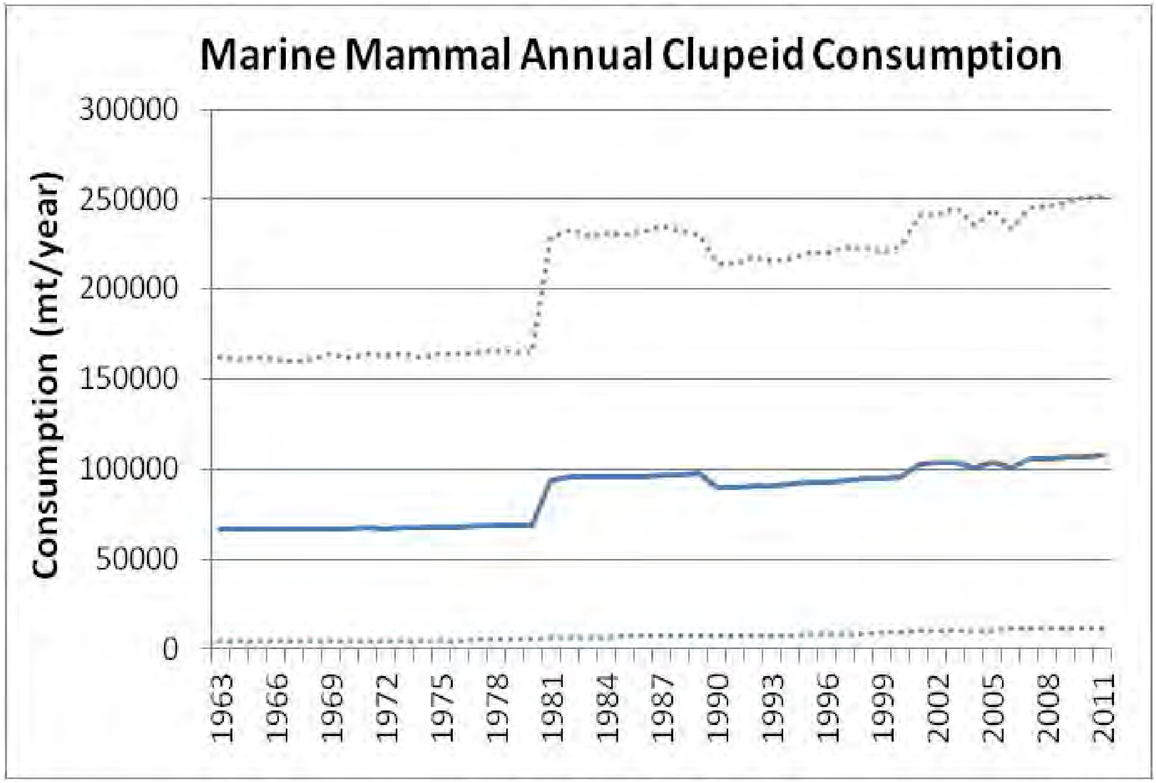


Figure A6-6. Total Atlantic herring consumption by marine mammals (± 80% CI).

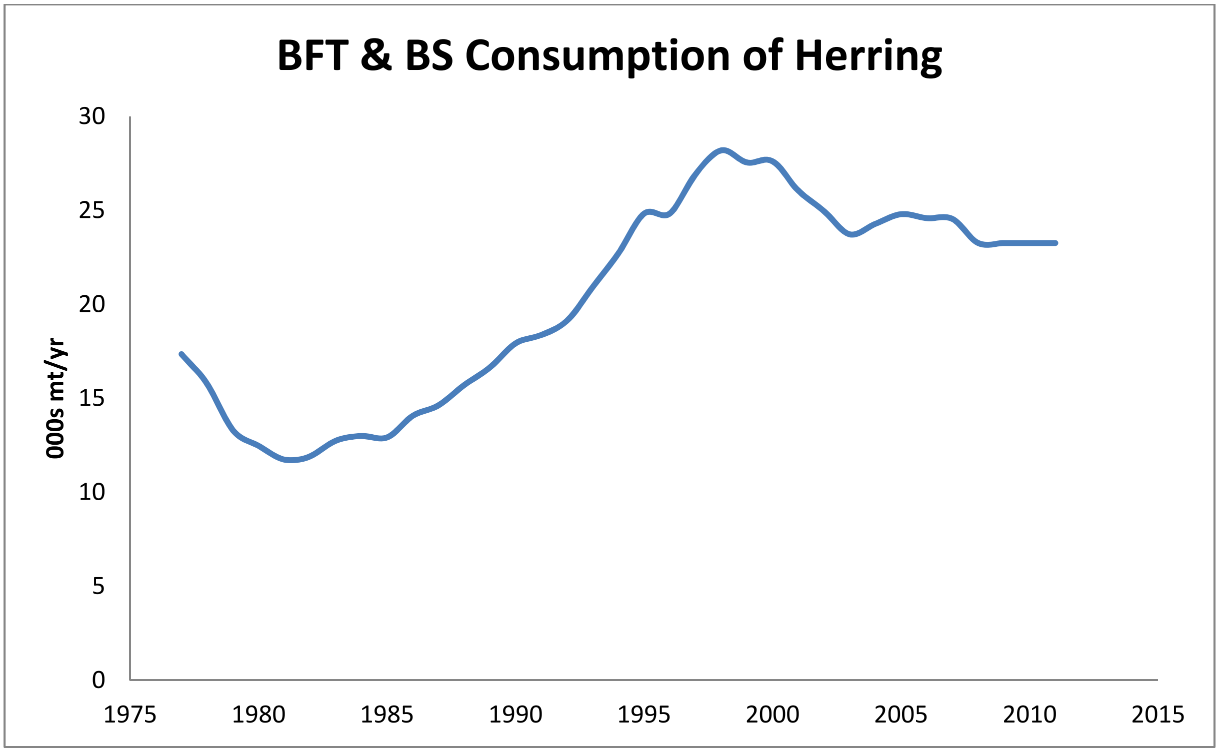


Figure A6-7. Annual estimates of Atlantic herring consumption by bluefin tuna and blue sharks.

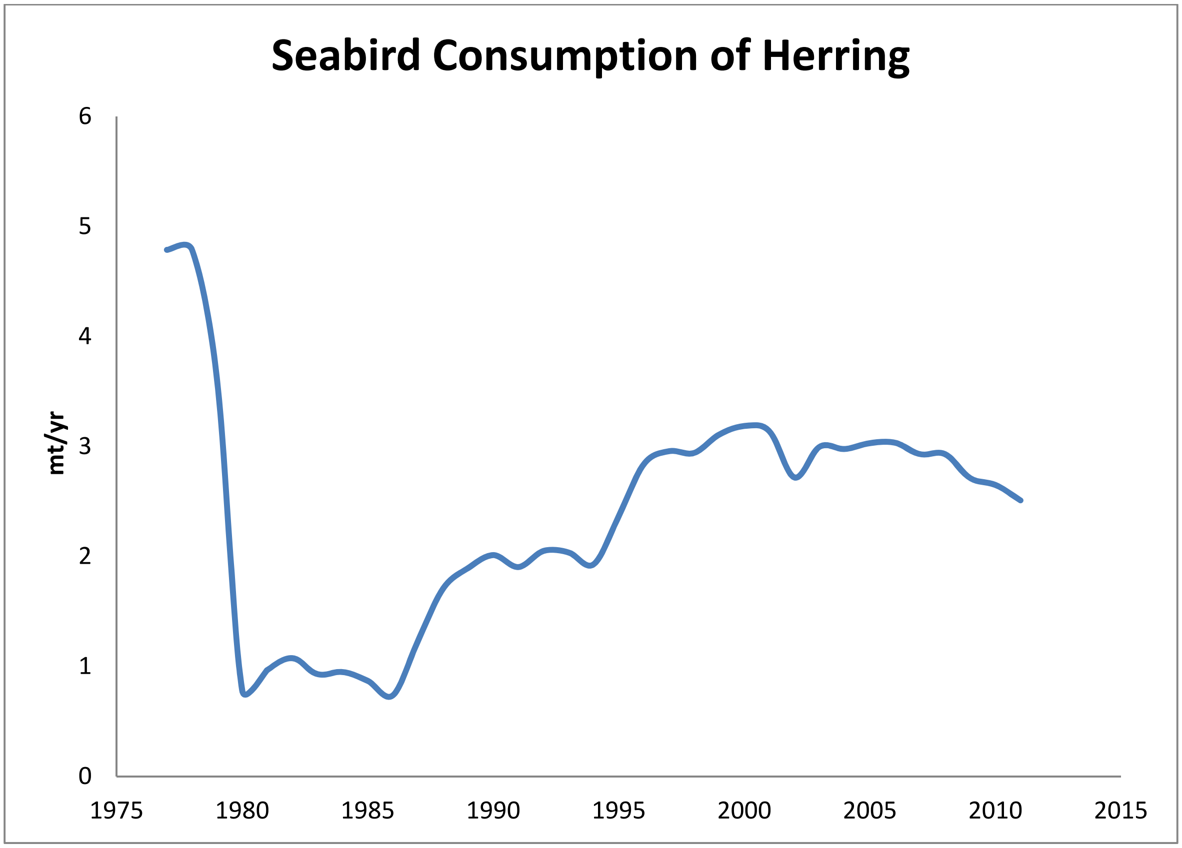


Figure A6-8. Annual estimates of consumption of Atlantic herring by seabirds.

TOR A5. *Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-6), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.*

Update of the 2009 TRAC ASAP model

The ASAP model (Age Structured Assessment Program, Legault and Restrepo 1998) formulation used during the 2009 TRAC was updated using data through 2011. This updated model continued to suffer from a retrospective pattern, similar to that produced by the 2009 TRAC assessment (Figure A5-1).

Given the continued severity of the retrospective pattern, nearly all data inputs and model settings were reconsidered during the development of this assessment. The major changes to the data are covered in detail under the discussions for other terms of reference, but they are summarized here for convenience. Natural mortality during the 2009 TRAC was assumed to equal 0.2 for all ages and years. For this assessment, natural mortality was treated in one of two ways: 1) using a “Lorenzen” method (Lorenzen 1996; see description below) or 2) modeling herring fish consumption directly as a fishing fleet (see TOR 6). The 2009 TRAC also used catch data combined among all fishing gears and assumed selectivity equaled 1.0 for all ages. This assessment included separate catches and estimated selectivity separately for two aggregate gear types; fixed and mobile gears (see TOR 1). This assessment also estimated selectivity for any survey with age composition data, which is in contrast to the 2009 TRAC which used age-specific indices. Also in regards to survey age composition, the 2009 TRAC used age-length keys borrowed from a combination of commercial sources to develop age composition for NMFS bottom trawl survey catches prior to 1987, when no age data was collected for herring during the surveys. Analyses done for this assessment demonstrated that applying commercial age-length keys to survey catches was likely inappropriate, and so this practice was not used during this assessment (see TOR 2). Finally, maturity at age varied through time in this assessment (see TOR 1), but was constant among years in the 2009 TRAC.

Summary of models considered for this assessment

Due to the major changes in data inputs since the 2009 TRAC, developing this assessment essentially involved starting from “scratch”. Consequently, much of the work in developing this assessment focused on ASAP, rather than some other modeling framework that would have added another dynamic element to the assessment. Furthermore, not enough time was available to fully develop models in more than one complex statistical modeling framework to the point of having a reasonable understanding and comfort with the methods and results. None the less, several other modeling frameworks were considered, albeit to a lesser degree than ASAP. A surplus production model, more specifically ASPIC (A Stock Production Model Including Covariates v5.34; available on the NOAA Fisheries Toolbox http://nft.nefsc.noaa.gov; Prager 1994), was tried. The results of ASPIC were not plausible and so a production model was considered an unsuitable modeling framework for Atlantic herring. A cursory attempt was made to use the Adaptive Framework Virtual Population Analysis (ADAPT-VPA) model (NOAA Fisheries Toolbox ADAPT-VPA version 2.7, 2007), but this model suffered from lack of convergence and was likely too inflexible for the dynamics (e.g., multiple fishing fleets) of the Atlantic herring fishery. A significant amount of time was dedicated to developing a SS (Stock Synthesis v3.23b; Methot 1990) model, but not enough time was available to fully explore this model and understand the results (but see Appendix A2). Similarly, researchers at the University of Maine (i.e., Yong Chen lab) have developed a length-based stock assessment model specifically for Atlantic herring, but this model has not yet been fully evaluated and so was not considered a plausible model for this assessment (WP A1). The working group agreed, however, that consideration of models that can accommodate length data may be useful for future herring assessments given the wealth of length data available for herring, uncertainty in aging, and the significant temporal changes in herring growth that might be important for modeling length-based selectivity.

ASAP base model data and configuration

In developing an ASAP base model, over 150 model runs were conducted. Early runs incrementally incorporated the new data inputs, while later runs focused on resolving diagnostic problems and refining the base model. The logic behind some of the modeling choices is described below.

The base model considered age 1 to an age 8 plus group and covered the time period 1965-2011. The age 8 plus group was based on the difficulties that ASAP had in estimating the abundance of age 9 and older herring in the first year (i.e., 1965) and concerns about the reliability of age data for older ages. The difficulty in estimating the abundance of the older ages in the first year was driven by a lack of data on the strength of these cohorts (e.g., see commercial age composition TOR 1). The model was started in 1965 when catch data from all sources (i.e., US and Canadian weir) was first available.

Despite the use of an age 8 plus group, estimates of abundance at age in the first year (i.e., 1965) in preliminary runs were still imprecise (e.g., CVs in the hundreds). To reduce this imprecision, a lognormal prior distribution with a variance partially defined by a CV equal to 0.9 was used for the estimates of the numbers at age in 1965. Model results were not sensitive to these relatively weak priors.

Natural mortality was an input in the assessment, but varied among ages and years. The M values were based on an adaptation of the Lorenzen method, where M is a function of fish weight, in combination with the Hoenig method (Hoenig 1983; Lorenzen 1996). Mean weights at age for Atlantic herring in each year were used to calculate age specific Ms through time (see TOR 6). For 1996-2011, the M values at all ages produced by the Lorenzen method were increased by 50%. This 50% increase was motivated by two factors: 1) a model using the original Lorenzen values exhibited a retrospective pattern in SSB that was largely resolved by the 50% increase, and 2) the 50% increase in M during 1996-2011 produced implied levels of consumption more consistent with estimates of herring predator consumption during those years. Although the original Lorenzen values were likely within any common confidence intervals that might surround the estimates of herring predator consumption, even though such measures of precision were not available, the increased M beginning in 1996 improved the retrospective pattern. A model using the original Lorenzen values is discussed below as an alternative run.

For the mobile gear fishery, selectivity-at-age was freely estimated for ages 1-4, while selectivity at ages 5-8 was fixed at 1.0. The working group agreed that the mobile gear fishery, which is characterized by mostly large scale trawlers and purse seine operations, should have a flat-topped selectivity curve, and hence the selectivity at older ages was fixed at 1.0. The model was not sensitive to fixing selectivity at 1.0 beginning at age 4 or 6, but using age 5 was supported by plots of age and length composition (see TOR 1). Selectivity at age for the fixed gear fishery was fixed at 1.0 for age 2, but estimated for all other ages. The fixed gear fishery almost exclusively harvests age 2 fish, while other ages are caught in relatively small proportions (see TOR 1). Because of the relatively small number of fish caught at ages other than 2, preliminary ASAP model fits had high levels of imprecision on selectivity estimates for most ages in the fixed gear fishery. Essentially, ASAP could produce a near zero age composition with a broad range of estimates for selectivity at most ages for the fixed gear and this translated to imprecision. To remedy the high degree of imprecision on the selectivity parameter estimates in the fixed gear fishery, lognormal prior distributions with a variance partially defined by a CV equal to 0.9 were used for all ages for which a parameter was estimated (i.e., all ages except age 2). Model results were not sensitive to these relatively weak priors.

Selectivity-at-age on the NMFS spring survey during 1968-1984 was fixed and equaled 0.0 at ages 1 and 2, 0.5 at age 3, and 1.0 at ages 4-8. Selectivity-at-age on the NMFS fall survey during 1965-1984 was fixed and equaled 0.0 at ages 1-3, 0.5 at age 4, and 1.0 at ages 5-8. Selectivity-at-age on the NMFS shrimp survey was fixed and equaled 0.0 for ages 1-5 and 1.0 for ages 5-8. The selectivities for these surveys were fixed because no age composition data was available. The values input for the selectivities were justified by examining length compositions for each survey (see TOR 2), and preliminary model runs were not sensitive to a broad range of selectivities for each survey.

The NMFS spring and fall surveys during 1985-2011 rarely caught any age 1 herring, but in few years caught a large proportion of age 1 fish (see TOR 2). Preliminary model runs suggested that ASAP would often “chase” these signals about year class strength and estimate a relatively high recruitment in those years with high age 1 catches in either of the surveys, which created retrospective patterns as more years of data about the given year class revealed a much weaker signal. The working group agreed that the rare high proportion of age 1 catches was likely caused by sampling variation, and so was not a good measure of cohort strength. Consequently, age 1 catches from these surveys were discarded from the base ASAP model (Table A5-1), which effectively means that selectivity at age 1 for both of these surveys equaled zero. For the NMFS spring survey during 1985-2011, selectivity-at-age was freely estimated for ages 2-4 and was fixed and equaled 1.0 for ages 5-8. For the NMFS fall survey during 1985-2011, selectivity was logistic. In preliminary model runs, both surveys had logistic selectivity patterns, but the spring survey had trends in the age composition residuals. These residual patterns were resolved by using an age specific selectivity pattern for the spring survey. The fall survey did not exhibit the same age composition residual patterns as the spring survey, and so the logistic selectivity was considered adequate for the fall survey.

The effective sample size (ESS) estimated for the fishery and survey age composition data was compared to the input ESS in an iterative fashion until the input ESS approximately matched the model estimated ESS. For the mobile gear fishery, the average model estimated ESS increased in the mid-1980s. The resulting input ESS for the mobile gear fishery equaled 13 during 1965-1984 and equaled 60 thereafter. For the fixed gear fishery, the age composition data during 1995-2011 was based almost exclusively on New Brunswick weir fishery catches because no age data was collected from US fixed gears. Furthermore, in a few years during this time frame the proportion of age 1 herring caught was unusually high (e.g., see 2006; TOR 1). Preliminary model runs suggested that ASAP would estimate a relatively high recruitment in those years with high age 1 catches in the fixed gear, which created retrospective patterns as more years of data about the given year class revealed a much weaker signal. Given these issues, the working group agreed that the age composition data during 1995-2011 for the fixed gear fishery should not be fit as well as age composition data from other years. Consequently, the input ESS during 1965-1994 for the fixed gear fishery equaled 29, which was based on the iterative process mentioned above, while the input ESS during 1995-2011 equaled 5, which was a number sufficiently low to resolve the problems associated with fitting the age composition in these years. For the NMFS spring survey during 1987-2011 (herring age sampling on NMFS surveys began in 1987), the input ESS equaled 19, and for the NMFS fall survey during 1987-2010 (age data in 2011 were not available at the time of the assessment) the input ESS equaled 28. Generally, these adjustments to the ESS led to slight improvements in statistical fit, but had little effect on model results.

The CVs on each survey data point were initially set equal to the CV estimated for the arithmetic mean numbers per tow in each year (see TOR 2). These CVs were then adjusted in an iterative fashion until the root mean square error (RMSE) of the standardized residuals for each survey was approximately within the 95% confidence intervals of the RMSE expected at the given sample size for each survey (Table A5-1). The RMSE in this context was used as a measure of the consistency between the input precision of the survey values (i.e., CVs) and the uncertainty in the fits to a given survey index (i.e., variance of the standardized residuals). An RMSE equal to 1.0 suggests that the input CVs exactly match the uncertainty in the model fit. An RMSE greater than 1.0 suggests that the CVs need to be increased and the opposite for an RMSE less than 1.0. In this assessment, when the RMSE was outside of the 95% confidence intervals of the RMSE expected at the given sample size for a survey, each input CV for that survey was multiplied by the RMSE and the model was refit. For example, if the RMSE equaled 1.5, each CV was multiplied by 1.5 (increasing the CVs by 50%) and the model was refit. This process was repeated until the RMSE agreed with expectations, which usually only required one iteration. CVs were not allowed to exceed 0.9 during this process, unless the initial CV estimate was greater than 0.9, then the CV equaled the initial estimate. Generally, these adjustments to input CVs led to improved consistency between model inputs and outputs, but had little effect on model results.

An annual CV of 0.1 was assumed in all years for the catch from both fisheries. Although ad hoc, this value admits some uncertainty in the catches and does not force an exact fit. Preliminary model runs, however, were not sensitive to the choice of CV over a range of values (e.g., 0.01 to 0.15).

The stock-recruitment parameters of a Beverton-Holt relationship (i.e., steepness and unexploited SSB) in the ASAP base model were freely estimated. The annual recruitment deviations were permitted to deviate from this underlying mean relationship with a CV equal to 1.0, which effectively equates to unconstrained annual recruitment estimates.

The Beverton-Holt stock-recruit relationship used in ASAP was modified so that unfished recruitment or steepness could be linear functions of some environmental covariates. Using a preliminary ASAP assessment run, improvements to model fit were explored by making unfished recruitment and steepness functions of a larval herring index (Appendix 5), a mean summer temperature time series, or a fall Georges Bank index of haddock biomass (herring egg predator). Incorporating each of these covariates provided only negligible improvements to a model without these covariates. Consequently, they were not included in the final assessment model.

Catchability for all surveys was freely estimated.

ASAP base model diagnostics

ASAP base model fits to the fishery catches were generally good. The residuals in both fisheries, however, had more positive than negative residuals, although the scale of these residuals was relatively small (Figures A5-2, A5-3). The input ESS for both fisheries appeared to be reasonable (Figures A5-4, A5-5). Fits to the mobile gear age composition did not exhibit any large residual runs or obvious year class effects (Figures A5-6, A5-7). Fits to the age 1 fixed gear fishery age composition had a run of small positive residuals (residual equals predicted minus observed) during 1990-2003, but the scale of these residuals was small (Figure A5-5:A5-8). Otherwise, fits to the fixed gear fishery age composition were generally good (Figures A5-8, A5-9). Model fits to the observed mean catch at age were good, with the exception of a few years at the beginning of the mobile gear fishery time series (Figures A5-10, A5-11). The mobile gear fishery selectivity increased in a near linear fashion to age-5, when full selection began (Figure A5-12). The fixed gear fishery selectivity increased from near 0.0 at age 1 to full selection at age 2 and then quickly declined at older ages (Figure A5-12). This selectivity pattern reflects the age composition of this fishery, with the largest proportion of the catch in most years being age 2.

Fits to the survey trends were generally good, with no long runs of residuals and residuals that were approximately centered on zero (Figures A5-13:A5-17). The only exception was a run of residuals during 2002 to 2009 of the NMFS fall survey (Figure A5-16). The model also did not predict an increase in 2010 and 2011 to the same degree as observed in the NMFS spring survey, although on a log scale these residuals were not exceptionally large (Figure A5-15). The input effective sample sizes for the NMFS spring and fall surveys during years with age composition appeared to be reasonable (Figures A5-18, A5-19). Fits to the age composition data for these surveys did not exhibit any large residual runs or obvious year class effects (Figures A5-20, A5-21). Model fits to the observed mean age were also reasonable and within the confidence intervals in nearly all years (Figures A5-22, A5-23).

The NMFS spring survey exhibits higher selectivity at younger ages than the fall survey (Figure A5-24). This pattern is consistent with the fall survey sampling of Atlantic herring during spawning, when fewer young, immature fish would be available than in the spring. The NMFS spring and fall surveys during 1965-1984 had lower selectivity on younger fish than during 1985-2011 (Figure A5-24).

The CVs on estimates of catchability (q) for all the surveys are approximately 1%. The q for the NMFS spring survey between the 1968-1984 period and the 1985-2011 period increased by a factor of 2.64 (0.0000018 to 0.0000048; Figure A5-25). The q for the NMFS fall survey between the 1965-1984 period and the 1985-2011 period increased by a factor of 13.6 (0.00000047 to 0.0000063; Figure A5-25). The most likely explanation for this degree of increase in catchability is a change in the doors used on the survey trawl gear. The NMFS shrimp survey q equaled 0.000013 and was the highest q of any of the surveys in the base model (Figure A5-25).

No two parameters of the ASAP base model had correlations greater than 0.9 or less than -0.9. The steepness and log unexploited SSB parameters, however, had a correlation of -0.89, which was the worst of any two parameters in the model. Steepness was estimated to be 0.53 with a CV of 24% and log unexploited SSB was estimated to be 13.1 with a CV of 1%. A steepness of 0.53 is within the 80% probability intervals of steepness estimated for Clupeidae in general and Atlantic herring specifically in a meta-analysis of stock-recruitment data, albeit at the low end of those intervals (Myers et al. 1999). Fit of the stock-recruitment data appeared reasonable (Figures A5-26, A5-27).

The Beverton-Holt stock-recruit relationship in ASAP was examined with a modification such that unfished recruitment or steepness could be linear functions of some environmental covariates (Appendix 5). Using a preliminary ASAP assessment run, improvements to model fit were explored by making unfished recruitment and steepness functions of a larval herring index, a mean summer temperature time series, or a fall Georges Bank index of haddock biomass (herring egg predator). Incorporating each of these covariates provided only negligible improvements to a model without these covariates. Consequently, they were not included in the final assessment model.

ASAP base model results

The base ASAP model estimated SSB in 2011 to be 517,930 mt, with SSB ranging from a minimum of 53,349 mt (1978) to a maximum of 839,710 mt (1997) over the entire time series (Figure A5-28; Table A5-2). The base ASAP model estimated total January 1 biomass in 2011 to be 1,322,446 mt, ranging from a minimum of 180,527 mt (1982) to a maximum of 1,936,769 mt (2009) over the entire time series (Figure A5-29; Table A5-2).

No common age is fully selected in both the mobile and fixed gear fishery. Consequently, reporting results for fishing mortality required deciding on a reference age. The working group agreed to use age 5 as the reference age for reporting results related to fishing mortality (F_5). This age is fully selected by the mobile gear fishery, which has accounted for over 80% of landings in recent years, and sometimes in excess of 95%. F_5 in 2011 equaled 0.138 and was near the all-time low of 0.129 (1994) (Figure A5-30; Table A5-2). F_5 in 2011, however, was not representative of fishing mortality rates in recent years, which averaged 0.231 during 2000-2009 and also showed an increasing trend during those years (Figure A5-30). Fishing mortality rates in 2010 and 2011 were relatively low due to the presence of a strong cohort (see below). The maximum F_5 over the time series equaled 0.798 (1980).

The implied consumption from the input natural mortality rates approximately matched the scale and trend of the estimates of herring consumption (Figure A5-31). This result suggested that the ASAP base model accounted for predator consumption demands on Atlantic herring and included ecosystem considerations.

With the exception of 2009, age 1 recruitment since 2006 has been below the 1996-2011 average of 15.8 billion fish (Figure A5-32; Table A5-2). The 2009 age 1 recruitment, however, was the largest in the time series at 59.4 billion fish. This large 2009 age 1 cohort consistently appeared in all sources of data that contain age composition. None the less, the appearance of this cohort is coincidental with the NMFS change in survey vessel beginning in 2009.

Although a stock-recruitment relationship was estimated in this assessment, a likelihood profile of the model over a broad range of steepness values suggested that the total negative log likelihood of the model does not vary much with changes in steepness, while MSY related reference points can change significantly (Table A5-3). So, although the model can estimate stock-recruitment parameters, the likelihood profile suggested that the model estimates are uncertain as are the MSY related reference points. This uncertainty, however, would not change the overfished or overfishing status of the Atlantic herring stock in 2011 (see TOR 8), except for relatively extreme low values of steepness (Figure A5-33).

Markov chain Monte Carlo (MCMC) simulation was performed to obtain posterior distributions of SSB and F_5 time series. An MCMC chain of length 400,000 was simulated with every 400th value saved to create an MCMC chain with length 1,000 for defining the posterior densities. The posterior densities of SSB and F_5 in all years had no obvious irregularities and are presumed to have converged. The posteriors for SSB and F_5 in 2011 are provided as an example (Figures A5-34). Time series plots of the 80% probability intervals are in Figure A5-35 while ASAP point estimates and the 80% probability intervals for SSB and F_5 in 2011 are below:

Metric	**ASAP point estimate**	**80% probability interval**
2011 SSB (mt)	517,927	390,006 - 688,321
2011 F5	0.138	0.100 - 0.186

The internal retrospective error in SSB and F_5 during 2004-2011 was relatively minor in scale and was characterized by errors in both positive and negative directions (Figures A5-36, A5-37). This result was expected given that M was adjusted in part to alleviate a retrospective error in SSB (see this TOR above). SSB relative retrospective error in the terminal years ranged from -0.12 in 2009 to 0.41 in 2005 and averaged (i.e., Mohn's Rho) 0.13. F_5 relative retrospective error in the terminal years ranged from -0.24 in 2005 to 0.13 in 2009 and averaged (i.e., Mohn's Rho) -0.07. Despite these generally positive features of the retrospective error, some concerns still remained. The retrospective error suggested a tendency to overestimate SSB and underestimate F_5 during

2004-2007, but errors were in the opposite direction for both metrics during 2008-2010 (Figures A5-36, A5-37). Furthermore, retrospective errors suggested a tendency to underestimate recruitment (age 1 numbers; Figure A5-38). Recruitment relative retrospective error in the terminal years ranged from -0.92 in 2009 to -0.19 in 2006 and averaged (i.e., Mohn's Rho) -0.52.

In addition to examining the retrospective errors in the terminal years of each peel as with using Mohn's Rho, the working group agreed that some measure of the duration of the retrospective pattern would be useful, especially for contrasting the results with the 2009 TRAC assessment. One approach would be to estimate the average number of consecutive years beginning with the terminal year that the relative retrospective error in SSB of each peel remains above 0.3. For example in the ASAP base run, this number would equal 2 for the 2005 peel because the errors for the 2005 and 2004 estimates are greater than 0.3 while all other errors for the peel are less than 0.3 (Figure A5-36). If the relative errors of a given peel are never greater than 0.3, as in 2008 for example, then a 0 is used for that peel in calculating the average. The value of 0.3 is arbitrary, but was selected because it provided a meaningful point of comparison given the scale and direction of the relative retrospective errors in SSB of the ASAP base run and the 2009 TRAC assessment. For the sake of brevity, we will refer to this metric throughout the remainder of the report as the average duration of the retrospective error. The average duration of the retrospective error in the ASAP base run during 2004-2011 (i.e., seven year peel) ranged from 0 in all years except 2006 and 2007, to 2 in 2007, and averaged 0.43. The average duration of the retrospective error in the 2009 TRAC assessment during 2001-2008 (i.e., seven year peel) ranged from 0 in 2007 to 18 in 2004, 2002, and 2001, and averaged 12.14. Thus, the retrospective pattern of the 2009 TRAC assessment persisted for a longer number of years at a more severe level than the ASAP base run.

Historical assessment retrospective

Estimates of SSB and fishing mortality among assessments from 1995, 2005, 2009 and the current ASAP base model were compared. Exact values from an assessment in 1998 were unavailable, but graphical representations of that assessment were similar in trend and scale as the 1995 assessment. The range of ages over which fishing mortality was calculated differed among assessments, and therefore F values are not directly comparable, but were still useful for examining temporal trends. Estimates of SSB from all assessments were similar prior to about 1988 (Figure A5-39). Assessments in 1995 and 1998, however, estimated SSB to be about four times higher in the mid-1990s than assessments in 2005-2012 (Figure A5-39). This contrast can be explained by a switch from a VPA model in 1995 and 1998 to an ASAP model for the other assessments. Estimates of SSB from the 2005, 2009, and 2012 base model were generally similar prior to about 2000, but suggested a tendency for updated models to estimate lower SSB in about the last five years of each assessment (Figure A5-39). Estimates of F from all the assessments showed generally similar trends among years (Figure A5-40). Changes in input data have occurred, especially between the 2012 base model and the 2005 and 2009 assessments, which mean these results are not entirely comparable. The differences in scale and trend were partially driven by changes to input data (e.g., temporal changes in M in base model not present in previous assessments) and not as a consequence of modeling choice.

ASAP base model sensitivity runs

The working group agreed that several variants of the base ASAP model should be presented as sensitivity runs. One of the sensitivities was to set natural mortality equal to 0.2 for all ages and years so that the consequence of the age and time variant natural mortality in the base run could be examined. This sensitivity would also serve to bridge at least some of the changes from previous assessments that also used 0.2. The working group strongly agreed, however, that age and time varying M developed either through the use of Lorenzen methods or direct modeling of a consumption fleet was preferred over 0.2, and that this sensitivity would be for demonstration only. The other sensitivity runs examined the effect of adding the NMFS acoustic, winter, and larval indices to the base model, with additional emphasis on the acoustic and winter surveys because the working group had extended discussions about these two data sources (see TOR 2 and 3).

A sensitivity run with M equal to 0.2 for all ages and years had similar trends in SSB and F_5 as the base run, but the scale of SSB was lower and F_5 was higher than the base run, especially since the late 1980s (Figure A5-41). This sensitivity run also produced implied levels of consumption that were less than the base run, and generally less than the estimates of herring consumption (Figure A5-42).

The addition of the NMFS acoustic, winter, or larval surveys to the base model, either alone or in combination, produced estimates of SSB and F_5 in 2011 that were within the 80% probability intervals of the base model with the exception of F_5 when all three surveys were added in combination (Figure A5-43). Furthermore, both the trends and scale of SSB and F_5 of these sensitivity runs were similar to the base model (Figures A5-44, A5-45). These results suggested a generally robust base model. A sensitivity run with the NMFS acoustic survey added to the base model exhibited a poor fit to this survey with patterned residuals (Figure A5-46). A sensitivity run with the NMFS winter survey added to the base model had similar problems (Figure A5-47).

"Alternative" ASAP runs

The working group spent considerable time examining models that were eventually eliminated from consideration as the base model. Two models were of particular interest: 1) a model that uses estimates of herring fish consumption as a fishery fleet, and 2) a model that uses the original Lorenzen natural mortality rates for the entire time series (without the 50% increase during 1996-2011 used in the base model). The working group agreed that these two models should be presented in an abbreviated form. The reasons these models were eliminated from consideration are discussed below and under other terms of reference.

The ASAP base model configuration was used to set-up a model run that used herring consumption by fish predators as a fishing fleet. All data and settings were identical to the base model with the following exceptions. The model began in 1968 because that is when consumption estimates were first available. Consumption of herring by fish predators was added as a third fishery (fixed and mobile gears being the other two). A consumption estimate for 2011 was not yet available and so was set equal to the consumption value estimated for 2010. Age composition data were not available for the consumption fleet. Furthermore, the length frequency of the herring consumed by predators was not considered to be representative of the consumption fleet selectivity pattern because stomach samples were taken from predators on NMFS spring and fall surveys, and the survey gear seemed to select only larger predators that tend to feed on larger herring. Furthermore, smaller herring may get digested at a faster rate than larger herring and so would be under-represented in samples. Thus, selectivity for the consumption fleet was a source of uncertainty. For this run, however, selectivity on the consumption fleet was input as fixed constants at age, with the values based on the time series average of the natural mortality rates from the ASAP base model rescaled to have a maximum of 1.0. Thus, the selectivity curve of the consumption fleet had the characteristic "Lorenzen shape" that declines exponentially with age (Figure A48). Input natural mortality, commonly referred to as M1, equaled 0.2 for all ages and years. This value was constant among ages because this source of mortality was intended to represent predation by migratory species and marine mammals, which were believed to fully select all herring. The value of 0.2 was chosen so that the implied consumption produced by this M1 approximately matched the best estimates of consumption for migratory species and marine mammals (see below). An annual CV of 0.6 was used for all years of the consumption fishing fleet. This value was chosen arbitrarily, but represents a greater degree of uncertainty in the consumption data than the commercial fishing fleets. Fits to the data from this run were similar to the ASAP base model (Table A5-4). The steepness and log unexploited SSB parameters, however, were correlated at -0.96. Estimates of SSB, F_5, and age 1 recruitment were generally similar in trend and scale to the ASAP base model (Figure A5-49). Some notable exceptions, however, are SSB and F_5 since the mid-2000s when this run had higher SSB and lower F_5 than the base run (Figure A5-49). The sum of the implied M1 consumption and the predicted catches for the fish predator consumption fleet approximately matched the estimates of total herring consumption (Figure A5-50). The internal retrospective error during 2004-2011 in SSB, F_5, and recruitment suggested a tendency to overestimate SSB and underestimate F_5 and recruitment (Figures A5-51, A5-53). SSB relative retrospective error in the terminal years ranged from -0.18 in 2008 to 1.9 in 2004 and averaged (i.e., Mohn's Rho) 0.88. F_5 relative retrospective error in the terminal years ranged from -0.67 in 2004 to 0.81 in 2008 and averaged (i.e., Mohn's Rho) 0.21. Recruitment relative retrospective error in the terminal years ranged from -0.88 in 2009 to 0.08 in 2006 and averaged (i.e., Mohn's Rho) 0.33. The average duration of the SSB retrospective error during 2004-2011 ranged from 0 in 2008-2010 to 6 in 2004 and 2005 and averaged 3.0. MSY related reference points were estimated for this run by externally fitting a Beverton-Holt stock-recruitment curve to the ASAP estimates of SSB and recruitment. For these calculations, natural mortality at each age equaled the sum of M1 and the Fs at age estimated for the fish predator consumption fleet in 2011. Commercial fishery selectivity equaled the sum of Fs at age estimated for the fixed and mobile gears in 2011 rescaled to a maximum of 1.0. Maturity and weights at age were set equal to the 2011 values used in ASAP. Inputs from 2011 were used for consistency with how ASAP calculated reference points internally (i.e., by using inputs from the final year of the assessment). F_{MSY} equaled 0.288, SSB_{MSY} equaled 1,552,180 mt, and MSY equaled 509,957 mt. As a sensitivity, this process of reference point estimation was repeated except natural mortality at each age equaled the sum of M1 and the average Fs at age estimated for the fish predator consumption fleet during 2007-2011. F_{MSY} equaled 0.221, SSB_{MSY} equaled 514,857 mt, and MSY equaled 135,701 mt. This result suggested that the reference points were highly sensitive and uncertain. This sensitivity was likely driven by the relatively high level of inter-annual variation in the fish predator consumption fleet estimates and subsequent F estimates (e.g., the 2011 "F" for the consumption fleet is relatively low). Thus, using "Fs" for the fish predator consumption fleet from 2011 or the average during 2007-2011 generated very different reference points. For this reason, projections based on these reference points were not conducted. A model that used estimates of herring fish consumption as a fleet was eliminated from consideration as the base model because the inter-annual variation of the fish predator consumption estimates was not well understood and was beyond what would be expected from a relatively constant predator fleet. Furthermore, ASAP would often track these inter-annual variations. Thus, the estimates of fish consumption were not considered an adequate measure of inter-annual variation in M, which is how they were treated in this context. Lastly, methods for estimating reference points and conducting short-term projections using a model with predator consumption as a fishing fleet are not well established, but results can vary widely, as demonstrated above. The recommendation was put forth by some members of the working group to form a multi-disciplinary task force to research and resolve some of these problems and maximize the utility of this data source in the future.

A predecessor to the ASAP base model run was a run that used the original Lorenzen natural mortality rates for each year and age (i.e., without the 50% increase in these Ms during 1996-2011). The difference in the input Ms was the only difference in the model configuration or data inputs between the Lorenzen run and the base model. Fits to the data from this run were similar to the ASAP base model (Table A5-4). The steepness and log unexploited SSB parameters, however, were correlated at -0.97. Estimates of SSB, F_5, and age 1 recruitment were generally similar in trend to the ASAP base model, but the scale of SSB and recruitment were lower and the scale of F_5 was higher than the ASAP base model, especially since about 1990 (Figure A5-49). The implied consumption from the input Lorenzen Ms (i.e., M1) was similar in scale to the estimates of herring consumption, but was generally less than the estimates of total consumption during 1996-2011 (Figure A5-54). The implied consumption being less than the estimates of total consumption during 1996-2011 were used to justify the 50% increase in M during these years in the ASAP base model (see above). The internal retrospective error during 2004-2011 in SSB, F_5, and recruitment generally overestimated SSB and underestimated F_5 and recruitment (Figures A5-55:A5-57). This retrospective pattern was the basis for eliminating this run as the base model. SSB relative retrospective error in the terminal years ranged from 0.04 in 2010 to 1.61 in 2005 and averaged (i.e., Mohn's Rho) 0.85. F_5 relative retrospective error in the terminal years ranged from -0.58 in 2005 to 0.001 in 2010 and averaged (i.e., Mohn's Rho) -0.36. Recruitment relative retrospective error in the terminal years ranged from -0.89 in 2009 to 0.59 in 2006 and averaged (i.e., Mohn's Rho) -0.14. The average duration of the SSB retrospective error during 2004-2011 ranged from 0 in 2009 and 2010, to 7 in 2005, and averaged 3.7. F_{MSY} equaled 0.413, SSB_{MSY} equaled 236,428 mt, and MSY equaled 121,580 mt from this Lorenzen run. Three year projections were conducted for this alternative for various harvest scenarios. Input data (e.g., weights at age, selectivity at age, M) were all set equal to the values used in 2011 for this ASAP alternative run. Abundances at age in year one of the projections were drawn randomly from the posterior distribution for these estimates, with the posterior being based on an MCMC as described above for the base model. These abundances were also adjusted for the retrospective pattern using age specific retrospective adjustment factors based on the Mohn's Rho calculated using a seven year peel of the numbers at age estimates for this run (Table A5-5). Results of the projections are presented in Table A5-6.

Exploratory runs aimed at reducing the retrospective pattern

Since the base ASAP model was partially chosen in an attempt to reduce the retrospective pattern of the Lorenzen run described above, the working group agreed that alternative models should be considered that make changes to the Lorenzen run which might be plausible and also reduce the retrospective pattern. Two alternatives were considered. One alternative increased catch of the mobile and fixed gears during 1996-2011 until the retrospective pattern in SSB was eliminated. A second alternative rescaled the Lorenzen Ms in all years so that they averaged 0.3 during 1965-1995 and 0.5 during 1996-2011. Although this step change in M is similar to the base run, they are distinct in that this run changes the average M while the base run used a percentage increase in M. Increasing catch by a factor of three was required to eliminate the retrospective pattern in SSB. Catch during 1996-2011, however, was thought to be relatively well estimated. Consequently, the working group agreed that an increase in catch by a factor of three was likely unreasonable. The step change in M produced implied levels of consumption that were on average 551,000 mt higher than estimates of total consumption during 1996-2011 (Figure A58). The working group agreed that this was also likely unreasonable.

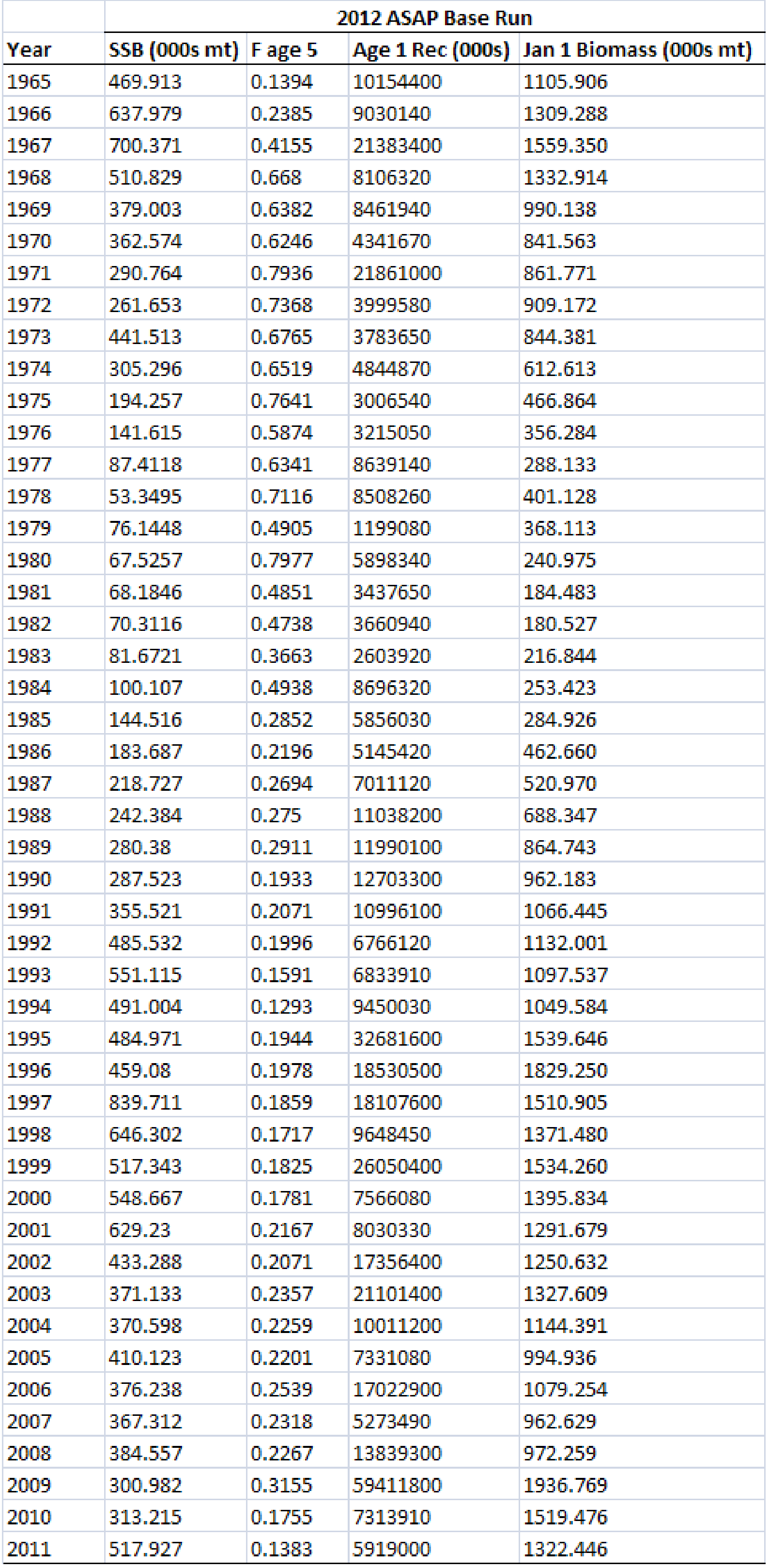
Comparison of Model and Acoustic results

Acoustic measurements of herring abundance on Georges Bank were conducted in the fall of 2006 by the two systems. The ratio of 2006 fall survey abundance estimates for Georges Bank to the entire mixed stock area was used to adjust acoustic estimates for comparison to the ASAP model results. The comparison was between ASAP number and biomass estimates for fish age 2 and greater. Details are provided in Appendix A6. In general, the daily estimates from OAWRS under-estimated stock sizes compared to NMFS acoustic and model results. However, the integrated numbers and biomass from OAWRS were quite similar to the ASAP base run. The NEFSC was consistently less than OAWRS and ASAP base runs, but similar to the ASAP Lorenzen model. The integrated OAWRS, NEFSC acoustic and ASAP models were all similar in scale for 2006.

Table A5-1. Mean numbers per tow and coefficients of variation input for each survey data point used in the ASAP base run. -999 indicates no observation for that year.

	Spring 1968-1984		Fall 1965-1984		Spring 1985-2011		Fall 1985-2011		Shrimp	
Year	Mean #	CV	Mean #	CV	Mean #	CV	Mean #	CV	Mean #	CV
1965	-999.00	-999.000	2.72	0.761	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1966	-999.00	-999.000	6.03	0.630	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1967	-999.00	-999.000	1.97	0.758	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1968	26.91	0.869	0.76	0.547	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1969	11.15	0.953	0.38	0.788	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1970	8.23	0.854	0.34	0.971	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1971	1.81	0.580	1.74	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1972	2.86	0.584	0.51	0.811	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1973	8.27	0.570	0.06	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1974	5.66	0.661	0.11	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1975	1.15	0.949	0.53	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1976	1.10	0.421	0.12	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1977	1.03	0.900	0.06	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1978	3.06	0.862	0.49	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1979	5.48	0.878	0.04	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1980	6.23	0.620	0.01	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1981	2.19	0.791	0.01	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1982	0.60	0.900	0.10	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1983	0.40	0.729	0.17	0.855	-999.00	-999.000	-999.00	-999.000	2.04	0.589
1984	2.83	0.853	1.04	0.900	-999.00	-999.000	-999.00	-999.000	-999.00	-999.000
1985	-999.00	-999.000	-999.00	-999.000	3.97	0.459	2.18	0.900	0.26	0.900
1986	-999.00	-999.000	-999.00	-999.000	34.46	0.900	1.05	0.831	0.63	0.787
1987	-999.00	-999.000	-999.00	-999.000	7.76	0.443	10.69	0.876	8.12	0.625
1988	-999.00	-999.000	-999.00	-999.000	14.32	0.482	12.51	0.900	25.44	0.900
1989	-999.00	-999.000	-999.00	-999.000	9.70	0.699	15.96	0.900	8.93	0.567
1990	-999.00	-999.000	-999.00	-999.000	9.34	0.405	15.72	0.900	16.77	0.565
1991	-999.00	-999.000	-999.00	-999.000	23.61	0.385	23.32	0.900	13.98	0.520
1992	-999.00	-999.000	-999.00	-999.000	36.32	0.492	63.50	0.573	8.96	0.617
1993	-999.00	-999.000	-999.00	-999.000	72.25	0.588	18.89	0.961	13.53	0.422
1994	-999.00	-999.000	-999.00	-999.000	34.70	0.383	15.35	0.520	20.77	0.540
1995	-999.00	-999.000	-999.00	-999.000	28.10	0.434	78.44	0.847	75.47	0.912
1996	-999.00	-999.000	-999.00	-999.000	64.92	0.672	42.19	0.739	40.23	0.695
1997	-999.00	-999.000	-999.00	-999.000	66.92	0.534	41.42	0.817	16.00	0.509
1998	-999.00	-999.000	-999.00	-999.000	51.69	0.543	23.19	0.247	45.99	0.553
1999	-999.00	-999.000	-999.00	-999.000	86.92	0.366	15.15	0.451	41.08	0.738
2000	-999.00	-999.000	-999.00	-999.000	33.28	0.476	23.21	0.622	8.26	0.594
2001	-999.00	-999.000	-999.00	-999.000	35.07	0.387	28.42	0.601	24.28	0.591
2002	-999.00	-999.000	-999.00	-999.000	27.27	0.613	86.83	0.900	30.22	0.522
2003	-999.00	-999.000	-999.00	-999.000	17.85	0.539	38.58	0.900	48.30	0.491
2004	-999.00	-999.000	-999.00	-999.000	47.87	0.811	45.73	0.530	30.63	0.552
2005	-999.00	-999.000	-999.00	-999.000	19.68	0.526	28.79	0.615	33.95	0.389
2006	-999.00	-999.000	-999.00	-999.000	27.15	0.689	31.63	0.900	25.51	0.900
2007	-999.00	-999.000	-999.00	-999.000	17.12	0.480	25.76	0.468	24.59	0.617
2008	-999.00	-999.000	-999.00	-999.000	16.66	0.693	25.65	0.792	9.61	0.419
2009	-999.00	-999.000	-999.00	-999.000	29.71	0.419	57.62	0.900	5.90	0.534
2010	-999.00	-999.000	-999.00	-999.000	88.70	0.436	26.89	0.466	19.89	0.792
2011	-999.00	-999.000	-999.00	-999.000	112.16	0.486	42.35	0.820	23.59	0.906

Table A5-2. Estimates of SSB, age 5 fishing mortality, age 1 recruitment, and total biomass from the ASAP base run.



	2012 ASAP Base Run			
Year	SSB (000s mt)	F age 5	Age 1 Rec (000s)	Jan 1 Biomass (000s mt)
1965	469.913	0.1394	10154400	1105.906
1966	637.979	0.2385	9030140	1309.288
1967	700.371	0.4155	21383400	1559.350
1968	510.829	0.668	8106320	1332.914
1969	379.003	0.6382	8461940	990.138
1970	362.574	0.6246	4341670	841.563
1971	290.764	0.7936	21861000	861.771
1972	261.653	0.7368	3999580	909.172
1973	441.513	0.6765	3783650	844.381
1974	305.296	0.6519	4844870	612.613
1975	194.257	0.7641	3006540	466.864
1976	141.615	0.5874	3215050	356.284
1977	87.4118	0.6341	8639140	288.133
1978	53.3495	0.7116	8508260	401.128
1979	76.1448	0.4905	1199080	368.113
1980	67.5257	0.7977	5898340	240.975
1981	68.1846	0.4851	3437650	184.483
1982	70.3116	0.4738	3660940	180.527
1983	81.6721	0.3663	2603920	216.844
1984	100.107	0.4938	8696320	253.423
1985	144.516	0.2852	5856030	284.926
1986	183.687	0.2196	5145420	462.660
1987	218.727	0.2694	7011120	520.970
1988	242.384	0.275	11038200	688.347
1989	280.38	0.2911	11990100	864.743
1990	287.523	0.1933	12703300	962.183
1991	355.521	0.2071	10996100	1066.445
1992	485.532	0.1996	6766120	1132.001
1993	551.115	0.1591	6833910	1097.537
1994	491.004	0.1293	9450030	1049.584
1995	484.971	0.1944	32681600	1539.646
1996	459.08	0.1978	18530500	1829.250
1997	839.711	0.1859	18107600	1510.905
1998	646.302	0.1717	9648450	1371.480
1999	517.343	0.1825	26050400	1534.260
2000	548.667	0.1781	7566080	1395.834
2001	629.23	0.2167	8030330	1291.679
2002	433.288	0.2071	17356400	1250.632
2003	371.133	0.2357	21101400	1327.609
2004	370.598	0.2259	10011200	1144.391
2005	410.123	0.2201	7331080	994.936
2006	376.238	0.2539	17022900	1079.254
2007	367.312	0.2318	5273490	962.629
2008	384.557	0.2267	13839300	972.259
2009	300.982	0.3155	59411800	1936.769
2010	313.215	0.1755	7313910	1519.476
2011	517.927	0.1383	5919000	1322.446

Table A5-3. Likelihood profile over a range of steepness values for the ASAP base run, including the objective function value (objfxn) and MSY reference points.

steepness	objfxn	MSY	B_{MSY}	F_{MSY}
35	3472.07	40051	277370	0.12
40	3471.42	42872	221840	0.16
45	3471.02	46530	190400	0.20
50	3470.82	50317	168300	0.24
55	3470.81	54073	150810	0.29
60	3470.92	57784	135930	0.33
65	3471.14	61490	122610	0.38
70	3471.44	65257	110180	0.44
74	3471.72	68375	100560	0.49
80	3472.19	73385	86072	0.59
85	3472.61	78104	73305	0.70
90	3473.06	83773	58860	0.87
95	3473.51	91621	40294	1.19

Table A5-4. Comparison of various aspects of alternative ASAP runs (table carries onto several pages).

	Model Run		
Data Source	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Mobile Gear Catch (1965-2011)	x	x	x
Fixed Gear Catch (1965-2011)	x	x	x
Mobile Gear Age Comp (1965-2011)	x	x	x
Fixed Gear Age Comp (1965-2011)	x	x	x
Fall NMFS Bottom Trawl (1965-1984)	x	x	x
Spring NMFS Bottom Trawl (1968-1984)	x	x	x
Fall NMFS Bottom Trawl (1985-2011)	x	x	x
Spring NMFS Bottom Trawl (1985-2011)	x	x	x
Fall NMFS Bottom Trawl Age Comp (1987-2011)	x	x	x
Spring NMFS Bottom Trawl Age Comp (1987-2011)	x	x	x
Winter NMFS Bottom Trawl (1992-2007)			
Shrimp NMFS Trawl (1983-2011)	x	x	x
Larval (1977-2009)			
Acoustic NMFS (1999-2011)			
Acoustic NMFS Age Comp (1999-2011)			
Fish Predator Consumption (1968-2010)			x

Model Structure	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Time period	1965-2011	1965-2011	1968-2011
Number of Fisheries	2	2	3
Number of Indices	5	5	5

Biology	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Maturity-at-age	Fixed; Age and Time Variable	Fixed; Age and Time Variable	Fixed; Age and Time Variable
Weight-at-age	Fixed; Age and Time Variable	Fixed; Age and Time Variable	Fixed; Age and Time Variable
Natural Mortality	Fixed; Lorenzen Age and Time Variable; 50% increase 1996-2011	Fixed; Lorenzen Age and Time Variable	M1=0.2; M2 Estimated Age and Time Variable

Table A5-4. (cont'd)

Stock Recruitment	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Unexploited Stock Size	Estimated	Estimated	Estimated
Steepness	Estimated	Estimated	Estimated
CV on Recruitment Deviations	1	1	1
Initial Conditions	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Fishing Mortality in Year 1 (Fishery1; Fishery2;…)	Estimated; Estimated	Estimated; Estimated	Estimated; Estimated; Estimated
Numbers-at-age in Year 1	Estimated	Estimated	Estimated
Fishery Selectivities	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Parameterization (Fishery1; Fishery2;…)	Estimated; Estimated	Estimated; Estimated	Estimated; Estimated; Fixed
Shape (Fishery1; Fishery2;…)	By age; By age	By age; By age	By age; By age; Decline with age
Time Blocks (Fishery1; Fishery2;…)	None; None	None; None	None; None; None
Indices Selectivities (If Age Comp Available)	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Parameterization	Estimated if age comp, else fixed	Estimated if age comp, else fixed	Estimated if age comp, else fixed
Shape	Spring 1985-2011 by age; Fall 1985-2011 logistic	Spring 1985-2011 by age; Fall 1985-2011 logistic	Spring 1985-2011 by age; Fall 1985-2011 logistic
Catchability	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
Parameterization for all Indices	Estimated	Estimated	Estimated

Table A5-4. (cont'd)

Likelihood Component	**ASAP Base Run**	**Lorenzen Run**	**Consumption Fleet Run**
__Catch_Fleet_1	472	472	440
__Catch_Fleet_2	412	412	384
__Catch_Fleet_3	NA	NA	513
__Index_Fit_1	41	41	41
__Index_Fit_2	16	17	4
__Index_Fit_3	111	117	112
__Index_Fit_4	114	115	115
__Index_Fit_5	109	111	109
Catch_Age_Comps	815	816	762
Survey_Age_Comps	472	470	470
__Sel_Param_1	0	0	0
__Sel_Param_2	0	0	0
__Sel_Param_3	0	0	0
__Sel_Param_4	0	0	0
__Sel_Param_9	-2	-2	-1
__Sel_Param_11	0	0	-1
__Sel_Param_12	-1	-1	-1
__Sel_Param_13	2	2	1
__Sel_Param_14	0	0	0
__Sel_Param_15	-2	-2	-2
__Sel_Param_16	-3	-3	-3
__Index_Sel_Param_18	0	0	0
__Index_Sel_Param_19	0	0	0
__Index_Sel_Param_20	0	0	0
__Index_Sel_Param_25	0	0	0
__Index_Sel_Param_26	0	0	0
q_year1_Total	0	0	0
q_devs_Total	0	0	0
__Fmult_year1_fleet_1	0	0	0
__Fmult_year1_fleet_2	0	0	0
__Fmult_year1_fleet_3	NA	NA	0
Fmult_year1_fleet_Total	0	0	0
Fmult_devs_fleet_Total	0	0	0
N_year_1	118	115	110
Recruit_devs	796	778	727
SRR_steepness	0	0	0
SRR_unexpl_stock	0	0	0
Fmult_Max_penalty	0	0	0
F_penalty	0	0	0
Total	3471	3459	3780

Table A5-4. (cont'd)

Key Parameters (CV in parentheses)	ASAP Base Run	Lorenzen Run	Consumption Fleet Run
ln(unexploited SSB)	13.074 (0.01)	13.893 (0.01)	15.66 (0.03)
Steepness	0.53016 (0.24)	0.84196 (0.13)	0.81127 (0.08)
Initial ln(F) Fishery 1	-2.1764 (-0.11)	-2.2364 (-0.10)	-0.22884 (-0.73)
Initial ln(F) Fishery 2	-1.6247 (-0.08)	-1.6588 (-0.08)	-1.809 (-0.07)
Initial ln(F) Fishery 3	NA	NA	-1.8679 (-0.24)
SSB 1965	469910 (0.24)	484380 (0.22)	NA
SSB 2011	517930 (0.22)	507000 (0.23)	995660 (0.24)

Table A5-5. Retrospective adjustment factors applied to abundances at age in the first year of projections for an ASAP run using original Lorenzen natural mortality. Abundances at age were multiplied by these values.

Age	Retrospective Adjustment Factor
1	1.158
2	0.789
3	0.604
4	0.602
5	0.631
6	0.603
7	0.587
8	0.572

Table A5-6. Results of three year projections for an ASAP run using original Lorenzen natural mortality.

Fmsy = 0.413	SSBmsy = 236428 mt	steepness = 0.842	MSY = 121580 mt
2011 F (age 5)	SSB 2011		2011 catch
0.144	506996 mt		85,000 mt
2012 catch = 87,683 mt (quota)			
	2013	**2014**	**2015**
	F_{msy}		
F	0.413	0.413	0.413
SSB	352,253 mt	307,891 mt	297,278 mt
80% CI	254,851 - 483,750 mt	229,681 - 416,344 mt	232,960 - 386,175
catch	193,377 mt	164,157 mt	149,135 mt
80% CI	142,576 - 260-696 mt	126,265 - 214,636 mt	115,382 - 196,142 mt
	$F_{75\%\ msy}$		
F	0.31	0.31	0.31
SSB	382,214 mt	358,382 mt	361,995 mt
80% CI	276,935 - 523,068 mt	266,869 - 485,308 mt	283,169 - 469,913 mt
catch	150,936 mt	137,383 mt	131,121 mt
80% CI	111,346 - 203,634 mt	105,378 - 179,838 mt	101,425 - 171,955 mt
	$F_{status\ quo}$		
F	0.144	0.144	0.144
SSB	435,451 mt	459,647 mt	503,259 mt
80% CI	316,673 - 592,369 mt	341,918 - 622,416 mt	392,282 - 654,636 mt
catch	74,888 mt	76,469 mt	79,795 mt
80% CI	55,264 - 101,237 mt	58,389 - 100,454 mt	61,575 - 104,585 mt
	MSY		
F	0.24	0.26	0.26
80% CI	0.18 - 0.34	0.18 - 0.37	0.18 - 0.40
SSB	403,413 mt	392,553 mt	403,525 mt
80% CI	270,452 - 576,873 mt	250,128 - 590,929 mt	253,355 - 607,975 mt
catch	121,580 mt	121,580 mt	121,580 mt
	Status quo catch		
F	0.17	0.17	0.16
80% CI	0.12 - 0.24	0.12 - 0.24	0.12 - 0.24
SSB	426,828 mt	442,441 mt	479,394 mt
80% CI	294,319 - 600,486 mt	298,055 - 641,847 mt	328,505 - 684,967 mt
2012 quota	87,683 mt	87,683 mt	87,683 mt

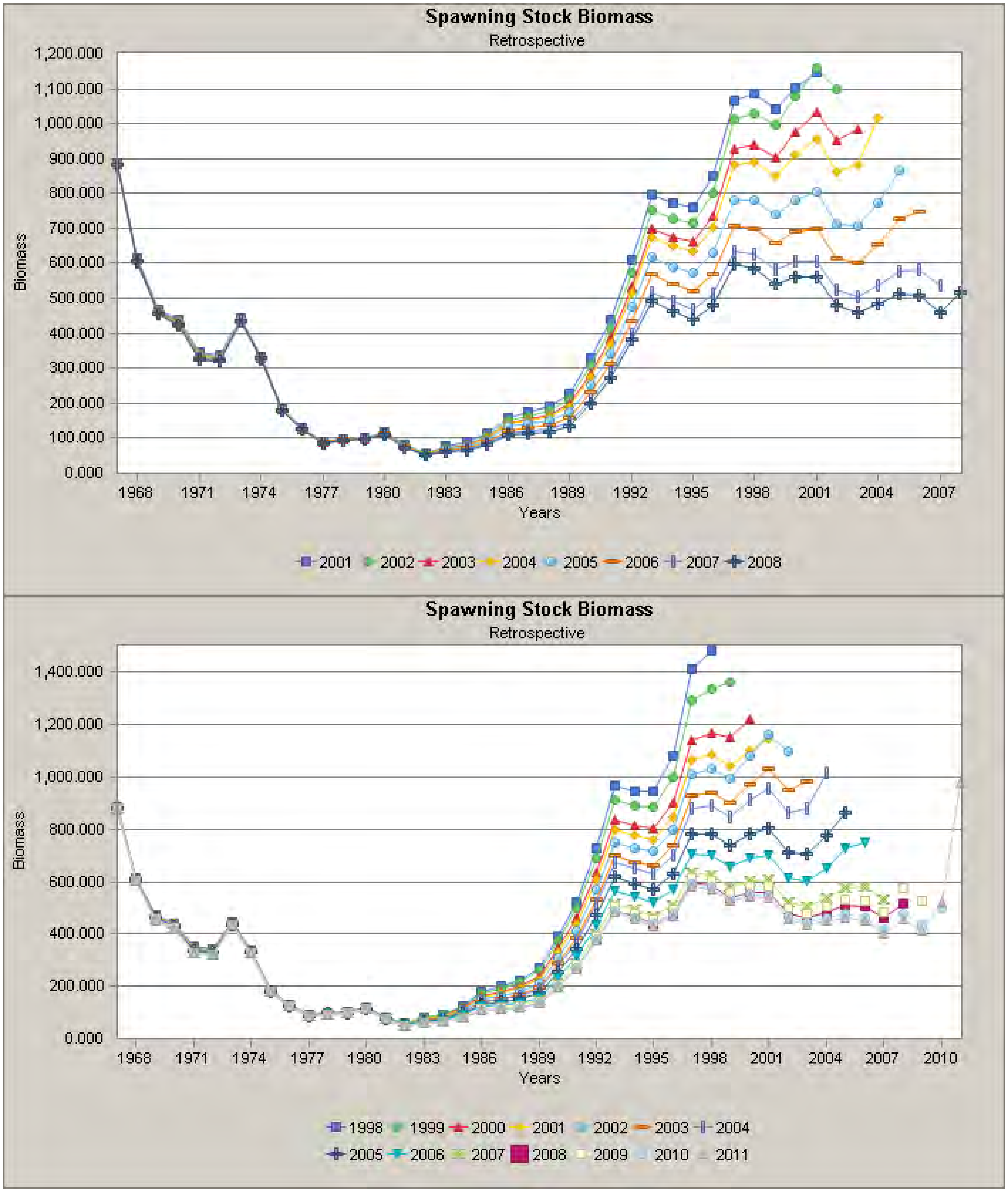


Figure A5-1. Internal retrospective pattern for spawning stock biomass from the 2009 TRAC assessment (top panel) and 2009 TRAC assessment updated using data through 2011 (bottom panel).

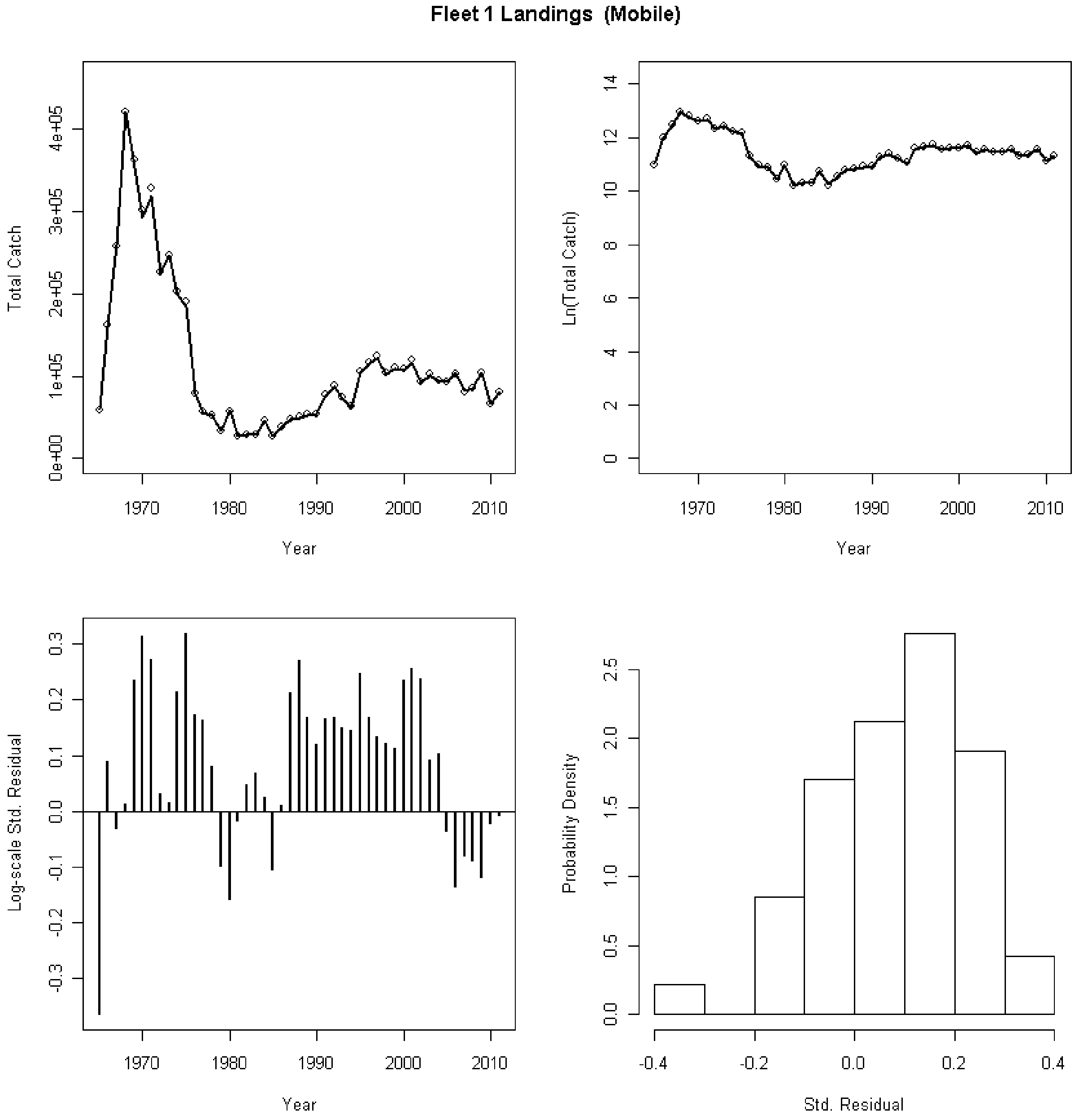


Figure A5-2. ASAP base model fit to mobile gear fishery catches.

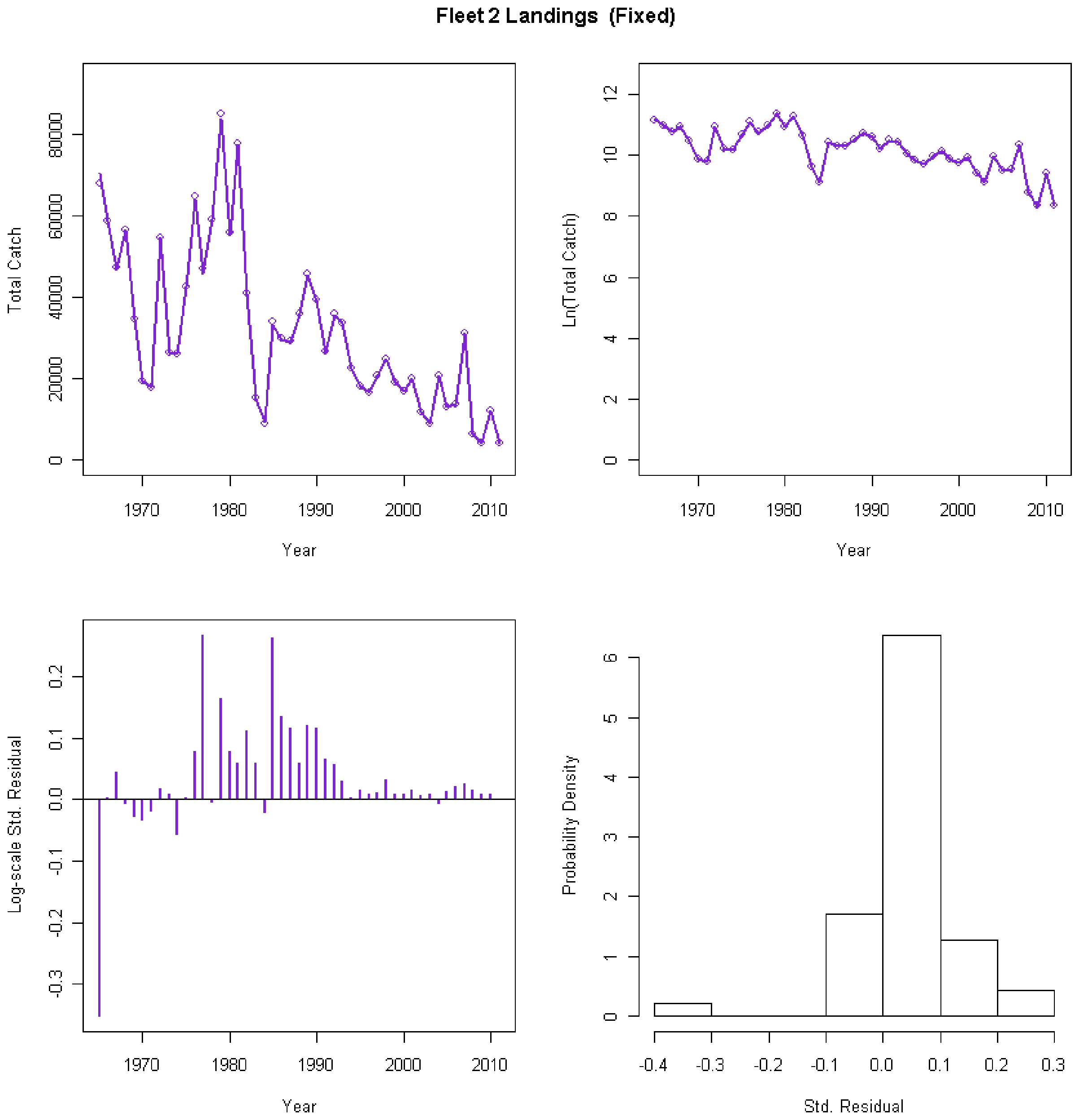


Figure A5-3. ASAP base model fit to fixed gear fishery catches.

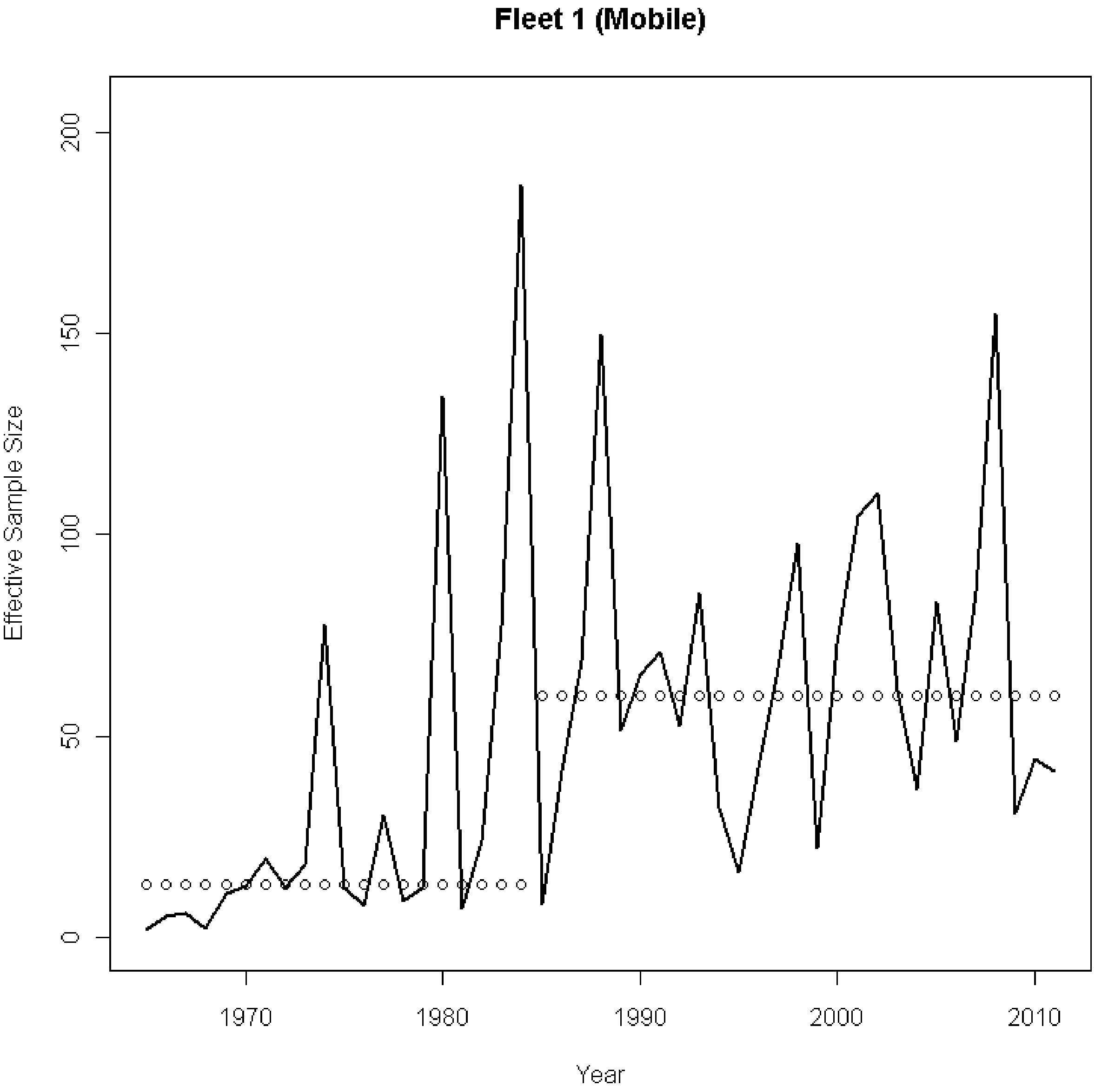


Figure A5-4. Input and estimated effective sample sizes from the ASAP base run for the mobile gear fishery.

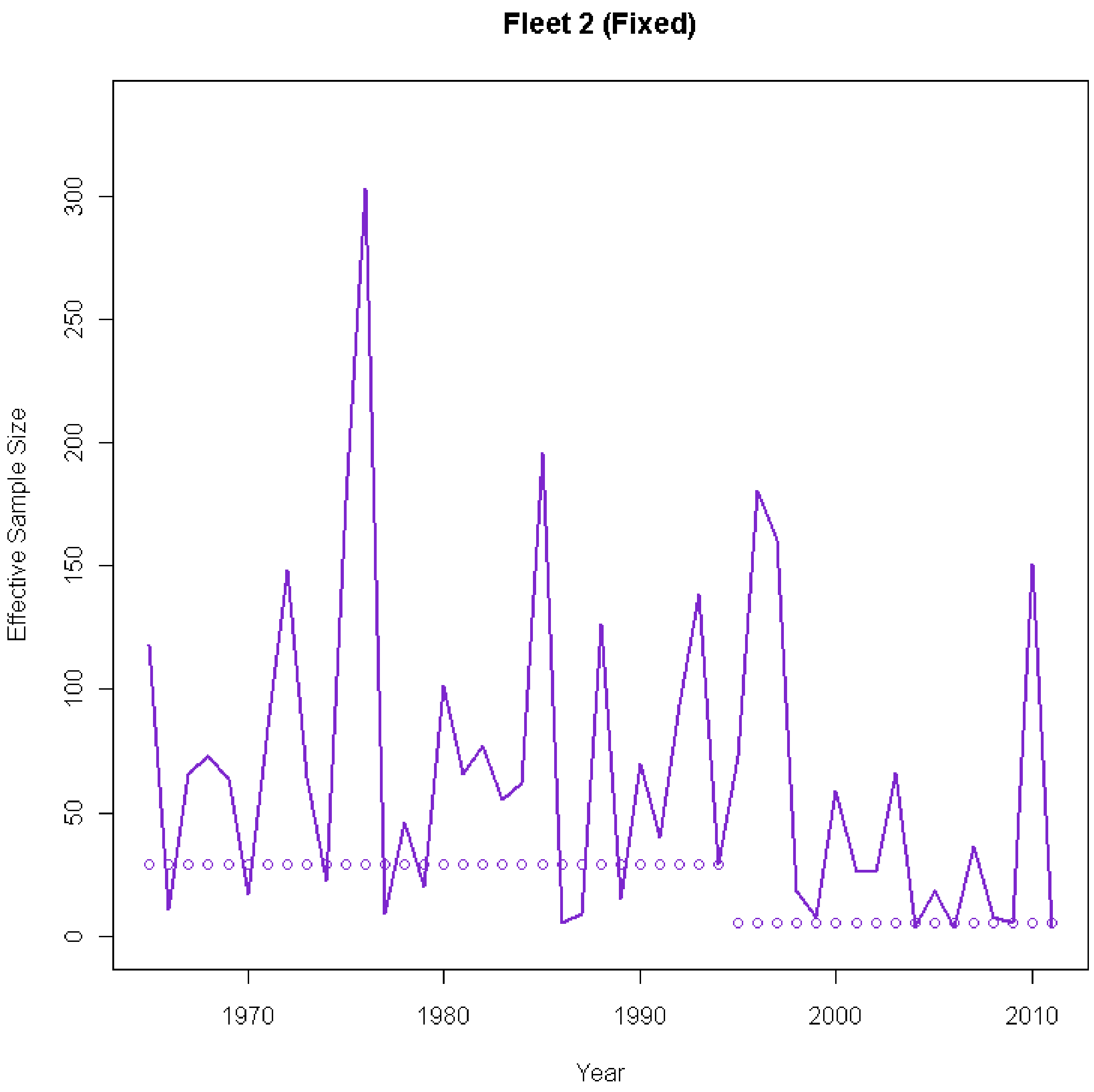


Figure A5-5. Input and estimated effective sample sizes from the ASAP base run for the fixed gear fishery.

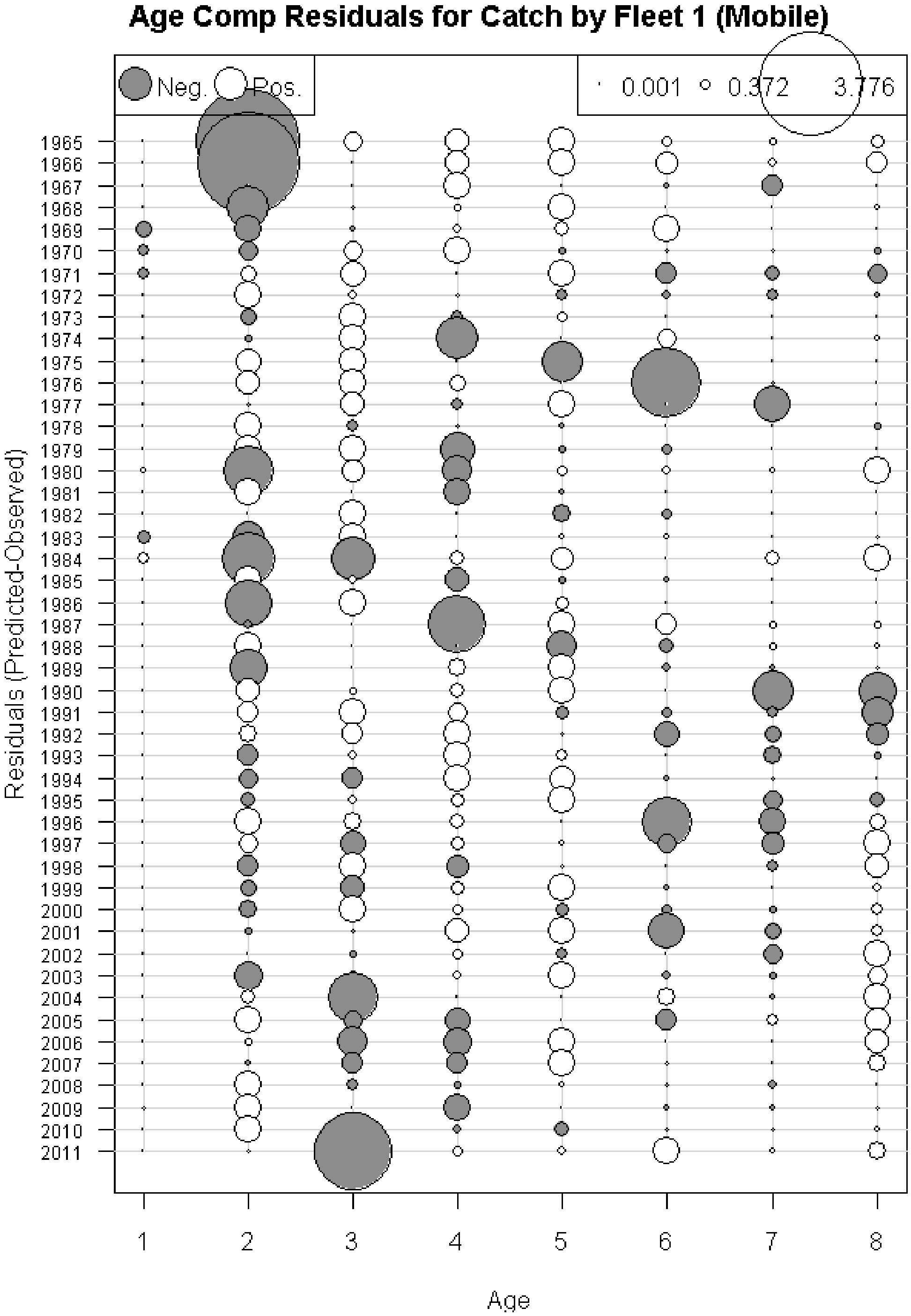


Figure A5-6. Age composition fits from the ASAP base run for the mobile gear fishery.

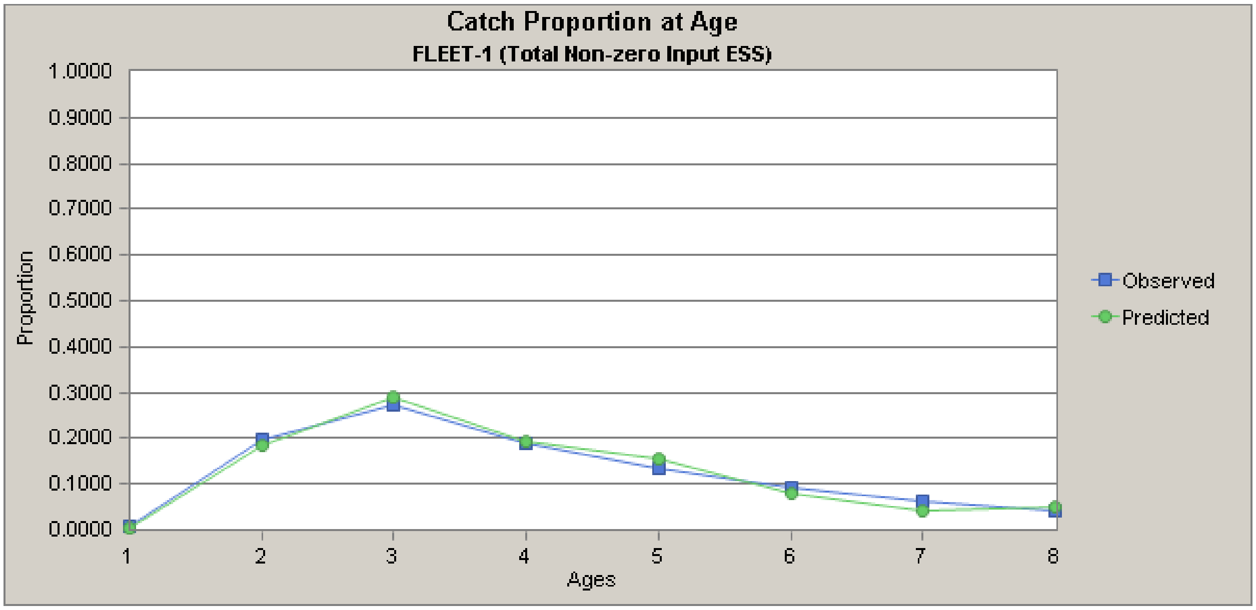


Figure A5-7. Total age composition fit from the ASAP base model for the mobile gear fishery.

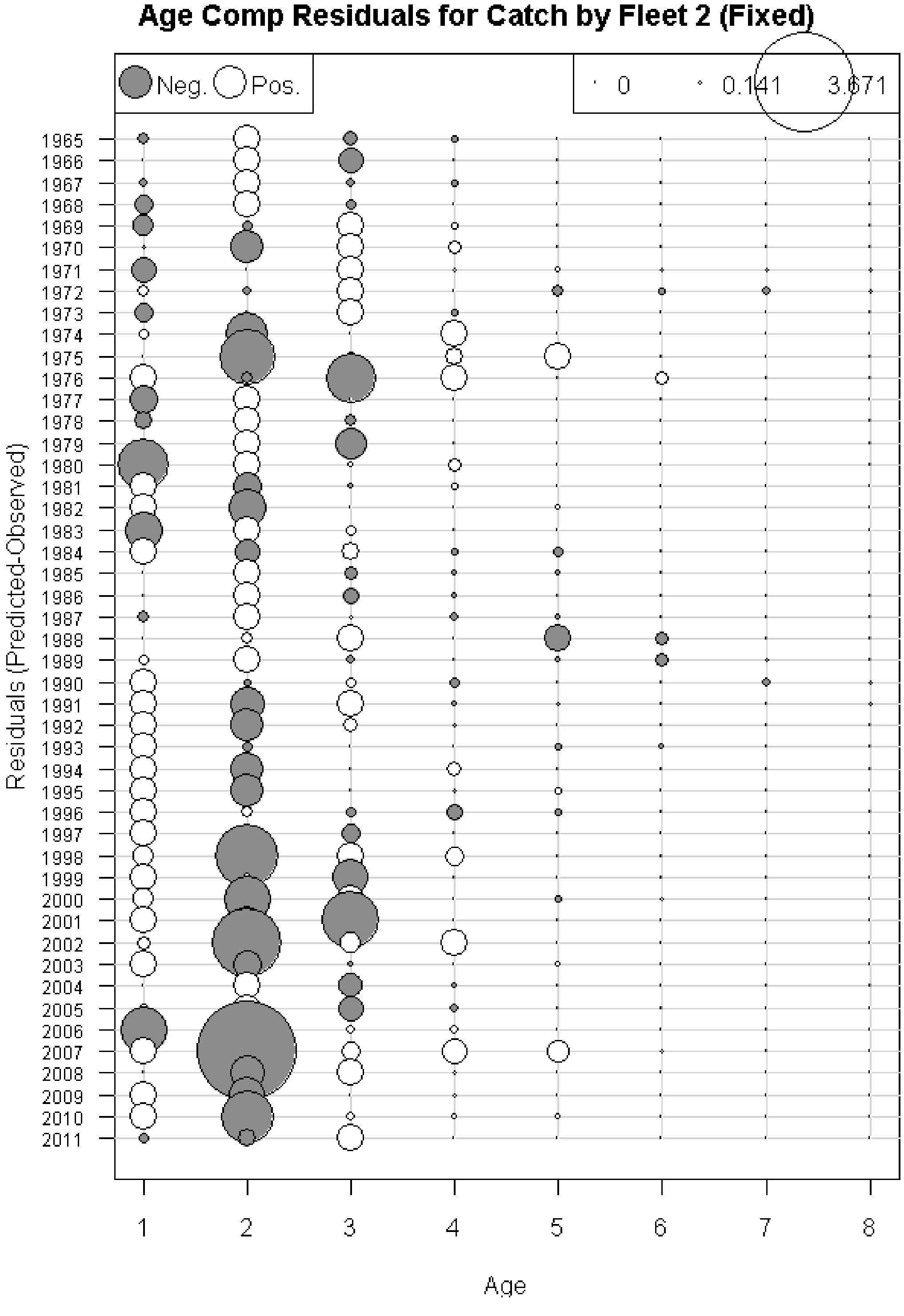


Figure A5-8. Age composition fits from the ASAP base run for the fixed gear fishery.

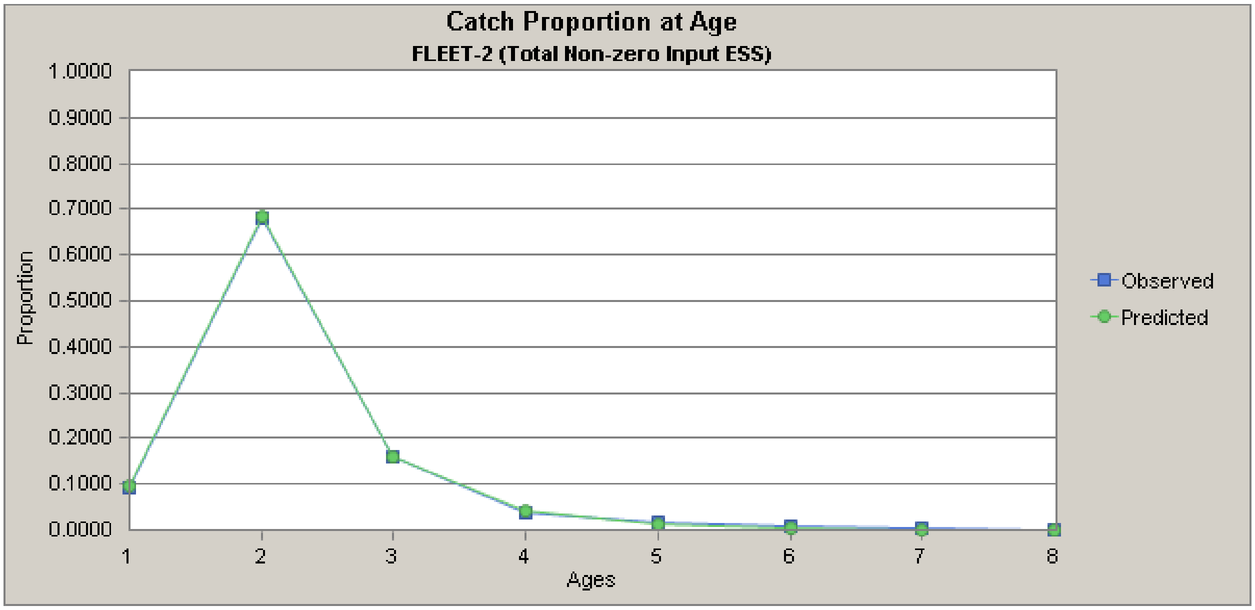


Figure A5-9. Total age composition fit from the ASAP base model for the fixed gear fishery.

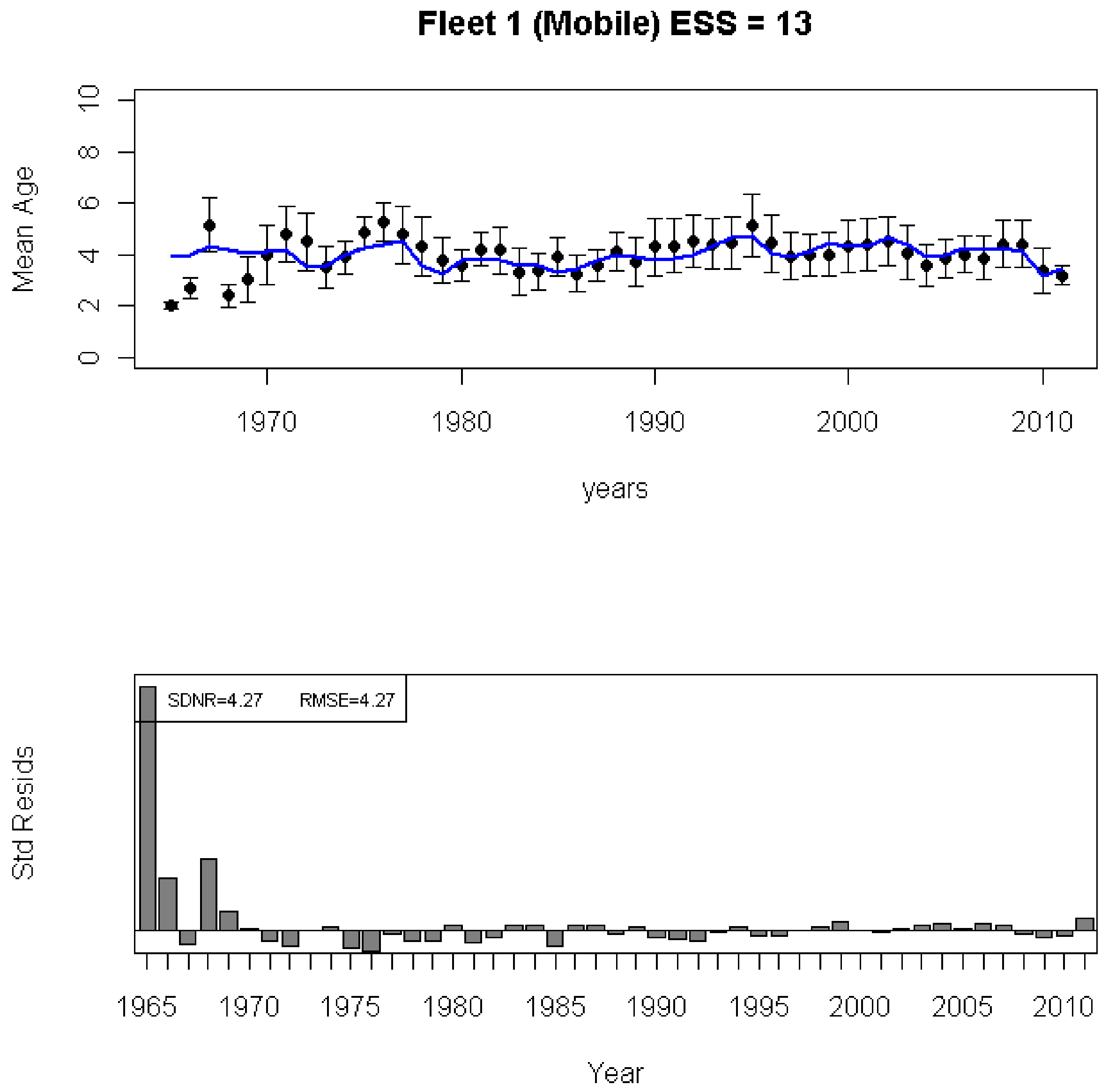


Figure A5-10. Fits to the observed mean age from the ASAP base model for the mobile gear fishery.

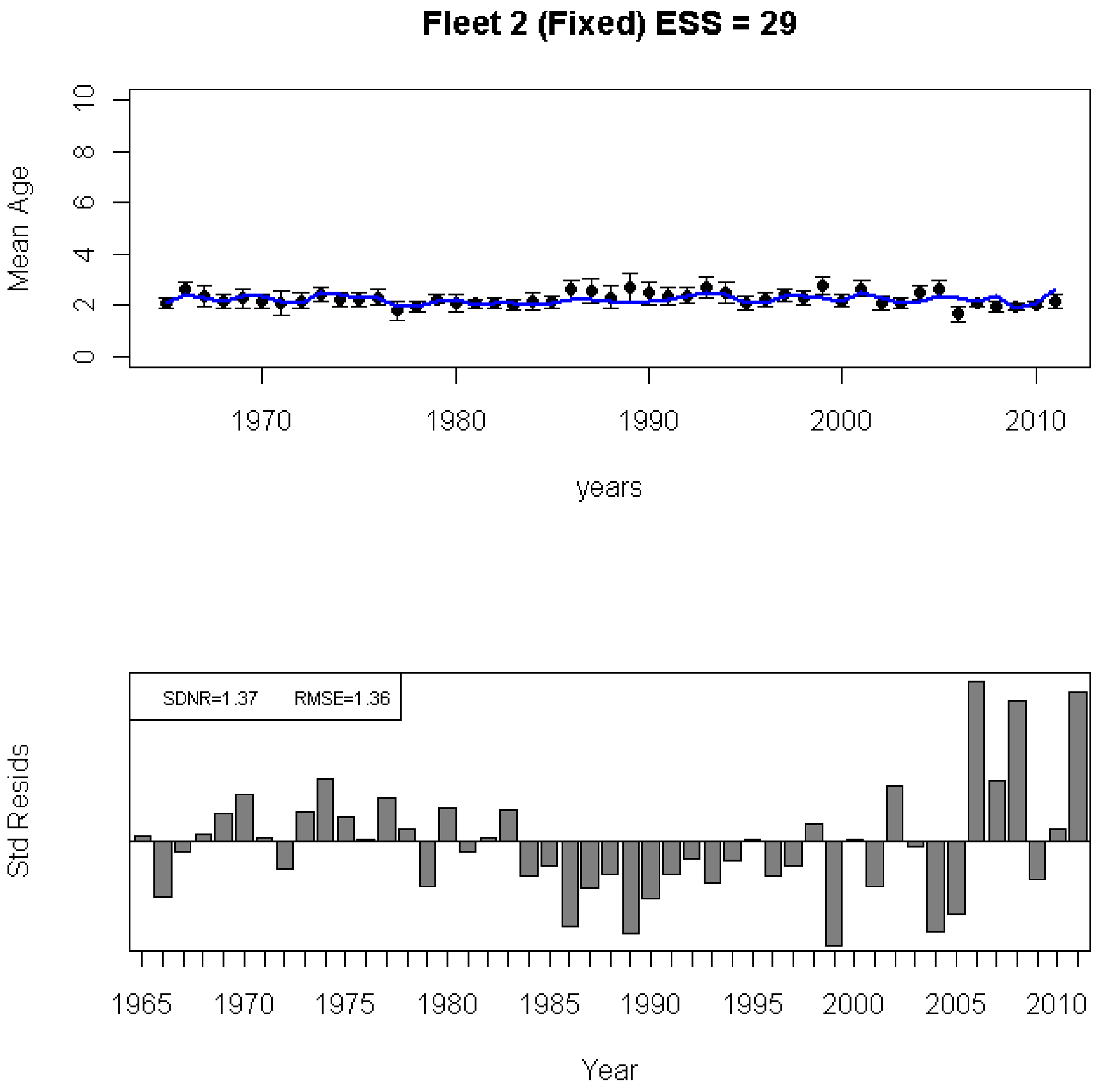


Figure A5-11. Fits to the observed mean age from the ASAP base model for the fixed gear fishery.

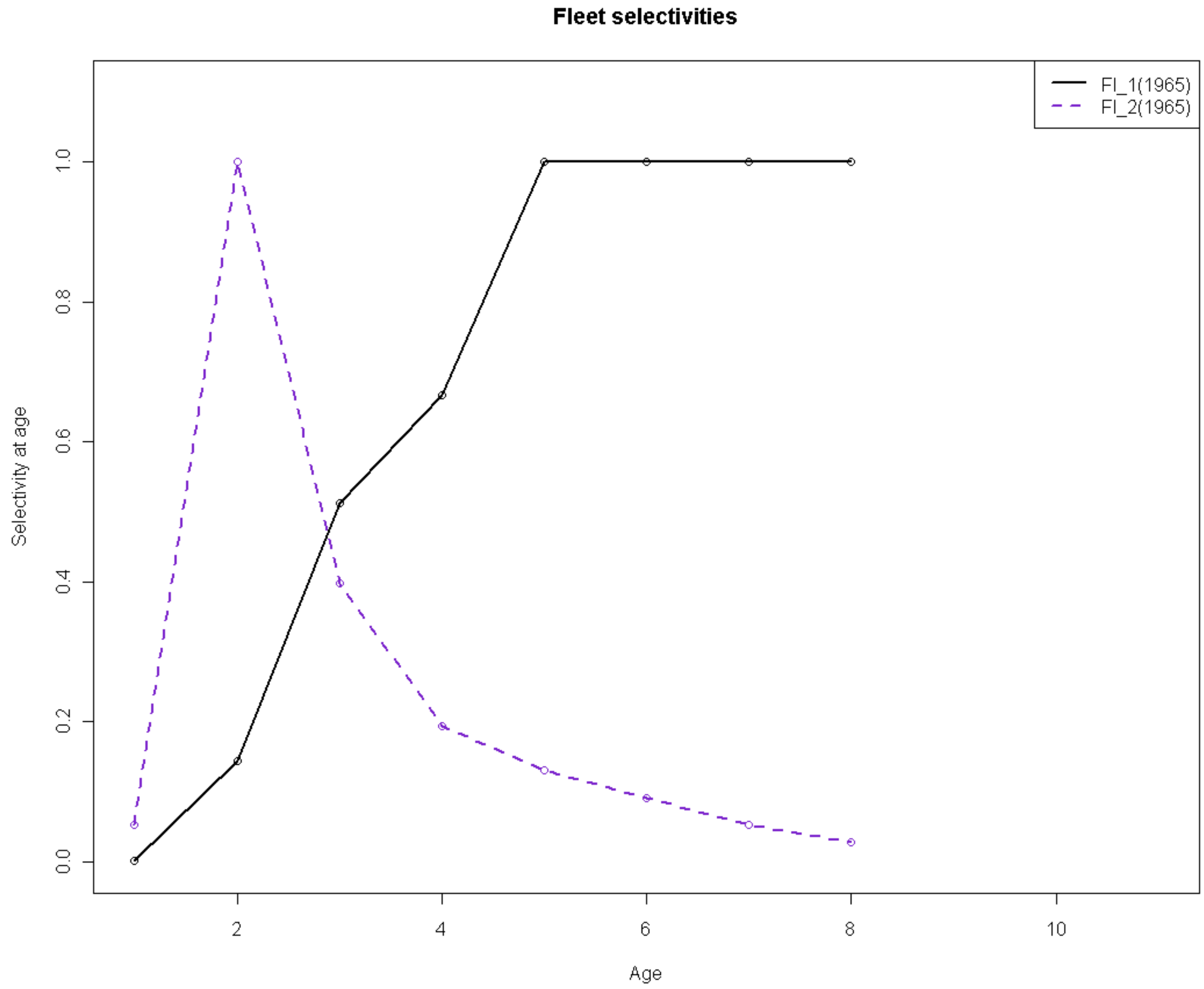


Figure A5-12. Selectivity patterns from the ASAP base run for the mobile gear fishery (black line) and the fixed gear fishery (purple dashed line).

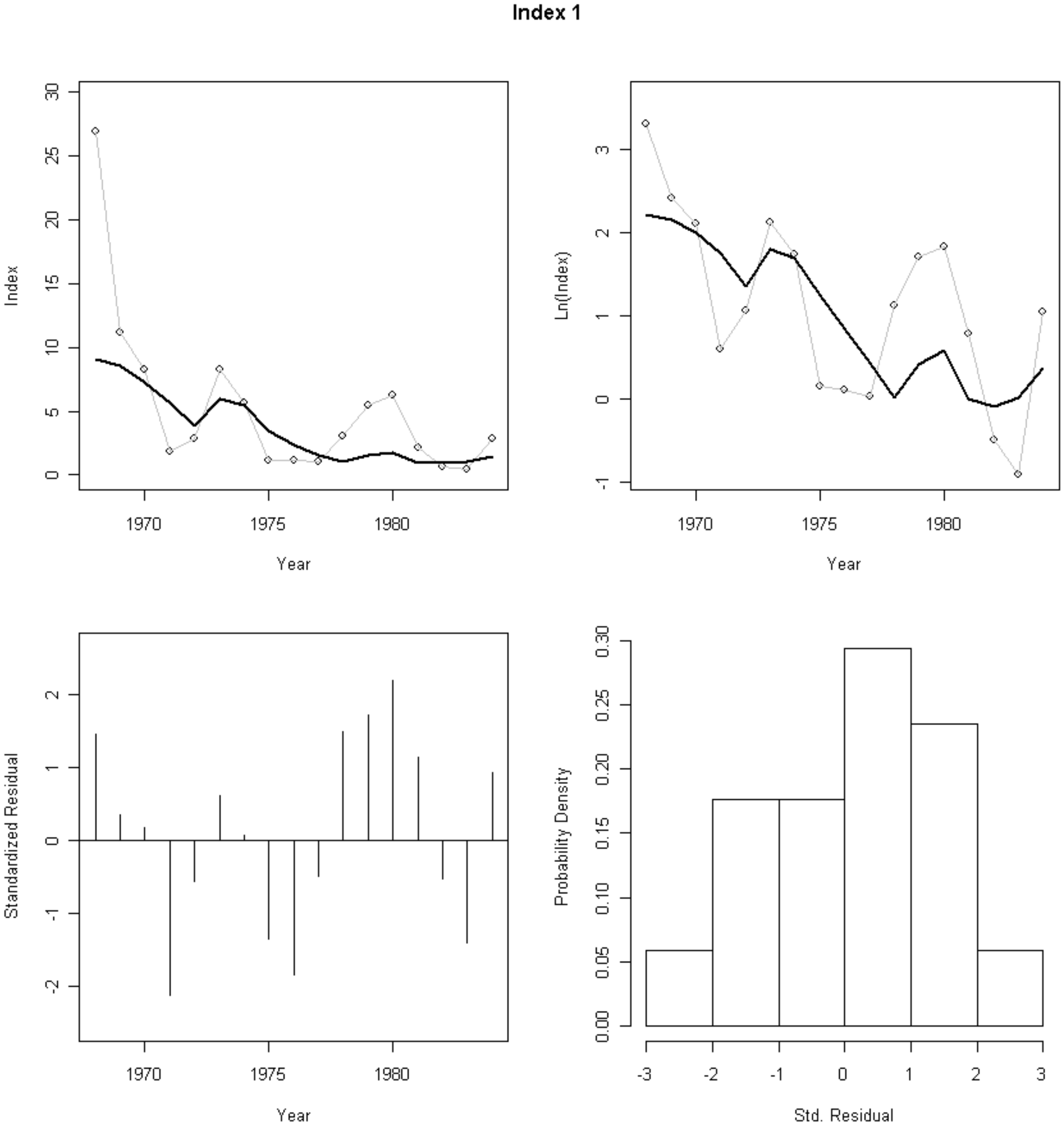


Figure A5-13. Fit to the NMFS spring survey during 1968-1984 from the ASAP base run.

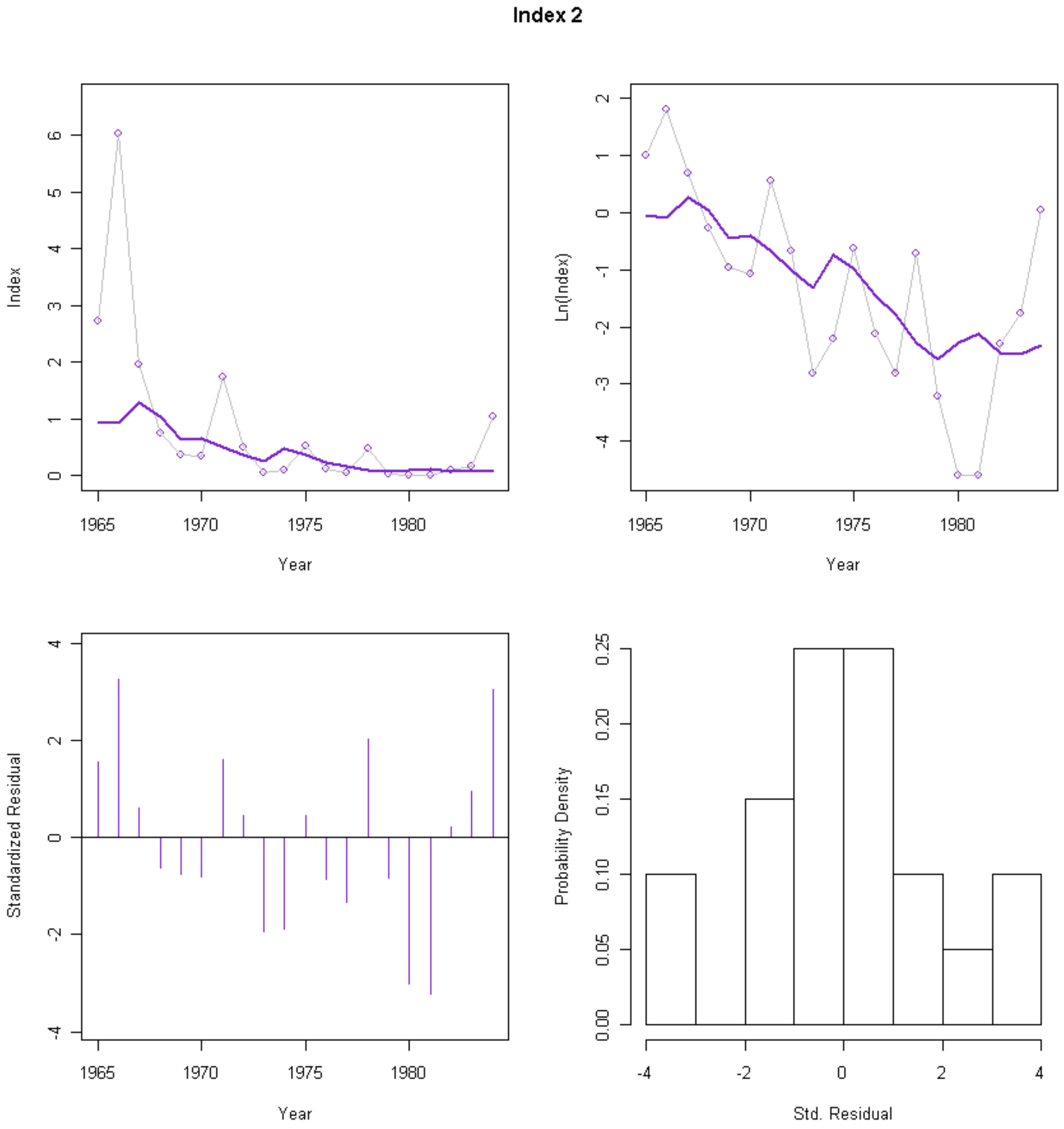


Figure A5-14. Fit to the NMFS fall survey during 1965-1984 from the ASAP base run.

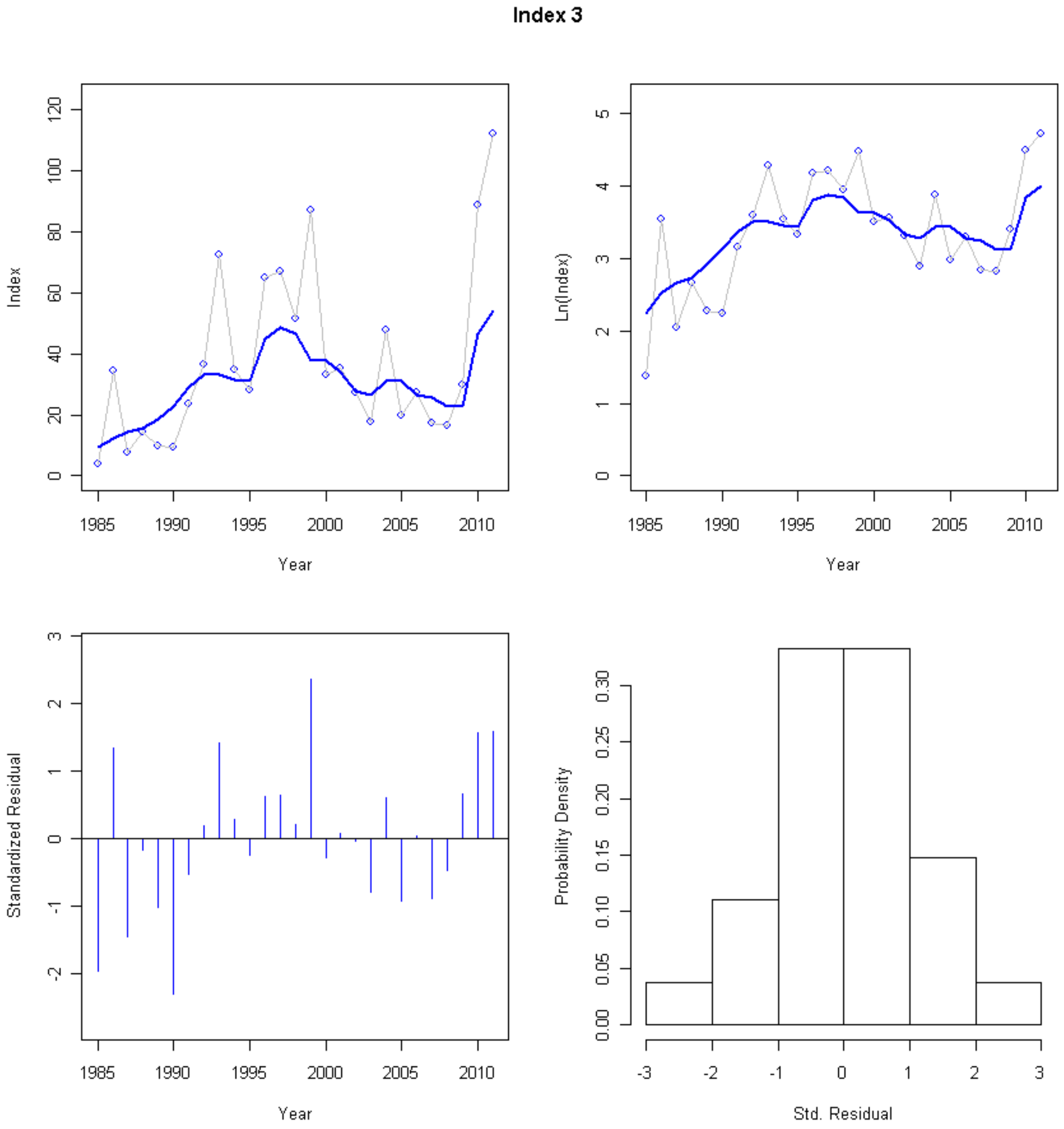


Figure A5-15. Fit to the NMFS spring survey during 1985-2011 from the ASAP base run.

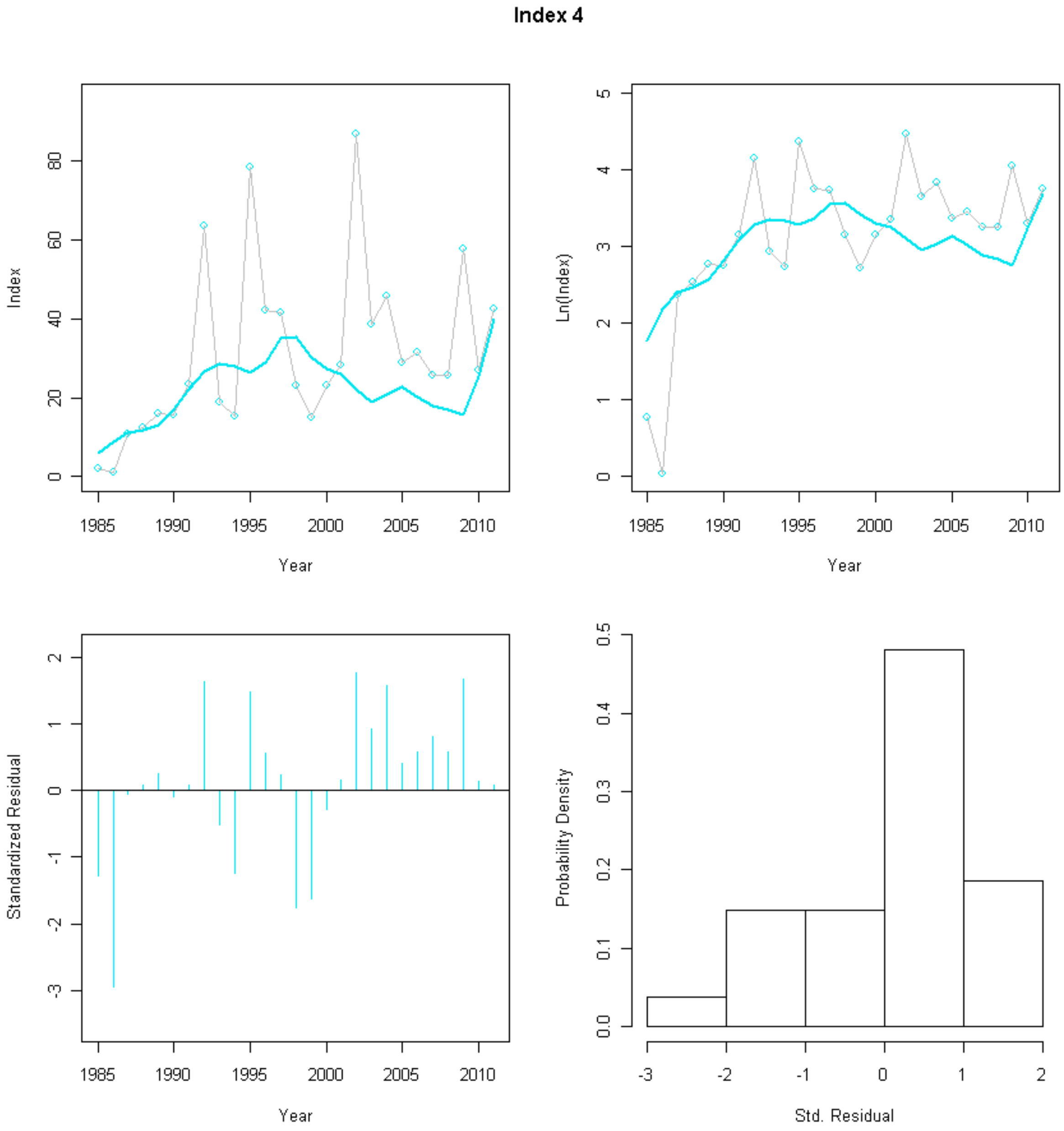


Figure A5-16. Fit to the NMFS fall survey during 1985-2011 from the ASAP base run.

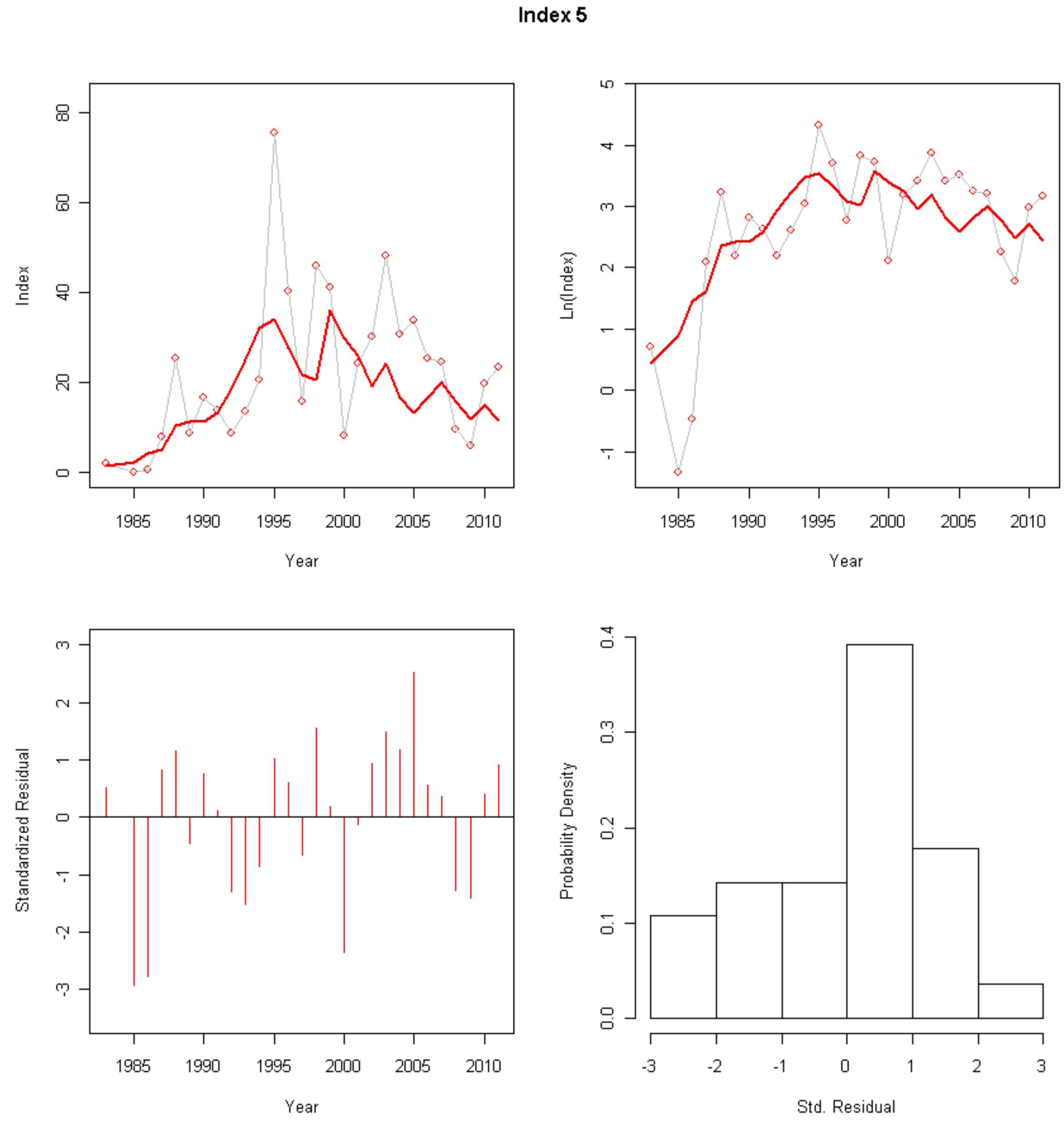


Figure A5-17. Fit to the NMFS shrimp survey during 1983 and 1985-2011from the ASAP base run.

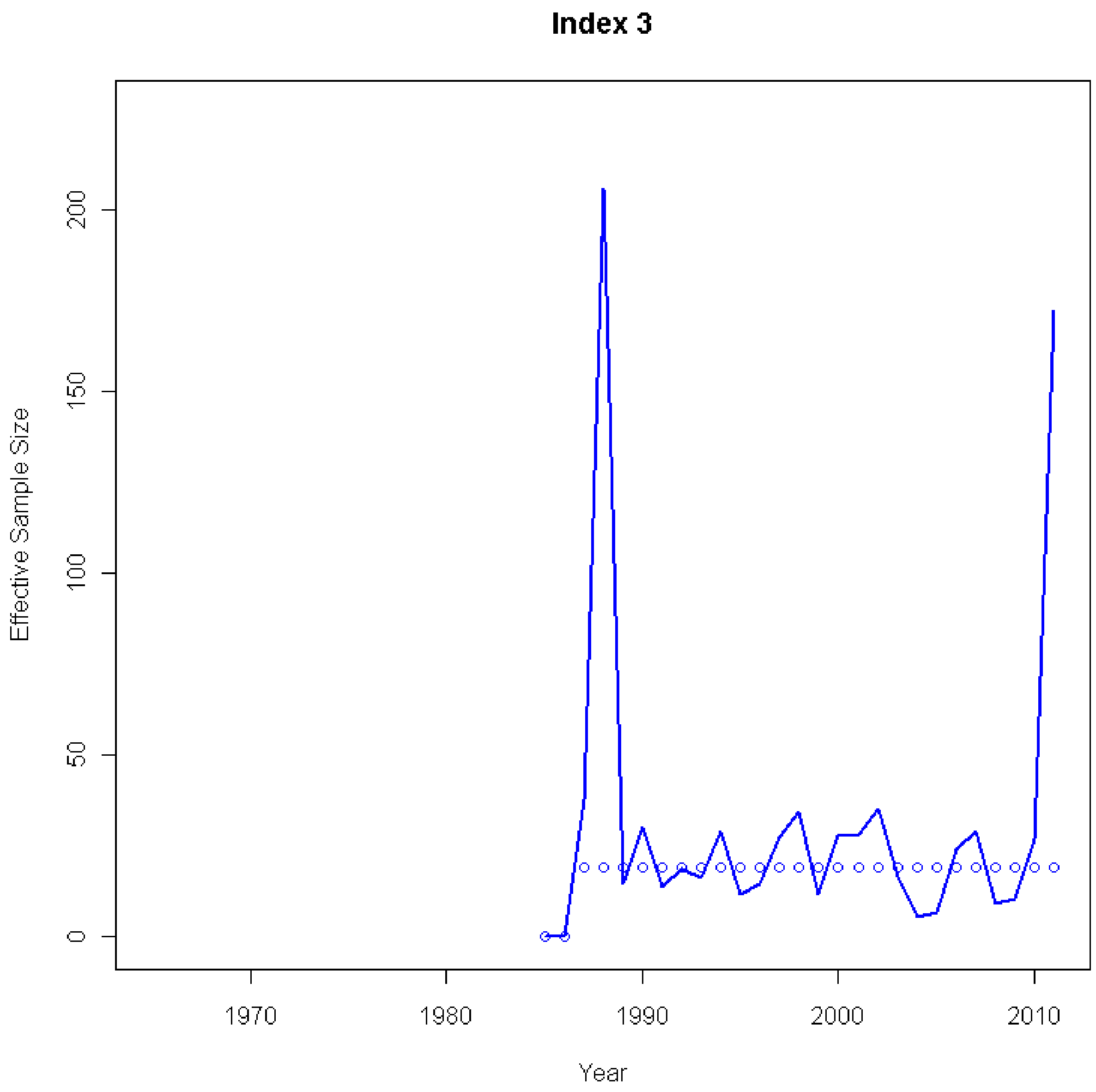


Figure A5-18. Input and estimated effective sample sizes from the ASAP base run for the NMFS spring survey during 1985-2011.

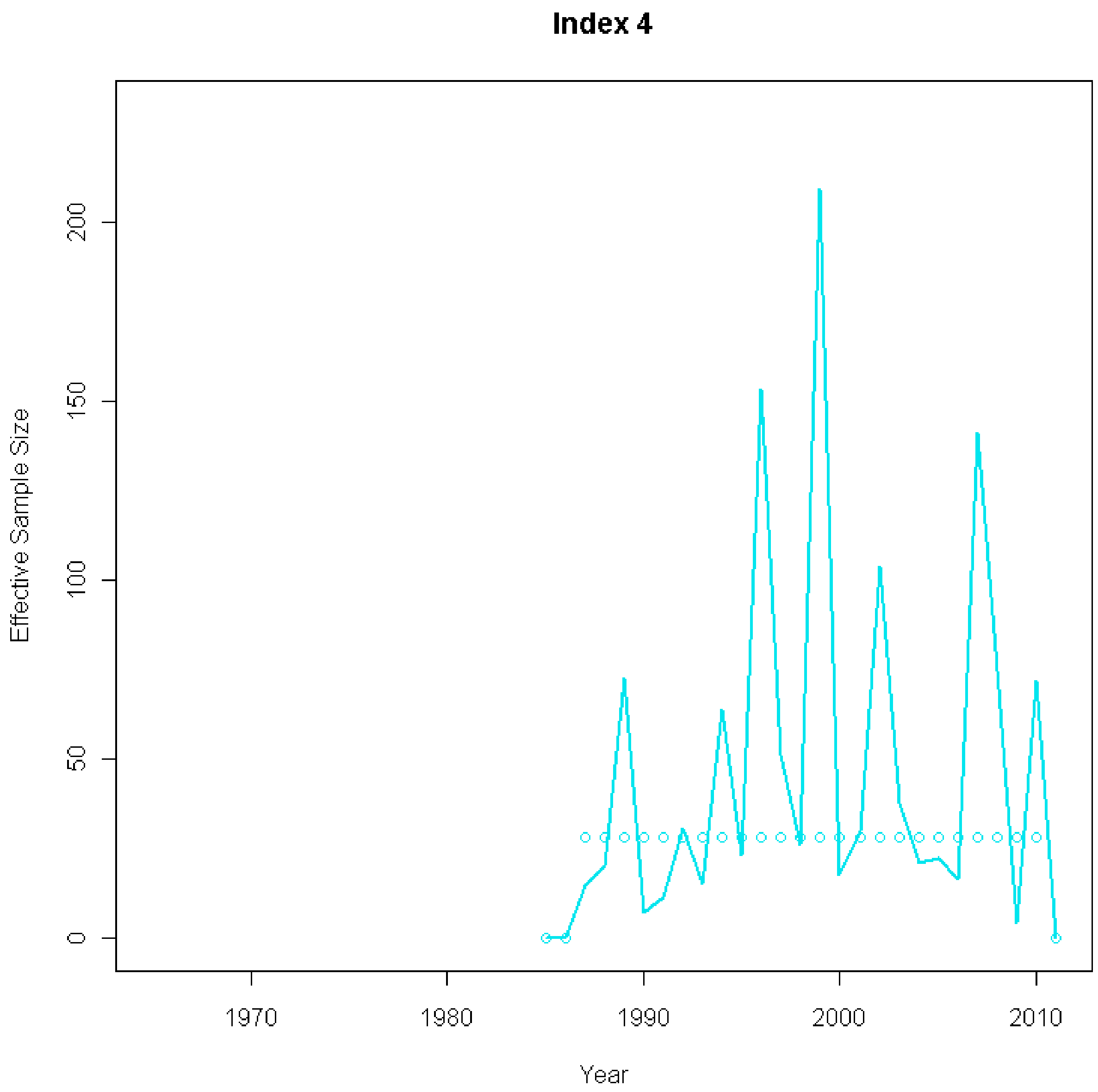


Figure A5-19. Input and estimated effective sample sizes from the ASAP base run for the NMFS fall survey during 1985-2010.

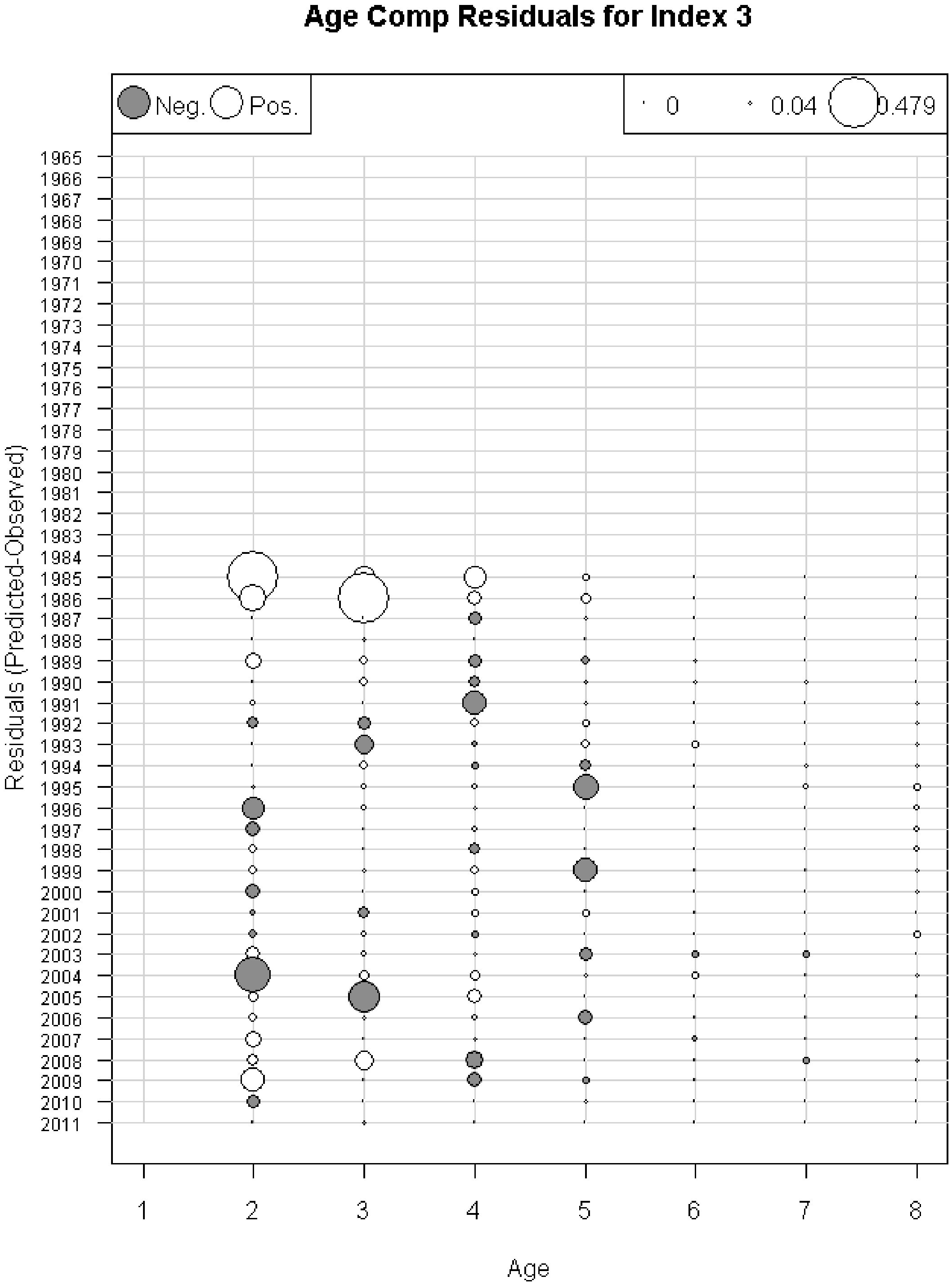


Figure A5-20. Age composition fits from the ASAP base run for the spring survey during 1987-2011. Note that no age composition data was available during 1985 and 1986. So the clusters of positive residuals early in the time series are a plotting anomaly and are not real.

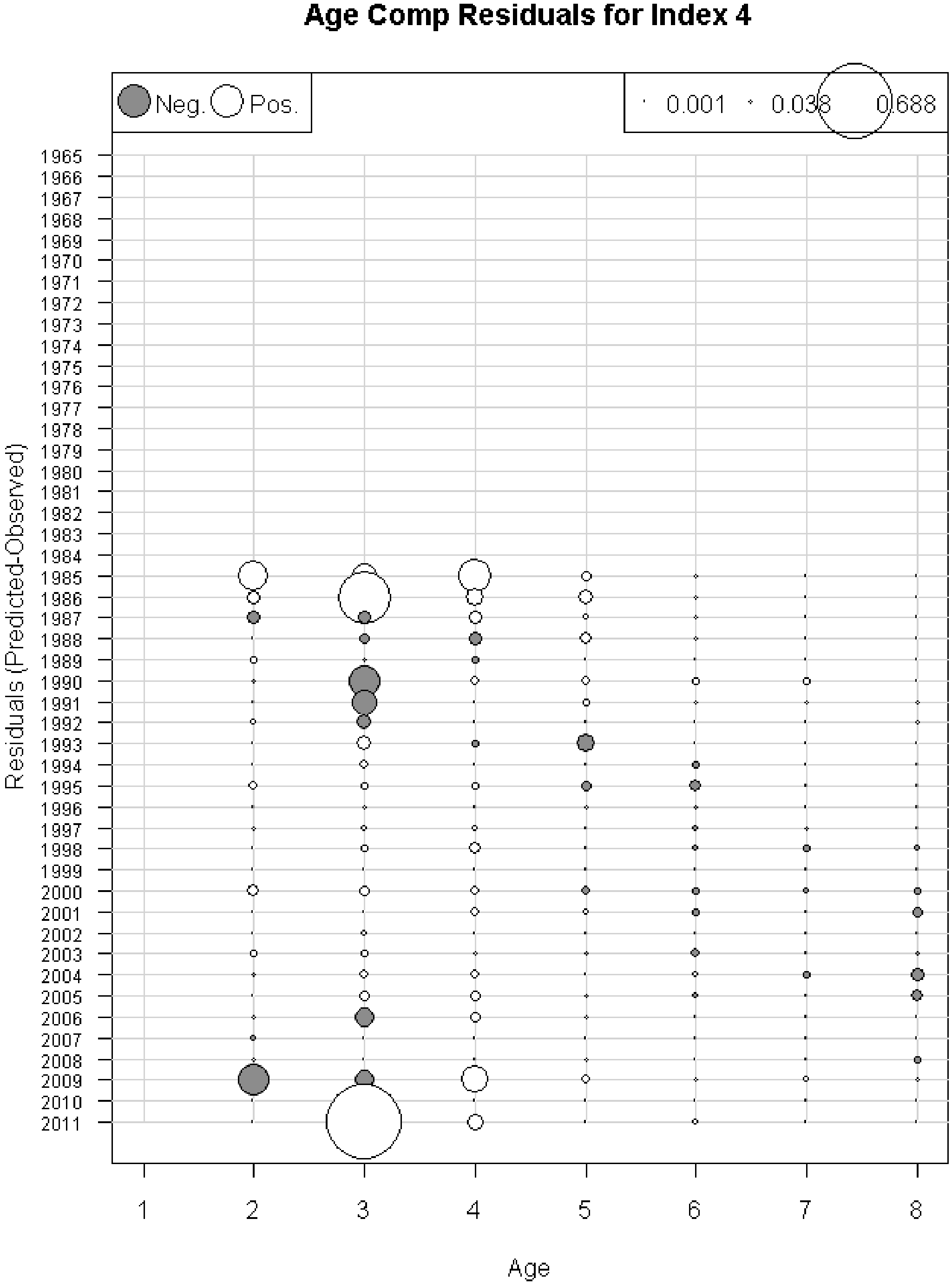


Figure A5-21. Age composition fits from the ASAP base run for the fall survey during 1987-2010. Note that no age composition data was available during 1985 and 1986. So the clusters of positive residuals early in the time series are a plotting anomaly and are not real.

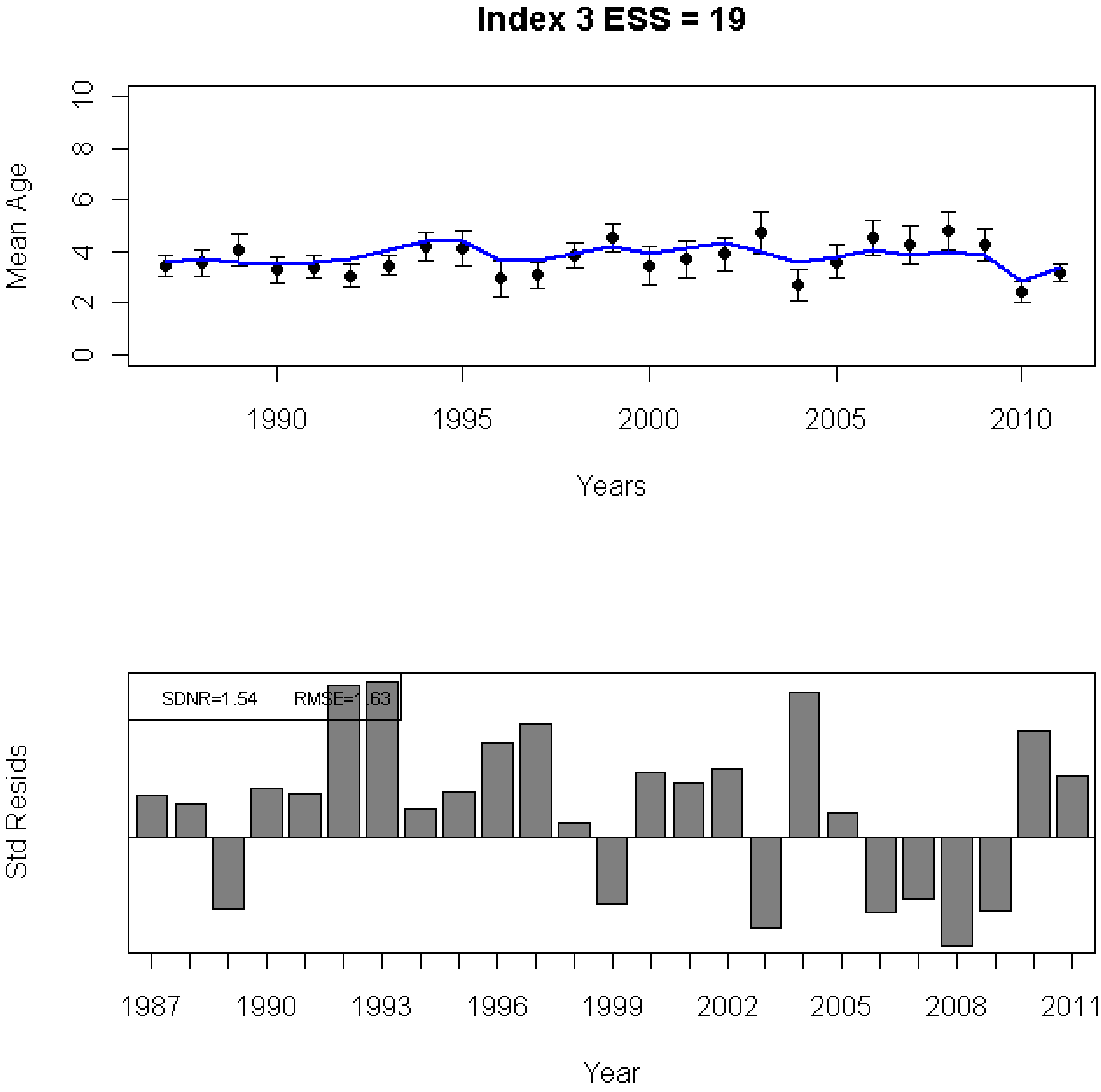


Figure A5-22. Fits to the observed mean age from the ASAP base model for the NMFS spring survey during 1987-2011.

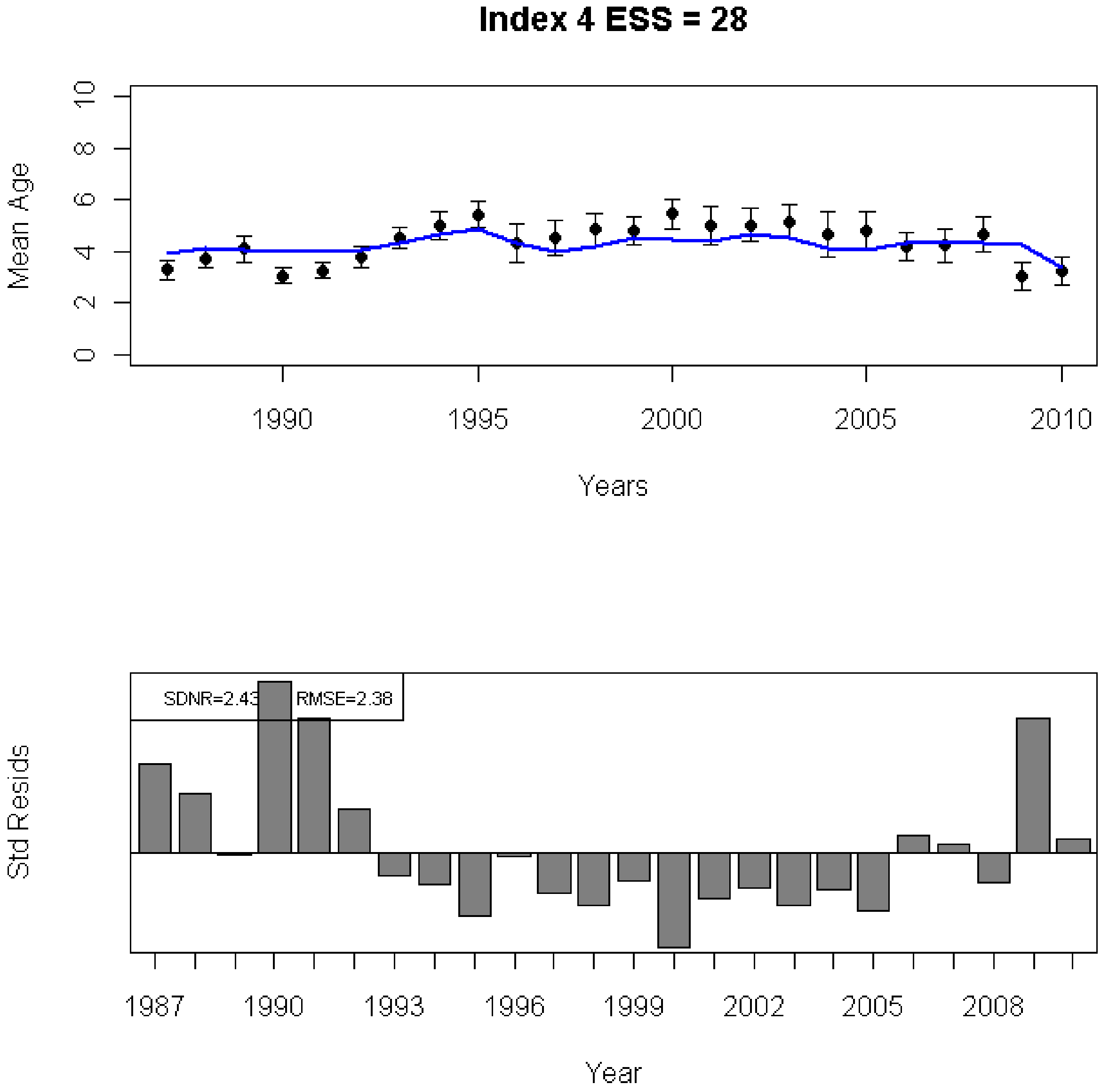


Figure A5-23. Fits to the observed mean age from the ASAP base model for the NMFS fall survey during 1987-2010.

