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.

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TORA9 – Harvest Policies

TORA10 – Projections
Table A10

TORA11 – Research Recommendations

References

Appendix1

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.

<u>Geographic Distribution</u>

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).

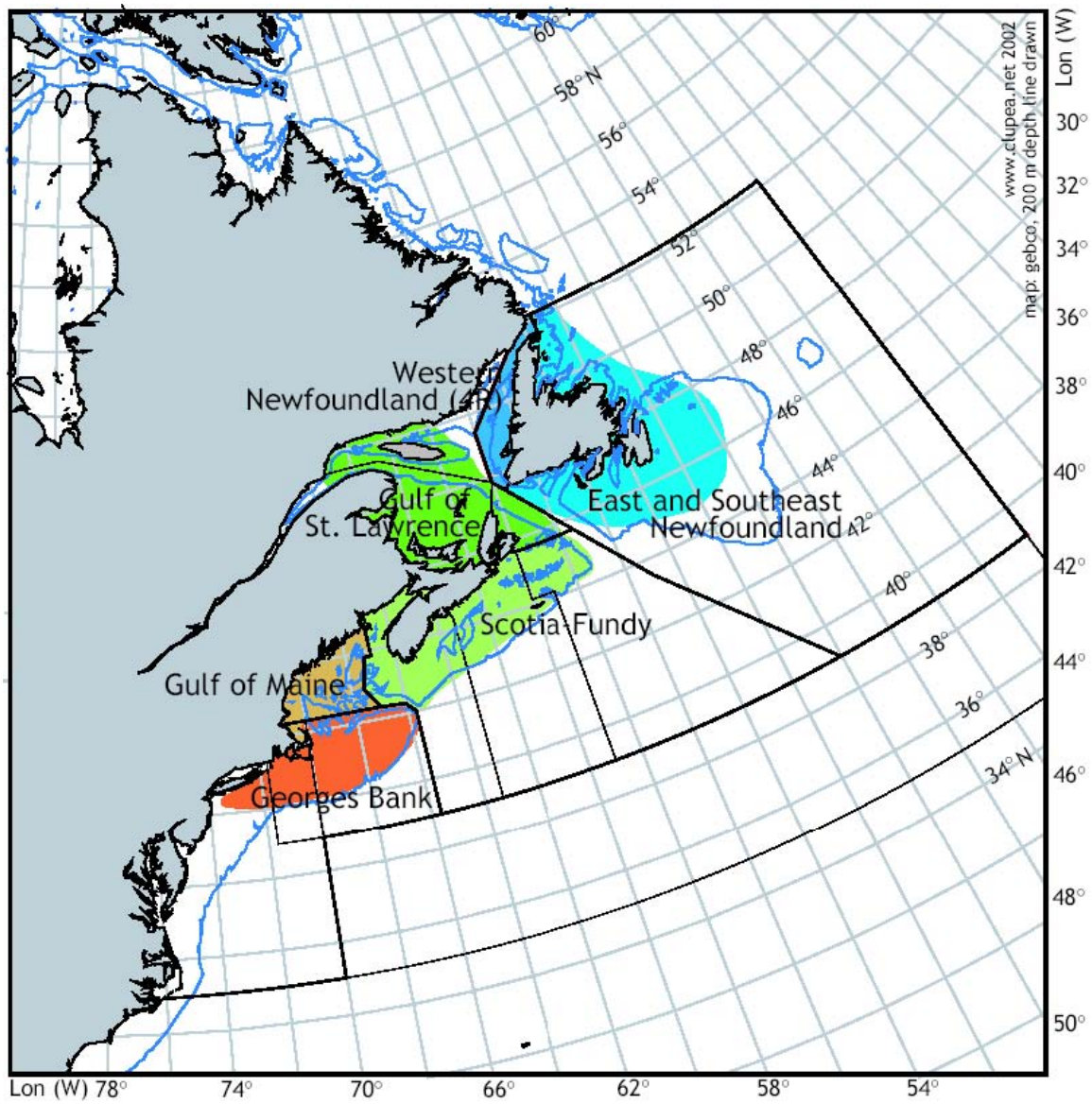


Figure A4-1b. ICNAF view of Atlantic herring stock structure (double lines indicate stock boundaries; from ICNAF 1972)

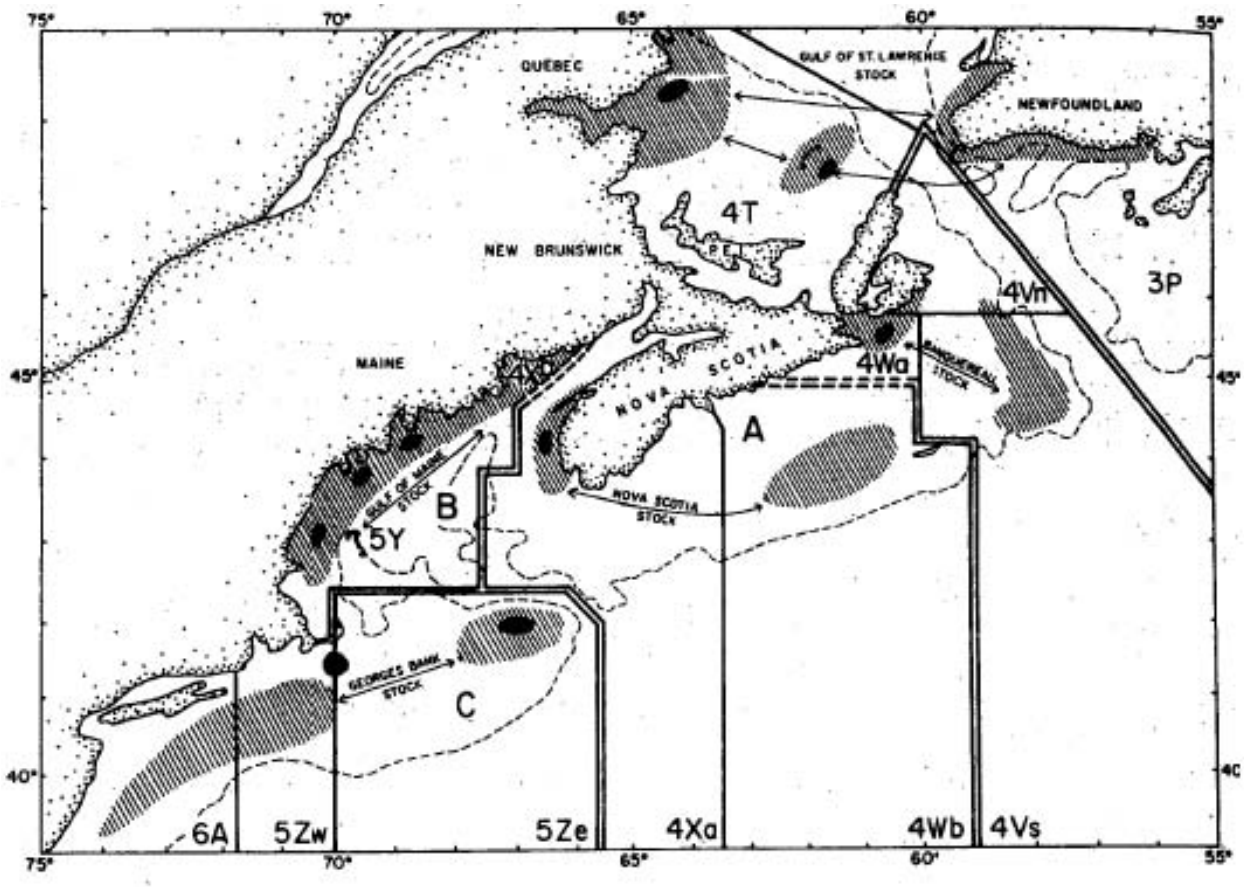


Figure A4-2. Management boundaries for Atlantic herring in the Gulf of Maine and on Georges Bank (lines indicate original boundaries, shaded area indicates 2006 revision to area 3 boundaries).

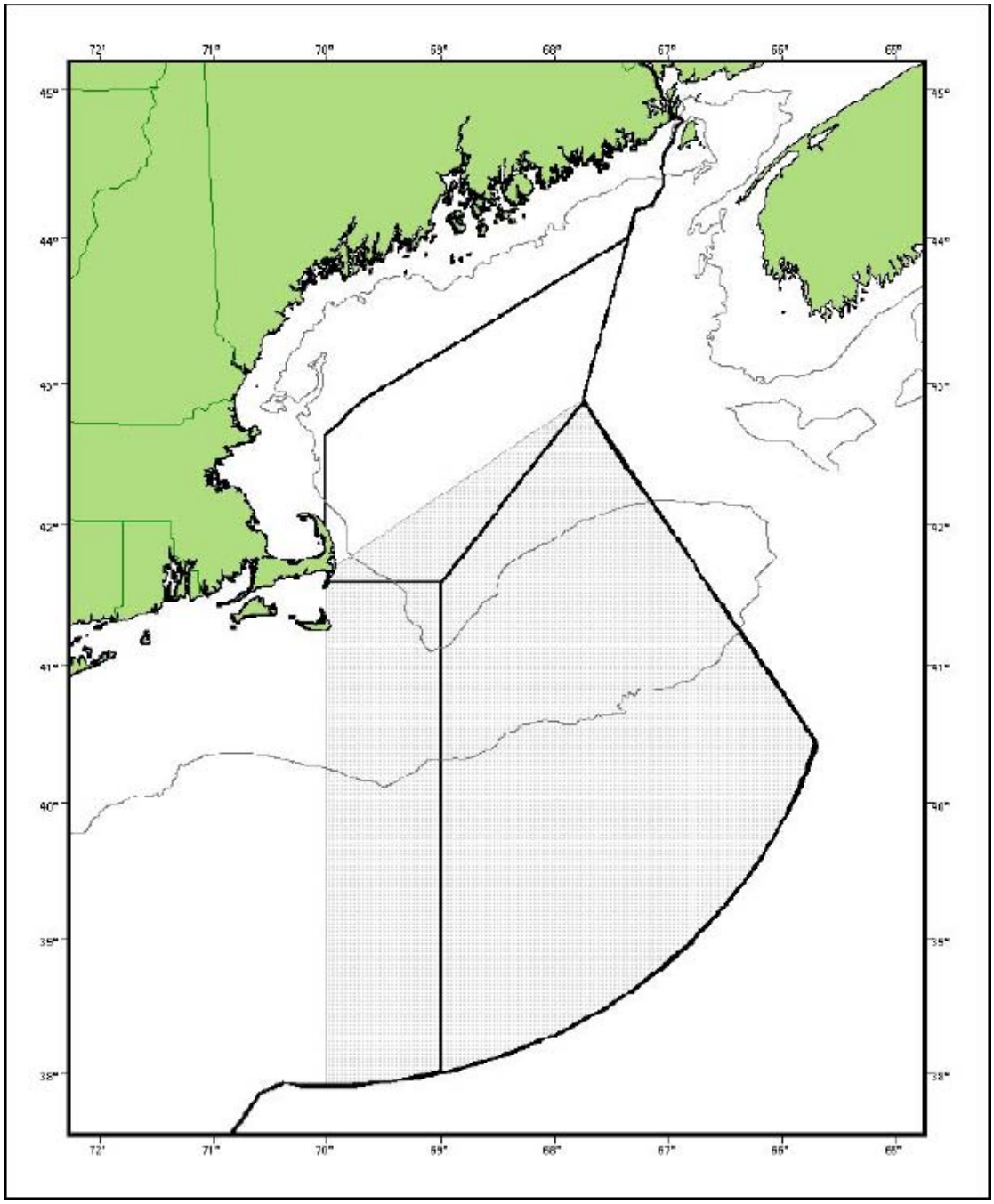


Figure A4- 3. Generalized view of the current major herring spawning areas in the Gulf of Maine and on George Bank (from Overholtz et al. 2004)

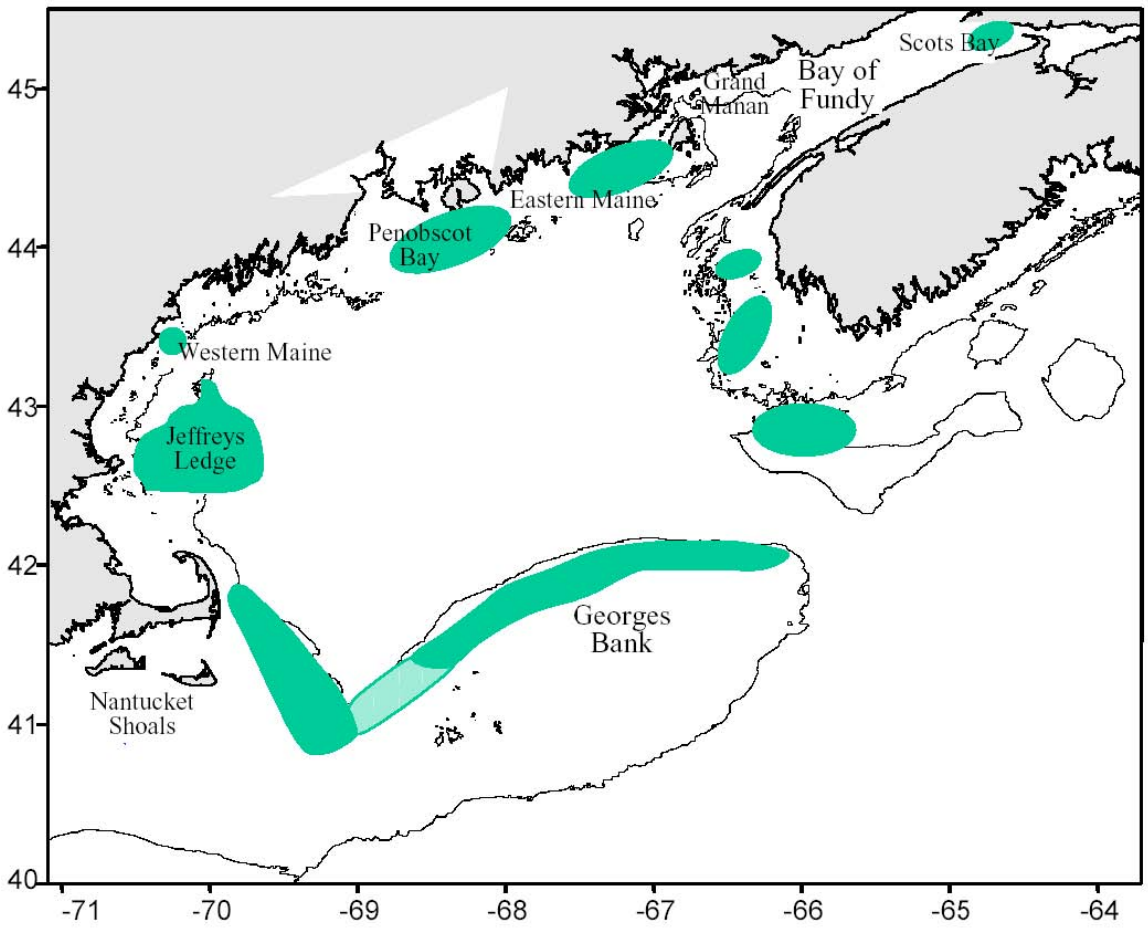


Figure A4-4. Distribution and abundance of Atlantic herring observed in the U.S. fall bottom trawl survey (A) and U.S. spring survey (B); from Overholtz et al.(2004).

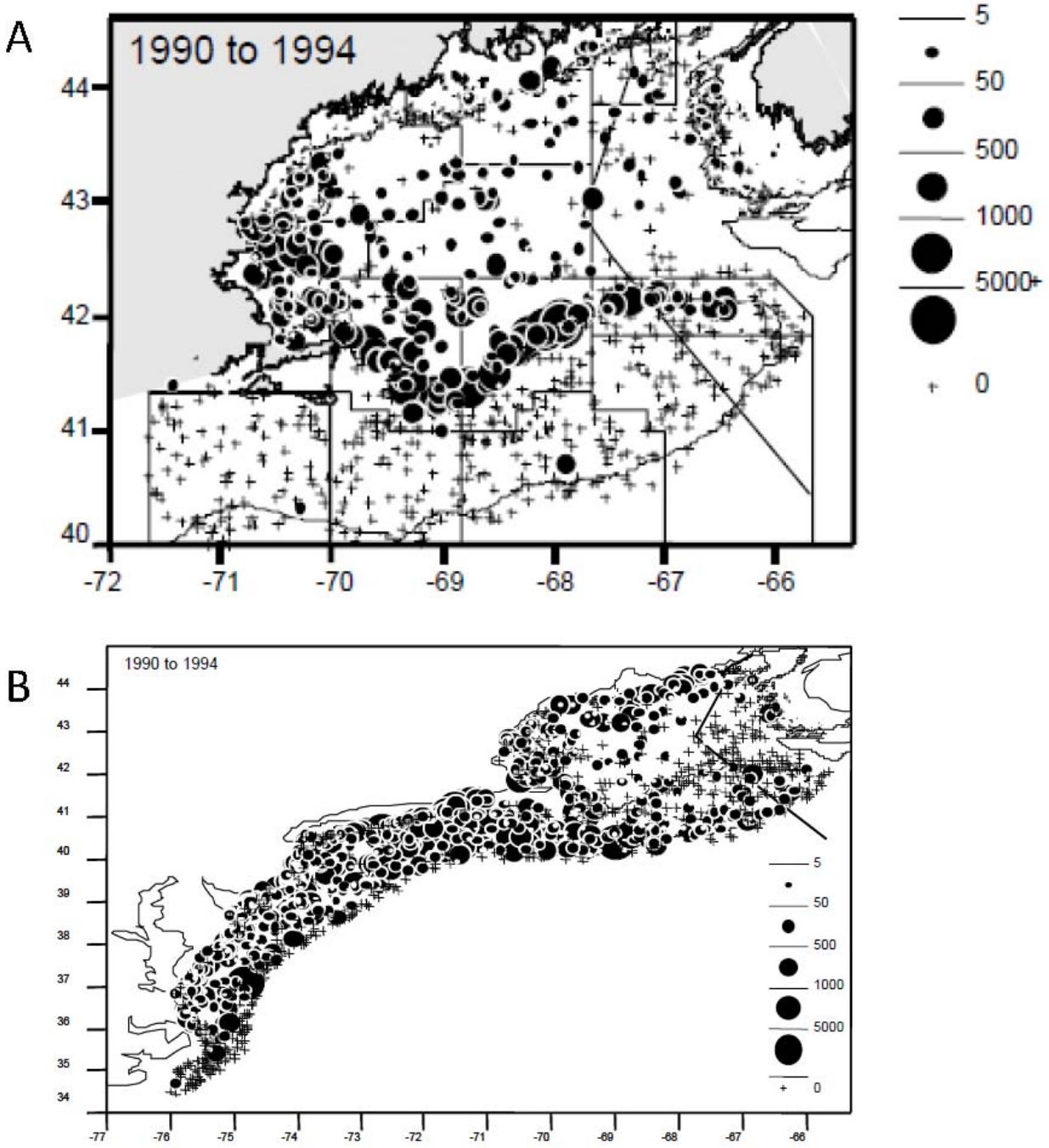
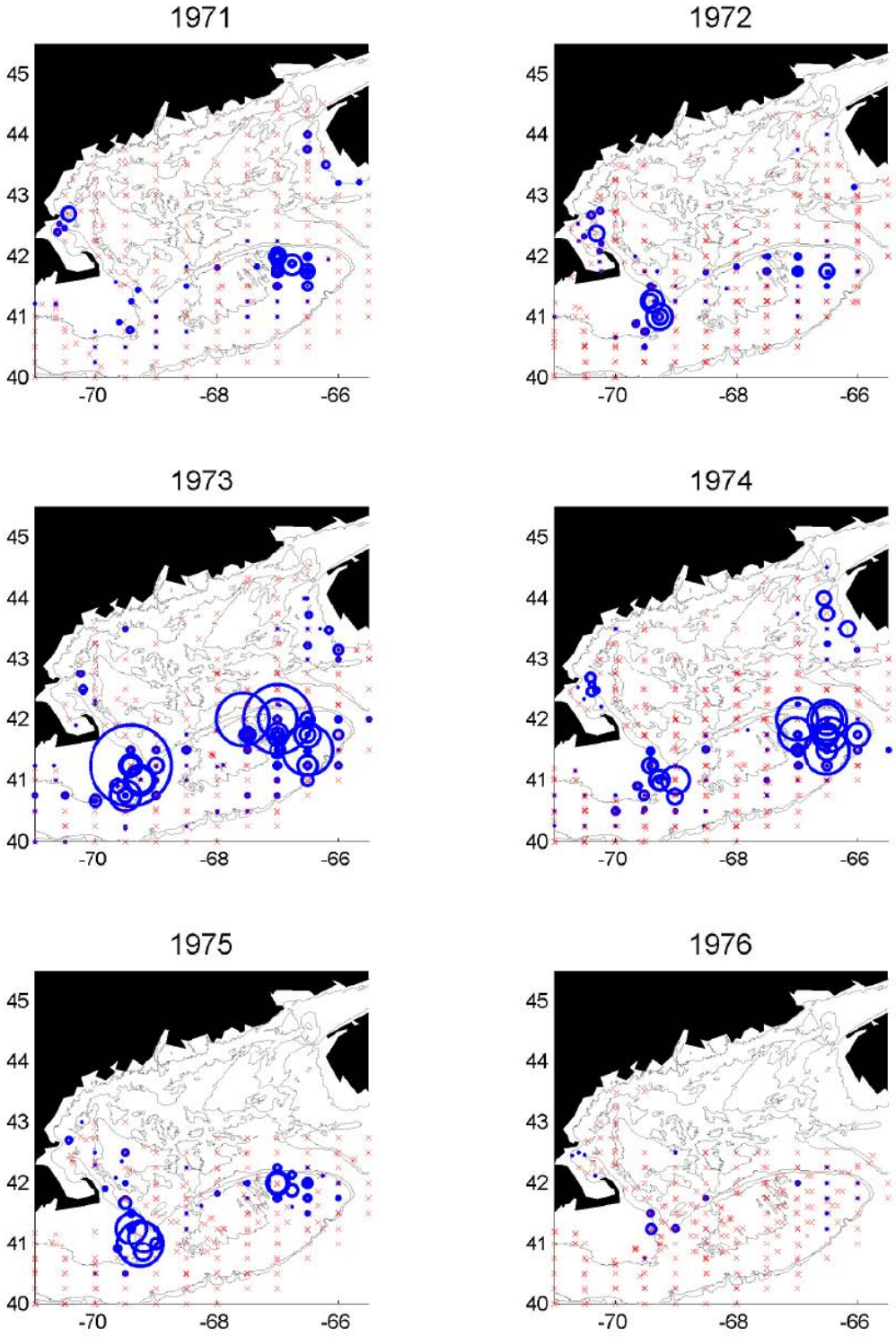
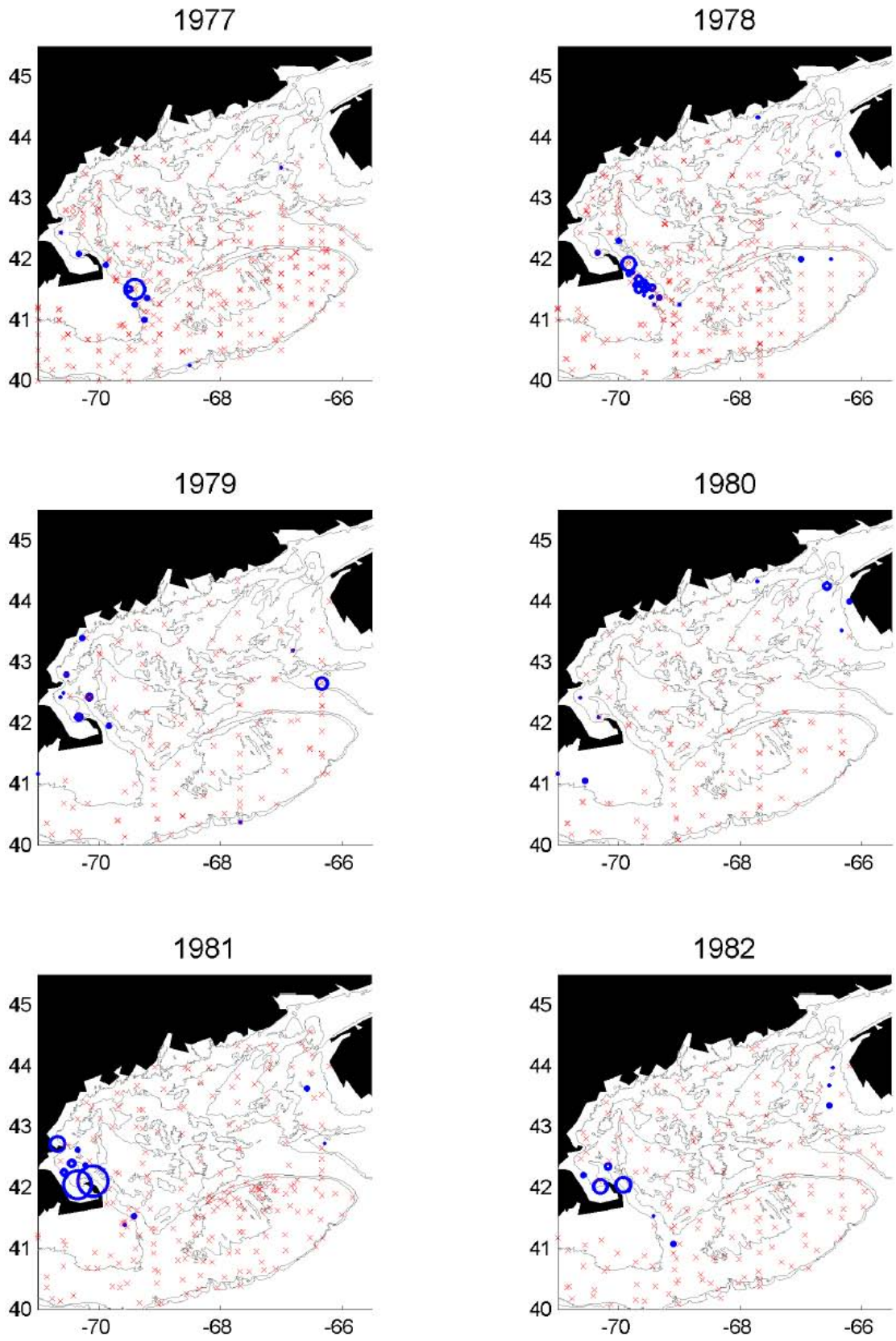


Figure A4-5. Annual distribution of small larvae (<9mm) during sampling in Oct-Dec. Red x's indicate samples with no larvae (continued on following pages).

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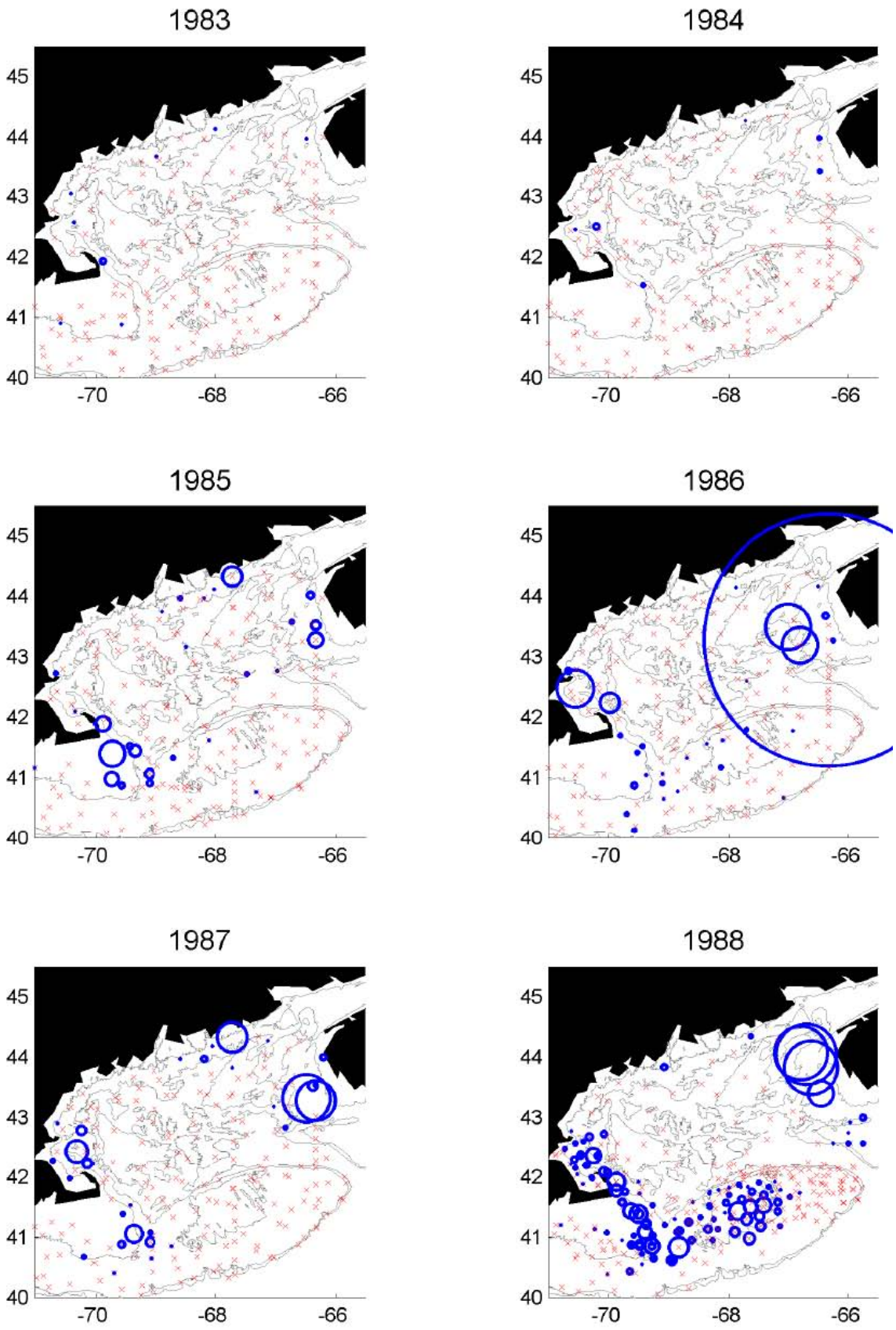
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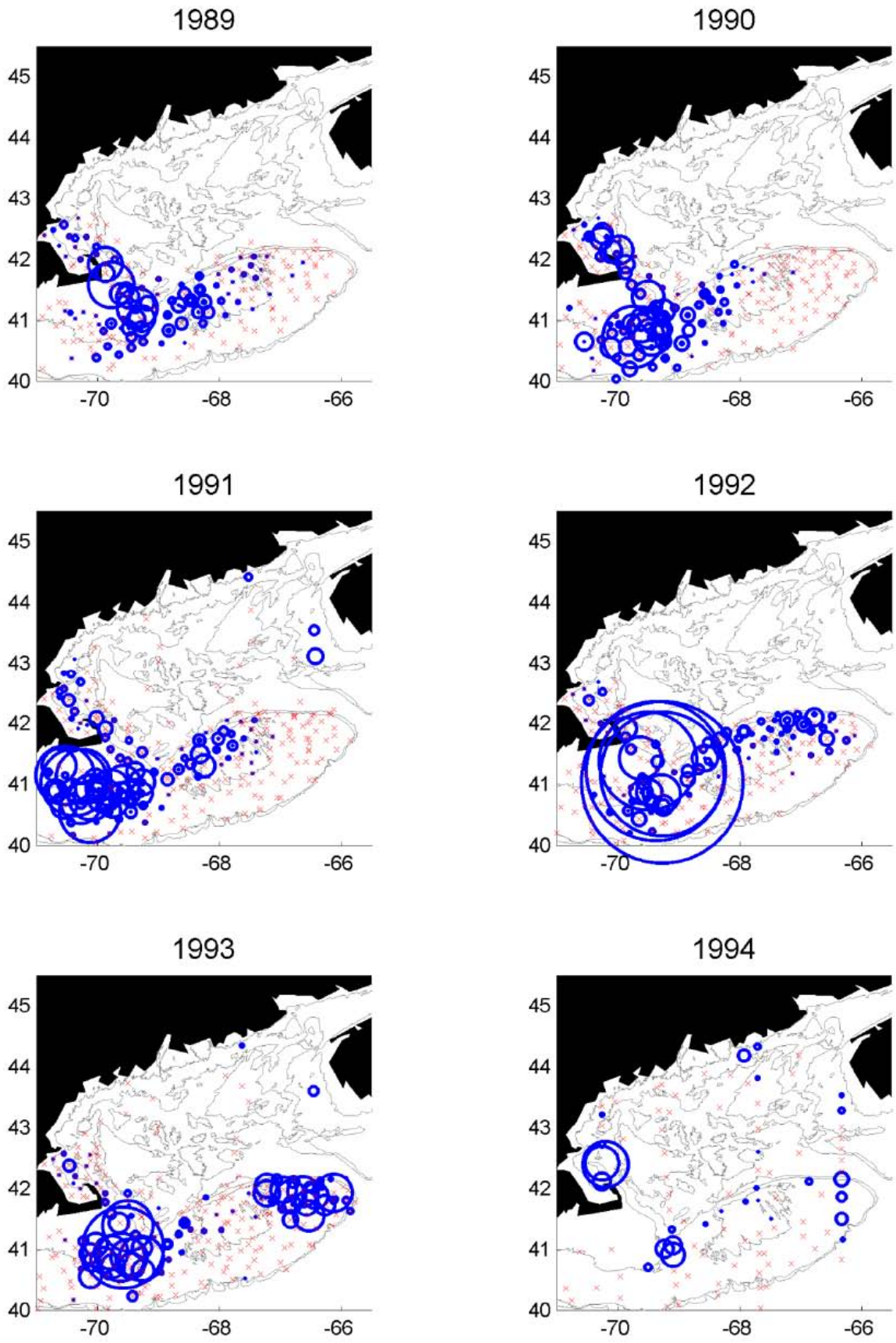
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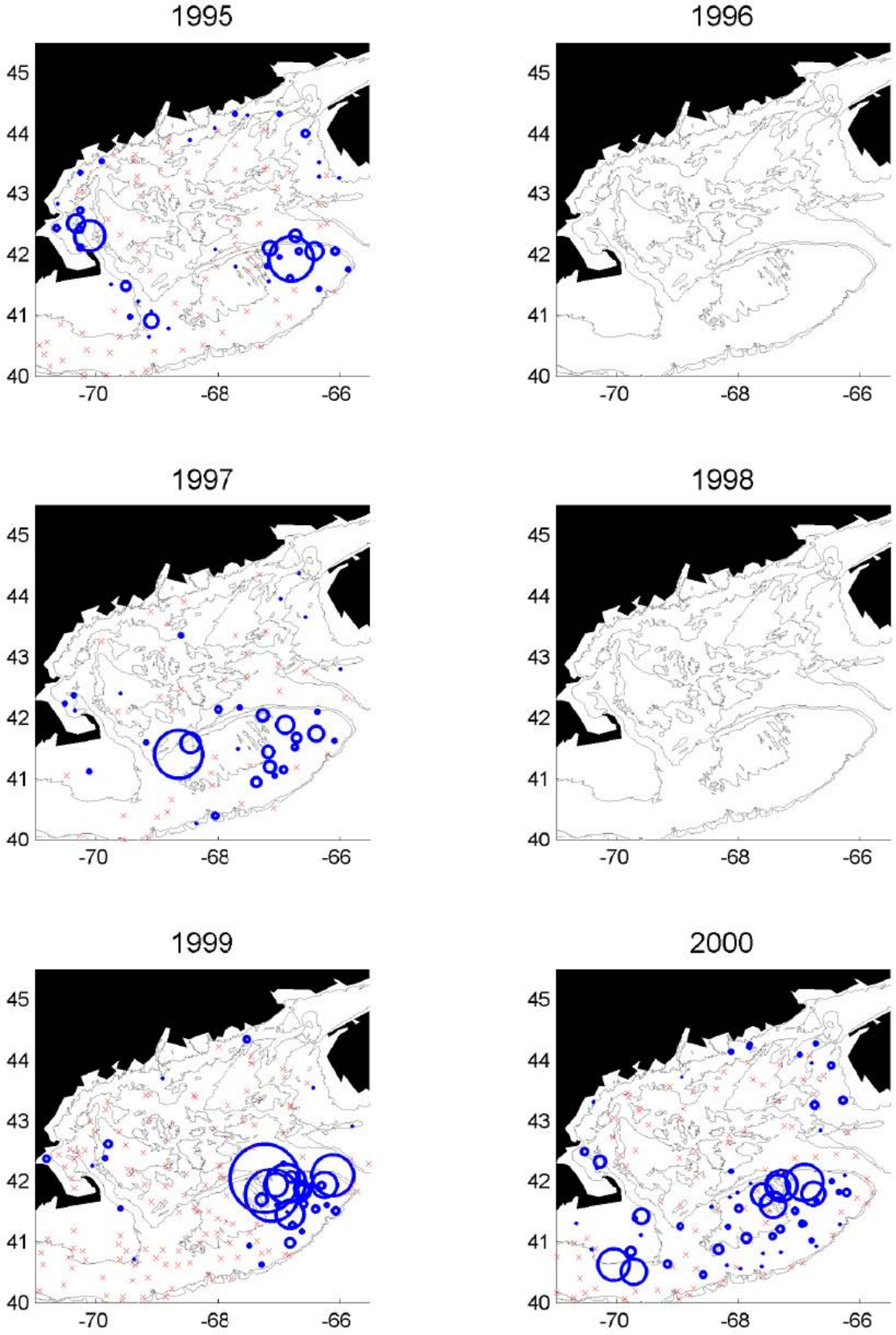
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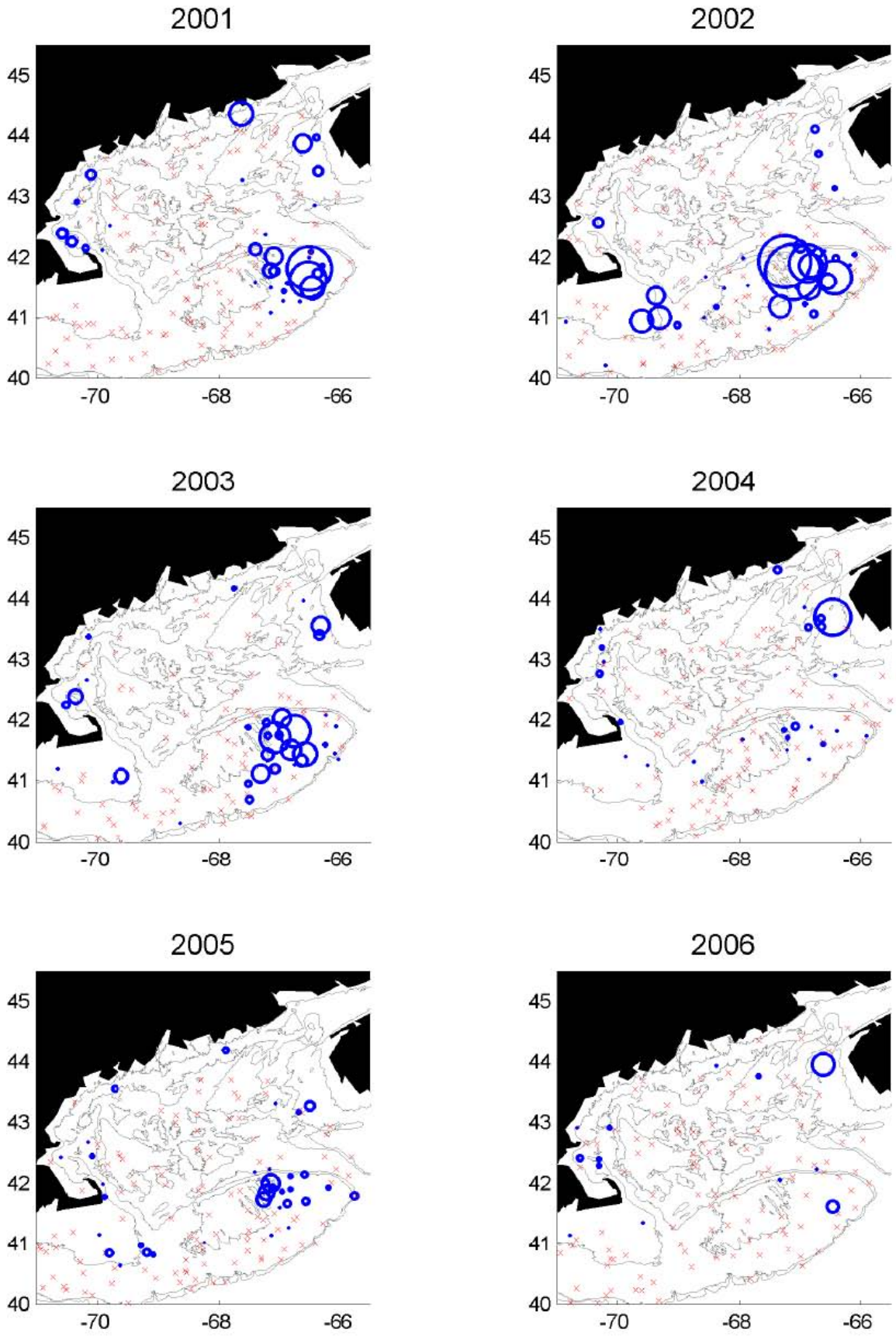
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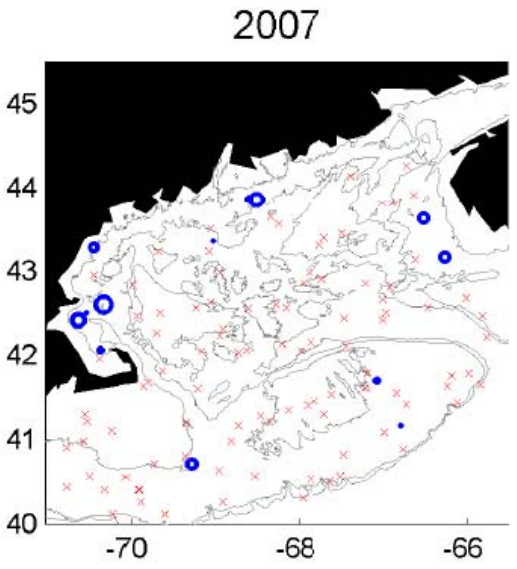
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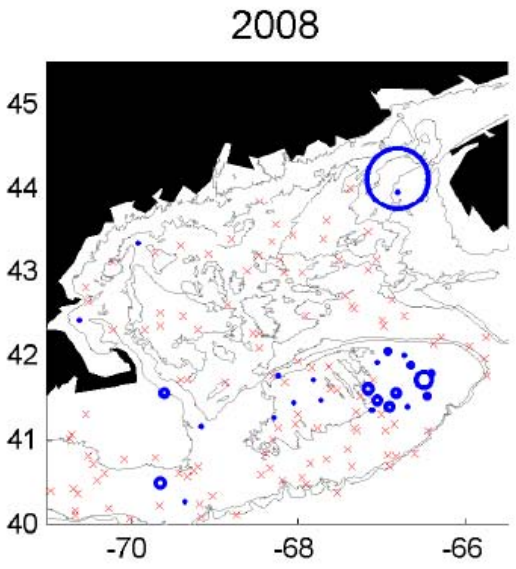
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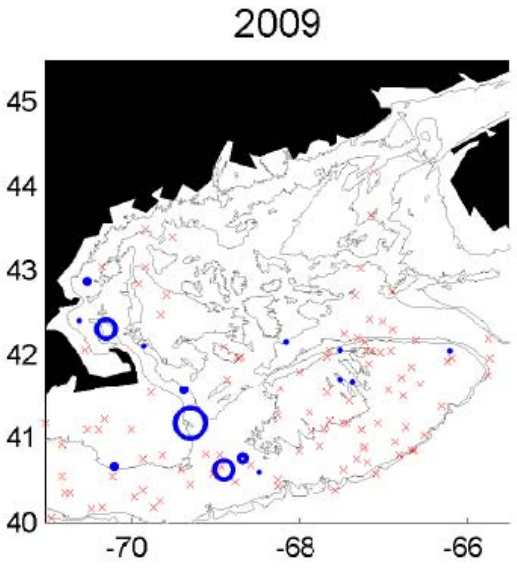
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Figure A4-6. Spatial patterns of length at age in the NEFSC spring and fall surveys, 2009 and 2010.

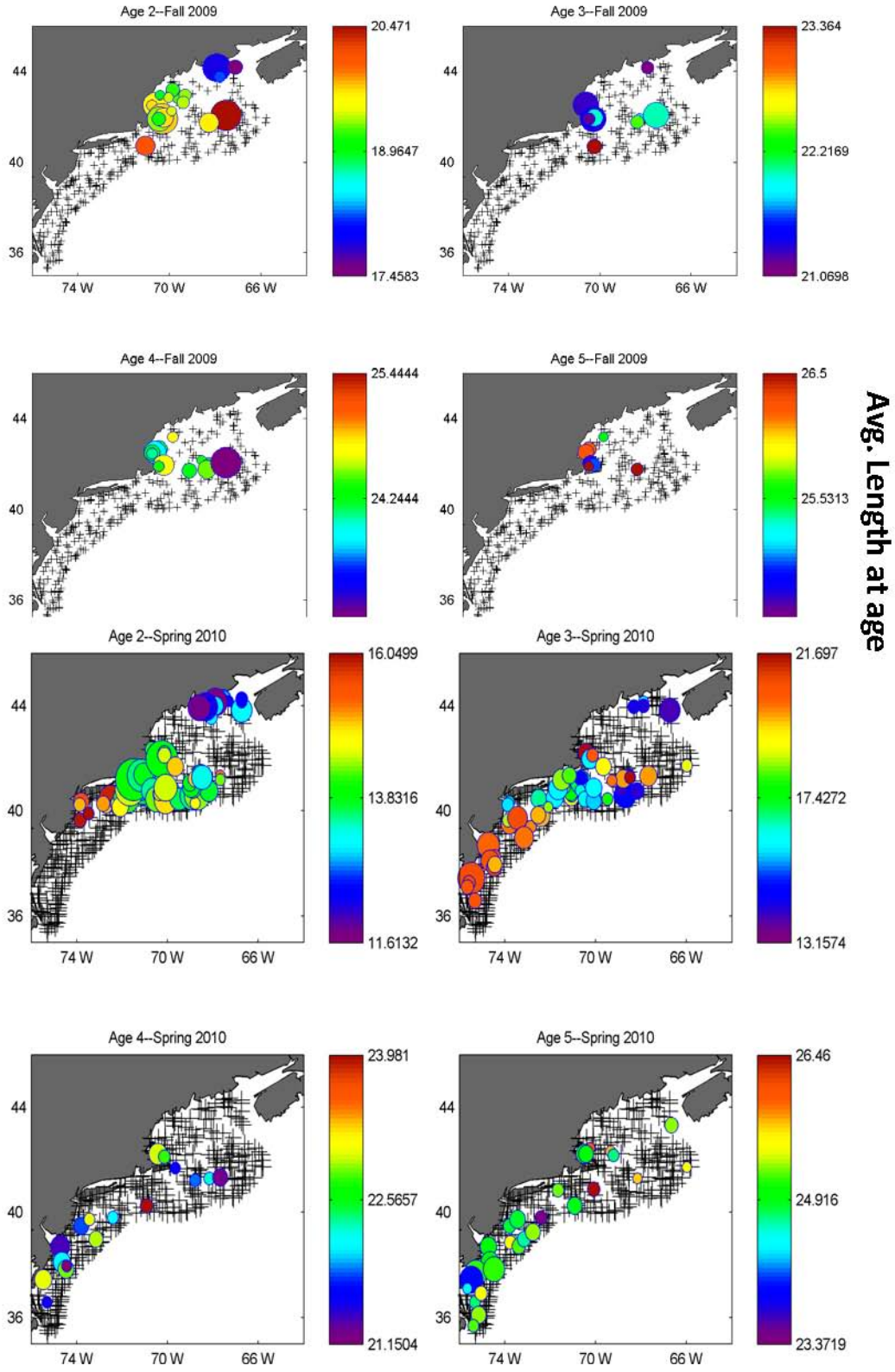


Figure A4-7. Average length calculated using SURVAN Southern Strata (1-25 and 69-76) and Northern Strata (33-40).

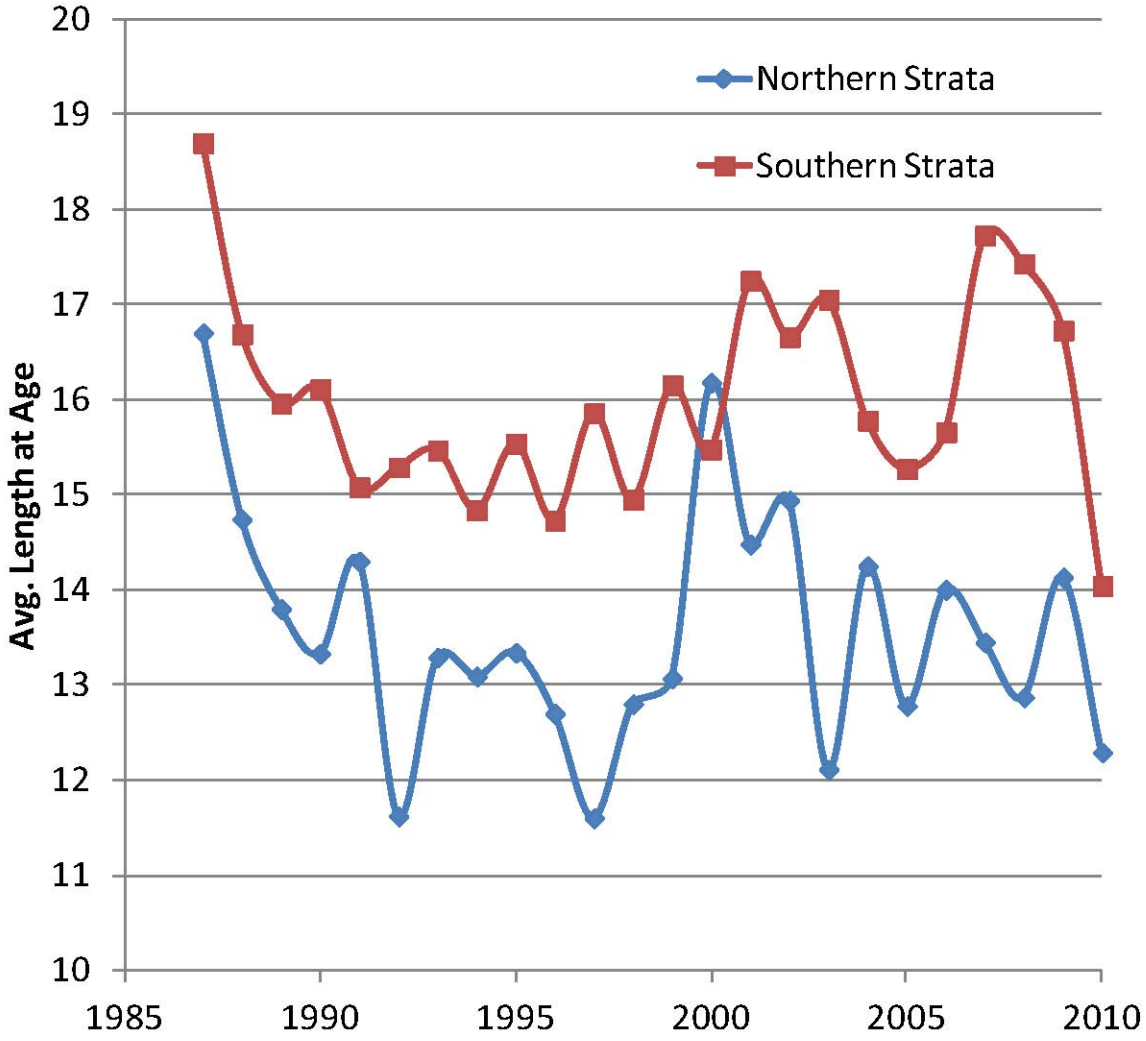


Figure A4-8. Hypothesized seasonal movements of three Atlantic herring spawning stocks inhabiting U.S. waters (from Reid et al. 1999).

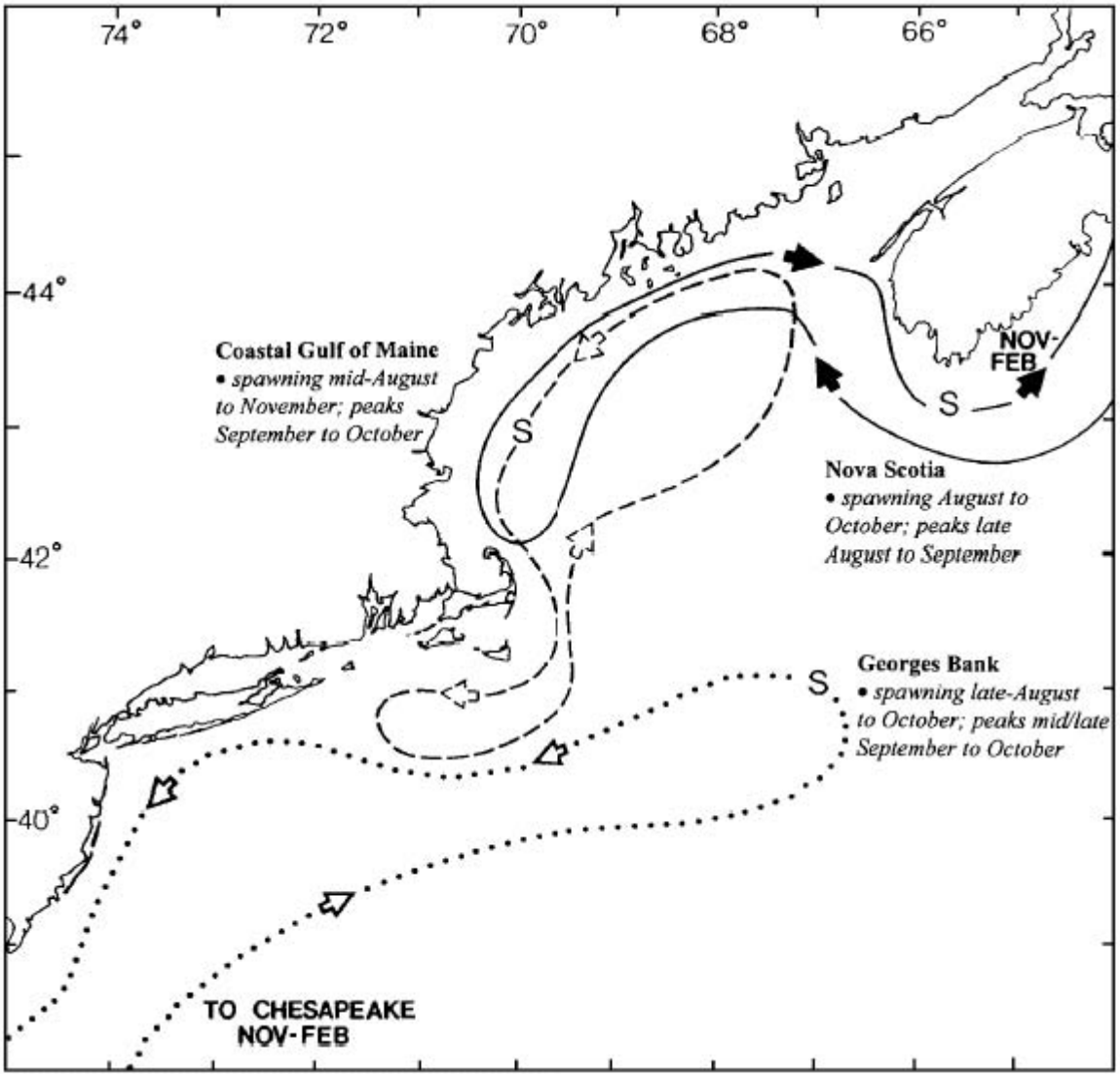
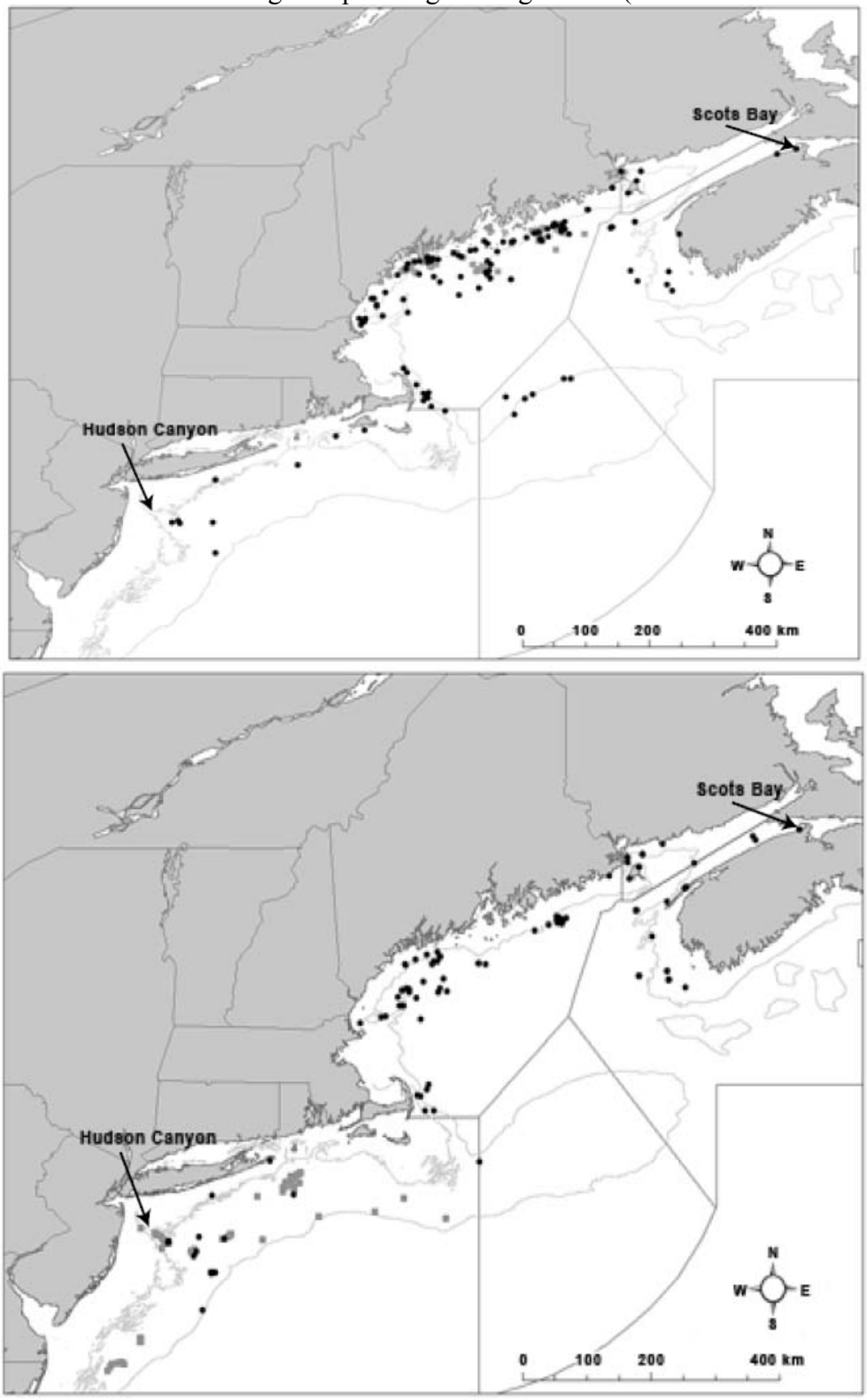


Figure A4-9. Tagging locations (gray dots) and returns (black dots) from Atlantic herring released in the Gulf of Maine during the spawning/feeding season (from Kanwit and Libby 2009).



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

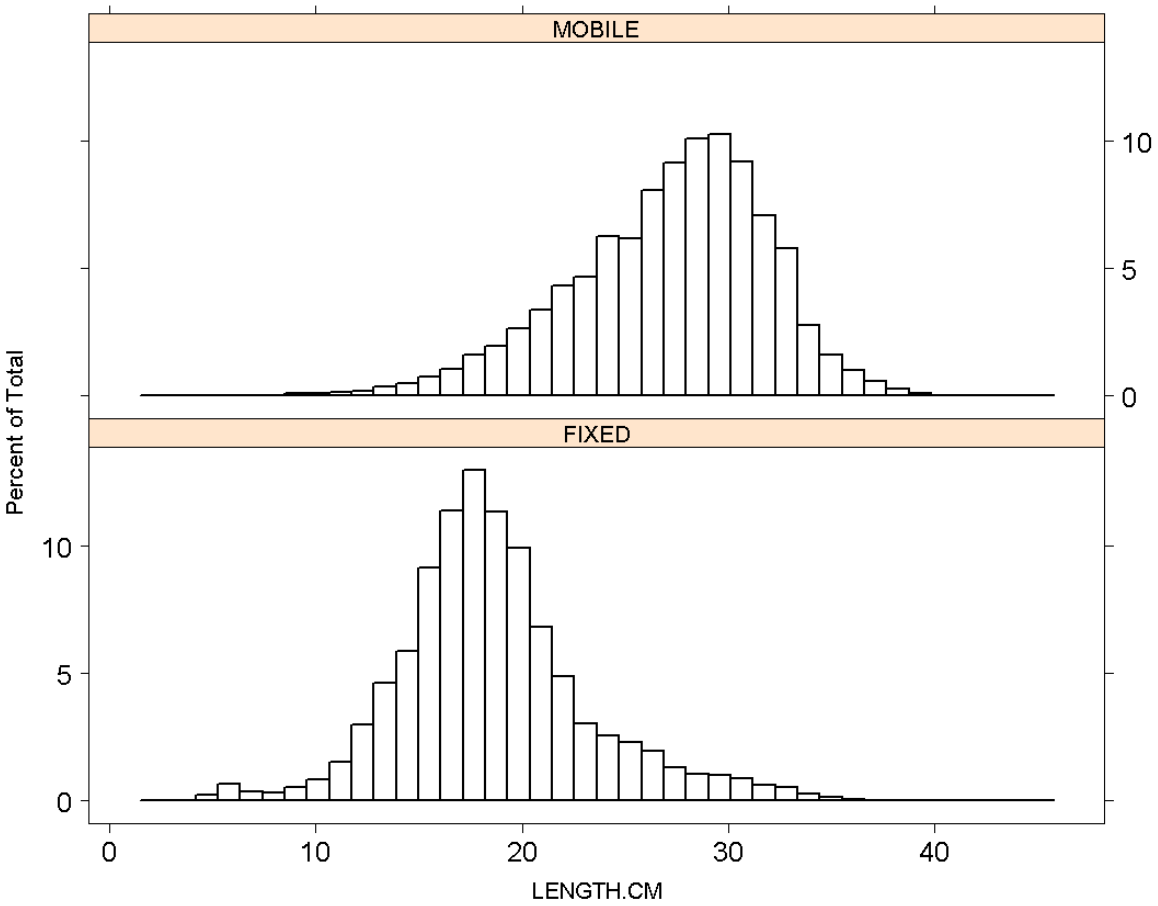


Figure A1-1. Length frequency of US commercial catches for fixed and mobile gear types during 1964-2011.

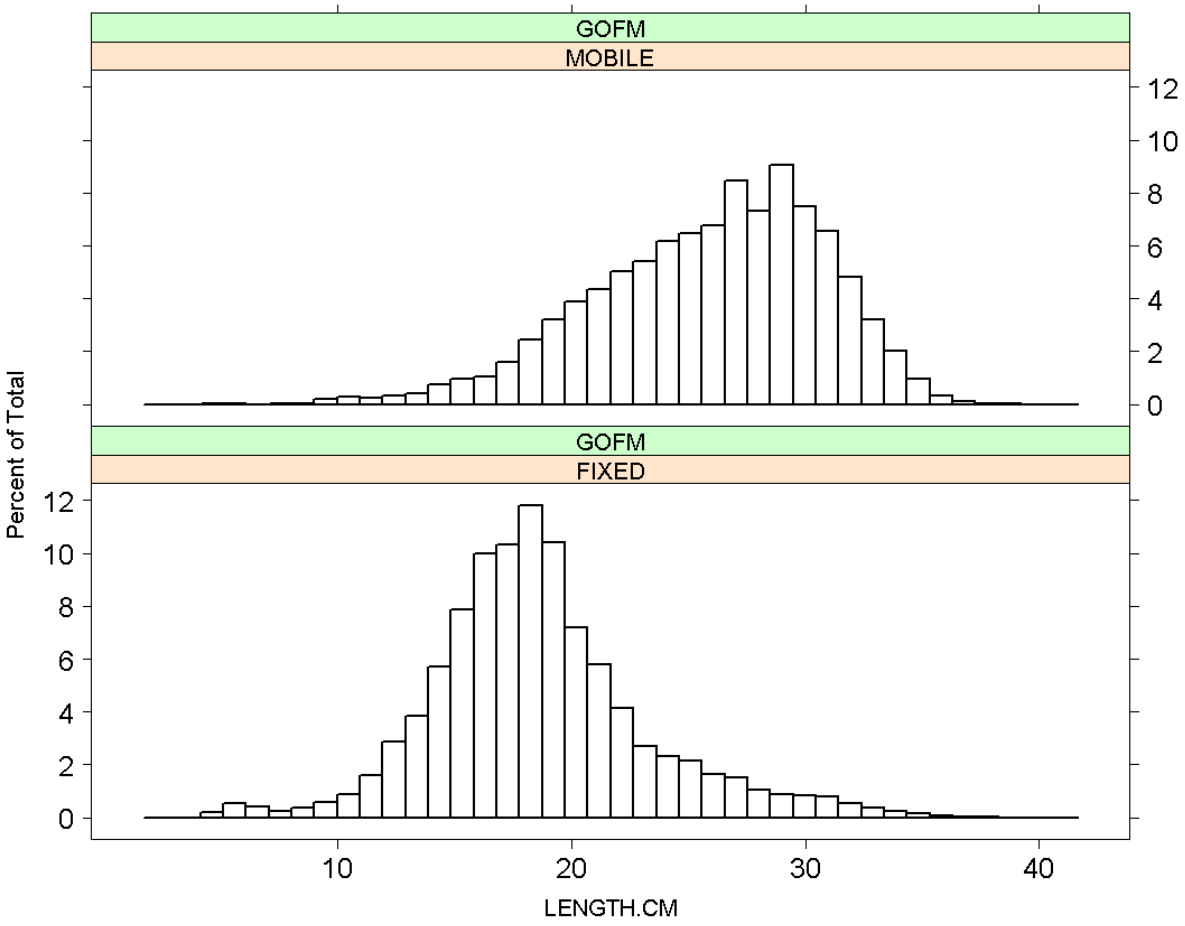


Figure A1-2. Length frequency of US commercial catches for fixed and mobile gear types in the Gulf of Maine during 1964-2011.