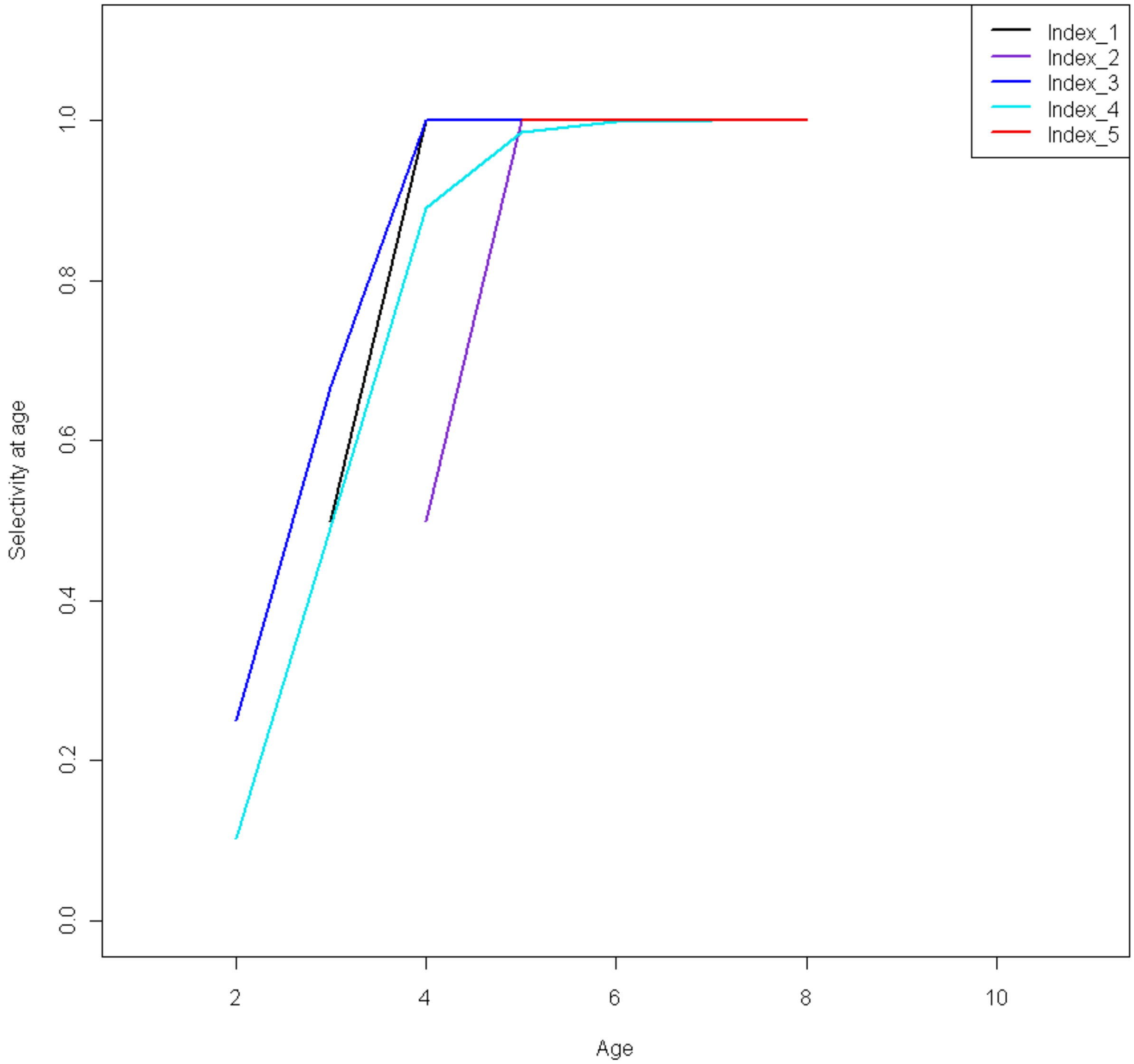


Figure A5-24. Selectivity patterns for the surveys used in the ASAP base run. Spring 1968-1984 is black, Index_1. Fall 1965-1984 is purple, Index_2. Spring 1985-2011 is dark blue, Index_3. Fall 1985-2011 is light blue, Index_4. Shrimp is red, Index_5.

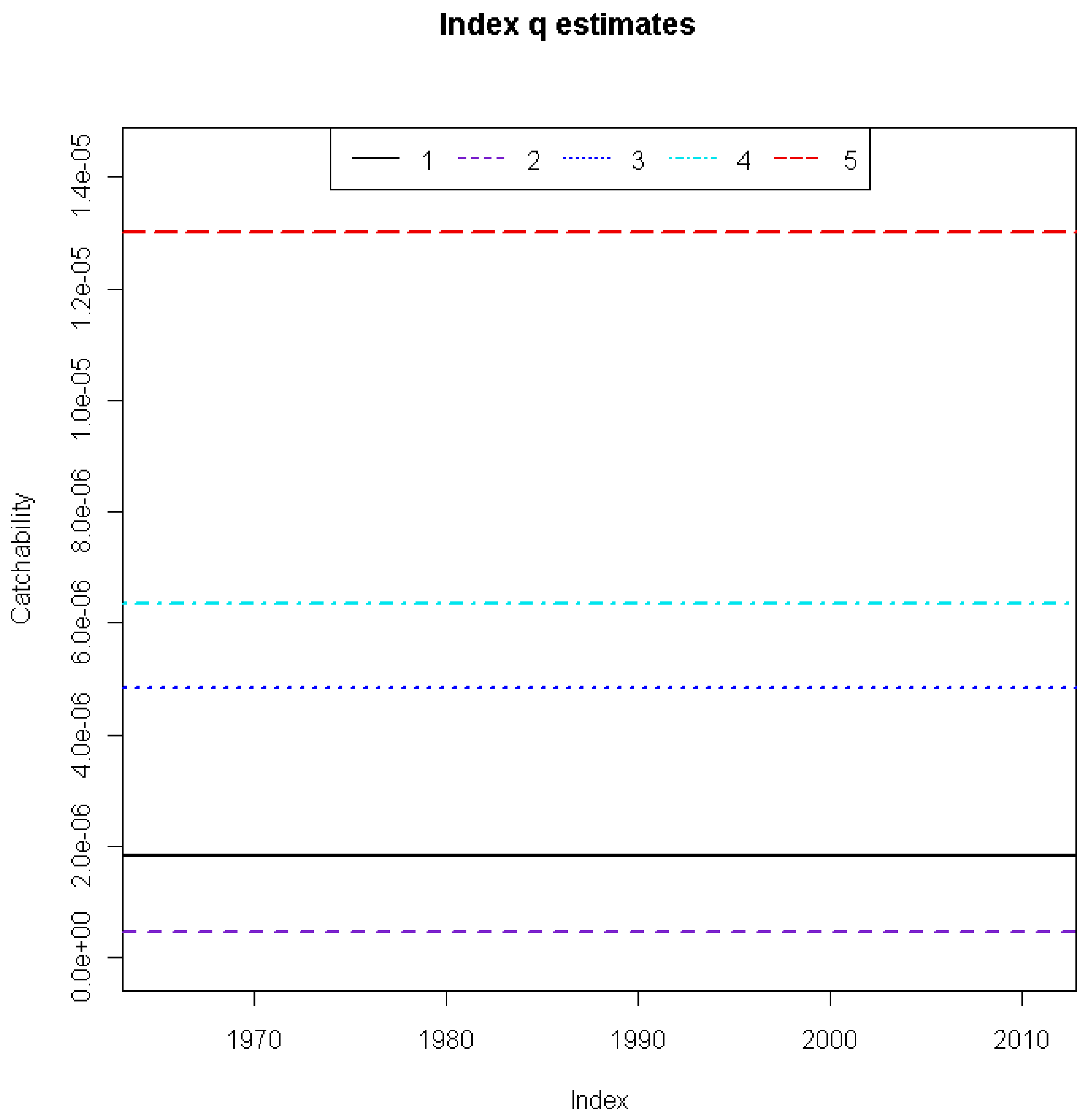


Figure A5-25. Catchability estimates for each survey used in the ASAP base model. Spring 1968-1984 is black, Index_1. Fall 1965-1984 is purple, Index_2. Spring 1985-2011 is dark blue, Index_3. Fall 1985-2011 is light blue, Index_4. Shrimp is red, Index_5.

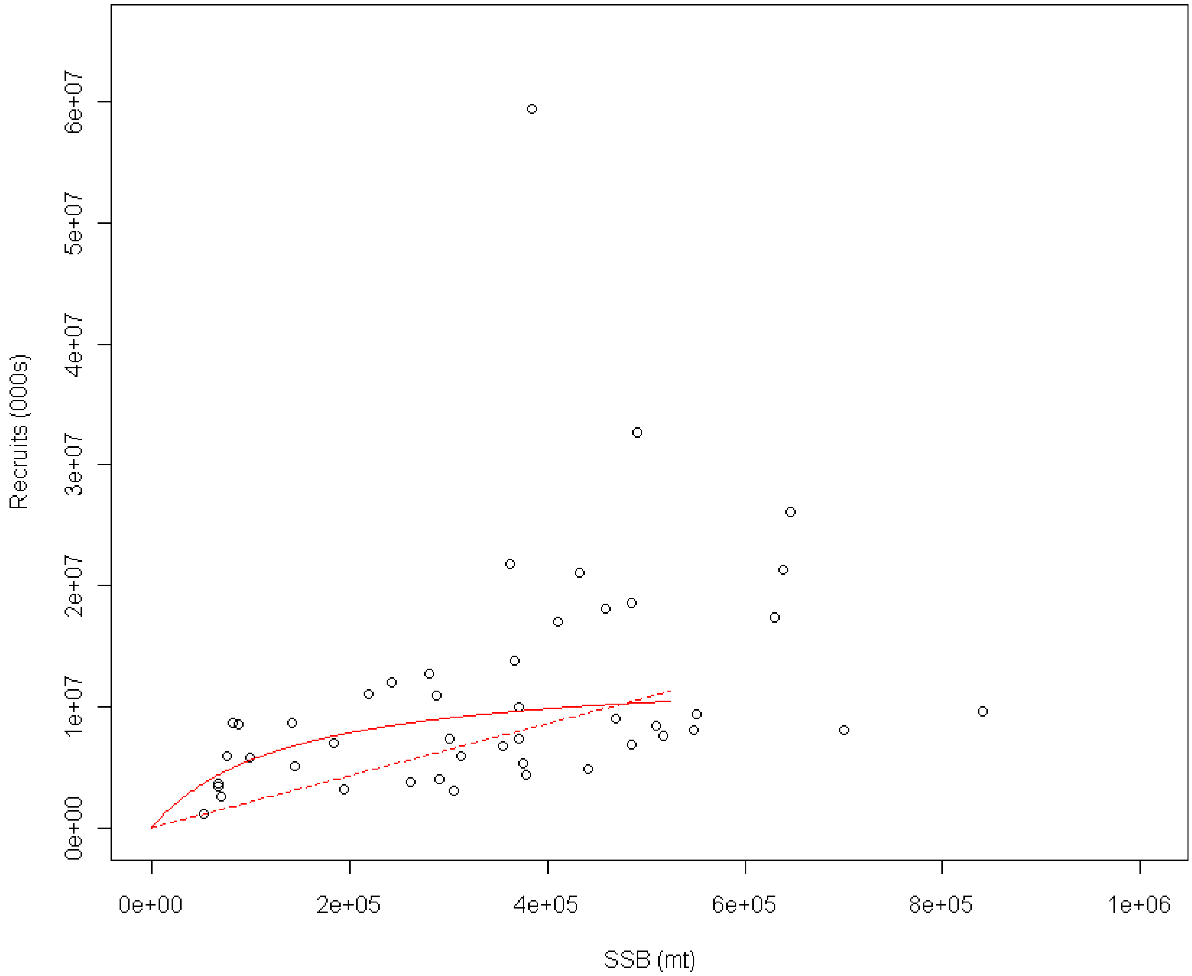


Figure A5-26. Stock-recruitment fit of the ASAP base run.

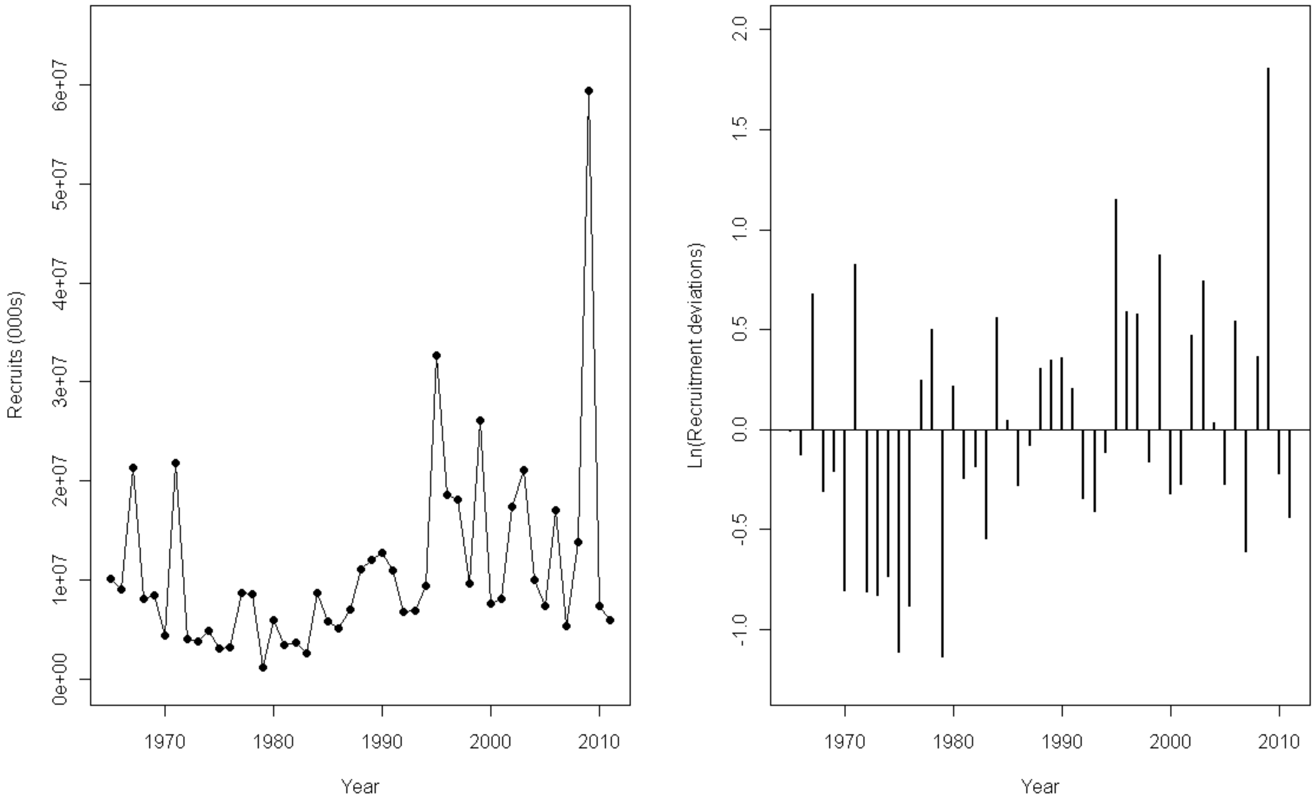


Figure A5-27. Recruitment time series and log recruitment deviations from the ASAP base run.

Figure A5-28. Spawning stock biomass time series estimated from the ASAP base run.

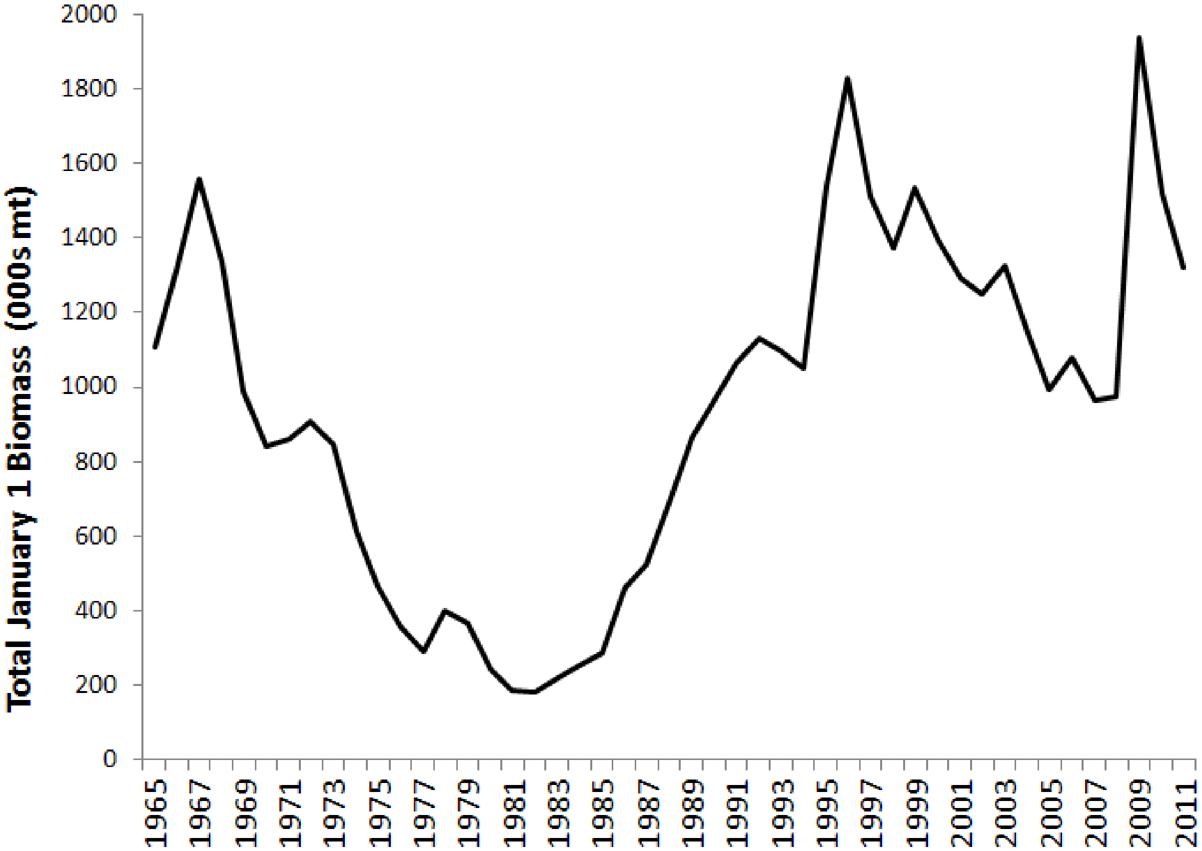


Figure A5-29. Total biomass time series estimated from the ASAP base run.

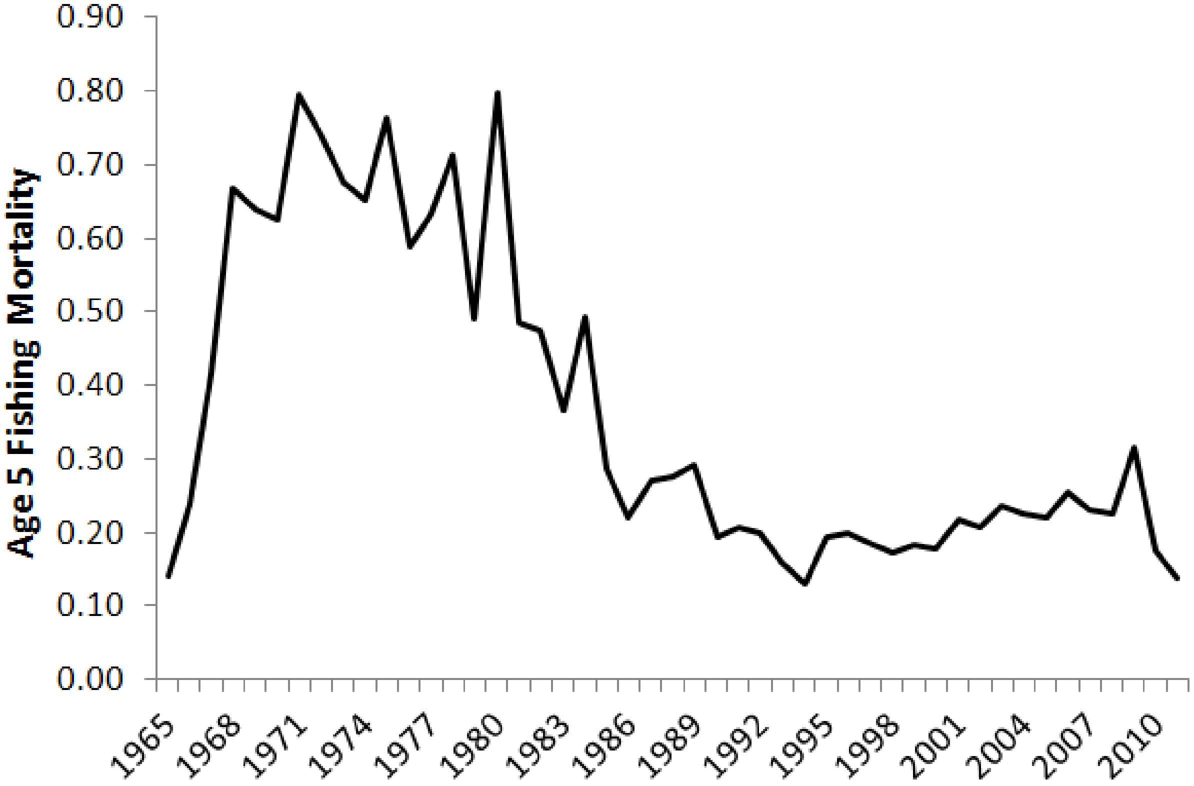


Figure A5-30. Age 5 fishing mortality estimated from the ASAP base run.

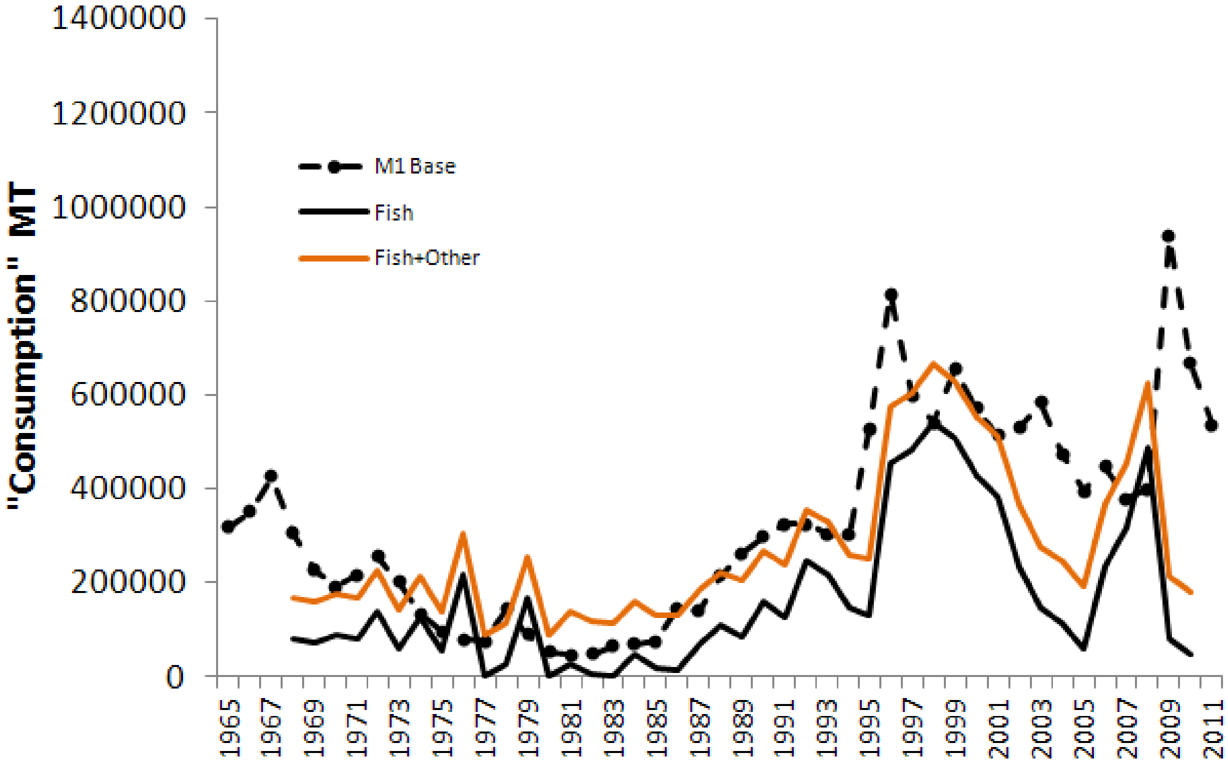


Figure A5-31. The deaths, considered largely attributable to consumption, implied by the natural mortality rates used in the ASAP base run (M1 Base; black dashes with circles), estimates of consumption of herring by fish predators (Fish; black line), and estimates of consumption of herring by "all" predators (fish, birds, migratory species, and marine mammals) (Fish+Other; orange line).

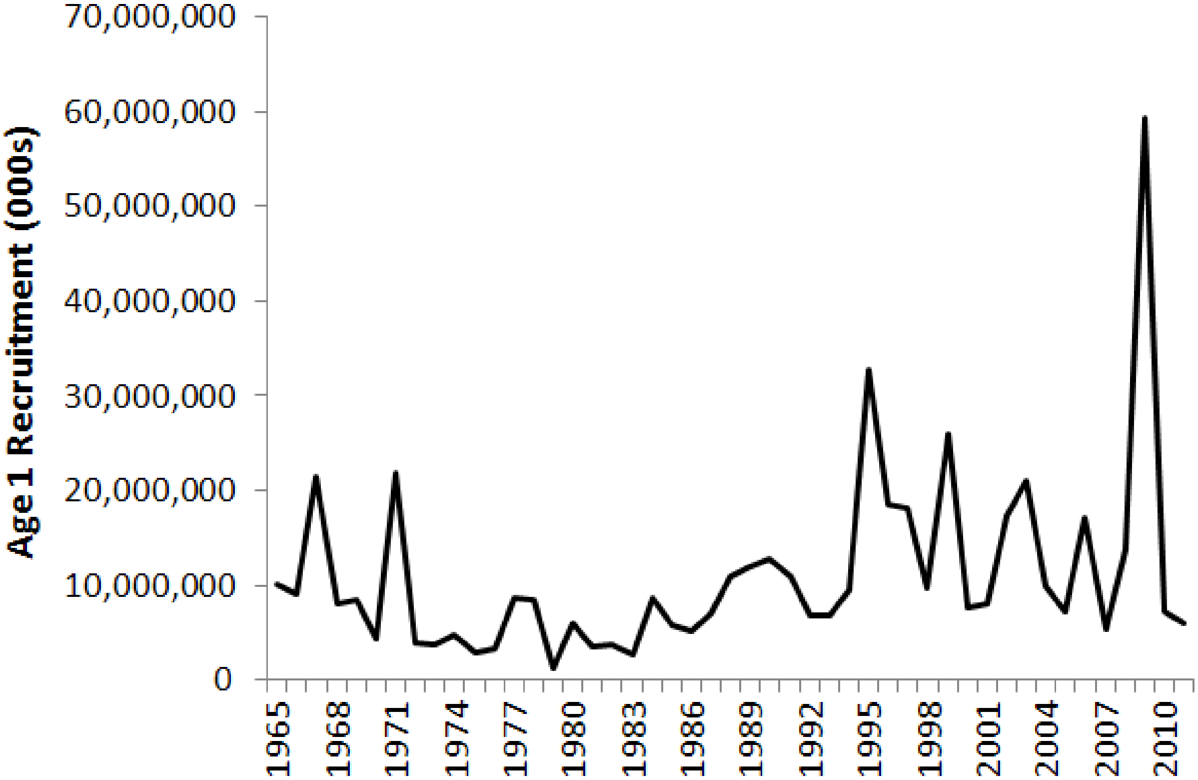


Figure A5-32. Age 1 recruitment estimated from the ASAP base run.

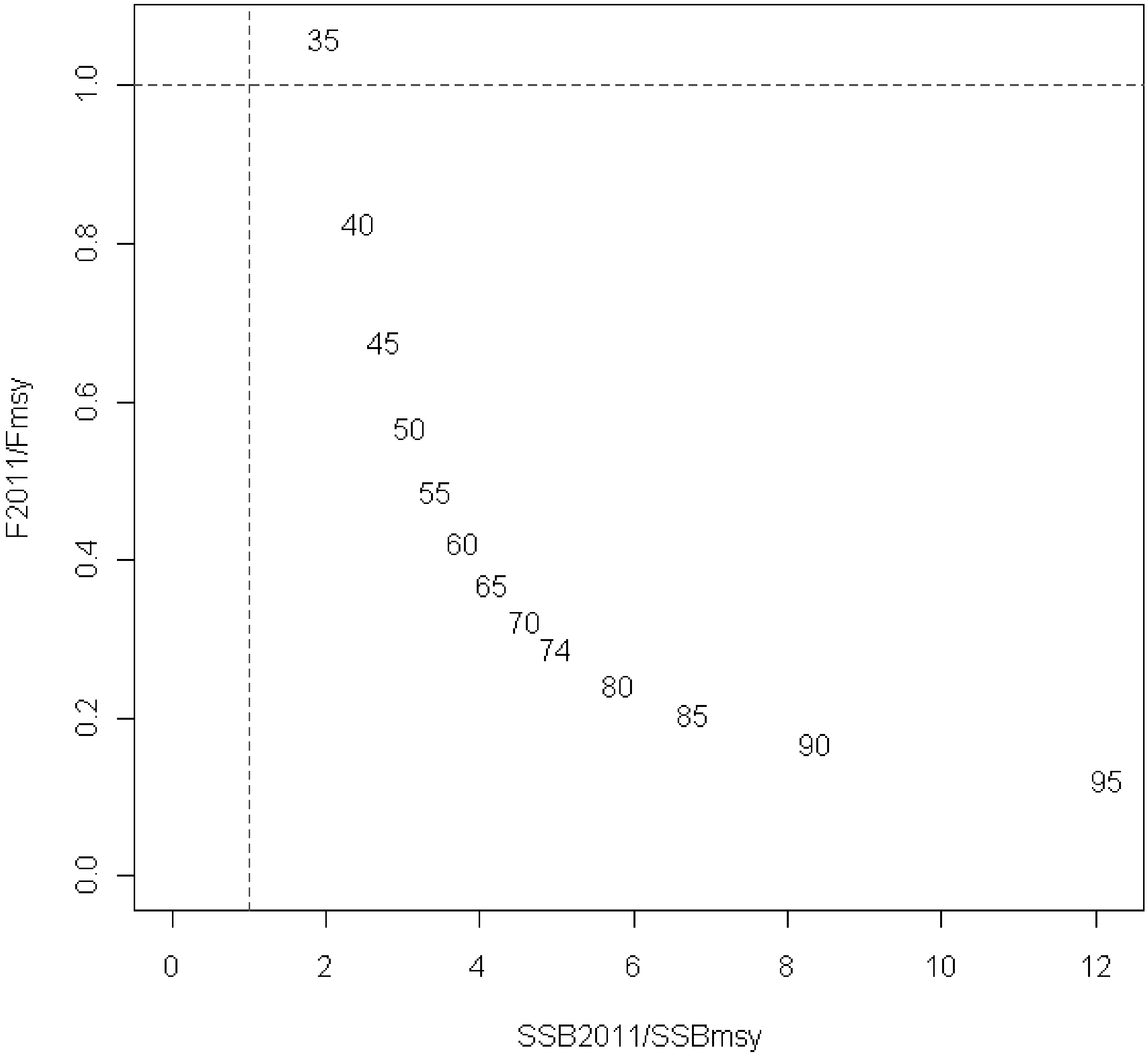


Figure A5-33. The status of Atlantic herring in 2011 relative to F_{msy} (y-axis) and SSB_{msy} (x-axis) from the ASAP base run, profiled over values of the steepness parameter, which are the numbers within the plot. The dashed lines index the locations where F or SSB in 2011 equal s F_{msy} or SSB_{msy}.

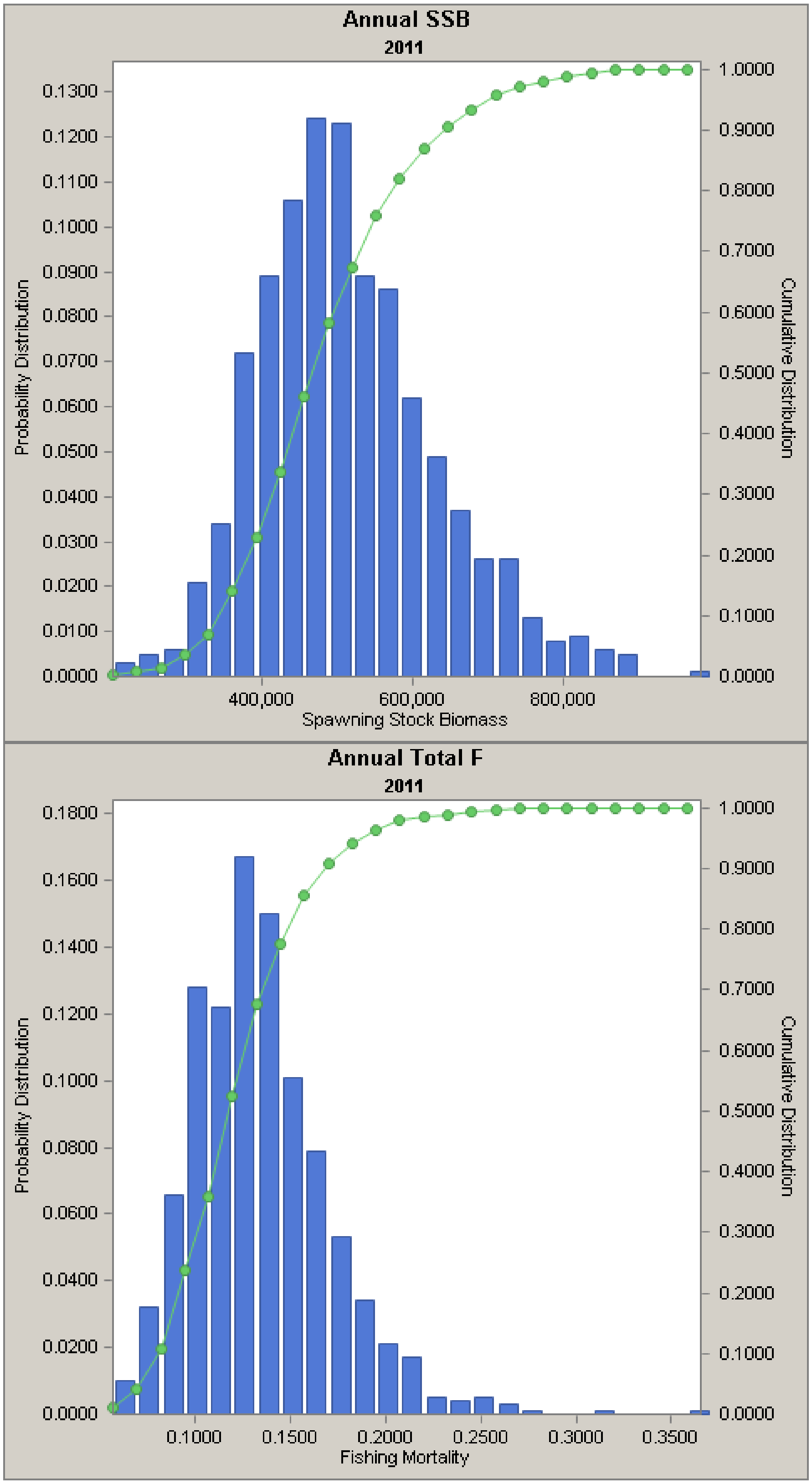


Figure A5-34. Posterior densities of SSB and F in 2011 from the ASAP base run.

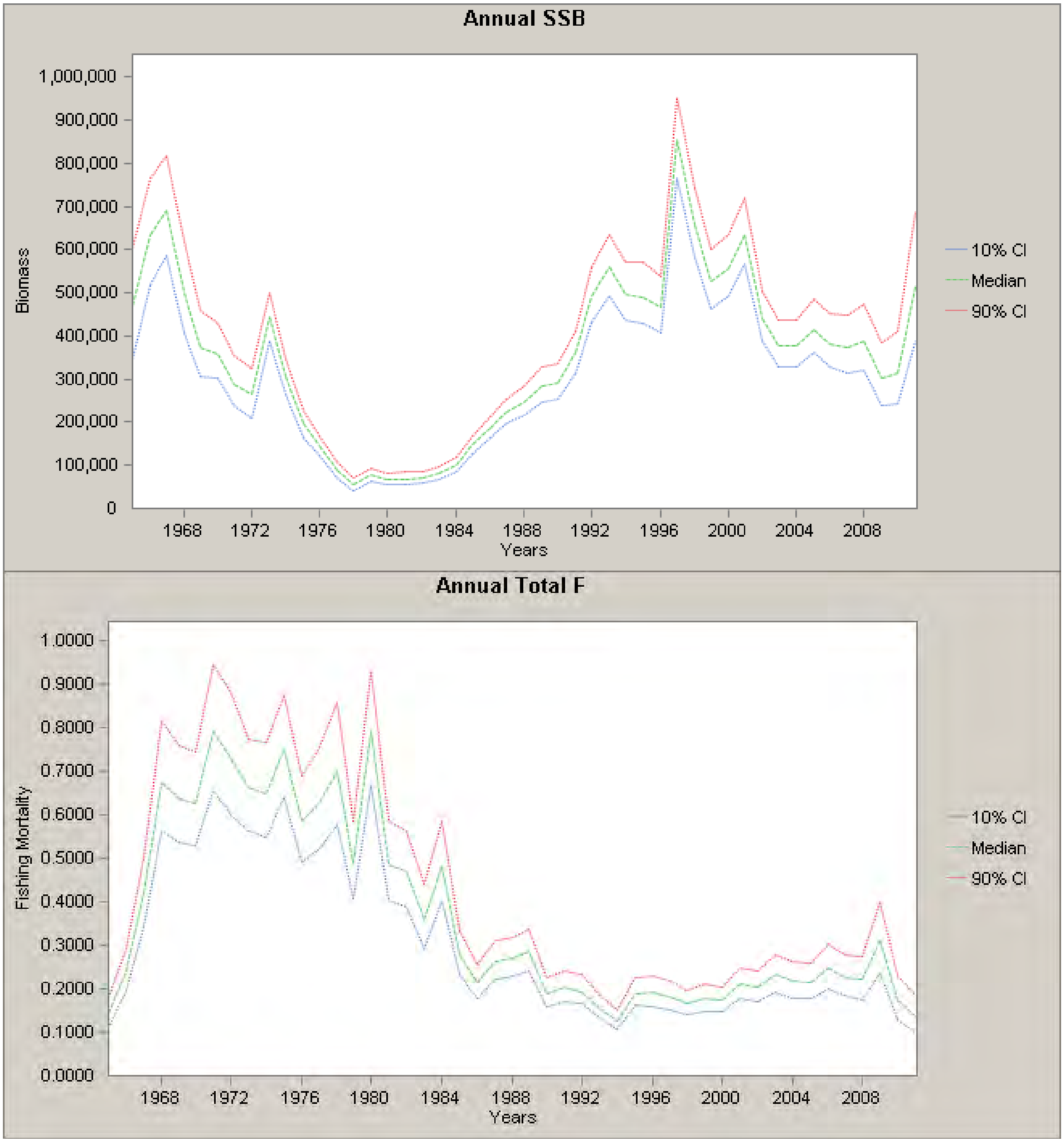


Figure A5-35. Time series plots of SSB and F with 80% probability intervals from the ASAP base run.

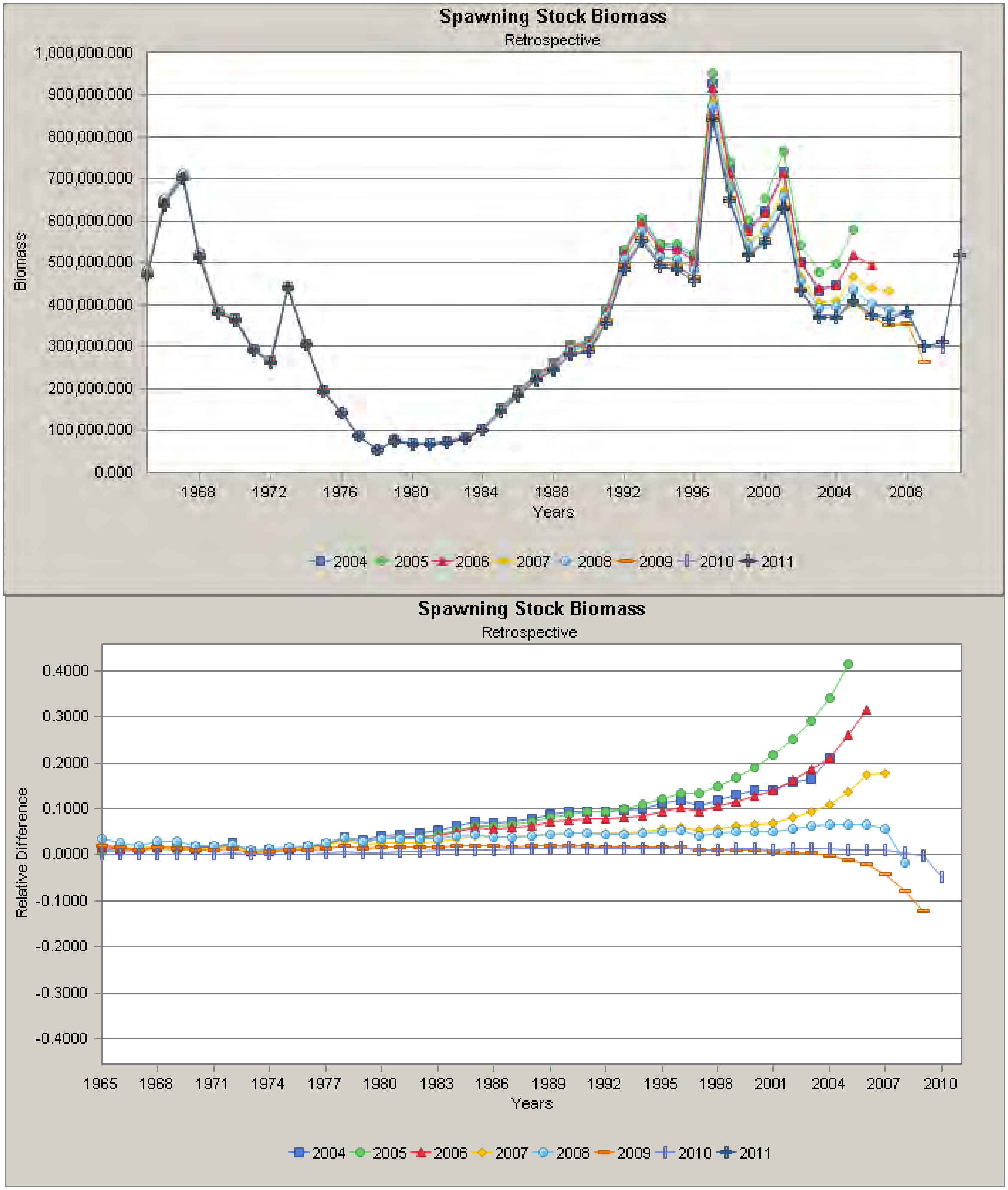


Figure A5-36. Retrospective pattern in spawning stock biomass from the ASAP base run.

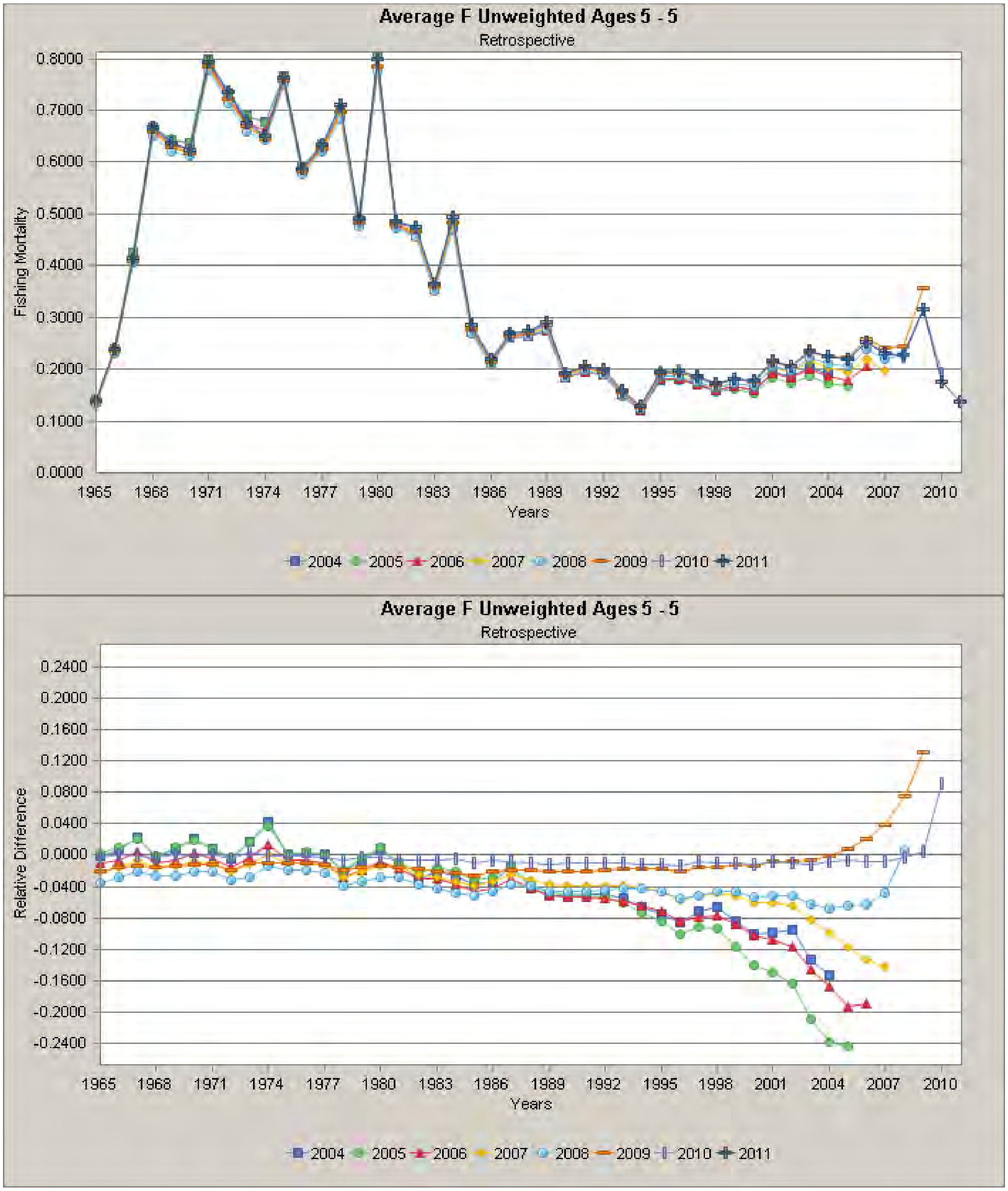


Figure A5-37. Retrospective pattern in fishing mortality from the ASAP base run.

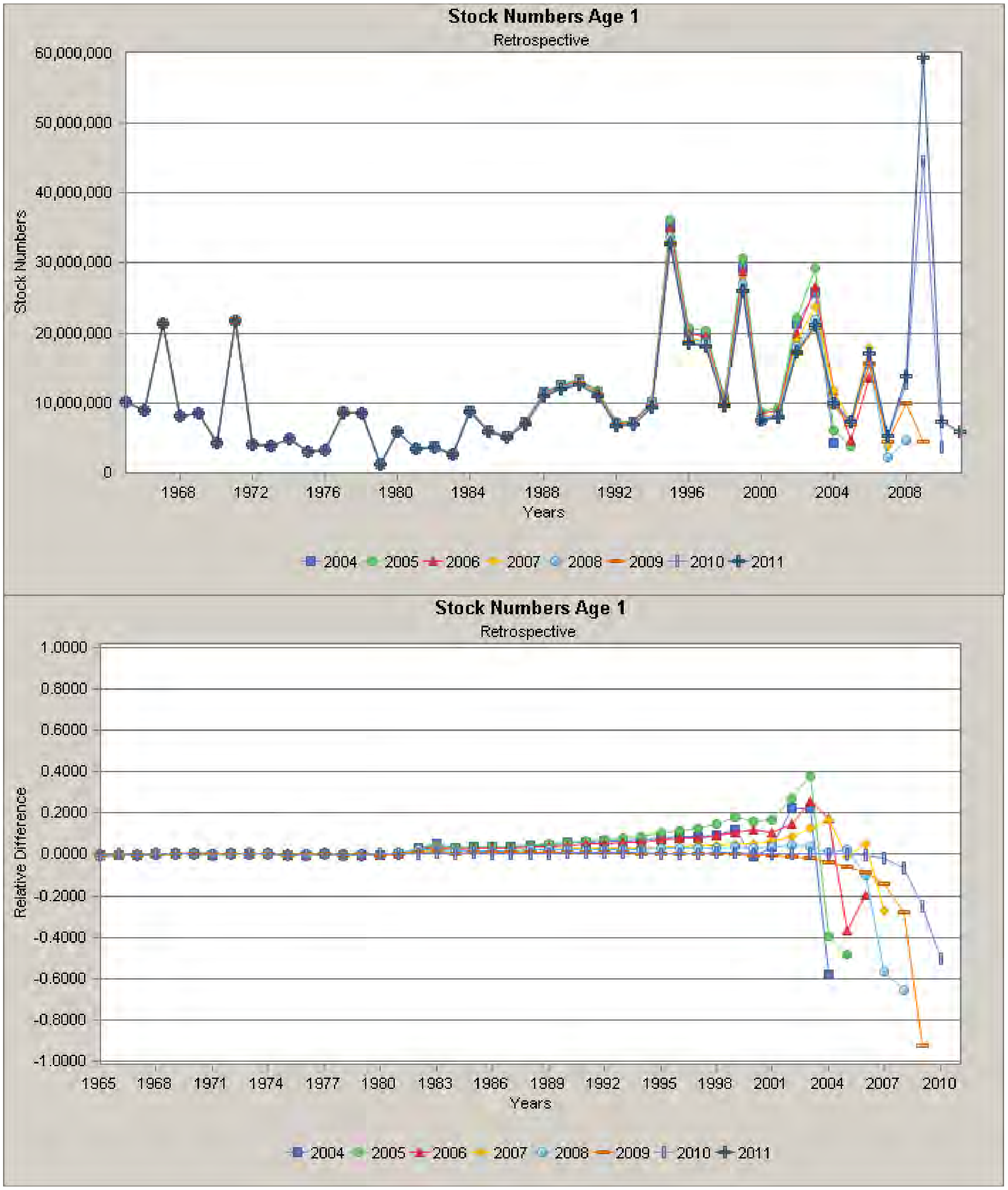


Figure A5-38. Retrospective pattern in recruitment from the ASAP base run.

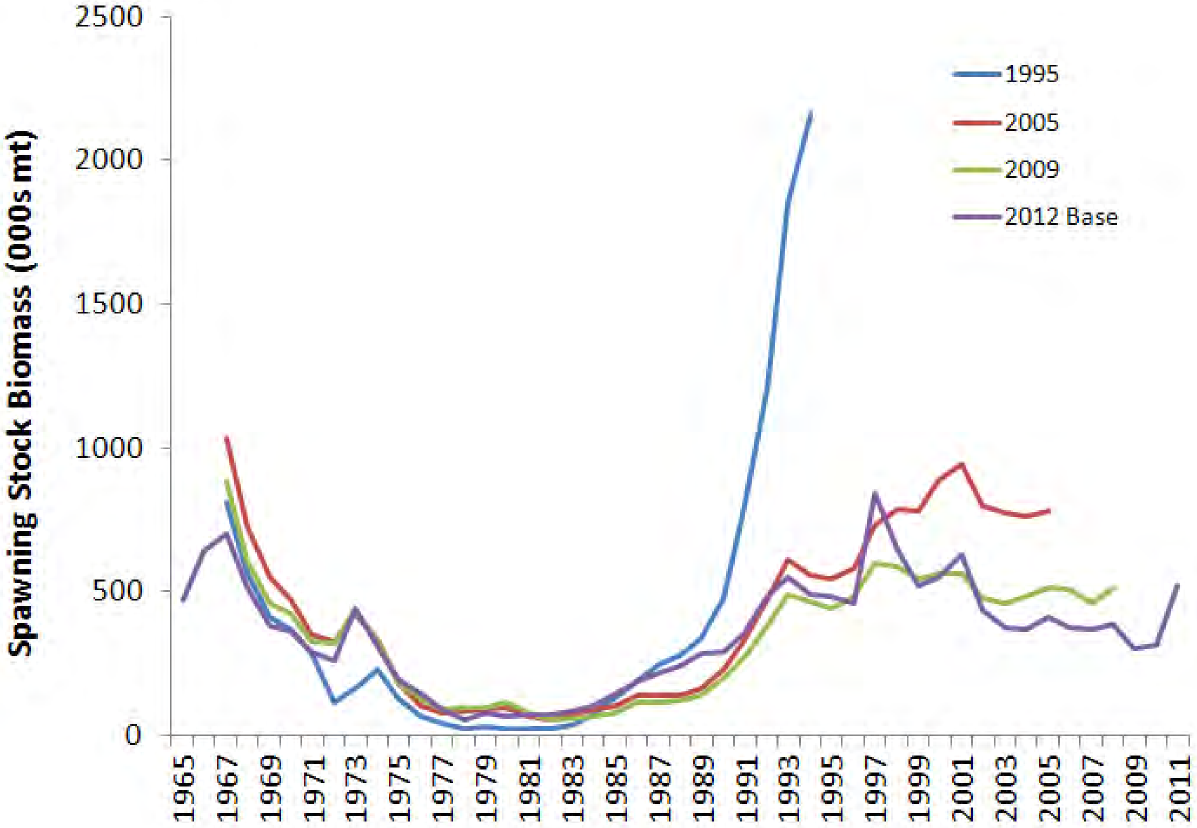


Figure A5-39. Historic retrospective pattern in spawning stock biomass for assessments done in 1995, 2005, 2009, and the proposed ASAP base run.

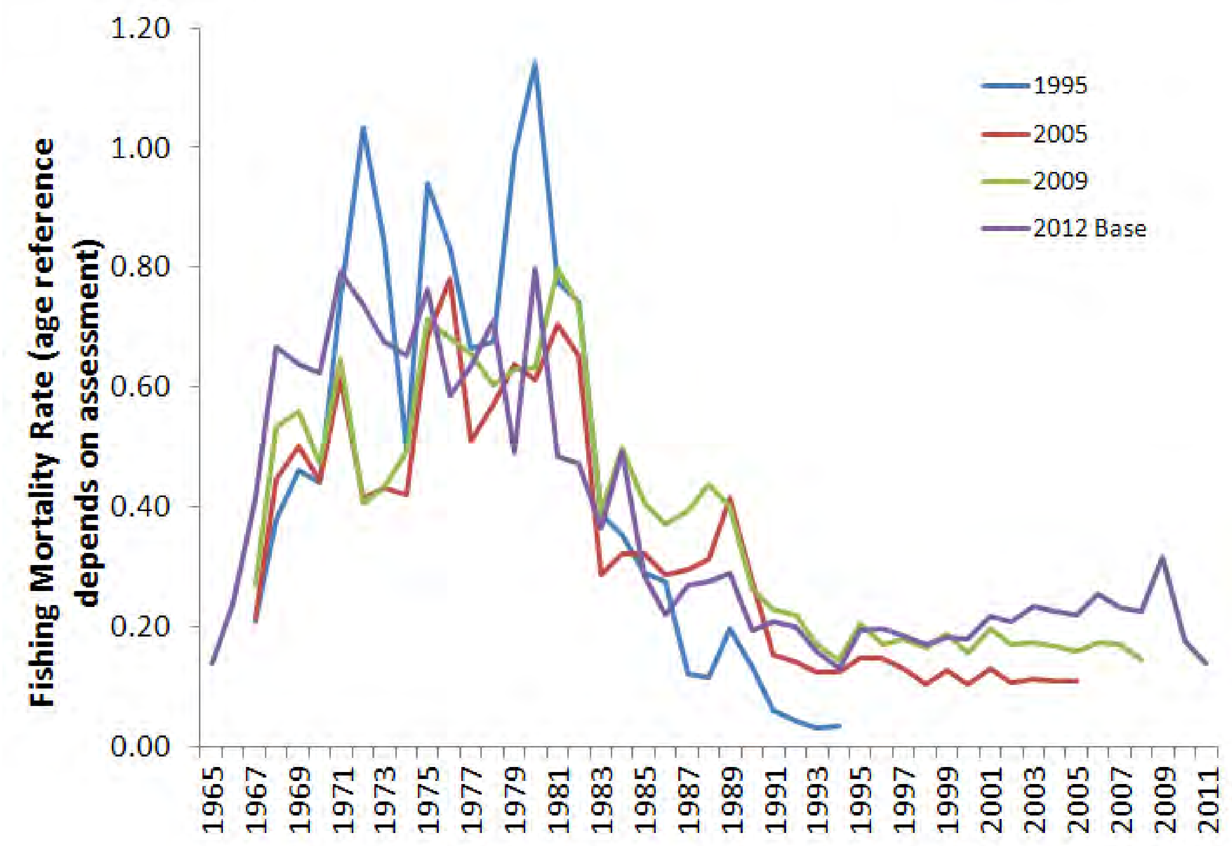


Figure A5-40. Historic retrospective pattern in fishing mortality for assessments done in 1995, 2005, 2009, and the proposed ASAP base run.

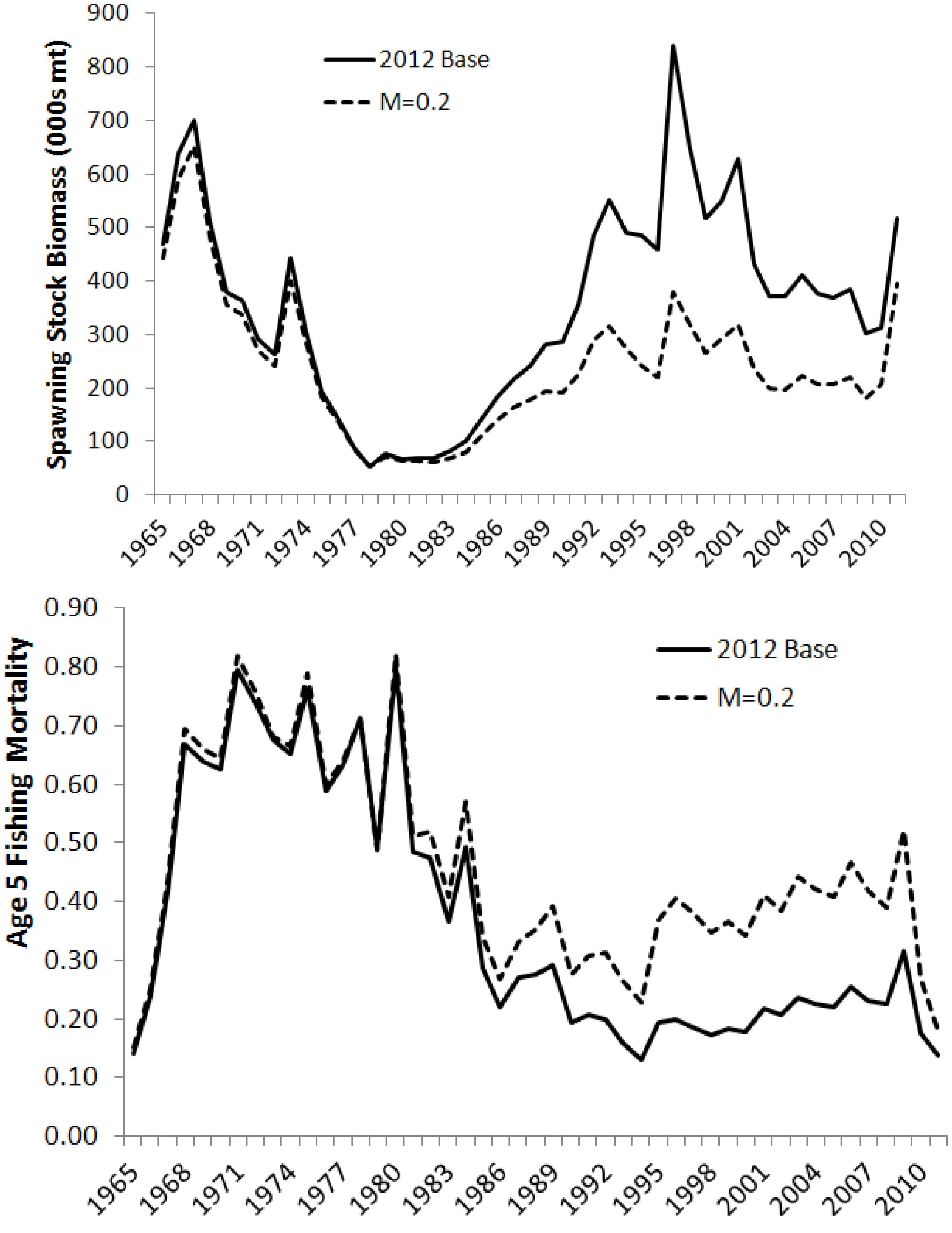


Figure A5-41. Estimates of spawning stock biomass and age 5 fishing mortality for the ASAP base run and a run with natural mortality equal to 0.2 for all ages and year.

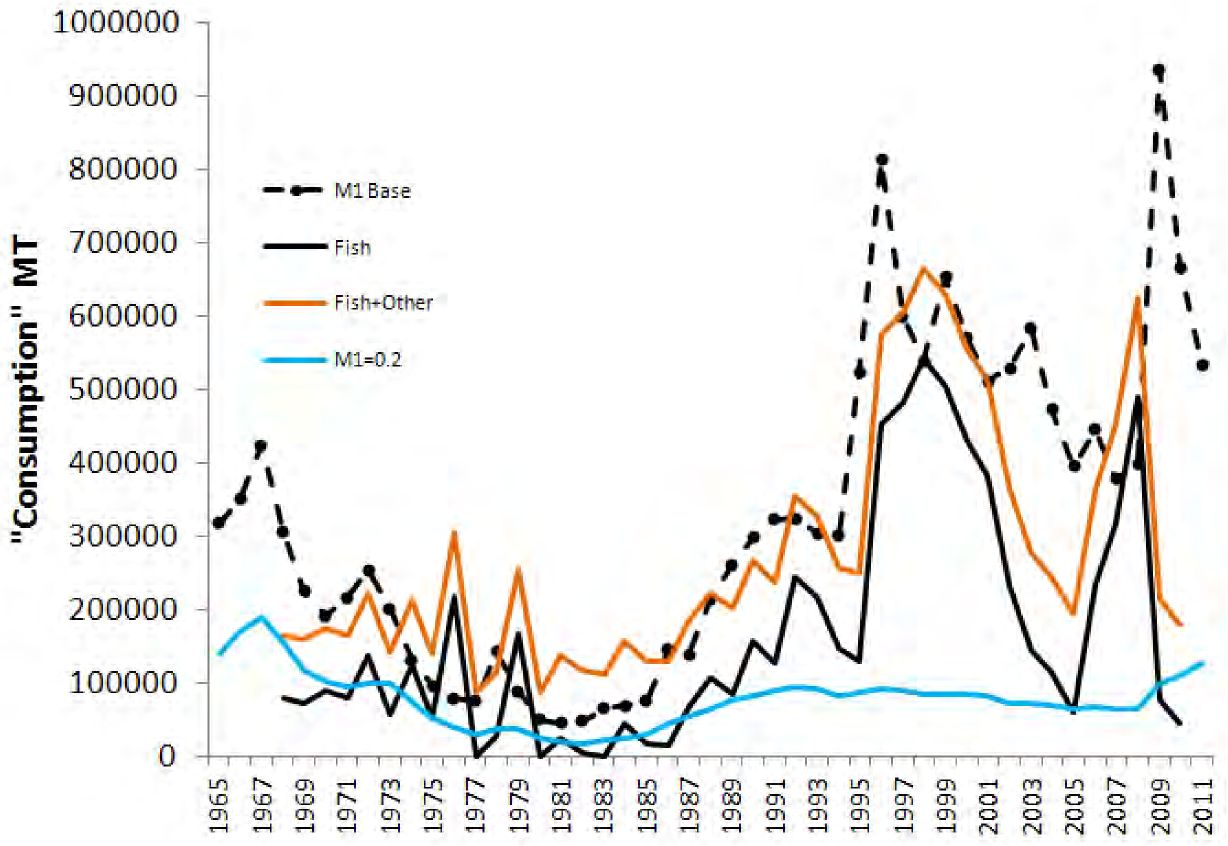
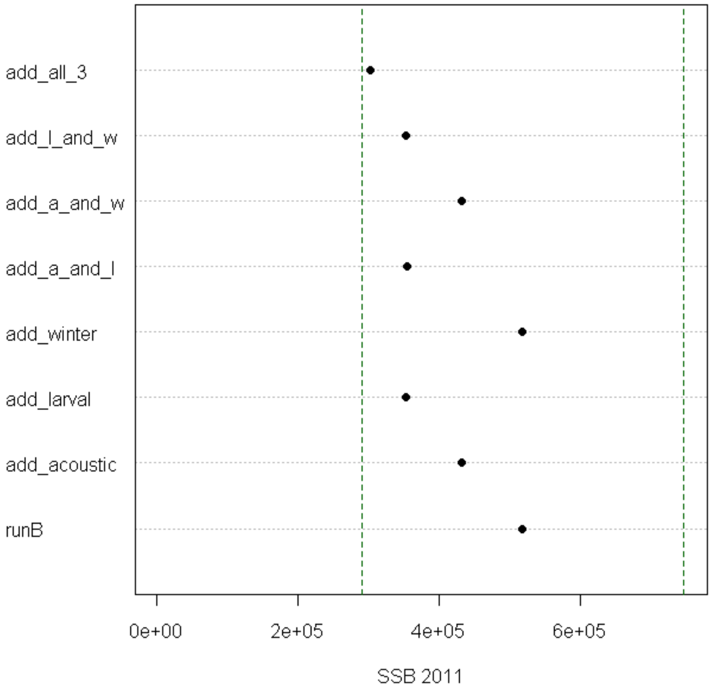


Figure A5-42. As in Figure A31 except with addition of the implied consumption from a model with natural mortality equal to 0.2 for all ages and year.



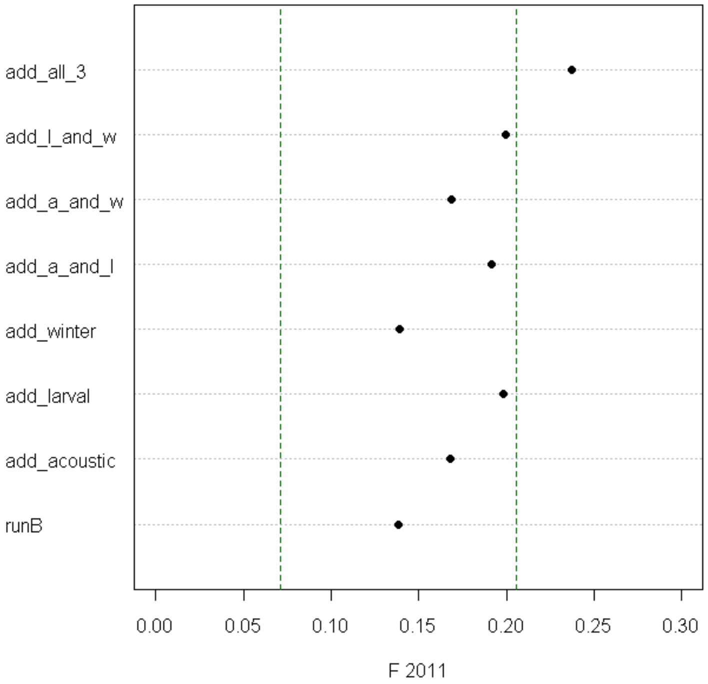


Figure A5-43. Estimates of SSB and F from the ASAP base run (runB) and sensitivities. Vertical bars are the 80% probability intervals from the ASAP base run.

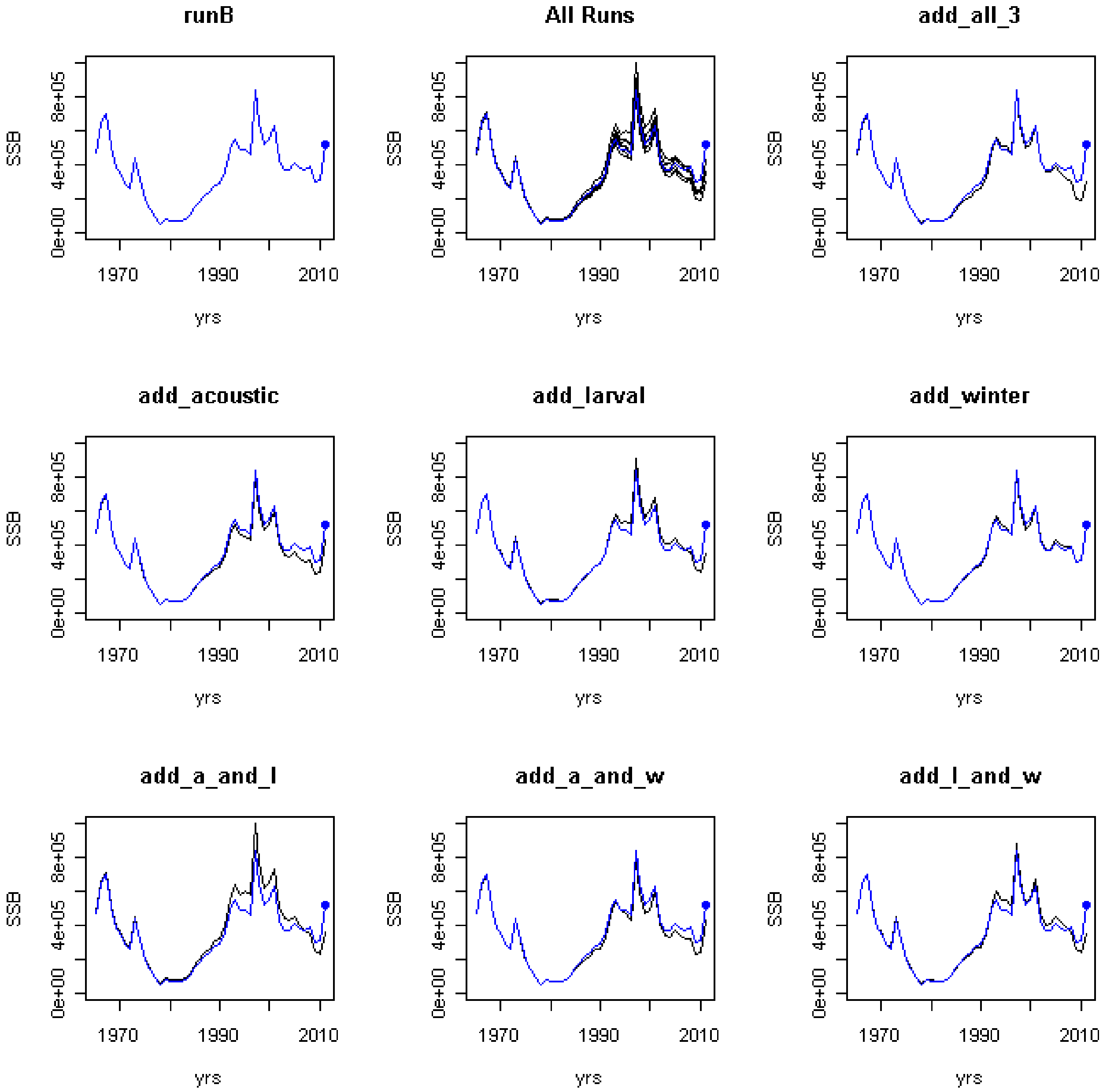


Figure A5-44. Time series estimates of SSB from the ASAP base run (run B) and sensitivities.

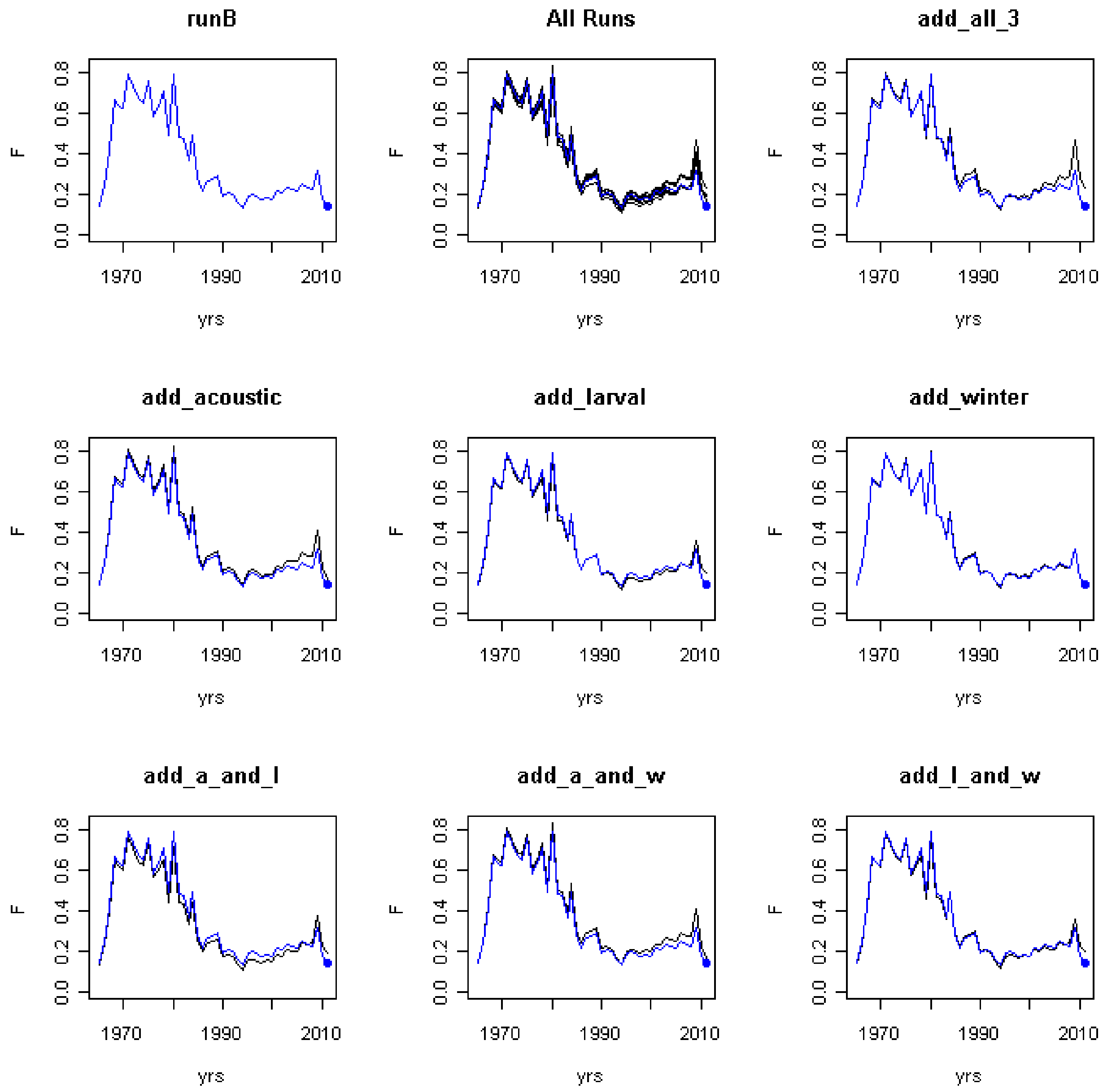


Figure A5-45. Time series estimates of fishing mortality from the ASAP base run (run B) and sensitivities.

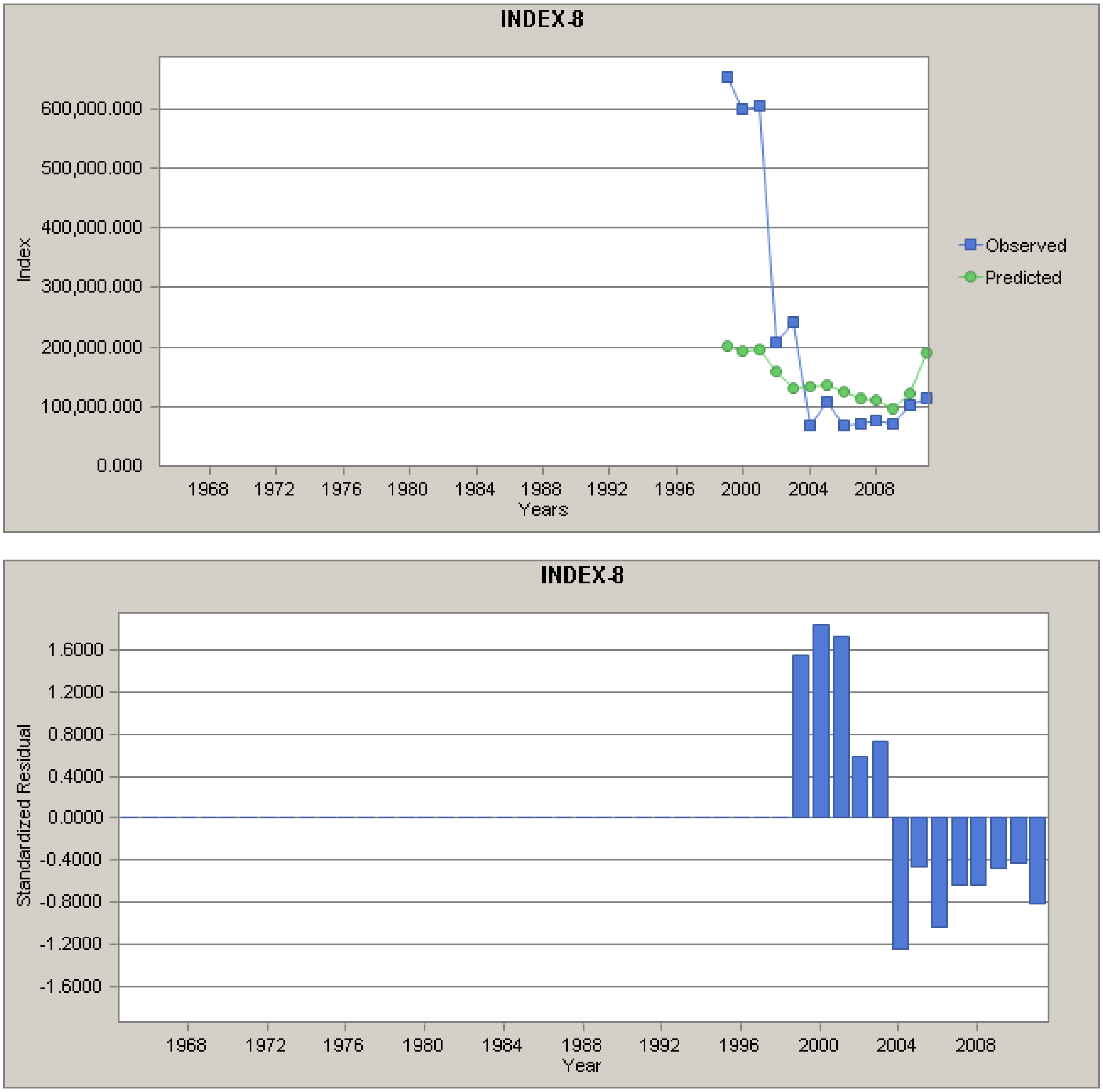


Figure A5-46. Fit of the NMFS acoustic survey index when added to the ASAP base run.

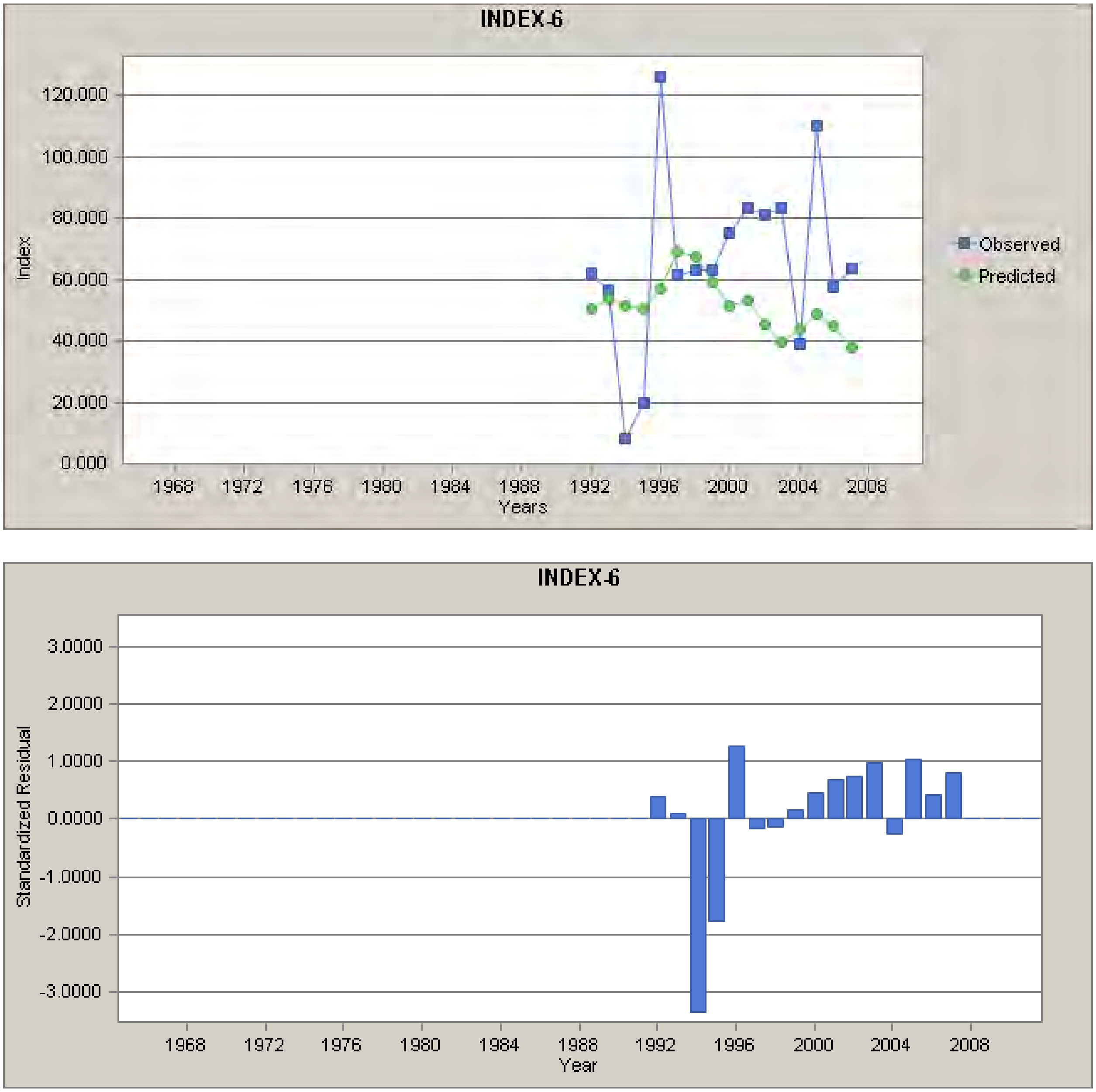


Figure A5-47. Fit of the NMFS winter survey index when added to the ASAP base run.

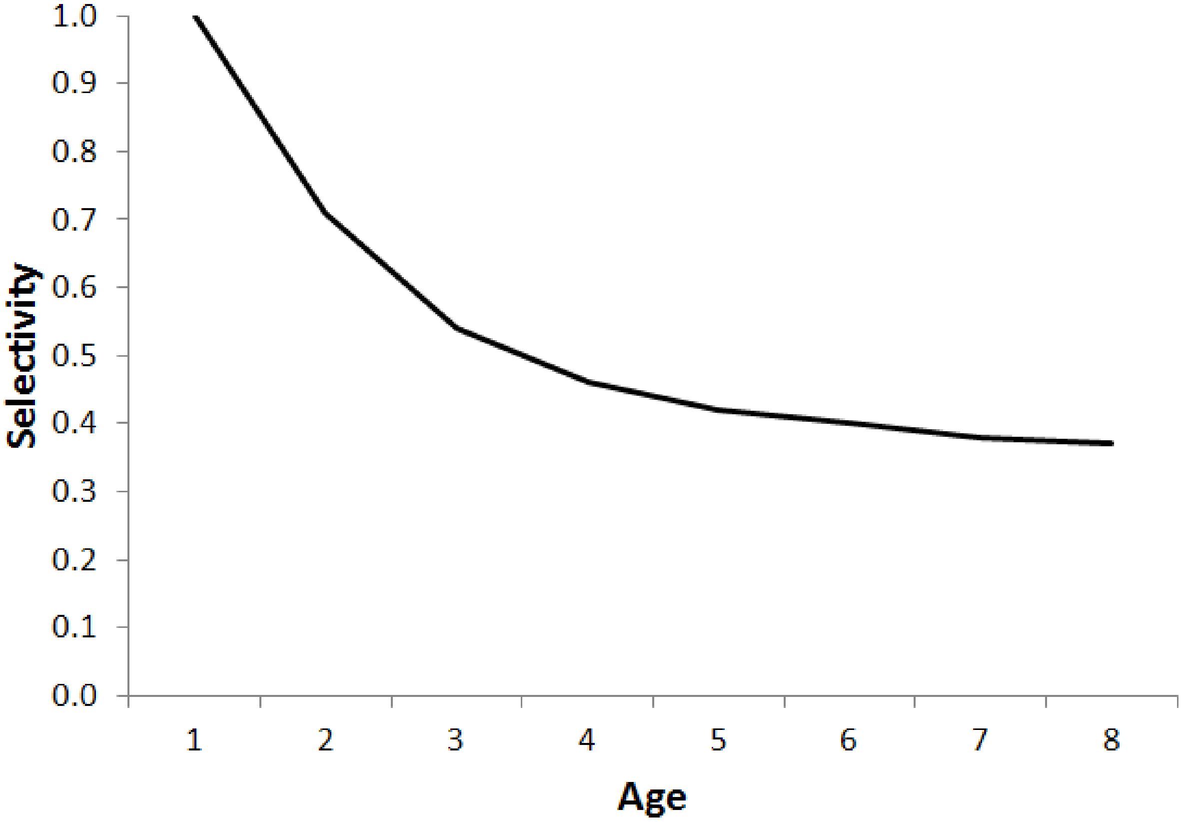


Figure A5-48. Selectivity at age for the Atlantic herring, fish predator consumption “fleet”.

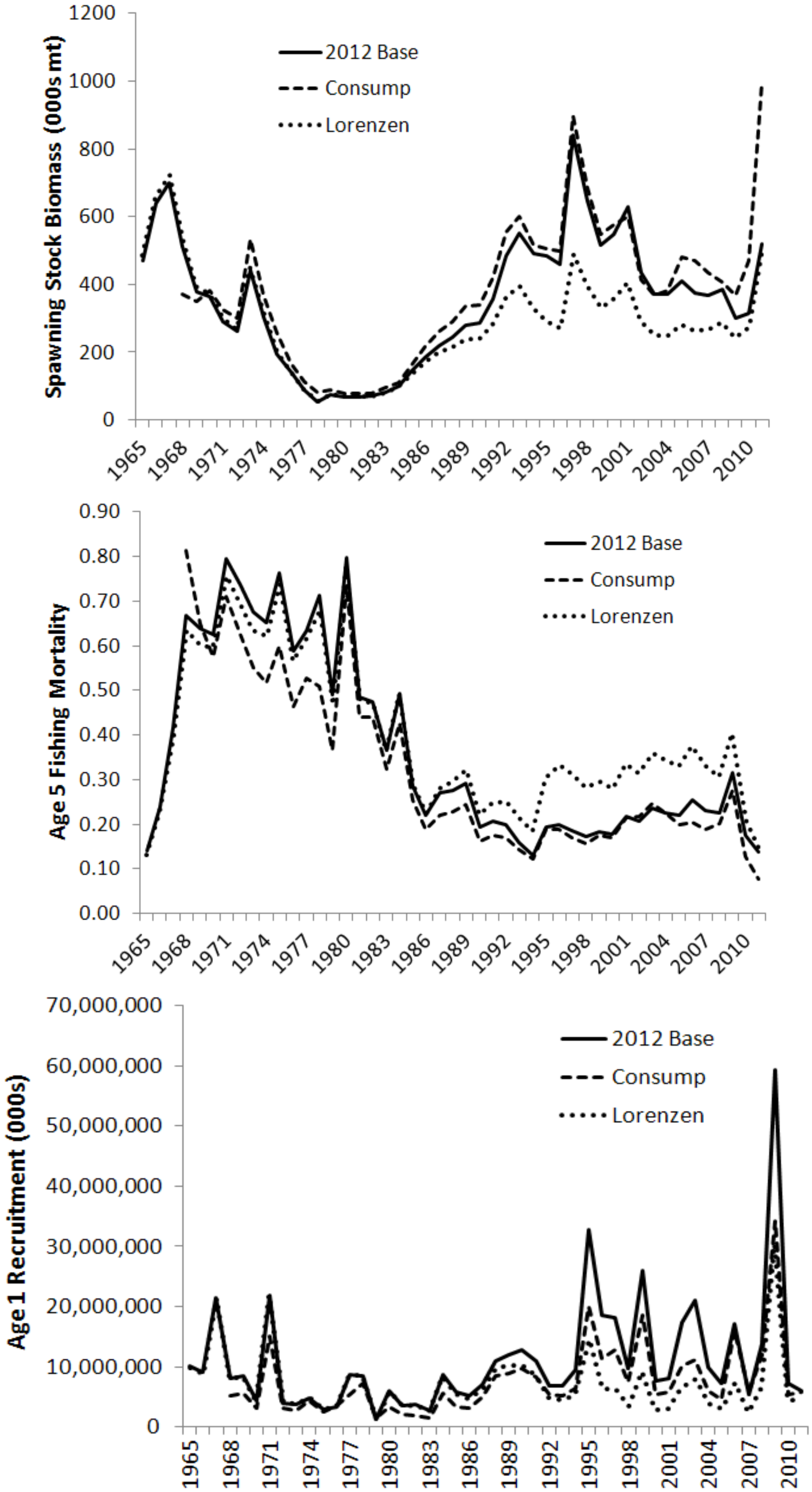


Figure A5-49. Time series estimates of spawning stock biomass, fishing mortality, and recruitment, for the 2012 ASAP base run (2012 Base), a similar run with fish consumption as a fleet (Consump), and a run with original Lorenzen natural mortality (Lorenzen).

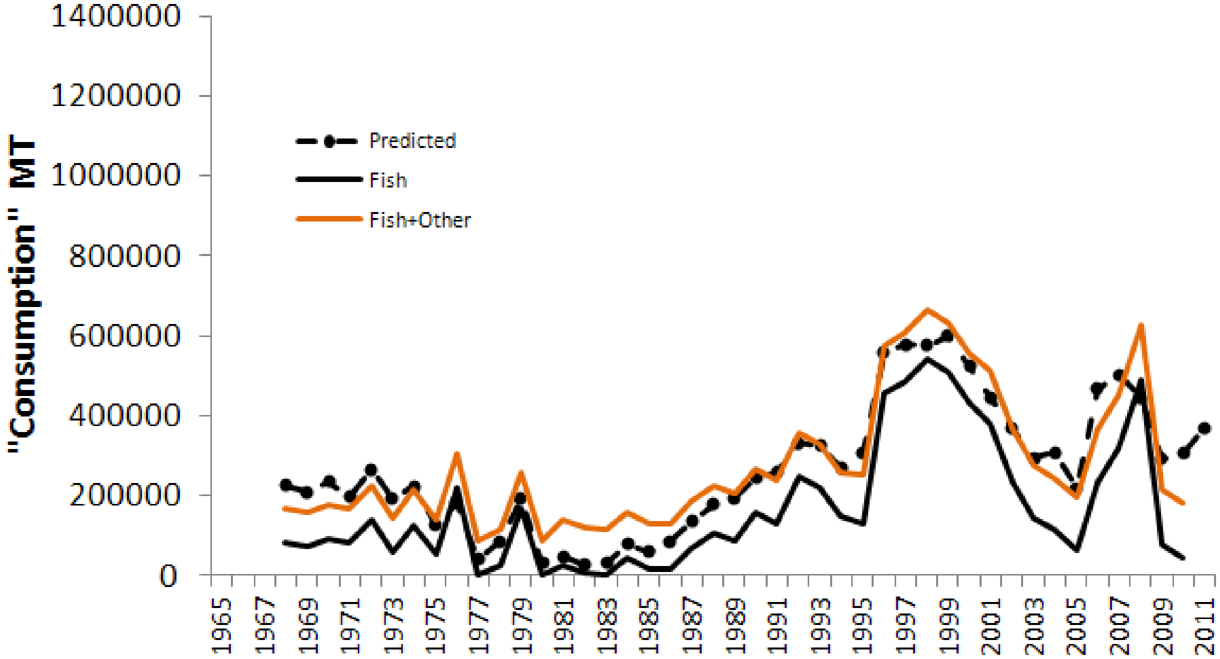


Figure A5-50. As in Figure A31, except with the addition of the predicted deaths by natural causes from an ASAP model using consumption as a fishing fleet (Predicted; dashed line with dots; represents deaths from M1 plus estimated deaths from M2).

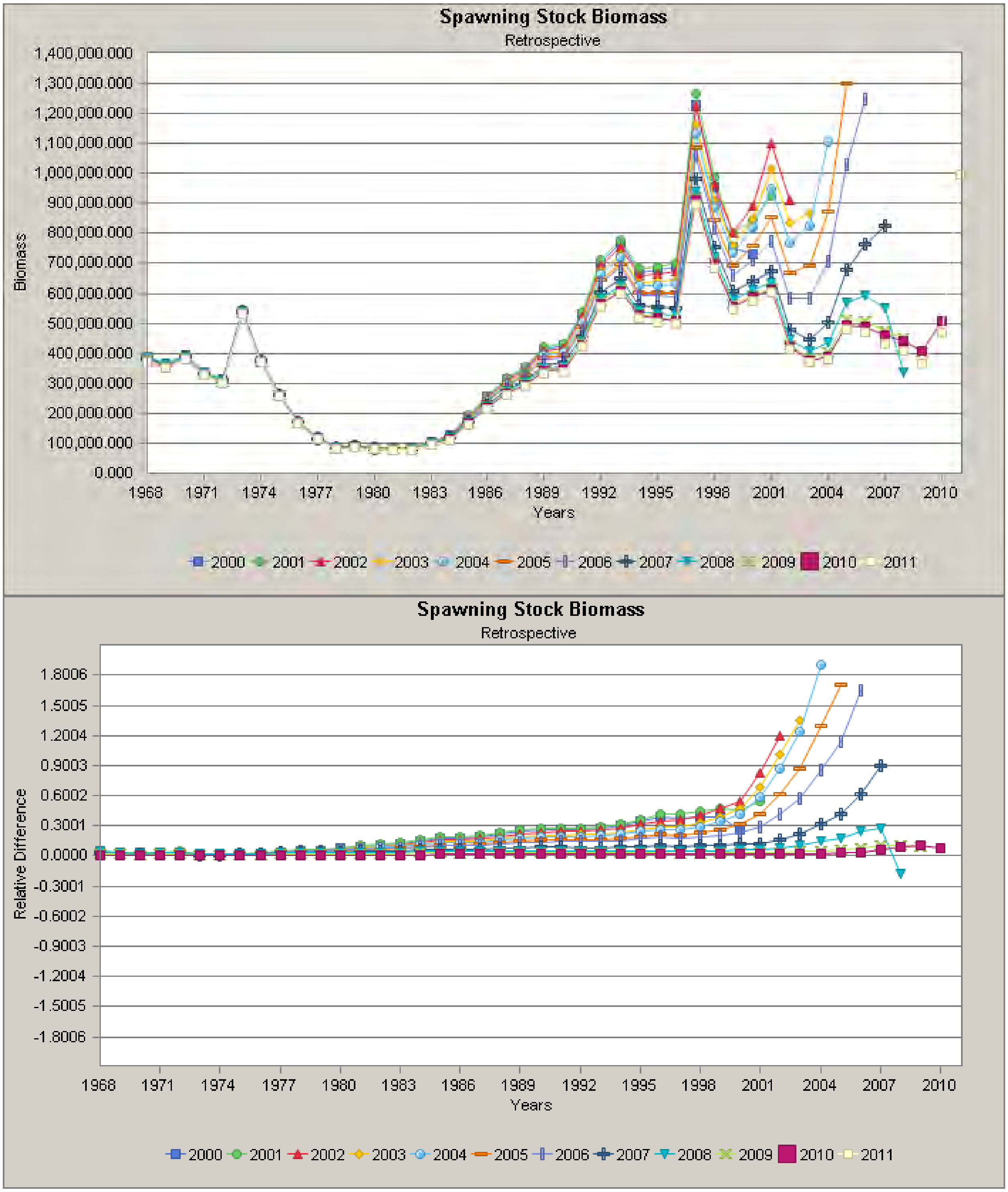


Figure A5-51. Retrospective pattern for spawning stock biomass from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

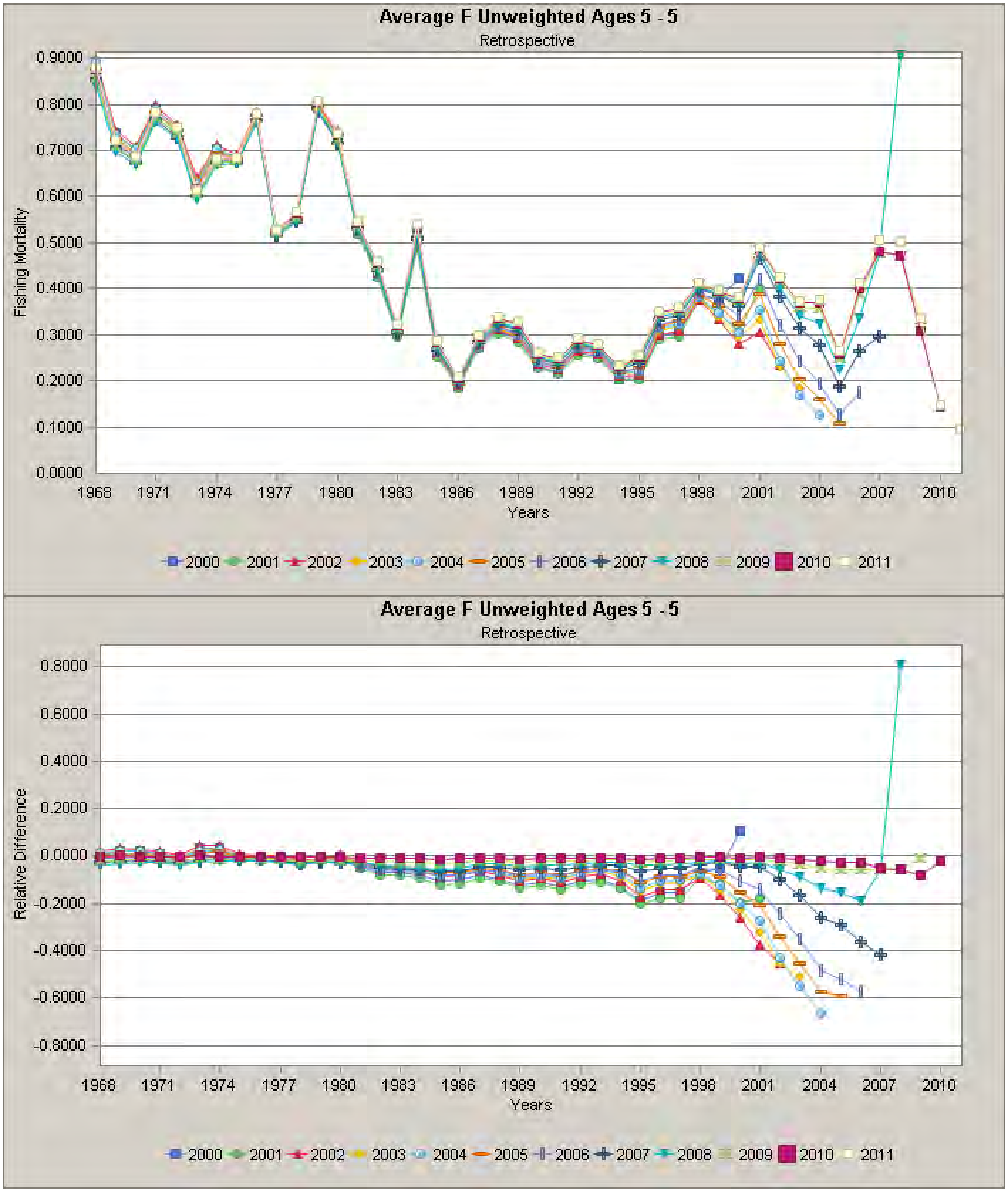


Figure A5-52. Retrospective pattern for age 5 fishing mortality from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

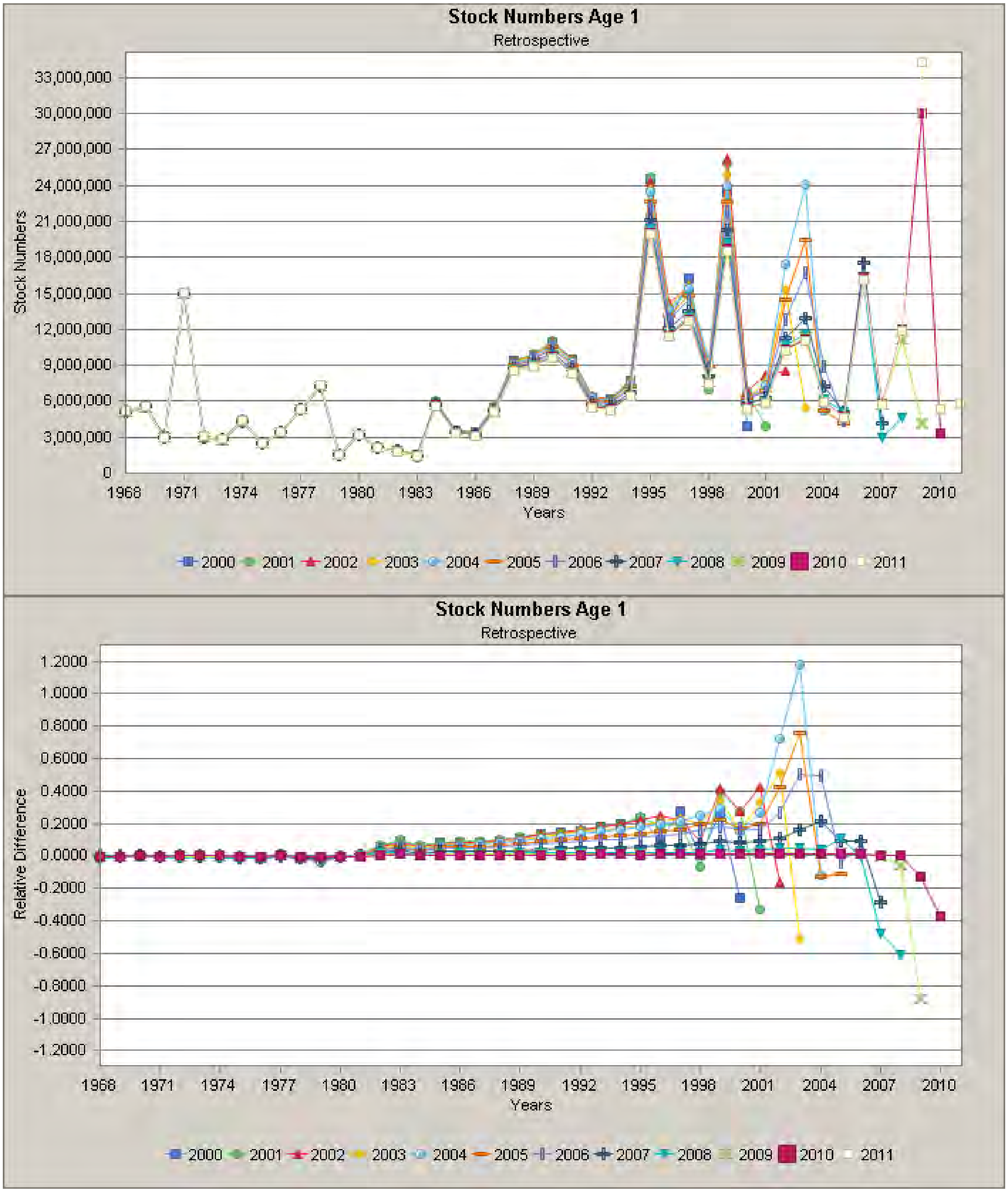


Figure A5-53. Retrospective pattern for recruitment from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

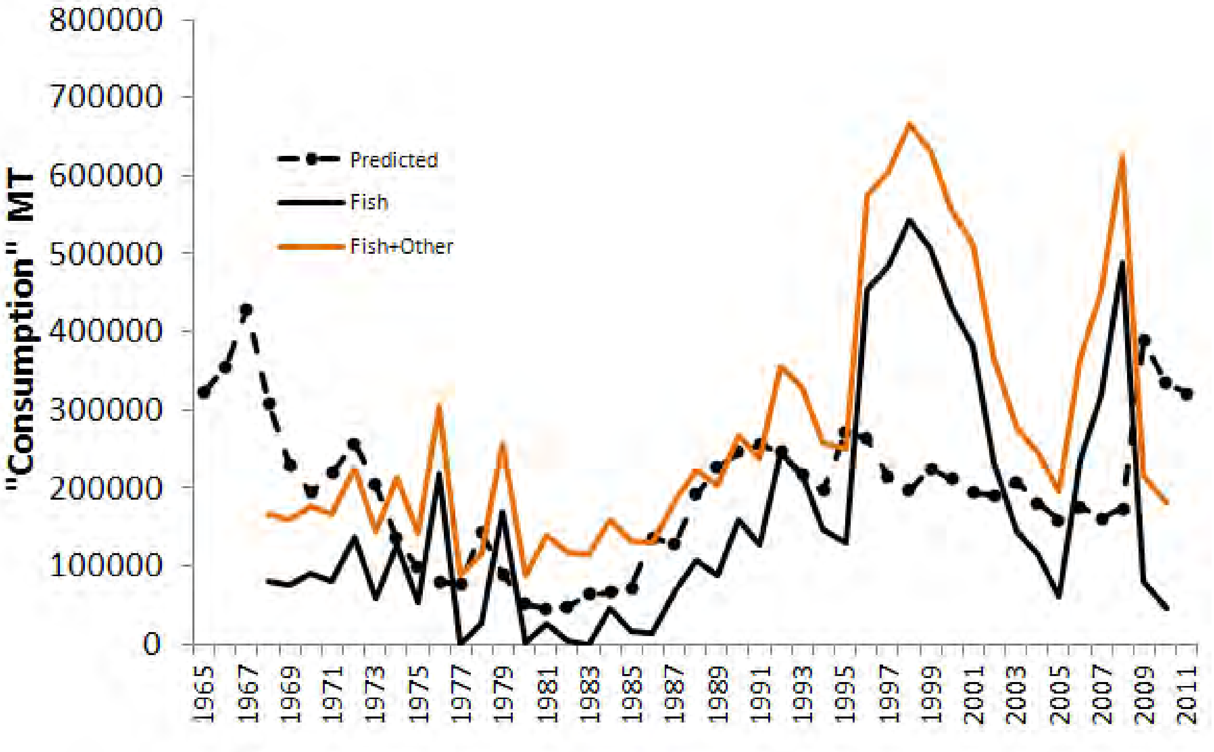


Figure A5-54. As in Figure A5-31, except with the addition of the implied consumption from M1 from an ASAP run using the original Lorenzen values for natural mortality (Predicted; dashed line with dots).

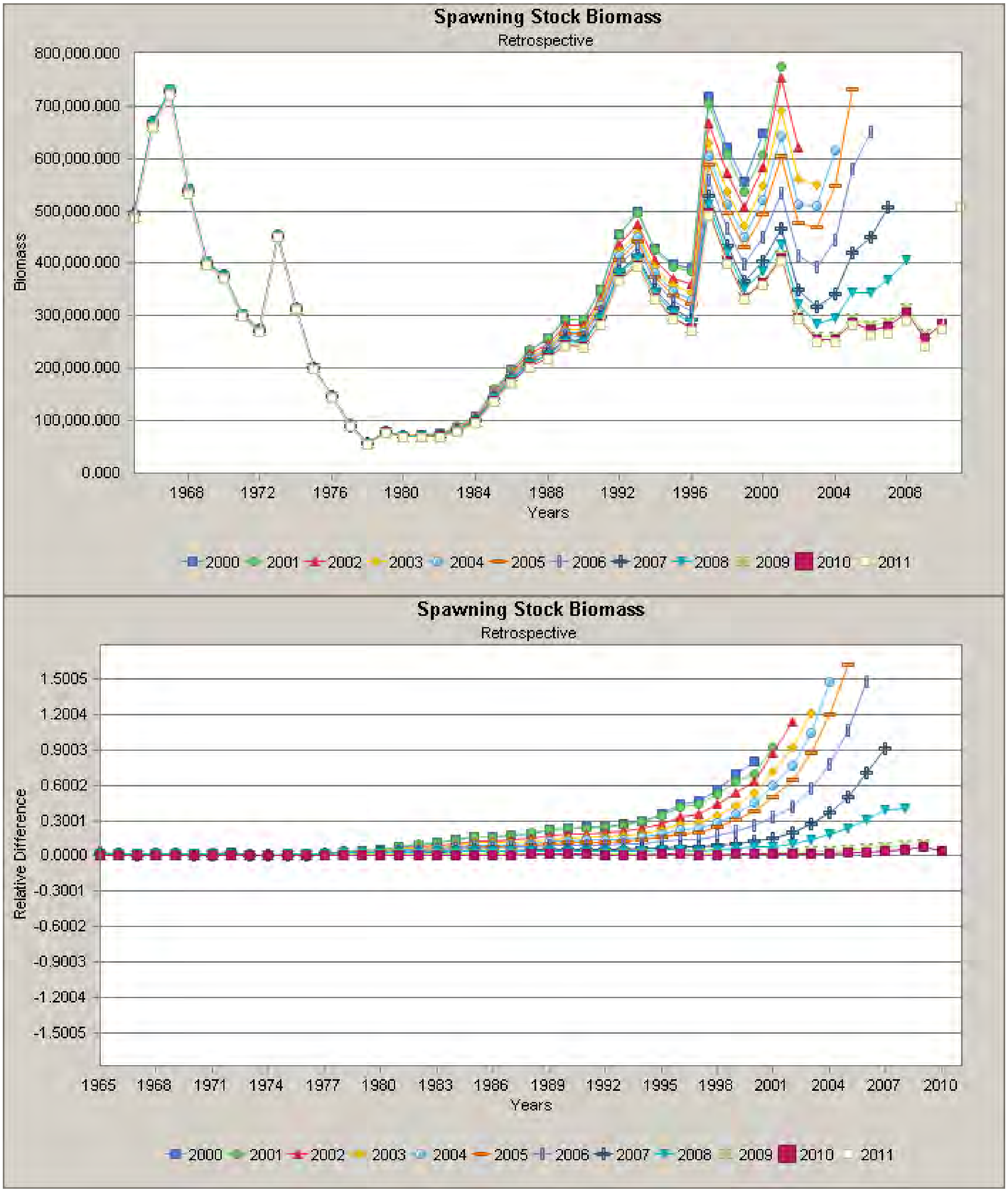


Figure A5-55. Retrospective pattern for spawning stock biomass from an ASAP model that uses original Lorenzen natural mortality.

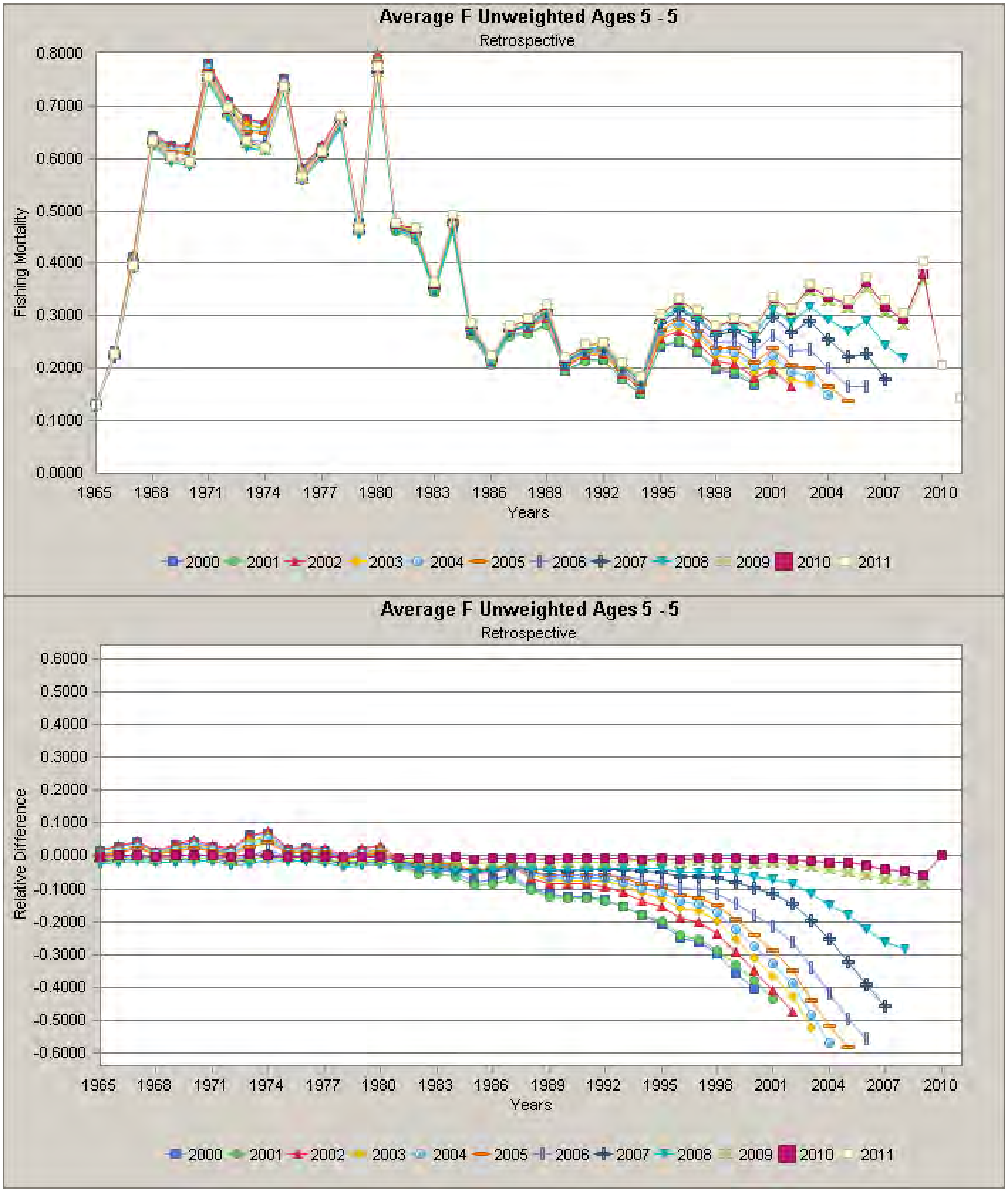


Figure A5-56. Retrospective pattern for age 5 fishing mortality from an ASAP model that uses original Lorenzen natural mortality.

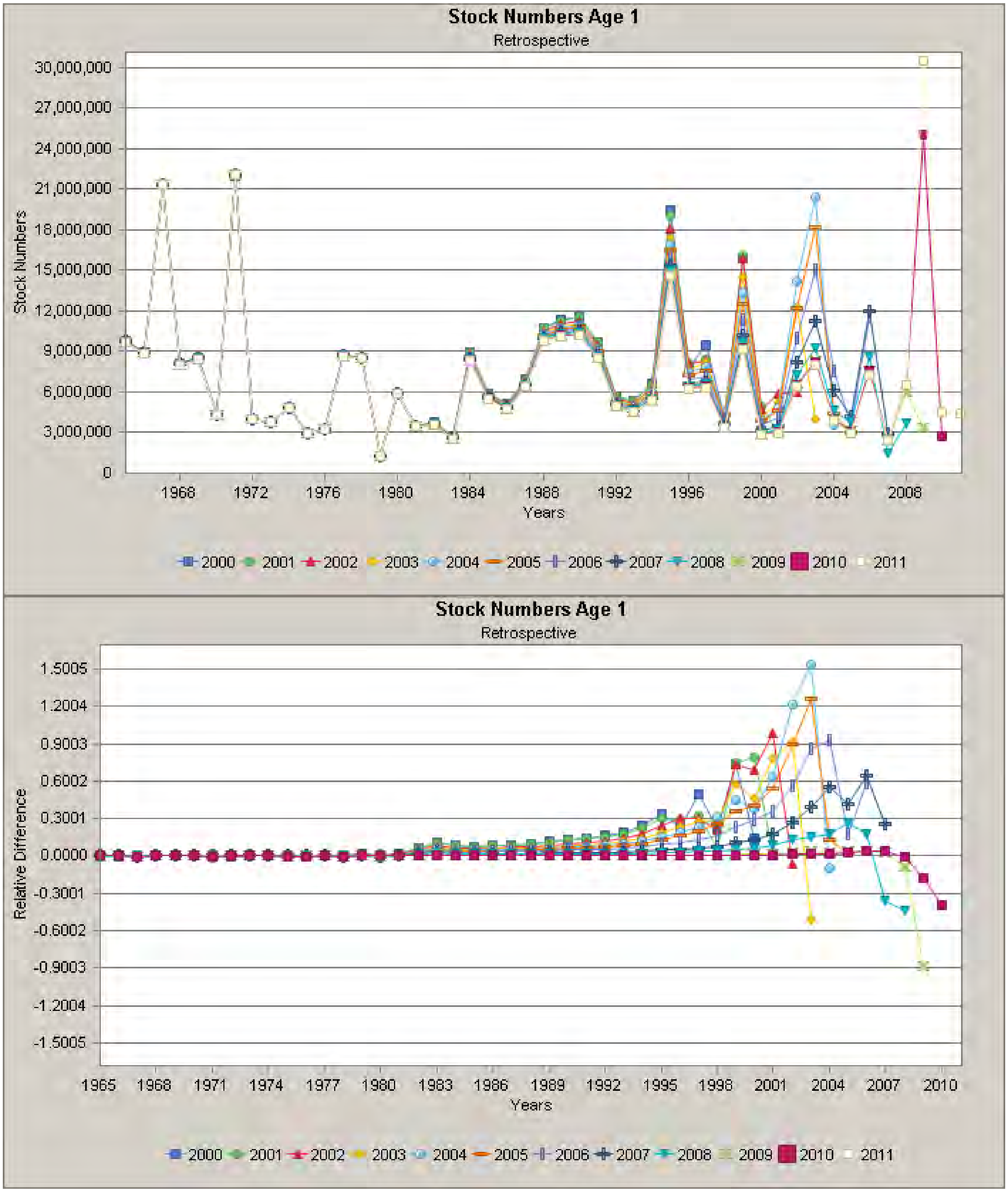


Figure A5-57. Retrospective pattern for recruitment from an ASAP model that uses original Lorenzen natural mortality.

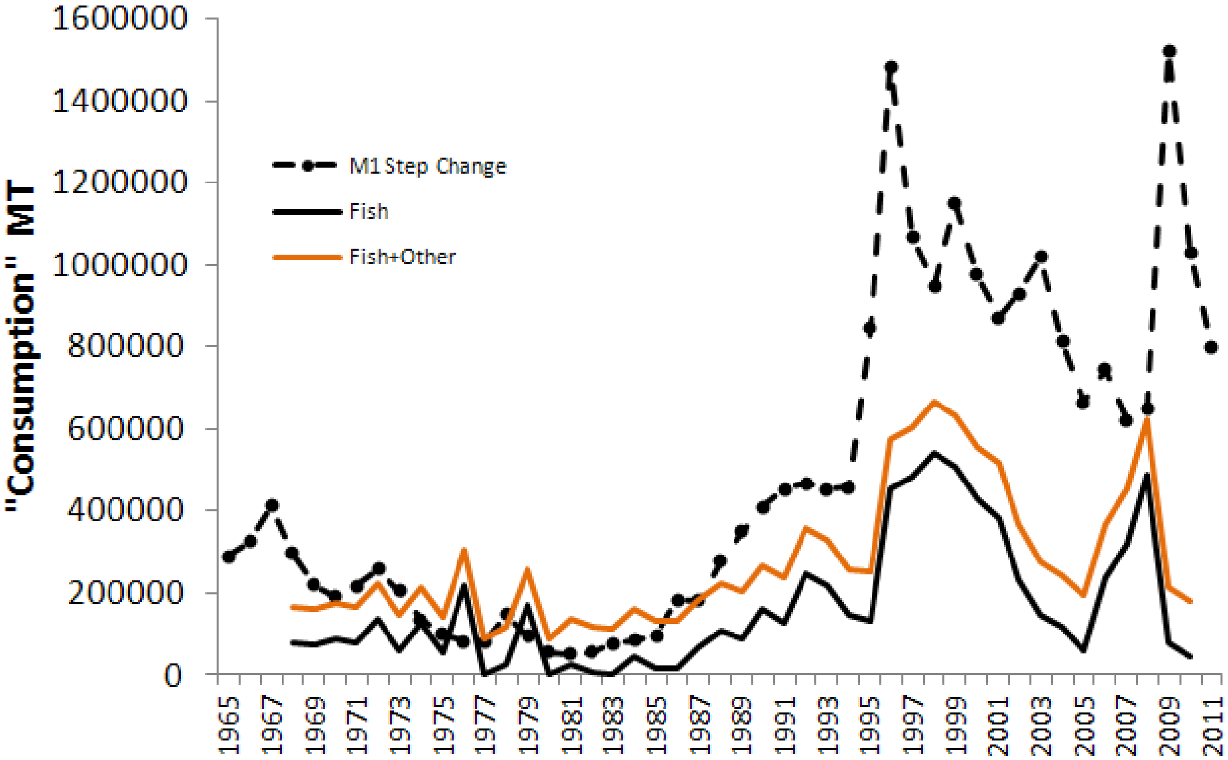


Figure A5-58. As in Figure A5-31, except with the addition of the implied consumption from M1 from an ASAP run using a step change in average natural mortality from an average of 0.3 during 1965-1995 to an average of 0.5 during 1996-2011.

TOR A7. *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 scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.*

The existing MSY reference points are based on the fit of a Fox surplus production model (TRAC 2009). The overfishing definition is $F_{MSY} = 0.27$. The stock is considered overfished if SSB is less than half SSB_{MSY}. The existing overfished definition is ½ SSB_{MSY} = 0.5 x 670,600 mt = 335,300 mt. MSY = 178,000 mt

Updated MSY reference points were estimated based on the fit to a Beverton-Holt stock-recruitment curve, which was estimated internally to the ASAP base run (see TOR A5, Figure A5-26). For calculating these reference points, ASAP used the inputs (e.g., weights at age, M) from the terminal year of the assessment (i.e., 2011). Using inputs from the terminal year of the assessment had the consequence of using natural mortality rates from the period when these rates were increased by 50%. Steepness of the Beverton-Holt curve = 0.53, $F_{MSY} = 0.27$, SSB_{MSY} = 157,000 mt (½ SSB_{MSY} = 78,500), and MSY = 53,000 mt. A Beverton-Holt stock-recruitment model was also fit external to ASAP using the base ASAP run estimates of age 1 recruitment and SSB, which produced similar reference points. Eighty percent probability intervals for the MSY reference points were based on MCMC simulations of the base ASAP run (see TOR A5):

Metric	**80% probability interval**
F_{MSY}	0.16 - 0.39
SSB_{MSY}	119,738 - 214,282 mt
MSY	41,392 - 62,342 mt

The MSY reference points from the 2009 TRAC, estimated using an external surplus production model, created an inconsistency between the model used to estimate the reference points and the model used to estimate current F and SSB. Consequently, long-term stochastic projections at F_{MSY} based on results from the ASAP model (e.g., recruitment time series) did not produce equivalent SSB_{MSY} or MSY estimates.

Furthermore, measures of uncertainty for the MSY reference points from the 2009 TRAC may have been underestimated because the methods for propagating errors between ASAP model estimates and a surplus production model fit to the ASAP model estimates are not well established.

The 2012 MSY reference points from the base ASAP run are internally consistent. For example, long-term stochastic projections at F_{MSY} based on results from the base ASAP run (e.g., stock-recruitment relationship) produce values similar to the point estimates of SSB_{MSY} and MSY. In this way, the new reference points are an improvement over the existing reference points from the 2009 TRAC. Use of the Fox model during the 2009 TRAC and the differences in natural mortality rates were largely responsible for the differences in reference points between assessments.

TOR A8. *Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model, should one be developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).*

  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 and their estimates (from TOR-7).*

The model from the 2009 TRAC was updated using data through 2011. From this model, fully selected F in 2011 was estimated to be 0.07 and SSB in 2011 was 979,000 mt. A comparison of these values to the existing MSY reference points from the 2009 TRAC suggest that overfishing is not occurring and that the stock is not overfished.

The base ASAP run estimated fishing mortality at age 5 (see TOR 5) in 2011 to be 0.14 and SSB in 2011 was 517,930 mt. A comparison of these values to the new MSY reference points from the base ASAP run suggest that overfishing is not occurring and that the stock is not overfished.

TOR A9. *Using simulation/estimation methods, evaluate consequences of alternative harvest policies in light of uncertainties in model formulation, presence of retrospective patterns, and incomplete information on magnitude and variability in M.*

Several research projects have been undertaken to address this term of reference. Several projects from researchers at the University of Maine focused on causes and solutions of retrospective patterns.

Another project from NMFS biologists in Woods Hole (J. Deroba) used simulation modeling to quantify the consequences (e.g., SSB, F, quotas) of either ignoring retrospective patterns or adjusting for retrospective patterns using Mohn's Rho. Some collaborative research is also underway by NMFS biologists (J. Deroba and A. Schueller) to quantify the extent of bias in stock assessment estimates when natural mortality varies among years and ages, but this variation is mis-specified in the assessment model. The working group did not discuss any of these projects in detail because they focus on more general topics that did not immediately inform decisions for this assessment. The details of some of the University of Maine project are provided in a working paper.

TOR A10. *Develop approaches and apply them to conduct stock projections and to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).*

A10.a. *Provide numerical annual projections (3 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 results of the base ASAP run. The projections did not account for any retrospective error because natural mortality in the base ASAP run was altered to eliminate the retrospective pattern (see TOR 5). Numbers-at-age in 2012 were drawn from 1000 vectors of numbers-at-age produced from MCMC simulations of the base ASAP run (see TOR 5). The projections assumed that catch in 2012 equaled the annual catch limit.

Age 1 recruitment was based on the Beverton-Holt relationship estimated in the base ASAP run (see TOR 5) with lognormal error:

$$R_y = \frac{\tilde{\alpha}\, SSB_{y-1}}{\beta + SSB_{y-1}} e^{\omega} \;\; ;$$

where R_y is recruitment in year y, *SSB* is spawning stock biomass, β is a parameter estimated in the base ASAP run (Table A10-1), and $\omega \sim N(0, \sigma^2)$. $\tilde{\alpha}$ is a bias corrected parameter:

$$\tilde{\alpha} = \alpha e^{-\sigma^2/2};$$

where α is a parameter estimated in the base ASAP run (Table A10-1). The variance, σ^2, equaled the variance of the log recruitment deviations estimated by the base ASAP run (Table A10-1).

Projections were conducted for a range of harvest scenarios, including F_{MSY}, 0.75 F_{MSY}, F_5 in 2011, MSY, and status quo catch (i.e., 2012 annual catch limit; Table A10-2). Results are summarized as the median of catch and SSB with 80% confidence intervals (Table A10-2).

A10.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.*

Natural mortality is an uncertainty in this assessment. Of particular importance is acceptance of the scale of the herring consumption estimates. The 50% increase in natural mortality from the original natural mortality values during 1996-2011 used in the ASAP model was employed to reduce retrospective patterns in SSB and to make implied biomass removals from input natural mortality rates and the consumption data more consistent. Furthermore, the reference points and projections were made under the assumption that prevailing conditions would persist. If life history traits such as M change rapidly, and prevailing conditions become altered, the associated biological reference points and projections would likewise need to be changed.

An ASAP assessment model using the original Lorenzen M values exhibited a retrospective pattern that the working group felt would not be acceptable to reviewers or managers (see TOR 5). Reference points and projection results from the ASAP run using the original Lorenzen M values also differ from the base ASAP model (see TOR 5).

Stock structure is another uncertainty for this assessment (see TOR 4). The working group acknowledged that a retrospective pattern in the Atlantic herring assessment may be inevitable as long as we are assessing a mixed stock complex. For example, varying contributions from the Scotian Shelf (4WX) stock can produce retrospective patterns.

A10.c. *Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.*

The unknown contributions of the Scotian Shelf (4WX), Gulf of Maine, and Georges Bank stocks can affect the stocks vulnerability to becoming overfished. For example, if the Scotian Shelf stock is contributing a significant amount of fish and that contribution decreases, the vulnerability to overfishing would increase. The vulnerability of the stock has been demonstrated by the historical collapse of the Georges Bank component in the 1980s, which also demonstrated that the multiple spawning groups can be differentially impacted by fishing.

In the short-term, the 2009 age 1 cohort (2008 year class) may reduce the vulnerability of this stock to overfishing. The strength of large cohorts is often overestimated in the short-term, however. So, the strength of this cohort should be interpreted cautiously and any decisions based on this assessment should consider this concern. If the signal about the strength of the 2009 age 1 cohort does in fact weaken with additional years of data, decisions made based on this assessment would be overly optimistic and some members of the working group warned that future assessments will likely be prone to worsening retrospective patterns. In contrast, some members of the working group noted that the warnings of a weakening signal were based only on conjecture and that the 2009 age 1 cohort has already been selected by fishery and survey gears for 2-3 years.

Recent catches were generally greater than the estimate of MSY from the base ASAP run. This result suggests that in the long-term this stock may become more vulnerable to overfishing. The reference points (e.g., MSY), however, are uncertain, as evidenced by analysis done on the base ASAP run and the results of the alternative and sensitivity runs (see TOR 5).

The working group acknowledged that a retrospective pattern in herring may be inevitable as long as we are assessing a mixed stock complex. Varying contributions from the Scotian Shelf (4WX) stock can produce retrospective patterns in a catch at age model. The unknown contributions of this stock can also make the stocks vulnerable to over-exploitation if that contribution stops. The vulnerability of the stock has been demonstrated with the historical collapse of the Georges Bank component in the 1980s. The stock structure complex which involves multiple spawning groups can be differentially impacted by fishing. In addition, changes in the predator field will influence M which in turn impacts reference points and quota estimates.

Table A10-1. Stock-recruitment parameters from the base ASAP run used in projections.

Parameter	Value
Alpha α	13177700
Variance σ^2	0.3712
Bias-corrected Alpha $\tilde{\alpha}$	10945342
Beta β	135600

Table A10-2. Results of three year projections for the base ASAP run.

Fmsy = 0.267	SSBmsy = 157,000 mt	steepness = 0.53	MSY = 53,000 mt
2011 F (age 5)	SSB 2011		2011 catch
0.14	518,000 mt		85,000 mt
2012 catch = 87,683 mt (quota)			
	2013	**2014**	**2015**
	F_{msy}		
F	0.267	0.267	0.267
SSB	496,064 mt	368,501 mt	308,949 mt
80% CI	362,965 - 688,585 mt	275,695 - 517-815 mt	237,755 - 411,808 mt
Prob < SSBmsy/2	0	0	0
catch	168,775 mt	126,589 mt	104,430 mt
80% CI	124,868 - 230,764 mt	95,835 - 171,145 mt	79,505 - 139,925 mt
	$F_{75\%\ msy}$		
F	0.2	0.2	0.2
SSB	523,243 mt	409,309 mt	354,559 mt
80% CI	382,573 - 723,975 mt	306,011 - 574,128 mt	272,751 - 473,021 mt
Prob < SSBmsy/2	0	0	0
catch	130,025 mt	102,470 mt	87,574 mt
80% CI	96,216 - 177,894 mt	77,476 - 138,665 mt	66,739 - 117,318 mt
	$F_{status\ quo}$		
F	0.14	0.14	0.14
SSB	548,788 mt	450,496 mt	402,551 mt
80% CI	401,571 - 760,028 mt	336,594 - 631,502 mt	309,334 - 537,414 mt
Prob < SSBmsy/2	0	0	0
catch	93,159 mt	76,823 mt	67,912 mt
80% CI	68,954 - 127,518 mt	58,022 - 104,055 mt	51,752 - 91,001 mt
	MSY		
F	0.08	0.09	0.1
80% CI	0.06 - 0.11	0.07 - 0.12	0.07 - 0.14
Prob > Fmsy	0	0	0
SSB	576,092 mt	492,162 mt	448,725 mt
80% CI	413,046 - 813,298 mt	351,530 - 716,931 mt	321,209 - 633,132 mt
Prob < SSBmsy/2	0	0	0
catch	53,000 mt	53,000 mt	53,000 mt
	Status quo catch		
F	0.13	0.16	0.19
80% CI	0.1 - 0.18	0.11 - 0.23	0.13 - 0.27
Prob > Fmsy	1%	4%	10%
SSB	551,686 mt	446,496 mt	385,995 mt
80% CI	388,989 - 789,568 mt	306,349 - 669,721 mt	259,178 - 569,560 mt
Prob < SSBmsy/2	0	0	0
2012 quota	87,683 mt	87,683 mt	87,683 mt

TOR A11. *For any research recommendations listed in recent peer reviewed assessment and review panel reports, review, evaluate and report on the status of those research recommendations. Identify new research recommendations.*

<u>*New Research Recommendations*</u>

a. More extensive stock composition sampling including all stocks (i.e. Scotian Shelf).

b. Develop (simple) methods to partition stocks in mixed stock fisheries.

c. More extensive monitoring of spawning components.

d. Analyze diet composition of archived mammal stomachs. Improve size selectivity of mammal prey. Also sea birds.

e. Consider alternative sampling methods such as HabCam.

f. Research depth preferences of herring.

g. Simulation study to evaluate ways in which various time series can be evaluated and folded into model.

h. Evaluate use of Length-based models (Stock Synthesis and Chen model)

i. Develop indices at age from shrimp survey samples

j. Evaluate prey field to determine what other prey species are available to the predators that could explain some of the annual trends in consumption.

k. Develop statistical comparison of consumption estimates and biomass from model M.

l. Consider information on consumption from other sources (i.e. striped bass in other areas) and predators inshore of the survey.

m. Investigate why small herring are not found in the stomachs of predators in the NEFSC food habits database.

n. Develop an industry-based LPUE or some other abundance index (Industry Based Survey).

o. Develop objective criteria for inclusion of novel data streams (consumption, acoustic, larval, etc) and how can this be applied.

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Appendix I

Atlantic Herring Data Working Group meeting
January 30-February 3, 2012
Atlantic Herring Model Working Group meeting
April 9-April 13, 2012
Woods Hole, MA

Participants:
Jon Deroba – NEFSC - *Assessment Lead Scientist*
Gary Shepherd – NEFSC -*Working Group chair*
Mike Jech – NEFSC - *Acoustics*
Brian Smith – NEFSC - *Food Habits*
Laurel Col – NEFSC- *Marine Mammals*
Dave Richardson – NEFSC - *Icthyoplankton*
Larry Jacobson –NEFSC - *SS3*
Matt Cieri - ME DMF - *Catch*
Nick Markis – MIT –*OAWRS*
Jon Hare – NEFSC- *Oceanography*
Jason Link – NEFSC – *Ecosystems*
Steve Cadrin –SMAST –*Stock Structure*
Al Seaver - NEFSC
Andrew Cooper - Dept. of State
Bob Gamble – NEFSC
Chris Legault - NEFSC
Dan Hennen - NEFSC
Deb Palka - NEFSC
Fred Serchuk - NEFSC
Jeff Kaelin - Lund Fisheries
John Crawford - PEW
Julie Nieland - NEFSC
Kathy Sosebee -NEFSC
Liz Brooks - NEFSC
Loretta O'Brien – NEFSC
Lori Steele – NEFMC
Mark Terceiro – NEFSC
Mary Beth Tooley - O'Hara Fisheries
Micah Dean, MA DMF
Michael Fogarty - NEFSC
Michael Palmer - NEFSC
Paul Nitschke - NEFSC
Paul Rago - NEFSC
Peter Corkeron - NEFSC
Piera Carpi - SMAST
Purnima Ratilal - Northeastern Univ.
Rich McBride - NEFSC
Sarah Gaichas - NEFSC
Sean Lucey - NEFSC
Sigrid Lehuta - GMRI
Steve Weiner - CHOIR
Susan Wigley - NEFSC
Tom Dempsey - NEFMC
Tim Essington - Univ. Washington
Vincent Manfredi - MA DMF
Wendy Gabriel - NEFSC
Wenjiang Guan - Univ. Maine
Yong Chen - Univ. Maine

Appendix 2: Exploratory Stock Synthesis models for herring

Summary

Stock Synthesis (SS3) models were developed for herring to determine if incorporating length data directly into the assessment, modeling selectivity as a function of length and using other advanced features of SS3 would improve the stability and accuracy of stock size and mortality estimates for herring. We hoped that SS3 or a similar approach would facilitate modeling when age data are not available (e.g. in the terminal year or for an entire survey), help deal with changes in survey timing and growth and, in particular, reduce retrospective patterns. A large number of SS3 model runs were carried out but all SS3 estimates and results shown here are from a single demonstration run.1

These SS3 results shown here were not completely reviewed by the Coastal Pelagic Working Group (WG) and are not useful for management purposes. The best use of this information is in identifying modeling approaches that might be useful in future. Both SS3 and the current assessment model (ASAP) were originally intended for use in working group deliberations. However, the lead stock assessment scientist and Working Group were unable to review the SS3 model configuration, resolve all data and modeling questions or consider results in the available time.

Based on preliminary results, the focus in modeling on length data and SS3 model configuration appear promising because retrospective patterns were reduced without having to make assumptions about high natural mortality during recent years (Figure A2-1). Survey and fishery selectivity appear to be a function of size with the exception of young fish in coastal waters that are not found in offshore fisheries and surveys. It was possible to estimate time varying growth parameters that were similar to external estimates. Size data, time varying growth and estimation of size selectivity curves helped accommodate changes in survey timing and effects of changes in growth on selectivity. Fit to most data sources was good and it was possible to use survey data when ages were unavailable without assuming an age selectivity pattern.

SS3 configuration of SS3 for herring is summarized in Table A2-1. Data are summarized in Figure A2-2. Suggestions for future modeling and information about details with explanations follow.

Suggestions for future modeling

Historical catch data are required in SS3 and can be important because the model was originally designed for long-lived groundfish assumed to have been reduced from the virgin state to some initial level based on an average annual historical catch level. In this way, model stability was increased because the estimate of virgin biomass, the estimated spawner recruit curve (which can be used to independently calculate virgin biomass as in the ASAP model), MSY reference points (which are linked to the spawner-recruit curve and virgin biomass) and assumptions about historical catch are interdependent. This approach may be misleading and inappropriate for dynamic short lived fish like herring that experienced long periods of significant and variable amounts of fishing pressure prior to the onset of the modeled time period. The effect of this potential problem on preliminary SS3 estimates was not evaluated.

In future, it would be useful to try reducing the importance of historical catch data by

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1 The SS3 run shown here was identified as the “Cadillac” run in working group meeting documents.

establishing very weak priors for historical fishing mortality parameters and by estimating recruitment offset parameter available in the model. The weak priors for fishing mortality parameters would effectively mean that the historical catch data were imprecise allowing the model to estimate initial stock size to maximize fit to the available data, rather than correspondence between virgin and initial stock size. The recruitment offset parameter effectively rescales the spawner-recruit curve during the historical period so that virgin and initial stock sizes are not directly linked by the spawner-recruit curve used elsewhere in the model and so that initial stock size is estimated to maximize fit to the available data.

These assumptions about ageing errors are based on recent QA/QC experiments and probably understate the actual imprecision of herring age data, particularly for older individuals and because they ignore possible changes in ageing criteria over time. It may be advisable to carry out historical and current age reader experiments that compare ages from the same otoliths collected by historical and current age readers.

A prior on the variance of spawner-recruit residuals from Overholtz et al. (2004) was used in SS3 but probably incorrectly. It might be advisable to assume more temporal variability in catchability or, perhaps, selectivity parameters when modeling the fall survey prior to 1985 when the survey doors changed (Figure A2-19 and see below). Historical catch estimates should be refined in possible.

Details and additional explanation

All of the likelihood weights used in fitting SS3 was zero. Some adjustments were made to assumed sample size and variances based on preliminary fits. A total of 190 parameters were estimated in SS3 (see below). Most of parameters were annual deviations in the von Bertalanffy growth parameters L_{max} and K. Selectivity curves required a relatively high number of parameters because there were seven surveys and four fisheries, length selectivity was often domed and because logistic selectivity at age was estimated in addition to selectivity at length for offshore fisheries and surveys that do not capture young herring of any size.

Parameter type	N parameters
Natural mortality and growth	5
Growth deviations (L_{max} and K)	78
Spawner-recruit	2
Recruit deviations	47
Historical fishing mortality	4
Survey catchability	4
Size and age selectivity	50
Total	190

“Exact” instantaneous fishing mortality rates during the modeled time period were calculated in SS3 using they hybrid method because Pope-type approximations may be inaccurate when mortality rates are high. With this approach, catch data are fit exactly (Figure A2-3). In contrast, SS3 uses fishing mortality rate parameters (one per fishery) to fit assumed levels of average historical catch that link virgin stock size to initial stock size in the model.

Four fisheries defined in SS3 were defined in terms of gear and season. In particular, we modeled the fixed gear (nearshore) semester 1 (January-June) and semester 2 (July-December), and mobile gear (offshore) semester 1 and semester 2 fisheries separately. Length and age data were available for all years in the mobile gear fisheries. Length and age data were used for the fixed gear fisheries if sampling was sufficient and included data from the US component. Commercial length data for herring appear to be informative (Figure A2-4).

The SS3 run shown here treated fall and spring surveys carried by the NOAA Research Vessel Albatross IV and Delaware II prior to 2009 and fall and spring surveys carried out by the

NOAA Research Vessel Bigelow during 2009-2011 as separate surveys, even though the Bigelow series were only three years in length. In the basecase ASAP run, Bigelow catches were calibrated to Albatross equivalents and used to extent the Albatross time series through 2011. The standard approach was not used in SS3 to determine the shape of Bigelow survey selectivity curves and if three years of data were sufficient to start a new bottom trawl survey time series. Results for size data in the Bigelow spring survey (see below) suggest that the Bigelow survey time series are too short (3 years) at this time to by analyzed separately as uncalibrated time series.

In addition to the spring and fall Albatross and Bigelow bottom trawl survey data series, we used the winter bottom trawl and shrimp survey time series. Length data were available for all surveys and fisheries and appear informative (Figure A2-5). Age composition data were available for all years and all surveys except for Bigelow fall survey during 2011 and in all years for the shrimp survey.

Based on NEFSC routine QA/QC age reader experiments, age data in SS3 were assumed to have unbiased measurement errors that increased with age (Figure A2-6). The standard deviation of errors in the age data was assumed to be 0 y at age zero and increased linearly from 0.09 y at age one to 0.83 y at ages 11+.

The NEFSC fall bottom trawl survey for herring is difficult to interpret because the fall survey does not cover the entire herring stock so that seasonal migration patterns and overlap between the stock and survey may be variable and time dependent. Mean Julian dates of the fall NEFSC bottom trawl survey tows used for herring increased by roughly 30 days during 1963-1984 while bottom temperatures increased by about 3^{o} C (Figures A2-7 and A2-8). Fall sea surface temperatures increased during 1963-1985 and declined afterwards (Figures A2-8). Mean length at age in the fall and spring surveys declined beginning in the mid-1980s as growth apparently slowed to relatively low levels in recent years. Herring grow quickly, particularly at small sizes, and a 30 day delay in survey timing, additional growth, migratory movements and changes in temperature may result in substantial and continuous changes to fall survey catchability and selectivity at age if these parameters are actually functions of size when the survey is conducted.

The changes in survey timing, water temperatures and growth correspond and are probably aliased with the switch from BMW to Polyvalent bottom trawl survey doors in 1984-1985. Based on visual examination of trends and model results, the door change had a major effect on fall and spring survey catchability. Potential door effects on survey selectivity are not clear.

Random walks were used in SS3 to deal with continuous or abrupt changes in growth, selectivity and catchability parameters, particularly in the fall survey. In particular, fall and spring survey catchability parameters were allowed to change abruptly in 1985 (assuming a large variance on the deviation for 1985) to account for the door change. We also experimented with letting the fall survey catchability parameter follow a slow random walk during 1968-2006.

It is very important to use good estimates of growth in models that use size data. We modeled the growth parameters K and L_{max} using a random walk during 1968-2006 because we hypothesized that the changes in size at age (growth) and size selectivity might be sufficient to capture many of the effects of changes in the fall survey and water temperatures on size and selectivity at age. SS3 was able to estimate complicated temporal growth parameters that matched estimates made externally from the same data (Figure A2-9 and A2-10). The growth parameter t_0 was constant and modeled as an estimated parameter.

At the outset, we tried to use estimate selectivity at size only when fitting the SS3 model to survey and fishery length and age composition data. In SS3, selectivity at age S_a is a function of selectivity at length S_L:

$$S_a = s_a \sum_L \frac{S_L N_{L,a}}{N_{+,a}}$$

where s_a is selectivity at age ignoring size, $N_{L,a}$ is the estimated population abundance of herring that are age a and length L in the current time step and$N_{+,a} = \sum_L N_{L,a}$. Thus, $\frac{N_{L,a}}{N_{+,a}}$ is one element in the estimated population age-length key and the term in the summation on the right is mean selectivity at size for age a. In SS3 modeling, we initially assumed A_a=1 for all ages in all surveys and fisheries so that only size selectivity was important. However, it proved necessary to estimate logistic selectivity at age curves as well for all of the fisheries and surveys (except shrimp with no age data) because virtually no age one herring of any size are taken in any fishery or survey.

We experimented with random walks for survey selectivity parameters in the fall survey prior to 1985 and abrupt changes in survey size selectivity parameters during 1984-1985 but these approaches did not appear necessary as long as the model allowed for temporal variation in size at age and door effects on survey catchability.

The commercial and survey size selectivity curves for herring were logistic or dome shaped (Figure A2-11) and the decision about which type of curve to use was usually obvious on inspection of the corresponding size and age composition data and after preliminary model runs. The offshore mobile gear fisheries as well as shrimp and winter bottom trawl surveys which catch very large herring in greatest numbers had logistic shape size selectivity while all other fisheries and surveys had dome shaped size selectivity indicating that large herring are hard to catch in survey bottom trawls. The estimated age selectivity curves in SS3 were all logistic with nearly 100% selectivity at ages two to four years (Figure A2-12).

With the exception of the spring Bigelow survey, the SS3 model fit commercial and survey size and age composition data well (Figure A2-13 and A2-14). The spring Bigelow survey had a surprisingly high number of small herring during 2010-2011 (Figure A2-15). We hypothesize that the data for 2010-2011 were anomalous and distort the average size composition for the short spring Bigelow survey. In contrast to the spring survey, relatively low numbers of small herring were taken in the fall Bigelow survey as well as in the original Albatross spring survey. Also, paired tow vessel calibration data collected by the two vessels did not show the same pattern. Additional years of survey data will probably be necessary to clarify the size composition and selectivity of the spring and possibly fall Bigelow surveys.

Very large changes in survey catchability during 1984 and 1985 were required to fit the spring and fall survey trends. Catchability increased from about 79 to about 325 (by 410%) in the spring survey and from about 3.6 to about 154 (by 4280%) in the fall survey (Figure A2-16). Thus, the remarkably low herring catches prior to the door change appear due primarily to very low survey bottom trawl catchability.

Fit to the spring bottom trawl survey trend was good (Figure A2-17). The SS3 model fit the spring and fall Bigelow surveys well although the short time series show different trends (Figure A2-18). The model fit fall bottom trawl survey trend reasonably well after accommodating the change in catchability but there was a tendency for the model to over predict the survey in the years prior to the door change (Figure A2-19). For the fall survey, it might be better to build more temporal variability in catchability or, perhaps, selectivity parameters during years prior to the door change. The observed and predicted winter survey values seem poorly correlated (Figure A2-20). The model fit the shrimp survey trends reasonably well with the exception of the three earliest years (1982 and 1985-1986, Figure A2-21).

Recruitment estimates from SS3 suggest that the high biomass and productivity during the early 1960s may have been to a few years of unusually good recruitment (Figures A2-22 and A2-23). The assumption of a Beverton-Holt recruitment curve appears reasonable.

Fishing mortality is complicated to quantify in the SS3 model for herring because there are four fisheries with markedly different selectivity patterns. For simplicity, fishing mortality was quantified as total annual catch biomass divided by age 1+ biomass on July 1 (Figure A2-24). This simple calculation accommodates differences in fishery selectivity, seasonal growth and seasonal population dynamics.

Spawning biomass estimates from SS3 differ markedly from the ASAP basecase estimates (Figure A2-25). Comparisons are difficult, however, because assumptions about natural mortality in recent years are very different in the two models.

References

Northeast Fisheries Science Center. 2008. 47th Northeast Regional Stock Assessment Workshop (47th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 08-12a; 335 p.

Northeast Fisheries Science Center. 2010. 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-03; 383 p.

Overholtz, W.J.; Jacobson, L.D., Melvin, G.D., Cieri, M., Power, M., Libby, D., Clark, K. 2004. Stock assessment of the Gulf of Maine - Georges Bank Atlantic herring complex, 2003. Northeast Fish. Sci. Cent. Ref. Doc. 04-06, 290 p.

Table A2-1. Summary of SS3 model configuration for herring.

Item	Descriptor	Note
Years covered	1963-2011	All years with survey data
Seasons	2	Season 1 = January-June, Season 2 = July-December
Number areas	1	
Number sexes	1	
Number "morphs"	1	
Lengths	4-35 cm	
Length bins	1 cm	
Ages	0-15+ y	
Age bins	1 y	
Commercial fleets	4	Mobile gear season 1, Mobile gear season 2, Fixed gear season 1, Fixed gear season 2
Commercial selectivity at length	Mobile S1	Logistic
	Mobile gear (S2)	Logistic
	Fixed gear S1	Domed
	Fixed gear S2	Domed
Commercial selectivity at age	Mobile S1	Logistic
	Mobile gear (S2)	Logistic
	Fixed gear S1	Not used (one for all ages)
	Fixed gear S2	Not used (one for all ages)
Assumed historical catch (pre-1963)	96171 mt	Prorated by fleet based on proportions by mobile and fixed gear fleets during 1964 (US and Canada). Fleet values broken down by semester based on US&CA data (season 1) or US data only (season 2)
Fishing mortality	Instantaneous rates	Hybrid method
Survey data (mean N/tow, vessel correction factors applied but no Albatross-Bigelow calibration factors)	Winter	1992-2007
	Spring	1968-2008 (before the R/V Bigelow) with length and age data for all years
	Spring Bigelow	2009-2011 with length and age data for all years
	Shrimp	1983-2011 with length data for all years (no ages)
	Fall	1963-2008 (before the R/V Bigelow)
	Fall Bigelow	2009-2011 with length and age data except ages unavailable for 2011

Survey selectivity at length	Winter	Domed
	Spring	Domed
	Spring Bigelow	Domed
	Shrimp	Logistic
	Fall	Logistic
	Fall Bigelow	Domed
Survey selectivity at age	Winter	Logistic
	Spring	Logistic
	Spring Bigelow	Logistic
	Shrimp	Not used (one for all ages)
	Fall	Logistic
	Fall Bigelow	Logistic
Survey catchability	Winter	Median unbiased (calculated internally)
	Spring	Random walk (very low variance) except for 1984 (higher variance) to accommodate door change (breaks the time series trend while using the same selectivity curve for early and late periods), base and deviation parameters estimated
	Spring Bigelow	Median unbiased (calculated internally)
	Shrimp	Median unbiased (calculated internally)
	Fall	Same as spring
	Fall Bigelow	Median unbiased (calculated internally)
Ageing errors	Based on NEFSC ageing QA/QC experiments	Unbiased with standard deviations that increase with age from 0.09 y at age 1 to 0.838 y at ages 12+
Natural mortality	Average of natural mortality rates at age used in the ASAP model	Constant over time but increase at age from 0.66 y-1 at ages 0 and 1 to 0.22 y-1 at age 13+
Mean size at age (growth)	von Bertalanffy	t_0 estimated, K and L_{max} follow random walk during 1968-2006 with estimated deviations (sd=1)
Variability in size at age	Standard deviation a linear function of length at age	Standard deviation for size at age 1 and at L_{max} estimated
Maturity at age	Assumed	From earlier stock assessment
Spawner-recruit relationship	Beverton and Holt	R_0 estimated, steepness fixed at 0.85, variance estimated with lognormal prior (mean 0.904, sd=1.010, based on meta-analysis in Overholtz et al. 2006) - **This was probably not done correctly.**
Years with freely estimated recruitments	1959-2005	Earlier and later years from spawner-recruit model
Likelihood weights	All one (1.0)	Used to weight each term in the negative log likelihood

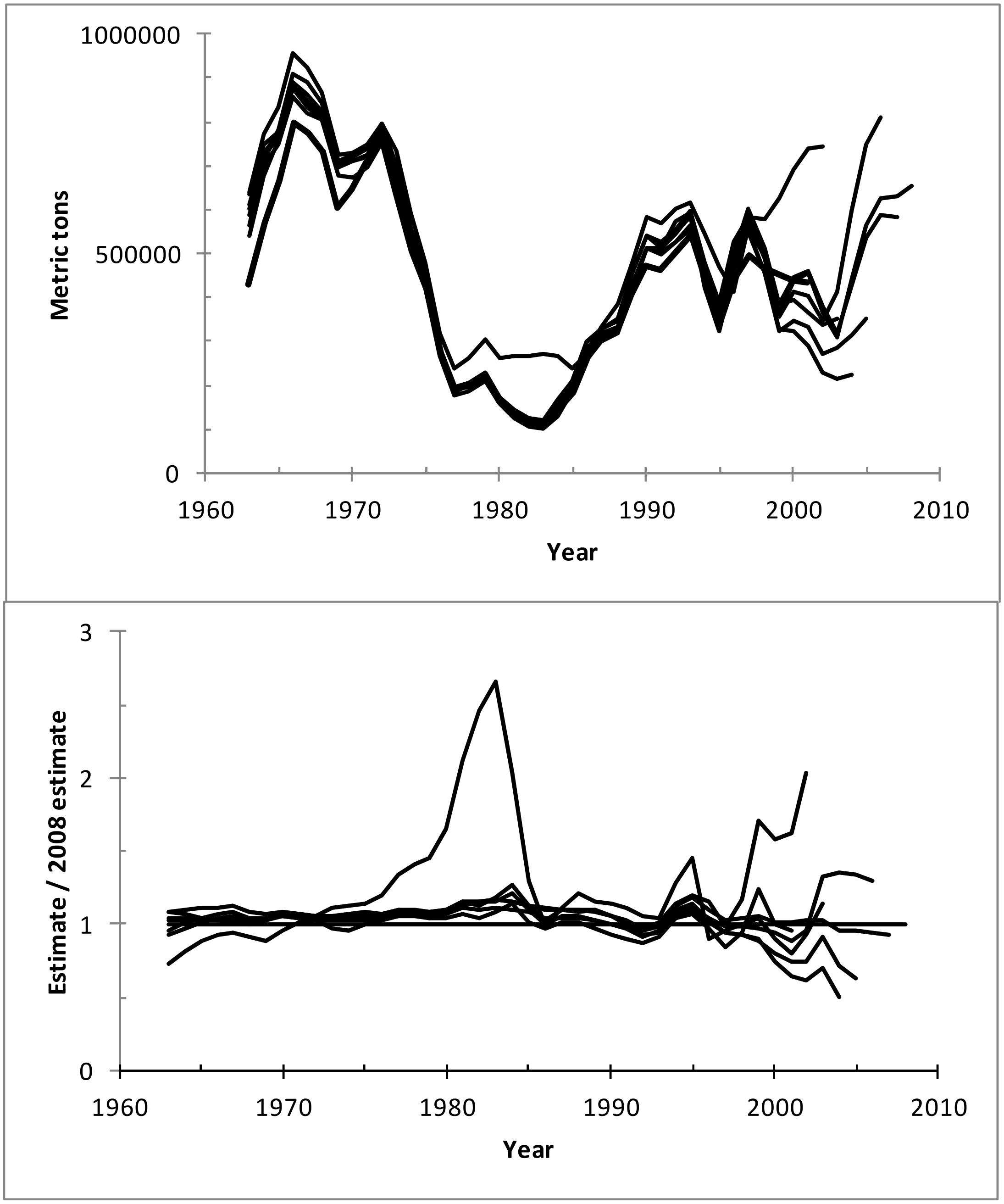

Figure A2-1. Retrospective analysis for herring spawning stock biomass estimates from SS3. The terminal year was 2008 to avoid inconsistencies using in the retrospective analysis due to the short 2009-2011 Bigelow surveys.

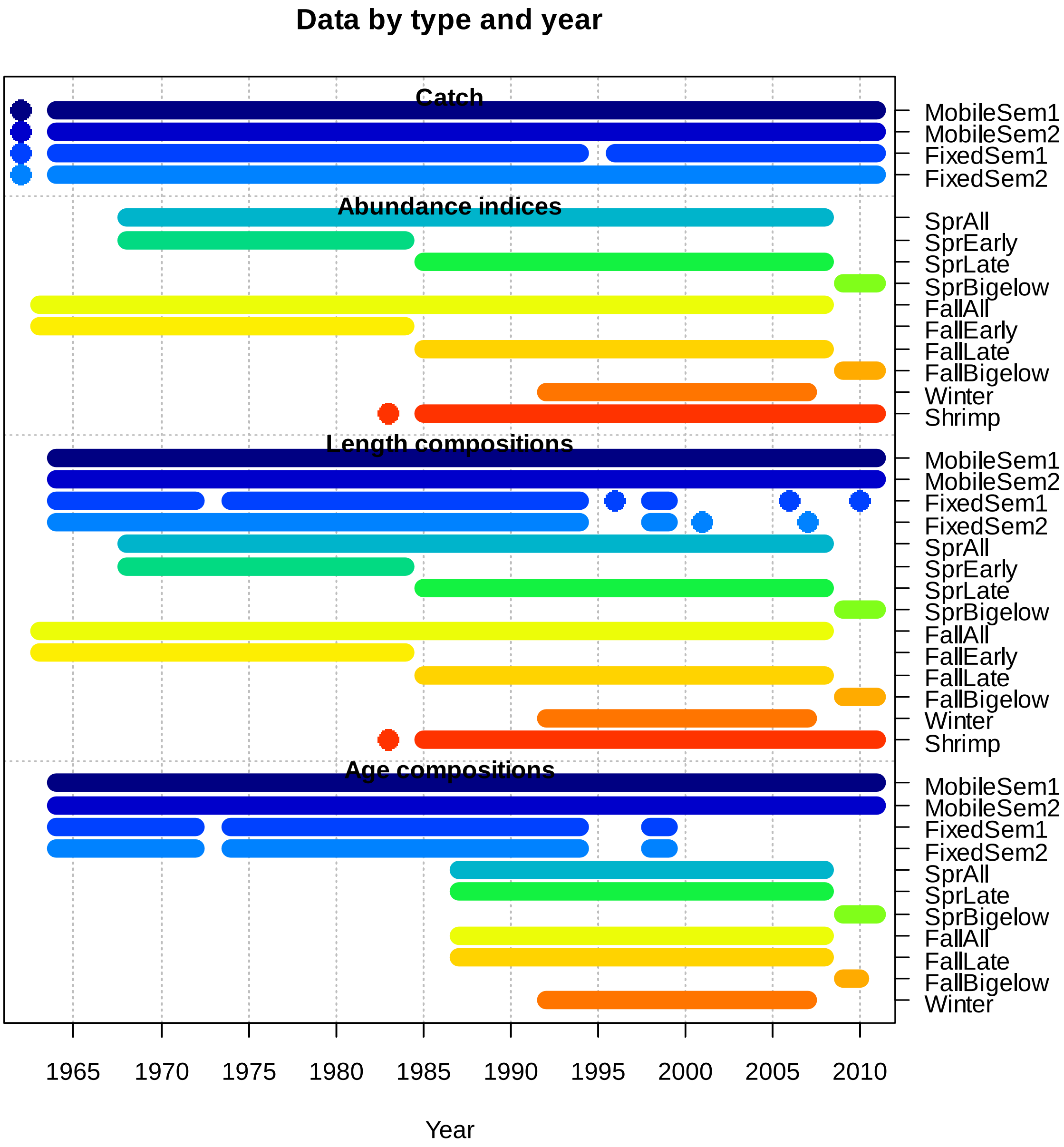

Figure A2-2. Summary of commercial and survey data for herring used in SS3. The surveys SprEarly, SprLate, FallEarly and FallLate (spring and fall surveys separated at 1984/1985 to accommodate survey door changes as in ASAP) were included in data files but were not used in the SS3 run shown here.

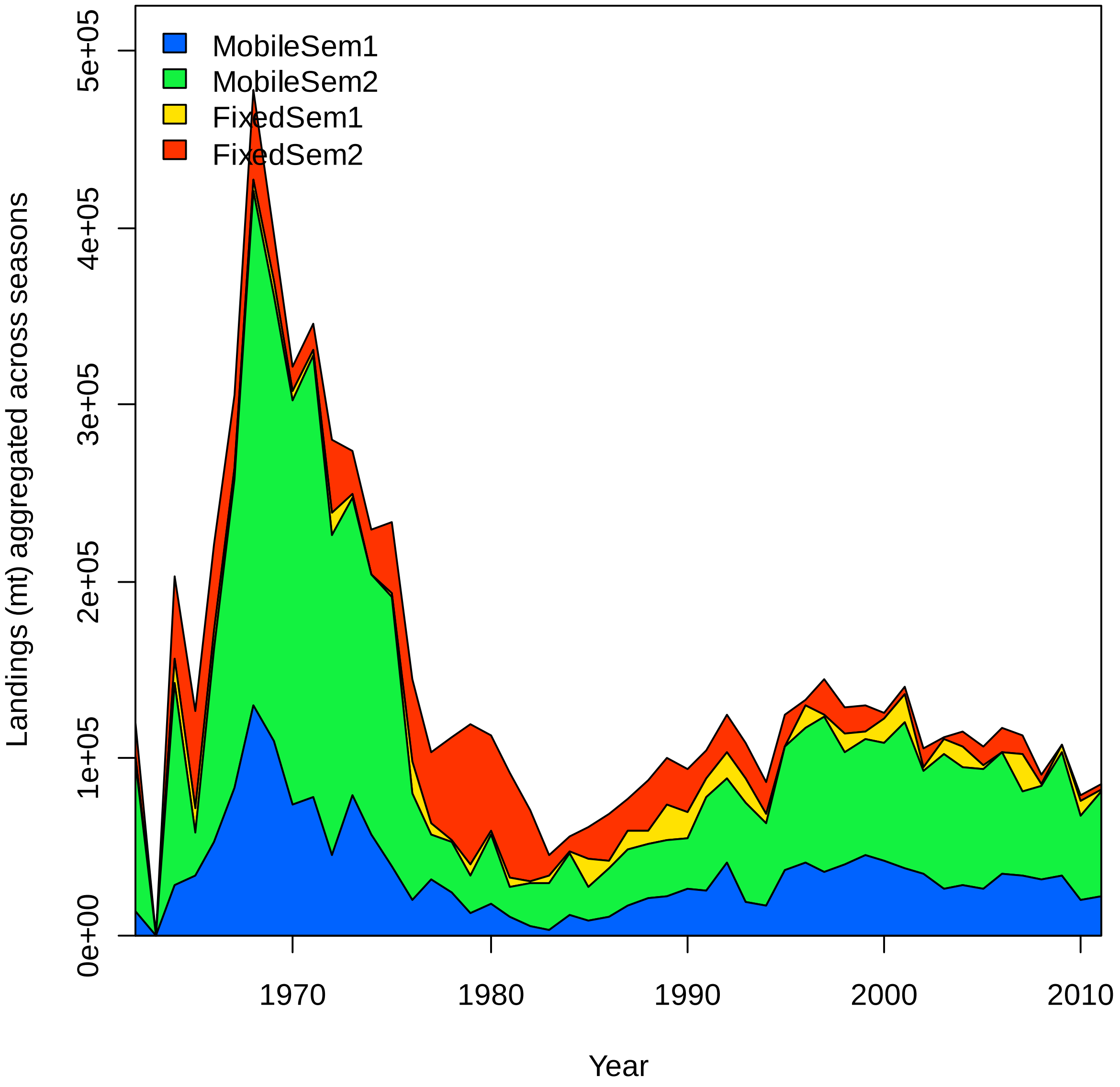

Figure A2-3. Commercial catch data for herring by fleet and season during 1963-2011 as used in the SS3 model.

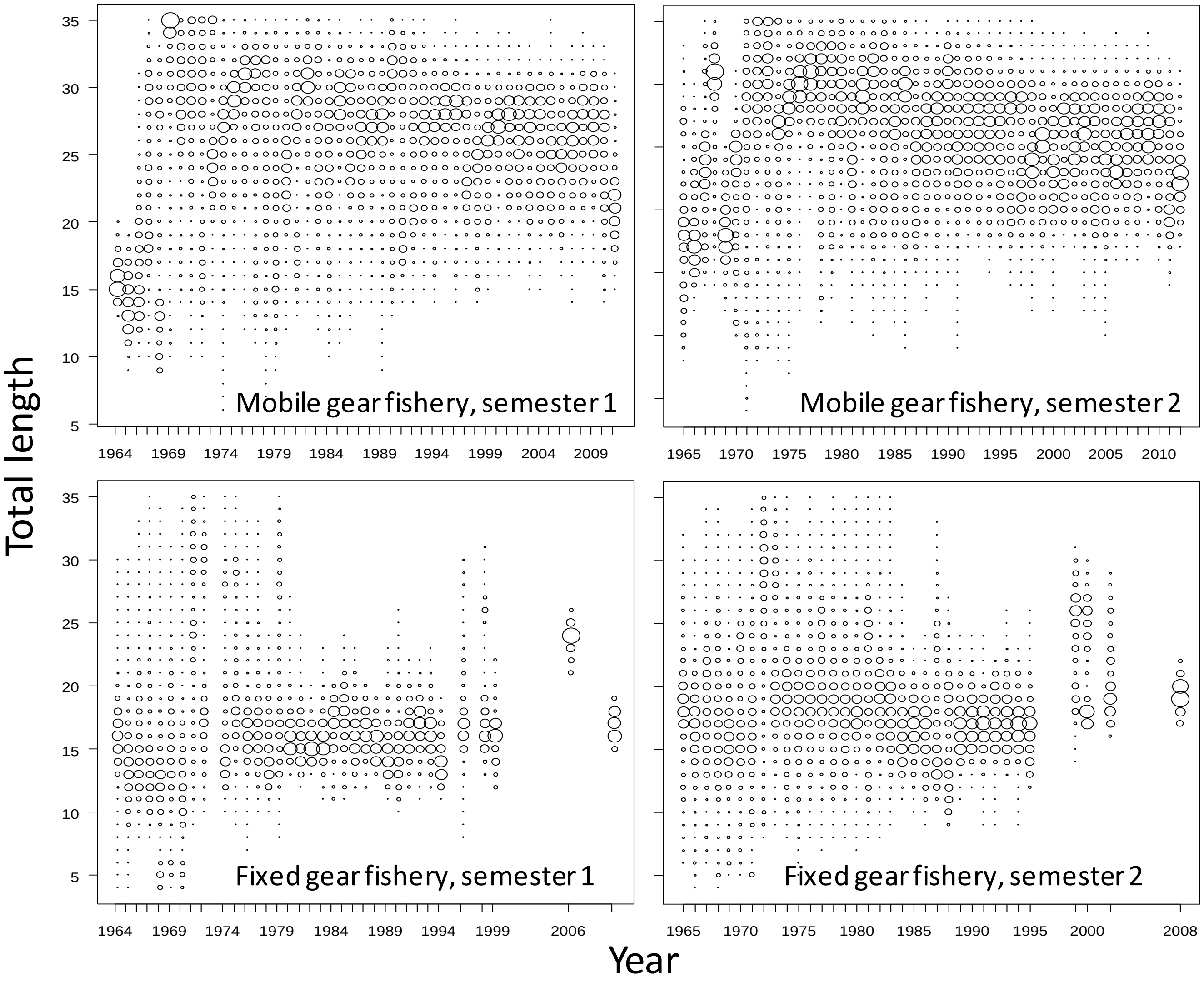

Figure A2-4. Commercial size composition data for herring used in SS3.

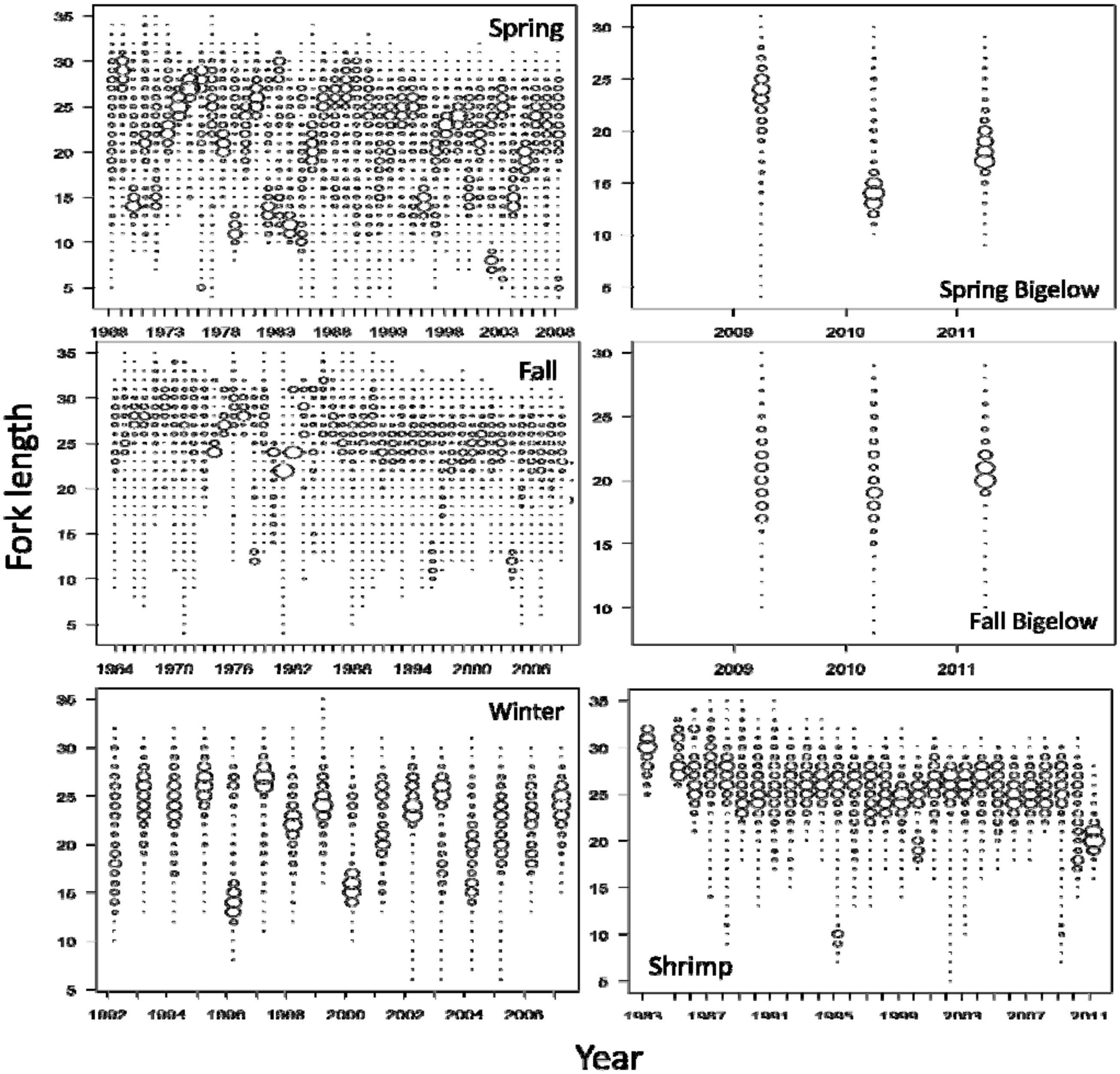

Figure A2-5. Survey size composition data for herring used in SS3.

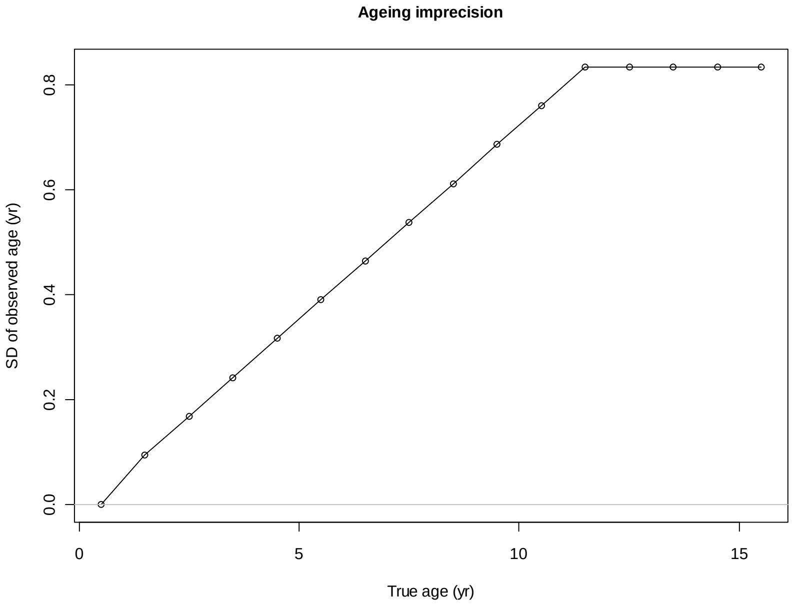

Figure A2-6. Assumed standard deviations for ageing imprecision in herring assumed in SS3.

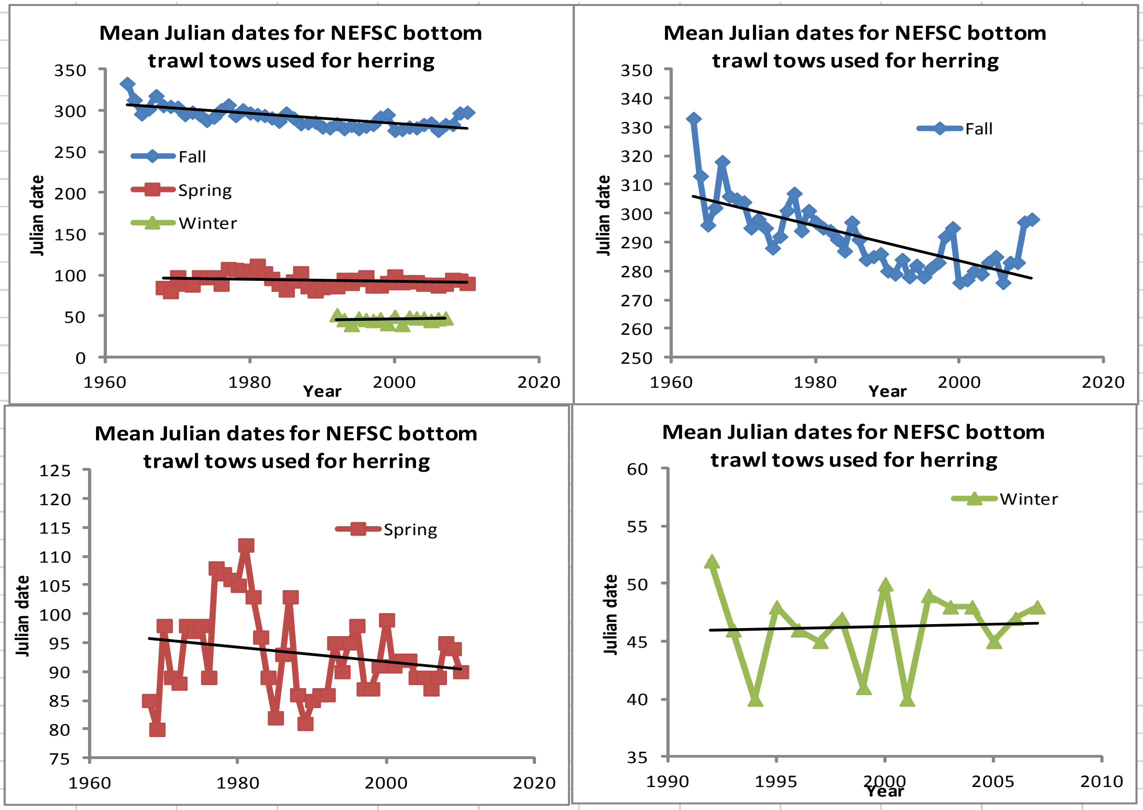

Figure A2-7. Mean annual Julian dates used for bottom trawl survey tows used for herring in SS3.

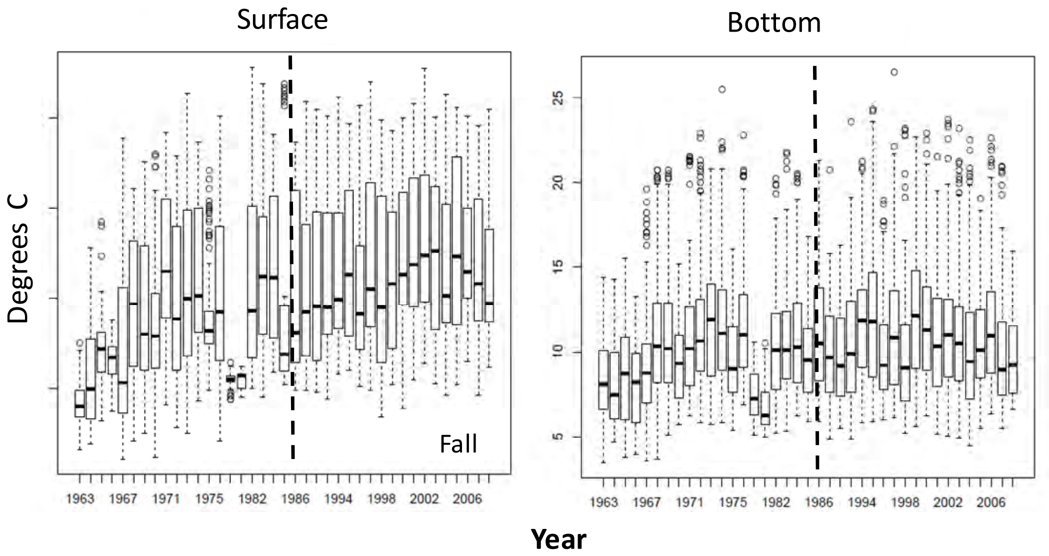

Figure A2-8. Surface and bottom temperatures for NEFSC fall survey tows used in the herring assessment. The short dark horizontal lines are the median temperatures. The dash vertical line shows the change in bottom trawl survey doors during 1984/1985.

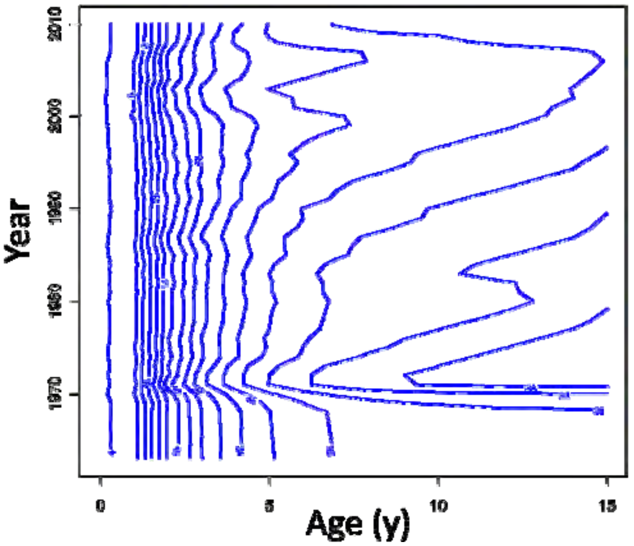

Figure A2-9. Estimated size at age in the SS3 model for herring during 1963-2011 based on von Bertalanffy growth curves with random walk parameters.

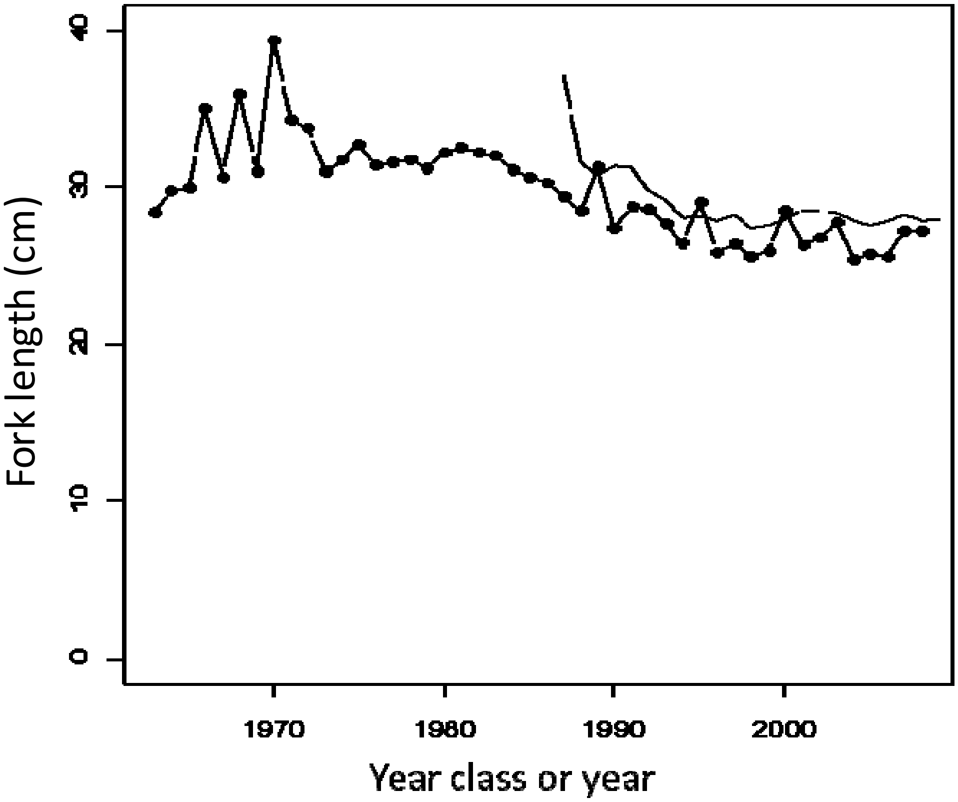

Figure A2-10. Von Bertalanffy L_{max} parameter estimates for herring from SS3 (January 1, solid symbols) and from growth curves fit externally to spring survey data. The SS3 estimates are by year class while the external estimates are by calendar year.

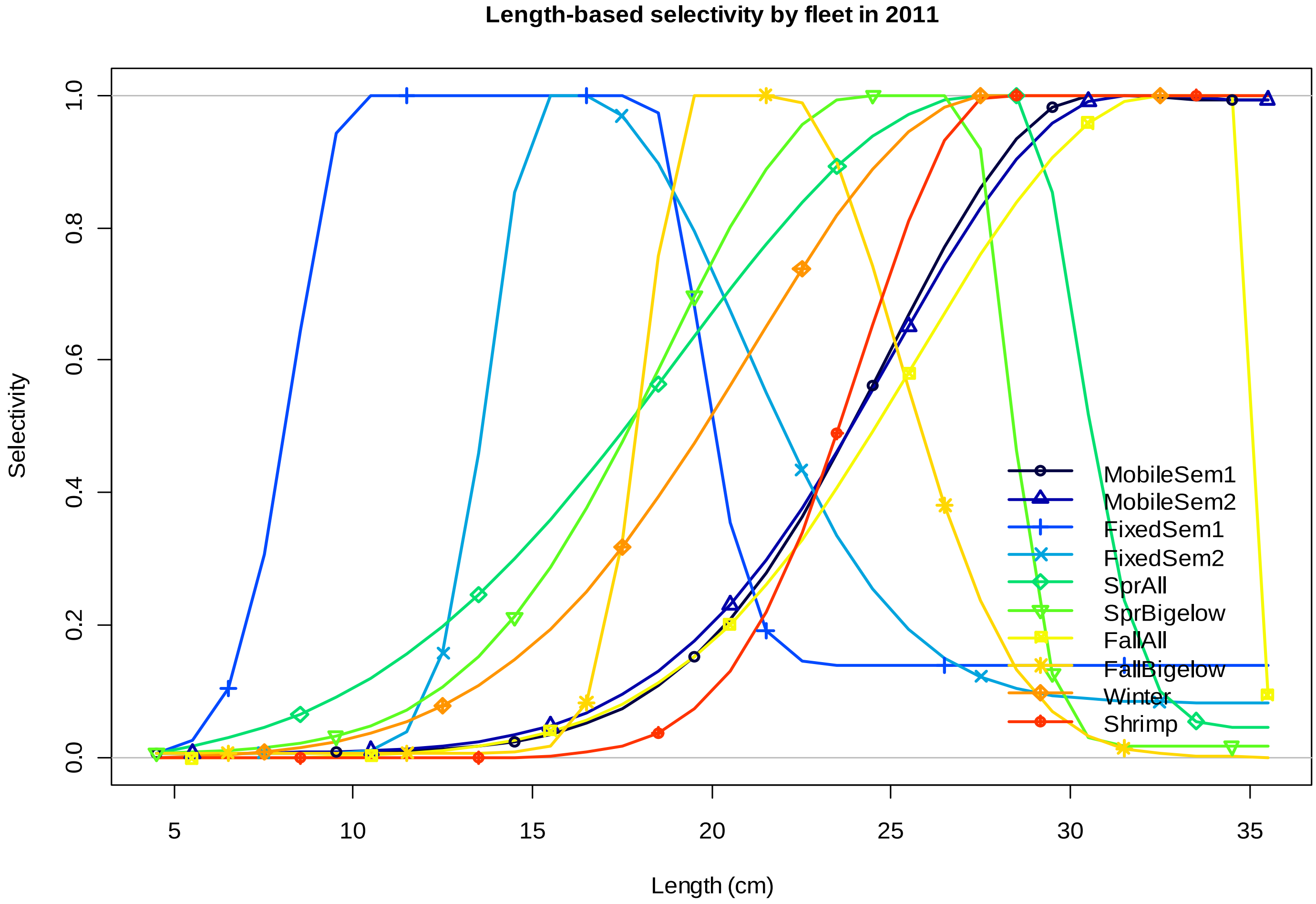

Figure A2-11. Selectivity at length curves for herring in commercial fisheries and surveys estimated in SS3.

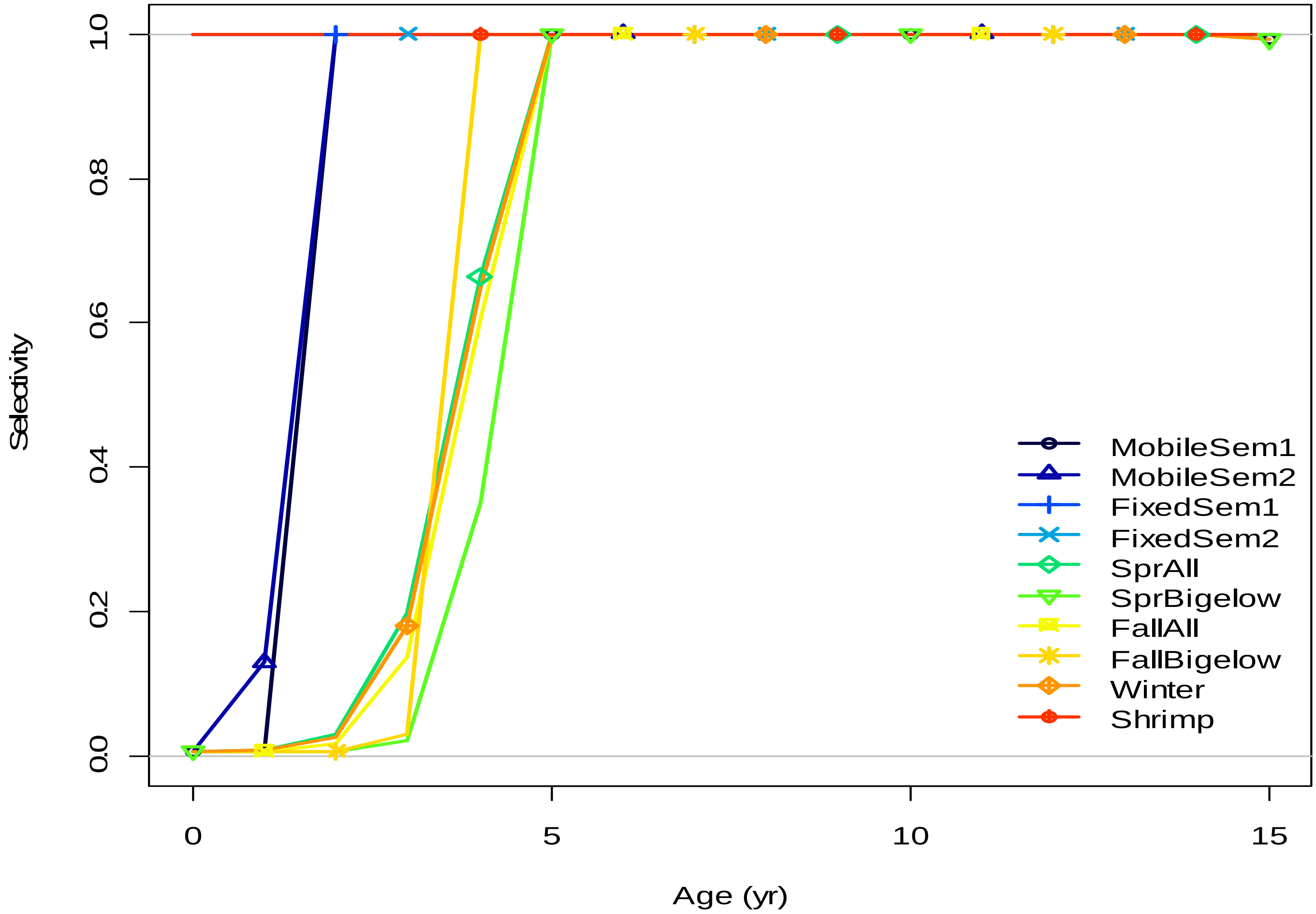

Figure A2-12. Selectivity at length curves for herring in commercial fisheries and surveys estimated in SS3.

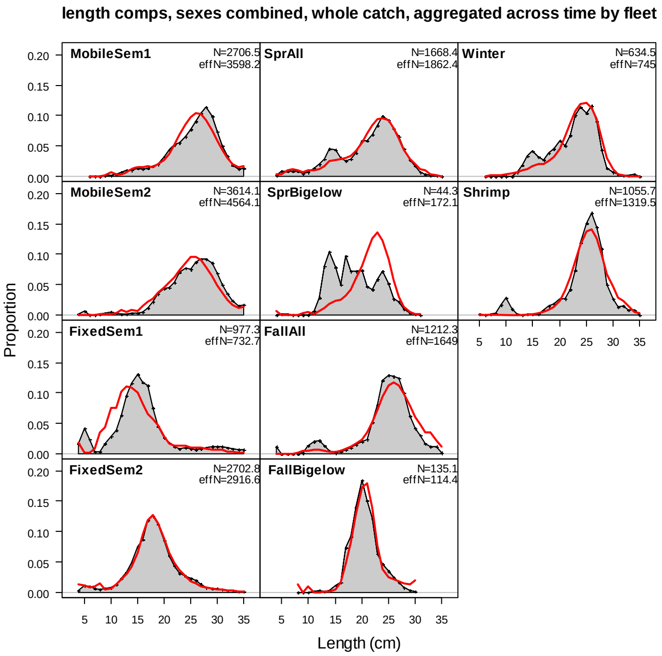

Figure A2-13. Average commercial and survey length composition data (in grey) and average predicted values (red line) for herring in the SS3 model.

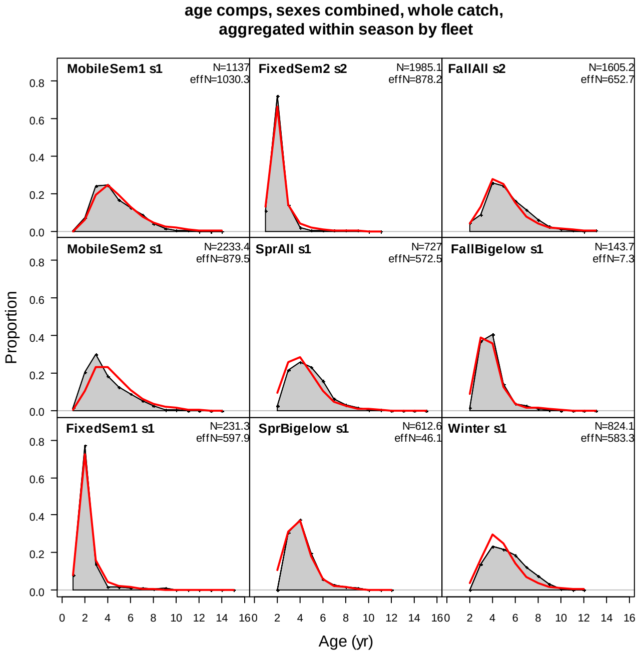

Figure A2-14. Average commercial and survey age composition data (in grey) and average predicted values (red line) for herring in the SS3 model.

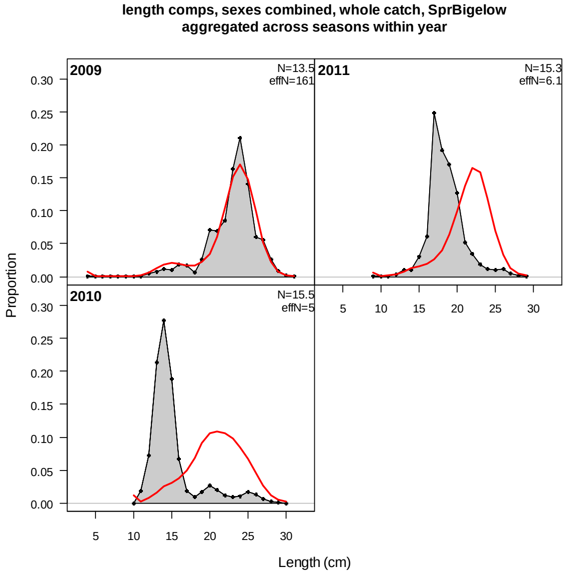

Figure A2-15. Annual observed spring Bigelow survey size composition data (in grey) for herring with predicted values (red line) from the SS3 model for herring.

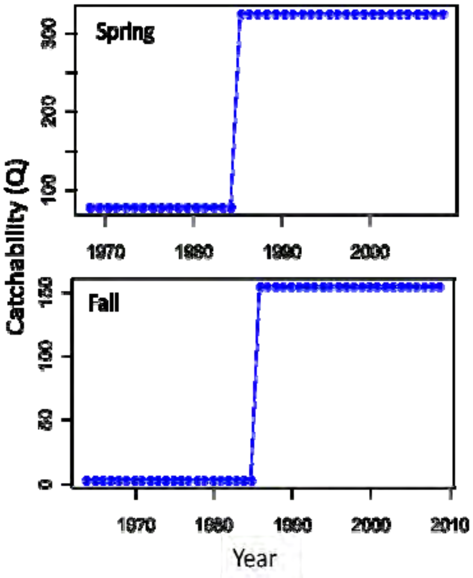

Figure A2-16. Changes in catchability for herring in the spring and fall bottom trawl surveys estimated in SS3.

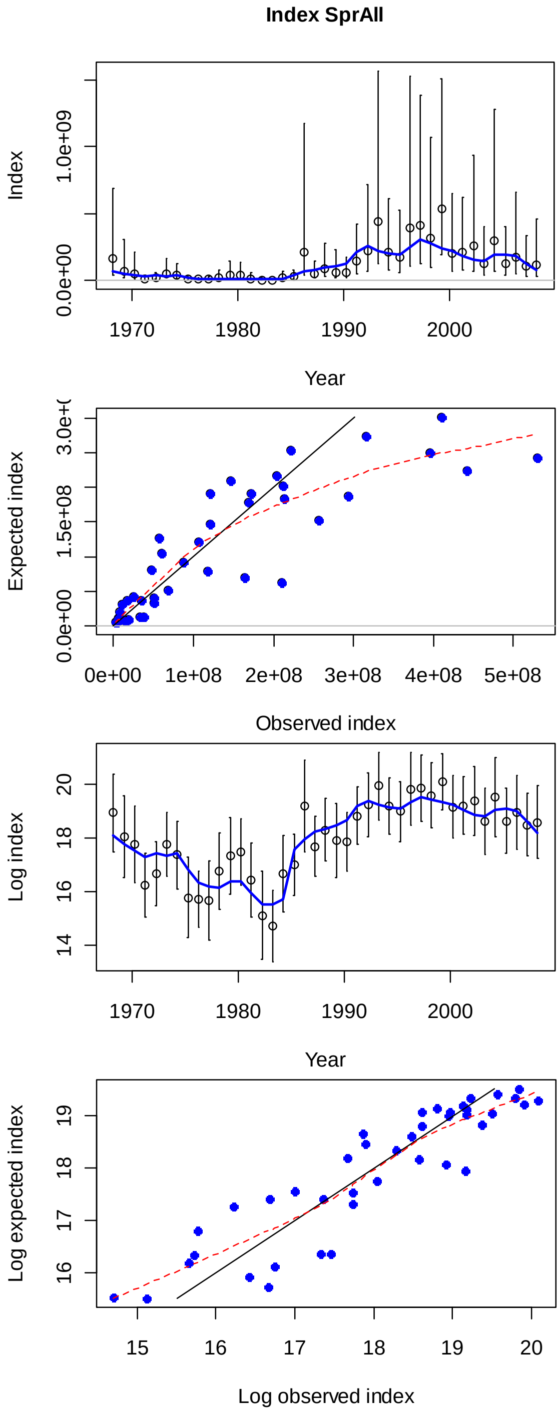

Figure A2-17. Goodness of fit plots for the SS3 model and herring in the NEFSC spring bottom trawl survey.

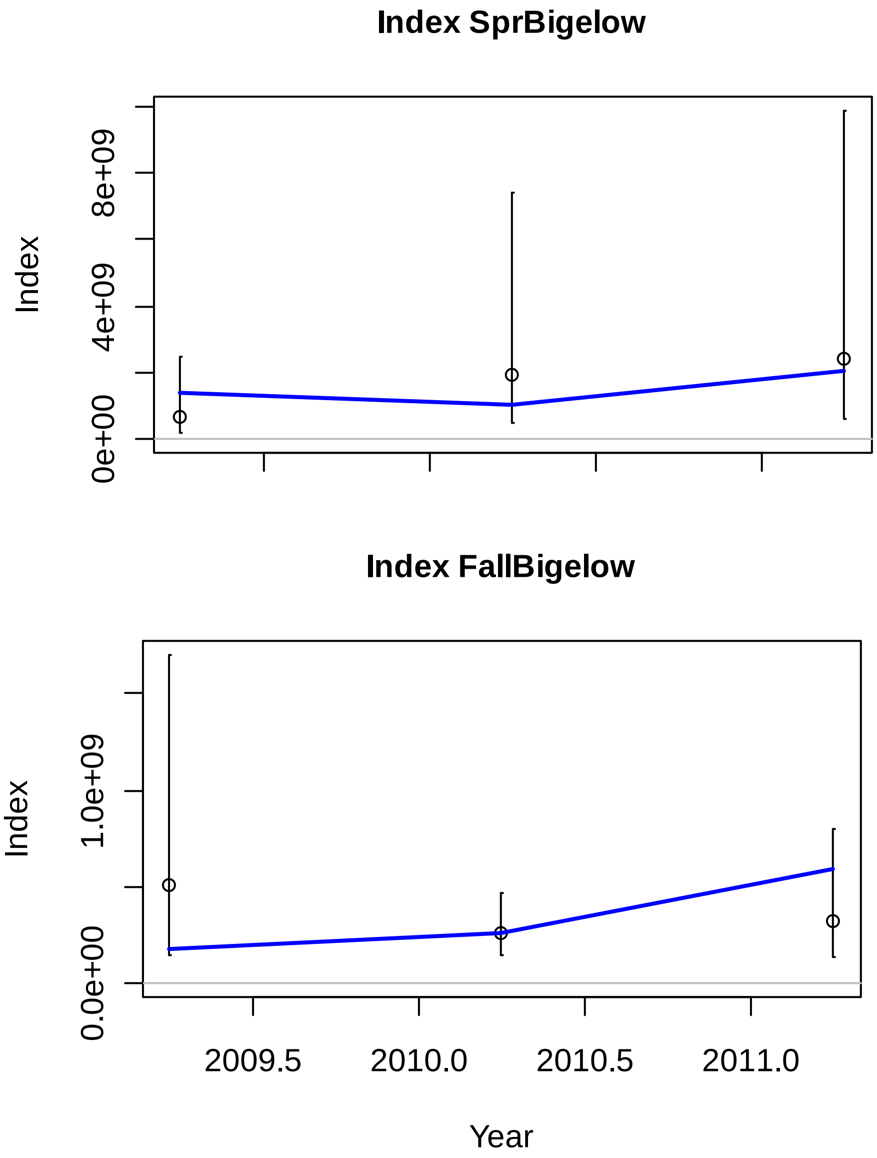

Figure A2-18. Goodness of fit plots for the SS3 model and herring in the NEFSC Bigelow spring and fall bottom trawl surveys.

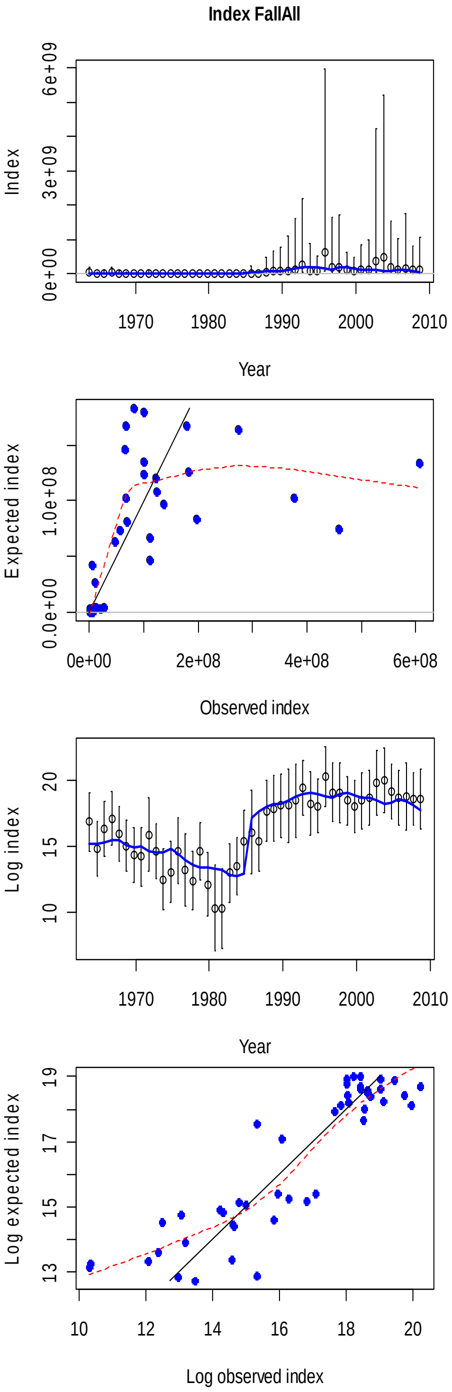

Figure A2-19. Goodness of fit plots for the SS3 model and herring in the NEFSC fall bottom trawl survey.

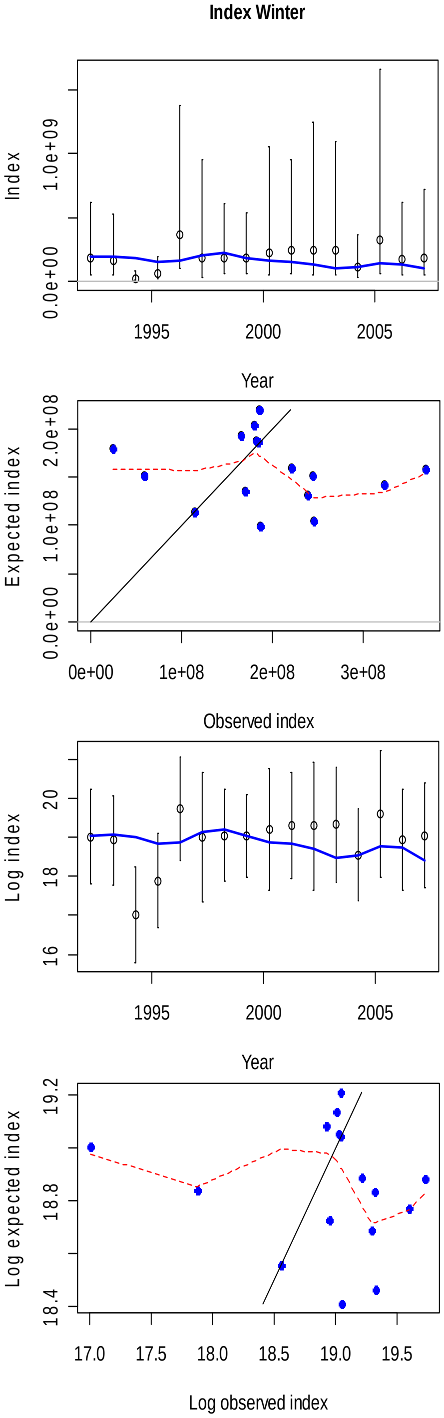

Figure A2-20 Goodness of fit plots for the SS3 model and herring in the NEFSC winter bottom trawl survey.

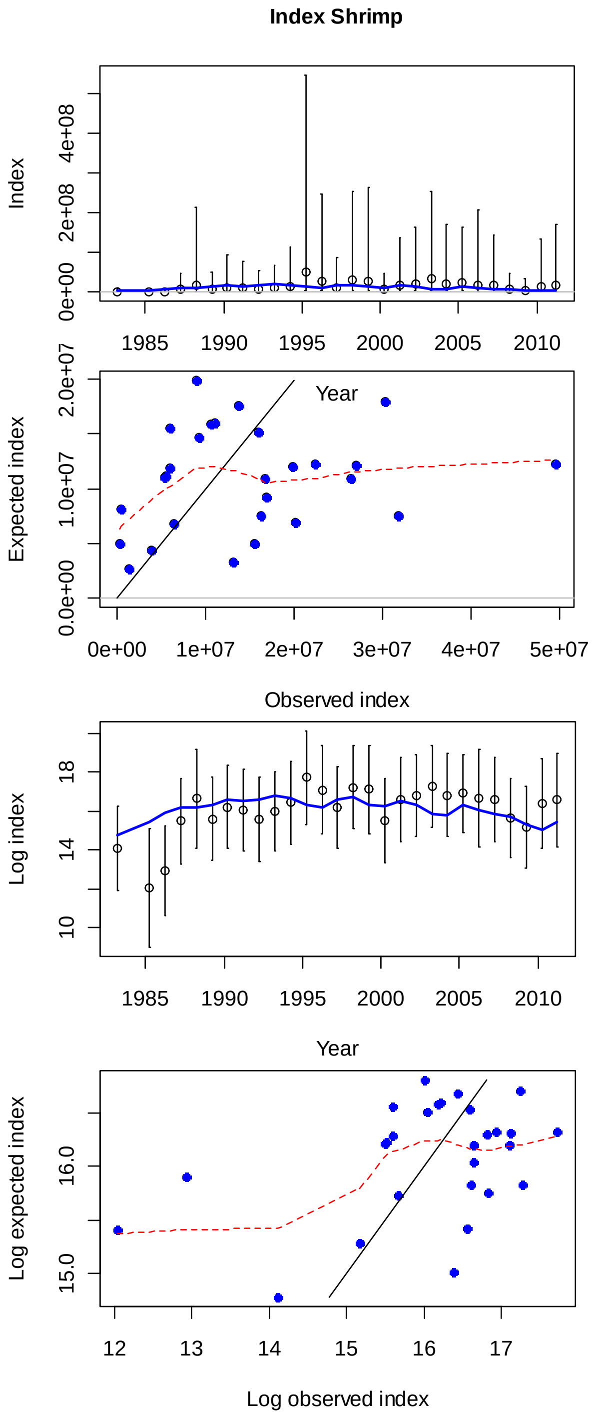

Figure A2-21. Goodness of fit plots for the SS3 model and herring in the NEFSC shrimp bottom trawl survey.

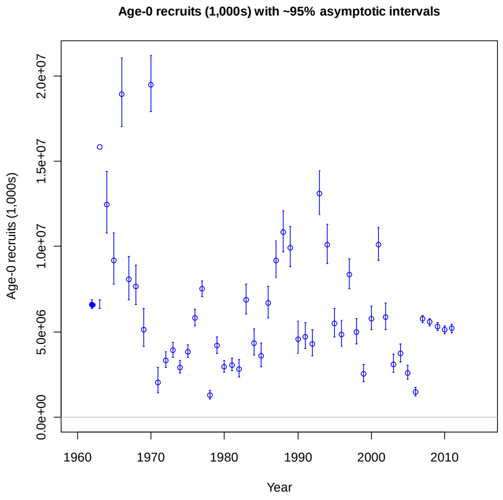

Figure A2-22. Recruitment estimates for herring from SS3. The first two estimates on the left are at the virgin and initial equilibrium recruitment levels. The third point from the left is the initial (1962) recruitment estimates. Other recruitments are estimates for 1963-2011. Recruitments were also estimated for 1959-1961 and used in initializing the population age and length composition. Recruitment estimates for 2006-2011 were from the model's estimated spawner-recruit curve.

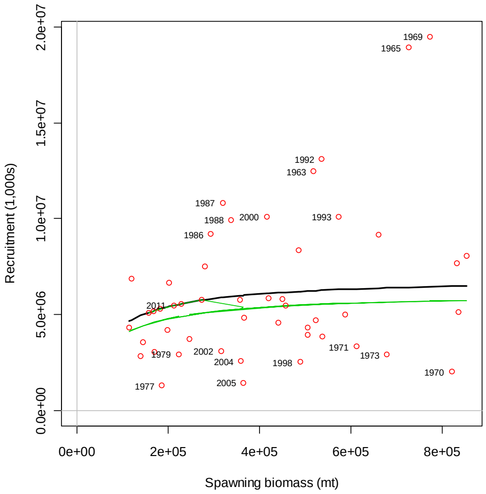

Figure A2-23. Spawner-recruit curve for herring estimated in SS3. The green line shows the geometric mean recruitment relationship and the black line shows the mean recruitment relationship. The 2006-2011 recruitments at spawning biomass levels of around2. 2.5 x 10^6 mt are expected values from the spawner-recruit curve.

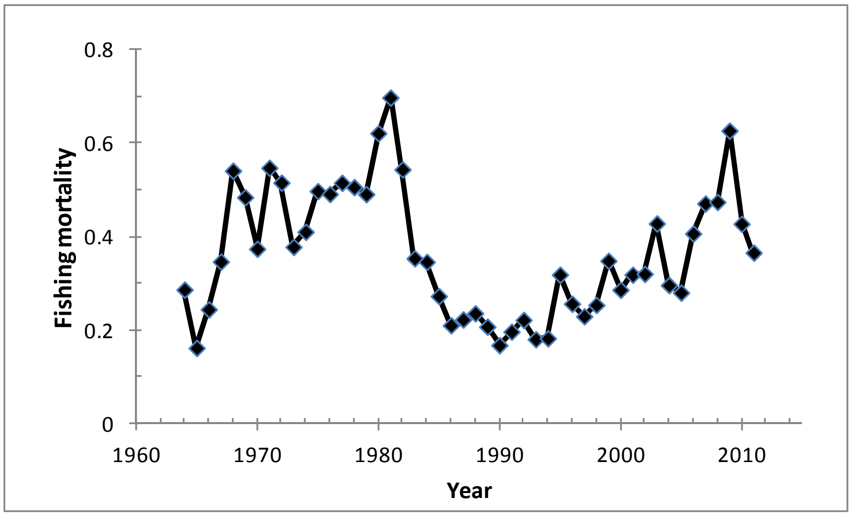

Figure A2-24. Approximate annual fishing mortality rate estimates for herring during 1964-2011 from SS3. The approximation for each year was computed as total annual landings divided by the biomass of herring age 1+ on July 1.

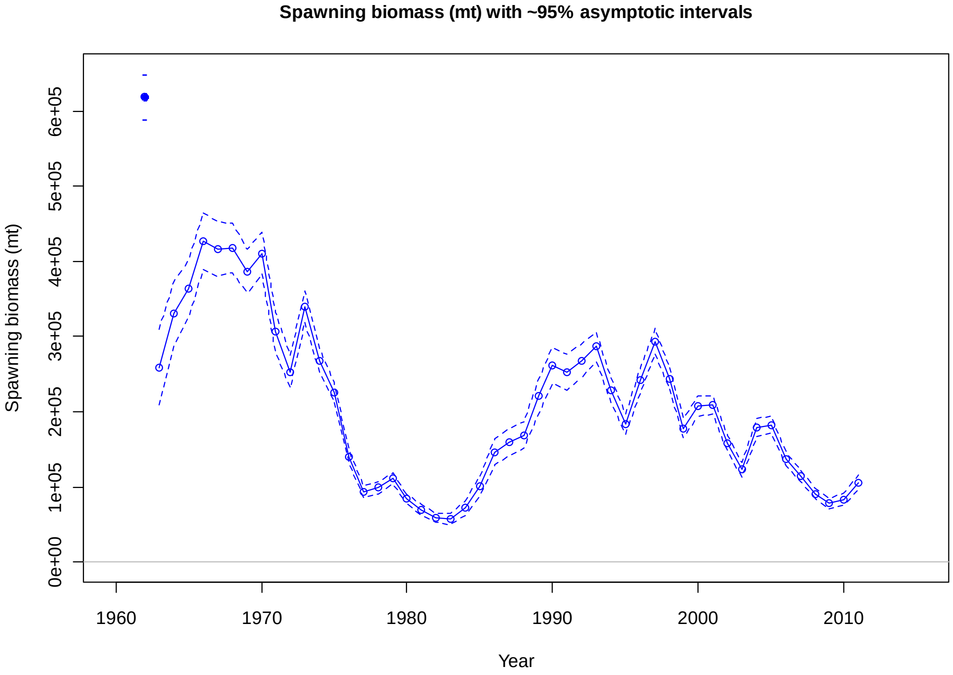

Figure A2-24. Approximate spawning stock biomass estimates (+ 95% CI) for herring during 1964-2011 from SS3.

SARC 54 Pelagics Working Group (SDWG)

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Atlantic Herring Length-based Bottom Trawl Survey Calibration

Tim Miller, NEFSC Population Dynamics Branch

May 15, 2012

Introduction

In 2009, the *NOAA SHIP Henry B. Bigelow* replaced the *R/V Albatross IV* as the primary vessel for conducting spring and fall annual bottom trawl surveys for the Northeast Fisheries Science Center (NEFSC). There are many differences in the vessel operation, gear, and towing procedures between the new and old research platforms (NEFSC Vessel Calibration Working Group 2007). To merge survey information collected in 2009 onward with that collected previously, we need to be able to transform indices (perhaps at size and age) of abundance from the *Henry B. Bigelow* into those that would have been observed had the *Albatross IV* still been in service. The general method for merging information from these two time series is to calibrate the new information to that of the old (e.g., Pelletier 1998, Lewy et al. 2004, Cadigan and Dowden 2010). Specifically we need to predict the relative abundance that would have been observed by the *Albatross IV* ($\hat{R}_A$) using the relative abundance from the *Henry B. Bigelow* (R_B) and a "calibration factor" (ρ),

$$\hat{R}_A = \rho R_B . \quad (1)$$

To provide information from which to estimate calibration factors for a broad range of species, 636 paired tows were conducted with the two vessels during 2008. Paired tows occurred at many stations in both the spring and fall surveys. Paired tows were also conducted during the summer and fall at non-random stations to augment the number of non-zero observations for some species. Protocols for the paired tows are described in NEFSC Vessel Calibration Working Group (2007).

The methodology for estimating the calibration factors was proposed by the NEFSC and reviewed by a panel of independent scientists in 2009. The reviewers considered calibration factors that could potentially be specific to either the spring or fall survey (Miller et al. 2010). They recommended using a calibration factor estimator based on a beta-binomial model for the data collected at each station for most species, but also recommended using a ratio-type estimator under certain circumstances and not attempting to estimate calibration factors for species that were not well sampled.

Since the review, it has become apparent that accounting for size of individuals can be necessary for many species. When there are different selectivity patterns for the two vessels, the ratio of the fractions of available fish taken by the two gears varies with size. Under these circumstances, the estimated calibration factor that ignores size reflects an average ratio weighted across sizes where the weights of each size class are at least in part related to the number of individuals at that size available to the two gears and the number of stations where individuals at that size were caught. Applying calibration factors that ignore real size effects to surveys conducted in subsequent years when the size composition of the available population is unchanged should not produce biased predictions (eq. 1). However, when the size composition changes, the frequency of individuals and number of stations where individuals are observed at each size changes and the implicit weighting across size classes used to obtain the estimated calibration factor will not be applicable to the new data. Consequently, the predictions from the constant calibration factor of the numbers per tow that would have been caught by the *Albatross IV* will be biased.

Length-based calibration has been performed for groundfish (cod, haddock, and yellowtail flounder through the Trans-boundary Resource Assessment Committee process and silver, offshore, and red hakes during SARC 51 and loligo squid during SARC 51 (Brooks et al. 2010, NEFSC 2011). For those length-based calibrations, the same basic beta-binomial model from Miller et al. (2010) was assumed, but various functional forms were assumed for the relationship of length to the calibration factor. Since then, Miller (submitted) has explored two types of smoothers for the relationship of relative catch efficiency to length and the beta-binomial dispersion parameter. The smoothers (orthogonal polynomials and thin-plate regression splines) allow much more flexibility than the functional forms previously considered for other species by Brooks et al. (2010) and NEFSC (2011). Catch efficiency at length, $q(L)$, as defined here relates the expected catch to the density of available individuals on a per unit swept area basis,

$$E\left(C_{ik}\left(L\right)\right)=q_k\left(L\right)f_{ik}A_{ik}D_i\left(L\right)$$

where $D_i\left(L\right)$ is the density of available fish at station i, and f_{ik} and A_{ik} are the fraction of the catch sampled for lengths and swept area for vessel/gear k. Relative catch efficiency is the ratio of the catch efficiencies for two vessels and is related to the calibration factor,

$$\rho\left(L\right)=\frac{E\left(C_{i1}\left(L\right)\right)}{E\left(C_{i2}\left(L\right)\right)}=\frac{q_1\left(L\right)}{q_2\left(L\right)}\frac{f_{i1}A_{i1}}{f_{i2}A_{i2}}.$$

Miller (submitted) analyzed data for six species and these methods were also used to estimate length-based calibration factors for each of the winter flounder stocks in the 2011 winter flounder assessment (Miller 2011). Here we use the same methods to estimate length-based calibration factors for Atlantic herring. We also explore differences in the effects of length on the models by season.

Methods

The data used in to fit the herring calibration models are numbers sampled by vessel, station, and 1 cm length class. Fish less than 12 cm in length were observed at a very small number of stations and some length classes are completely unobserved (Figure 1). However, substantial numbers of fish were caught at these few stations and most of them by the *Albatross IV* (Figure 2). Furthermore, when looking at spring and fall survey stations separately, it is apparent that most of the observations for these small fish and the largest numbers caught occurred in the spring (Figures 3 and 4). Because there was a large number of length classes without any observations between these small fish and larger sizes where most of the observations occurred, including these small fish caused difficulties in model fitting. Therefore, observations for fish less than 12 cm in length were excluded from further analysis.

I considered the orthogonal polynomial and thin-plate regression spline smoothers described by Miller (submitted). These models also allow for effects of swept area (SA) and sampling fraction (SF) on the beta-binomial dispersion parameter. I also considered models where effects on the relative catch efficiency and beta-binomial dispersion parameter differed for spring and fall seasons as well as the site-specific stations (outside the survey stations). I compared relative goodness-of-fit of the models using Akaike Information Criteria corrected for small sample size bias (AIC_c; Hurvich and Tsai 1989). I fit models in the R statistical programming environment (R Development Core Team 2010) and used the GAMLSSS package (Rigby and Stasinopoulos 2005, Stasinopoulos and Rigby 2007).

Results and Discussion

The best model without seasonal effects had a fifth order orthogonal polynomial smoother of the effects of length on the relative catch efficiency (Table 1). The best model also had a third order orthogonal polynomial smoother of the effects of length and effects of swept area and sampling fraction of each vessel on the beta-binomial dispersion parameter. All of the top 10 ranking models included the effects of swept area and sampling fraction on the dispersion parameter and the top four models all performed similarly with respected to AIC_c. The predicted relative catch efficiency from the best model is largest for the smallest and largest fish, but the uncertainty is also greatest for these sizes. The Henry B. Bigelow is estimated to be at least 2.5 times as efficient as the Albatross IV across all sizes between 12 and 31 cm (Figure 5 and Table 2). The dispersion parameter estimates are generally lower for all but the smallest size classes implying that there is less variability in the relative catch efficiency for smaller sizes from station to station (Figure 6). The residuals for this model show no concerning patterns (Figure 7) and there are substantial differences in the predicted relative catch efficiency between the best model with the orthogonal polynomial smoother and the best model with the thin-plate spline smoother (Rank 50) (Figure 8).

For data collected during the spring survey, the best model had no length effect on relative catch efficiency and a third order polynomial smoother for the effect of length on the dispersion parameter (Table 3). Effects of either swept area or sampling fraction or both were important in all of the top 10 ranking models and the fifth ranking model had a thin-plate spline smoother of the effects of length on relative catch efficiency and the dispersion parameter.

For fall data, the best model had a seventh order polynomial smoother for the effect of length on relative catch efficiency and a second order polynomial smoother for the effect of length on the dispersion parameter (Table 4). None of the top 10 ranking models had effects of sampling fraction on the dispersion parameter and four had an effect of swept area. Three of the top ten models had thin-plate spline smoothers for the effects of length on relative catch efficiency and the dispersion parameter. All of the top ten models performed similarly with respect to AIC_c.

Among site-specific stations, the one model with thin-plate spline smoothers and one with orthogonal polynomials performed identically as the best model (Table 5) The model with orthogonal polynomials had a first order smother (linear on the log scale) of length on the relative catch efficiency and a second order smoother for the effect on the dispersion parameter and the total number of estimated parameters was fewer. All of the top ten ranking models had effects of sampling fraction and swept area on the dispersion parameter.

The AIC_c (4111.32) obtained from the best fitted models for each of the subsets of data (spring, fall, site-specific) that was more than 100 units less than the best model (AIC_c = 4216.36) when the same model was fit to data from each subset. This substantial reduction in the performance measure would suggest using seasonal results for calibration. The dramatic difference in the length effects on relative catch efficiency for the spring (no length effect) and fall (high order polynomial) are reflected in the predicted values (Figure 9 and Tables 6 and 7). There is less difference in the length effects on the dispersion parameter (Figure 10). There are no concerning patterns in the residuals for the best spring and fall models (Figure 11) and the small differences between the best fitting orthogonal polynomial and thin-plate spline smoothers for the respective seasons reflects the small difference in their overall rank with respect to AIC_c (Figure 12).

When applying the relative catch efficiencies to surveys conducted in 2009 and beyond with the *Henry B. Bigelow*, there is an important caution to note. Lengths may be observed in these surveys that are outside of the range of lengths observed during the calibration study. Caution must be taken in predicting catches in *Albatross IV* units at these sizes. This problem can be exacerbated when the data are broken down into seasonal subsets for estimation of relative catch efficiency because the limits of the range of sizes available in the subsets can be narrower than the range of the entire data set, but this turned out to not be a concern for herring.

Lastly, the swept areas for tows during the 2009 and 2010 surveys would ideally be used to predict Albatross catches at each station, but if there is little variability in the swept areas a mean can be used and the mean number per tow at length in *Henry B. Bigelow* “units” can be converted to *Albatross IV* units (Table 8).

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Table 1. Model type (thin-plate regression spline, SP, orthogonal polynomial, OP), relative catch efficiency, dispersion, and total degrees of freedom, dispersion covariates, and log-likelihood for best performing models based on AIC_C. Results are based on data for fish at least 12cm in length collected at all stations.

Rank	Model Type	# Total df	ρ df	ϕ df	ϕ Covariates	LL	AIC_C	Δ (AIC_C)
1	OP	12	6	6	SA, SF	-2096.07	4216.36	0.00
2	OP	13	7	6	SA, SF	-2095.06	4216.39	0.03
3	OP	14	7	7	SA, SF	-2094.05	4216.40	0.04
4	OP	13	6	7	SA, SF	-2095.13	4216.52	0.16
5	OP	9	3	6	SA, SF	-2099.78	4217.69	1.32
6	OP	15	8	7	SA, SF	-2093.90	4218.15	1.79
7	OP	14	8	6	SA, SF	-2094.96	4218.23	1.87
8	OP	10	3	7	SA, SF	-2099.17	4218.49	2.13
9	OP	15	9	6	SA, SF	-2094.50	4219.34	2.98
10	OP	16	9	7	SA, SF	-2093.48	4219.35	2.99

Table 2. Predicted relative catch efficiencies and coefficient of variation from the best fitted beta-binomial model with respect to AIC$_c$ (see Table 1) based on data collected at all stations in 2008 for fish at least 12cm in length.

Length (cm)	$\hat{\rho}$	$CV(\hat{\rho})$
12	4.405	1.022
13	16.762	0.552
14	27.213	0.419
15	26.219	0.376
16	19.209	0.313
17	12.757	0.233
18	8.610	0.162
19	6.289	0.115
20	5.083	0.092
21	4.507	0.078
22	4.262	0.067
23	4.135	0.064
24	3.965	0.066
25	3.657	0.068
26	3.228	0.070
27	2.798	0.080
28	2.551	0.099
29	2.759	0.131
30	4.253	0.249
31	12.078	0.565

Table 3. For data collected during the spring survey, model type (orthogonal polynomial, OP or thin-plate spline, SP), relative catch efficiency, dispersion, and total degrees of freedom, dispersion covariates, and log-likelihood for best performing models based on AIC$_c$. Results are based on data for fish at least 12cm in length.

Rank	Model Type	# Total df	ρ df	ϕ df	ϕ Covariates	LL	AIC$_c$	Δ (AIC$_c$)
1	OP	7.00	1.00	6.00	SA,SF	-761.70	1537.58	0.00
2	OP	6.00	1.00	5.00	SA,SF	-763.12	1538.38	0.80
3	OP	11.00	5.00	6.00	SA,SF	-758.19	1538.80	1.22
4	OP	8.00	1.00	7.00	SA,SF	-761.37	1538.96	1.39
5	SP	7.94	2.00	5.94	SA,SF	-761.43	1539.05	1.48
6	OP	8.00	2.00	6.00	SA,SF	-761.42	1539.06	1.48
7	OP	7.00	2.00	5.00	SA,SF	-762.70	1539.57	1.99
8	OP	6.00	1.00	5.00	SA	-763.85	1539.83	2.26
9	OP	6.00	1.00	5.00	SF	-763.89	1539.90	2.33
10	OP	10.00	5.00	5.00	SA,SF	-759.86	1540.06	2.49

Table 4. For data collected during the fall survey, model type (orthogonal polynomial, OP or thin-plate spline, SP), relative catch efficiency, dispersion, and total degrees of freedom, dispersion covariates, and log-likelihood for best performing models based on AIC$_c$. Results are based on data for fish at least 12cm in length.

Rank	Model Type	# Total df	ρ df	ϕ df	ϕ Covariates	LL	AIC$_c$	Δ (AIC$_c$)
1	OP	11.00	8.00	3.00		-405.68	833.99	0.00
2	OP	10.00	8.00	2.00		-406.76	834.06	0.07
3	SP	7.96	6.96	1.00		-408.80	834.16	0.17
4	OP	12.00	8.00	4.00	SA	-404.71	834.17	0.18
5	OP	10.00	8.00	2.00	SA	-406.83	834.19	0.20
6	OP	9.00	8.00	1.00		-407.90	834.23	0.24
7	OP	11.00	8.00	3.00	SA	-405.83	834.30	0.32
8	SP	9.00	7.00	2.00	SA	-407.77	834.32	0.34
9	OP	10.00	7.00	3.00		-407.05	834.63	0.65
10	SP	9.16	7.16	2.00		-407.77	834.67	0.68

Table 5. For data collected from site-specific stations (outside of the fall and spring surveys), model type (orthogonal polynomial, OP or thin-plate spline, SP), relative catch efficiency, dispersion, and total degrees of freedom, dispersion covariates, and log-likelihood for best performing models based on AIC_c. Results are based on data for fish at least 12cm in length.

Rank	Model Type	# Total df	ρ df	ϕ df	ϕ Covariates	LL	AIC_c	$\Delta(AIC_c)$
1	OP	7.00	2.00	5.00	SA,SF	-862.73	1739.63	0.00
2	SP	10.45	2.00	8.45	SA,SF	-859.22	1739.80	0.00
3	OP	8.00	2.00	6.00	SA,SF	-862.10	1740.41	0.78
4	OP	9.00	2.00	7.00	SA,SF	-861.12	1740.50	0.88
5	OP	8.00	3.00	5.00	SA,SF	-862.25	1740.70	1.07
6	OP	9.00	3.00	6.00	SA,SF	-861.48	1741.21	1.59
7	OP	10.00	3.00	7.00	SA,SF	-860.50	1741.32	1.70
8	OP	12.00	3.00	9.00	SA,SF	-858.53	1741.52	1.89
9	OP	9.00	4.00	5.00	SA,SF	-862.04	1742.34	2.71
10	OP	11.00	4.00	7.00	SA,SF	-860.04	1742.46	2.84

Table 6. Predicted relative catch efficiencies and coefficient of variation from a fitted beta-binomial model with fourth degree orthogonal polynomials in length for the mean parameter and first degree (linear) polynomial in length for the dispersion parameter (best performing orthogonal polynomial model without gamma assumption) based on data collected during the spring survey for fish at least 12cm in length.

Length (cm)	$\hat{\rho}$	$CV(\hat{\rho})$
14	6.070	0.074
15	6.070	0.074
16	6.070	0.074
17	6.070	0.074
18	6.070	0.074
19	6.070	0.074
20	6.070	0.074
21	6.070	0.074
22	6.070	0.074
23	6.070	0.074
24	6.070	0.074
25	6.070	0.074
26	6.070	0.074
27	6.070	0.074
28	6.070	0.074
29	6.070	0.074
30	6.070	0.074
31	6.070	0.074

Table 7. Predicted relative catch efficiencies and coefficient of variation from a fitted beta-binomial model with fourth degree orthogonal polynomials in length for the mean parameter and first degree (linear) polynomial in length for the dispersion parameter (best performing orthogonal polynomial model without gamma assumption) based on data collected during the fall survey for fish at least 12cm in length.

Length (cm)	$\hat{\rho}$	$CV(\hat{\rho})$
12	2.430	1.323
13	14.515	0.699
14	35.491	0.595
15	33.642	0.578
16	16.701	0.630
17	6.513	0.592
18	2.835	0.473
19	1.705	0.347
20	1.496	0.258
21	1.760	0.195
22	2.351	0.149
23	2.973	0.137
24	3.125	0.140
25	2.663	0.138
26	2.035	0.148
27	1.708	0.166
28	1.957	0.183
29	3.277	0.280
30	5.745	0.433
31	3.511	1.063

Table 8. Mean swept area (sq. nm) per tow for each vessel at all offshore stations where herring at least 12 cm in length were observed, across all seasons or during spring and fall surveys. Note that swept area is not known for every tow.

	Albatross IV	*Henry B. Bigelow*
All stations	0.011668	0.007188
Spring	0.011644	0.006835
Fall	0.010966	0.007321

Figure 1. Number of stations where fish were observed by length class (top) and the proportions of stations where fish were observed aboard the *Henry B. Bigelow* only (black), *Albatross IV* only (white) or both vessels (gray).

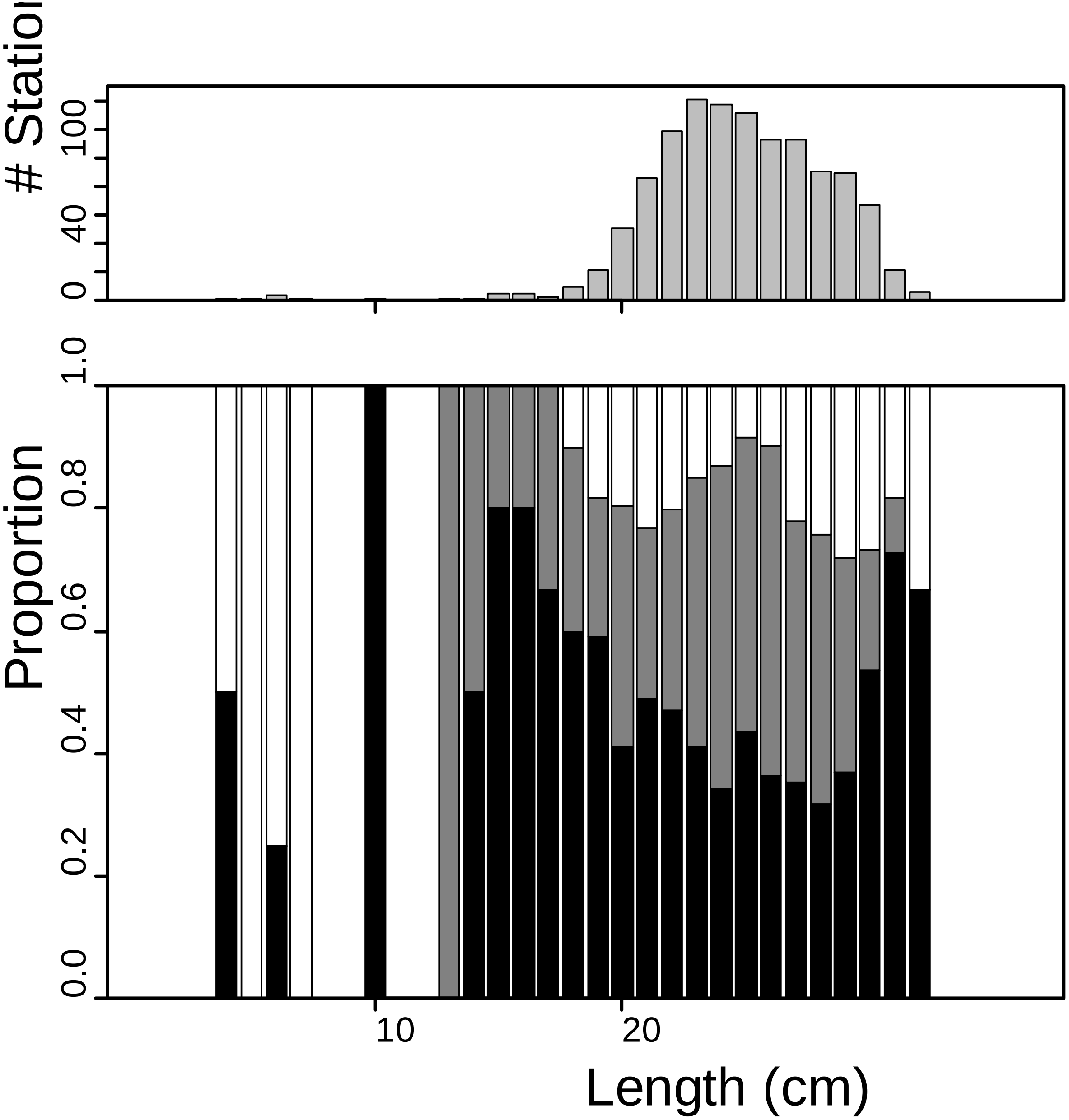


Figure 2. Total number of fish captured at each station in offshore strata (both vessels combined) at length (top) and proportions captured by the *Albatross IV* (white) and *Henry B. Bigelow* (gray) (bottom) from data collected at all stations in 2008 for fish at least 12cm in length.

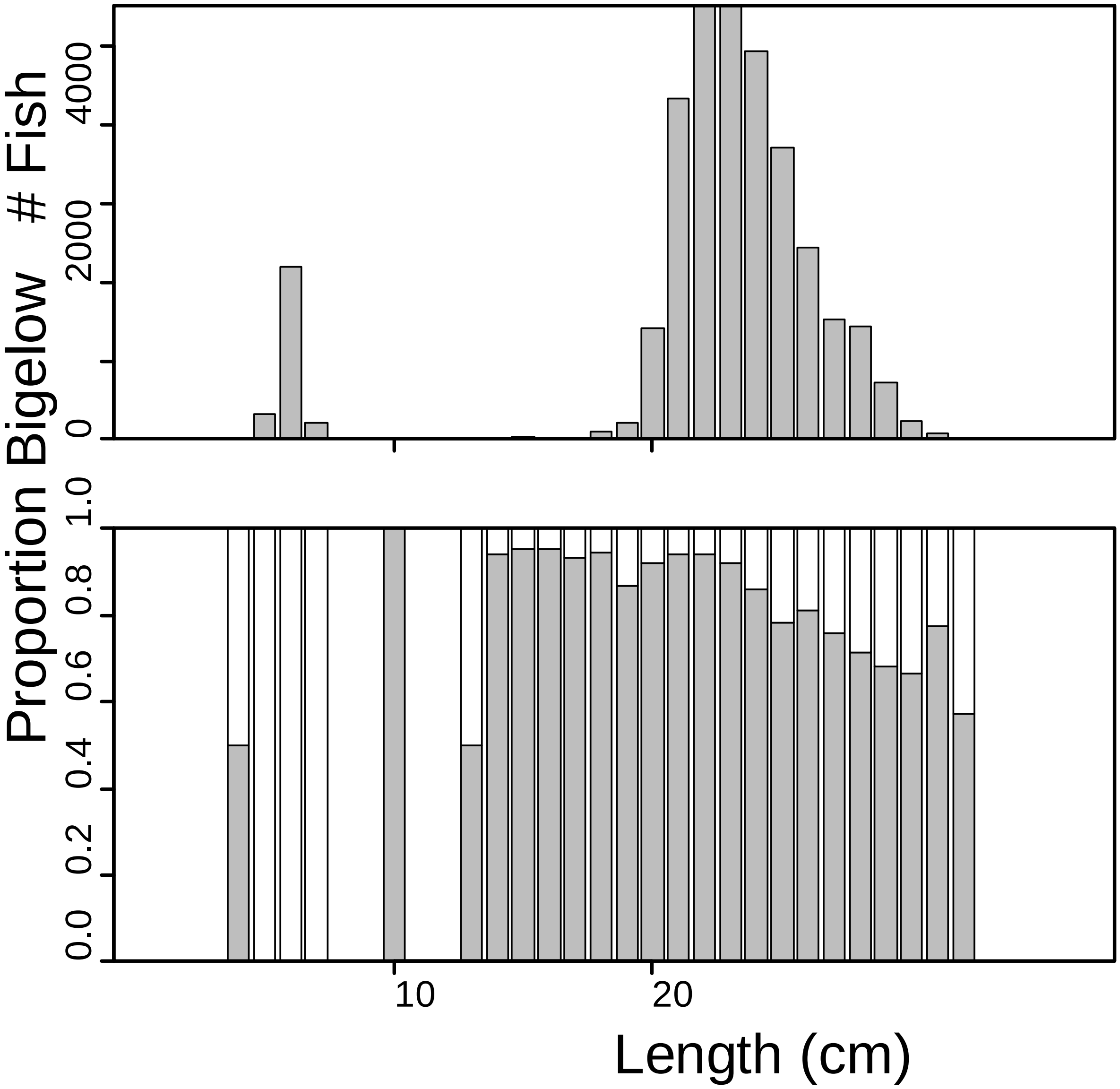


Figure 3. Number of stations where fish were observed by length class (top) and the proportions of stations where fish were observed aboard the *Henry B. Bigelow* only (black), *Albatross IV* only (white) or both vessels (gray) for data collected from stations during the spring (left) and fall (right) surveys in 2008.

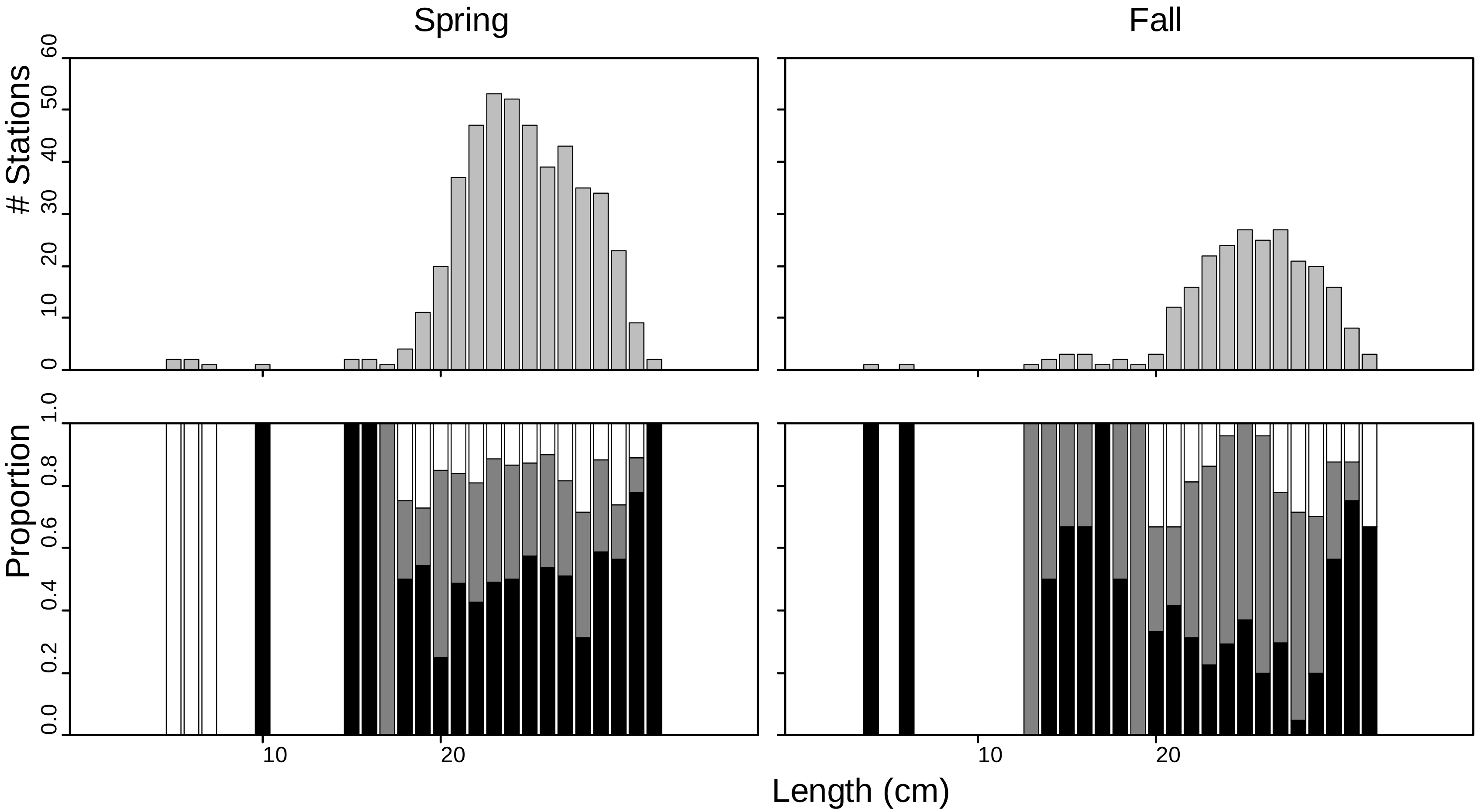


Figure 4. Total number of fish captured at each station (both vessels combined) at length (top) and proportions captured by the *Albatross IV* (white) and *Henry B. Bigelow* (gray) (bottom) for data collected from stations during the spring (left) and fall (right) surveys in 2008.

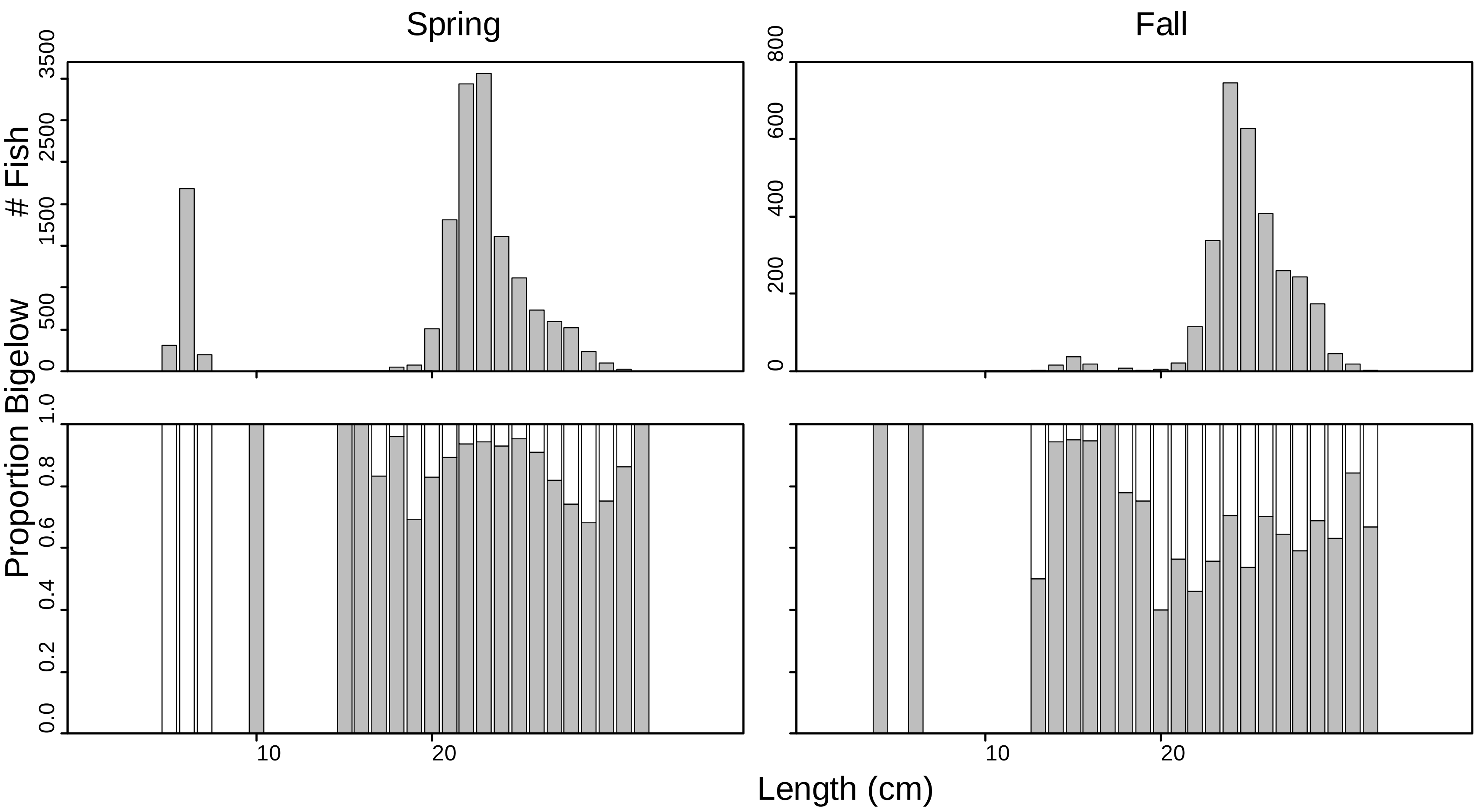


Figure 5. Predicted relative catch efficiency from the best performing model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected at all stations in 2008 for fish at least 12cm in length.

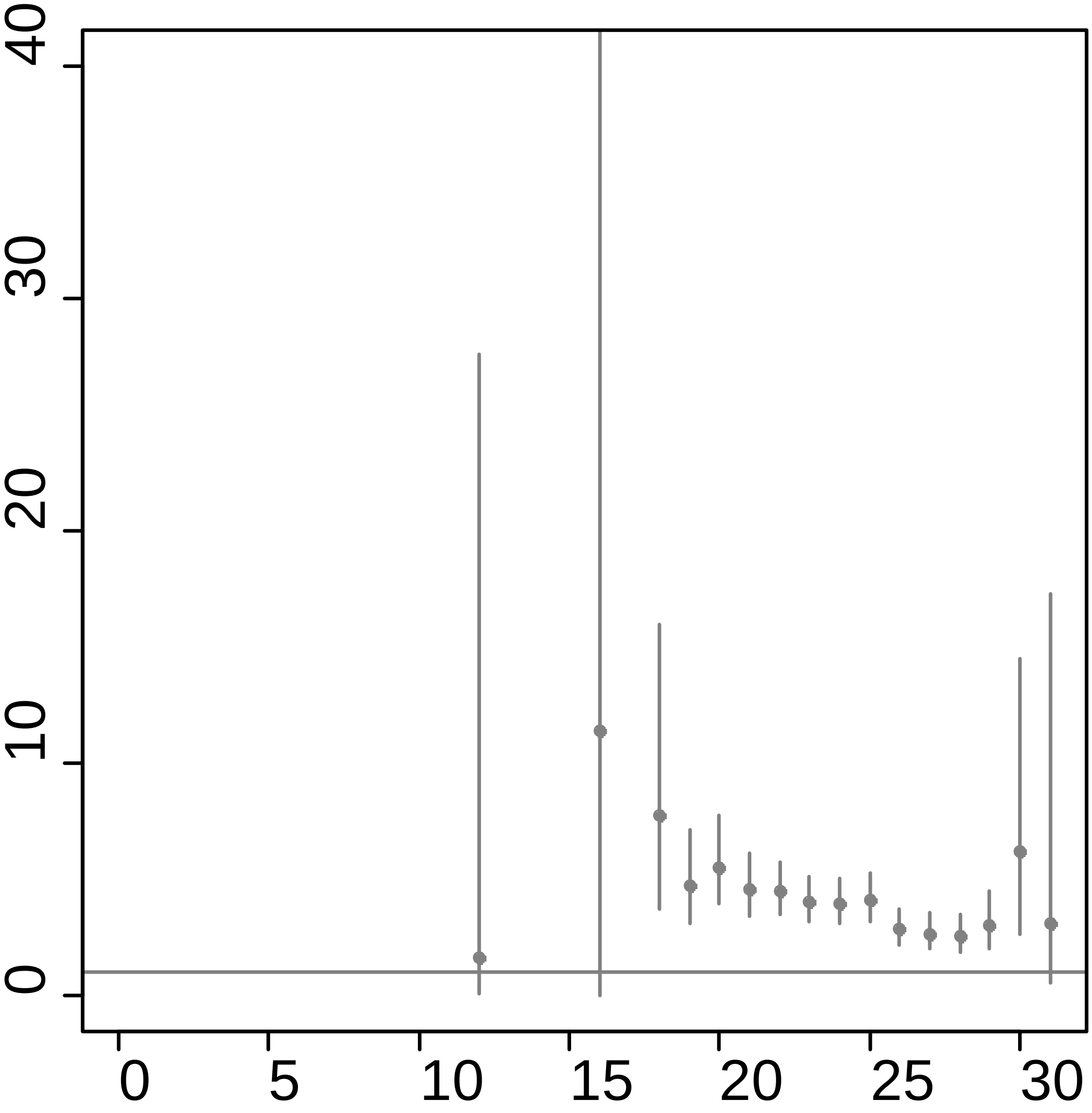


Figure 6. Predicted beta-binomial dispersion parameter from the best performing model (red) and 95% confidence intervals (dashed lines) and predicted dispersion parameter by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected at all stations in 2008 for fish at least 12cm in length.

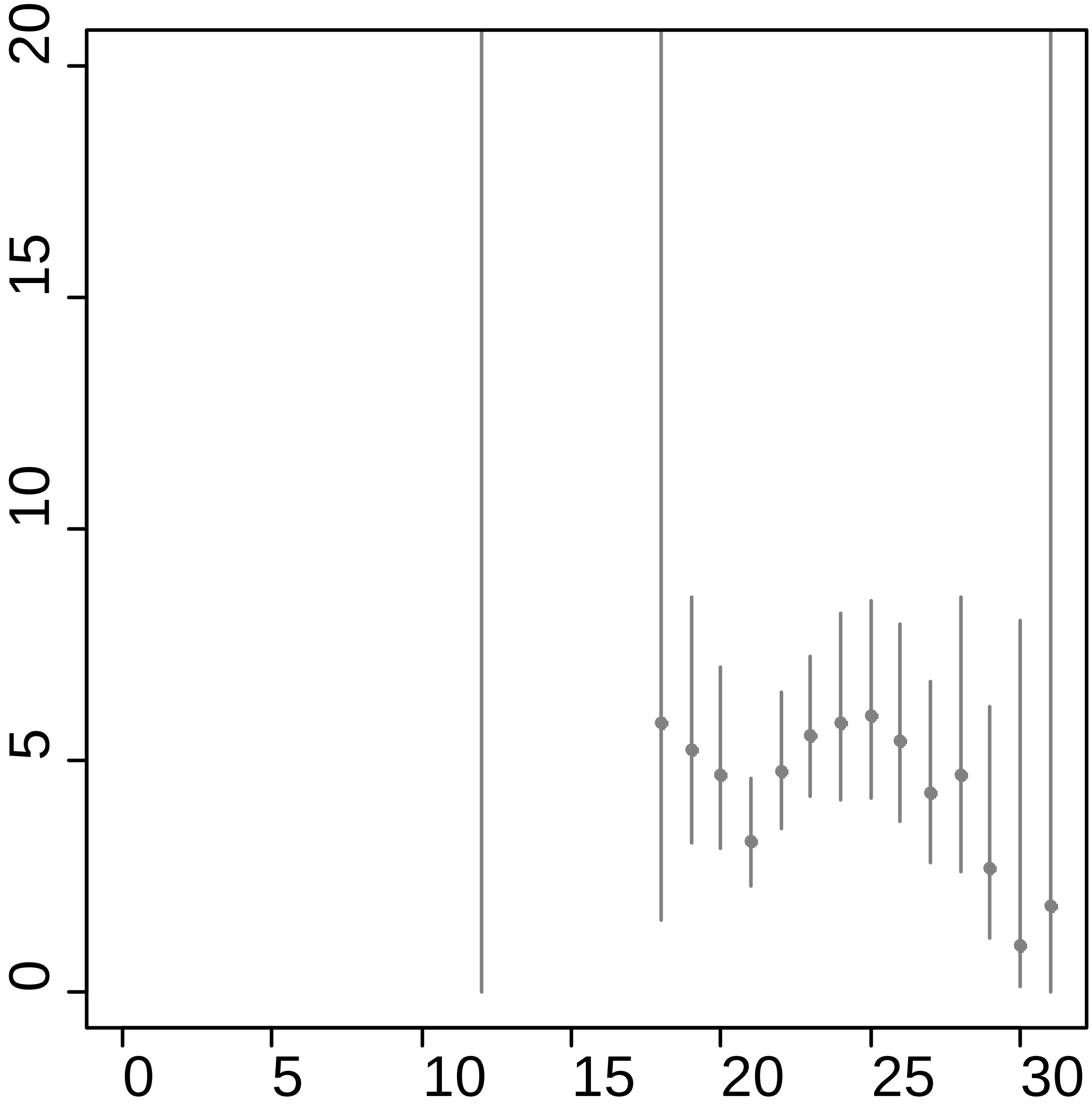


Figure 7. Randomized quantile residuals of the best performing model (as measured by AICc, see Table 1) in relation to the predicted number captured by the *Henry B. Bigelow* (left), the total number of fish captured at a station (middle), and their normal quantiles (right). Results are based on data collected at all stations in 2008 for fish at least 12cm in length.

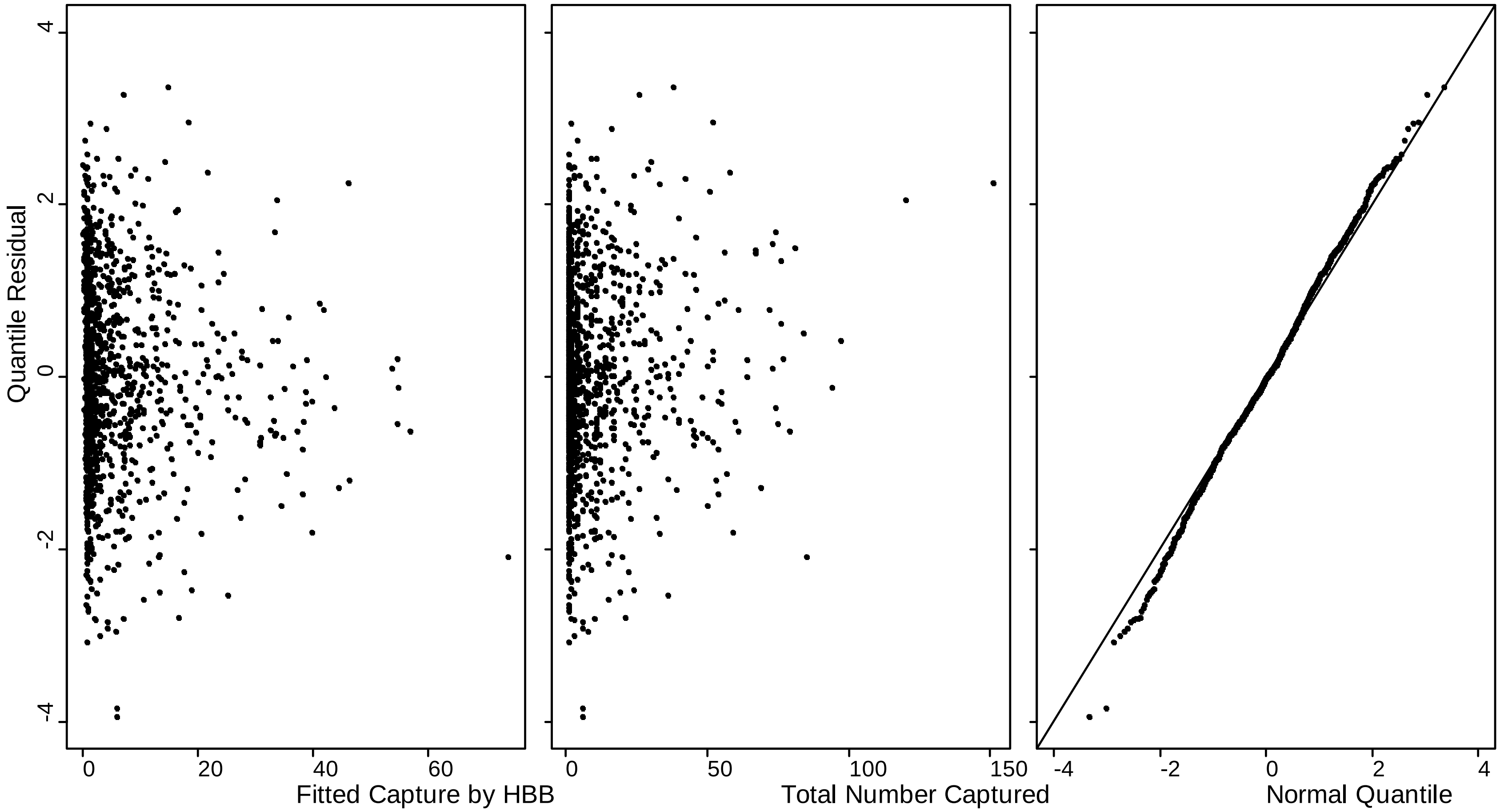


Figure 8. Predicted relative catch efficiency (left) and proportion captured by *Henry B. Bigelow* (right) from the best performing model and the best thin-plate regression spline smoother (Rank 50 with respect to AIC$_c$). Results are based on data collected across all stations in 2008 for fish at least 12cm in length.

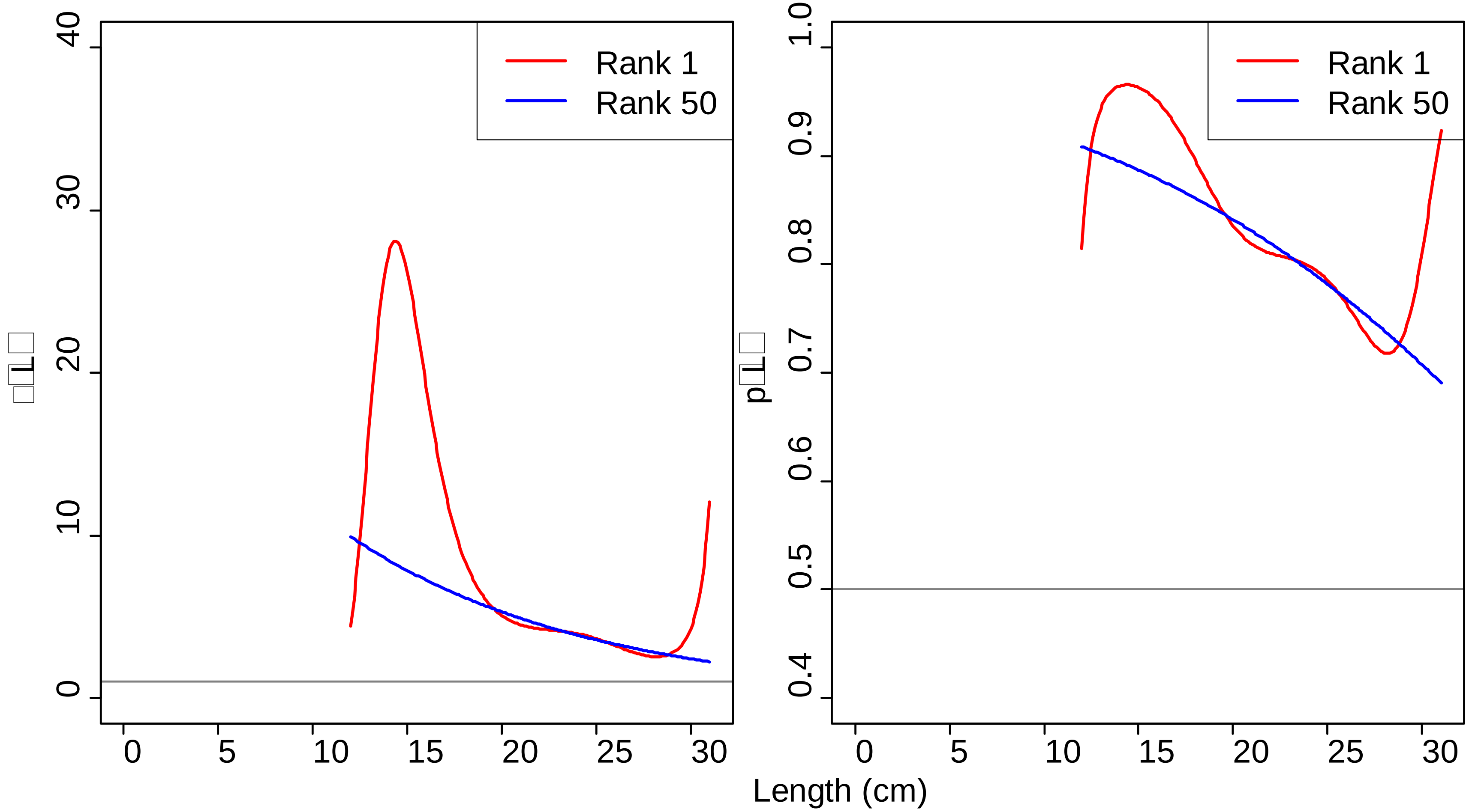


Figure 9. Predicted relative catch efficiency from the best performing orthogonal polynomial (without gamma assumption) model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected from stations during the spring (left) and fall (right) surveys in 2008 for fish at least 12cm in length.

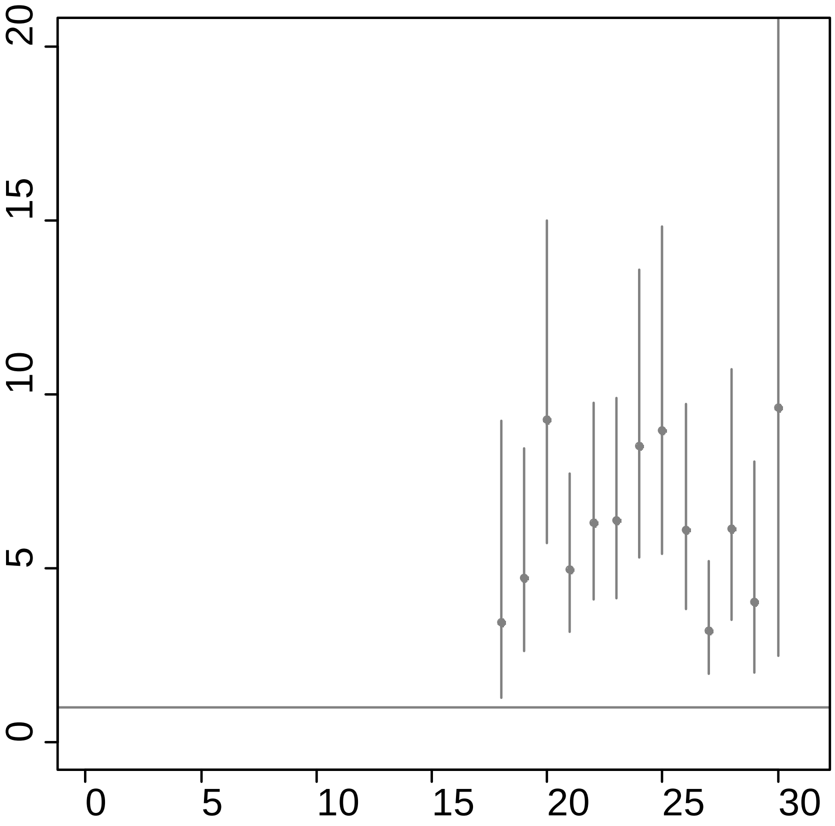


Figure 10. Predicted dispersion parameter from the best performing orthogonal polynomial model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected from stations during the spring (left) and fall (right) surveys in 2008 for fish at least 12cm in length.

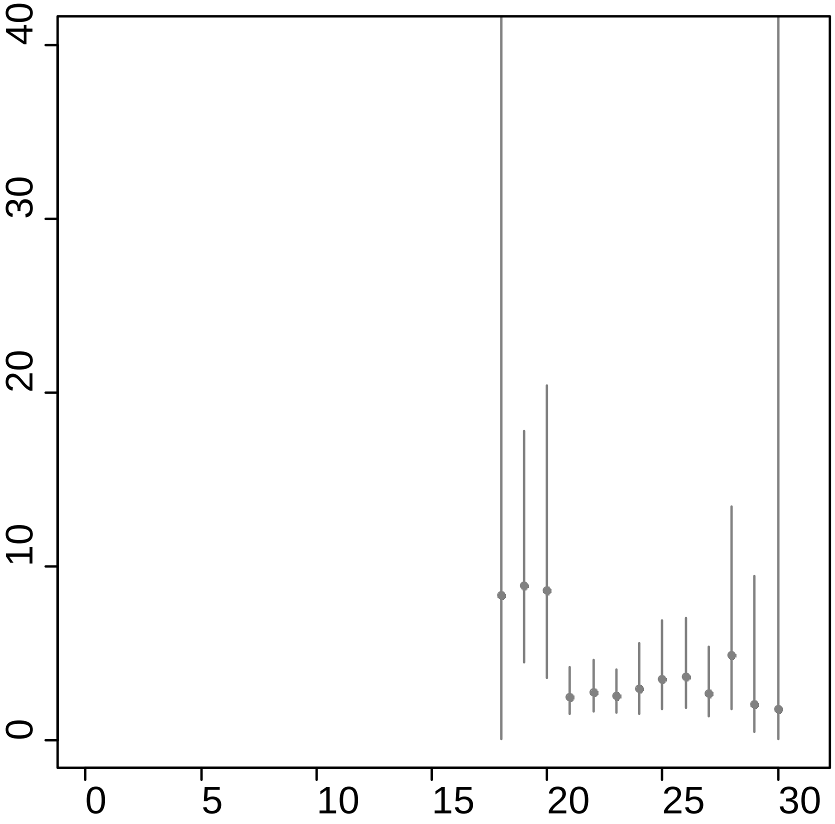


Figure 11. Randomized quantile residuals of the best performing (as measured by AICc) in relation to the predicted number captured by the *Henry B. Bigelow* (left), the total number of fish captured at a station (middle), and their normal quantiles (right). Results are based on data collected from stations during the spring (top) and fall (bottom) surveys in 2008 for fish at least 12cm in length.

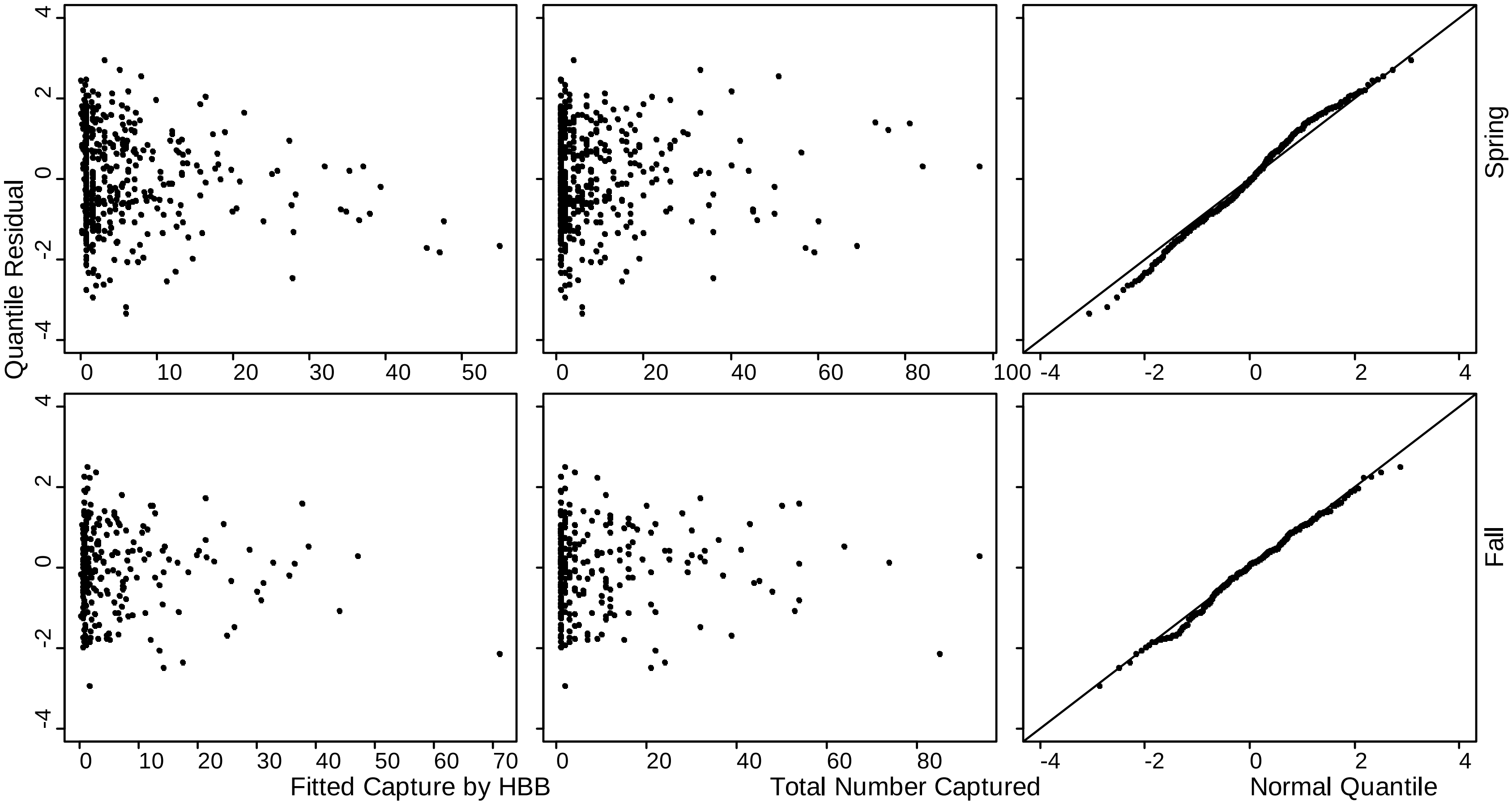
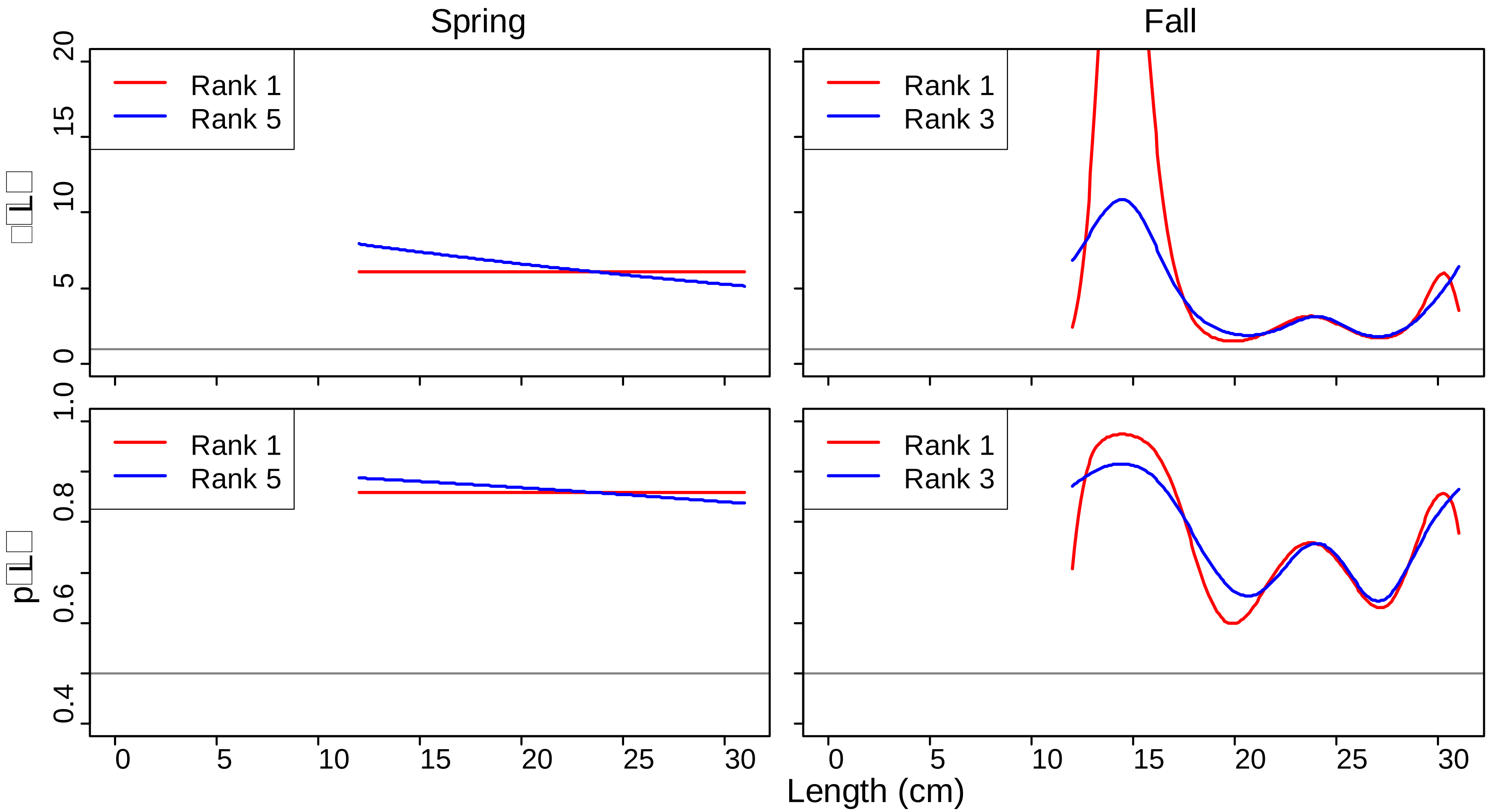


Figure 12. Predicted relative catch efficiency (top) and proportion captured by *Henry B. Bigelow* (bottom) from the best performing model (orthogonal polynomials, rank 1) and the best thin-plate spline smoother (Rank 12 for spring data, 11 for fall data) for data collected from stations during the spring (left) and fall (right) surveys in 2008 for fish at least 12cm in length.



An evaluation of whether changes in the timing and distribution of Atlantic herring spawning on Georges Bank may have biased the NEFSC acoustic survey

Preliminary results from a NOAA FATE funded project to:

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SUMMARY

At the 2009 TRAC assessment it was proposed that the NEFSC acoustic survey may not be sampling a fixed proportion of the Atlantic herring population year-to-year, resulting in a biased index. We used larval herring data collected by the NEFSC to evaluate changes in the timing and distribution of Atlantic herring egg hatching, which we use as a measure of spawning distributions. We did not find any evidence that herring spawning shifted from 2000 to 2003, the time period when the herring acoustic index declined substantially.

BACKGROUND

Acoustic surveys are used throughout the world to measure the size of stocks of pelagic species (Webb et al. 2008) and are generally the preferred method for surveying pelagic stocks (Simmonds & MacLennan 2005, McQuinn 2009). The NEFSC acoustic survey targets pre-spawning Atlantic herring on Georges Bank and was started in 1999 (Overholtz et al. 2006). However, during the 2009 TRAC assessment for Gulf of Maine/Georges Bank Atlantic herring, the abundance index derived from the NEFSC acoustic survey was excluded from the assessment model. During the assessment it was suggested that a change in the spatial-temporal overlap between the acoustic survey and herring spawning could have biased the index downward at the end of the time series. More generally, concern was raised that the dominant trend in the acoustic survey, a ≈70% decline between the 1999-2001 time period and the 2002-2004 time period (Figure 1), was not apparent in the NEFSC bottom trawl survey indices for Atlantic herring. In this working paper we evaluate changes in the timing and distribution of Atlantic herring egg hatching using larval herring data collected during the NEFSC ichthyoplankton surveys. The objective of this working paper is to evaluate the hypothesis that a change in overlap between the acoustic survey and the distribution of spawning on Georges Bank underlies the decline in the acoustic index

SAMPLING PROGRAMS

NEFSC ichthyoplankton sampling

NEFSC ichthyoplankton sampling is described in detail elsewhere (Richardson et al. 2010). Briefly, the NEFSC has performed 4-8 plankton surveys per year since 1971 using a 61-cm bongo net. Five different sampling programs (ICNAF, MARMAP, herring-sand lance interaction, GLOBEC, ECOMON) have occurred during this time period. Some of these programs have targeted specific species (e.g. GLOBEC, cod and haddock), while others were more general. The result is a consistent sampling method, but variability in the timing and spatial extent of sampling. The Ecosystem Monitoring (EcoMon) program started in its current form in 1999, the same year the acoustic survey was initiated. The EcoMon program is designed to sample twice during the fall spawning season of Atlantic herring. The first fall sampling is piggybacked on the fall trawl survey which generally occupies Georges Bank in early October. The second fall sampling occurs in early to mid November on a dedicated plankton survey. An additional Jan-Feb survey also provides useful information on larval herring abundance and distribution.

Data on the distribution of larval Atlantic herring from NEFSC plankton surveys have previously been used to describe the decline of the Georges Bank herring spawning in the late 1970s and the recolonization of Georges Bank in the late 1980s (Smith & Morse 1993). An index of larval herring abundance has also been developed for the Georges Bank spawning component of Atlantic herring (Richardson et al. 2010). This larval index incorporates functions describing the seasonality of spawning and larval mortality. Interannual variability in larval abundance on Georges Bank was recently proposed to be a function of both the abundance of adult herring spawning on Georges Bank and the survival of herring eggs from haddock predation (Richardson et al. 2011).

NEFSC Acoustic survey

The NEFSC initiated an acoustic survey for Atlantic herring in 1998, and established the current sampling design in 1999 (Overholtz et al. 2006). The details of the acoustic survey operations, equipment and data analysis are described elsewhere. The relevant information for this analysis is the spatial design of the sampling and the timing of the survey.

The acoustic survey samples evenly spaced parallel north-south transects (i.e. a systematic parallel design) off the northern edge of Georges Bank and the Great South Channel (Figure 2). The timing of the survey is designed to sample pre-spawning aggregations of Atlantic herring. The survey has consistently been performed during the last two weeks of September, with the exception of 2007 when the survey occurred during the last two weeks of October (Table 1). During 2003, the survey was repeated three times (Sept 4-12, Sep 18-25, Oct 3-10) with the middle survey used to calculate the index. In 2000 and 2001 Georges Bank was also sampled multiple times, using three different sampling designs (zig-zag, parallel systematic, parallel with random spacing).

METHODS

We first addressed the question of whether the spatial distribution of adult herring in the acoustic survey is consistent with the spatial distribution of larval herring in the EcoMon surveys. The spatial distribution of Atlantic herring in the acoustic survey was determined by first averaging the backscatter attributed to herring along a 0.22° longitude by 0.06° latitude grid for each year of the survey. The grid spacing in longitude was established to match the spacing of parallel transects along the survey. Higher resolution sampling occurs in the north-south direction thus allowing the finer latitudinal grid spacing. For each survey the proportion of the total herring backscatter in each grid cell was calculated; these proportional abundances were then averaged across years to generate the mean distribution map.

Larval herring distributions are a function of spawning locations and larval transport after hatching; larval distributions will tend to be broader than spawning distributions. We used a larval transport model to estimate the locations of egg hatching based on observed larval distributions in our EcoMon surveys. The larval transport model was run forward for 75 days. Initial release locations (N=327) were located on a 1/6th degree grid of stations <200 m depth in the western Gulf of Maine and Georges Bank. Particles were released every three days from mid-September to mid-December. Only 2008 and 2009 releases were available for this analysis; model runs from 1999-2007 are ongoing. An analytical technique was developed to estimate the magnitude of egg hatching at each of the 327 release locations given the observed abundance at age of herring larvae sampled on the EcoMon survey from 1999-2009. There is currently a mismatch between the sample years and model release years used in this analysis; this mismatch does contribute uncertainty to the analysis and will be corrected as more model output becomes available. Notably, many of the dominant circulation features on Georges Bank are consistent year to year.

Our second analysis addressed changes in the spatial distribution of spawning. In the Georges Bank region the spatial distribution of herring spawning primarily changes in the east-west direction. To capture spatial changes in egg hatching locations, we calculated the annual weighted mean longitude of Atlantic herring larvae <9 mm (about 10-15 days post-hatch) during October and November. Only Georges Bank and Southern New England samples were included in this index; samples from the western Gulf of Maine and the Scotian Shelf were excluded.

Finally we addressed changes in the timing of spawning. The temporal distribution of Atlantic herring egg hatching can be calculated based on the \ age distribution of larvae collected during sampling. The methodology we have used to estimate a larval index for Atlantic herring includes functions describing the seasonality of egg hatching and larval mortality (Richardson et al. 2010). Specifically a three parameter skew-logistic function was used to describe the average seasonality of hatching over the entire 41 year time series, while a two parameter Pareto function was used to describe larval mortality. We modified this larval index methodology to estimate inter-annual variability in egg hatching (versus a time-series mean). The skew-logistic hatching seasonality function was replaced with a two parameter normal curve. We further minimized the number of estimated parameters by only allowing the mean day of spawning to vary year-to-year; a single spawning season duration value was calculated for all years.

RESULTS

On average herring were in highest abundance in the acoustic survey at the northern edge of Georges Bank. An area between 68.5 W and 67.5 W contained the highest average abundances of herring in the acoustic survey. During the 1999-2009 period small (<9 mm and <10-15 days post hatch) larval herring were collected in highest abundances along the northeastern portion of Georges Bank, with fewer larvae collected along the western Great South Channel.

The analysis using the larval transport model and observed larval abundance-at-age data suggested a strong concentration of egg hatching at 67.2 W and 42 N for the years 1999-2009. For the years 1999 to 2009 combined, egg hatching was also predicted for the western Great South Channel and the western Gulf of Maine in proximity to Stellwagen Bank. For the period 1999-2009, 81% of egg hatching in the region was predicted to occur on the northern edge of Georges Bank, 12% in the western Great South Channel, and 7.5% in the western Gulf of Maine. Areas of the Gulf of Maine north of 43.5° N were not included in these calculations. In general, the location of highest herring acoustic backscatter corresponded well to the predicted location of highest egg hatching.

From 1977-present the weighted mean longitude of herring larvae varied (Figure 5). From 1980-1992 herring larvae were most abundant at the western edge of the Great South Channel with a mean longitude of 69.5 W. The recolonization of the northeastern edge of Georges Bank shifted the mean longitude of larvae to around 67 W in the mid 1990s (Figure 5). During the first 8 years of the acoustic survey (1999-2006) the mean longitude of larvae of herring larvae in the Georges Bank region remained stable, with a large majority of the larvae occurring on the eastern edge of George Bank (Figure 6). However, a westward shift occurred around 2007, as a higher proportion of larvae were collected along the western Great South Channel.

As with the weighted mean longitude of larvae the estimated mean day of egg hatching has varied over decadal time scales. During the 1980s and early 1990s the mean day of hatching was around day 300. Around 1994, concurrent with the shift in the spatial distribution of egg hatching, there was a shift to a mean day of hatching around day 288. From 1999-2005 the timing of egg hatching remained relatively stable, with certain years (2001, 2004) indicating earlier spawning and others (2005,2007) indicating later spawning (Figure 6).

Discussion

In order to provide a meaningful index of abundance the NEFSC acoustic survey must sample a relatively fixed proportion of the Atlantic herring population. If the timing or spatial distribution of herring spawning changes relative to the survey, the index could be biased. The acoustic index presented at the 2009 TRAC herring assessment declined substantially from 2001 to 2002, and was low for the remaining years. During the same 2001-2003 period, the spatial and temporal distribution of larval herring on Georges Bank remained relatively stable with a peak day of hatching around Oct 15th and a peak location of hatching along the northeastern portion of Georges Bank. Egg durations for Gulf of Maine Atlantic herring at 10° C were 11 days in laboratory studies (Lough et al. 1982), suggesting peak spawning during the beginning of October. With the exception of 2007 the spatial coverage and the timing of the acoustic survey has been relatively stable. This comparison of the acoustic survey design and the larval distribution data does not provide support for the hypothesis that a shift in the timing or distribution of spawning was responsible for the decline in the acoustic index in the early 2000s.

One consideration in evaluating larval herring data is that the relationship between the magnitude of Atlantic herring spawning and the number of eggs hatching into larvae is not fixed in time or space due to variability in egg mortality. On Georges Bank, substantial interannual variability in egg mortality has been suggested. Specifically, major declines in larval abundance on Georges Bank from 1975 to 1976 and 2003 to 2004 have been attributed to increased egg predation by the 1975 and 2003 year classes of haddock rather than reduced levels of spawning (Richardson et al. 2011). This raises a question of whether another scenario is possible, relatively stability in the spatial and temporal distribution of larval herring despite a substantial change in the pattern of spawning. We consider this scenario unlikely, as it requires a concurrent change in the distribution of egg predation and spawning distribution.

Overall, we did not find evidence that the spatial or temporal distribution of Atlantic herring spawning changed in the early 2000s, though there was year to year variability in our estimates of the timing of egg hatching. Our analysis did not provide any evidence that the acoustic survey has violated the requirement that it sample a fixed proportion of the herring population.

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Table 1. NEFSC Atlantic herring acoustic surveys from 1999 to 2010. Surveys are numbered and labeled based on the survey design (prlll: systematic parallel design; Syszz: systematic zig zag; Rndpl: random parallel) .Transect lines labeled in red are the ones used to calculate the index for the assessment.

DATE/ CRUISE	Sept. 1st week	Sept. 2nd week	Sept. 3rd week	Sept. 4th week	Oct. 1st week	Oct. 2nd week	Oct. 3rd week	Oct. 4th week
DE199909					prlll16			
DE200008		syspl05	rndpl06	syszz07	prlll08, prlll09			
DE200109			prlll05	rndpl01	zigzg02			
DE200208			prlll06					
DE200308	prlll01		prlll03		prlll05			
DE200413			prlll03			prlll05		
DE200512			prlll02					
DE200615			prlll03					
DE200710							prlll02	
DE200809			prlll01					
DE200910				prlll02				
DE201010				prlll03				

Figure 1: Acoustic survey index for Atlantic herring from the 2009 TRAC assessment.

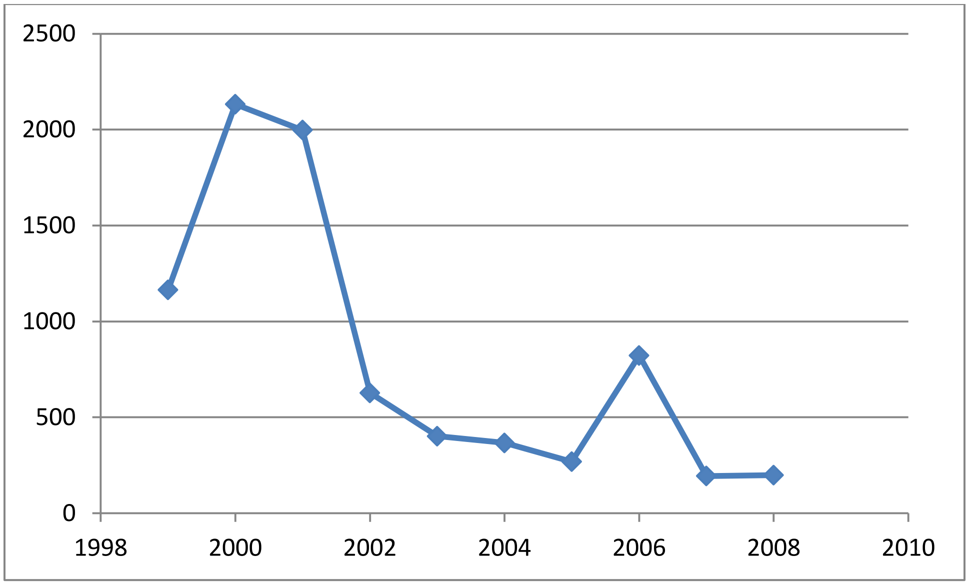


Figure 2. Spatial coverage of the acoustic survey with the systematic parallel sampling design.

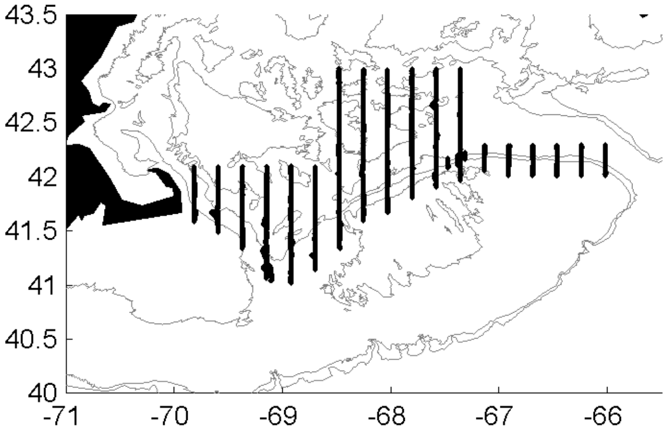


Figure 3. Distribution of small larval herring (< 9 mm) from the October and November ECOMON surveys for 1999-2010. Red x's indicate sampling locations where no small larvae were collected. Circle diameter is proportional to the square root of abundance. The larval distribution is a function of spawning location and larval drift, which is generally clockwise around Georges Bank. Acoustic survey track is overlaid on the figure.

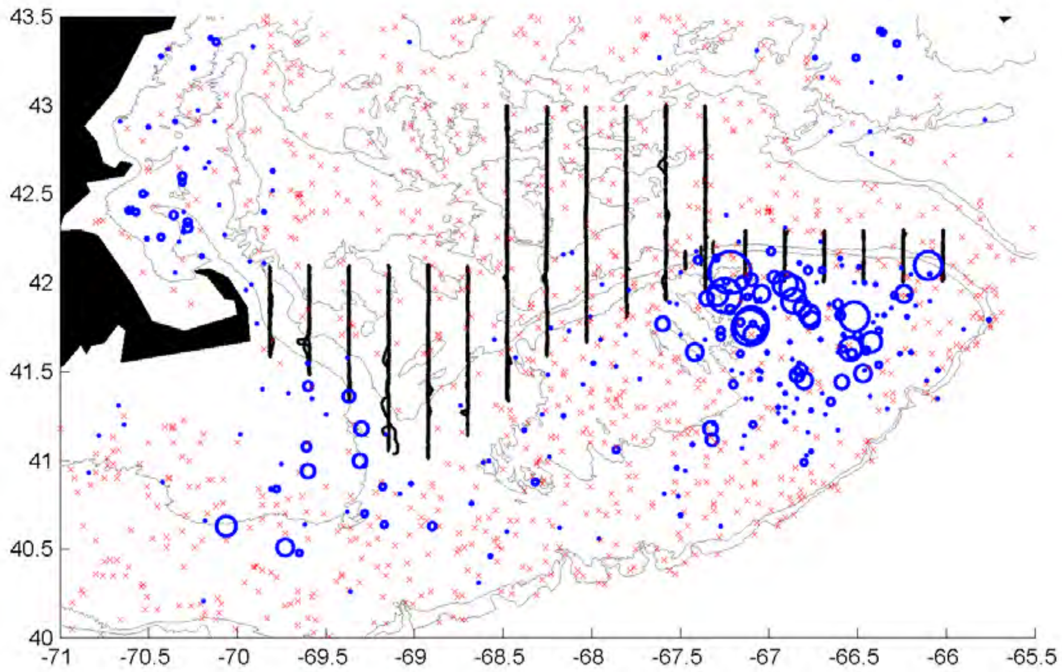


Figure 4. Predicted locations of herring egg hatching (circles) and measured abundances of herring on the acoustic survey (surface) for the years 1999-2009. The egg hatching locations are estimated using a larval transport model and the observed abundances of larval Atlantic herring at age; results are preliminary until further transport model runs are complete.

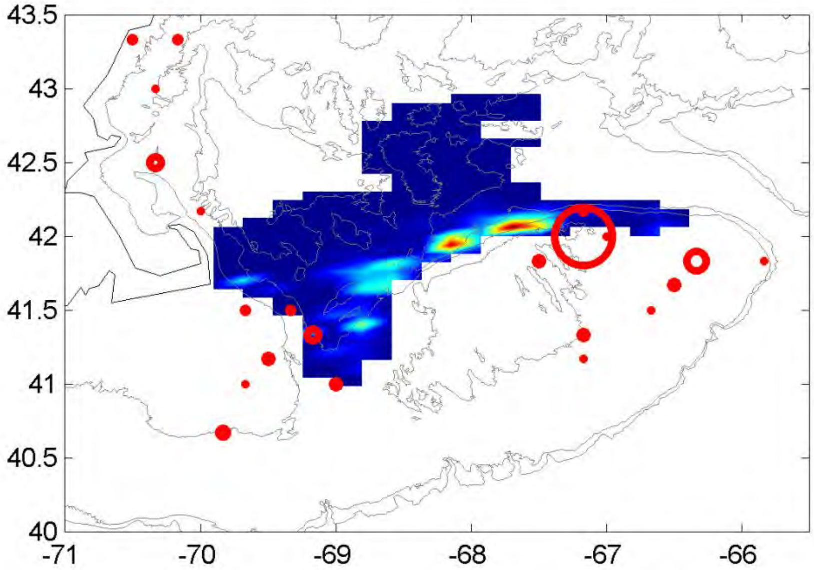


Figure 5. Estimated timing of mean hatch day of larval herring and average longitude of recently hatched larval herring on Georges Bank. Mean hatch day was determined on an annual basis using the approach used to develop a larval index in Richardson et al (2010). A two parameter normal distribution of spawning was substituted for the three parameter skew-logistic curve used in that manuscript. Average longitude of larvae is based on larvae <9mm sampled on either Georges Bank or the broader Nantucket Shoals area during October and November. Values are not calculated during years when the Oct/Nov time period was not sampled. A three year moving average is plotted for each value.