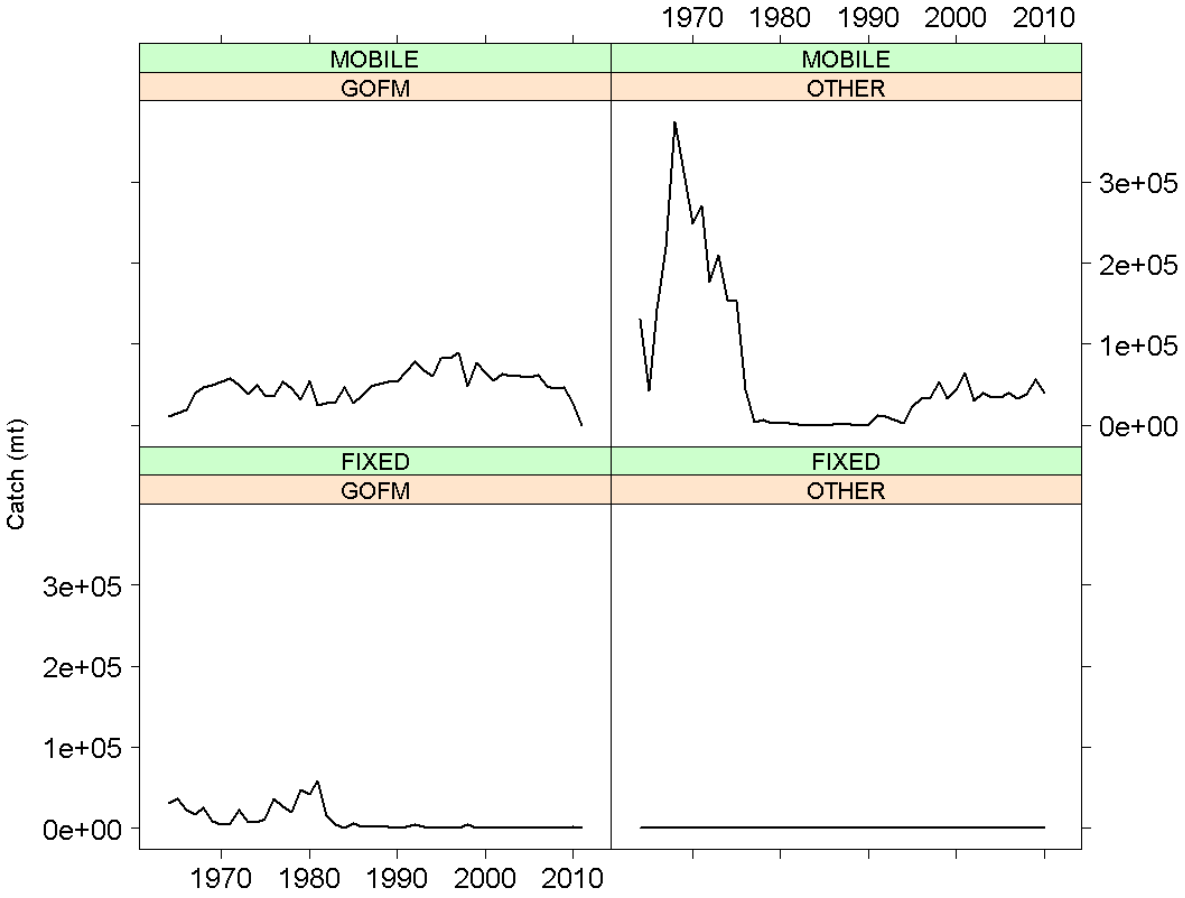


Figure A1-3. Atlantic herring catch during 1964-2011 for US mobile gears and US fixed gears in the Gulf of Maine and all other areas.

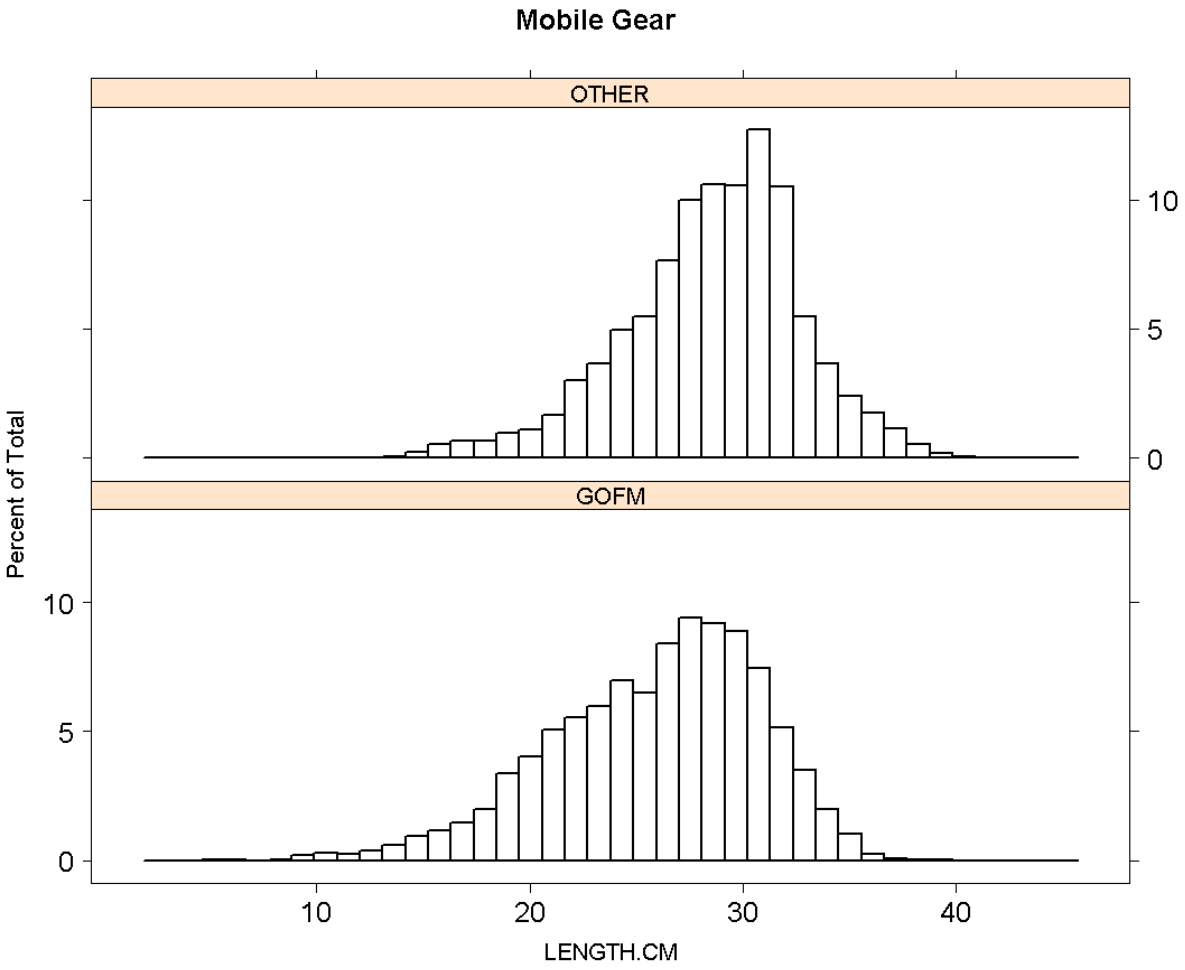


Figure A1-4. Length frequency of US commercial catches for mobile gears in the Gulf of Maine and other areas during 1964-2011. Only one fixed gear trip was sampled outside the Gulf of Maine during the entire time series, and so that data is not presented.

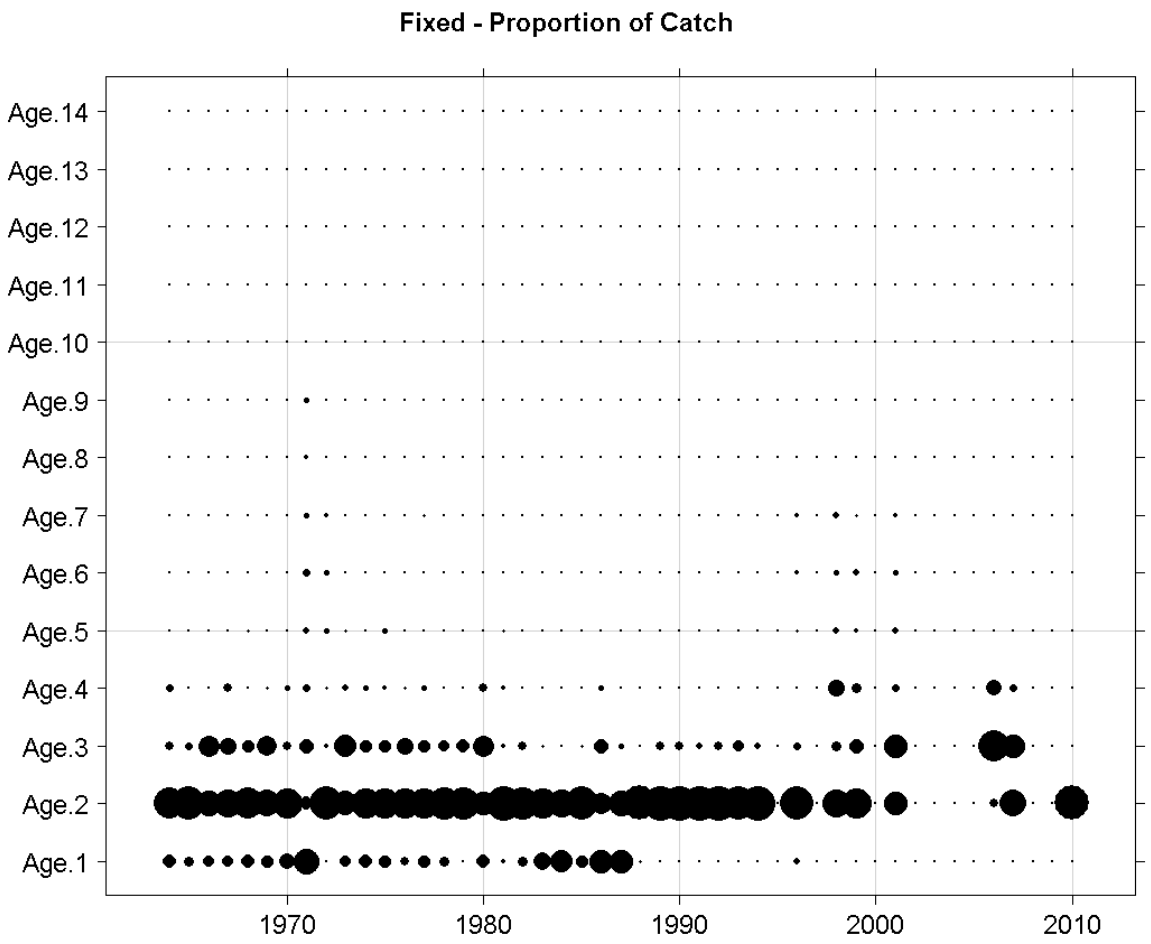


Figure A1-5. "Bubble plot" of the proportion of the catch in each year that is comprised of a given age for the US fixed gear category.

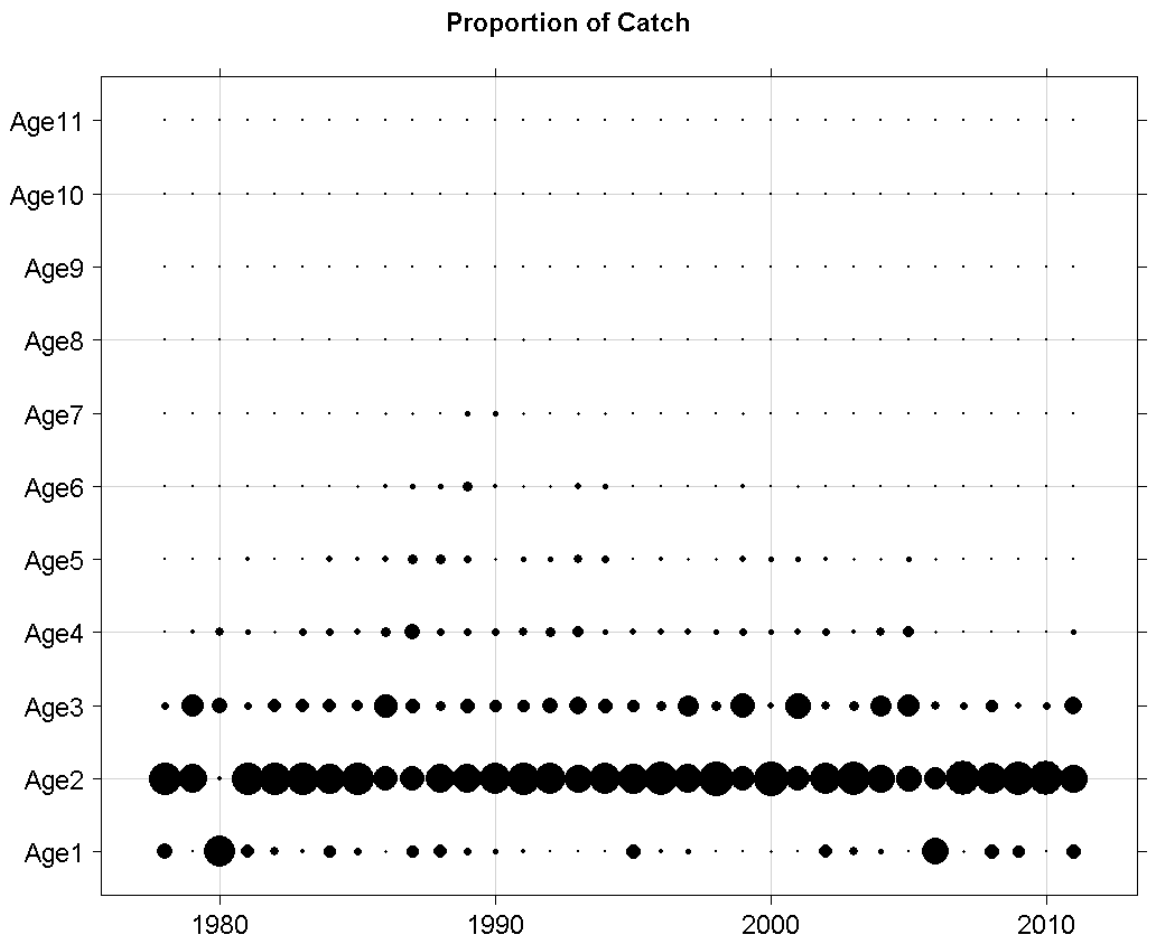


Figure A1-6. "Bubble plot" of the proportion of the catch in each year that is comprised of a given age for the New Brunswick, CA weir fishery.

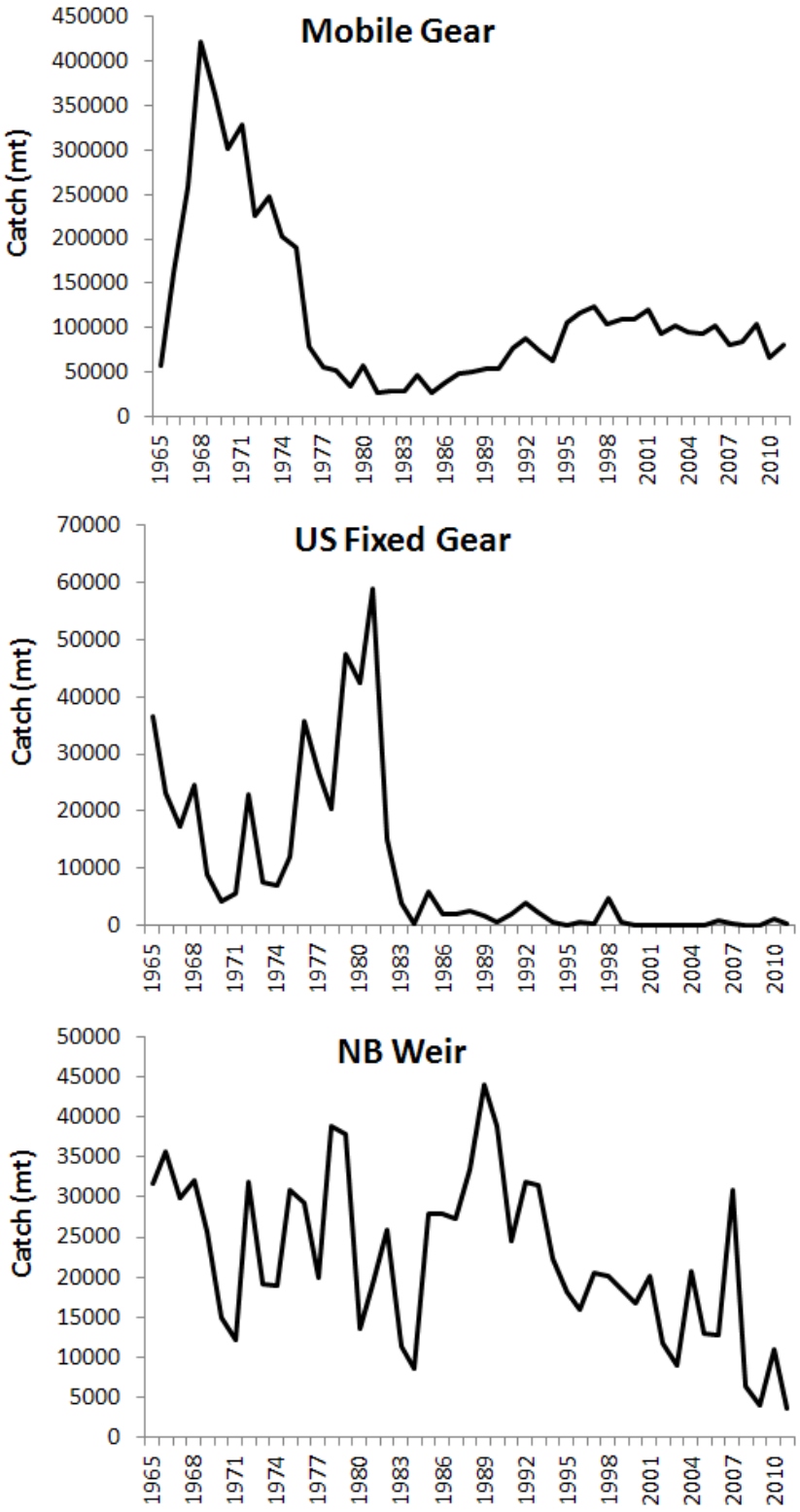


Figure A1-7. Atlantic herring catch during 1965-2011 for US mobile gears, US fixed gears, and NB weir fishery. Discards were only available since 1996.

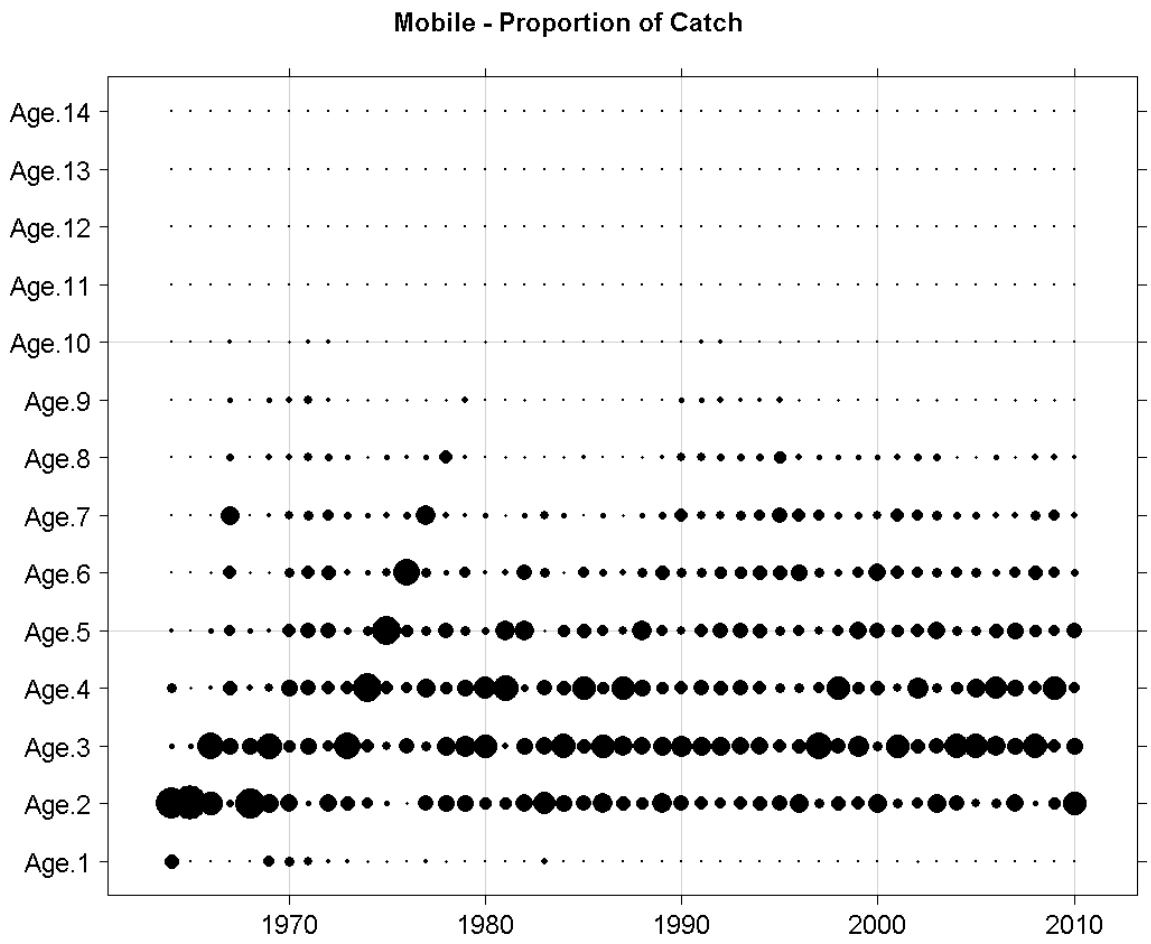


Figure A1-8. "Bubble plot" of the proportion of the catch in each year that is comprised of a given age for the US mobile gear category.

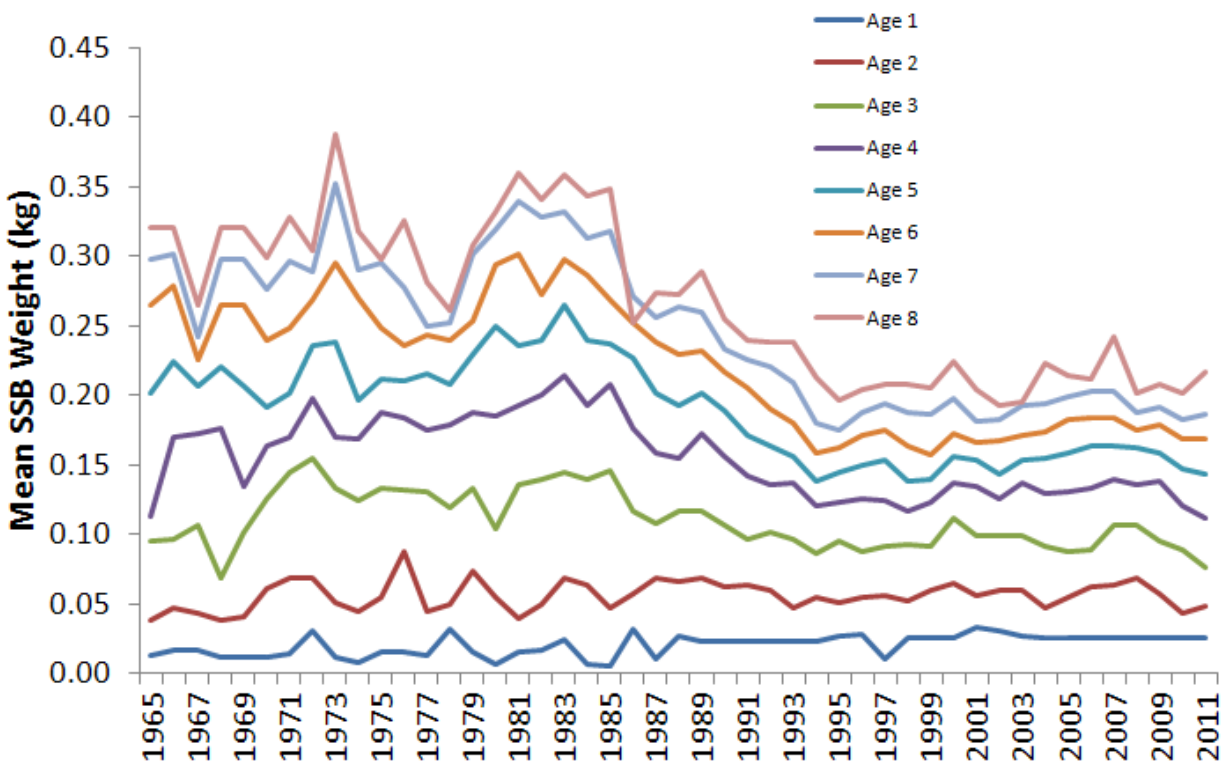


Figure A1-9. Mean spawning stock biomass (SSB) weights at age during 1965-2011.

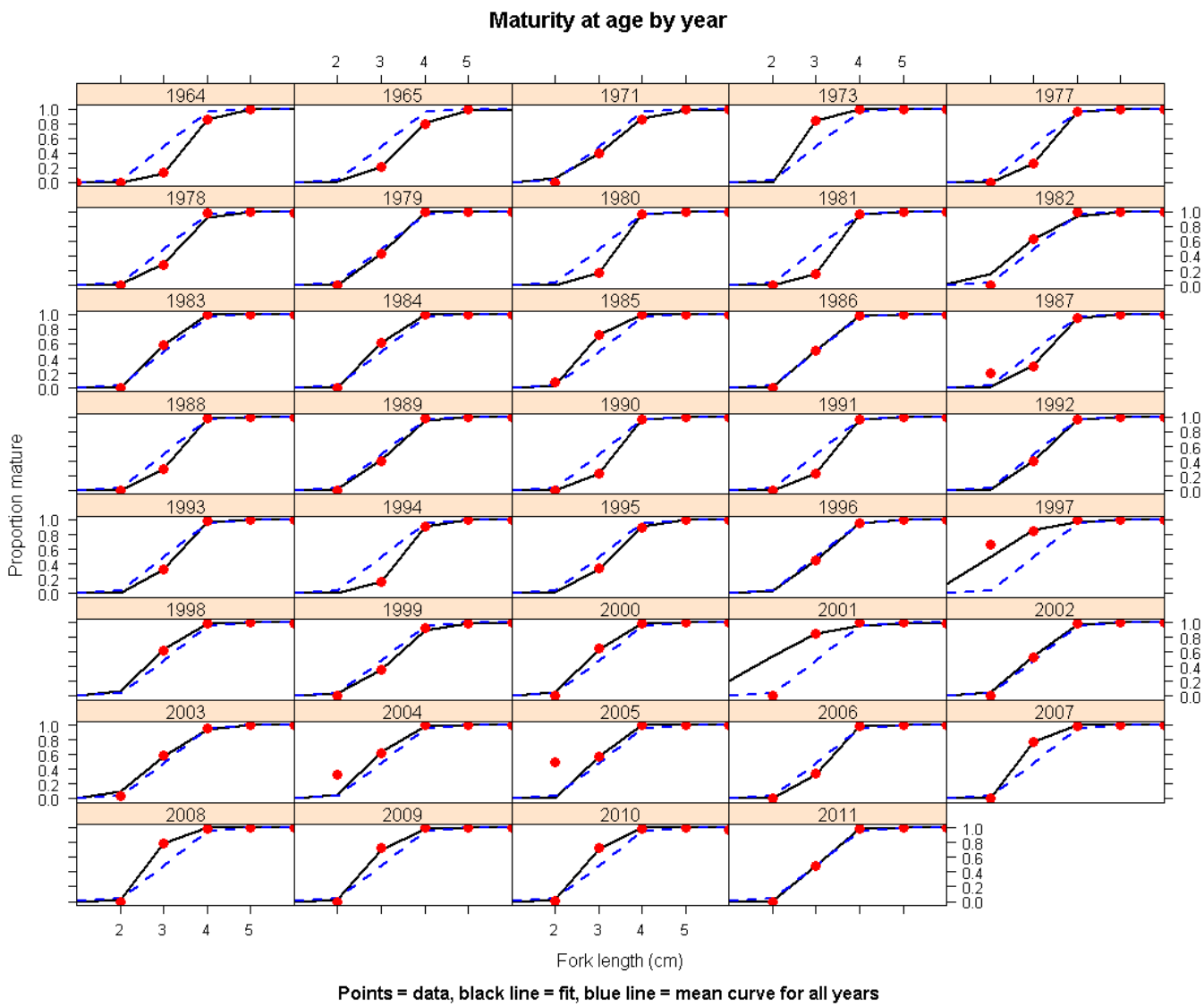


Figure A1-10. Maturity at age in each year, 1964-2011. Red dots are observed proportion mature, blue line is the mean among all years, and black line is the predicted maturity at age from a general additive model.

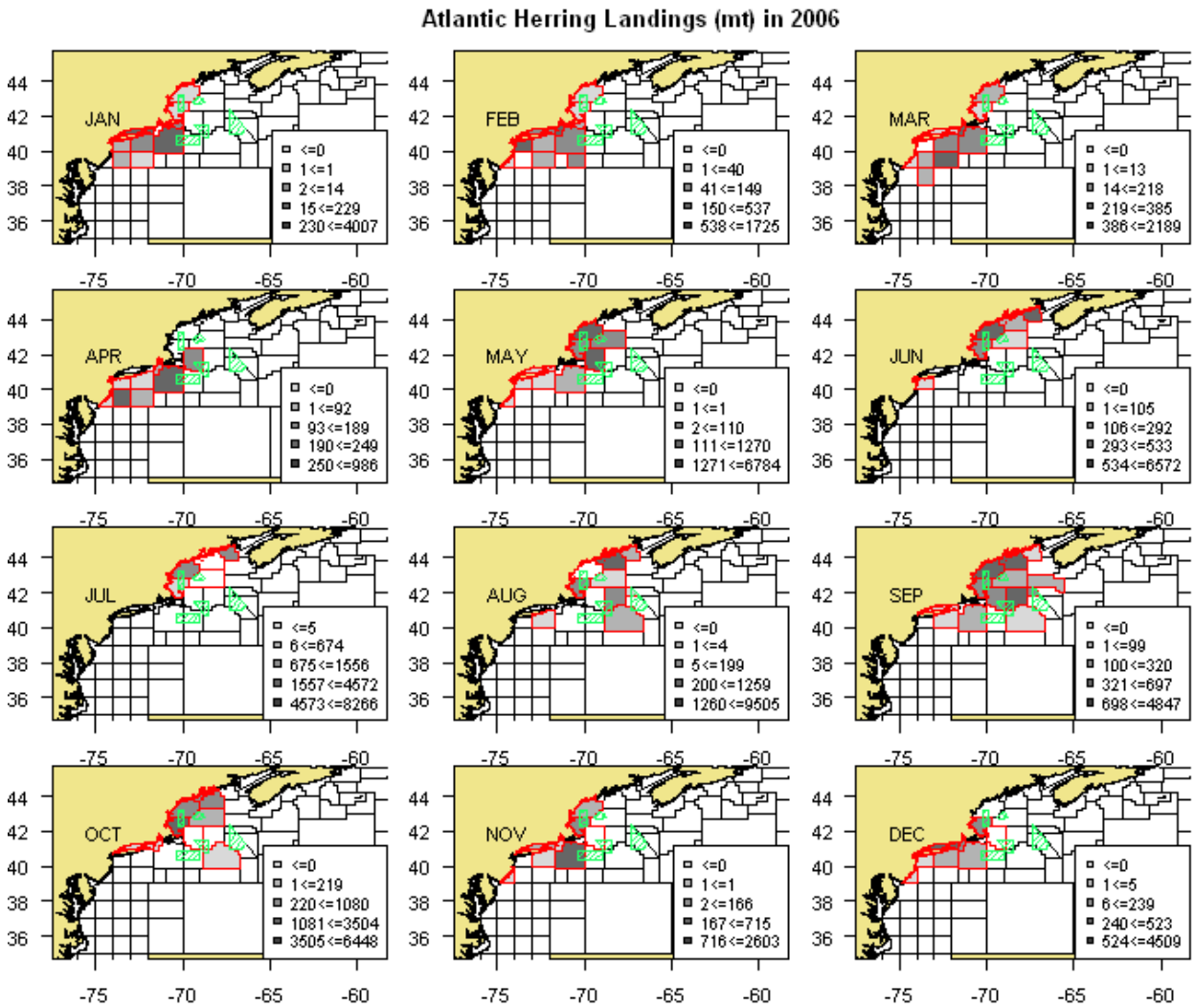


Figure A1-11. Distribution of Atlantic herring landings by month in 2006.

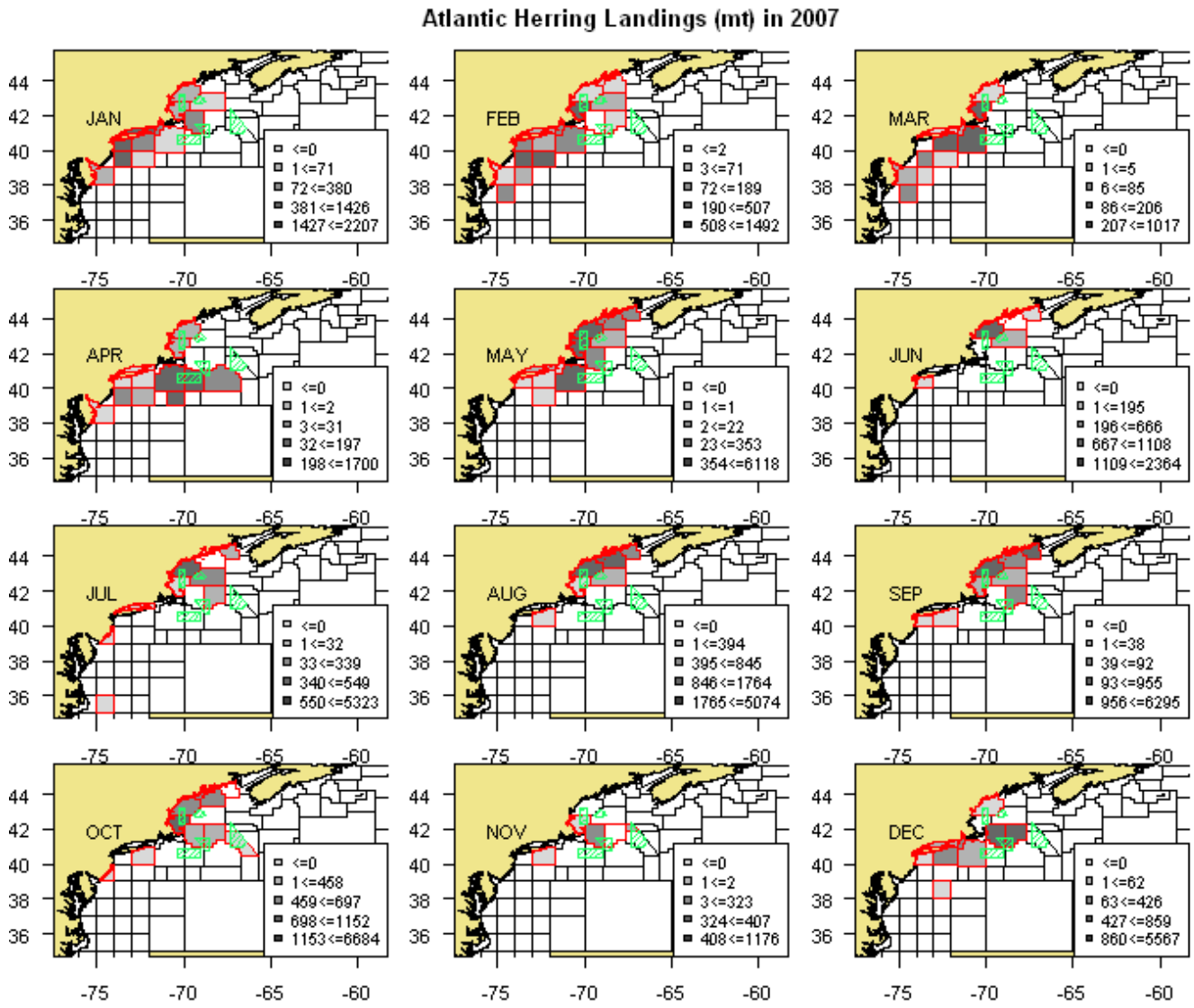


Figure A1-12. Distribution of Atlantic herring landings by month in 2007.

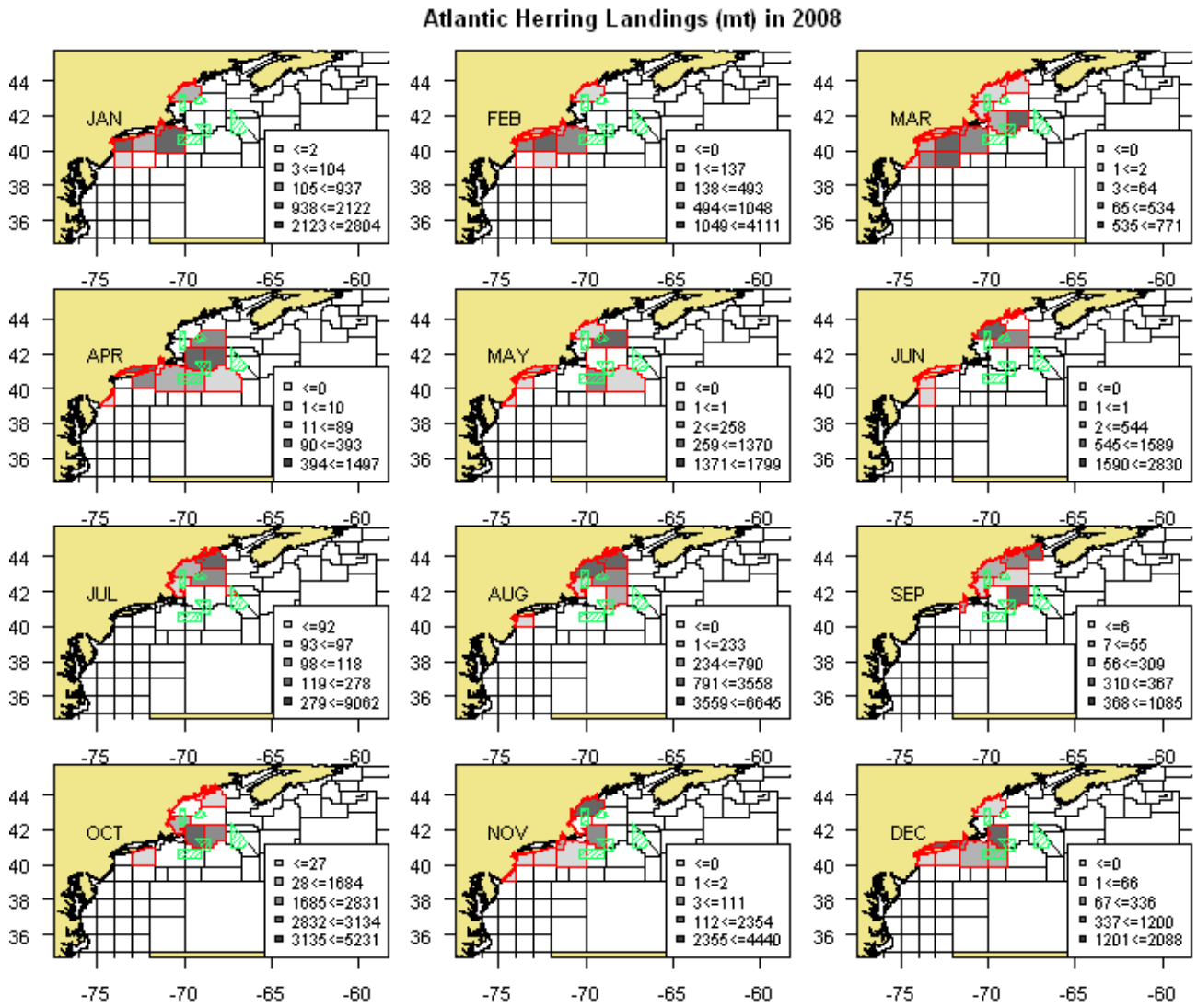


Figure A1-13. Distribution of Atlantic herring landings by month in 2008.

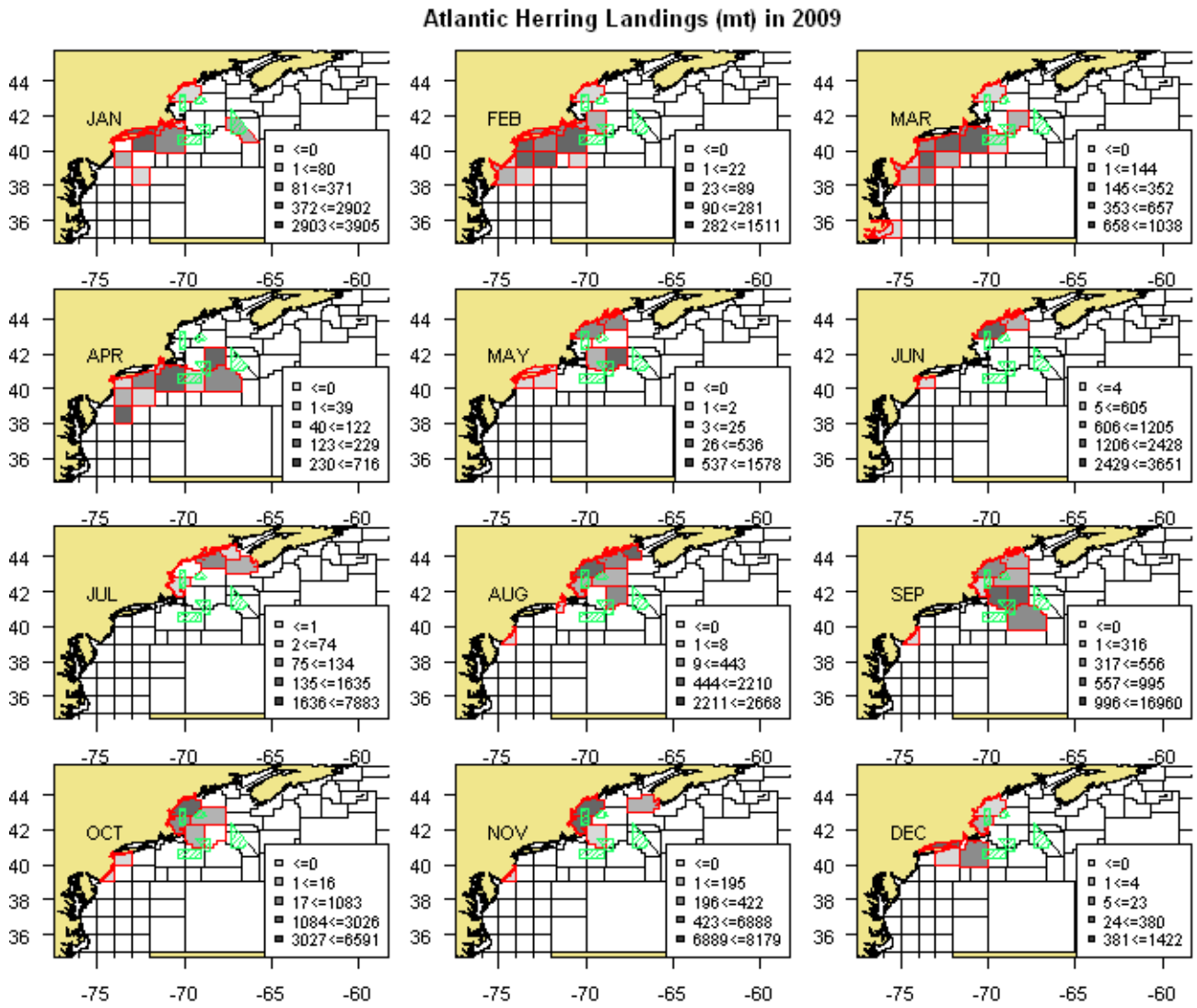


Figure A1-14. Distribution of Atlantic herring landings by month in 2009.

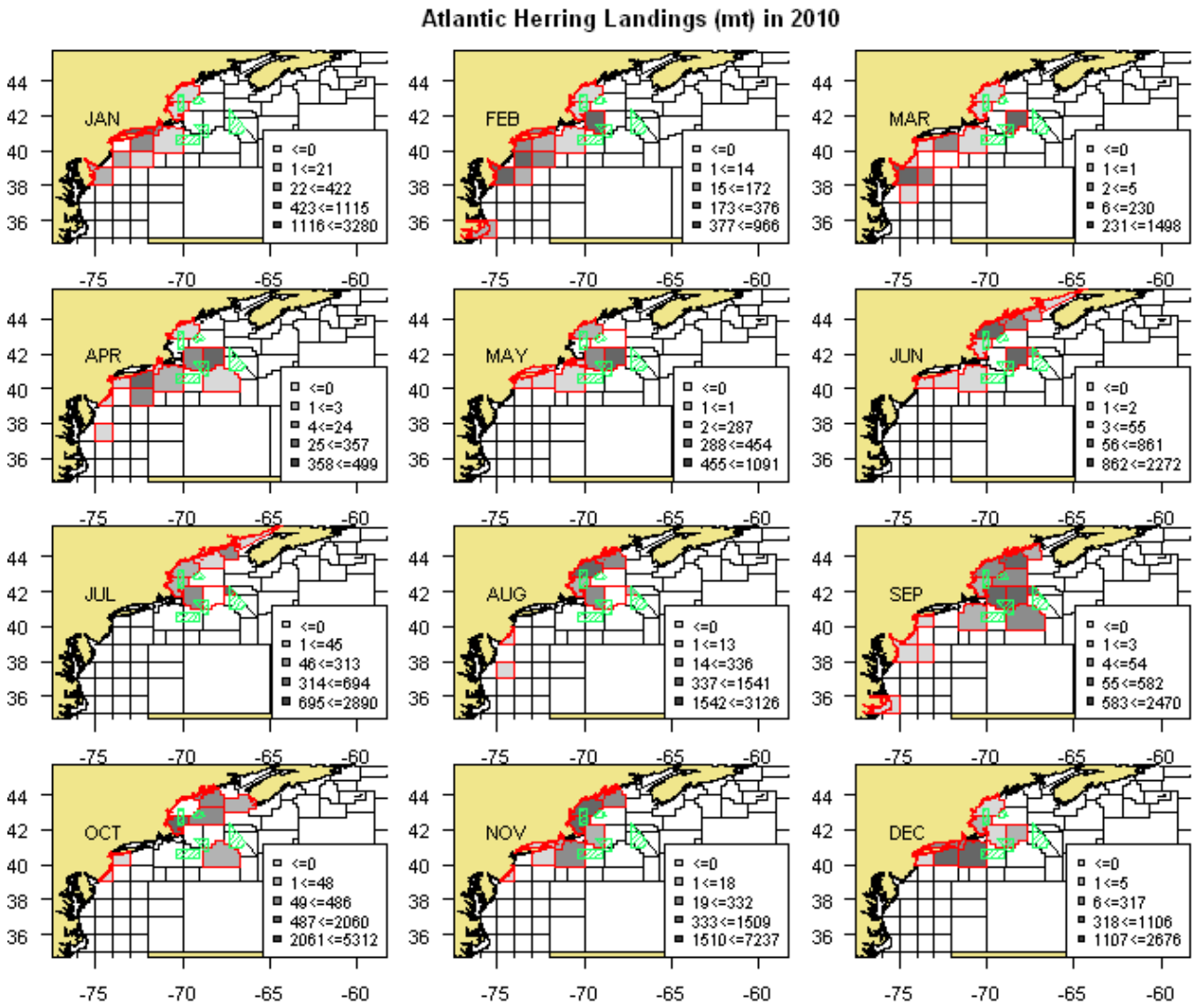


Figure A1-15. Distribution of Atlantic herring landings by month in 2010.

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

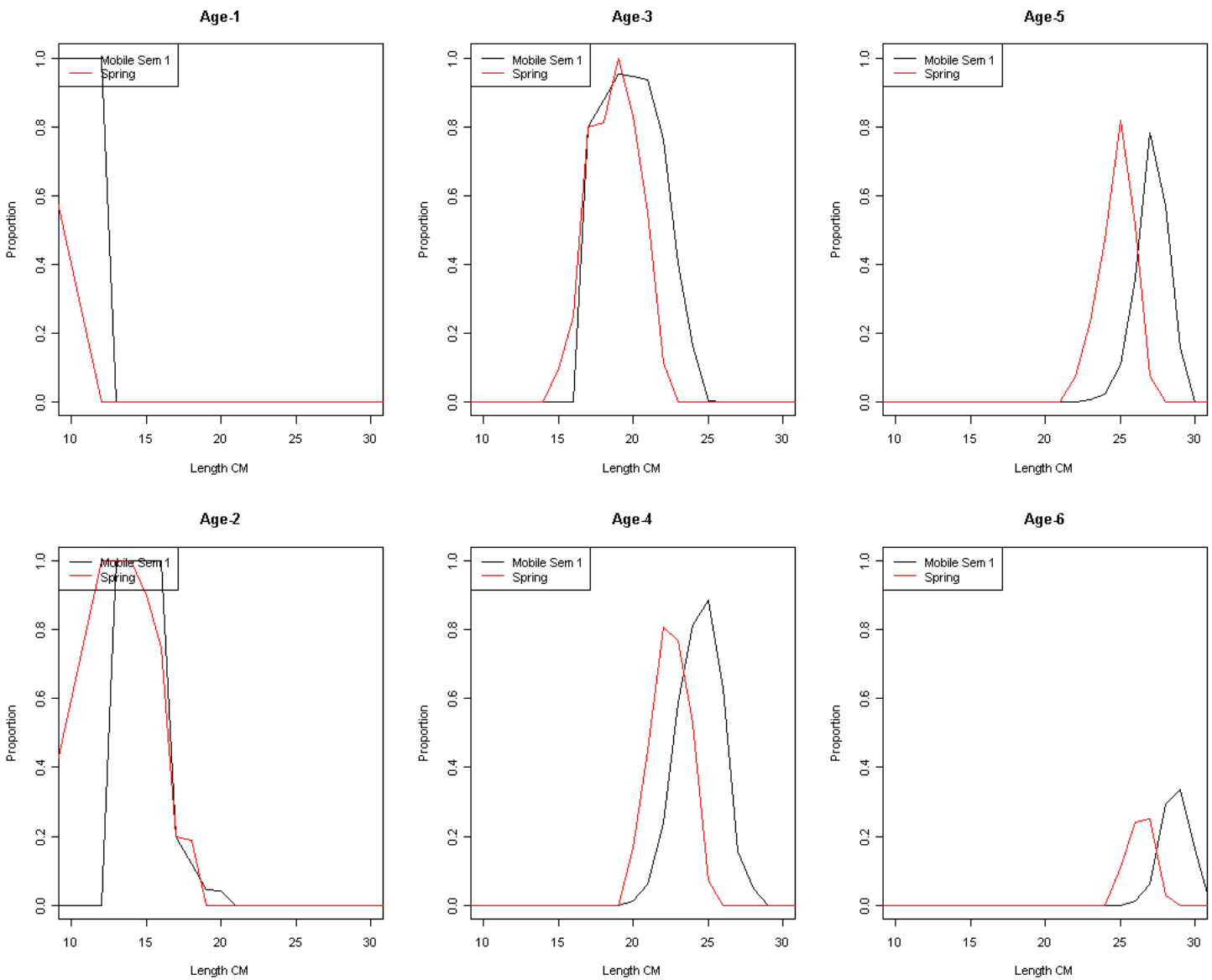


Figure A2-1. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2006.

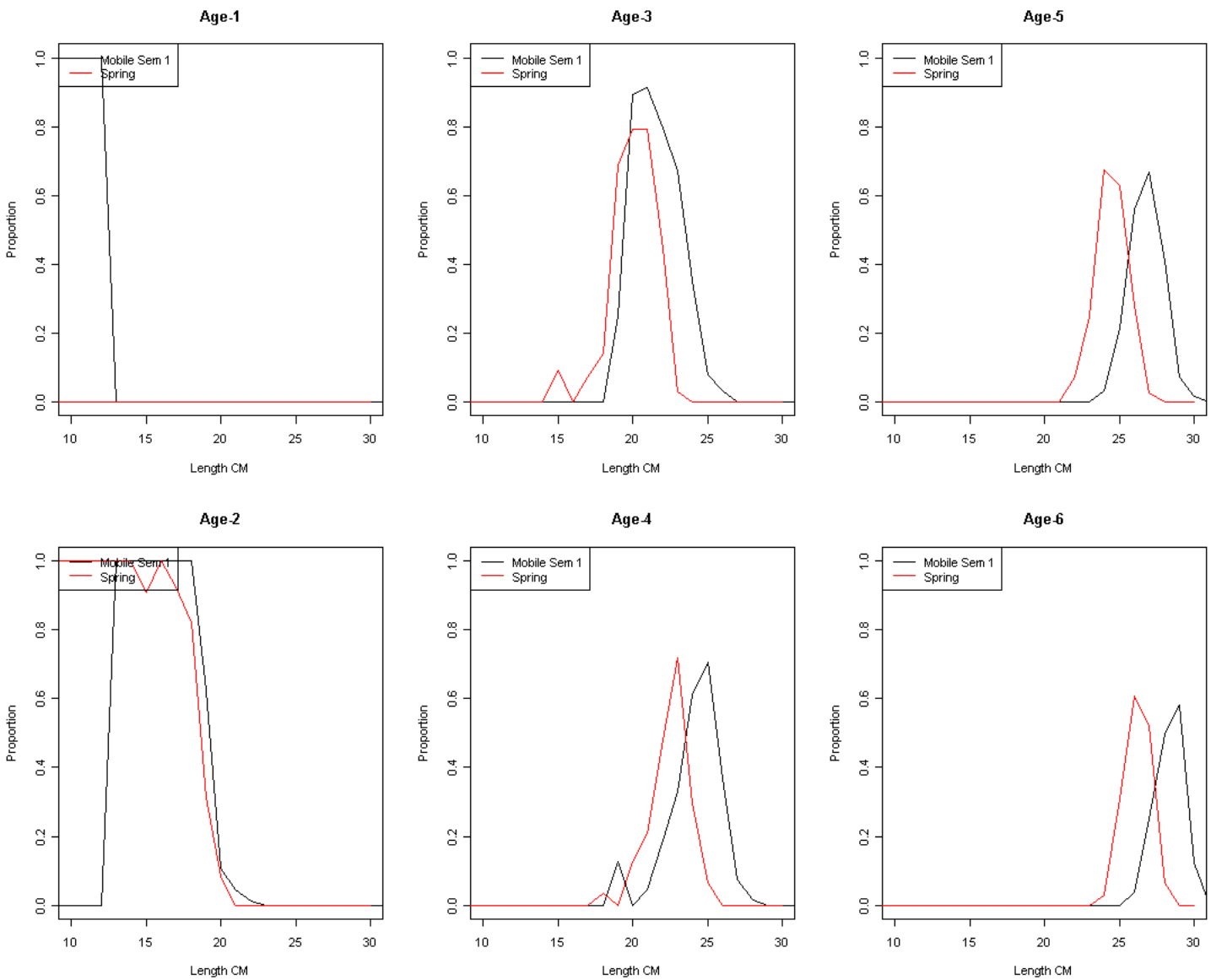


Figure A2-2. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2007.

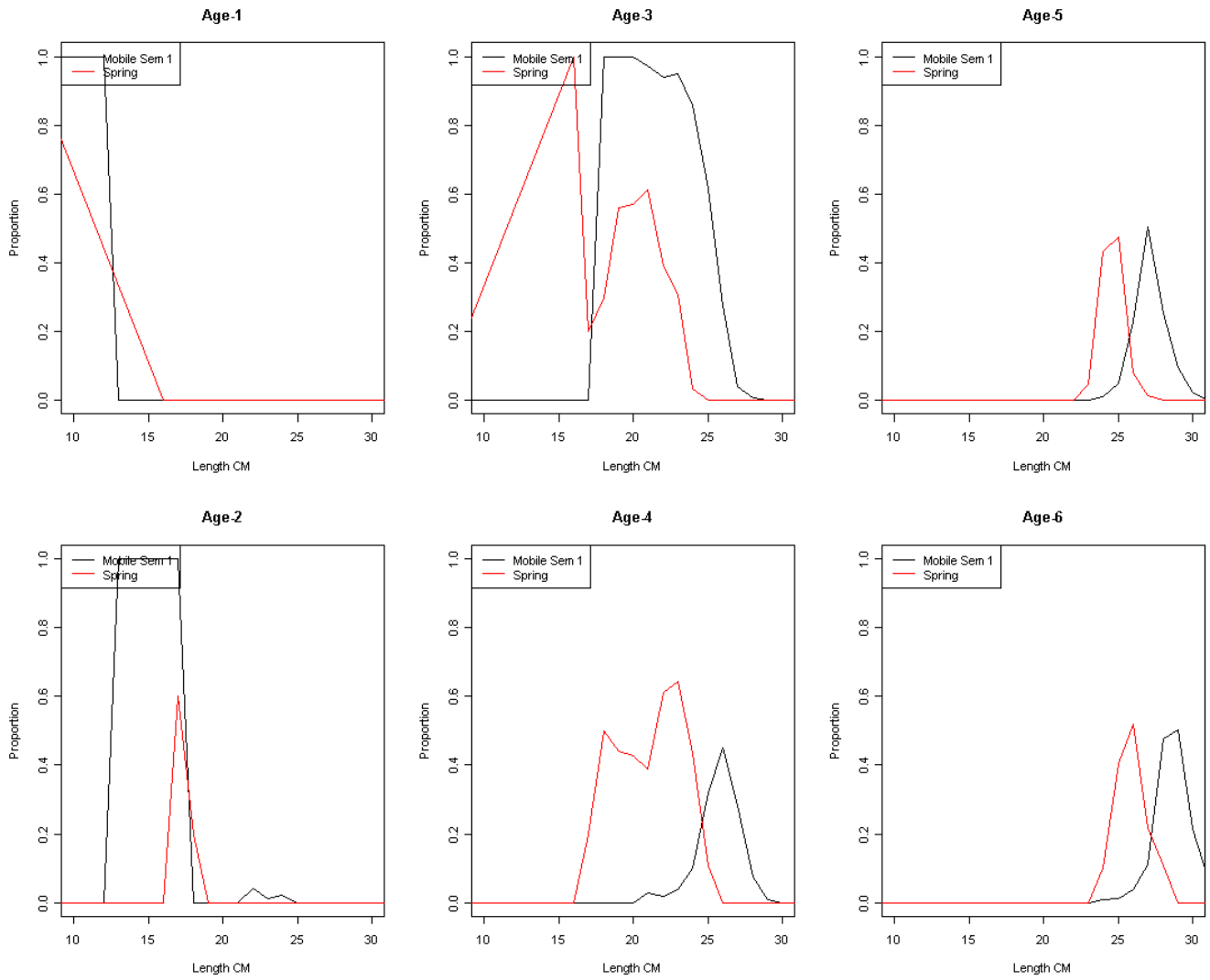


Figure A2-3. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2008.

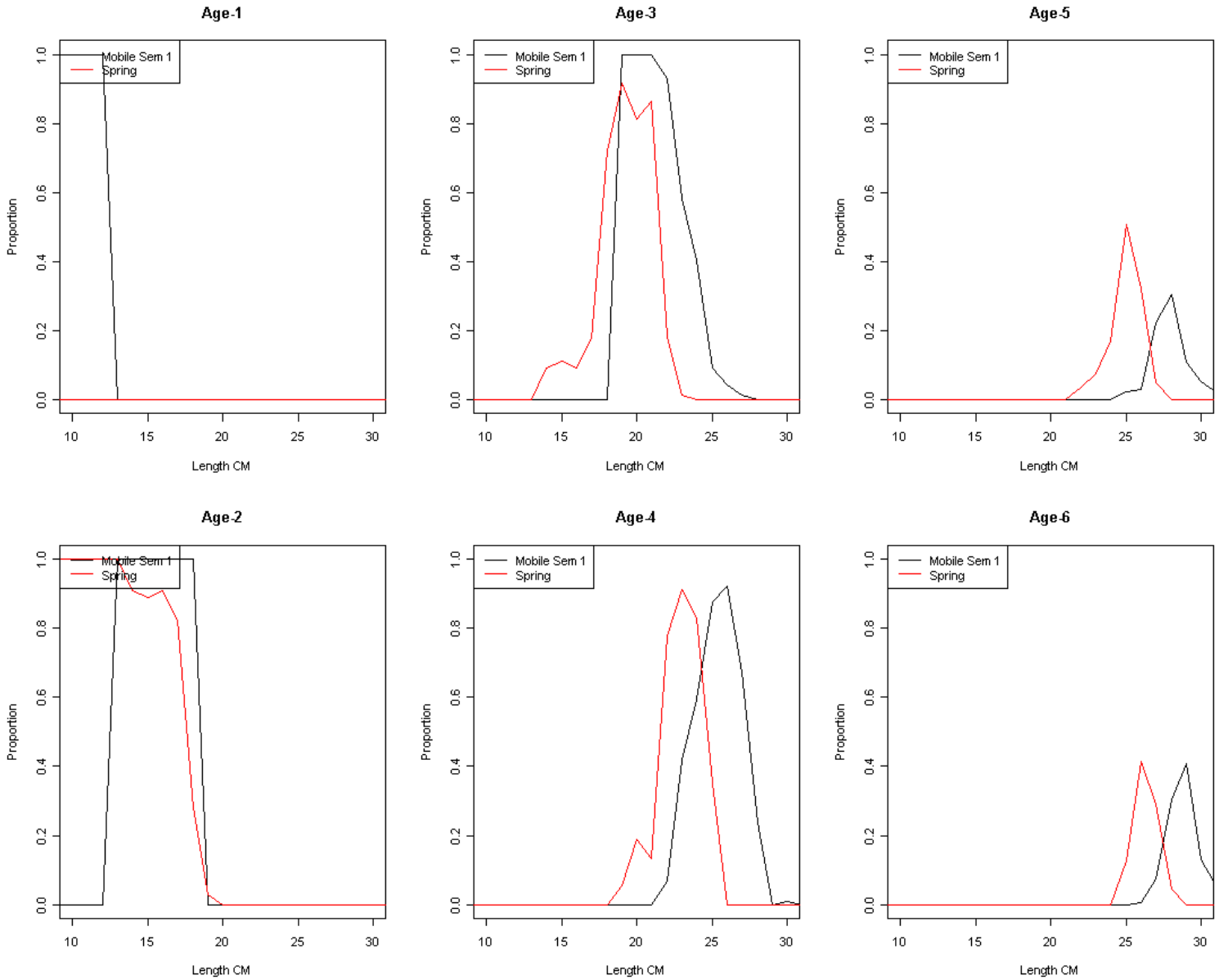


Figure A2-4. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2009.

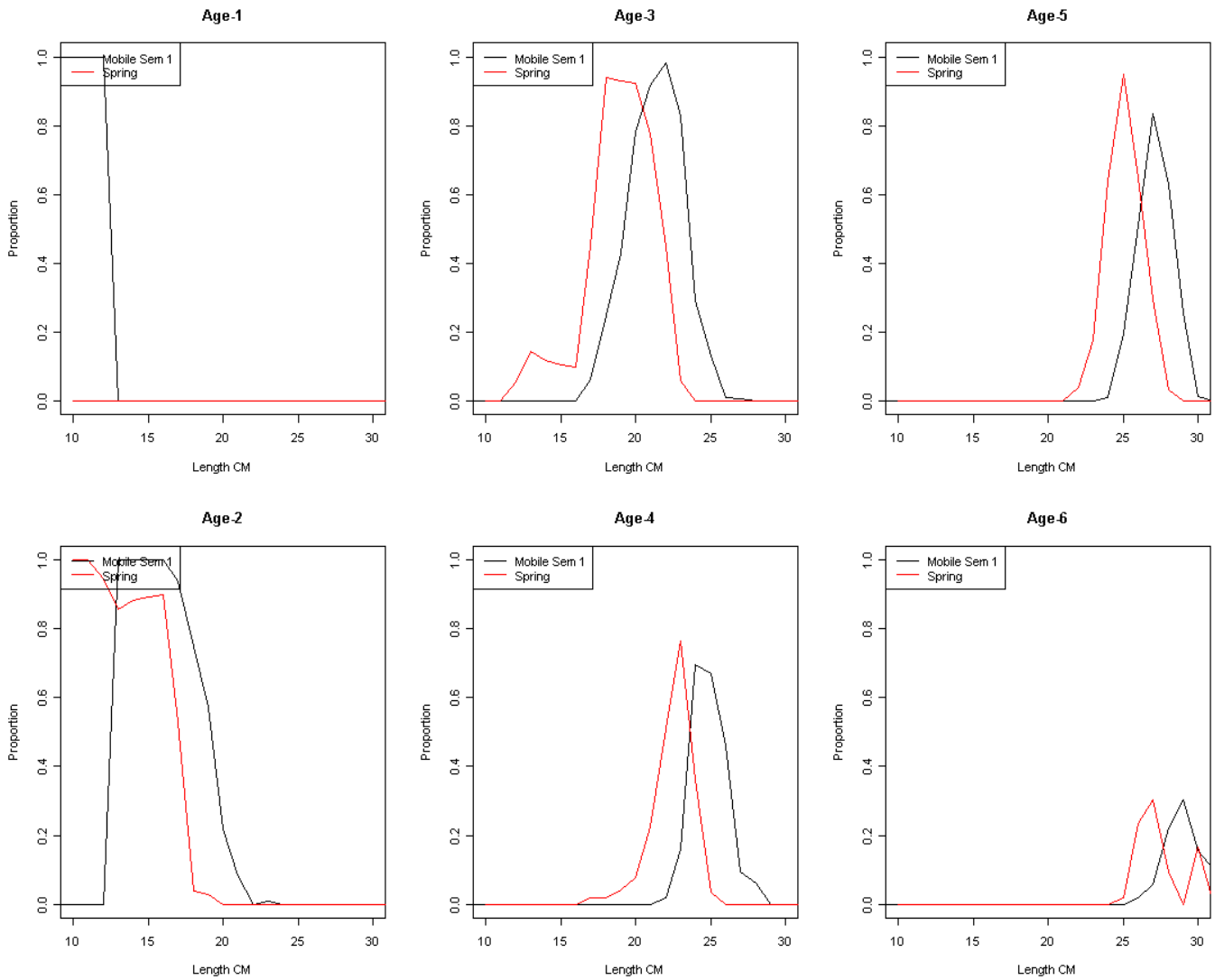


Figure A2-5. Graphical representation of age-length keys (i.e., the proportion of fish at each length that are of a given age) for the mobile gear fishery during January-June (black) and the NMFS spring survey (red) in 2010.