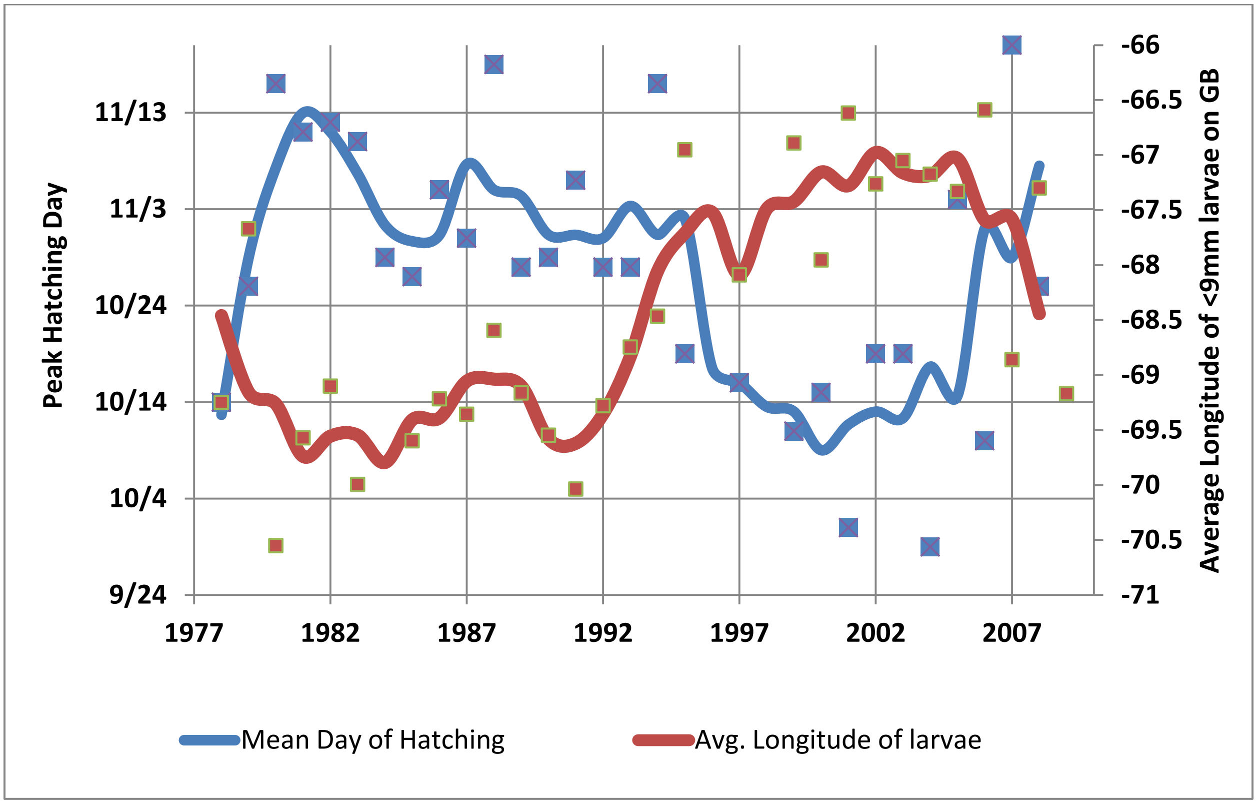


Figure 6. Same as figure 5, but with a focus on the 1999-2009 period of the acoustic survey.

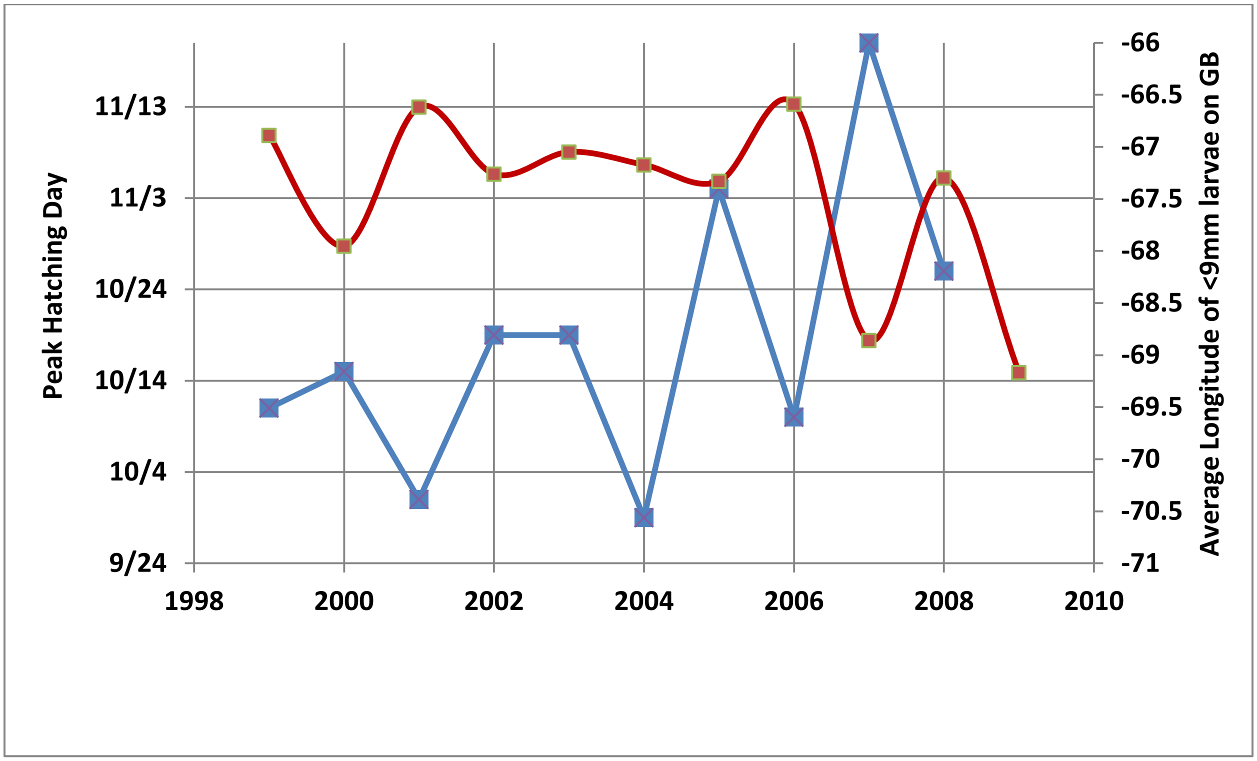
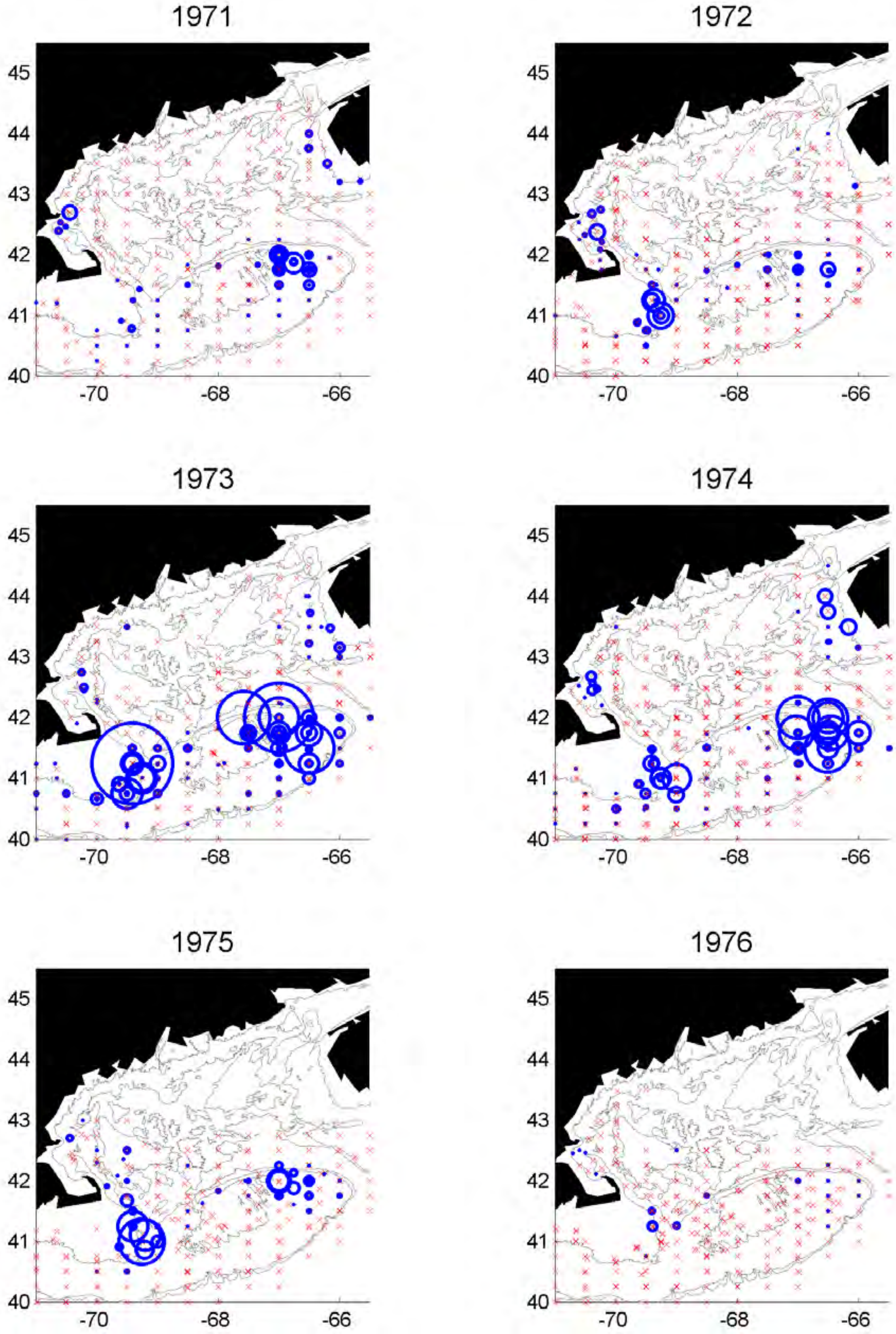


Figure 6 Annual distribution of small larvae (<9mm) during sampling in Oct-Dec.



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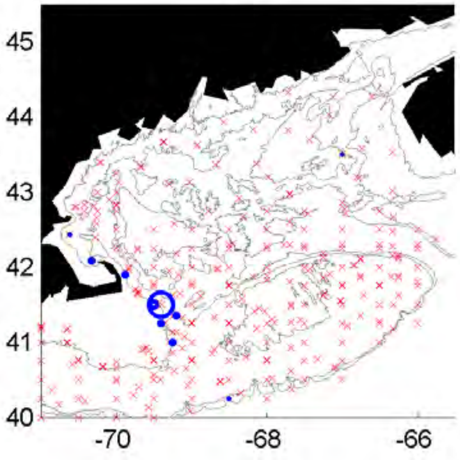

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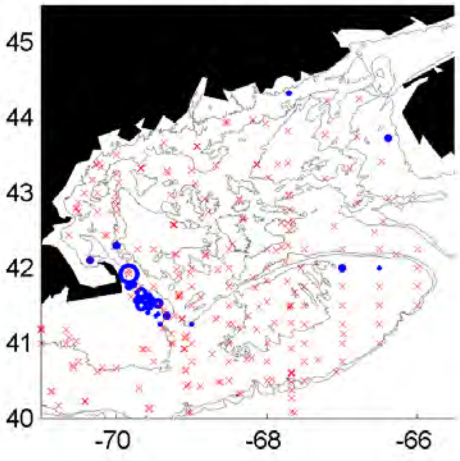

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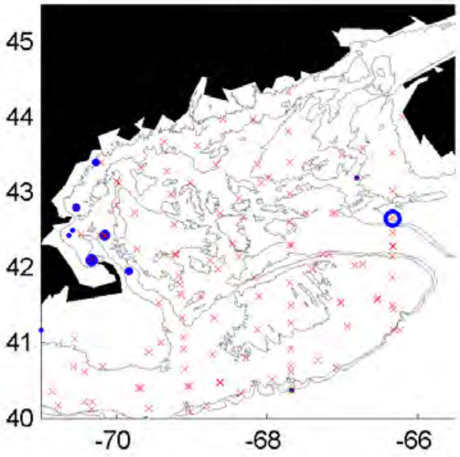

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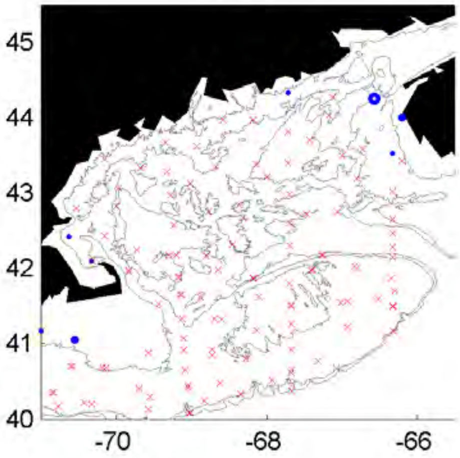

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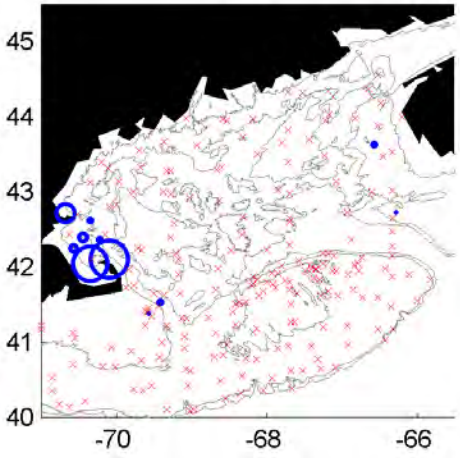

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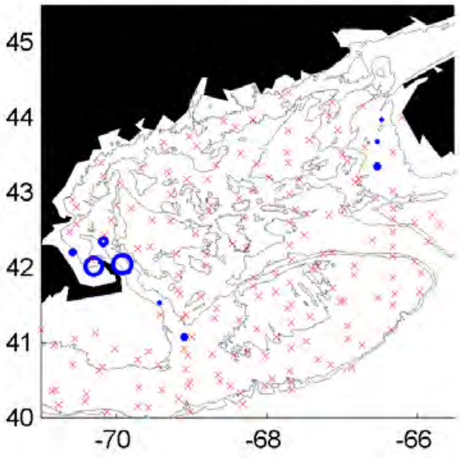

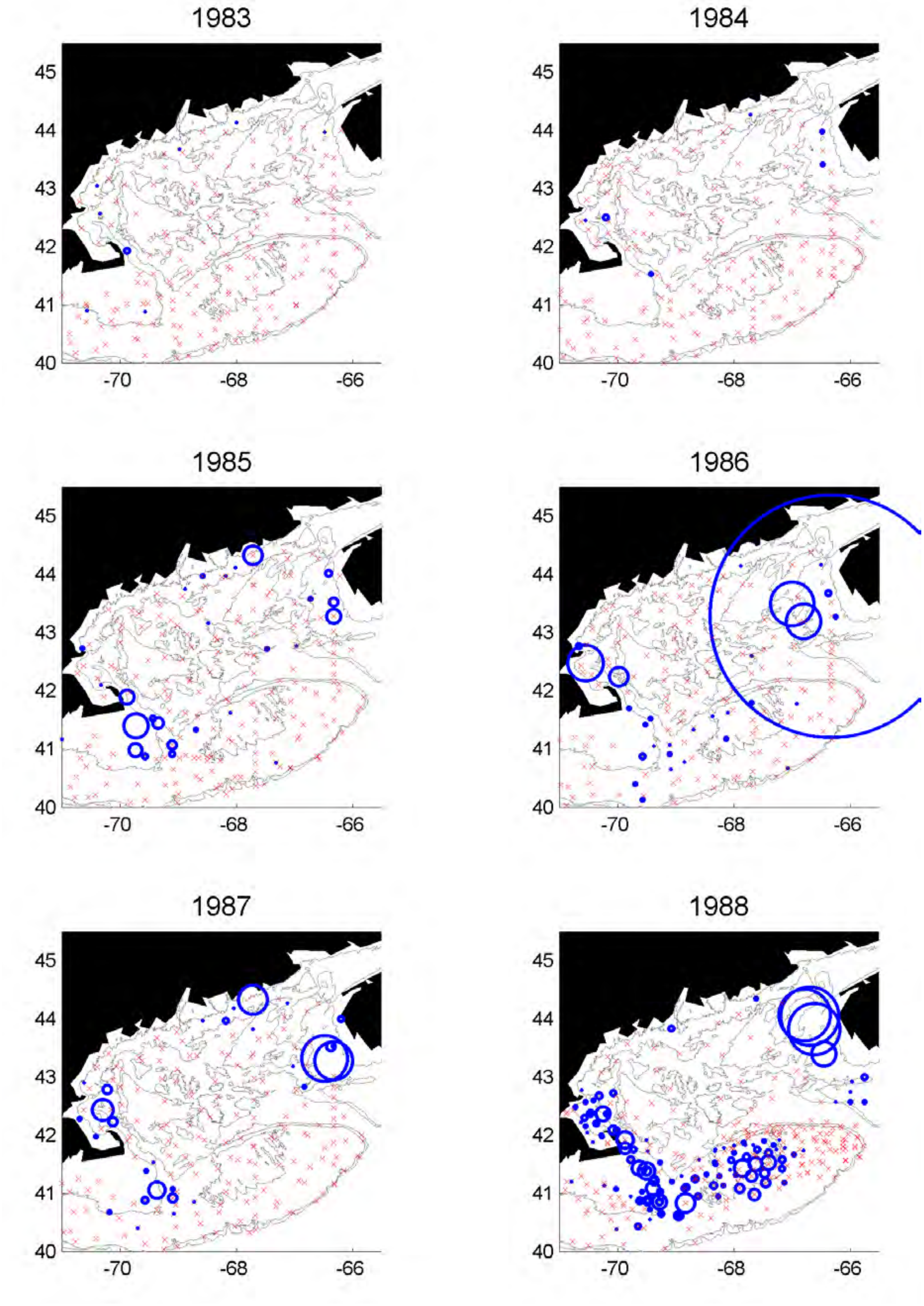
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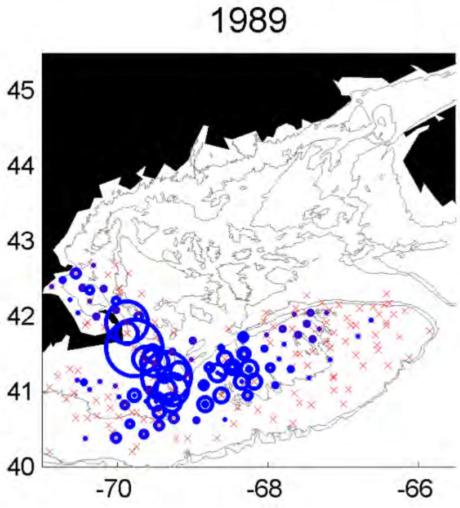
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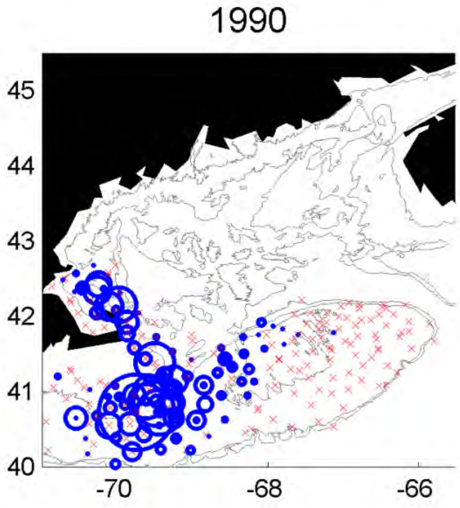
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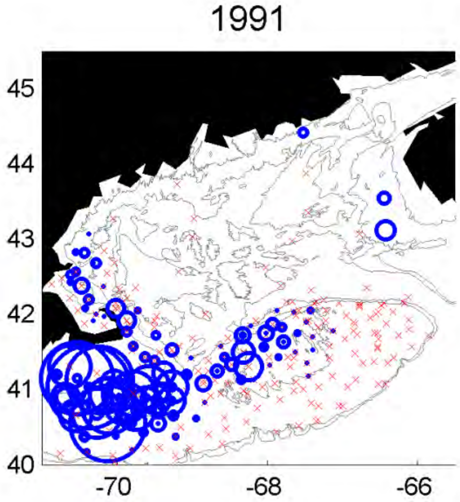
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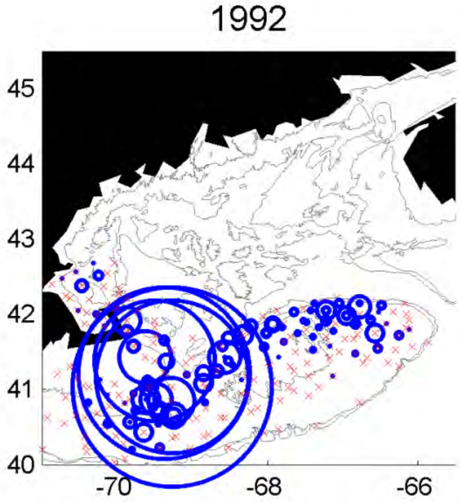
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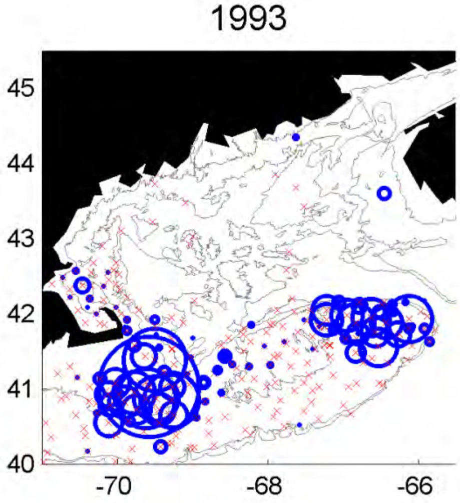
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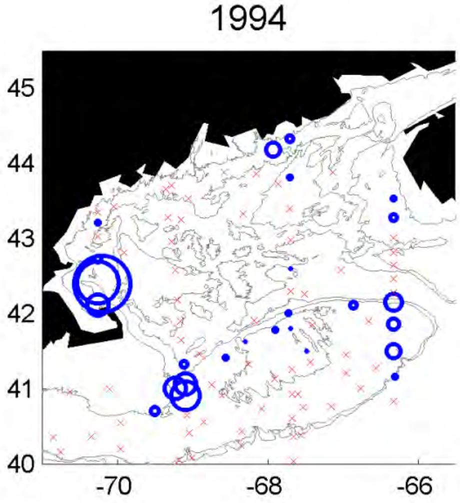
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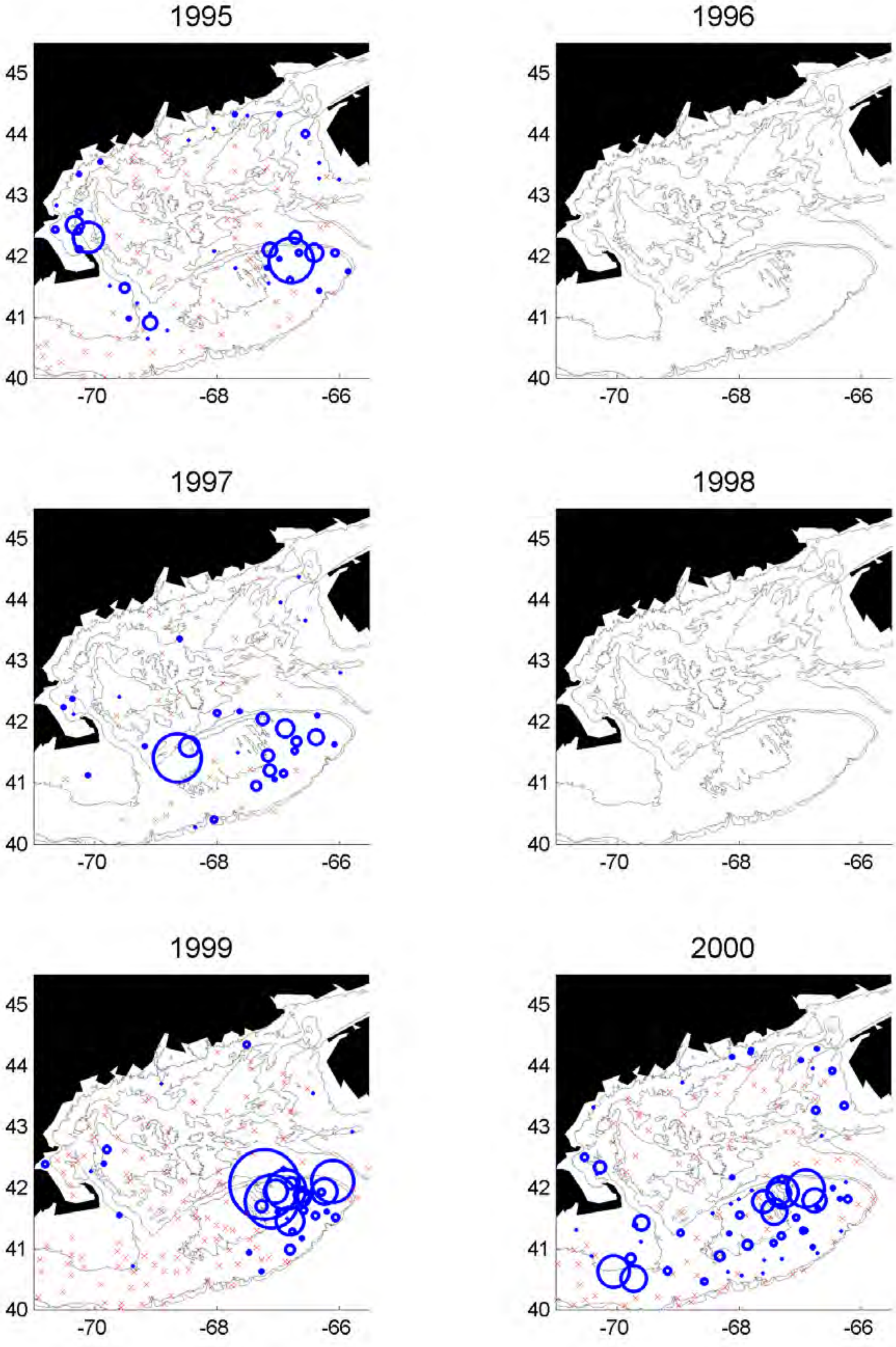
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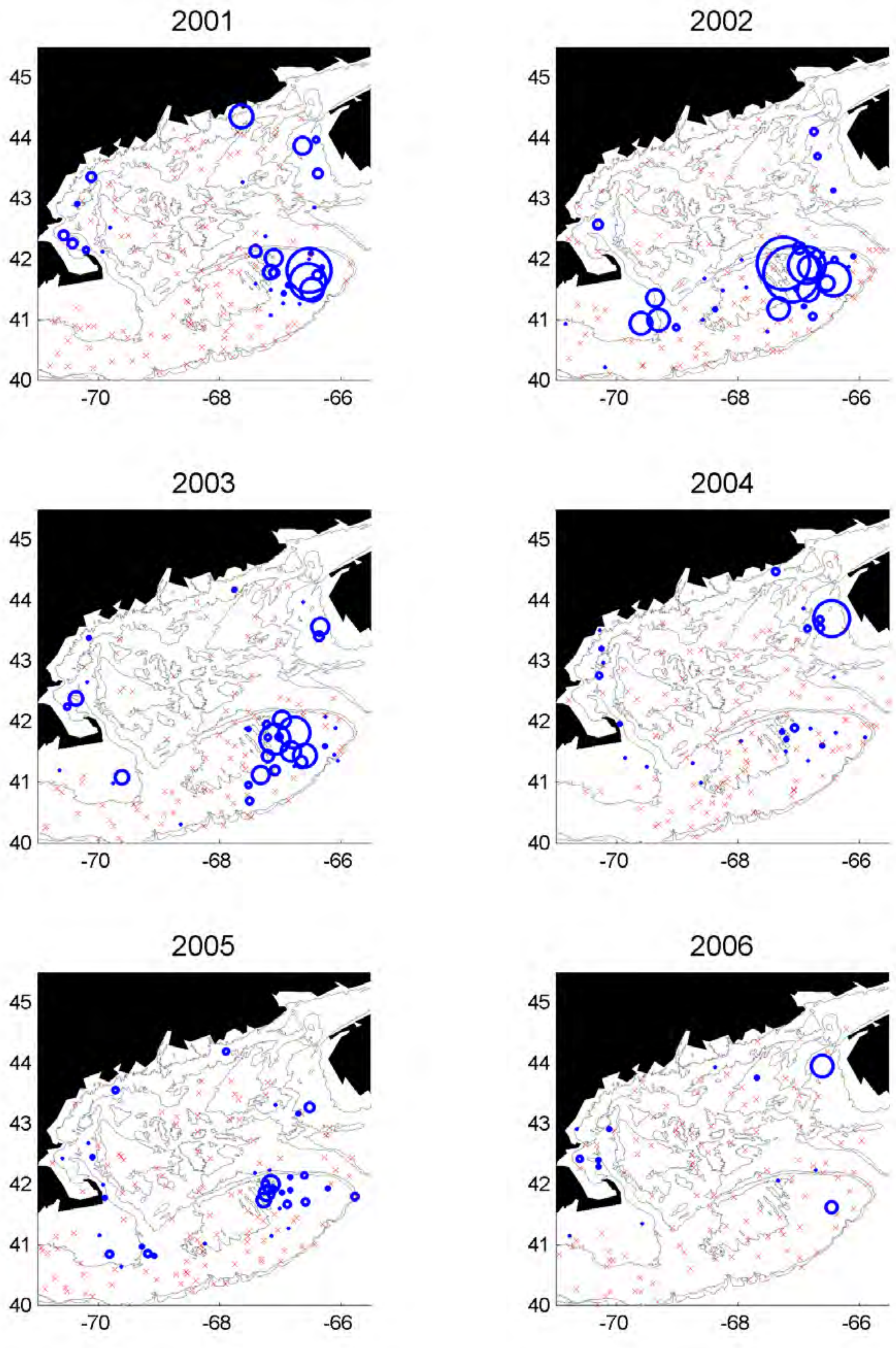
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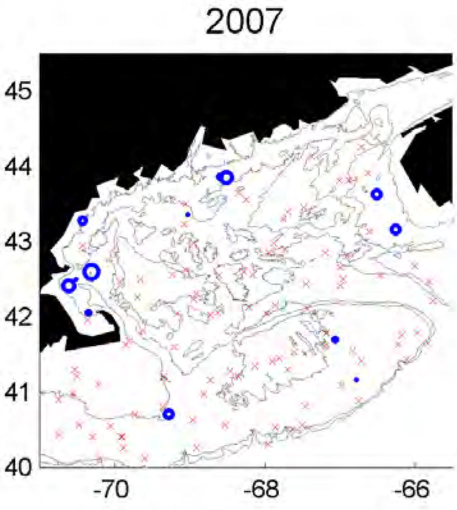

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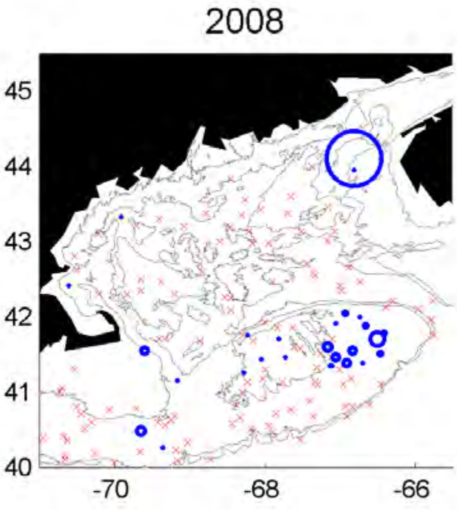

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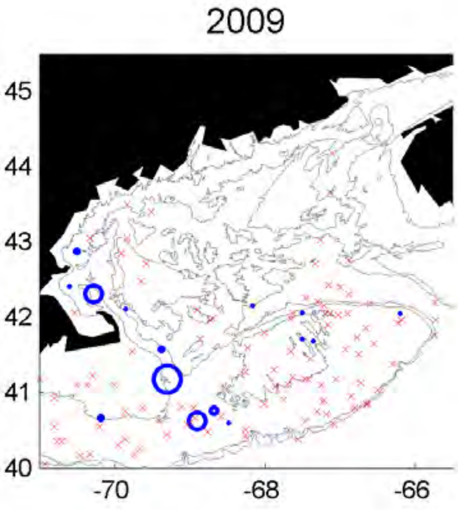

2009

An implementation of ASAP that allows modeling of environmental covariate effects on stock-recruit parameters and application to Atlantic herring

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Introduction

The objective of this working paper is to both present details of an extension of the age-structured assessment model ASAP (ASAP 2008) to allow estimation of covariate effects on stock-recruitment (ASAP$_\text{e}$) and investigate models for Atlantic herring that incorporate effects in the stock-recruit relationship.

Methods

Beverton-holt stock-recruit relationship

The Beverton-Holt stock-recruit relationship in ASAP models recruitment at the beginning of year y as a function spawning biomass (S) and unfished spawning biomass per recruit (ρ_0) at time of spawning in year $y-1$ and steepness (h) and, in the next version to be released, unfished recruitment (R_0) rather than unfished spawning biomass,

$$R_y = \frac{\alpha S_{y-1}}{\beta + S_{y-1}} = \frac{4hR_0S_{y-1}}{\rho_{0,y-1}R_0(1-h) + (5h-1)S_{y-1}}.$$

The unfished spawning biomass per recruit can change from year to year due to inter-annual changes in weight, maturity or natural mortality at age.

The stock-recruit relationship can be modified in various ways to account for effects of auxiliary variables. In this implimentation of ASAP, I allow four alternative modifications. First, transformations of unfished recruitment and steepness are allowed to be to be linear in the covariates,

$$R_0 = e^{\mathbf{X}_{R_0}\boldsymbol{\beta}_{R_0}}$$

$$h = 0.2 + \frac{0.8}{1+e^{-\mathbf{X}_h\boldsymbol{\beta}_h}}$$

This approach is analogous to the way link functions are used in generalized linear models and is helpful in avoiding parameter boundary issues. The other modifications now allowed in the stock recruit relationship involve scalar multipliers to either predicted recruitment (f) or spawning biomass (g). These scalars are modeled as functions of covariates identical to unfished recruitment,

$$f = e^{\mathbf{X}_f\boldsymbol{\beta}_f}$$

and

$$g = e^{\mathbf{X}_g\boldsymbol{\beta}_g}.$$

The resulting general Beverton-Holt stock recruit relationship is

$$R_y = f(\boldsymbol{\beta}_f)\frac{4h(\boldsymbol{\beta}_h)R_0(\boldsymbol{\beta}_{R_0})g(\boldsymbol{\beta}_g)S_{y-1}}{\rho_{0,y-1}R_0(\boldsymbol{\beta}_{R_0})(1-h(\boldsymbol{\beta}_h)) + (5h(\boldsymbol{\beta}_h)-1)g(\boldsymbol{\beta}_g)S_{y-1}}$$

where each of the parameters can now change annually depending on the annual values of the covariates.

The f multiplier is intended to model effects of covariates on the recruitment predicted from the stock-recruit relationship whereas the SSB multiplier g is intended to model covariates that change the effective spawning biomass in the stock-recruit relationship. Lastly, there is also an option to use g instead of spawning biomass in the "stock-recruit" relationship. In all cases, the data $\mathbf{X}$ is a design matrix where there is at least one column of 1 for each year of the model and potentially additional columns for covariates. It is probably not advisable to attempt to fit the stock-recruit relationship with covariates in each of the various ways possible simultaneously because there will likely be some confounding of effects. In the absence of user-specified covariates, the default will be to either fix parameters (for f and g) or estimate a single parameters at constant values (for h and R_0) to retain the traditional constant Beverton-holt relationship. Note that the model can be configured to allow effects on expected recruitment through the R_0 parameter without assuming a stock-recruit relationship by setting $h = 1$.

Years where a covariate is unavailable, is a common practical difficulty in fitting these models. This is dealt with by providing an indicator vector of when the covariate is available and allowing the recruitment to influence the objective function only in those years where the covariate is available. This can be useful in evaluating whether the covariate is helpful by comparing fits of a null model (no effect) or the model with the effect estimated where the same years influence the objective function in both cases. The objective function and its components can be inspected for differences between the models. When the objective function is much lower when the parameters are estimated this may suggest that there is an improvement to the overall fit of the model, but there is no real justifiable statistical method of comparison for this type of model.

Atlantic Herring Application

The covariates that I considered were the herring larval index from the data group working paper by Miller et al., the summer temperature series from the Hare data working group paper and the fall Georges Bank haddock biomass index from the most recent assessment (NEFSC 2012). The larval index and summer temperature were investigated based on the results of Hare's working paper and the haddock index was considered based on the results of (Richardson et al. 2011) which found haddock to be an important predator of herring eggs.

For all of these results I take the input file for one of the earlier ASAP models (run51) that Jon Deroba evaluated for Atlantic herring and augment it for use in the $\mathrm{ASAP_E}$ version. I fit several models that include the larval index as an explanatory variable affecting steepness, unfished recruitment, and the scalar multipliers f and g. I also fit models without a stock-recruit relationship (steepness = 1) and effects of larval index on f which effectively models the effect of the larval index on annual recruitment. I compared these models to the null models without the effect of larval index on any parameter, but including the same years of recruitments in the objective function (all models described in Table 1). For summer temperature, I fit models with effects on steepness or unfished recruitment and compared them to the null model without the effects, but including the same years of recruitments in the objective function (described in Table 2). For haddock abundance, I fit models with effects on the scalar multiplier g and compared them to the null model without the effects, but including the same years of recruitments in the objective function. The haddock index was included in this way to allow the abundance to change the effective spawning biomass in the stock-recruit relationship. Larval and haddock abundance indices were log-transformed and centered at their mean values for all analyses (described in Table 3).

Results and Discussion

None of the covariates in any of the parameterizations investigated here appeared to provide more than a negligible improvement to the overall fit for run51. For all of the models that included the larval index, the minimized objective function was between 0.67 units less and 2.54 units greater than that of the base (null) run51 model that did not include larval index effects, but only included recruitments in the likelihood for years where the larval index was available (see Table 1). For summer temperature, the largest decrease in the minimized objective funtion was 1.23 for model st_1 where it was assumed to affect steepness (Table 2). Lastly, including the fall Georges-Bank haddock biomass index effects on a modifier of spawning biomass in the stock-recruit relationship results in a minimized objective function 0.22 units lower than the null model.

Of the models fit, st_1 with summer temperature affecting steepness provided the largest reduction in the minimized objective function. Although this model would have an AIC value 0.46 units lower than the null model, there is no justification for using AIC with statistical catch at age models. The estimated coefficient (1.83) had a standard error estimate of 1.27 which would result in a non-significant difference from zero for the coefficient, but again, statistical tests of significance may not be appropriate.

References

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Richardson, D. E., Hare, J. A., Fogarty, M. J., and Link, J. S. 2011. The role of egg predation by haddock in the decline of an Atlantic herring population. Proceedings of the National Academy of Sciences USA **108**: 13606–13611.

Table 1. All models investigated for Atlantic herring that incorporated the larval index are based on the model configuration run51 provided by Jon Deroba.

Model Name	Description	Difference in # of parameters from li_0	Minimized Objective function
li_0	Larval index null model with no effects, but SRR for years of index is included in objective function	0	3372.73
li_1	Larval index effect on g through slope parameter, $log(g) = \beta_1 \log(LI)$	1	3372.46
li_2	Larval index in place of spawning biomass, $gS = LI$	0	3375.27
li_3	Larval index effect on f through slope parameter, $log(f) = \beta_1 \log(LI)$	1	3372.43
li_4	larval index effect on steepness, $\log((h - 0.2)/(1 - h)) = \beta_0 + \beta_1 \log(LI)$	1	3372.41
li_5	larval index effect on unfished recruitment, $log(R_0) = \beta_0 + \beta_1 \log(LI)$	1	3372.06
li_6	No effect of larval index or spawning biomass, steepness = 1	-1	3374.73
li_7	larval index effect on average recruitment, $log(R_y) = log(R_0) + \beta_1 \log(LI)$	0	3374.19

Table 2. All models investigated for Atlantic herring that incorporated summer temperature (from Jon Hare's working paper) are based on the model configuration run51 provided by Jon Deroba.

Model Name	Description	Difference in # of parameters from st_0	Minimized Objective function
st_0	Summer temperature null model with no effects, but SRR for years of index is included in objective function	0	3452.68
st_1	Summer temperature effect on steepness, $\log((h - 0.2)/(1 - h)) = \beta_0 + \beta_1 \log(ST)$	1	3451.45
st_2	Summer temperature effect on unfished recruitment, $log(R_0) = \beta_0 + \beta_1 \log(ST)$	1	3452.48

Table 3. All models investigated for Atlantic herring that incorporated haddock abundance indices (from NEFSC (2012)) are based on the model configuration run51 provided by Jon Deroba.

Model Name	Description	Difference in # of parameters from hi_0	Minimized Objective function
hi_0	Haddock index null model with no effects, but SRR for years of index is included in objective function	0	3635.17
hi_1	Haddock index effect on g through slope parameter, $log(g) = \beta_1 \log(HI)$	1	3634.95

Appendix 6

Comparison of Atlantic herring acoustic abundance estimates with catch at age model results

May 5, 2012

Acoustic estimates of herring on Georges Bank were conducted in the fall of 2006 by two systems, the NEFSC herring acoustic survey and the MIT OAWRS system. The details were previously described. The Georges Bank stock is one component of the exploited mixed stock complex evaluated in the catch at age model. The percent of fish present on Georges Bank during the acoustic surveys was estimated using the ratio of the NEFSC fall survey results of Georges Bank strata and the entire stock complex. Ratio of number and biomass of the survey expanded population estimates for herring 15 cm and greater were compared. The percentage by number and weight for 2006 as well as the 2005-2007 average is provided in Table 1. These percentages were used to expand the acoustic estimates to the total stock complex for comparison to the catch at age model results.

Various estimates from the acoustic surveys were expanded using both the 2006 ratio and the 3 year average. The candidates were the minimum and maximum values from the two OAWRS integreated methods, the minimum, average and maximum daily OAWRS estimates, and the NEFSC acoustic estimates. Acoustic estimates in number were multiplied by average weight of 0.099 kg in samples during the NEFSC survey. These were compared to the ASAP number and biomass estimates for fish age 2 and greater. Acoustic estimates were conducted in autumn, so for comparisons ASAP January 1 stock sizes for 2006 and 2007 are provided. Two ASAP models are provided; the base model with increased M and the model with only Lorenzen M.

In general the daily estimates from OAWRS under-estimated stock sizes compared to NMFS acoustic and model results. However, the integrated numbers and biomass from OAWRS were quite similar to the ASAP base run. The NEFSC was consistanly less than OAWRS and ASAP base runs, but similar to the ASAP Lorenzen model. The integrated OAWRS, NEFSC acoustic and ASAP models were all similar in scale for 2006.

Table 1. Expansion of acoustic abundance estimates for 2006 using 2006 ratio and 2005-2007 average ratio.

2006 proportion

GB= 14.5%

3 yr avg. = 27%

2006 expanded total number

	OAWRS integrated	% GB	Age 2+	millions
	method 1			
min	1,680,000,000	15%	11,586,206,897	11,586
max	1,770,000,000	15%	12,206,896,552	12,207
	method 2			
min	1,350,000,000	15%	9,310,344,828	9,310
max	1,450,000,000	15%	10,000,000,000	10,000

	OAWRS integrated	% GB	Age 2+	millions
	method 1			
min	1,680,000,000	27%	6,222,222,222	6,222
max	1,770,000,000	27%	6,555,555,556	6,556
	method 2			
min	1,350,000,000	27%	5,000,000,000	5,000
max	1,450,000,000	27%	5,370,370,370	5,370

OAWRS daily	% GB	Age 2+	millions
average			
154,000,000	15%	1,062,068,966	1,062
154,000,000	27%	570,370,370	570
minimum			
52,100,000	15%	359,310,345	359
52,100,000	27%	192,962,963	193
maximum			
325,200,000	15%	2,242,758,621	2,243
325,200,000	27%	1,204,444,444	1,204

	% GB	Age 2+	millions
NEFSC acoustic			
693,000,000	15%	4,779,310,345	4,779
693,000,000	27%	2,566,666,667	2,567

ASAP - total number		Age 2+	millions
Base Run	1-Jan-06	9,193,008,000	9,193
	1-Jan-07	11,988,033,000	11,988
Lorenzen M	1-Jan-06	5,642,008,000	5,642
	1-Jan-07	7,287,197,200	7,287

Table 1. Expansion of acoustic biomass estimates for 2006 using 2006 ratio and 2005-2007 average ratio.

2006 proportion
GB= 18.5%
3 yr avg. = 30.7%
avg wt -acoustic
0.099 kg

2006

	kg		expanded total kg	
	OAWRS integrated	% GB	Age 2+	mt
	method 1			
min	166,320,000	19%	899,027,027	899,027
max	175,230,000	19%	947,189,189	947,189
	method 2			
min	133,650,000	19%	722,432,432	722,432
max	143,550,000	19%	775,945,946	775,946

	OAWRS integrated	% GB	Age 2+	mt
	method 1			
min	166,320,000	31%	541,758,958	541,759
max	175,230,000	31%	570,781,759	570,782
	method 2			
min	133,650,000	31%	435,342,020	435,342
max	143,550,000	31%	467,589,577	467,590

OAWRS daily	% GB	Age 2+	mt
average			
15,246,000	19%	82,410,811	82,411
15,246,000	31%	49,661,238	49,661
minimum			
5,157,900	19%	27,880,541	27,881
5,157,900	31%	16,800,977	16,801
maximum			
32,194,800	19%	174,025,946	174,026
32,194,800	31%	104,869,055	104,869

NEFSC acoustic	% GB	Age 2+	mt
68,510,000	19%	370,324,324	370,324
68,510,000	31%	223,159,609	223,160

ASAP - biomass		Age 2+	mt
Base Run	1-Jan-06	789,864,729	789,865
	1-Jan-07	1,090,800,651	1,090,801
Lorenzen M	1-Jan-06	510,558,758	510,559
	1-Jan-07	692,982,794	692,983

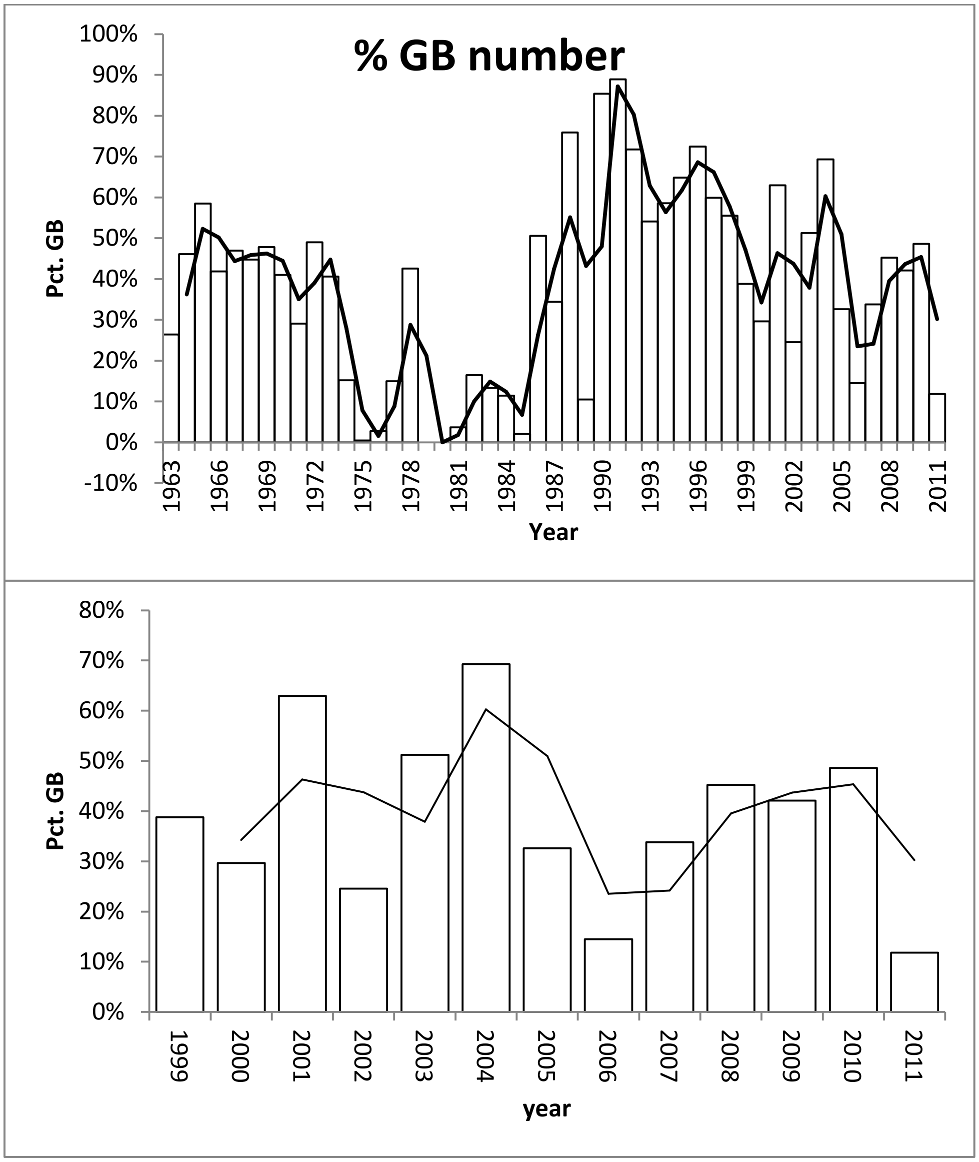


Figure 1. Proportion of herring abundance (>= 15 cm) on Georges Bank from NEFSC bottom trawl survey.

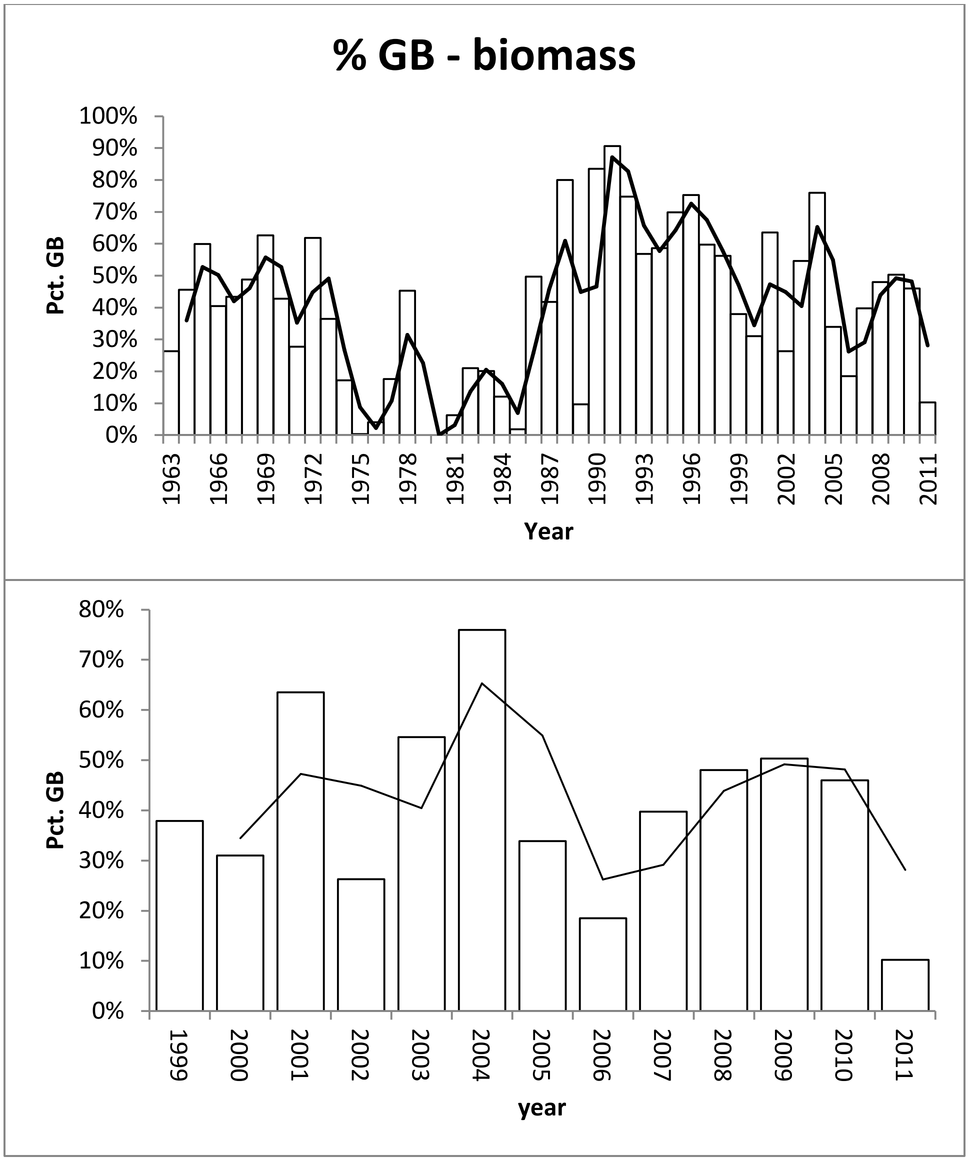


Figure 1. Proportion of herring biomass (>= 15 cm) on Georges Bank from NEFSC bottom trawl survey.

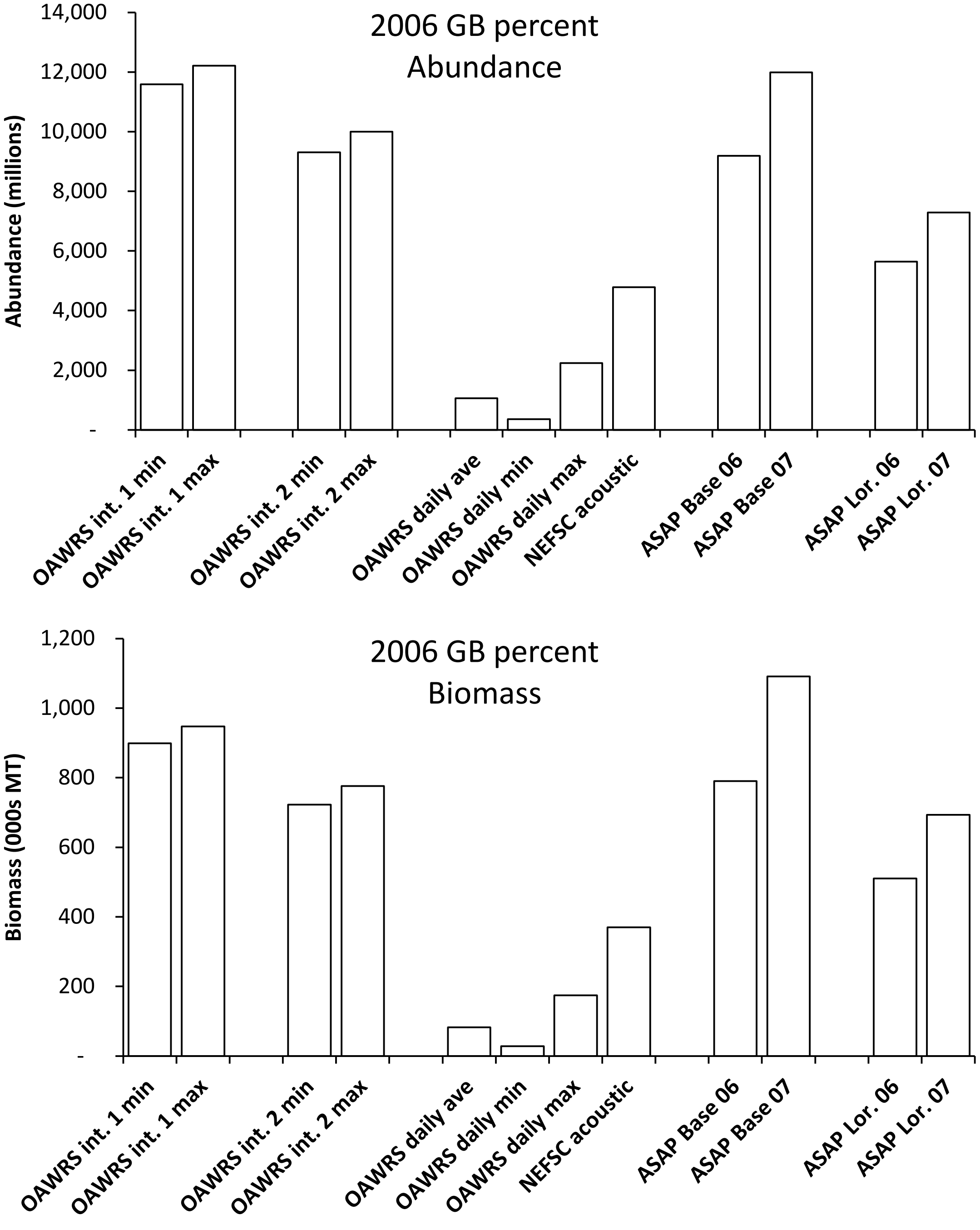
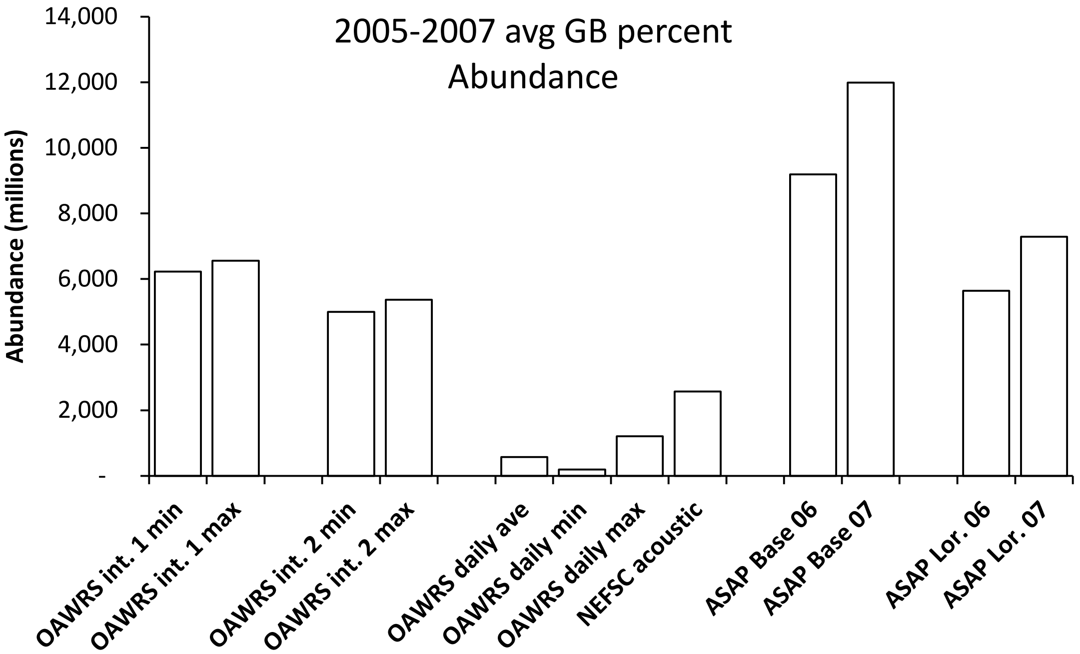


Figure 3. Comparison of abundance and biomass among methods based on 2006 survey ratio.



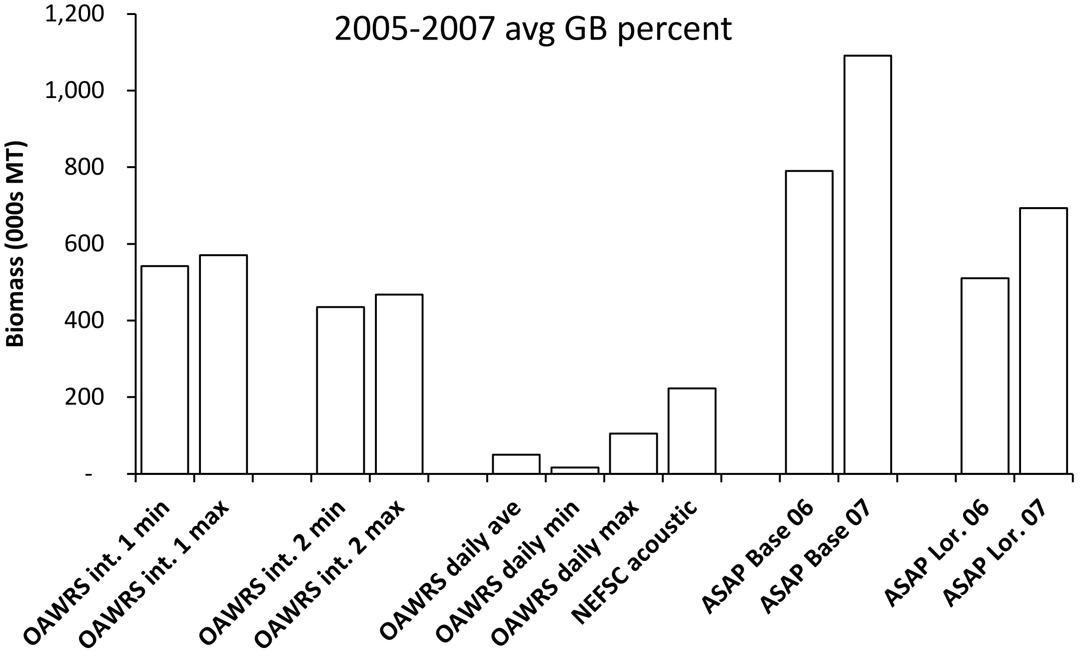


Figure 4. Comparison of abundance and biomass among methods based on 2005-2007 survey ratio.

Appendix 7

A summary of analysis done during the SAW/SARC 54 meeting

Jonathan J. Deroba

Throughout the course of the SAW/SARC meeting several analyses were undertaken to evaluate the uncertainty and robustness of the assessment model to various parameters. These analyses are summarized in this appendix.

Evaluating the 50% increase in natural mortality during 1996-2011

The 50% increase in natural mortality (M) beginning in 1996 in the base model was evaluated using alternative increases of 0%, 30%, 40%, 60%, and 70%. Furthermore, the sensitivity of the model to rescaling the Lorenzen M rates to the average value of 0.3 produced by the Hoenig method was tested by reducing the average M among ages in each year to 0.2 (Hoenig 1983; Lorenzen 1996). The value of 0.3 was produced by using the maximum age herring observed in commercial or survey catches (age 14). Age data, however, was only collected after several years of significant exploitation. So, the maximum age may actually be greater than 14. A maximum age greater than 14 would generate a lower M using the Hoenig method. Consequently, only a reduction in the average M was explored. The value of 0.2 was arbitrary, but is a conventional value used for stock assessment and was sufficient to address the sensitivity analysis. The 1996-2011 M values in the M=0.2 sensitivity analysis were increased by 90%, which produced a Mohn's rho similar to that of the base ASAP run.

Each of the sensitivity runs were compared to the base model using fit to data, degree of retrospective pattern, and similarity between levels of implied consumption and estimates of consumption. Fit to data was compared using the negative log likelihood values for fits to survey trends and age composition. The degree of retrospective pattern was evaluated using the Mohn's rho estimated for spawning stock biomass using the average of a 7-year peel. The similarity between implied levels of consumption and estimates of consumption was compared using the ratio of the geometric mean of the implied consumption values to the geometric mean of the consumption estimates. These ratios were calculated separately for the periods before and after 1996 when the 50% increase in M was used in the base model (i.e., 1968-1995 and 1996-2010). Because the estimates of consumption do not fully account for all sources of natural mortality, ratios greater than 1.0 were preferred, which would suggest that the implied levels of consumption are slightly greater than the estimates of consumption.

Based on the comparisons to the sensitivity runs, the base model 50% increase in M during 1996-2011 seemed appropriate. For all data sources, the base assessment model provided the best fit or within two likelihood values of the best fit (Table 1). Only 60% and 70% increases in M during 1996-2011 produced smaller Mohn's rho values than the base model (Table 1). These two runs, however, produced implied levels of consumption during 1996-2011 that were higher than estimates of consumption, and less consistent than the implied levels of consumption from the base model (Table 1).

Projections

Several sensitivity runs of projections through 2015 were conducted.

1) The results of projections from the base run were compared to the reference points from an assessment run with no increase in M during 1996-2011 (i.e., original Lorenzen values; 0% increase). This comparison was intended to evaluate the sensitivity of the probability of overfishing/overfished to the reference points produced using different assumptions about M during 1996-2011. For all the harvest scenarios projected, the probability of overfishing and for the stock to become overfished equaled zero (Table 2). These results are similar to the projections done exclusively with the base model, suggesting that stock status and the probability of overfishing/overfished are robust to the assumptions about M during 1996-2011 and the subsequent reference points.

2) Projections were conducted at F_{MSY} for the sensitivity assessment run described above with the average M in each year equal to 0.2 and a 90% increase in the underlying average M values during 1996-2011. This sensitivity was intended to evaluate the robustness of the probability of overfishing/overfished to an alternative assumption about M. Numbers-at-age in 2012 were drawn from 1000 vectors of numbers-at-age produced from MCMC simulations of this assessment sensitivity run. The projection results were compared to reference points estimated for this sensitivity run. The probability for the stock to become overfished equaled zero, suggesting robustness to alternative assumptions about M (Table 3 and 4).

3) Projections were conducted at F_{MSY} with the base assessment model reconfigured so that steepness in the stock recruitment model was fixed at 0.35 or 0.85, which approximate the 95% probability intervals of this parameter in the base model. This sensitivity was intended to test the robustness of the probability of overfishing/overfished to a range of steepness values, which was an uncertain parameter in the base model. Numbers-at-age in 2012 were drawn from 1000 vectors of numbers-at-age produced from MCMC simulations of each assessment sensitivity run. The projection results were compared to reference points estimated for each sensitivity run. The probability for the stock to become overfished equaled zero for both values of steepness, suggesting robustness to alternative assumptions about steepness (Table 3 and 4).

4) The robust nature of the assessment model results in the sensitivity runs for projections described above may be driven by the 2009 age 1 cohort, which was estimated to be the largest recruitment on record. To test the sensitivity of the probability of overfishing/overfished to the presence of this cohort, projections using the base assessment model through 2015 at F_{MSY} were conducted with the size of that cohort cut in half, which made the 2009 age 1 cohort approximately equal to previous high recruitments. The probability of the stock becoming overfished remained at zero, suggesting robustness to the size of the 2009 age 1 cohort (Table 3 and 4). Furthermore, an assessment model sensitivity run was conducted with the variation of the annual recruitments from the underlying Beverton-Holt stock recruitment model more restricted than in the base model. In the base model, the coefficient of variation (CV) that partially defined how much the recruitment deviations could vary from the underlying Beverton-Holt relationship equaled 1, but in the sensitivity run the CV equaled 0.67. The value of 0.67

was the CV of the recruitment deviations estimated in the base assessment model. This sensitivity suggested that even with these additional restrictions on recruitment variation, the age 1 2009 cohort would still be the largest on record.

Assessment model sensitivities

The base assessment model was tested for sensitivity to the way in which age composition data were weighted in model fitting. More specifically, the input effective sample sizes (ESS) were iteratively reweighted as described in Francis (2011). The input ESS used in the base assessment model for the mobile gear fishery, fixed gear fishery, spring survey during 1985-2011, and fall survey during 1985-2011 were multiplied by 0.37, 0.44, 0.63, and 0.28, respectively. The base assessment model and the results from the sensitivity run with the ESS values reweighted produced generally similar results (Figure 1).

The base assessment model was tested for robustness to age variation in the input M values. An assessment model was fit without the age varying M values that were used in the base model. More specifically, in this sensitivity run the M for all ages during 1965-1995 equaled 0.3 and during 1996-2011 equaled 0.45. Fits to the data were similar between the base model and the sensitivity run and the two models produced generally similar results (Table 5; Figure 2). So, although age variation in M may be justified using biological or theoretical arguments (Chen and Watanbe 1989; Lorenzen 1996; Chu et al., 2008), such additional realism does not necessarily lead to pragmatic differences in model results and may not be parsimonious. Age variation in M can, however, improve fits to data relative to using a constant M.

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Figure 1.—Time series estimates of spawning stock biomass, fishing mortality, and recruitment for the base model and a model with effective sample sizes adjusted as in Francis (2011).

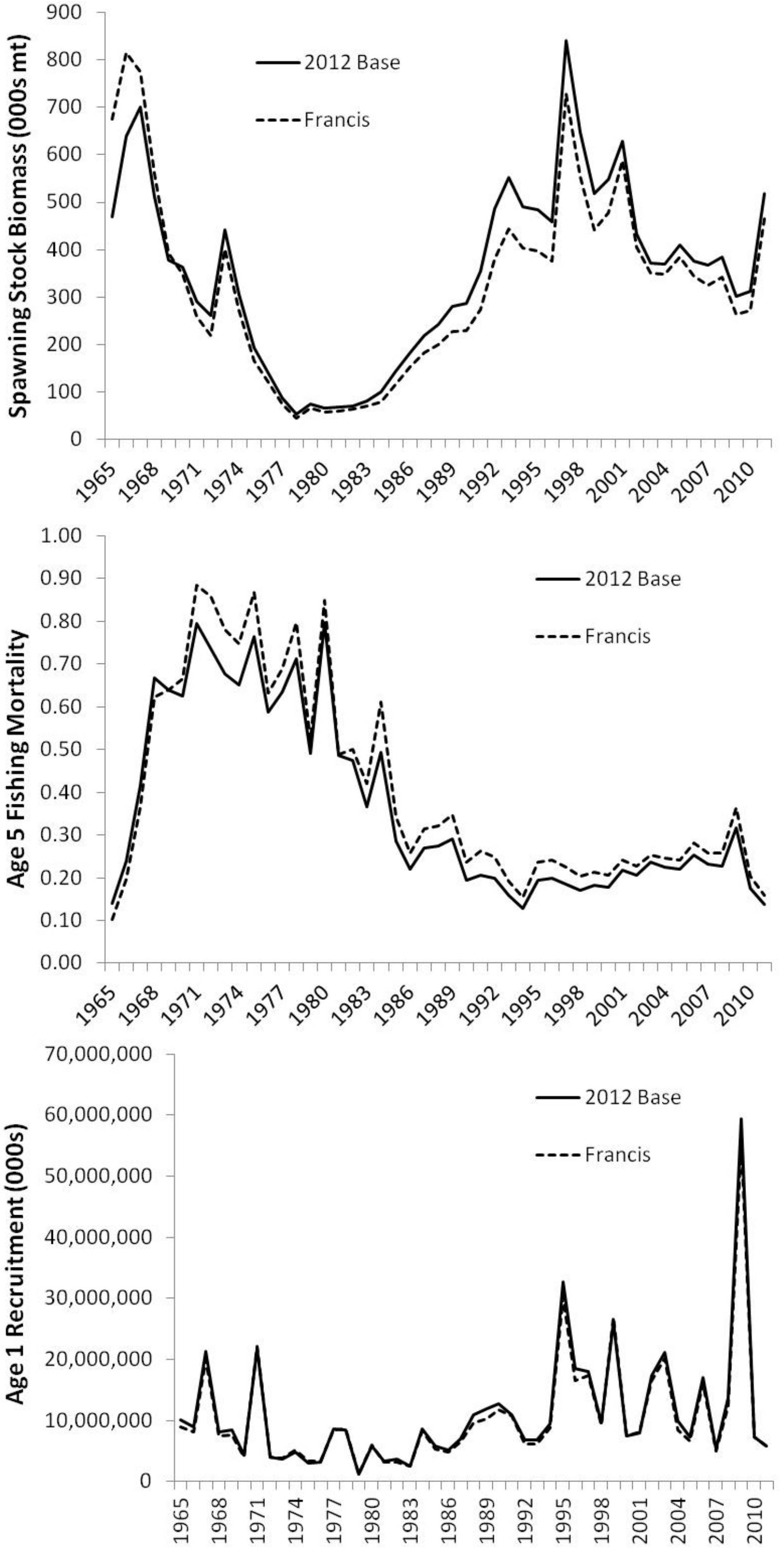

Figure 2. Time series estimates of spawning stock biomass, fishing mortality, and recruitment for the base model and a model without age variation in natural mortality.

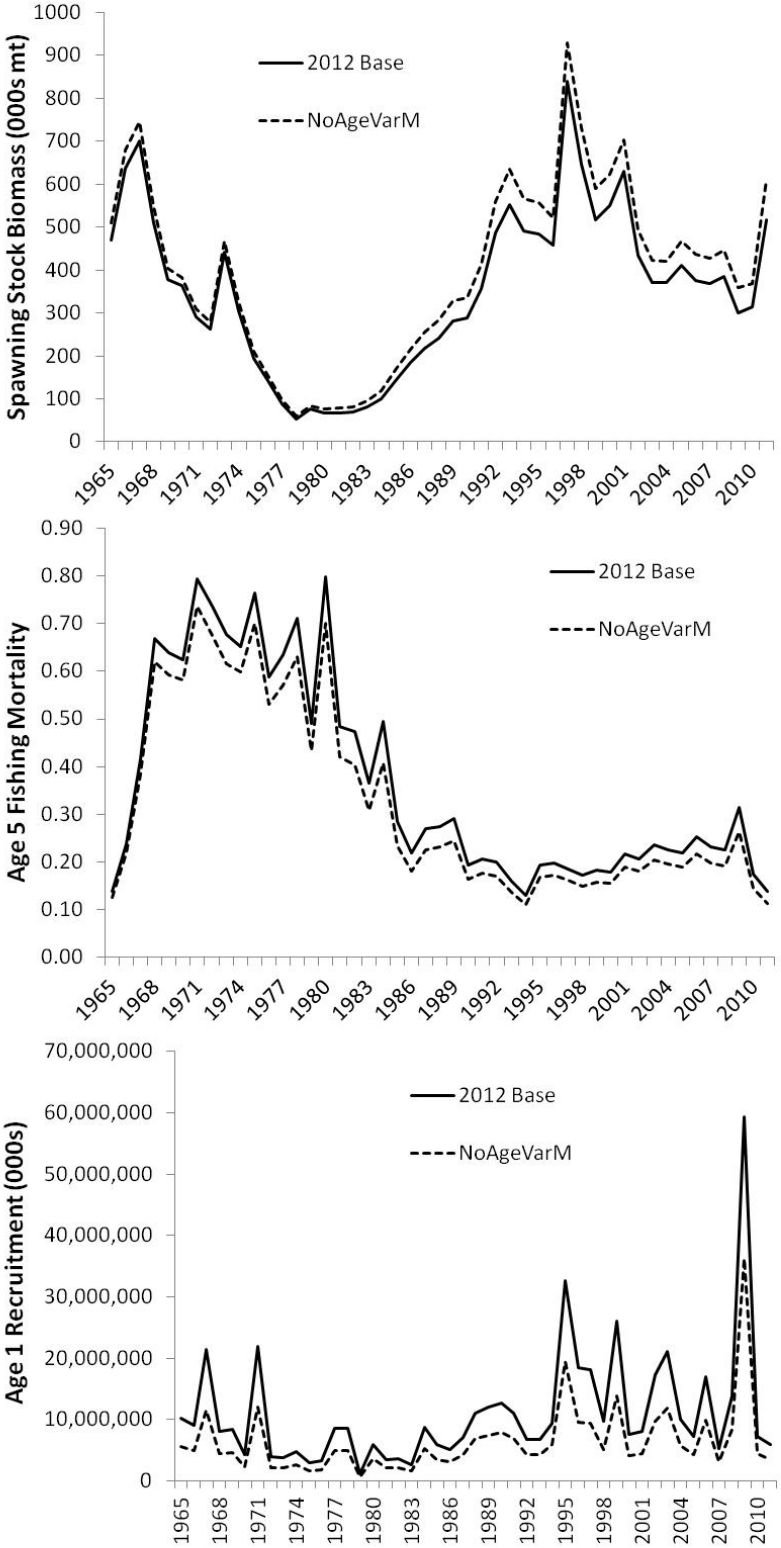

Table 1.—Negative log likelihood values for various data sources, the Mohn's rho for spawning stock biomass (SSB) estimated as the average of a 7-year peel, and the ratio of the geometric means for levels of implied consumption from each run (Imp.) to estimated consumption (Est.) for two time periods, reported for the base assessment model and various sensitivity runs. The Total row is the sum of all the likelihoods in the table for each run.

Comparison Metric	**Percent Increase in M during 96-11**						
	0% (Lorenzen)	**30%**	**40%**	**50% (base)**	**60%**	**70%**	**0.2/90%**
Spring 68-84	41	41	41	41	41	41	41
Fall 65-84	17	16	16	16	17	20	17
Spring 85-11	117	114	112	111	111	109	111
Fall 85-11	115	115	114	114	114	114	114
Shrimp	111	109	109	109	108	108	108
Catch_Age_Comps	816	815	815	815	815	813	816
Survey_Age_Comps	470	487	471	472	473	473	472
Total	1688	1696	1679	1678	1678	1678	1679
SSB Mohn's Rho	0.85	0.20	0.25	0.13	0.04	-0.08	0.14
Geo Mean Ratio 96-11 (Imp./Est.)	0.54	1.06	1.15	1.40	1.67	2.15	0.83
Geo Mean Ratio 68-95 (Imp./Est.)	0.77	0.87	0.83	0.85	0.87	0.91	0.42

Table 2.—Probabilities of overfishing/overfished estimated by comparing results of projections from the base run to the reference points from a run without an increase in natural mortality during 1996-2011 (original Lorenzen values) using various harvest scenarios.

Lorenzen Ref Points			
Fmsy = 0.41	SSBmsy = 236,428 mt		MSY = 121,580
2012 catch = quota	**2013**	**2014**	**2015**
	F_{msy}		
F	0.267	0.267	0.267
SSB	496,064 mt	368,501 mt	308,949 mt
80% CI	362,965 - 688,585 mt	275,695 - 517-815 mt	237,755 - 411,808 mt
Prob < SSBmsy/2	0	0	0
catch	168,775 mt	126,589 mt	104,430 mt
80% CI	124,868 - 230,764 mt	95,835 - 171,145 mt	79,505 - 139,925 mt
	$F_{75\%\ msy}$		
F	0.2	0.2	0.2
SSB	523,243 mt	409,309 mt	354,559 mt
80% CI	382,573 - 723,975 mt	306,011 - 574,128 mt	272,751 - 473,021 mt
Prob < SSBmsy/2	0	0	0
catch	130,025 mt	102,470 mt	87,574 mt
80% CI	96,216 - 177,894 mt	77,476 - 138,665 mt	66,739 - 117,318 mt
	$F_{status\ quo}$		
F	0.14	0.14	0.14
SSB	548,788 mt	450,496 mt	402,551 mt
80% CI	401,571 - 760,028 mt	336,594 - 631,502 mt	309,334 - 537,414 mt
Prob < SSBmsy/2	0	0	0
catch	93,159 mt	76,823 mt	67,912 mt
80% CI	68,954 - 127,518 mt	58,022 - 104,055 mt	51,752 - 91,001 mt
	MSY		
F	0.08	0.09	0.1
80% CI	0.06 - 0.11	0.07 - 0.12	0.07 - 0.14
Prob > Fmsy	0	0	0
SSB	576,092 mt	492,162 mt	448,725 mt
80% CI	413,046 - 813,298 mt	351,530 - 716,931 mt	321,209 - 633,132 mt
Prob < SSBmsy/2	0	0	0
catch	53,000 mt	53,000 mt	53,000 mt
	Status quo catch		
F	0.13	0.16	0.19
80% CI	0.1 - 0.18	0.11 - 0.23	0.13 - 0.27
Prob > Fmsy	0	0	0
SSB	551,686 mt	446,496 mt	385,995 mt
80% CI	388,989 - 789,568 mt	306,349 - 669,721 mt	259,178 - 569,560 mt
Prob < SSBmsy/2	0	0	0
2012 quota	87,683 mt	87,683 mt	87,683 mt

Table 3. Probabilities of overfishing/overfished at the fishing mortality rate associated with maximum sustainable yield for the base model and various sensitivity runs.

	Base Model		
	2013	**2014**	**2015**
F	0.267	0.267	0.267
SSB	496,064 mt	368,501 mt	308,949 mt
80% CI	362,965 - 688,585 mt	275,695 - 517-815 mt	237,755 - 411,808 mt
Prob < SSBmsy/2	0	0	0
catch	168,775 mt	126,589 mt	104,430 mt
80% CI	124,868 - 230,764 mt	95,835 - 171,145 mt	79,505 - 139,925 mt
	Average M = 0.2 with 90% Increase 1996-2011		
F	0.29	0.29	0.29
SSB	396,643 mt	301,811 mt	254,490 mt
80% CI	283,749 - 545,038 mt	219,886 - 411,460 mt	193,777 - 332,169 mt
Prob < SSBmsy/2	0	0	0
catch	142,085 mt	108,898 mt	90,773 mt
80% CI	102,392 - 192,607 mt	80,695 - 144,607 mt	68,361 - 119,094 mt
	Steepness = 0.35		
F	0.12	0.12	0.12
SSB	605,335 mt	513,679 mt	482,295 mt
80% CI	428,135 - 824,517 mt	369,059 - 707,783 mt	352,699 - 650,573 mt
Prob < SSBmsy/2	0	0	0
catch	90,530 mt	77,524 mt	70,985 mt
80% CI	64,223 - 122,488 mt	56,138 - 103,752 mt	51,441 - 96,428 mt
	Steepness = 0.85		
F	0.7	0.7	0.7
SSB	339,734 mt	179,453 mt	119,242 mt
80% CI	244,841 - 458,585 mt	135,762 - 239,971 mt	92,918 - 161,063 mt
Prob < SSBmsy/2	0	0	0
catch	356,988 mt	192,046 mt	127,255 mt
80% CI	262,388 - 479,137 mt	147,502 - 250,723 mt	96,720 - 174,479 mt
	2009 Age 1 Cohort Reduced by Half		
F	0.267	0.267	0.267
SSB	325,668 mt	268,161 mt	246,368 mt
80% CI	232,900 - 461,216 mt	197,151 - 381,017 mt	187,995 - 332,871 mt
Prob < SSBmsy/2	0	0	0
catch	110,377 mt	92,273 mt	81,708 mt
80% CI	81,128 - 157,019 mt	69,290 - 126,034 mt	61,183 - 111,824 mt

Table 4.Maximum sustainable yield reference points for the base model and various sensitivity runs.

	Base	0.2/90%	Steepness=0.35	Steepness=0.85	2009 Age 1 Halved
F at MSY	0.27	0.29	0.12	0.7	0.27
SSB at MSY	157,000	140,803	277,371	73,305	157,000
MSY	53,000	50730	40051	78,104	53,000

Table 5.— Negative log likelihood values for various data sources from the base assessment model and a model without age variation in natural mortality.

	Base	No Age M
Catch Total	884	884
Index Fit Total	391	392
Catch Age Comps	815	813
Survey Age Comps	472	473

B. SOUTHERN NEW ENGLAND MID-ATLANTIC YELLOWTAIL FLOUNDER (*Limanda ferruginea*) STOCK ASSESSMENT FOR 2012, UPDATED THROUGH 2011

SAW 54 Terms of Reference

B. Southern New England Mid-Atlantic Yellowtail Flounder (*Limanda ferruginea*)

1. Estimate landings and discards by gear type and where possible by fleet, from all sources. Describe the spatial distribution of fishing effort. Characterize uncertainty in these sources of data.

2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Investigate the utility of commercial or recreational LPUE as a measure of relative abundance, and characterize the uncertainty and any bias in these sources of data.

3. Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas.

4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-5), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

5. Investigate causes of annual recruitment variability, particularly the effect of temperature. If possible, integrate the results into the stock assessment (TOR-4).

6. State the existing stock status definitions for “overfished” and “overfishing”. Then update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY 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 scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.

7. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model, should one be developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).
    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 and their estimates (from TOR-6).

8. Develop approaches and apply them to conduct stock projections and 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 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, and recruitment as a function of stock size).
    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 research recommendations listed in most recent peer reviewed assessment and review panel reports. Identify new research recommendations.

Southern Demersal Working Group (SDWG) Meetings

The Southern New England Mid-Atlantic assessment was prepared by the Southern Demersal Working Group (SWDG). The working group held three different meetings over a three month period with each meeting dates and location provided below. Working group participation varied by meeting but did not influence the quality of input and attention to the assessment. A complete summary of the meeting notes including list of participants is presented in Appendices 1-3.

- SDWG Southern New England Mid-Atlantic Yellowtail Flounder Industry Meeting (SDIM)
    - February 27, 2012
    - University of Massachusetts School of Marine Science and Technology (SMAST), Fairhaven, MA

- SDWG Southern New England Mid-Atlantic Yellowtail Flounder Data Working Group Meeting (SDDWG)
    - April 2-4, 2012
    - Northeast Fisheries Science Center (NEFSC), Woods Hole, MA

- SDWG Southern New England Mid-Atlantic Yellowtail Flounder Models and Biological Reference Points Working Group Meeting (SDMBRPWG)
    - April 30 – May 4, 2012
    - Northeast Fisheries Science Center, Woods Hole, MA

Executive Summary

The Southern New England-Mid Atlantic yellowtail flounder stock was last assessed at the Groundfish Assessment Meeting III (GARM III) in 2008 (NEFSC, 2008). That assessment was based on a virtual population analyses (VPA) with a 6+ age group formulation. The GARM III assessment indicated that fishing mortality declined continuously from 2005, and in 2007 it was the lowest in the time series. Spawning Stock Biomass (SSB) from the GARM III assessment showed modest increases relative to the previous years and was expected to show continued growth with the support of a potential incoming 2005 strong year class. Biological Reference points were estimated from spawning stock biomass per recruit (SSB/R) and yield per recruit (YPR) analyses, by sampling the recruitment time series from a two stanza cumulative distribution function (CDF) with recruitment values associated with SSB above and below 5,000 mt (NEFSC, 2008). The value for $F_{40\%}$ *(i.e. proxy for* F_{MSY}*) was 0.25, and corresponding* SSB_{MSY} *and MSY estimates were 27,400 mt and 6,100 mt respectively. The GARM III VPA estimate of* SSB_{2007} *(3508 mt) was 13% of* SSB_{MSY} *and the estimate of* F_{2007} *(0.41) was more than one and a half times* F_{MSY}*, indicating that the stock was overfished and overfishing was occurring.*

The current benchmark assessment uses a new Statistical Catch at Age model, Age Structured Assessment Program (ASAP; Legault and Restrepo 1999), revises the 1994-2011 fishery catch estimates to reflect changes in the LW relationship, and revises the spatial stratification used for estimating discards. The discard mortality assumption was also revised in this assessment based on Reflex Action Mortality Predictor (RAMP) study of yellowtail flounder (Barkely and Cadrin 2012). The ASAP model maintained the age-6+ formulation by incorporating the entire time series of catch data, and it is tuned to the Northeast Fisheries Science Center (NEFSC) winter, spring and fall survey swept area biomass indices.

Natural mortality in previous assessments was based on the traditional longevity approach as described in Hoenig (1983) and was assumed to equal 0.2 for all ages and years. For this assessment, natural mortality was based on the Lorenzen method, with alternative life history approaches (i.e. gonadosomatic index approach, average maximum size in the population approach and Hoenig's method) providing the scale of natural mortality and the Lorenzen method defining how natural mortality declined with age (Lorenzen 1986, Gunderson and Dygert 1988, Gunderson 1997, McElroy et al. 2012). Recognizing the potential uncertainties associated with the Lorenzen approach (i.e. non-species specific parameters and the anomalous shift in age-1 weights at age during the mid-1990's), a time series average of age-specific yellow tail flounder natural mortality values, 0.3, was used in this assessment.

Biological reference points for this assessment were re-evaluated based on $F_{40\%}$ *as a proxy for* F_{MSY}*, and a corresponding* SSB_{MSY} *was derived from sampling age-1 recruitment from an empirical CDF. In this assessment, the overfishing determination is relatively certain. In contrast, the overfished determination is uncertain due to unresolved questions about the causes of temporal changes in stock productivity. Some analyses attempted to address this by examining oceanographic processes, specifically a cold pool index (see below). There was no*

clear evidence to explain the sudden drop in recruitment since the 1990's, although there is some evidence of broader ecosystem changes, which may be related to reduced Southern New England Mid-Atlantic yellowtail flounder productivity since the 1990's (i.e., in recent years). Due to uncertainty about the appropriate overfished biological reference point (i.e. reference point associated with biomass), two recruitment scenarios were explored, with sampling from the empirical CDF, to account for the temporal decline in recruitment. The two scenarios lead to very different conclusions about the biomass stock status.

The first scenario uses age-1 recruitment from a "recent" time period, 1990-2010, recognizing a potential reduction in stock productivity since about the 1990's. The second scenario uses the entire age-1 recruitment time series, from 1973-2010, with "two stanzas" of recruitment determined by whether SSB is either above and below 4,319 mt. For both scenarios the overfishing threshold was $F_{40\%} = 0.316$*, and overfishing was not occurring based on comparisons of the threshold with the terminal year fishing mortality estimate from ASAP (2011* $F_{4\text{-}5} = 0.12$*). Biomass reference points and conclusions about whether the stock is overfished would depend on which recruitment scenario was adopted. Under the "recent" low recruitment scenario,* SSB_{MSY} *= 2,995 mt (2,219-3,820 mt; a 90% confidence interval) and MSY = 773 mt (573-984 mt), which would lead to the conclusion that the stock is not overfished relative to the ASAP model terminal year estimate of SSB (2011 SSB = 3,873mt). Because this stock is under a rebuilding plan with a rebuilding date set for 2014, the stock would also be considered rebuilt under the scenario of "recent" low recruitment. Under the "two stanza" recruitment scenario,* SSB_{MSY} *= 22,615 mt (13,164 - 36,897 mt) and MSY = 5,834 mt (3,415-9,463 mt), which would lead to the conclusion that the stock is still overfished. Neither recruitment scenario could be ruled out with a high degree of certainty.*

Determining the cause of recent low recruitment was the largest source of uncertainty in this assessment. As a possible mechanism for reduced recent recruitment, the cold pool (i.e. remnant winter sea water under the summer thermocline) was investigated and modeled in ASAP. However, it could not fully explain the recent low productivity. The cold pool analyses did show that SSB_{MSY} *and MSY tend to decrease in recent years as cold pools have gotten smaller and warmer. Environmental changes may be responsible for some of the changes in the stock which no longer exhibits the abundance throughout its range that existed in the 1970's and 1980's when recruitment was higher. If weak recruitment continues, the stock will not be able return to historically observed levels.*

Introduction

Yellowtail flounder, *Limanda ferruginea*, is a demersal flatfish whose range in United States (US) waters extends from Labrador to Chesapeake Bay, generally at depths between 40 and 70 m (20 and 40 fathoms). Off the US coast, three stocks are considered for management purposes (Figure B1; Cadrin 2003): Cape Cod–Gulf of Maine, Georges Bank, and Southern New England–Mid-Atlantic . Yellowtail flounder have been described as relatively sedentary, although recent evidence from mark–recapture studies counters this classification with off-bottom movements (Cadrin and Westwood 2004; Walsh and Morgan 2004; Cadrin and Moser 2006), limited seasonal movements (Royce et al. 1959; Lux 1963; Stone and Nelson 2003), and transboundary movements (Stone and Nelson 2003; Cadrin 2005).

Spawning occurs during spring and summer, peaking in May (Cadrin 2003). Eggs are deposited on or near the bottom and float to the surface after fertilization. Larvae drift for approximately 2 months, then change form and settle to the bottom.

Off the northeast coast of the US, yellowtail flounder grow up to 55 cm (22 in) total length and can attain weights of 1.0 kg (2.2 lb). Growth is sexually dimorphic, with females growing at a faster rate than males (Lux and Nichy 1969; Moseley 1986; Cadrin 2003). Yellowtail flounder mature earlier than most flatfish, with approximately half of the females mature at age 2 and almost all females mature by age 3 (NEFSC, 2008).

Assessment History

The first quantitative stock assessment of yellowtail flounder was on the southern New England - Mid Atlantic resource and fishery. Royce et al. (1959) evaluated landings, length and age composition, effort, and tagging data to conclude that fishing mortality was approximately 0.30 in the 1940s. However, retrospective estimates of F during the 1940s were substantially greater (approximately 0.6, Lux 1969). Lux (1964) concluded that the stock was not overfished during the 1950s, but age-based mortality estimates for the 1960s were high (Lux 1967[1], 1969).

Subsequent assessments of yellowtail flounder in the southern New England area excluded Mid-Atlantic catch and survey data, but indicated increasing F and declining stock size in the late 1960s (Brown and Hennemuth 1971a, 1971b; Pentilla and Brown 1973). Starting in 1974, Mid Atlantic and southern New England yellowtail resources were treated as separate assessment and management units, but analyses for each area indicated high mortality and low stock size in the 1970s (Parrack 1974, Sissenwine et al. 1978, McBride and Sissenwine 1979, McBride et al. 1980, Clark et al. 1981). In the early 1980s, there was indication of strong recruitment of yellowtail from surveys and commercial catches in both southern New England and Mid Atlantic areas, but discard rates were high and F exceeded F_{max} in southern New England (McBride and Clark 1983, Clark et al. 1984, NEFC 1986).

Assessment methods used for southern New England yellowtail progressed to a calibrated VPA in the late 1980s. The 1988 assessment indicated high F in the 1970s and early 1980s and a strong 1980 cohort (F=0.60-1.48; NEFC 1989). Later stock assessments showed another dominant cohort spawned in 1987, but F continually increased through the 1980s, and the stock was depleted to record low biomass in the early 1990s (Conser et al. 1991, Rago et al. 1994). The

VPA-based assessment of southern New England yellowtail was updated annually from 1997 to 1999, and assessments indicated a reduction in F in the late 1990s, but little rebuilding of stock biomass (NEFSC 1997, 1998; Cadrin 2000). In 2000, an updated VPA was attempted, but was rejected as a basis for management advice because sampling in 1999 was inadequate to estimate catch at age reliably (Cadrin 2001b). Subsequent assessments of southern New England yellowtail were based on projections of observed catch from the 1999 VPA (Cadrin 2001b, NEFSC 2002).

In the last decade, Southern New England Mid-Atlantic yellowtail flounder has undergone three peer review assessments SAW 36 (NEFSC 2003), GARM II (NEFSC 2005) and GARM III (NEFSC 2008). Summaries and resulting stock status are presented in Table B1 and B2. All of these assessments were conducted using the ADAPT-VPA model with starting year in 1973. Prior to 2002, an analytical assessment of Mid Atlantic yellowtail flounder has not been developed, and management advice were based on descriptive summaries of landings and survey data.

SAW36 in 2002 conducted an extensive review of the yellowtail stock structure based on new evidence on morphometrics and life history information. Overall, it was concluded that there was very little evidence to support discrete stocks for the Southern New England and Mid-Atlantic. Consequently, SAW36 assessment underwent data revisions to reflect the new stock definition. Input data included fishery catch data and NEFSC survey indices through 2001with the NEFSC spring survey index through 2002. Biological reference points were based on the non-parametric yield per recruit analyses with $F_{40\%}$ used as a proxy for F_{MSY} due to the lack of a defined stock-recruit relationship. The spawning stock threshold, SSB_{MSY} was estimated at approximately 69,500 mt and $F_{40\%}$ was 0.26. Despite revisions to the stock definition in the SAW36 assessment, , SNEMA yellowtail flounder was considered overfished and overfishing was occurring.

GARM II represents updates to SARC 36 model inputs with catch data and survey indices through 2004 and the spring through 2005. The VPA results indicated that fishing mortalty remained high during 2002 -2004, averaging 0.84 and spawning stock biomass decreased to 695mt, second lowest in the time series. Reference points were updated adopting similar approach from the SAW36 assessment. Biological reference points remained unchanged from SAW 36 values and therefore the resource was considered severely overfished with overfishing occurring.

The 2008 GARM III assessment represents a benchmark update. Major changes from the previous assessment include a thorough consideration of commercial discard and revisions to the biological reference points. Biological reference points were re-estimated similarly to the previous assessments but adopted a two stanza approach for sampling the cumulative distribution for recruitment to account for apparent change in productivity. The reference points were estimated as follows: $F_{MSY} = 0.254$ and $SSB_{MSY} = 27{,}400$mt. Despite the decrease in terminal estimates of F (0.411) and increase in terminal SSB (3,508mt), the stock was still considered overfished and overfishing was occurring. The large increase in SSB was contingent on the relative strength of the 2005 and to a greater degree, the 2004 year class. The 2004 year class was estimated at 10.9 million, the highest observed in the last decade and half.

Fisheries Management

From 1950 to 1977, the International Commission for the Northwest Atlantic Fisheries managed yellowtail flounder resources in southern New England, Georges Bank and the Gulf of Maine (i.e., in ICNAF subarea 5). Gear restrictions and total allowable catch were the primary management strategies of ICNAF, but minimum fish size, fishing effort and closed area and season regulations were also regulated. Minimum trawl mesh size was 114 mm in the 1950s and 1960s. National catch quotas were implemented for southern New England yellowtail flounder from 1971 to 1976, but these were exceeded in most years.

Following the implementation of the Magnuson Fisheries Conservation and Management Act (FCMA) in 1976, U.S. yellowtail resources have been managed by the New England Fisheries Management Council (Table B3). Groundfish regulations included minimum cod end mesh size, minimum fish size, seasonal area closures, mandatory reporting, trip limits and annual quotas. Minimum size for yellowtail was increased from 28cm in 1982 to 30cm in 1986 and 33cm in 1989. Minimum mesh size increased from 140 mm in 1991 (diamond and square mesh) to 140mm diamond-152mm square in 1994 and to 165mm in 1999. A large area south of Nantucket Shoals was closed to fishing since December 1994. Scallop dredge vessels were limited to possession of 136kg of yellowtail flounder since 1996, and in 1999 minimum twine top mesh was increased from 203mm to 254mm to reduce yellowtail by catch.

The effort controls first adopted in 1994 were frequently changed making it difficult to isolate the effects of individual regulations. At the end of 1994, the NEFMC reacted to collapsed stocks of Atlantic cod, haddock, and yellowtail flounder on Georges Bank by recommending a number of emergency actions to tighten existing regulations to reduce fishing mortality. Prime fishing areas on Georges Bank (Areas I & II) and in the Nantucket Lightship Area were closed. The NEFMC also addressed an expected re-direction of fishing effort into Gulf of Maine and Southern New England waters while also developing Amendment 7 to the FMP. Under FMP Amendment 7, DAS controls were extended, and any fishing by an EEZ-permitted vessel required use of not less than 6 inch (152 mm) diamond or square mesh in Southern New England east of 72° 30'. Framework 27 in 1999 increased the square mesh minimum size to 6.5 inches (165 mm) in the Gulf of Maine, Georges Bank, and Southern New England mesh areas.

In 2010 the groundfish fishery experienced a major management change with the passage of Amendment 16 with the introduction of annual catch limits (ACLs) which represented a return to the hard TAC days of ICNAF. Additionally, 17 new groundfish sectors were approved and those vessels not members of a groundfish sector were subject to additional cut back 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 catch was allocated throughout the year was solely up to 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 on the yellowtail resource is still unknown and too soon to understand what other changes may have occurred.

Length-Weight Relationship

The length-weight relationship in previous assessments of Southern New England Mid-Atlantic yellowtail flounder for converting catch weights to numbers at age have been based estimates derived from Lux 1969 (equations 1 and 2). The study design used quarterly port samples from fish lengths and round weights of fish caught in 1955-1962 by commercial otter trawls in Southern New England and on Georges Bank. Given the apparent change in productivity in the Southern New England Mid-Atlantic yellowtail flounder stock coupled with poor recruitment in the last two decades, it is quite plausible that fish condition may have been changed over time. Additionally, fishery conditions in the 1960's are different from current conditions, warranting an evaluation of the existing LW relationship with respect to re-estimated length-weight equations.

$$(1)\ W = 0.000011298L^{2.937}\ (Spring: April - June)$$
$$(2)\ W = 0.0000019143L^{3.451}\ (Fall: July - September)$$

A comparison of the Lux 1969 LW relationship to the updated NEFSC survey-based estimates of Wigley et al. (2003) indicate differences between the approaches. Differences between both approaches could be possibly be explained by differences in the data used to estimate the LW relationships. For instance, a fishery-dependent (i.e. landings-based) LW equation is likely derived based on catches of (heavier) fish at length and therefore a fishery-independent (i.e. survey-based) length weight equation may be biased low, particularly at greater lengths. Alternatively, a fishery-independent LW relationship may be appropriate when large portions of the catch consist of discards or when catch-weights-at-age are also used to estimate stock-weights due to sparse sampling of older ages in the surveys. In the case of Southern New England Mid-Atlantic yellowtail flounder, a LW relationship based on fishery independent approach is valid. 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. Updated survey-based length weight equations were compared to the existing length weight equations by either aggregating data across all three stocks or using the Southern New England Mid-Atlantic strata sets alone. Both seasonal (spring/fall) and annual updates were evaluated. First, to address concerns that Southern New England Mid-Atlantic yellowtail flounder condition have changed over time, the time series was divided into roughly five year blocks (fall:1992-2010; spring 1992-2011) and the relationships from each of the blocks were examined (Figure B2). Temporal trends in LW relationship for either all three stocks combined or for the SNEMA region only were nearly identical for the fall and spring season. This suggests that there is temporal stability in the LW relationship and that yellowtail condition has not changed at least within the time frame of the analyses (1992-2011). Given the stability in the LW relationship, data from 1992-2011 were aggregated to estimate updated spring and fall relationships (Equations 3-6). The updated values were then compared to the existing LW relationship (Figure B3). The updated relationships show that there was no statistical difference in the fall and in the spring when all three stocks are combined, evidenced by the 95% confidence intervals. Although, when all three stocks were combined in the spring, the LW relationship differed from the existing estimates, particularly at larger sizes (40cm +; Table B4). This could possibly be related to changes in fecundity or growth patterns during the spring in the northern extent of the stocks relative the SNEMA region. Although the relative difference at the smaller size groups appears substantial, the absolute magnitudes of the difference in the predicted weights are negligible.

(3) $W = 0.0000040023L^{3.23}\ (Spring: SNEMA)$
(4) $W = 0.0000039591L^{3.22}\ (Spring: All\ Stocks\ Combined)$
(5) $W = 0.0000097147L^{2.96}\ (Fall: SNEMA)$
(6) $W = 0.000010136L^{2.95}\quad (Fall: All\ Stocks\ Combined)$

Based on these results, the SARC panel agreed to use the revised LW relationship in the 2012 benchmark assessment. Application of these length weight equations were based only on the SNEMA region estimates and was restricted the period of the LW analyses (1994-2011) while the application for pre-1994 were based on the previous assessment estimates Lux (1969).

Growth and Maturity

Yellowtail flounder off the coast of United states are known to exhibit geographical variation in growth patterns. Generally, yellowtail flounder attend to grow slower in the northern, colder waters (i.e. from Cape Cod Gulf of Maine) compared to the southern waters (i.e. Georges Bank south; Lux and Nichy, 1969; Mosely, 1986; Cadrin 2010; Figure B4). For the 2012 benchmark assessment, von Bertalanffy growth parameters were re-estimated using the NEFSC bottom trawl survey data from 1963-2011 (Equations 7 and 8). The number of ages derived from scale samples in the analyses are presented in Table B5. Due to sparse availability or low sampling of older ages, the precision of L_{inf} may be poorly estimated. Overall, the difference in growth parameters between CCGOM, GB and SNEMA lends support for each stock to be treated differently.

(7) $L_t = 35.6\left(1 - e^{-0.97(t-0.63)}\right)\qquad (Spring)$
(8) $L_t = 35.2\left(1 - e^{-0.85(t+0.14)}\right)\qquad (Fall)$

Examination of monthly trends in mean length of Southern New England Mid-Atlantic yellowtail flounder in the commercial fishery suggests that the majority of somatic growth tend to occur between April and December with little growth occurring between January and March (Figure B5). Mean catch weight at age suggests that fish size at age declined around the mid-1990's, particularly for the ages 1-4 and less apparent in the older ages and have increased subsequently without trend (Figure B6). This pattern is less evident in the survey data, with many of the ages with variable patterns among the various age classes (Figure B7). Non-standardized fishery catch weights at age indicated that catch weights have been fairly stable in the last five to six years, fluctuating about the time series average in the last five to six years (Figure B8). A comparison between the non-standardized spring survey mean weights at age to the fishery catch show that they are similar for ages 2-5 (Figure B9). The lack of coherence observed for the ages 1 and 6+ group is likely related to selectivity differences between the survey and commercial gears and the lack of availability of older age fish in the population.

Estimates of maturity ogives in previous assessments have been based on the time series average of the observe proportions at age. This assessment explored the logistic regression method described by O'brien et al. 1993 to fit maturity at age from the NEFSC spring survey data. In attempt to smooth the noise in the data and increase sample sizes for those years with low sampling (Table B6), a 3-year and a 5-year centered moving average was explored (Figures B10a and B10b). The application of the three year moving average was based in part on the precedence of the GARM III assessments for other species and also due to the fact that the 3-year average was tended to improve the sample size so that ogives could be estimated for years with few observations. The assessment examined the 3-year and 5-year average and concerns were raised as to whether there were enough samples to use a 5-year moving average. Examination of sample size indicated that there were some years with very limited samples (2003-2008 at age 2, Table B6). As a result, the decision for this assessment was to default to the previous approach of utilizing the time series average of observed proportion at age for the range of years in the assessment (Figure B11).

Natural Mortality

Previous assessments of Southern New England Mid-Atlantic yellowtail flounder have assumed a constant natural mortality (M) = 0.2 (NEFSC 2008, Cadrin and Legault 2005, NEFSC 2002). This assessment 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 maximum age (t_{max}) in a population. Depending on whether the maximum age observed from the surveys (t_{max} = 11) or the maximum age in the fishery (t_{max} = 13) is used (Figures B12a and B12b), this approach yields estimates of M = 0.27 or 0.23. This approach was further refined by Hewitt and Hoenig (2005). This approach yielded of M of 0.38 and 0.32 for the fishery and survey maximum ages respectively.

Contrary to the observed maximum age approach described above, the assessment explored the application of the maximum age models using a size-dependent approach of estimating natural mortality based on the predicted average maximum age of the population using the NEFSC survey data. The relationship between length and predicted mean age is presented in Figure B13. Length distributions used in the analyses are also presented in Figure B14. A maximum length of 54cm with corresponding predicted mean age of 8.9 for the population resulted in estimated M = 0.34 (Hoenig 1983) or M = 0.47 (Hewitt and Hoenig 2005). The decision to use a survey maximum size of 54cm was considered reasonable for this analysis because the maximum observed size (60cm) in the fishery was fairly consistent with the survey.

An alternative approach that relies on the gonadosomatic index (GSI) uses the ratio of gonad weight to the somatic weight (Gunderson 1997). The general premise is that M is positively correlated with reproductive effort, more specifically female reproductive effort. Estimates of GSI were derived from Southern New England yellowtail flounder collected primarily from commercial vessels participating in the Northeast Fisheries Science Center, Northeast Cooperative Research Program (NEFSC-NCRP) study fleet from 2009-2011. Supplemental samples of yellowtail were also obtained in months leading up to and during spawning. Details of the sample processing are provided in McElroy et al. (2012). Using a mean GSI estimate of 0.178 (Figure B15) yielded an M estimate of approximately 0.32.

Recognizing that natural mortality is likely vary with age ad time, this assessment explored the application of the Lorenzen method to estimating natural mortality. The Lorenzen approach is premised on the empirical relationship between fish body size and natural mortality with M being a power function of fish weight (Lorenzen 1996). Using average catch weights from 1973-2011 , Rivard calculations were used to convert average catch weights to January 1 weights. The Lorenzen Model was then applied to the January 1 weights to generate age and year specific M’s. Parameters for the Model were based on the ocean ecosystem as presented in Lorenzen (1996). However, due to the very high M estimates that were generated using the raw weights at age, probably due to inter-species variation that is not accounted for in the Lorenzen’s ecosystem model parameters, the M values were rescaled for consistency with yellowtail flounder life history. Given that natural mortality estimates from previous analyses ranged from 0.2-0.5 and the stock has experienced high fishing mortality over the time series, M was rescaled to 0.3. Further examination of the weights-at-age used to derive the Lorenzen M indicated an abrupt shift in 1994 for age-1 leading to a shift in M as well which could not be explained. As a result, a time series average Lorenzen M scaled to 0.3 was used in this assessment (Table B7 and Figure B16).

Attempts to explore predatory consumption of yellowtail flounder using the NEFSC Food Habits Database (FHDB) as another avenue to estimating M was considered. However, there is very little data with the occurrences of yellowtail flounder showing up as prey in the FHDBS. Chances are that many of the yellowtail flounder seen in stomachs automatically get aggregated into higher taxa and are not identified to species level (per Comm. Brian Smith).

Provided the number of analyses explored to evaluate M, the WG had an extensive discussion as to whether to retain the currently assumed natural mortality of 0.2 over the alternative estimates. The Lorenzen method suggests that for older ages, this assumption may be adequate, but neither the survey nor the fishey catch a lot of older fish. The traditional longevity models resulted in higher M of 0.27 or 0.32 (given observed maximum age of 11 and 13 years respectively), while other methods estimated M ranging from 0.3-0.5. Based on the available evidences of M being higher and notion of fewer older ages in the survey and commercial catch, the it was concluded to use the time series average Lorenzen age-specific M scaled to 0.3(Table B7 and Figure B16).

TOR 1. Estimate landings and discards by gear type and where possible by fleet, from all sources. Describe the spatial distribution of fishing effort. Characterize uncertainty in these sources of data.

Overview

In the recent period (1973-present), total catch has ranged from approximately 22,000mt to 290mt (Tables B8a-B8b. and Figure B17). Prior 2005, landings constituted roughly 70-80% of the total catch, but recently landings have only contributed approximately 40-50% (Figure B19) of the total catch. The magnitude of landings has been very low averaging about 400mt in the last 5 years partly due to significant restrictions on commercial landings leading to increase in commercial discards and to a greater degree the very low productivity of the resource over the last two decades.

Starting in 2005, commercial discards became a significant component, accounting for over 50% of the overall catch (Figure B19). Notable increases in discards were partly the result of restrictive trip limits that were in effect from 2003 through 2008 (Table B3). The scallop fleet has also been a primary contributor of yellowtail discarding (Table B24) for market reasons and despite efforts to gradually relax the trip limits, discards of yellowtail still constitutes up to 60%

of the total catch in the recent years (Table B8a-8b).

Commercial Landings

Since 1964 when modern statistics began, commercial landings of Southern New England Mid-Atlantic yellowtail flounder have ranged from 113mt to over 25,000mt (Tables B8a-8b). Total species landings were derived from the weighout reports of commercial seafood dealers and generally considered a census. A secondary source was 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 yellowtail 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 VTR's, the port interview process stopped and the area and effort information had to be inferred from the VTR's. 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 in the NEFSC allocation (AA) tables. Landings are matched to VTRs in a hierarchical manner, with landings matched at the top tier (level A, direct matching) having a higher confidence than those matched at lower tiers. The matching rates have improved overtime with approximately 60% of the Southern New England Mid-Atlantic yellowtail flounder landings being matched at the highest level since 2008 and near 90% of the landings being matched in 2011 (Figure B19). The overall precision associated with this process, in terms of CV is estimated at less than 0.1 (Table B9)

An additional source of uncertainty with stock landings stems from 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 multiple statistical areas frequently under-report the number of statistical areas fished (Palmer and Wigley 2007, 2009 and 2011). The impacts of this misreporting are generally known to be low for most stocks but could have disproportional effects on low abundant stocks such as Southern New England Mid-Atlantic yellowtail flounder, with the impacts decreasing overtime (< 5% in 2007 and 2008; Palmer and Wigley 2011).

The commercial fishery is primarily conducted by vessels fishing with trawl gear constituting between 88%-99% of the landings (Tables B10-B11 and Figure B20). Patterns of landings by statistical area show that highest concentration of the landings came from the in the Southern New England region in statistical areas 526, 537 and 539 contributing approximately 80-90% of the total landings (Figure B21). Commercial landings of Southern New England Mid-Atlantic yellowtail flounder are classified by four primary categories: Unclassified, Large, Small and Medium. Generally the large and small market categories have dominated the landed markets, constituting over 70% of the total landings (Tables B12-13; Figure B22)

Temporal landings patterns of Southern New England Mid-Atlantic yellowtail flounder have changed slightly over the last six years. Although yellowtail flounder is a year round fishery, from 2007 through 2011, the fishery was most active between January and April and then slows down for the rest of the year (Figure B23). Presumably the slowdown in the fishery between April and December were a result of limited days at sea and restricted allocations under the sector management system, particularly in 2011.

Landings at age and mean weights at age were determined by port sampling of small, medium, large and unclassified market categories (Tables B14-B15) and pooled age-length keys by half year, when possible (Table 16). A summary of port samples are listed in Tables B14-B15. Sampling intensity has increased in recent years resulting in lower variability in landings at age estimates (Table B19). However, there is considerable uncertainty in the estimates of landings-at-age among some of the older ages, particularly in the plus 6 group where average CV exceeds 30%. Overall younger ages have become less prevalent in the commercial landings with increases in the minimum retention size (Figure B24). Estimates of weights-at-age from landings in commercial fishery are presented in Table B18 and Figure B24.

Changed in the method used to estimate landings-at-age relative to GARM III assessment included: LW equation and possibly differences in the imputation process in filling missing gaps in the ALK. Given these changes, the revised estimates were compared to the GARM III estimates. Overall the differences averaged approximately 11% for landed numbers at age (Table B20) and less than 1kg for landed mean weights at age (Table B22).

Commercial Discards

Estimates of discards for the southern New England – Mid Atlantic yellowtail fishery for 1963-1969 were derived from interviews with vessel captains; historical discards were approximated by Brown and Hennemuth (1971a) from the 1963-1969 average discard rates (Tables 8a-8b). Discards for 1970-1977 were also based on interview data, however yellowtail flounder interview data were suspect from 1978 to 1982 when trip limits were imposed (McBride et al. 1980, Clark et al. 1981). Discards during 1978-1982 were estimated from observer data when available (Sissenwine et al. 1978), derived directly from field selectivity studies (McBride et al. 1980), or from application of selectivity estimates to survey size frequencies (McBride and Clark 1983). Discards for 1983 were from interview data (Clark et al. 1984). Discards at age from southern New England, 1984-1993 were from a combination of sea sampling, interviews and survey data (Conser et al.1991, Rago et al. 1994). Direct sampling of commercial fishery discard has been conducted by fisheries observers since 1989. Of the Southern New England Mid-Atlantic yellowtail flounder observed by discarded by fishery observers, the following gear types account for greater than 99% of the total observed discards: Small mesh (<5.5") otter trawl, Large mesh (≥5") otter trawl, Scallop dredge limited category permit, Scallop dredge general category permits and scallop trawls (Table B24). It should be noted that GARM III discard estimates did not include scallop trawls which only constitute a very small fraction of total discards.

The total number of observed trips among these gear types ranged from a low of 23 trips in 1994 to a current high of 787 trips (Table B25). The large increase in the number of trips in 2010 and 2011 were due to additional contribution of ASMs that were required by the groundfish fishery by Amendment 16. In 2010 ASM coverage averaged approximately 25% of the total groundfish trips whereas regular observer trips (NEFOP) averaged about 7%. A comparison of the estimated discard rates between ASM and NEFOP observers was undertaken in SARC 52 (Wigley 2011) and showed no statistical difference for the majority of the gears and quarters examined. Generally, the Southern New England Mid-Atlantic yellowtail flounder ASM discard rates show no statistical difference from the NEFOP discard rates as evidenced by the 95% confidence intervals (Figure B25).

Discarded catch for years 1994-2011 was estimated using the Standardized Bycatch Reporting Methodology (SBRM) recommended in the GARM III Data meeting (GARM 2007; Wigley et al. 2007b). Observed ratios of discarded yellowtail flounder to kept of all species for all the gears mentioned above were applied to the total yellowtail flounder landings by gear and half year, with uncertainty estimated by the SBRM.

At the southern demersal industry meeting (SDIM), concerns were raised about the spatial stratification that has been used in previous assessments to derive discard rates due to differences in observer coverage between the Southern New England and the Mid-Atlantic regions. Typically, discard rates in previous assessments have been estimated by pooling the SNE and MA regions owing to low observer coverage earlier in the time series and recognizing the impacts of further stratification on the precision of estimates of discards estimates. However, due to increased sampling in the recent years, apparent differences in the spatial density of yellowtail flounder and disproportional observer coverage between SNE and the MA regions, there is potential for these discard rates to be different. Alternatively, it should be recognized that the choice to pool across multiple strata to account for low sampling/coverage may be statistically justified to avoid problems related to over-stratification, but does not address the underlying spatial differences that may exist in sampling.

Based on the observed differences in observer coverage between Southern New England region (SNE, statistical areas 526, 530, 531, 533, 534, 536, 537, 538, 539, 611, 612, and 613) and the Mid-Atlantic region (MA, statistical areas greater than 613), regional specific (SNE and MA) discard rates were estimated for years 1999-2011 in this assessment. For years 1994- 1999, the GARM III, non-stratified approach was used to mitigate the effect of low observer coverage earlier in the time series. For years 2000, 2004-2008 when there was activity in the access areas (i.e. Nantucket Lightship Area), discard estimates for the limited access scallop fleet were developed by further stratifying the SNE region to account for differences in discard rates between the open and the Nantucket Lightship access area (NLS). Although standard protocol for estimating discard is based on the ratio of kept yellowtail flounder to kept all species, discard rates for the scallop open and access areas were calculated as the ratio of observed discarded yellowtail to observed kept scallops. Personal communication with Susan Wigley of the NEFSC indicates that using K_scallops (scallop landings) as the expansion factor is sufficient for estimating discard rates, and nearly identical to using kept (landings) of all species given that the scallop dredge fleet rarely retains finfish other than scallops (e.g., occasionally monkfish and fluke are retained in minimal amounts). Note that the discard rates for years in the NLS access area were estimated on an annual scale due to the lack of consistent observer coverage by half year. Uncertainty by fleet in the manner of CV's were re-estimated for years with "blended" discard estimates (i.e. combined ratio for the groundfish trawl trips and cumulative ratio for the scallop dredge by open and access areas) to explicitly account for different sources of variances contributing to the total discard estimates. 95% confidence intervals were estimated for examine the impacts of the various spatial stratifications.

Estimates of discards using the blended stratification approach (open vs. access areas) suggested that when you account for open and closed area discard rates, total discard were generally higher compared to estimates derived using the region specific approach. The differences were significant for years 2000, 2007 and 2008 evidenced by the non-overlapping 95% confidence intervals. However, for years 2004, 2005, and 2010, there were no significant differences between the blended and non-blended approach (Figure B29). There was some evidence of improvement in the estimated CV's with the blended approach, particularly for years 2000 and 2010, but the CV's for years 2004-2008 were slightly higher.

While further stratification in the SNE area for the limited access scallop fleets could potentially provide a representative estimate of discarding rates between the open and access areas, there are several sources of uncertainty with the blended approach. The potential for tradeoff in the precision of discard estimates could occur if the level of observer coverage is not adequate to support finer level area-specific discard estimation. Secondly, the impact of spatial stratification on trip allocation remains unclear. Scenarios when trip allocations results from multiple sub trips occurring in multiple areas, as imposed by the stratification in the discard estimation (i.e. the difficulty of trip identification in open and closed area in the landings database) could result in different estimates. Lastly, area-specific stratification may not be supported by the resolution of biological sampling to adequately develop the appropriate discards-at-age, which could result in subjective decisions. While future work will need to thoroughly investigate these potential sources of uncertainty, the SARC Panel did not consider the blended approach as a major source of uncertainty in the assessment.

Discards at age (Table B26, Table 28, and Figure 30) and associated mean weights at age were estimated from sea sampled lengths and pooled age-length keys derived from commercial landings, observer and survey data.

Changes in the method used to estimate discards-at-age relative to GARM III included: differences in spatial stratification for deriving discard rates, Revised LW equation, and differences in the imputation process in filling missing gaps in the ALK. Given these changes, the revised estimates were compared to the GARM III estimates. Overall the differences between this assessment discarded at age in numbers and mean weights are presented in Tables B27 and B29.

Discard Mortality

A new study by Barkely and Cadrin 2012 summarized findings from a Reflex Action Mortality Predictor (RAMP) experiment on yellowtail flounder to estimate discard mortality. Fish were kept up to 60 days in situ, but the analyses used 20 days since most of the mortality occurred within this time frame. The tow times of 1-2 hours were approximately commercial tow times and gave the fish a range of stress conditions. The relationship between RAMP and mortality was derived from a logistic regression analyses based on a range of RAMP scores in the laboratory before sampling commercial activities. The study showed no direct evidence of additional mortality from predators or starvation, but there was likely some additional source of unknown mortality. The fish with the lowest RAMP score would be the ones more likely to evade predators. Commercial trips occurred in the Gulf of Maine (otter trawl) and on Georges Bank (scallop dredge). Monthly sampling was conducted to capture seasonal trends in mortality imposed by temperature. Information on species composition and catch size were examined. There was no evidence that tow time was a significant factor on mortality but air exposure was significant. Effects of size dependent mortality were tested for and was concluded not significant in the study. The Effects of various discarding practices (i.e. use of shovels, picks, conveyor belt etc) were explored. However, there seems to be consistency in discard mortality estimates (80-85% mortality) regardless of method. Prior discard mortality studies by the Massachusetts Department of Marine Fisheries (MA DMF) suggest 33-50% mortality. Given that 85% seems to be a lower bound on the RAMP-based discard mortality study and some mortality likely occurs post-release, the SDDWG agreed to use a value of 90% for commercial fishery discard mortality for the purpose of this assessment.

Total Catch at Age and Mean Weights at Age

Estimates of total catch at age were determined by summing the numbers at age across all the catch components: commercial landings and discards (Table B32 and Figure B33). The age structure of the fishery catch was truncated during the mid to late 1970's. The truncation has persisted through the late 1990's and it appears to be subtle expansion in the age structure in the recent years. Mean catch weights at age were estimated by using a number weighted average of the individual catch component's mean weight at age (Table B34 and Figure B8). Relative difference between the GARMIII mean catch mean weights at age compared to this assessment are presented in Table in B35).

TOR 2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Investigate the utility of commercial or recreational LPUE as a measure of relative abundance, and characterize the uncertainty and any bias in these sources of data.

A total of five surveys were available as tuning indices in this assessment. The NEFSC spring and fall bottom trawl survey which began in 1968 and 1963 respectively, provide a long time series of fishery independent indices. The winter survey which began in 1992 and ended in 2007 was designed specifically to efficiently catch flounders. The MARMAP (1977-1987) and the EcoMon Icthyoplankton surveys (1999-present) both provided an index of larval abundance. During the SDDWG meeting, it was discussed whether to include the southern strata in the winter survey (Strata 69-74). Traditionally, previous Southern New England Mid-Atlantic yellowtail flounder assessments have included the southern strata in the winter survey. However, given the disappearance of yellowtail by the late 1980's and 1990's in those strata that resulted in poor sampling, it was concluded that it was reasonable to exclude them from the winter survey (Figures B38 and B44). The impacts of excluding the southern strata from the winter survey resulted in an overall trend that was not markedly different with the inclusion of the southern strata.

A frequent criticism of the NEFSC bottom trawl surveys is that they do not cover the same areas where the commercial fisheries catch yellowtail flounder, and thus 'missing' much of the yellowtail flounder that exists in Southern New England. A comparison of the NEFSC spring and fall survey catches to commercial landings (binned by ten minute squares) show close agreement between survey and industry catches (Figure B39).

The NEFSC bottom trawl survey has utilized three different vessels and three different door configurations throughout the time series of the survey (Table B36). In effort to maintain consistency in the survey time series, the survey indices were converted to "Albatross IV/Polyvalent door' equivalents using several conversion factors (Table B37). The largest change in the survey 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 B41). Calibration experiments to estimate survey differences were carried out in the fall and spring of 2008 (Brown 2009). The results of those experiments were peer reviewed by a panel of external experts and then summarized in Miller et al. (2010). These results provided annual calibration coefficients both in terms if abundance and biomass. Further work by Brooks et al. (2010) developed length-specific abundance calibration coefficients for yellowtail flounder. This method uses a segmented regressions model where a constant is applied to fish ≤ 20cm and ≥ 28cm, and a constant decreasing linear regression is fit to fish between 20cm and 28cm (Figure B40). Estimates of converted fall and spring survey indices are presented in Figure B41.

During a pre-SARC54 meeting with the fishing industry, there were concerned expressed by the industry with regards to the 24-hr operation of the survey. There was a sense that there were differences in the relative catchability of yellowtail flounder between day and nighttime hours. These observations are supported by archival tagging studies of yellowtail flounder showing off-bottom movements typically between 1800 and 2200 hrs lasting an average of four hours (Cadrin and Westwood 2004). 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 evening time tows. However, the trends between day and night tows were very similar and in most years the day/night surveys fell within the 80% CI of the aggregated index (Figure B42). Because the trends were similar it was decided by the WG to use the aggregated index to calculate indices for the assessment.

Aggregated survey indices are presented in Table B40 along with corresponding CV's. Generally, survey indices were higher in the earlier time periods, reaching lows starting in the early 1990's and has remained constant over the past decade. The winter survey however varied over time without any persistent trend. Indices at age expressed as minimum swept are estimates are presented in Tables B41-B42 and B44 and Figures B45-B47. Similar to the trends observed in the commercial fisheries, there are fewer older fish present in the survey catch at age since the 1980's. However in the recent five years, there appears to be some subtle expansion in the age structure.

Examination of spatial trends in the NEFSC survey catches over time to see if these could inform the understanding small scale distribution of yellowtail show that there has been a general decline in the overall abundance of yellowtail flounder since the 1970's through the present time (Figure B48-B50).

Attempts were made by the WG to examine CPUE index for yellowtail flounder. However, there are currently no estimates of CPUE or effort for this species. Given the major changes in management, mainly the reduction in allowable days at sea (DAS) and the 2 for 1 counting of DAS, and changes in the reporting methodology, CPUE is not likely to be a good indicator of stock status. The fishery has also changed from one dominated by a directed fleet that took substantial amounts of fish to a by-catch fishery.

TOR 3. Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas.

Geographic Distribution

Fishing Patterns: Fishing for yellowtail off the east coast of the U.S have been localized to three principal fishing grounds including Southern New England, Georges Bank and off Cape Cod with smaller portion of the landings from the northern Gulf of Maine and the Mid-Atlantic Bight. Spatial analyses on the patterns of yellowtail landings in the U.S suggest that yellowtail is harvested primarily from the three discrete fishing grounds (Lux, 1963; Chang 1990). McBride and Brown (1980) describe yellowtail flounder on Georges Bank and Southern New England as self sustaining units, based on the different patterns of landings between Southern New England and Georges Bank. Their rationale was premised on the notion that limited exchanges occur between Georges Bank and Southern New England, explaining the different trends in landings among the fishing grounds. Yellowtail flounder commercial catches updated through 2010 in Figure B51 show differences in the pattern of harvest between three management units. In southern New England, yellowtail flounder commercial catches have been low and stable for almost the last two decades while catches on Georges Bank increased briefly in the mid 2000's and has remained relatively stable.

Resource distribution: Several sources of fishery independent surveys also suggest two harvest stocks of yellowtail flounder with a boundary on the southwest of Georges Bank (Cadrin 2003). Efron (1971) indicated that there are two relatively distinct concentrations of yellowtail delineated east and west of Nantucket Shoals. Research surveys in the 1950's through the late 1960's illustrated that yellowtail are distributed along the continental shelf edge from the Mid-Atlantic Bight to the northeast peak of Georges Bank. An update of the spatial distribution of yellowtail flounder distribution from the Northeast fisheries Science Center bottom Trawl survey from 1963 to 2011 indicate a continuous distribution of yellowtail from the Mid-Atlantic to the northeast peak of Georges Bank and what appears to be a separate resource on Cape Cod-Gulf of Maine (Figure B53). Exploratory analyses of the trawl survey abundance by Cadrin (2003) demonstrated differences between the northern and southern strata, with the south peaking in the early to late 1980's and the north subsequently increased during the 1990's (Figure B53). Cadrin (2003) further illustrated that there is a boundary of mixing zone between the northern and southern clusters located on the southwestern Georges Bank; further confirming the subsidy hypothesis that movement between adjacent stocks may not be adequate to replenish the depleted southern stock in a desirable time frame for management purposes.

Spawning and Icthyoplankton Distribution: Yellowtail flounder exhibit four distinct geographic spawning distributions (Table B8; Neilson et al 1989; Sherman et al. 1987; Berrien and Sibunka, 1999) with geographical gradient in peak spawning time occurring earlier in the south than the north. The geographic spawning aggregations for yellowtail flounder include: Cox Ledge off Southern New England southward, a large band from Nantucket Shoals along the northern edge of Georges Bank to the southwest part of Georges Bank, north and east of Cape Cod and on Brown's Bank (Lux and Livingston, 1982; Neilson, 1986; Cadrin, 2010). Spatial and temporal distribution of icthyoplankton surveys suggest that that yellowtail flounder eggs and larvae are distributed over the continental shelf, but seasonal difference in spawning seasons south and north of Cape Cod may partially result in reproductive isolation among the areas (Cadrin, 2010).

Juvenile and Adult Distribution: Based on bottom trawl surveys, yellowtail flounder occur from Nova Scotia south to the Chesapeake Bay. Yellowtail yearlings have been reported to exhibit more seasonal movements relative to adults in response to following a narrower temperature range (Maurawski and Finn, 1998). Juveniles and adults migrate away from coastal areas off southern New England, especially around Long Island and the New York Bight, during autumn. In the spring, dense concentrations of adults appear on Georges Bank, frequently along the southern flank and northeast peak. In the winter, adults are present on Georges Bank, Southern New England and the Mid-Atlantic Bight. In the summer, adults appear along the coastal Gulf of Maine including coastal waters east of Cape Cod and from Cape Cod Bay to Ipswich Bay. In the case of yellowtail flounder juvenile geographic distribution, three distinct concentrations have been defined based on research survey catches: 1) Massachusetts Bay and Cape Cod Bay and along outer Cape Cod in the spring and fall 2) on the southern edge of Georges Bank in the spring shifting north and east in the fall and 3) southern New England in relatively shallow water in the spring and slightly deeper in the fall (Wigley and Gabriel, 1991). Overall, yellowtail distribution occurs on the continental shelf ranging from the Mid-Atlantic to the Grand Banks, delineated by deep channels and shallow shoals that define the fishing grounds (Cadrin, 2010).

Geographic Variation

Genetics: Cadrin (2010) reported on allozyme analyses conducted by Doggett et al. (unpublished) which concluding that yellowtail flounder stocks from Brown Bank, Georges Bank and the Mid-Atlantic Bight were distinguishable and were relatively discrete stocks. However, samples from Nantucket Shoals and the Cape Cod grounds were not distinguishable from Georges Bank and the Long Island area appears to consist of samples from the southern area. In contrast, Kuzirian and Chikarmane (2004) indicated that 90-95% genetic homogeneity exists among all management areas based on random amplified polymorphic DNA (RAPD).

Life History Patterns: Previous studies have shown that yellowtail flounder exhibit spatial differences in growth rates with slower growth in the northern colder regions (Cape Cod and northwards) relative to the southern regions (Georges Bank and southwards). The difference in growth rates between the Cape Cod region and the southern areas have persisted for several decades. Results from a von Bertalanffy growth analysis using data derived from the Northeast Fisheries Science Center bottom trawl survey from 1963-2011 also further supports the notion of regional growth difference among the three yellowtail flounder stocks (Figure B4, Table B47).

Geographic variation in yellowtail flounder maturity has also been reported in several studies and a summary of age and size at 50% maturity are provided in Table B10. Cadrin (2010) summary suggested that yellowtail flounder from the southern New England were significantly more fecund at length compared to those from the Grand Banks and may be related to smaller size at maturity in the southern extent of the population. Begg et al. (1999a) indicated that yellowtail maturity in the U.S. water vary by management region. Cape Cod yellowtail was found to mature later at age and length than those from Georges Bank southern New England and the Mid-Atlantic Bight. Estimated maturity at age and at length using data derived from the Northeast Fisheries Science Center bottom trawl survey from 1963-2011 also further supports the notion of regional differences in maturity among the three yellowtail flounder stocks (Table B48).

Morphology: Morphometrics analyses of yellowtail flounder on U.S. fishing grounds in the 1950's and 1960's evaluated the number of dorsal and anal fin rays and found no differences among the three fishing grounds (Lux, 1963). Subsequent work by Cadrin and Silva (2005) also show that yellowtail flounder off Newfoundland have shorter-deeper bodies than those off the coast of U.S. and also found no variation among the U.S. management areas.

Movements and Migration

Icththyoplankton Dispersion: Yveseyenko and Nevinskiy (1981) evaluated geographic distribution of yellowtail flounder eggs based on patterns in the gyre system to infer drift of eggs and larvae distribution. Results of their analyses indicated that the circular flow dynamics of various closed water masses sufficiently provide pockets of larvae retention in favorable habitats including the Grand Bank, Brown Bank, Georges Bank and the Mid-Atlantic shelf. However, it was further suggested that some leakage may occur from the Brown Bank to the Gulf of Maine and from Georges Bank to southern New England. Later work by Nielson et al. (1986) also supported the previous conclusions on larvae retention with little opportunity for larvae transport. Sinclair and Iles (1986) reviewed information distribution of spawning of yellowtail flounder, icthyoplankton distribution, larvae behavior and oceanographic patterns and concluded that discrete stocks off southern New England-Mid Atlantic, Georges Bank, off Browns Bank were formed by larvae retention.

Tagging observations: Royce et al (1959) tagged and released yellowtail flounder on U.S. fishing grounds in the early to late 1940's and concluded that groups of yellowtail flounder are relatively localized with short seasonal migrations and minimal mixing among fishing grounds. However, frequent movement was observed between the Mid-Atlantic Bight to southern New England. Lux (unpublished) also tagged yellowtail off Cape Anne (northern extent of Massachusetts) in 1963 and found nearly all recaptures were caught near release sites. Stone and Nelson (2003) also tagged and released yellowtail from 1992-2002 on eastern Georges Bank and found that all but one fish were recaptured on the eastern portion of the Bank. From 2003-2006, an extensive cooperative tagging study with New England fishermen tagged and released over 46,000 conventional and data storage tags from the Gulf of Maine to the Mid-Atlantic to estimate movement and mortality rates among fishing grounds (Cadrin and Westwood, 2004; Cadrin and Moser, 2006, Cadrin 2009). Results from recaptures of the conventional tags showed that frequent movement occurred within Cape Cod and Georges Bank but very little movement among stock areas. Off-bottom movement analyses from sixty tags recaptured from the same study suggested that frequency of yellowtail off-bottom movements varied geographically among the three management areas with an average of once every ten days off Cape Cod and once every three days on Georges Bank.

Patterns of Parasite infestation: Lux (1963) reported observation from incidences of parasite infestation in yellowtail flounder and concluded that yellowtail flounder sampled from Cape Cod area were geographically isolated from those of the southern New England and Georges Bank region. Large percentage of yellowtail flounder sampled from the Cape Cod area were infested with intertidal host dependent trematodes likely due to yellowtail flounder habiting the near-shore environment for portion of their lives. However, none of the samples from Georges Bank or southern New England were infested. Subsequent work by Testerverde (1987) also concluded that geographical differences exist in the number of parasites and the degree of infestation among the three management areas.

The scientific evidence available with respect to variation in geographic abundance, life history, morphometrics and movement, suggests that there are three stocks despite homogeneity in genetic variation. Fishing patterns for yellowtail indicate that there are three harvest stocks but patterns of abundance and biomass overtime suggest two harvest stocks with a boundary on southwest of Georges Bank. Geographic patterns of maturity indicate two phenotypic stocks with a boundary on northern Georges Bank. However, growth patterns suggest that there maybe three phenotypic stocks. While yellowtail flounder appears to be a single genetic stock, variation in life history characteristics and patterns in abundance provides scientific support to assess each stock separately.

TOR 4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-5), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

Update of the GARM III VPA Model

There were major changes in the treatment of the underlying data for SAW54 assessment update relative the data used in the GARM III assessment. The major changes include LW relationships, updated maturity ogive, revised assumption about natural mortality and discard mortality, re-estimation of fishery data from 1994 to present which included re-estimated landings and discards-at-age, and estimates of weights-at-age to reflect landings and discards. Additionally, the NEFSC winter survey was revised to better reflect the geographic availability of the resource, a larval index was considered for the first time as part of the tuning indices and finally four additional years of catch and survey data from 2008-2011 was included in the model time series. To fully understand how these data changes may impact the 2011 update, a bridge was built from the GARM III assessment to fully a fully updated assessment.

The GARM III assessment was conducted using the Adaptive Framework Virtual Population Analysis (ADAP-VPA) model (NOAA Fisheries Toolbox ADAPT-VPA version 2.8, 2007). This version relied on the pope's approximation to solve catch equation and allowed only for the 'backward' calculation of the plus group. The most recent version of the ADAPT-VPA software (version 3.2, 2012) provides additional options for forward and combined calculation of the plus group. However, these alternative options for plus group handling were not fully explored by the working group.

The model formulation used in GARM III utilized a truncated age range of age 6+ relative to previous assessments which had used a 7+(GARM I and GARM II) and a 8 plus group (SAW 36). Commercial landings and discards from 1973 to 2007 were accounted for in the model. Tuning indices included the NEFSC spring, fall and winter surveys all with ages 1-6+. Maturity-at age was calculated based on the time series average of the proportion at age mature. Spawning stock biomass (SSB) was calculated assuming May 1st spawning (0.4167 into the calendar year). The GARM III assessment results indicated that there was evidence of increasing stock numbers since 2004 potentially driven by what appeared to be moderately strong year classes in 2004 and 2005. Spawning Stock Biomass (SSB) from the GARM III assessment showed modest increases relative to the previous years and was expected to show continued growth with the support of a potential incoming 2005 strong year class

The general approach used to build the bridge from the GARM III VPA to an updated VPA was as follows (Note: The run numbers correspond to the run summaries presented in Table B49.

- **Run 1** - Recreated GARM III results using v.2.7 with GARM III data set to confirm model data were correctly applied.
- **Run 2** - Migrate to v.3.2 using the GARM III data set to quantify the impact of using an 'exact' solution to the catch equation. Continue to handle the plus-group using the GARM III formulation with backward calculation.
- **Run 3** – Only updated Maturity at age ogive only
- **Run 7** – Only replaced const M = 0.2 with lifetime Lorenzen M at age rescaled to 0.3
- **Run 9** – Updated commercial landings and discards-at-age and average catch weights-at-age (1994-2007)
- **Run10** – (Combo data update) Updated commercial landings and discards-at-age, average catch weights-at-age, updated maturity-at-age, revised natural mortality to utilize Lorenzen estimates of M at age
- **Run 11**- Using data updates from the run 10 model formulation, applied 90% discard mortality to the commercial discards-at age matrix, weights
- **Run 15b** – Updated biological, commercial and survey data time series through 2011
- **Run 20** – Utilizing the full time series as described in Run15b, replaced the lifetime Lorenzen M at age to use a time series average Lorenzen M at age, revised the winter survey data to exclude southern Strata sets. **This Model represents an updated VPA model by the SDMBRPWG.**

Selected runs from the bridge building exercise are presented in Table B50. There were no major diagnostic with the GARM III model following the VPA software updates (run 2, Table B50). Survey residuals were largely un-patterned. The NEFSC survey and fleet selectivities suggested constant increasing selectivity up to the maximum age, with no declines in subsequent ages (i.e. flat-topped). The impacts of discard mortality rates were examined at various rates (80-100%). Discard mortality resulted in very minimal impacts on F, SSB and recruitment estimates with decreases in retrospective patterns. However, with updates in the model time series through 2011(run 15b, Table B50), the retrospective patterns increased for F (13% to 55%) while it decreased for both SSB and recruitment. As a result, the SDMBRPWG explored the previous assumption for natural mortality, M = 0.2 (both constant and at age) to resolve the F retrospective patterns. The retrospective for F did decrease as a result of lowering M, however, this lead to slight increases in the retrospective for SSB but was still considerably lower compared to the GARM III results.

The SDMBRPWG discussed the possible model alternative runs utilizing M at age (Lifetime Lorenzen rescaled to 0.3 and 0.2). Provided that the SDMBRPWG felt there were strong evidences supporting natural mortality estimates higher than 0.2, the decision was to move forward with a Lorenzen type M formulation at age, rescaled to 0.3 as the basis for developing a suitable model. The weights-at-age used to derive the Lorenzen M had an abrupt shift for age-1 in 1994, resulting in a shift in M at age during the same period. Given the unexplained abrupt shift in The working group decided to use a time series average Lorenzen M scaled to 0.3 (Run 20, Table B50).

Updated VPA Model (through 2011)

The working group picked a base VPA (Run 20; Table B50) with time series average Lorenzen M scaled to M of 0.3. There was no patterning in the residuals (Figures B54- B56) and no indication of doming in the survey catchabilities and the fleet selectivities (Figures B57 - B58). The winter survey catchabilities (qs) were high but with the ground gear on the winter survey net, herding is expected between the doors and the net. The CVs on age-2 estimates in the terminal year were high but given that there was no spring survey estimate for 2012, they are not unexpected (Run20, Table B50).

The IBS in 2004/2005 and IBS in 2011 are less than mean biomass estimates so there were no apparent catchability issues. The retrospective pattern is underestimating fishing mortality in the terminal year (Figure B60). SSB at the start of the model was approximately 22,000 mt, declined to lower levels and had two excursions to higher SSBs due to two large year classes (Figure B62). Recruitment has been poor since the 1987 year class (Figure B64) although SSB is now starting to increase due to low F.

Development of an ASAP Statistical Catch-at-Age Model

Use of statistical catch at age model for the Southern New England Mid-Atlantic yellowtail flounder assessment was explored. More specifically, the statistical catch at age model, ASAP (Age Structured Assessment Program v.2.0.20, Legault and Restrepo 1998), which can be obtained from NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/) was explored. ASAP was considered as an alternative modeling frame work in this assessment for a variety of reasons of which include, the ability to explore alternative model formulations to counter/lend support to the VPA results, ability to explore starting condition assumptions (e.g. ability to extend the time series beyond 1973, however, not explored in this assessment), ability to estimate stock-recruit relationship internal to the model, and the ability to explicitly model data uncertainty. Given some of the changes that have occurred in the fishery (gear, selectivity, targeting, and management), and the change to a new survey vessel (for which a calibration cannot be estimated), and the importance of age structure (maturity and growth), ASAP provides a very flexible platform to account for the various dynamics in the fishery and the survey.

As described at the NFT software website, 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 fleet-specific computations and y allowing the selectivity at age to change in blocks of years. Weights are input for different components of the objective functions 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).

ASAP Base Model Configuration

In developing the base ASAP model configuration, almost 30 model configurations were explored. These model configurations took advantage of ASAP flexibility of handling selectivity time blocks and indices without age information (i.e. the larval index). Summary of selected ASAP model configurations runs are presented in Table B51. A decision was made to use an age 6 plus group in the ASAP base model configuration. This decision was based on the difficulties of the VPA to estimate older ages with any precision due to the appearance of a continued truncation in the age structure over the most recent years, the high CV's in the landings-at-age observed during the early 1990's (Table B19) which could possibly be even higher prior to the 1990's and the difficulties in precisely estimating fishery selectivities of older ages as observed in GARM III (NEFSC, 2008).

Selectivity at age was initially freely estimated while the three NEFSC surveys were fixed at 1.0 for ages 4 and older (i.e. flat top selectivity). In subsequent explorations, the fishery selectivity was also fixed at 1.0 for ages 4 and older. The choice for the flat top selectivity pattern for the NEFSC survey indices was informed by the VPA results, which suggested increasing catchability with age, and the likelihood calculated in ASAP for dome versus flat-topped scenarios. Additionally, there is no biological mechanism to suggest decreasing selectivity with age.

Staring with a single selectivity for the fishery, the diagnostics (Run 1, Table B52) were examined for trends in age composition residuals. With one selectivity block (i.e. the same selectivity assumed for years 1973-20211), there were notable trends in the age composition residuals with runs of positives and negatives. Several intermediate models were explored for various selectivity blocks to capture major changes in the fisheries regulations (Table B3). Specifically, periods of changes in minimum retention size and changes in mesh regulations from

1978 to 2006. Additionally, the period of 1989 -1994 encompasses major changes in data availability, reporting sources and fisheries management. The model with six fishery selectivity blocks (1973-1977; 1978-1985; 1986-1988; 1989-1993; 1994-2001; 2002-2011) and a single time invariant selectivity block for each of the NEFSC surveys exhibited the lowest objective function and offered considerable fit to the age composition in the way of residual patterning (Run16; Table B52).

Additional model sensitivity runs were explored by including a larval index both as a single time series (1977-2011) and a split series (77-87 and 88-11), recognizing the change in survey mesh size in 1988. Relative to the single series option, the split series exhibited better model diagnostics as indicated by lower objective function, better fit to the total index and both survey and fleet age composition. Additionally, the root mean square residual estimates from the split series larval index were generally lower compared to the single series formulation (Run 20 and 22; Table B52b). However, the model diagnostics from the larval split series formulation was not an improvement over the base ASAP run. The WG considered additional attempts to improve the model formulation with the split series larval index by down weighting the CV on the larval index (per Comm. David Richardson) as well as each of the NEFSC surveys. The decision was to double the CV on the larval index owning to the uncertainty associated with the changes in the survey selectivity. Subsequent examination of the model fits for to the survey indices suggested a need for additional down weighting of the survey CV's. A constant of 0.1 was added to each of the NEFSC survey CV's including the larval index, which resulted in model improvement over the base model (Run 26; Table B52).

An alternative model examination that investigates the influence of the cold pool index on recruitment (Run28) was considered by the WG using ASAP base model Run26. The cold pool index was modeled as a covariate in a Beverton-Holt stock-recruit relationship internally estimated within ASAP to determine the effects of the cold pool on the predicted recruitment. This model formulation show that as cold pool index goes down, predicted recruitment increases. Although the cold pool model formulation is not directly comparable to the Base Model Run 26, which assumes no stock-recruit relationship, the trends in F and SSB were similar to the ASAP base Model Run 26, with tendency for the cold pool model to estimate SSB slightly lower. However, the recruitment estimates from the cold pool model formulation were drastically different in scale and magnitude. The 1980 and 1987 year classes were not reflected in the cold pool model formulation as observed in the base ASAP model 26 and other previous model formulations.

The SDMBRPWG further re-examined models with varying selectivity blocks on Run 26. The six selectivity blocks seem to produce selectivity estimates that do not necessarily agree with the expectations from the regulations. However, the SDMBRPWG deemed the improvement to the model fit with the six selectivity blocks acceptable to warrant keeping all the six blocks. Additionally, the retrospective patters were reduced and the RMSE with the six blocks. As a result, the SDMBRPWG chose ASAP model Run26 (Table B52) as the base model for this assessment.

The effective sample size (ESS) estimated for both the fishery and survey catch at age (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 50 and 10 for each of the NEFSC surveys.

ASAP Base Model 26 Diagnostics

ASAP base model 26 fits to the fishery catches were good, with no patterning of residuals over time and generally in good agreement between the model and observed catches (Figure B65). Fishery ESS of 50 appeared reasonable (Figure B66), and achieved reasonable fits between the observed catch at age (Figures B67- B71) with no large runs or obvious year class effects apparent in the residual patterning (Figure B72). Model fits to the observed mean catch at age are good, with a RMSE 1.48. Fishery selectivities were generally flat topped (Figure B73). As indicated earlier, the patterns in the selectivity blocks are somewhat noisy and not well explained by biological or management mechanisms.

Fit to the NEFSC winter survey index exhibited no strong residual patterning (Figure B72). The input ESS was generally supported by the modeled estimates (Figure B 75) with no strong patterning to the index age composition (Figure B76) Fits to the mean age were reasonable (RMSE = 0.89) lending additional support to the input ESS

Model fits to the spring survey also did not show no strong residual patterning with reasonable coherence between observed and predicted model estimate (Figure B 77). ESS value of 10 was generally supported by the model estimates, though there is some indication of increased ESS earlier and in the recent periods (Figure B78). There is very little patterning to the survey age composition (Figure B79) and the overall fit to the mean age is reasonable and comparable to the winter survey (RMSE = 0.95), further supporting the input for the ESS.

Similar to the winter and spring survey, the fall survey are reasonably good with the model tracking the observed index values fairly well with no strong residual patterns (Figure B80). The model ESS is somewhat noisy earlier and midway through the time series, but overall, the input ESS seems reasonable (Figure B81). The age composition residuals were reasonably well estimated with no long runs of residuals (either positive or negative) was observed (Figure B82). Estimated mean ages were close to the observed mean ages, with RMSE of 0.88.

Relative to the survey indices, the larval index exhibits somewhat a reduced fit between the observed and predicted model estimates (Figures B83 and B 84) but more apparent in the post 1987 period. Some patternings were observed in the early and late 2000's. However, the magnitudes of the residuals are comparable to those observed in the surveys.

The NEFSC survey fall survey exhibits higher selectivity for ages 1 and 2 fish but at age 3, the winter survey shows higher selectivity relative to the spring and fall survey (Figure B85). Similarly to the VPA, the winter survey catchabilities (q's) for the NEFSC winter survey tend to be high (> 1.00) compared to other surveys due to potential herding between the doors and the net. The spring and fall survey (q's) are approximately 0.6 and 0.4 respectively, suggesting that the survey is 40-60% efficient. However, this is possibly related to decline in the resource and lack of availability to the survey gear. Considering calibration coefficients applied to the Bigleow survey years, this would suggest greater than 100% efficiency over the last three years. Caution needs to be taken when interpreting the area swept converted q's given the assumption inherent in the calculations, such as constant tow length, no herding by the gear, 100% of survey area is habitable and the survey area is identical to the stock area which the catches come from.

ASAP Base Model 26 Results

The ASAP base model run 26 reflects the consensus opinion of the SDMBRPWG as the best model with which to evaluate stock status and provide catch advice and was accepted by the SARC 54 Panel. The assessment indicates that the total SSB ranged from 621 mt to 21,760 mt during the assessment time period, with current SSB in 2011 estimated at 3,873 mt (Table B53 and Figure B93). The model estimates SSB in 2007 at 1,920 mt, 55% of the 3,508 mt estimated at the GARM III. Currently total biomass is estimated at 5,305 mt. Current F's are near historic lows (Figure B93), with $F_{avg4\text{-}5} = 0.12$ (Table B54). Fishing Mortalities at age are presented in Table B55. Age-1 recruitment over the past two decades has been poor despite modest increases in SSB (Figures B92 and B93). Age-1 recruitment has not exceeded 10million since 1999 and has only exceeded it only once in the past 20 years (Table B56). Over the entire time series there, is no well defined stock-recruit relationship. The two highest recruitment events in the time series were spawned in 1980 and 1987 when SSB were at moderate and low stock sizes (~8900 mt and 2000 mt respectively). The current population structure is comprised primarily of ages 1-3, consisting of approximately 76% of the population. In 2011, there has been some expansion in the 6+ group (8% of the population), rising to the fourth highest in the time series (Table B56 and Figures B96-B97).

MCMC simulations were performed to obtain posterior distributions of SSB, and $F_{avg4\text{-}5}$ time series. Two MCMC chains of length of initial length of 10,000 were simulated with every 200th value saved. The trace of each chain's saved suggested good mixing (Figure B98). As the MCMC simulations appear to converge, 90% probability intervals as well as plots of the posterior for SSB2011 and $F_{avg4\text{-}5(2011)}$ are shown in Figures B100 and B101.

Retrospective analysis for the 2004-2011 terminal years indicates some retrospective error in F and SBB with tendency for the model to overestimate F although 2004 is a high flier) and underestimate SSB (Figures B87 –B88). F retrospective error ranged from 0.46 in 2006 to 0.26 in 2004. SSB retrospective error ranged from -0.29 in 2004 to 0.56 in 2006. Retrospective error for age-1 recruitment varied from -0.49 in 2010 to 0.63 in 2004 (Table B57). It is worth noting that the ASAP model does not exhibit nearly as severe retrospective pattern relative to the updated VPA run 20.

Historical Assessment Retrospective

Comparison between the results of the accepted ASAP (Model Run 26) for this assessment and the four previous assessments (GARM I, SAW 36, GARM II, GARM III, SARC 54) are provided in Figures B103 – B104. This historical "retrospective" examination of past model performance illustrates that the updated ASAP model appears to be consistent in trends with previous assessments. There is tendency for SSB to be slightly lower and recruitment to be estimated higher relative to previous assessments. F appeared to be within the same magnitude as previous assessments. These patterns are in addition to the intra-model retrospective errors that are present in the existing ASAP base model run 26. Given the major changes in the data that have occurred in the most recent update, the accepted assessment (Model Run26) is not entirely comparable with previous assessments. Much of the scale differences between current assessment and previous assessment are driven by changes to the underlying data and not necessarily results of the assessment.

TOR 5. Investigate causes of annual recruitment variability, particularly the effect of temperature. If possible, integrate the results into the stock assessment (TOR-4).

Recruitment of several cold-temperate fishery species has been linked to the dynamics of the cold pool, a summertime feature of the Southern New England and Mid-Atlantic Bight shelf. The cold pool is cold, remnant winter water separated from warm surface water by a strong seasonal thermocline. Taylor et al. (1957) proposed that yellowtail flounder (*Limanda ferruginea*) declined off Southern New England during the 1940's as a result of increasing temperatures. Sissenwine (1974) built upon this report and developed predictive equations for yellowtail flounder recruitment based on air temperature and the strong regional link between air temperature and coastal water temperature (Taylor et al. 1957). Sullivan et al (2005) hypothesized that yellowtail flounder recruitment was related to cold pool dynamics based on observations that yellowtail flounder settle almost exclusively to the cold-pool during the summer (Steves et al. 2000; Sullivan et al. 2000). Their analysis found that yellowtail flounder recruitment was higher when the cold pool was colder and de-stratification occurred later.

Hare et al (2012) explores the NEFSC hydrographic database to develop indices for SNEMA yellowtail flounder cold pool. A number of indices were developed bases on data collection in September

- Mean, maximum, and minimum temperature of area occupied by juvenile yellowtail flounder
- Width of temperatures <12°C along four cross-shelf transects: south of Martha's Vineyard, south of Long Island, east of New Jersey, and east of Delaware Bay.
- Bottom temperature anomaly along the mid-line of the cold-pool.
- Area of bottom water on the Mid-Atlantic Bight shelf <10 °C, <11 °C, <12 °C, <13 °C, <14 °C, <15 °C, and <16 °C.

15 resulting indicators were summarized using Principal Component Analysis (PCA) and the first axis explained 68% of the variance. PCA was used to summarize the cold pool indices since all of the above indices are particular measures of the cold pool. Rather than picking just one index, using the first PCA captures to dominant signal of variability across all indices. Using this approach, a positive PCA 1 is associated with a small/warm cold pool and a negative PCA 1 is associated with a large/cold cold pool (Figure B105). The PCA 1 is termed Cold Pool Index.

Relationships between cold-pool dynamics and recruitment were explored using environmentally-explicit stock recruitment models. The first axis from the PCA was used as the environmental term and estimates from GARM III, 2012 VPA, 2012 ASAP models were used for recruitment and spawning stock biomass. In all cases, the residuals of the standard Beverton Holt models were correlated with the Cold Pool Index (Figure B106). The environmental explicit stock recruitment modeling indicated the models with the cold pool index provided a better fit than those based on spawning stock biomass alone (Table B58). Recruitment was lower in years when the cold pool was warmer and smaller. Because of a trend in the Cold Pool Index over the time series (cold pool shrinking and warming), maximum recruitment is estimated to be different comparing the first half of the time series to the second half of the time series. This suggests that stock productivity is decreasing because of changing environmental conditions.

The values from the first PCA of cold pool indices are presented in Table B59. The initial values were calculated using data through 2007. These data were updated through 2010 and some of the individual variable calculations were modified so the updated values are identical to the previous values. The correlation between the two indices for years of overlap (1967-2007) are highly correlated (r=0.99).

The environmental explicit Beverton-Holt stock recruitment models tend to fit better than the standard model for all three assessment models evaluated (Table B58): GARM III, 2012 VPA, and 2012 ASAP. Results of the cold pool index were examined in ASAP (Run 28; See TOR 4) to explore the influence the cold pool index on predicted recruitment assuming a Beverton-Holt stock-recruit relationship.

TOR 6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY 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 scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The existing reference points for Southern New England Mid-Atlantic yellowtail flounder are based on a spawning potential ratio (SPR) of 40%. The overfishing definition is $F_{MSY} = F_{40\%} = 0.254$. A stock is considered overfished if spawning biomass is less than SSBMSY. The existing overfished definition is SSB_{MSY} = SSB40% = 27,400mt. A history of reference points values since 2002 are available in Table B2.

The existing reference points were derived from a VPA with a plus group at age 6. There are a numbers of reasons why a new reference points are needed for the new ASAP base model for the current assessment. There has been a revision to the commercial fishery data, particularly discards. With discard constituting more than 50% of the yellowtail catch in the recent five years, this has implications on changing the weights and selectivities at all ages. Changes in the L-W relationship parameters were re-estimated (this also affects weights at all ages). Assumption on natural mortality has been completely revised to allow for age-specific natural mortality, consequently accounting for differential in survival at different age groups.

Reference points based on parametric stock-recruit relationship was explored by the SDMBRPWG. Initial attempts to fit a Beverton-Holt function occurred without success due to the anomalous high 1980 and 1987 year class recruitment estimates at very low to moderate stock sizes. There was consensus among the SDMBRPWG that an approach to developing a proxy for reference point will be reasonable to estimate updated reference points. Yield per recruit (YPR) analysis was performed with a 5-year average for the most recent years (2007-2011) for weights at age, and selectivity at age. The rest of the inputs, maturity at age and selectivity for natural mortality were time invariant. Inputs for the YPR analyses can be found in Table B60.

The current reference points were derived at GARM III, and are based on $F_{40\%}$. The decision to use F40% as a proxy was endorsed by the independent reviewers at GARM III meeting, stating that "If recruitment and spawning stock biomass derived from the assessment are not informative about a relationship, the panel recommended use of $F_{40\%}$MSP as a proxy for F_{MSY} (NEFSC 2002) and SSB_{MSY} proxy computed using a stochastic projection approach, also referred to as the "non-parametric approach" (NEFSC 2008, p979). Additional analyses by the SDMBRPWG evaluated various proxies for F_{MSY} by comparing estimated SSB and recruitment ratios (SSB/R) with expected spawning biomass per recruit (SPR) at alternative fishing mortalities (F=0, $F_{30\%}$ and $F_{40\%}$) to investigate potential for replacement under equilibrium assumptions (i.e. constant F over the lifespan). The stock was considered to able to replace itself at $F_{40\%}$ in both early and late years, but at $F_{30\%}$, the stock would not have replaced itself in the later years.

As a result, the SDMBRPWG concluded that $F_{40\%}$ was a good proxy for F_{MSY} which was endorsed by the SARC 54 Panel.

To arrive at $SSB_{40\%}$ and corresponding MSY long term projections were run, sampling from the empirical distribution of recruitments estimates from the preferred ASAP model 26 under two recruitment scenarios. It should be noted that in this assessment, the overfishing determination is relatively certain, however, the overfished determination is uncertain due to the lack of evidence explaining the underlying mechanism related to the change in productivity of the resource. Biomass reference points and conclusions about whether the stock is overfished depended on which recruitment scenario is used. The first scenario used age-1 recruitment from a "recent" time period, 1990-2010, recognizing a potential reduction in stock productivity since about the 1990's. Following the precedent from GARM III, the second scenario used the entire assessment time series of age-1 recruitment from 1973-2010, with "two stanzas" of recruitment determined by recruitment values associated with SSB either above or below 4,319 mt. The 4,319 mt SSB threshold was derived based on a minimum residual variance analyses by relating SSB to Age-1 recruitment to allow recruitment to be sampled from the appropriate stanza depending on the given value of SSB. While there was no clear evidence to explain the sudden drop in recruitment since the 1990's, evidence of broader ecosystem changes, which may be related to Southern New England Mid-Atlantic yellowtail flounder productivity since 1990's (recent years) is more likely than not.

To approximate the distribution of SSB and MSY distributions, the long term projections were made from 1,000 estimates in 2011, which were estimated by performing MCMC simulation of the ASAP base model (described in TOR4). The resulting reference points and their 90% confidence interval corresponding with $F_{40\%}$ indicated that under the recent recruitment scenario, SSB_{MSY} = 2,995 mt (2,219-3,820 mt) and MSY = 773 mt (573-984 mt). However, when the entire age-1 recruitment time series with the two stanza approach is used, SSB_{MSY} = 22,615 mt (13,164 - 36,897 mt) and MSY = 5,834 mt (3,415-9,463 mt).

TOR 7. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model, should one be developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).

TOR 7a. 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 bridge was built from existing VPA model structure to the updated VPA model structure. The updated VPA model which includes changes to the catch (revision to discards), weights at age, etc., estimates SSB_{2011} = 4,044 mt.

This is less than the existing overfished threshold of 27,400 mt; therefore the stock would be considered overfished. The updated VPA estimates average fishing mortality on ages 4-5, $F_{(4-5)2011}$ is 0.16. This is less than the existing overfishing threshold of 0.254 and therefore overfishing is not occurring. This is a change in the overfishing status from the GARM III model results which indicated that overfishing was occurring.

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

The revised reference points are F_{MSY} proxy = F40% = 0.316 and SSB_{MSY} = 2,995 mt under the recent recruitment scenario and = 22,615 mt under the two stanza recruitment assumption. The new ASAP base model 26 estimate of SSB_{2011} is 3,873 mt. This is less than the overfished threshold of 22,615 mt under the two stanza recruitment conditions and therefore would be considered overfished. However, under recent recruitment conditions, SSB in 2011 exceeds the overfished target and therefore the stock would be considered rebuilt.

Overall, the updated model with respect to the existing reference points (GARM III) and the new new ASAP base model with respect to the two stanza recruitment reference points indicate that the stock is overfished and overfishing is not occurring. In contrast, the new ASAP model with respect to the recent recruitment scenario reference points would suggest that the stock is rebuilt and overfishing is not occurring (Table B61, Figure B107).

TOR 8. Develop approaches and apply them to conduct stock projections and 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 8a. Provide numerical annual projections (3 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, and recruitment as a function of stock size).

Short term projections of future stock status were conducted based on the new ASAP model assessment results under the two recruitment scenarios as defined previously. Numbers at age in 2011 were derived from 1000 different vectors of numbers at age produced from the MCMC chain. Short term projections assumed catch in 2012 to be equal to the catch in 2011 based on the approach from previous GARM III assessment. It should also noted that Annual Catch Limits (ACL's) in these two years were similar (2011 = 404 mt and 2012 = 552 – 585 mt) which lends additional support for the 2012 catch assumption.

Recruitment was sampled from a cumulative density function (CDF) of estimated age-1 recruitment assuming the two recruitment conditions as described on TOR 6. Projections were run under different F assumptions: $F_0 = 0.00$, $F_{MSY(40\%)} = 0.316$, and $F_{75\%FMSY} = 0.237$.

Projection results are summarized in terms of median spawning stock biomass and fishery yield under all the three F scenarios in Tables B62-B63. Under the two stanza recruitment assumption, the stock cannot rebuild to SSB_{MSY} by 2014 even at F equal zero. However, under the recent recruitment assumption, SSB in 2014 will exceed SSB_{MSY} under all three F assumptions by 27% at F_{MSY} and up to 75% at F_0. Results of the projections under F_0 and F_{MSY} in terms of rebuilding scenario or levels of SBB and yield are presented in Figures B109-B108.

TOR 8b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

Sources of uncertainties in the projections include the moderate retrospective patterns that have been observed in the last seven years. Given these patterns, there are additional sources of uncertainty in the catch advice based on these projections. Moreover, the projections are sensitive to realized to recruitment assumptions. Recruitment has been weak with no strong recruitment in over 20 years. Continued weak recruitment will impede the ability of the stock to rebuild. However, it is possible that the stock is in a new productivity regime and hence assuming recent recruitment trends could possibly be the new reality for the stock as evidenced by the levels of recruitment in the recent years.

TOR 8c. 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 etc) were used as model validation. Vulnerabilities that were not accounted for by the assessment and reference point models were evaluated using exploratory modeling and testing the influence of environmental factors on recruitment dynamics. Additional considerations of vulnerability and productivity are the implications of change in distribution, recruitment and possibly increased natural mortality. Consumption of yellowtail flounder by other fish and mammals may be increasing as predators increase; however, the empirical evidence is lacking to directly support this hypothesis.

The cause of the recent low recruitment was considered the largest uncertainty in this assessment. As a possible mechanism for reduced recent recruitment, the cold pool (i.e. remnant winter water under the summer thermocline) was investigated and modeled explicitly in ASAP. However, it could not fully explain the recent low productivity. The cold pool analyses did show that SSB_{MSY} and MSY tend to decrease in recent years as cold pools have gotten smaller and warmer. Environmental changes may be responsible for some of the changes in the stock which no longer exhibits the abundance throughout its range that was associated with the large recruitments of the 1970's and 1980's. If weak recruitment continues, the stock will not be able return to historically observed levels.

TOR 9. Review, evaluate and report on the status of research recommendations listed in most recent peer reviewed assessment and review panel reports. Identify new research recommendations.

GARM I

- *None was developed*

SAW36

- Explore the use of effort-based and discard/kept ratios for the scallop fisheries
    - *No longer applicable. The adopted approach uses a trip-based allocation approach*

- Analyze the impacts of applying SNE samples to MA landings for years where adequate samples exist for both areas.
    - *No longer applicable. Since SAW 36, the SNE and MA region has been assessed as a single stock and sampling effort has improved in recent years*

- Consider using a forward projection model that allows for error in catch at age, because of the extremely poor sampling in 1999 and more flexible assumptions about selectivity.
    - *Addressed in this assessment. A forward projecting statistical catch at age model is being proposed as the base model for SAW 54.*

- Investigate changes in maturity at age over time.

- Examine mean weights at age from surveys to confirm trends observed in the commercial mean weights.

    - *Addressed in this assessment (See section under 'Growth and Maturity")*

- Incorporate data from the entire stock area for the fall survey calibration index.
    - *Addressed in SAW 36 as well as in this assessment. It was concluded that the trend and magnitude were similar between the two series. SARC36 accepted the analyses conducted with the spatially restricted series to gain benefits of the longer time series. Similar decision was made for this assessment.*
    -
- Improve sea sampling coverage for otter trawl and scallop vessels to allow for better estimation of discards.
    - *No longer applicable. Recent sampling has improved over the previous years. However, sampling on a quarterly time step needs to be explored to determine if sampling is adequate for such temporal resolution.*

- Increase the sampling frequency of SNE-MA yellowtail flounder during the bottom trawl surveys.
    - *No longer applicable. Recent sampling has improved over the previous years. However, sampling on a quarterly time step needs to be explored to determine if sampling is adequate for such temporal resolution.*

- Collect adequate numbers of quarterly commercial samples for length and age composition
    - *Carried forward in this assessment*

GARM II

- Given the large decline in the stock abundance, the Panel noted that changes in maturity would be expected and recommended that this be explored in future assessments.
    - *Updated maturity ogive for in this assessment using the most up to data survey time series*

- Results appear to be sensitive to the 'oldest age' assumption, and alternative methods should be considered for the next benchmark assessment.
    - *No longer applicable. Plus group application was addressed in GARM III and determined a pus group at age 6 was most suitable provided the continued truncation in the age structure*

  -

- The NEFSC winter survey is now showing a trend in recent years, and should be included in future ASPIC runs
  - *No longer applicable. Current assessment models are based on age-structured models*

GARM III

- The use of 'windows' of biomass rather than the breakpoint should be explored to create the stanzas in the stock – recruitment relationship. This may better address inconsistencies in rebuilding plans that might arise as the biomass grows from the lower to the higher stanza.

New from SAW 54

- Consider using fine-level stratification to develop discard estimates for scallop rotational areas, especially the Nantucket Lightship Area (NLS), for 2000 and later years.
  - *Completed in this assessment (See TOR 2)*
  - *Previous assessment does not apply any spatial stratification to derive discards rates in the fishery. This assessments adopted discard rates derived from spatially stratifying SNE from the MA region as well as for the open and closed areas in SNE to account for differential in discard rate between open and access areas for the limited access scallop trips.*

- Develop approaches (e.g., hindcast ratios) to develop discard estimates for fishery strata with little to no observer overage
  - *Completed in this assessment (See TOR 2)*
  - *Adopted a blended approach for deriving discard rates (i.e. unstratify for years with low observer coverage and stratify for years with adequate coverage)*

- Update the length-weight parameters used to convert commercial landings (in weight) into numbers of fish. This could be accomplished by expanding existing data collection programs (e.g., Cooperative Research, Industry Based Surveys, NEFSC port sampling) to collect individual fish weights while collecting length and age data. This research recommendation is applicable to numerous species/stocks in the northeast, not just SNE/MA yellowtail flounder.
  - *Partly completed in this assessment based on data available*
  - *This assessment revised the existing LW relationship from over 40 years ago and adopted spring LW relationship as basis for fishery weights to numbers*

- The work on the influence of the cold pool and associated environmental parameters on yellowtail population dynamics has not been fully developed, and merits further research.

  - *Explored the application of the cold pool index in this assessment by explicitly incorporating the cold pool index in the ASAP model. Further work will continue to explore the application of environmental data in the assessment.*

- If the volume of commercial landings increases in the future, ensure that adequate samples of the landings are obtained for all market categories on at least a quarterly basis.
  - *Quarterly resolution was not explored in this assessment for deriving fishery catch data.*

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Tables

Table B1. Summary of model inputs and formulations used to assess the Southern New England Mid-Atlantic Southern New England Mid-Atlantic yellowtail flounder over the last ten years.

Year	Meeting	Stock	Model	Starting Year	Catch Data Series		Survey Series				Plus group
					Commercial landings	Commercial discards	NEFSC_Fall	NEFSC_Spring	NEFSC_Winter	Scallop	
2002	GARM I	SNE	VPA	1973	1973-2001	1973-2001	1973-2001	1973-2002	1992-2003	1982-2002	7+
2002	SAW 36	SNE/MA	VPA	1973	1973-2001	1973-2001	1973-2001	1973-2002	1992-2002	1982-2002	8+
2005	GARM II	SNE/MA	VPA	1973	1973-2004	1973-2004	1973-2004	1973-2004	1973-2004	NA	7+
2008	GARM III	SNE/MA	VPA	1973	1973-2007	1973-2007	1973-2007	1973-2007	1973-2007	NA	6+

Table B2. Summary of the results of the Southern New England Mid-Atlantic yellowtail flounder assessments over the last ten years and resulting stock status determinations based on existing biological reference points at the time of the assessment.

Year	Stock	Meeting	SSB (mt) terminal	F-terminal	F avg	Reference Points	SSBMSY (mt)	FMSY	MSY	Stock Status
2002	SNE	GARM I	1900	0.46	F_{avg4-5}	YPR	45,200	0.27	9,000	Overfished and Overfishing is occurring
2002	SNE/MA	SAW 36	1905	0.91	F_{avg4-5}	YPR	69,500	0.26	14,200	Overfished and Overfishing is occurring
2005	SNE/MA	GARM II	694	0.99	F_{avg4-5}	YPR	69,500	0.26	14,200	Overfished and Overfishing is occurring
2008	SNE/MA	GARM III	3508	0.41	F_{avg4-5}	YPR	27,400	0.25	6,100	Overfished and Overfishing is occurring

Table B3. Summary of major regulatory actions that have affected the Southern New England Mid-Atlantic yellowtail flounder fishery since 1978.

	Management Program	**Closed Areas**	**Minimum Codend Mesh Size -SNE/MA Area**	**Minimum Fish Size**	**Trip Limits**	**DAS/Effort Restrictions**	**Other**
1978	Open Access/YTF quotas		5.125 in. but numerous small mesh exemptions	11 in./28 cm.			Note that in SNE the fluke fishery allowed smaller mesh than the groundfish fishery in all years.
1979							
1980							
1981	Open Access/Gear Restrictions						
1982							
1983							
1984							
1985		Seasonal closed area					
1986				12 in./30.5 cm.			
1987							
1988							
1989				13 in./33 cm.			
1990							
1991							
1992							
1993							
1994	Limited Entry/Amendment 5 Effort Control/DAS System	Nantucket Lightship Closed Area (seasonal 1994; year-round 1995 and later)	6 inch sq. or dia.			DAS/Trip Boats	
1995							
1996						DAS extended to most vessels	
1997							
1998							
1999			6.5 in. sq., 6 in. dia.				
2000							
2001							
2002			6.5 in. sq. or 7 in. dia.			DAS Reduction	
2003					Mar-June: 250 lbs./DAS; Jul-Feb: 750 lbs/DAS, 3000		
2004			7 in. dia., 6.5 in. sq.			DAS Reduction	
2005							
2006					May, June, Oct, Nov: 250 lb/trip;All other 500 lb/DAS, 2,000 lbs/trip;	DAS Reduction; differential DAS areas	
2007			6.5 in. sq. or dia.		250 lbs/DAS, 1,000 lbs./trip		
2008							
2009						DAS Reduction	
2010	Sectors/ACLs				250 lbs/DAS, 1,500 lbs./trip (non-	Change in DAS counting	SNEMA WFL possession prohibited
2011							
2012							

Table B4. Summary of relative percent change in predicted weight for Southern New England Mid-Atlantic yellowtail flounder derived from length-weight relationships. Percent change was calculated as the difference between the Lux (1969) predicted weights and updated survey predicted weights divided by the Lux (1969) predicted weights.

Spring

Age	1	2	3	4	5	6+
Typical Length_cm	Avg. 5-14	28	32	39	44	46
Lux_SPR_Kg	0.0063	0.1889	0.2994	0.5926	0.8986	1.0476
SNEMA_SPR_Kg	0.0076	0.1861	0.2863	0.5419	0.7997	0.9230
% Change	-20%	1%	4%	9%	11%	12%

Fall

Age	1	2	3	4	5	6+
Typical Length_cm	24	29	37	40	44	45
Lux_FALL_Kg	0.1278	0.2229	0.4558	0.5731	0.7583	0.8100
SNEMA_FALL_Kg	0.1188	0.2080	0.4279	0.5391	0.7149	0.7641
% Change	7%	7%	6%	6%	6%	6%

Table B5. Summary depicting the number of yellowtail flounder scales sampled from the Northeast Fisheries Science Center (NEFSC) surveys from 1963 to 2011 by survey, stock and age. Scale samples that were not aged have been excluded from this summary.

	Cape Cod Gulf of Maine		Georges Bank		Southern New England Mid-Atlantic	
Age	Fall	Spring	Fall	Spring	Fall	Spring
0	21		153		18	1
1	1120	212	2183	325	2034	399
2	1967	1245	3212	2953	3843	3560
3	1275	1887	3072	3503	2710	4157
4	340	943	1161	1995	1694	3204
5	111	234	398	726	667	1155
6	24	58	113	199	114	541
7	12	25	47	81	38	136
8	4	11	9	21	6	35
9	4	8	6	3	2	9
10	2	2		2	1	3
11		1	1	1		2
12	1	1				
13						
14			1			

Table B6. Summary of the number of the number of female yellowtail flounder maturity samples taken from the Northeast Fisheries Science Center (NEFSC) spring survey from 1973 to 2011 by age.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Age-11	Total
1971	8	27	44	20	10	12	2	1				124
1972	16	76	84	86	51	26	25	5				369
1973	16	96	89	91	55	29	27	5				408
1974	16	172	103	100	58	41	30	6				526
1975	40	214	148	103	63	47	32	8		1		656
1976	73	267	124	107	60	35	32	9	1	1		709
1977	106	289	144	53	23	22	10	5	1	1		654
1978	149	437	310	183	38	31	9	6	2	1	1	1,167
1979	160	463	357	207	49	22	6	5	2	1	1	1,273
1980	136	466	377	225	59	23	5	3	2		1	1,297
1981	97	414	507	215	58	23	3	1	1		1	1,320
1982	56	351	463	231	58	24	2	1	1		1	1,188
1983	15	204	297	97	45	12	2					672
1984	4	156	259	68	33	10	2					532
1985	4	115	210	49	18	3	1					400
1986	14	94	60	39	15	5	1					228
1987	19	143	52	14	11	3	1					243
1988	21	125	174	39	7	3						369
1989	32	75	196	102	26	4						435
1990	34	71	187	116	26	4						438
1991	23	74	191	115	24	2						429
1992	19	26	184	112	28	3						372
1993	16	42	57	89	26	4		1	1			236
1994	5	41	24	31	7	2		1	1			112
1995	5	64	32	24	10	2		1	1			139
1996	8	85	32	26	11	2		1	1			166
1997	9	82	65	34	10	1		1	1			203
1998	8	66	68	33	10							185
1999	8	66	70	31	12							187
2000	9	56	56	28	12							161
2001	7	28	54	24	12							125
2002	6	26	22	17	11		1					83
2003	13	28	20	16	16		2					95
2004	15	44	7	11	12		3	1				93
2005	12	40	23	6	9		3	1				94
2006	10	37	27	17	9		3	1				104
2007	25	60	40	44	31	2	3	1				206
2008	36	108	76	54	52	5	2	1				334
2009	46	111	95	80	63	22	3	1				421
2010	46	102	78	79	63	22	3	1				394
2011	46	102	72	67	61	22	3	1				374
Total	1,388	5,543	5,478	3,083	1,252	468	216	68	15	5	5	17,521

Table B7. Estimates of natural mortality at age from 1973-2011 derived from average catch weights at age using the Lorenzen approach (Lorenzen, 1996)

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1973	0.356	0.311	0.294	0.288	0.281	0.270
1974	0.360	0.318	0.296	0.284	0.276	0.266
1975	0.355	0.327	0.294	0.282	0.277	0.265
1976	0.353	0.329	0.301	0.281	0.275	0.260
1977	0.364	0.330	0.302	0.276	0.267	0.262
1978	0.358	0.337	0.310	0.282	0.261	0.251
1979	0.383	0.325	0.305	0.281	0.259	0.246
1980	0.371	0.346	0.307	0.287	0.263	0.226
1981	0.418	0.325	0.298	0.270	0.251	0.238
1982	0.351	0.360	0.313	0.285	0.260	0.230
1983	0.386	0.333	0.313	0.282	0.256	0.230
1984	0.371	0.339	0.309	0.285	0.259	0.237
1985	0.373	0.331	0.302	0.287	0.266	0.242
1986	0.374	0.333	0.308	0.278	0.264	0.243
1987	0.340	0.342	0.307	0.294	0.269	0.249
1988	0.326	0.338	0.319	0.296	0.280	0.241
1989	0.559	0.296	0.281	0.246	0.224	0.194
1990	0.337	0.390	0.316	0.294	0.249	0.215
1991	0.483	0.312	0.287	0.271	0.240	0.207
1992	0.452	0.341	0.290	0.269	0.245	0.202
1993	0.439	0.347	0.285	0.273	0.251	0.205
1994	0.486	0.326	0.272	0.252	0.243	0.221
1995	0.505	0.342	0.270	0.251	0.231	0.200
1996	0.450	0.343	0.288	0.262	0.243	0.215
1997	0.418	0.359	0.280	0.269	0.251	0.222
1998	0.403	0.342	0.301	0.268	0.256	0.231
1999	0.455	0.338	0.298	0.272	0.255	0.182
2000	0.400	0.350	0.292	0.271	0.251	0.235
2001	0.439	0.325	0.292	0.266	0.249	0.228
2002	0.415	0.345	0.287	0.270	0.246	0.237
2003	0.501	0.323	0.279	0.254	0.235	0.209
2004	0.429	0.359	0.282	0.261	0.246	0.223
2005	0.469	0.334	0.281	0.257	0.240	0.219
2006	0.451	0.352	0.282	0.258	0.240	0.217
2007	0.449	0.344	0.290	0.262	0.242	0.212
2008	0.410	0.358	0.296	0.275	0.256	0.205
2009	0.465	0.326	0.287	0.258	0.245	0.219
2010	0.468	0.339	0.275	0.259	0.239	0.220
2011	0.413	0.357	0.287	0.263	0.252	0.228
Average	0.414	0.338	0.294	0.272	0.254	0.228

Table B8a. Estimates of total catch (mt) of yellowtail flounder from the Southern New England-Mid Atlantic stock. Estimates of both United States (US) and foreign fleet are shown.

Year	U.S. Commercial landings (mt)	U.S. Commercial discards (mt)	Foreign catch (mt)	Total catch (mt)	Percent discards
1935	6,000	2,400	-	8,400	29%
1936	6,800	2,700	-	9,500	28%
1937	7,600	3,000	-	10,600	28%
1938	7,700	3,100	-	10,800	29%
1939	9,500	3,800	-	13,300	29%
1940	14,200	5,700	-	19,900	29%
1941	19,300	7,700	-	27,000	29%
1942	28,400	9,900	-	38,300	26%
1943	18,000	7,300	-	25,300	29%
1944	10,600	4,800	-	15,400	31%
1945	10,400	4,200	-	14,600	29%
1946	10,800	4,400	-	15,200	29%
1947	12,100	4,900	-	17,000	29%
1948	9,900	4,000	-	13,900	29%
1949	4,900	1,900	-	6,800	28%
1950	4,900	1,900	-	6,800	28%
1951	2,900	1,100	-	4,000	28%
1952	3,200	1,200	-	4,400	27%
1953	2,300	800	-	3,100	26%
1954	1,700	600	-	2,300	26%
1955	2,500	900	-	3,400	26%
1956	4,100	1,400	-	5,500	25%
1957	6,200	2,200	-	8,400	26%
1958	9,500	3,600	-	13,100	27%
1959	8,200	3,100	-	11,300	27%
1960	8,800	3,200	-	12,000	27%
1961	13,000	4,700	-	17,700	27%
1962	13,500	5,300	-	18,800	28%
1963	22,600	5,400	200	28,200	19%
1964	21,809	9,500	-	31,309	30%
1965	22,517	7,000	1,400	30,917	23%
1966	22,540	5,300	700	28,540	19%
1967	25,140	7,700	2,800	35,640	22%
1968	25,372	6,300	3,500	35,172	18%
1969	23,686	2,400	18,283	44,369	5%

Table B8b. (Cont'd). Estimates of total catch (mt) of yellowtail flounder from the Southern New England-Mid Atlantic stock. Estimates of both United States (US) and foreign fleet are shown.

Year	U.S. Commercial landings (mt)	U.S. Commercial discards (mt)	Foreign catch (mt)	Total catch (mt)	Percent discards
1970	21,350	4,500	2,618	28,468	16%
1971	15,867	2,200	1,261	19,328	11%
1972	17,574	1,800	3,117	22,491	8%
1973	12,441	1,711	397	14,549	12%
1974	8,284	8,688	116	17,088	51%
1975	3,833	1,896	3	5,732	33%
1976	1,853	1,583	-	3,436	46%
1977	3,335	1,888	-	5,223	36%
1978	3,059	5,026	-	8,085	62%
1979	5,452	4,431	-	9,883	45%
1980	6,300	1,721	-	8,021	21%
1981	5,400	1,207	-	6,607	18%
1982	10,726	5,038	-	15,764	32%
1983	18,500	3,711	-	22,211	17%
1984	10,100	1,125	-	11,225	10%
1985	3,600	1,217	-	4,817	25%
1986	3,548	1,072	-	4,620	23%
1987	1,771	881	-	2,652	33%
1988	994	1,788	-	2,782	64%
1989	2,897	5,452	-	8,349	65%
1990	8,236	9,680	-	17,916	54%
1991	4,113	2,317	-	6,430	36%
1992	1,640	1,055	-	2,695	39%
1993	674	97	-	771	13%
1994	367	367	-	735	50%
1995	200	142	-	343	42%
1996	477	282	-	759	37%
1997	849	373	-	1,222	31%
1998	690	396	-	1,087	36%
1999	1,307	96	-	1,403	7%
2000	1,122	275	-	1,397	20%
2001	1,295	154	-	1,449	11%
2002	792	153	-	945	16%
2003	496	169	-	666	25%
2004	489	130	-	619	21%
2005	242	104	-	346	30%
2006	209	187	-	396	47%
2007	205	296	-	502	59%
2008	192	391	-	583	67%
2009	185	268	-	453	59%
2010	113	177	-	291	61%
2011	245	145	-	390	37%

Table B9. Estimates of Total Landings of Southern New England Mid-Atlantic yellowtail flounder from 1994 to 2011 and the coefficient of variation (CV) associated with the landings allocated procedure (AA tables, Wigley et al. 2008)

Year	Lanndings (mt)	CV
1994	367	0.019
1995	200	0.016
1996	477	0.009
1997	849	0.006
1998	690	0.015
1999	1307	0.009
2000	1122	0.012
2001	1295	0.011
2002	792	0.016
2003	496	0.022
2004	489	0.046
2005	242	0.043
2006	209	0.028
2007	205	0.022
2008	192	0.016
2009	185	0.011
2010	113	0.021
2011	245	0.006

Table B10. Southern New England Mid-Atlantic yellowtail flounder estimated commercial landings (mt) by gear and year from 1994 to 2011

Year	Trawl	Scallop Dredge	Gillnet	Other/ Unknown	Total
1994	324.04	41.60	1.35	0.50	367.49
1995	174.01	14.58	2.18	9.63	200.40
1996	459.29	15.69	0.91	1.31	477.20
1997	824.74	22.24	1.66	0.44	849.07
1998	669.20	16.55	2.50	1.92	690.17
1999	1286.12	14.26	4.19	2.50	1307.08
2000	1109.31	7.20	0.20	5.34	1122.06
2001	1259.48	28.09	4.27	3.57	1295.41
2002	766.23	20.49	2.72	2.49	791.92
2003	492.97	0.60	2.56	0.09	496.22
2004	348.63	0.02	6.56	133.96	489.18
2005	195.88	5.02	1.80	39.45	242.16
2006	175.22	7.51	1.16	25.16	209.05
2007	201.96	0.73	1.51	1.12	205.32
2008	185.85	0.71	1.43	4.29	192.27
2009	171.23	3.49	1.93	8.84	185.50
2010	108.17	2.59	0.68	1.84	113.27
2011	244.20	0.43	0.12	0.45	245.20

Table B11. Southern New England Mid-Atlantic yellowtail flounder percent commercial landings by gear and year from 1994 to 2011.

Year	Trawl	Scallop Dredge	Gillnet	Other/ Unknown	Total
1994	88.2%	11.3%	0.4%	0.1%	100%
1995	86.8%	7.3%	1.1%	4.8%	100%
1996	96.2%	3.3%	0.2%	0.3%	100%
1997	97.1%	2.6%	0.2%	0.1%	100%
1998	97.0%	2.4%	0.4%	0.3%	100%
1999	98.4%	1.1%	0.3%	0.2%	100%
2000	98.9%	0.6%	0.0%	0.5%	100%
2001	97.2%	2.2%	0.3%	0.3%	100%
2002	96.8%	2.6%	0.3%	0.3%	100%
2003	99.3%	0.1%	0.5%	0.0%	100%
2004	71.3%	0.0%	1.3%	27.4%	100%
2005	80.9%	2.1%	0.7%	16.3%	100%
2006	83.8%	3.6%	0.6%	12.0%	100%
2007	98.4%	0.4%	0.7%	0.5%	100%
2008	96.7%	0.4%	0.7%	2.2%	100%
2009	92.3%	1.9%	1.0%	4.8%	100%
2010	95.5%	2.3%	0.6%	1.6%	100%
2011	99.6%	0.2%	0.0%	0.2%	100%

Table B12. Southern New England Mid-Atlantic yellowtail flounder commercial landings (mt) by market category from 1994 to 2011

Year	Unclassified	Large	Small	Medium	Total
1994	21.52	183.91	162.04	0.02	367.49
1995	42.95	65.01	92.33	0.10	200.40
1996	177.50	98.24	201.06	0.39	477.20
1997	532.27	134.25	182.37	0.18	849.07
1998	234.64	168.19	287.15	0.19	690.17
1999	395.86	386.00	525.14	0.08	1307.08
2000	264.31	436.18	421.06	0.51	1122.06
2001	253.95	563.18	478.01	0.27	1295.41
2002	124.17	423.45	242.19	2.11	791.92
2003	85.01	258.48	152.72	0.02	496.22
2004	36.51	348.87	94.11	9.69	489.18
2005	22.58	117.71	85.90	15.98	242.16
2006	14.40	94.14	71.67	28.85	209.05
2007	23.79	63.28	81.67	36.58	205.32
2008	13.11	98.93	55.57	24.66	192.27
2009	19.97	114.03	35.95	15.55	185.50
2010	10.47	58.47	29.37	14.95	113.27
2011	11.60	150.56	57.90	25.14	245.20

Table B13. Southern New England Mid-Atlantic yellowtail flounder percent commercial landings by market category from 1994 to 2011

Year	Unclassified	Large	Small	Medium	Total
1994	5.9%	50.0%	44.1%	0.0%	100%
1995	21.4%	32.4%	46.1%	0.1%	100%
1996	37.2%	20.6%	42.1%	0.1%	100%
1997	62.7%	15.8%	21.5%	0.0%	100%
1998	34.0%	24.4%	41.6%	0.0%	100%
1999	30.3%	29.5%	40.2%	0.0%	100%
2000	23.6%	38.9%	37.5%	0.0%	100%
2001	19.6%	43.5%	36.9%	0.0%	100%
2002	15.7%	53.5%	30.6%	0.3%	100%
2003	17.1%	52.1%	30.8%	0.0%	100%
2004	7.5%	71.3%	19.2%	2.0%	100%
2005	9.3%	48.6%	35.5%	6.6%	100%
2006	6.9%	45.0%	34.3%	13.8%	100%
2007	11.6%	30.8%	39.8%	17.8%	100%
2008	6.8%	51.5%	28.9%	12.8%	100%
2009	10.8%	61.5%	19.4%	8.4%	100%
2010	9.2%	51.6%	25.9%	13.2%	100%
2011	4.7%	61.4%	23.6%	10.3%	100%

Table B14. Total number of length samples derived from commercially landed yellowtail flounder from 1994 to 2011 by market category and calendar half year. Sampling intensity is expressed as lengths per 100 metric tons

	Unclassified		Large		Small				
Year	Half 1	Half2	Half 1	Half2	Half 1	Half2	Total	Landings (mt)	Lengths/100mt
1994			102	170	228	254	754	367.49	205
1995	78						78	200.40	39
1996		129		752		939	1820	477.20	381
1997	277	319	736	328	915	548	3123	849.07	368
1998	92	230	283		596	127	1328	690.17	192
1999	535		1016	84	560	239	2434	1307.08	186
2000	85	51	251	186	555	411	1539	1122.06	137
2001		212	336	413	1227	514	2702	1295.41	209
2002	373	214	643	347	533	329	2439	791.92	308
2003			341	209	515	84	1149	496.22	232
2004	40		277	99			416	489.18	85
2005	47		205	191	61	192	696	242.16	287
2006	73	83	536	452	726	629	2499	209.05	1195
2007	379	720	563	1191	1077	1697	5627	205.32	2741
2008	444	70	1661	1028	2081	1093	6377	192.27	3317
2009	101		1789	307	982	96	3275	185.50	1766
2010			1775	303	1094	67	3239	113.27	2860
2011	207		2044	1439	1097	1000	5787	245.20	2360

Table B15. Total number of Southern New England Mid-Atlantic yellowtail flounder ages sampled from commercial landings from 1994 to 2010 by market category and calendar half year.

	Unclassified		Large		Small		Medium		
Year	Half 1	Half2	Half 1	Half2	Half 1	Half2	Half 1	Half2	Total
1994			28	48	53	75			204
1995	36								36
1996		32		183		241			456
1997	122	33	148	54	193	154	25		729
1998	25		75		200	37			337
1999	24		147	16	120	30			337
2000		23	45	60	129	91			348
2001		48	92	132	321	143			736
2002	75	48	157	18	160	95			553
2003			86	32	143	28			289
2004			57	15					72
2005			43	26	30	29			128
2006	50	25	154	123	251	248			851
2007	114	203	147	280	315	438			1497
2008	135		346	202	531	342			1556
2009	50		386	65	254	30			785
2010			456	47	391	29			923
2011	29		421	262	413	287			1412

Table B16. Observer length sampling aggregated to estimate length composition of commercially landed yellowtail flounder by market category and calendar half from 1994 to 2011.

<table>
<tr><th></th><th colspan="2">Unclassified Market</th><th></th><th colspan="2">Large Market</th><th></th><th colspan="2">Small Market</th><th></th><th colspan="2">Medium Market</th></tr>
<tr><th>Year</th><th>Half 1</th><th>Half 2</th><th>Year</th><th>Half 1</th><th>Half 2</th><th>Year</th><th>Half 1</th><th>Half 2</th><th>Year</th><th>Half 1</th><th>Half 2</th></tr>
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<tr><td>2005</td><td colspan="2"></td><td>2005</td><td></td><td></td><td>2005</td><td></td><td></td><td>2005</td><td>■</td><td>■</td></tr>
<tr><td>2006</td><td></td><td></td><td>2006</td><td></td><td></td><td>2006</td><td></td><td></td><td>2006</td><td>■</td><td>■</td></tr>
<tr><td>2007</td><td></td><td></td><td>2007</td><td></td><td></td><td>2007</td><td></td><td></td><td>2007</td><td>■</td><td>■</td></tr>
<tr><td>2008</td><td></td><td></td><td>2008</td><td></td><td></td><td>2008</td><td></td><td></td><td>2008</td><td>■</td><td>■</td></tr>
<tr><td>2009</td><td colspan="2" rowspan="2"></td><td>2009</td><td></td><td></td><td>2009</td><td></td><td></td><td>2009</td><td>■</td><td>■</td></tr>
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Table B17. Summary of the 2011 Southern New England Mid-Atlantic yellowtail flounder Industry based survey (IBS) biological sampling

Month	Total Length Samples	Total Age Samples	IBS Catch (mt)
Sptember	357	0	0.57
October	1601	127	2.44
November	516	69	0.41
Total	2474	196	3.42

Table B18. Southern New England Mid-Atlantic yellowtail flounder commercial landings at age in thousands of fish.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Total
1973	28	2,650	10,595	7,927	5,226	5,305	917	63	0	0	32,711
1974	130	1,853	4,760	7,325	3,687	1,598	1,474	276	0	0	21,103
1975	176	2,692	1,883	1,120	1,597	792	416	244	0	0	8,920
1976	0	1,474	1,167	327	449	477	230	189	0	0	4,312
1977	68	2,260	4,848	507	278	304	167	178	0	0	8,610
1978	21	4,089	2,157	1,470	247	61	70	48	0	0	8,163
1979	19	5,114	8,548	1,062	438	101	29	1	0	0	15,312
1980	137	4,774	6,577	3,829	512	129	22	16	0	0	15,996
1981	0	3,016	7,259	2,926	1,111	161	17	5	0	0	14,494
1982	56	17,980	13,453	1,855	415	79	7		0	0	33,845
1983	57	14,416	37,156	3,584	385	146	37	9	0	0	55,789
1984	47	3,058	19,038	8,054	878	245	16	14	0	0	31,351
1985	166	5,030	2,155	1,968	1,109	204	38	4	0	0	10,673
1986	40	6,215	3,287	635	356	127	21	1	0	0	10,681
1987	76	1,403	2,349	926	167	55	9	1	0	0	4,986
1988	0	1,213	532	506	134	26	6	0	0	0	2,418
1989	0	5,918	1,513	331	42	3	0	0	0	0	7,807
1990	0	423	18,922	1,536	79	5	0	0	0	0	20,965
1991	0	253	2,343	6,814	156	34	17	0	0	0	9,617
1992	0	301	1,011	2,080	264	14	4	0	0	0	3,675
1993	0	245	432	702	145	4		0	0	0	1,528
1994	0	15	287	239	227	78	5	0	0	0	851
1995	0	0	164	236	51	11	15	0	0	0	476
1996	0	295	624	174	20	14	5	3	0	0	1,135
1997	0	35	1,027	700	92	17	19	5	3	0	1,897
1998	0	656	815	297	44	5	1	0	0	0	1,818
1999	65	344	2,038	459	88	39	0	0	0	0	3,033
2000	2	688	1,244	503	55	9	0	0	0	0	2,501
2001	0	407	1,727	505	136	27	14	2	0	0	2,818
2002	0	240	1,021	411	25	0	0	0	0	0	1,697
2003	0	122	538	352	23	3	2	1	0	0	1,040
2004	0	17	313	278	197	84	6	10	0	0	905
2005	0	101	135	128	87	24	13	0	0	0	488
2006	0	94	165	105	42	27	17	3	2	0	456
2007	0	37	304	97	26	11	4	2	1	0	482
2008	0	4	122	261	20	3	1	1	0	0	411
2009	0	23	38	183	120	5	0	0		0	369
2010	0	3	76	42	70	27	1	0	0	0	218
2011	0	27	129	128	108	68	9	0	0	0	469

Table B19. Southern New England Mid-Atlantic yellowtail flounder sampling coefficient of variation (CV) of landings at age from 1994 to 2011.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1994		77%	13%	14%	17%	27%
1995			17%	11%	23%	22%
1996		27%	10%	27%	29%	31%
1997		33%	10%	13%	33%	39%
1998		11%	10%	13%	39%	76%
1999	91%	28%	9%	20%	38%	48%
2000	131%	15%	9%	12%	45%	77%
2001		20%	6%	10%	24%	37%
2002		17%	8%	16%	44%	
2003		16%	8%	15%	50%	74%
2004		32%	8%	11%	15%	17%
2005		12%	13%	13%	10%	25%
2006		12%	8%	8%	13%	13%
2007		12%	3%	7%	15%	14%
2008		32%	7%	3%	15%	26%
2009		16%	16%	5%	7%	38%
2010		57%	7%	10%	6%	10%
2011		13%	6%	6%	7%	8%

Table B20. Relative difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder commercially landed numbers at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Relative differences were expressed as the ratio of the current assessment numbers at age to the 2008 assessment numbers at age (*ratios less than one indicate fewer fish at age*).

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1994		1.04	1.05	1.08	1.07	1.07
1995			1.97	0.94	1.09	0.88
1996		1.01	1.00	1.00	0.99	0.99
1997		0.90	1.08	1.08	1.08	1.08
1998		1.33	1.06	0.88	0.91	1.10
1999		1.32	0.99	1.20	0.80	5.46
2000	1.07	1.00	1.14	1.08	1.05	1.16
2001		1.04	1.06	1.08	1.09	1.09
2002		1.07	1.08	1.09	1.09	
2003		1.29	1.16	1.16	0.29	0.29
2004		0.09	1.68	1.11	0.75	1.00
2005		1.23	0.91	1.16	1.01	0.98
2006		1.07	1.07	1.08	1.09	1.10
2007		0.97	1.00	1.11	1.19	1.20

Table B21. Mean weights at age (kg) of commercially landed Southern New England Mid-Atlantic yellowtail flounder from 1994 to 2011

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10
1973	0.210	0.295	0.344	0.374	0.382	0.418	0.474	0.640	0.000	0.000
1974	0.203	0.303	0.351	0.396	0.439	0.431	0.477	0.498	0.000	0.000
1975	0.218	0.289	0.376	0.432	0.435	0.457	0.505	0.518	0.000	0.000
1976	0.000	0.301	0.407	0.498	0.499	0.543	0.548	0.603	0.000	0.000
1977	0.215	0.282	0.381	0.504	0.513	0.481	0.586	0.606	0.000	0.000
1978	0.234	0.284	0.383	0.536	0.662	0.686	0.636	0.647	0.000	0.000
1979	0.189	0.300	0.364	0.475	0.590	0.673	0.620	0.830	0.000	0.000
1980	0.205	0.280	0.384	0.500	0.682	0.874	1.132	1.054	0.000	0.000
1981	0.140	0.262	0.342	0.474	0.596	0.669	0.475	0.649	0.000	0.000
1982	0.226	0.263	0.353	0.499	0.660	0.822	0.956	0.000	0.000	0.000
1983	0.175	0.261	0.338	0.496	0.668	0.815	0.834	0.821	0.000	0.000
1984	0.181	0.236	0.295	0.388	0.487	0.652	0.662	0.724	0.000	0.000
1985	0.183	0.258	0.365	0.408	0.504	0.577	0.745	0.867	0.000	0.000
1986	0.186	0.284	0.331	0.463	0.587	0.614	0.804	0.804	0.000	0.000
1987	0.248	0.268	0.353	0.404	0.520	0.587	0.863	0.905	0.000	0.000
1988	0.000	0.293	0.396	0.493	0.611	0.795	0.937	0.000	0.000	0.000
1989	0.000	0.340	0.400	0.555	0.735	0.957	0.000	0.000	0.000	0.000
1990	0.000	0.327	0.377	0.452	0.758	0.884	0.000	0.000	0.000	0.000
1991	0.000	0.336	0.380	0.426	0.698	0.900	0.599	0.000	0.000	0.000
1992	0.000	0.347	0.386	0.460	0.631	0.804	1.375	0.000	0.000	0.000
1993	0.000	0.350	0.430	0.451	0.641	1.040	0.000	0.000	0.000	0.000
1994	0.000	0.306	0.335	0.409	0.511	0.628	0.861	0.000	0.000	0.000
1995	0.000	0.000	0.341	0.404	0.585	0.790	0.750	0.000	0.000	0.000
1996	0.000	0.372	0.412	0.467	0.622	0.703	0.799	0.876	0.000	0.000
1997	0.000	0.313	0.410	0.471	0.591	0.721	0.774	0.806	0.808	0.000
1998	0.000	0.312	0.375	0.506	0.547	0.867	0.859	0.000	0.000	0.000
1999	0.128	0.310	0.400	0.558	0.626	1.705	0.000	0.000	0.000	0.000
2000	0.230	0.343	0.448	0.567	0.668	0.733	0.000	0.000	0.000	0.000
2001	0.000	0.364	0.423	0.571	0.688	0.788	0.839	1.130	0.000	0.000
2002	0.000	0.359	0.441	0.574	0.763	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.356	0.429	0.571	0.712	0.866	0.980	1.130	0.000	0.000
2004	0.000	0.335	0.438	0.548	0.582	0.785	0.924	0.834	0.000	0.000
2005	0.000	0.324	0.436	0.522	0.635	0.699	0.918	0.000	0.000	0.000
2006	0.000	0.310	0.398	0.483	0.608	0.718	0.804	0.817	0.944	1.130
2007	0.000	0.332	0.379	0.488	0.630	0.754	0.815	0.837	0.932	1.331
2008	0.000	0.350	0.406	0.474	0.605	0.765	0.884	2.414	0.763	0.000
2009	0.000	0.353	0.412	0.480	0.584	0.729	0.922	0.859	0.000	0.000
2010	0.000	0.383	0.421	0.484	0.579	0.709	0.857	1.088	1.162	0.000
2011	0.000	0.350	0.431	0.502	0.577	0.681	0.812	0.000	0.000	0.000

Table B22. Absolute difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder commercially landed mean weights at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Absolute difference were expressed as current assessment mean weights at age minus the GARM III estimates of mean weights at age (*negative weights imply lighter fish at age*)

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Age-11
1994	0.00	-0.02	-0.02	-0.03	-0.04	-0.05	-0.05	0.00	0.00	0.00	0.00
1995	0.00	0.00	-0.07	-0.05	-0.01	-0.11	-0.09	0.00	0.00	0.00	0.00
1996	0.00	-0.01	0.00	0.00	0.02	0.03	0.04	0.05	0.00	0.00	0.00
1997	0.00	-0.01	-0.03	-0.04	-0.06	-0.08	-0.09	-0.10	-0.08	0.00	0.00
1998	0.00	-0.02	-0.03	-0.03	-0.04	-0.11	-0.11	0.00	0.00	0.00	0.00
1999	0.13	-0.07	-0.03	-0.05	-0.14	0.55	0.00	0.00	0.00	0.00	0.00
2000	-0.02	-0.03	-0.04	-0.06	-0.08	-0.10	0.00	0.00	0.00	0.00	0.00
2001	0.00	-0.02	-0.02	-0.04	-0.07	-0.08	-0.10	-0.17	0.00	0.00	0.00
2002	0.00	-0.02	-0.03	-0.06	-0.09	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	-0.03	-0.02	-0.05	0.09	0.13	0.11	-0.18	0.00	0.00	-0.86
2004	0.00	0.00	0.04	0.06	0.01	0.00	0.29	-0.23	-0.92	0.00	0.00
2005	0.00	-0.02	-0.01	-0.02	-0.03	-0.11	0.04	-1.13	0.00	-1.13	0.00
2006	0.00	-0.02	-0.03	-0.04	-0.06	-0.08	-0.09	-0.09	-0.13	-0.17	0.00
2007	0.00	-0.02	-0.02	-0.03	-0.05	-0.08	-0.06	-0.08	-0.11	-0.22	0.00

Table B23. Southern New England Mid-Atlantic yellowtail flounder estimated discards (mt) by gear and estimated coefficient of variation (CV) from 1994 to 2011.

Year	Discards (mt)	CV
1994	367	31%
1995	142	28%
1996	282	25%
1997	373	43%
1998	396	75%
1999	96	39%
2000	275	19%
2001	154	31%
2002	153	24%
2003	169	45%
2004	130	51%
2005	104	31%
2006	187	25%
2007	296	20%
2008	391	14%
2009	268	21%
2010	177	18%
2011	145	14%

Table B24. Southern New England Mid-Atlantic yellowtail flounder discards by gear in mt (Top) and by proportion (Bottom) from 1994 to 2011

Year	Trawl Small Mesh	Trawl Large Mesh	Scallop Dredge and Scallop Trawls	Total
1994	305	3	59	367
1995	2	5	135	142
1996	20	27	236	282
1997	4	172	196	373
1998	9	270	118	396
1999	0	4	92	96
2000	3	0	115	117
2001	20	0	133	154
2002	0	3	149	153
2003	45	17	107	169
2004	4	104	12	121
2005	7	31	51	88
2006	35	50	57	142
2007	18	58	104	180
2008	10	47	135	192
2009	7	165	96	268
2010	18	15	118	151
2011	4	31	110	145

Year	Trawl Small Mesh	Trawl Large Mesh	Scallop Dredge and Scallop Trawls	Total
1994	83%	1%	16%	100%
1995	2%	4%	95%	100%
1996	7%	9%	84%	100%
1997	1%	46%	53%	100%
1998	2%	68%	30%	100%
1999	0%	4%	96%	100%
2000	2%	0%	98%	100%
2001	13%	0%	87%	100%
2002	0%	2%	98%	100%
2003	27%	10%	63%	100%
2004	3%	86%	10%	100%
2005	8%	35%	57%	100%
2006	25%	35%	40%	100%
2007	10%	32%	58%	100%
2008	5%	25%	70%	100%
2009	3%	62%	36%	100%
2010	12%	10%	78%	100%
2011	3%	22%	76%	100%

Table B25. Total number of Southern New England Mid-Atlantic yellowtail flounder trips observed by gear from 1994 to 2011. In 2010-2011, the number of observed trips includes trips observed both at-sea monitors and observers.

Year	Otter Trawl Small Mesh	Otter Trawl Large Mesh	Scallop Dredge_Gen Category Permit	Scallop Dredge_Limited Category Permit	Scallop Trawl
1994	10	6	0	7	0
1995	48	36	0	12	0
1996	42	25	0	22	0
1997	32	10	1	10	0
1998	16	6	4	7	0
1999	27	4	2	8	0
2000	24	14	11	59	0
2001	42	22	0	4	0
2002	39	12	3	8	0
2003	56	44	6	15	0
2004	169	162	14	39	8
2005	179	345	25	36	9
2006	111	158	35	66	1
2007	164	235	69	78	18
2008	102	221	113	113	28
2009	262	231	16	61	1
2010	318	278	39	84	16
2011	265	406	23	90	3

Table B26. Southern New England Mid-Atlantic yellowtail flounder commercial discards at age in thousands of fish.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Total
1973	192	2,982	1,355	52	0	0	0	0	0	0	4,581
1974	731	26,666	796	45	0	0	0	0	0	0	28,238
1975	8,734	1,438	1	10	0	0	0	0	0	0	10,182
1976	214	5,203	14	0	0	0	0	0	0	0	5,431
1977	5,445	2,767	43	0	0	0	0	0	0	0	8,255
1978	8,677	10,102	7	0	0	0	0	0	0	0	18,786
1979	186	14,305	119	0	0	0	0	0	0	0	14,610
1980	869	5,441	18	0	0	0	0	0	0	0	6,328
1981	38	4,013	319	0	0	0	0	0	0	0	4,370
1982	113	17,716	905	3	0	0	0	0	0	0	18,737
1983	2,611	4,872	5,682	18	0	0	0	0	0	0	13,182
1984	470	3,141	951	75	0	0	0	0	0	0	4,638
1985	2,073	3,044	20	0	0	0	0	0	0	0	5,138
1986	423	3,755	39	0	0	0	0	0	0	0	4,217
1987	1,518	2,034	19	0	0	0	0	0	0	0	3,571
1988	5,899	896	4	0	0	0	0	0	0	0	6,799
1989	24	14,002	1,834	131	6	0	0	0	0	0	15,997
1990	192	1,634	23,721	673	11	0	0	0	0	0	26,231
1991	446	1,357	2,826	2,889	12	0	0	0	0	0	7,530
1992	477	1,152	1,086	659	33	0	0	0	0	0	3,407
1993	13	212	15	9	0	0	0	0	0	0	249
1994	196	642	279	187	89	15	0	0	0	0	1,409
1995	1	376	122	41	7	2	2	1	2	0	555
1996	4	218	564	71	12	6	1	1	0	0	877
1997	19	163	549	245	26	2	3	1	0	0	1,008
1998	5	640	390	140	38	12	0	0	0	0	1,225
1999	5	99	104	26	7	1	2	0	0	0	245
2000	19	533	202	60	2	1	1	0	0	0	818
2001	0	97	243	47	4	0	0	0	0	0	390
2002	8	161	148	62	10	1	0	0	0	0	390
2003	3	124	214	67	13	5	3	0	0	0	430
2004	323	175	38	30	8	2	0	0	0	0	576
2005	35	93	61	45	33	7	6	0	0	0	281
2006	57	289	155	59	20	11	10	4	1	0	607
2007	10	268	443	88	21	10	7	3	1	0	851
2008	33	71	373	446	35	2	1	0	0	0	962
2009	16	161	129	150	146	9	1	0	0	0	612
2010	4	71	119	70	98	28	2	0	0	0	392
2011	18	43	83	77	53	36	9	1	0	0	320

Table B27. Relative difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder discarded numbers at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Relative differences were expressed as the ratio of the current assessment numbers at age to the 2008 assessment numbers at age (*ratios less than one indicate fewer fish at age*).

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1994	0.54	0.77	2.21	1.02	1.05	1.77
1995	1.11	1.01	1.07	1.13	1.78	0.87
1996	1.20	0.96	1.13	1.22	1.02	1.14
1997	0.86	0.37	0.97	1.72	1.05	3.51
1998	0.26	0.66	1.07	2.34	11.64	0.45
1999	0.53	0.47	0.64	1.09	0.46	3.52
2000	8.40	2.46	2.01	1.23	1.06	0.30
2001		7.19	4.24	5.12	4.25	
2002	7.89	6.30	7.26	5.62	4.99	2.06
2003	1.55	2.07	1.63	1.66	1.27	1.61
2004	81.27	2.17	0.67	0.50	0.16	0.07
2005	0.53	0.65	0.90	1.14	1.05	0.90
2006	2.95	1.29	0.82	1.43	3.65	2.13
2007	1.59	1.30	1.70	1.86	0.95	

Table B28. Mean weights at age (kg) of commercially discarded Southern New England Mid-Atlantic yellowtail flounder from 1994 to 2011

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10
1973	0.210	0.298	0.381	0.420	0.000	0.000	0.000	0.000	0.000	0.000
1974	0.203	0.308	0.359	0.429	0.000	0.000	0.000	0.000	0.000	0.000
1975	0.218	0.290	0.385	0.439	0.000	0.000	0.000	0.000	0.000	0.000
1976	0.228	0.303	0.427	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.215	0.284	0.385	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.234	0.296	0.402	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.189	0.301	0.366	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1980	0.206	0.281	0.384	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1981	0.140	0.262	0.343	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.226	0.263	0.354	0.502	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.175	0.262	0.341	0.499	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.182	0.239	0.298	0.388	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.183	0.264	0.370	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.186	0.285	0.335	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.247	0.268	0.361	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.270	0.293	0.398	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.311	0.337	0.389	0.546	0.736	0.000	0.000	0.000	0.000	0.000
1990	0.301	0.327	0.378	0.461	0.800	0.000	0.000	0.000	0.000	0.000
1991	0.206	0.248	0.302	0.387	0.413	0.000	0.000	0.000	0.000	0.000
1992	0.167	0.308	0.351	0.354	0.344	0.000	0.000	0.000	0.000	0.000
1993	0.122	0.358	0.430	0.471	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.078	0.246	0.304	0.357	0.393	0.495	0.000	0.000	0.000	0.000
1995	0.076	0.216	0.300	0.384	0.537	0.568	0.799	0.587	0.799	0.000
1996	0.102	0.280	0.315	0.428	0.570	0.686	0.743	0.745	0.000	0.000
1997	0.139	0.236	0.366	0.451	0.558	0.801	0.814	0.952	0.742	0.000
1998	0.160	0.258	0.348	0.464	0.592	0.649	0.000	0.000	0.000	0.000
1999	0.172	0.303	0.395	0.543	0.668	0.845	1.891	0.000	0.000	0.000
2000	0.181	0.289	0.416	0.504	0.641	0.909	0.763	0.000	0.000	0.000
2001	0.000	0.343	0.388	0.523	0.539	0.000	0.000	0.000	0.000	0.000
2002	0.164	0.283	0.415	0.577	0.767	0.679	0.922	0.000	0.000	0.000
2003	0.095	0.267	0.369	0.581	0.742	0.881	1.042	0.000	0.000	0.000
2004	0.136	0.291	0.418	0.463	0.544	0.806	1.106	0.000	0.000	0.000
2005	0.102	0.260	0.365	0.475	0.630	0.746	0.974	0.000	0.000	0.000
2006	0.110	0.230	0.343	0.460	0.606	0.729	0.842	1.025	0.946	1.130
2007	0.111	0.258	0.351	0.452	0.625	0.743	0.905	1.130	1.217	0.000
2008	0.151	0.261	0.382	0.453	0.554	0.767	1.005	1.104	0.763	0.000
2009	0.105	0.269	0.353	0.531	0.617	0.730	1.088	0.859	0.000	0.000
2010	0.099	0.276	0.409	0.460	0.568	0.670	0.917	1.299	0.988	0.000
2011	0.130	0.231	0.378	0.470	0.562	0.690	0.969	1.259	0.000	0.000

Table B29. Absolute difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder discarded mean weights at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Absolute difference were expressed as current assessment mean weights at age minus the GARM III estimates of mean weights at age (*negative values imply lighter fish at age*)

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Age-11
1994	-0.05	0.05	-0.04	-0.04	0.00	0.06	-0.64	0.00	0.00	0.00	0.00
1995	0.00	-0.01	-0.02	-0.02	-0.04	-0.07	-0.10	-0.06	-0.10	0.00	0.00
1996	0.00	-0.02	-0.02	-0.05	-0.06	-0.10	-0.08	-0.08	0.00	0.00	0.00
1997	-0.05	-0.01	0.03	-0.06	-0.16	-0.10	0.08	0.95	0.74	0.00	0.00
1998	-0.01	0.01	0.00	0.05	-0.02	0.02	0.00	0.00	0.00	0.00	0.00
1999	-0.03	-0.04	-0.04	-0.05	-0.13	0.06	1.89	0.00	0.00	0.00	0.00
2000	0.11	0.02	-0.01	-0.08	-0.09	-0.06	-0.05	0.00	0.00	0.00	0.00
2001	0.00	0.05	0.02	-0.06	-0.06	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	-0.01	0.00	0.01	0.07	-0.12	0.92	0.00	0.00	0.00	0.00
2003	-0.01	-0.01	-0.02	-0.04	-0.03	-0.05	-0.01	0.00	0.00	0.00	0.00
2004	-0.02	0.00	0.00	-0.03	-0.03	0.14	0.36	-1.02	-0.98	0.00	0.00
2005	0.01	-0.01	-0.01	-0.03	-0.05	-0.09	0.01	-1.12	0.00	-1.63	0.00
2006	-0.01	0.01	-0.02	-0.10	-0.15	-0.08	-0.08	-0.21	0.95	1.13	0.00
2007	-0.01	0.00	-0.01	-0.01	-0.16	0.74	0.91	1.13	1.22	0.00	0.00

Table B30. Total number of length and age samples derived from commercially discarded yellowtail flounder from 1994 to 2011 by gear and calendar half year. Sampling intensity is expressed as lengths per 100 metric tons

	Otter Trawl		Scallop Trawl		Scallop Dredge					
Year	Half 1	Half2	Half 1	Half2	Half 1	Half2	Total Lengths	Total Ages	Discards (mt)	Lengths/100mt
1994		25			6	36	67	507	367.34	18
1995	5	10			30	12	57	334	142.41	40
1996	4	44			62	140	250	747	282.00	89
1997	48	34			98	32	212	1194	372.62	57
1998	8	20			20	49	97	705	396.40	24
1999					39	38	77	822	95.86	80
2000	24	17			65	147	253	606	274.66	92
2001	8				25	1	34	764	154.01	22
2002		16				86	102	767	152.63	67
2003	74	18			91	38	221	511	169.34	131
2004	32	77			3	296	408	199	130.23	313
2005	142	225		7	115	140	629	273	103.60	607
2006	253	120		16	102	362	853	1290	186.83	457
2007	93	133	6	20	323	535	1110	1332	296.45	374
2008	129	64	10	17	587	638	1445	1160	390.93	370
2009	150	145	4		322	201	822	924	267.82	307
2010	77	73	51	12	352	364	929	1307	177.43	524
2011	371	115	12		448	161	1107	1405	144.89	764

Table B31. Observer length sampling aggregated to estimate length composition by commercially discarded yellowtail flounder by gear and calendar half year from 1994 to 2011.

<table>
<tr><th></th><th colspan="2">Large Mesh Otter Trawl</th></tr>
<tr><th>Year</th><th>Half 1</th><th>Half 2</th></tr>
<tr><td>1994</td><td colspan="2"></td></tr>
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<table>
<tr><th></th><th colspan="2">Small Mesh Otter Trawl</th></tr>
<tr><th>Year</th><th>Half 1</th><th>Half 2</th></tr>
<tr><td>1994</td><td colspan="2"></td></tr>
<tr><td>1995</td><td colspan="2"></td></tr>
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<tr><td>2011</td><td></td><td></td></tr>
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<table>
<tr><th></th><th colspan="2">Scallop Dredge and Scallop Trawl</th></tr>
<tr><th>Year</th><th>Half 1</th><th>Half 2</th></tr>
<tr><td>1994</td><td></td><td></td></tr>
<tr><td>1995</td><td></td><td></td></tr>
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<tr><td>2011</td><td></td><td></td></tr>
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Table B32. Southern New England Mid-Atlantic yellowtail flounder total catch at age (landings + discards) in thousands of fish.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+	Total
1973	201	5,333	11,815	7,973	5,226	6,286	36,834
1974	788	25,853	5,477	7,366	3,687	3,347	46,517
1975	8,037	3,986	1,884	1,129	1,597	1,452	18,084
1976	193	6,156	1,179	327	449	896	9,200
1977	4,968	4,750	4,886	507	278	649	16,039
1978	7,830	13,181	2,163	1,470	247	179	25,070
1979	186	17,988	8,655	1,062	438	131	28,461
1980	919	9,671	6,593	3,829	512	167	21,691
1981	34	6,627	7,546	2,926	1,111	183	18,427
1982	158	33,925	14,267	1,858	415	86	50,709
1983	2,407	18,801	42,269	3,600	385	192	67,654
1984	470	5,885	19,895	8,121	878	276	35,525
1985	2,032	7,769	2,173	1,968	1,109	246	15,297
1986	421	9,594	3,322	635	356	149	14,476
1987	1,442	3,234	2,366	926	167	65	8,200
1988	5,309	2,020	536	506	134	32	8,537
1989	22	18,520	3,164	449	48	3	22,205
1990	173	1,893	40,271	2,142	89	5	44,573
1991	401	1,475	4,886	9,414	166	51	16,394
1992	429	1,338	1,989	2,674	294	18	6,741
1993	12	436	445	711	145	4	1,752
1994	177	593	539	407	307	96	2,119
1995	1	339	274	273	57	31	976
1996	4	491	1,131	238	31	30	1,924
1997	17	182	1,521	920	115	49	2,804
1998	5	1,232	1,166	423	78	16	2,920
1999	69	433	2,132	482	94	42	3,253
2000	18	1,167	1,426	558	57	10	3,237
2001	0	494	1,946	547	139	43	3,169
2002	7	385	1,154	467	34	1	2,049
2003	3	234	731	413	34	13	1,428
2004	291	174	347	305	204	101	1,423
2005	32	185	190	168	117	49	740
2006	51	354	304	159	61	72	1,002
2007	9	279	703	176	45	36	1,248
2008	30	67	458	662	51	9	1,277
2009	14	168	154	318	252	14	920
2010	3	67	183	105	158	55	571
2011	16	65	204	198	157	118	758

Table B33. Relative difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder commercially catch numbers at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Relative differences were expressed as the ratio of the current assessment numbers at age to the 2008 assessment numbers at age (*ratios less than one indicate fewer fish at age*).

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1994	0.61	0.87	1.44	1.11	1.10	1.14
1995	1.25	1.14	1.57	0.97	1.15	0.89
1996	1.35	1.04	1.11	1.08	1.04	1.05
1997	0.97	0.46	1.09	1.21	1.10	1.19
1998	0.30	0.97	1.10	1.10	1.54	0.63
1999	9.00	1.00	0.98	1.20	0.77	5.32
2000	5.61	1.35	1.22	1.10	1.05	0.84
2001		1.23	1.16	1.15	1.11	1.09
2002	8.88	1.57	1.20	1.21	1.38	2.32
2003	1.74	1.64	1.29	1.23	0.39	0.58
2004	91.42	0.66	1.50	1.02	0.68	0.85
2005	0.59	0.94	0.93	1.18	1.05	0.99
2006	3.32	1.33	1.00	1.22	1.40	1.33
2007	1.79	1.37	1.37	1.41	1.13	2.42

Table B34. Mean weights at age (kg) of commercially caught Southern New England Mid-Atlantic yellowtail flounder from 1994 to 2011

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1973	0.210	0.296	0.348	0.374	0.382	0.428
1974	0.203	0.308	0.352	0.396	0.439	0.457
1975	0.218	0.289	0.376	0.432	0.435	0.481
1976	0.228	0.303	0.408	0.498	0.499	0.557
1977	0.215	0.283	0.381	0.504	0.513	0.542
1978	0.234	0.292	0.383	0.536	0.662	0.656
1979	0.189	0.301	0.364	0.475	0.590	0.662
1980	0.206	0.281	0.384	0.500	0.682	0.925
1981	0.140	0.262	0.342	0.474	0.596	0.650
1982	0.226	0.263	0.353	0.499	0.660	0.833
1983	0.175	0.261	0.339	0.496	0.668	0.819
1984	0.182	0.237	0.295	0.388	0.487	0.656
1985	0.183	0.260	0.365	0.408	0.504	0.608
1986	0.186	0.284	0.331	0.463	0.587	0.642
1987	0.247	0.268	0.353	0.404	0.520	0.631
1988	0.270	0.293	0.396	0.493	0.611	0.821
1989	0.311	0.338	0.394	0.553	0.735	0.957
1990	0.301	0.327	0.378	0.455	0.763	0.884
1991	0.206	0.263	0.339	0.415	0.680	0.800
1992	0.167	0.317	0.369	0.436	0.602	0.918
1993	0.122	0.354	0.430	0.451	0.641	1.040
1994	0.078	0.247	0.321	0.387	0.480	0.622
1995	0.076	0.216	0.325	0.401	0.579	0.758
1996	0.102	0.335	0.368	0.457	0.604	0.740
1997	0.139	0.251	0.396	0.466	0.584	0.768
1998	0.160	0.287	0.367	0.494	0.567	0.726
1999	0.131	0.309	0.400	0.557	0.629	0.760
2000	0.185	0.321	0.444	0.561	0.667	0.752
2001	0.145	0.360	0.419	0.567	0.684	0.824
2002	0.164	0.330	0.438	0.574	0.764	0.751
2003	0.095	0.313	0.413	0.572	0.722	0.945
2004	0.136	0.295	0.436	0.540	0.581	0.799
2005	0.102	0.295	0.415	0.511	0.634	0.795
2006	0.110	0.251	0.373	0.475	0.607	0.783
2007	0.111	0.268	0.363	0.472	0.628	0.834
2008	0.151	0.266	0.388	0.461	0.574	1.077
2009	0.105	0.281	0.367	0.502	0.601	0.753
2010	0.099	0.281	0.414	0.470	0.573	0.702
2011	0.130	0.280	0.412	0.491	0.572	0.717

Table B35. Absolute difference in the estimates of Southern New England Mid-Atlantic yellowtail flounder mean weights at age from the 2008 Groundfish Assessment Review Meeting (GARM III) compared to the current assessment through 2007. Relative differences were expressed as the ratio of the current assessment numbers at age to the 2008 assessment numbers at age (*negative values imply lighter fish at age*).

Bc	-0.05	0.05	-0.03	-0.03	-0.03	-0.05
1995	0.00	-0.01	-0.04	-0.05	-0.02	-0.09
1996	0.00	-0.01	-0.02	-0.01	-0.01	0.01
1997	-0.05	0.00	-0.01	-0.05	-0.08	-0.07
1998	-0.01	0.00	-0.02	-0.03	-0.02	0.02
1999	-0.07	-0.05	-0.03	-0.05	-0.14	-0.36
2000	0.03	-0.03	-0.04	-0.07	-0.08	-0.13
2001	-0.01	-0.02	-0.03	-0.05	-0.07	-0.09
2002	0.00	-0.05	-0.04	-0.05	-0.08	-0.05
2003	-0.01	-0.04	-0.02	-0.05	0.09	0.11
2004	-0.02	-0.03	0.03	0.05	0.00	0.05
2005	0.01	-0.01	-0.01	-0.02	-0.04	-0.04
2006	-0.01	-0.01	-0.02	-0.06	-0.07	-0.07
2007	-0.01	-0.01	-0.02	-0.03	-0.10	-0.04

Table B36. Summary vessels and trawl doors used in the Northeast Fisheries Science Center (NEFSC) surveys from 1963 to 2011

Year	Spring	Autumn	Winter	Door	Gear
1963		Albatross IV		BMV	Yankee 36
1964		Albatross IV		BMV	Yankee 36
1965		Albatross IV		BMV	Yankee 36
1966		Albatross IV		BMV	Yankee 36
1967		Albatross IV		BMV	Yankee 36
1968	Albatross IV	Albatross IV		BMV	Yankee 36
1969	Albatross IV	Albatross IV		BMV	Yankee 36
1970	Albatross IV	Albatross IV		BMV	Yankee 36
1971	Albatross IV	Albatross IV		BMV	Yankee 36
1972	Albatross IV	Albatross IV		BMV	Yankee 36
1973	Albatross IV	Albatross IV		BMV	Yankee 41
1974	Albatross IV	Albatross IV		BMV	Yankee 41
1975	Albatross IV	Albatross IV		BMV	Yankee 41
1976	Albatross IV	Albatross IV		BMV	Yankee 41
1977	Albatross IV	Delaware II		BMV	Yankee 41
1978	Albatross IV	Delaware II		BMV	Yankee 41
1979	Albatross IV/Delaware II	Albatross IV/Delaware II		BMV	Yankee 41
1980	Albatross IV/Delaware II	Delaware II		BMV	Yankee 41
1981	Delaware II	Albatross IV/Delaware II		BMV	Yankee 41
1982	Delaware II	Albatross IV		BMV	Yankee 36
1983	Albatross IV	Albatross IV		BMV	Yankee 36
1984	Albatross IV	Albatross IV		BMV	Yankee 36
1985	Albatross IV	Albatross IV		Polyvalent	Yankee 36
1986	Albatross IV	Albatross IV		Polyvalent	Yankee 36
1987	Albatross IV/Delaware II	Albatross IV		Polyvalent	Yankee 36
1988	Albatross IV	Albatross IV/Delaware II		Polyvalent	Yankee 36
1989	Delaware II	Delaware II		Polyvalent	Yankee 36
1990	Delaware II	Delaware II		Polyvalent	Yankee 36
1991	Delaware II	Delaware II		Polyvalent	Yankee 36
1992	Albatross IV	Albatross IV	Albatross IV/Delaware II	Polyvalent	Yankee 36
1993	Albatross IV	Delaware II	Albatross IV	Polyvalent	Yankee 36
1994	Delaware II	Albatross IV	Delaware II	Polyvalent	Yankee 36
1995	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
1996	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
1997	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
1998	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
1999	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2000	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2001	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2002	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2003	Delaware II	Albatross IV	Delaware II	Polyvalent	Yankee 36
2004	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2005	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2006	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2007	Albatross IV	Albatross IV	Albatross IV	Polyvalent	Yankee 36
2008	Albatross IV	Albatross IV		Polyvalent	Yankee 36
2009	Henry B. Bigelow	Henry B. Bigelow		PolyIce Oval	4 Seam, 3 Bridle
2010	Henry B. Bigelow	Henry B. Bigelow		PolyIce Oval	4 Seam, 3 Bridle
2011	Henry B. Bigelow	Henry B. Bigelow		PolyIce Oval	4 Seam, 3 Bridle

Table B37. 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
Delaware II to Albatross IV	Biomass (weight)	NA	0.850000	Forrester et al. 1997
	Abundance (numbers)	NA	0.850000	
Yankee 41 to Yankee 36	Biomass (weight)	NA	1.730000	
	Abundance (numbers)	NA	1.760000	
BMV door to Polyvalent door	Biomass (weight)	NA	1.280000	
	Abundance (numbers)	NA	1.220000	
Bigelow to Albatross IV	Biomass_Spring (Weight)	NA	2.244000	Miller et al. 2010
	Biomass _Fall (weight)	NA	2.402000	
	Abundance (numbers)	≤ 20	3.857302	Brooks et al 2010
		21	3.621597	
		22	3.385892	
		23	3.150187	
		24	2.914482	
		25	2.678777	
		26	2.443072	
		27	2.207367	
		≥ 28	1.971662	

Table B38. Summary differences in survey protocol from FSV Albatross IV (2008 and earlier) and FSV Henry B. Bigelow (2009-present). Adapted from Brooks et al (2010)

Measure	FSV Henry Bigelow	FSV Albatross IV
Tow Speed	3.0 kot SOG	3.8 Knots SOG
Tow duration	20 mins	30 mins
Headrope height	3.5 - 4.0 meters	1.0 - 2.0 meters
Ground Gear	Rockhopper Sweep	Roller Sweep
(Cookies, rock hoppers etc)	Total Length - 25.5 meters	Total Length 24.5 meters
	Center - 8.9 meter length, 16" rockhoppers	Center - 5.0 meters length, 16" rollers
	Wings - 8.2 meter each	Wings - 9.75 meters each, 4" cookies
	14" rockhoppers	
Mesh	Poly webbings	Nylon webbing
	Forward portions of trawls (jibs, upper and lower wing end, 1st & 2nd side panels, 1st 1st botom 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 polyvalent	450 kg polyvalent
Other Coments	Wing end to door distance Distance = 36.5m	Wing end to door distance Distance = 9.00

Table B39. Summary of the Northeast Fisheries Science Center (NEFSC) Southern New England Mid-Atlantic offshore survey strata and number of tow by survey (Spring/Fall/Winter) *The spring survey did not begin until 1968. The winter survey began in 1992 and ended in 2007.

Year	Strata Sampled			Tows Sampled			Proportion Positive Tows		
	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter
1963		6			30			0.77	
1964		6			28			0.79	
1965		6			26			0.81	
1966		6			28			0.82	
1967		6			42			0.88	
1968	9	6		48	44		0.83	0.80	
1969	9	6		56	40		0.89	0.83	
1970	9	6		63	45		0.84	0.87	
1971	9	6		63	53		0.75	0.70	
1972	9	6		59	46		0.83	0.70	
1973	9	6		90	41		0.78	0.37	
1974	9	6		51	40		0.67	0.28	
1975	9	6		55	44		0.53	0.32	
1976	9	6		65	43		0.49	0.40	
1977	9	6		65	40		0.57	0.48	
1978	9	6		63	67		0.57	0.54	
1979	9	6		71	71		0.65	0.56	
1980	9	6		112	39		0.72	0.56	
1981	9	6		54	40		0.69	0.70	
1982	9	6		55	40		0.76	0.55	
1983	9	6		54	40		0.74	0.60	
1984	9	6		54	38		0.63	0.53	
1985	9	6		54	37		0.59	0.30	
1986	9	6		55	39		0.60	0.28	
1987	9	6		56	40		0.34	0.25	
1988	9	6		56	39		0.34	0.49	
1989	9	6		55	40		0.69	0.50	
1990	9	6		55	40		0.64	0.53	
1991	9	6		55	40		0.62	0.45	
1992	9	6	6	54	40	43	0.44	0.15	0.65
1993	9	6	6	54	40	39	0.28	0.25	0.54
1994	9	6	6	55	41	31	0.24	0.27	0.61
1995	9	6	6	55	38	42	0.44	0.29	0.60
1996	9	6	6	57	40	45	0.44	0.20	0.56
1997	9	6	6	55	40	42	0.42	0.43	0.71
1998	9	6	6	55	40	41	0.53	0.50	0.61
1999	9	6	6	55	40	42	0.51	0.28	0.57
2000	9	6	6	55	40	41	0.44	0.28	0.54
2001	9	6	6	55	40	54	0.36	0.28	0.61
2002	9	6	6	55	39	51	0.27	0.41	0.65
2003	9	6	6	50	40	26	0.20	0.23	0.58
2004	9	6	6	55	40	43	0.22	0.20	0.53
2005	9	6	6	55	40	31	0.31	0.48	0.55
2006	9	6	6	55	50	46	0.38	0.30	0.76
2007	9	6	6	55	40	41	0.36	0.18	0.71
2008	9	6		55	40		0.29	0.35	
2009	9	6		72	47		0.53	0.32	
2010	9	6		66	44		0.61	0.36	
2011	9	6		60	42		0.63	0.33	

Table B40. Northeast Fisheries Science Center (NEFSC) spring and fall survey indices and coefficients of variation (CV) from 1963 to 2011 for Southern New England Mid-Atlantic yellowtail flounder. *The spring survey did not begin until 1968. The winter survey began in 1992 and ended in 2007.

Year	Spring				Fall				Winter			
	Mean number/tow	CV	Mean weight/tow (kg)	CV	Mean number/tow	CV	Mean weight/tow (kg)	CV	Mean number/tow	CV	Mean weight/tow (kg)	CV
1963					54.1	0.19	19.1	0.19				
1964					54.8	0.19	18.1	0.20				
1965					51.8	0.35	13.1	0.22				
1966					60.4	0.22	11.6	0.17				
1967					81.9	0.16	18.0	0.14				
1968	102.7	0.16	23.9	0.16	76.0	0.23	16.7	0.20				
1969	81.8	0.13	18.3	0.13	72.5	0.27	17.8	0.28				
1970	62.0	0.15	15.4	0.13	79.3	0.27	20.8	0.26				
1971	50.0	0.13	12.2	0.12	59.2	0.31	11.5	0.29				
1972	51.6	0.17	13.8	0.15	150.5	0.37	40.4	0.37				
1973	27.5	0.12	7.9	0.12	15.1	0.43	4.0	0.38				
1974	11.0	0.22	3.6	0.23	6.3	0.42	2.0	0.42				
1975	2.9	0.19	1.0	0.16	2.9	0.5	0.7	0.50				
1976	3.6	0.21	1.1	0.2	8.7	0.35	2.5	0.35				
1977	4.2	0.29	1.3	0.26	4.6	0.33	1.2	0.36				
1978	11.2	0.18	2.6	0.15	7.8	0.26	2.2	0.26				
1979	3.5	0.22	0.8	0.18	6.9	0.2	2.0	0.20				
1980	8.8	0.13	3.2	0.12	5.3	0.37	1.5	0.37				
1981	16.2	0.19	4.4	0.19	21.4	0.25	4.4	0.23				
1982	26.0	0.19	6.4	0.19	30.5	0.41	7.3	0.40				
1983	18.2	0.15	5.2	0.13	23.6	0.32	5.7	0.31				
1984	5.0	0.18	1.7	0.18	5.6	0.29	1.3	0.29				
1985	3.6	0.26	0.9	0.24	1.2	0.35	0.3	0.37				
1986	4.2	0.13	1.1	0.12	2.7	0.33	0.7	0.34				
1987	1.0	0.24	0.3	0.27	2.0	0.42	0.4	0.46				
1988	1.2	0.26	0.4	0.25	5.0	0.25	0.5	0.28				
1989	10.2	0.18	1.8	0.18	10.3	0.32	2.0	0.32				
1990	15.5	0.21	4.3	0.2	4.8	0.35	1.1	0.31				
1991	6.9	0.14	2.1	0.14	2.3	0.3	0.6	0.27				
1992	2.2	0.20	0.8	0.21	0.5	0.48	0.1	0.48	13.0	0.14	4.8	0.15
1993	0.9	0.23	0.3	0.23	0.5	0.37	0.1	0.31	6.3	0.28	2.1	0.24
1994	0.3	0.29	0.1	0.35	1.5	0.41	0.3	0.40	10.9	0.33	3.3	0.3
1995	1.4	0.20	0.3	0.18	1.2	0.69	0.3	0.69	14.5	0.51	3.5	0.52
1996	2.3	0.25	0.7	0.23	0.9	0.48	0.2	0.43	10.6	0.25	3.3	0.26
1997	2.5	0.35	0.8	0.32	3.1	0.32	0.9	0.33	15.8	0.18	5.7	0.19
1998	3.7	0.23	0.8	0.21	2.7	0.41	0.7	0.42	10.8	0.22	2.8	0.19
1999	3.1	0.13	1.1	0.14	2.0	0.61	0.5	0.59	14.3	0.2	5.2	0.2
2000	2.9	0.18	1.0	0.18	2.2	0.53	0.7	0.52	9.3	0.31	3.0	0.27
2001	1.6	0.24	0.7	0.26	1.2	0.47	0.4	0.51	11.5	0.26	4.8	0.27
2002	1.7	0.37	0.5	0.34	3.0	0.46	1.1	0.48	7.5	0.18	2.6	0.17
2003	0.4	0.36	0.2	0.43	2.3	0.55	0.4	0.55	4.2	0.29	1.5	0.31
2004	0.6	0.36	0.2	0.34	0.3	0.35	0.1	0.46	2.1	0.2	0.8	0.25
2005	0.7	0.25	0.2	0.33	2.6	0.26	0.5	0.32	3.0	0.22	0.9	0.27
2006	2.0	0.38	0.4	0.37	3.5	0.32	0.7	0.33	24.6	0.29	3.8	0.27
2007	1.5	0.20	0.4	0.21	1.7	0.42	0.5	0.42	15.8	0.23	3.9	0.23
2008	1.3	0.58	0.4	0.59	3.3	0.39	0.9	0.41				
2009	2.0	0.29	0.7	0.32	1.7	0.34	0.4	0.33				
2010	2.8	0.12	0.8	0.13	12.3	0.52	3.7	0.53				
2011	2.3	0.17	0.7	0.17	1.7	0.68	0.6	0.73				

Table B41. Northeast Fisheries Science Center (NEFSC) spring survey minimum swept area numbers (000's) at age. These values were computed from offshore Strata 1, 2, 5, 6, 9, 10, 69, 73 and 74 which combined have an area of 18718 square nautical miles. To convert these values to catch/tow in numbers or biomass divide by 1671.25 (=1000*18718/0.0112, where 1000 is the units in the VPA, 18718 is the survey area, and 0.0112 is the area swept by a single tow).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total
1973	913	5,523	15,093	8,483	6,581	9,401	45,993
1974	592	2,508	2,956	5,700	3,477	3,087	18,319
1975	414	1,513	451	585	1,050	826	4,839
1976	19	4,301	580	279	265	500	5,943
1977	1,524	1,634	2,882	263	165	458	6,925
1978	3,065	11,880	2,110	901	293	483	18,731
1979	981	2,902	1,546	278	121	61	5,890
1980	666	6,520	4,418	2,786	274	109	14,774
1981	849	18,261	4,744	2,447	587	113	27,000
1982	340	29,951	9,723	2,438	799	273	43,524
1983	66	10,832	17,949	1,220	352	37	30,456
1984	78	924	1,838	4,457	677	423	8,398
1985	446	2,696	678	803	1,193	259	6,074
1986	27	4,835	1,530	395	207	26	7,021
1987	0	144	1,171	278	0	0	1,593
1988	402	596	208	290	491	48	2,035
1989	230	15,926	762	161	0	0	17,078
1990	127	690	21,805	3,138	90	0	25,849
1991	346	844	3,565	5,904	765	85	11,510
1992	33	85	955	2,670	0	0	3,742
1993	27	423	187	738	118	0	1,493
1994	0	382	23	0	97	27	530
1995	26	1,953	114	154	31	115	2,394
1996	0	664	2,178	947	120	0	3,909
1997	88	1,479	1,912	546	112	0	4,137
1998	113	5,040	645	269	61	34	6,163
1999	59	1,087	3,226	583	124	38	5,118
2000	32	1,936	2,478	329	26	0	4,801
2001	0	116	1,935	401	137	38	2,627
2002	82	1,990	393	334	112	0	2,911
2003	52	126	339	179	54	0	750
2004	27	227	488	137	91	32	1,003
2005	246	343	162	113	255	26	1,144
2006	84	2,647	374	177	0	53	3,335
2007	0	963	1,321	146	0	0	2,430
2008	0	83	1,145	802	82	0	2,112
2009	130	776	720	1,100	501	38	3,266
2010	136	1,503	1,693	607	748	53	4,738
2011	298	876	999	1,052	284	319	3,828

Table B42. Northeast Fisheries Science Center (NEFSC) fall survey minimum swept area numbers (000's) at age. These values were computed from offshore Strata 1, 2, 5, 6, 9, 10 which combined have an area of 12867 square nautical miles. To convert these values to catch/tow in numbers or biomass divide by 1148.84 (=1000*12867/0.0112, where 1000 is the units in the VPA, 12867 is the survey area, and 0.0112 is the area swept by a single tow).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total
1973	2,069	2,611	5,902	3,233	2,292	1,236	17,343
1974	1,017	1,604	569	2,241	949	690	7,069
1975	1,908	525	193	291	277	144	3,338
1976	2,752	5,893	490	65	102	714	10,017
1977	2,693	1,714	673	39	33	127	5,279
1978	2,478	5,684	353	281	29	89	8,912
1979	1,778	3,911	1,881	287	31	30	7,918
1980	1,374	3,464	902	372	0	0	6,112
1981	11,209	11,315	1,612	235	137	30	24,538
1982	2,826	24,940	6,155	750	334	0	35,006
1983	2,659	15,819	7,852	650	54	37	27,071
1984	2,024	1,787	2,143	468	0	0	6,422
1985	823	416	106	53	0	0	1,398
1986	539	1,869	526	151	17	0	3,102
1987	1,162	565	492	45	38	27	2,330
1988	5,020	365	162	162	15	30	5,754
1989	23	10,224	1,420	169	11	0	11,847
1990	27	1,953	3,318	264	0	0	5,563
1991	552	238	1,501	359	0	0	2,650
1992	192	27	82	327	0	0	629
1993	324	27	127	101	0	0	580
1994	847	513	123	133	61	29	1,705
1995	160	741	296	133	0	61	1,389
1996	515	185	367	0	0	0	1,067
1997	945	596	1,676	311	27	0	3,556
1998	1,023	1,861	142	56	0	26	3,108
1999	1,422	450	321	32	32	0	2,257
2000	57	1,917	348	197	0	26	2,545
2001	448	702	182	82	0	0	1,414
2002	291	2,008	982	161	0	0	3,443
2003	1,344	10	309	263	0	29	1,954
2004	81	112	0	26	55	29	303
2005	2,169	533	213	56	55	0	3,026
2006	1,370	2,472	196	22	0	0	4,060
2007	257	1,286	409	0	30	0	1,983
2008	1,224	452	1,233	768	68	29	3,774
2009	430	720	431	321	23	0	1,925
2010	340	6,589	3,627	2,603	932	0	14,092
2011	243	323	709	366	204	25	1,870

Table B43. Northeast Fisheries Science Center (NEFSC) winter survey percent contribution by strata for Southern New England Mid-Atlantic yellowtail flounder. Northern strata includes 1, 2, 5, 6, and 10 while the Southern Strata includes 69, 73 and 74.

Year	Northern Strata (1, 2, 5, 6, 9, 10)	Southern Strata (69, 73, 74)
1992	90%	10%
1993	92%	8%
1994	94%	6%
1995	54%	**46%**
1996	88%	**12%**
1997	96%	4%
1998	94%	6%
1999	97%	3%
2000	95%	5%
2001	98%	2%
2002	99%	1%
2003	99%	1%
2004	100%	0%
2005	98%	2%
2006	97%	3%
2007	93%	7%

Table B44. Northeast Fisheries Science Center (NEFSC) winter survey minimum swept area numbers (000's) at age. These values were computed from offshore Strata 1, 2, 5, 6, 9, 10 which combined have an area of 12867 square nautical miles. To convert these values to catch/tow in numbers or biomass divide by 1148.84 (=1000*12867/0.0131, where 1000 is the units in the VPA, 12867 is the survey area, and 0.0131 is the area swept by a single tow).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total
1973	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	14	2,049	3,496	9,958	1,225	0	16,742
1993	852	2,617	1,199	3,182	385	0	8,235
1994	317	10,046	878	1,943	1,187	577	14,947
1995	125	7,052	3,386	856	334	220	11,972
1996	0	1,568	10,411	1,044	200	137	13,360
1997	190	3,333	13,068	4,187	771	0	21,548
1998	169	10,623	2,275	1,458	158	26	14,709
1999	45	4,071	14,271	957	394	80	19,819
2000	39	6,863	4,114	1,437	92	63	12,608
2001	40	1,279	12,196	2,177	286	123	16,101
2002	17	3,822	3,684	2,925	143	28	10,619
2003	474	996	3,661	759	61	37	5,988
2004	72	1,374	456	842	189	78	3,010
2005	545	1,041	914	779	759	107	4,145
2006	994	25,397	6,569	494	127	205	33,787
2007	46	9,039	10,137	1,615	135	0	20,973
2008	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0

Table B45. Larval indices for Southern New England Mid-Atlantic yellowtail flounder for years during which the 505µm (1977-1987) and the 330 µm (1995-2011) mesh sizes were used. Note that these indices are not comparable and were treated as separate indices in the model.

Year	Abundance (N)		Year	Abundance (N)
1977	33.6		1995	42.2
1978	27.3		2000	59.1
1979	38.2		2001	243.9
1980	112.5		2002	119.8
1981	68.2		2004	77.1
1982	47.3		2005	57.2
1983	166.0		2006	47.3
1984	51.5		2007	48.9
1985	16.6		2009	64.6
1986	22.2		2010	200.2
1987	70.2		2011	222.1

Table B46. Spawning seasons of yellowtail flounder adapted from Cadrin (2010). Range indicated by “-----“ and peak by “X”

Stock	Feb	Mar	Apr	May	June	Jul	Aug	Source
Grand Bank					XXX			Pitt, 1970
Scotian Shelf				---------	XXX	---------		Colton et al. 1979
						---------		Scott, 1983
					XXX	---------	---------	Sherman et al. 1987
				---------	---------	---------	---------	Neilson et al. 1988
Cape Cod				---------	---------	---------	---------	Silverman, 1983
			---------	---------	XXX	---------	---------	Sherman et al. 1987
Georges Bank		---------	XXX	XXX	---------			Colton et al. 1979
		---------	---------	---------	---------	---------	---------	Berrien, 1981
			---------	---------	---------	---------	---------	Silverman, 1983
			---------	XXX	XXX	---------	---------	Sherman et al. 1987
Southern New England		---------	---------	XXX	---------	---------	---------	Smith et al. 1975
		---------	XXX	XXX	---------			Colton et al. 1979
	---------	---------	---------	---------	---------	---------	---------	Berrien, 1981
			---------	---------	---------	---------	---------	Silverman, 1983
			---------	XXX	XXX	---------	---------	Sherman et al. 1987
Mid-Atlantic Bight		---------	---------	XXX	---------	---------	---------	Smith et al. 1975
		---------	XXX	XXX	---------			Colton et al. 1979
		---------	---------	---------	---------	---------	---------	Berrien, 1981
			---------	XXX	---------	---------	---------	Silverman, 1983
			---------	XXX	XXX	---------	---------	Sherman et al. 1987

Table B47. Estimated growth parameters for yellowtail flounder by stock and survey from data derived from the NEFSC bottom trawl survey from 1963-2011

Stock/Survey	**Linf_cm**	**k**	**t0**
CCGOM_Spring	44.6	0.43	0.23
GB_Spring	41.9	0.73	0.52
SNEMA_Spring	35.6	0.97	0.63
CCGOM_Fall	46.2	0.4	-0.5
GB_Fall	42.9	0.62	-0.26
SNEMA_Fall	35.8	0.84	-0.16

Table B48. Estimates of age at 50% maturity (A50) and length at 50% maturity (L50) of yellowtail adapted from Cadrin 2010. Note Table has been modified to include maturity estimates for CCGOM, GB and SNEMA yellowtail from the NEFSC spring bottom trawl survey from 1968-2011

Stock	A50 female (yr)	A50 male (yr)	L50 female (cm)	L50 male (cm)	Source
Grand Bank	6	5	37	31	Pitt, 1970
	6.3	5	34	28	Walsh and Morgan, 1999
			29	23	Duran et al. 1999
Scotian Shlef	7	7	40	40	Scott, 1954
	3.5	3	26	22	Beachman, 1983
Cape Cod	2.6	2.5	27	27	O'Brien et al. 1993
	3.1	2.6	30	26	Begg et al. 1999a
Cape Cod-Gulf of Maine	2.7	2.2	29.1	24.2	Alade and Cadrin, 2012; SDWGDM SARC54
Georges Bank	1.8	1.3	26	21	O'Brien et al. 1993
	2.3	2	29	21	Begg et al. 1999a
	2.1	1.6	29.3	21.7	Alade and Cadrin, 2012; SDWGDM SARC54
Southern New England	2.5	2.5	32	32	Scott 1954
			27	24	Morse and Morris 1981
	1.7	1.8	26	20	O'Brien et al, 1993
	2.3	2	27	23	Begg et al., 1999a
Mid-Atlantic Bight			25	24	Morse and Morris, 1981
	2.4	2.1	27	22	Begg et al., 1999a
Southern New England/Mid-Atlantic	2	1.6	27.4	22	Alade and Cadrin, 2012; SDWGDM SARC54

Table B49. Summary of Southern New England Mid-Atlantic yellowtail flounder ADAPT-VPA model formulation used to build a 'bridge' from GARM III ADAPT-VPA model to the 2011 update. *Note: the model run numbers were used for internal tracking only and don't necessarily indicate sequential model runs

Run	Model	Software Version	Population estimation	Years	Catch	Natural Mortality	Discard Mortality	Selectivity blocks	Plus Group handling	Time of Spawning	Survey Selectivity	Survey Indices	NEFSC Survey			
													Spring (1973-2011)	Fall (1973-2011)	Winter (1992-2007)	Larval index (1977-2011)
1	VPA	v2.8	Exact	1973-2007	GARM III	Const M = 0.2	100%	N/A	Backward	May	N/A	Unadjusted	6+	6+	6+	None
2	VPA	**v3.2**	Exact	1973-2007	GARM III	Const M = 0.2	100%	N/A	Backward	May	N/A	Unadjusted	6+	6+	6+	None
11	VPA	v3.2	Exact	1973-2007	**Updated commercial catch from 1994-2007 (Revised LW and discard estimation) and updated maturity.**	**Lifetime Lorenzen M rescaled to M = 0.3**	**90%**	N/A	Backward	May	N/A	Updated	6+	6+	6+	None
15b	VPA	v3.2	Exact	1973-2011	Full catch series with with revised catch series specified in Run 11 Catch Stream through 2011	Lifetime Lorenzen M rescaled to M = 0.3	90%	N/A	Backward	May	N/A	Updated	6+	6+	6+	None
20*	VPA	v3.2	Exact	1973-2011	Full catch series as described in Run 15b	**Time series average Lorenzen M rescaled to M = 0.3**	90%	N/A	Backward	May	N/A	Updated; NEFSC Winter Survey (Exclude Southern Strata set)	6+	6+	6+	None

Table B50. Summary Southern New England Mid-Atlantic yellowtail flounder results from the ‘bridge building’ exercise performed to update the GARM III ADAPT-VPA model to the 2011 update. *Note: the model run numbers were used for internal tracking only and don’t necessarily indicate sequential model runs.

Run		1	2	11	15b	**20***
Model description		GARM III; Discard Mortality = 100%	Software update; Discard mortality = 100%	Revised commercial catch from 1994-2007 (Revised LW and discard estimation) and updated maturity; Lifetime Lorenzen M rescaled to M = 0.3; Discard Mortality = 90%	Full catch series with with revised catch series specified in Run 11 Catch Stream through 2011; Discard Mortality = 90%	Full catch series as described in Run 15b. Time series Average Lorenzen M rescaled to M = 0.3; Discard Mortality = 90%; NEFSC Winter Survey (Southern Strata Excluded)
# of Parameters		4	4	4	4	4
RSS		337	337	332	403	403
MSR		0.746	0.746	0.733	0.814	0.818
Terminal year CV's	Age-2	0.51	0.51	0.51	0.65	0.65
	Age-3	0.34	0.34	0.34	0.46	0.47
	Age-4	0.31	0.31	0.31	0.39	0.39
	Age-5	0.37	0.37	0.39	0.19	0.19
Terminal estimates	$F_{4-5, 2007}$	0.41	0.41	0.49	NA	NA
	$F_{4-5, 2011}$	N/A	N/A	N/A	0.16	0.16
	SSB_{2007}	3,508	3,508	3,048	NA	NA
	SSB_{2011}	N/A	N/A	N/A	3,988	4,044
Retrospective (Mohn's Rho) *7 year peels	F_{4-5}	47%	47%	13%	52%	52%
	SSB	11%	11%	11%	1%	3%
	Age-1 N	46%	46%	37%	28%	32%

Table B51. Summary of Southern New England Mid-Atlantic yellowtail flounder ASAP model configurations including the base model (Run26) and various sensitivity models.

Run	Model	Software Version	Years	Catch	Fishery Selectivity Blocks	Discard Mortality	Natural Mortality	Stock-recruit	Survey Indices	Survey Selectivity	Survey Selectivity Block	NEFSC Survey			
												Spring (1973-2011)	Fall (1973-2011)	Winter (1992-2007)	Larval index (1977-2011)
1	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	None	90%	Const M = 0.2	None	Survey Updated	Fixed at 100% for age 4 only; all other ages estimated	Single Block for all surveys	1-6+	1-6+	1-6+	None
3	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(2 blocks) 1973-1993; 1994-2011	90%	Lifetime Lorenzen M rescaled to M = 0.3	None	Survey Updated	Fixed at 100% for age 4 only; all other ages estimated	Single Block for all surveys	1-6+	1-6+	1-6+	None
6	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(4 blocks) 1973-1985; 1986-1988; 1989-1993; 1994-2011	90%	Lifetime Lorenzen M rescaled to M = 0.3	None	Survey Updated	Fixed at 100% for ages 4+; estimates ages 1-3 (Flat topped)	Single Block for all surveys	1-6+	1-6+	1-6+	None
8	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(4 blocks) 1973-1985; 1986-1988; 1989-1993; 1994-2011	90%	Time series average Lorenzen M rescaled to M = 0.3	None	Survey Updated	same as Run 6	Single Block for all surveys	1-6+	1-6+	1-6+	None
16	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(6 blocks) 1973-1977; 1978-1985; 1986-1988; 1989-1993; 1994-2001; 2002-2011	90%	Time series average Lorenzen M rescaled to M = 0.3	None	Survey Updated; Winter (Southern strata excluded)	same as Run 6	Single Block for all surveys	1-6+	1-6+	1-6+	None
20	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(6 blocks) 1973-1977; 1978-1985; 1986-1988; 1989-1993; 1994-2001; 2002-2011	90%	Time series average Lorenzen M rescaled to M = 0.3	None	Survey Updated; Winter (Southern strata excluded)	Run 6 Specification; Larval survey 100% at ages 2+	Single Block for all surveys	1-6+	1-6+	1-6+	Total, tuned to ages 2+
22	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(6 blocks) 1973-1977; 1978-1985; 1986-1988; 1989-1993; 1994-2001; 2002-2011	90%	Time series average Lorenzen M rescaled to M = 0.3	None	Survey Updated; Winter (Southern strata excluded)	Run 6 Specification; Larval survey 100% at ages 2+	2 Blocks Larval survey 1977-1987; 1988-2011	1-6+	1-6+	1-6+	Total, tuned to ages 2+
26*	ASAP	v2.0.21 Intermediate Release	1973-2011	Single fleet with revised series (1994-2011)	(6 blocks) 1973-1977; 1978-1985; 1986-1988; 1989-1993; 1994-2001; 2002-2011	90%	Time series average Lorenzen M rescaled to M = 0.3	None	Survey Updated; Winter (Southern strata excluded)	Run 6 Specification; Larval survey 100% at ages 2+	2 Blocks Larval survey 1977-1987; 1988-2011	1-6+	1-6+	1-6+	Total, tuned to ages 2+

Table B52a. Summary of the Southern New England Mid-Atlantic yellowtail flounder model fit from the ASAP runs and various sensitivity analyses

Run		1	3	6	8	16
Model description		Start year in 1973; 6+ age group; NO fishery selectivity block; fishery selectivity fixed ages 4+; survey selectivity fixed age 4 ONLY (possible dome); recruitment (geometric mean); Lifetime M rescaled to 0.3	Start year in 1973; 6+ age group; fishery selectivity blocks = 2; fishery selectivity fixed ages 4+; survey selectivity fixed age 4 ONLY (possible dome); recruitment (geometric mean); Lifetime M rescaled to 0.3	Start year in 1973; 6+ age group; fishery selectivity blocks = 4; fishery selectivity fixed ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Lifetime M rescaled to 0.3	Start year in 1973; 6+ age group; fishery selectivity blocks = 4; fishery selectivity fixed ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Time series average M rescaled to 0.3	Start year in 1973; 6+ age group; fishery selectivity blocks = 6; fishery selectivity = ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Time series average M rescaled to 0.3; Winter Survey (No southern strata)
# of Parameters		105	108	108	108	114
Objective function		4804	4729	4704	4703	4675
Components of Objective function	Survey age comp.	1195	1180	1175	1175	1174
	Catch age comp.	3674	3619	3594	3592	3568
	index fit total	13	9	11	12	10
	catch total	-77	-78	-77	-77	-76
	Recr_Devs	NA	NA	NA	NA	NA
RMSE	catch total	0.80	0.78	0.82	0.82	0.83
	Index 1 = Winter	1.55	1.56	1.55	1.56	1.50
	Index2 = Spring	1.78	1.76	1.78	1.78	1.78
	Index 3 = Fall	1.67	1.63	1.65	1.65	1.64
	Index 4 = larval 77-11	NA	NA	NA	NA	NA
	Index 4 = larval 77-87	NA	NA	NA	NA	NA
	Index 5 = larval (88-11)	NA	NA	NA	NA	NA
	Index Total	1.70	1.67	1.69	1.69	1.68
	Recr_devs	NA	NA	NA	NA	NA
SSB (mt), 2011		3,844	4,020	4,355	4,303	4,223
F Avg4-5, 2011		0.11	0.12	0.12	0.12	0.11

Table B52b (Cont'd). Summary of the Southern New England Mid-Atlantic yellowtail flounder model fit from the ASAP runs and various sensitivity analyses

Run		20	22	**26***	28
Model description		Start year in 1973; 6+ age group; fishery selectivity blocks = 6; fishery selectivity = ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Time series average M rescaled to 0.3; Winter Survey (No southern strata); Include larval index	Start year in 1973; 6+ age group; fishery selectivity blocks = 6; fishery selectivity = ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Time series average M rescaled to 0.3; Winter Survey (No southern strata); split larval index (87/88)	Start year in 1973; 6+ age group; fishery selectivity blocks = 6; fishery selectivity = ages 4+; survey selectivity fixed ages 4+ (flat topped); recruitment (geometric mean); Time series average M rescaled to 0.3; Winter Survey (No southern strata); split larval index (87/88); Inrease CV on all surveys (0.1)	Start year in 1973; 6+ age group; fishery selectivity blocks = 6; fishery selectivity = ages 4+; survey selectivity fixed ages 4+ (flat topped); Time series average M rescaled to 0.3; Winter Survey (No southern strata); split larval index (87/88); recruitment (B-H) with Cold-pool index as a covariate; Inrease CV on all surveys (0.1)
# of Parameters		115	116	116	118
Objective function		5644	4683	4640	4654
Components of Objective function	Survey age comp.	1228	1173	1172	1172
	Catch age comp.	3694	3565	3560	3559
	index fit total	724	21	-8	-7
	catch total	-3	-77	-84	-84
	Recr_Devs	NA	NA	NA	13
RMSE	catch total	2.11	0.82	0.54	0.55
	Index 1 = Winter	2.32	1.53	1.13	1.14
	Index2 = Spring	3.13	1.81	1.38	1.4
	Index 3 = Fall	1.91	1.65	1.34	1.34
	Index 4 = larval 77-11	7.30	NA	NA	NA
	Index 4 = larval 77-87	NA	1.68	1.36	1.33
	Index 5 = larval (88-11)	NA	1.37	1.14	1.15
	Index Total	3.92	1.67	1.31	1.32
	Recr_devs	NA	NA	NA	1.02
SSB (mt), 2011		11,075	3,662	3,873	4,127
F Avg4-5, 2011		0.04	0.13	0.12	0.12

Table B53. Southern New England Mid-Atlantic yellowtail flounder January 1 biomass (mt) and spawning stock biomass (mt) from 1973 to 2011 as estimated from ASAP base model Run 26

Year	January 1 biomass (mt)	SSB (mt)
1973	40,940	21,760
1974	25,041	9,738
1975	14,784	3,422
1976	12,423	4,147
1977	20,528	4,460
1978	28,457	5,809
1979	26,678	7,978
1980	28,793	8,983
1981	36,959	10,464
1982	52,075	17,896
1983	38,551	17,077
1984	18,211	5,904
1985	11,100	2,668
1986	8,238	2,826
1987	7,989	2,042
1988	62,098	2,818
1989	33,838	11,553
1990	22,968	11,103
1991	9,307	4,065
1992	3,276	1,685
1993	1,887	1,024
1994	1,645	621
1995	1,522	821
1996	2,360	1,504
1997	3,476	1,349
1998	3,428	1,427
1999	3,778	1,668
2000	3,749	1,670
2001	3,381	1,561
2002	2,338	1,272
2003	1,649	1,030
2004	1,399	711
2005	1,665	686
2006	2,340	1,127
2007	2,878	1,920
2008	3,703	2,336
2009	3,919	2,648
2010	4,262	3,319
2011	5,305	3,873

Table B54. Southern New England Mid-Atlantic yellowtail flounder average (ages 4-5) fishing mortality from 1973 to 2011 as estimated from ASAP base model Run 26

	Average F 4-5		
Year	Unweighted	N-Weighted	B-Weighted
1973	0.617	0.617	0.617
1974	1.471	1.471	1.471
1975	1.116	1.116	1.116
1976	0.488	0.488	0.488
1977	0.768	0.768	0.768
1978	1.354	1.354	1.354
1979	1.237	1.237	1.237
1980	0.894	0.894	0.894
1981	0.646	0.646	0.646
1982	0.896	0.896	0.896
1983	1.353	1.353	1.353
1984	1.901	1.901	1.901
1985	1.734	1.734	1.734
1986	1.160	1.160	1.160
1987	1.040	1.040	1.040
1988	0.377	0.377	0.377
1989	1.679	1.679	1.679
1990	3.115	3.115	3.115
1991	2.340	2.340	2.340
1992	2.041	2.041	2.041
1993	1.041	1.041	1.041
1994	1.711	1.711	1.711
1995	0.767	0.767	0.767
1996	0.854	0.854	0.854
1997	1.457	1.457	1.457
1998	1.458	1.458	1.458
1999	1.570	1.570	1.570
2000	1.515	1.515	1.515
2001	1.755	1.755	1.755
2002	1.177	1.177	1.177
2003	0.885	0.885	0.885
2004	1.028	1.028	1.028
2005	0.709	0.709	0.709
2006	0.634	0.634	0.634
2007	0.431	0.431	0.431
2008	0.332	0.332	0.332
2009	0.213	0.213	0.213
2010	0.112	0.112	0.112
2011	0.121	0.121	0.121

Table B55. Southern New England Mid-Atlantic yellowtail flounder fishing mortality at age from 1973 to 2011 as estimated from the ASAP base model Run 26

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1973	0.08	0.58	0.60	0.62	0.62	0.62
1974	0.20	1.39	1.43	1.47	1.47	1.47
1975	0.15	1.05	1.09	1.12	1.12	1.12
1976	0.07	0.46	0.47	0.49	0.49	0.49
1977	0.10	0.73	0.75	0.77	0.77	0.77
1978	0.04	0.58	1.23	1.35	1.35	1.35
1979	0.04	0.53	1.12	1.24	1.24	1.24
1980	0.03	0.38	0.81	0.89	0.89	0.89
1981	0.02	0.28	0.59	0.65	0.65	0.65
1982	0.03	0.38	0.81	0.90	0.90	0.90
1983	0.04	0.58	1.23	1.35	1.35	1.35
1984	0.06	0.81	1.73	1.90	1.90	1.90
1985	0.06	0.74	1.57	1.73	1.73	1.73
1986	0.11	0.93	0.97	1.16	1.16	1.16
1987	0.10	0.84	0.87	1.04	1.04	1.04
1988	0.04	0.30	0.32	0.38	0.38	0.38
1989	0.03	0.30	0.70	1.68	1.68	1.68
1990	0.06	0.56	1.29	3.11	3.11	3.11
1991	0.04	0.42	0.97	2.34	2.34	2.34
1992	0.04	0.37	0.85	2.04	2.04	2.04
1993	0.02	0.19	0.43	1.04	1.04	1.04
1994	0.01	0.22	1.08	1.71	1.71	1.71
1995	0.00	0.10	0.48	0.77	0.77	0.77
1996	0.00	0.11	0.54	0.85	0.85	0.85
1997	0.01	0.19	0.92	1.46	1.46	1.46
1998	0.01	0.19	0.92	1.46	1.46	1.46
1999	0.01	0.20	0.99	1.57	1.57	1.57
2000	0.01	0.19	0.96	1.52	1.52	1.52
2001	0.01	0.23	1.11	1.75	1.75	1.75
2002	0.02	0.19	0.70	1.18	1.18	1.18
2003	0.02	0.14	0.53	0.88	0.88	0.88
2004	0.02	0.16	0.61	1.03	1.03	1.03
2005	0.01	0.11	0.42	0.71	0.71	0.71
2006	0.01	0.10	0.38	0.63	0.63	0.63
2007	0.01	0.07	0.26	0.43	0.43	0.43
2008	0.01	0.05	0.20	0.33	0.33	0.33
2009	0.00	0.03	0.13	0.21	0.21	0.21
2010	0.00	0.02	0.07	0.11	0.11	0.11
2011	0.00	0.02	0.07	0.12	0.12	0.12

Table B56. Southern New England Mid-Atlantic yellowtail flounder January 1 numbers at age (000’s) from 1973 to 2011 as estimated from the ASAP base model Run 26.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+
1973	41,676	22,142	36,195	18,955	10,919	12,298
1974	15,134	25,596	8,832	14,767	7,767	9,825
1975	43,352	8,292	4,558	1,570	2,577	3,173
1976	18,597	24,908	2,065	1,145	391	1,479
1977	67,922	11,621	11,225	955	534	906
1978	70,610	40,884	4,020	3,955	337	525
1979	54,614	45,054	16,404	875	776	175
1980	66,932	34,981	19,000	3,970	193	215
1981	178,114	43,354	17,075	6,278	1,234	131
1982	84,812	116,314	23,527	7,069	2,501	555
1983	19,611	54,932	56,721	7,757	2,191	970
1984	25,499	12,514	22,048	12,356	1,523	638
1985	31,703	15,981	3,976	2,920	1,403	252
1986	9,652	19,978	5,453	613	392	227
1987	18,486	5,756	5,620	1,531	146	152
1988	190,454	11,152	1,783	1,745	411	82
1989	43,348	122,489	5,886	966	909	263
1990	12,046	28,003	64,615	2,180	137	170
1991	3,963	7,572	11,394	13,181	74	11
1992	3,318	2,528	3,544	3,207	964	6
1993	3,670	2,129	1,249	1,129	316	98
1994	7,961	2,400	1,260	603	303	114
1995	6,907	5,276	1,376	318	83	59
1996	5,019	4,594	3,416	630	112	51
1997	11,458	3,337	2,941	1,481	204	54
1998	6,549	7,601	1,977	871	262	47
1999	10,026	4,344	4,503	585	154	56
2000	5,846	6,648	2,537	1,242	92	34
2001	4,537	3,877	3,910	724	207	22
2002	2,069	3,006	2,211	959	95	31
2003	1,909	1,349	1,782	816	225	30
2004	3,248	1,252	838	782	256	82
2005	9,478	2,125	760	338	212	94
2006	7,954	6,238	1,357	370	126	118
2007	4,207	5,242	4,030	692	149	101
2008	7,496	2,783	3,498	2,319	341	127
2009	7,860	4,968	1,887	2,135	1,264	262
2010	5,156	5,222	3,432	1,236	1,311	959
2011	8,173	3,432	3,666	2,388	840	1,588

Table B57. Retrospective Rho statistics for Southern New England Mid-Atlantic yellowtail flounder $F_{ages4-5}$, SSB and Age 1 recruitment using 7-year peels.

Year	2004	2005	2006	2007	2008	2009	2010	Min	Max	Mohn's Rho (7 year Peel)
F4-5	0.26	-0.27	-0.46	-0.31	-0.25	0.00	-0.09	-0.46	0.26	-0.16
SSB	-0.29	0.26	0.56	0.21	0.20	-0.04	0.11	-0.29	0.56	0.14
N Age 1	0.63	-0.16	0.44	-0.41	0.30	-0.29	-0.49	-0.49	0.63	0.00
N Age 2	-0.10	0.42	0.41	0.18	-0.37	0.03	0.14	-0.37	0.42	0.10
N Age 3	-0.27	0.09	0.52	0.11	0.17	-0.30	0.16	-0.30	0.52	0.07
N Age 4	-0.29	0.04	0.43	0.30	0.25	-0.03	-0.09	-0.29	0.43	0.09
N Age 5	-0.08	0.19	0.55	0.44	0.38	0.09	0.12	-0.08	0.55	0.24
N Age 6	0.35	0.40	0.77	0.71	0.53	0.15	0.13	0.13	0.77	0.44

Table B58. Summary statistics for fit of standard Beverton Holt Stock Recruitment Models and Environmentally Explicit Beverton Holt Stock Recruitment Models. Recruitment was log-transformed prior to use in the stock recruitment model.

Assessment Model	Stock Recruiment Model	AICc	AIC weight
GARM III	Standard BH Model	16.86	0.1
	Environmental BH Model	12.58	0.9
2012 VPA	Standard BH Model	5.87	0.15
	Environmental BH Model	2.43	0.85
2012 ASAP	Standard BH Model	5.91	0.04
	Environmental BH Model	-0.39	0.96

Table B59. Cold Pool Index Derived from 15 Measures of Cold Pool Magnitude and Area

Year	Cold Pool Index (PCA1 through 2007)	Cold Pool Index (PCA1 through 2010)
1973	2.9319	2.9953
1974	3.0977	2.9576
1975	1.0994	0.9272
1976	-0.3608	-0.5362
1977	1.3321	1.0362
1978	-2.6783	-2.8946
1979	-1.8562	-2.1015
1980	-0.5846	-0.8412
1981	-2.5168	-2.5674
1982	1.515	0.9275
1983	-0.9842	-1.1852
1984	-1.8064	-1.9438
1985	4.3491	4.1785
1986	2.2052	2.4237
1987	-1.8991	-2.0332
1988	-3.3023	-3.6673
1989	-0.1167	-0.0407
1990	1.2867	1.2379
1991	-0.7287	-0.9686
1992	0.0869	-0.1202
1993	-2.6737	-2.7746
1994	2.1854	1.8481
1995	5.4394	5.284
1996	0.3991	-0.1767
1997	1.2235	0.8876
1998	-3.7895	-3.6034
1999	6.6025	6.4353
2000	4.4595	4.2452
2001	1.8013	1.6367
2002	0.5781	0.3118
2003	1.1521	1.0147
2004	0.502	0.0686
2005	-2.603	-2.8502
2006	5.929	5.6464
2007	-1.2874	-1.4038
2008	NaN	-1.478
2009	NaN	6.6792
2010	NaN	2.2914

Table B60. Inputs to the Southern New England Mid-Atlantic yellowtail flounder yield per recruit (YPR) analysis.

Age	Selectivity on Fishing Mortality	Selectivity on Natural Mortality	Natural Mortality	Stock Weights	Catch Weights	Spawning Stock Weights	Fraction Mature
1	0.02	1.00	0.41	0.08	0.12	0.11	0.01
2	0.16	0.83	0.34	0.18	0.27	0.24	0.47
3	0.60	0.73	0.30	0.32	0.39	0.37	0.98
4	1.00	0.68	0.28	0.43	0.48	0.46	1.00
5	1.00	0.63	0.26	0.53	0.59	0.57	1.00
6+	1.00	0.57	0.23	0.82	0.82	0.82	1.00

Table B61. Biological reference points from the GARM III assessment and this updated assessment for Southern New England Mid-Atlantic yellowtail flounder yellowtail flounder.

Recent Recruitment (Recruitment Series 1990-2010)		
	GARM III	SARC 54
FMSY	0.25	0.32
SSBMSY (mt)	27,400	2,995
MSY (mt)	6,100	773

Two Stanza Recruitment (All Recruitment series 1973-2010)		
	GARM III	SARC 54
FMSY	0.25	0.32
SSBMSY (mt)	27,400	22,615
MSY (mt)	6,100	5,834

Table B62. Summary of median short-term yield and spawning stock biomass projections for Southern New England Mid-Atlantic yellowtail flounder under three assumptions of fishing mortalities (F_0, $F_{75\%\ MSY}$ and F_{MSY}) and assuming the two stanza recruitment condition (i.e. all recruitment time series from 1973-2010)

SSB (mt) - Two Stanza Recruitment									
	F_0			$F_{75\%MSY}$			F_{MSY}		
Year	5% CI	Median	95% CI	5% CI	Median	95% CI	5% CI	Median	95% CI
2012	3,140	4,013	4,988	3,140	4,013	4,988	3,140	4,013	4,988
2013	3,468	4,476	5,791	3,201	4,122	5,365	3,118	4,011	5,230
2014	4,130	5,681	11,632	3,212	4,542	10,224	2,963	4,229	9,814
2015	4,705	8,654	22,492	3,205	5,595	18,904	2,848	4,927	17,943
2016	5,501	13,796	32,564	3,211	8,393	25,285	2,794	6,887	23,405
2017	7,903	20,249	40,179	3,292	12,084	29,292	2,806	9,852	26,617
2018	11,567	26,404	48,441	3,340	15,640	32,945	2,817	12,763	29,448
2019	15,969	32,340	55,039	3,475	18,286	35,208	2,903	15,069	30,949
2020	19,891	37,459	60,761	3,631	20,398	37,223	2,971	16,755	32,648
2021	23,593	41,606	65,345	3,876	21,885	38,803	3,111	17,963	33,748
2022	26,882	44,848	68,769	4,171	23,057	39,327	3,226	18,998	34,248

Yield (mt) - Two Stanza Recruitment									
	F_0			$F_{75\%MSY}$			F_{MSY}		
Year	5% CI	Median	95% CI	5% CI	Median	95% CI	5% CI	Median	95% CI
2012	390	390	390	390	390	390	390	390	390
2013	0	0	0	659	840	1,078	850	1,085	1,393
2014	0	0	0	652	876	1,496	794	1,071	1,873
2015	0	0	0	645	1,032	2,881	752	1,199	3,601
2016	0	0	0	642	1,411	4,472	729	1,560	5,456
2017	0	0	0	657	2,087	5,498	734	2,214	6,484
2018	0	0	0	670	2,843	6,358	735	3,010	7,352
2019	0	0	0	686	3,464	6,886	745	3,679	7,845
2020	0	0	0	720	3,931	7,258	771	4,204	8,200
2021	0	0	0	760	4,268	7,621	799	4,559	8,603
2022	0	0	0	809	4,507	7,795	830	4,825	8,749

Table B63. Summary of median short-term yield and spawning stock biomass projections for Southern New England Mid-Atlantic yellowtail flounder under three assumptions of fishing mortalities (F_0, $F_{75\%\ MSY}$ and F_{MSY}) and assuming recent recruitment conditions (recruitment time series from 1990-2010). *Note that the stock is considered rebuilt under this scenario.*

SSB (mt) - Recent Recruitment									
	F_0			$F_{75\%MSY}$			F_{MSY}		
Year	5% CI	Median	95% CI	5% CI	Median	95% CI	5% CI	Median	95% CI
2012	3,140	4,013	4,988	3,140	4,013	4,988	3,140	4,013	4,988
2013	3,466	4,468	5,758	3,192	4,117	5,344	3,109	4,008	5,205
2014	4,030	5,248	7,130	3,131	4,122	5,733	2,885	3,815	5,353
2015	4,493	5,809	7,658	3,030	4,007	5,354	2,679	3,579	4,803
2016	4,781	6,169	7,961	2,910	3,853	4,981	2,512	3,358	4,354
2017	5,078	6,534	8,447	2,853	3,781	4,874	2,417	3,246	4,190
2018	5,274	6,765	8,544	2,774	3,694	4,682	2,322	3,146	4,010
2019	5,430	6,923	8,574	2,735	3,632	4,550	2,282	3,084	3,909
2020	5,572	7,055	8,604	2,709	3,593	4,515	2,251	3,045	3,873
2021	5,681	7,144	8,704	2,693	3,564	4,492	2,238	3,019	3,857
2022	5,768	7,219	8,745	2,673	3,541	4,459	2,226	3,004	3,827

Yield (mt) - Recent Recruitment									
	F_0			$F_{75\%MSY}$			F_{MSY}		
Year	5% CI	Median	95% CI	5% CI	Median	95% CI	5% CI	Median	95% CI
2012	390	390	390	390	390	390	390	390	390
2013	0	0	0	655	837	1,061	845	1,080	1,369
2014	0	0	0	637	824	1,107	775	1,004	1,357
2015	0	0	0	615	810	1,113	715	946	1,306
2016	0	0	0	585	776	1,020	661	883	1,162
2017	0	0	0	573	759	983	633	848	1,099
2018	0	0	0	558	740	941	608	819	1,044
2019	0	0	0	546	727	914	592	800	1,013
2020	0	0	0	541	718	901	586	790	999
2021	0	0	0	537	710	894	580	780	992
2022	0	0	0	534	706	890	575	776	990

Figures

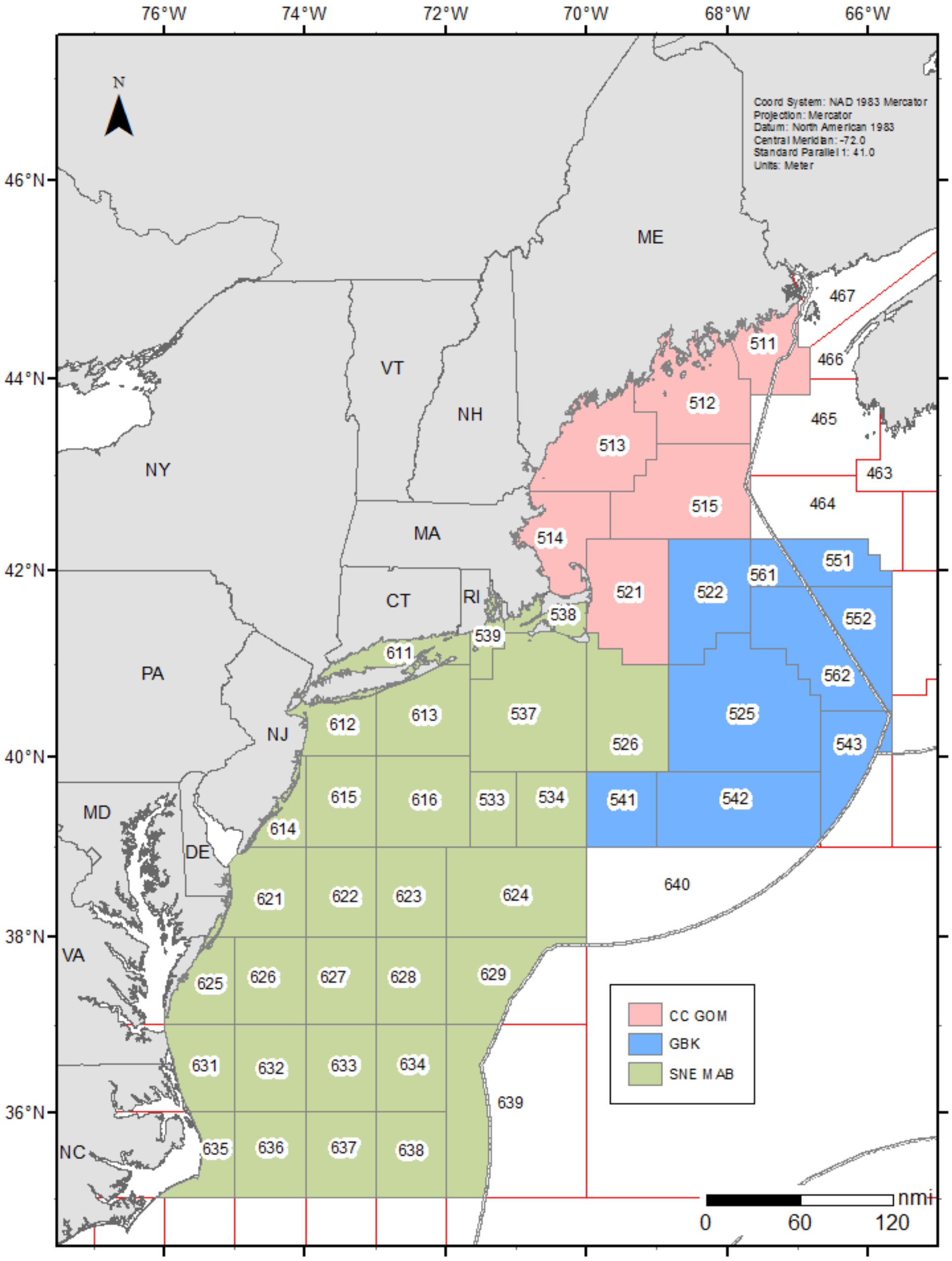


Figure B1. Map of Southern New England Mid-Atlantic yellowtail flounder management and assessment area.

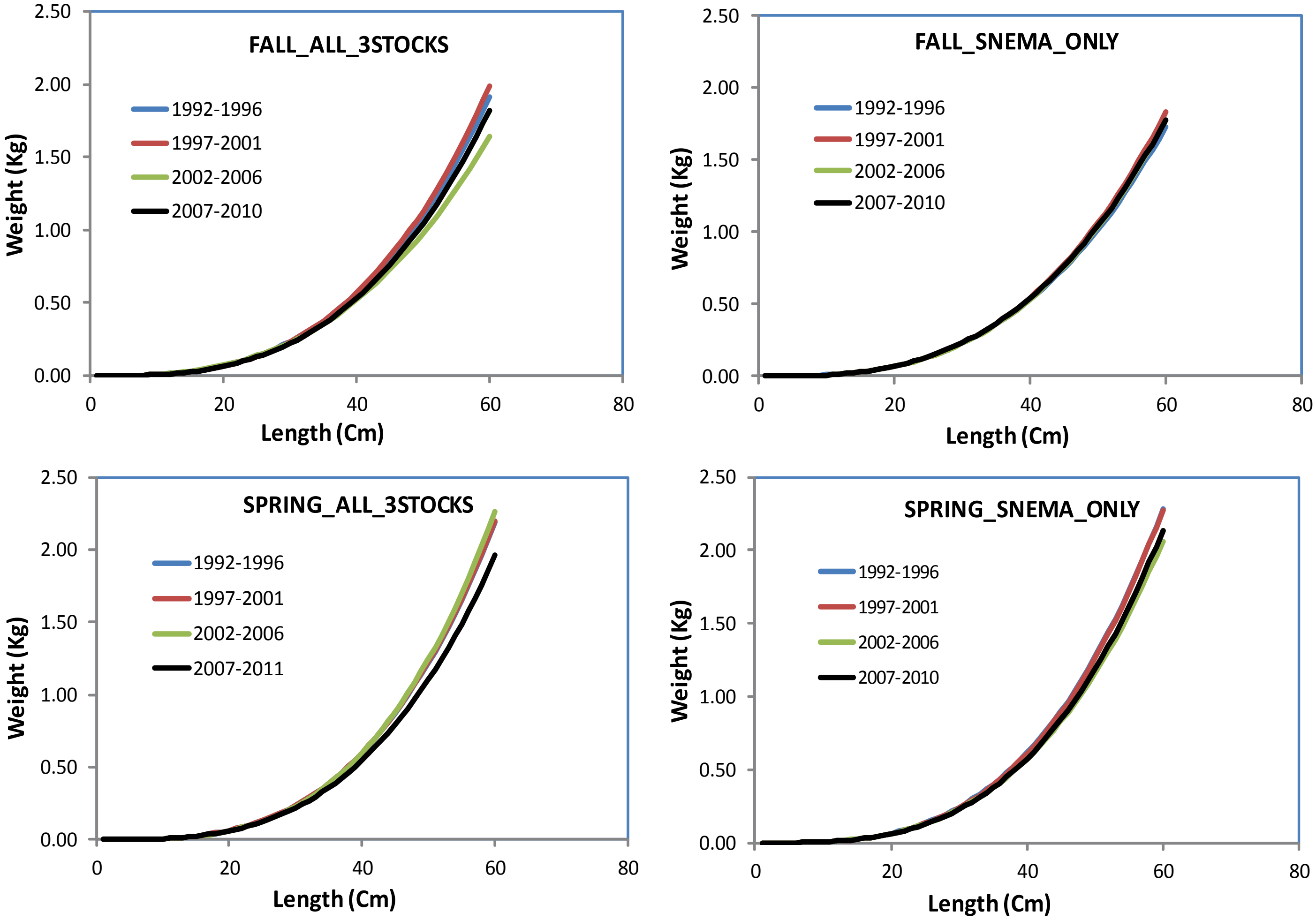


Figure B2.Temporal comparison of seasonal length-weight relationships for all three stocks combined and for ONLY the Southern New England Mid-Atlantic (SNEMA) region by time blocks estimated from the Northeast Fisheries Science Center (NEFSC) survey data

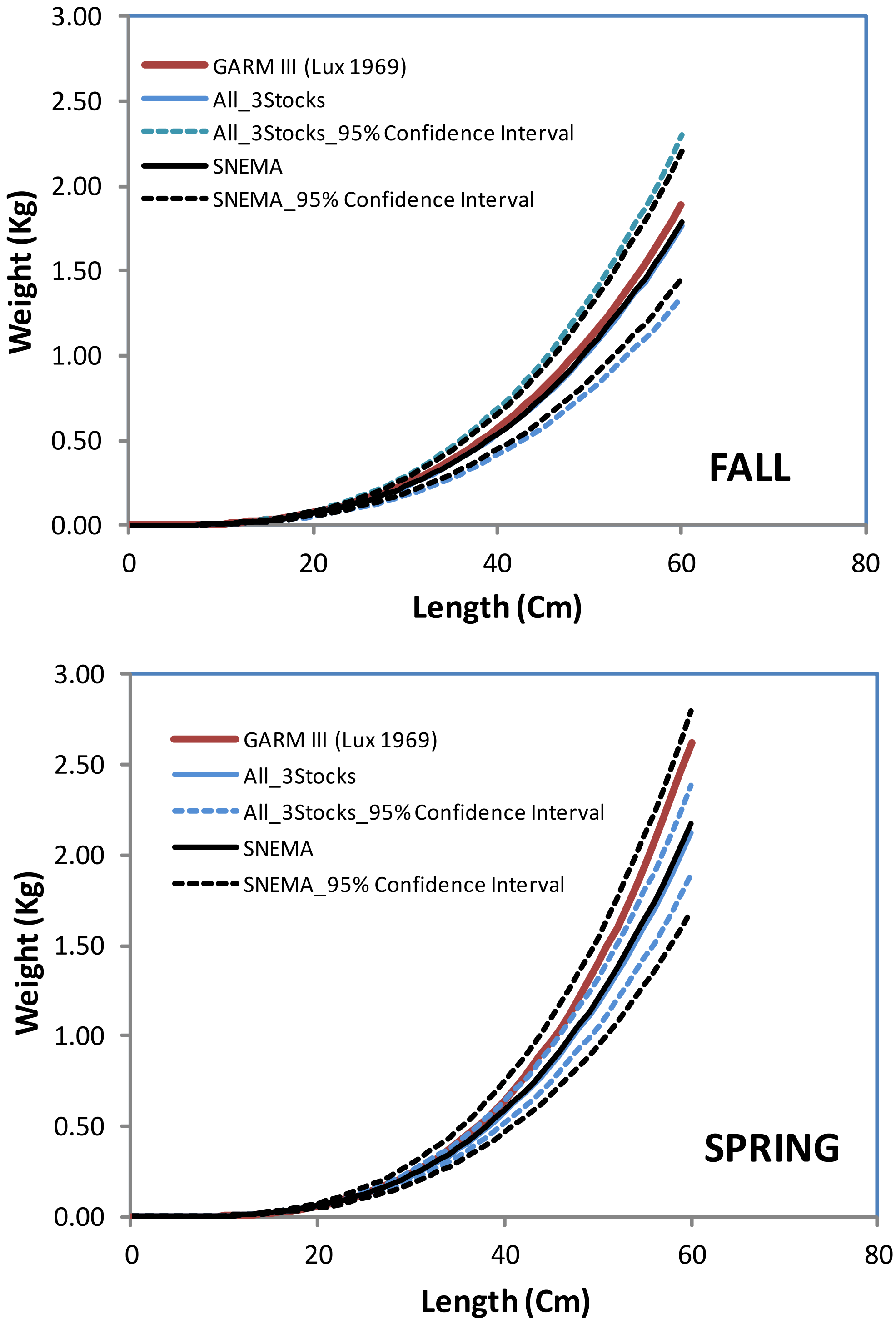


Figure B3. Comparison of seasonal length-weight relationships for all three stocks combined and for the Southern New England Mid-Atlantic strata sets estimated from the NEFSC survey data relative to length-weight relationship used in previous Southern New England Mid-Atlantic yellowtail flounder

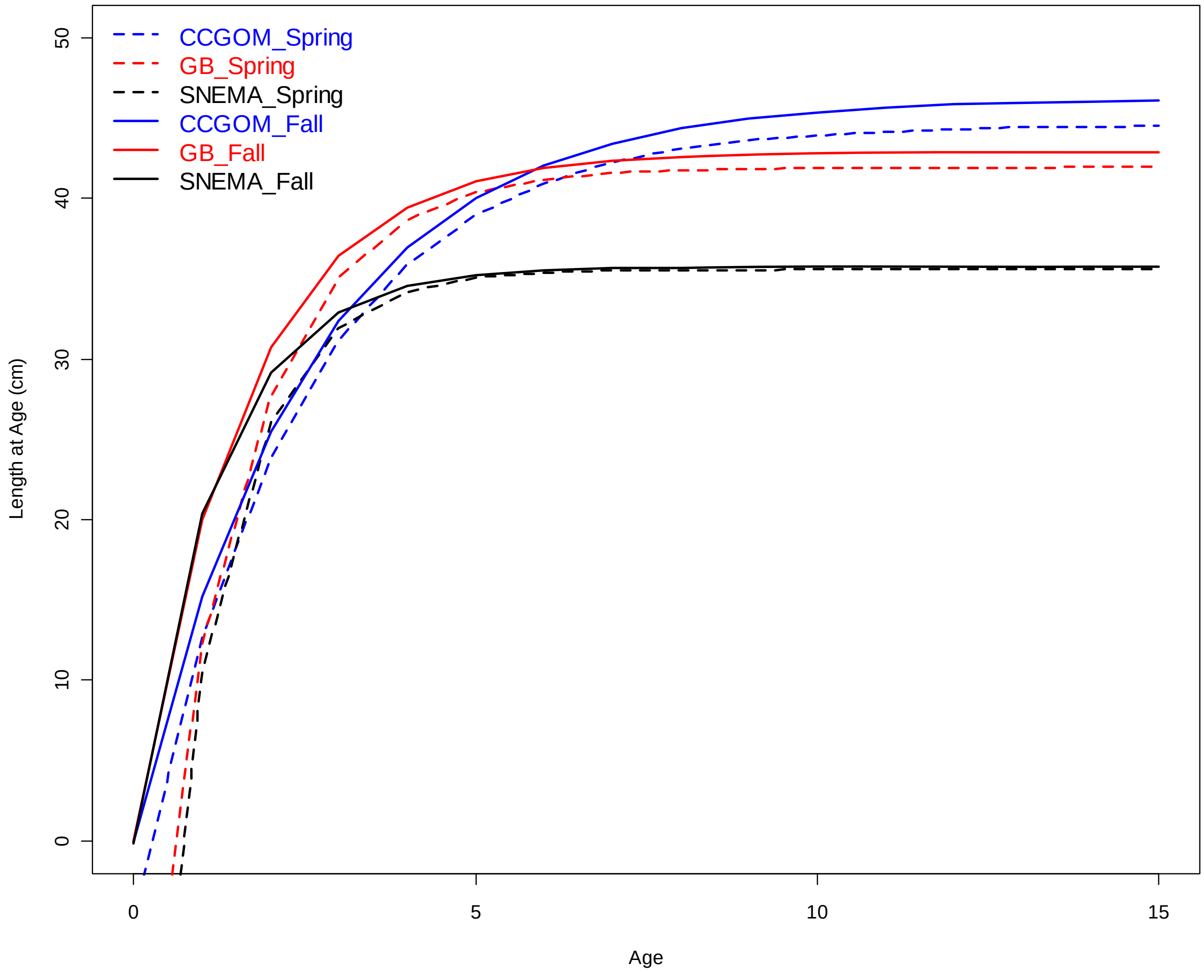


Figure B4. Von Bertalanffy growth curves for Cape Cod Gulf of Mine (CCGOM), Georges Bank (GB), and Southern New England Mid-Atlantic (SNEMA) yellowtail flounder estimated from data collected the Northeast Fisheries Science Center bottom trawl surveys between 1963 and 2011. Estimated growth parameters for the Southern New England Mid-Atlantic stock were L_{inf} = 35.6cm, K=0.97, t_0 = 0.63 in the Spring and L_{inf}= 35.2cm, K= 0.85, t_0 = -0.14 in the Fall.