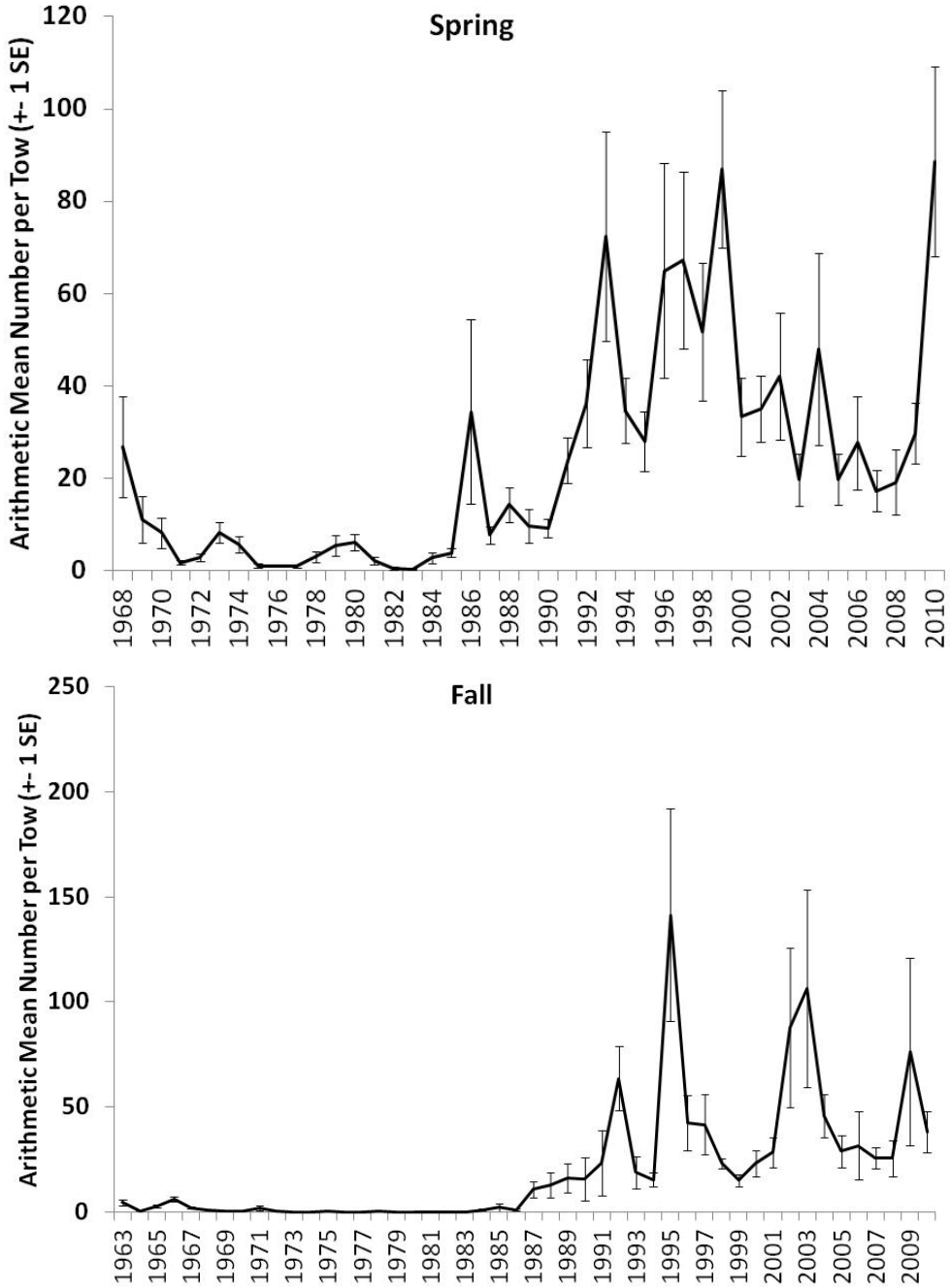


Figure A2-6. NMFS spring and fall bottom trawl survey time series, ± one standard error.

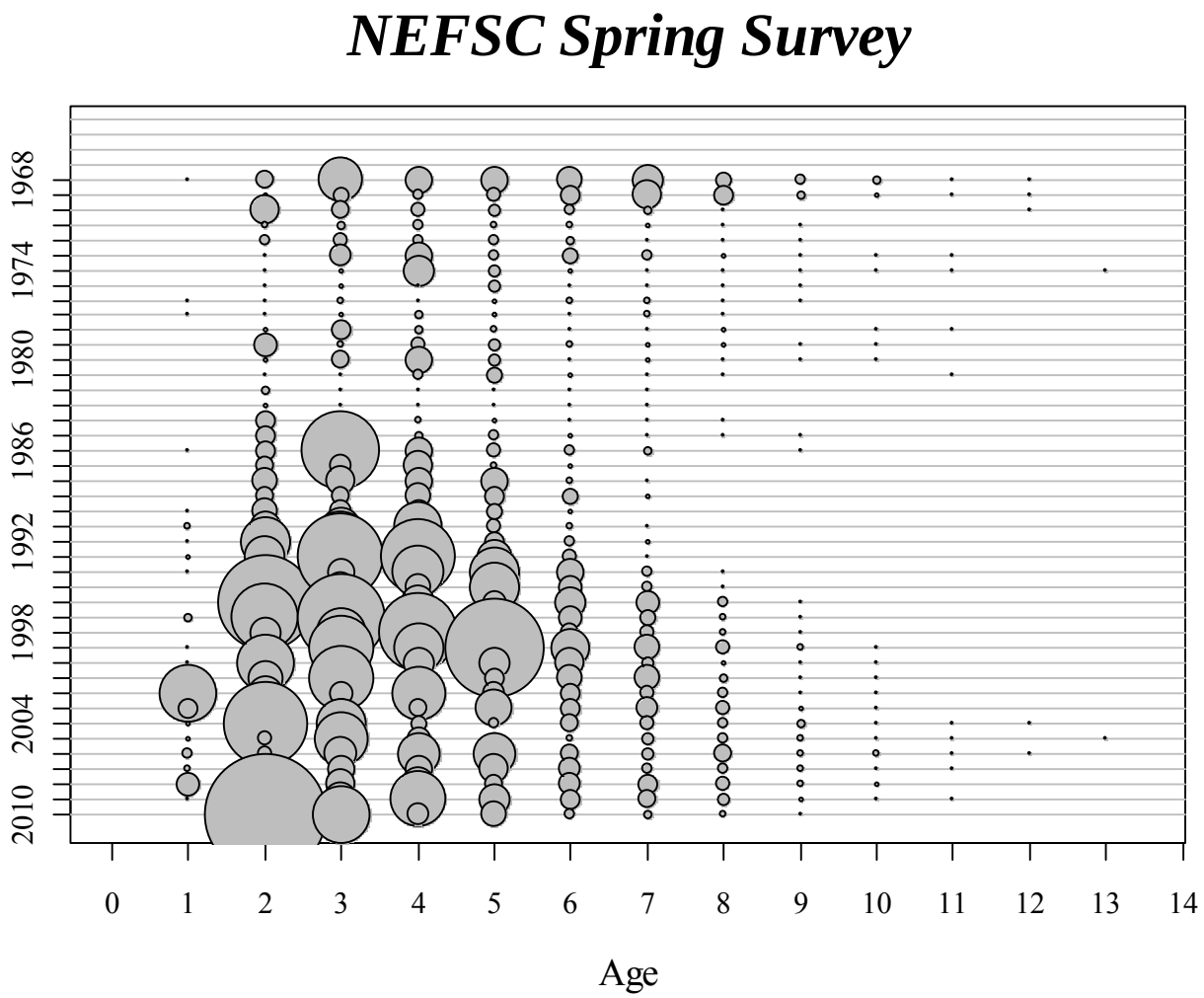


Figure A2-7. "Bubble" plot of NMFS spring survey age composition. Age data prior to 1987 was not used in the assessments (see TOR 2).

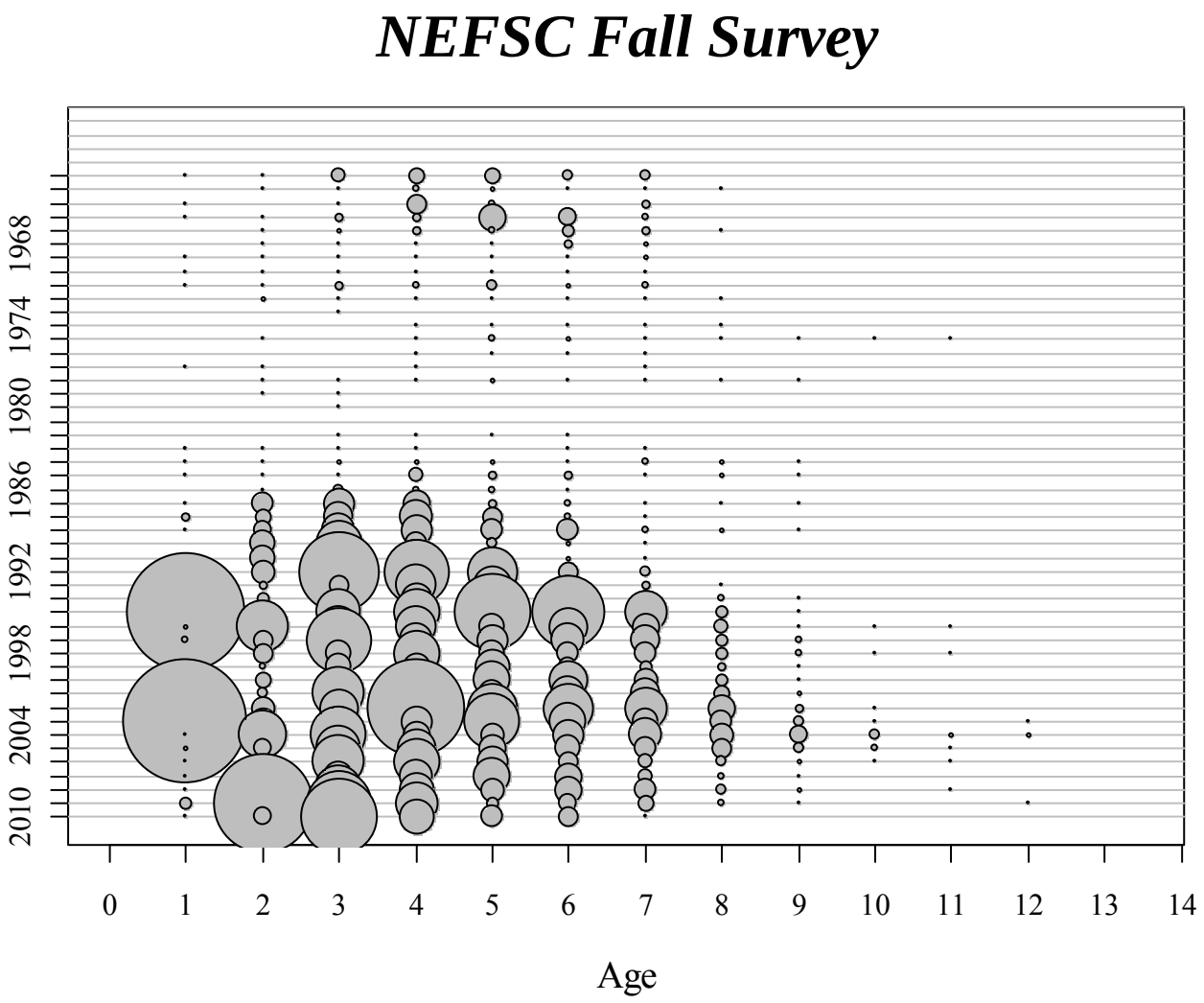


Figure A2-8. "Bubble" plot of NMFS fall survey age composition. Age data prior to 1987 was not used in the assessments (see TOR 2).

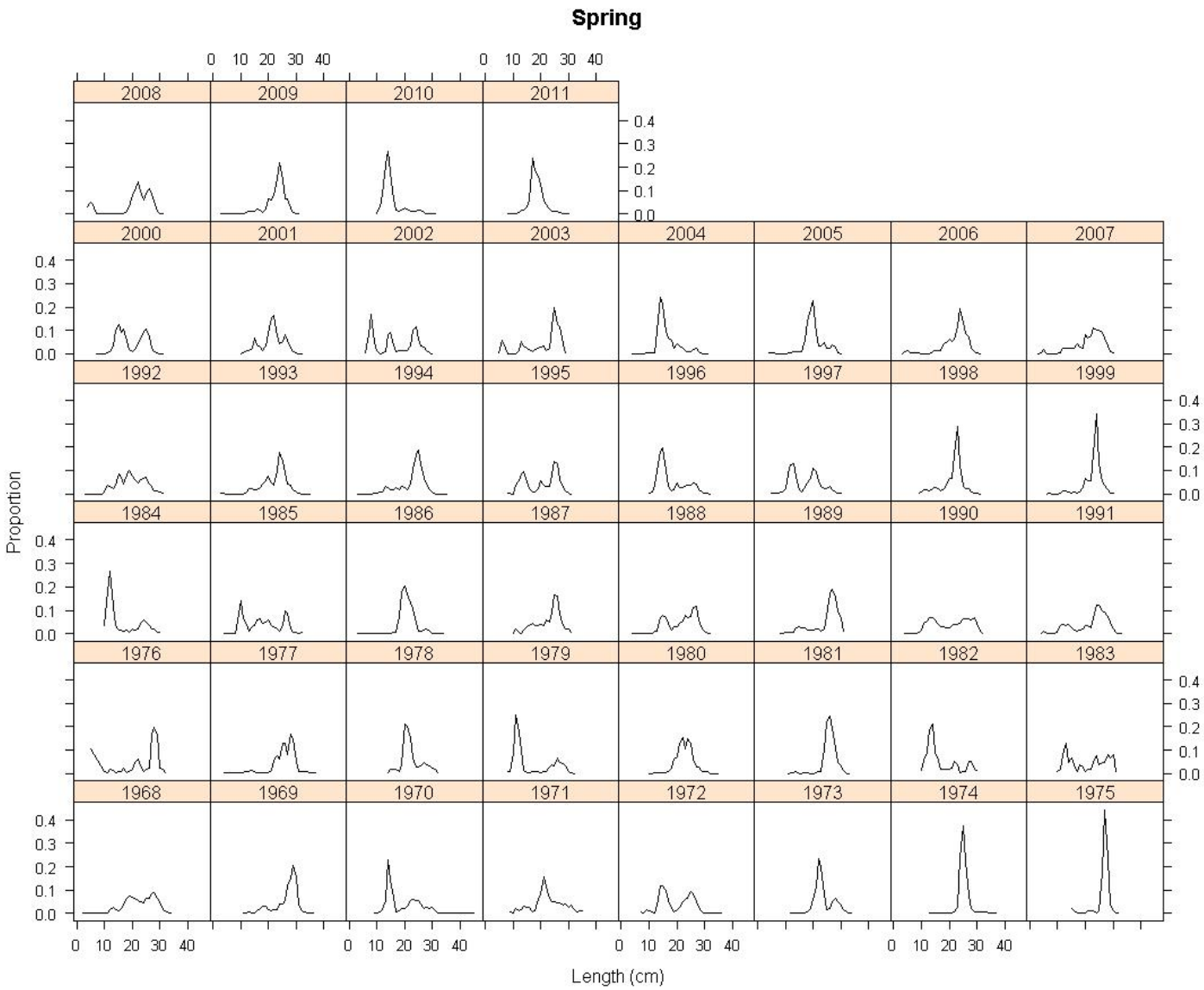


Figure A2-9. Annual length frequencies from the NMFS spring survey.

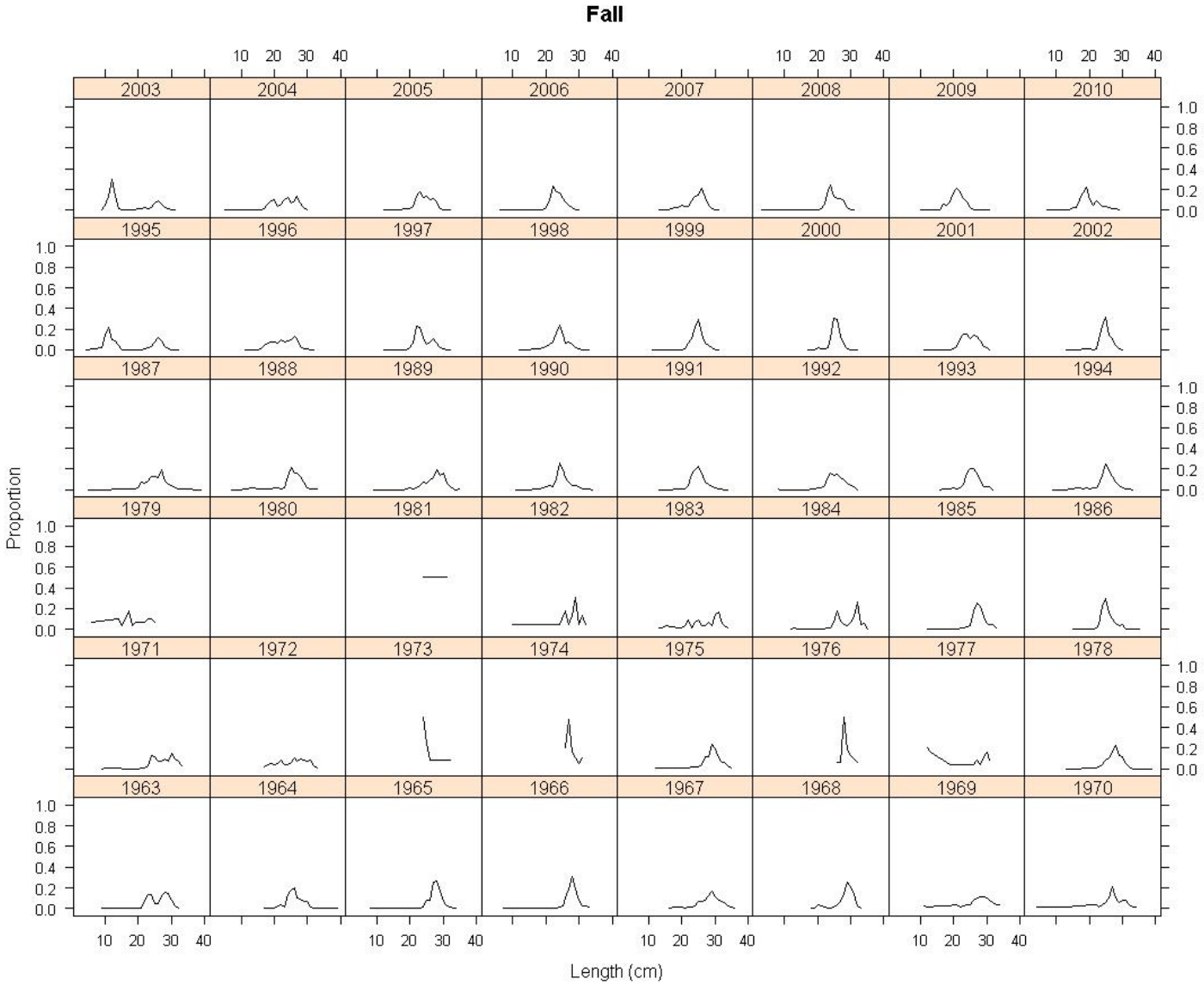


Figure A2-10. Annual length frequencies from the NMFS fall survey.

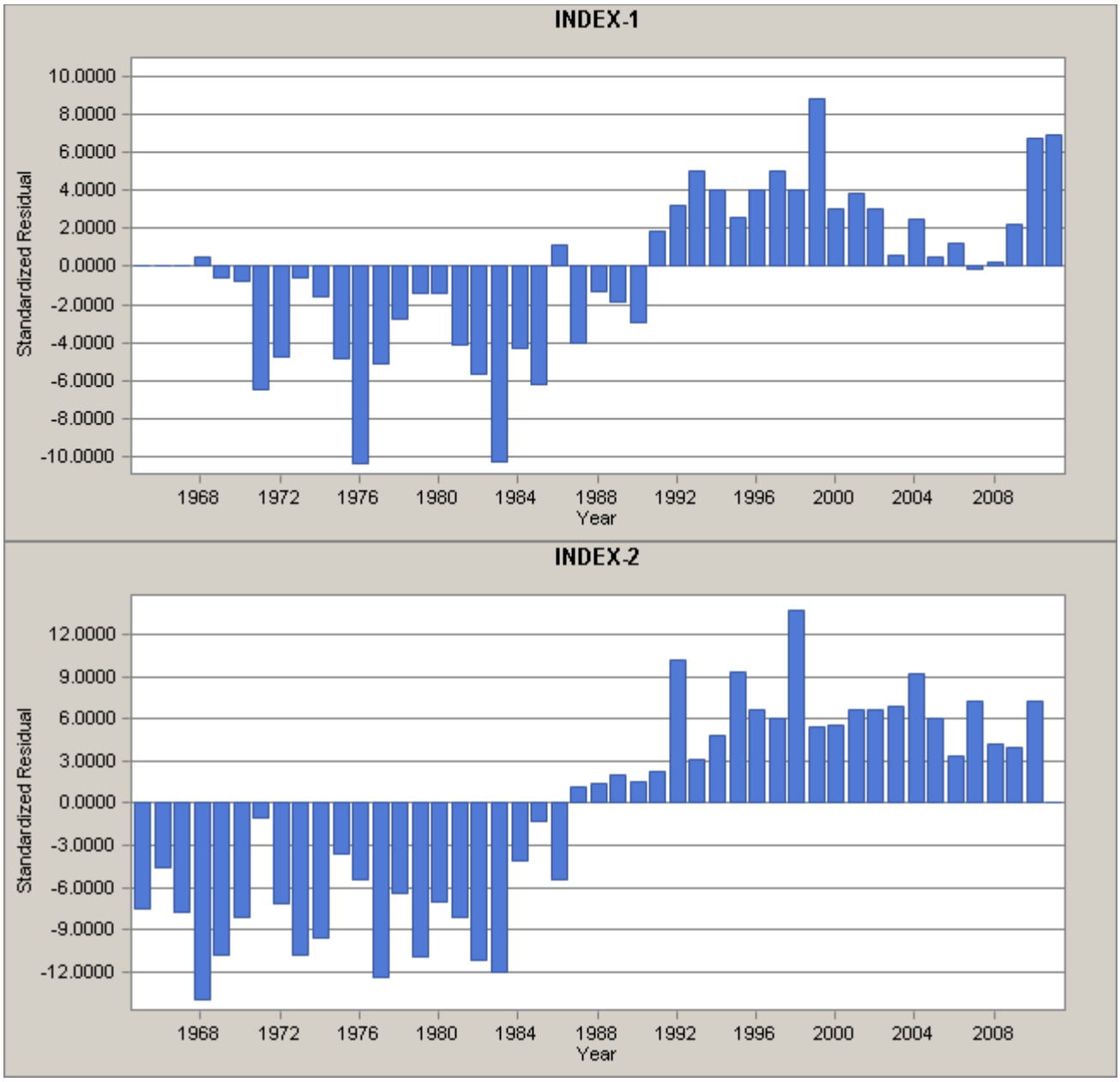


Figure A2-11. Standardized residuals of the fit to the NMFS spring survey (top panel) and fall survey (bottom panel) from a preliminary ASAP model run.

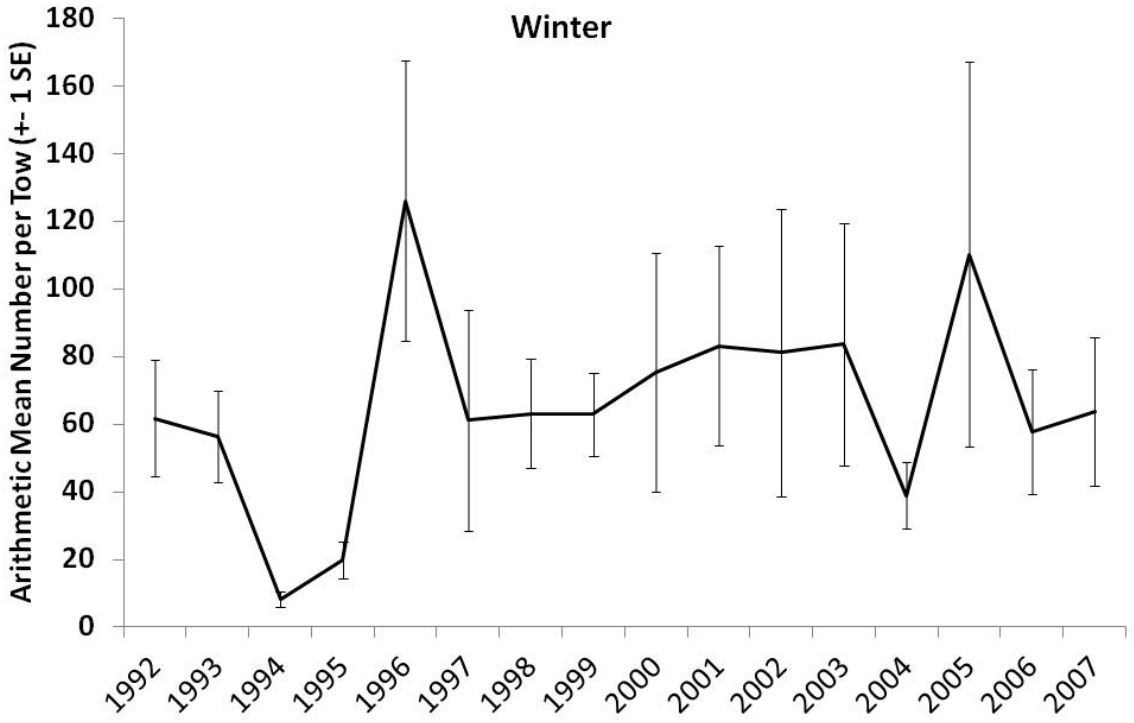


Figure A2-12. NMFS winter bottom trawl survey time series, ± one standard error.

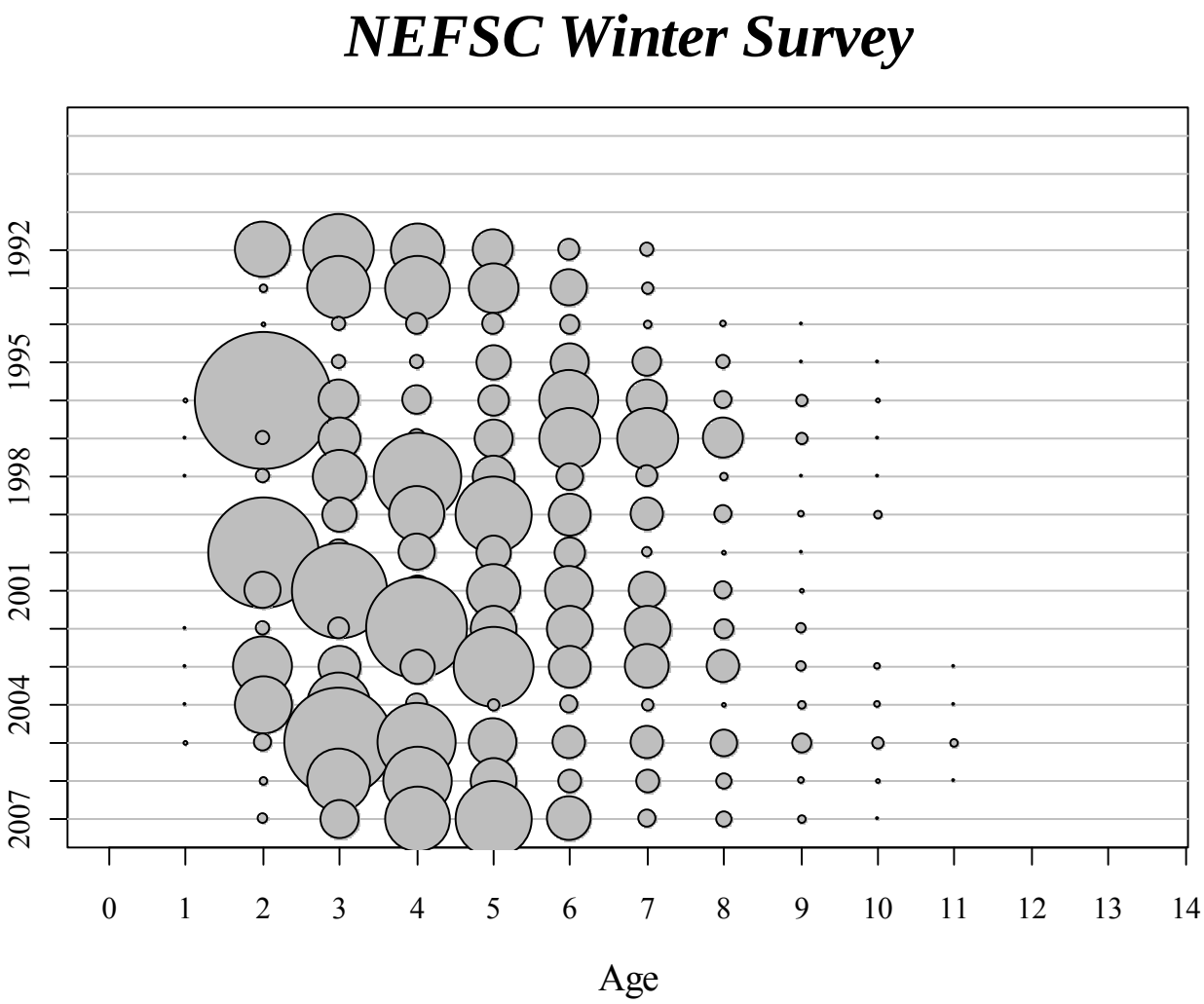


Figure A2-13. "Bubble" plot of NMFS winter survey age composition.

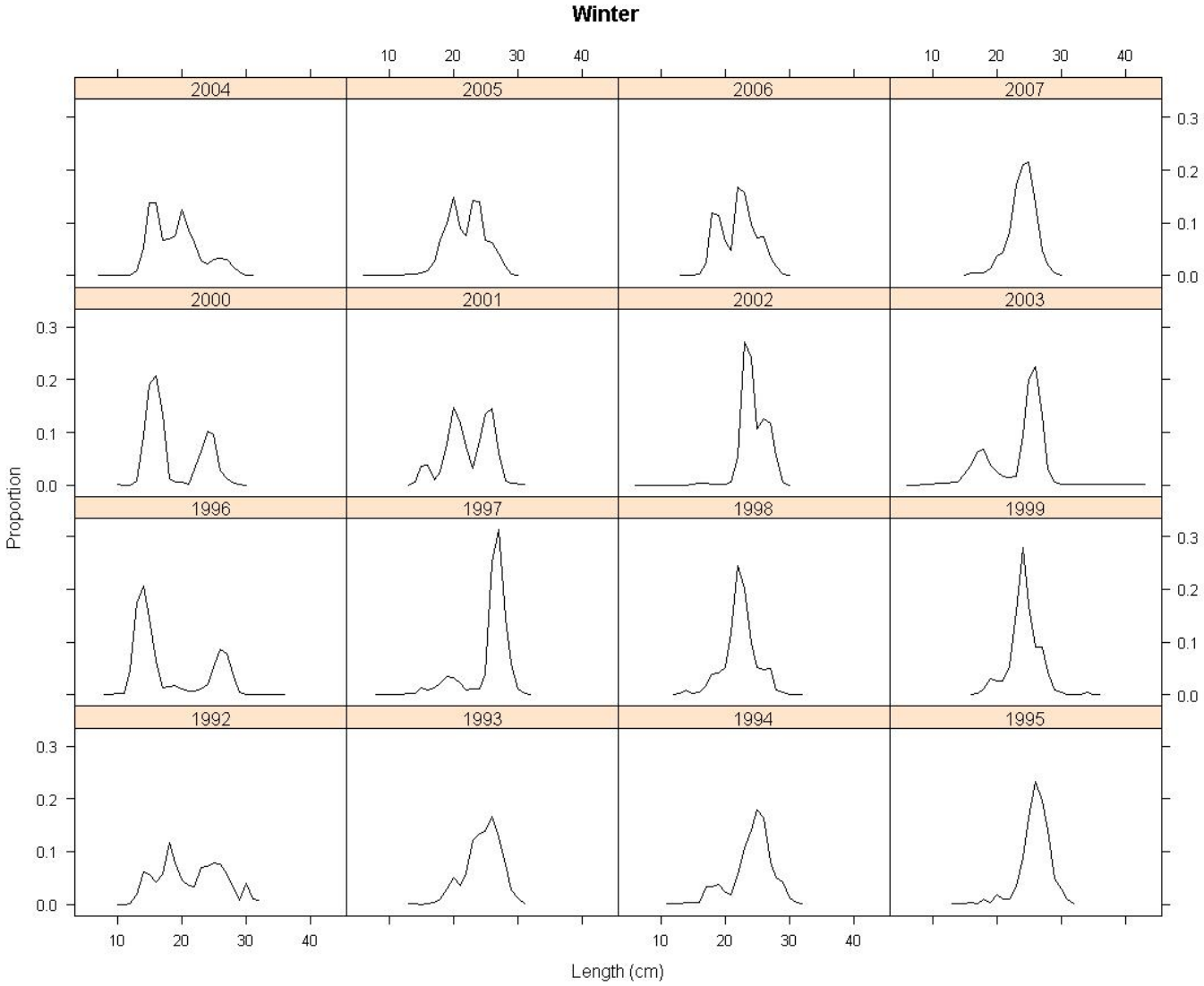


Figure A2-14. Annual length frequencies from the NMFS winter survey.

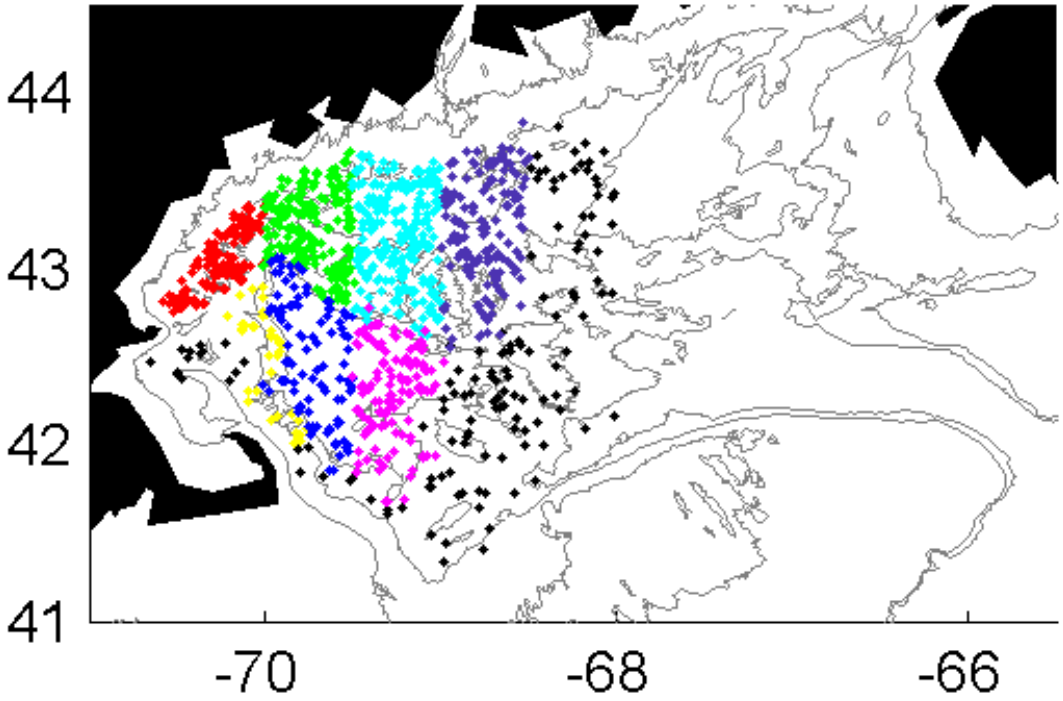


Figure A2-15. Location of tows taken during the NMFS shrimp survey that captured herring during 1983-2011. Different colors represent different survey strata.

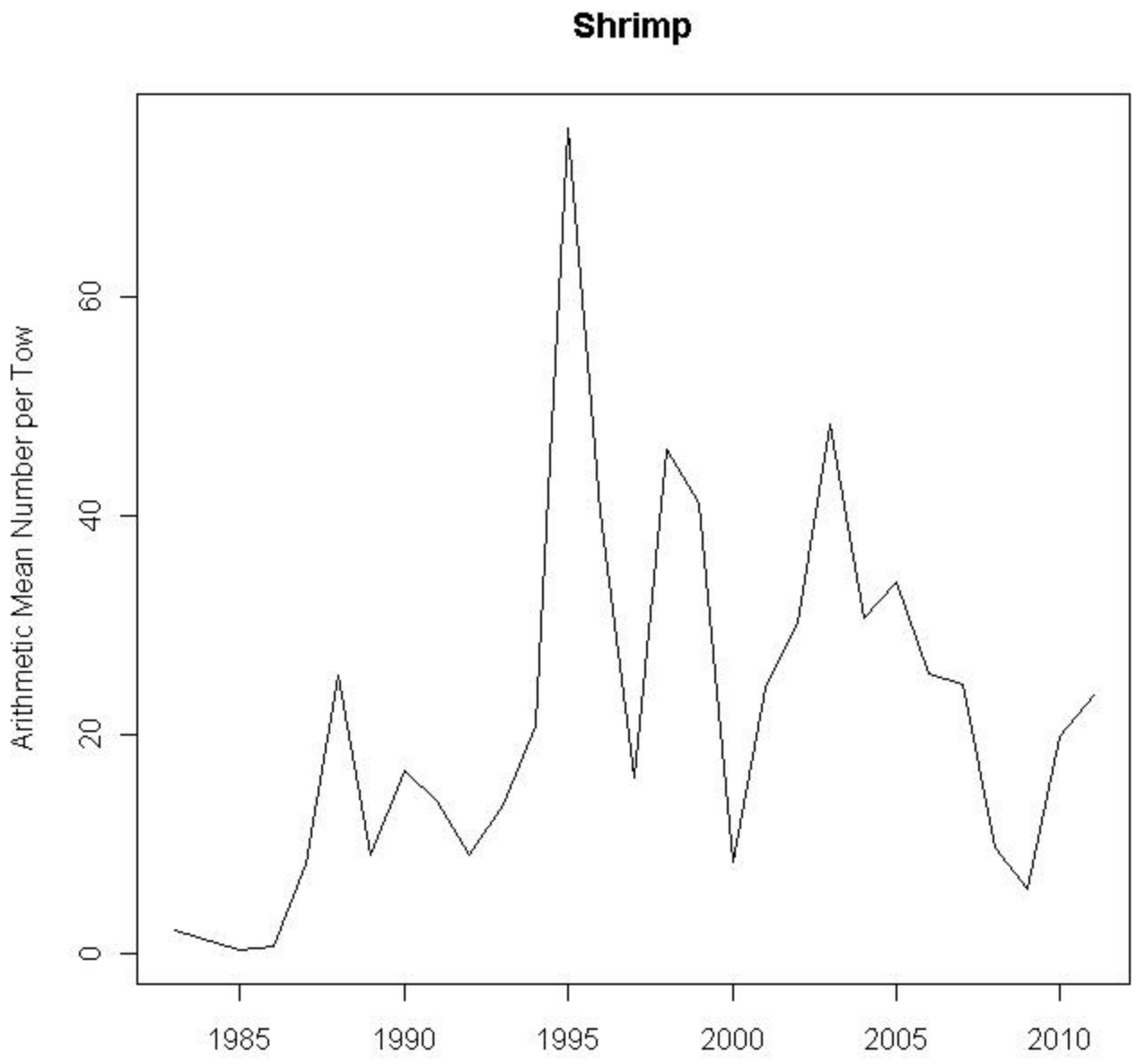


Figure A2-16. NMFS summer shrimp bottom trawl survey time series.

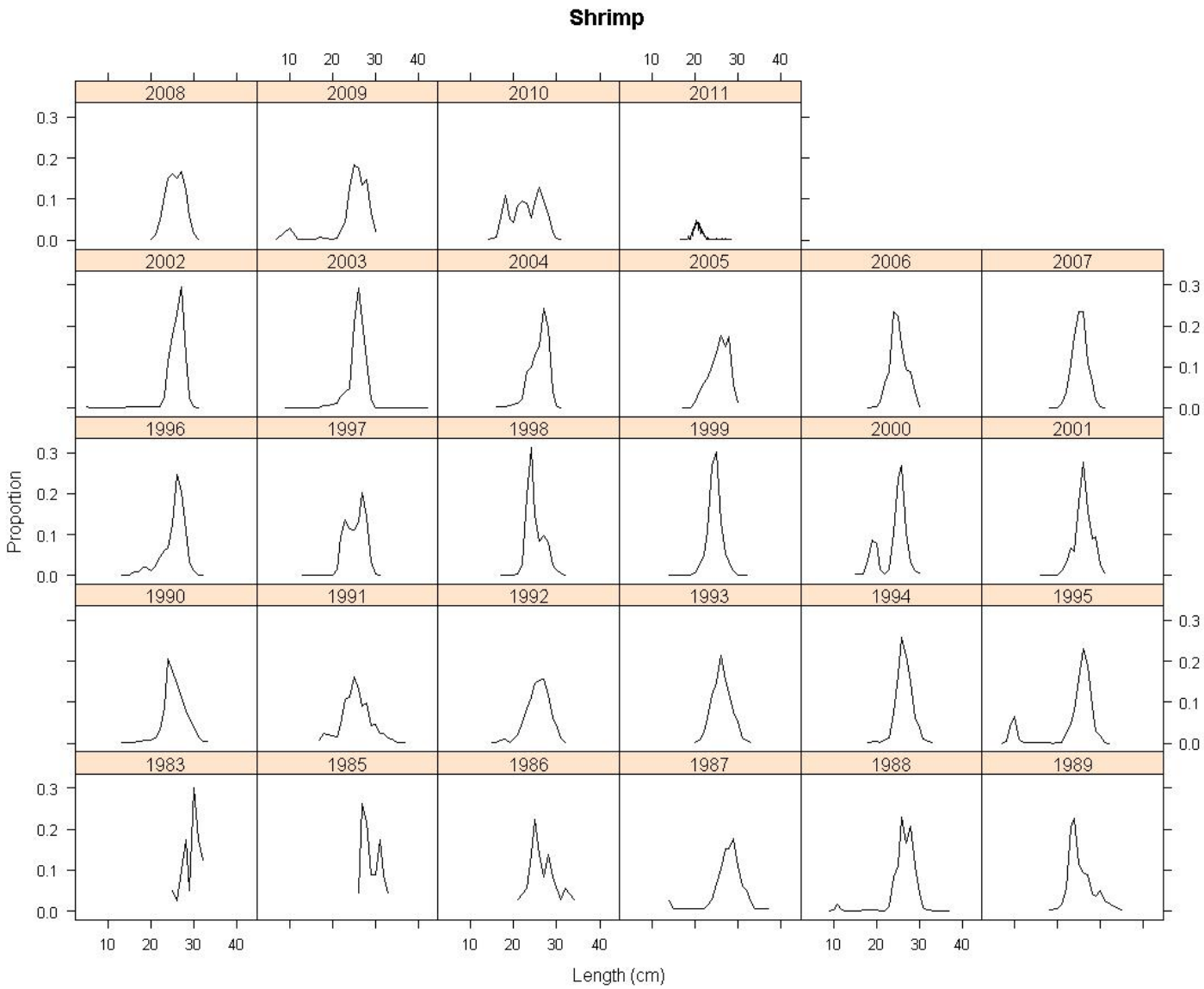


Figure A2-17. Annual length frequencies from the NMFS summer shrimp survey.

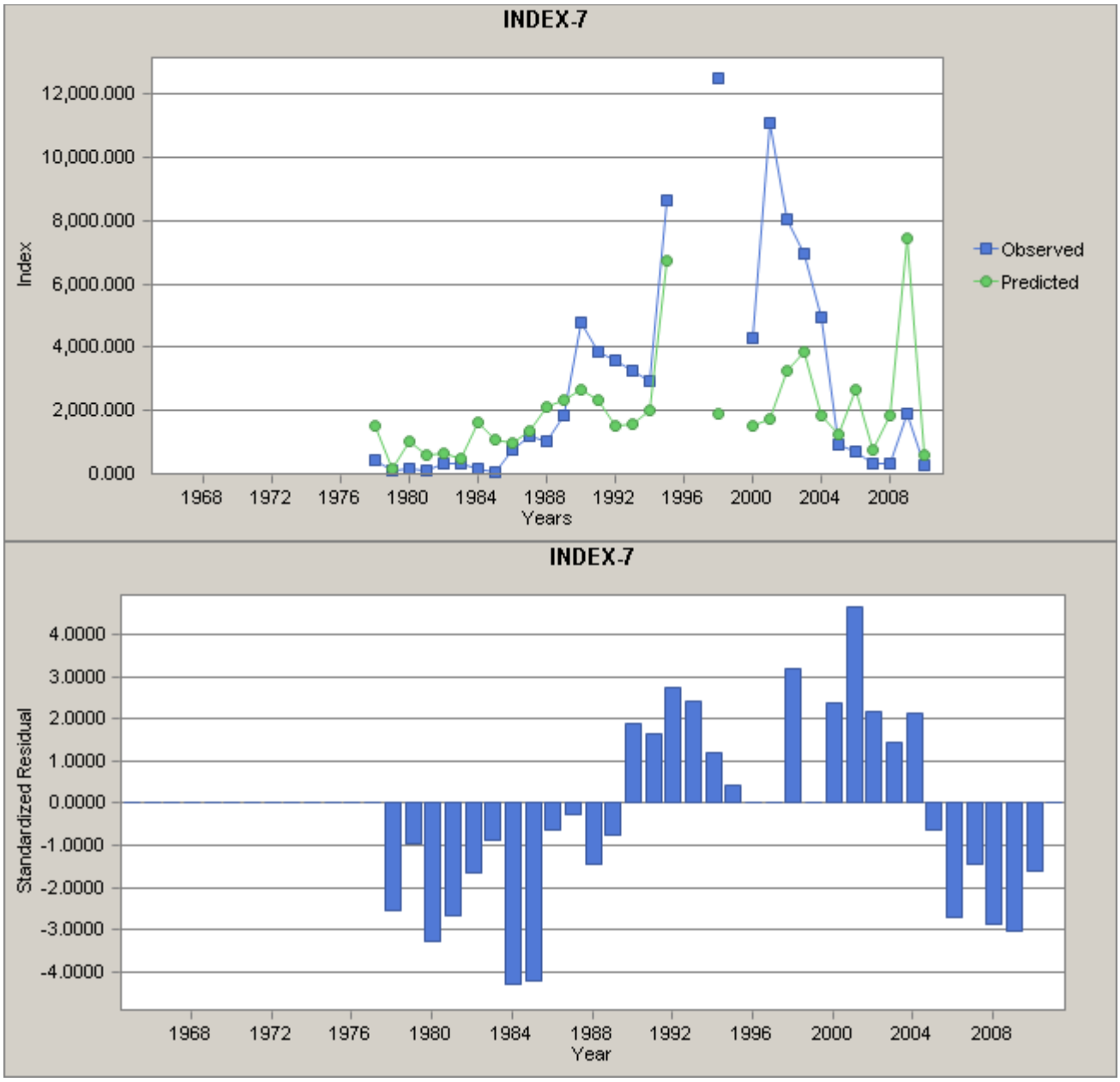


Figure A2-18. Time series (top panel) and standardized residuals (bottom panel) of the fit to the larval index from a preliminary ASAP model run.

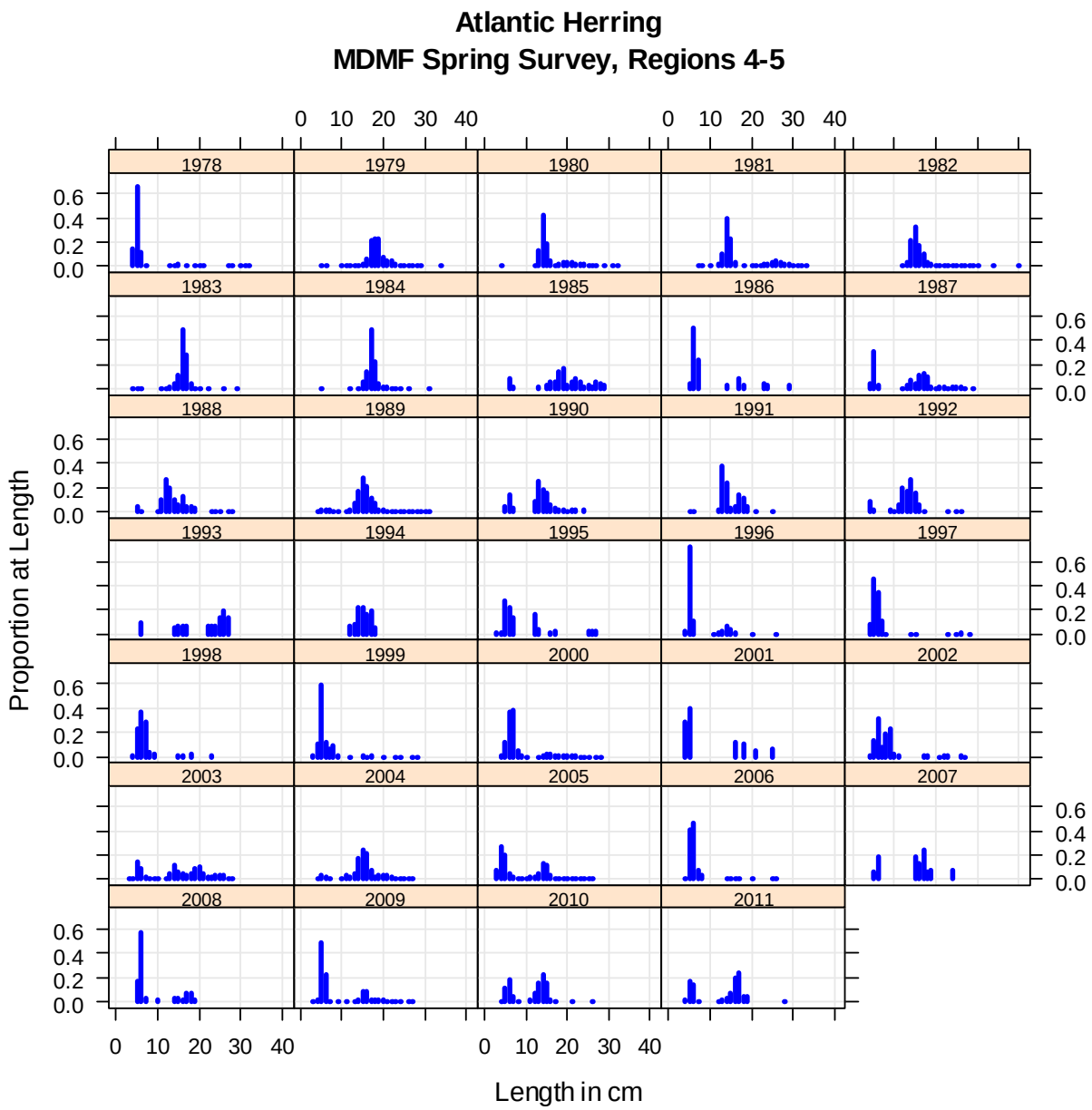


Figure A2-19. Proportion of mean number per tow at length for MA DMF spring survey.

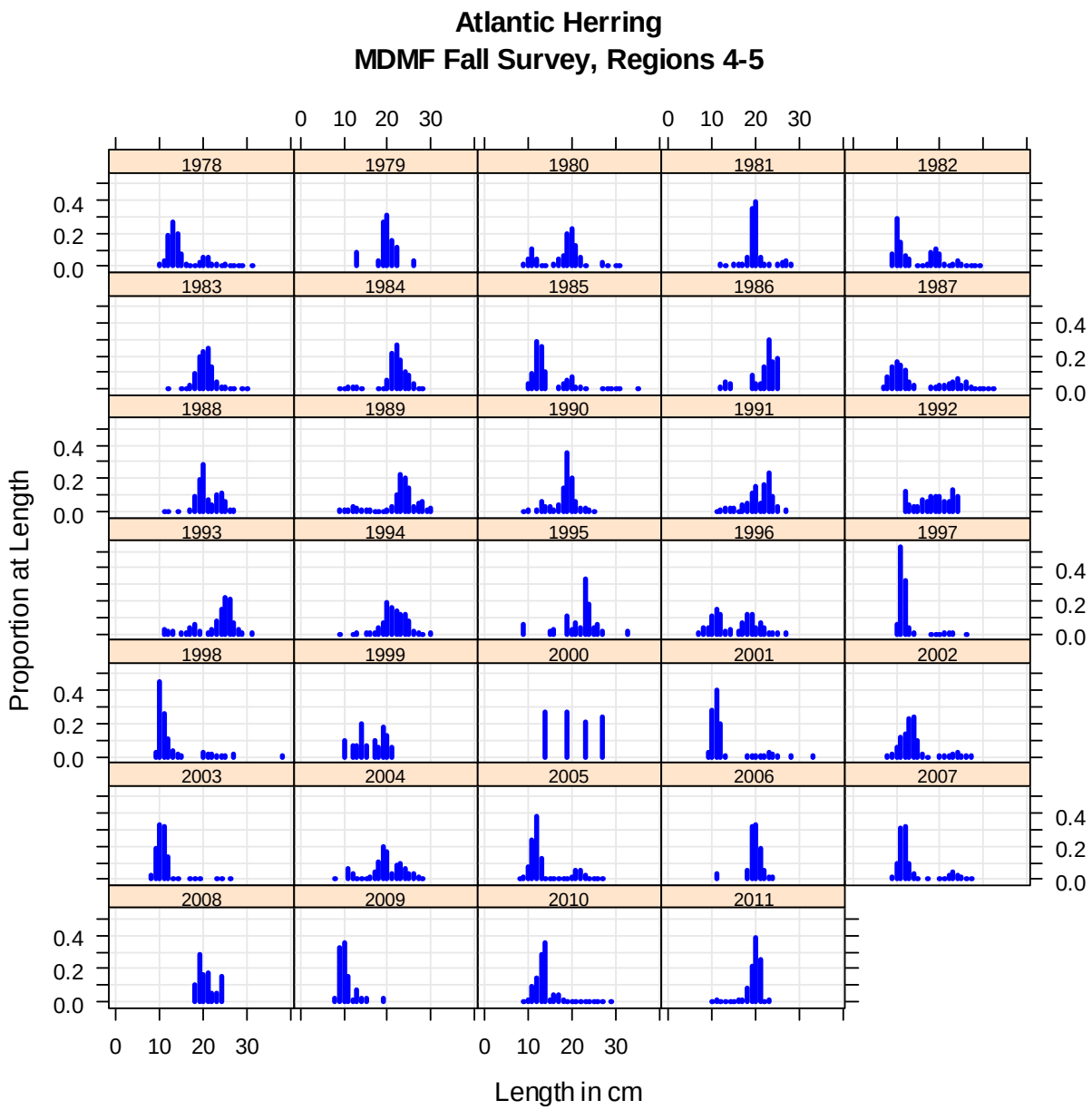


Figure A2-20. Proportion of mean number per tow at length for MA DMF fall survey.

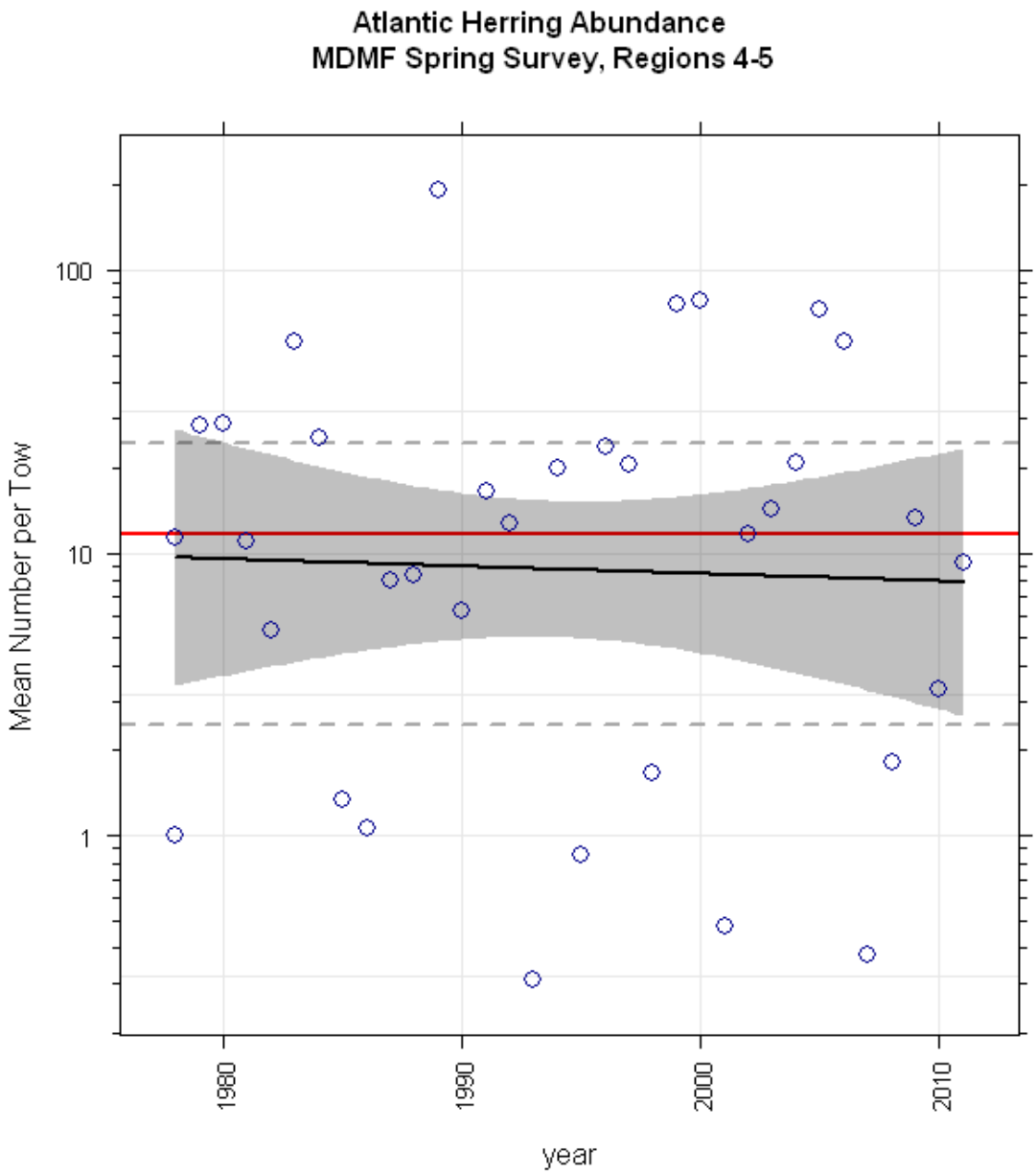


Figure A2-21. MA DMF spring survey abundance. Solid black line is a GAM fit. Solid red line is the time series median and dashed gray lines delimit inter-quartile range.

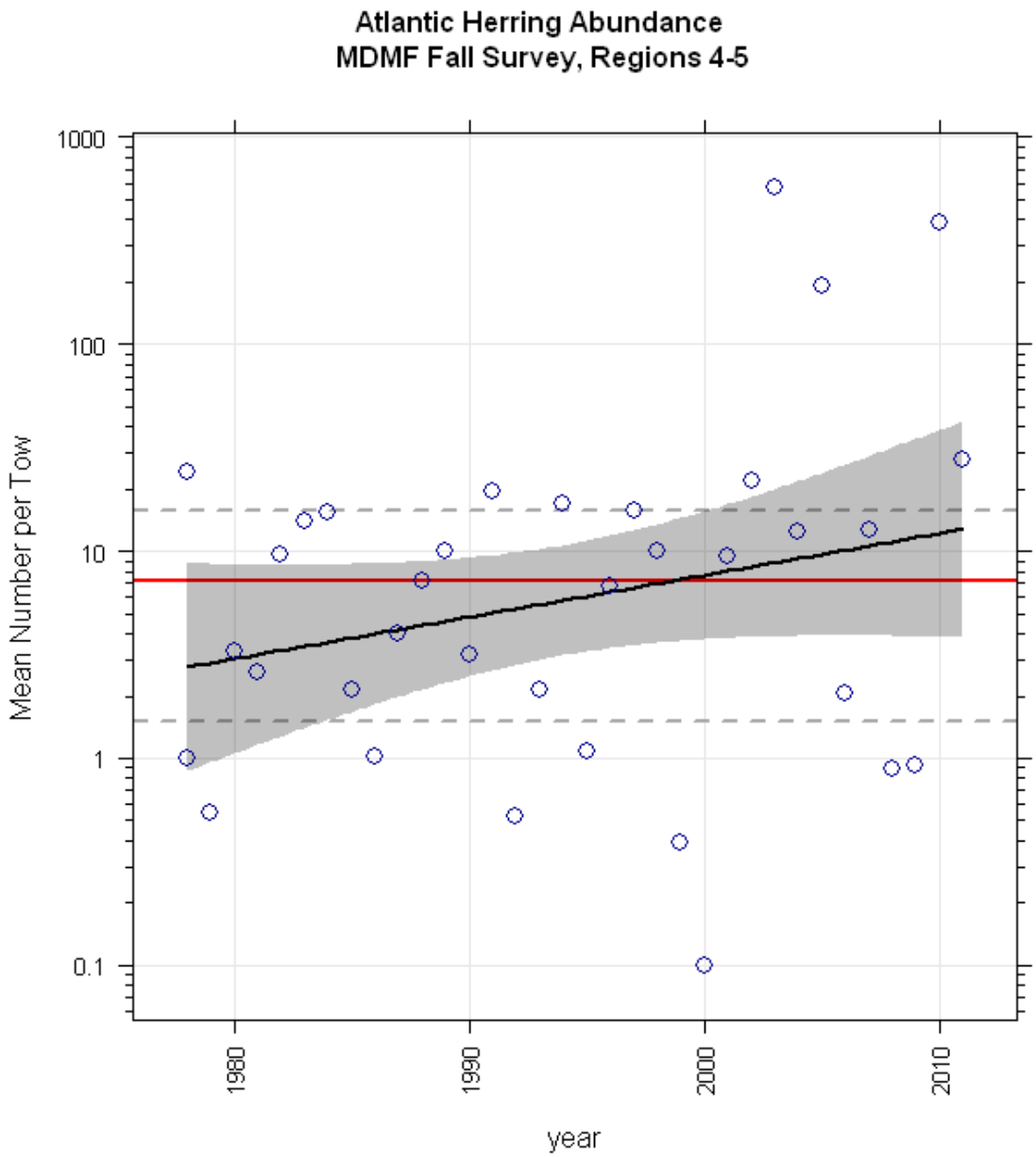


Figure A2-22. MA DMF fall survey abundance. Solid black line is a GAM fit. Solid red line is the time series median and dashed gray lines delimit inter-quartile range.

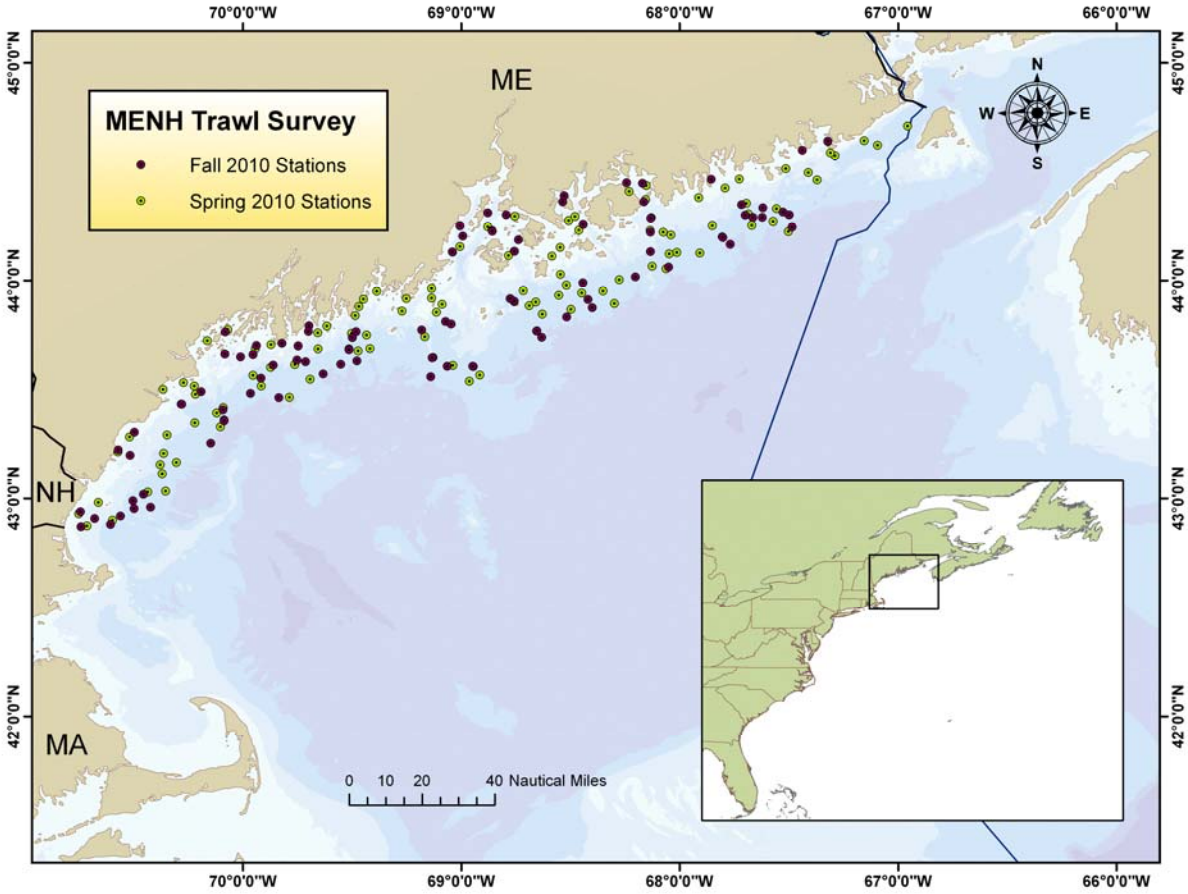


Figure A2-23. Location of tows during the Maine/New Hampshire survey in the spring and fall of 2010.