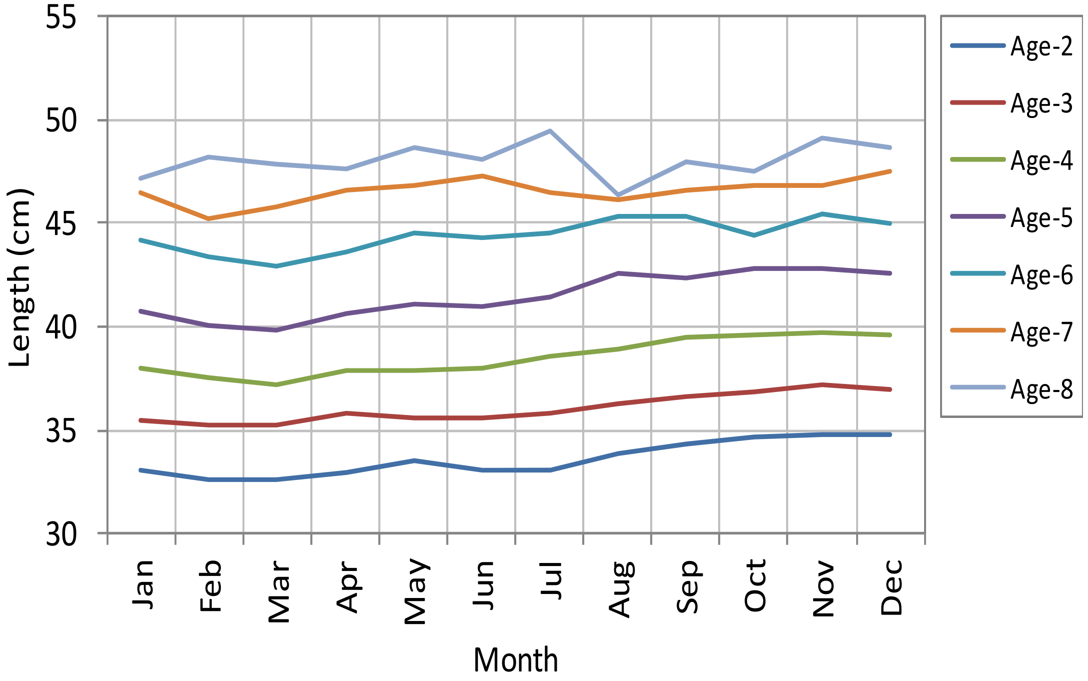


Figure B5. Mean length-at-age of Southern New England Mid-Atlantic yellowtail flounder landed by commercial fishery by month. Estimated from port samples taken between 1994-2011

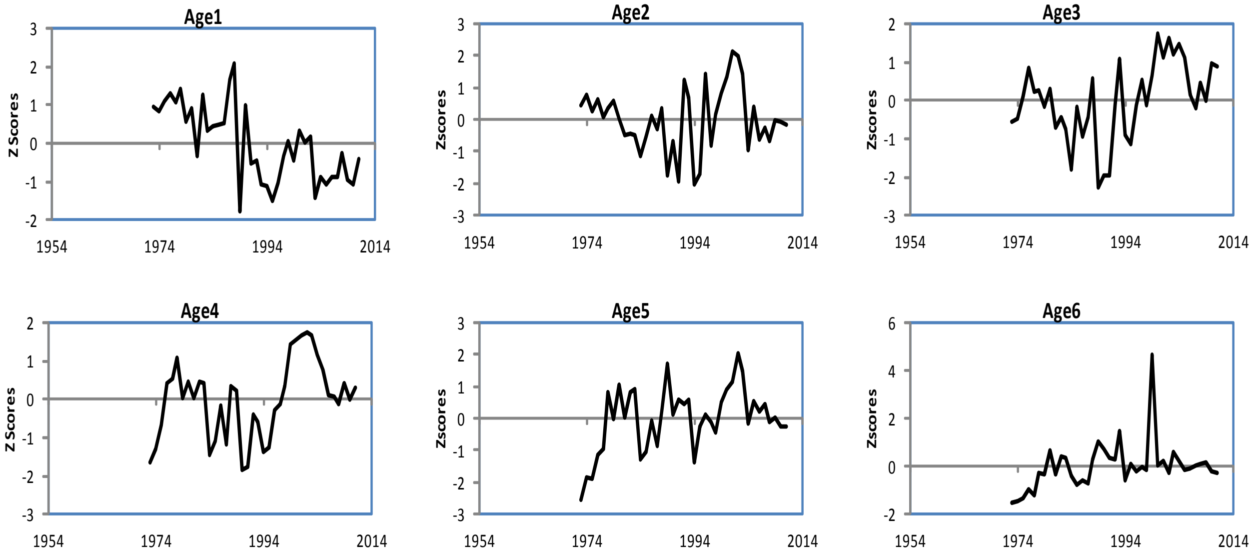


Figure B6. Average Catch weights at age for age-1through age-6+ for Southern New England Mid-Atlantic yellowtail flounder from 1973-2011. Weights at Age were estimated using a number weighted average commercial landings and discards weight at age. Average weight are presented as z-scores ([x-μ]/σ)

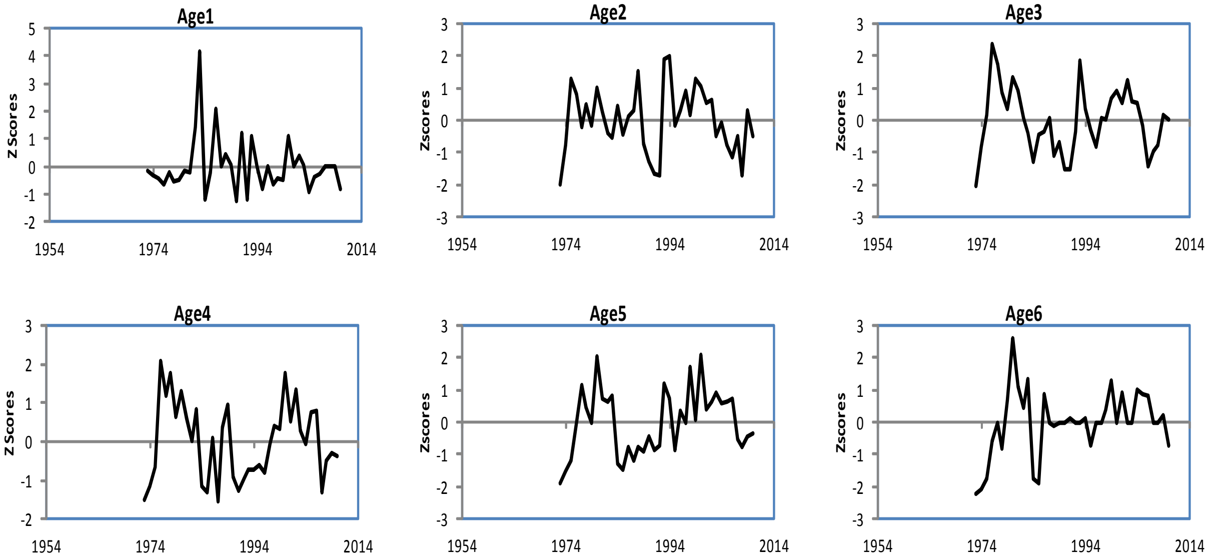


Figure B7. Average survey weights at age for ages1 through ages 6+ for Southern New England Mid-Atlantic yellowtail flounder from 1973-2011. Survey weights are based on the average weight-at-age of yellowtail sampled from the Northeast Fisheries Science Center Spring bottom trawl survey.

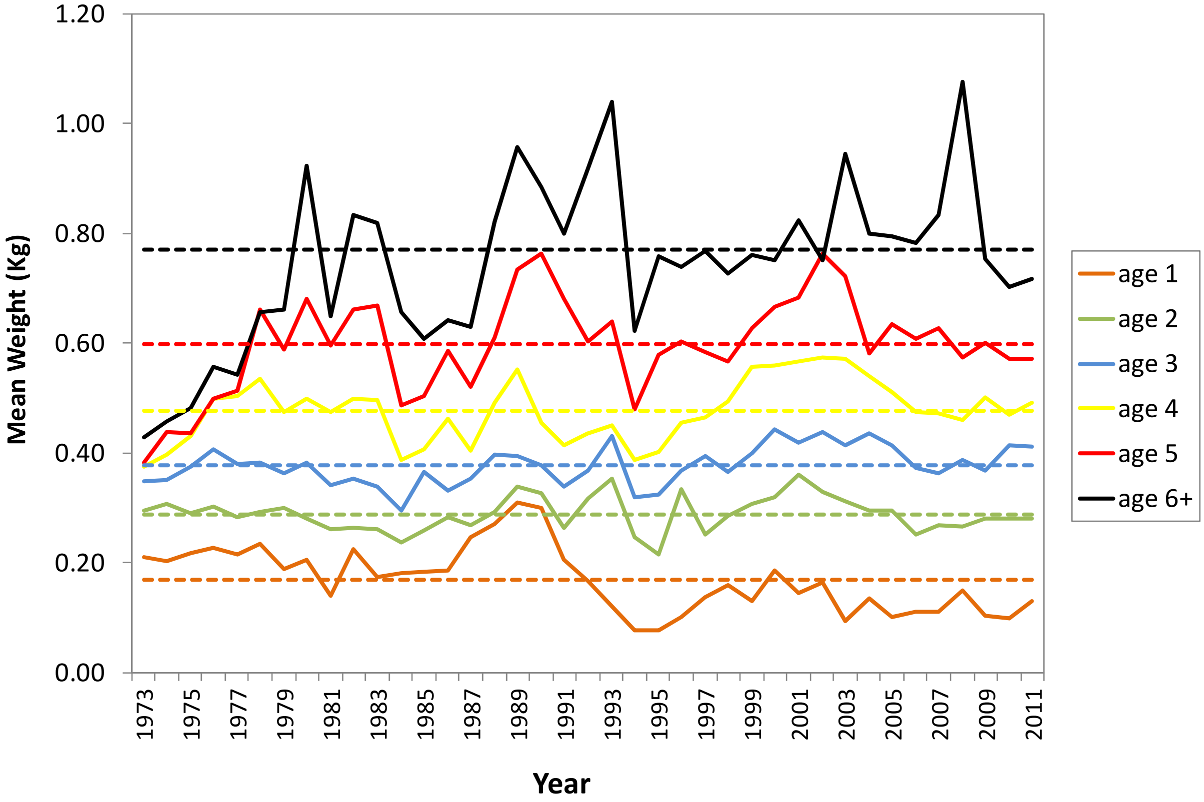


Figure B8: Non-standardized average catch weights at age for Ages 1 through 6+ for Southern New England Mid-Atlantic yellowtail flounder from 1973 to 2011. Dash lines denote the time series average.

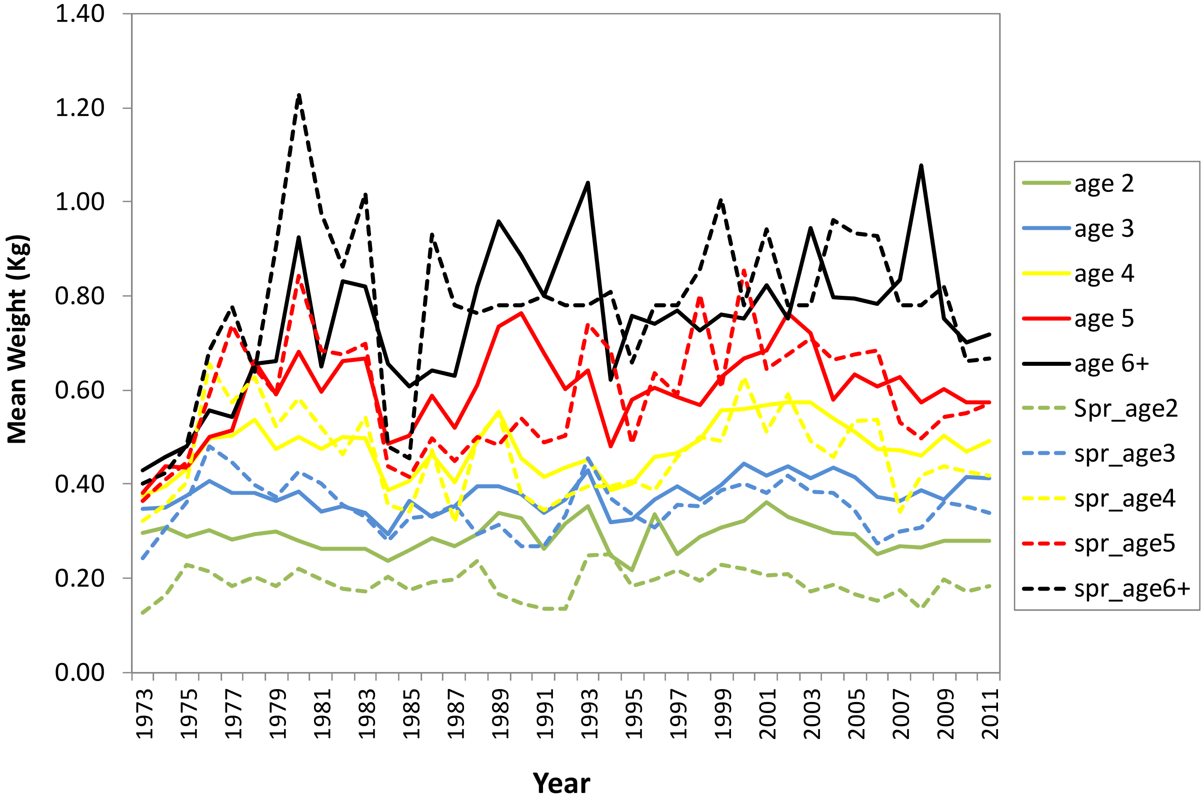


Figure B9. Comparison between catch weights-at-age and spring weights-at-age for ages-1 through 6+ for Southern New England Mid-Atlantic yellowtail flounder from 1973-2011

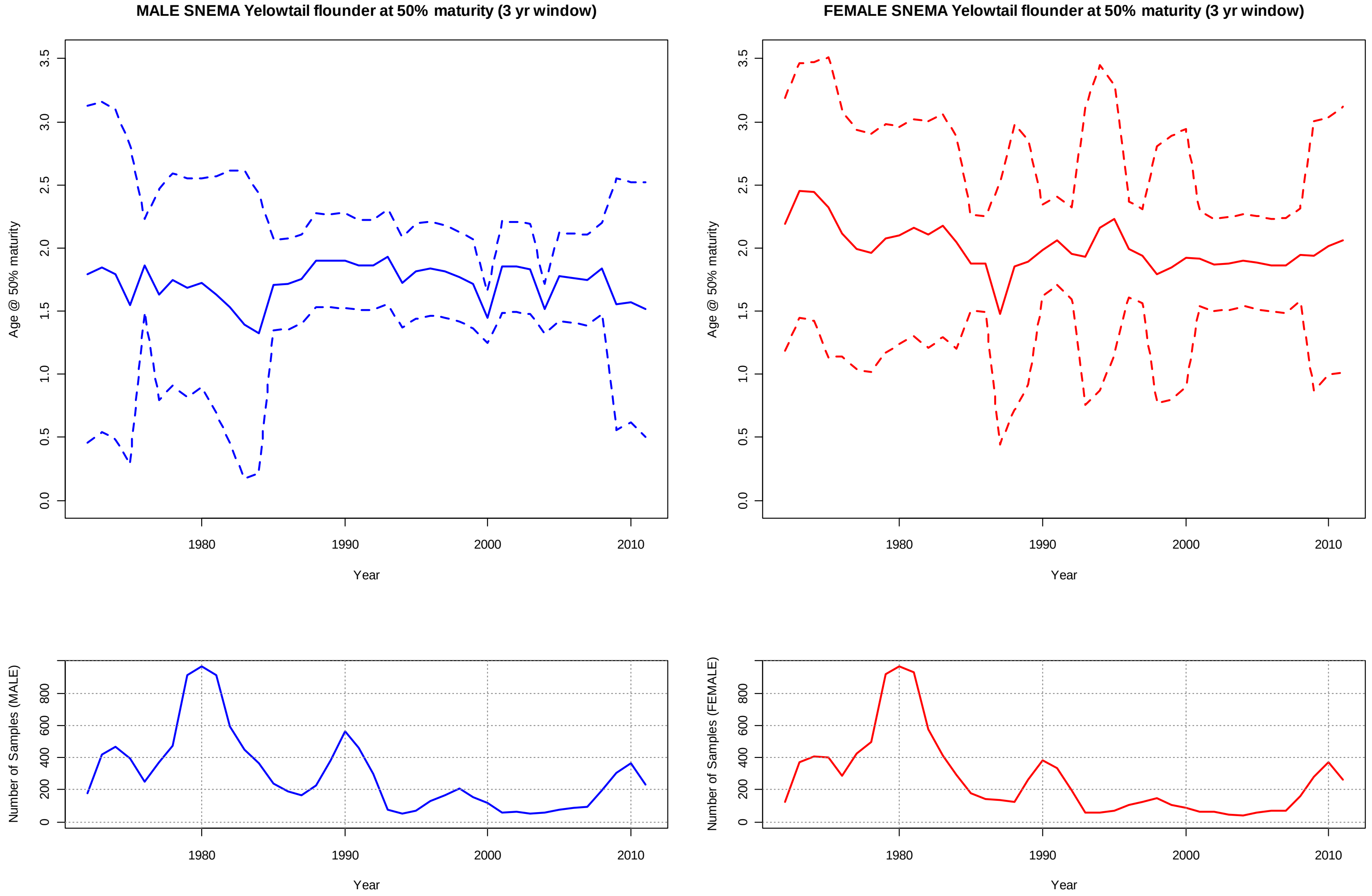


Figure B10a. Top panel-Three year moving averages of age at 50% maturity (A50) for males (left panel) and females (right panel) Southern New England Mid-Atlantic yellowtail flounder from 1973-2011 estimated from data collected from the Northeast Fisheries Science Center (NEFSC) spring trawl Survey. Samples sizes are provided in the bottom panels

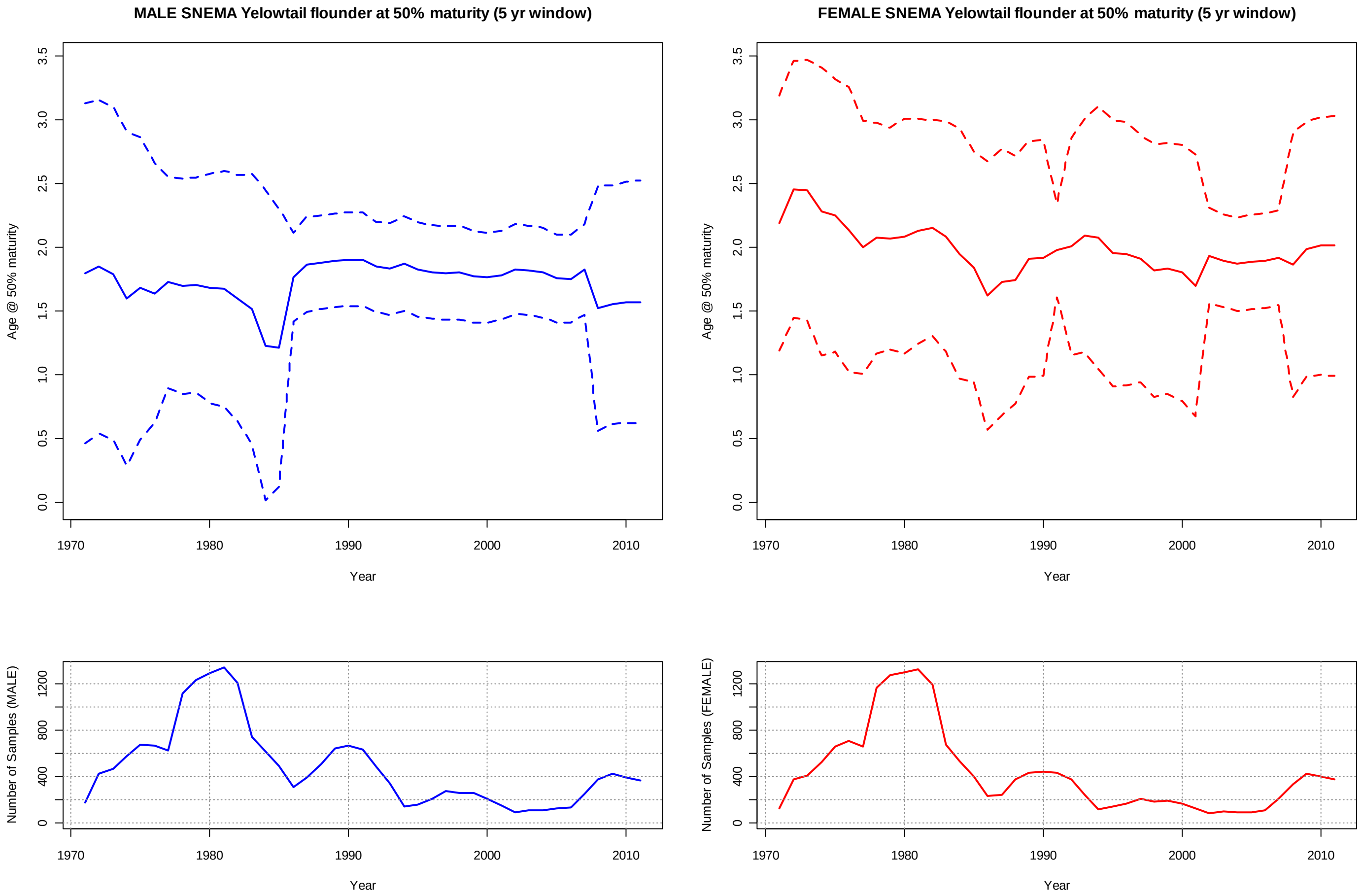


Figure B10b. Cont'd). Top panel-Five year moving averages of age at 50% maturity (A50) for males (left panel) and females (right panel) Southern New England Mid-Atlantic yellowtail flounder from 1973-2011 estimated from data collected from the Northeast Fisheries Science Center (NEFSC) spring trawl Survey. Samples sizes are provided in the bottom panels

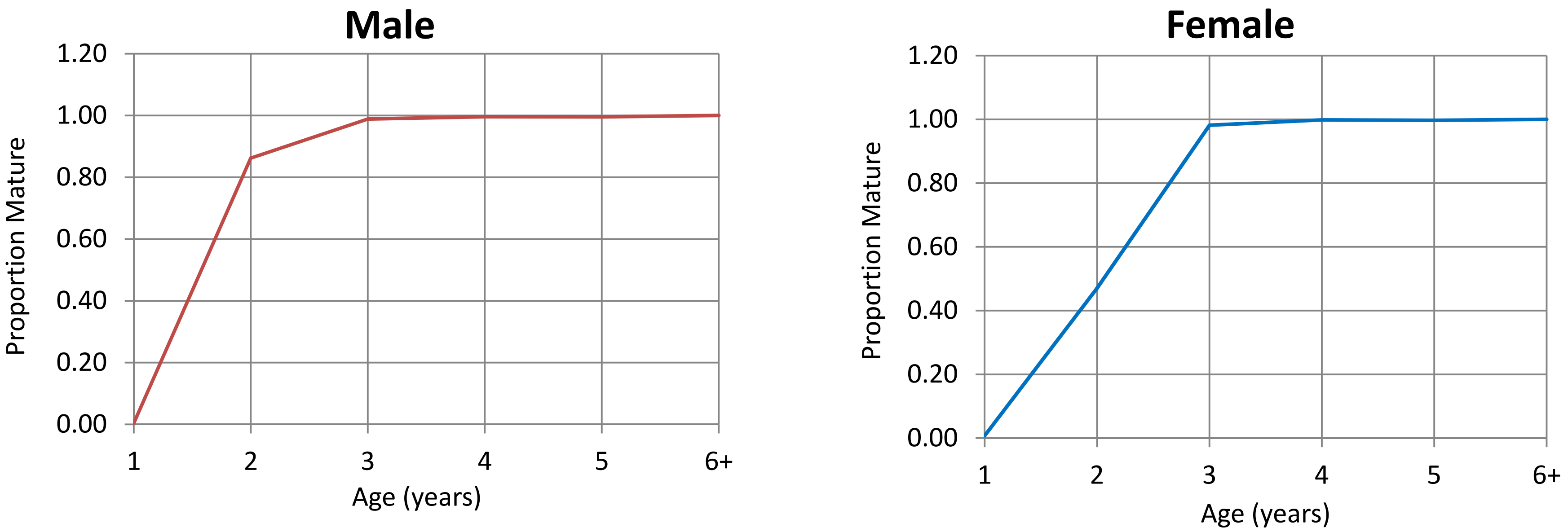


Figure B11. Observed maturity ogives for male (left) and female (right) Southern New England Mid-Atlantic yellowtail flounder from 1973-2011 from data collected from the Northeast Fisheries Science Center (NEFSC) Spring trawl Survey.

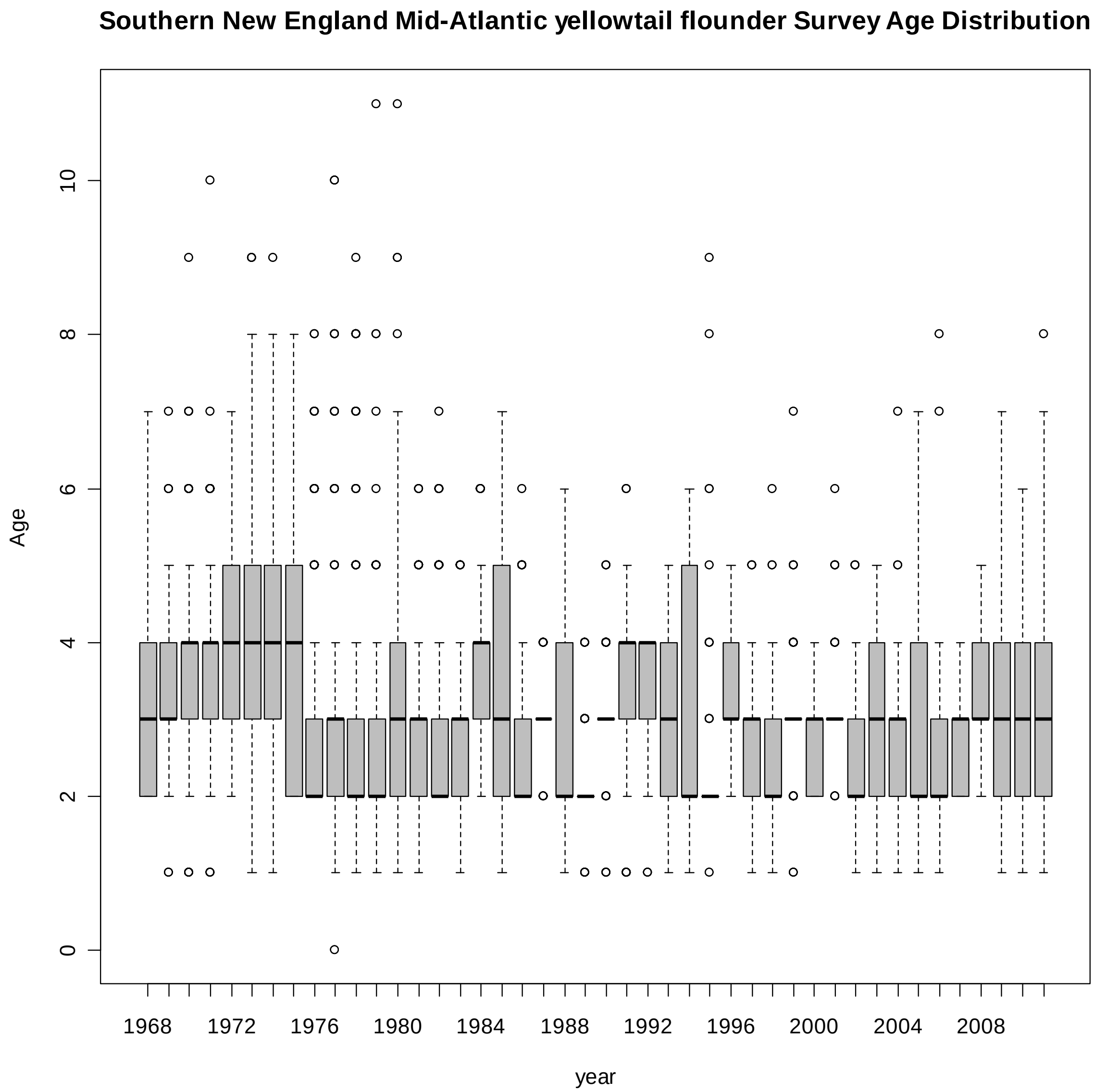


Figure B12. Age distribution of Southern New England Mid-Atlantic yellowtail flounder from the Northeast Fisheries Science Center Spring and Fall survey combined from 1973-2011. Observed maximum age of 11 resulted in natural mortality estimates ranging from 0.27 – 0.38 depending on the method.

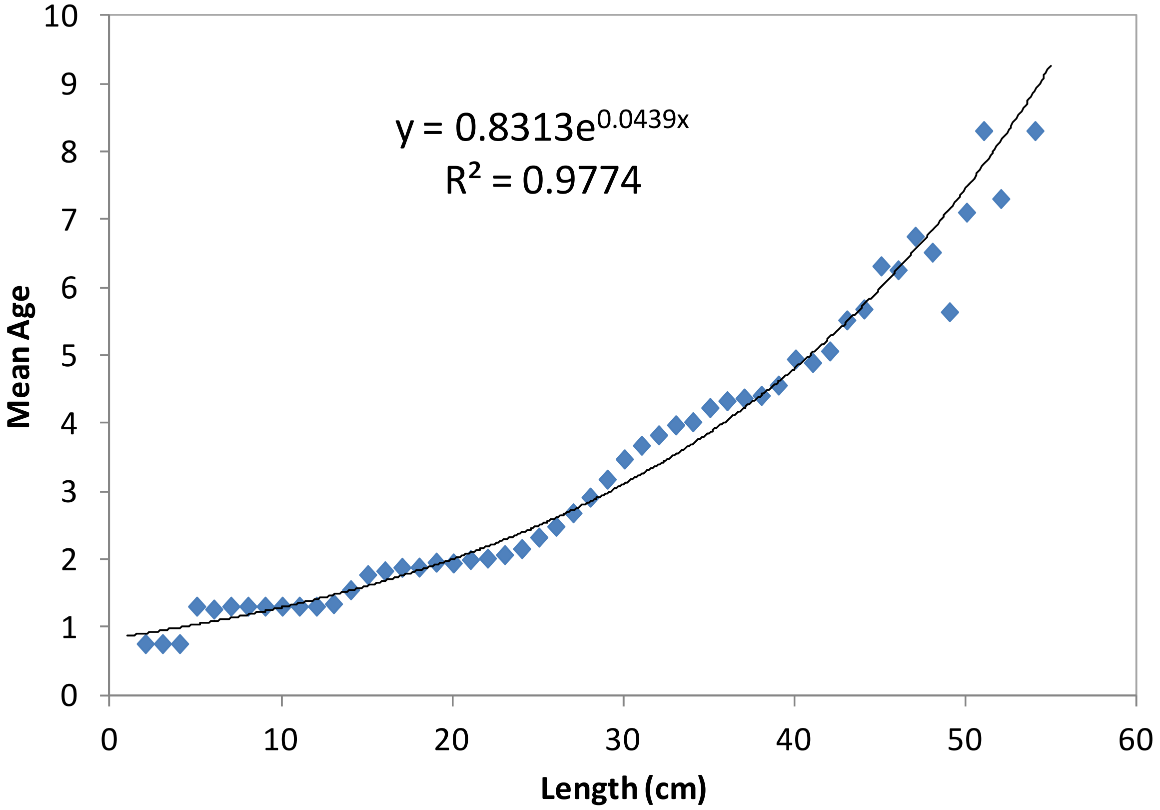


Figure B13. Observed and predicted mean age at length of Southern New England Mid-Atlantic yellowtail flounder modeled as power function from age and length data derived from the Northeast Fisheries Science Center fall and Spring Survey combined from 1973-2011.

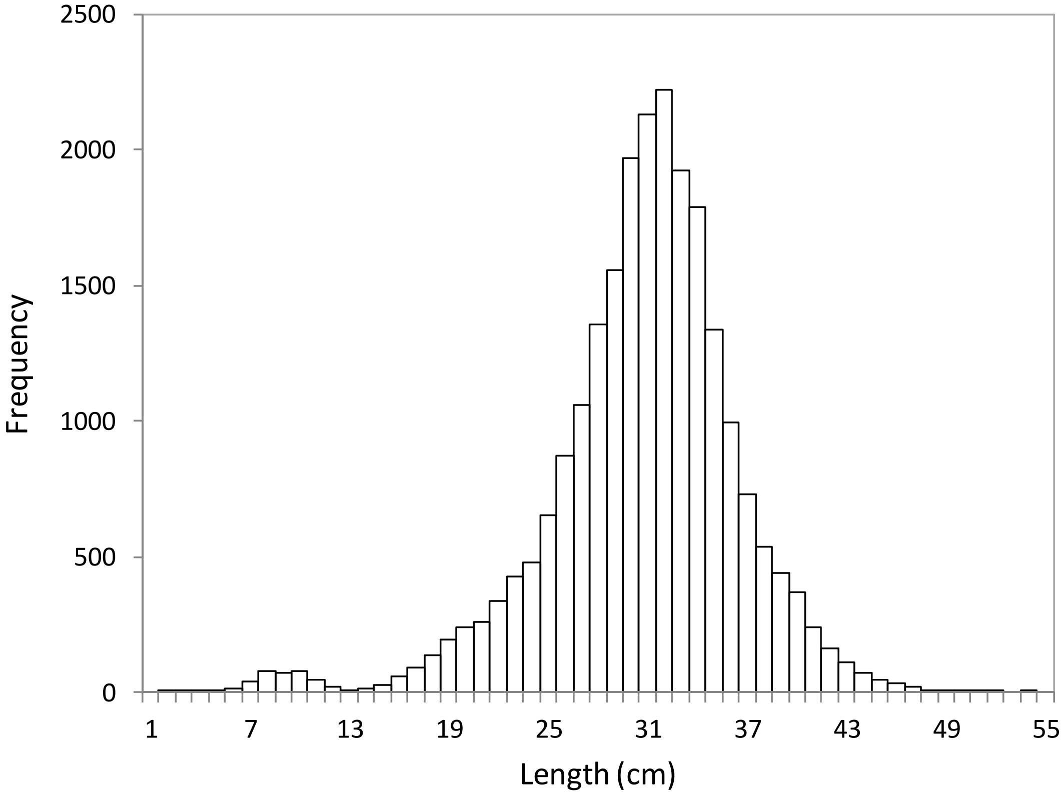


Figure B14. Southern New England Mid-Atlantic yellowtail flounder length distributions from the Northeast Fisheries Science center spring and fall survey from 1973-2011. The observed maximum length of 54cm resulted in estimated mean age of 8.9 with natural mortality estimates ranging from 0.34 – 0.47

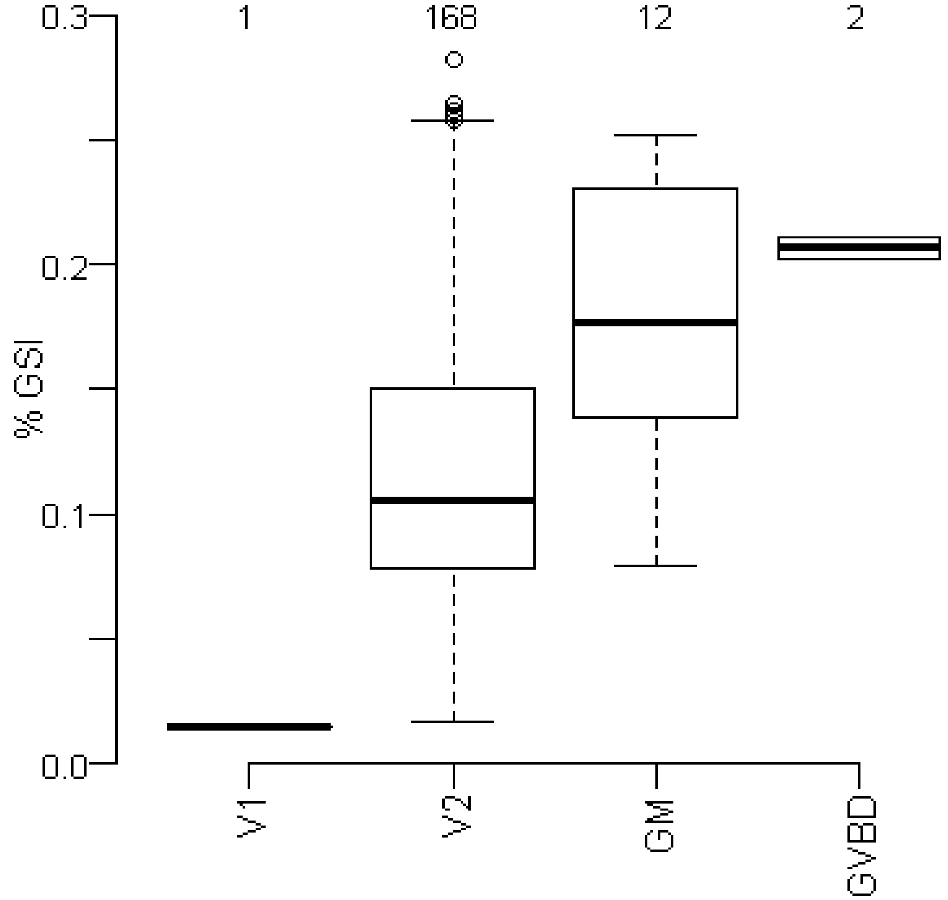


Figure B15. Gonadosomatic index (GSI) for mature (pre-spawning) female Southern New England Mid-Atlantic yellowtail flounder reported by most advanced oocytes stage from data collected from the Northeast Fisheries Science Center Northeast Cooperative Research program (NEFSC-NCRP) study fleet from December 2009 through April 2011. Fish were confirmed as pre-spawning by the lack of post-ovulatory follicles in the gonad histology sample. Numbers at the top indicate sample sizes.

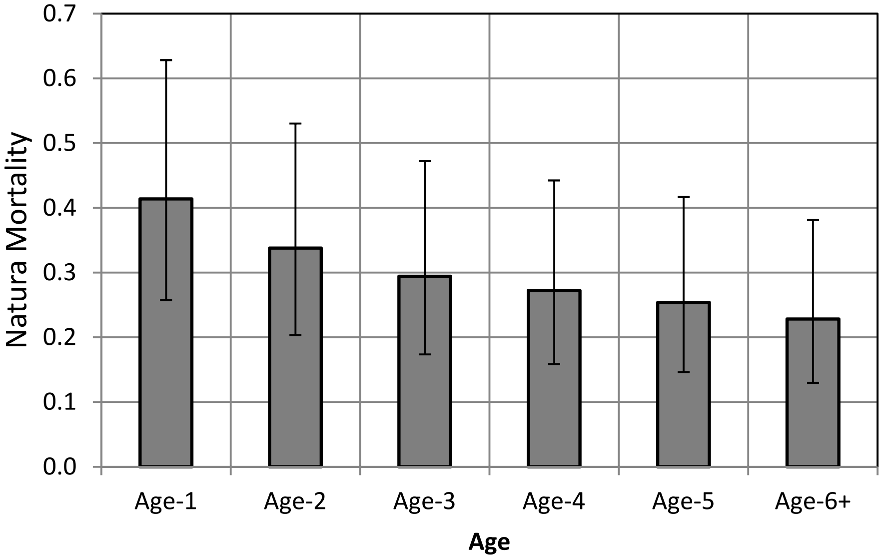


Figure B16. Southern New England Mid-Atlantic yellowtail flounder time series average estimates of natural mortality (rescaled to M = 0.3) and 95% confidence interval based on Lorenzen's method. Parameters for the power function were derived from Lorenzen (1996)

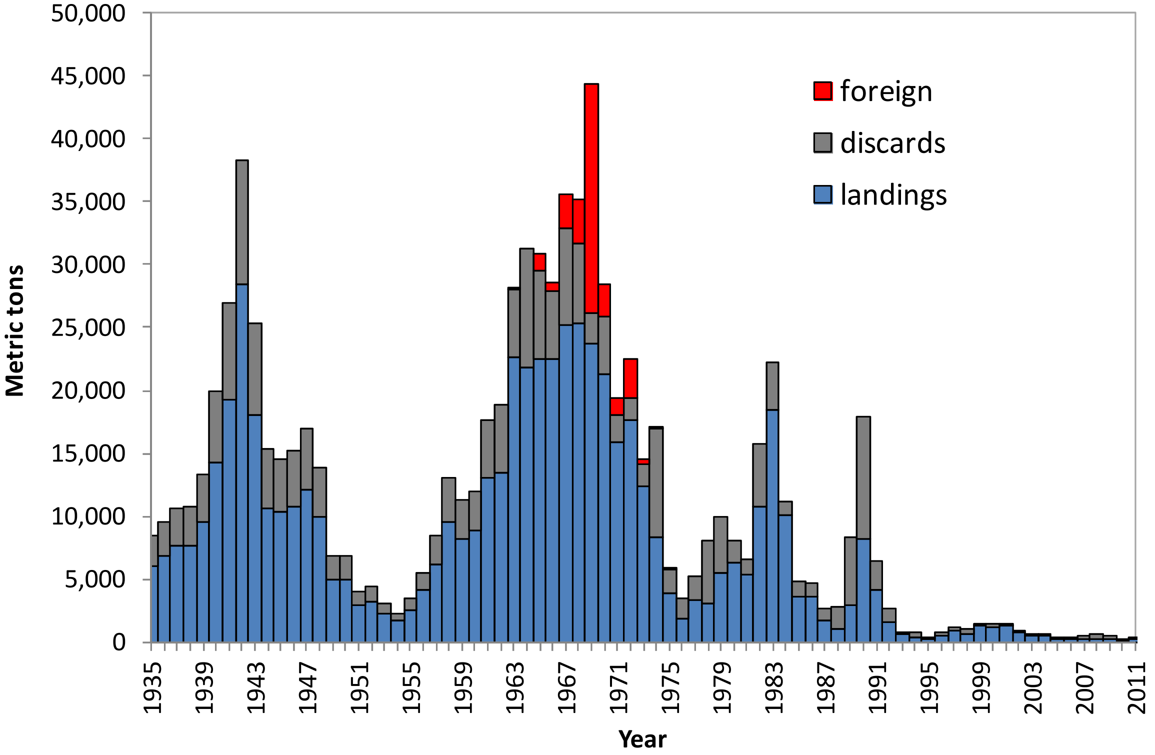


Figure B17. Total catch of Southern New England Mid-Atlantic yellowtail flounder in metric tons from 1935 – 2011 by disposition (landed and discarded)

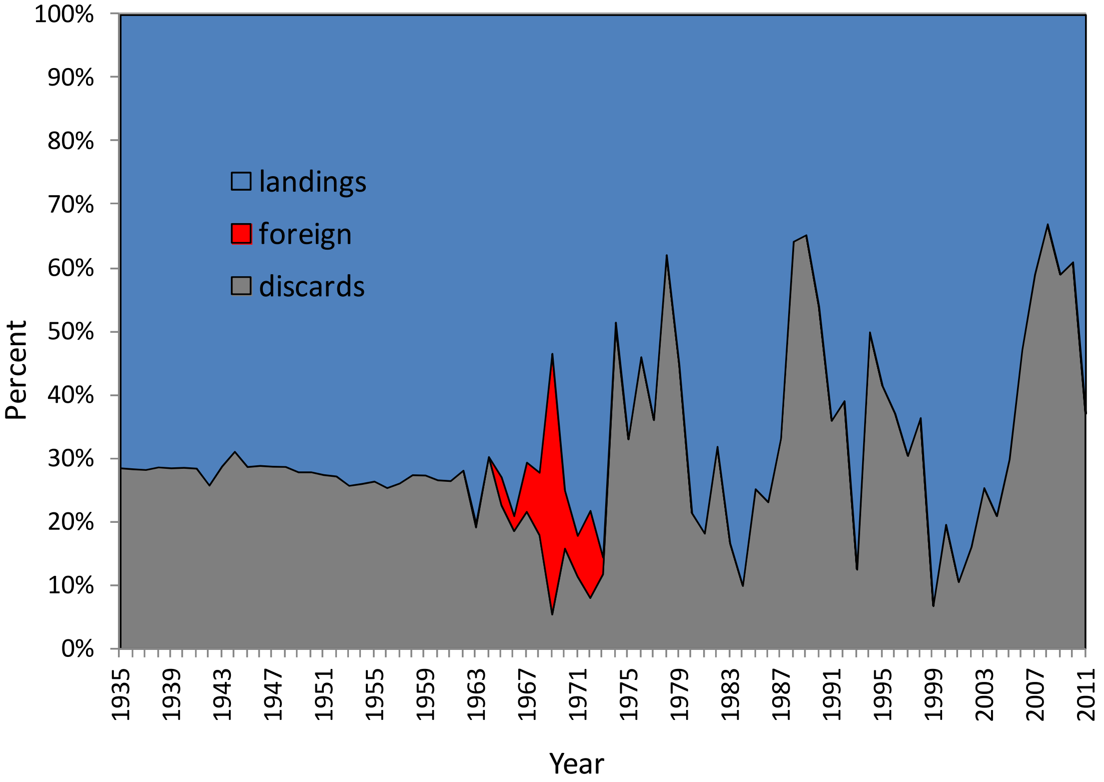
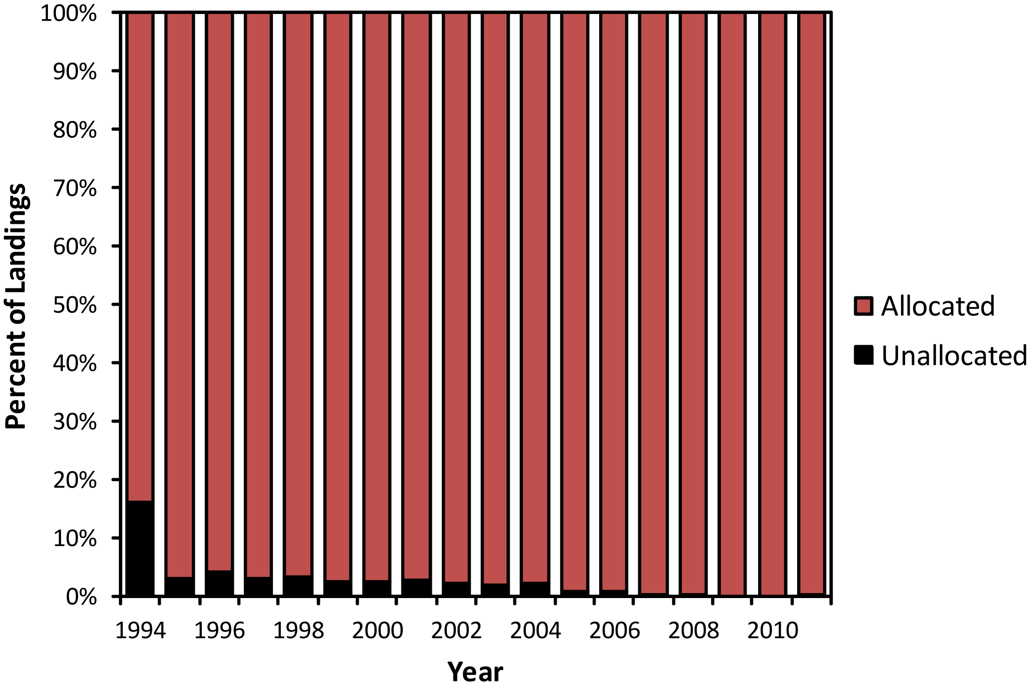


Figure B18. Total catch of Southern New England Mid-Atlantic yellowtail flounder in metric tons from 1935 – 2011 by disposition (landed and discarded) expressed as proportions



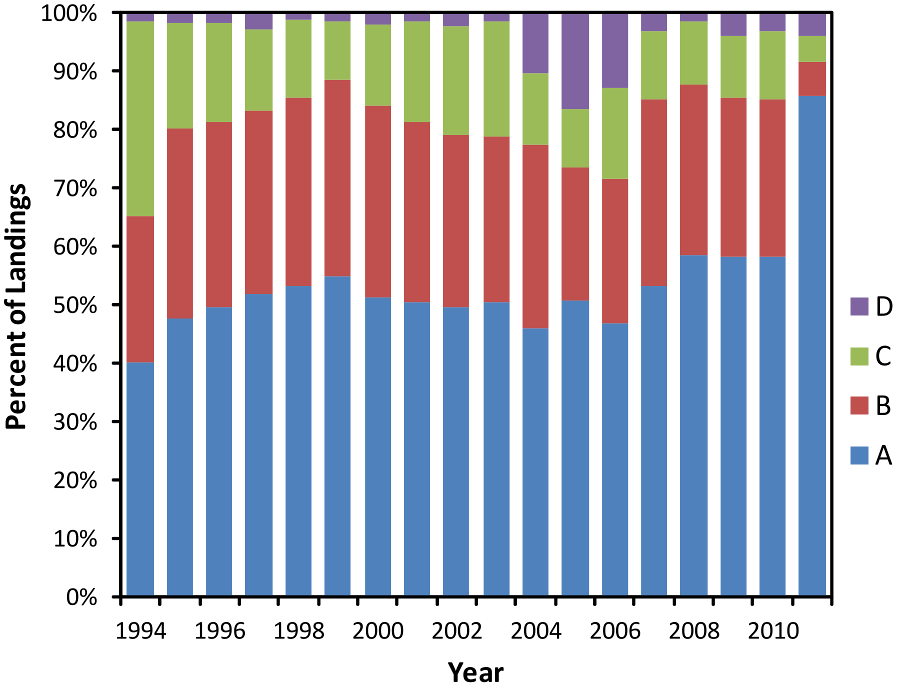
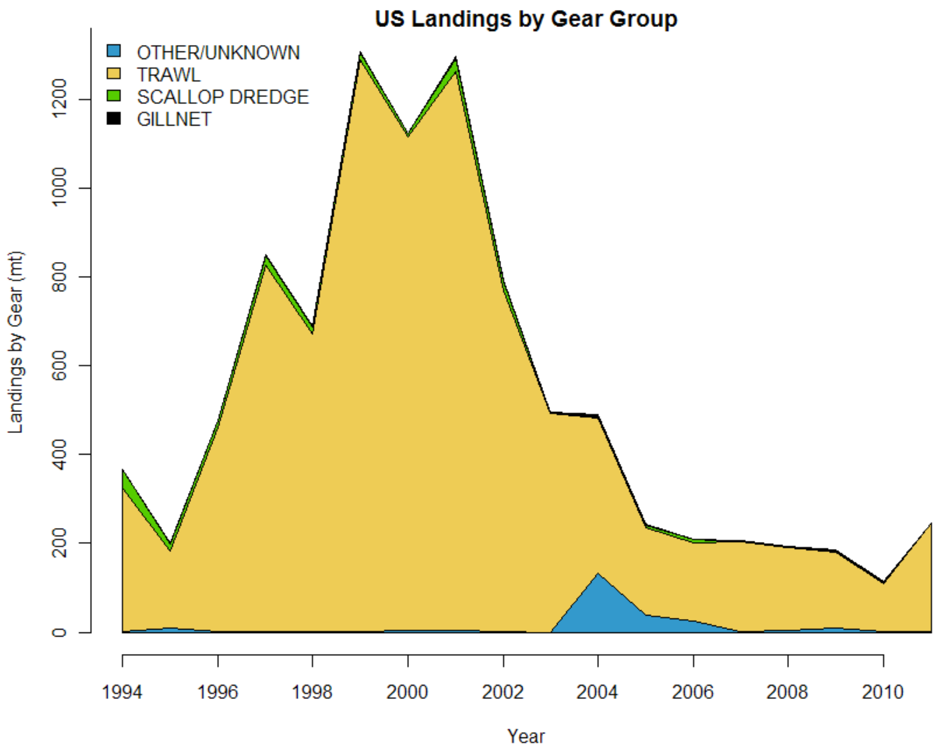


Figure B19. Fraction of commercial landings Area Allocation level (AA, See Wigley et al. 2008) for Southern New England Mid-Atlantic yellowtail flounders from 1994-2011. Certainty of landings increases from level D to A. Unallocated landings do not enter the allocation procedure.



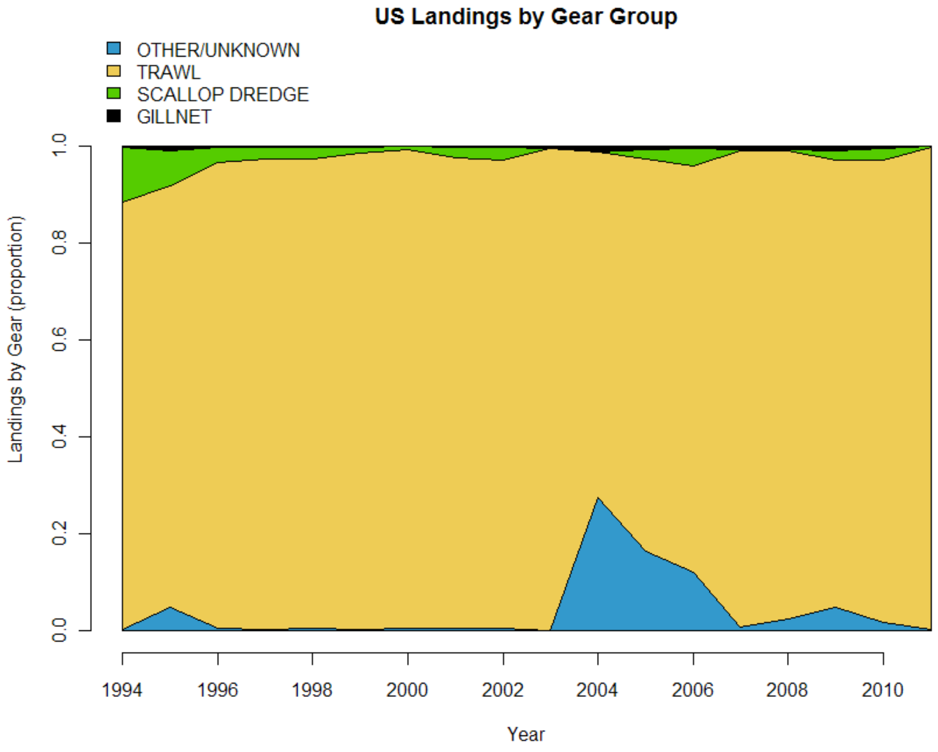


Figure B20. Total (top) and fractional (as fraction of the total, bottom) commercial landings of Southern New England Mid-Atlantic yellowtail flounder by gear from 1994-2011.

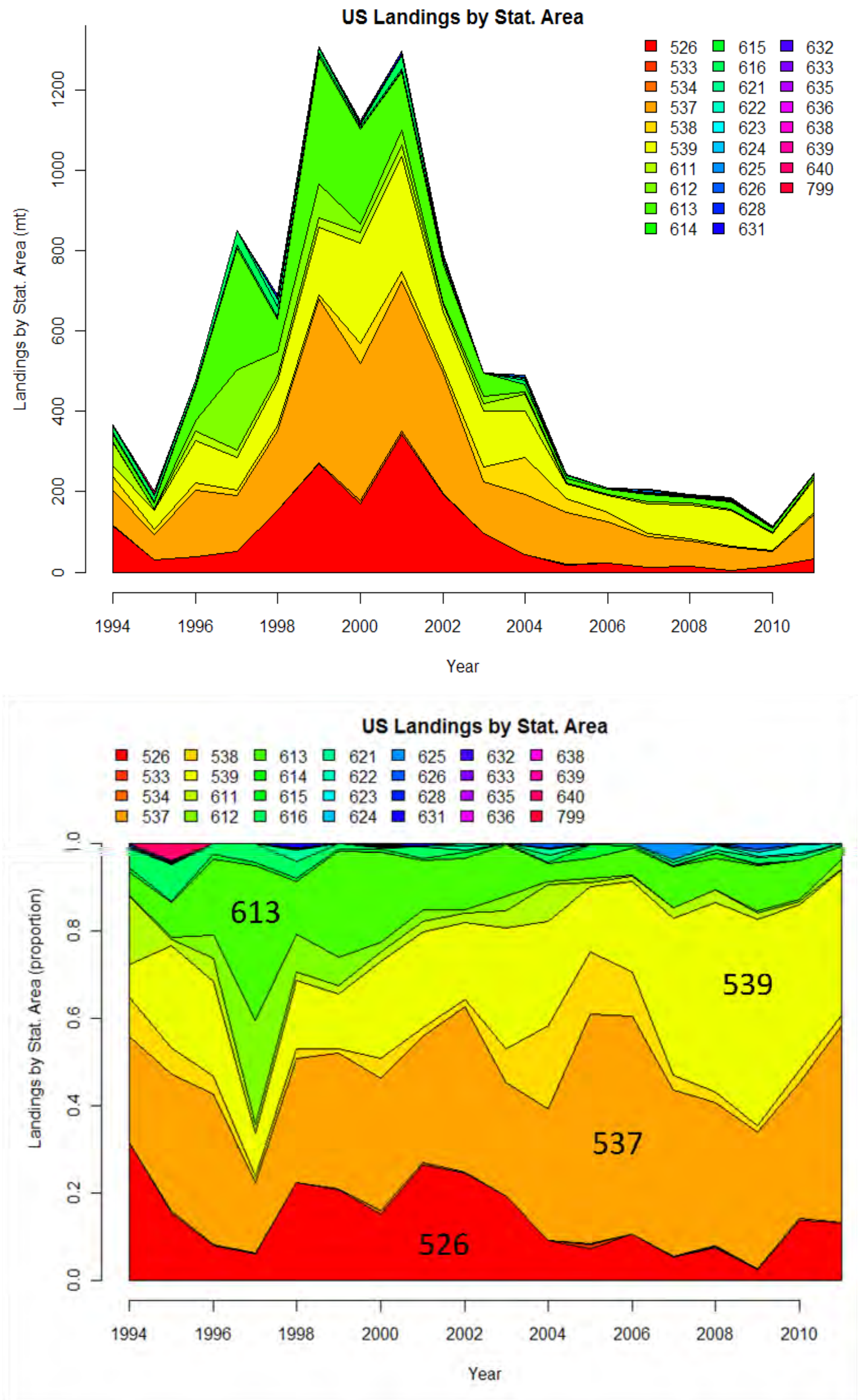
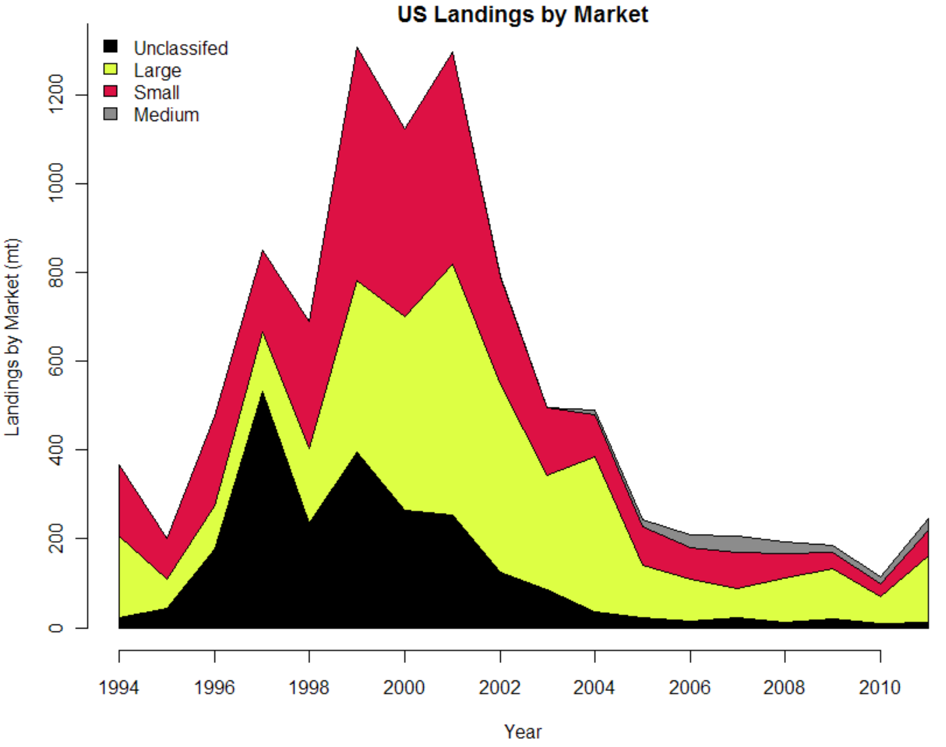


Figure B21. Total (top) and fractional (as fraction of the total, bottom) commercial landings of Southern New England Mid-Atlantic yellowtail flounder by statistical area from 1994-2011.



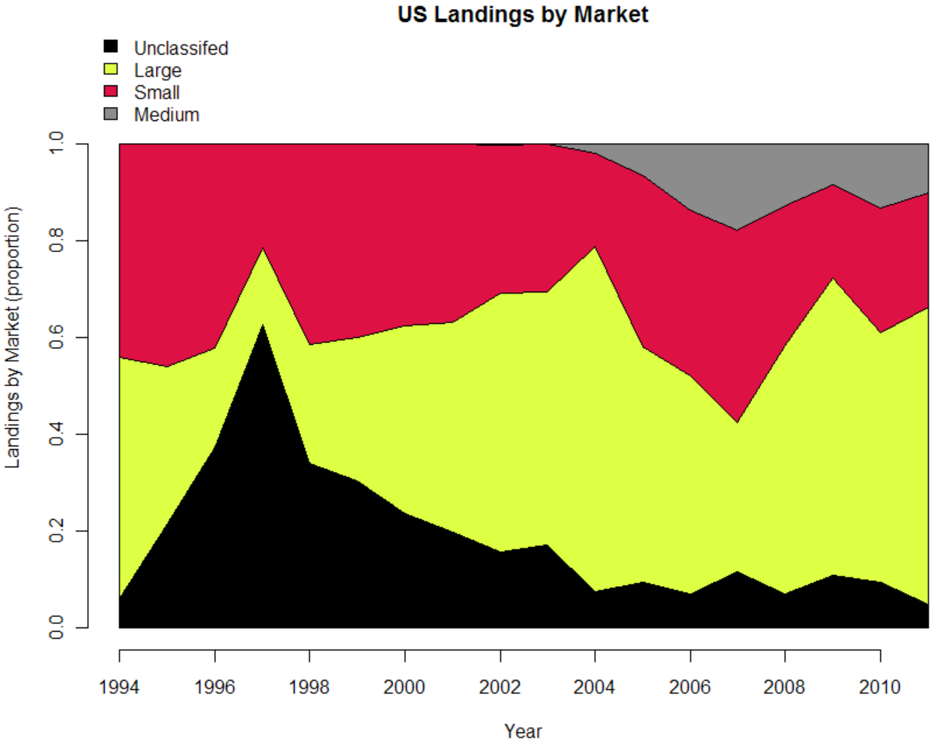


Figure B22. Total (top) and fractional (as fraction of the total, bottom) commercial landings of Southern New England Mid-Atlantic yellowtail flounder by market category from 1994-2011.

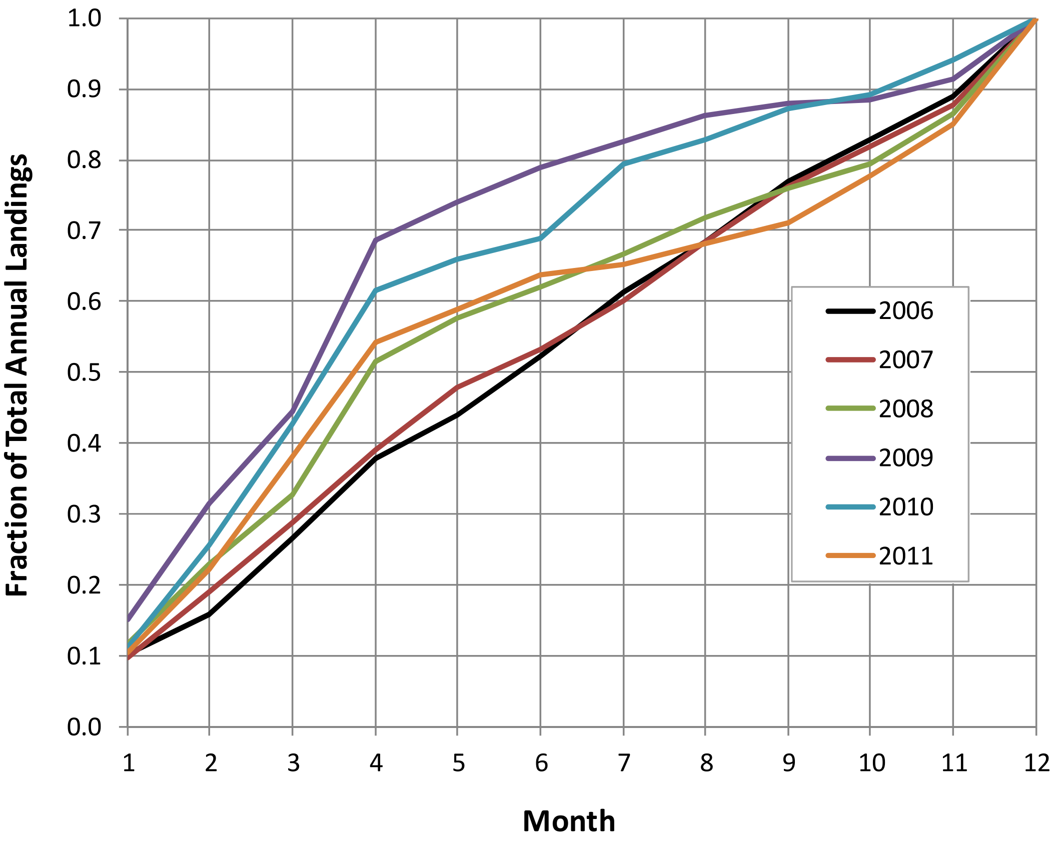


Figure B23. Cumulative monthly commercial landings of Southern New England Mid-Atlantic yellowtail flounder by year from 2006-2011

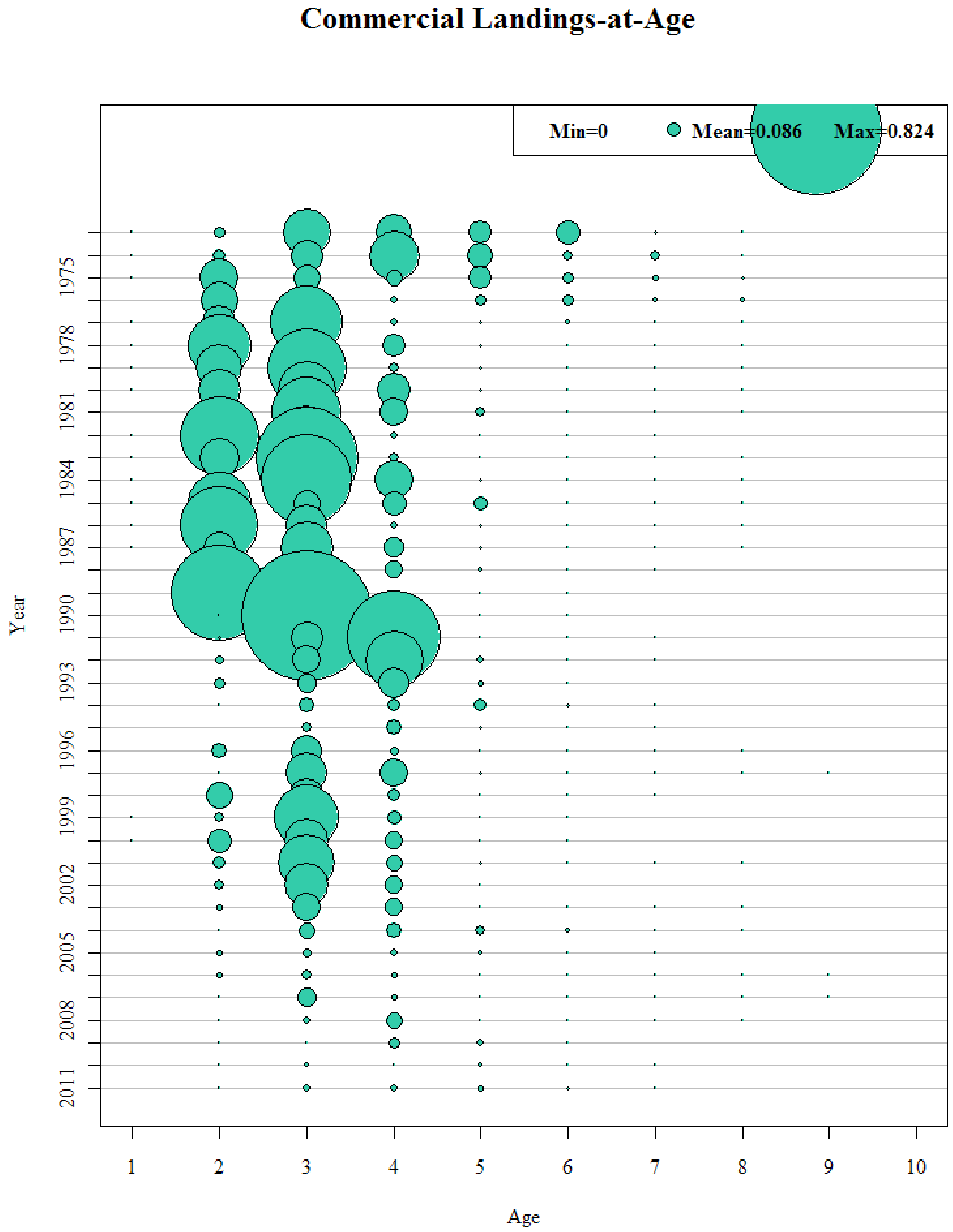


Figure B24. Commercial: landings-at-age for Southern New England Mid-Atlantic yellowtail flounder from 1973 to 2011

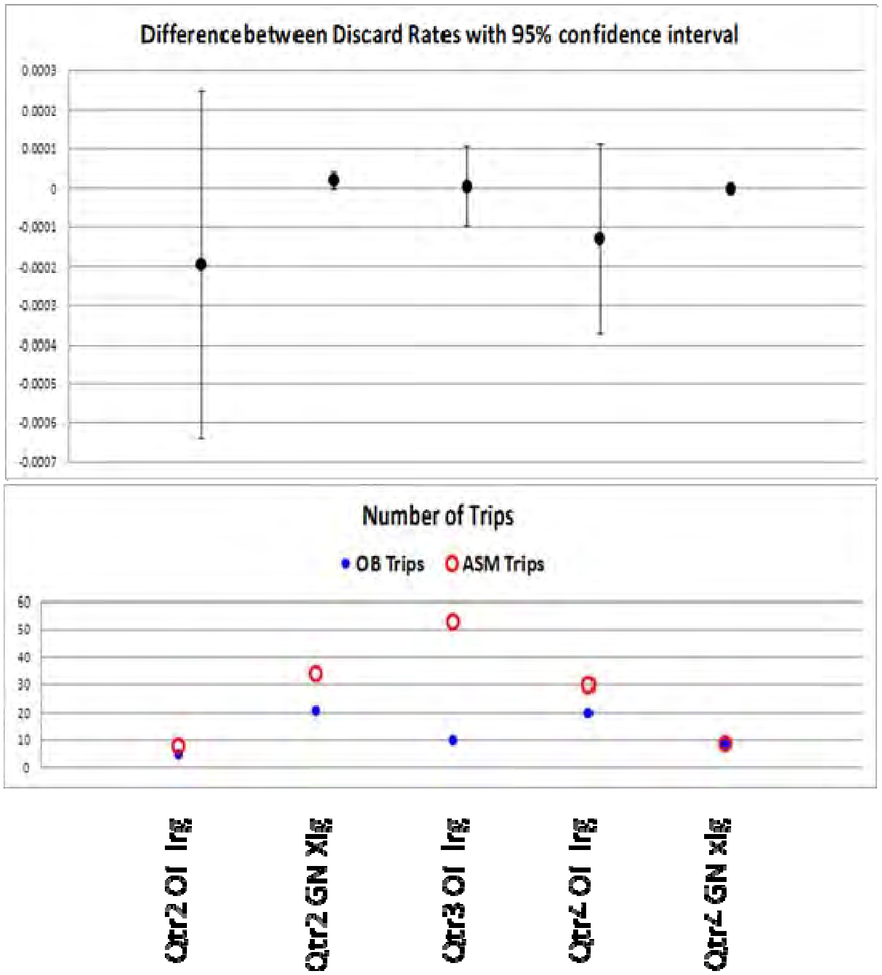


Figure B25.
Differences between the Southern New England Mid-Atlantic yellowtail flounder discard rates estimated from data collected by groundfish At-Sea Monitors (ASMs) and certified Observers showing 95% confidence intervals (top panel) and the number of trips included in each analyses (bottom panel) disaggregated by gear-mesh combination and quarter (from Wigley et al. 2011). Gera categories include Large mesh otter trawl (OT lrg), and extra large mesh Gillnet (GN Xlg).

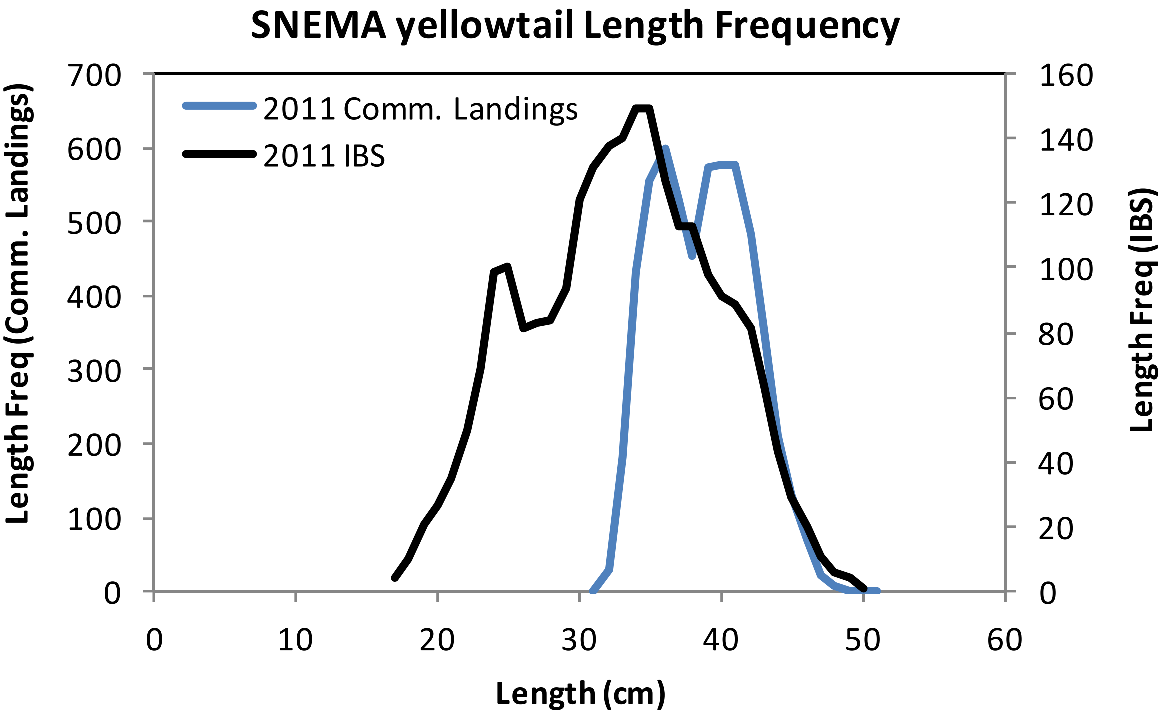


Figure B26. A comparison between Southern New England Mid-Atlantic yellowtail Industry based Survey (IBS) and 2011 commercial landings length distribution.

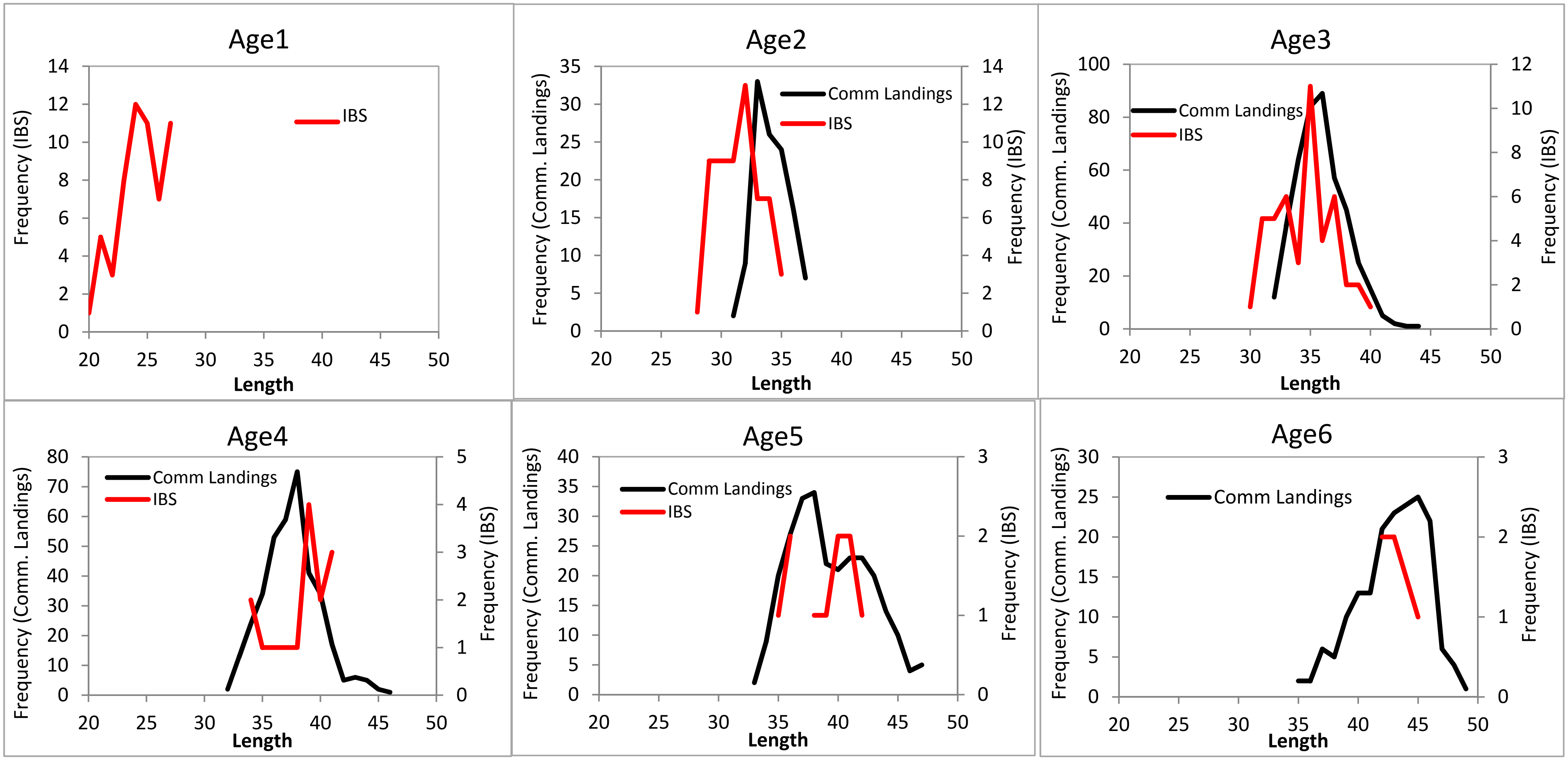


Figure B27. A comparison between Southern New England Mid-Atlantic yellowtail Industry based Survey (IBS) and 2011 commercial landings age distribution.

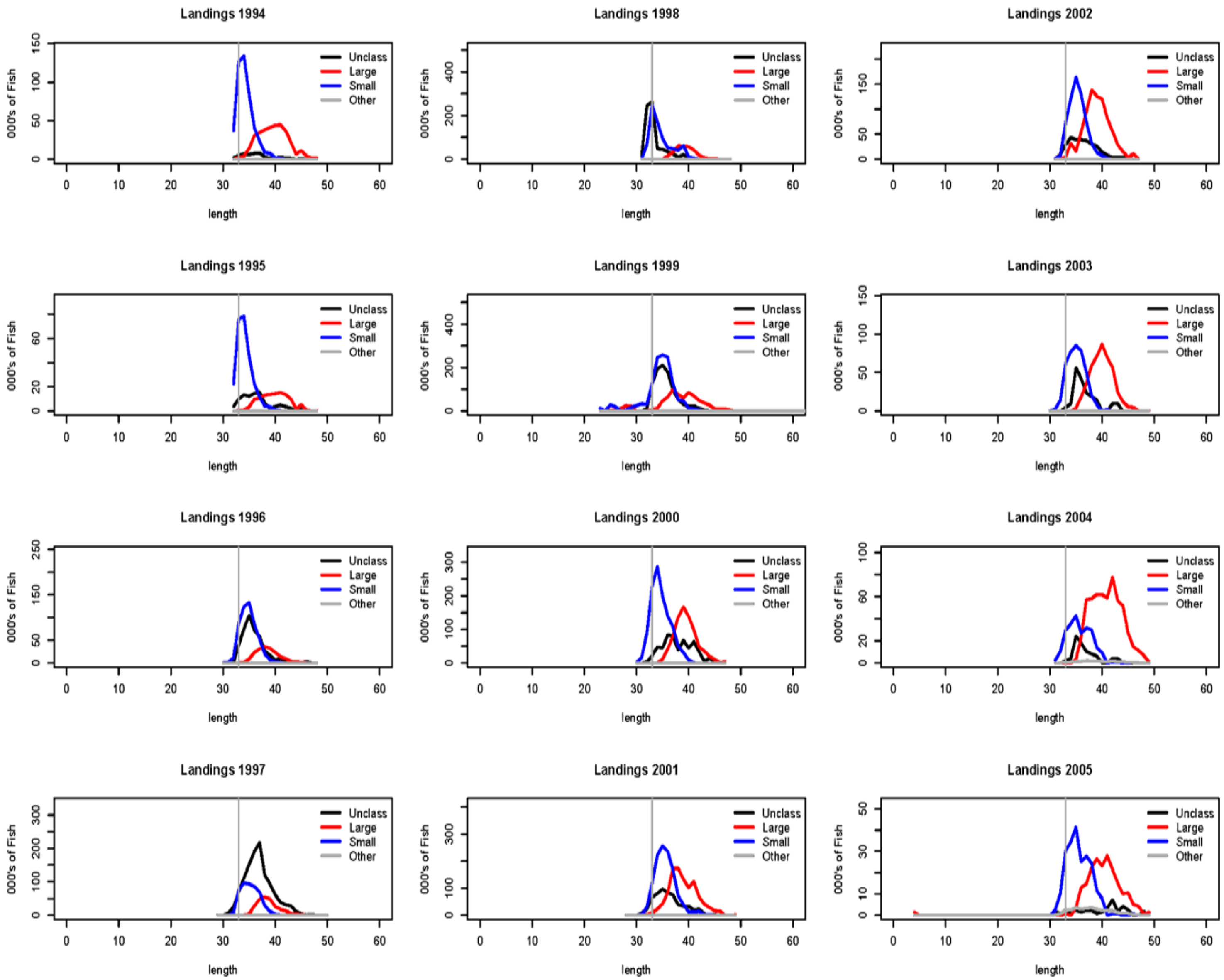


Figure B28a. Length frequency distribution of landed Southern New England Mid-Atlantic yellowtail flounder by market category in 000's of fish from 1994 and 2005. Market groups include: Unclassified, Large, Small and Other. The 1989 –current commercial minimum retention size of 13 inches (33cm) is indicated by a dash grey line.

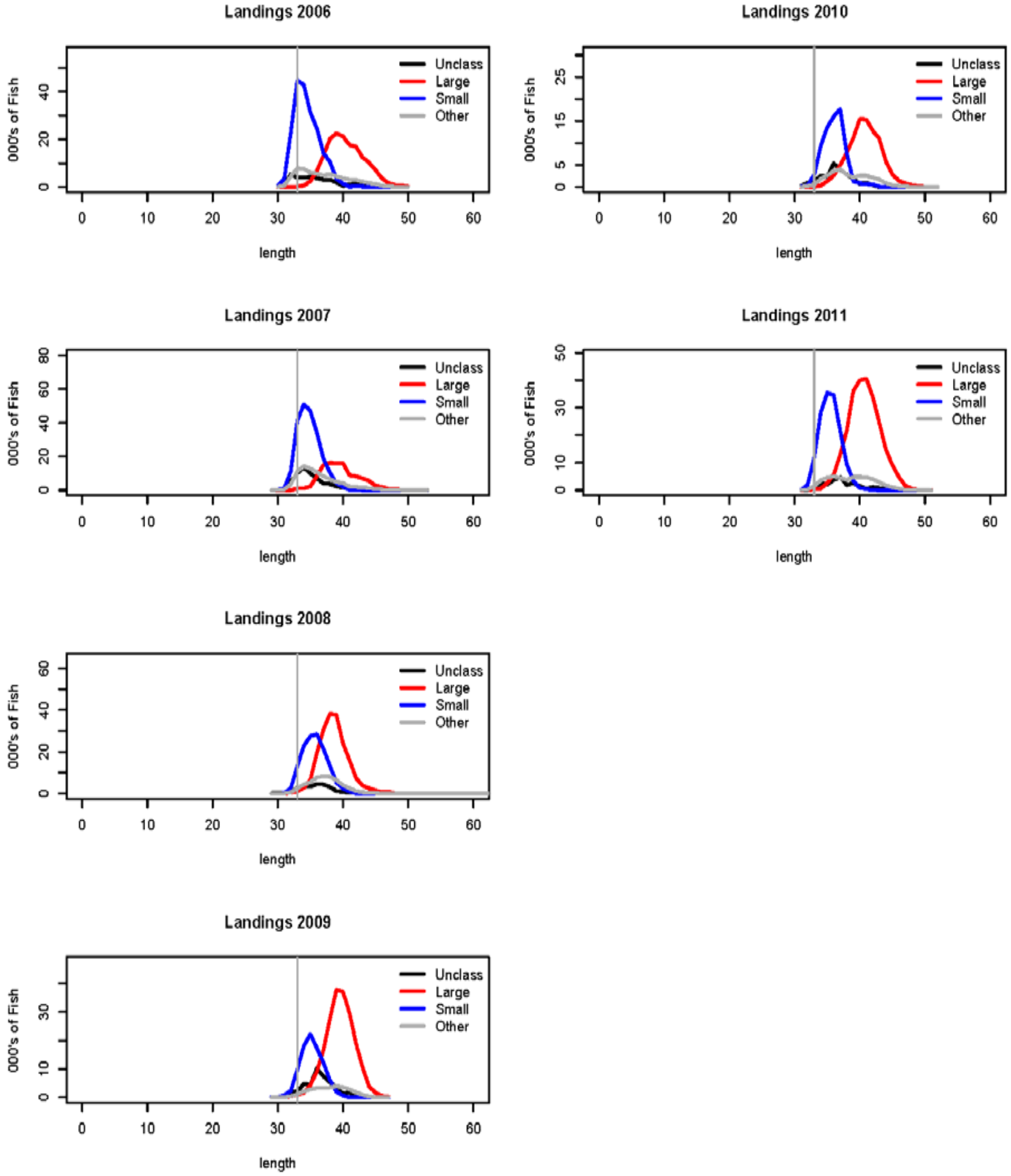


Figure B28b. (cont'd). Length frequency distribution of landed Southern New England Mid-Atlantic yellowtail flounder by market category in 000's of fish from 2006 to 2011. Market groups include: Unclassified, Large, Small and Other. The 1989 –current commercial minimum retention size of 13 inches (33cm) is indicated by a dash grey line.

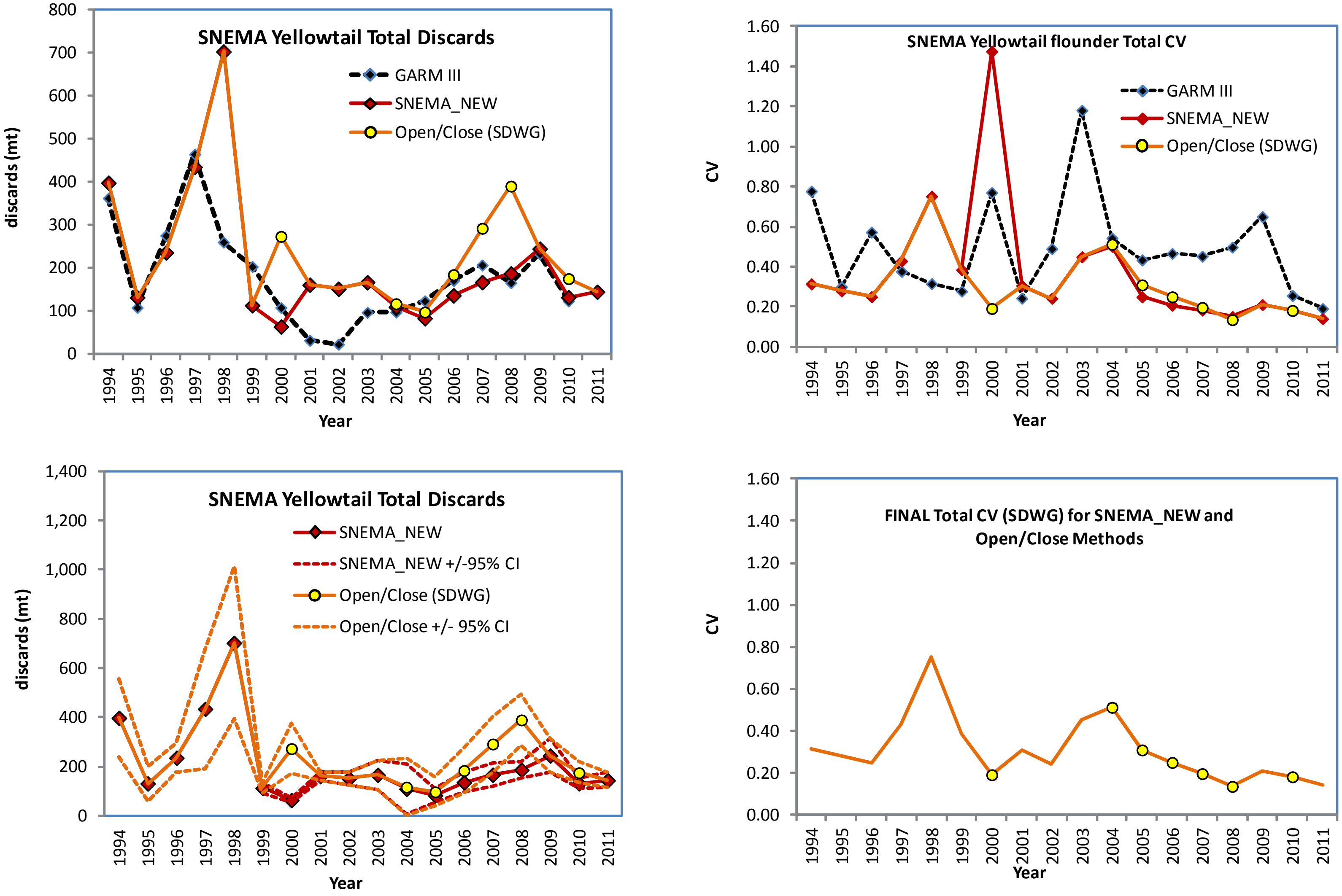


Figure B29. Comparison of the annual discard estimates for Southern New England Mid-Atlantic (SNEMA) yellowtail flounder (Left) and corresponding coefficient of Variations (CV, right) using three different spatial stratification schemes: No stratification (GARM III), SNE-MA stratification, SNE-MA with open-access area stratification in SNE for the limited access scallop fishery fleet. Note. SNE closed area is defined by the Nantucket Light-Ship (NLS). 95% CI are presented in the bottom left plot and the final accepted CV by the Southern Demersal Working Group (SDWG).

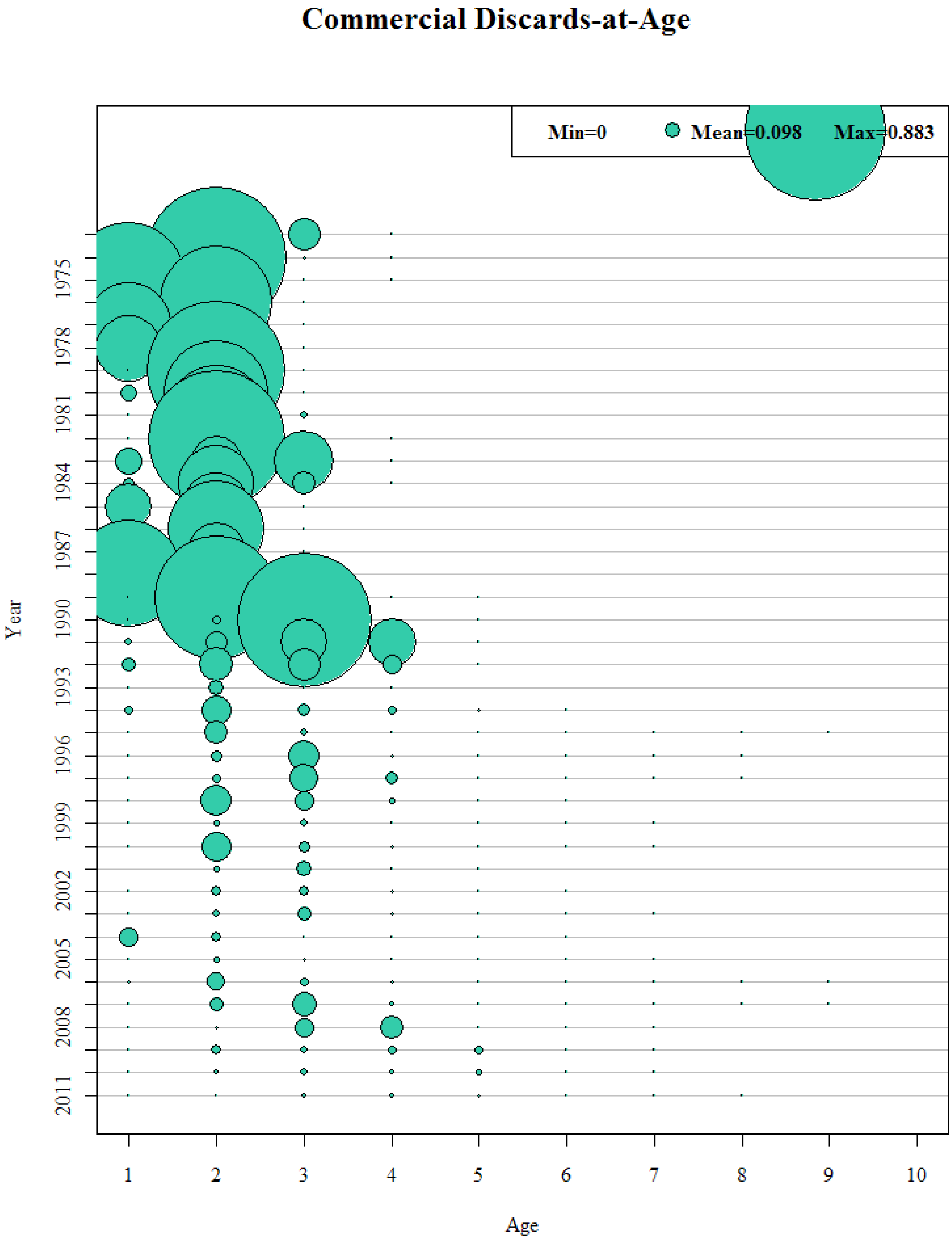


Figure B30. Commercial discards-at-age of Southern New England Mid-Atlantic yellowtail flounder from 1973 to 2011

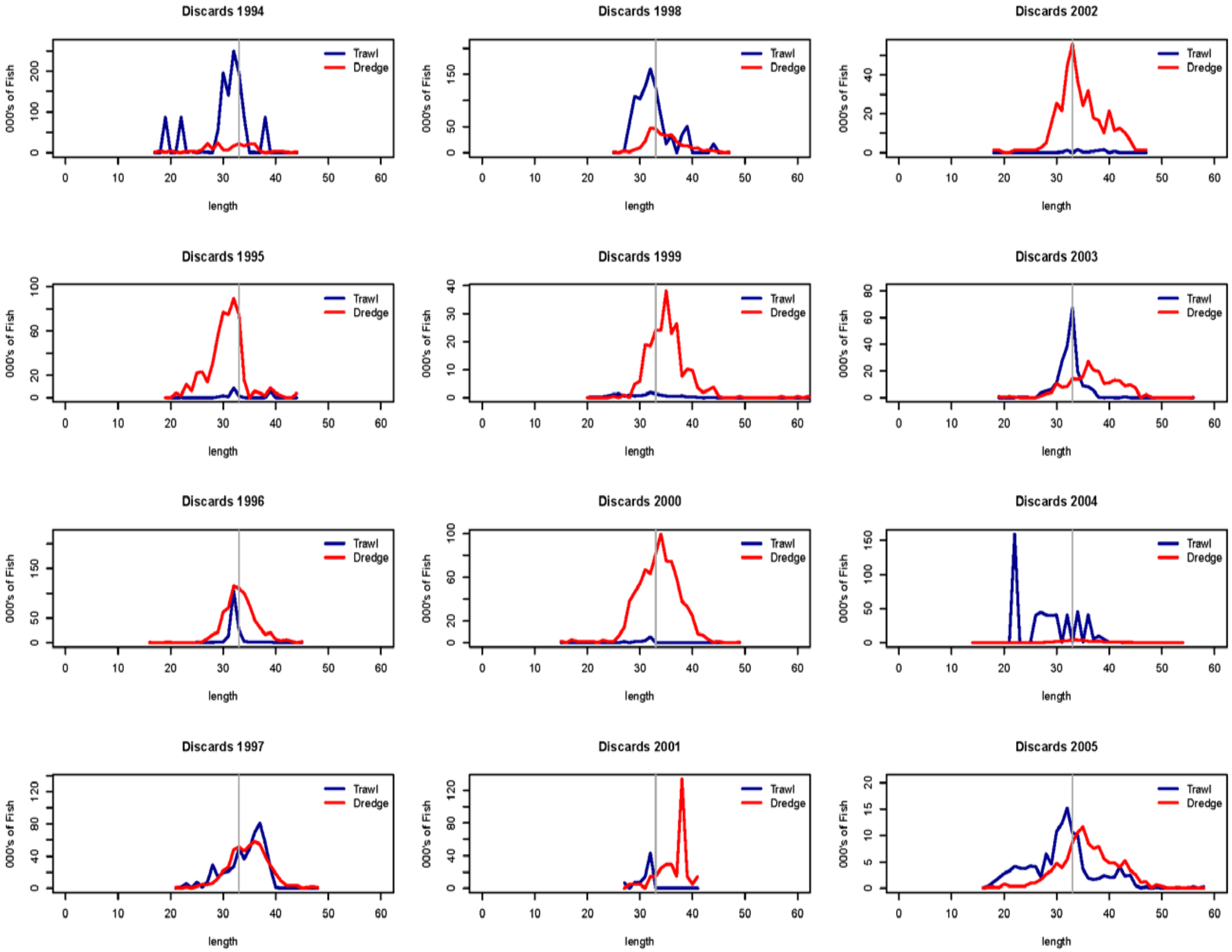


Figure B31a. Length frequency distribution of discarded Southern New England Mid-Atlantic yellowtail flounder by gear groupings (Trawl and Dredge) in 000's of fish from 194 and 2005. Commercial. The 1989 –current commercial minimum retention size of 13 inches (33cm) is indicated by a dash grey line.

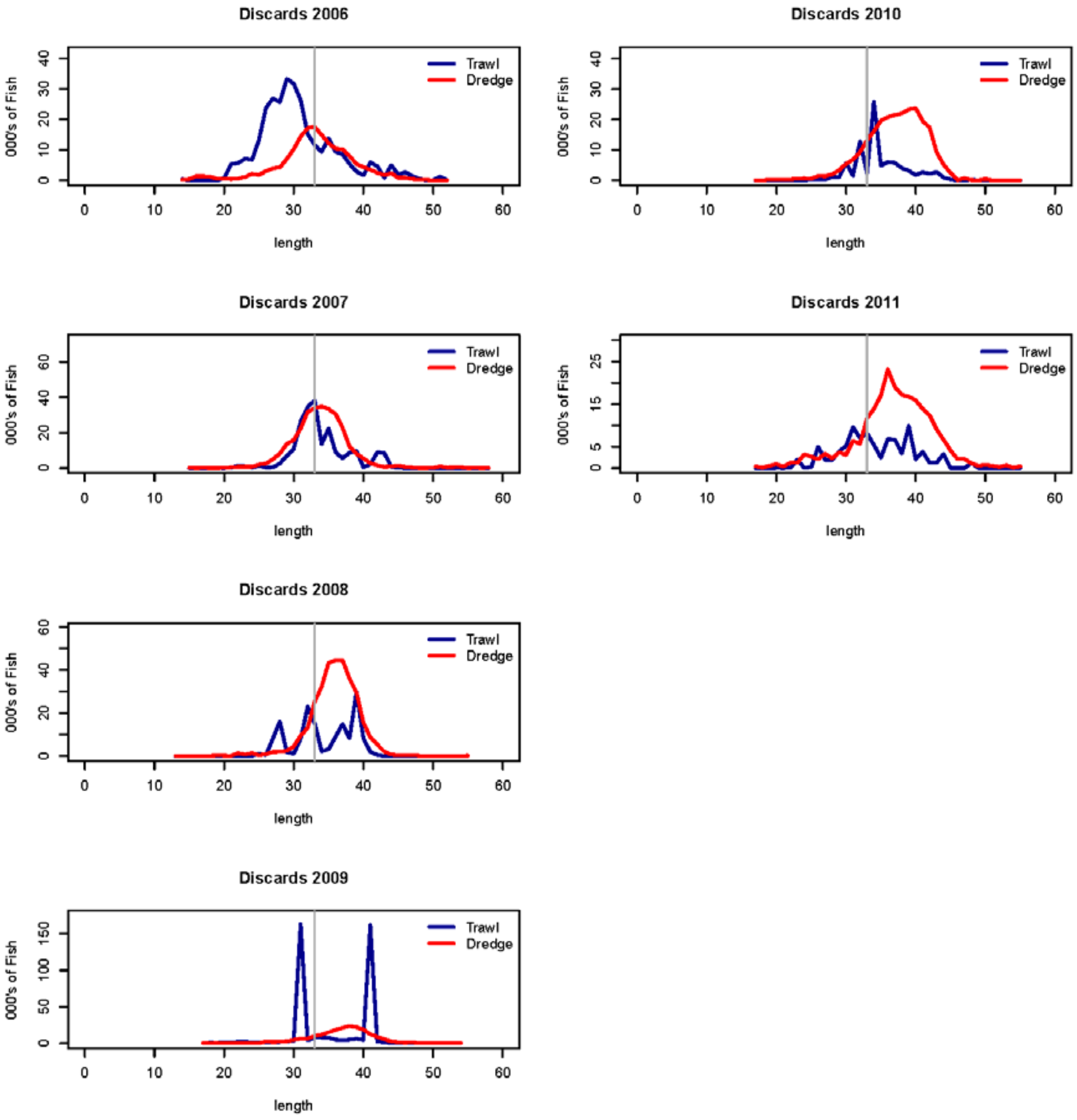


Figure B31b. (cont'd). Length frequency distribution of discarded Southern New England Mid-Atlantic yellowtail flounder by gear groupings (Trawl and Dredge) in 000's of fish from 2006 and 2011. The 1989 –current commercial minimum retention size of 13 inches (33cm) is indicated by a dash grey line.

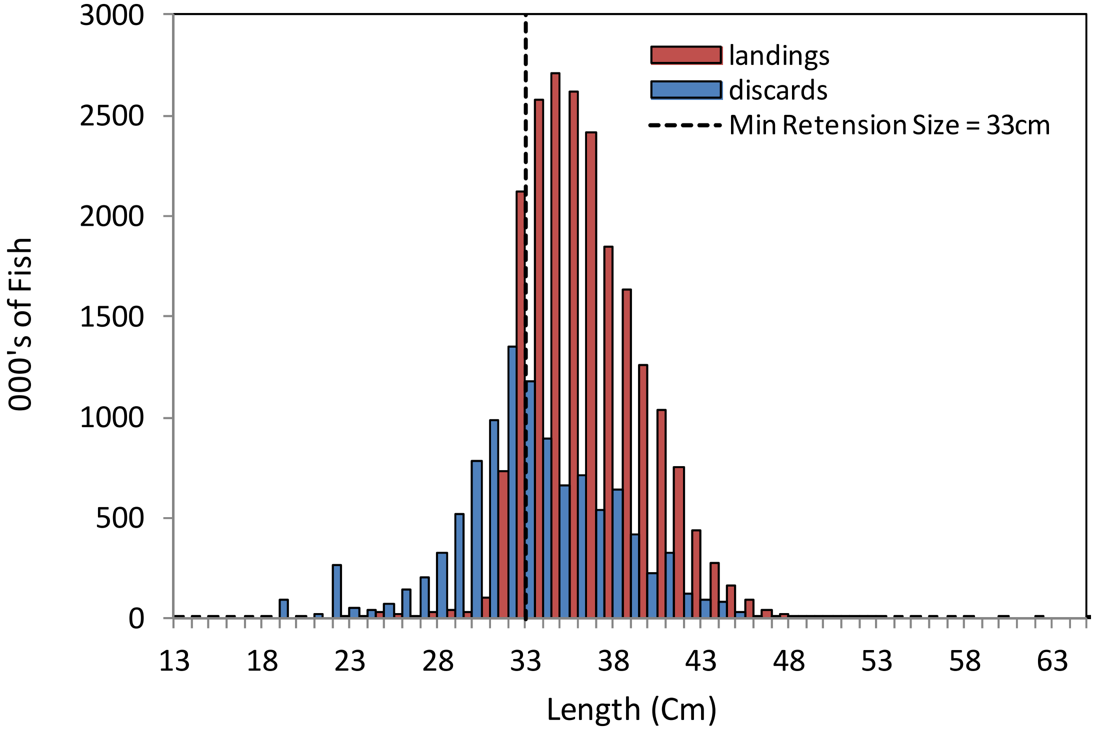


Figure B32. Length frequency distributions of Southern New England Mid-Atlantic yellowtail flounder in 000's of fish caught in the commercial fishery from 1994 to 2011. The 1989 –current commercial minimum retention size of 13 inches (33cm) is indicated by a dash grey line.

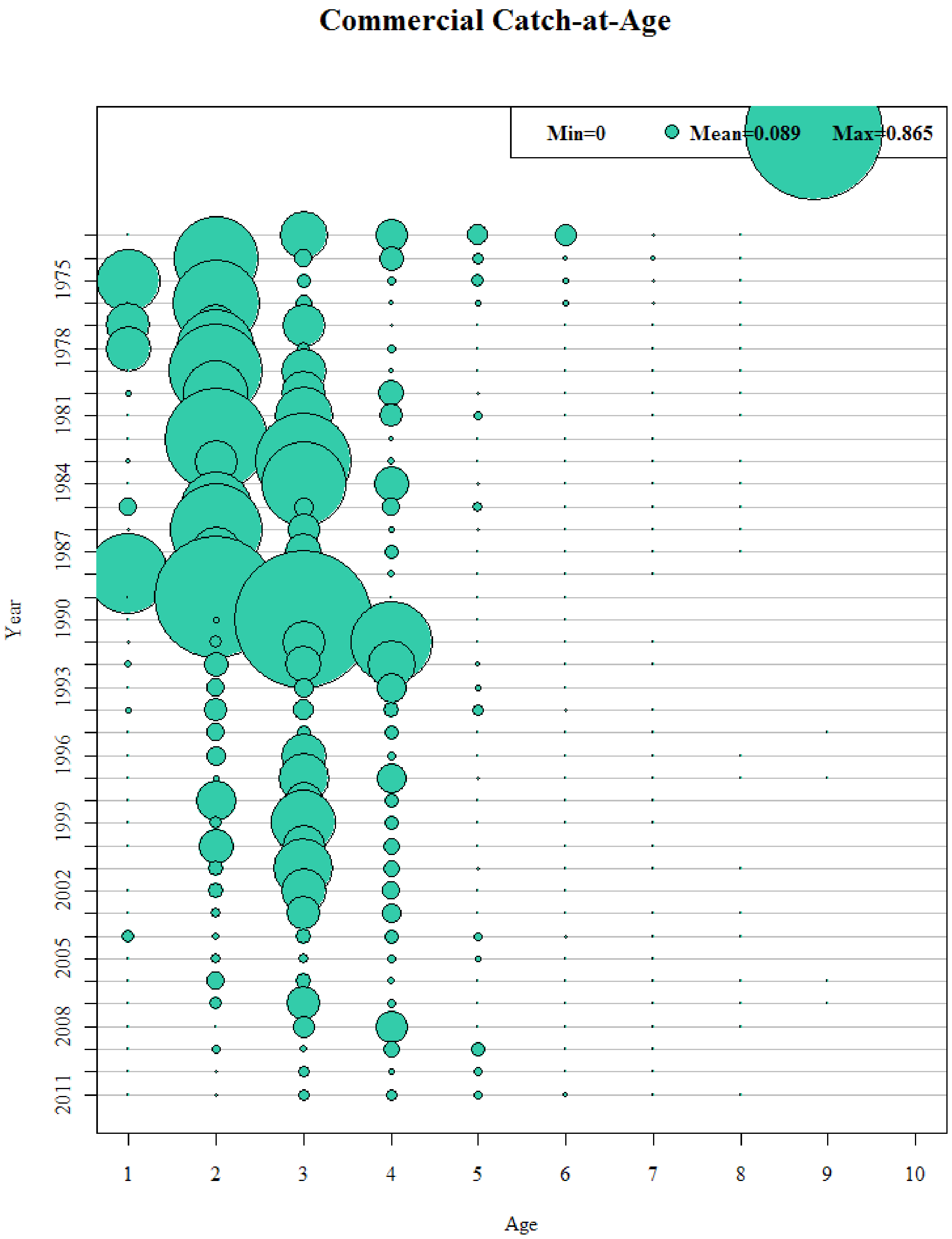


Figure B33. Commercial catch-at-age of Southern New England Mid-Atlantic yellowtail flounder from 1973 to 2011

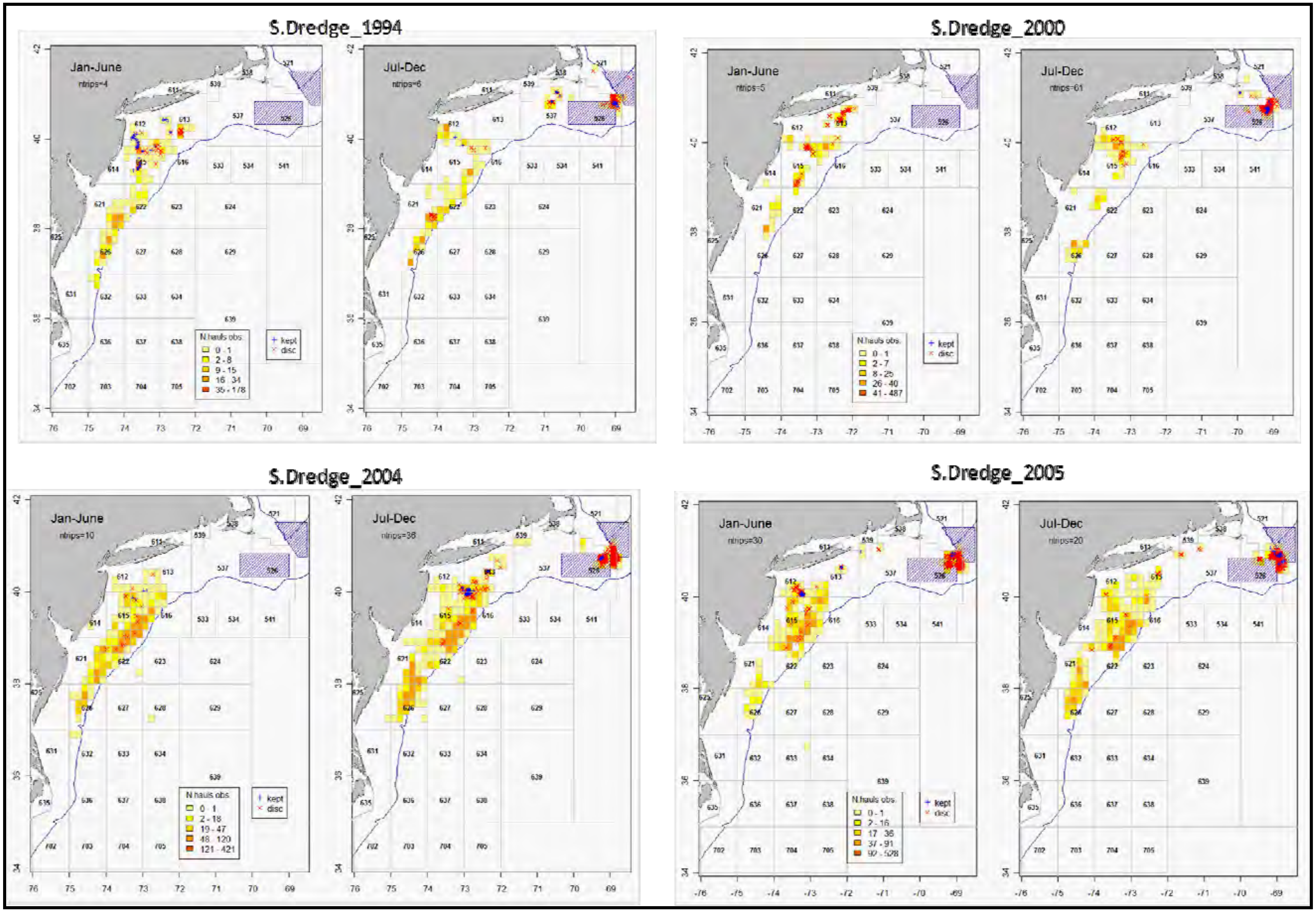


Figure B34. Spatial distributions of observed scallop dredge effort determined by the number of hauls by half year for selected years (1994, 2000 and 2004-2005) in the SNEMA region. Note: Observed kept and discarded yellowtail reflect general patterns of activity by the dredge fleet in the Southern New England Mid-Atlantic region and does not characterize the relative magnitude of the observed catches.

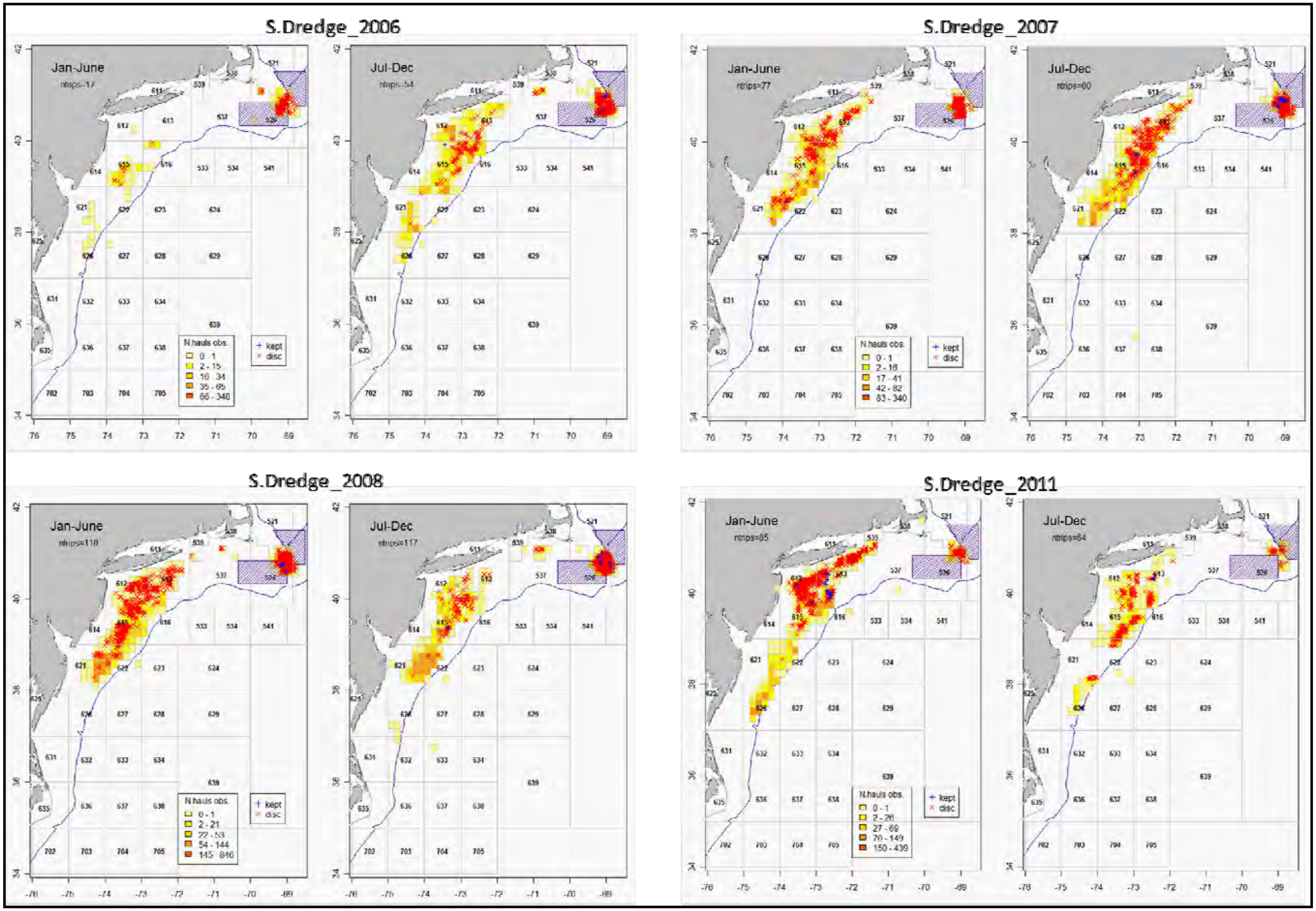


Figure B35. Spatial distributions of observed scallop dredge effort determined by the number of hauls by half year for selected years (2006-2008 and 2011) in the SNEMA stock region. Note: Observed kept and discarded yellowtail reflect general patterns of activity by the dredge fleet in the Southern New England Mid-Atlantic region and does not characterize the relative magnitude of the observed catches.

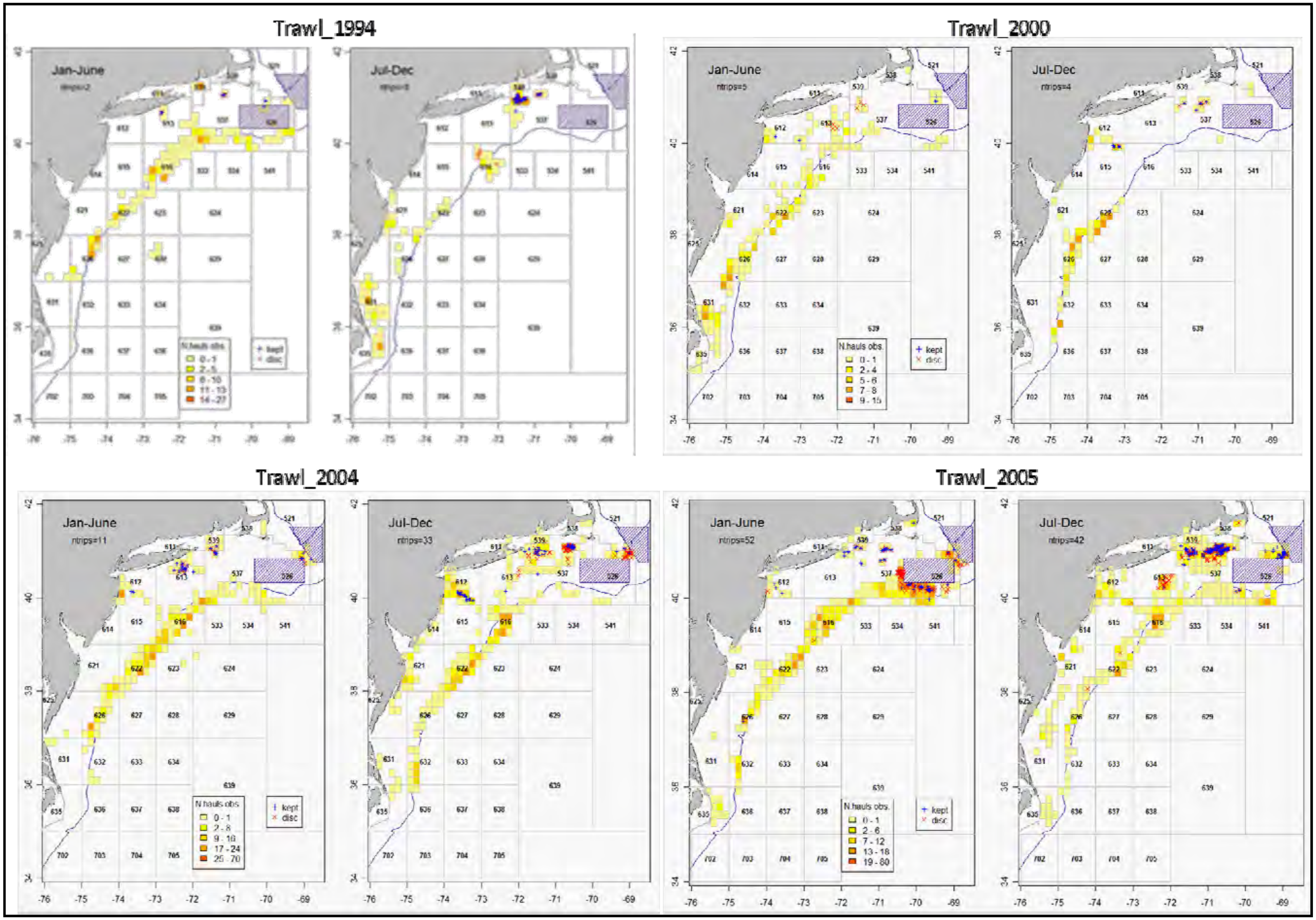


Figure B36. Spatial distributions of observed bottom trawl effort determined by the number of hauls by half year for selected years (1994, 2000 and 2004-2005)) in the SNEMA stock region. Note: Observed kept and discarded yellowtail reflect general patterns of activity by the dredge fleet in the Southern New England Mid-Atlantic region and does not characterize the relative magnitude of the observed catches.

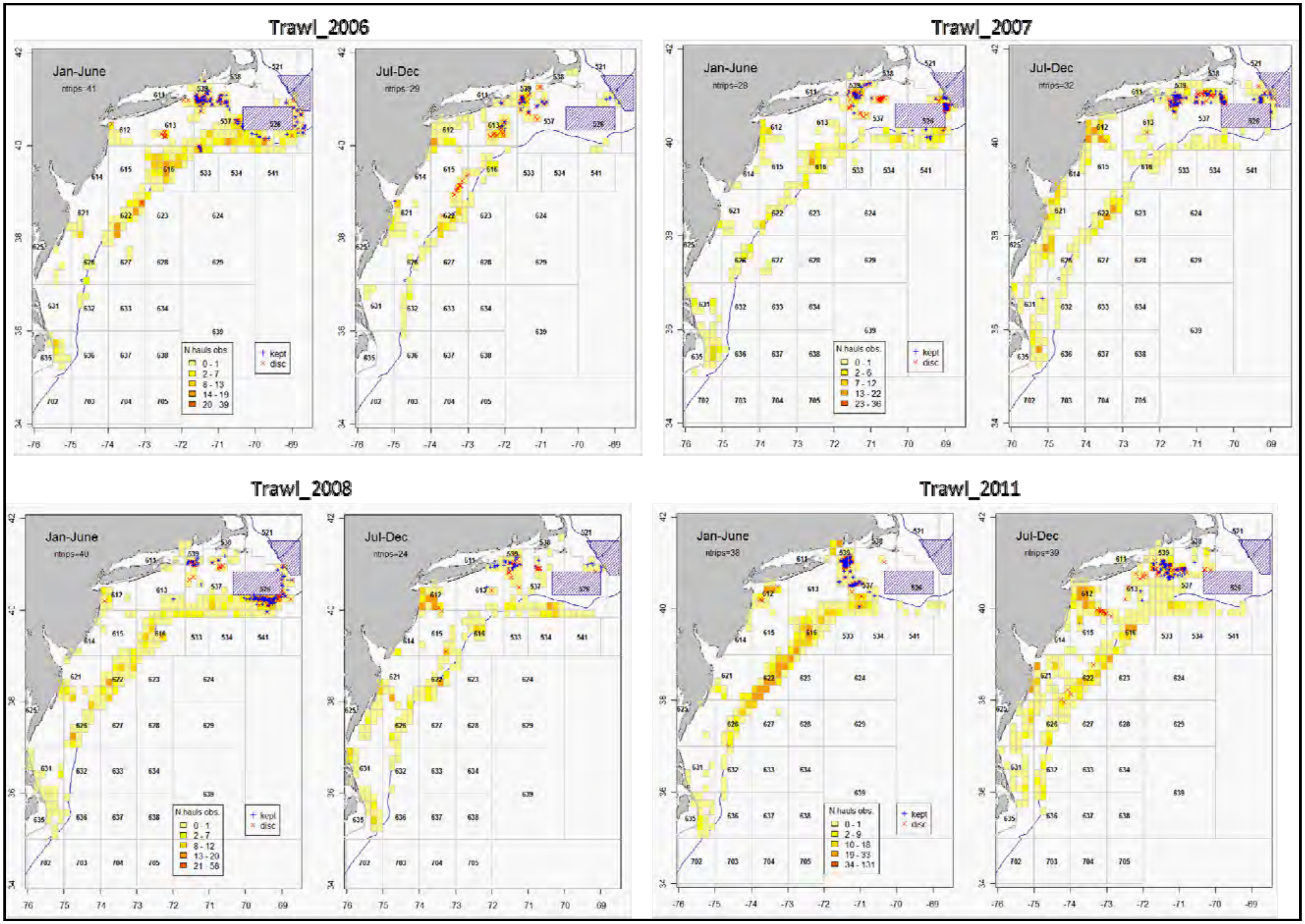


Figure B37. Spatial distributions of observed bottom trawl effort determined by the number of hauls by half year for selected years (2006-2008 and, 2011) in the SNEMA stock region. Note: Observed kept and discarded yellowtail reflect general patterns of activity by the dredge fleet in the Southern New England Mid-Atlantic region and does not characterize the relative magnitude of the observed catches.

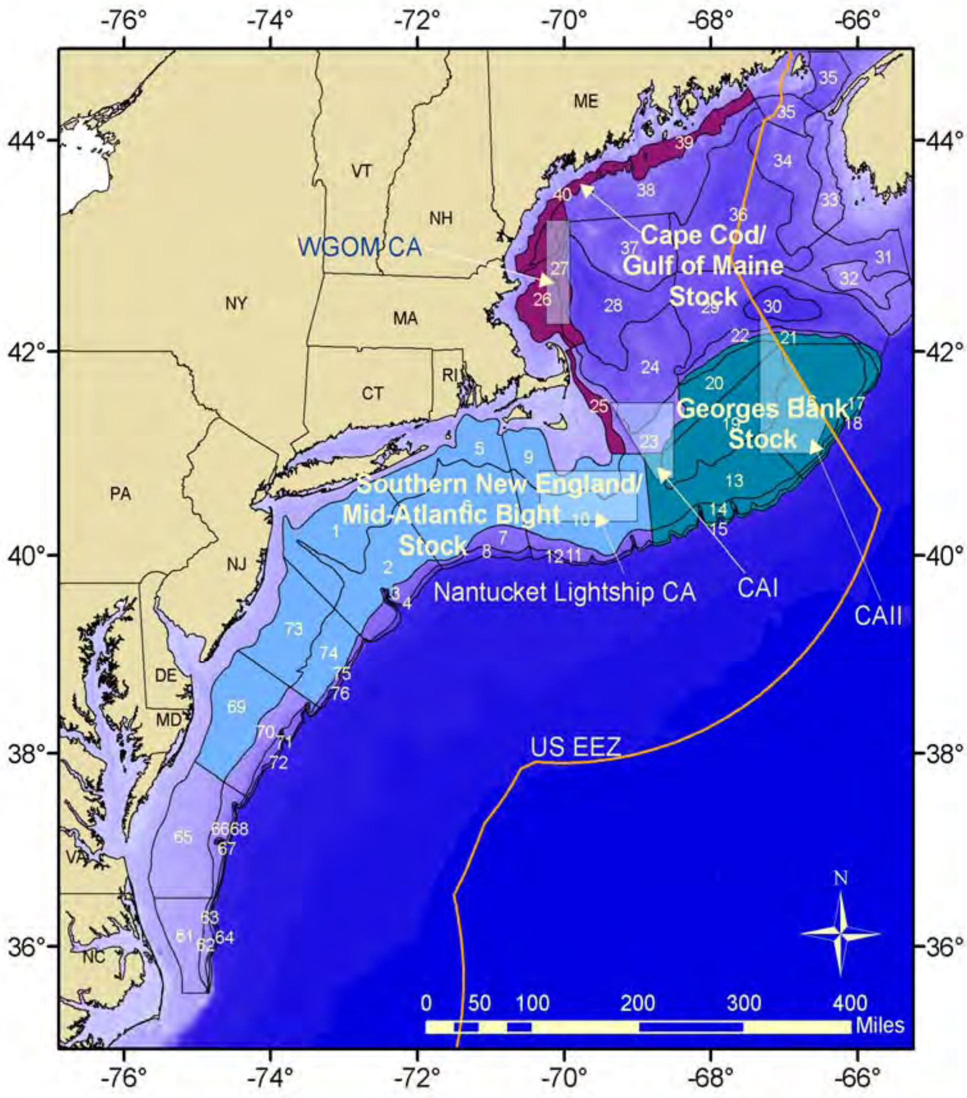


Figure B38. Map of the Northeast Fisheries Science Center (NEFSC) bottom trawl offshore survey strata included in the Southern New England Mid-Atlantic stock assessment. Strata include: (1, 2, 5, 6, 9, 10, 69, 73, and 74)

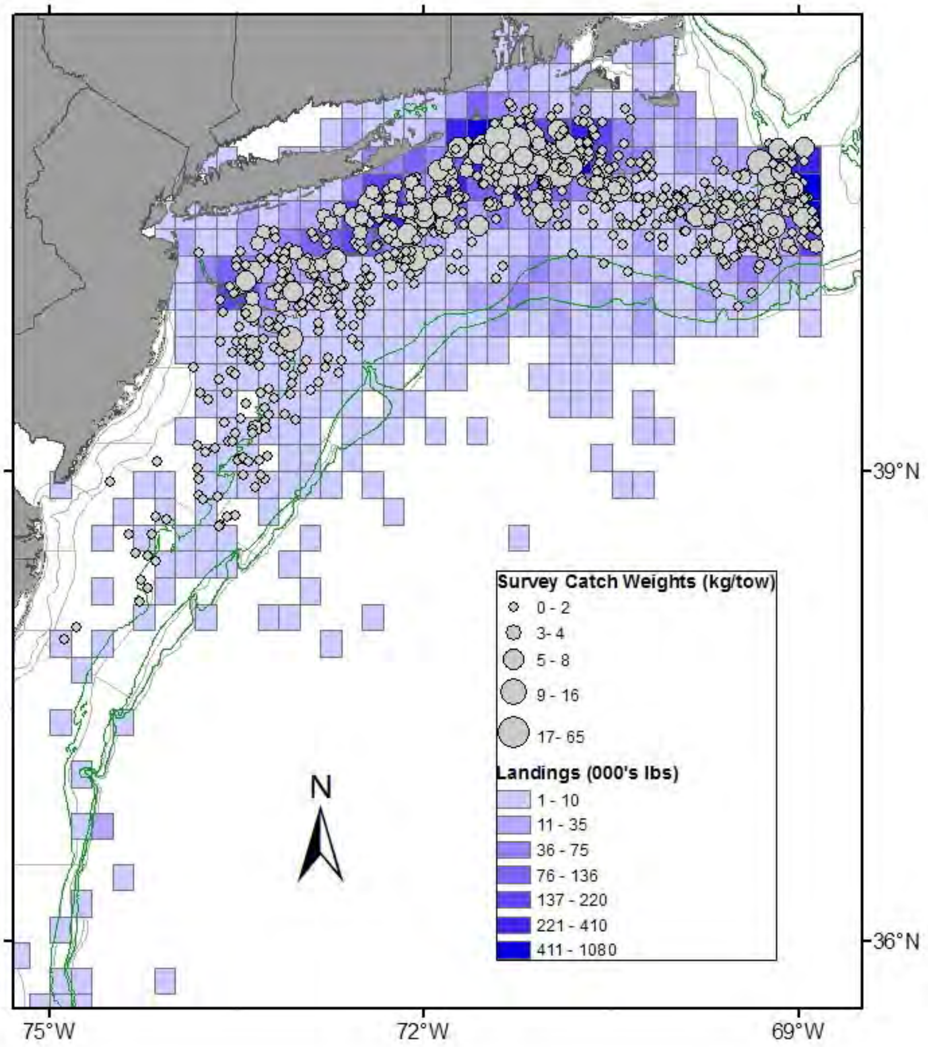


Figure 39. Spatial overlay of survey catches (kg/tow) from 1994-2011 of Southern New England Mid-Atlantic yellowtail flounder from the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey (spring and fall combined) on commercial landings binned by ten minute squares for the same time period.

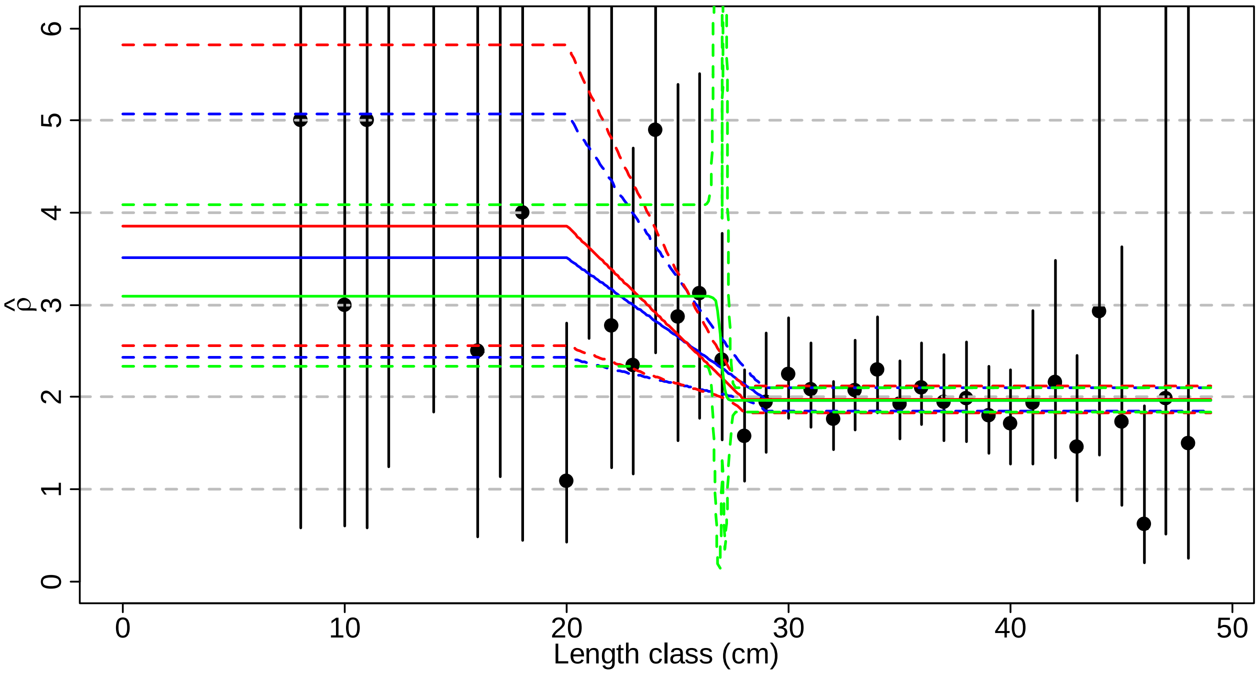


Figure B40. Beta-binomial based estimates of calibration factors and corresponding 95% confidence intervals by length class (1 cm bins) for yellowtail flounder. The black points and vertical bars represent results where different calibration factors are estimated for each length class. The blue lines represent results from a segmented regression model where the two points connecting the segments are known (20 and 29 cm), the red lines represent results from a segmented regression model where the first point (20 cm) is known but the second is estimated, and the green lines represent results from the logistic model. Segmented-regression and logistic model fits are based on data from fish ≥20 cm.

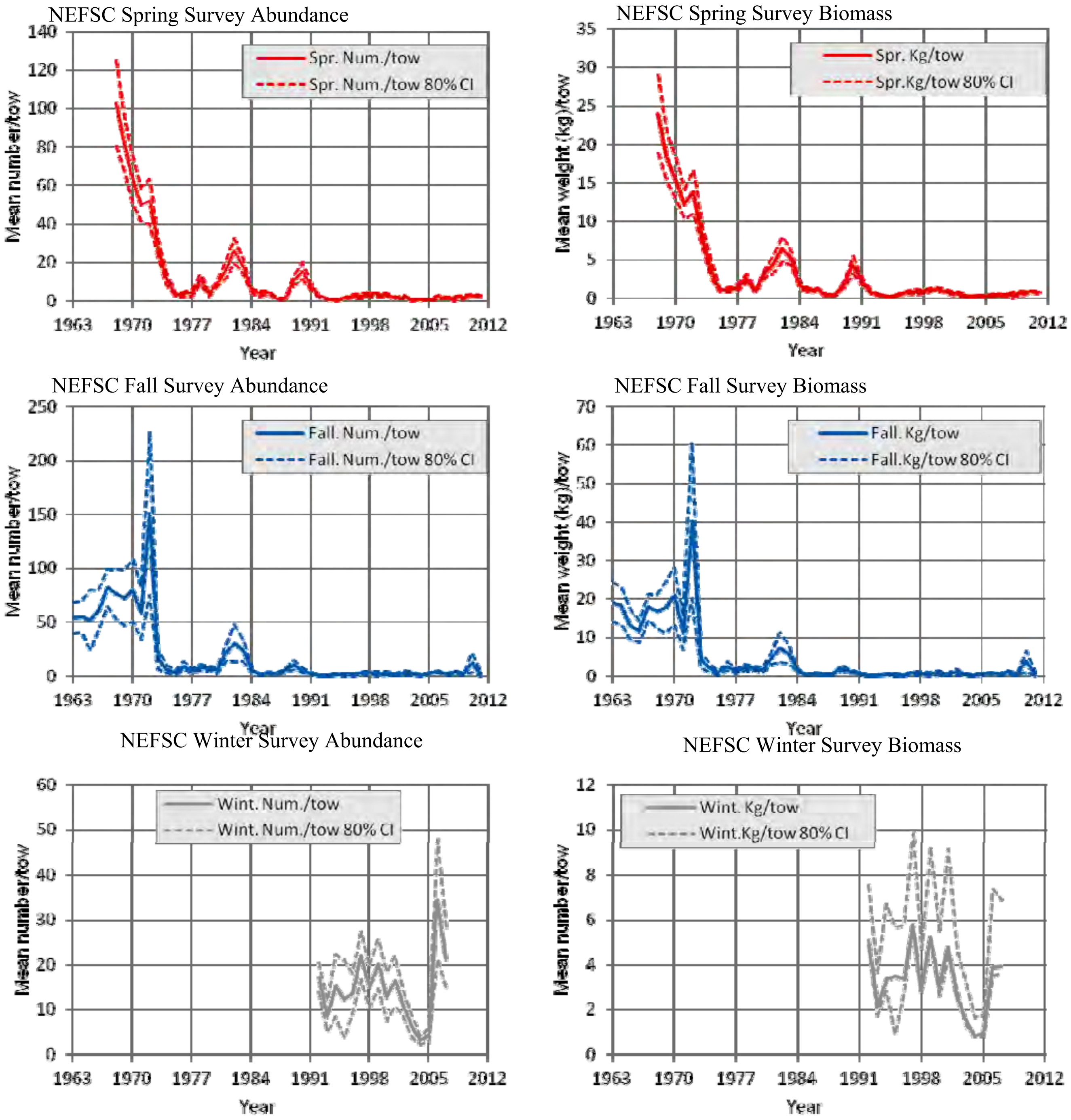


Figure B41. Northeast Fisheries Science Center Spring (Top Panels), Fall (Middle Panels) and Winter (Bottom panels) survey indices of abundance (left panels) and biomass (right panels) showing both Bigelow unconverted indices for the fall and spring (08-11) and converted indices in Albatross units for Southern New England Mid-Atlantic yellowtail flounder.

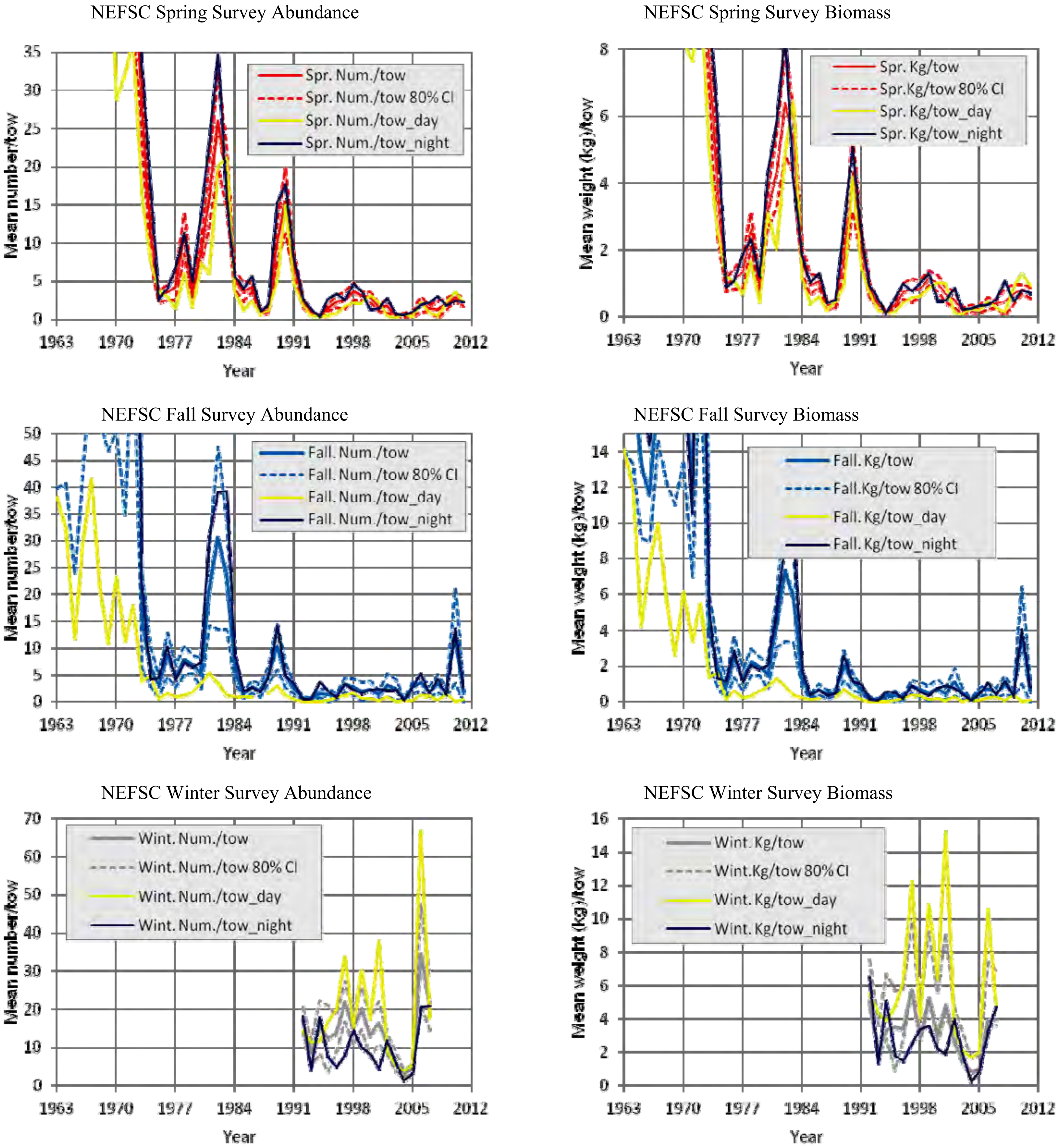
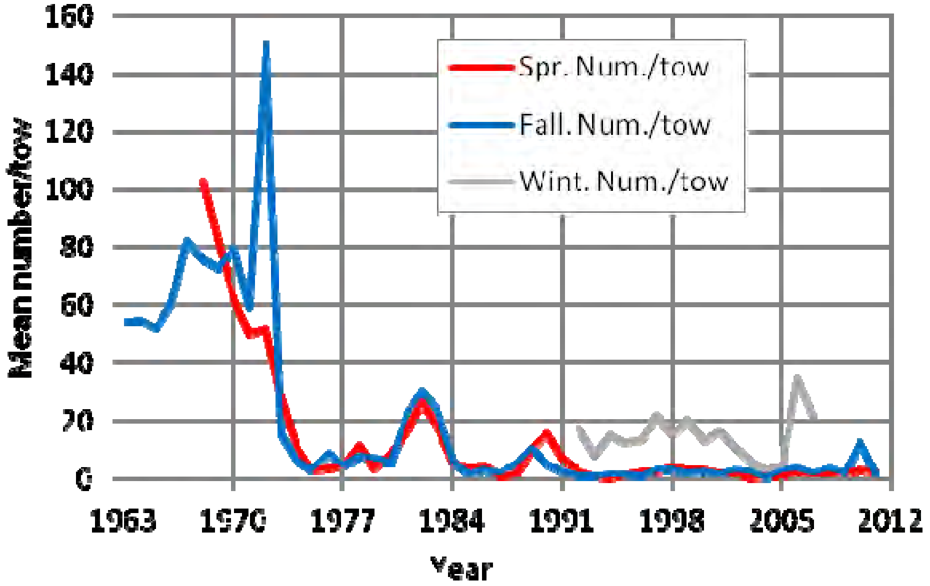


Figure B42. Northeast Fisheries Science Center Spring (top panels), Fall (Middle panels) and Winter (bottom panels) survey indices of abundance (left panels) and biomass (right panels) disaggregated by day and night only tows compared to the aggregate index (day and night combined) and its associated 80% confidence interval.

NEFSC Survey Abundance



NEFSC Survey Biomass

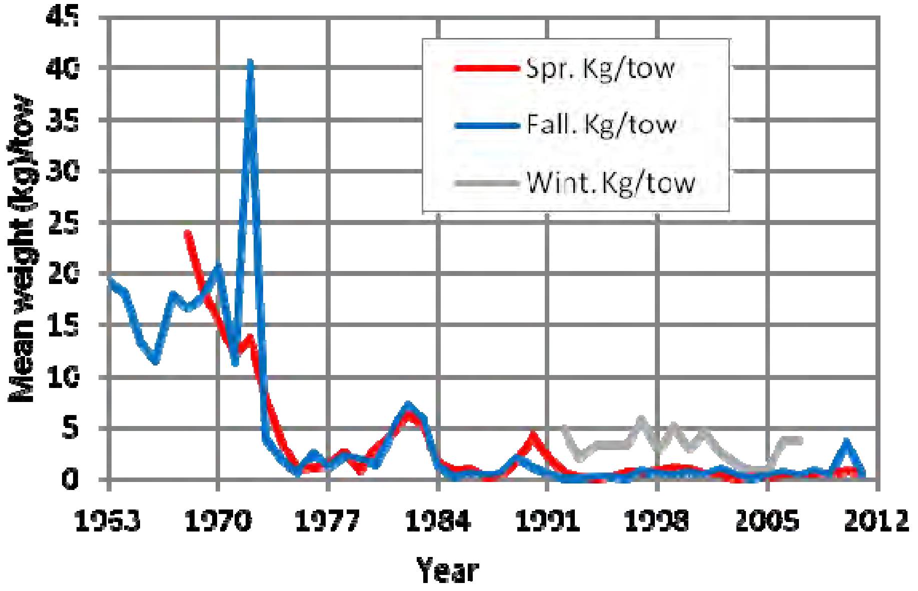
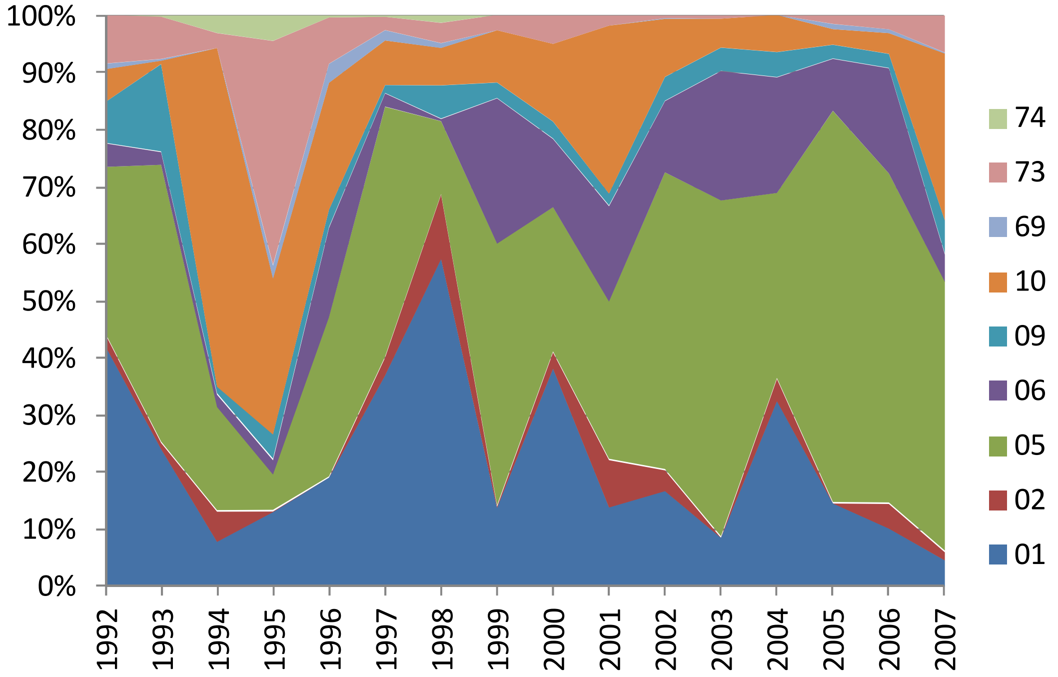


Figure B43. Northeast Fisheries Science Center spring, winter and fall bottom trawl survey of abundance (top) and biomass (bottom) from 1963 to 2011 for Southern New England Mid-Atlantic yellowtail flounder. Note: Spring survey did not begin until 1968 and the winter survey started in 1992 and ended in 2007

NEFSC Winter survey abundance contribution by Strata



NEFSC Winter Survey biomass contribution by Strata

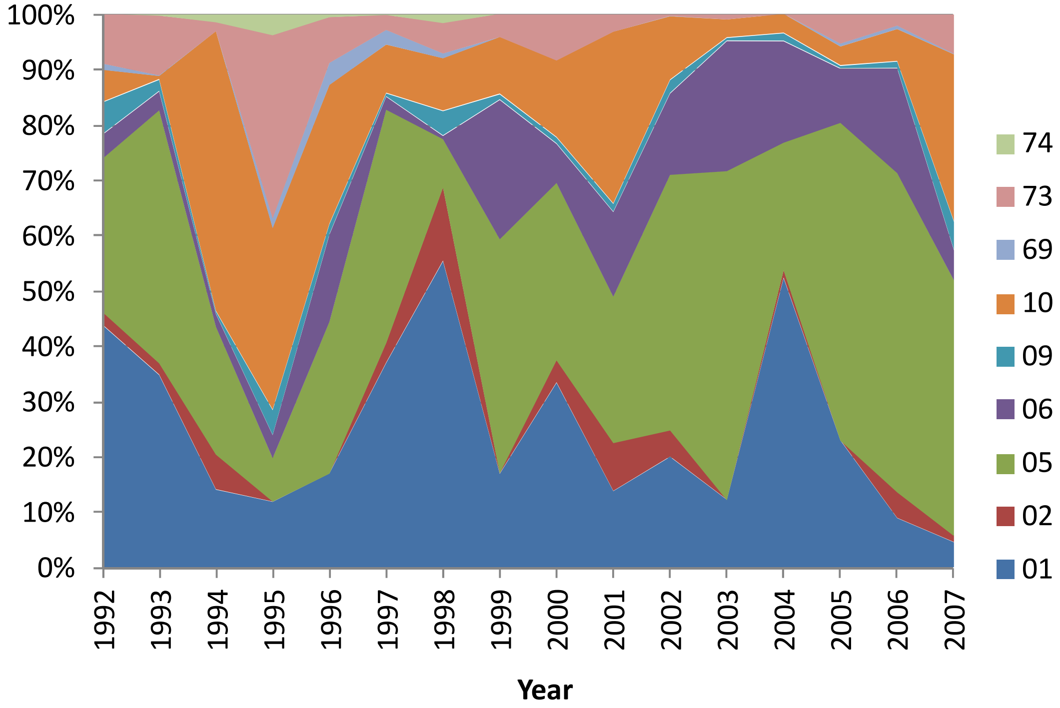


Figure B44. Northeast Fisheries Science Center winter trawl survey indices, expressed as proportions of abundance (Top) and biomass (Bottom) by strata from 1992 to 2007.

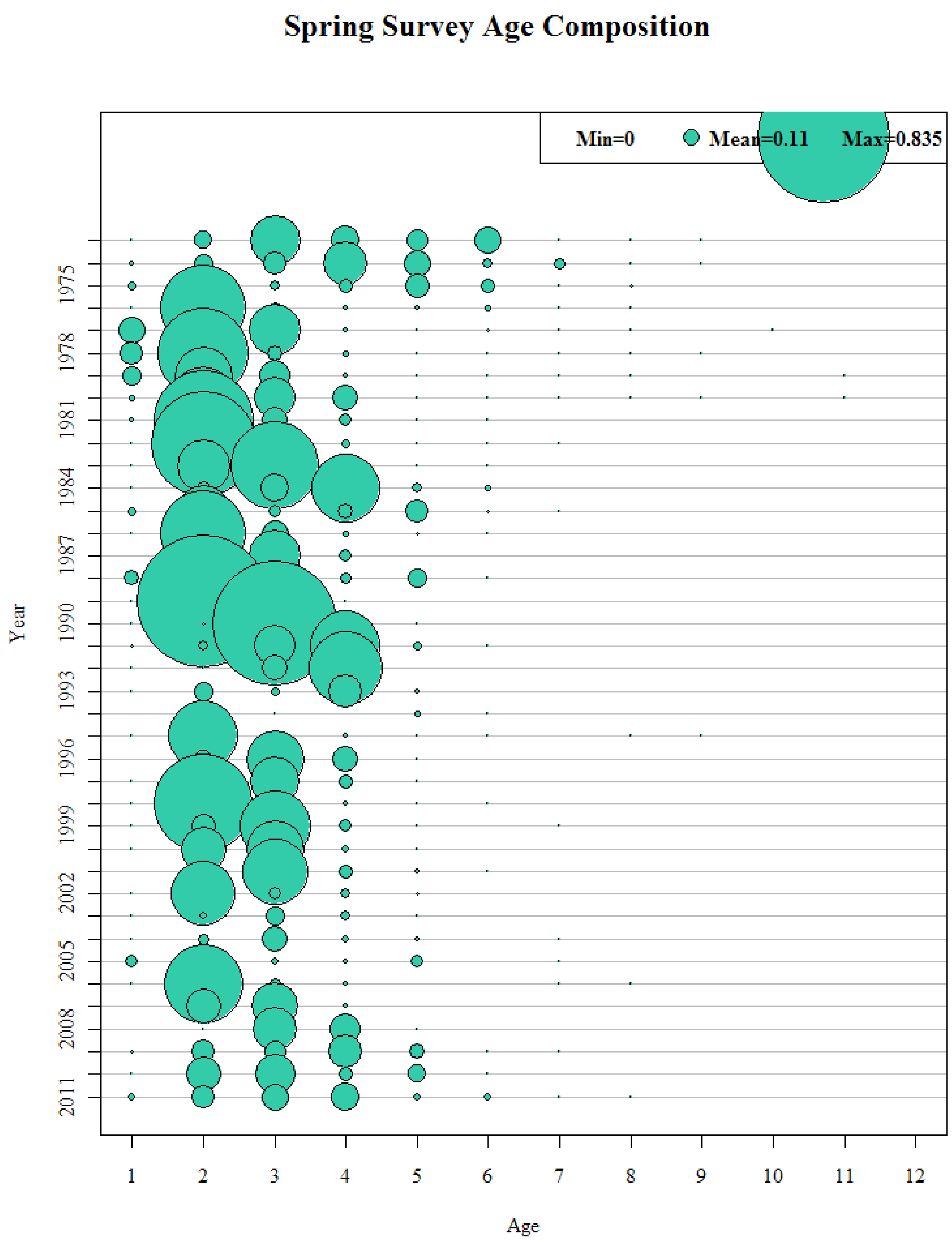


Figure B45. Numbers at age from the Northeast Fisheries Science Center (NEFSC) Spring bottom trawl survey, 1963-2011 for Southern New England Mid-Atlantic yellowtail flounder

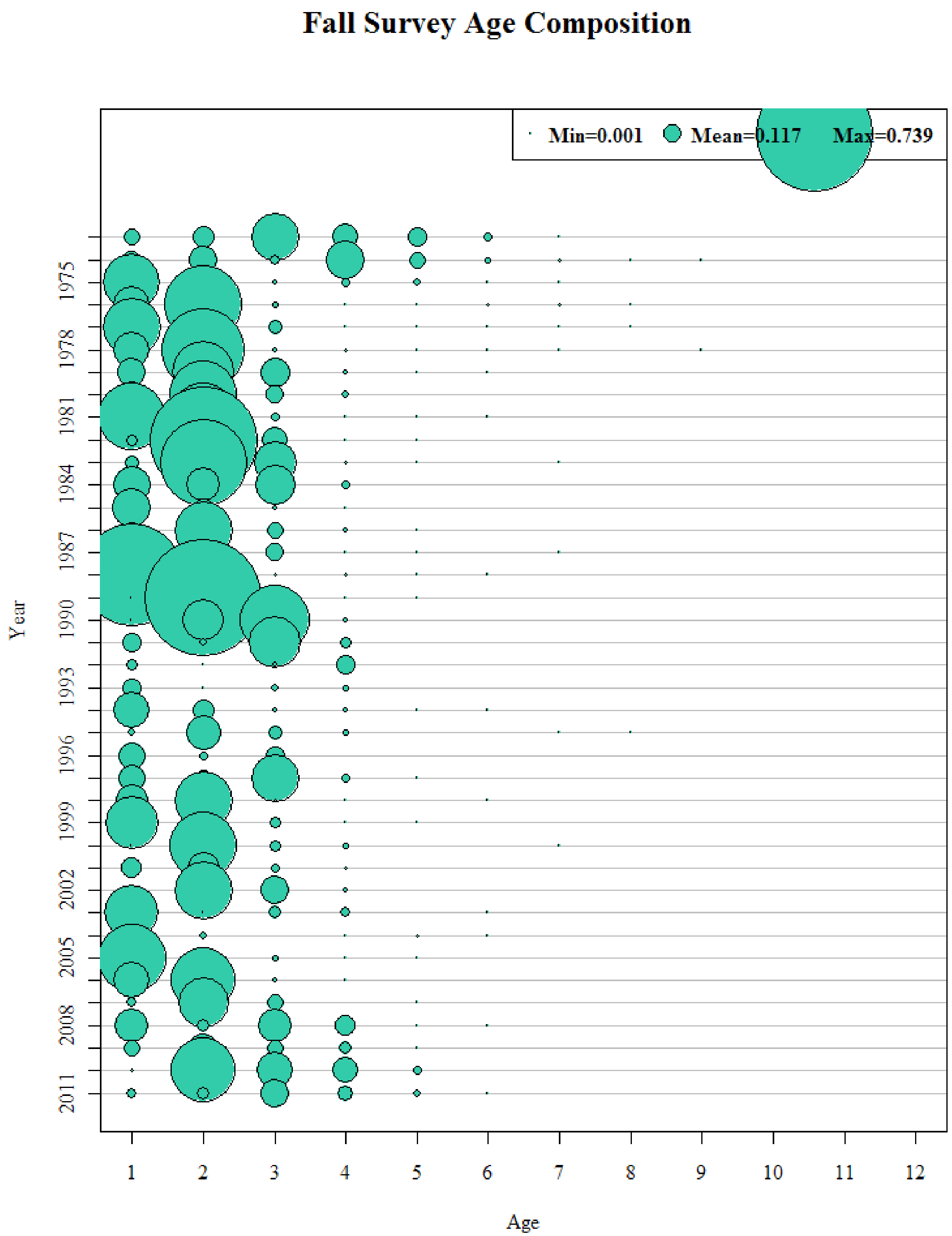


Figure B46. Numbers at age from the Northeast Fisheries Science Center (NEFSC) Fall bottom trawl survey, 1992-2007 for Southern New England Mid-Atlantic yellowtail flounder

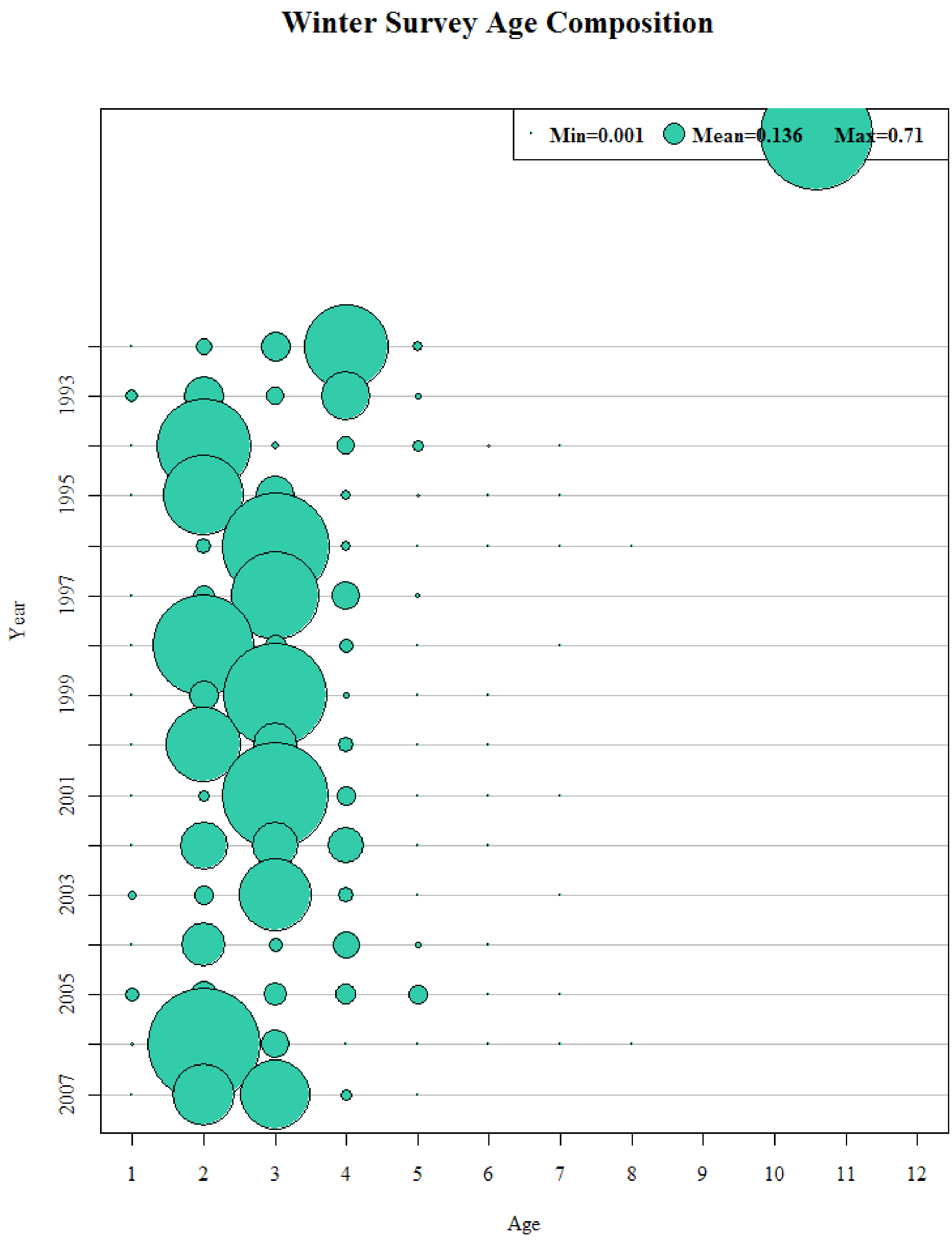


Figure B47. Numbers at age from the Northeast Fisheries Science Center (NEFSC) winter bottom trawl survey, 1968-2011 for Southern New England Mid-Atlantic yellowtail flounder

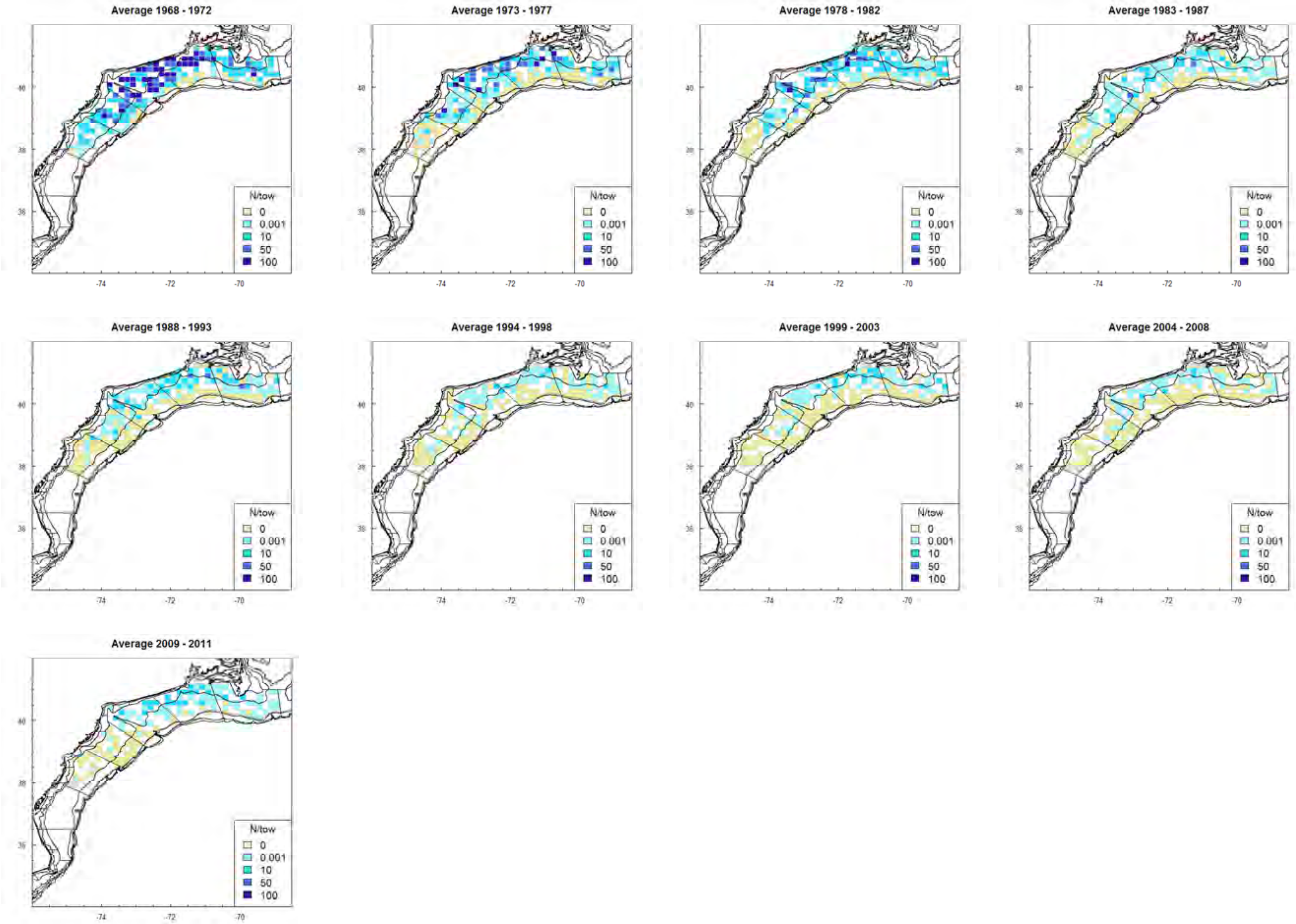

Average 1968 - 1972
Average 1973 - 1977
Average 1978 - 1982
Average 1983 - 1987
Average 1988 - 1993
Average 1994 - 1998
Average 1999 - 2003
Average 2004 - 2008
Average 2009 - 2011

Figure B48. Southern New England Mid-Atlantic yellowtail flounder Spring survey distribution of (numbers per tow) from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey from 1968-2011

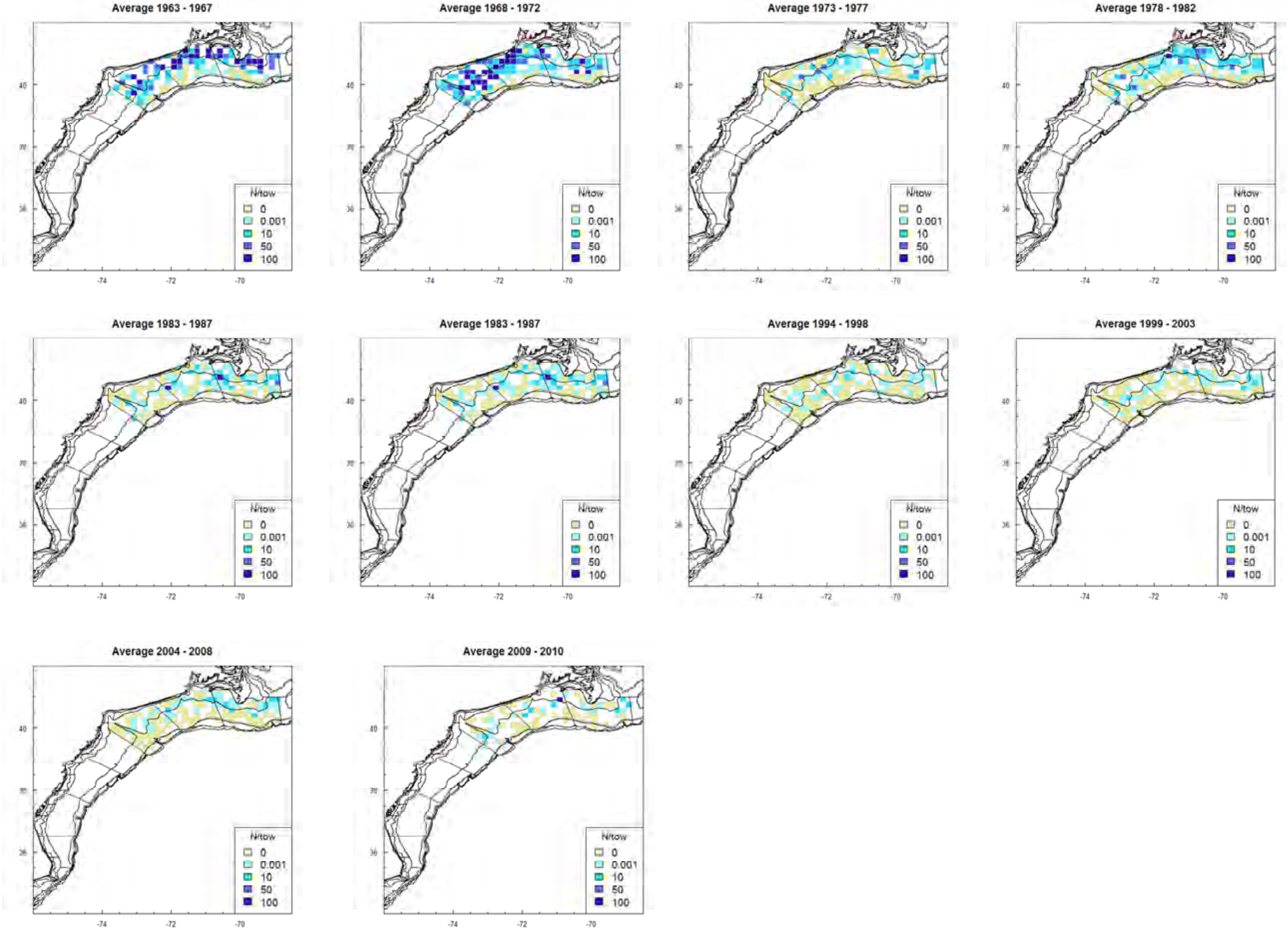
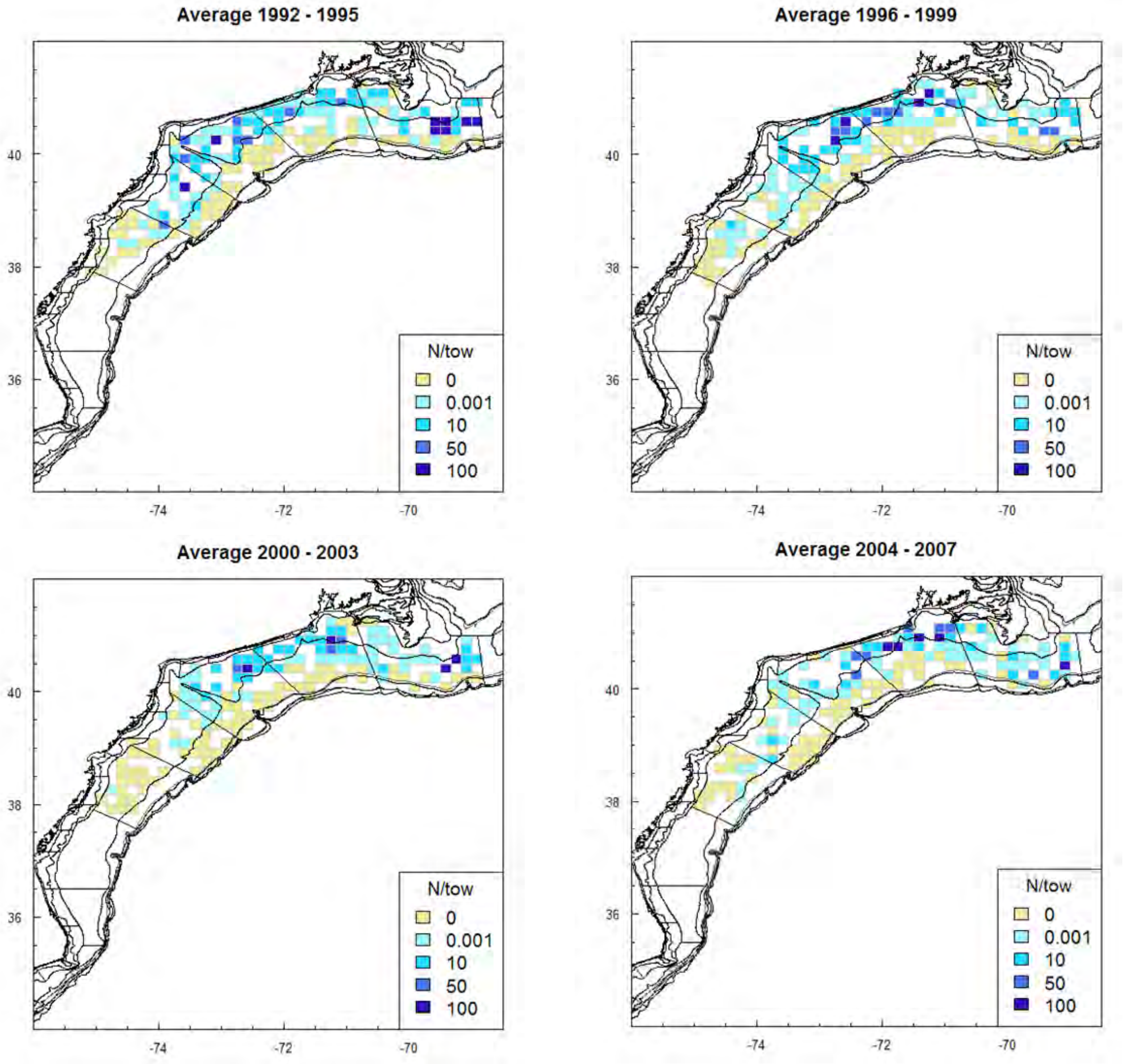


Figure B49. Southern New England Mid-Atlantic yellowtail flounder Fall distribution (numbers per tow) from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey from 1963-2010. Note: *Fall 2011 data was not available when maps were created.*


Average 1992 - 1995

Average 1996 - 1999

Average 2000 - 2003

Average 2004 - 2007

Figure B50. Southern New England Mid-Atlantic yellowtail flounder winter distribution (numbers per tow) from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey 1992-2007

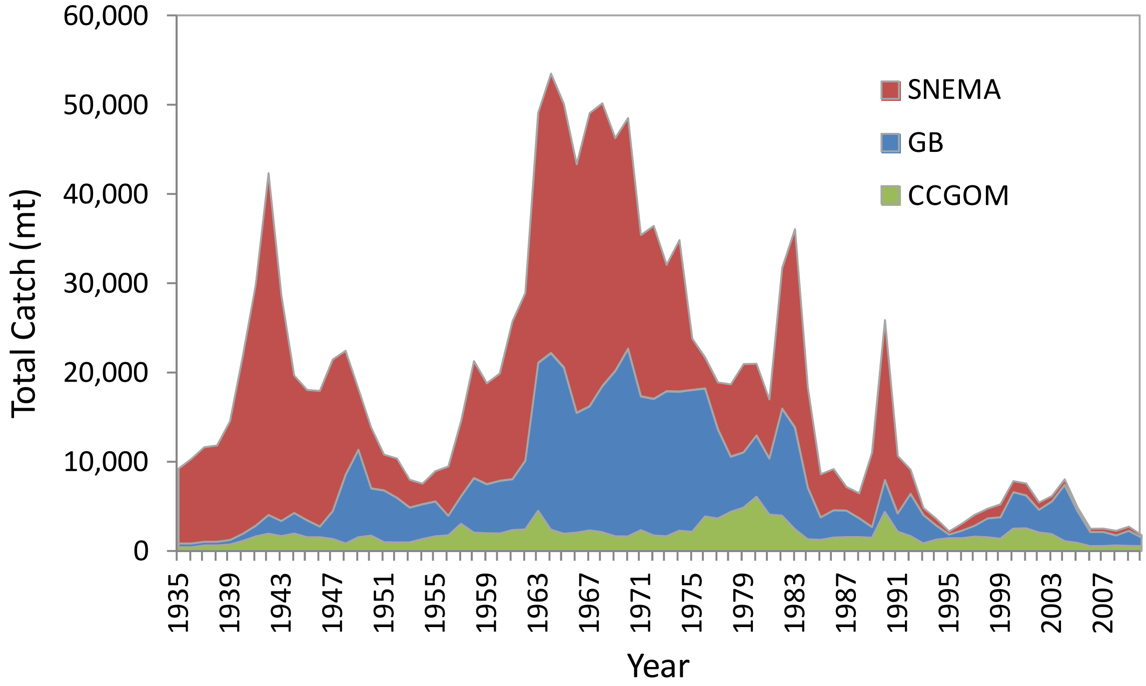


Figure B51. Total commercial catch of yellowtail flounder from 1935 to 2010 off the northeast U.S.

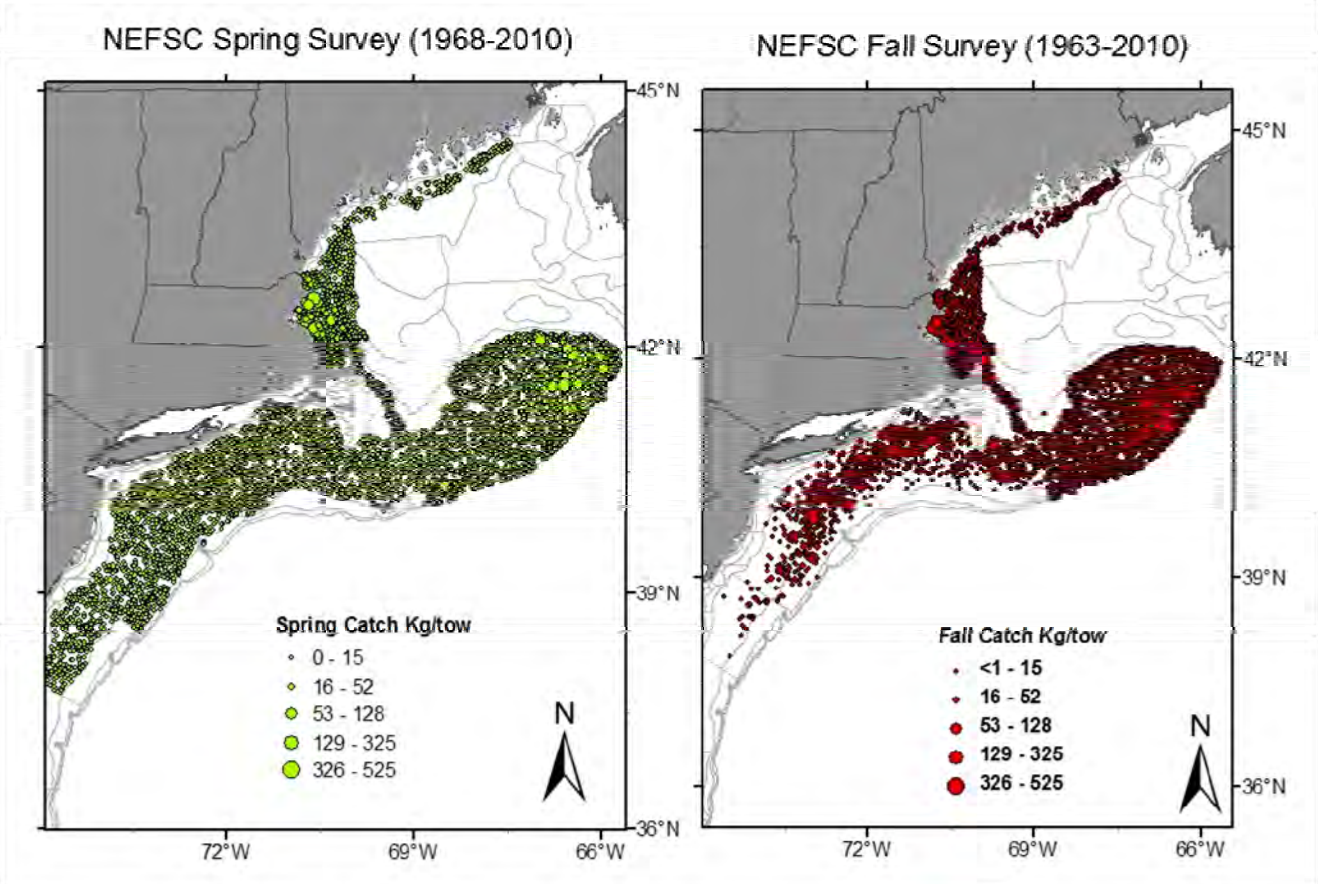


Figure B52. Geographic distribution of yellowtail flounder caught from the NEFSC fall and spring bottom trawl surveys combined from 1963-2011

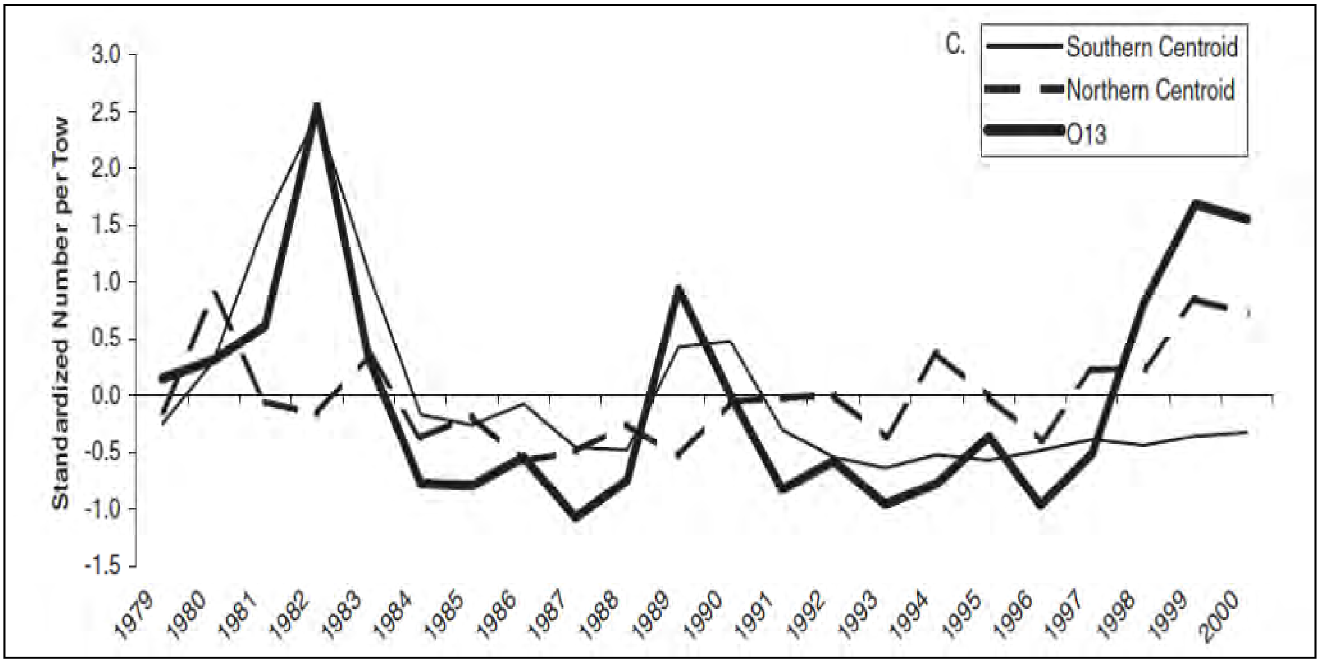


Figure B53. Standardized number per tow of yellowtail flounder in the northern strata and southern strata and “transitional stratum “O13” adapted from Cadrin 2010.

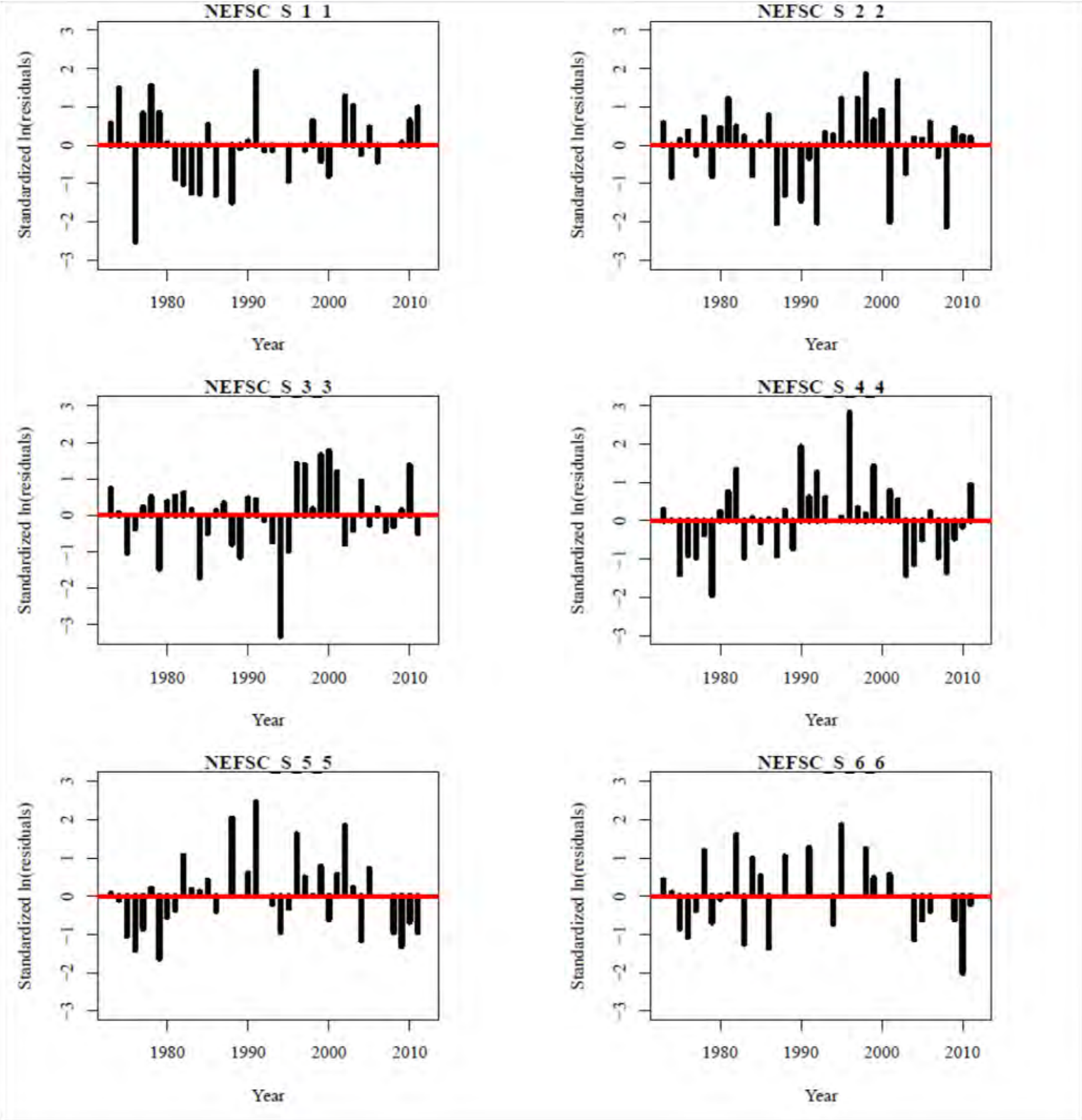


Figure B54. ADAPT-VPA Model 20 residual to the survey fits of the Northeast Fisheries Science Center Spring Southern New England Mid-Atlantic yellowtail flounder survey ages 1 through 6+

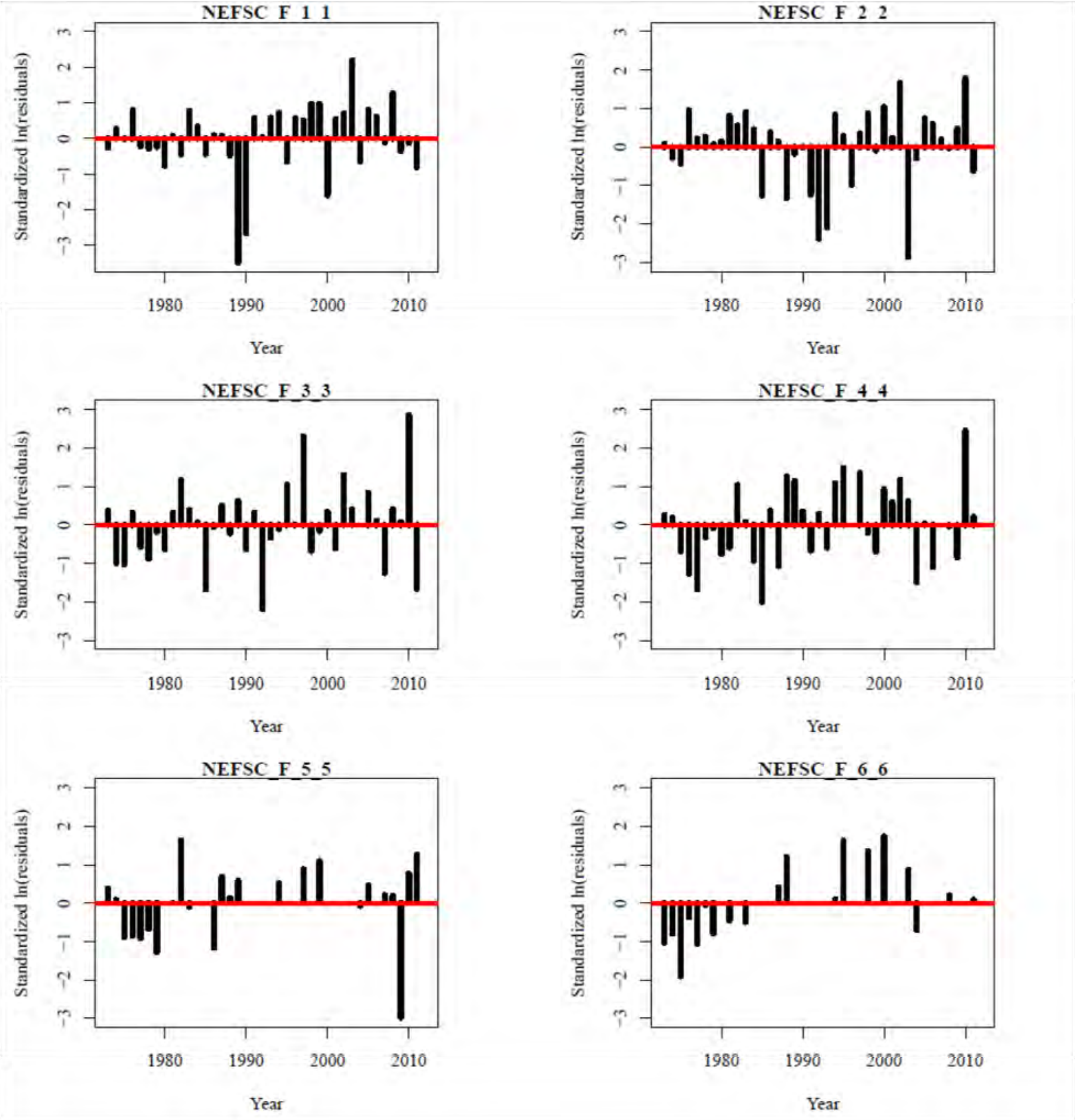


Figure B55. ADAPT-VPA Model 20 residual to the survey fits of the Northeast Fisheries Science Center Fall Southern New England Mid-Atlantic yellowtail flounder survey ages 1 through 6+

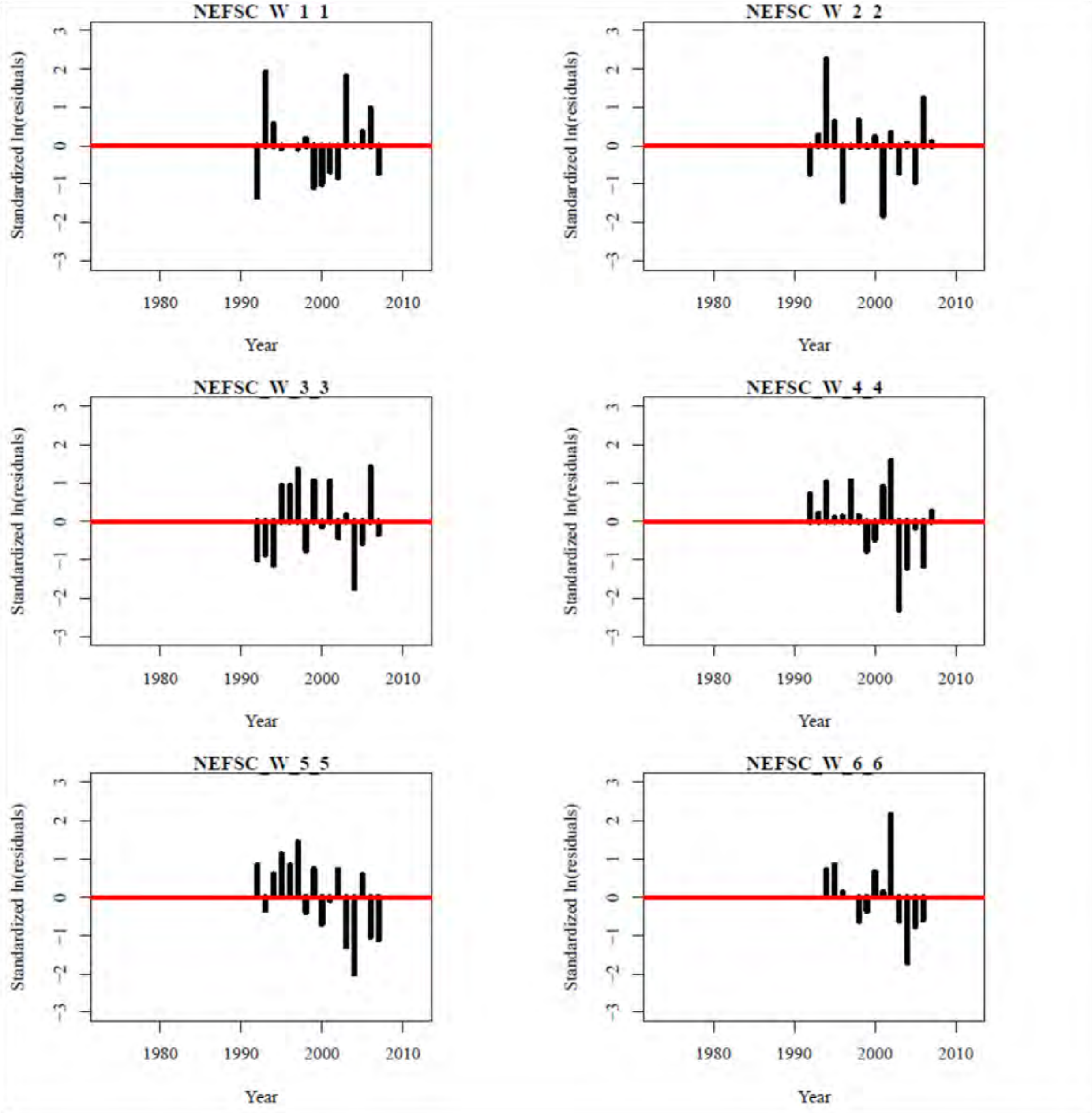


Figure B56. ADAPT-VPA Model 20 residual to the survey fits of the Northeast Fisheries Science Center Winter Southern New England Mid-Atlantic yellowtail flounder survey ages 1 through 6+

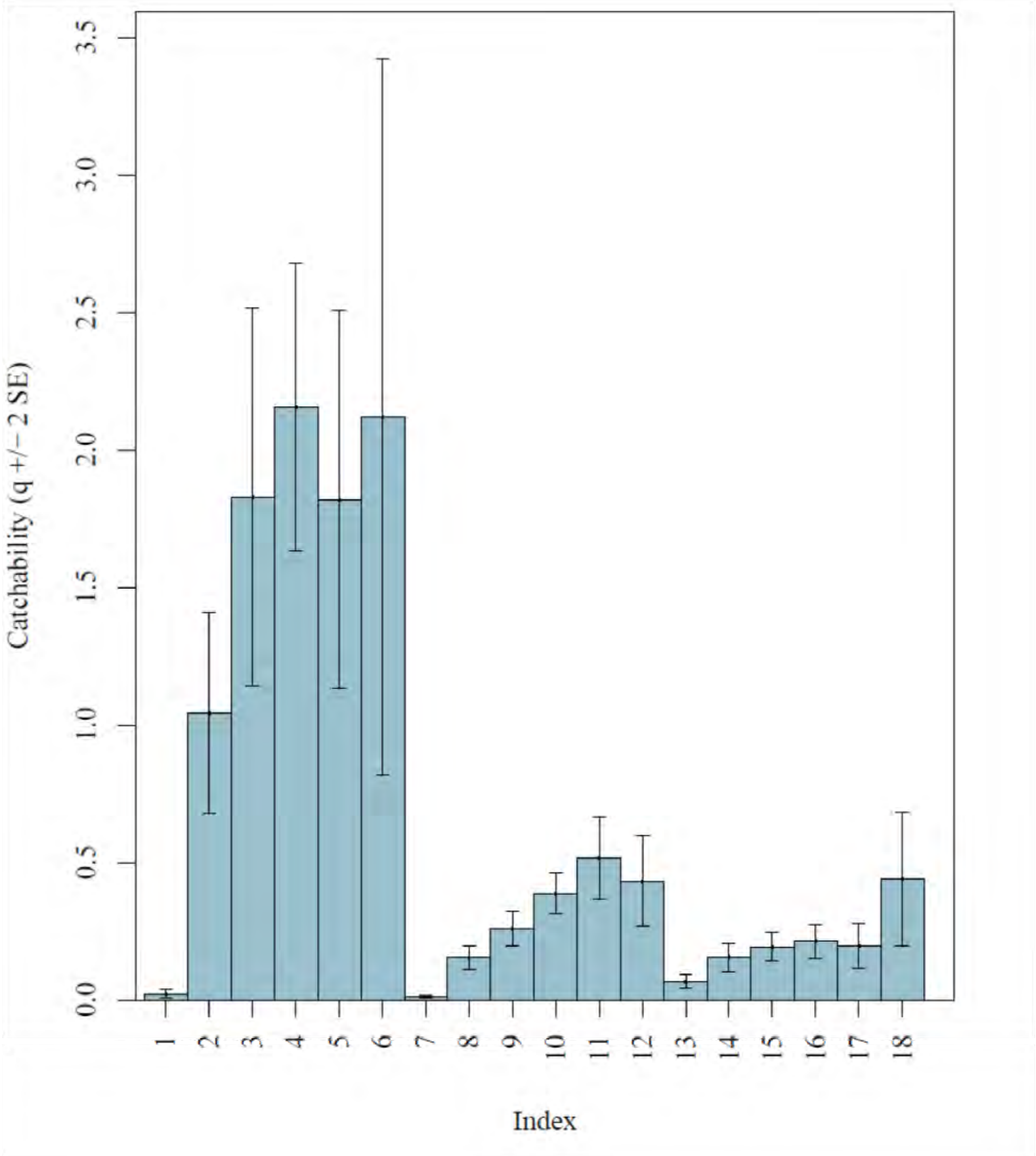


Figure B57. ADAPT-VPA model 20 patterns in survey catchability (q). Indices 1-6 = NEFSC Winter (ages 1-6+), indices 7-12 = NEFSC Spring (ages 1-6+), indices 13-18 = NEFSC Fall (ages 1-6+).

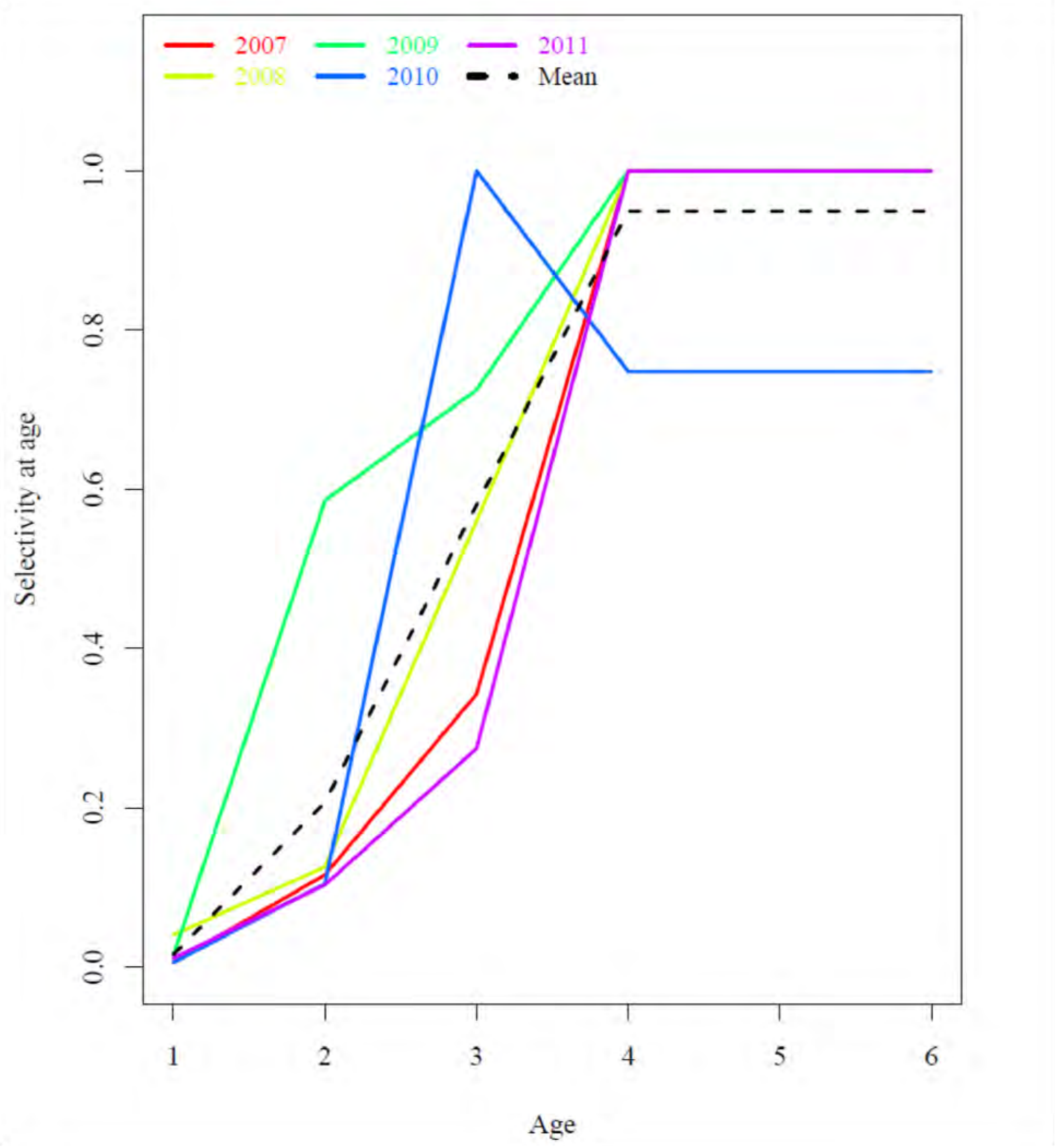
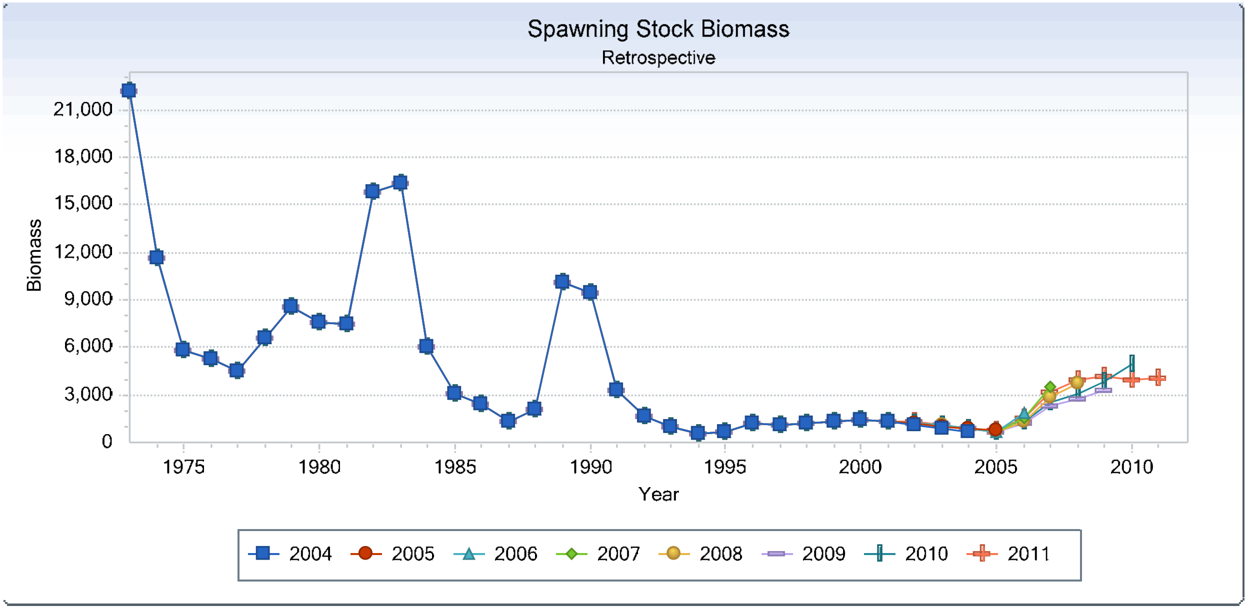


Figure B58. ADAPT-VPA model 20 catch selectivity for Southern New England Mid-Atlantic yellowtail flounder over the last five years of the model 2006 through 2011



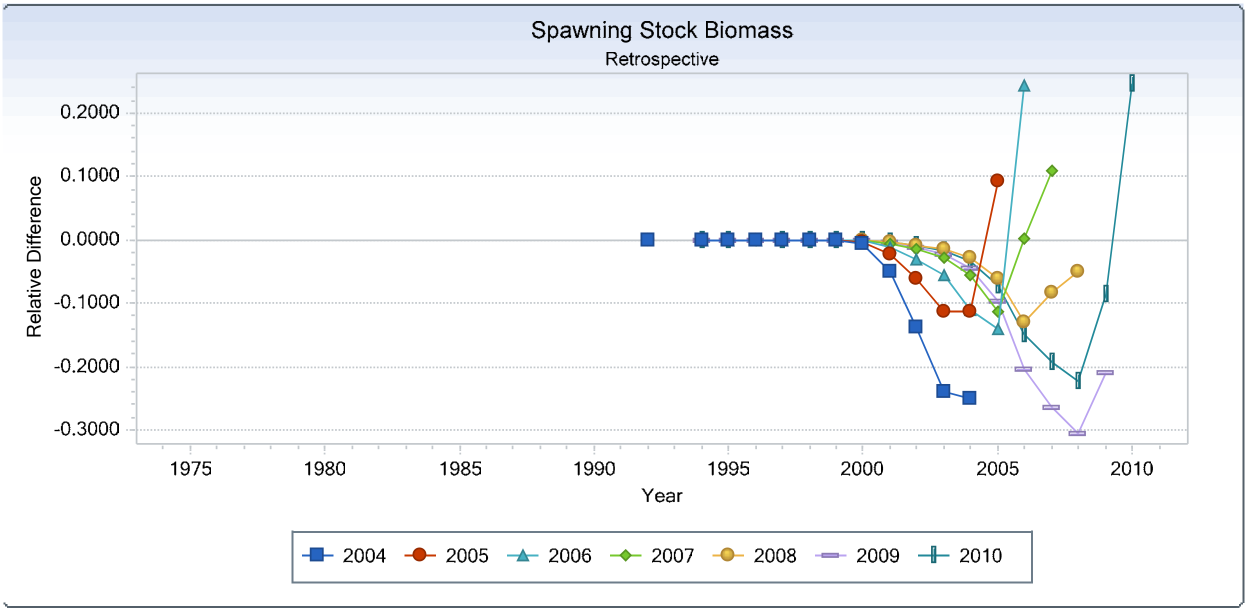
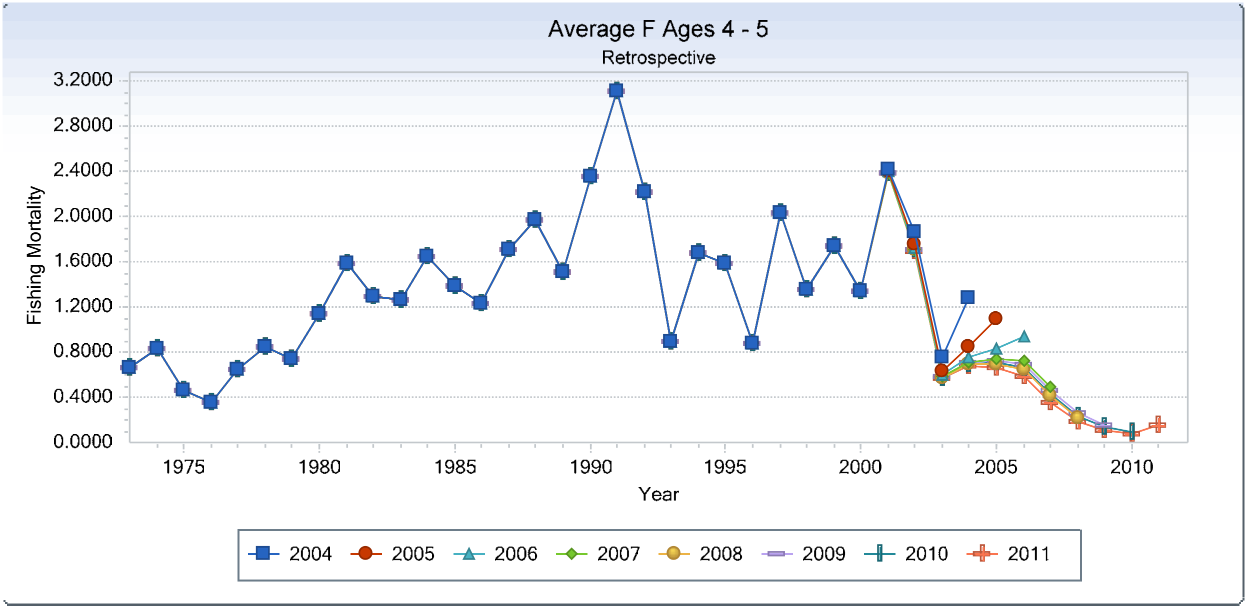


Figure B59. ADAT-VPA Model 20 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder spawning stock Biomass (mt) in absolute (top) and relative (bottom) terms.



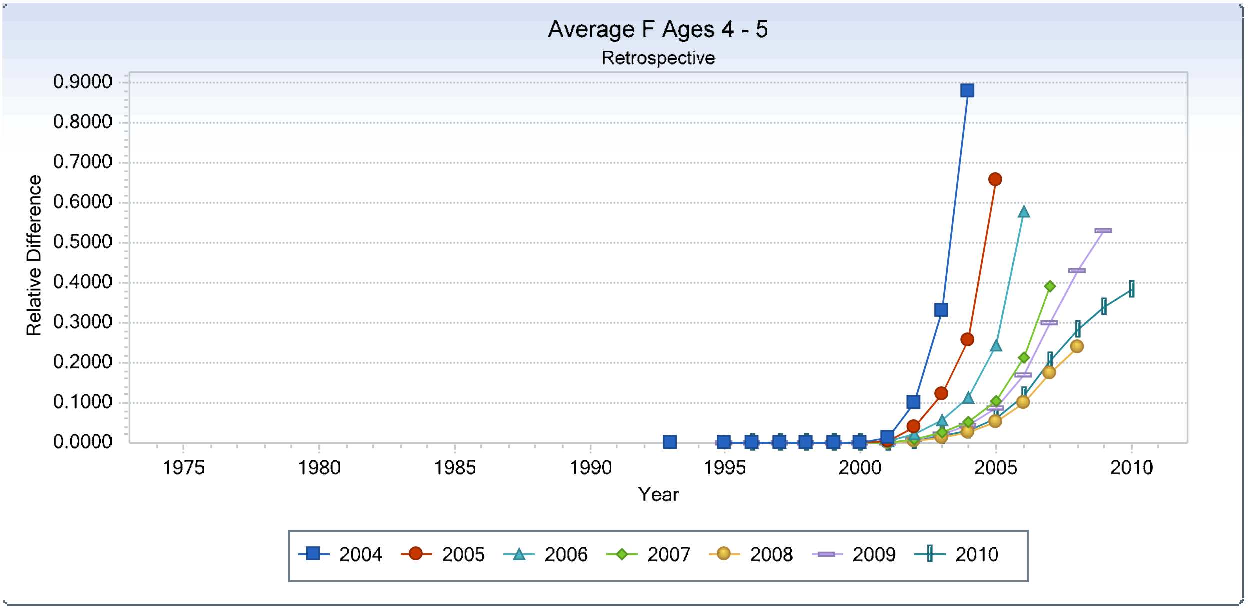
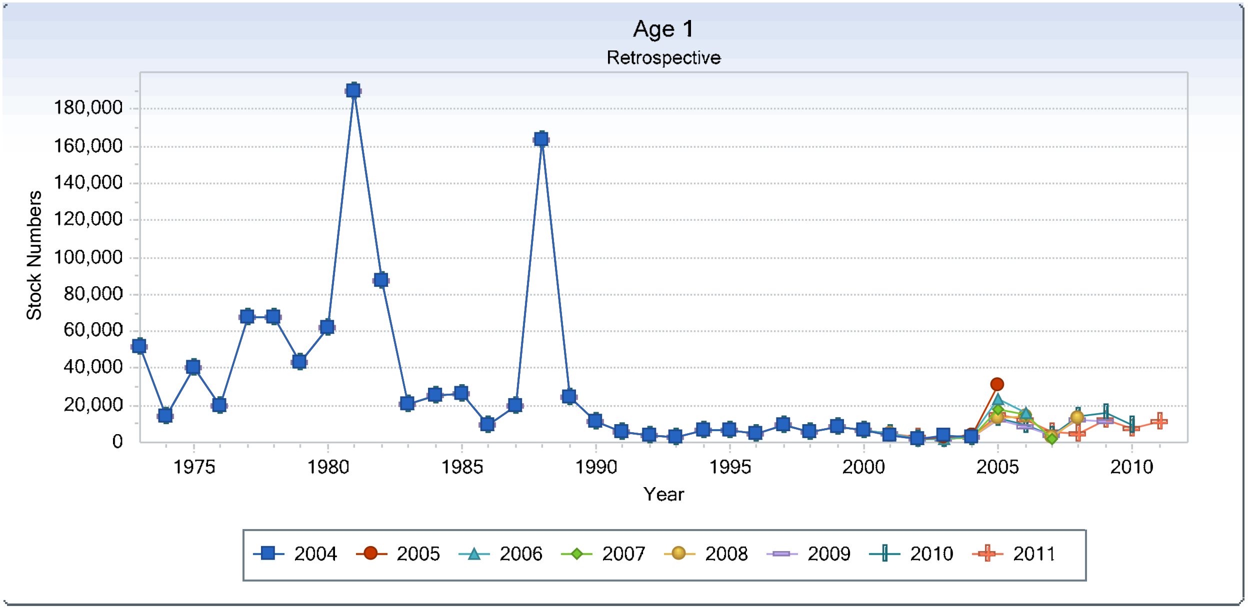


Figure B60. ADAT-VPA Model 20 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder fishing mortality (ages 4-5) in absolute (top) and relative (bottom) terms.



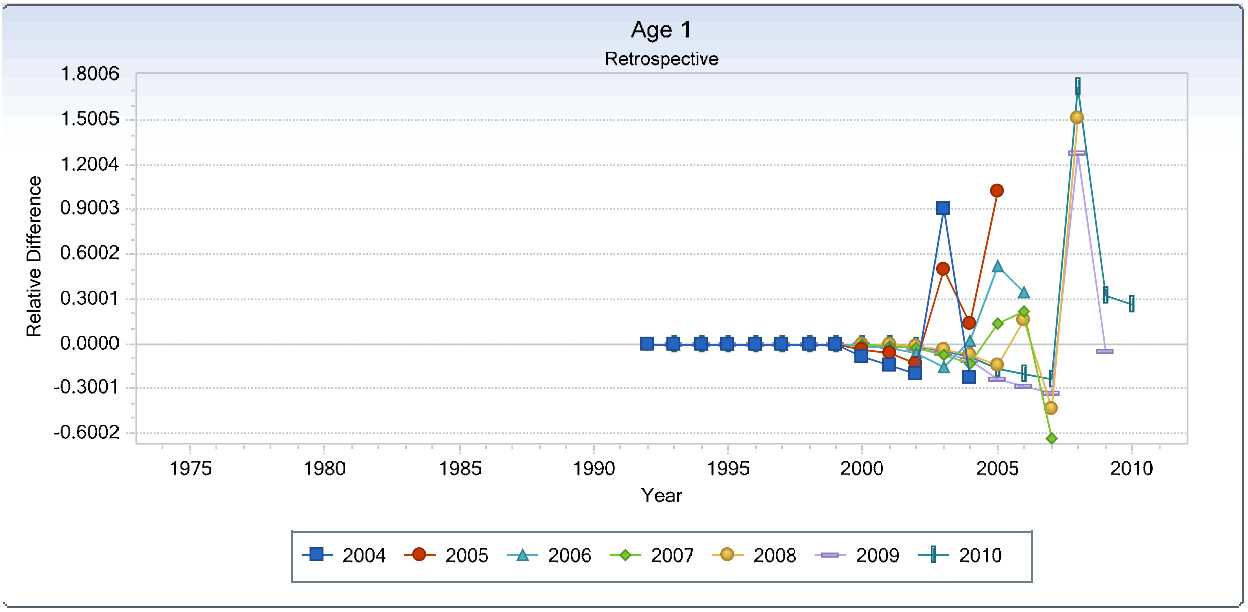


Figure B61. ADAT-VPA Model 20 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder age 1 recruitment (000's) in absolute (top) and relative (bottom) terms.

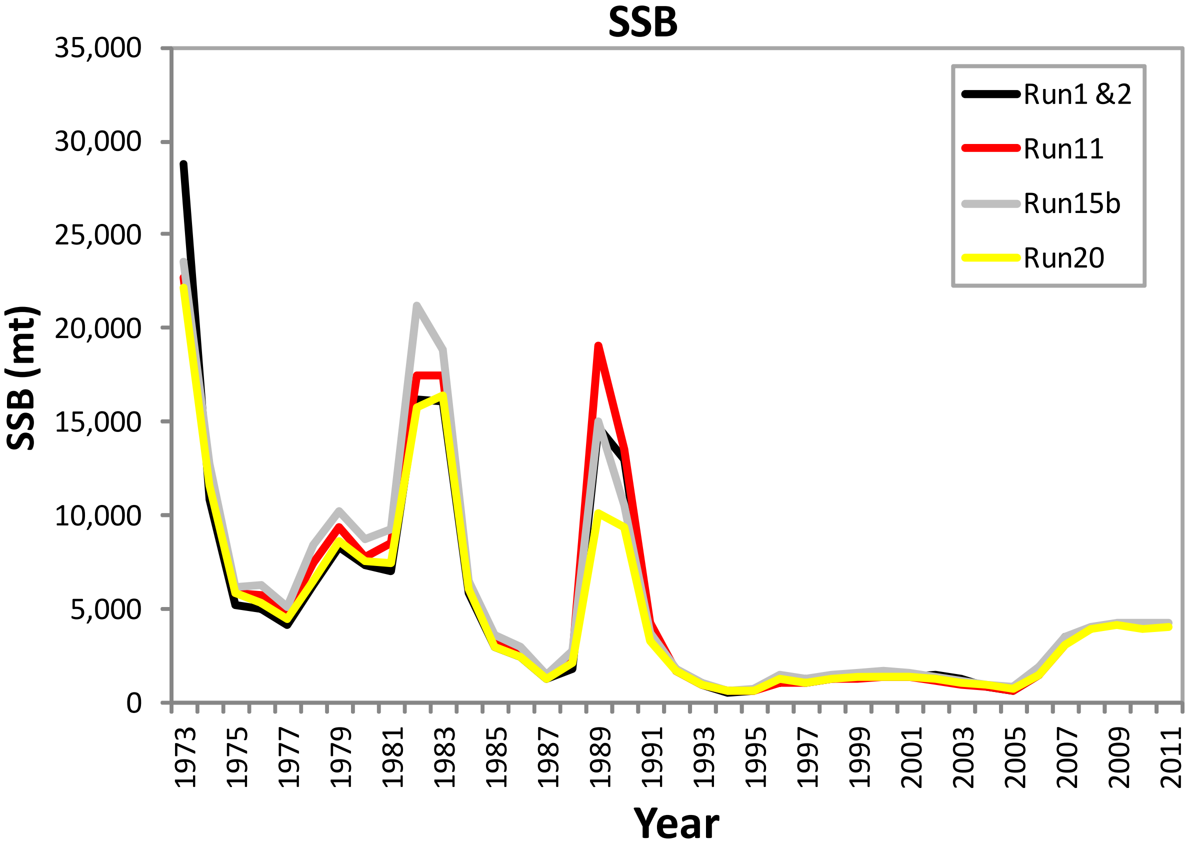


Figure B62. Comparison of estimates of Southern New England Mid-Atlantic yellowtail spawning stock biomass (mt) from ADAPT-VPA Model runs 2, 11, 15b and 20

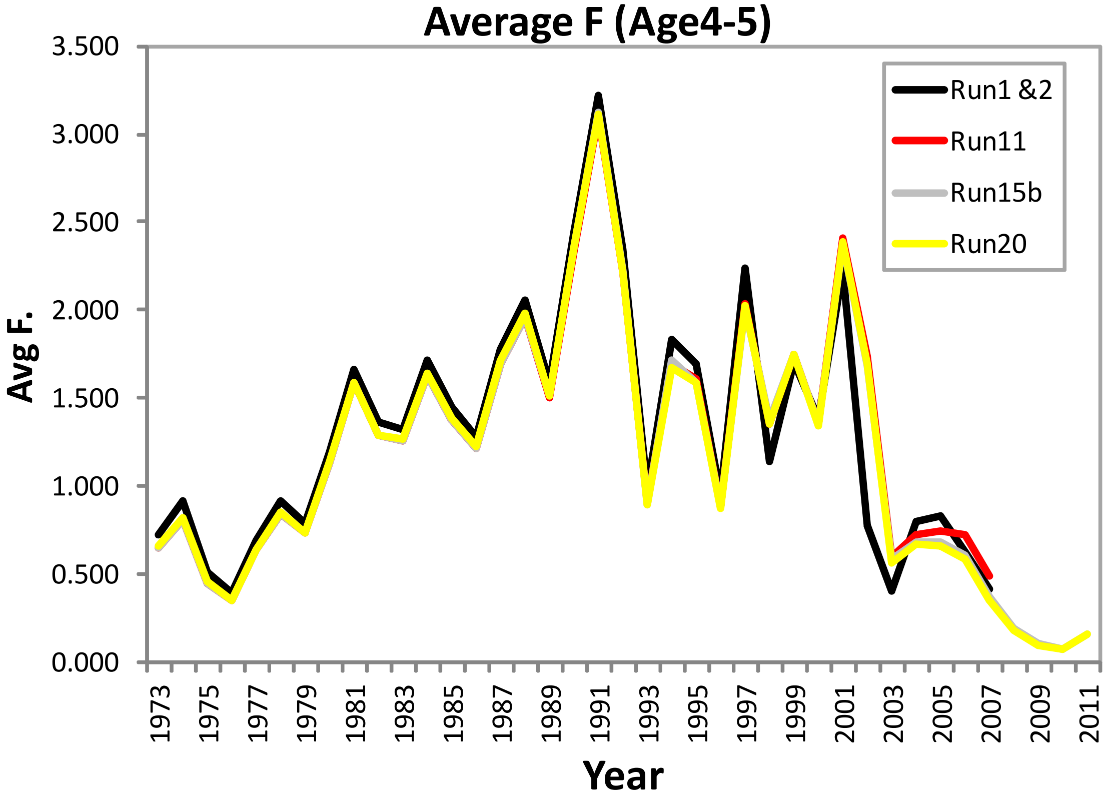


Figure B63. Comparison of estimates of Southern New England Mid-Atlantic yellowtail fishing mortality (ages 4-5) from ADAPT-VPA Model runs 2, 11, 15b and 20

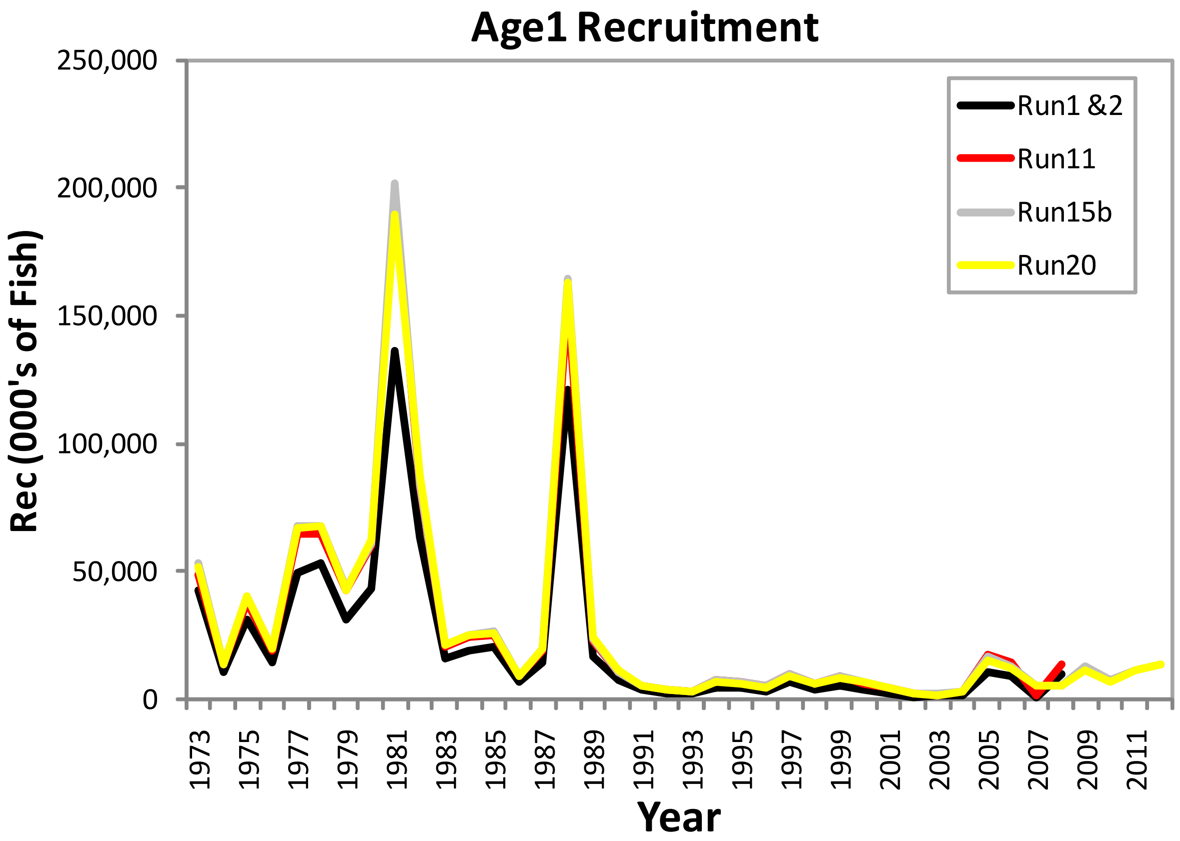


Figure B64. Comparison of estimates of Southern New England Mid-Atlantic yellowtail age 1 recruitment (000’s) from ADAPT-VPA Model runs 2, 11, 15b and 20

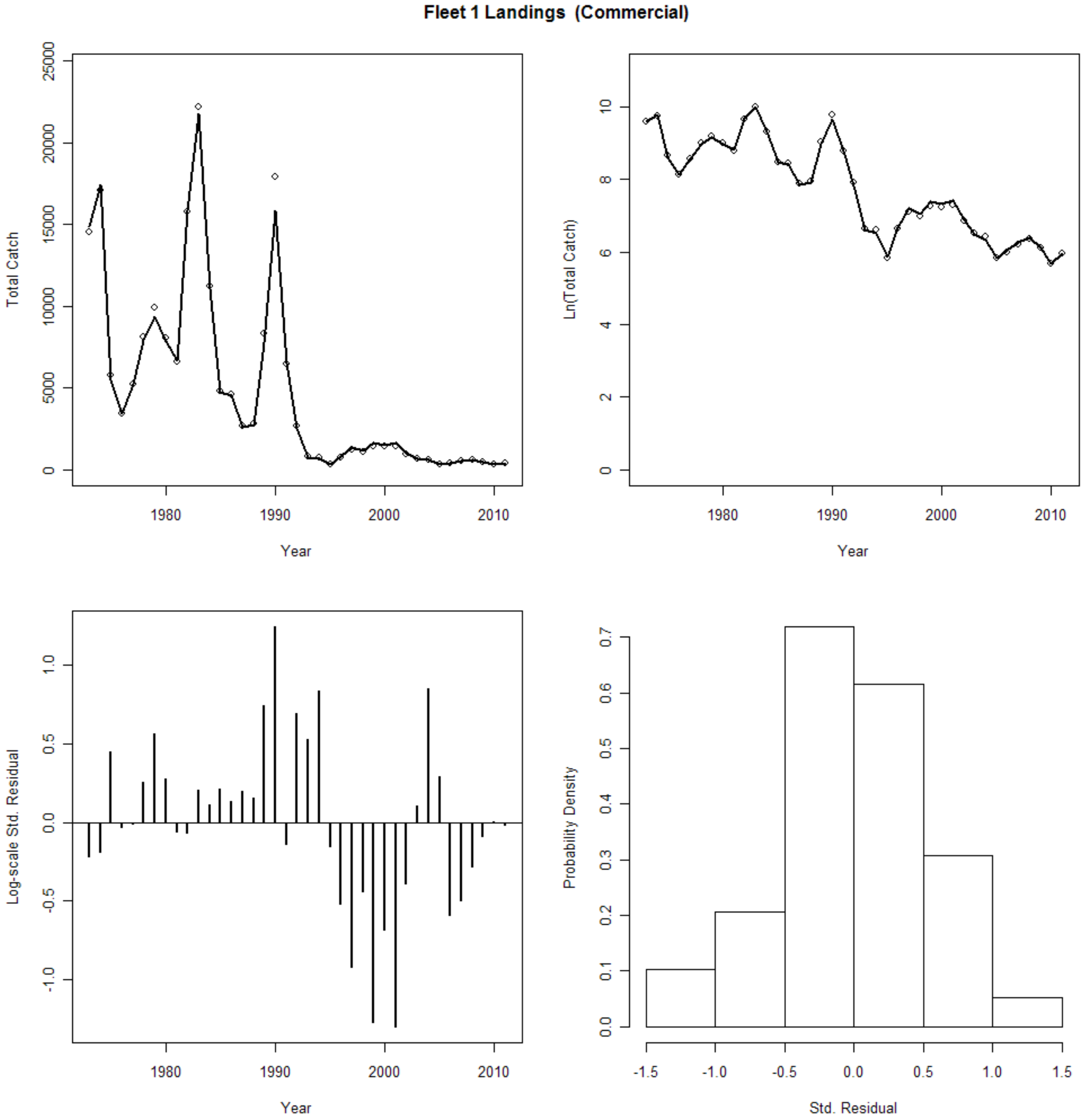


Figure B65. ASAP BASE Model 26 fit to the total Southern New England Mid-Atlantic yellowtail flounder fishery catch.

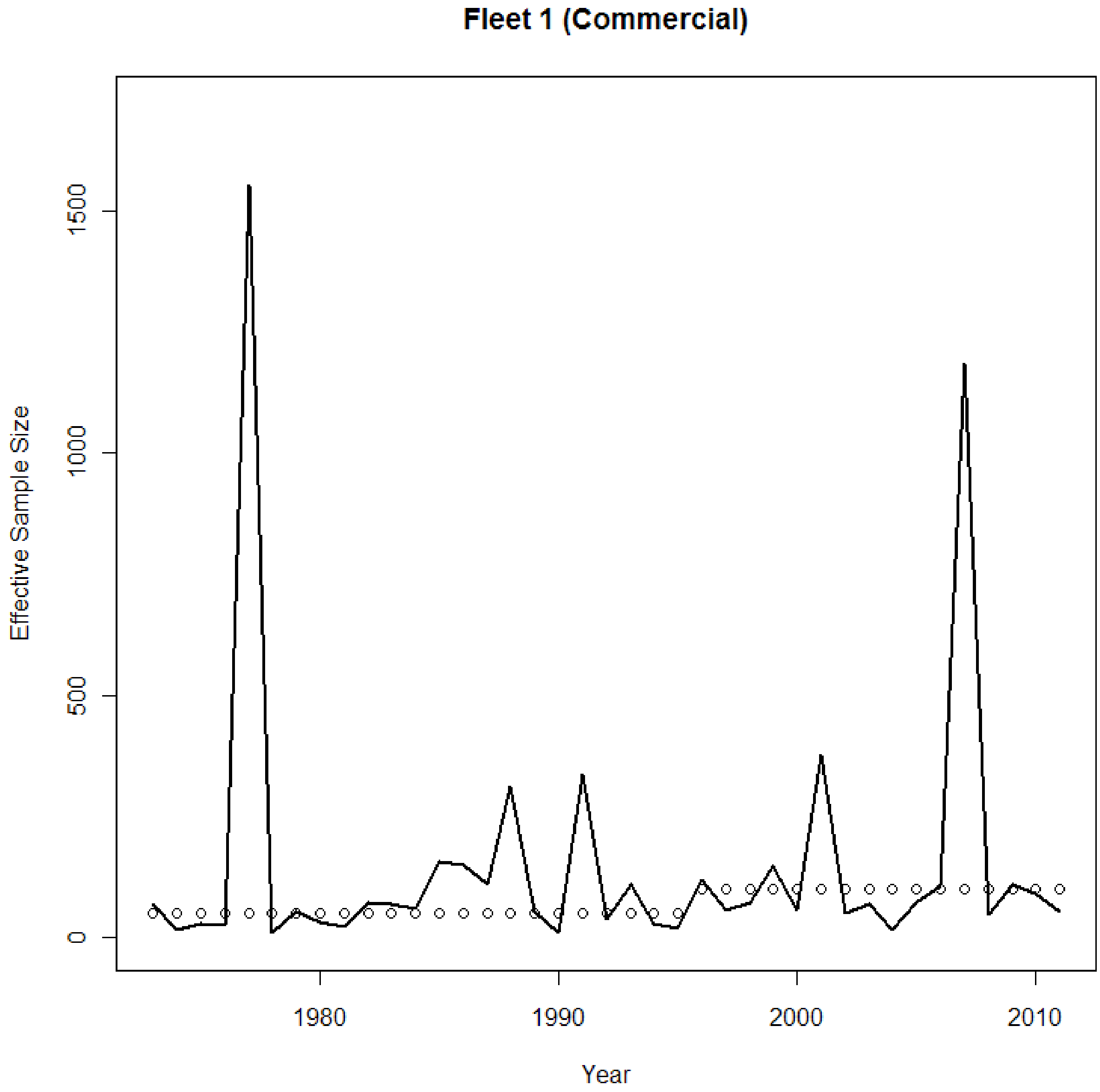


Figure B66. ASAP base Model 26 comparison of input effective sample size versus the model estimated effective sample size for Southern New England Mid-Atlantic yellowtail flounder fishery catch

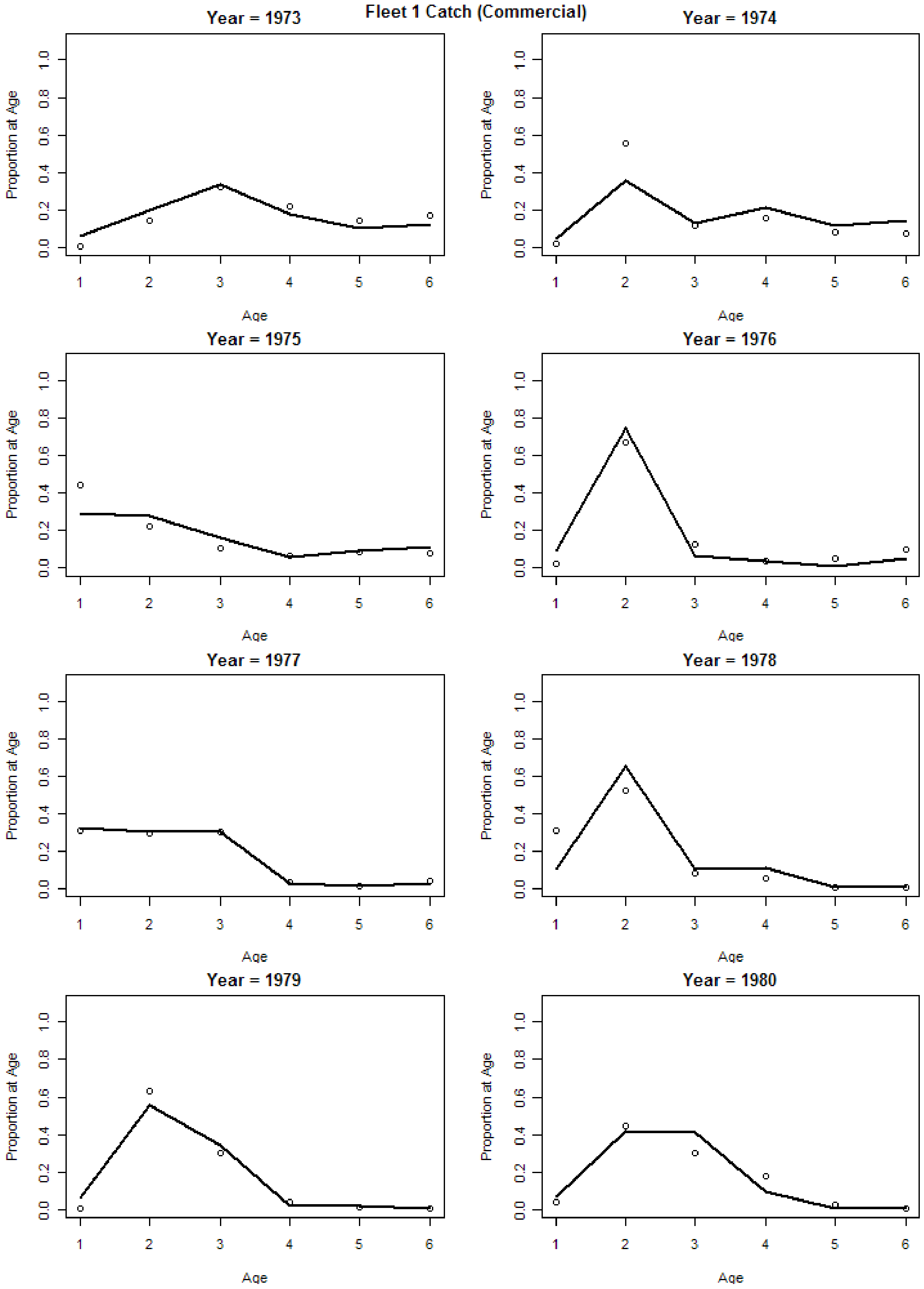


Figure B67. Comparison of the ASAP bade Model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder proportion at age in the fishery to the data estimates (1973-1980).

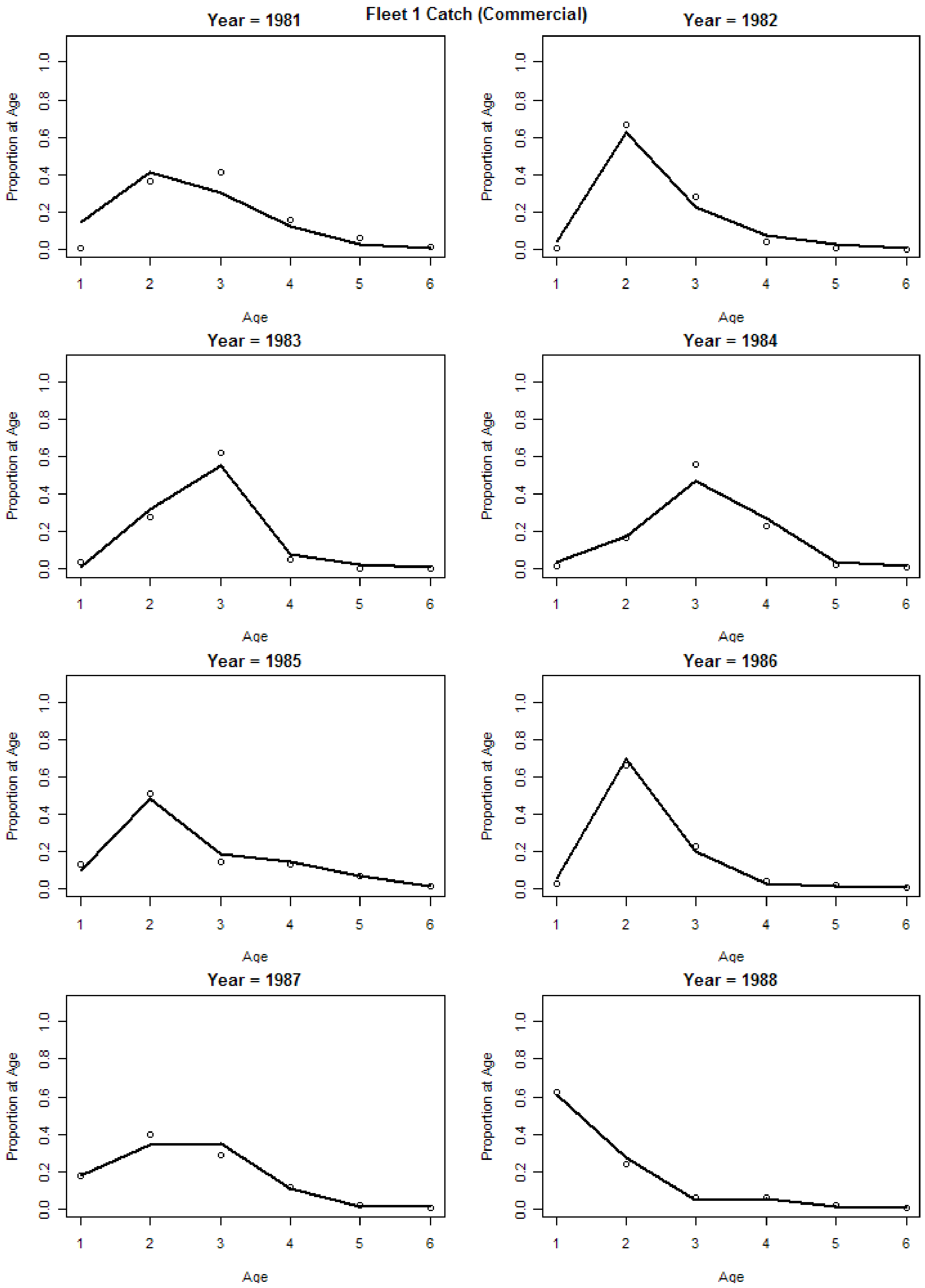


Figure B68. Comparison of the ASAP bade Model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder proportion at age in the fishery to the data estimates (1981-1988).

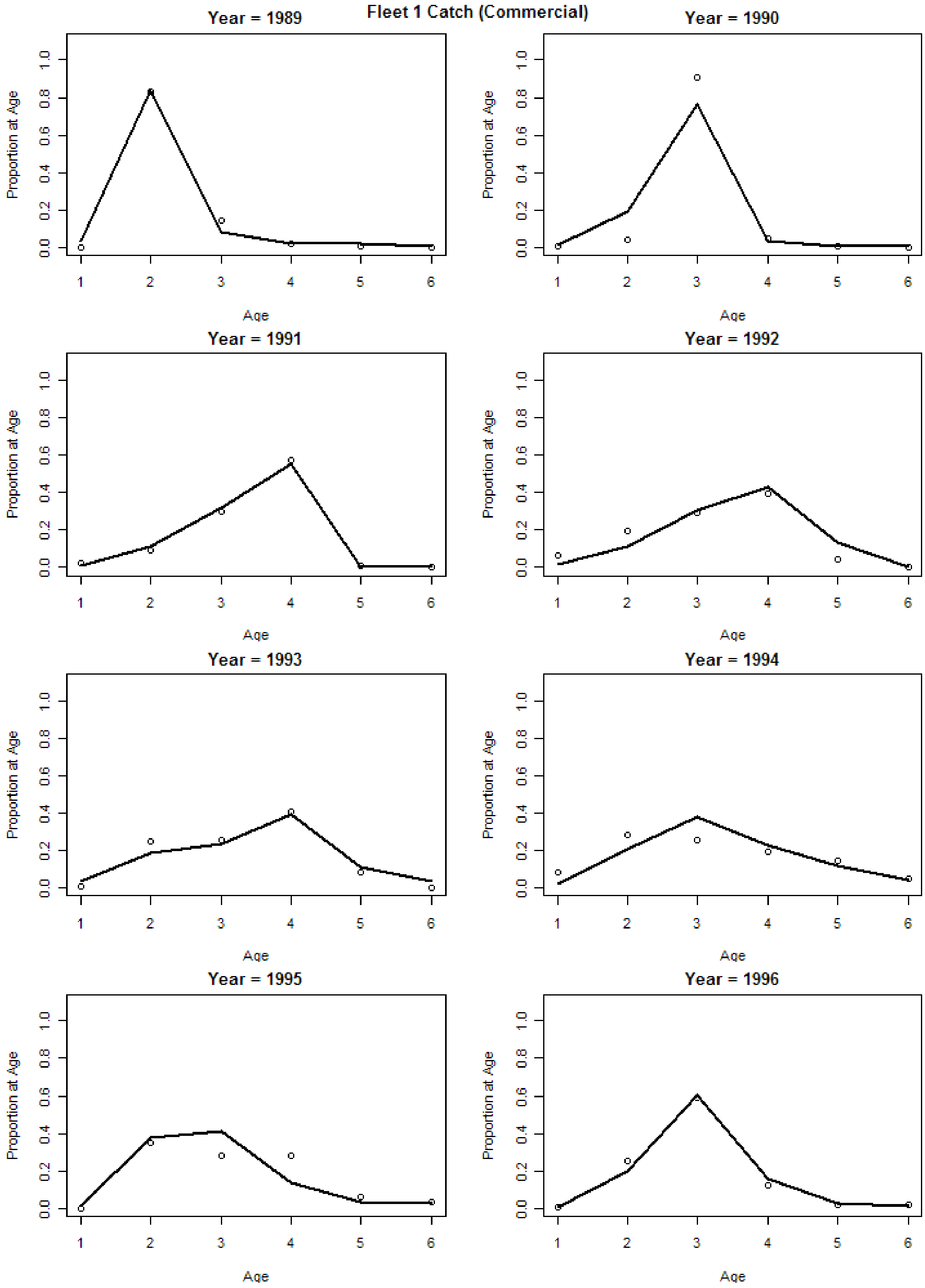


Figure B69. Comparison of the ASAP bade Model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder proportion at age in the fishery to the data estimates (1989-1996).

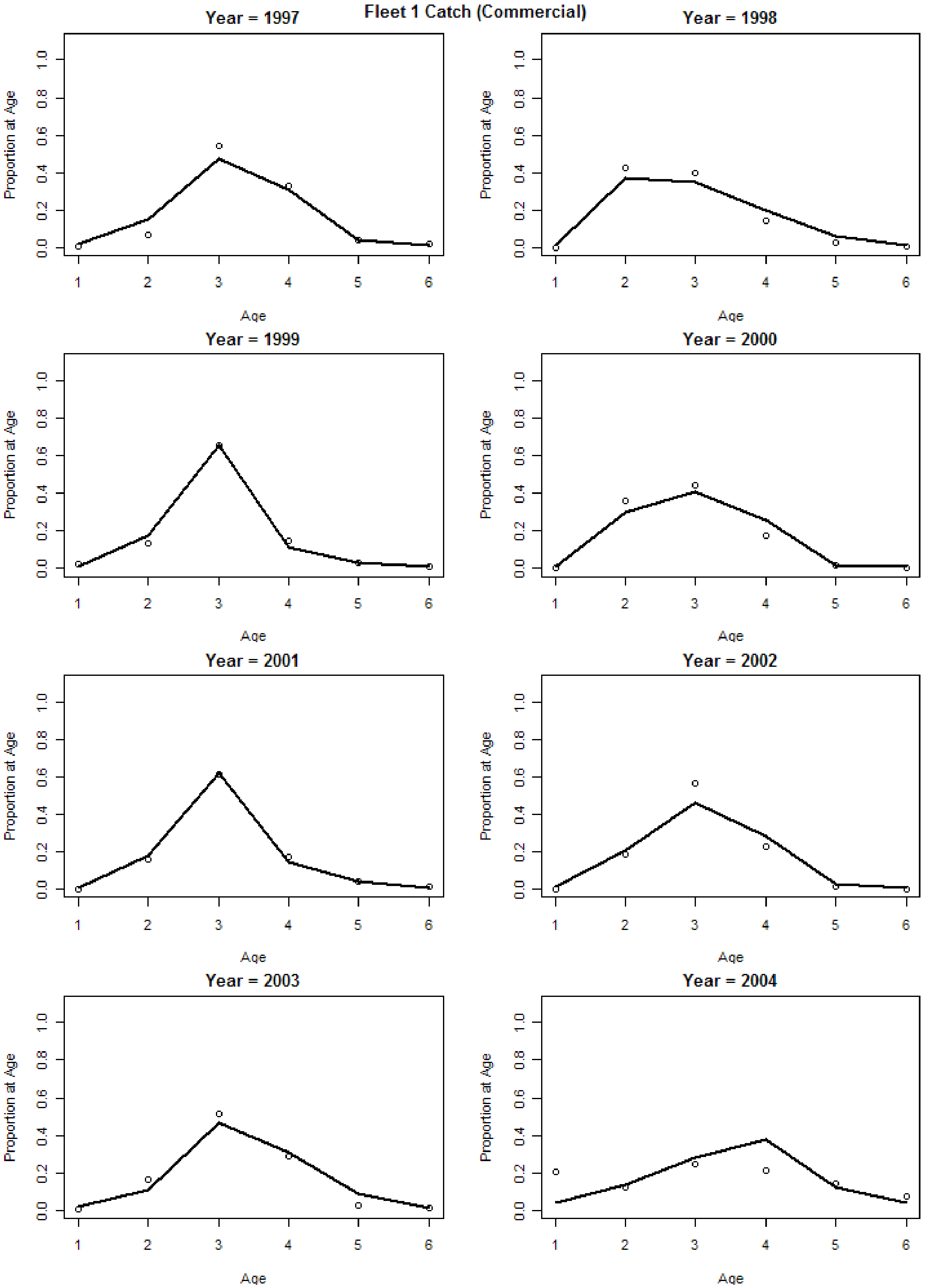


Figure B70. Comparison of the ASAP bade Model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder proportion at age in the fishery to the data estimates (1997-2004).

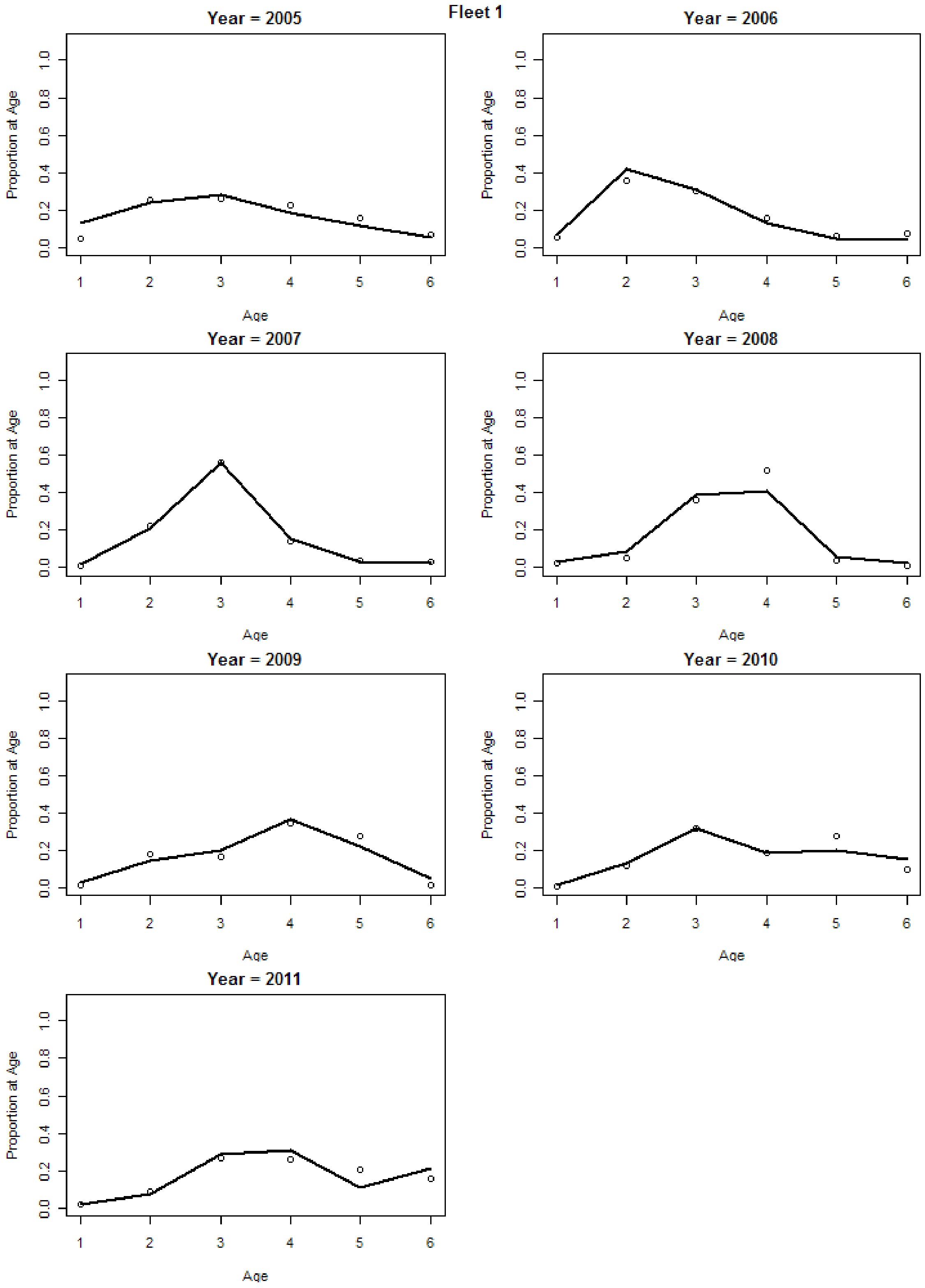


Figure B71. Comparison of the ASAP bade model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder proportion at age in the fishery to the data estimates (2005-2011).

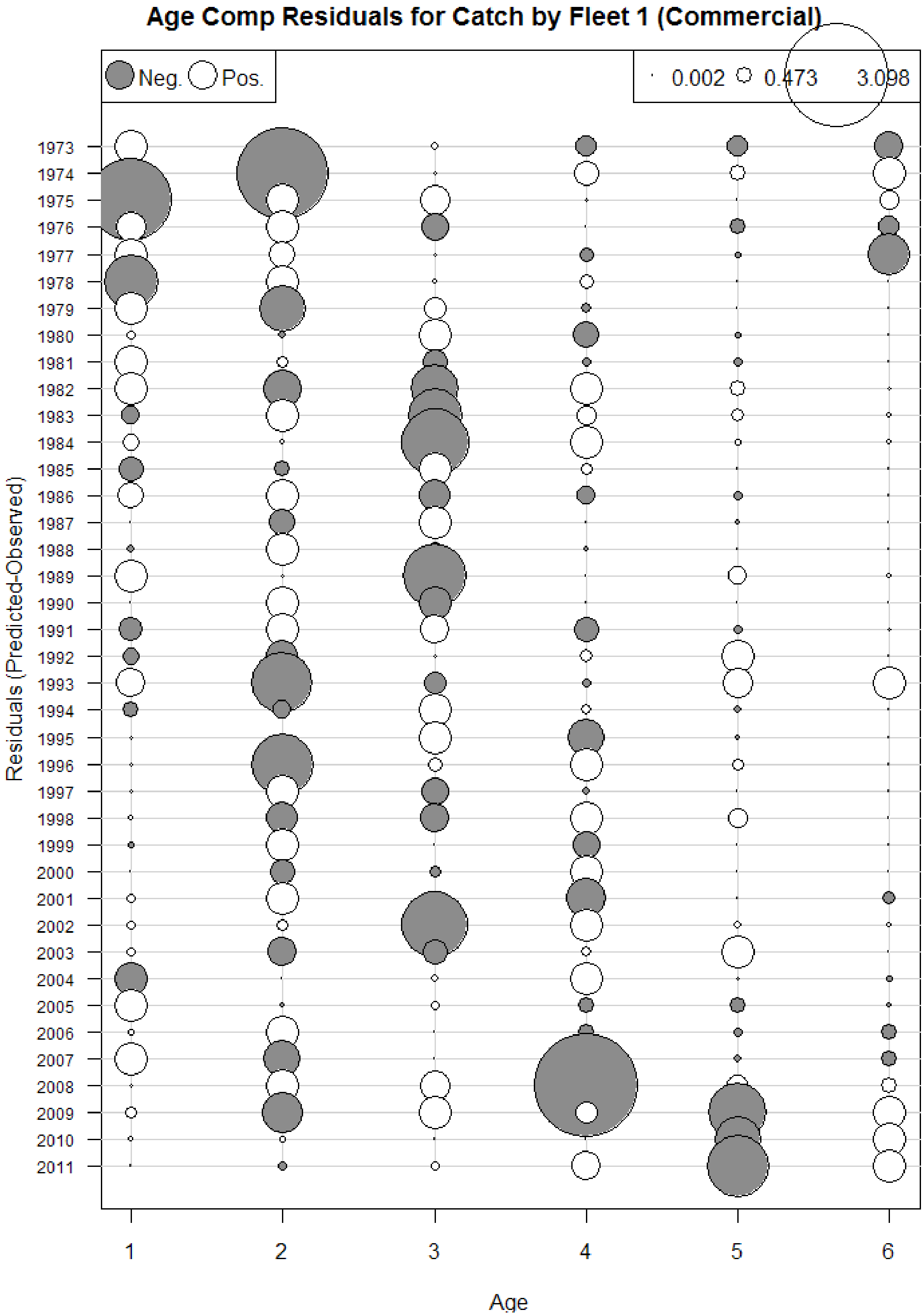


Figure B72. ASAP base Model 26) residual fit for the fishery (Fleet1) catch-at-age of the Southern New England yellowtail flounder

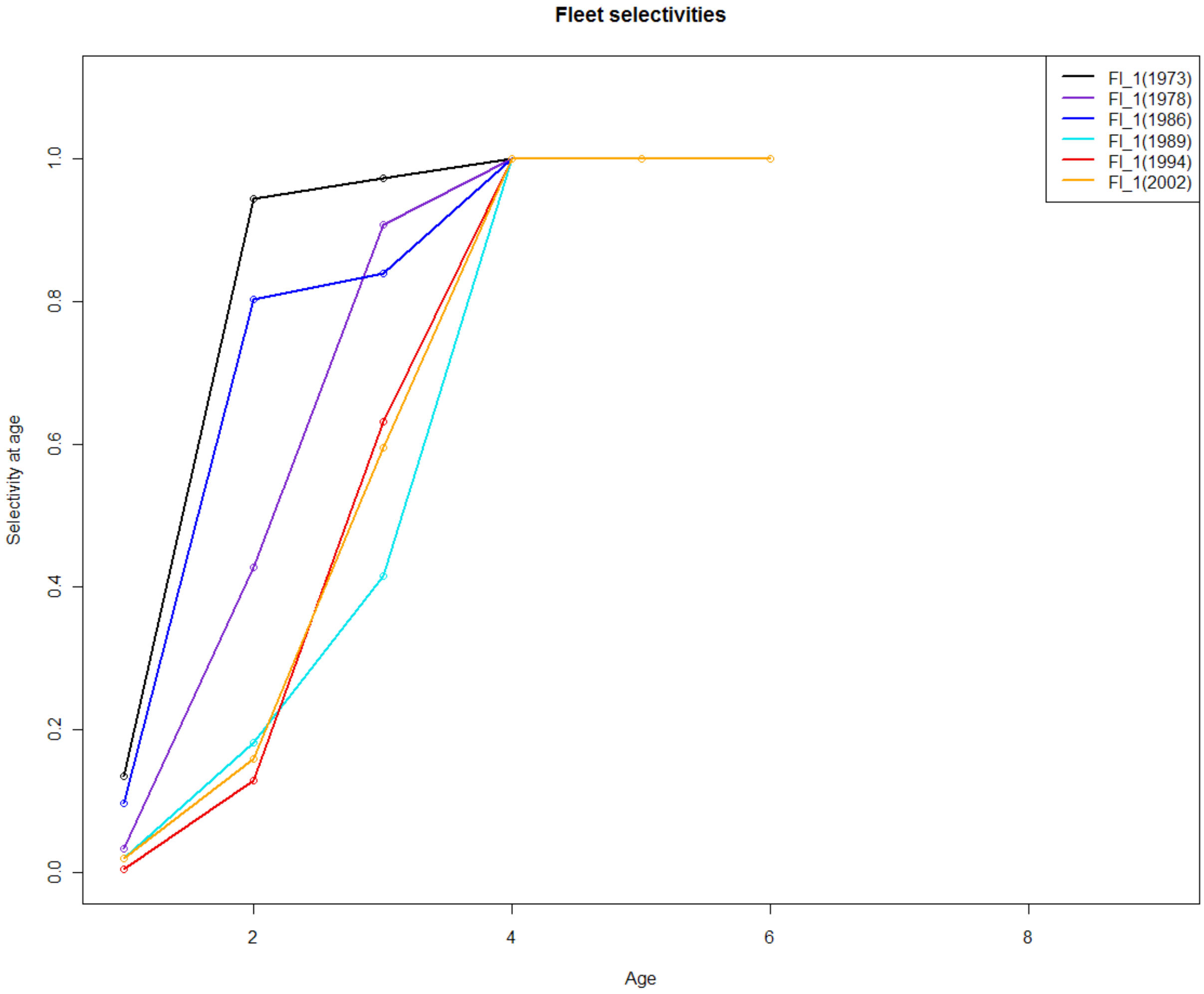


Figure B73. ASAP base Model 26 estimated selectivity blocks for Southern New England Mid-Atlantic yellowtail flounder. Block 1 (1973-1977); Block2 (1978-1985); Block 3 (1986-1988); Block 4 (1989-1993); Block 5 (1994-2001); Block 6 (2002-2011). Note selectivity was estimated for ages 1-3 and fixed for ages 4 and older.

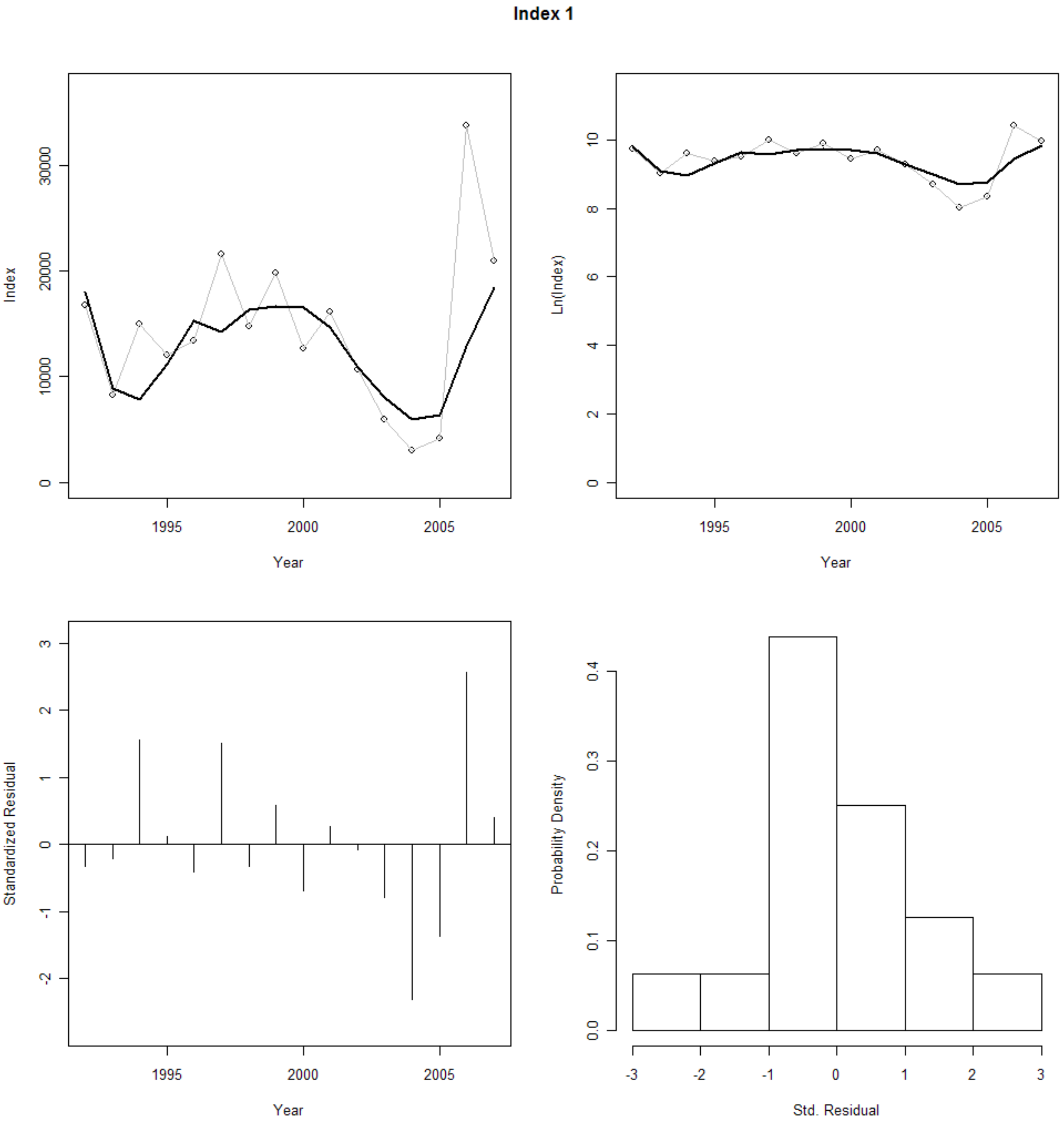


Figure B74. ASAP base Model 26 fit to the NEFSC Southern New England Mid-Atlantic yellowtail flounder winter survey (index1)

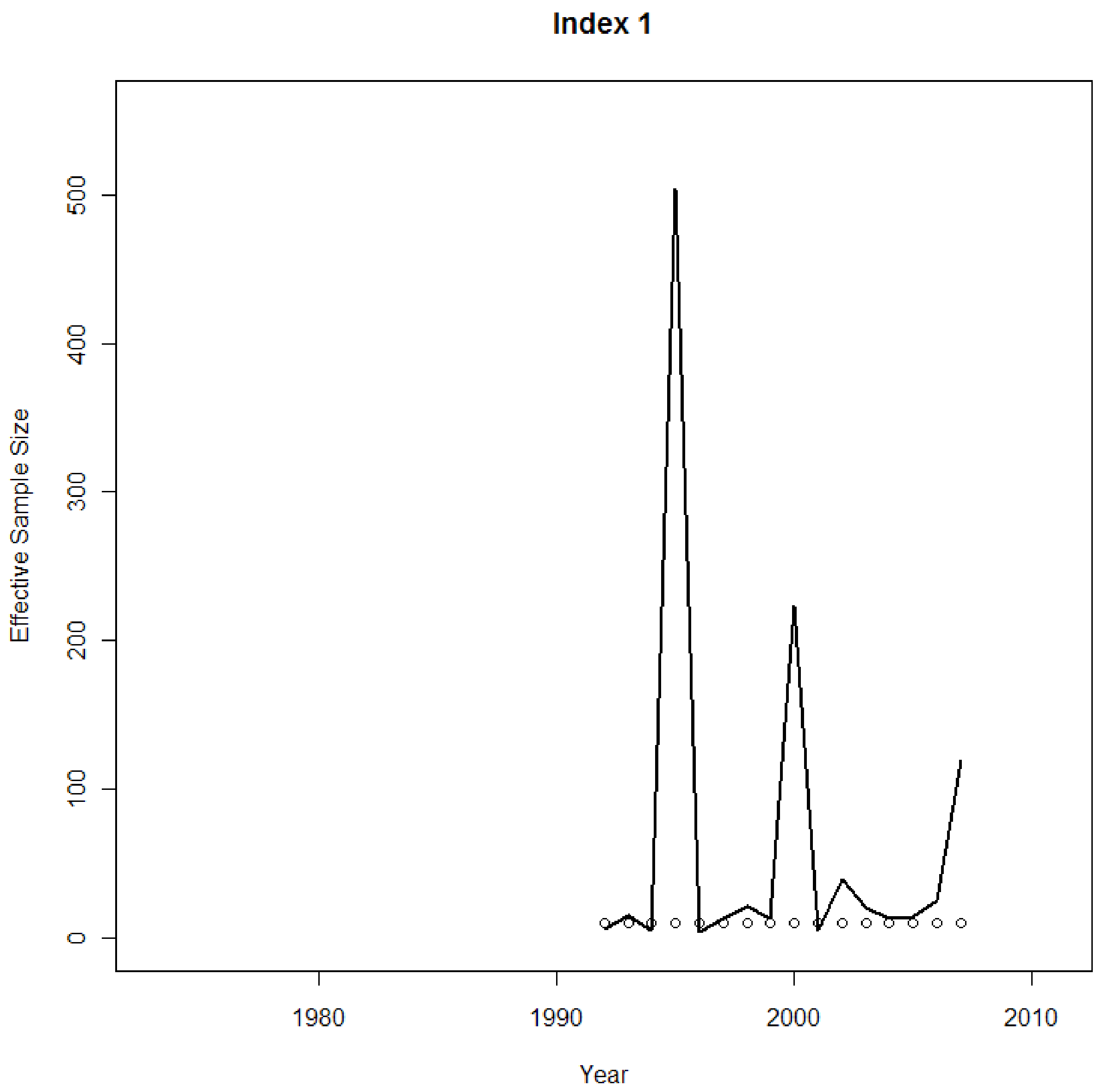


Figure B75. ASAP base Model 26 comparison of input effective sample size versus the model estimated effective sample size for the NEFSC winter survey (index 1) for the Southern New England Mid-Atlantic yellowtail flounder

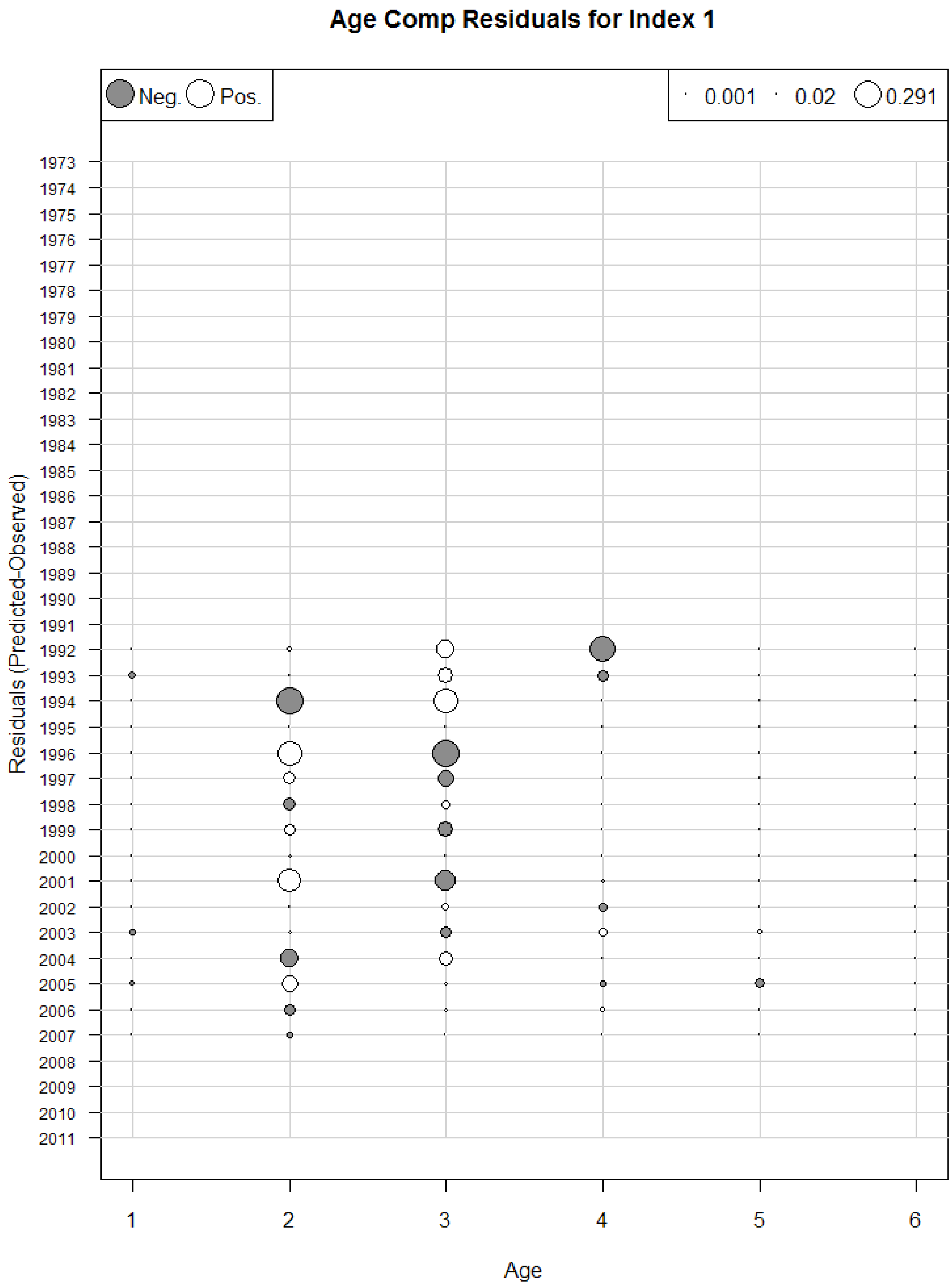


Figure B76. ASAP base Model 26 fit residuals for the NEFSC winter survey (index 1) for Southern New England Mid-Atlantic yellowtail flounder age composition

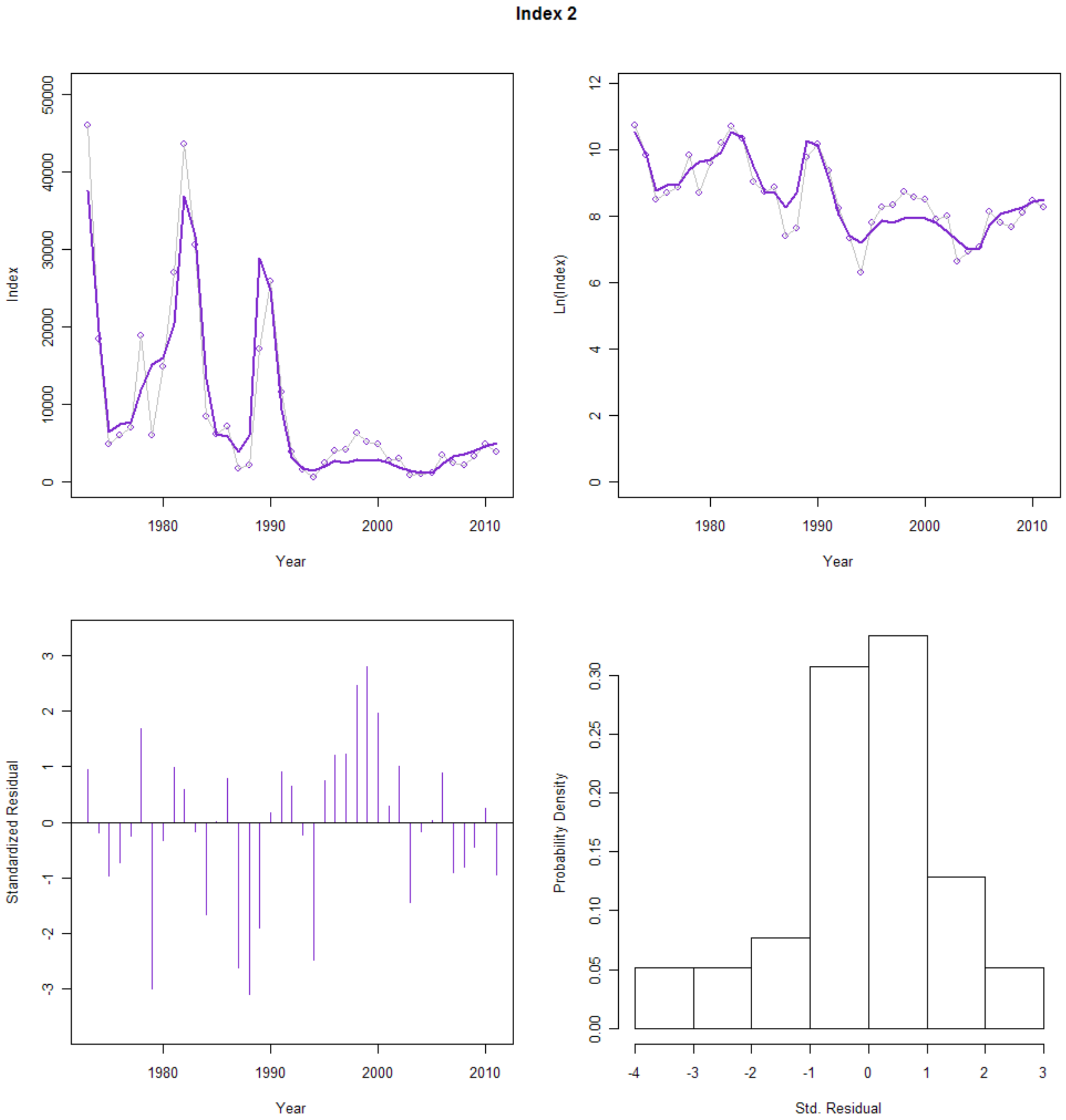


Figure B77. ASAP base Model 26 fit to the NEFSC Southern New England Mid-Atlantic yellowtail flounder spring survey (index2)

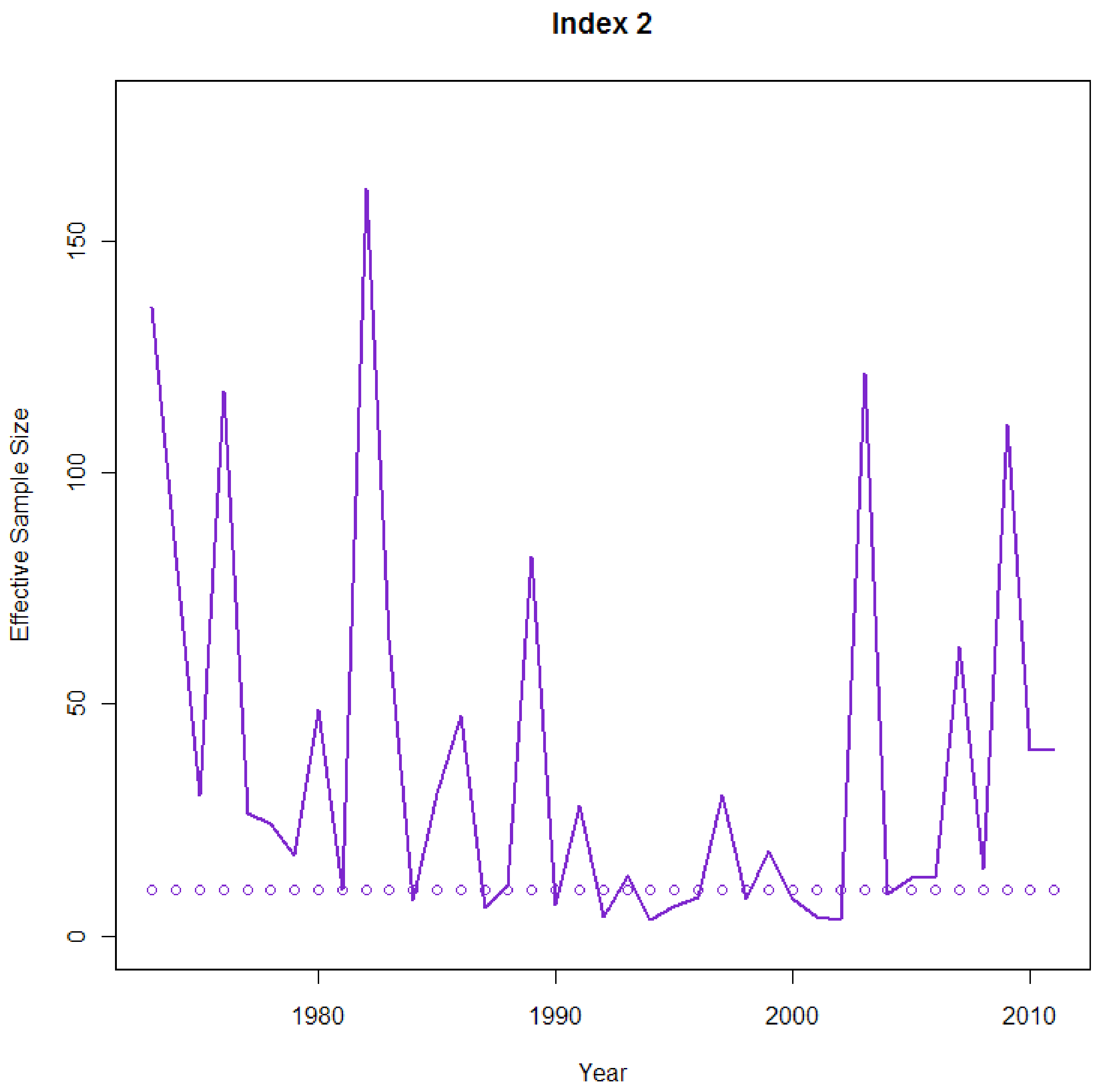


Figure B78. ASAP base Model 26 comparison of input effective sample size versus the model estimated effective sample size for the NEFSC spring survey (index 2) for the Southern New England Mid-Atlantic yellowtail flounder

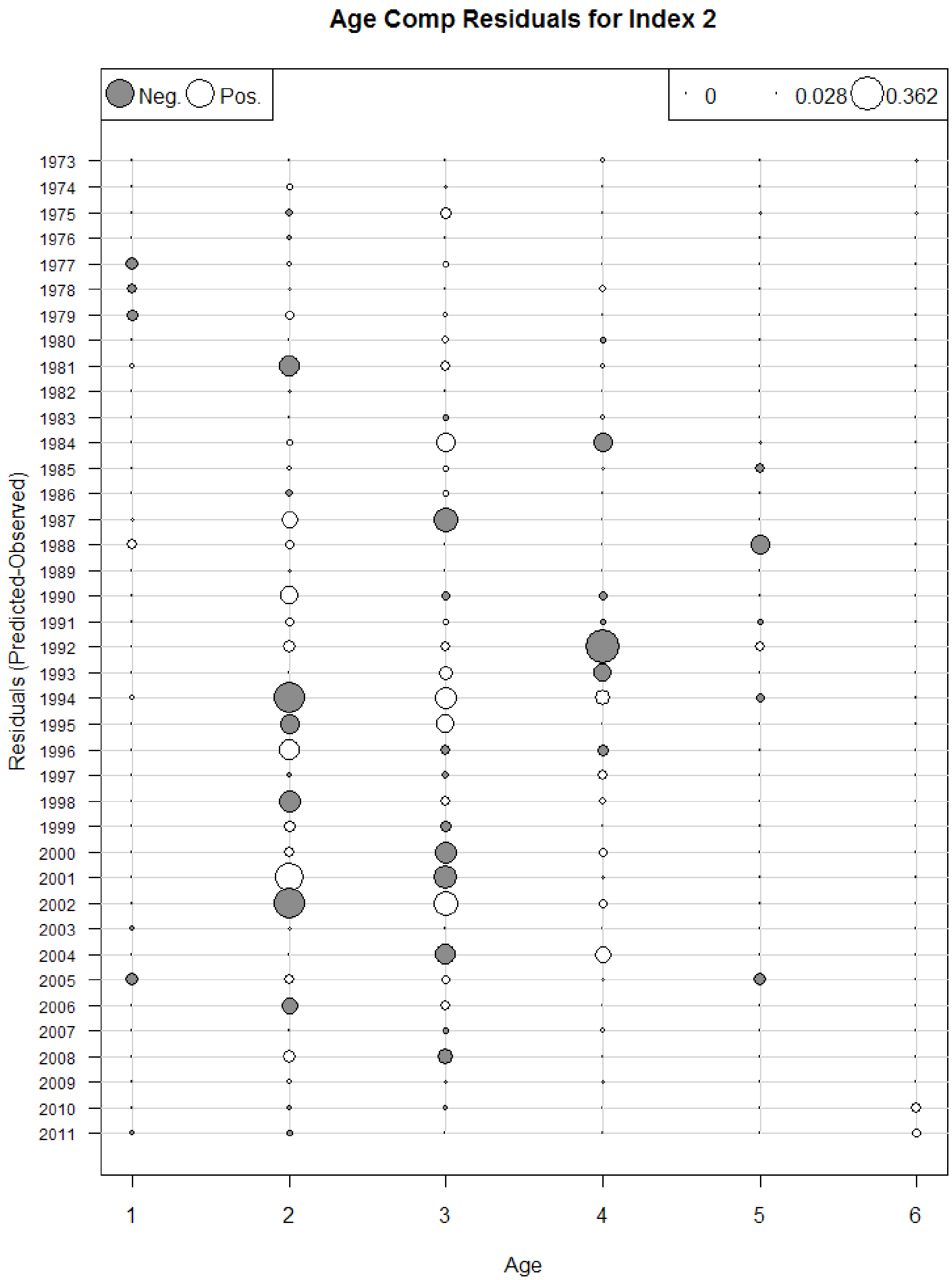


Figure B79. ASAP base Model 26 fit residuals for the NEFSC spring survey (index 2) for Southern New England Mid-Atlantic yellowtail flounder age composition

Index 3

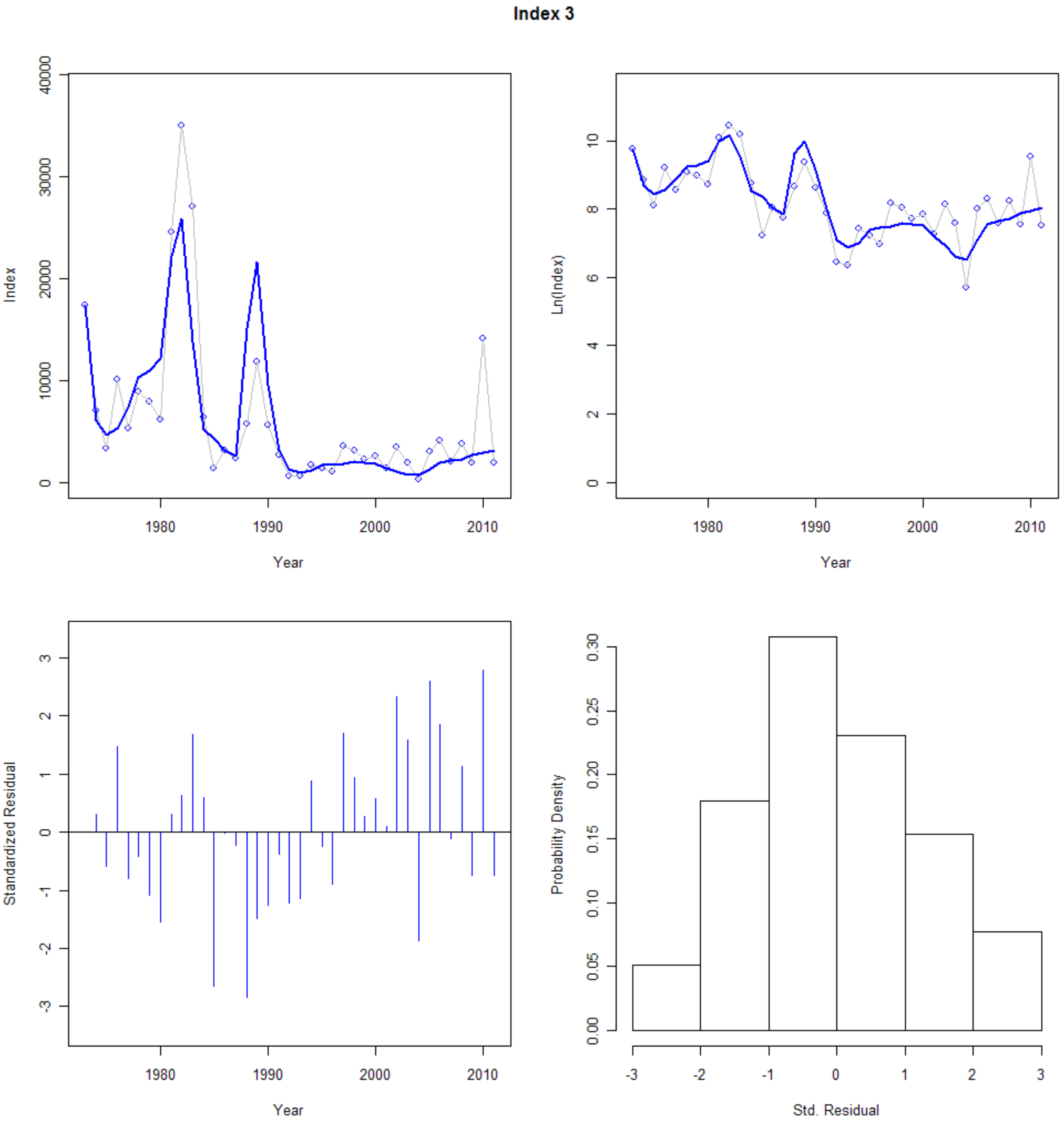


Figure B80. ASAP base model 26 fit to the NEFSC Southern New England Mid-Atlantic yellowtail flounder fall survey (index3)

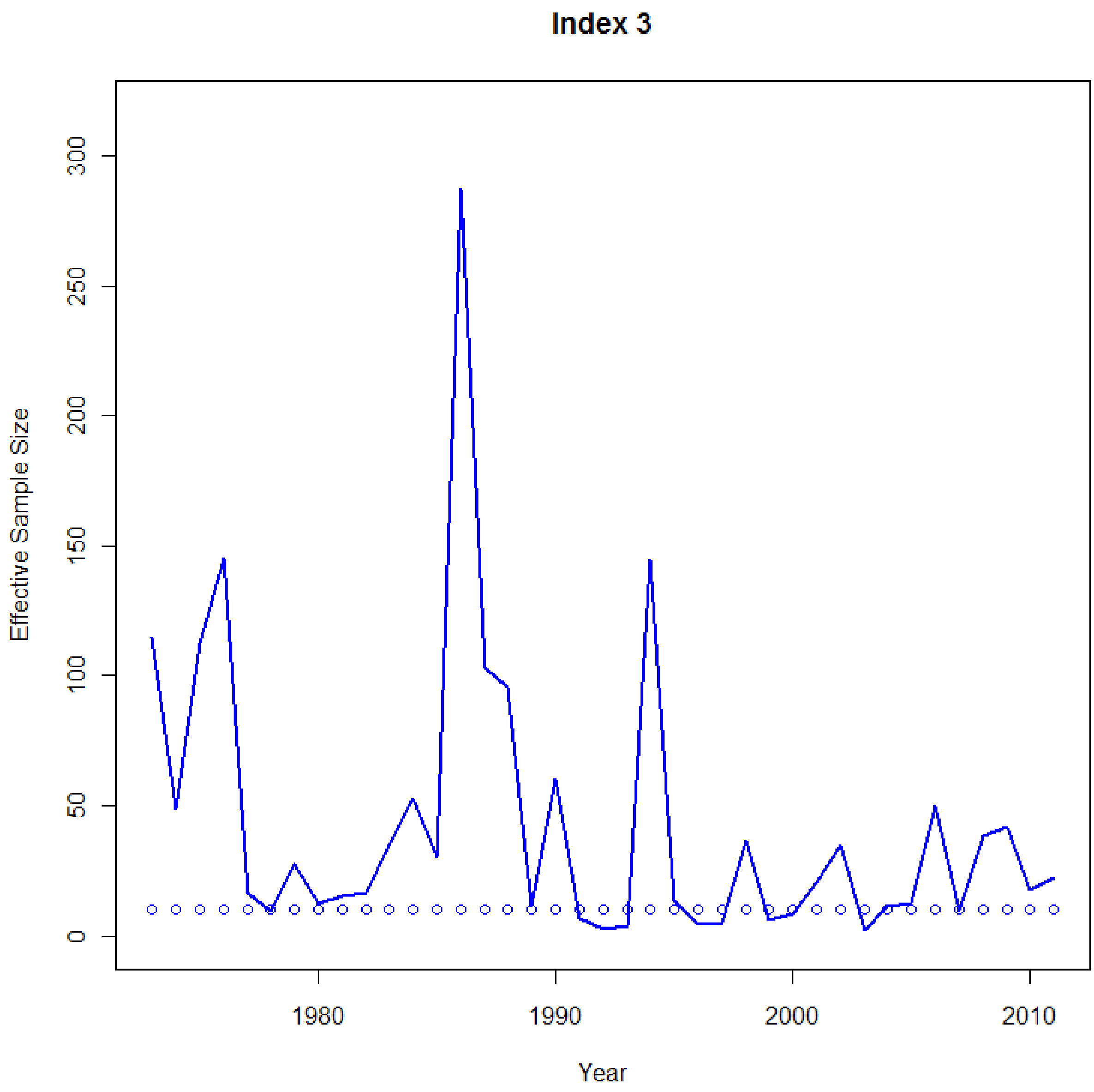


Figure B81. ASAP base Model 26 comparison of input effective sample size versus the model estimated effective sample size for the NEFSC fall survey (index 3) for the Southern New England Mid-Atlantic yellowtail flounder

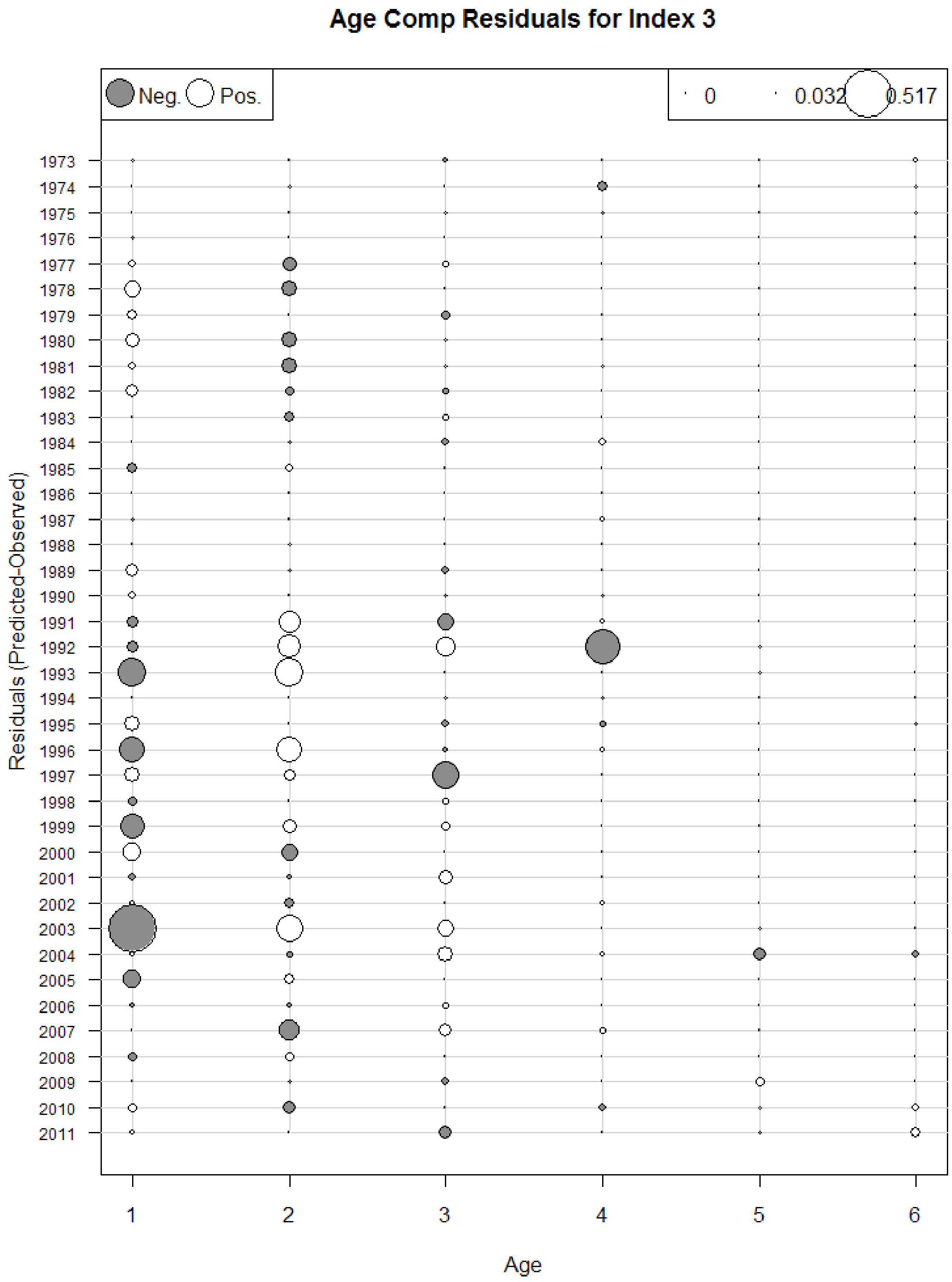


Figure B82. ASAP base Model 26 fit residuals for the NEFSC fall survey (index 3) for Southern New England Mid-Atlantic yellowtail flounder age composition

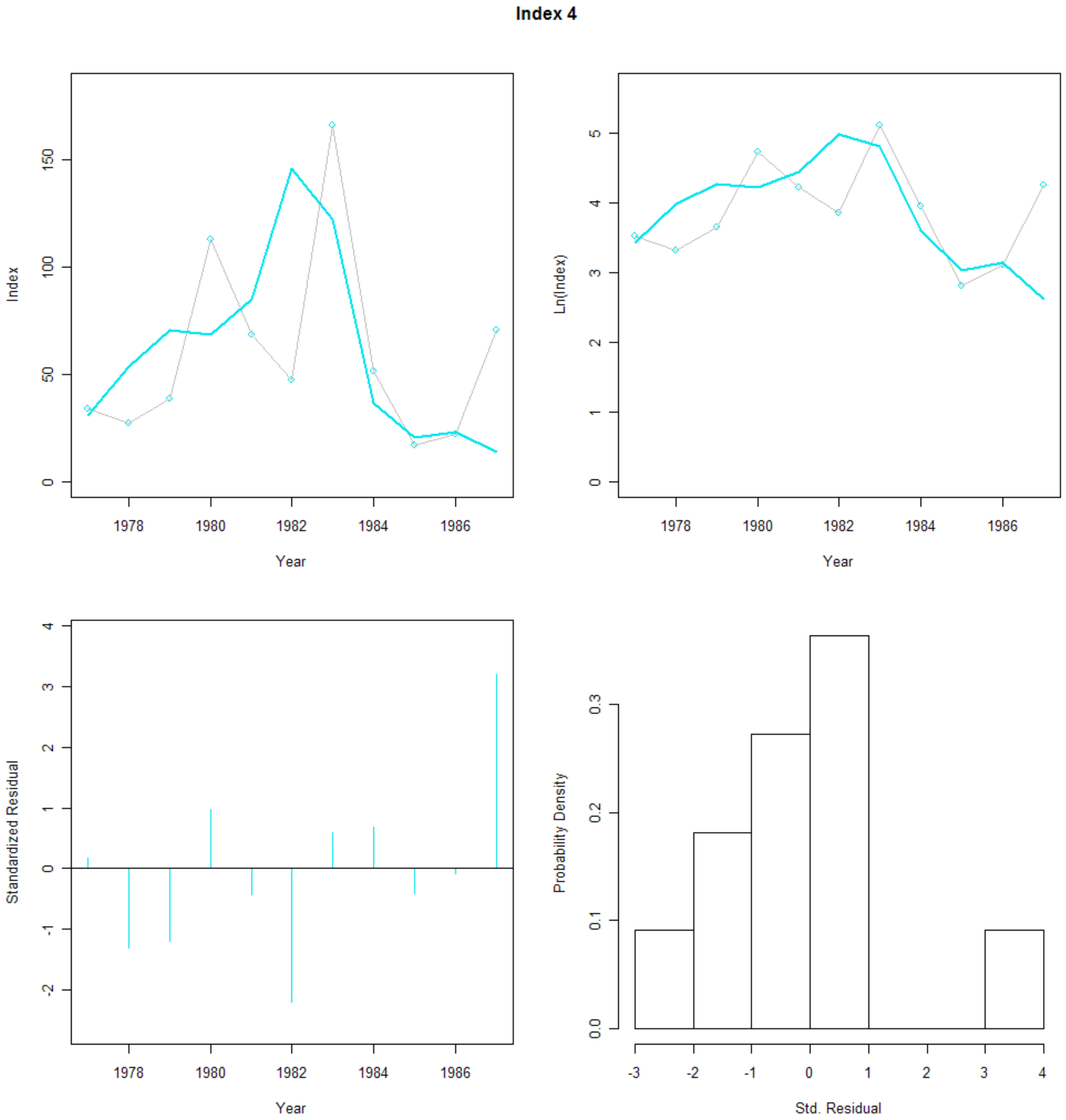


Figure B83. ASAP Model 26 fit to the NEFSC Southern New England Mid-Atlantic yellowtail flounder larval survey from 1977-1987 (index4)

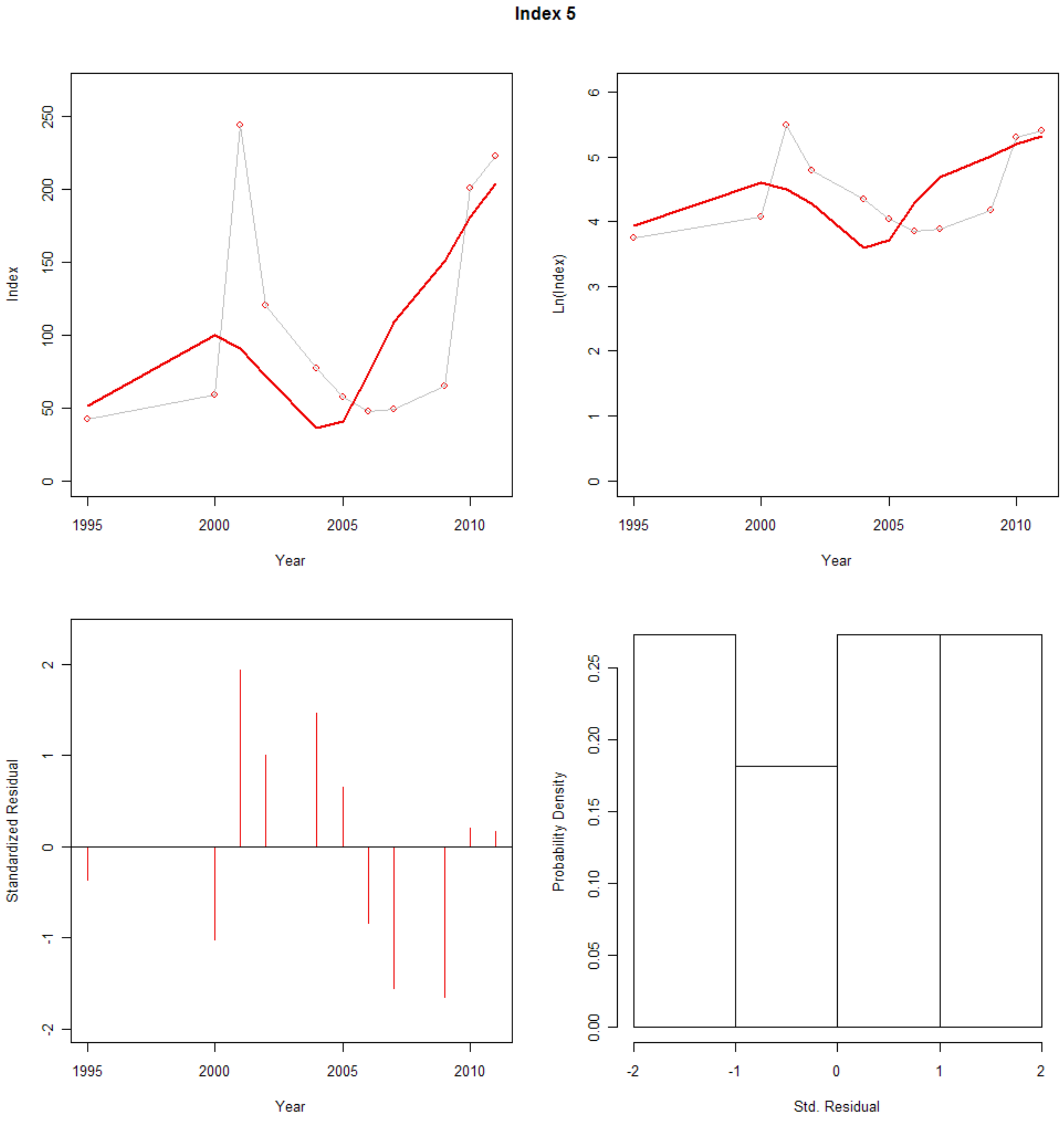


Figure B84. ASAP base Model 26 fit to the NEFSC Southern New England Mid-Atlantic yellowtail flounder larval survey from 1988-2011 (index5)

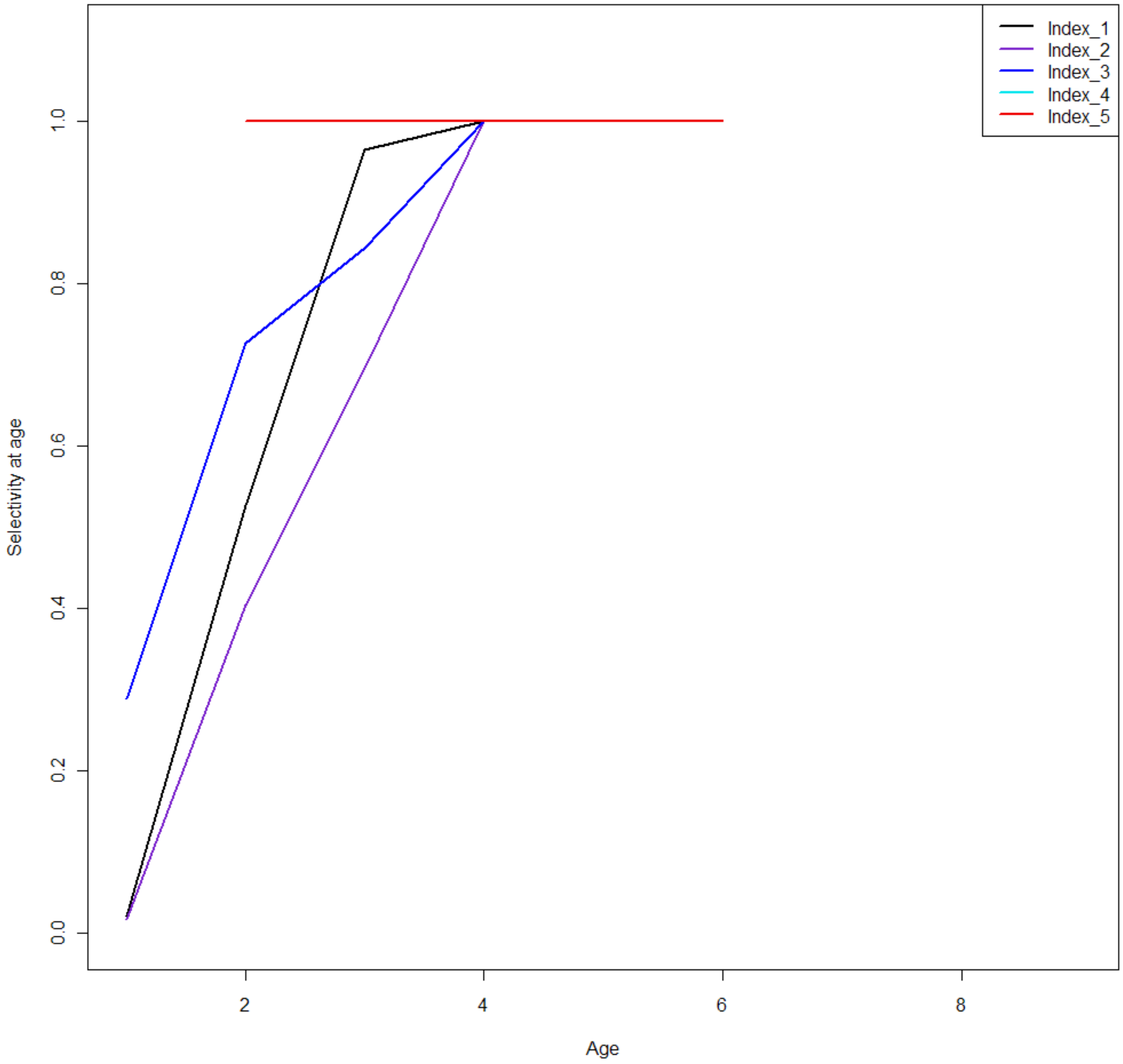


Figure B85. ASAP base Model 26 estimated selectivity at age for the NEFSC winter (index1), spring (index 2), fall (index3), larval survey 1977-1987 (index 4) and larval survey 1988-2011 (index5) of Southern New England Mid-Atlantic yellowtail flounder.