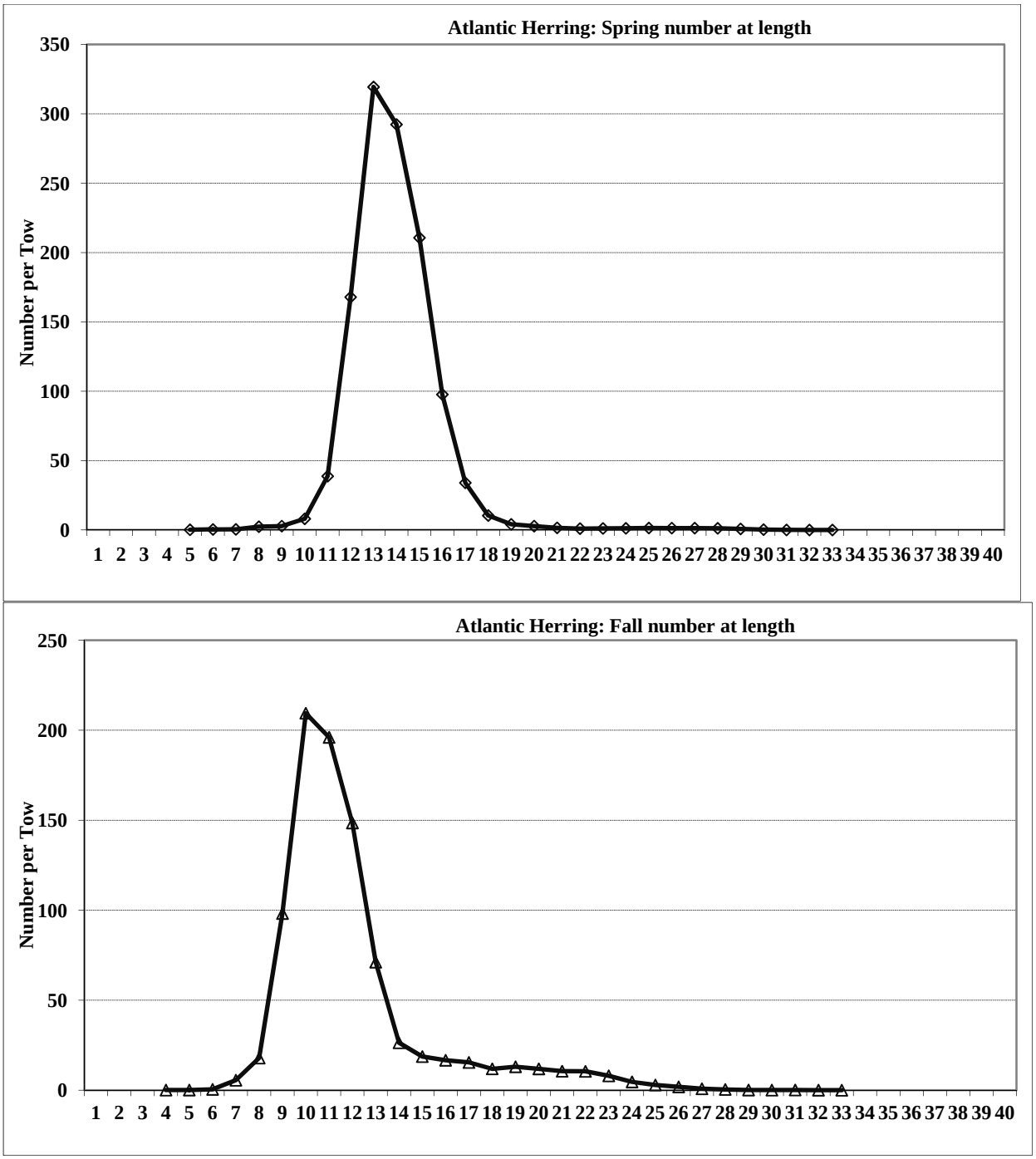


Figure A2-24. Example length frequency from the Maine/New Hampshire survey in the spring (top) and fall (bottom).

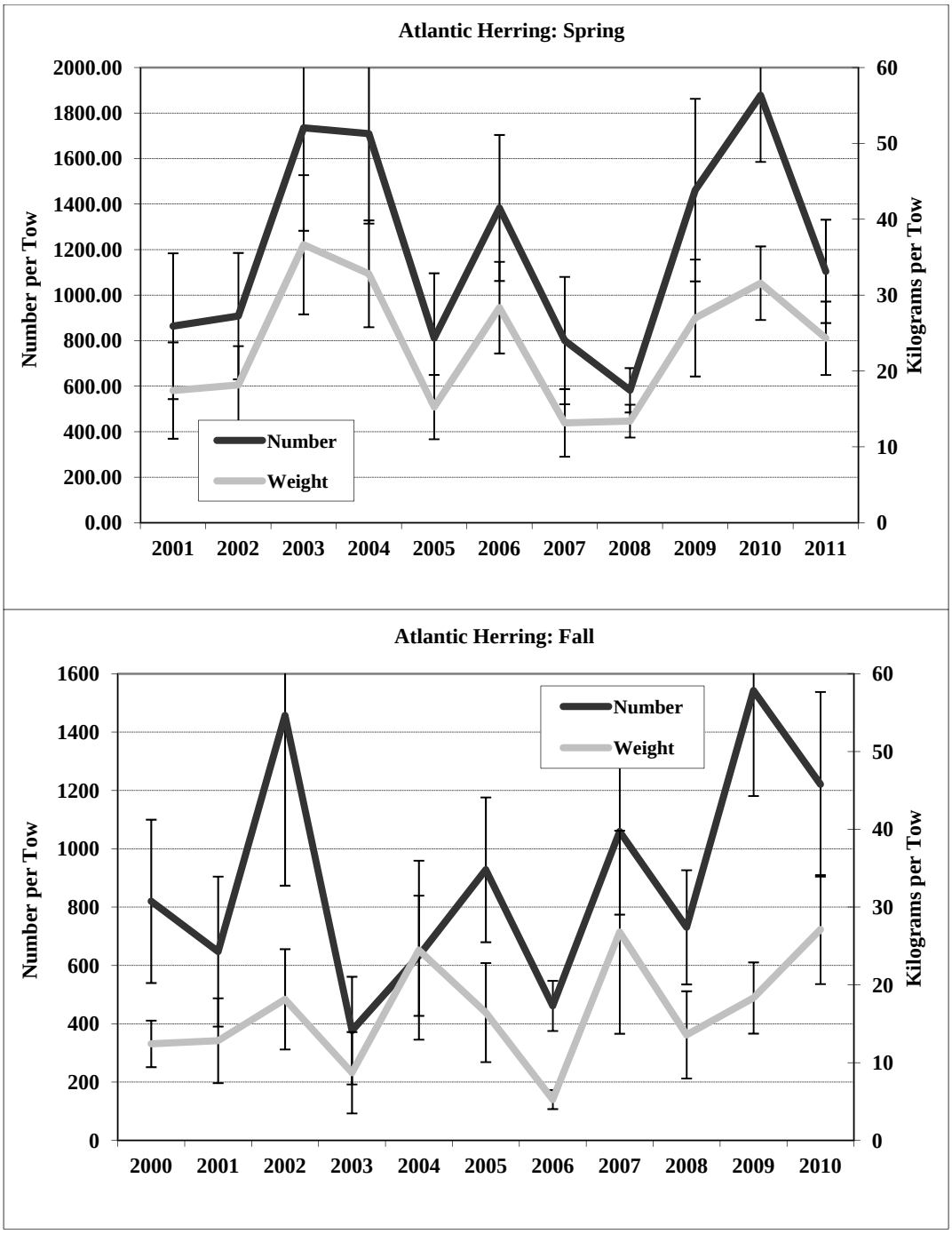


Figure A2-25. Maine/New Hampshire bottom trawl survey time series in numbers (black) and weight (grey).

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:

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

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:

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

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):

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

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:

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

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

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

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:

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

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

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

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:

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

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

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 jth length class) and then the number of herring in each age class is divided by the total number in that length class:

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

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

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

where P_{FL_j} is the proportion of herring in the jth 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):

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

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).

Year	Sept. 1st week	Sept. 2nd week	Sept. 3rd week	Sept. 4th week	Oct. 1st week	Oct. 2nd week	Oct. 3rd week	Oct. 4th week
1999					Prlll (10)			
2000		Prlll (10)						
2001								
2002			Prlll (8)					
2003			Prlll (10)					
2004			Prlll (10)					
2005			Prlll (10)					
2006			Prlll (10)					
2007							Prlll (10)	
2008			Prlll (10)					
2009				Prlll (8)				
2010				Prlll (8)				
2011				Prlll (8)				

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

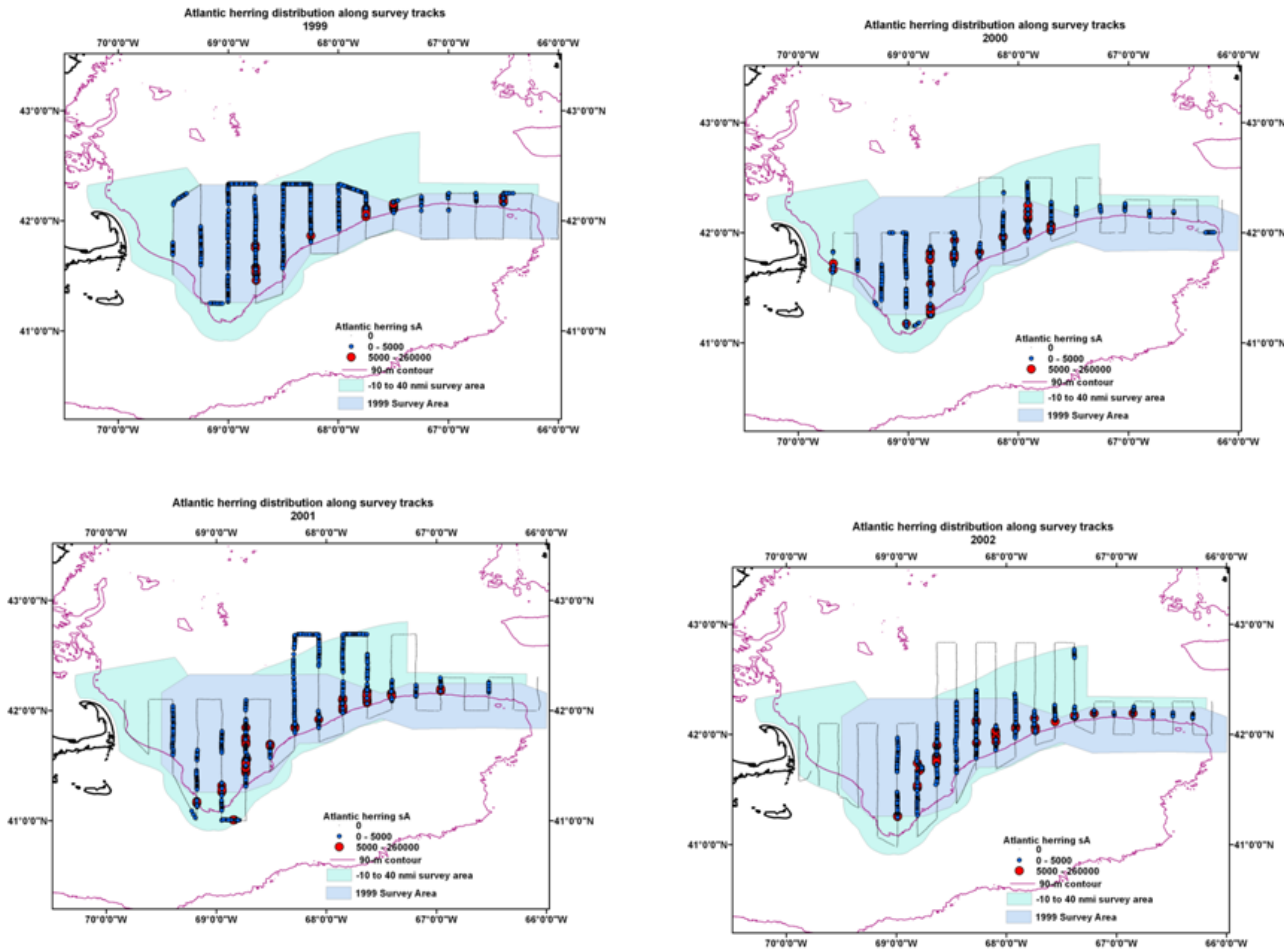


Figure A3-1. Acoustic s_A attributed to Atlantic herring along the systematic parallel transect surveys along the northern edge of Georges Bank for each year of the survey. The survey zone based on 40 nmi to the north of and 10 nmi to the south of the 90-m bathymetric contour (aka "common area") is displayed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

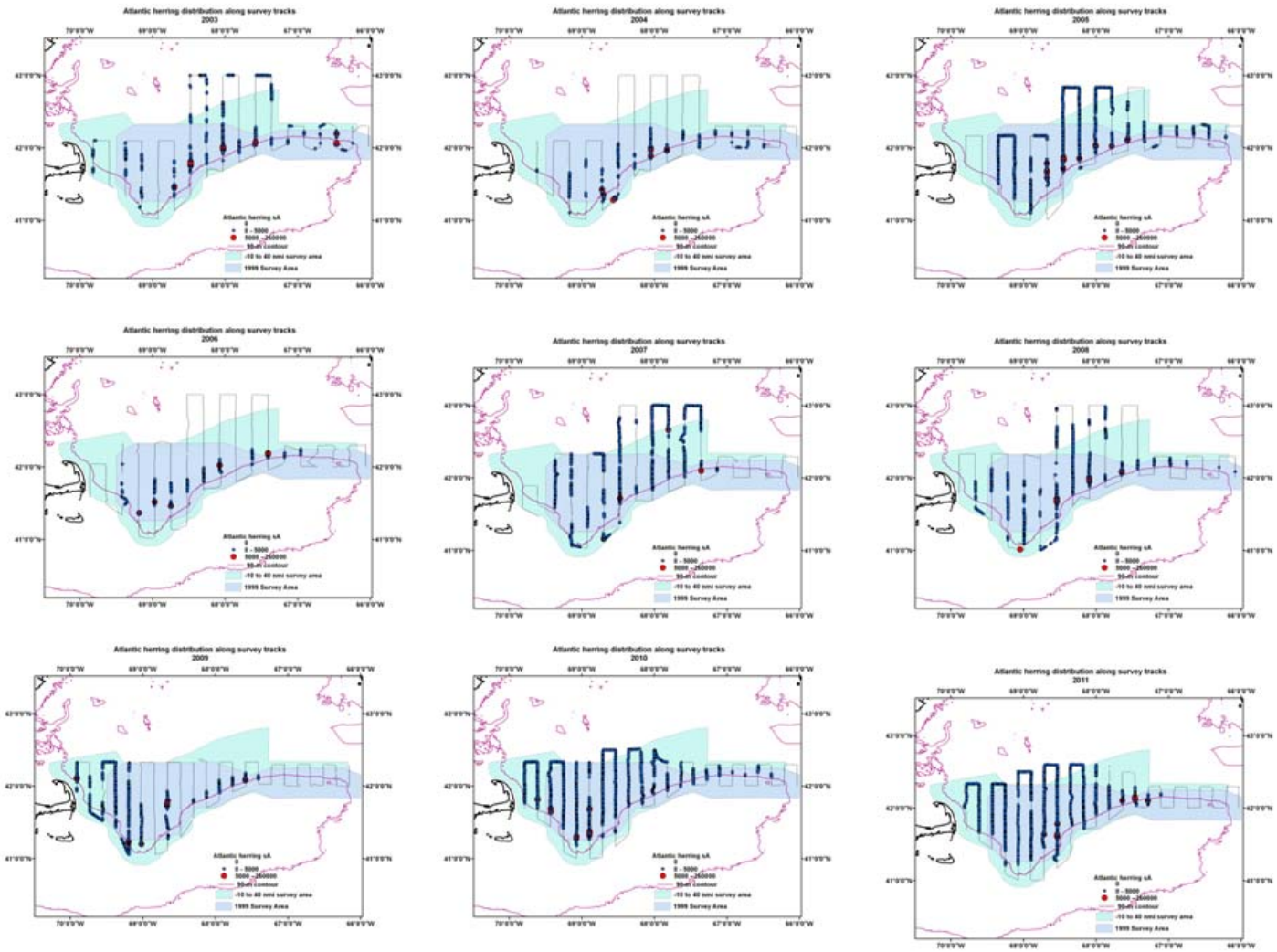


Figure A3-1 (cont'd). Acoustic s_A attributed to Atlantic herring along the systematic parallel transect surveys along the northern edge of Georges Bank for each year of the survey. The survey zone based on 40 nmi to the north of and 10 nmi to the south of the 90-m bathymetric contour (aka "common area")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

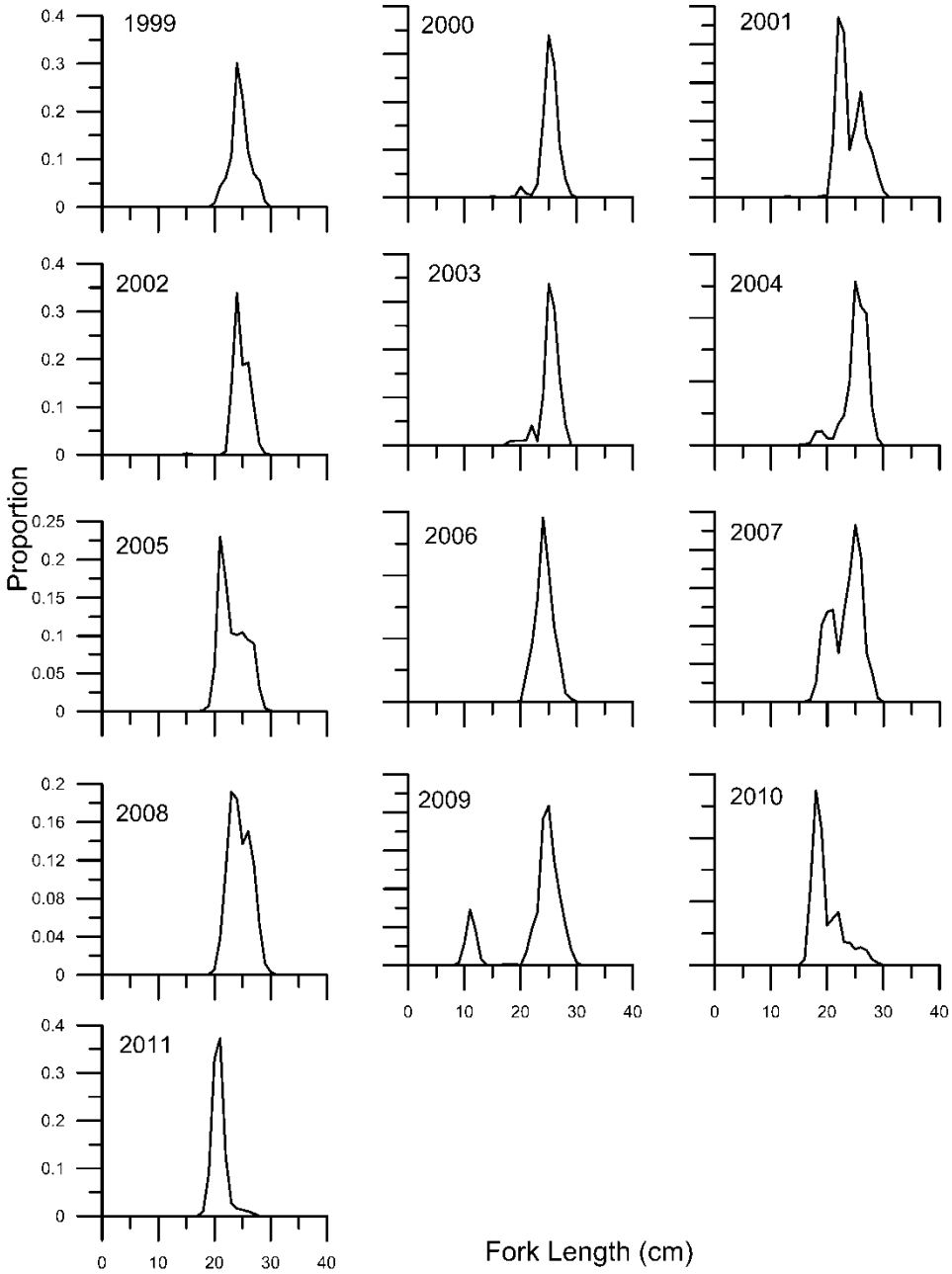


Figure A3-2. Atlantic herring length-frequency histograms for all midwater trawls conducted during each annual survey.

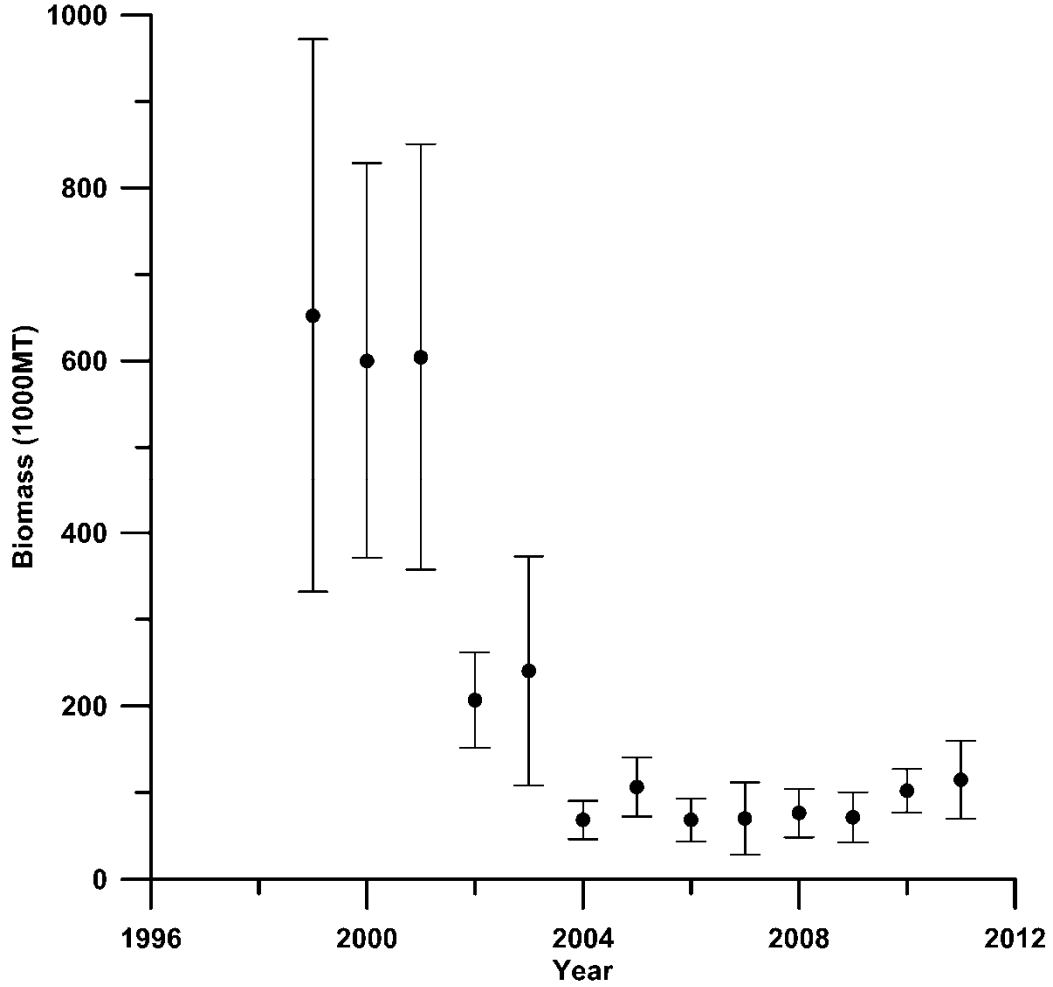


Figure A3-3. Biomass estimates and SE scaled to the 'common area' for each year.

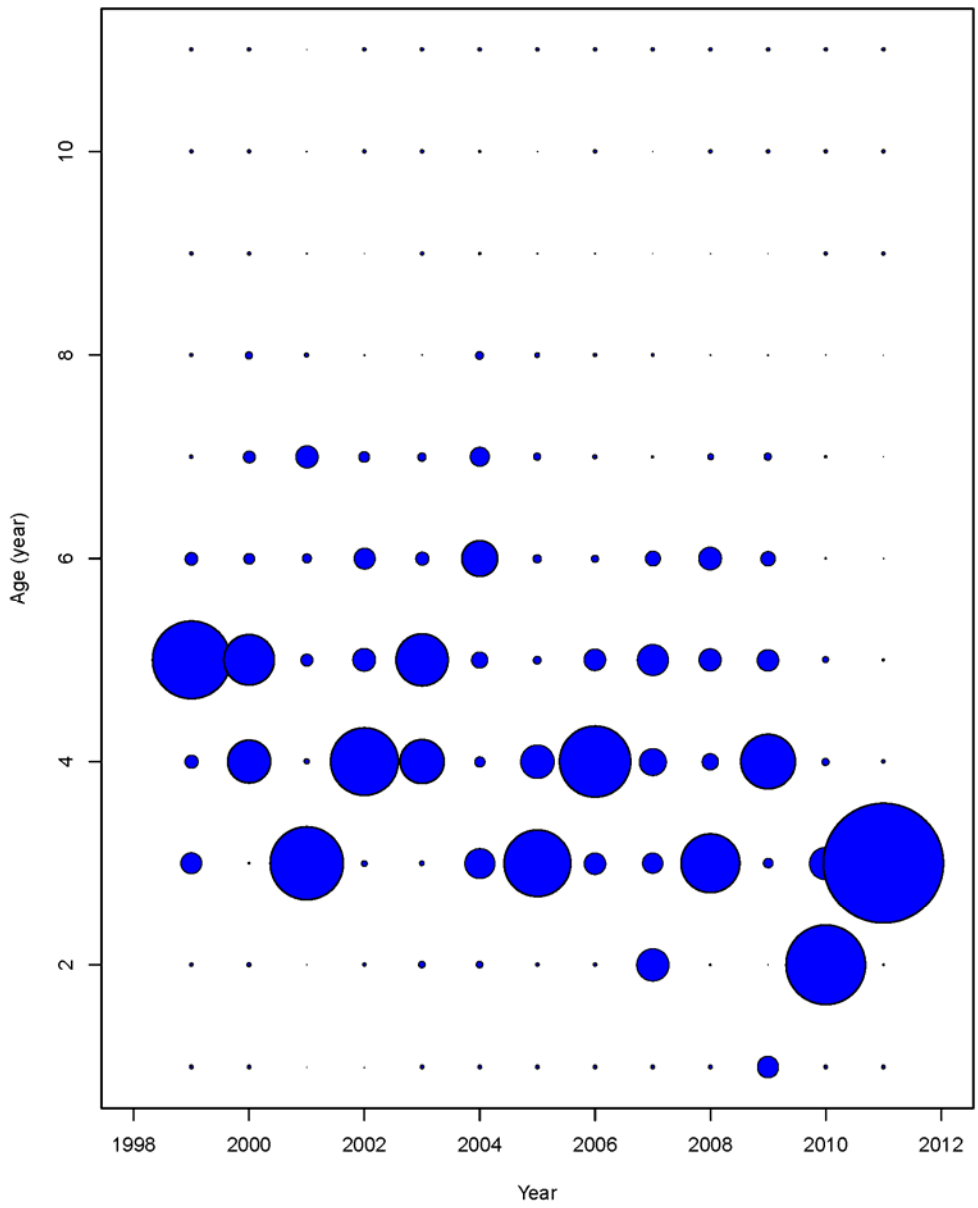


Figure A3-4. Age-based relative proportion of Atlantic herring from the annual surveys along the northern edge of Georges Bank.

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:

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

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

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

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:

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

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}:

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

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:

$$N_{ij} \text{ ¼ ½} D_{ij} _ SD_i \text{ þ} m_i _ _ SC_{ij} _ A \quad ;$$

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)

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

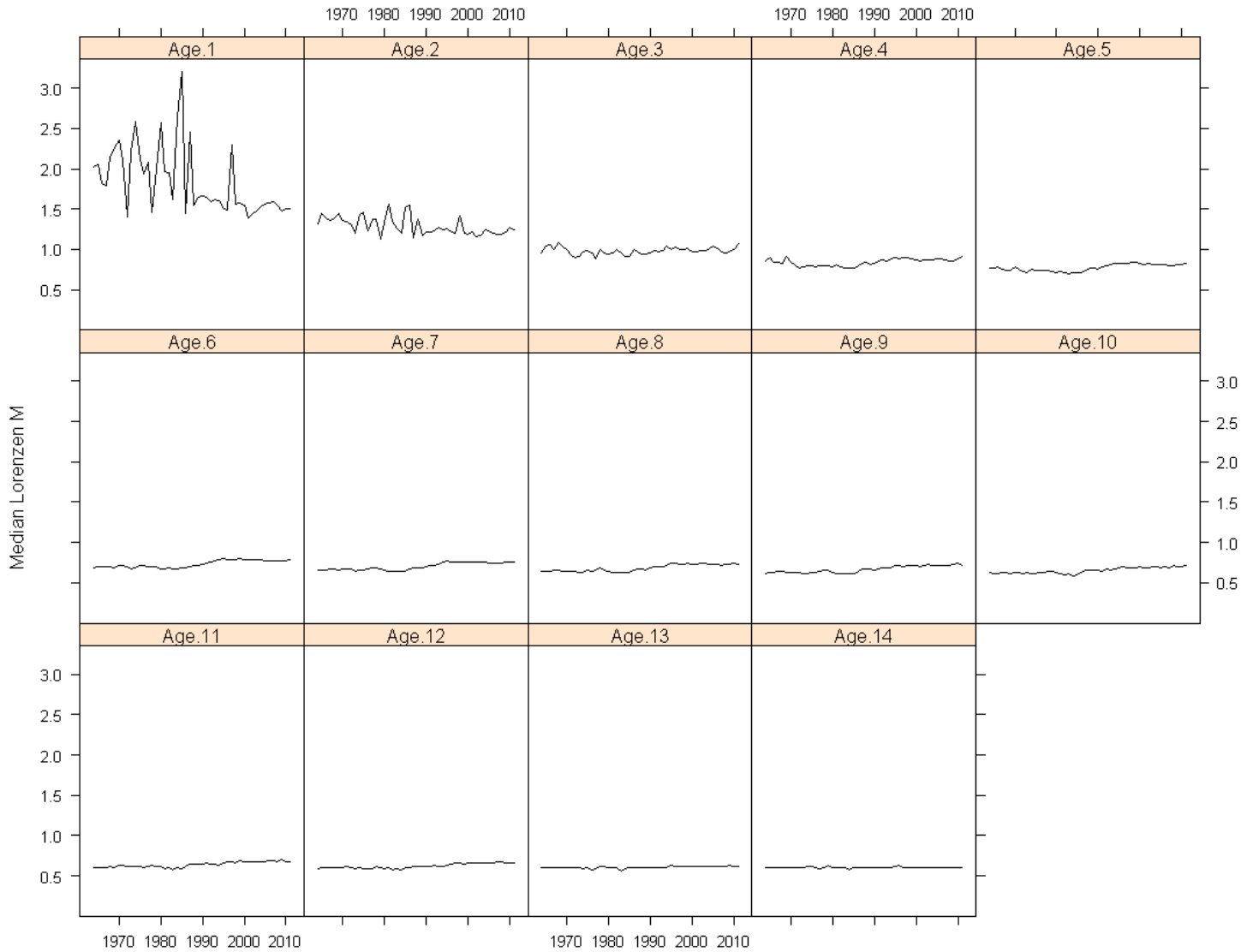


Figure A6-1. Lorenzen natural mortality (*M*) estimates for Atlantic herring during 1964-2011.

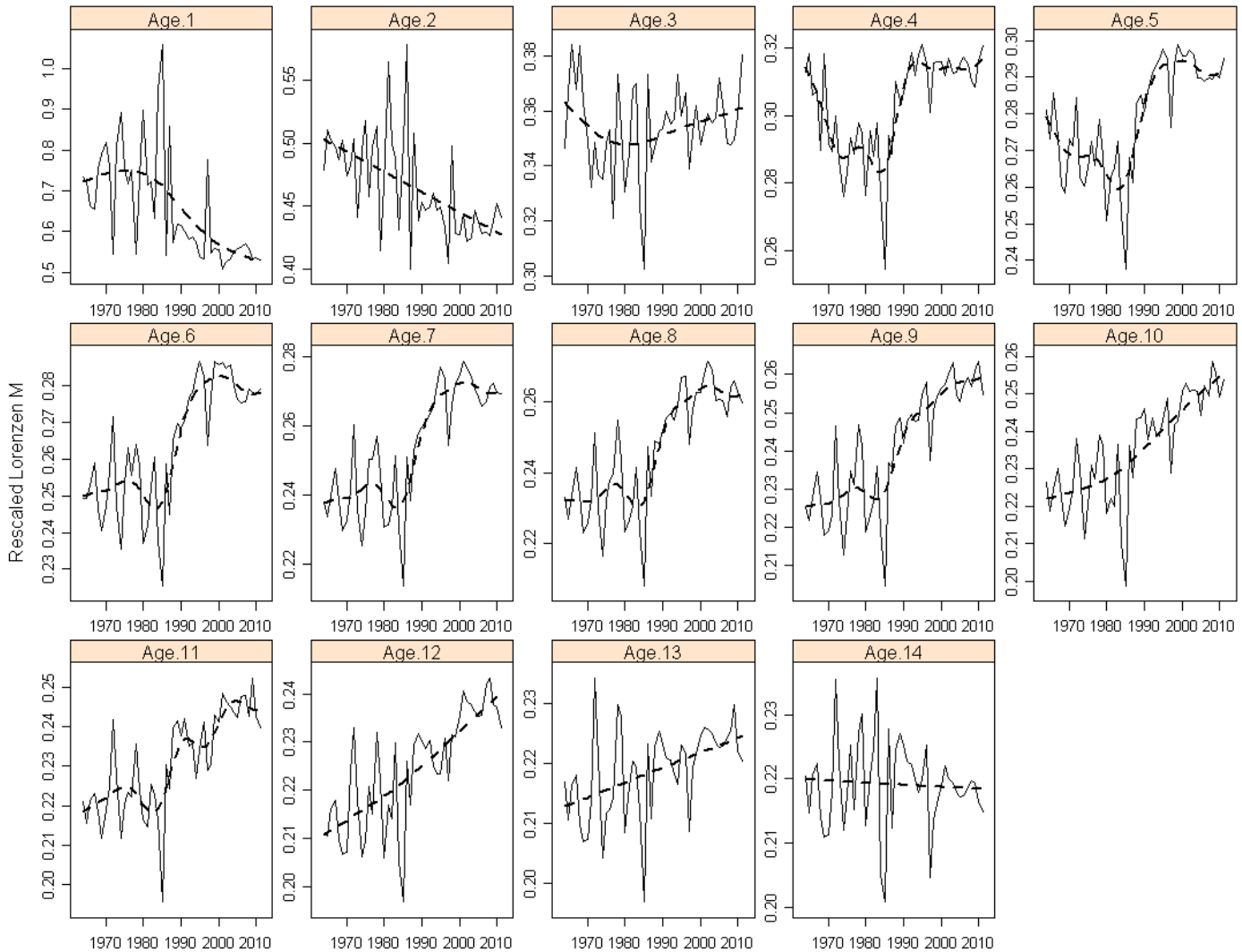


Figure A6-2.—Rescaled Lorenzen natural mortality (*M*) estimates for Atlantic herring during 1964-2011 (solid line). The dashed line is a smoothed temporal trend estimated using a general additive model. Note each panel has a unique scale.

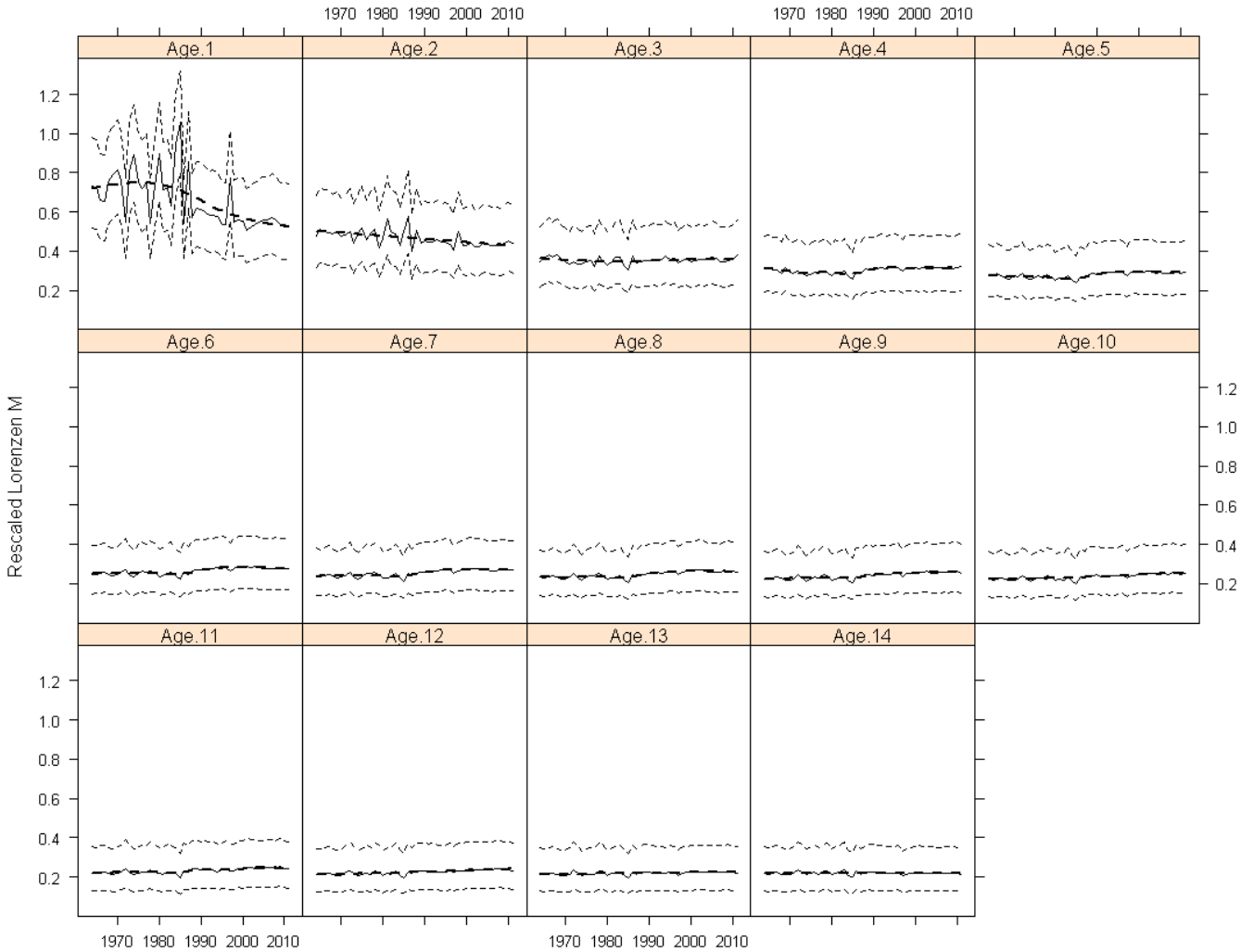


Figure A6-3.—As in Figure A2 except each panel has a standardized y-axis scale and the thin dashed lines are 90% confidence intervals. The confidence intervals only represent the uncertainty in the Lorenzen parameters, and so do not fully quantify the uncertainty.

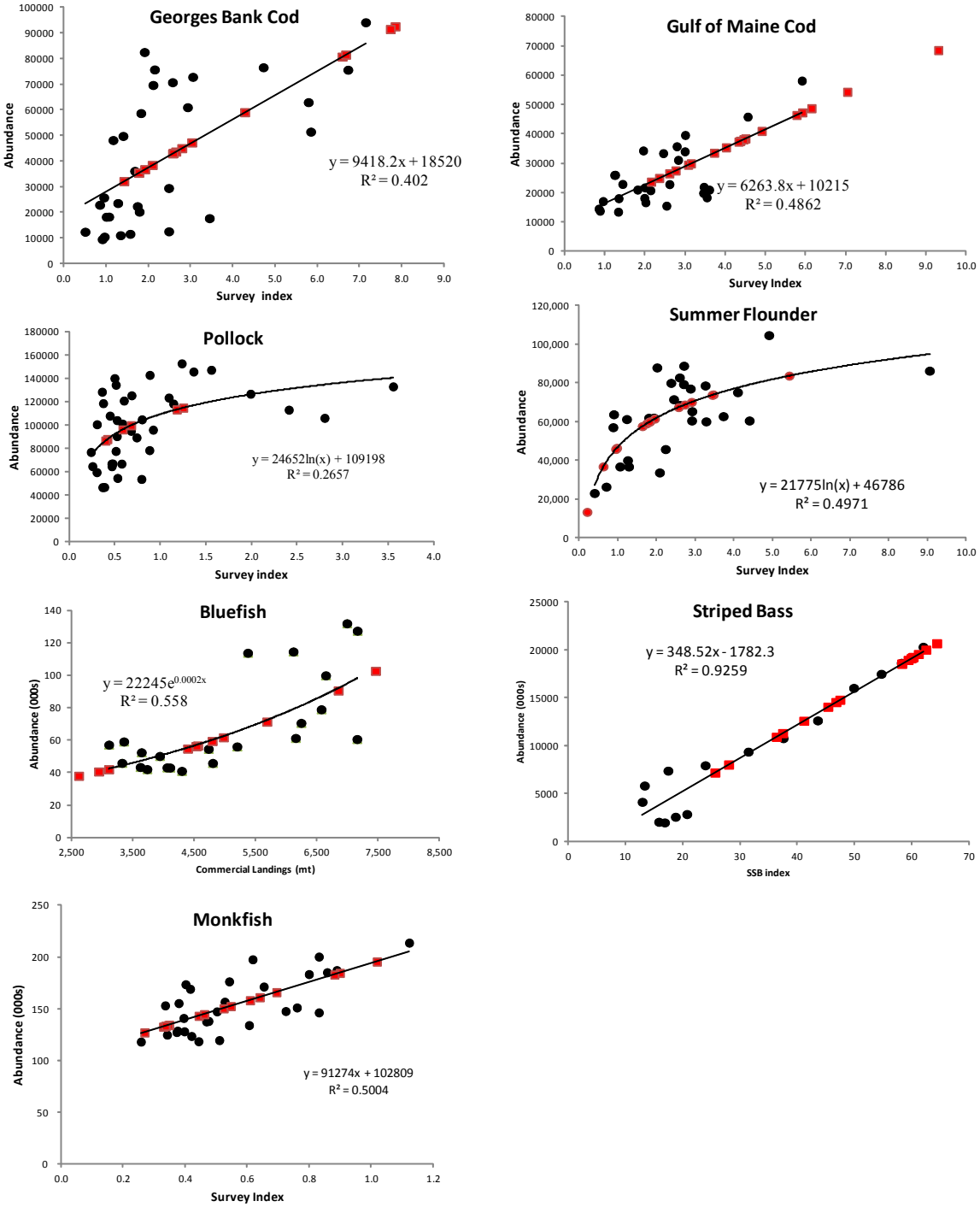


Figure A6-4. Relationships between indices and abundance estimates from assessment results.

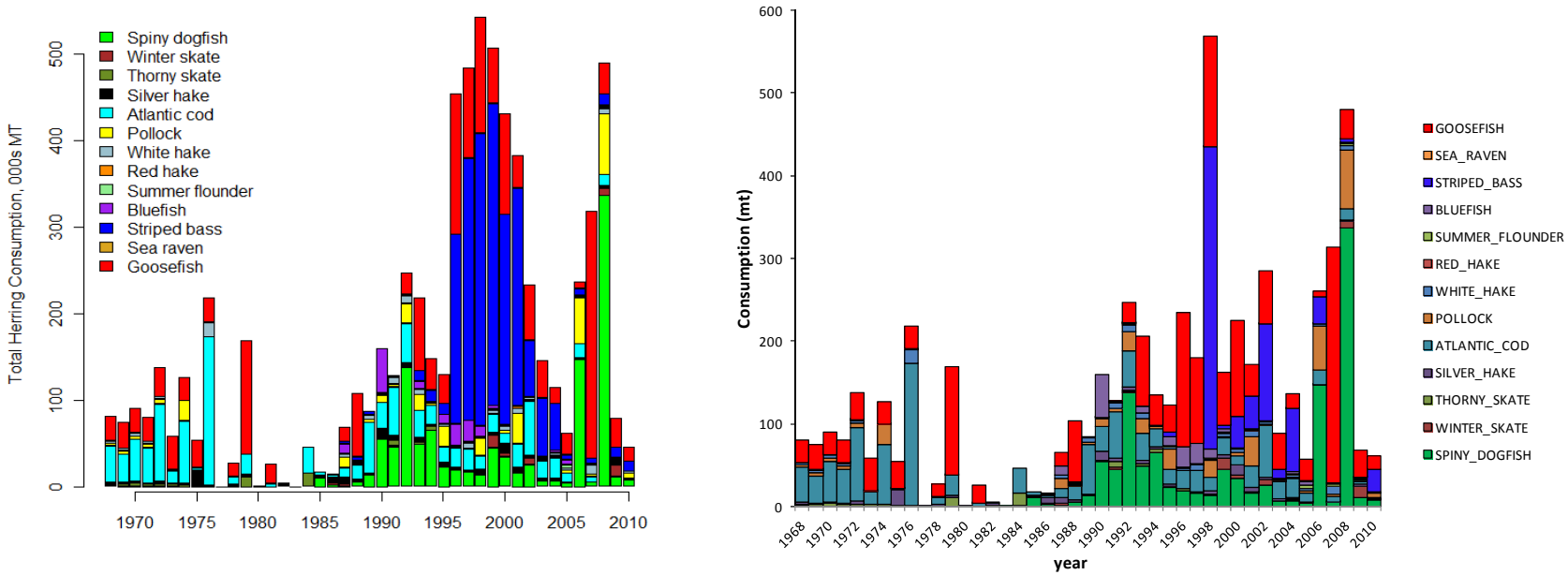


Figure A6-5. Total herring consumption by fish predator (non-HMS predators) using a moving average for striped bass for some years (left) and without using a moving average for striped bass (right). The left panel was used to inform the assessment.

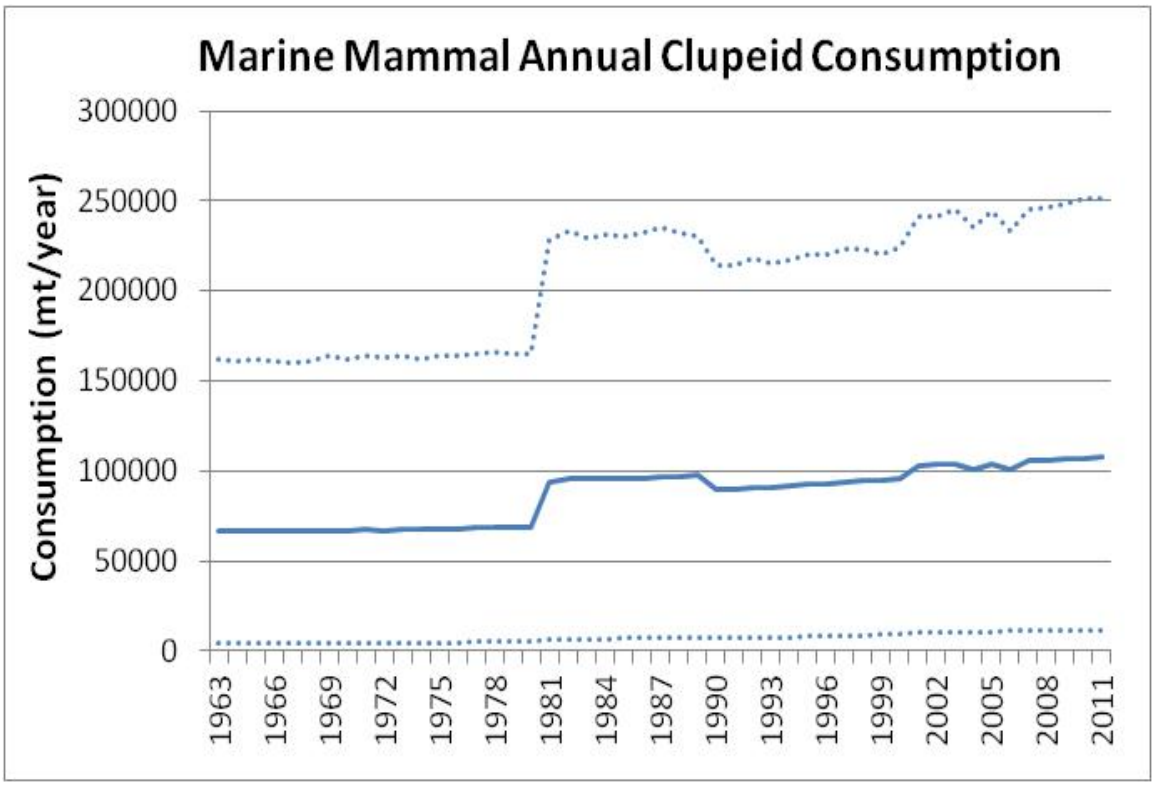


Figure A6-6. Total Atlantic herring consumption by marine mammals (± 80% CI).

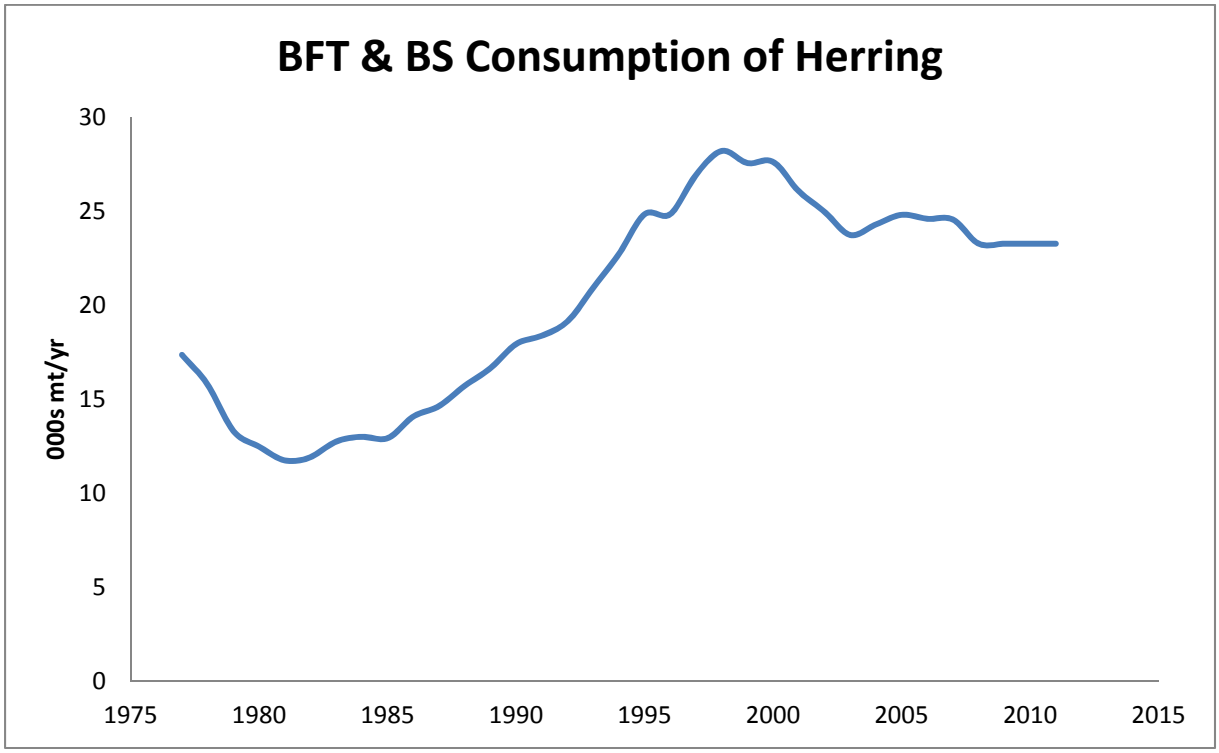


Figure A6-7. Annual estimates of Atlantic herring consumption by bluefin tuna and blue sharks.

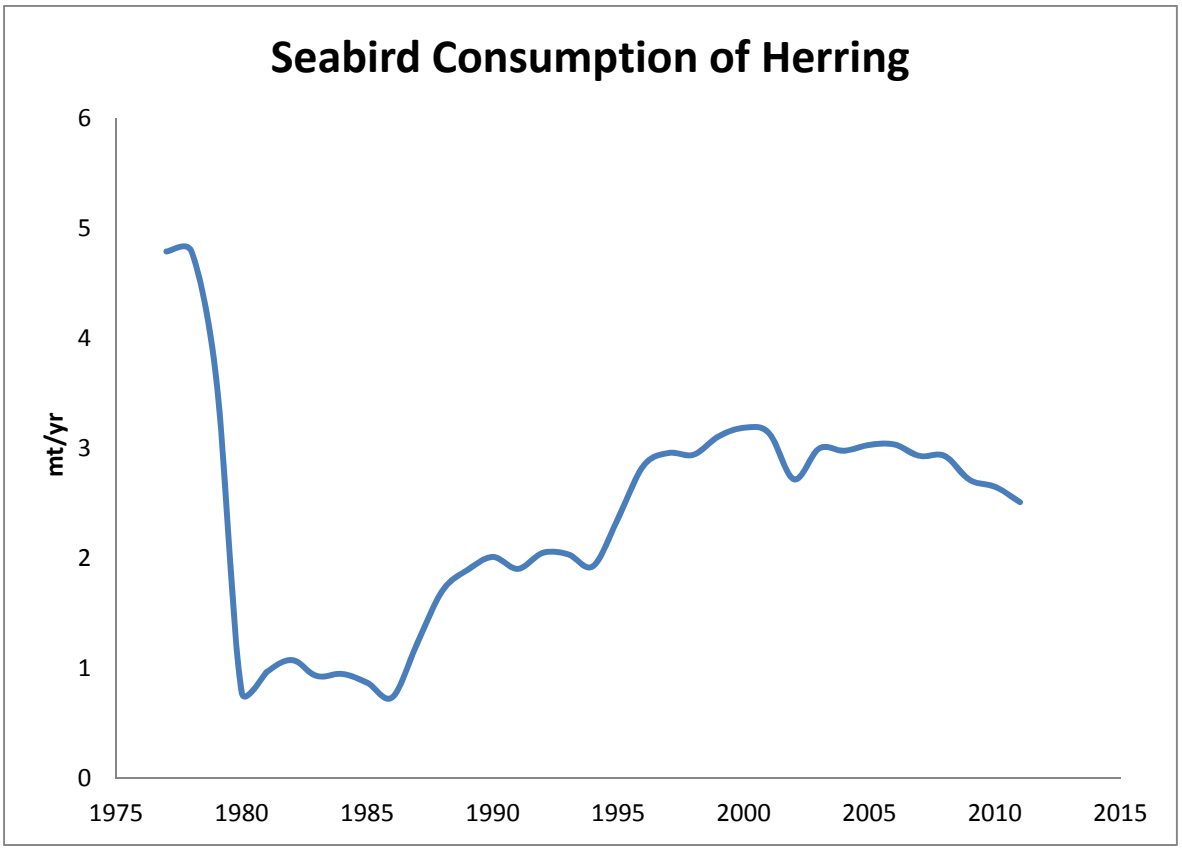


Figure A6-8. Annual estimates of consumption of Atlantic herring by seabirds.

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

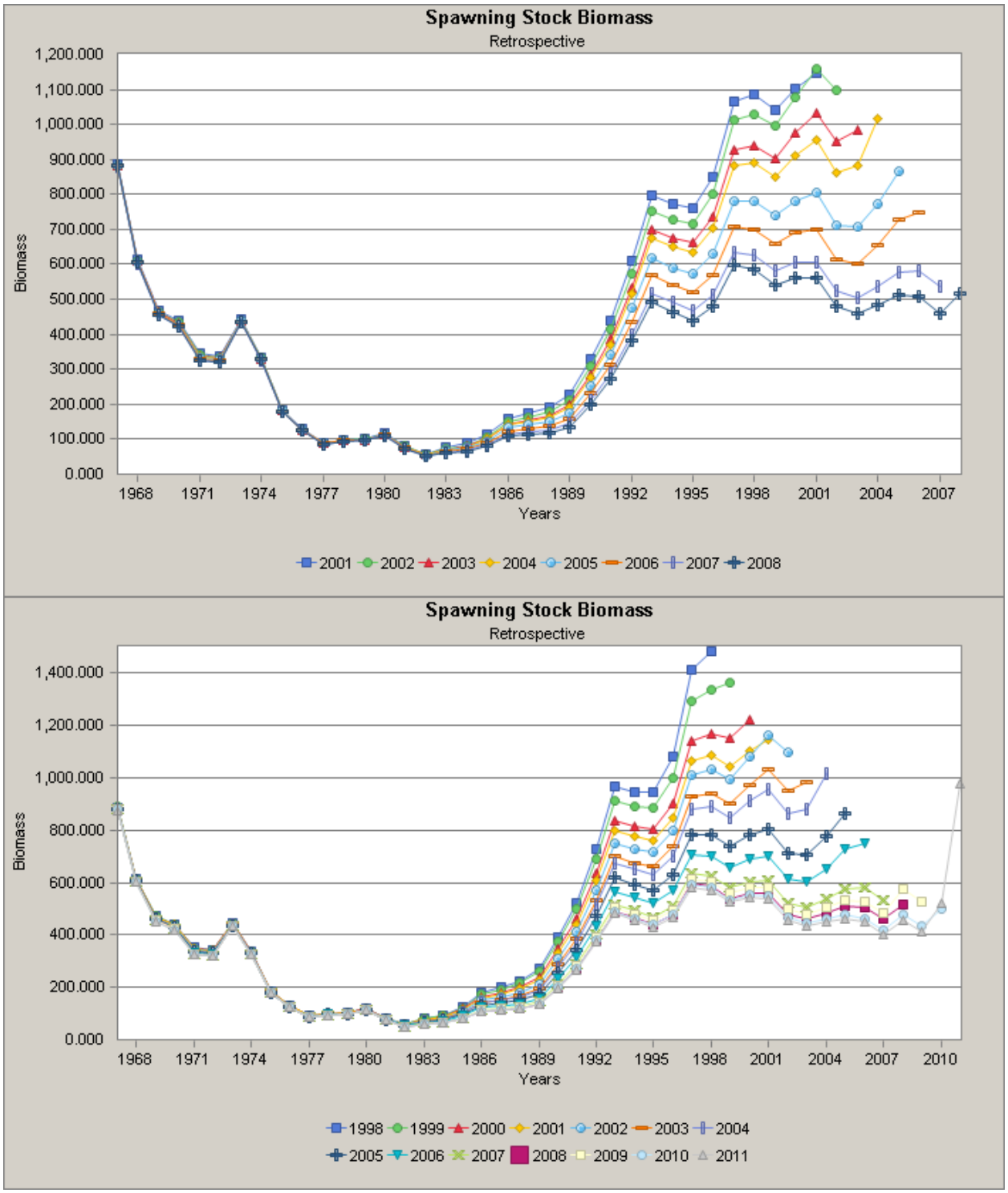


Figure A5-1. Internal retrospective pattern for spawning stock biomass from the 2009 TRAC assessment (top panel) and 2009 TRAC assessment updated using data through 2011 (bottom panel).

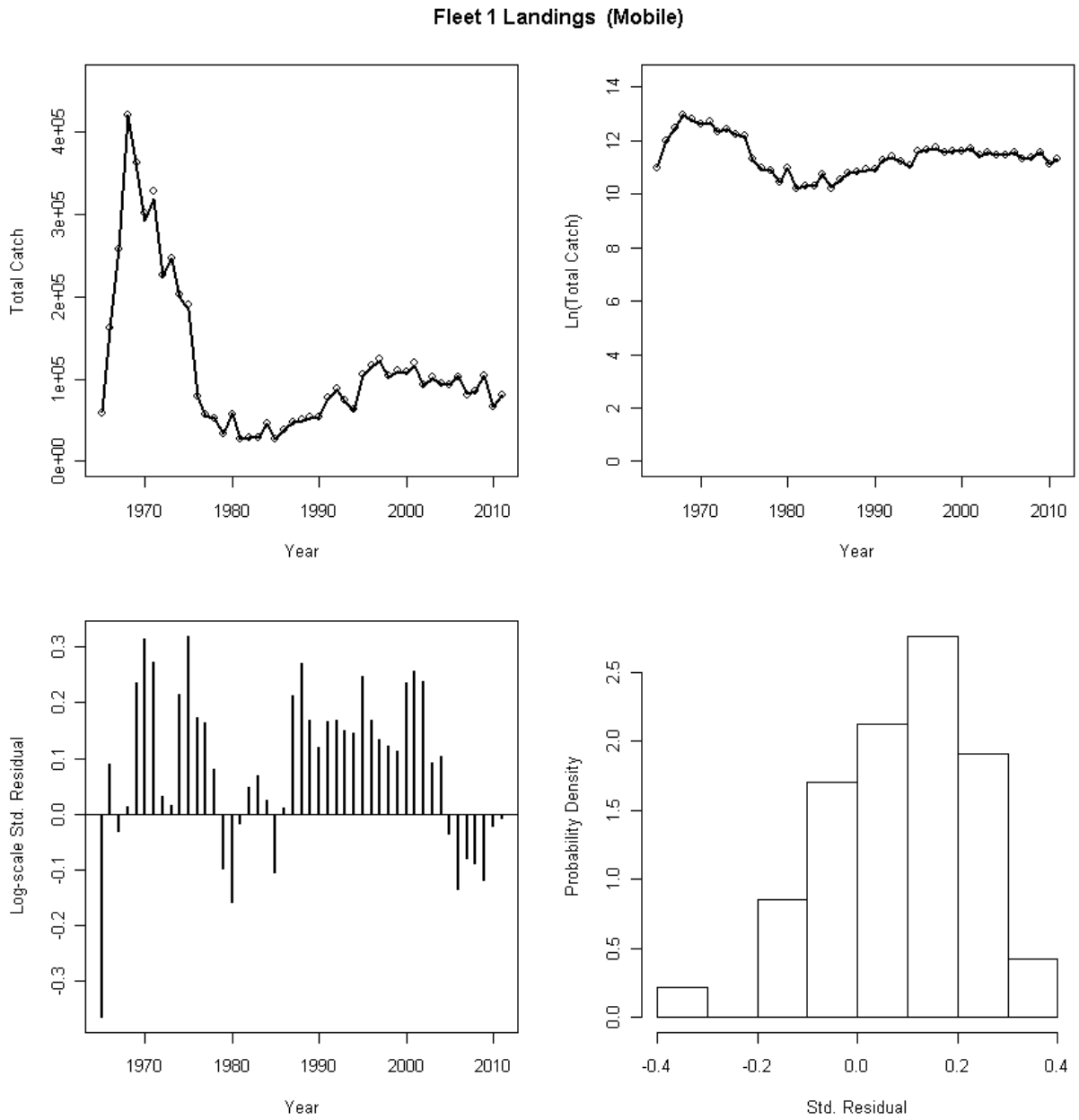


Figure A5-2. ASAP base model fit to mobile gear fishery catches.

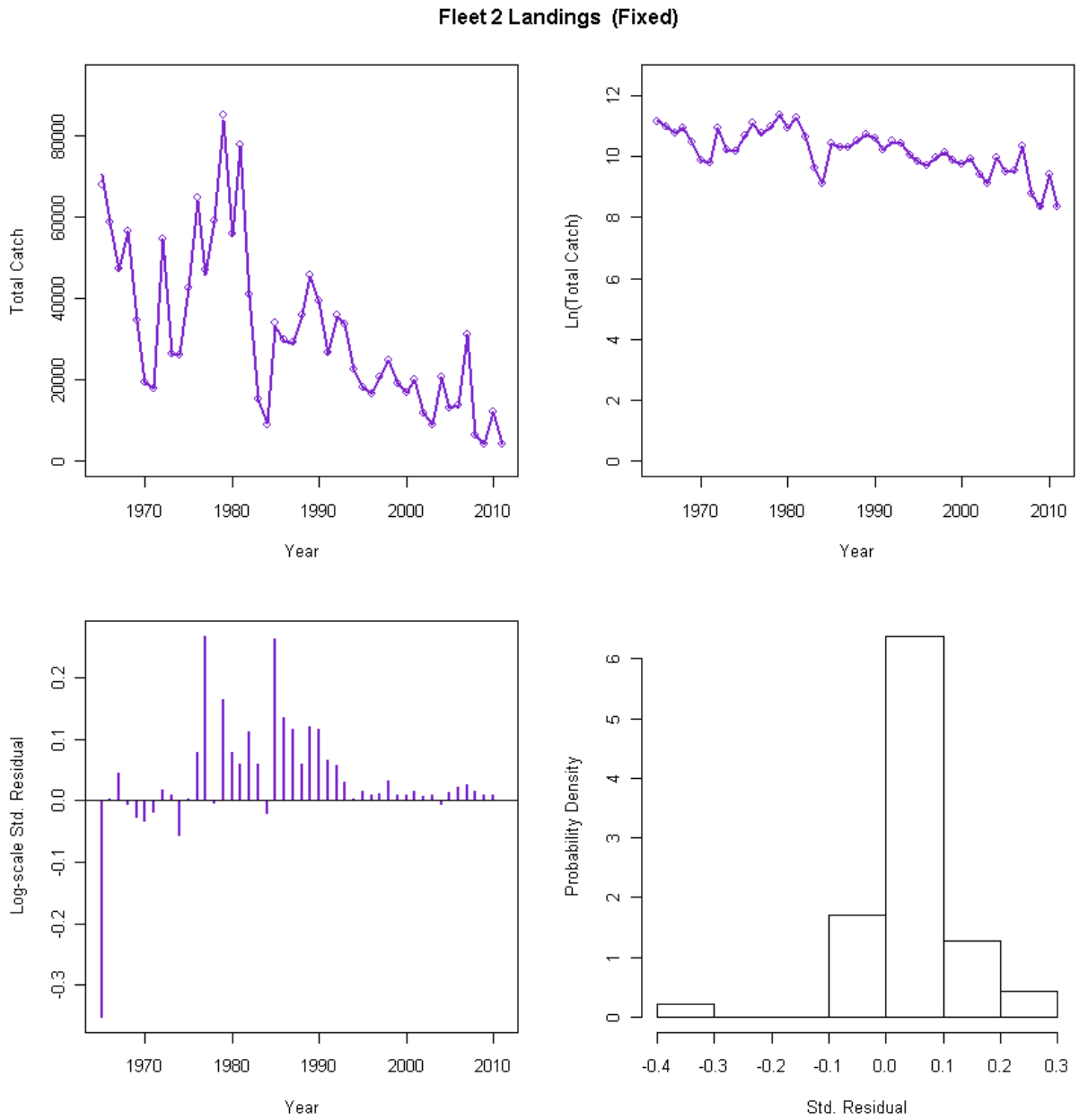


Figure A5-3. ASAP base model fit to fixed gear fishery catches.

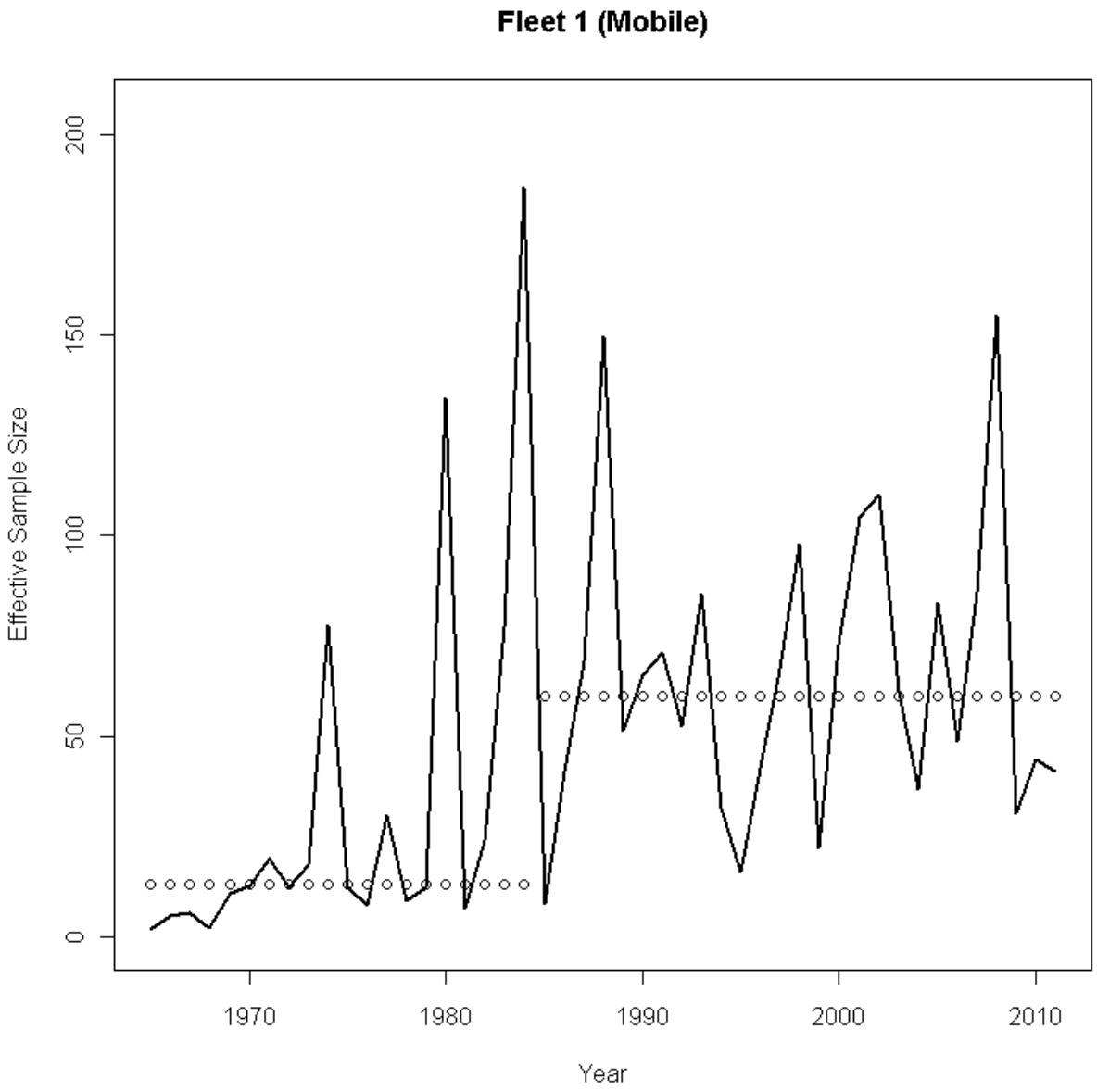


Figure A5-4. Input and estimated effective sample sizes from the ASAP base run for the mobile gear fishery.

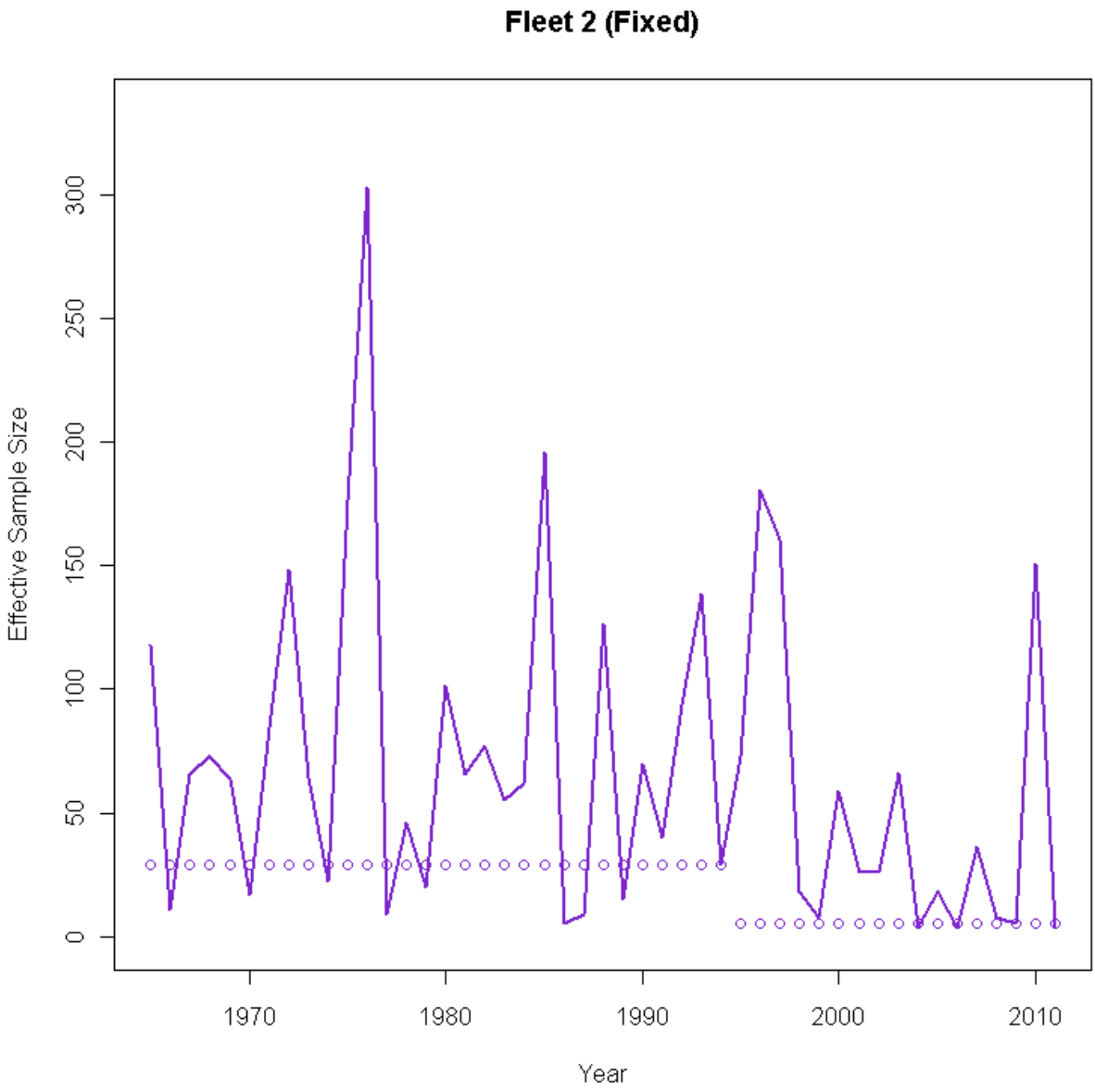


Figure A5-5. Input and estimated effective sample sizes from the ASAP base run for the fixed gear fishery.

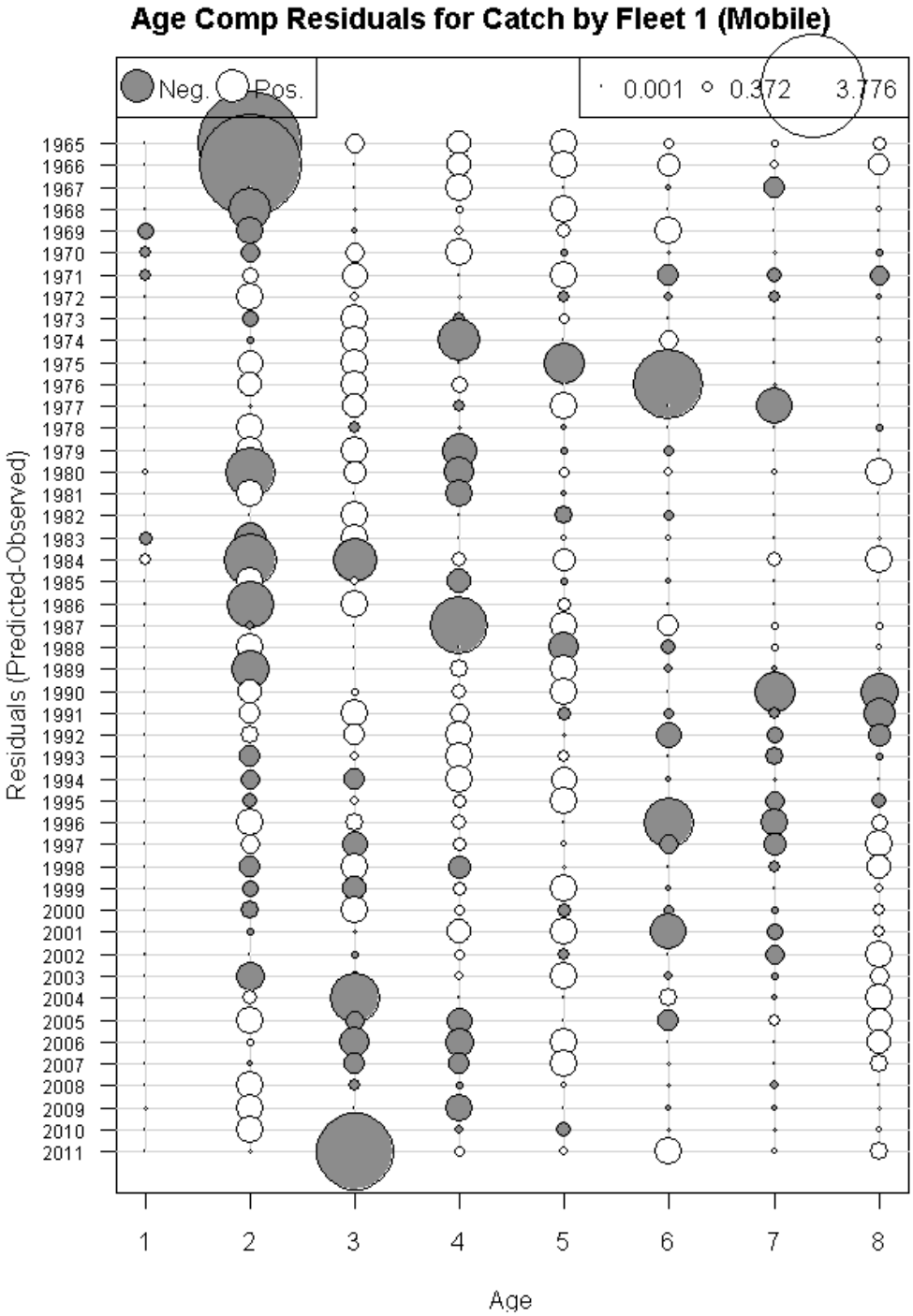


Figure A5-6. Age composition fits from the ASAP base run for the mobile gear fishery.

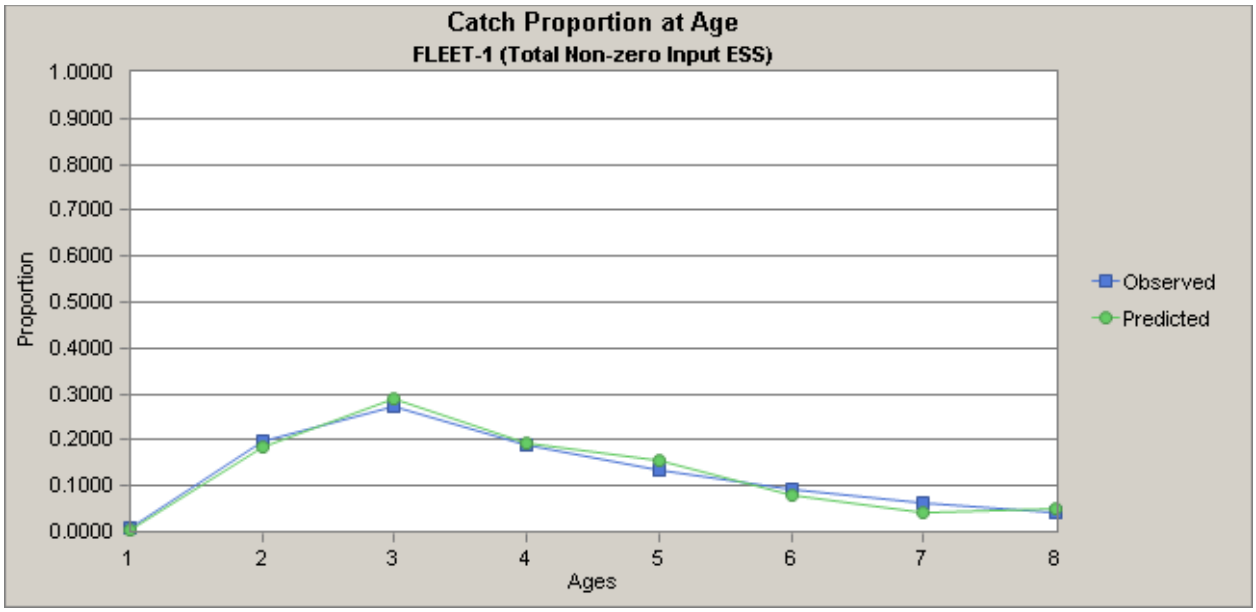


Figure A5-7. Total age composition fit from the ASAP base model for the mobile gear fishery.

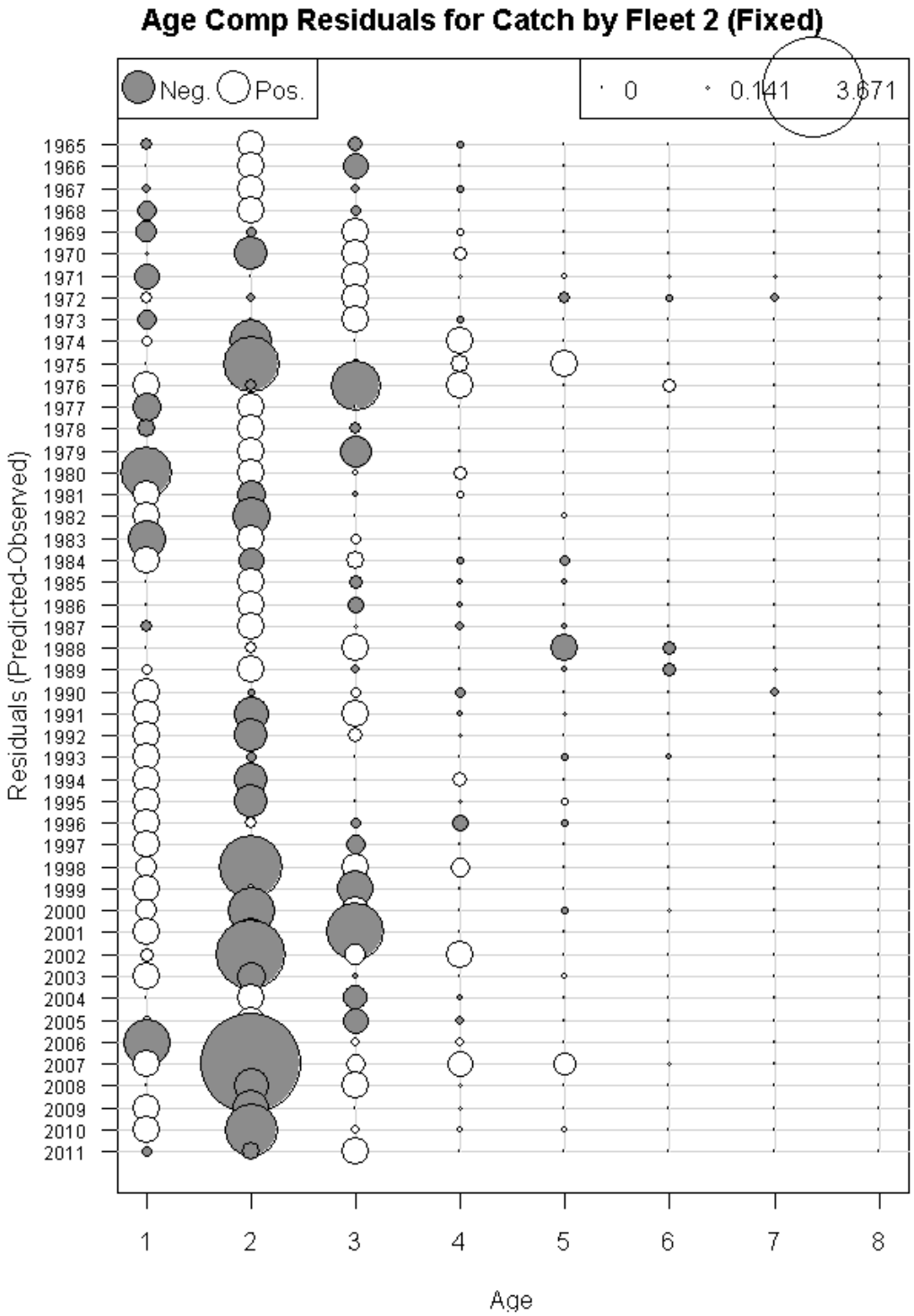


Figure A5-8. Age composition fits from the ASAP base run for the fixed gear fishery.

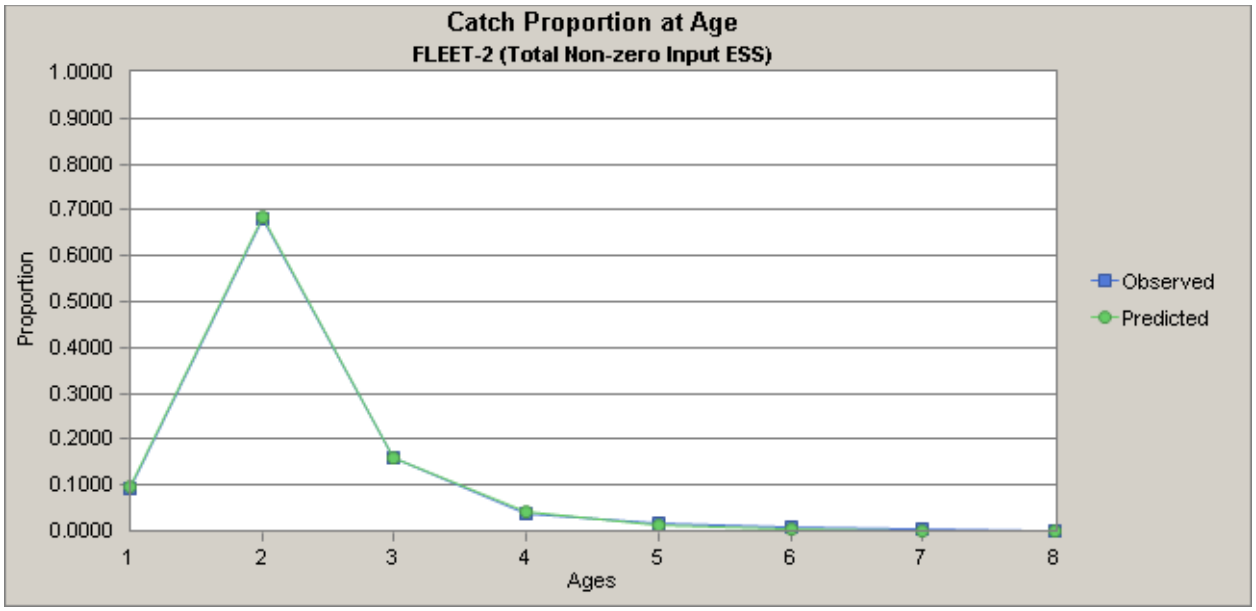


Figure A5-9. Total age composition fit from the ASAP base model for the fixed gear fishery.

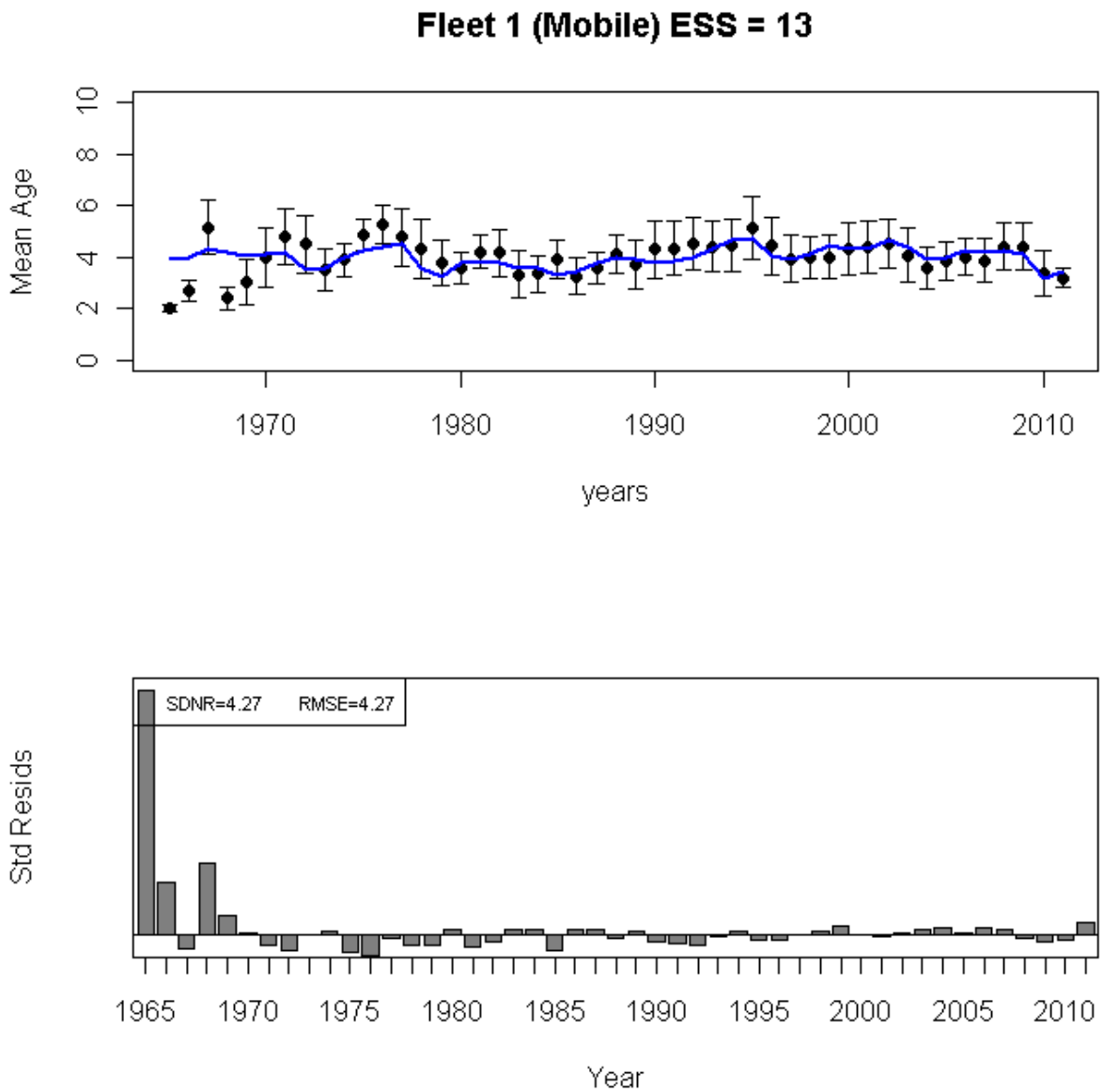


Figure A5-10. Fits to the observed mean age from the ASAP base model for the mobile gear fishery.

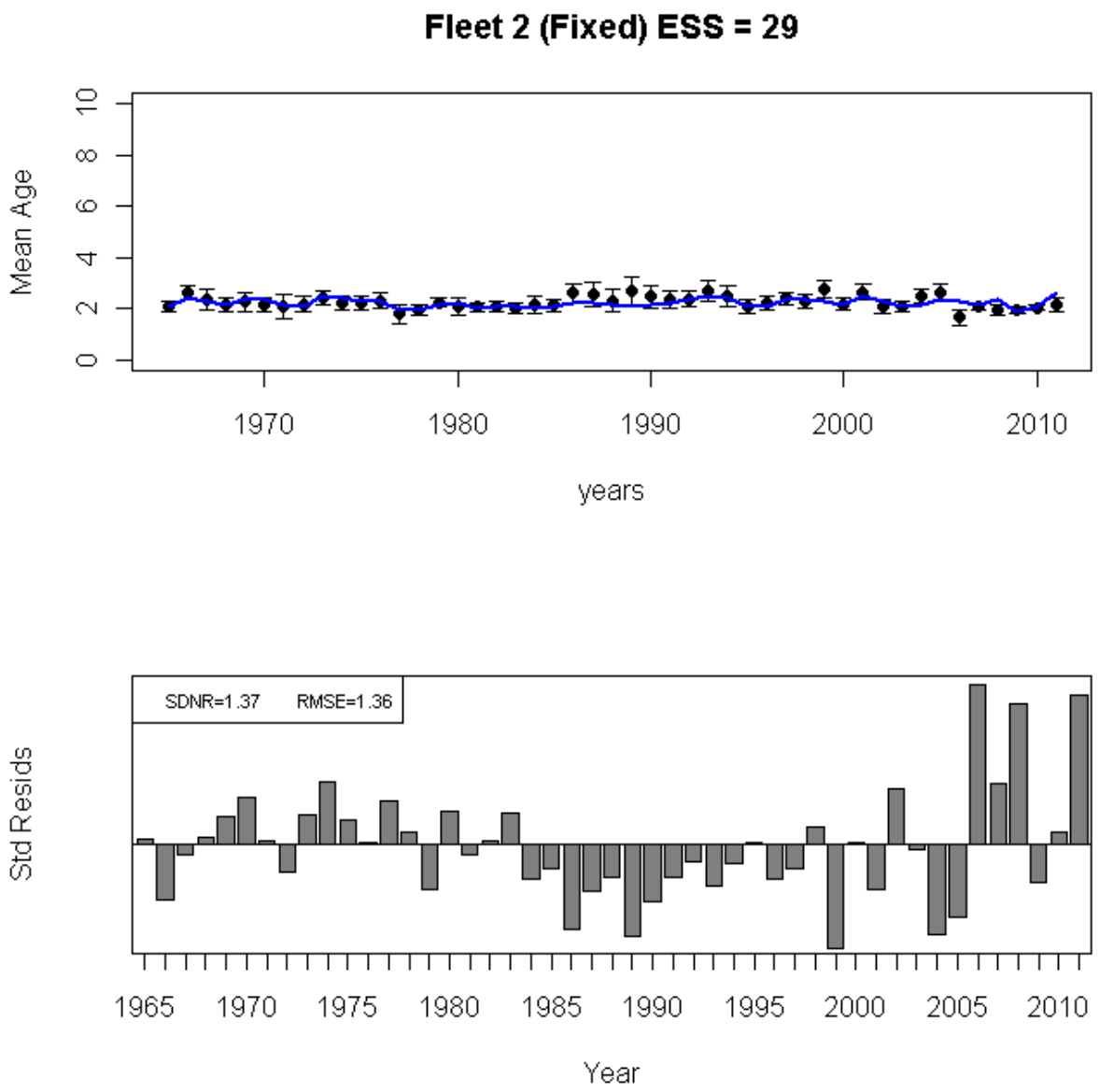


Figure A5-11. Fits to the observed mean age from the ASAP base model for the fixed gear fishery.

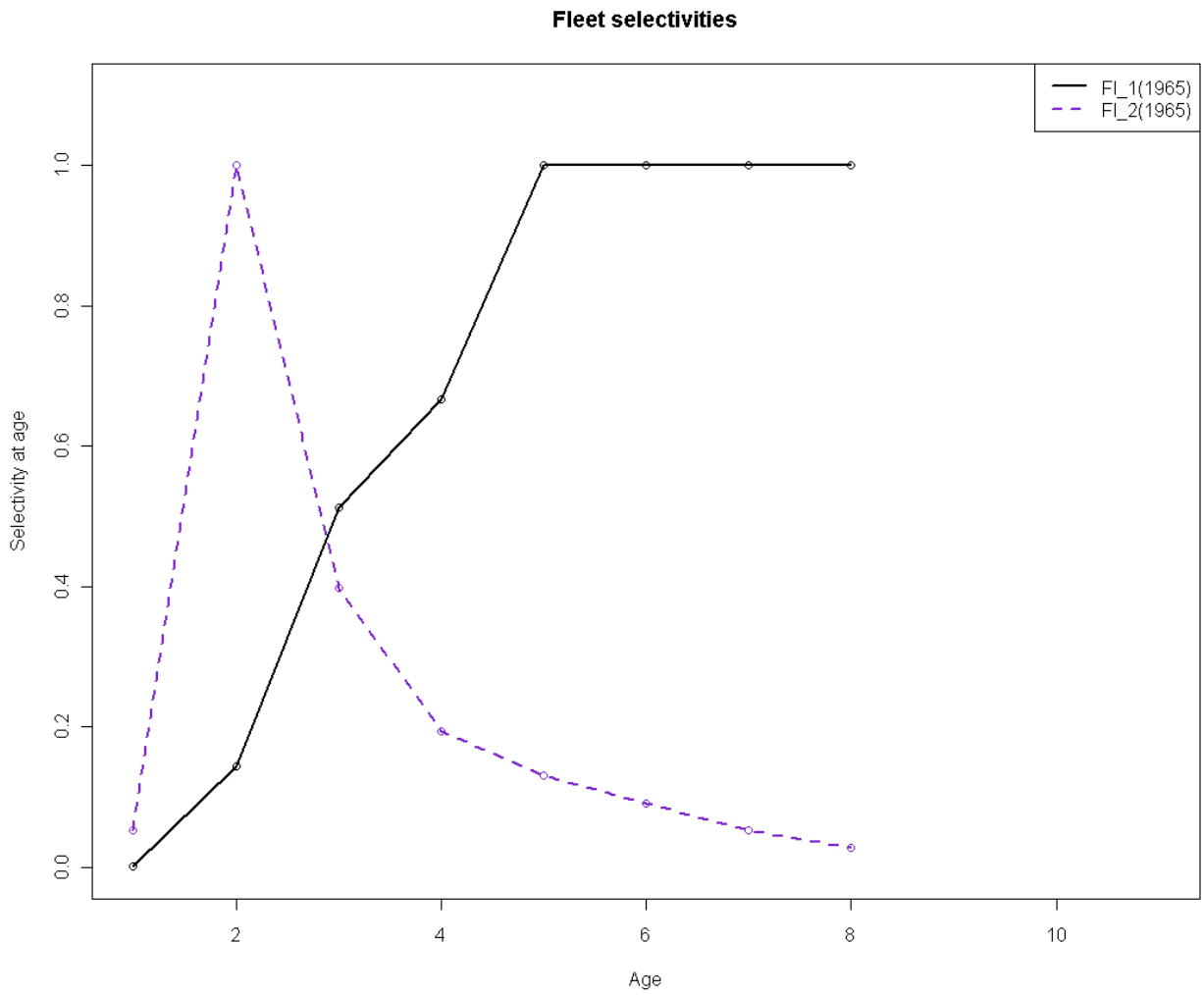


Figure A5-12. Selectivity patterns from the ASAP base run for the mobile gear fishery (black line) and the fixed gear fishery (purple dashed line).

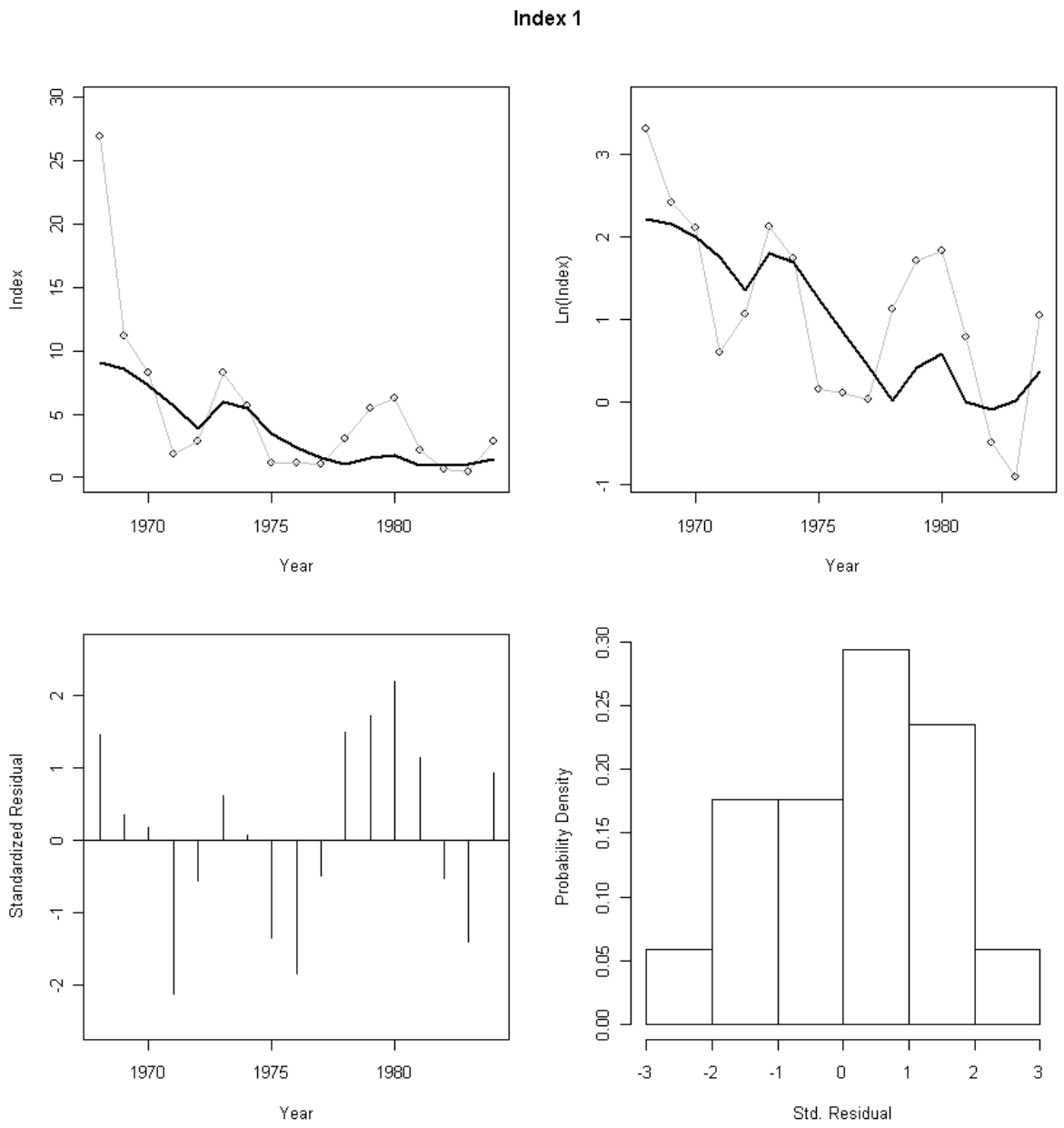


Figure A5-13. Fit to the NMFS spring survey during 1968-1984 from the ASAP base run.

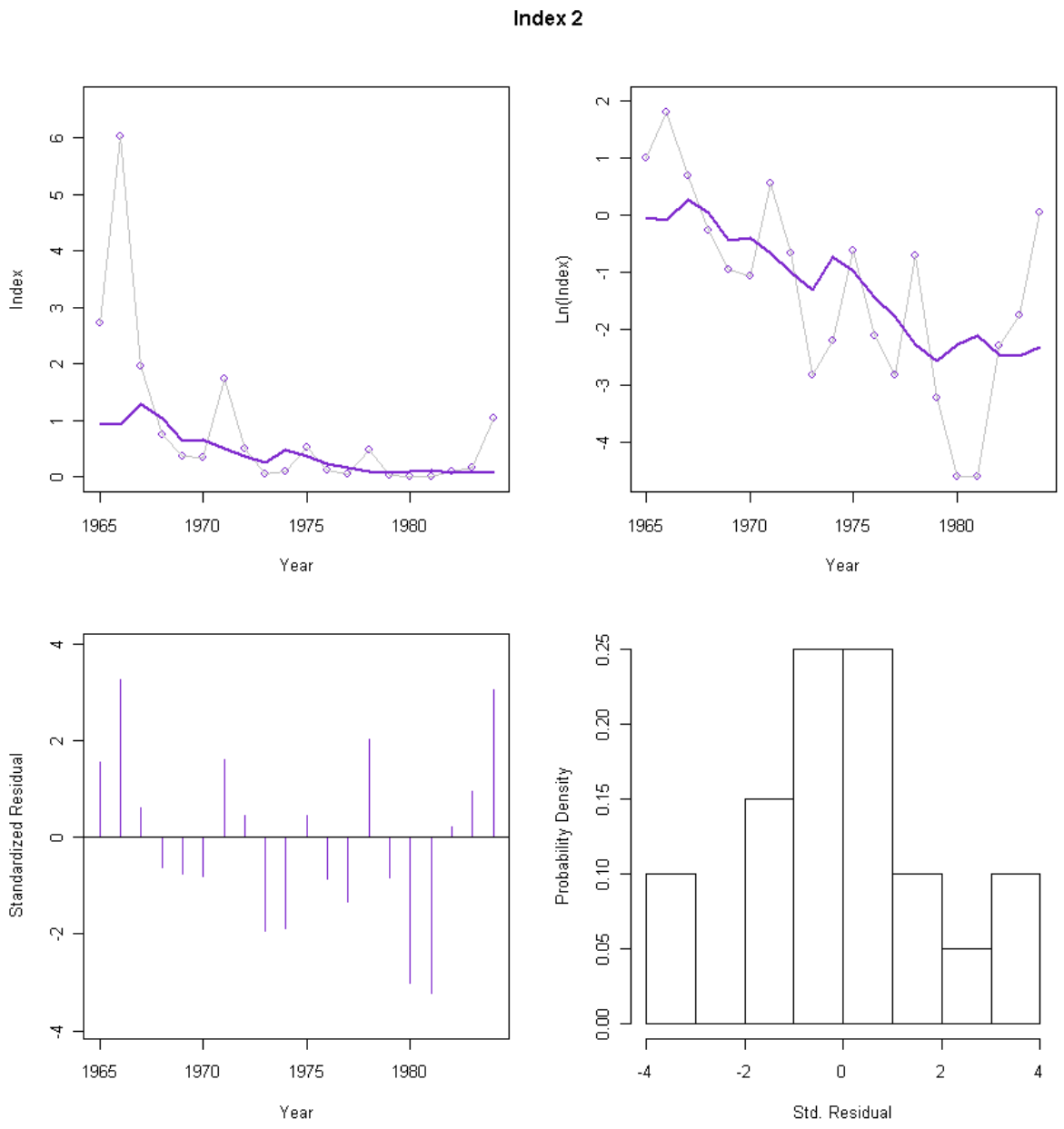


Figure A5-14. Fit to the NMFS fall survey during 1965-1984 from the ASAP base run.

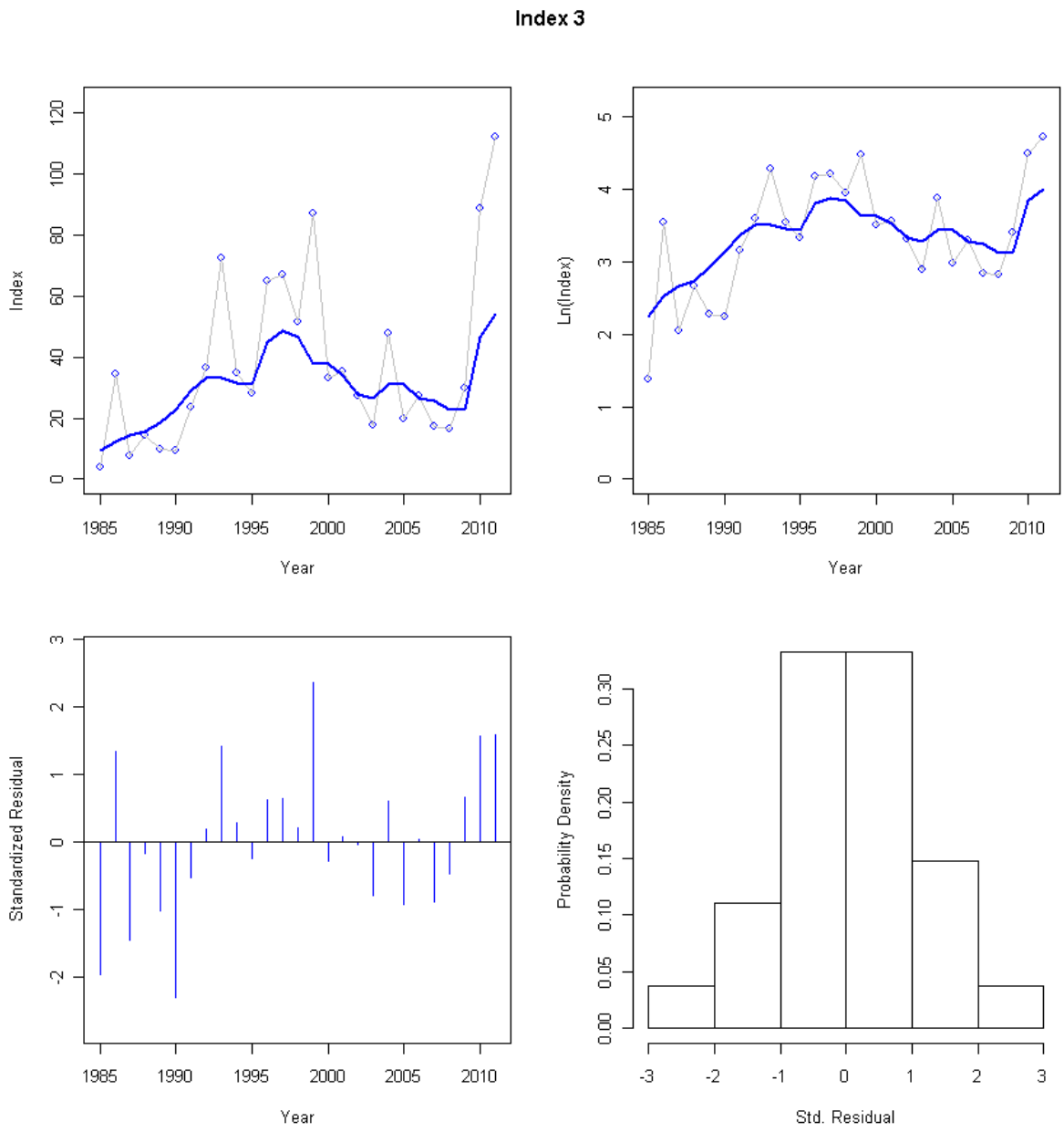


Figure A5-15. Fit to the NMFS spring survey during 1985-2011 from the ASAP base run.

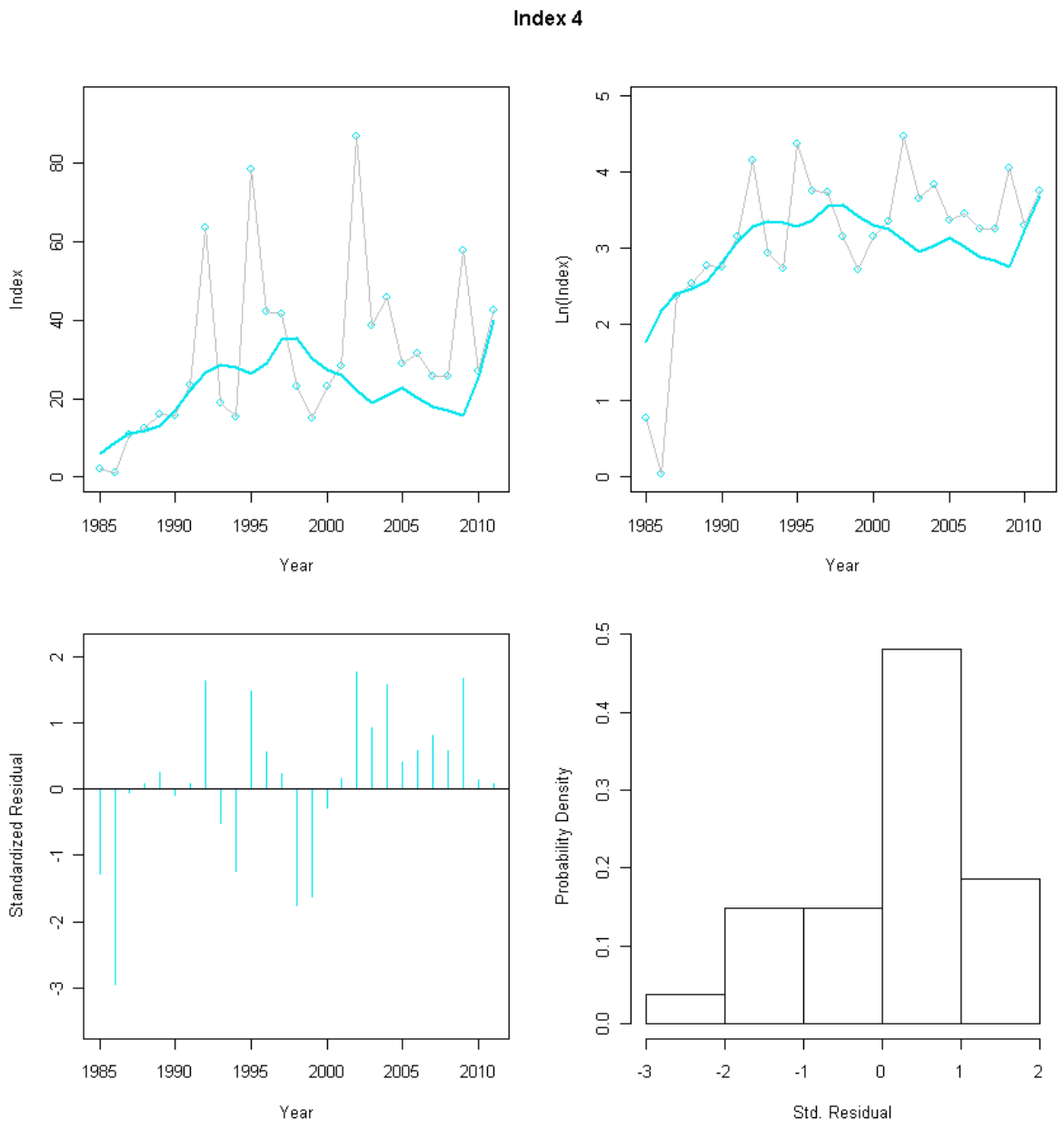


Figure A5-16. Fit to the NMFS fall survey during 1985-2011 from the ASAP base run.

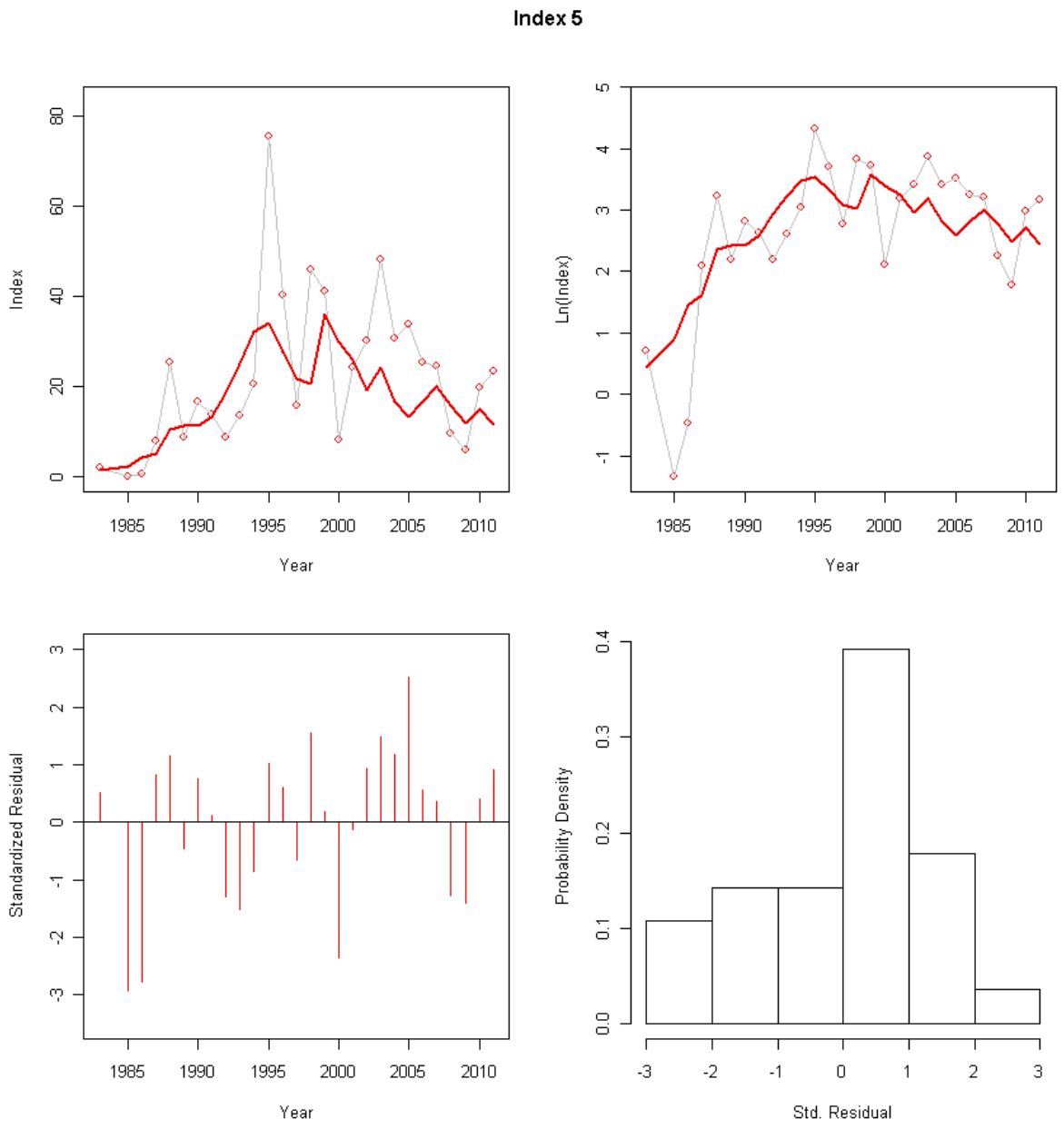


Figure A5-17. Fit to the NMFS shrimp survey during 1983 and 1985-2011from the ASAP base run.

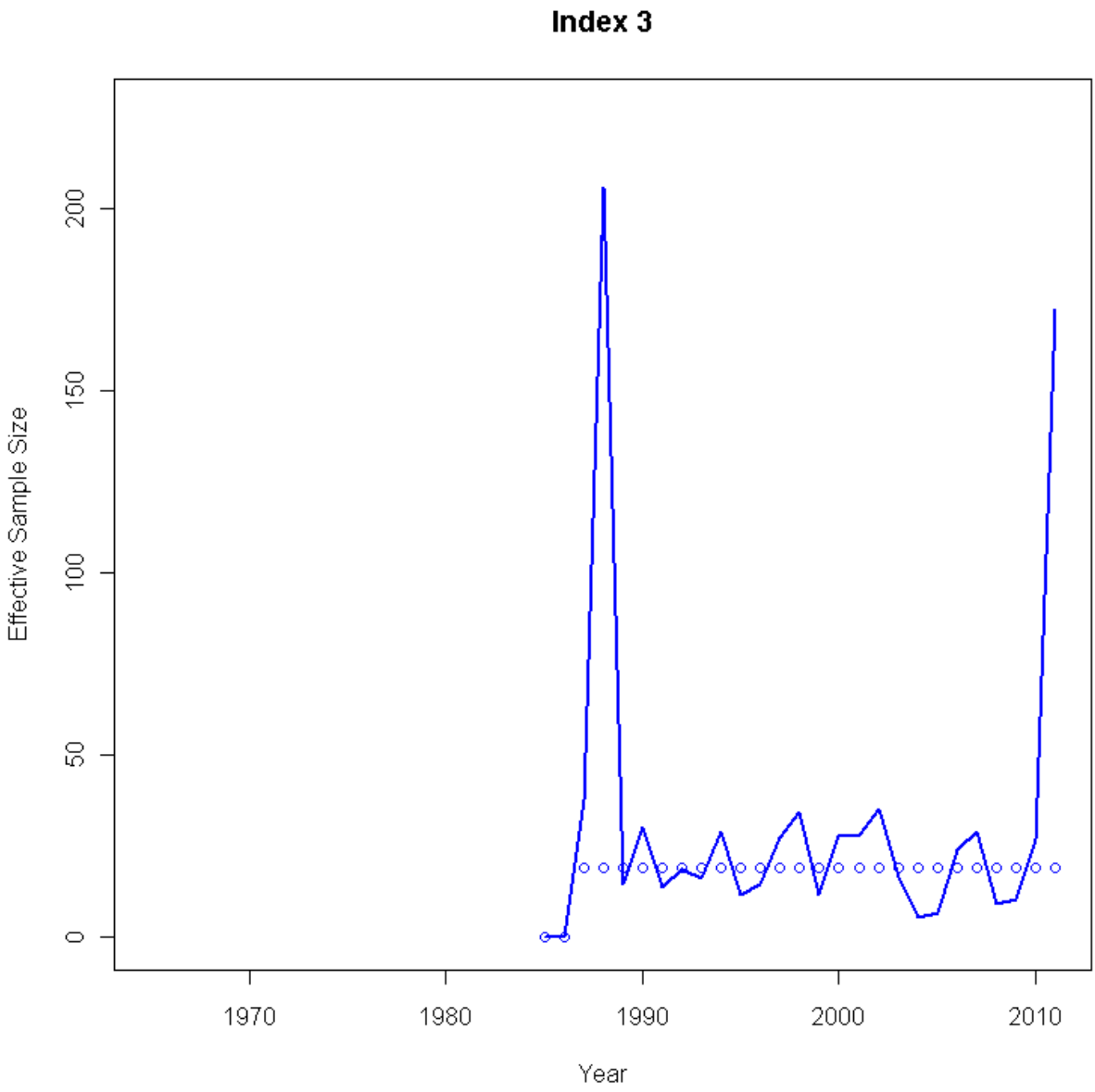


Figure A5-18. Input and estimated effective sample sizes from the ASAP base run for the NMFS spring survey during 1985-2011.

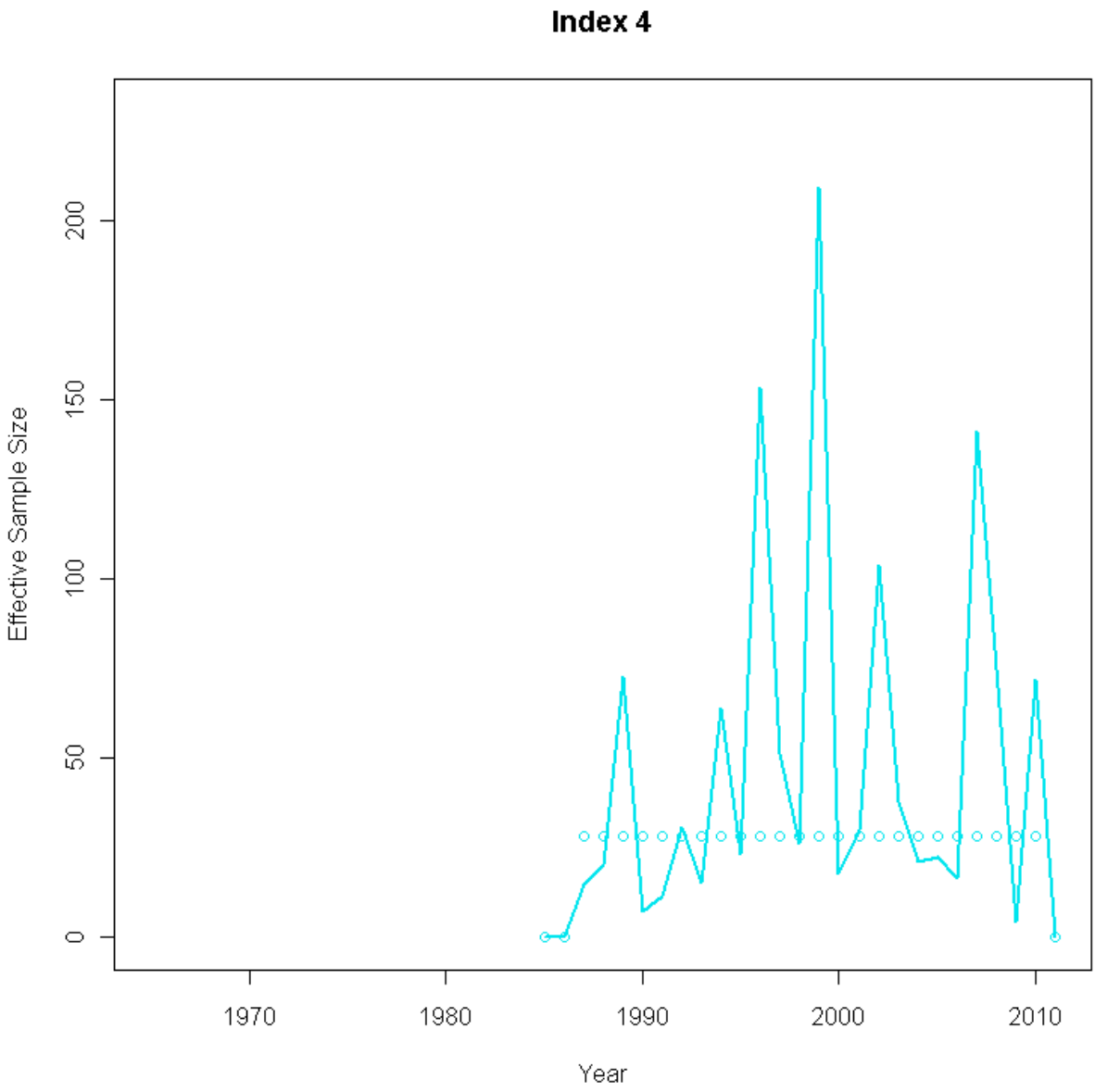


Figure A5-19. Input and estimated effective sample sizes from the ASAP base run for the NMFS fall survey during 1985-2010.

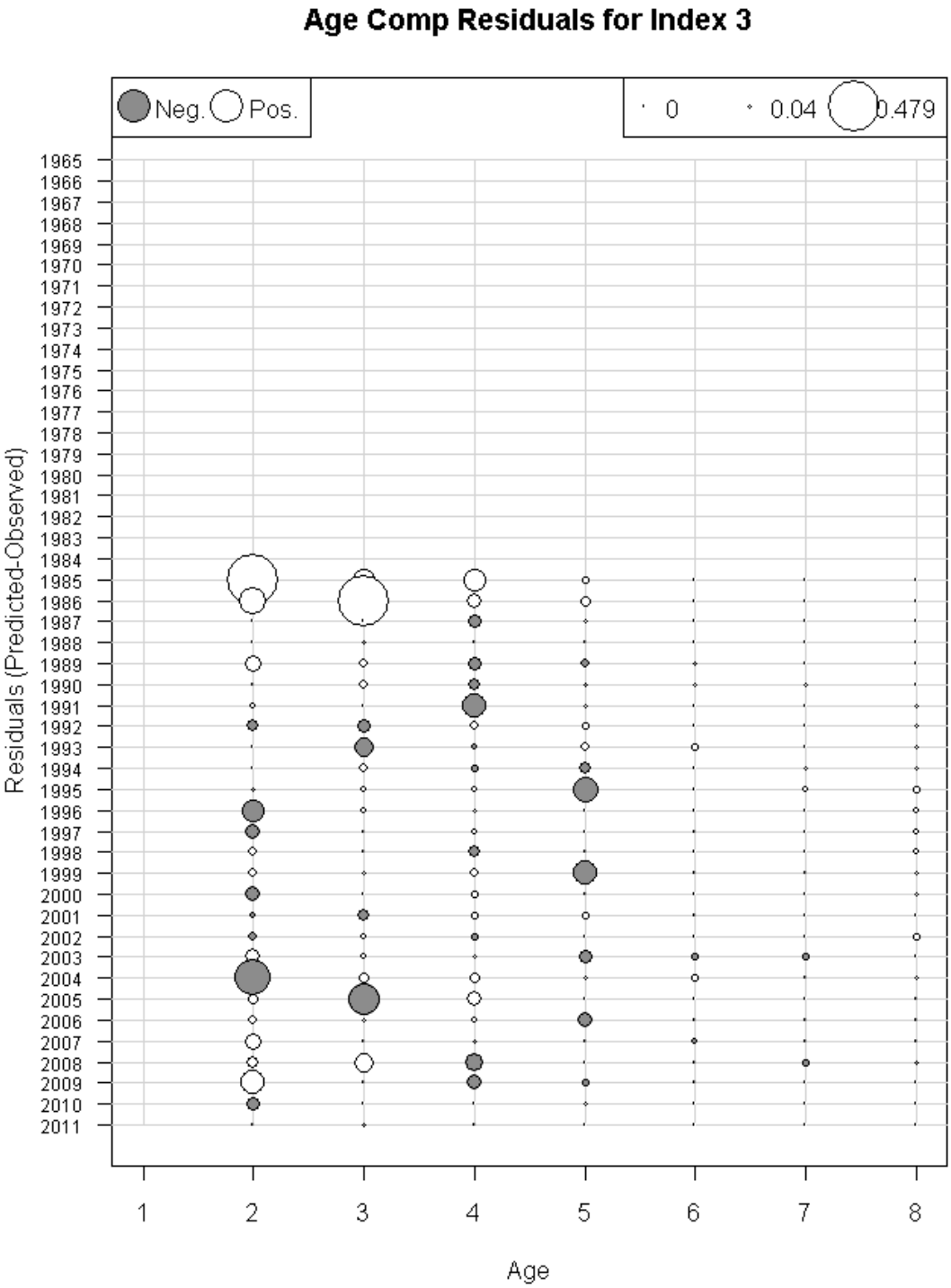


Figure A5-20. Age composition fits from the ASAP base run for the spring survey during 1987-2011. Note that no age composition data was available during 1985 and 1986. So the clusters of positive residuals early in the time series are a plotting anomaly and are not real.

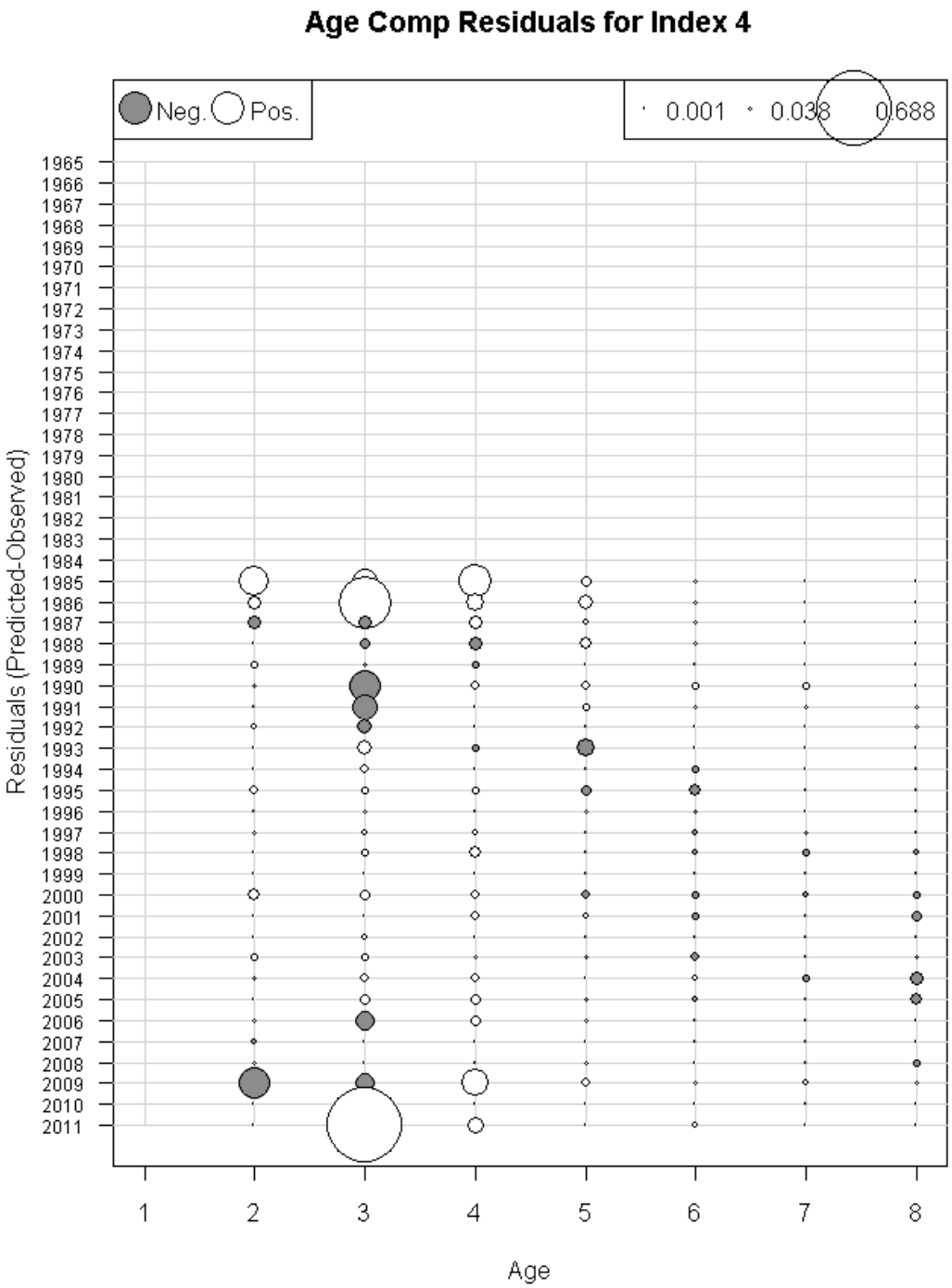


Figure A5-21. Age composition fits from the ASAP base run for the fall survey during 1987-2010. Note that no age composition data was available during 1985 and 1986. So the clusters of positive residuals early in the time series are a plotting anomaly and are not real.