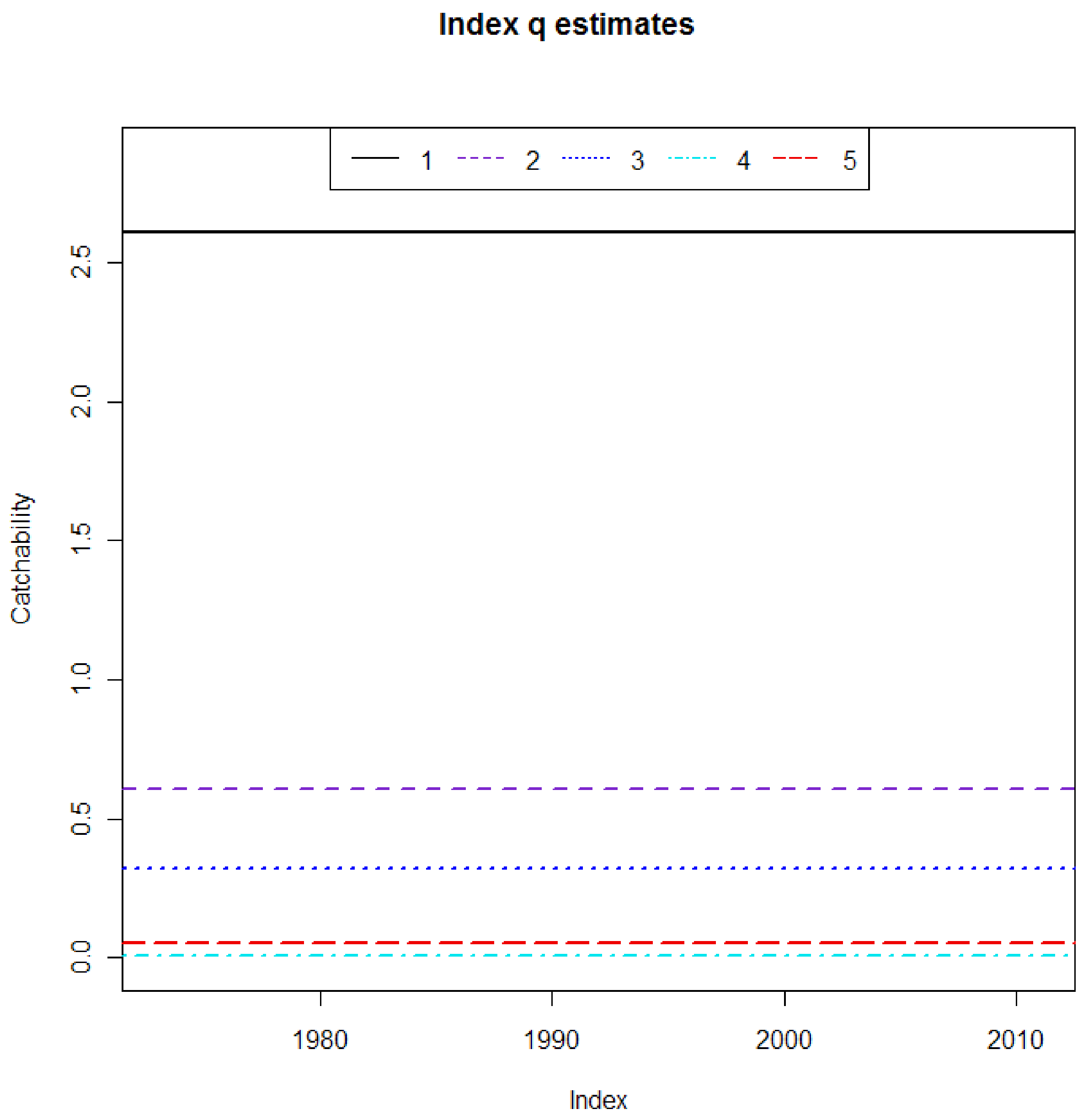
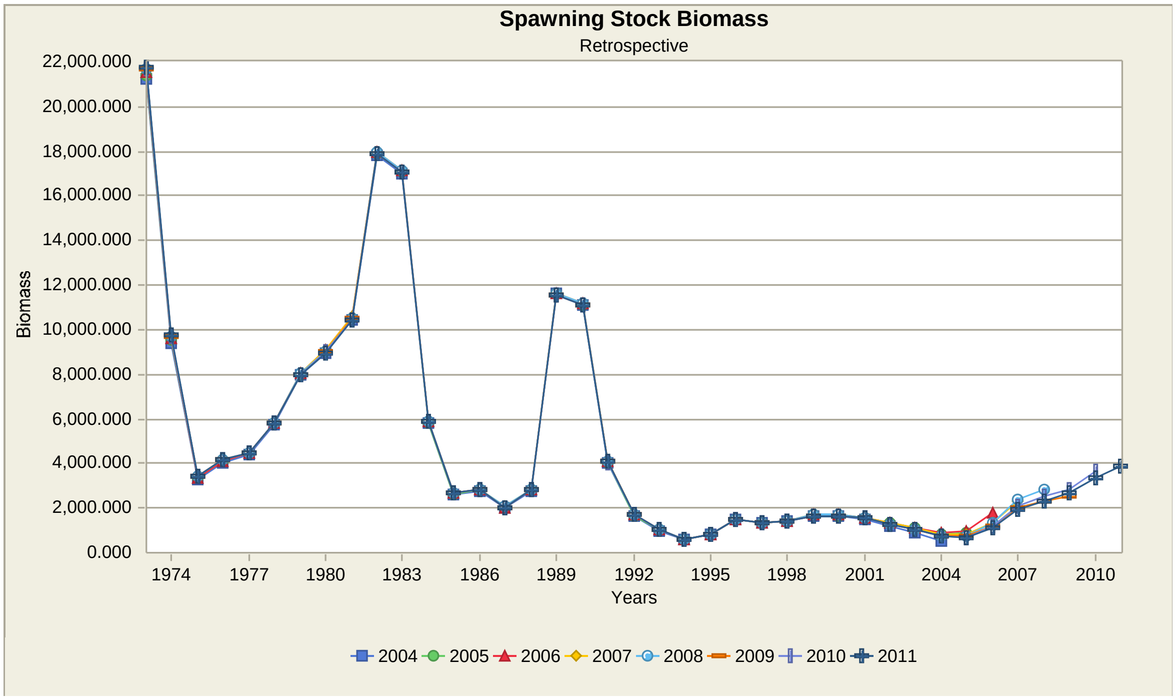


Figure B86. ASAP base Model 26 estimated survey catchability (q) for the NEFSC winter (index1), spring (index 2), fall (index3), larval survey 1977-1987 (index 4) and larval survey 1988-2011 (index5) of Southern New England Mid-Atlantic yellowtail flounder.



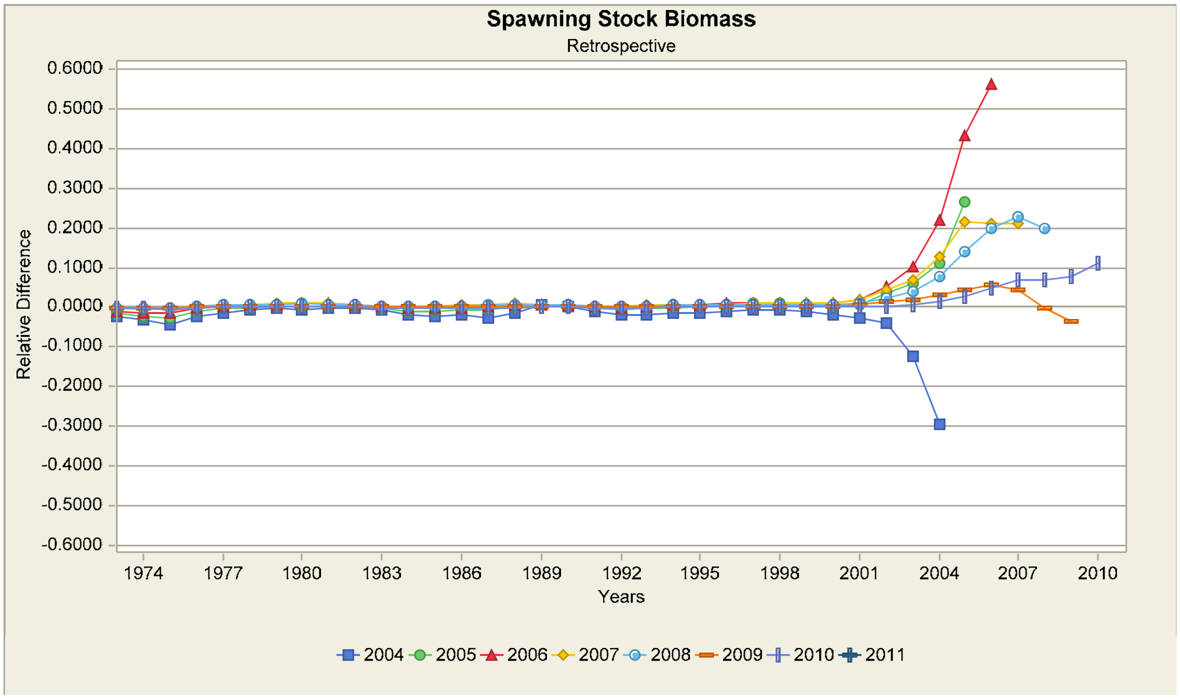
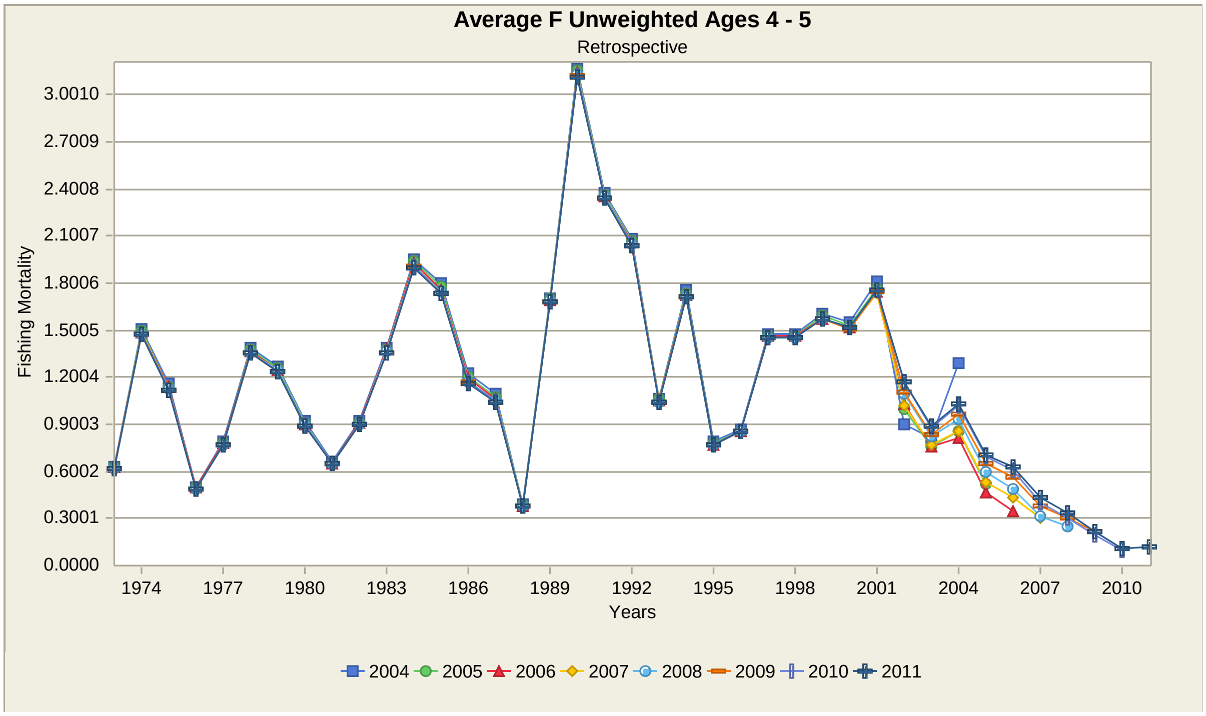


Figure B87. ASAP base Model 26 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder spawning stock Biomass (mt) in absolute (top) and relative (bottom) terms.



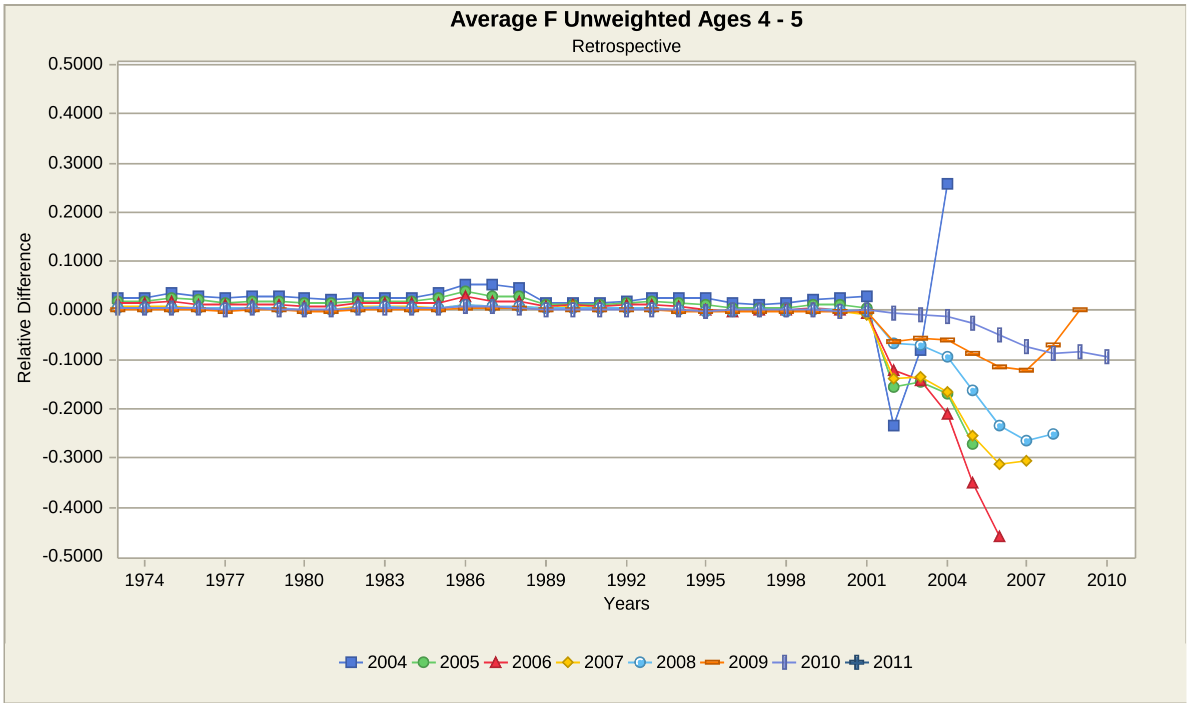
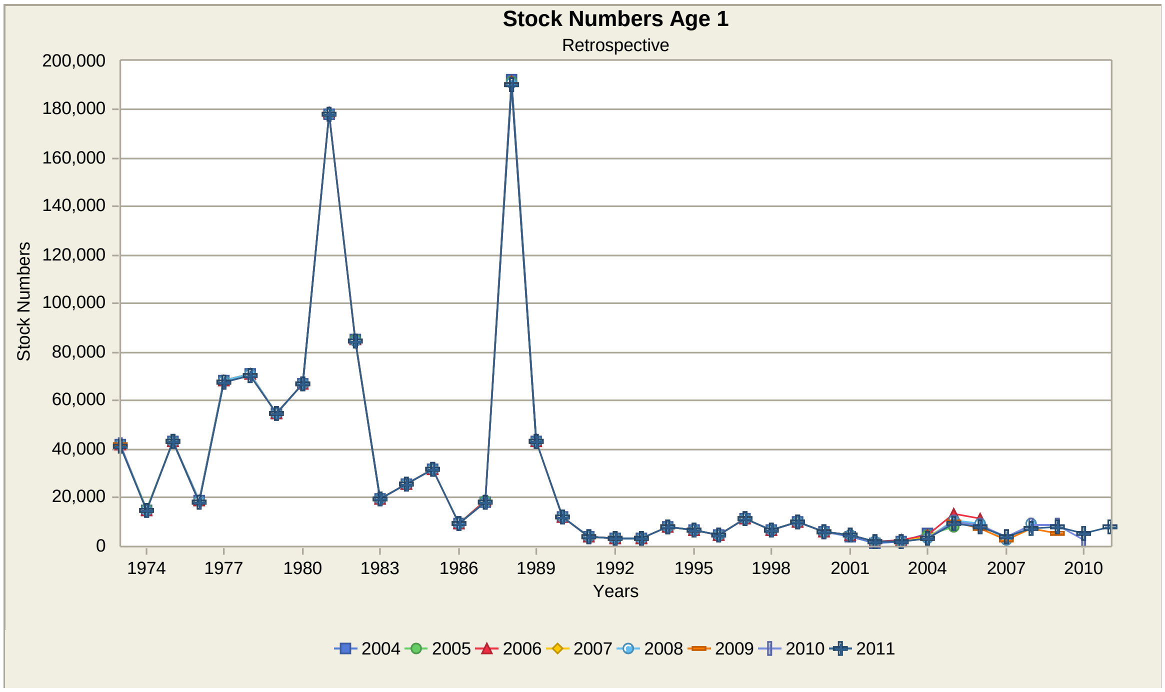


Figure B88. ASAP base Model 26 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder fishing mortality (ages 4-5) in absolute (top) and relative (bottom) terms.



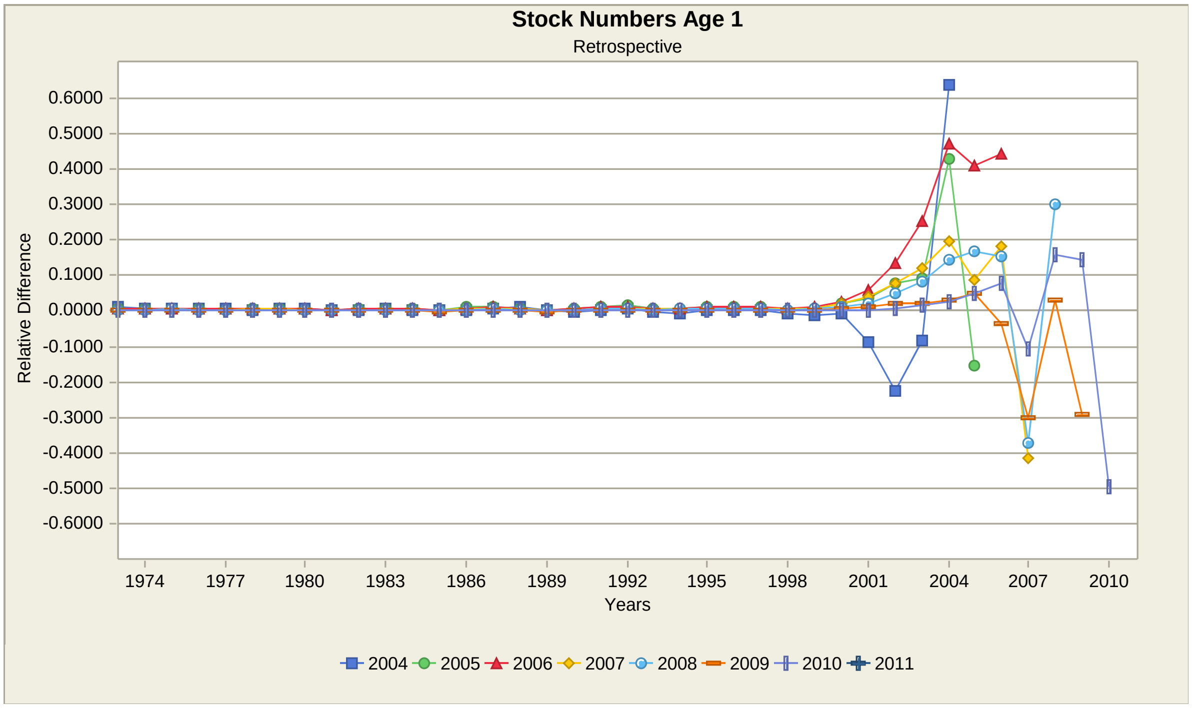


Figure B89. ASAP base Model 26 retrospective patterns in Southern New England Mid-Atlantic yellowtail flounder age 1 recruitment (000's) in absolute (top) and relative (bottom) terms.

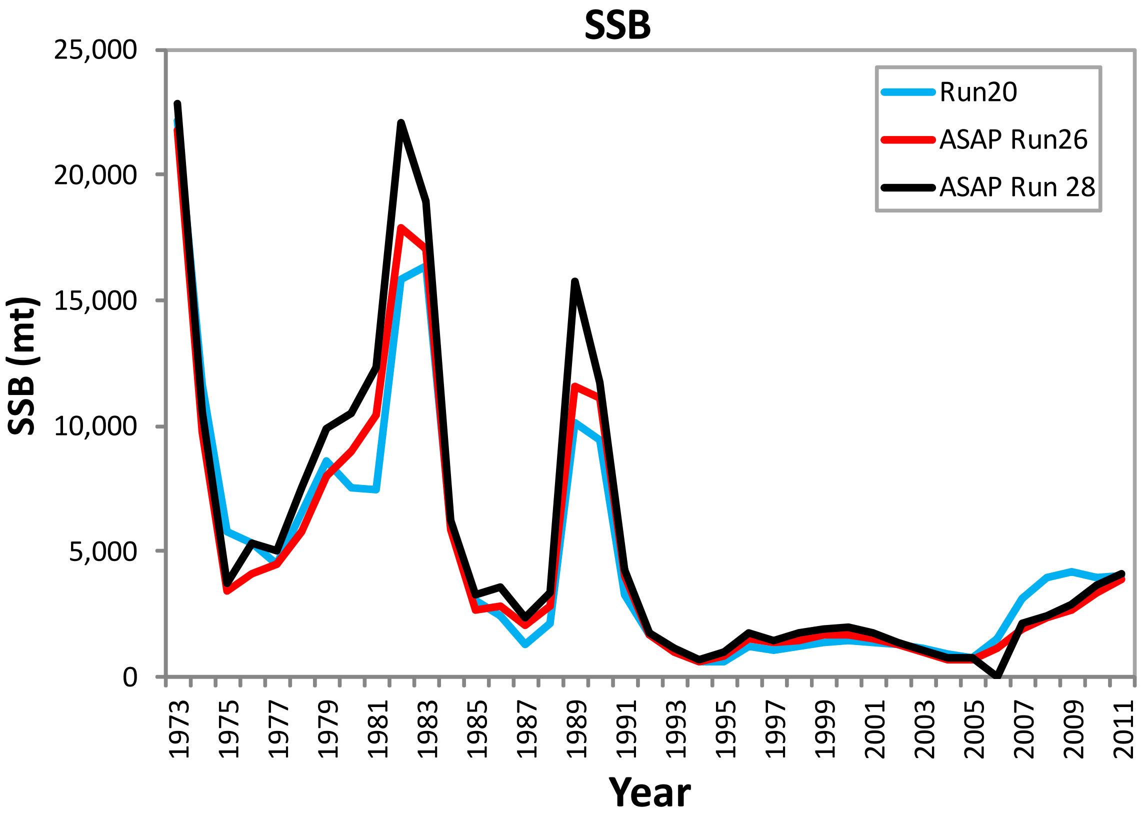


Figure B90. Comparison of estimates of Southern New England Mid-Atlantic yellowtail spawning stock biomass (mt) from ADAPT-VPA Model 20, ASAP base Model 26 ASAP and Model 28 with Cold Pool Indices

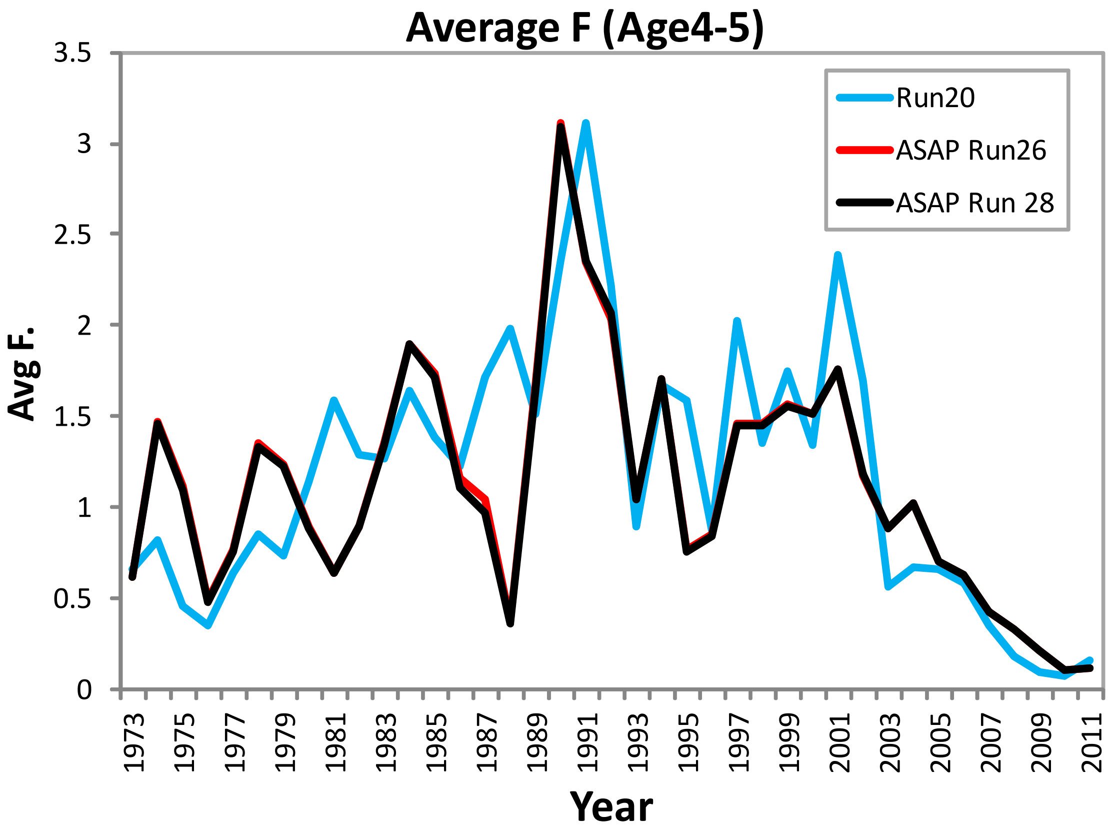


Figure B91. Comparison of estimates of Southern New England Mid-Atlantic yellowtail fishing mortality (ages 4-5) from ADAPT-VPA Model 20, ASAP base Model 26 and ASAP Model 28 with Cold Pool Indices

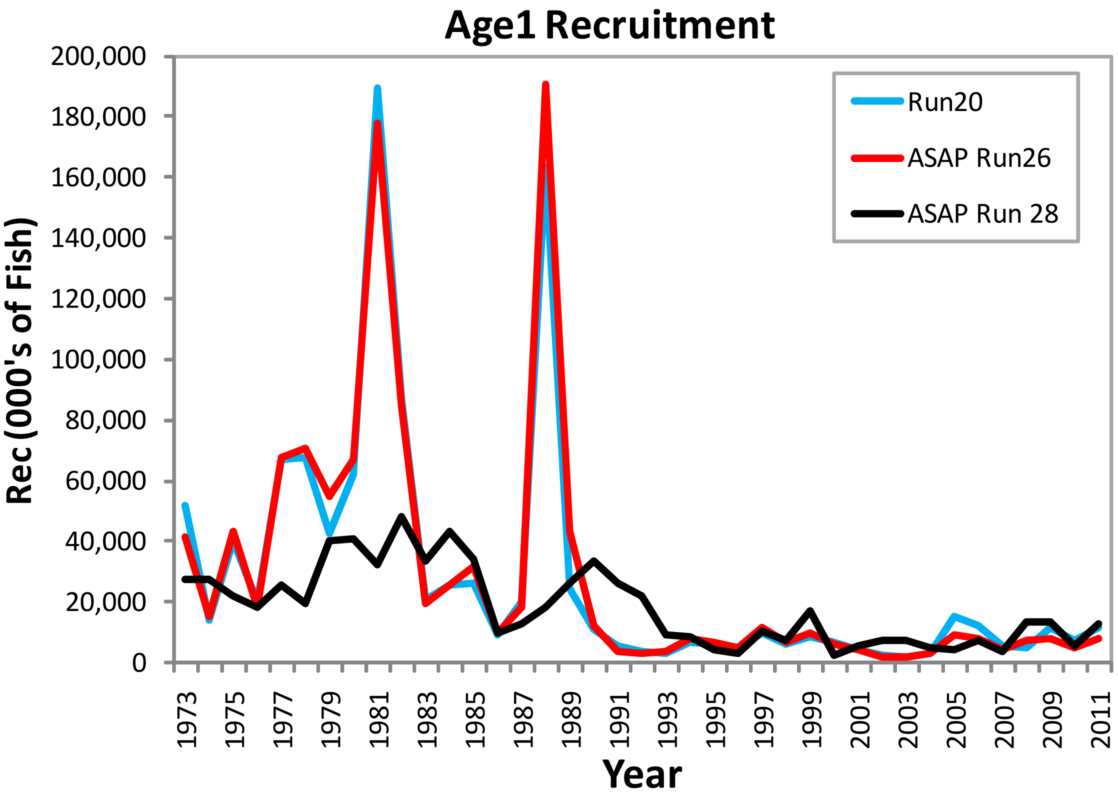
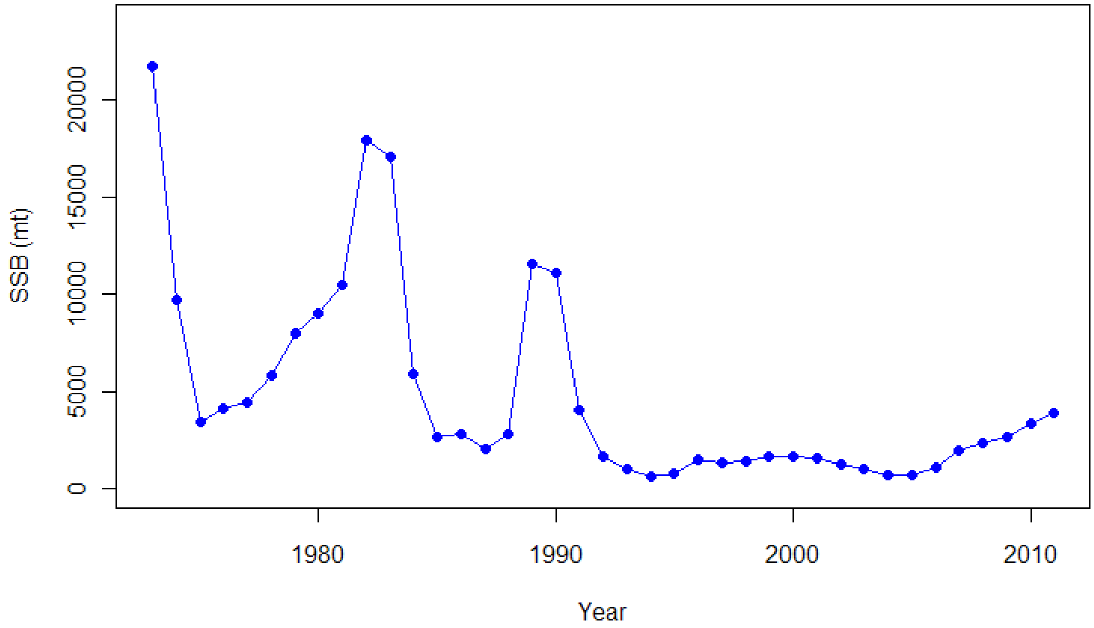


Figure B92. Comparison of estimates of Southern New England Mid-Atlantic yellowtail age 1 recruitment (000's) from ADAPT-VPA Model 20, ASAP base Model 26 and ASAP Model 28 with Cold Pool Indices



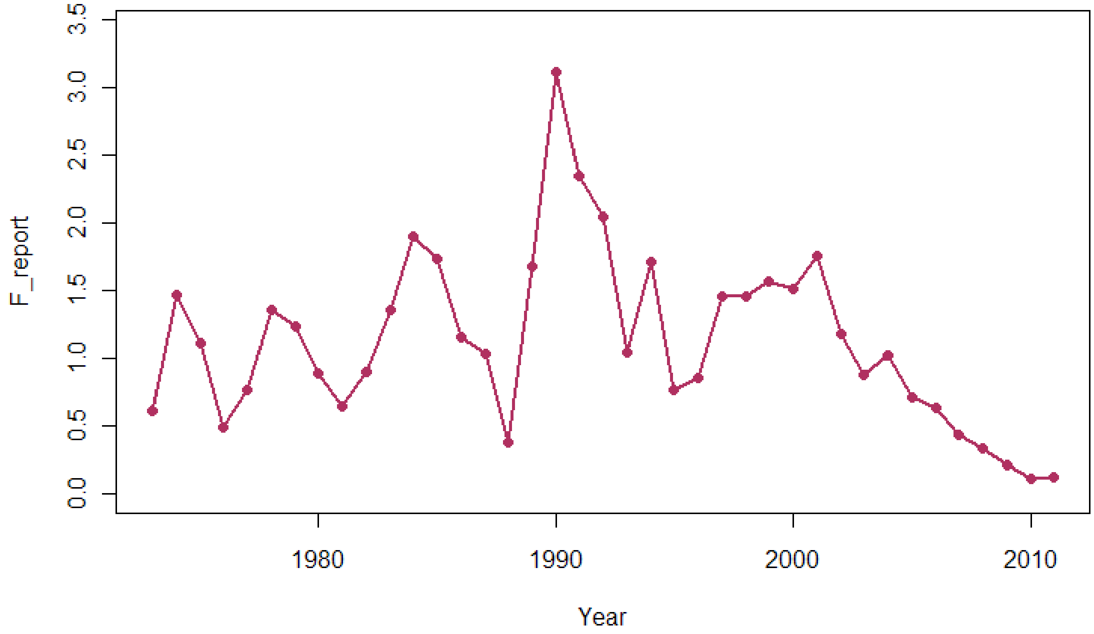


Figure B93. ASAP base Model 26 estimates of Southern New England Mid-Atlantic yellowtail flounder spawning stock biomass in mt (top) and average fishing mortality (bottom; $F_{4\text{-}5}$ = F report)

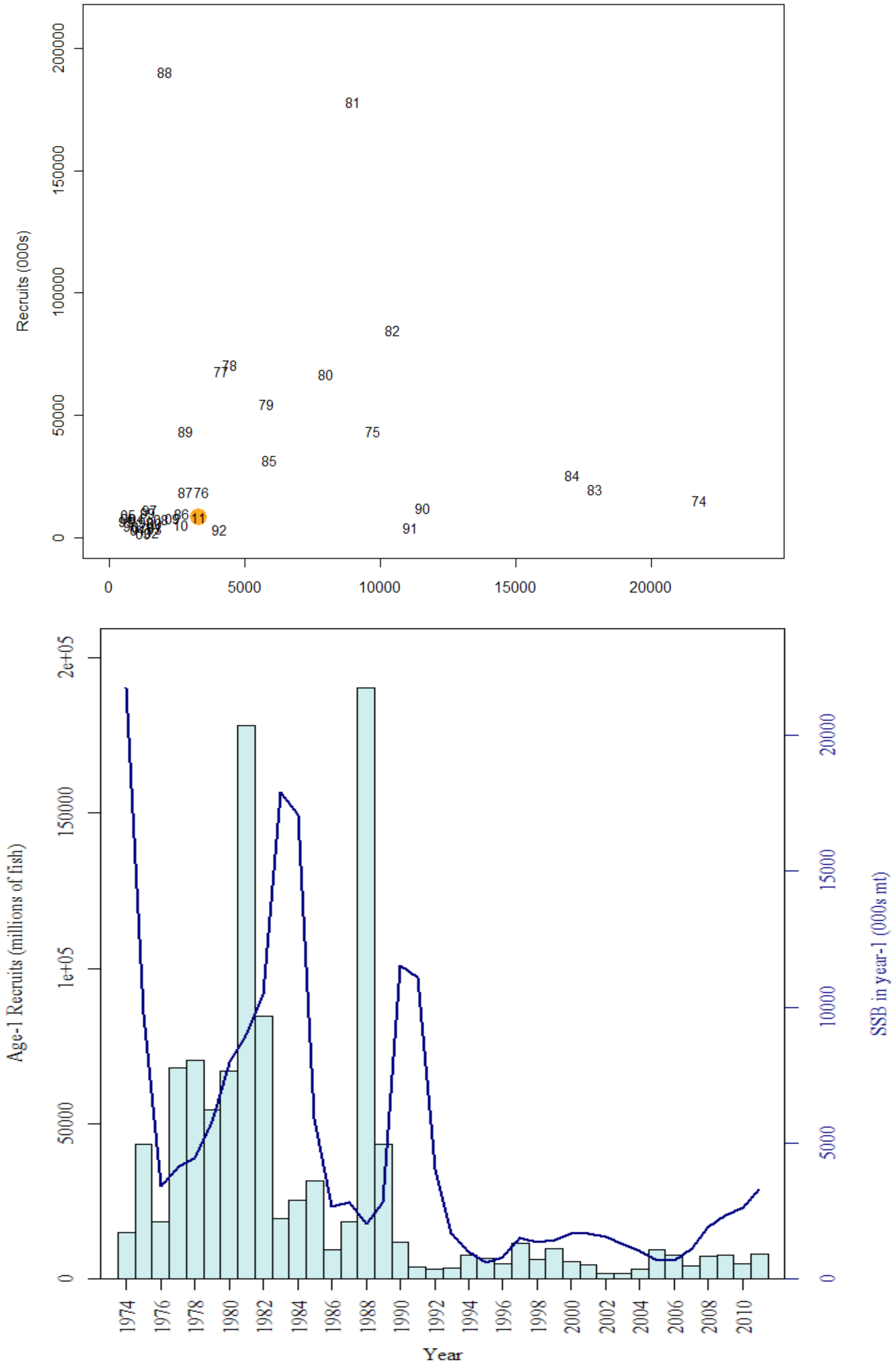


Figure B94. Top: scatter plot of ASAP model 26 estimates of Southern New England-Mid Atlantic yellowtail flounder spawning stock biomass in mt versus recruitment at age 1 (000's) . The symbol for each observation is the last two digits of the year (e.g. 88 indicated age 1 estimates of the 1987 year class). The most recent recruitment estimate is highlighted in an orange circle. Bottom: ASAP base Model 26 time series of SSB (blue line) and age1 recruitment (bars).

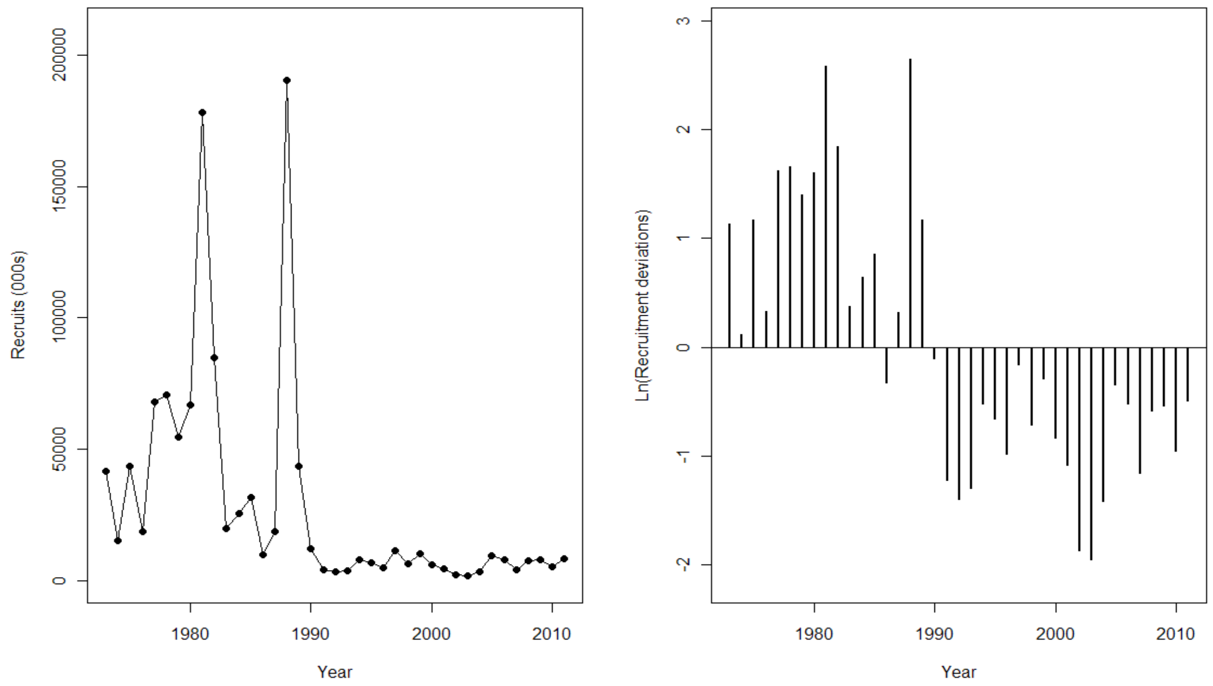


Figure B95. ASAP base Model 26 estimated Southern New England Mid-Atlantic yellowtail flounder recruitment residuals from the geometric mean.

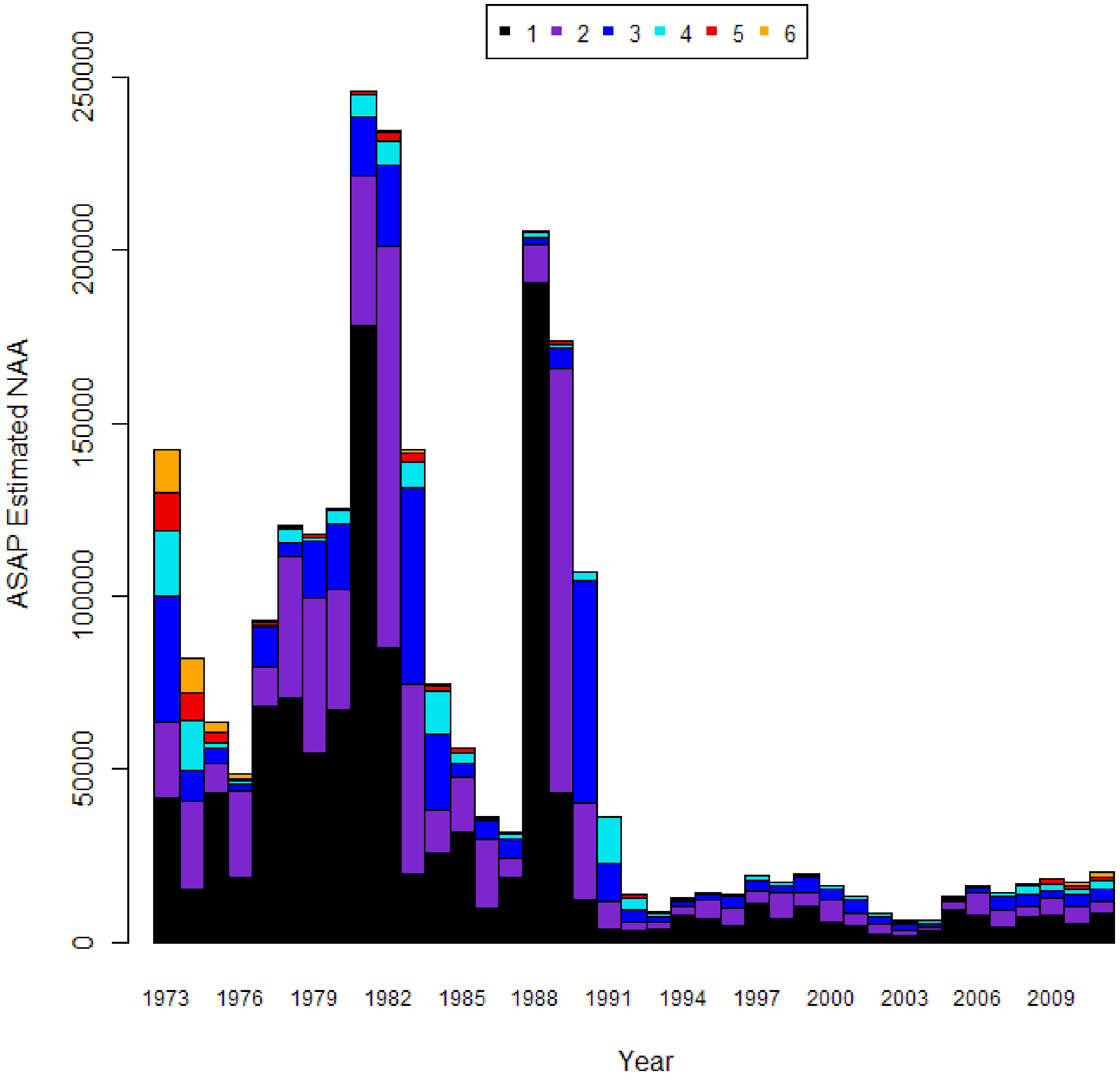


Figure B96. ASAP base Model 26 model estimates of Southern New England Mid-Atlantic yellowtail flounder numbers at age in 000's of fish

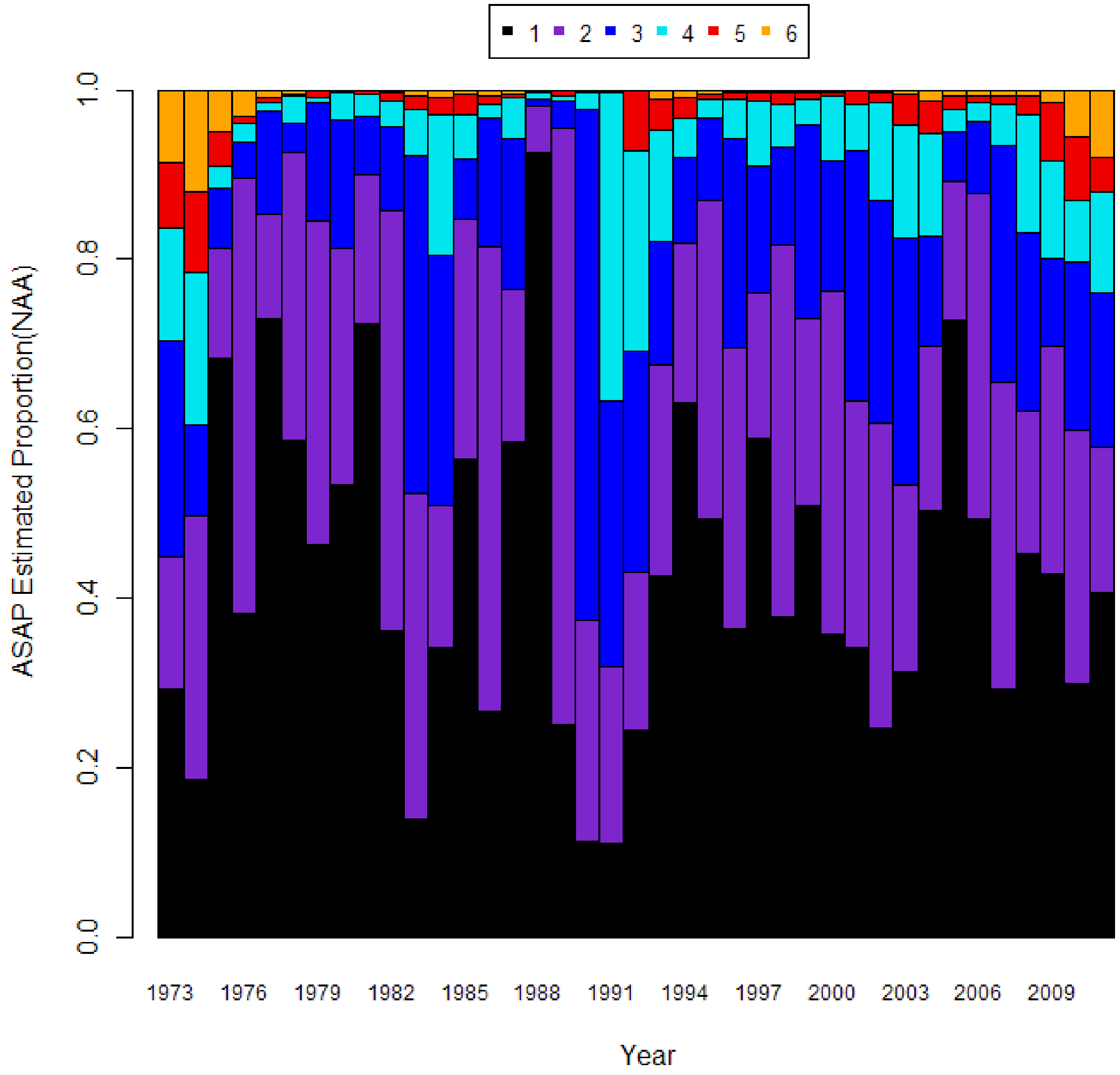


Figure B97. ASAP base Model 26 model estimates of Southern New England Mid-Atlantic yellowtail flounder numbers at age expressed as proportions

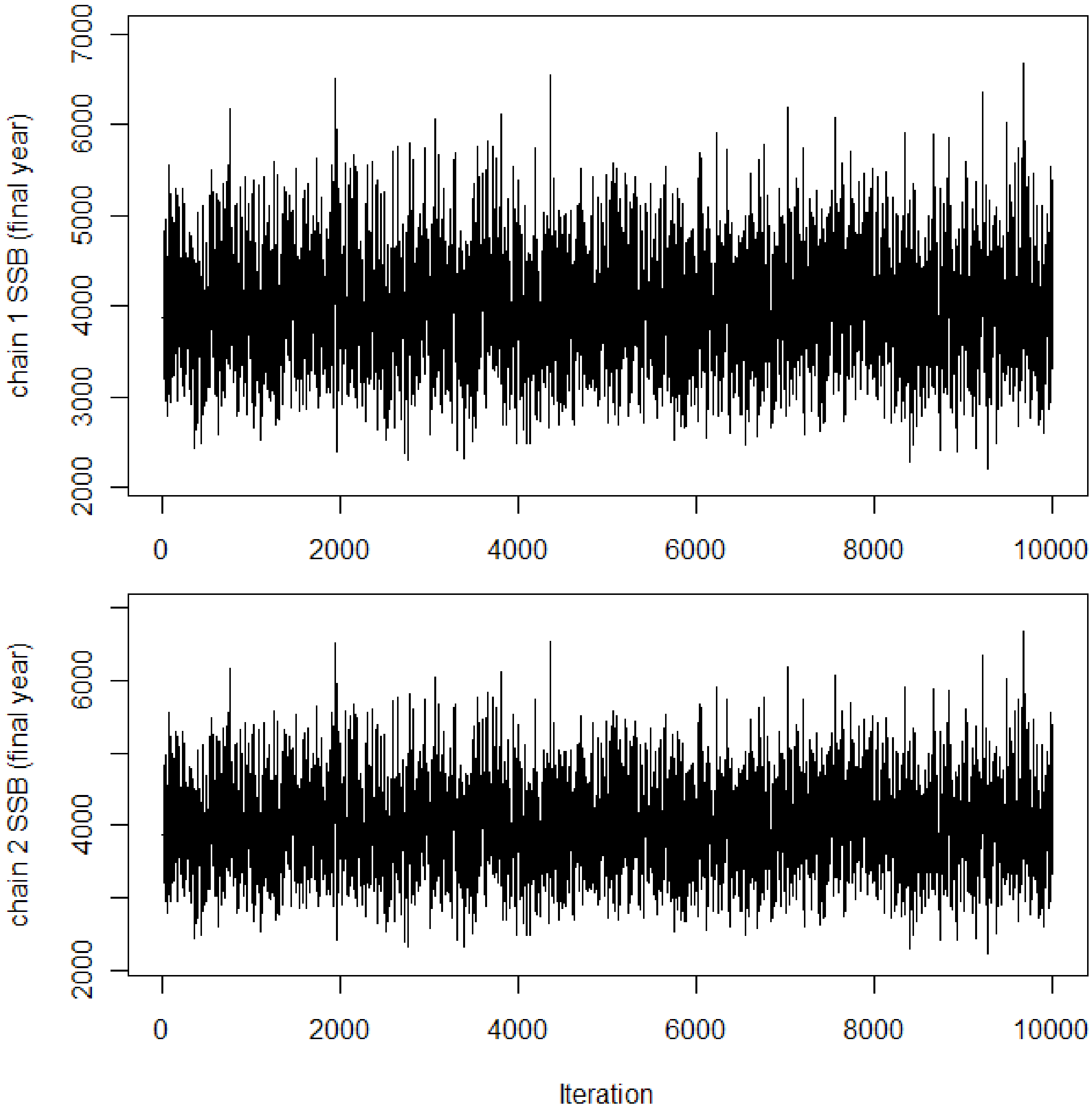


Figure B98. Trace MCMC chains for Southern New England mid-Atlantic yellowtail SSB2011, showing good mixing (ASAP base Model 26). Each chain had initial length of 10,000 and was thinned at a rate if one out of every 200th with remaining chain = 500 (above)

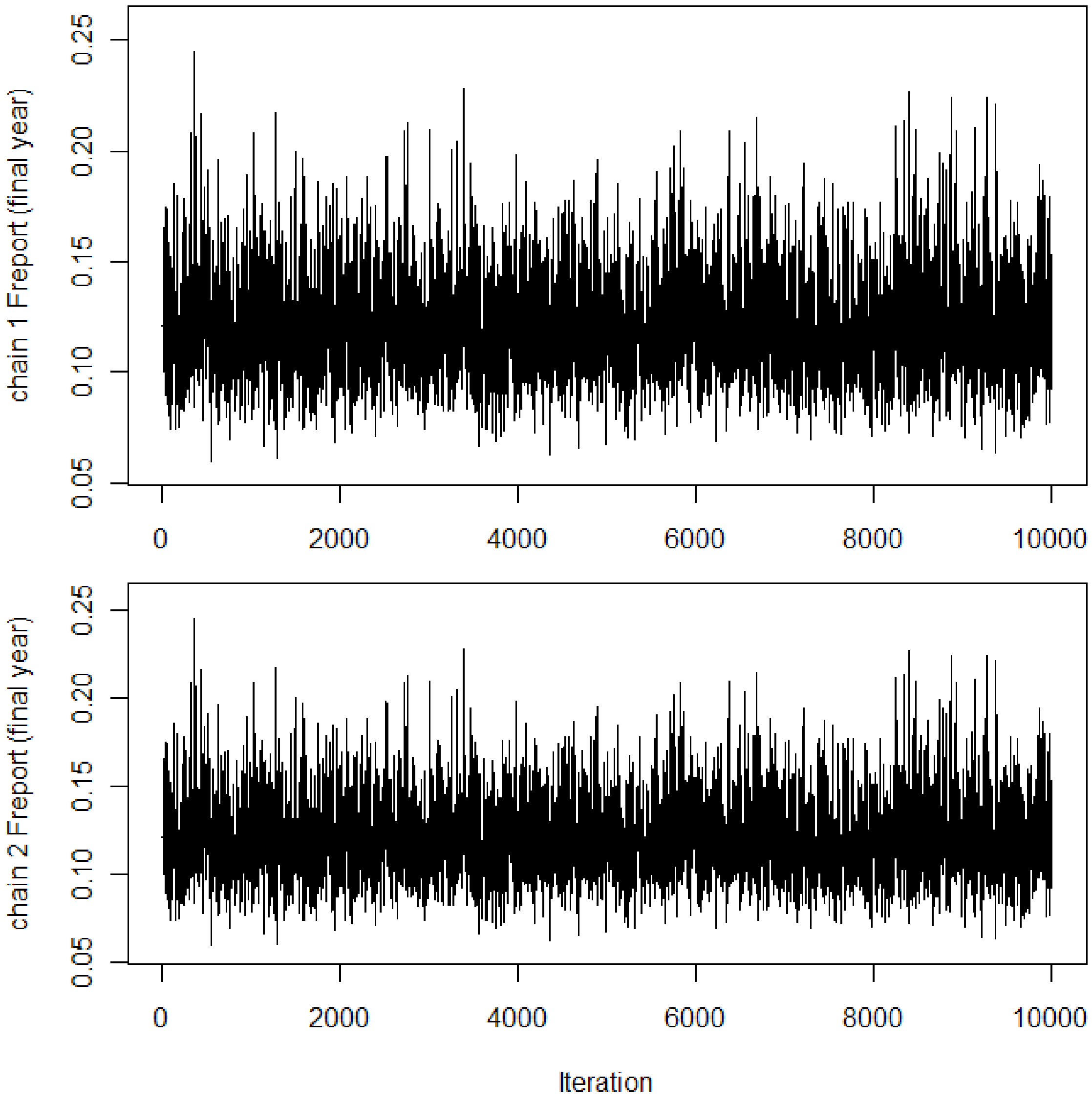
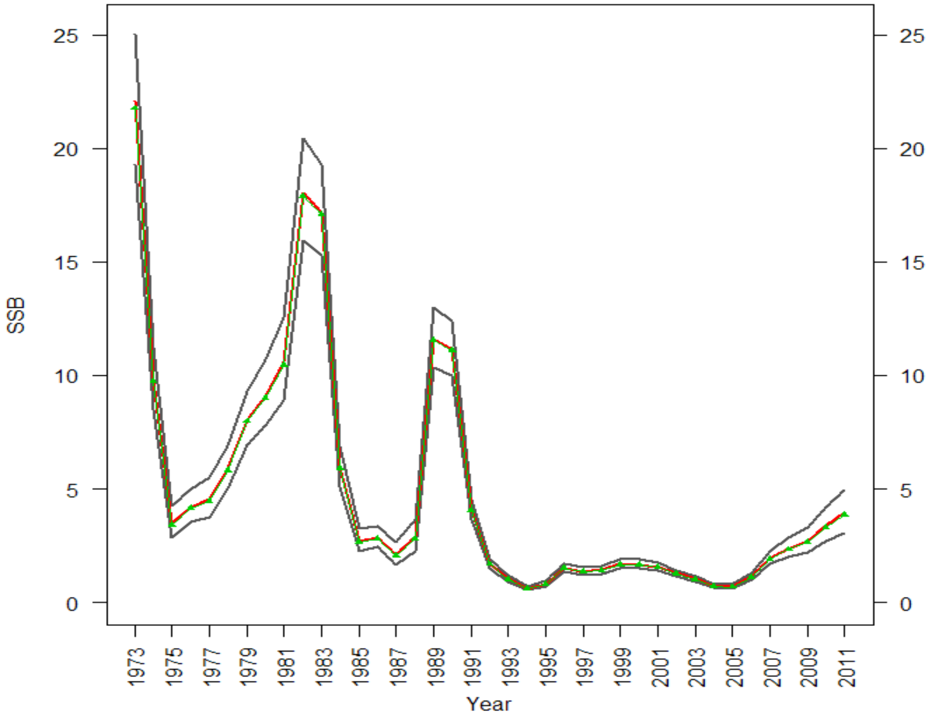


Figure B99. Trace MCMC chains for Southern New England mid-Atlantic yellowtail F 2011, showing good mixing (ASAP base Model 26). Each chain had initial length of 10,000 and was thinned at a rate if one out of every 200th with remaining chain = 500 (above)



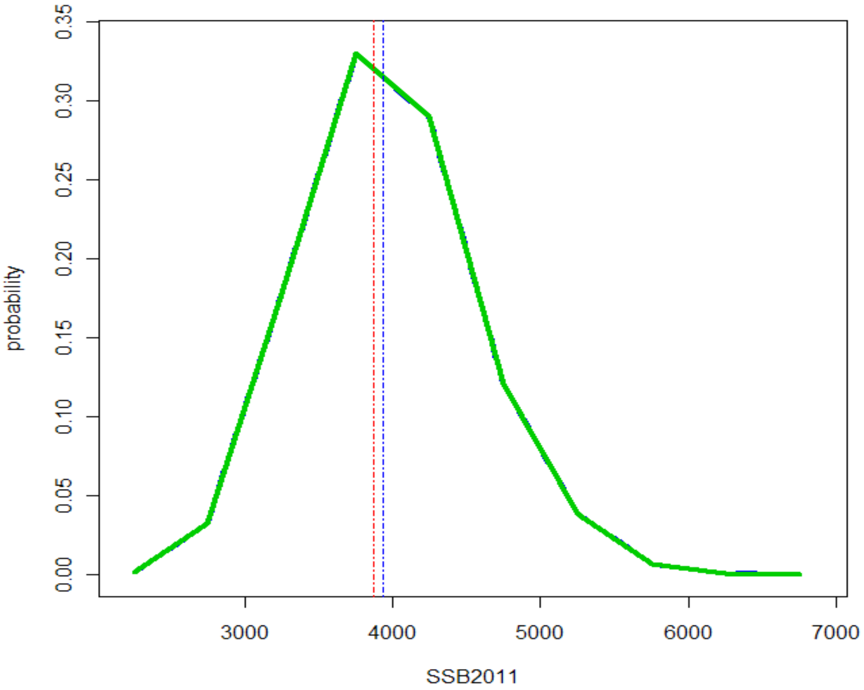


Figure B100. Top: 90% probability interval for Southern New England Mid-Atlantic yellowtail flounder spawning stock biomass from ASAP base Model 26. The median is value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model is shown in the thin green line with filled triangles. Bottom: MCMC distribution of spawning stock biomass in 2011, ASAP point estimate (red line) and median estimate (blue line) from the MCMC distribution indicated by the horizontal lines.

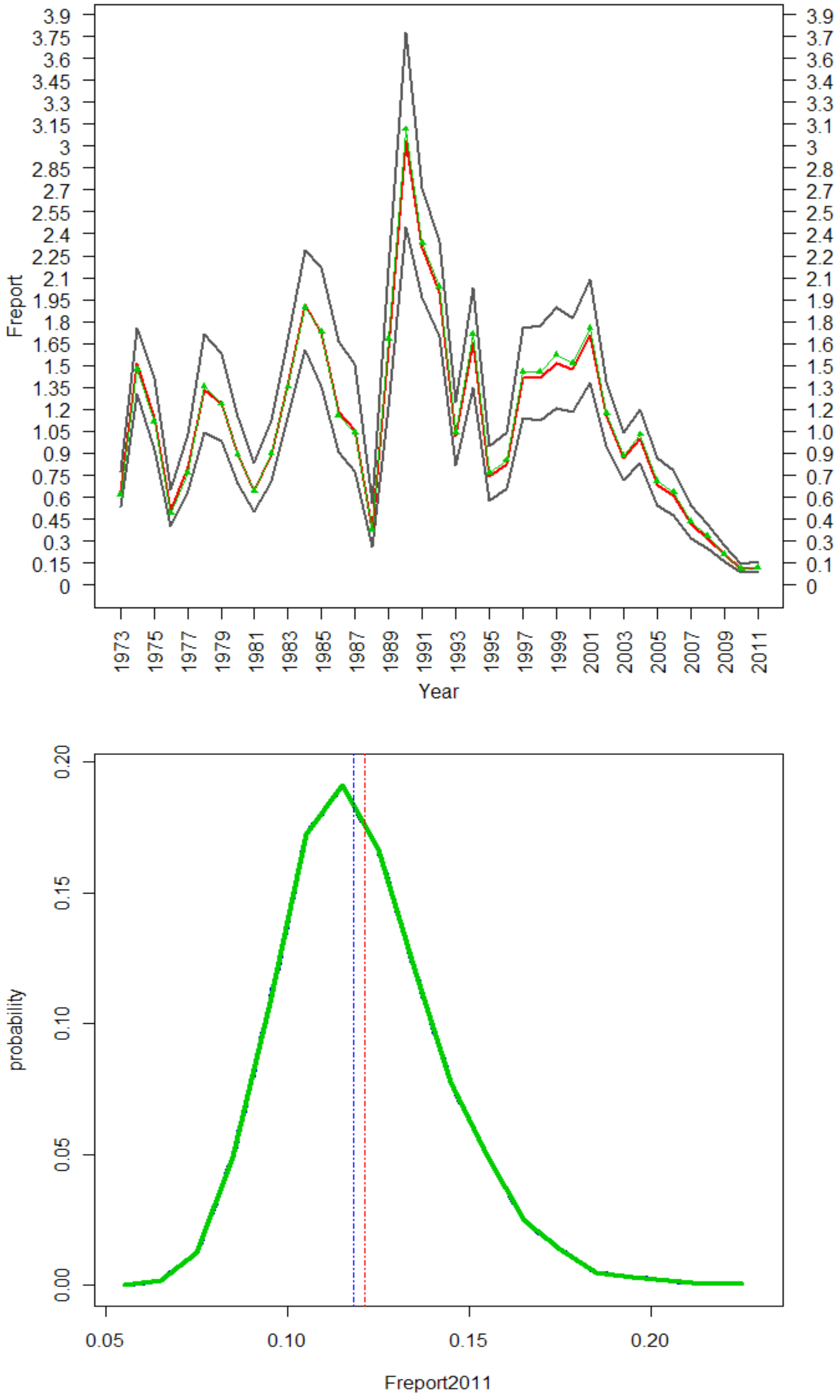


Figure B101. Top: 90% probability interval for Southern New England Mid-Atlantic yellowtail flounder average fishing mortality from ages 4 to 5 (avg. $F_{4\text{-}5}$) from ASAP base Model 26. The median is value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the base model is shown in the thin green line with filled triangles. Bottom: MCMC distribution of average fishing mortality from ($F_{4\text{-}5}$) in 2011, ASAP point estimate (red line) and median estimate (blue line) indicated by the horizontal line.

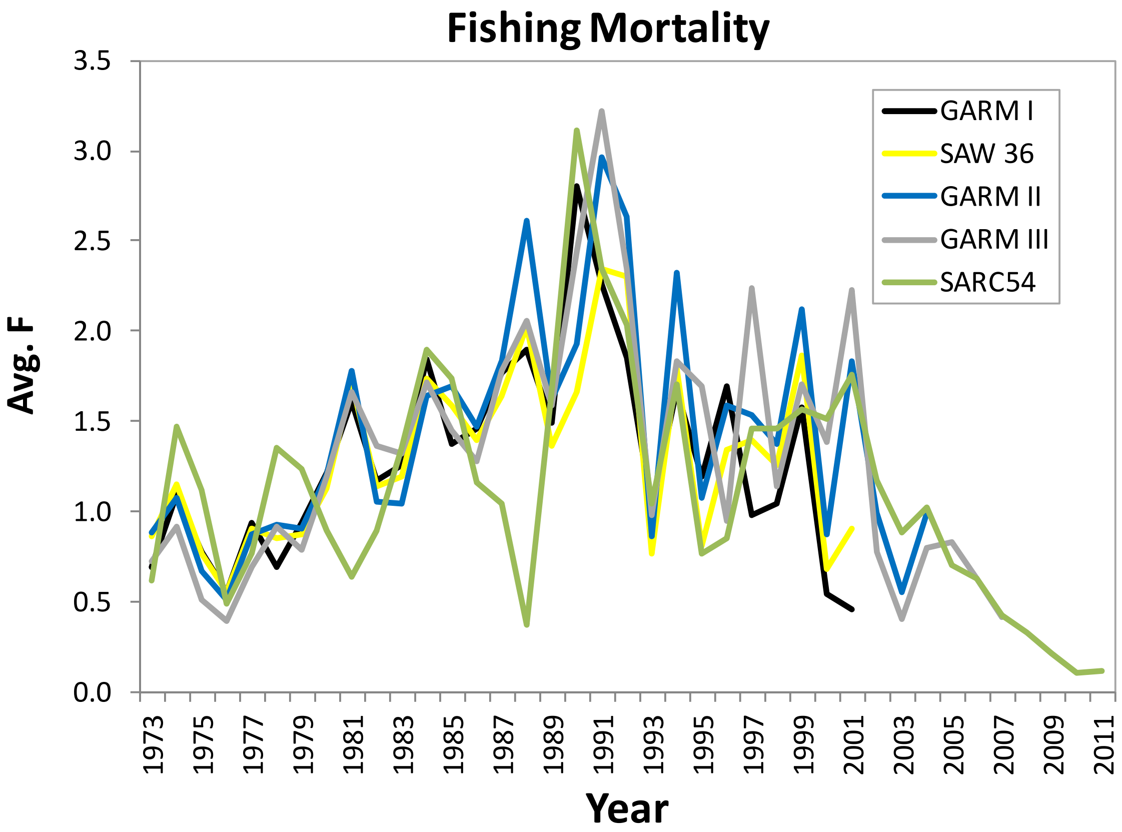


Figure B102. Comparison of average fishing mortality from previous Southern New England mid-Atlantic yellowtail stock assessments including estimates from the 2012 ASAP base Model 26 model assessment updates.

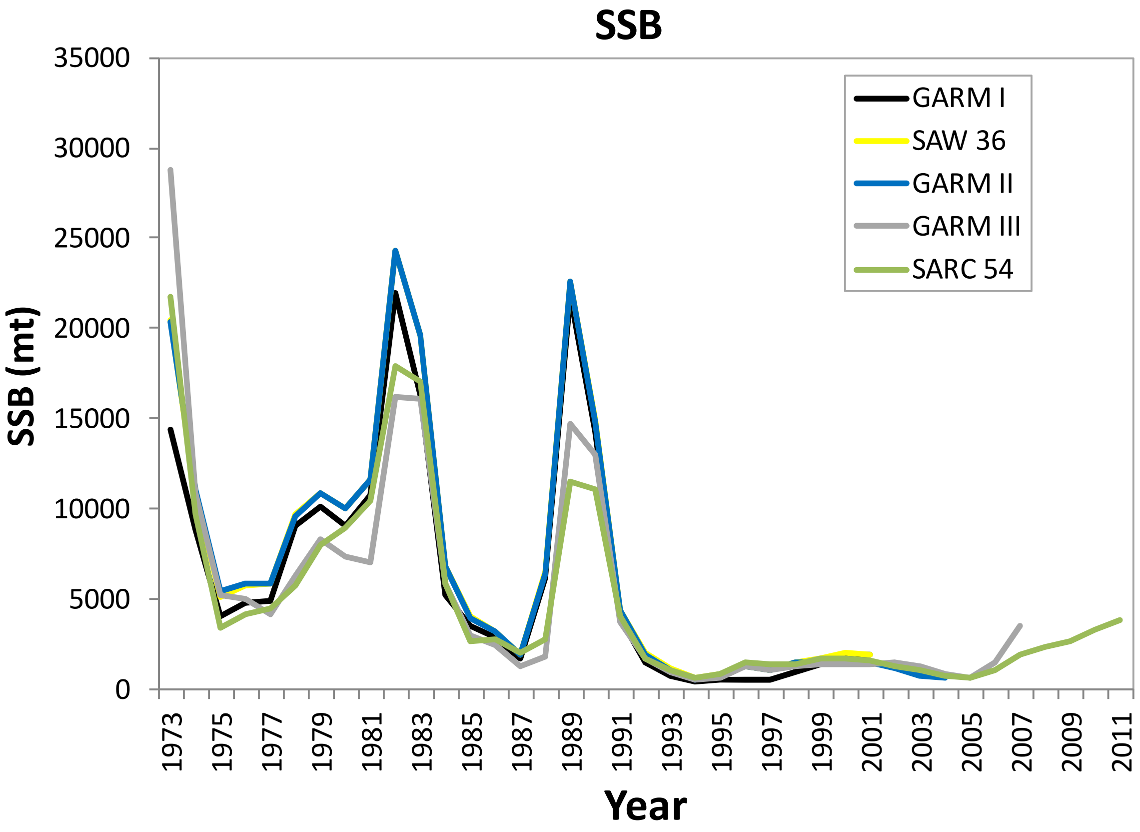


Figure B103. Comparison of spawning stock biomass (mt) from previous Southern New England mid-Atlantic yellowtail stock assessments including estimates from the 2012 ASAP base Model 26 model assessment updates.

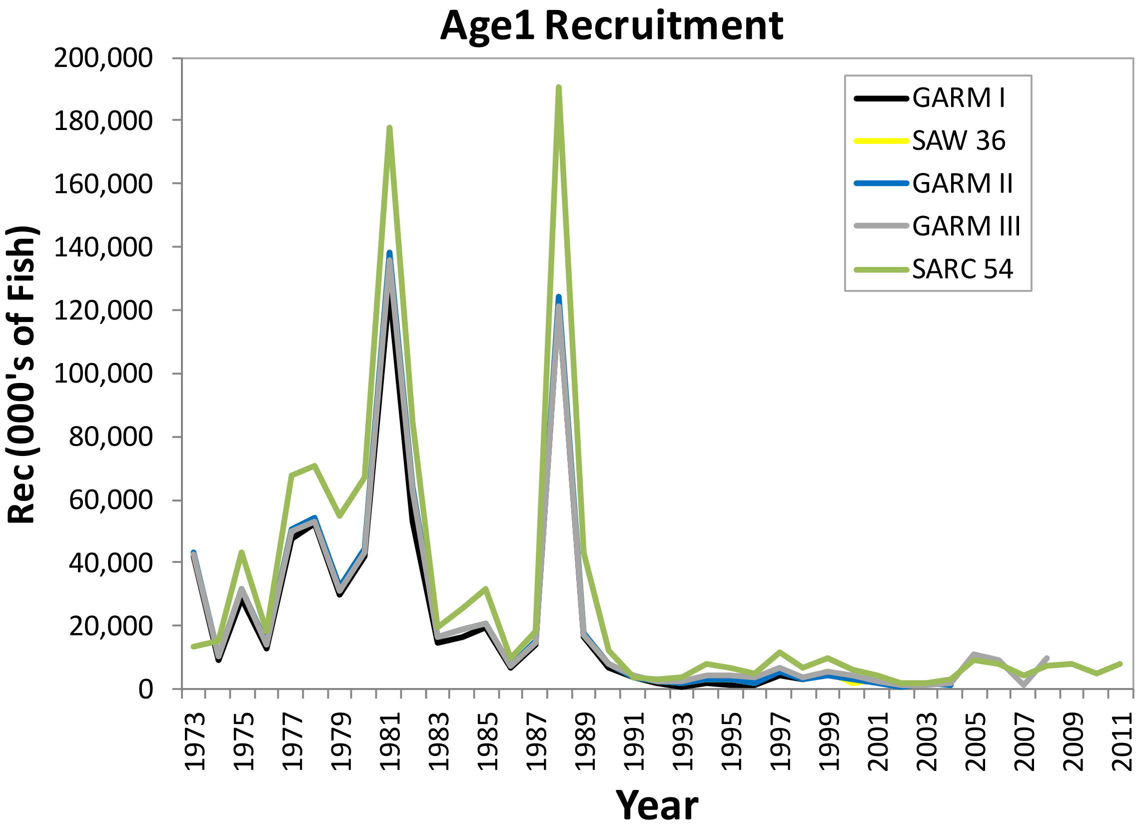


Figure B104. Comparison of age 1 recruitment from previous Southern New England mid-Atlantic yellowtail stock assessments including estimates from the 2012 ASAP base Model 26 model assessment updates.

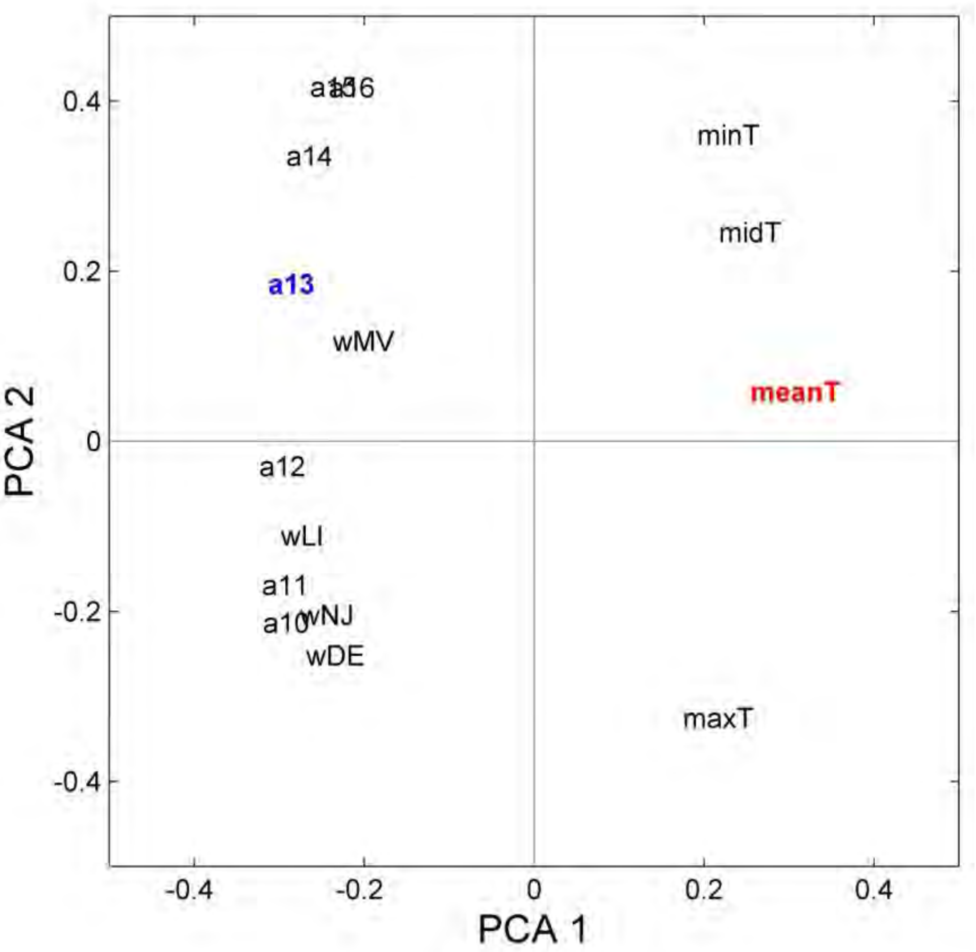


Figure B105. Ordination of 15 cold-pool variables resulting from Principal Components Analysis (PCA). Variables included are: mean (meanT), maximum (maxT), and minimum (minT) temperature of area occupied by juvenile yellowtail flounder; width of temperatures <12°C along four cross-shelf transects: south of Martha's Vineyard (wMV), south of Long Island (wLI), east of New Jersey (wNJ), and east of Delaware Bay (wDB); bottom temperature anomaly along the mid-line of the cold-pool (midT); area of bottom water on the Mid-Atlantic Bight shelf <10 °C (a10), <11 °C (a11), <12 °C (a12), <13 °C (a13), <14 °C (a14), <15 °C (a15), and <16 °C (a16).

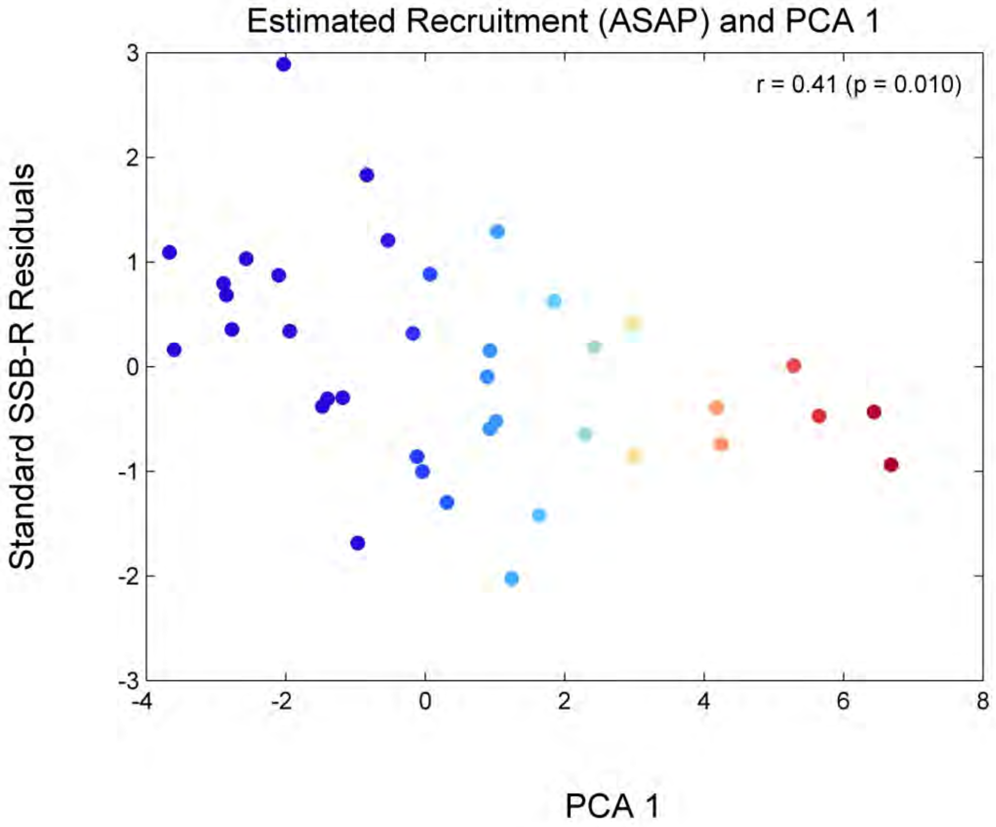


Figure B106. Relationship between residuals from the standard Beverton Holt model and the Cold Pool Index (PCA 1). Recruitment is above predicted when the cold pool is large and cold (negative PCA 1). Recruitment is below predicted when the cold pool is small and warm (positive PCA 1).

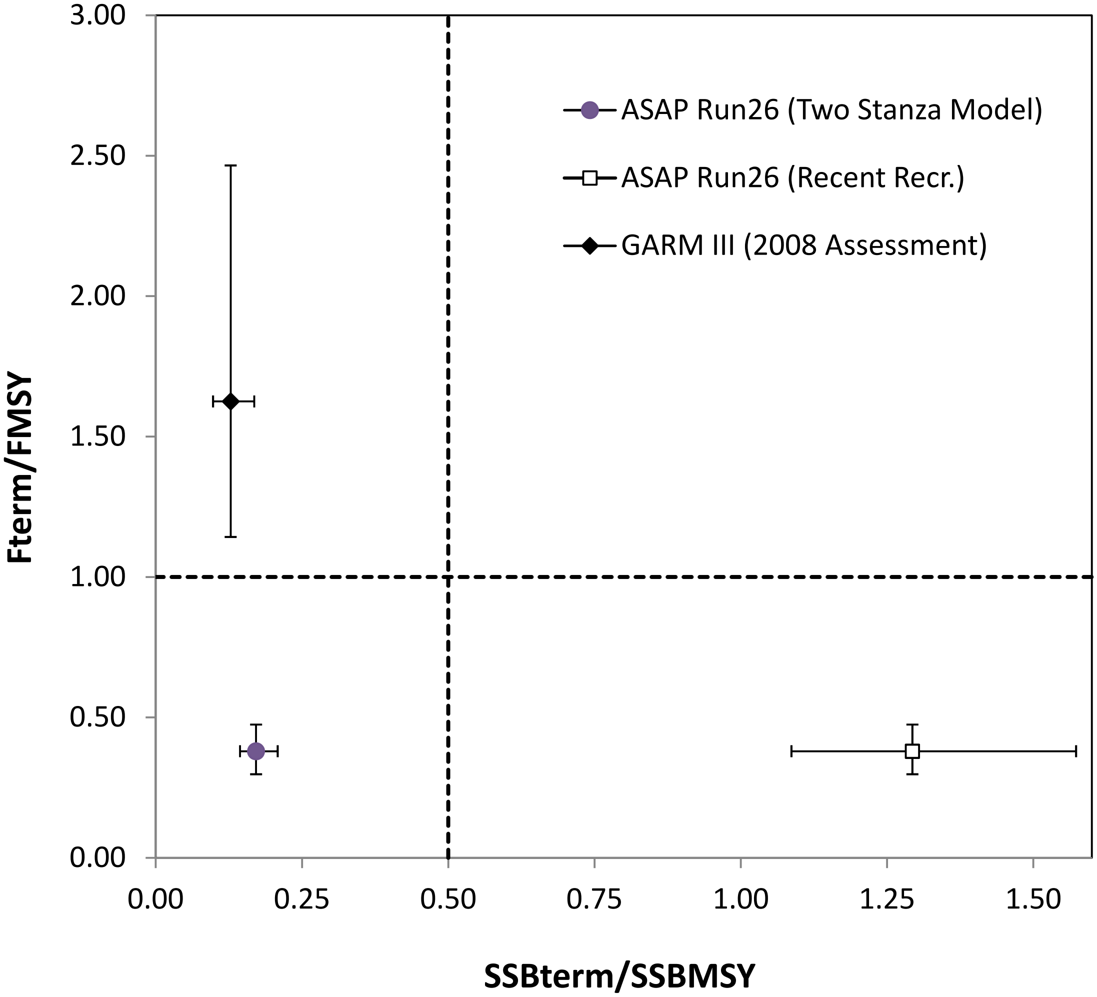


Figure B107. Status of 2011 fishing mortality and spawning stock biomass (SSB) of Southern New England Mid-Atlantic yellowtail flounder relative to F_{MSY} proxy ($F_{40\%}$) and SSB_{MSY}.

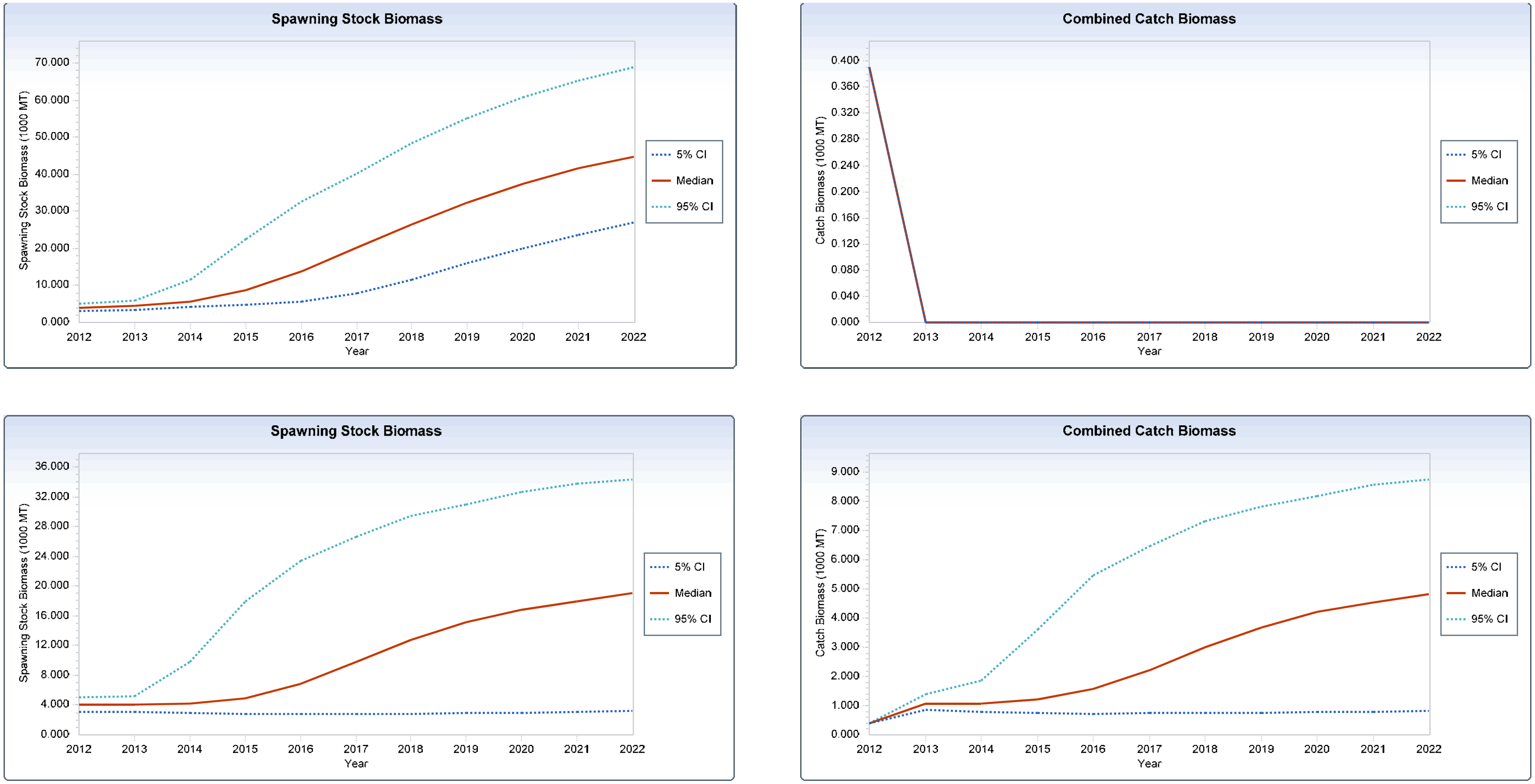


Figure B108. Short-term projections for Southern New England-Mid Atlantic yellowtail flounder in terms of fishery yields (catch, Right) and spawning stock biomass (SSB, Left) assuming the two stanza recruitment model (i.e. all recruitment series from 1973-2010) under F_0 (Top) and F_{MSY} (Bottom). Median estimates are shown (red) along with the 90% confidence interval.

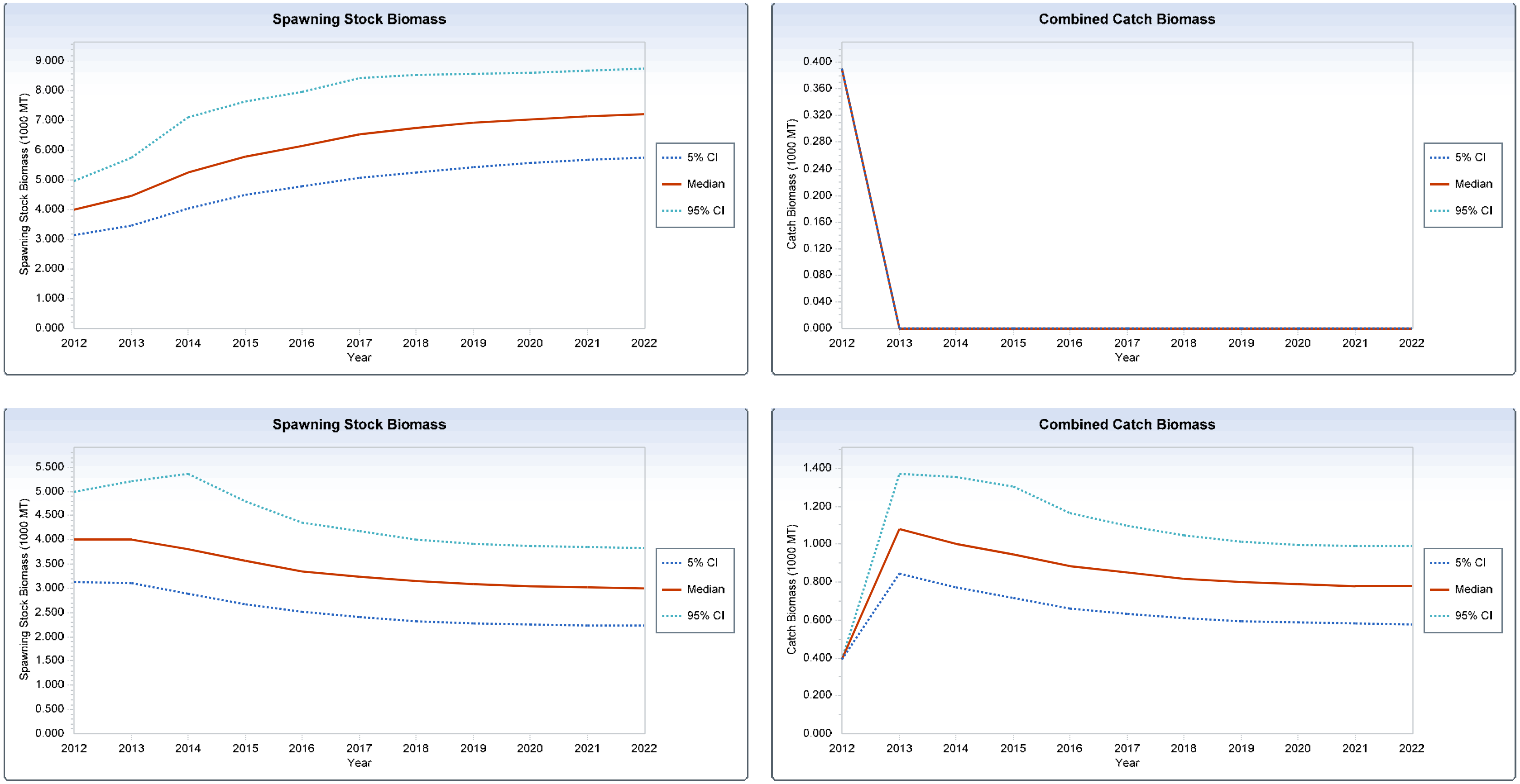


Figure B109**.** Short-term projections for Southern New England-Mid Atlantic yellowtail flounder in terms of fishery yields (catch, Right) and spawning stock biomass (SSB, Left) assuming recent recruitment conditions (i.e. recruitment series from 1990-2010) under F_0 (Top) and F_{MSY} (Bottom). Median estimates are shown (Red) along with the 90% confidence interval.

Appendix 1

SNE/MA Yellowtail flounder Industry Meeting Participants: February 27th, 2012

Name	Affiliation
Larry Alade	NEFSC
Adam Barkley	SMAST
Gene Bergson	Harbor Blue Seafood
Jeff Bolton	Atlantic Capes Fisheries
Jason Boucher	SMAST
Katie Burchard	NEFSC
Steve Cadrin	SMAST
Richie Canastra	Buyers and Sellers Exchange NE
Peter Cura	F/V Fisherman
Dan Eilertsen	Nordic Inc
Ronnie Enoksen	Nordic Fisheries
Dan Georgianna	SMAST
Brian Gervalis	NEFSC
Dan Goethel	SMAST
Eric Hansen	F/V Endeavor
John Haran	Northeast Fisheries Sector 13
John Hoey	NEFSC
Robert Johnston	NEFSC
Jim Kendall	New Bedford Seafood Consultants
Chris Legault	NEFSC
Dave Martins	SMAST
Linda McCann	Northeast Fisheries Sector 7 & 8
Chris Medeiros	Quinn Fisheries
Cate O'Keefe	SMAST
Peg Parker	Commercial Fisheries Research Foundation
Ted Platz	Ocean Harvest
Charlie Quinn	Quinn Fisheries
Judith Rosellon	SMAST
Daniel Salerno	Northeast Fisheries Sector 5
Ron Smolowitz	Fisheries Survival Fund
Kevin Stokesbury	SMAST
Mark Terceiro	NEFSC
Doug Zemeckis	SMAST

54th Northeast Regional Stock Assessment Workshop
Southern New England/Mid Atlantic Yellowtail Flounder
Pre-Assessment Meeting with Fishermen

Monday February 27, 2012 10:00am
School for Marine Science & Technology (SMAST)
200 Mill Road
Fairhaven, MA
Room 158

Meeting Agenda:

- Welcome & Introductions
- Review of the 2008 stock assessment
- Growth, maturity and natural mortality
- Preliminary fishery data
- Preliminary survey data
- SMAST Industry-Based Survey
- Discard mortality
- Stock assessment models
- Discussion

Stock assessment scientists will review the most recent stock assessment of southern New England/Mid Atlantic yellowtail flounder, present updated information from the fishery and surveys, and summarize the plan to update the stock assessment this spring.

Steve Cadrin – School for Marine Science and Technology:
Opening introductions
Meeting agenda

Larry Alade – Northeast Fisheries Science Center:
Review of SAW 54 Terms of Reference:

1. estimate landings/discards
2. present survey data including vessel change
3. stock definition
4. estimate fishing mortality, recruitment, total and spawning stock biomass
5. describe causes of variability in annual recruitment
6. update Biological Reference Points
7. evaluate stock status with models
8. short-term projections and risk analysis

Timeline:

Data meeting: April 2 – 4, 2012
Model meeting: April 30 – May 4, 2012
SAW SARC 54 Review: June 5 – 9, 2012

Stock Status from GARM III (2008):

- Age 6+ VPA model formulation
- Natural mortality M=0.2
- Assumed constant maturity at age
- Model years included 1973-2007
- F_{MSY} proxy = $F_{40\%}$
- Stock status = overfished (SSB = 3,508) and overfishing occurring (F = 0.4129)

SAW 54 Updates/Inclusions:

- Re-evaluate all data sources and any data revisions
- Surveys: NEFSC Fall 1963-2010; NEFSC Spring 1968-2011; NEFSC Winter 1992-2007
- Survey calibrations applied to NEFSC Spring 2009-2011 and NEFSC Fall 2009-2010
- Revise landings and discards data based on database change in 2007
- Examine stratified discard estimate by area for scallop fishery, including analysis of observer coverage levels by area
- Include catch from scallop trawl vessels
- Include 2010 At-Sea Monitoring data
- Examine the discard mortality assumption (currently = 100%)
- Examine biological influences on recruitment – cold water pool indices
- Examine growth, maturity and stock structure assumptions

-

Presentation of Preliminary Data for SAW 54:

- Fishery data (landings and discards)
- Effort data
- Survey data
- Survey distributions

Discussion of presentation:

- Industry has seen larger fish than observed in the surveys, are any of the methods in the survey flawed or biased?
- There has been a strong decline in stock level since the early 1970s
- There has been two decades of poor recruitment
- Why is the level of discards in the scallop fishery so much greater than landings?
- Fishery has not been landing yellowtail and majority of catch is discarded
- The fishery has largely been a discard fishery for the last 6-8 years due to trip limits
- Industry has observed larger fish in the Northeast (i.e., Georges Bank) and small fish in the Southwest (i.e., Mid-Atlantic)

<u>Katie Burchard – Northeast Cooperative Research Program:</u>

Utility of electronic logbook data for assessment

- NOAA Study Fleet coverage in Southern New England/Mid-Atlantic stock area 2007-2011
- More observed effort in Study Fleet in Statistical Areas 537,539,611 than observer coverage
- Study Fleet data can be used to verify and complement observer data
  - Self-reported data is accurate compared to observer data
  - Can be used as an additional data source in the assessment
  - Study Fleet vessel level data can be more accurate due to consistency in reporting by captains
  - Study Fleet data is less random than observer data

Discussion of presentation:

- Possibly include any scallop dredge Study Fleet data to verify discard data
- Industry wants to push the use of Study Fleet data in the assessment process due to large investment in data collection

- Long-term plan for Study Fleet would include a reduction of observer coverage and increase in level of self-collected data
- Important to note that industry-collected data can be used to verify observer data

<u>Rob Johnston – Northeast Fisheries Science Center:</u>
Comparison of Sweep Type for Survey Calibration

- Albatross replaced with Bigelow in 2007/2008
- Limited time for vessel calibrations
- Decision to change entire survey system with new vessel
    - New net
    - Potential use of 2 different sweeps in different areas
    - Timeline for testing too short
    - Result in broken time series
    - Less efficient roller sweep chosen for survey purposes

Studies conducted to examine sweep efficiency:

- Twin trawl with cookie sweep on one side and roller sweep on the other, separated by a box in the middle
- Paired trawl study with two vessels, one towing a cookie sweep and the other with roller sweep
- Goal: evaluate efficiency, size selectivity, fill in gaps in biological sampling
- Results:
    - No significant differences for catchability by season
    - No differences in size selectivity
    - Twin trawl experiment:
        - Cookie sweep and rock hopper sweep compared closely
        - Cookie sweep significantly more efficient, however with a catch rate approximated at 1.2 : 1
    - Paired trawl experiment:
        - Cookie sweep significantly more efficient
        - Result very different from twin trawl
        - Cookie sweep efficiency approximated at 2 : 1 over rock hopper sweep
        - Unknown vessel effects may explain results

-

Discussion of presentation:

- Was there ever a direct comparison between the Albatross and Bigelow with all of the parameters identical, then varied (including tow time, sweep choice, tow speed)?
- Many calibration tows were conducted, did not directly compare catch from Albatross with 30 minute tow to Bigelow with 20 minute tow
- Tow time has a strong influence on catch – 30 (Albatross) vs. 20 (Bigelow) minutes is a major change and could have further reduced the efficiency of the rock hopper sweep due to the herding behavior of flounder
- Twin trawl comparisons do not account for herding behavior. It is likely that there was a significant amount of crossover behavior from the fish and the results that show similar efficiency may not be accurate.
- The pair trawl experiment results showed that the cookie sweep was approximately 2 times more efficient than the rock hopper sweep. Vessel effect alone does not adequately explain the results.
- Trouser trawl experiments have shown similar bias in efficiency estimates as a twin trawl due to the herding behavior and net crossover.
- The survey sweep (rock hopper sweep) should be compared with the NEAMAP survey vessel, F/V Darana R.

<u>Adam Barkley – School for Marine Science and Technology:</u>

Yellowtail Flounder Industry-Based Survey

- Rhode Island DEM collaborated in an Industry-Based Survey of yellowtail flounder in Southern New England, including the Nantucket Lightship Closed Area in 2003-2005
- Results from the 2003-2005 IBS were used in the GARM III SNE/MA yellowtail assessement
- Results suggested no difference in abundance or biomass inside vs. outside of the Nantucket Lightship area, and less than 3% of the stock inside the closed area
- SMAST replicated the survey in the Fall of 2011 to determine if there have been changes in the spatial distribution of the stock and utilization of the closed area
- SMAST survey used same net and vessels
- Results from the survey showed more catch outside the closed area than inside
- 57% of fish caught inside closed area were sub-legal size
- Exploitable biomass was estimated at 1,042mt
- Results showed a change in % biomass in open vs. closed area since the 2005 survey

-

Discussion of presentation:

- Could the closed area be less productive due to the fallow bottom? Does continuous towing increase productivity due to increased food availability, reduced predators?
- Very high abundance of skates and dogfish in Southern New England could be causing increased natural mortality of flounder.

The assessment could examine consumption rates of elasmobranches

- Clam boat effort has increased in Southern New England in the last decade and the effects of clamming on the seafloor could impact food availability.
- Are we sure that the current stock boundaries are correct? Historically there were clear differences in the fish in the eastern vs. western parts of the Nantucket Lightship Area, and extending north into the channel.
- Were the survey methods from 2003-2005 identical to the 2011 survey?
    - Tow time varied between survey: 2003-2005 survey focused on tow distance;

- 2011 survey set a tow time of 20 minutes

<u>Adam Barkley – School for Marine Science and Technology:</u>
Discard Mortality Estimation

- Reflex Action Mortality Predictor (RAMP) was tested on stressed and unstressed yellowtail flounder
- Process for testing included commercial capture, acclimation in test tank, branding for identification, exposure to stress through towing in trawl or held as a control in cages
- 7 RAMP tests conducted
- Factors affecting mortality include air exposure, tow time and stress from being towed
- Method was applied to yellowtail flounder caught in scallop dredges on Georges Bank, and trawl vessels in Southern New England
- Results show a discard mortality level of 82% for dredge-caught flounder and 81% for trawl-caught flounder

Discussion of presentation:

- This technique could be applied to skates in the gillnet fishery to examine discard mortality.

Appendix 2

SNE/MA Yellowtail flounder Data Meeting Participants: April 2-4, 2012

Name	Organization
Larry Alade	NEFSC
Adam Barkley	SMAST
Katie Burchard	NEFSC
Steve Cadrin	SMAST
Kiersten Curti	NEFSC
Greg DeCelles	SMAST
Brian Gervelis	NEFSC
Dan Goethel	SMAST
Jon Hare	NEFSC
Dvora Hart	NEFSC
Anne Hawkins	NEFMC
John Hoey	NEFSC
Chris Legault	NEFSC
Richard McBride	NEFSC
David McElroy	NEFSC
Murali Mood	NEFSC
Tom Nies	NEFMC
Paul Nitschke	NEFSC
Loretta O'Brien	NEFSC
Megan O'Conner	NEFSC
Cate O'Keefe	SMAST
Mike Palmer	NEFSC
Greg Power	NERO
Dave Richardson	NEFSC
Eric Robillard	NEFSC
Gary Shepherd	NEFSC
Ron Smolowitz	Coonamessett Farm
Katherine Sosebee	NEFSC
Mark Terceiro	NEFSC
Michele Traver	NEFSC
Susan Wigley	NEFSC
Tony Wood	NEFSC

SNE Yellowtail Data Meeting Notes: April 2-4, 2012

WG Consensus

- No evidence for change in stock structure for this assessment
- Adopt the proposed base (time series) and alternative (5-year moving average) as options for observed maturity proportions
- Larval index may be useful as SSB index for model calibration
- Use the NEFSC Survey-based L-W relationship for 1994 and later years
- Adopt an alternative lifetime M = 0.3 and to scale the Lorenzen curve to age 9 with spring, fall and commercial ages pooled. This is likely to be the preferred alternative with a sensitivity of constant 0.2 and 0.3 across all ages. Given that natural mortality estimates range from 0.3-0.5 and this stock has experienced high fishing mortality over the time series, WG consensus is that a lifetime M of 0.3 is reasonable.
- Information on the cold pool index should be incorporated into the discussion of the vulnerability TOR.
- Given that 85% seems to be a lower bound on the RAMP-based discard mortality and some mortality likely occurs post-release, the WG agreed to use a value of 90% for commercial fishery discard mortality in the assessment.

WG Research Recommendations

- Consider using fine-level stratification to develop discard estimates for scallop rotational areas, especially the Nantucket Lightship Area (NLS), for 2000 and later years.
- Develop approaches (e.g., hindcast ratios) to develop discard estimates for fishery strata with no observer coverage
- Update the length-weight parameters used to convert commercial landings (in weight) into numbers of fish. This could be accomplished by expanding existing data collection programs (e.g., Cooperative Research, Industry Based Surveys, NEFSC port sampling) to collect individual fish weights while collecting length and age data. This research recommendation is applicable to numerous species/stocks in the northeast, not just SNE/MA yellowtail flounder.
- The work on the influence of the cold pool and associated environmental parameters on yellowtail population dynamics has not been fully developed, and merits further research.
- If the volume of commercial landings increases in the future, ensure that adequate samples of the landings are obtained for all market categories on at least a quarterly basis.

Daily NotesApril 2 morning

Stock structure

- Cadrin: Brown coined the term “Harvest stocks” – even if there is exchange between stocks, we need to manage separately if they respond differentially to harvest. It seems like recruitment dynamics are different among stocks; Phenotypic boundary likely driven by temperature; Boundary between SNE and GB appears to be "squishy" and dependent on stock size

- Hare: Summary: Current stock definitions are appropriate, but we need to begin considering the northward shift in distribution documented in Nye et al. Is this a consequence of a shift in distribution or a difference in productivity? Currently unable to disentangle these two hypotheses; Greater differences in growth/maturity among stock areas earlier in the time series compared to later in the time series; Two hypotheses: 1) growth conditions becoming more similar among stock areas, or 2) greater mixing among stock areas
- Loretta: Did Jon Hare consider temperature changes when looking at changes in growth? Jon Hare: not yet.
- Cadrin: Trying to recall Friedland paper: Friedland found different growth patterns between GB and SNE, but found that growth differences became less pronounced. Friedland inferred greater mixing among areas; Cadrin feels that paper confirms vagueness of GB/SNE boundary, not increased mixing
- Legault: Stratum 16 becoming more dominant in terms of proportion of YT total catch. But 16 is in closed area 2 --- so differences could be due to management as well
- Megan: There are distribution differences by age, but some truncation of age-structure

WG consensus: No evidence for change in stock structure for this assessment.

Maturity

- McBride: Not collecting age-1 fish. Not sure if reason is because age-1's are not selected by the survey, or because all age-1 are males. Larry thinks it is likely selectivity.
- Cadrin: Age-1's in the spring are very small; therefore, not really caught in the spring survey, when maturity analyses are conducted
- Loretta: Are there two sets of eggs in the gonads?; McBride: in the spring, there is an unyolked set and a cohort developing for the current year. Also repeated batches through the summer. Would be unusual to have spawning before age-2
- Cadrin: Seems that the few fish that were called resting but histologically were immature do not impact maturity ogive. May be more appropriate to report proportion mature at age-2 --- Could then demonstrate insensitivity.
- Maturity: Sample issue leads to sample size issue in maturity which impacts curve fit.
- Maturity trends: Should we update the time series, or should we use some type of moving average to capture trends?
- Nitschke: Proportion mature of age-2 increasing, but A50 plots flat or even decreasing;
- Larry: But much variability around A50 (model estimate)
- Cadrin: But one is slope (A50) and one is position
- Cadrin: Assumed proportion of Age-2 mature could have big impacts on SSB

- Loretta: Since spawning season is in the summer, could we construct a maturity ogive in the fall to see if it further informs our analysis? Would also have more age-1's. We have a bit of a unique situation with spawning in the summer
- Loretta: If we are going to use annual weights, we should try to capture some temporal variability in maturity; If use a moving average, do not have an issue with time blocks. Suggests 5-year moving average
- Currently using a time-series average for maturity (age-2 would be most influential age)
- Richardson: Is dip in maturity in recent years due to selectivity changes with the Bigelow? If 1) larger age-2 individuals are the ones mature, and 2) the Bigelow is catching smaller fish, would the observed dip be due to selectivity?
- McElroy: Samples by age, by year --- collecting more age-1 in last three years….
- McBride: At least partly due to increased sampling in recent years
- Terceiro: Looking back in time, many age-1 samples in late 70's – early 80's. Therefore, at least partly due to stock size
- Cadrin: Maturity trends seem to be somewhat lagged with biomass – supports a density-dependent aspect of maturity
- Legault: Agrees with idea of using a moving average, but questions whether we have enough samples to use a 5-year moving average. Sample size is very limited in some years (2003-2008 at age-2), which would yield very imprecise estimates
- McBride: Could you just plot only those years with greater than X number of samples?
- Alade: The assessment traditionally uses the time-series average of the observed proportions-at-age
- Loretta, in cod: Fit annual curves to 5-year moving averages
- Legault: For the other YT stocks, it is difficult to fit a logistic curve to a single age. The logistic has two parameters, but we only have one piece of information for YT: Proportion mature at age-2.
- Terceiro proposes either a 1) 5-year average of observed proportions, or 2) time-series average of observed proportions
- Hare: Is there a size-correction for the last few years to account for the Bigelow?
- Terceiro: Is there a strong case for going against precedent?
- Loretta: Concern is that we may lose some dynamics by using time-series average.
- Cadrin: There may be some small age-2's that might now be sampled by the Bigelow but were not sampled by the Albatross. Provides support for the base-case
- Terceiro: But we did catch age-1 fish when stock size was much greater
- Terceiro: Base case = updated time-series average; Alternative case = 5-year moving average of observed proportions; Determine impact on SSB.

WG consensus: adopt the proposed base (time series) and alternative (5-year moving average) as options for observed maturity proportions.

Fecundity

- Gary: Were you able to look at any fish post-spawning to account for attrition? Realized vs potential fecundity
- McBride: Cod equals <5%
- Terceiro: Take-home point: SNE most fecund of the YT stocks;
- Cadrin: Most dominant year classes were from low-stock sizes

Length-weight relationship

- Larry proposes using 1) the most up-to-date data available (stock-specific estimates) for 1994-2011, and 2) the Lux relationship for pre-1994. Will apply spring for Jan-June, and fall for July-Dec
- McBride: Samples could be biased if only sampled during one portion of spawning season
- Wigley: Differences between commercial and survey length samples? Is it more appropriate to use survey relationships for discards but commercial relationships for landings?
- McElroy: If timing of spawning shifts and survey timing is constant, could impact length-weight relationships.
- Cadrin: Is torn regarding best way forward; Recommends looking at sample sizes from Lux and current analyses; Lux had very few fish smaller than 25 in the spring; Had quite a few small fish in the fall → Similar to survey, age-1's showing up in the fishery in the fall, but not in the spring
- Commercial catch-at-age: Not many age-1's post-1994…..
- Reserving judgment until see differences in sample size between studies; also need to decide whether to use survey length-weights for discards and fishery length-weights for landings.

Larval index

- Nitschke: Did the two peaks line up with the two big assessment year classes? Dave doesn't think of it as an index of recruitment
- Cadrin: Sullivan et al attributed year class success to settlement success -- -therefore, could have high larval index but not high recruitment.
- Hare: Larval index is generally viewed as an index of SSB, not recruitment
- Legault: Is there an estimate of the variance? Richardson: Tim Miller can calculate the CV's using an MLE approach.

- Terceiro: Will need some type of precision estimate for input into a statistical catch-at-age model

WG consensus is that larval index may be useful as SSB index for model calibration, Dave R. will talk to Tim Miller about calculating CV's.

Returning to Length-Weight relationship

- SNE sample size: ~ 3300 fish
- Lux: spring 418, Fall = 930; Size distribution: has very few fish less than 20 cm or greater than 45 cm in any season.
- Current study: Broader length distribution, increased sample size, more recent study

WG consensus is to adopt Larry's recommendation to use the NEFSC Survey-based L-W relationship for 1994 and later years.

Natural mortality

- Cadrin: Is this something that we estimate by species or by stock? We see older fish on Georges Bank; Terceiro: We are considering YTFl at large
- Greg: Are there any empirical estimates from tagging studies?
- Tony: Not directly on M --- the estimates that Tony recently derived were unreliable and ~ 1.6
- Gary: We are trying to look at the maximum age of the population; with the length approach, we are trying to predict the average maximum age (as opposed to picking the one extreme value and assuming it is representative of the population).

April 2 Afternoon

Natural mortality

- The group discussed retaining the currently assumed natural mortality rate of 0.2. The Lorenzen method suggests that for older ages this assumption may adequate, but neither the survey nor the commercial fishery catch a lot of older fish. The traditional 3/Tmax approach would lead to a higher M of 0.27 (given observed max age of 11 years), while other methods estimate 0.3 - 0.5. **The working group agreed on an alternative lifetime M = 0.3 and to scale the Lorenzen curve to age 9 with spring, fall and commercial ages pooled.** This is likely to be the preferred alternative with a sensitivity of constant 0.2 and 0.3 across all ages. The WG discussed changing M over time, but while there has been some age truncation over time, it does not warrant a change in M.

WG Consensus: Given that natural mortality estimates range from 0.3-0.5 and this stock has experienced high fishing mortality over the time series, WG consensus is that a lifetime M of 0.3 is reasonable.

Cold Pool Index

There is a link between geographic location, the extent of the Mid-Atlantic cold pool and the recruitment process. The cold pool is the preferred thermal habitat for YOY yellowtail flounder. When the cold pool is small there is less suitable habitat for settlement, while there is more suitable habitat when it is large. The temperature effect is significant, but explains less than half of the variance. In particular, the 1980 and 1987 year classes are not explained by the cold pool or spawning stock biomass. Yellowtail flounder settle in coldest part of cold pool. The WG suggested examining the center of the SSB using the larval data and whether it is closer to cold pool during these 2 years. The WG also suggested examining the scallop survey data for recruitment index. Information on the cold pool index should be incorporated into the discussion of the vulnerability TOR.

Discard Mortality Rate

The WG discussed the duration of the SMAST RAMP and discard mortality study. The fish were kept up to 60 days, but the analyses used 20 days since most of the mortality occurred within this time frame. There were also controls in cages on the sea floor which had a lower ramp score. The tow times of 1-2 hours were approximately commercial tow times gave the fish a range of stresses. For the relationship between RAMP and mortality, only a range of values was needed before sampling the commercial activities. There was no direct evidence of additional mortality from predators or starvation, but there is likely some additional mortality. The fish with the lowest RAMP would be the ones more likely to evade predators. Commercial trips occurred in the Gulf of Maine (otter trawl) and on Georges Bank (scallop). The full range of temperatures is that occur throughout the year is likely covered for scallop dredge and more otter trawl trips are planned. Information on species composition and catch size is being collected and will be examined. Tow time does not seem to be a significant factor while air exposure is significant. There do not seem to be any size dependent differences in mortality. The WG discussed the types of discarding practices that have been observed. Some use shovels and picks, which likely increase mortality more than a conveyor system. There does seem to be consistency in discard mortality estimates (80-85% mortality) regardless of method. When fish are being caught for tagging, the tow times are short and the handling very different than on a regular commercial trip. For yellowtail flounder there have been few, if any, multiple releases by commercial fisheries.

Prior studies by MA DMF suggest 33-50% mortality. Given that 85% seems to be a lower bound on the RAMP-based discard mortality and some mortality likely occurs post-release, the WG agreed to use a value of 90% for commercial fishery discard mortality in the assessment.

Study Fleet Discard Estimation

- There is likely more of a mix of types of trips in the NEFOP than in the Study Fleet. Discard rates in NEFOP are generally higher for large mesh otter trawl, but discards are estimated higher in Study Fleet. This needs to be checked. There is potential for use of these data as we now use At-Sea Monitor trips, but more exploration is needed. These data could be a good supplement to Observer program to fill in gaps in the coverage.

There is also potential to use the information for a CPUE index fleet. The difference between NEFOP and Study Fleet estimates of discards by species gets smaller as the amount of discards gets larger. The observer could be getting the estimate from the Captain.

Discard Estimation

- The high values early in the time series are explained by few trips in some cells and also require imputation. The blended method seems reasonable based on the number of trips by region, CVs and the early high values. The small mesh otter trawl values in the late 1990s are driving the high cvs. The WG discussed the stratification used and whether the scallop dredge fishery should be stratified into open/closed access areas. For 2000 and 2002, there was differential observer coverage between open/closed areas with most of the coverage in the closed areas, which tend to have lower bycatch rates. The observer data are easily separated into open/closed areas, but the landings for expanding to total discards require additional work.
- For the purposes of stock assessment, the working group decided to use the GARM III approach for years prior to 2002 and use the SNE/MA stratification for 2002-2011. The SNE/MA stratification should be re-done with areas 611-613 included in SNE.
- Scallop landings from trawl gear are 2 types, landings on flatfish trips should be in with all trawls. Directed scallop landings with a scallop trawl (052). These have been separated and a decision on what to do prior to 2004 will have to be made.

April 3 morning

Ageing QA/QC

Eric Robillard and Sarah Emery were in attendance to discuss the QA/QT of ageing SNEMAYT. Steve Cadrin requested to see the validation study that was done, as well as reference the workshop that was attended regarding the ageing. Rich McBride suggested that poster that was presented at AFS by Larry and Sam also be used since it is a wealth of information.

Discard Estimation

Dvora Hart made a presentation on the Scallop Fleet discards. She suggested we use: T = (D/Ktrawl)/(D/Kdredge). This is because she feels we need to patch the years with no observer coverage. Currently, when we lack observer coverage, we look at the percent discards and apply a ratio.

RESEARCH RECOMMENDATION: when looking at this issue, a more complex procedure should be considered other than apply a ratio.

- Discard estimates used in the assessment and ACL monitoring should be consistent. It may help release the current constraints. We have done that for the fleet, but we still need the patch the years that have no data. It would be helpful to have more communication between the NEFSC and the RO.

- Tom Nies asked what the results would be if the areas were "open north" and "open south". It would be a reasonable option to modify current stratification scheme to areas south of Long Island. Larry will run analyses with Dvora's idea (develop alternative set of estimates in redefined areas for both trawl and scallop dredge). It will be a matter of looking at the current stratification vs the proposed one before moving forward. However, we cannot use it back in time. Before 2003, the coverage varies by year so we'd have to pool it, but from 2003 on, there was lots of observer coverage. Cadrin proposed that we use Larry's current way prior to 2003 and Dvora's way post 2003, but no decision will be made until we have a chance to look at the results.

Industry Based Survey

- Greg DeCelles (SMAST) presented the Industry Based Survey (IBS) results. There was some discussion about the age frequency in the areas sampled. Age Age-1 total biomass is based on the length frequency and there is a lot of overlap in the Age-2's.
- A member of the audience asked about the areas that were not able to be sampled due to the bottom. Yes, they are included in the biomass estimates. The RI and SMAST surveys are comparable. Both surveys encountered the same issue with sea bottom. There are some holes due to the amount of dogfish. Greg et al tried to compare apples to apples and keep the same spatial density. It was requested that Greg et al take select survey strata to get swept area for their 3 data points to compare. The age-length keys are available.
- Rob Johnston was able to maximize the comparison between the RI and SMAST surveys. It was suggested to get the Confidence Intervals from our survey, then add it to theirs. However, there is no replication between cells.

Commercial Landings

- Larry presented landings information. The relative differences are fairly big due to the re-running of the analysis and updated length-weight relationship. It could also be from the imputing of the age-length keys. Yes, the AA tables were used. In the length frequencies, the mediums are not used (they are less than 10%); they assume the length frequency of the aggregate.
- No comprehensive age-length data are available from the 1950s. M is based on what we see in contemporary samples. The Royce paper has age compositions from the 1940s-1950s; few fish older than Age-6. The paper says that it is based on the environment, not necessarily all fishing. Spatial distribution can be part of the change, but it is definitely different from then until now. Steve Cadrin will write up a paragraph based on the Royce paper as to what supported those landings. It needs to be available to the SARC.

- It was suggested to use ASAP to plot the age compositions. Please plot proportion at age. It will give another interpretation. There was a clarification on how the z-scores were calculated. Larry needs to check the math on this one and re-do.
- It was requested that Larry make a table with the number of samples, possibly by quarter if there were enough to do it that way.

April 3, 2012 Afternoon

Miscellaneous Discussion

- Regulations: basically two broad stanzas of selectivity, up to the mid-nineties with no mesh size regs, then through the present; constantly are changing mesh size regs from then on.
- Ages, lengths and commercial length frequencies: Table of sample sizes - check the length numbers and age numbers. Are there some categories that are commercial and survey combined? Are the "unclassified" lengths stable over the years?
- In1999 the assessment was rejected as the age and length sampling was so sparse. If you use an ASAP model do not use certain years where the sampling is poor, especially where there are samples for only one half of the year as the growth is not constant through the year.
- Length-weight relationships: for commercial, some of them are 50 years old and need to be updated. Observer coverage is pretty high, there should be some data collected by them, or the port samplers, or cooperative research project participants, need individual kept lengths and weights to improve the models. **WG recommends Research Recommendation on this issue.**
- Proportion mature at age 2: The best estimates of proportion mature at age 2 might be different between the Albatross years and Bigelow years because the Bigelow catches smaller fish and smaller mature age 2s will be caught.

Appendix 3

SNE/MA Yellowtail flounder Model Meeting Participants: April 30 - May 2, 2012

Name	Organization
Larry Alade	NEFSC
Adam Barkley	SMAST
Liz Brooks	NEFSC
Katie Burchard	NEFSC
Steve Cadrin	SMAST
Jon Hare	NEFSC
Fiona Hogan	NEFMC
Chris Legault	NEFSC
Tom Nies	NEFMC
Paul Nitschke	NEFSC
Robert O'Boyle	Beta Scientific Consulting Inc.
Dave Richardson	NEFSC
Gary Shepherd	NEFSC
Katherine Sosebee	NEFSC
Mark Terceiro	NEFSC
Michele Traver	NEFSC
Susan Wigley	NEFSC
James Weinberg	NEFSC
Tony Wood	NEFSC

SNE Yellowtail Model Meeting Notes: April 30 – May 2, 2012

Daily Notes

April 30 morning

- The working group noted that there was a large increase in age 1 commercial catch which was likely driven more by revisions of the age-length key than by new discard estimates. This is because the discard estimates between GARM III and this assessment are similar. It may be useful to look at the ALK before the SARC. However, the number is not out of line with catches prior to 1994.
- The working group discussed whether to include the southern strata in the winter survey. The abundance of yellowtail flounder in those southern strata was high in the 1970s but by the late 1980s and early 1990s, yellowtail had disappeared from those strata. Therefore, it seems reasonable to exclude them from an index that began in 1992.
- The larval index was discussed by the working group. It was noted that the 2010 and 2011 indices increased significantly. The index was presented as a split series using Dave’s method and as a single index using Tim’s maximum likelihood method. There was a different mesh size used prior to 1987, and Tim’s method attempts to account for the difference in selectivity. There have been comparison tows, but more are needed and work is underway to complete these comparative tows.

VPA

- For the VPA runs that end in 2008, the last year of spring survey age composition residuals are all positive. The working group discussed using the spring survey weights for SSB and catch. The group decided that these shouldn’t be used for catch since the numbers are not scaled to total weight properly if catch weights are different. This has no impact on the fitting of the model. Since most of fishery occurs in the second half of the year, it would not be appropriate to use the spring survey weights at age for catch.
- The impact of different discard mortality rates was examined. The estimates of recruitment are not impacted by using 80, 90 or 100 percent discard mortality. The retrospective for F gets better with lower mortality.
- The retrospective for F gets worse with updates of the data so models with M=0.2 and a lifetime M scaled to 0.2 were run. The retrospective for F was decreased, but the retrospective for SSB increased but was still low.
- The working group discussed the possible models, Run 15b (Lorenzen 0.3) and Run 16b (Lorenzen 0.2). Since the working group agreed to use and M of 0.3, run 15b should be the starting point.

- All model runs have no information in year T+1 since the spring 2012 survey is not finished yet. It is the same formulation from GARM III, but GARM III was in August and had the spring survey information for year T+1. The working group discussed lagging the fall survey forward a year and an age to get some information for year T+1, but decided that this formulation is closer to any ASAP configuration.
- The weights-ate-age used to derive the Lorenzen scaled M had an abrupt shift in 1994 so the M at age 1 shifts as well. The working group decided to use a time series average Lorenzen M scaled to 0.3.
- The working group picked a base VPA (Run 20) with time series Lorenzen M scaled to a lifetime M of 0.3. There is no patterning in the residuals and no indication of doming in the survey catchabilities. The winter survey qs are high but with the ground gear on the winter survey net, herding is expected between the doors and the net. The CVs on age 2 estimates in the terminal year are high but given that there is no spring survey estimate for 2012 they are not unexpected.
- The RI IBS in 2004/2005 and IBS in 2011 are less than mean biomass estimates so there are no apparent catchability issues. The retrospective pattern is underestimating fishing mortality in the terminal year. SSB at the start of the model was 24,000 mt, declined to lower levels and had two excursions to higher SSBs due to two large year classes. Recruitment has been poor since the 1987 year class although SSB is now starting to increase due to low F.
- The working group decided to use the average of 2006-2010 for selectivity and 2007-2011 for mean weights (2007-2011) for reference points and projections. Recruitment will be handled with 2-stanzas of empirical estimates split at SSBs of around 5000 (Rago will re-run the razor).

April 30 Afternoon

Working session – no meeting

May 1 morning

Work during the morning session compared the different ASAP models and decided whether or not to continue to the VPA or move forward to the ASAP model.

- Run 1 vs Run 2:
    - Run 2 broke up residuals a bit. Small improvement seen. Coincides with major changes from 1994 onward in the management regime.

- Why doesn't the VPA F trend follow that of ASAP? Because there are fixed blocks and they are different models. Multinomial model used for age compositions.
    - Winter survey q was about 2 in VPA, about 3 here.
    - The F-report is different than VPA but they both have M = 0.2. (VPA selectivity changes every year so be careful when comparing to ASAP.)
    - In the CV plot, there are occasional spikes due to the lack of sample data.

- Bob O'Boyle asked to compare partial recruitment between VPA and ASAP.
    - VPA Run 20 with M = 0.3 compared to ASAP Run 16 to address Bob's request.
    - Recruitment patterns seem to match fairly well across all ages and are configured the same way; they are virtually identical.
    - F pattern general trend is very similar between the VPA and ASAP. ASAP is slightly smoother in later years.
    - Are there fishing effort trends that corroborate with the F trend? There's an increase in survey indices but a decrease in catch. There are 2-for-1 counting days at sea; the fleet has been trying to get fishing off SNEMA YT.
    - The shifts that are seen can be due to selectivity blocks (there are 6).
    - SSB patterns are similar between the two models; it is a little flatter with the VPA.
- Side by side comparison between VPA Run 20 and ASAP Run 16 to decide which model to use for the assessment.
    - The VPA shows recruitment to the fishery to be more gradual. ASAP shows full recruitment (95%) into the fishery at age 2 in the early time blocks.
    - There are 6 selectivity blocks, 1 fleet.
    - Bob O'Boyle requested to see differences between the two models over age and time. Chris Legault did this. ASAP F – VPA F (by age) and plotted.
        - Ages 4-6 are equally selected for both models.
        - No real strong patterns (Bob would like indices emailed to him.)
        - Last 10 years are very consistent between the two models.
        - Age 3 has more differences than ages 1 and 2.
        - Ages 4-6 are the same.

        - Blocks are split: 5-6 are similar, 4 has lower selectivity at age 3. It doesn't shift as nicely as hoped, but the blocks are short. Some only have 3 years for estimating 3 parameters.

- Retrospective patterns for ASAP Run 16 (looking at the various diagnostics).
    - F- 2004 is a "high flier."
    - SSB – ASAP is more consistent in direction (6 above, 1 below). If the two fliers are thrown out, it looks reasonable. The two fliers almost cancel each other out.
    - Recruitment in the last year is not well estimated. Both models have positives and negatives; they both bounce around.
    - Has Larry looked at the historical retrospective patterns yet? No because the beginning VPA is locked in.
        - Larry did a comparison using the GARM III VPA to "new" VPA (Run 20) to ASAP Run 16 for Jim Weinberg's request.
        - Recruitment is scaled up by increasing M (as expected).
        - Average F is nearly identical between old and new VPA. ASAP handles F differently. Trend is basically the same in all 3 models.
        - SSB – still end up in the same place in 2011, regardless of the model.

- The SARC has given guidance to move to a statistical catch at age model. What are the panel's thoughts?
    - Steve Cadrin says to use ASAP because there is more flexibility to improve the model.
    - Chris Legault says that it gives confidence in both models because they are both similar.
    - WG conclusion was to develop ASAP through the reference points and continue with ASAP model as the preferred model framework. Still need to decide how many selectivity blocks to use.

- ASAP Runs 17-19 are using the larval index.
    - Run 17 was taken out because it was agreed to use M = 0.3 and that one uses M = 0.47.
    - Run 19 uses M = 0.3, splits are 77-87 and 88-11.
    - Larval index used as an index of SSB.
        - What happens when a split in the larval index isn't used (Run 20)?
        - There is substantial impact on SSB, with a large increase at the end of the series.
        - RMSE is very large, indicating a need to increase the input CV.
        - The residuals are strongly patterned.

- Run 19 is not used for comparison. You have to increase the CV and decrease the influence. Create a Run 21 to replace Run 20 (make CV = 0.3, effectively doubling the original CV).
  - CV = 0.3, use the comparison tool. With this CV, it allowed the fit to be closer to Run 16.
  - Liz Brooks suggested that if there are year specific CVs, to double them instead of using a constant. The original CVs are very close (0.13-0.15). Larry ran it with doubling the CV.
- Run 22 will use a different larval index calculation.

May 1 Afternoon

Tuesday Afternoon

- The ASAP model has a better fit with Dave's larval indices than Tim's model-based estimates. The retrospective is improved with the addition of the larval indices compared to without, so the working group decided to include the larval indices from Dave.
- The working group examined models with varying selectivity blocks. The 6 selectivity blocks seem to produce selectivity estimates that do not necessarily agree with the expectations from the regulations. However, the improvement to the model fit is enough to warrant keeping in all six blocks. The retrospective pattern is also reduced with 6 blocks, so the WG chose the 6 block model. The final model increased the CVs on the survey indices by 0.1 to reduce the mean-square residuals.

RunID	Selex Blocks	Change in Parameters	Obj Function
22	6		4683
23	4	-6	4703
24	3	-9	4715
25	3 (+0.1 to sv cvs)	-9	4675
26	6(+0.1 to sv cvs)		4640
27	5(+0.1 to sv cvs)	-3	4652

- The working group reviewed an analysis by Steve Cadrin of SMAST of different Fmsy proxies. The stock was able to replace itself at F40 in both early and late years, but at F30 the stock would not have been able to replace itself in the later years using ASAP and VPA results. The working group concluded that F40 is a good proxy for Fmsy.

May 2 morning

SRFit VPA run 20

- No Ricker has been attempted because of work done back at the GARM suggesting this relationship was not reasonable for YT flounder.

Bootstrap outputs VPA run 20, AgePro VPA run 20

- Used Paul Rago's updated cut point (~4,000 mt), stock in 2011 is just under the breakpoint.

SRFit for ASAP run 26

- Everything the same except as for the VPA Run 20 except the fishery selectivity, with ASAP indicating a slightly higher fishery selectivity.

MCMC results; YPR

- F40% estimates from VPA and ASPA both about 0.3

Revisiting TORs

- Prepare plots that go back to SARC 36 for the historical retrospective: F, SSB, recruitment.
- WG chair noted that performance of the projections is NOT a term of reference for this assessment.
- The SR functions did not provide a good basis for BRPs. Steve Cadrin's work suggests F40 is an appropriate proxy. ASAP is the preferred assessment model.
- The WG noted that management in the near future is going to be about rebuilding. Long term SSBs at F40 are in the same neighborhood as what was being returned from the B-H S-R fucnion.
- WG recommended projections with the existing and new reference points to beyond the rebuild year of 2014 to evaluate when the stock might be rebuilt under different BRPs and recruitment scenarios.

May 2 afternoon

Projections

- The WG should note the concern in the report regarding the likelihood that recruits will jump up a bin in the rebuilding scenario.

Coldpool S-R- model

- Took run 26 and used modified ASAP which allows covariates in the S-R relationship to look at coldpool index. As the coldpool index goes down you have a higher predicted recruitment. Gives intermediate results between F40 run and the post-1990 recent low-recruitment scenario.

TORs

- TOR8: Projection with recruitment since 1990 is most realistic? Are we in a new productivity regime that will last for the foreseeable future?
- Two aspects that may not be independent: the first is climatic warming and the second is the change in geographic range. We no longer have the geographic range of the stock that was associated with the large recruitments of the 1970s and 1980s; starting the recruitment in 1990 is a reasonable alternative. Putting it forward as a scenario to the SARC reviewers will be informative.

Research Recommendations

No new model-related research recommendations were developed.

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