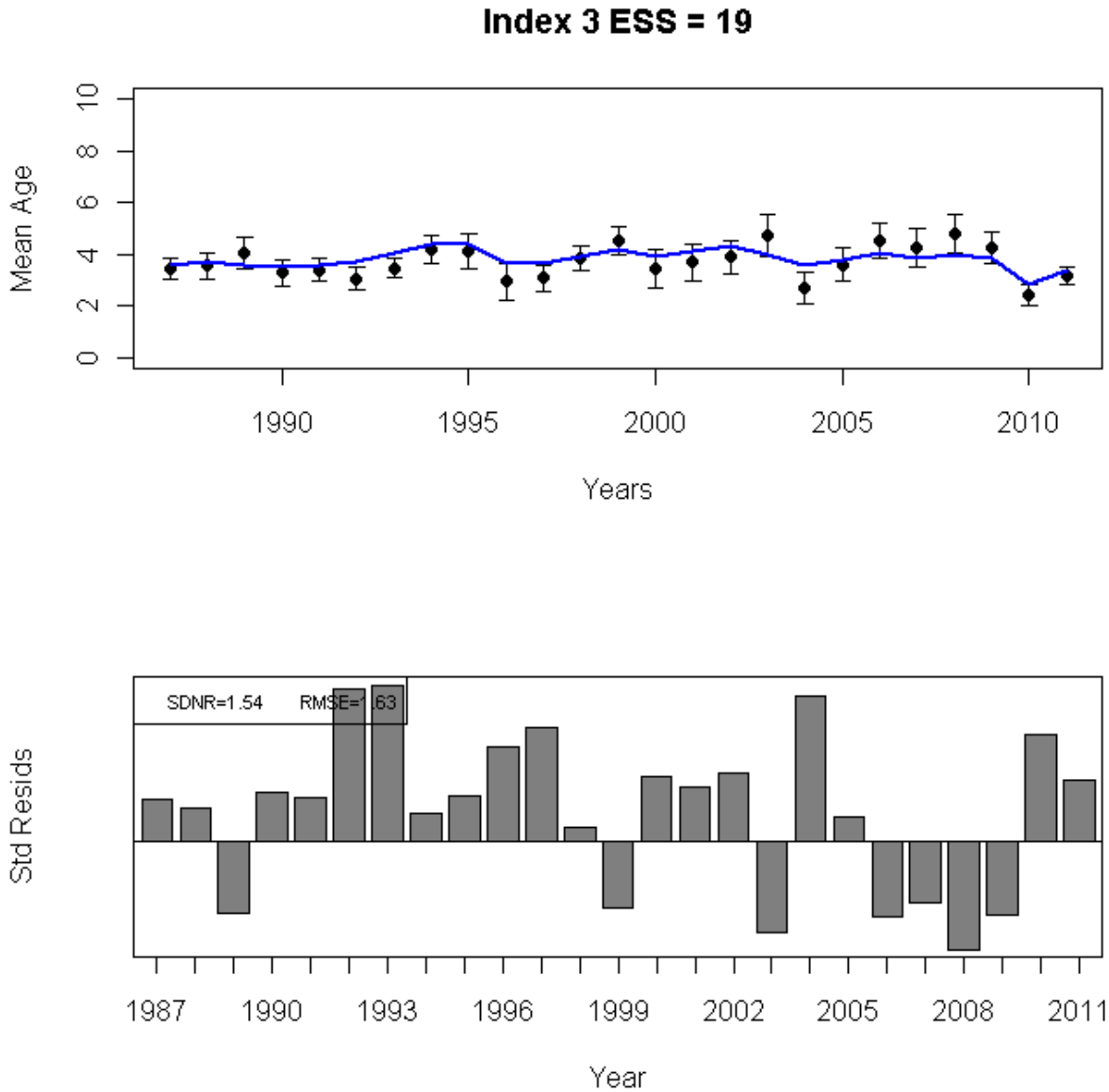


Figure A5-22. Fits to the observed mean age from the ASAP base model for the NMFS spring survey during 1987-2011.

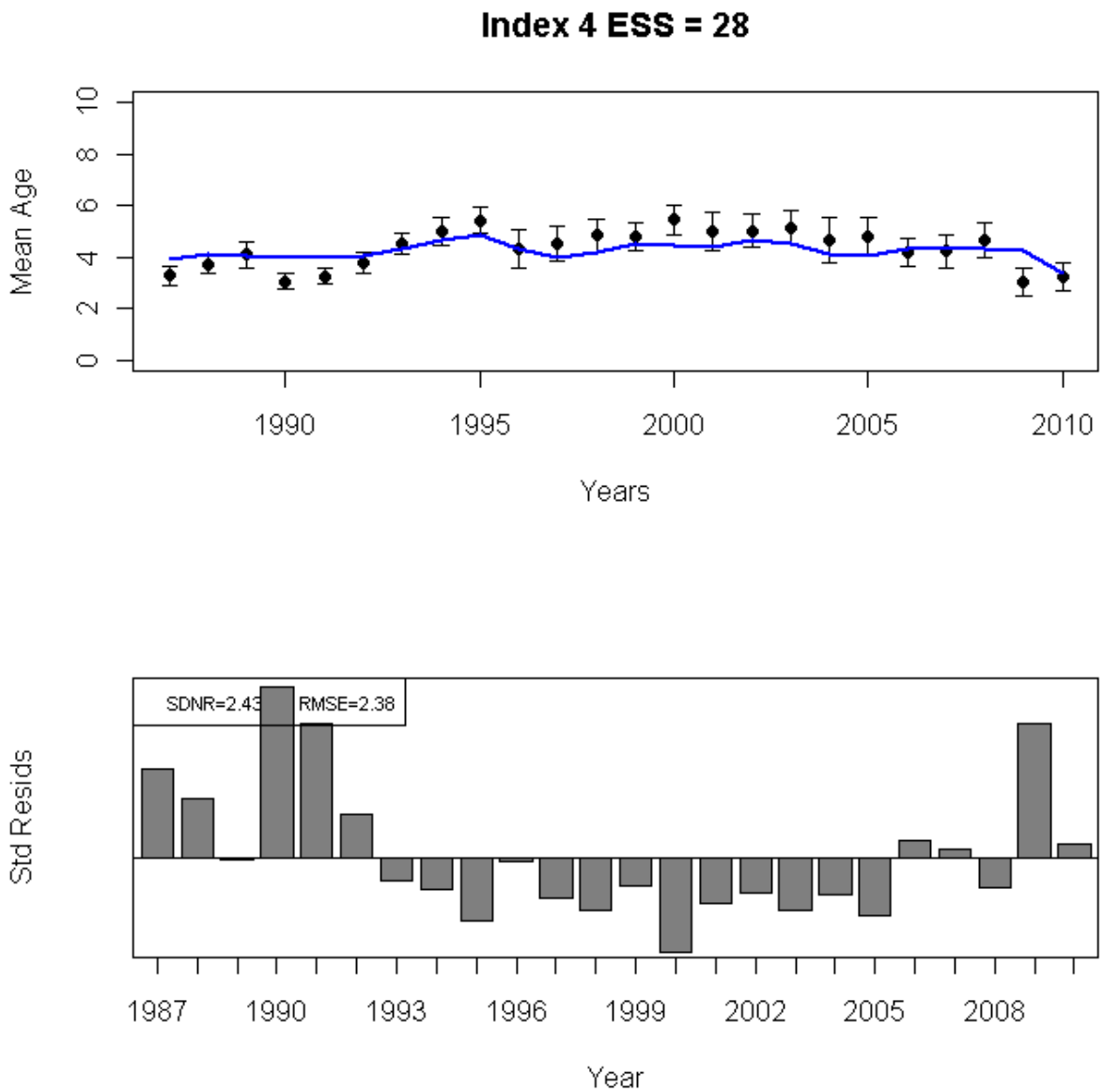


Figure A5-23. Fits to the observed mean age from the ASAP base model for the NMFS fall survey during 1987-2010.

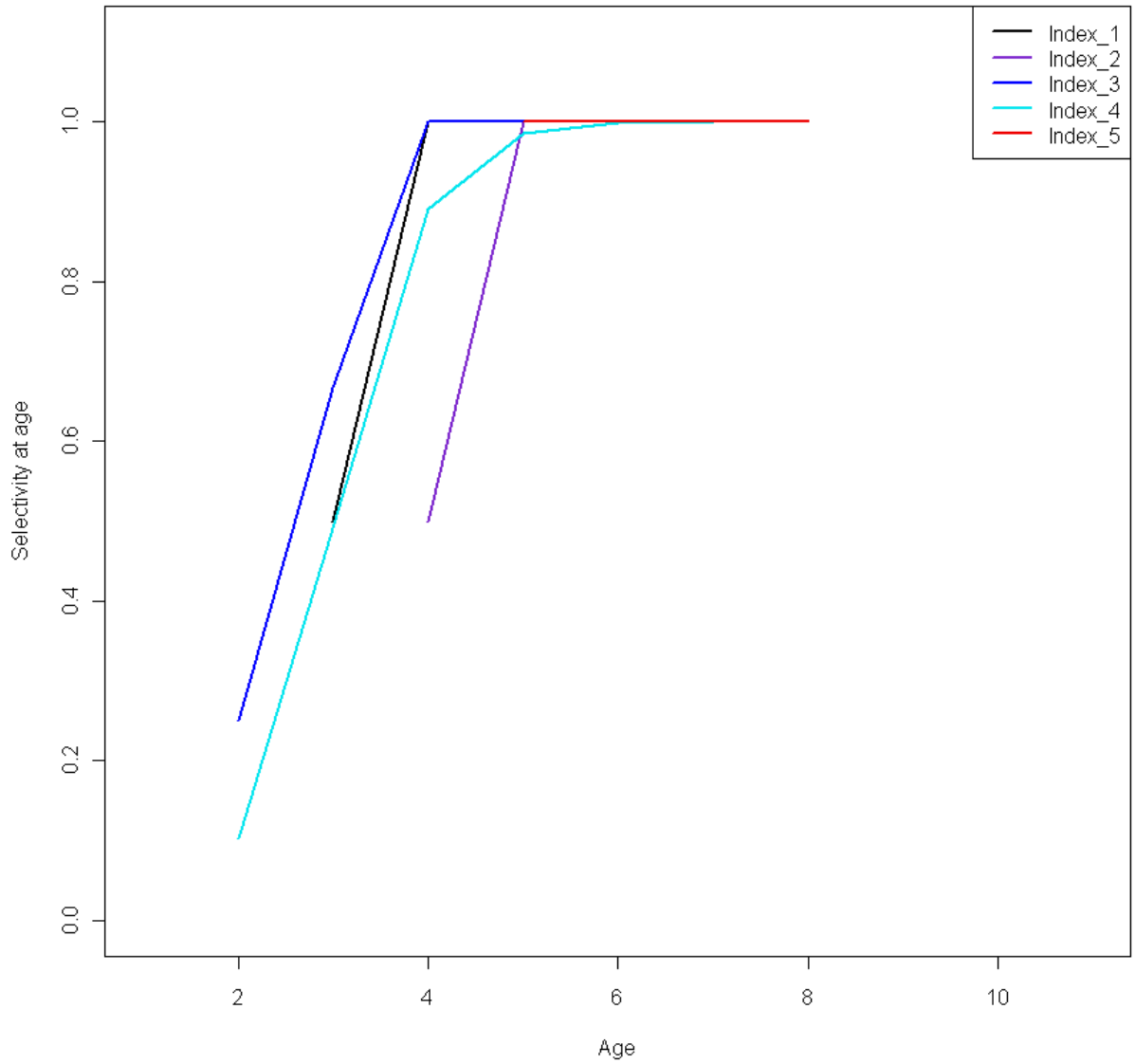


Figure A5-24. Selectivity patterns for the surveys used in the ASAP base run. Spring 1968-1984 is black, Index_1. Fall 1965-1984 is purple, Index_2. Spring 1985-2011 is dark blue, Index_3. Fall 1985-2011 is light blue, Index_4. Shrimp is red, Index_5.

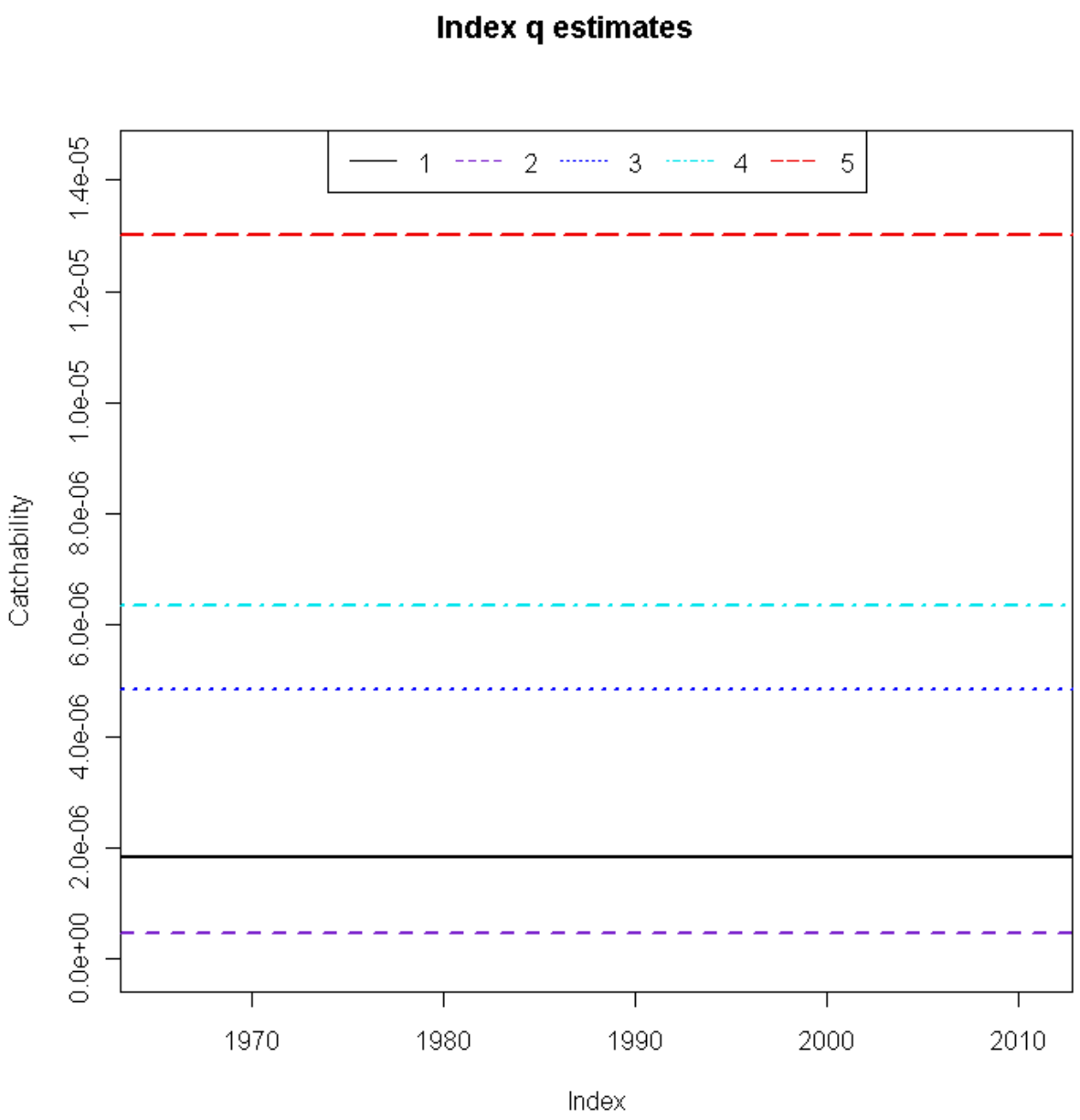


Figure A5-25. Catchability estimates for each survey used in the ASAP base model. Spring 1968-1984 is black, Index_1. Fall 1965-1984 is purple, Index_2. Spring 1985-2011 is dark blue, Index_3. Fall 1985-2011 is light blue, Index_4. Shrimp is red, Index_5.

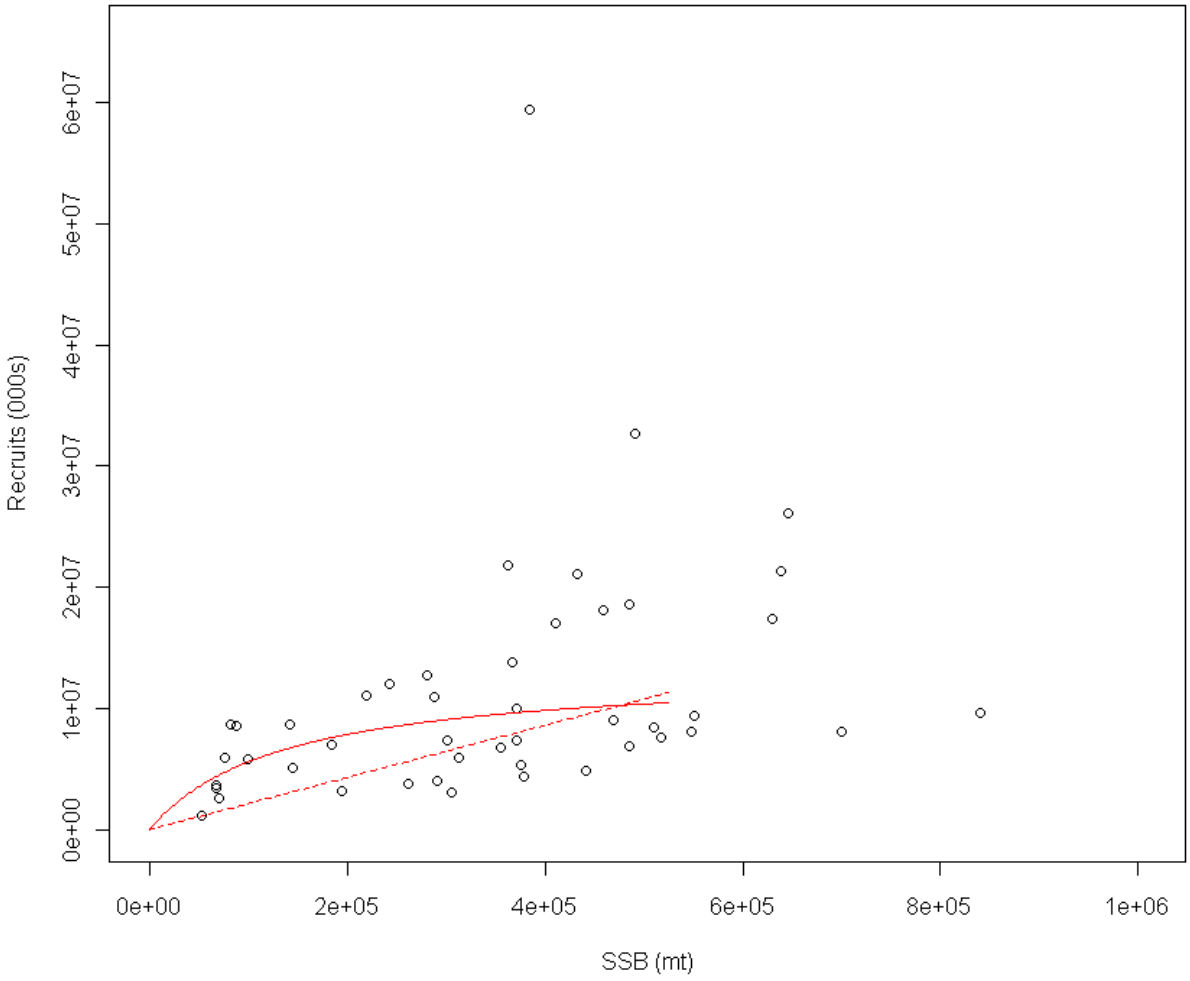


Figure A5-26. Stock-recruitment fit of the ASAP base run.

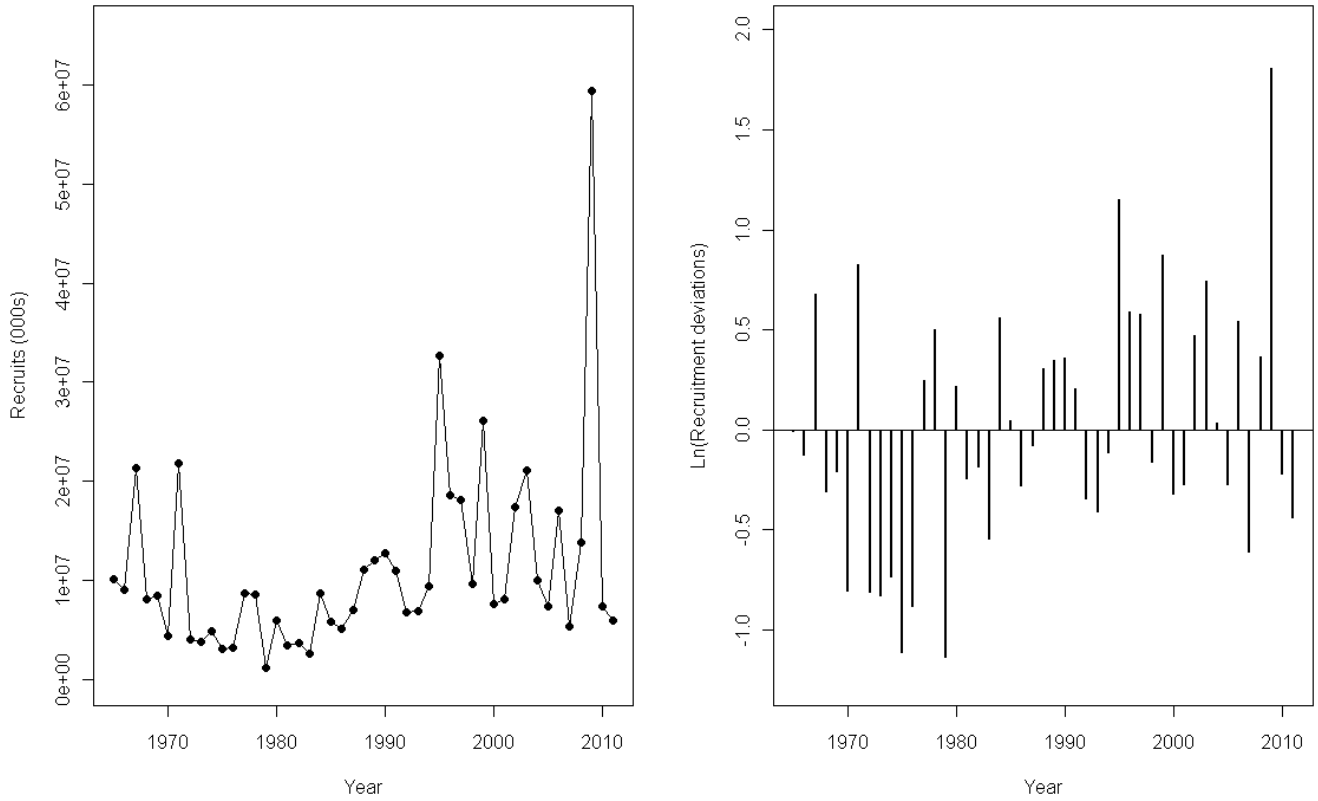


Figure A5-27. Recruitment time series and log recruitment deviations from the ASAP base run.

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

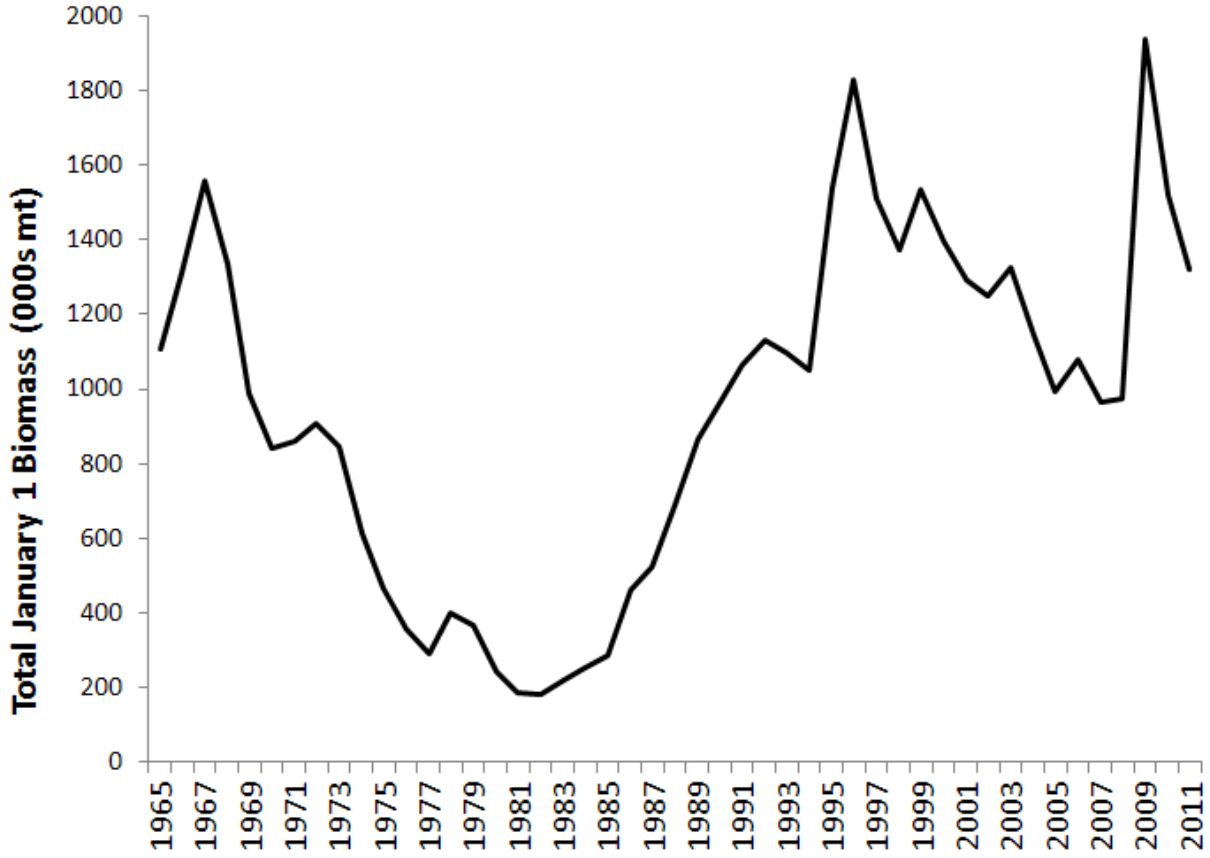


Figure A5-29. Total biomass time series estimated from the ASAP base run.

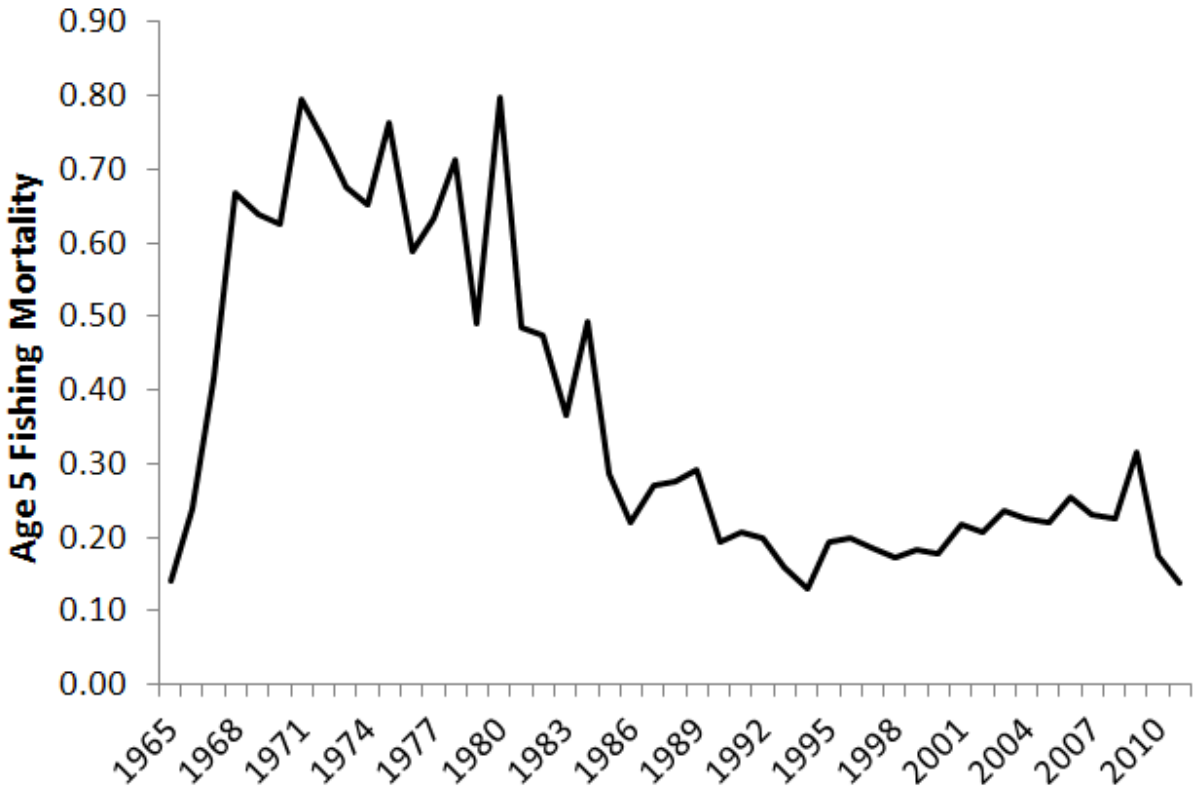


Figure A5-30. Age 5 fishing mortality estimated from the ASAP base run.

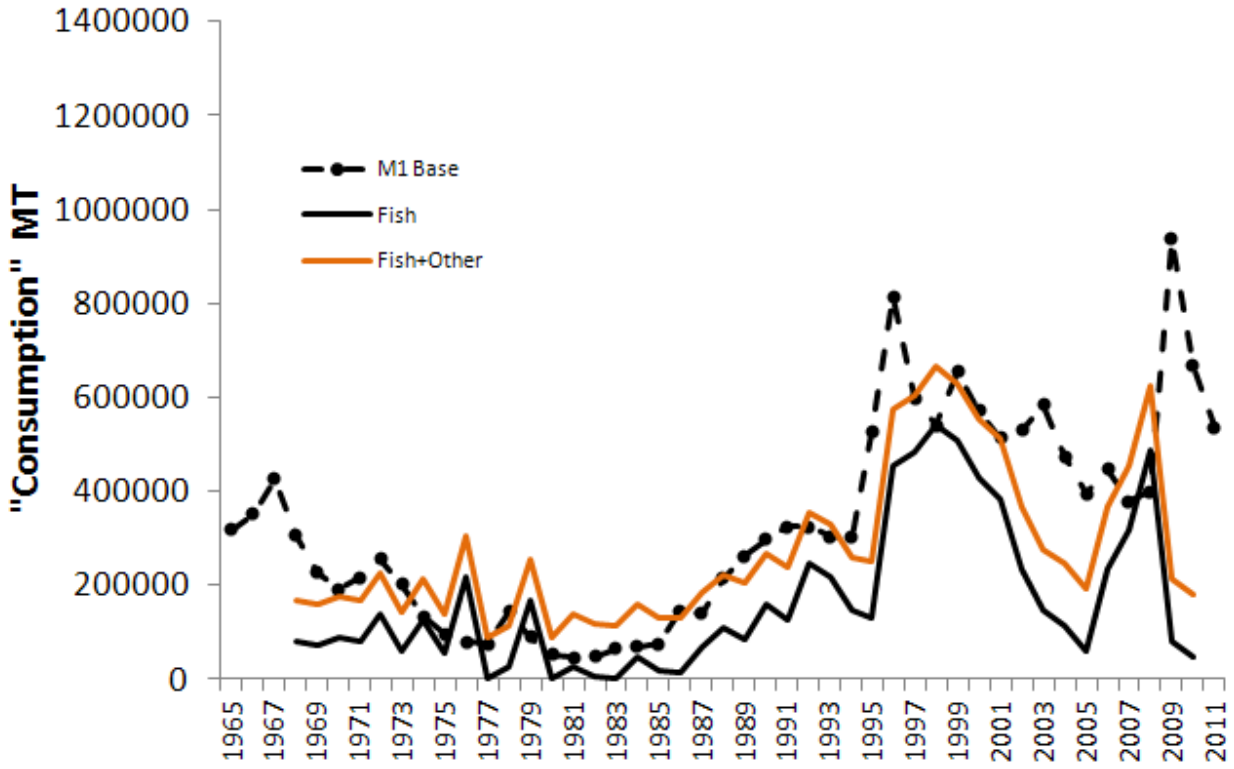


Figure A5-31. The deaths, considered largely attributable to consumption, implied by the natural mortality rates used in the ASAP base run (M1 Base; black dashes with circles), estimates of consumption of herring by fish predators (Fish; black line), and estimates of consumption of herring by "all" predators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

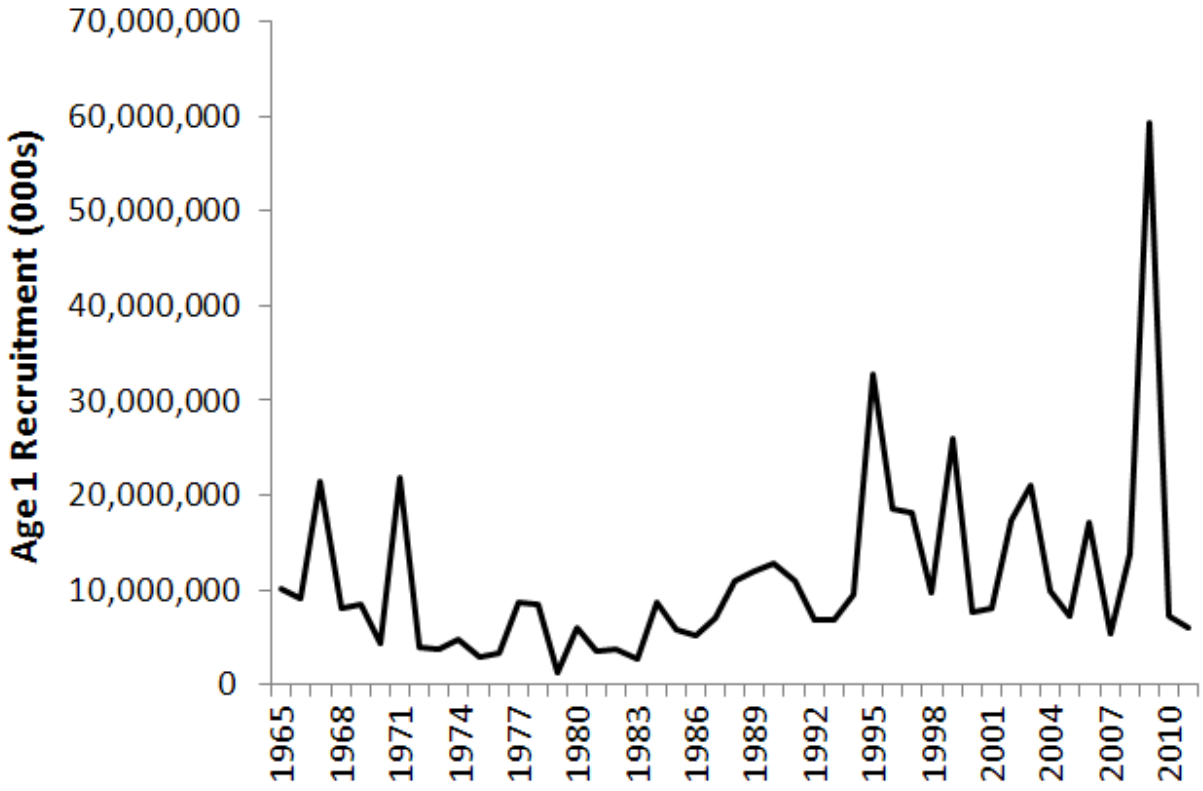


Figure A5-32. Age 1 recruitment estimated from the ASAP base run.

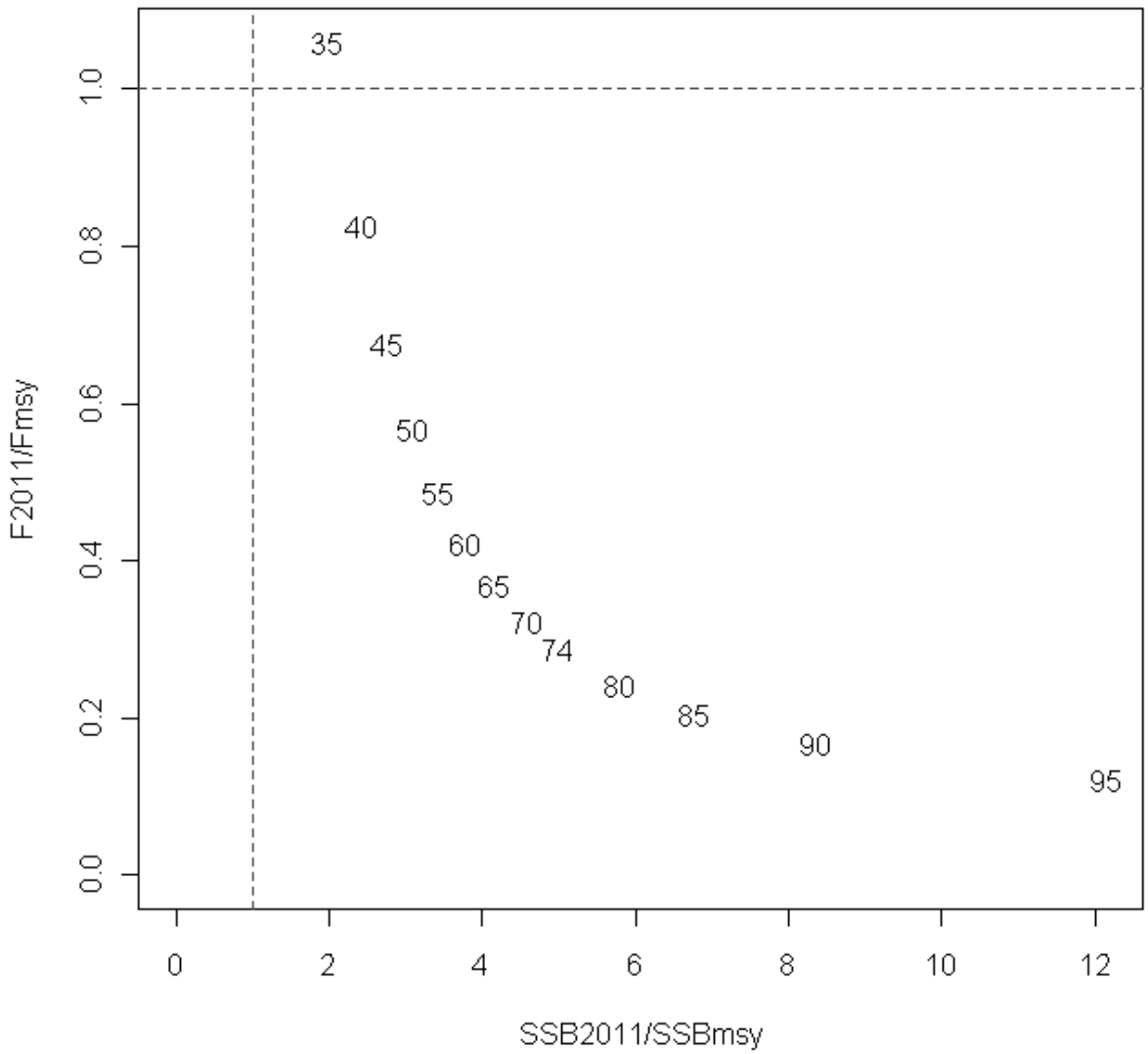


Figure A5-33. The status of Atlantic herring in 2011 relative to F_{msy} (y-axis) and SSB_{msy} (x-axis) from the ASAP base run, profiled over values of the steepness parameter, which are the numbers within the plot. The dashed lines index the locations where F or SSB in 2011 equal s F_{msy} or SSB_{msy}.

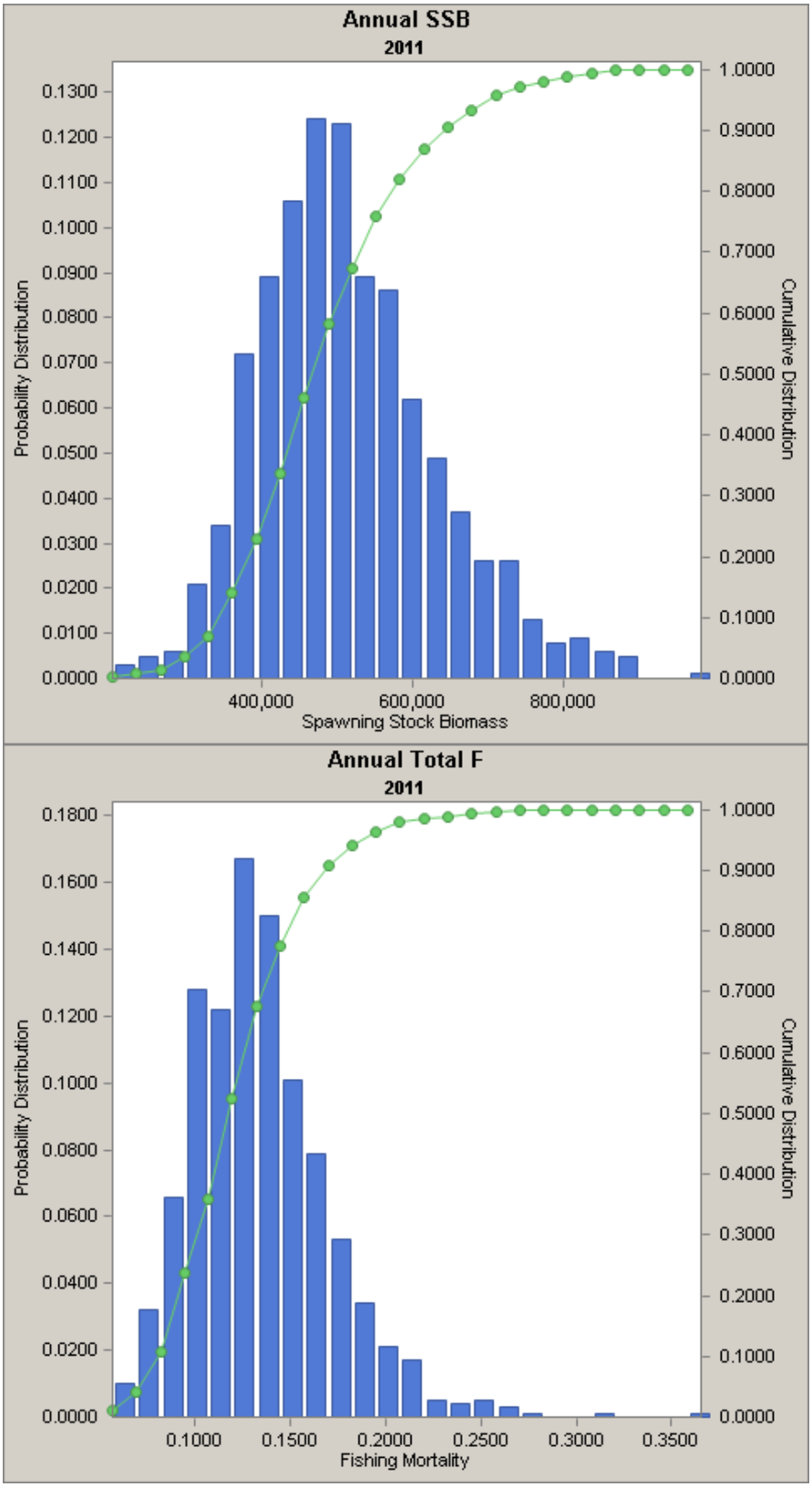


Figure A5-34. Posterior densities of SSB and F in 2011 from the ASAP base run.

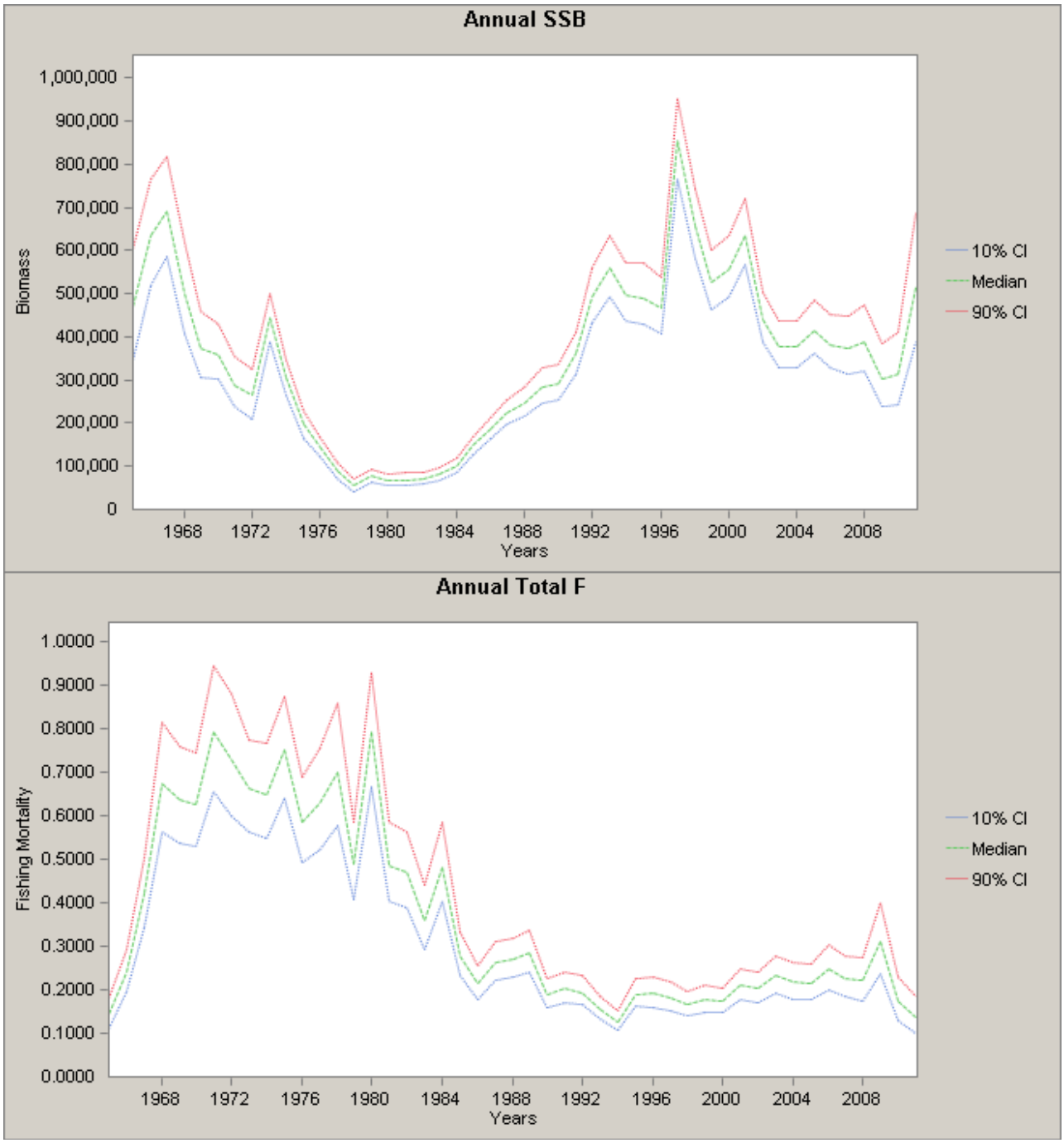


Figure A5-35. Time series plots of SSB and F with 80% probability intervals from the ASAP base run.

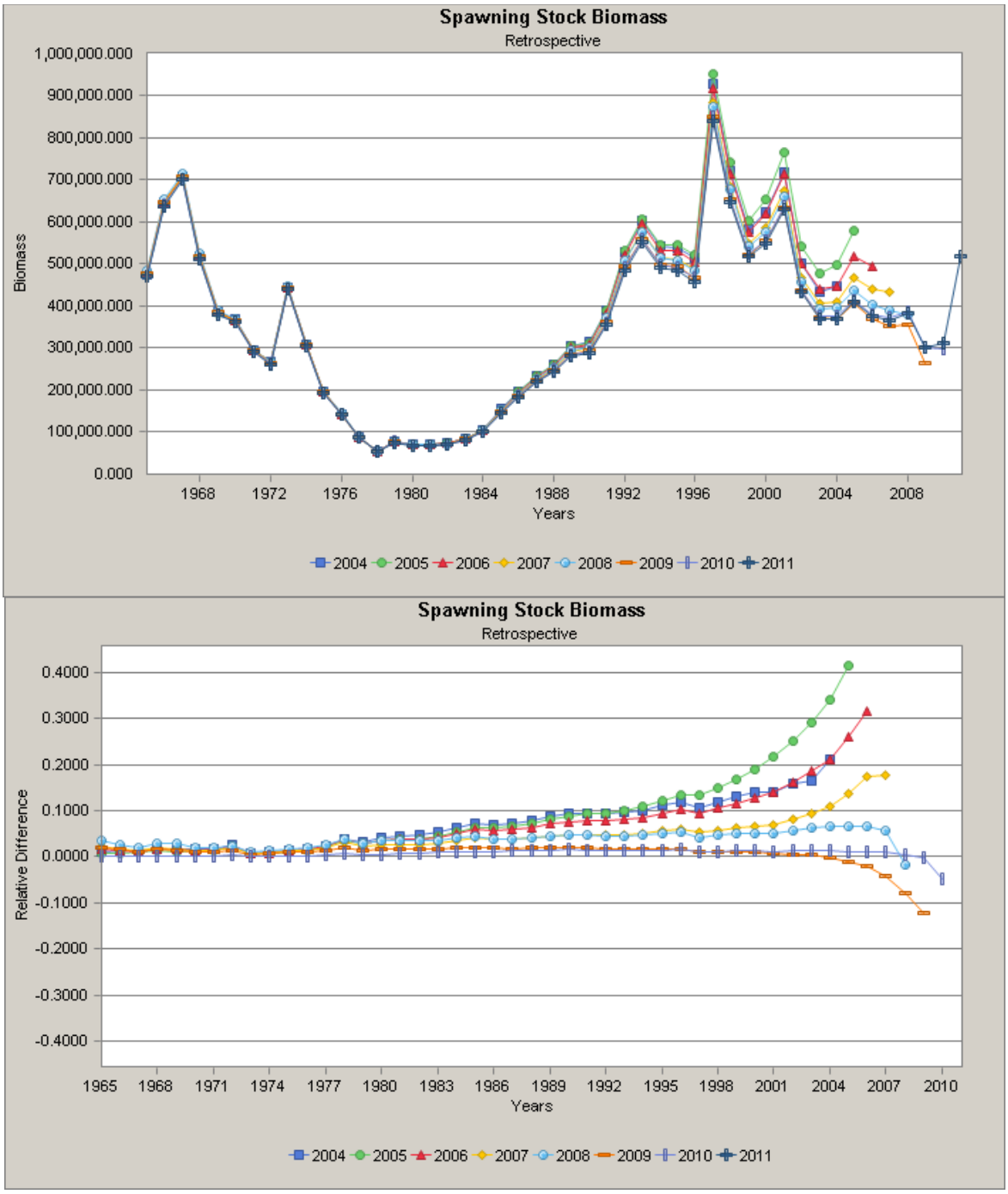


Figure A5-36. Retrospective pattern in spawning stock biomass from the ASAP base run.

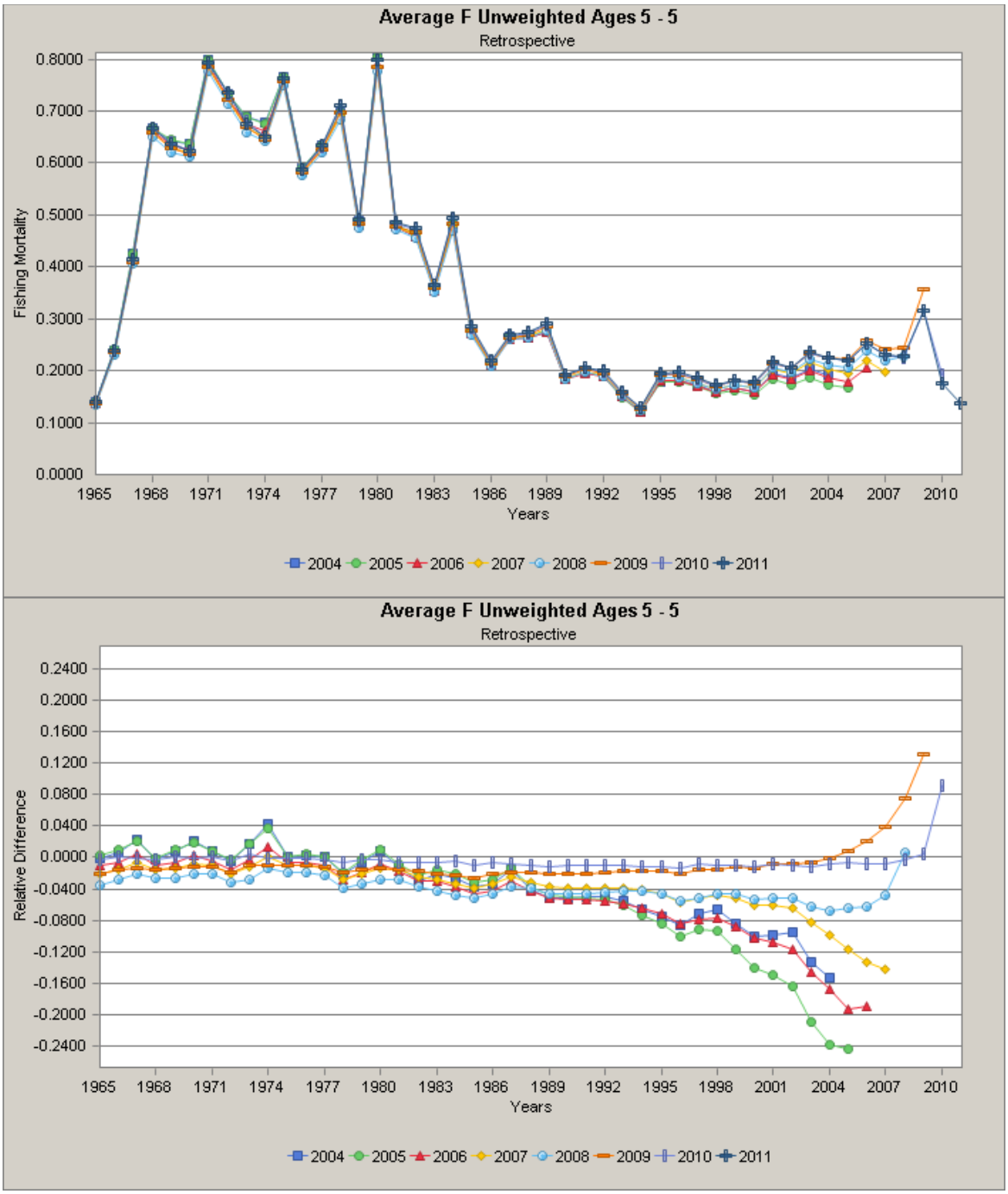


Figure A5-37. Retrospective pattern in fishing mortality from the ASAP base run.

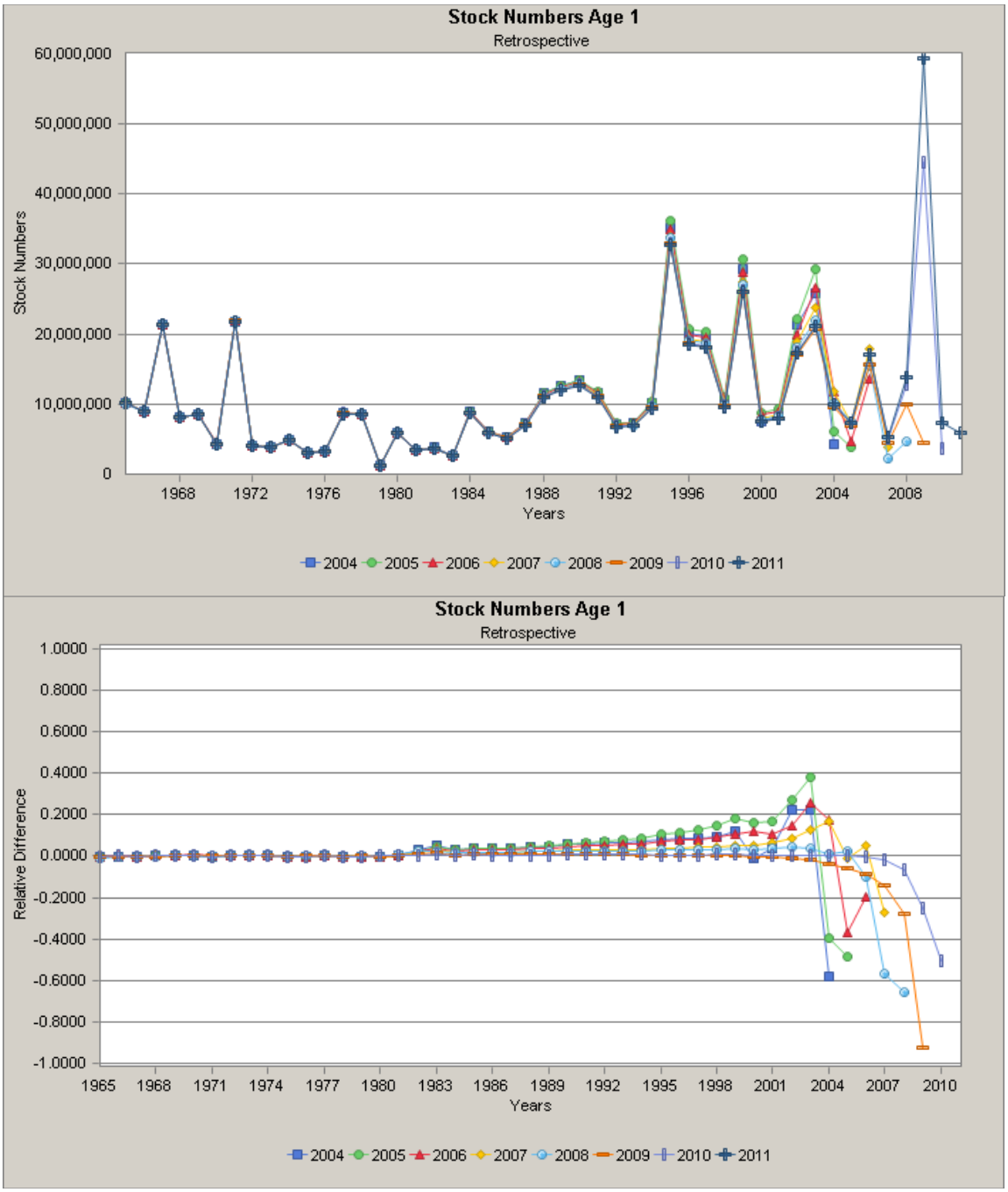


Figure A5-38. Retrospective pattern in recruitment from the ASAP base run.

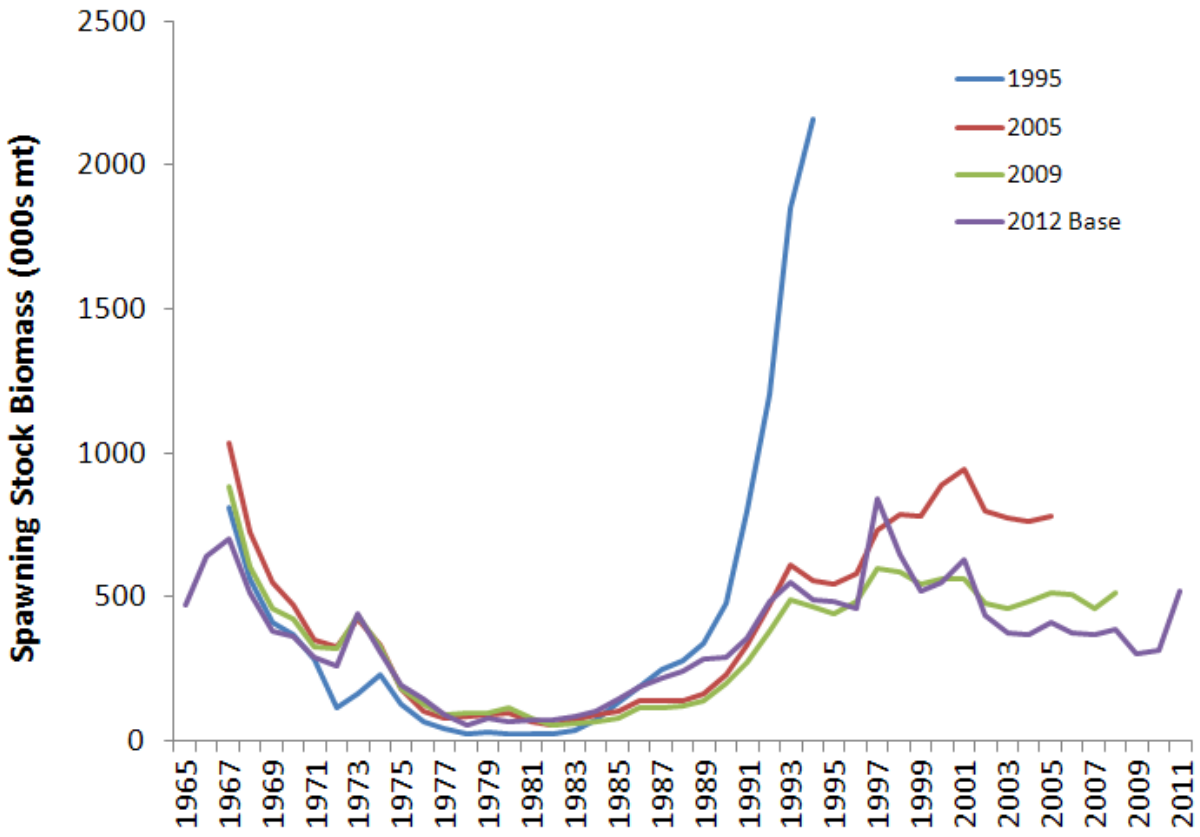


Figure A5-39. Historic retrospective pattern in spawning stock biomass for assessments done in 1995, 2005, 2009, and the proposed ASAP base run.

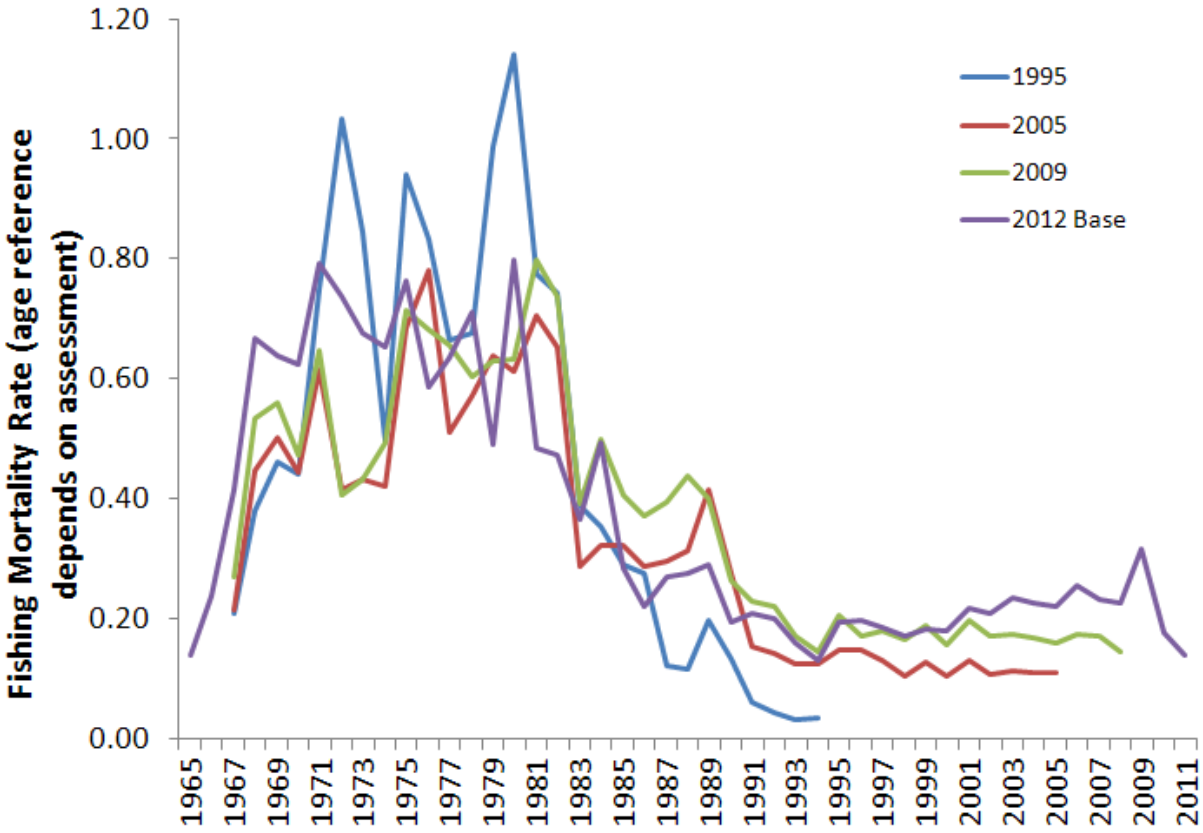


Figure A5-40. Historic retrospective pattern in fishing mortality for assessments done in 1995, 2005, 2009, and the proposed ASAP base run.

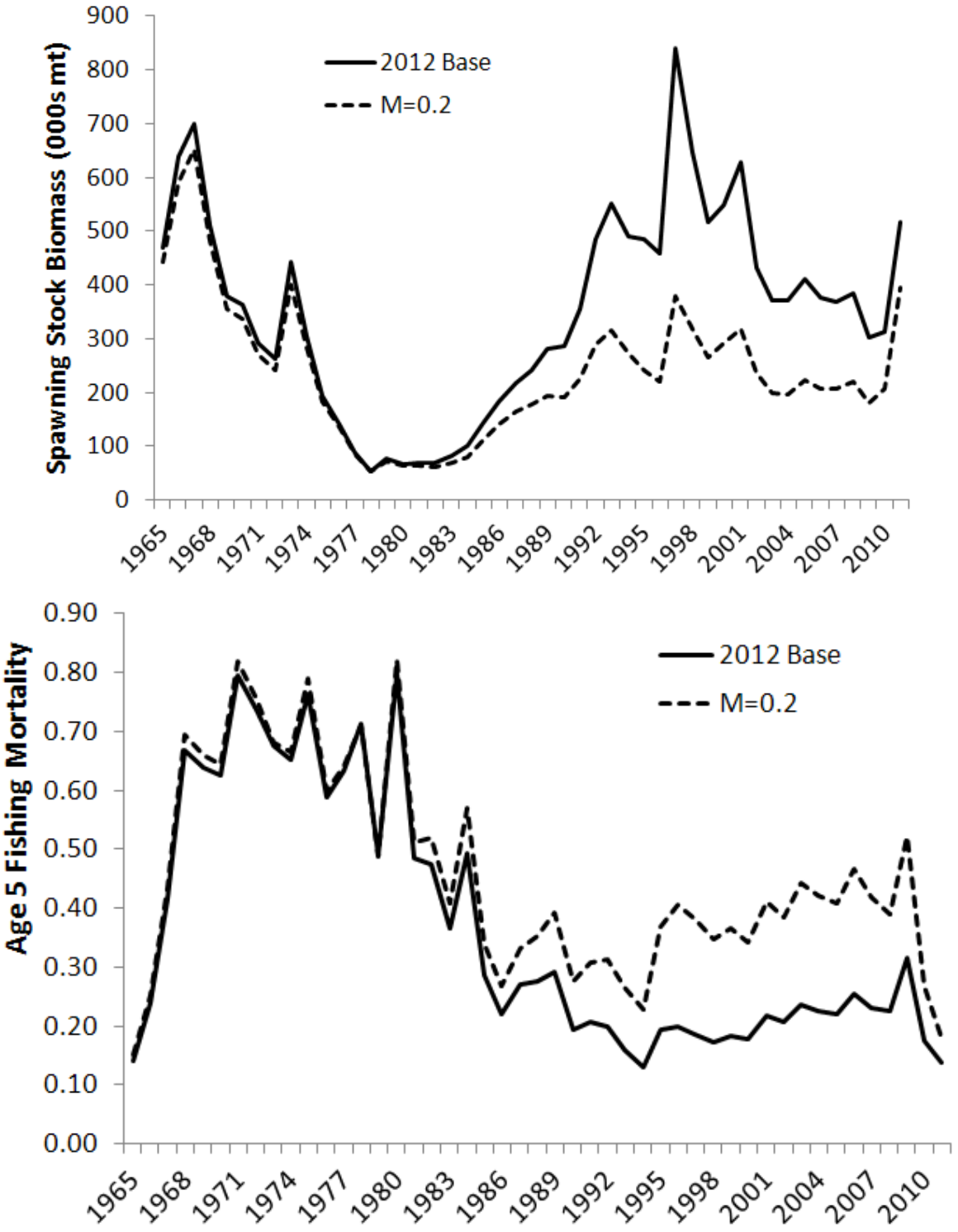


Figure A5-41. Estimates of spawning stock biomass and age 5 fishing mortality for the ASAP base run and a run with natural mortality equal to 0.2 for all ages and year.

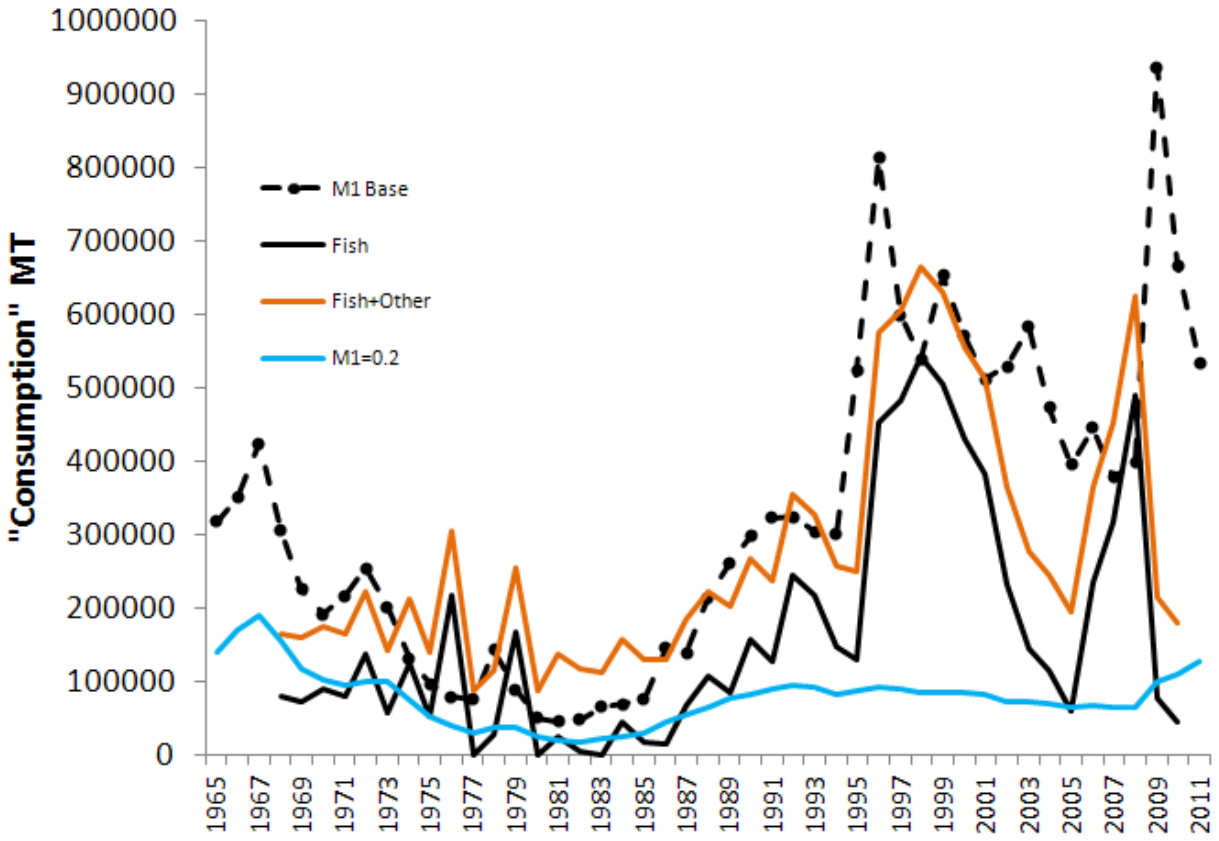


Figure A5-42. As in Figure A31 except with addition of the implied consumption from a model with natural mortality equal to 0.2 for all ages and year.

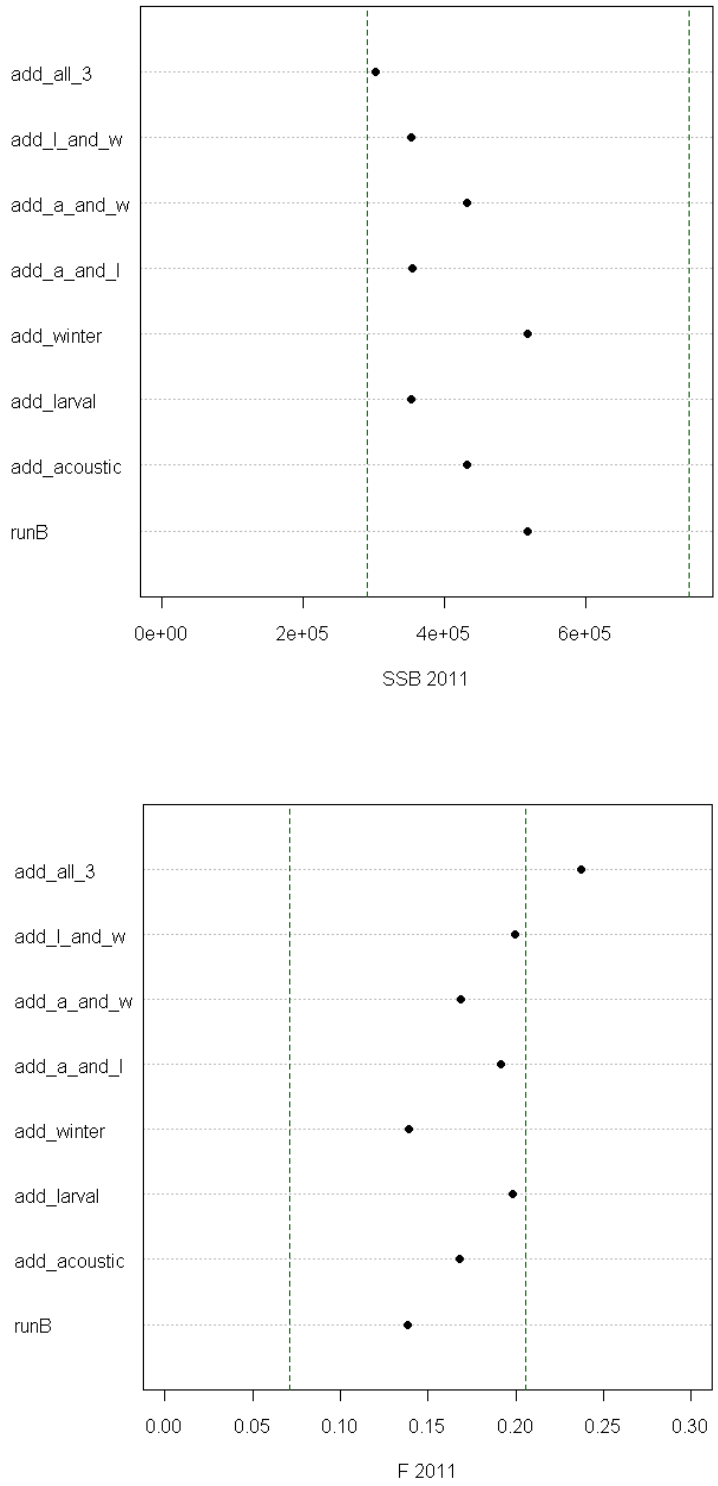


Figure A5-43. Estimates of SSB and F from the ASAP base run (runB) and sensitivities. Vertical bars are the 80% probability intervals from the ASAP base run.

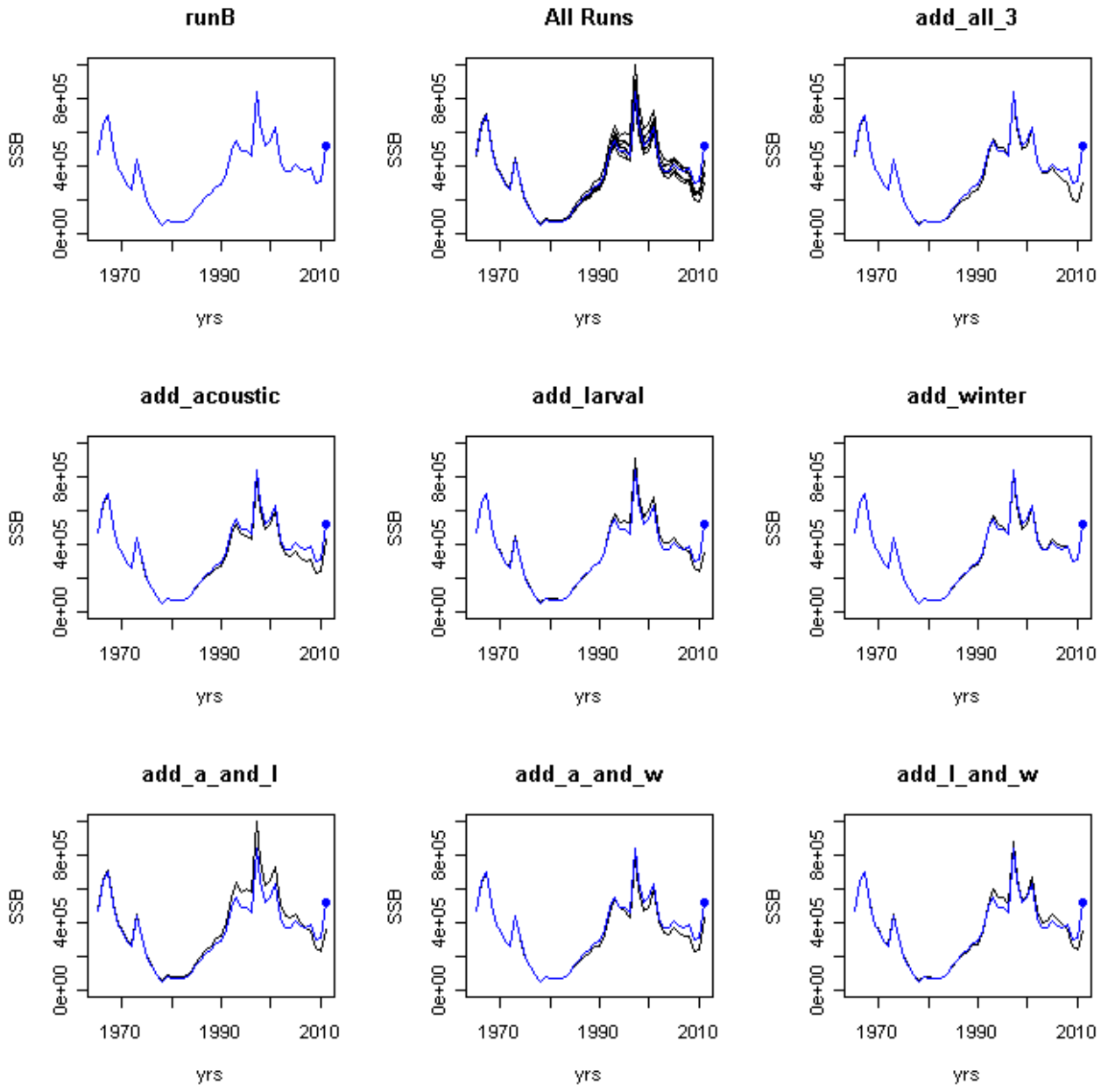


Figure A5-44. Time series estimates of SSB from the ASAP base run (run B) and sensitivities.

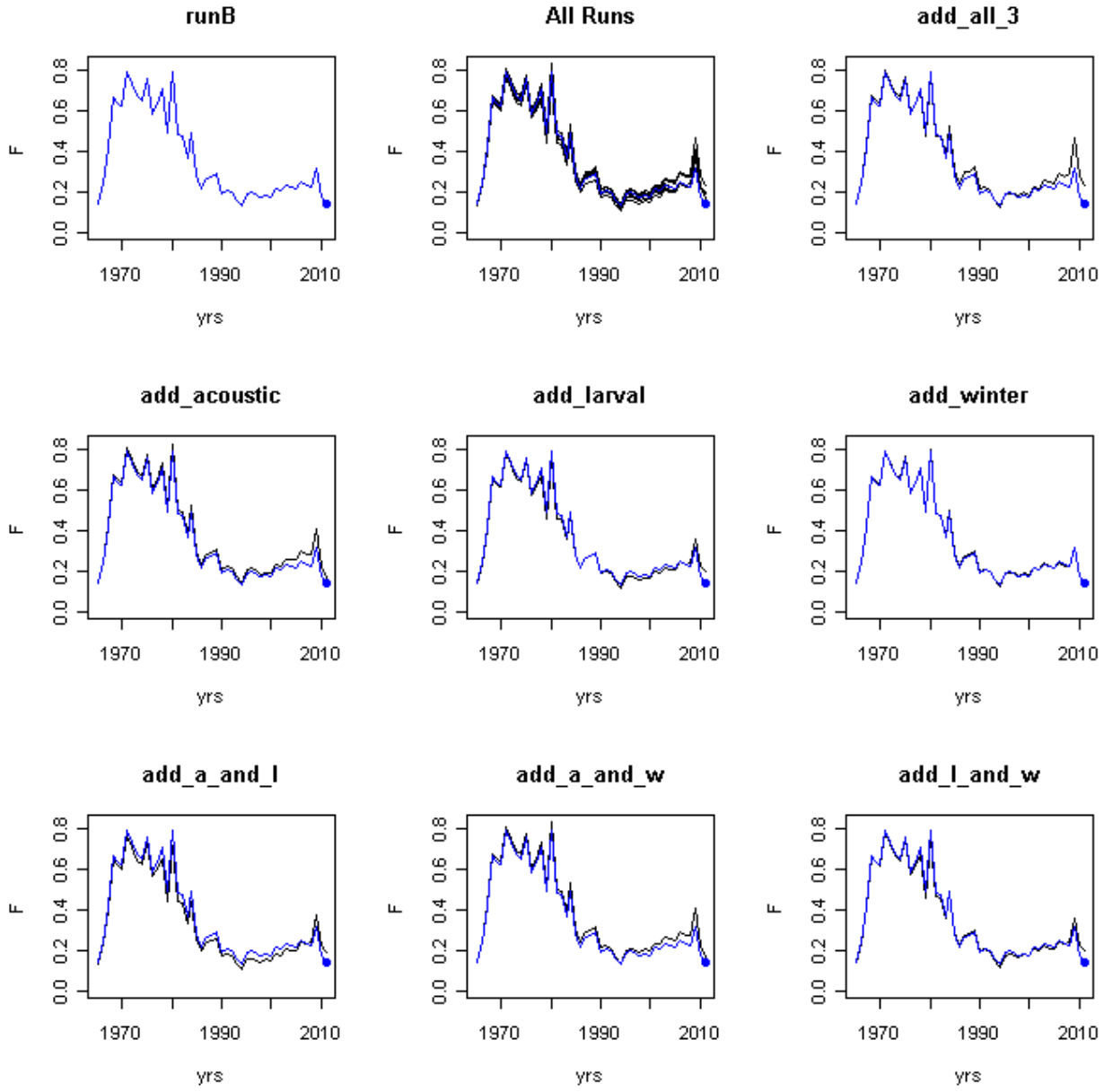
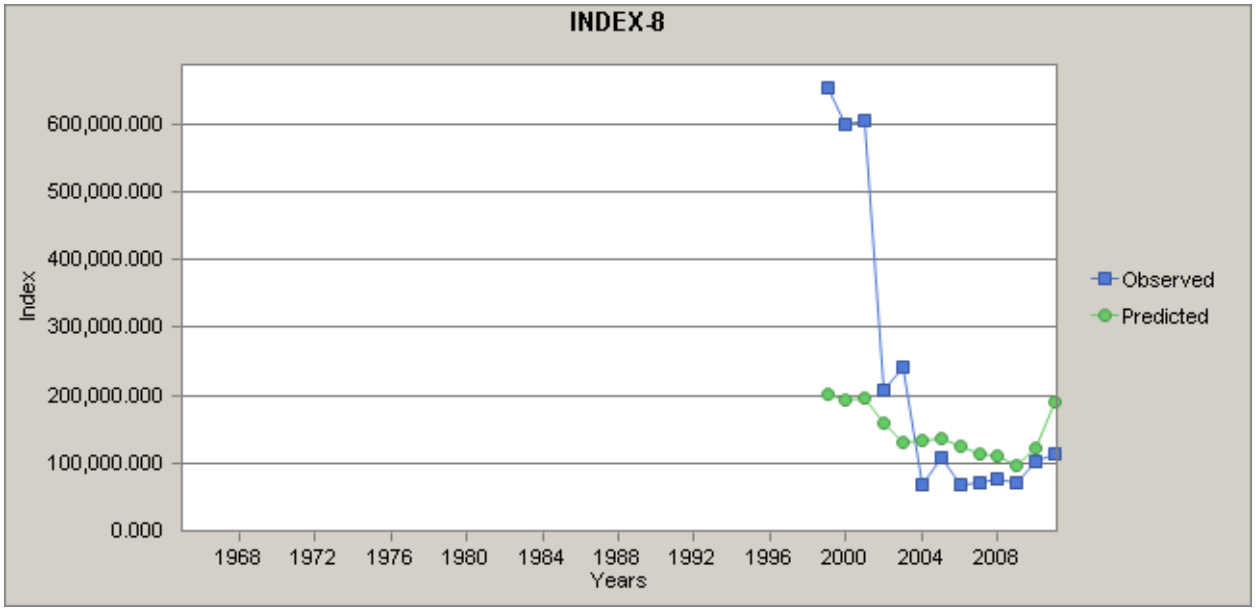


Figure A5-45. Time series estimates of fishing mortality from the ASAP base run (run B) and sensitivities.



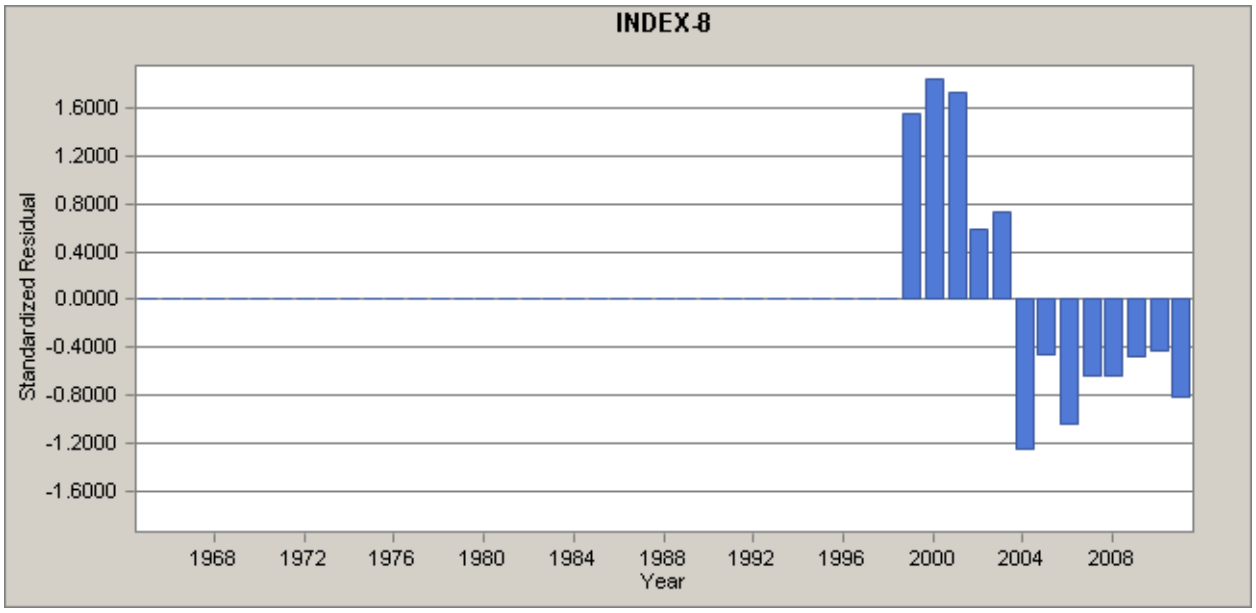


Figure A5-46. Fit of the NMFS acoustic survey index when added to the ASAP base run.

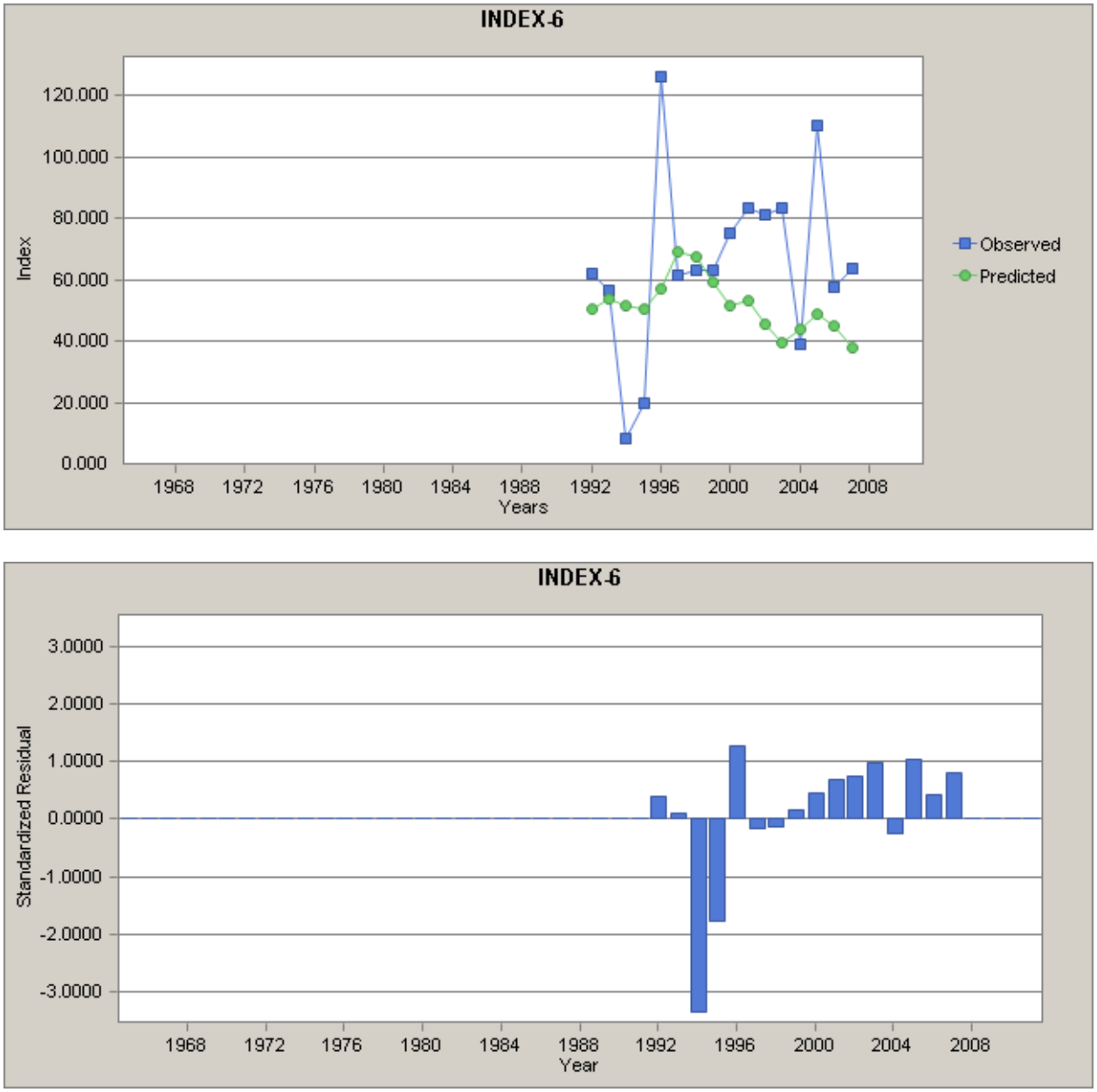


Figure A5-47. Fit of the NMFS winter survey index when added to the ASAP base run.

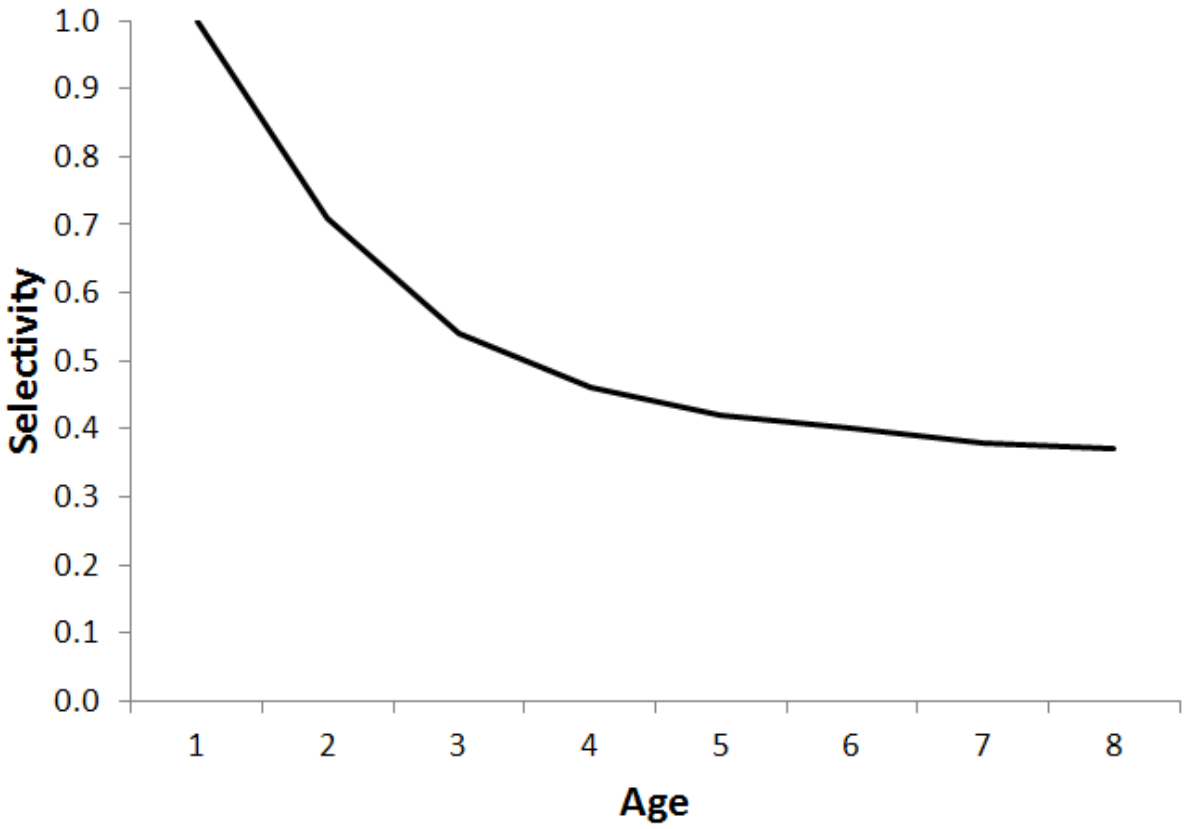


Figure A5-48. Selectivity at age for the Atlantic herring, fish predator consumption "fleet".

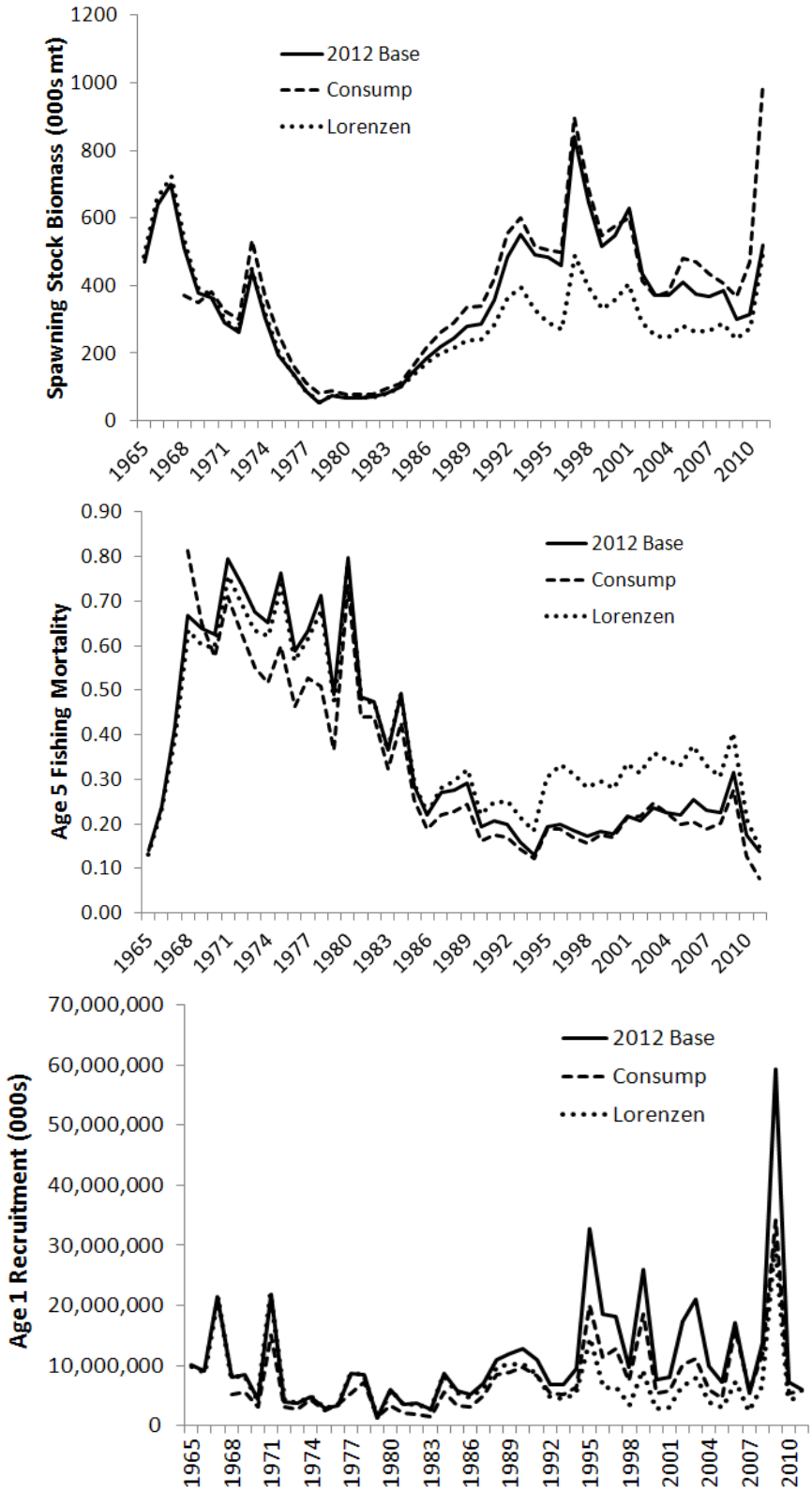


Figure A5-49. Time series estimates of spawning stock biomass, fishing mortality, and recruitment, for the 2012 ASAP base run (2012 Base), a similar run with fish consumption as a fleet (Consump), and a run with original Lorenzen natural mortality (Lorenzen).

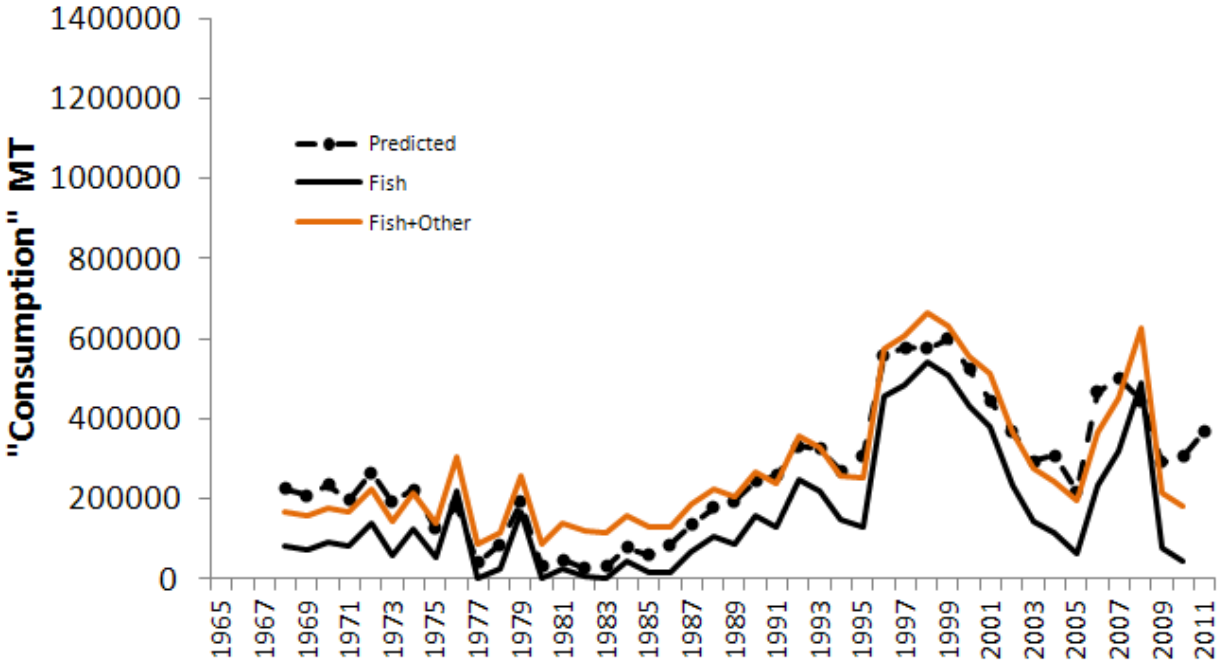


Figure A5-50. As in Figure A31, except with the addition of the predicted deaths by natural causes from an ASAP model using consumption as a fishing fleet (Predicted; dashed line with dots; represents deaths from M1 plus estimated deaths from M2).

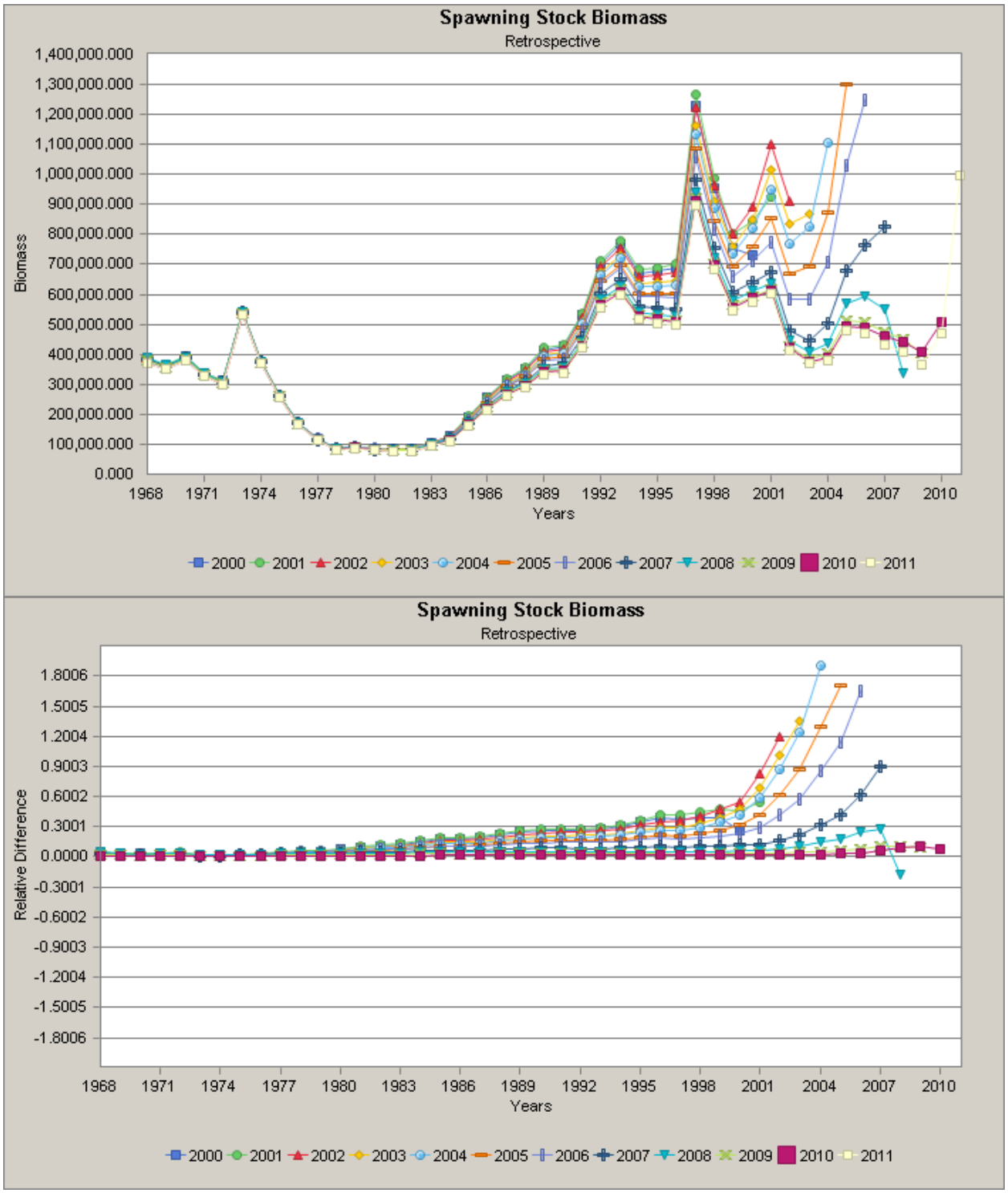


Figure A5-51. Retrospective pattern for spawning stock biomass from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

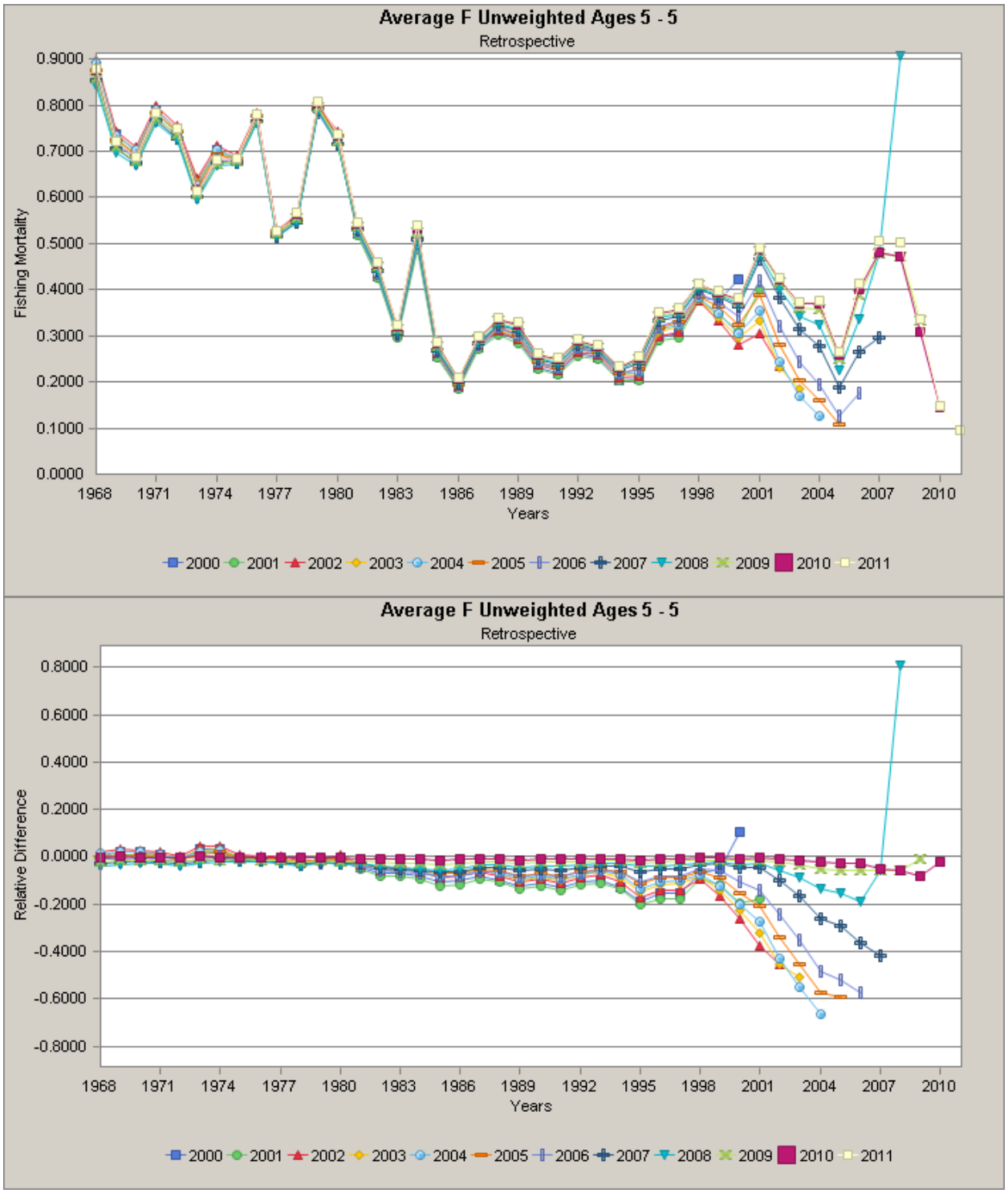


Figure A5-52. Retrospective pattern for age 5 fishing mortality from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

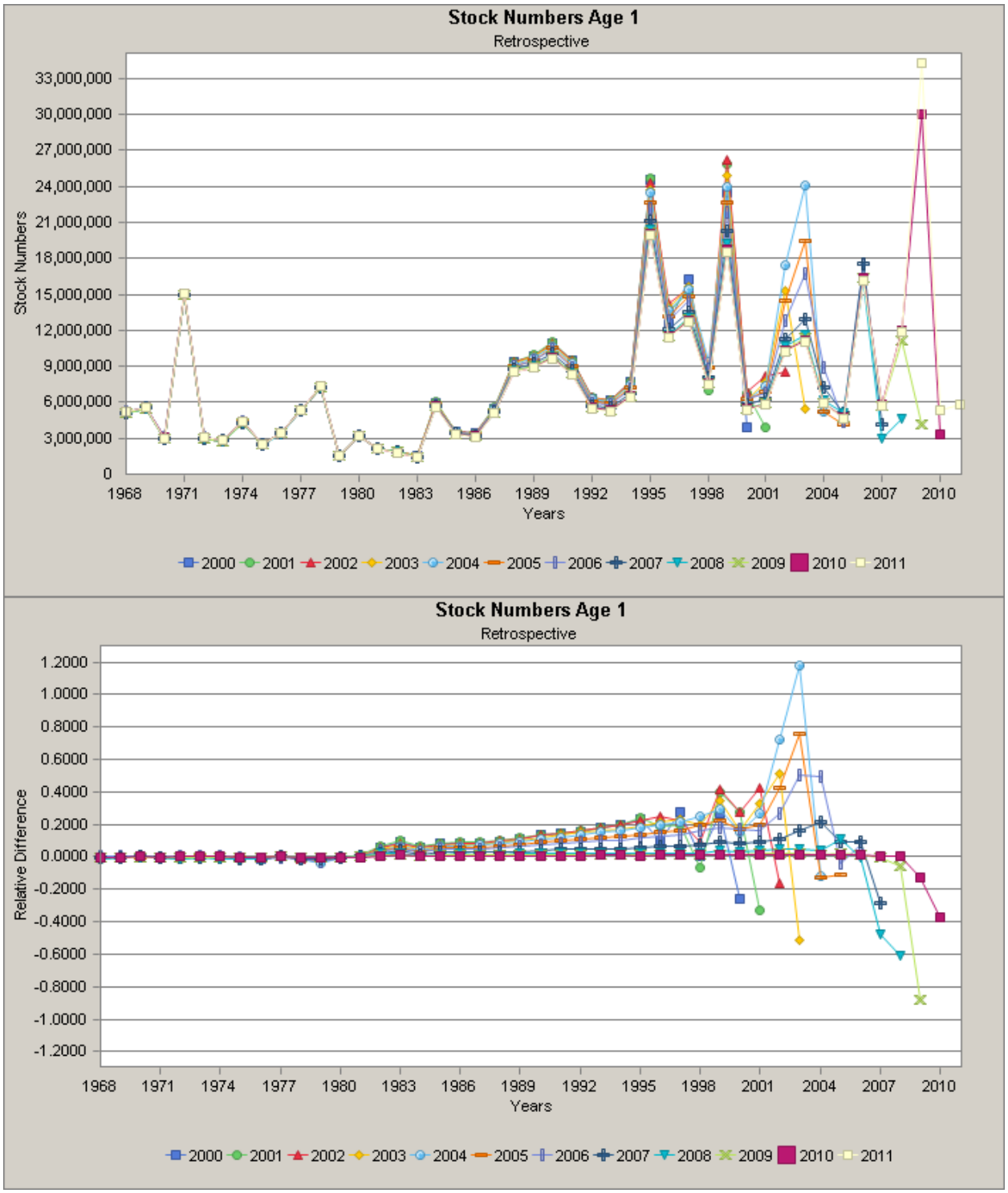


Figure A5-53. Retrospective pattern for recruitment from an ASAP model that uses Atlantic herring consumption by fish predators as a fleet.

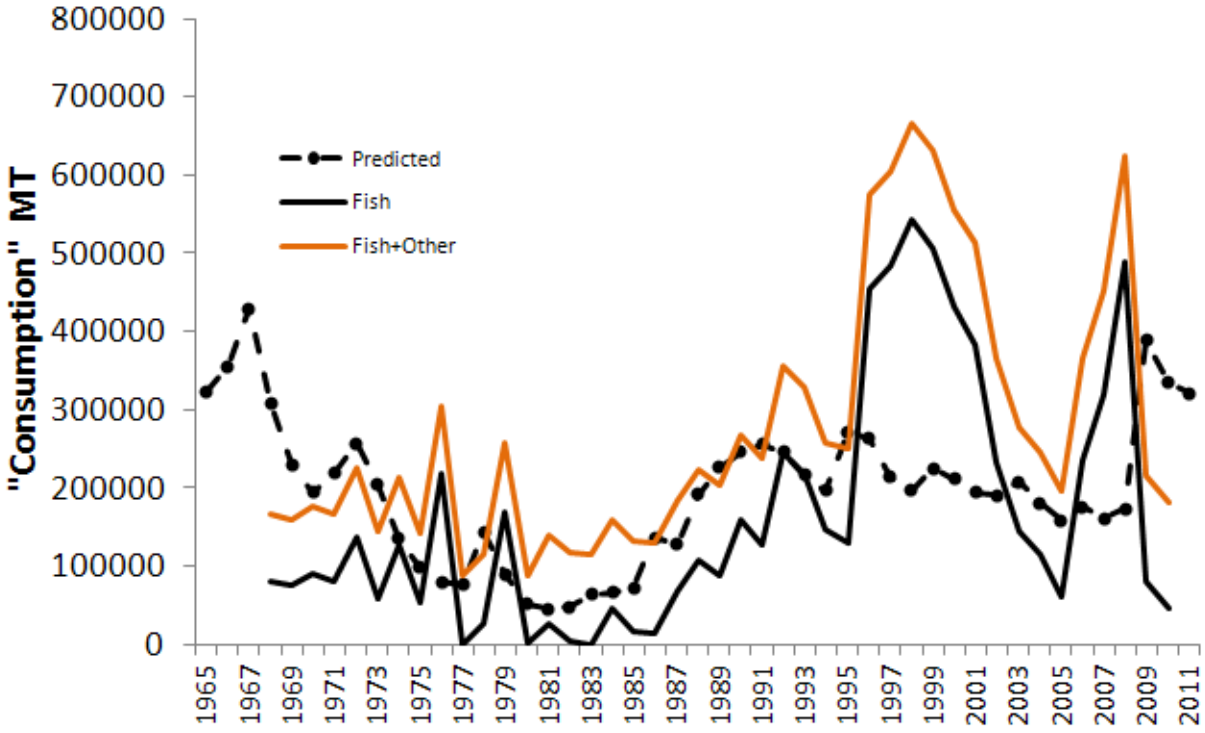


Figure A5-54. As in Figure A5-31, except with the addition of the implied consumption from M1 from an ASAP run using the original Lorenzen values for natural mortality (Predicted; dashed line with dots).

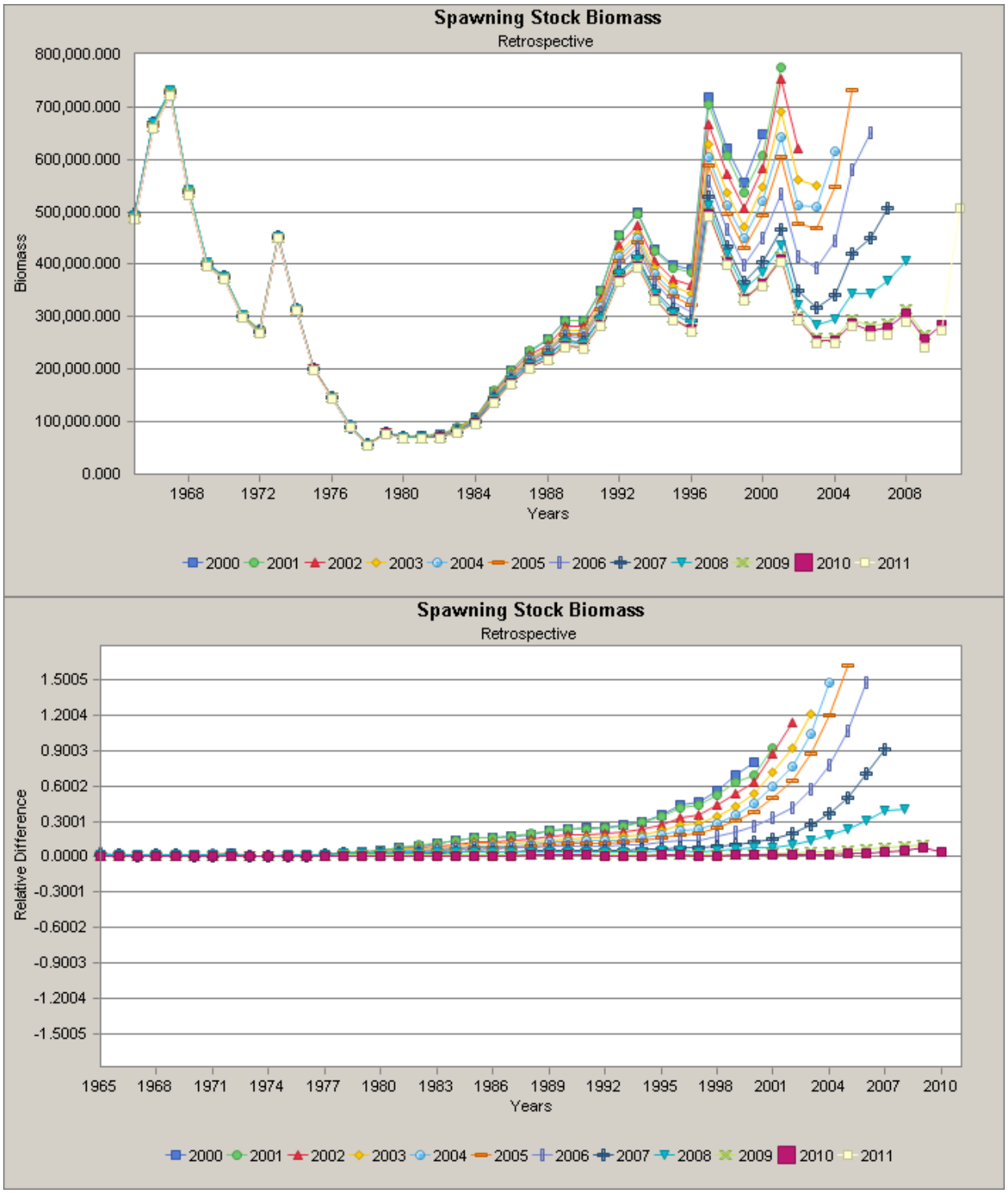


Figure A5-55. Retrospective pattern for spawning stock biomass from an ASAP model that uses original Lorenzen natural mortality.

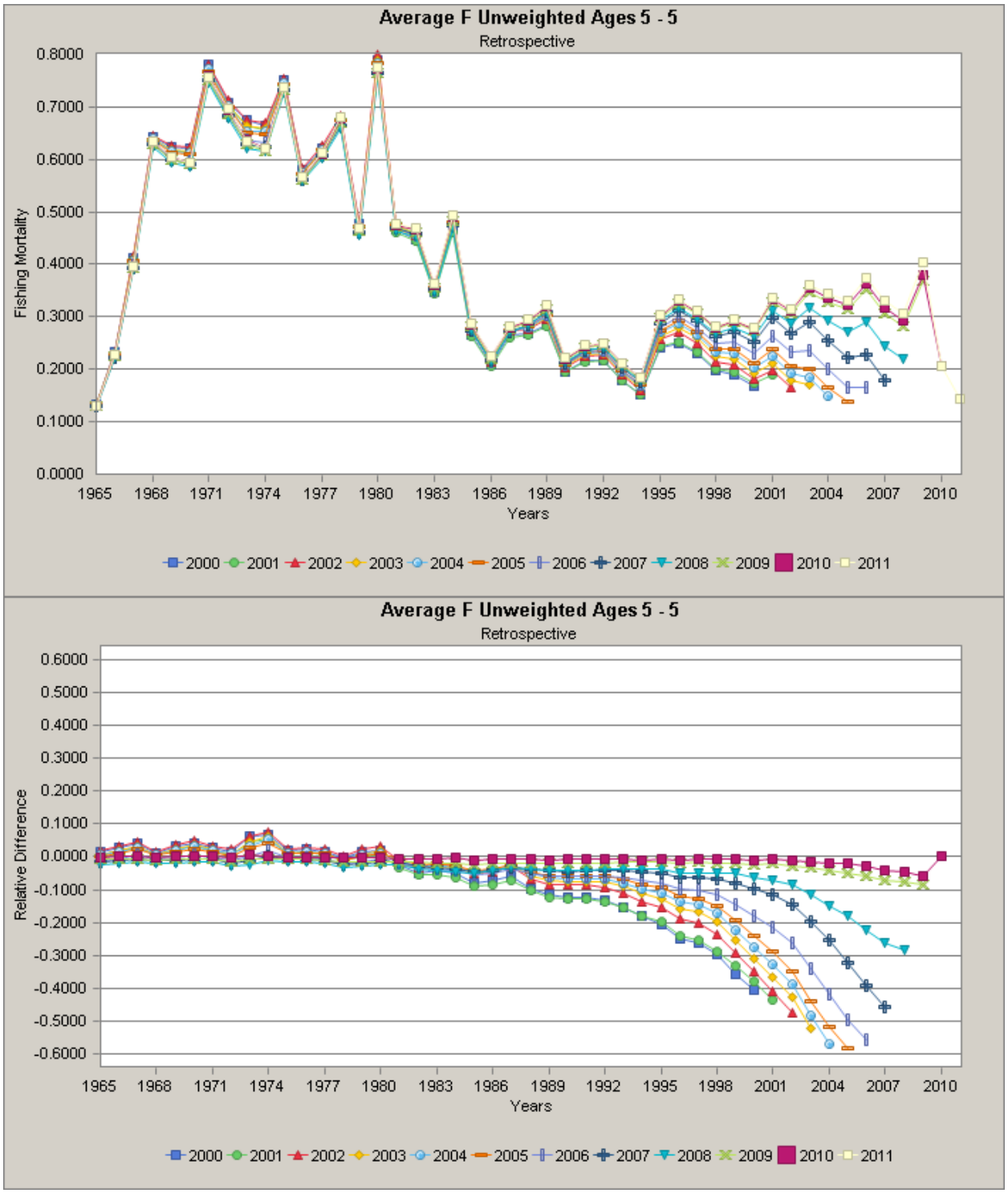


Figure A5-56. Retrospective pattern for age 5 fishing mortality from an ASAP model that uses original Lorenzen natural mortality.

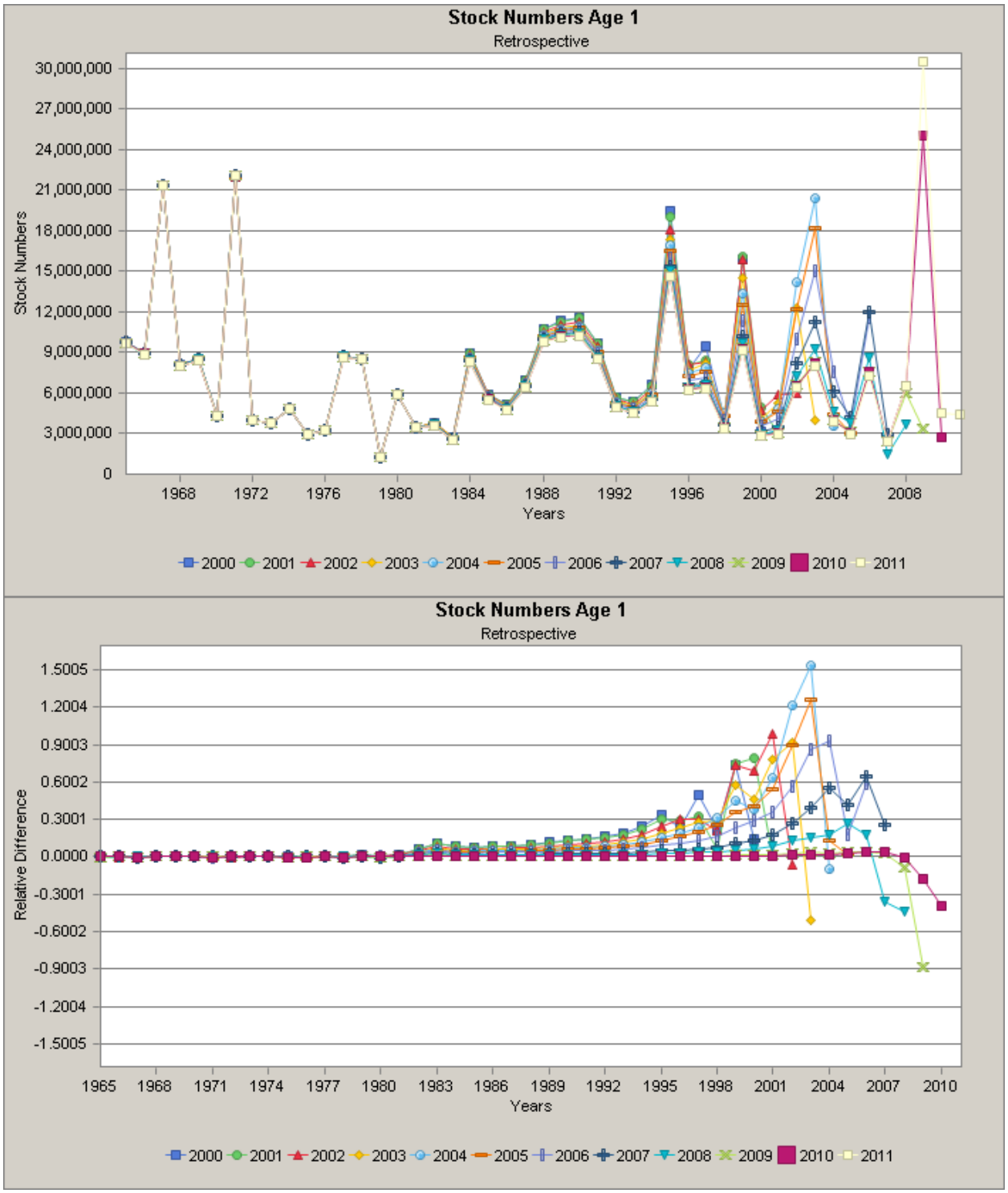


Figure A5-57. Retrospective pattern for recruitment from an ASAP model that uses original Lorenzen natural mortality.

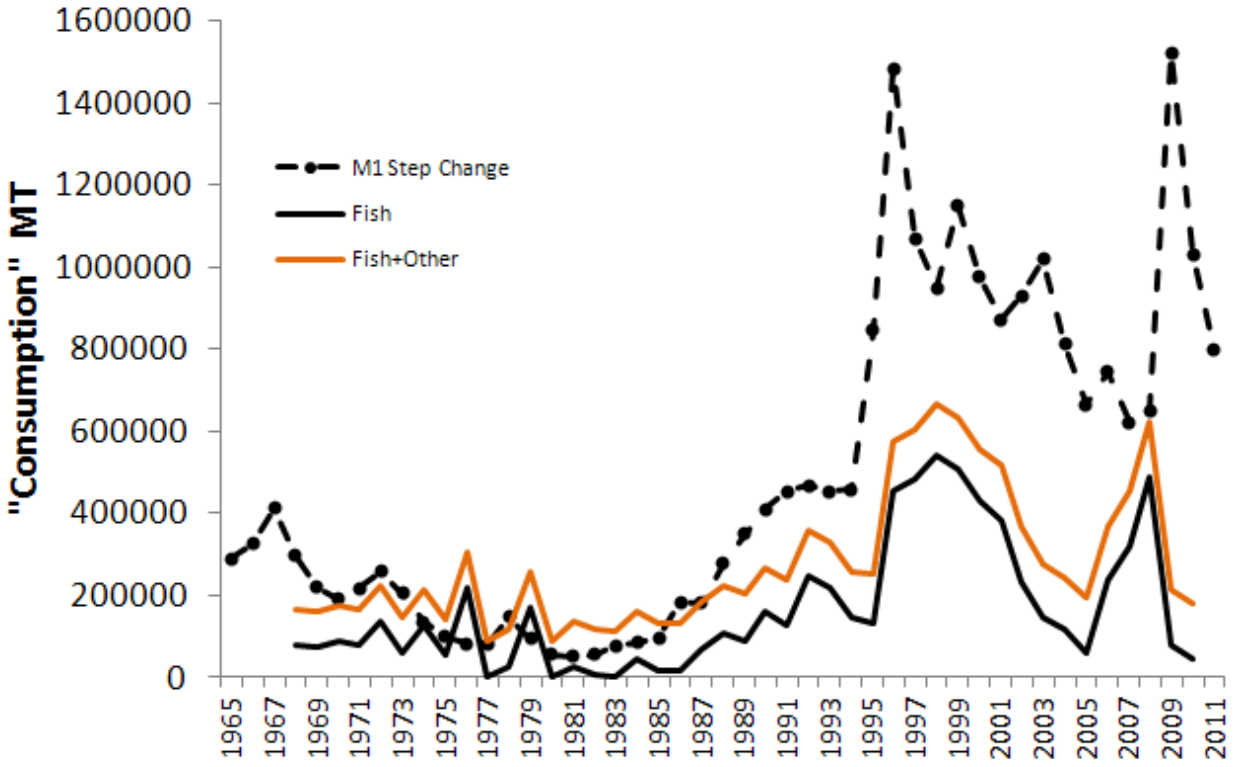


Figure A5-58. As in Figure A5-31, except with the addition of the implied consumption from M1 from an ASAP run using a step change in average natural mortality from an average of 0.3 during 1965-1995 to an average of 0.5 during 1996-2011.

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:

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

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.*

New Research Recommendations

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

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° 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

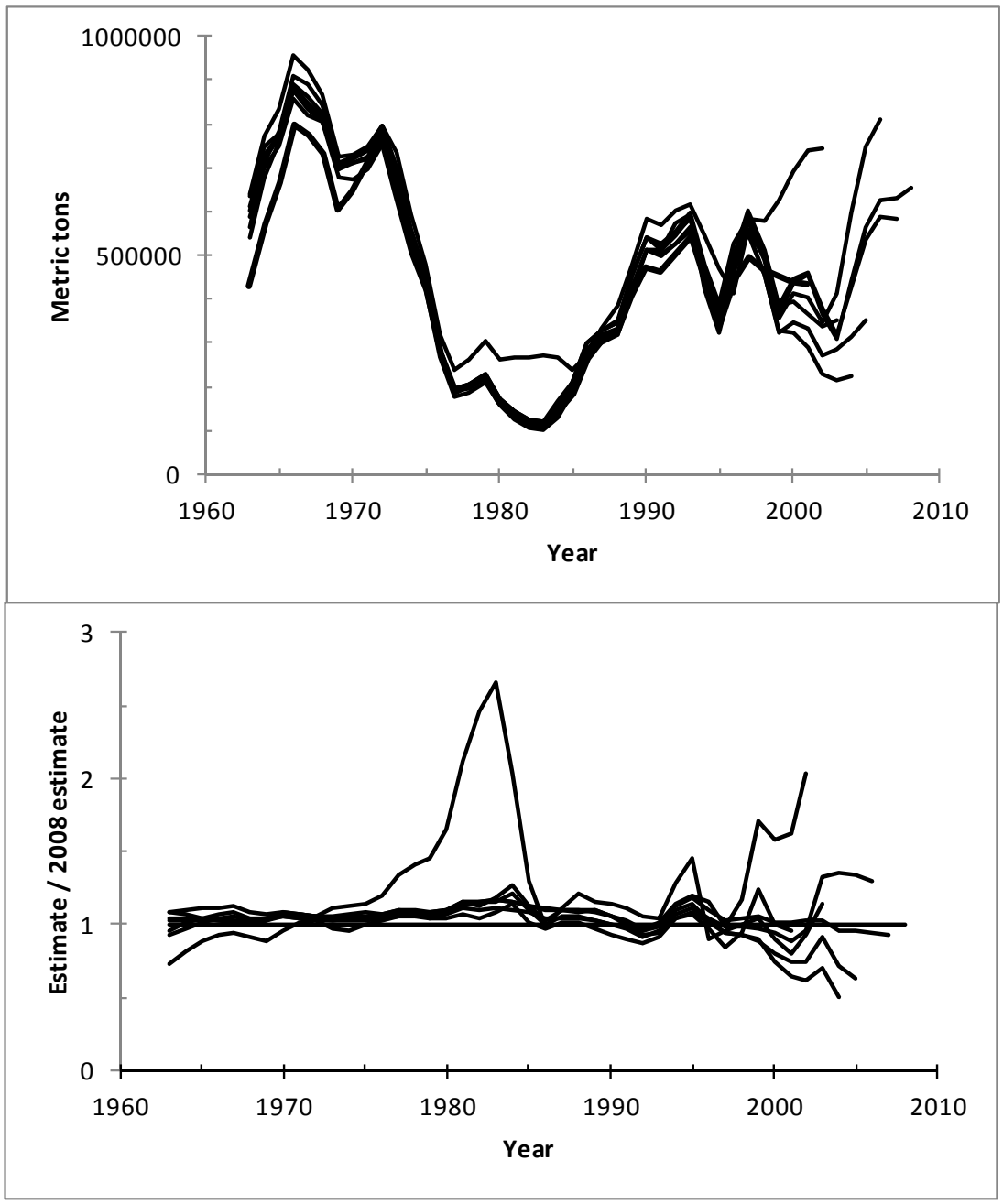

Figure A2-1. Retrospective analysis for herring spawning stock biomass estimates from SS3. The terminal year was 2008 to avoid inconsistencies using in the retrospective analysis due to the short 2009-2011 Bigelow surveys.

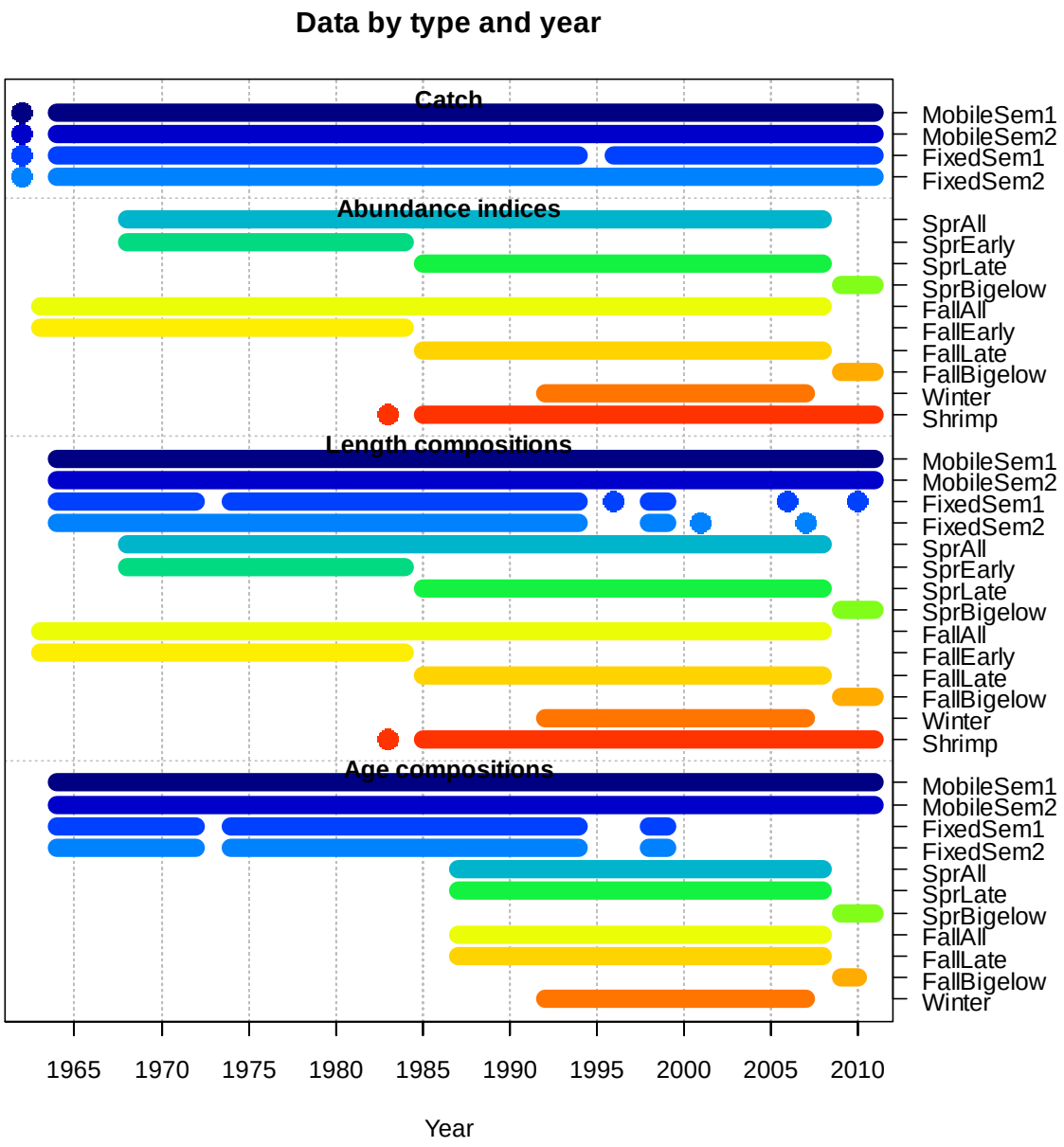

Figure A2-2. Summary of commercial and survey data for herring used in SS3. The surveys SprEarly, SprLate, FallEarly and FallLate (spring and fall surveys separated at 1984/1985 to accommodate survey door changes as in ASAP) were included in data files but were not used in the SS3 run shown here.

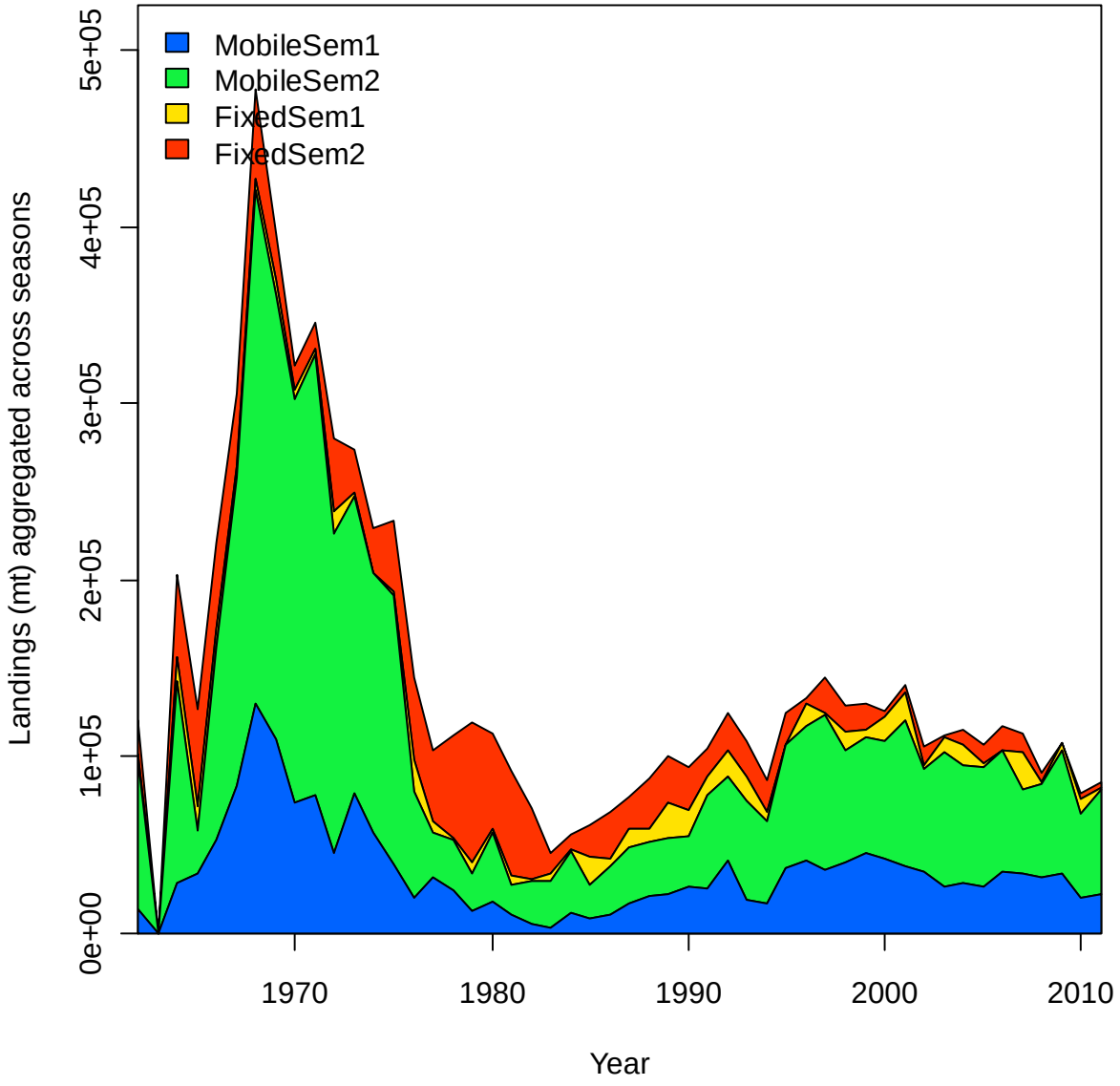

Figure A2-3. Commercial catch data for herring by fleet and season during 1963-2011 as used in the SS3 model.

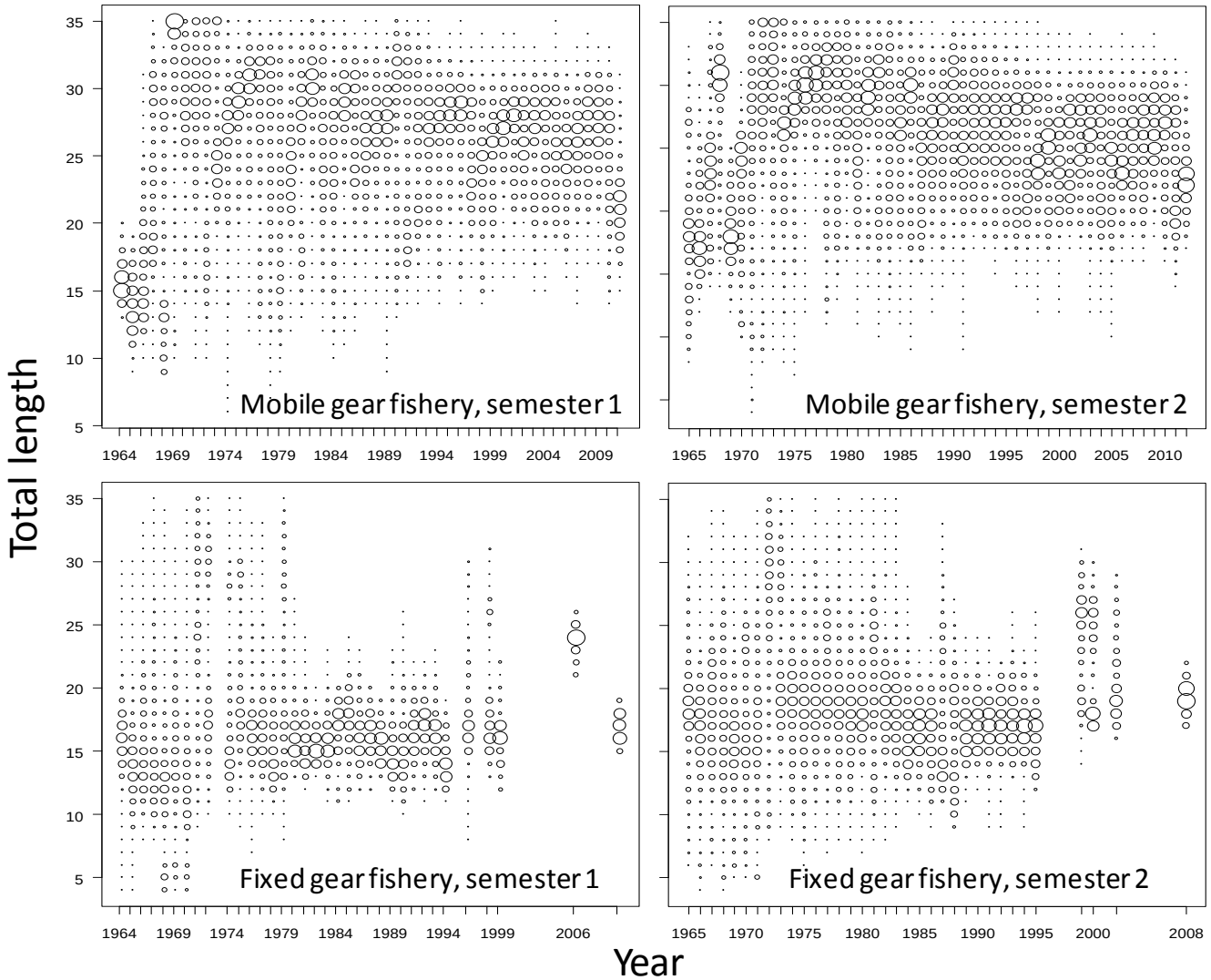

Figure A2-4. Commercial size composition data for herring used in SS3.

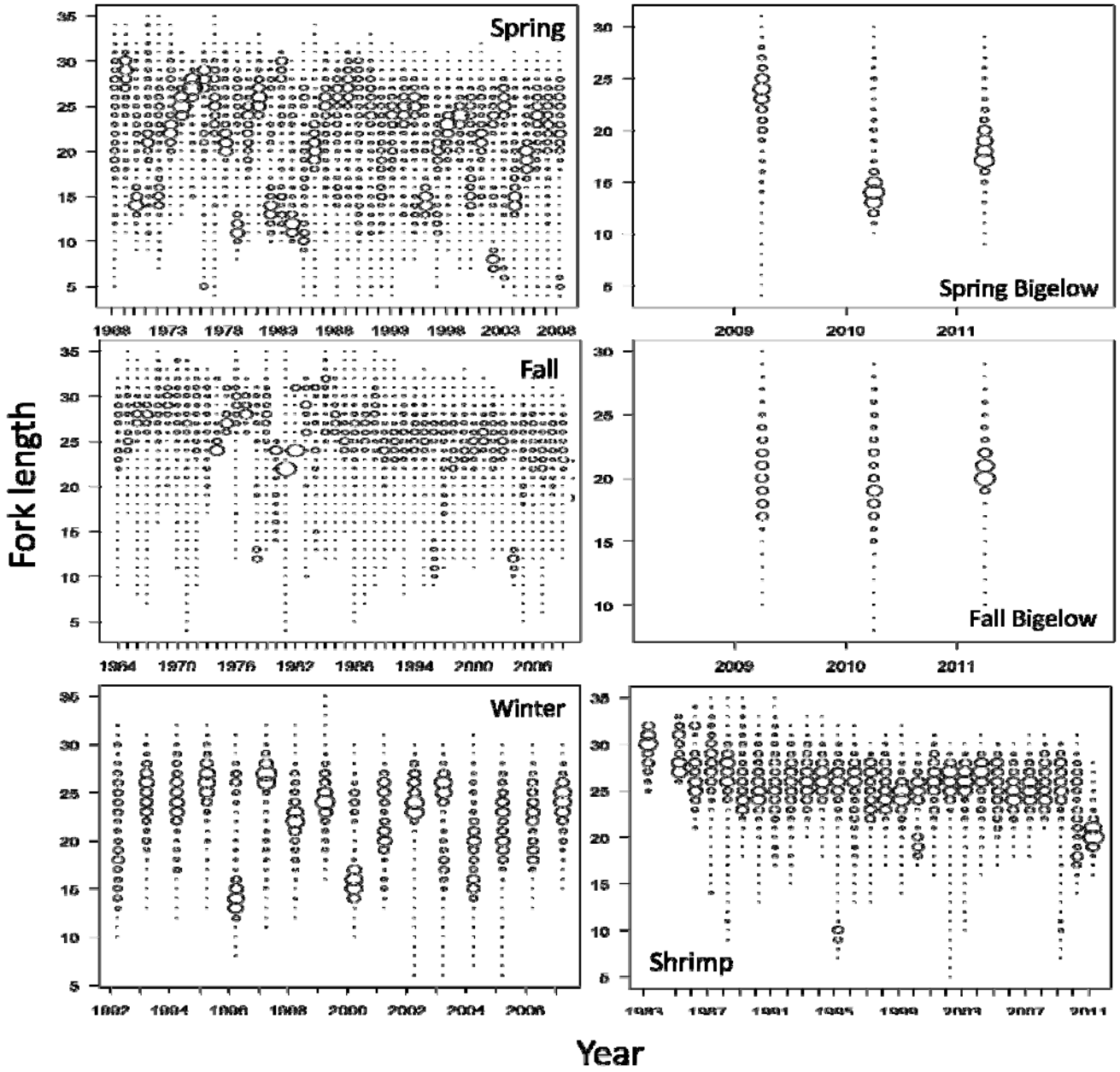

Figure A2-5. Survey size composition data for herring used in SS3.

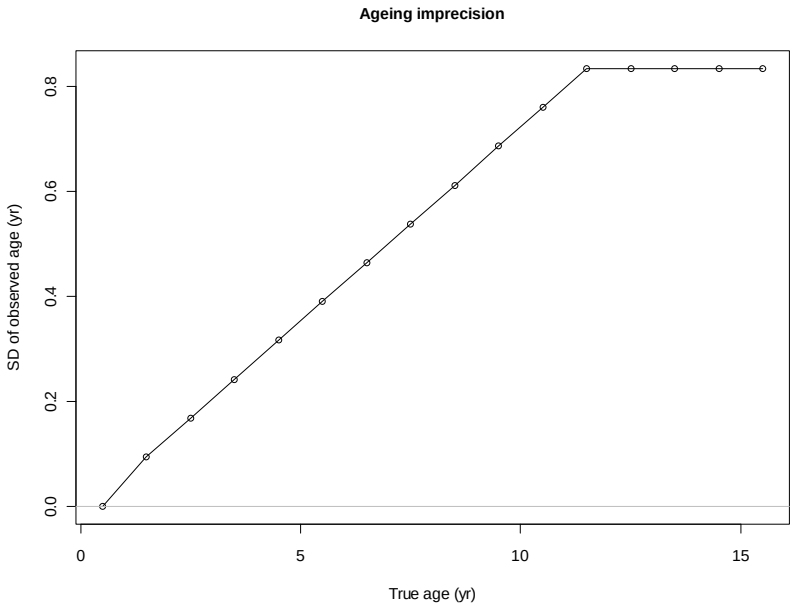

Figure A2-6. Assumed standard deviations for ageing imprecision in herring assumed in SS3.

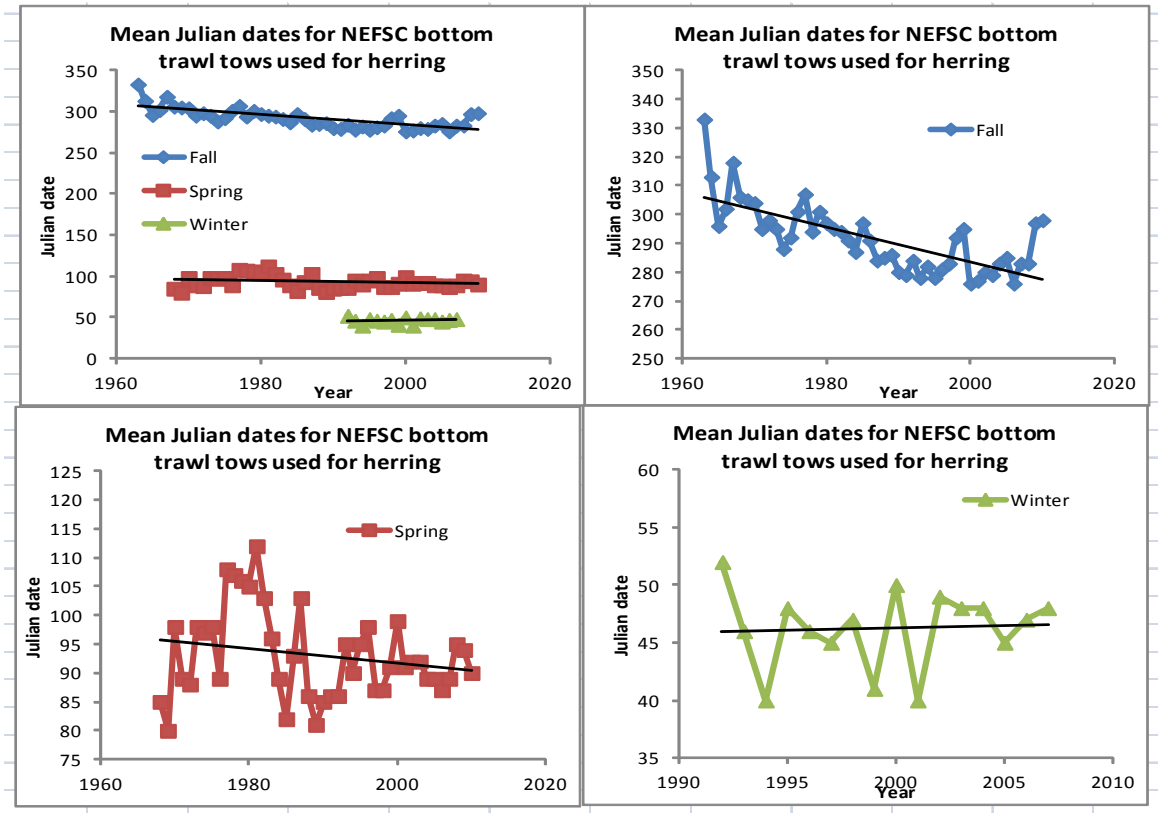

Figure A2-7. Mean annual Julian dates used for bottom trawl survey tows used for herring in SS3.

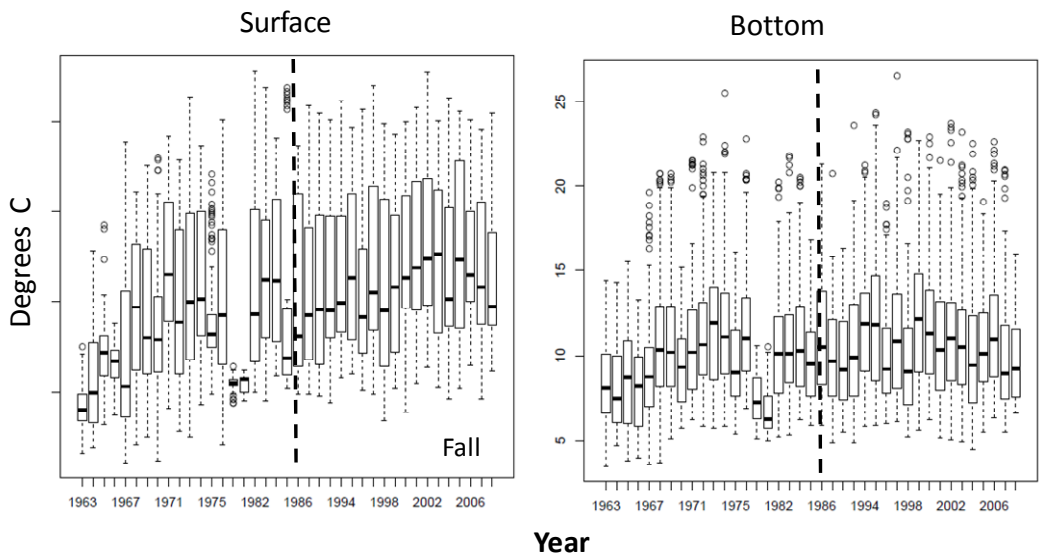

Figure A2-8. Surface and bottom temperatures for NEFSC fall survey tows used in the herring assessment. The short dark horizontal lines are the median temperatures. The dash vertical line shows the change in bottom trawl survey doors during 1984/1985.

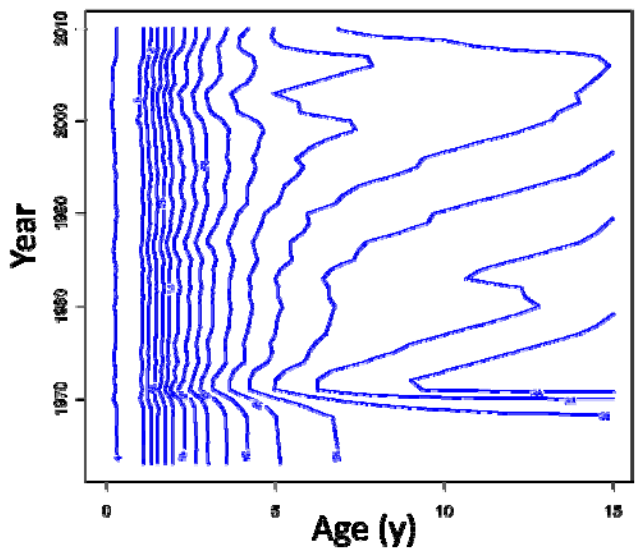

Figure A2-9. Estimated size at age in the SS3 model for herring during 1963-2011 based on von Bertalanffy growth curves with random walk parameters.

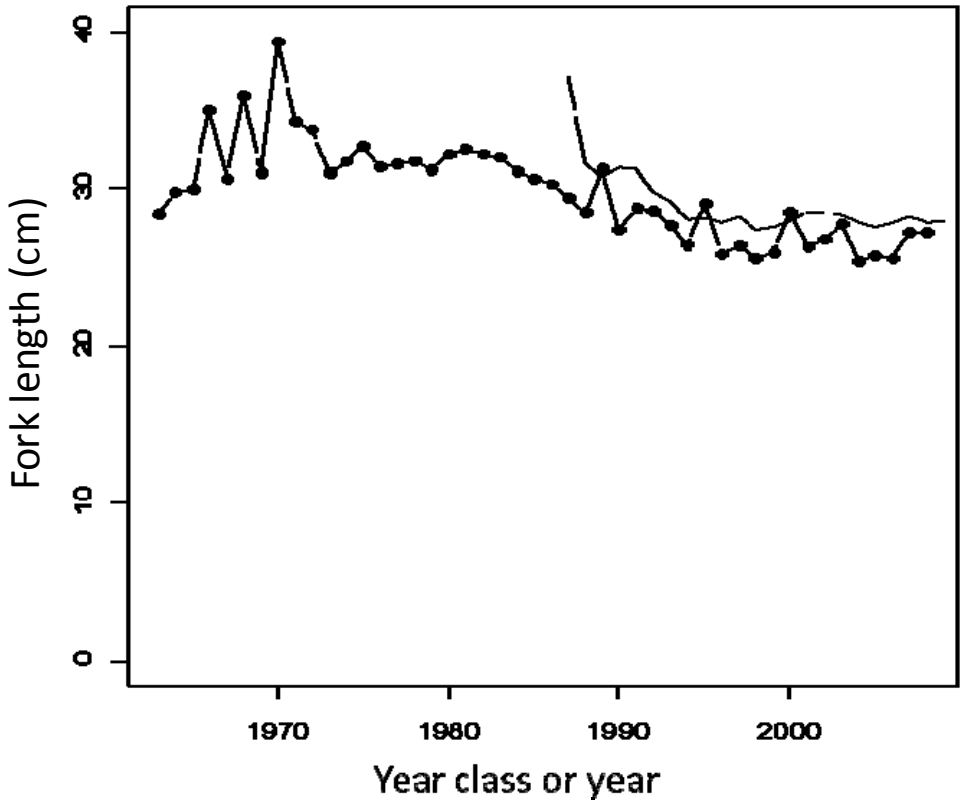

Figure A2-10. Von Bertalanffy L_{max} parameter estimates for herring from SS3 (January 1, solid symbols) and from growth curves fit externally to spring survey data. The SS3 estimates are by year class while the external estimates are by calendar year.

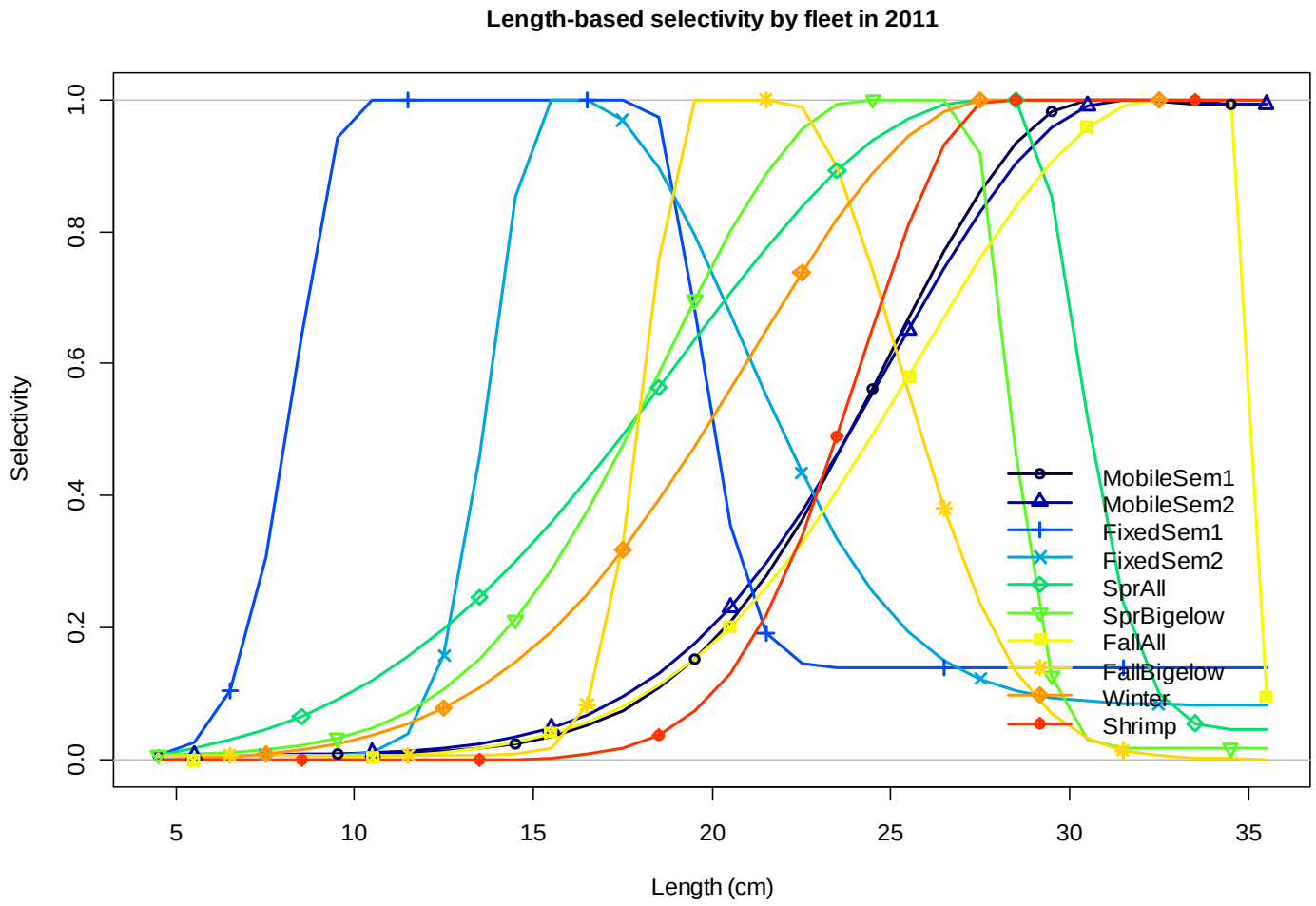

Figure A2-11. Selectivity at length curves for herring in commercial fisheries and surveys estimated in SS3.

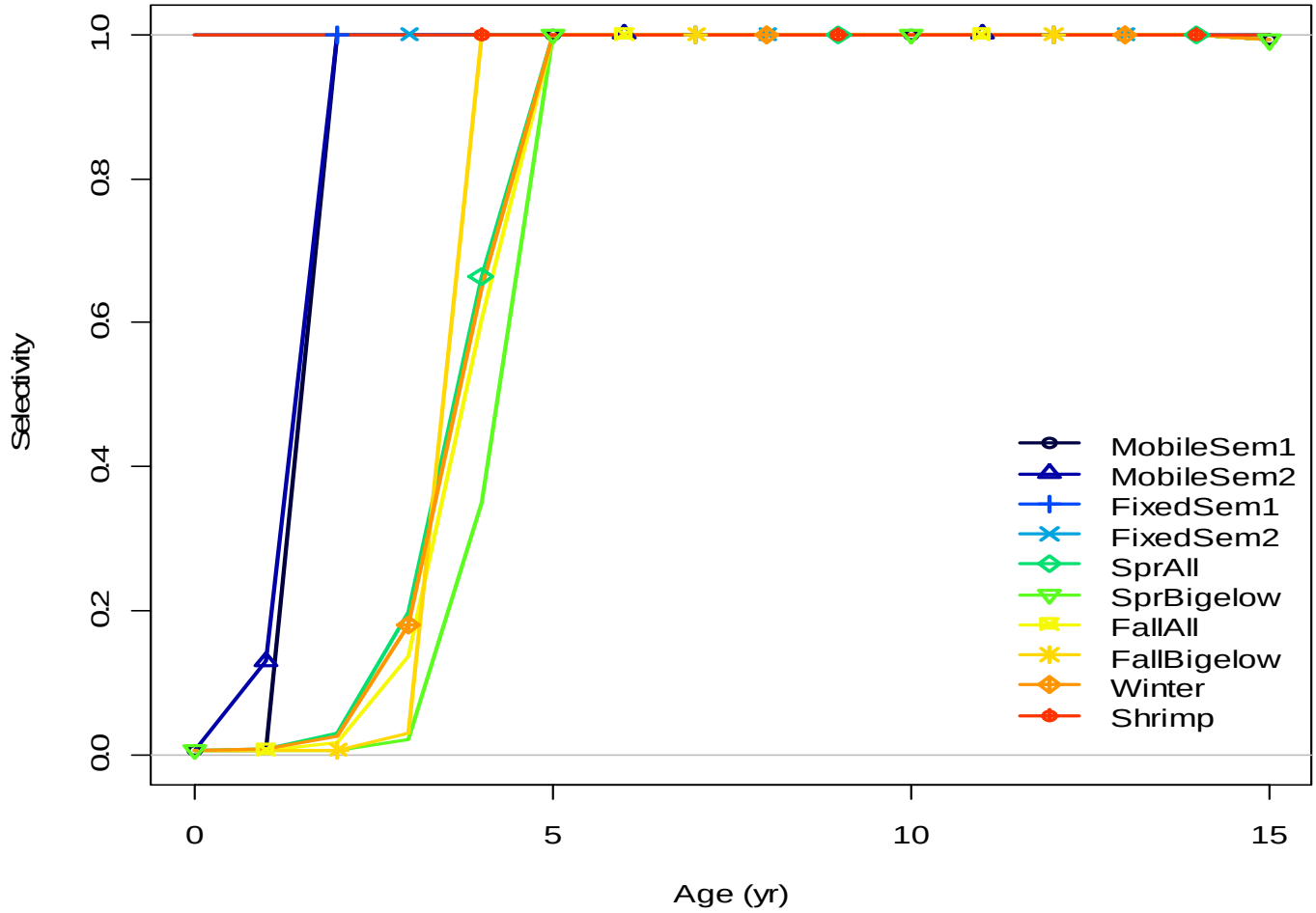

Figure A2-12. Selectivity at length curves for herring in commercial fisheries and surveys estimated in SS3.

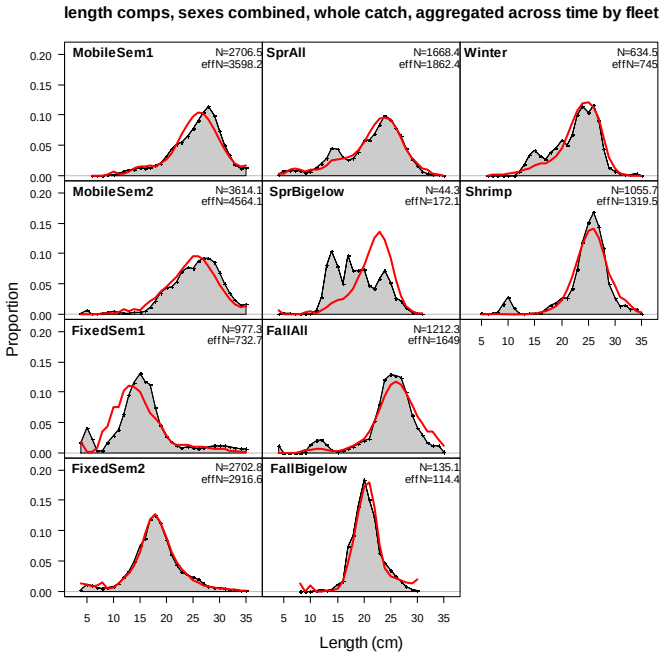

Figure A2-13. Average commercial and survey length composition data (in grey) and average predicted values (red line) for herring in the SS3 model.

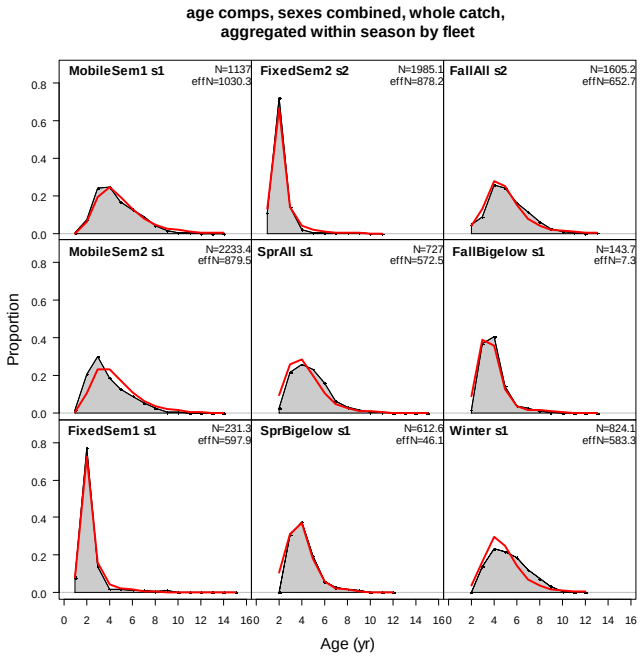

Figure A2-14. Average commercial and survey age composition data (in grey) and average predicted values (red line) for herring in the SS3 model.

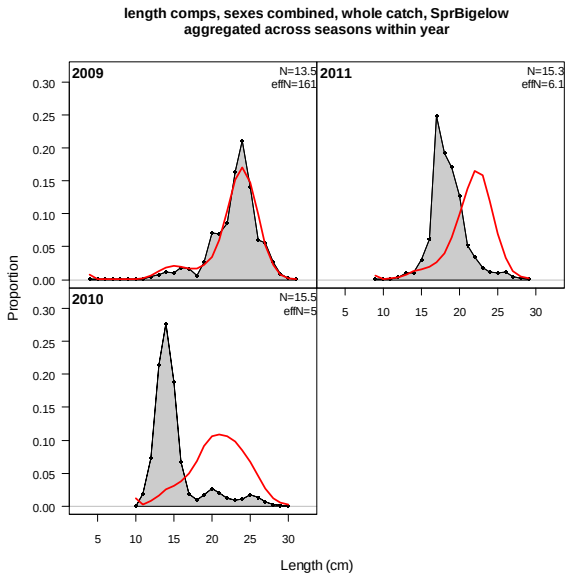

Figure A2-15. Annual observed spring Bigelow survey size composition data (in grey) for herring with predicted values (red line) from the SS3 model for herring.

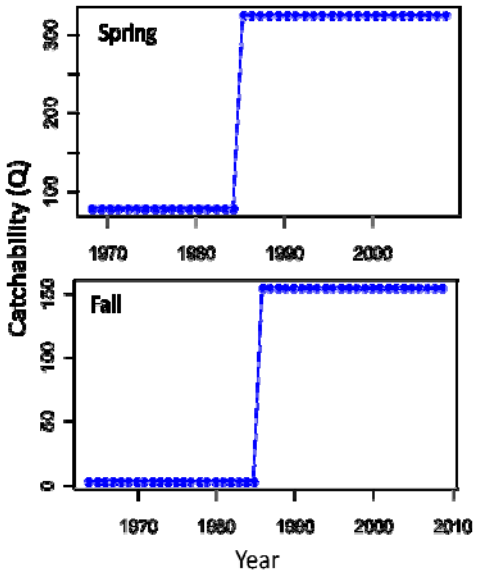

Figure A2-16. Changes in catchability for herring in the spring and fall bottom trawl surveys estimated in SS3.

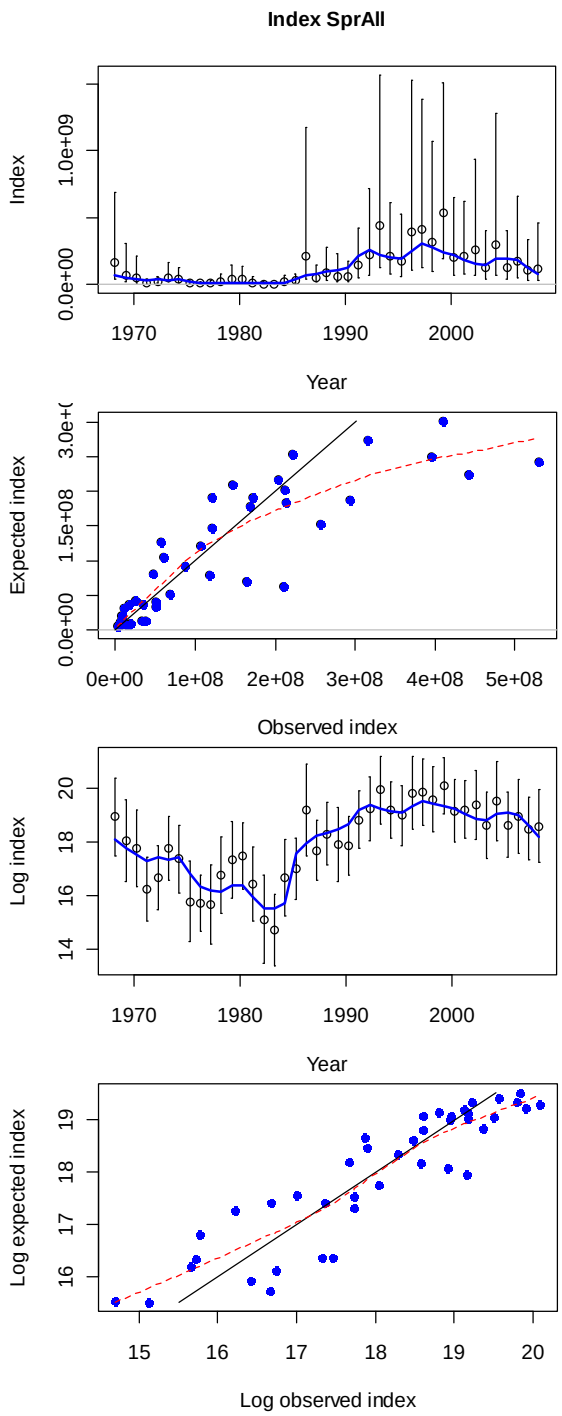

Figure A2-17. Goodness of fit plots for the SS3 model and herring in the NEFSC spring bottom trawl survey.

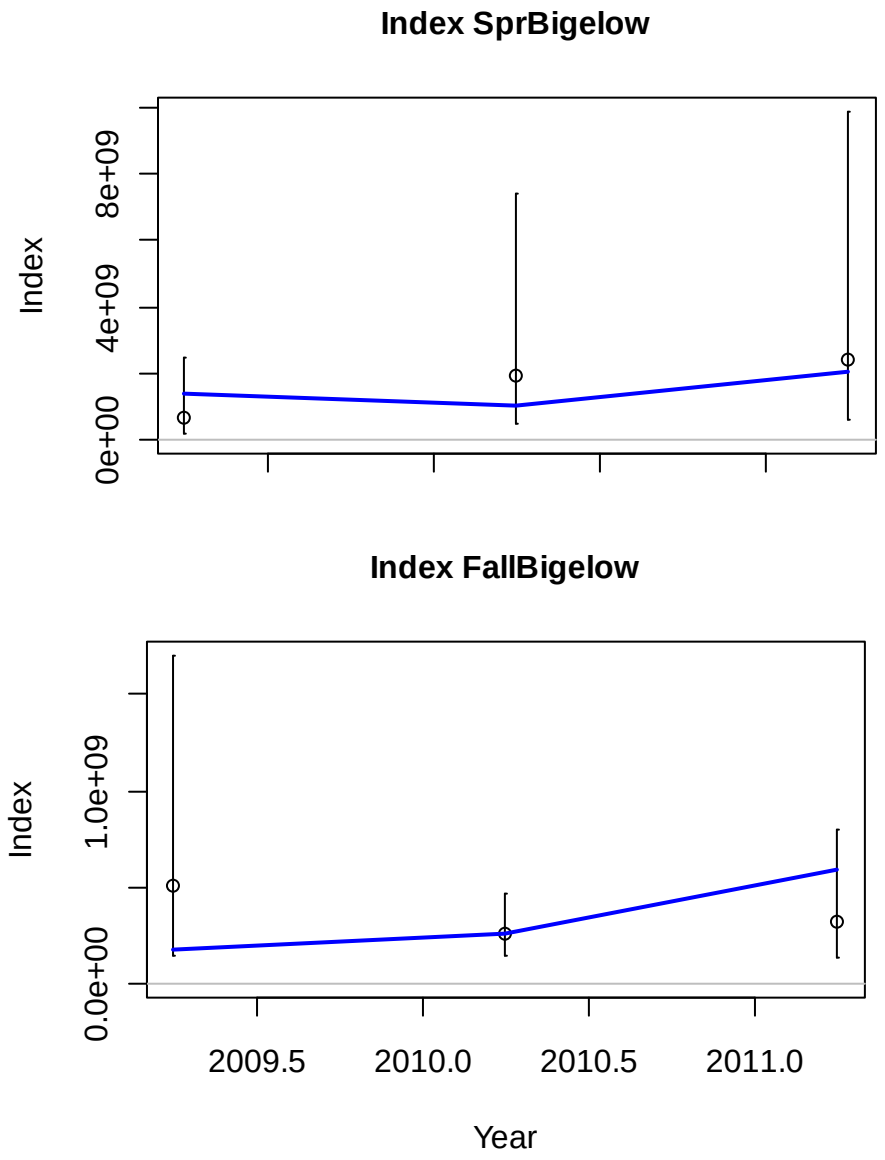

Figure A2-18. Goodness of fit plots for the SS3 model and herring in the NEFSC Bigelow spring and fall bottom trawl surveys.

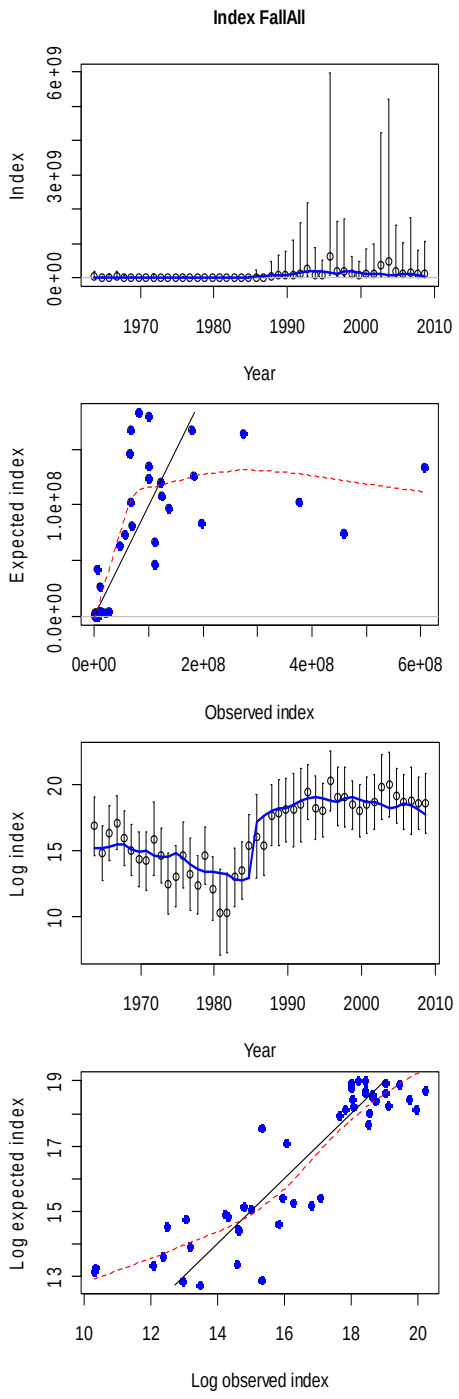

Figure A2-19. Goodness of fit plots for the SS3 model and herring in the NEFSC fall bottom trawl survey.

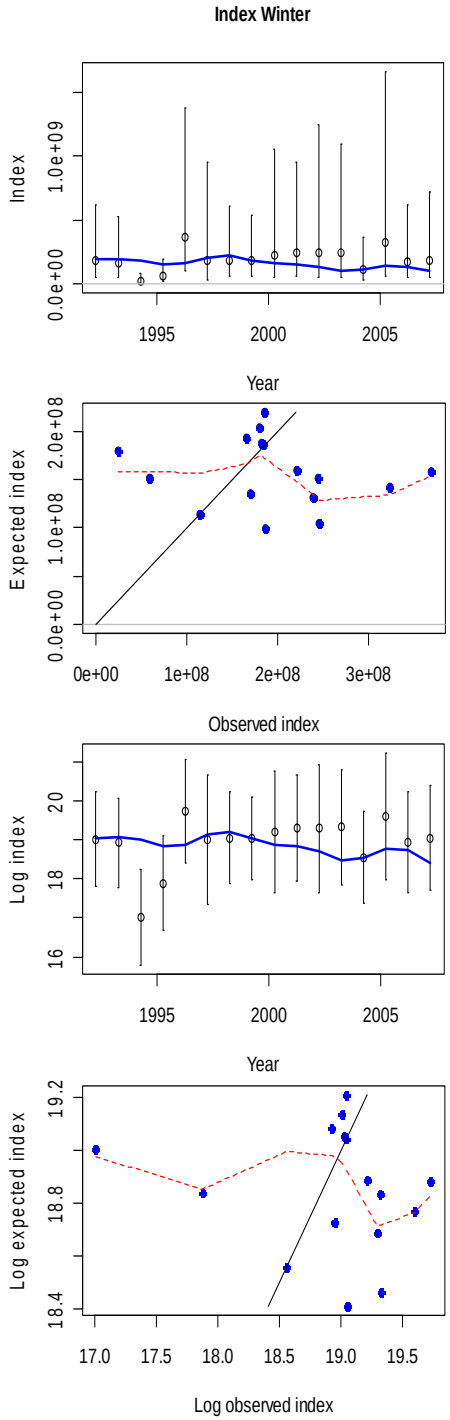

Figure A2-20 Goodness of fit plots for the SS3 model and herring in the NEFSC winter bottom trawl survey.

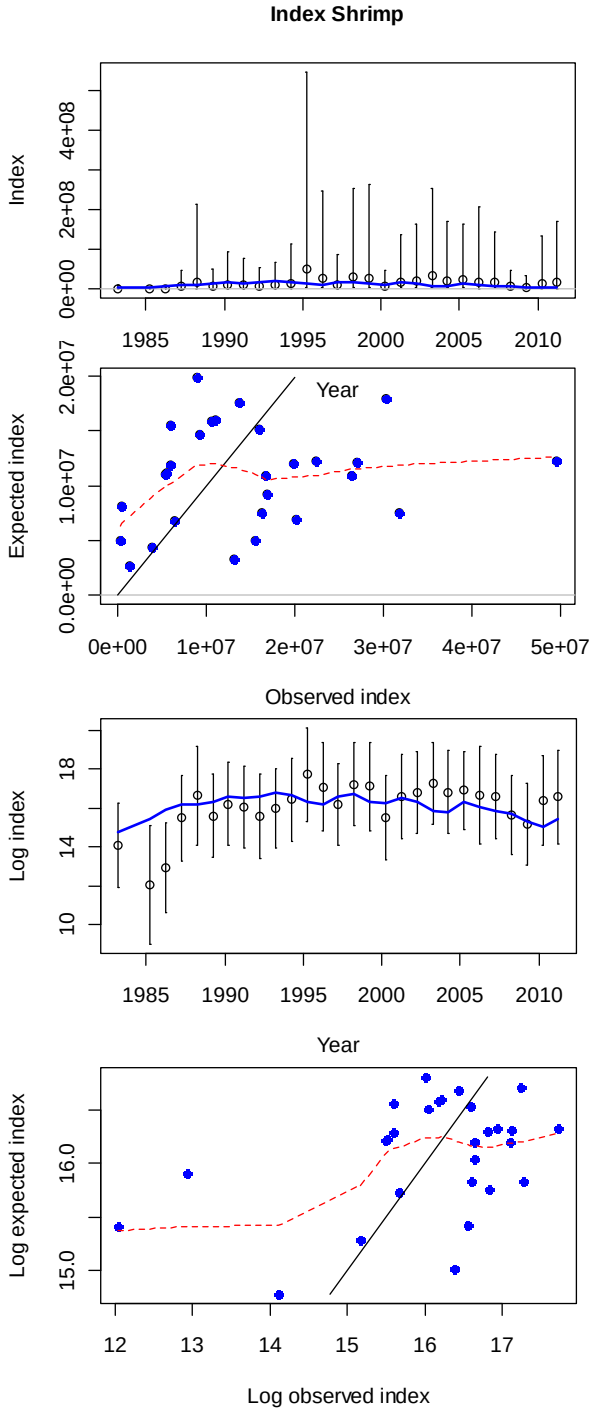

Figure A2-21. Goodness of fit plots for the SS3 model and herring in the NEFSC shrimp bottom trawl survey.

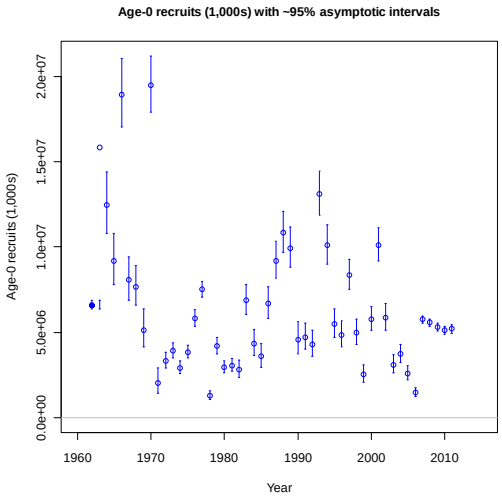

Figure A2-22. Recruitment estimates for herring from SS3. The first two estimates on the left are at the virgin and initial equilibrium recruitment levels. The third point from the left is the initial (1962) recruitment estimates. Other recruitments are estimates for 1963-2011. Recruitments were also 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.

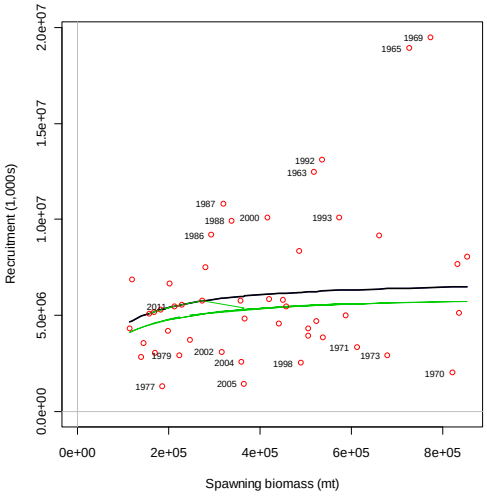

Figure A2-23. Spawner-recruit curve for herring estimated in SS3. The green line shows the geometric mean recruitment relationship and the black line shows the mean recruitment relationship. The 2006-2011 recruitments at spawning biomass levels of around2. 2.5 x 10^6 mt are expected values from the spawner-recruit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

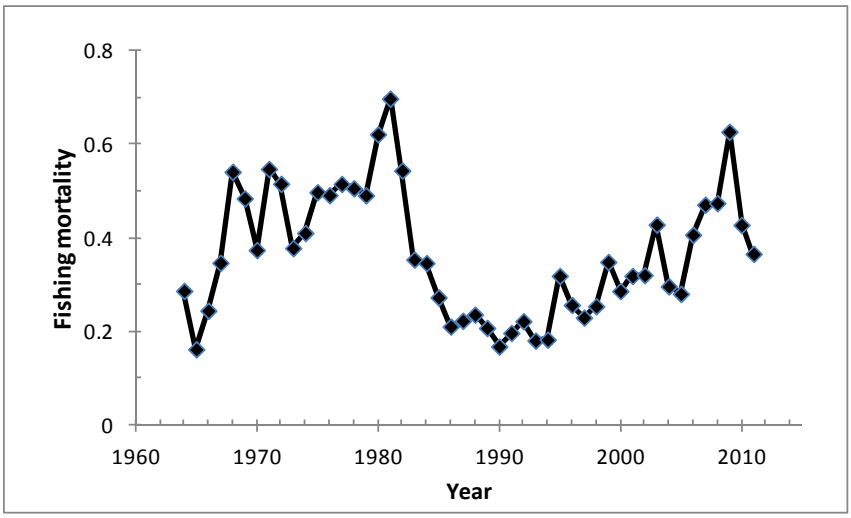

Figure A2-24. Approximate annual fishing mortality rate estimates for herring during 1964-2011 from SS3. The approximation for each year was computed as total annual landings divided by the biomass of herring age 1+ on July 1.

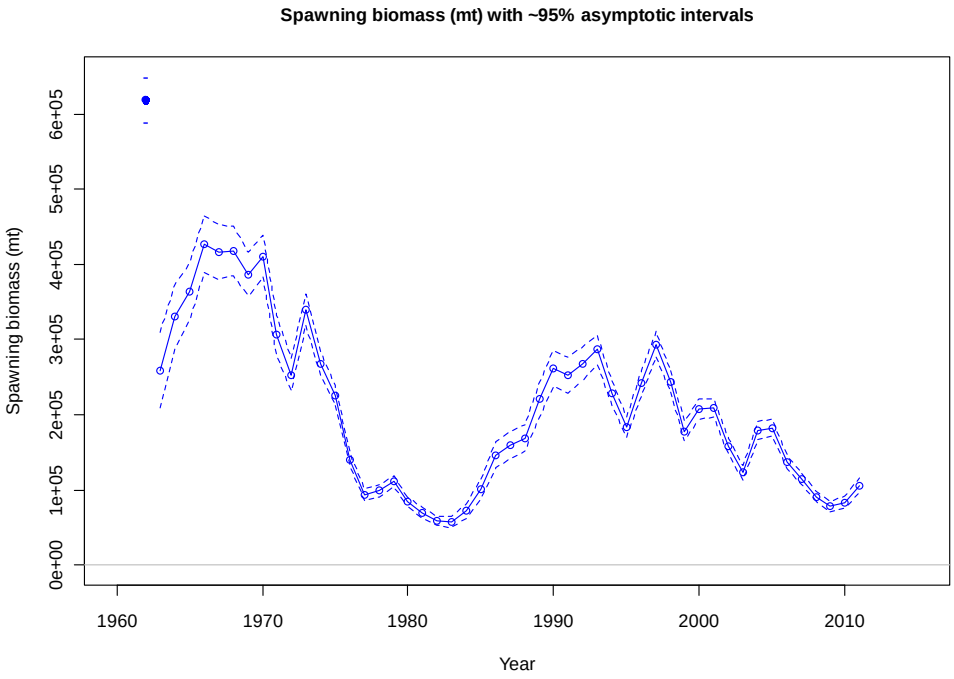

Figure A2-24. Approximate spawning stock biomass estimates (± 95% CI) for herring during 1964-2011 from SS3.

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),

$$\hat{R}_A = \rho R_B . \tag{1}$$

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	Δ (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).

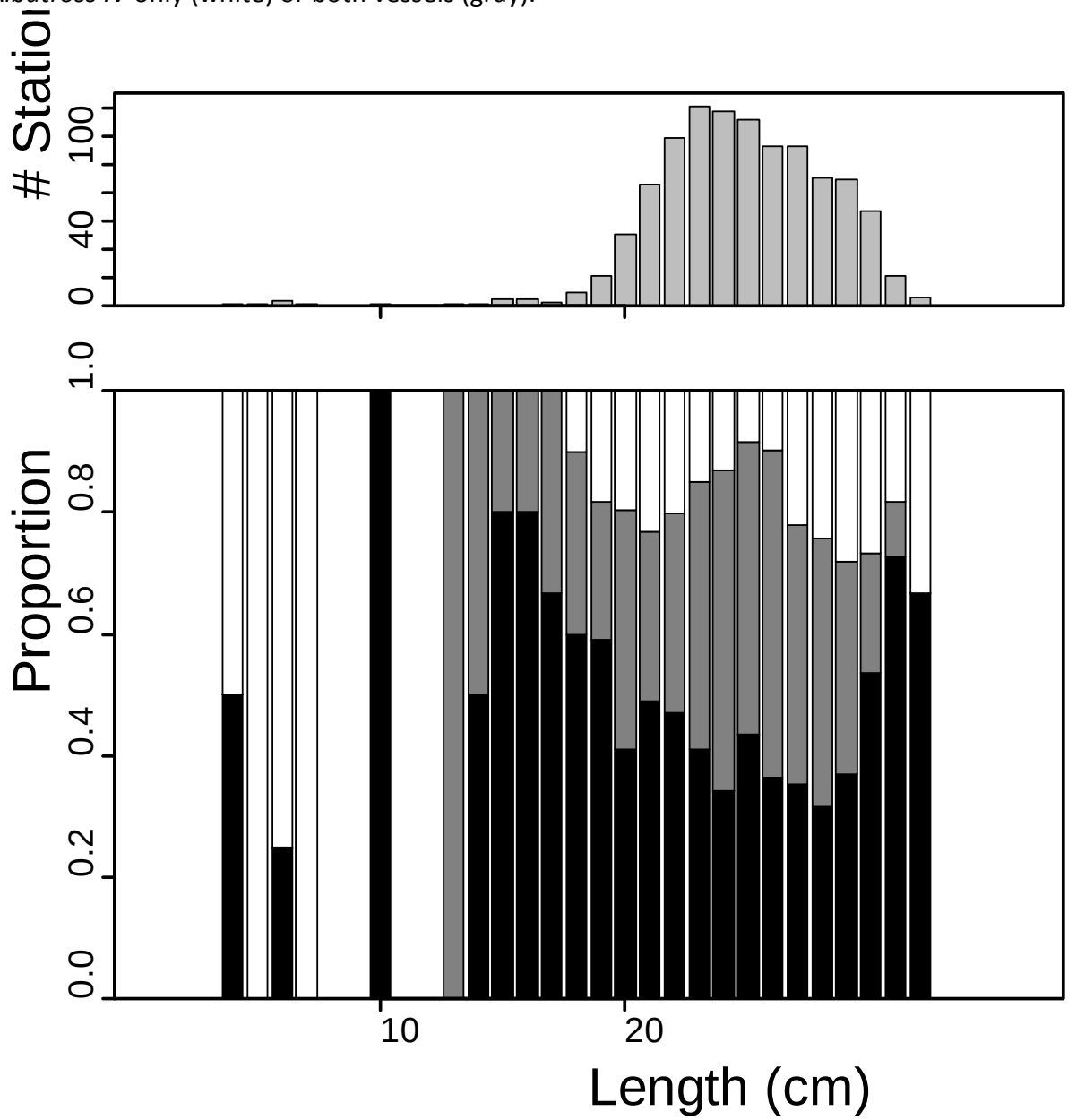


Figure 2. Total number of fish captured at each station in offshore strata (both vessels combined) at length (top) and proportions captured by the *Albatross IV* (white) and *Henry B. Bigelow* (gray) (bottom) from data collected at all stations in 2008 for fish at least 12cm in length.

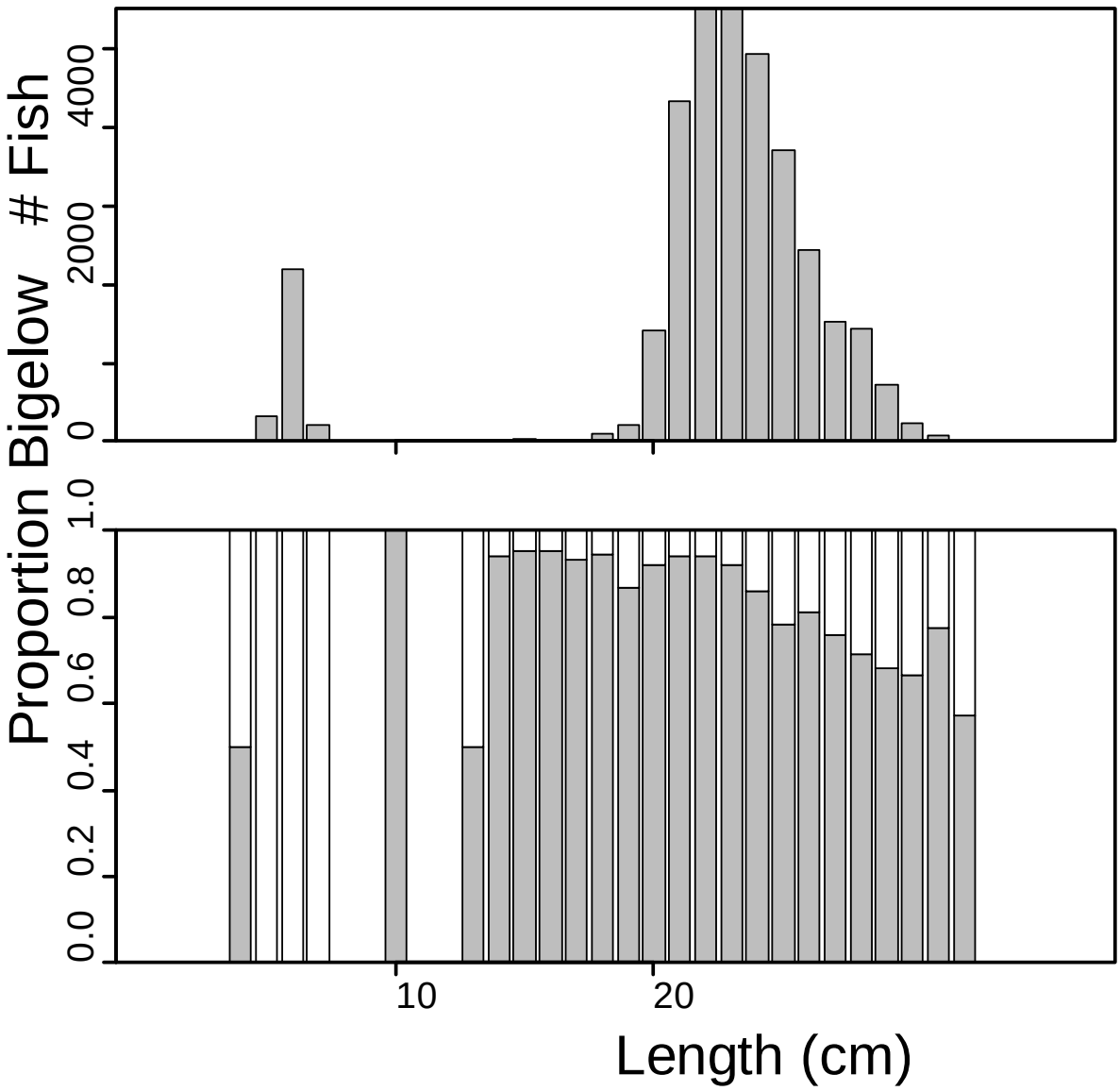


Figure 3. Number of stations where fish were observed by length class (top) and the proportions of stations where fish were observed aboard the *Henry B. Bigelow* only (black), *Albatross IV* only (white) or both vessels (gray) for data collected from stations during the spring (left) and fall (right)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

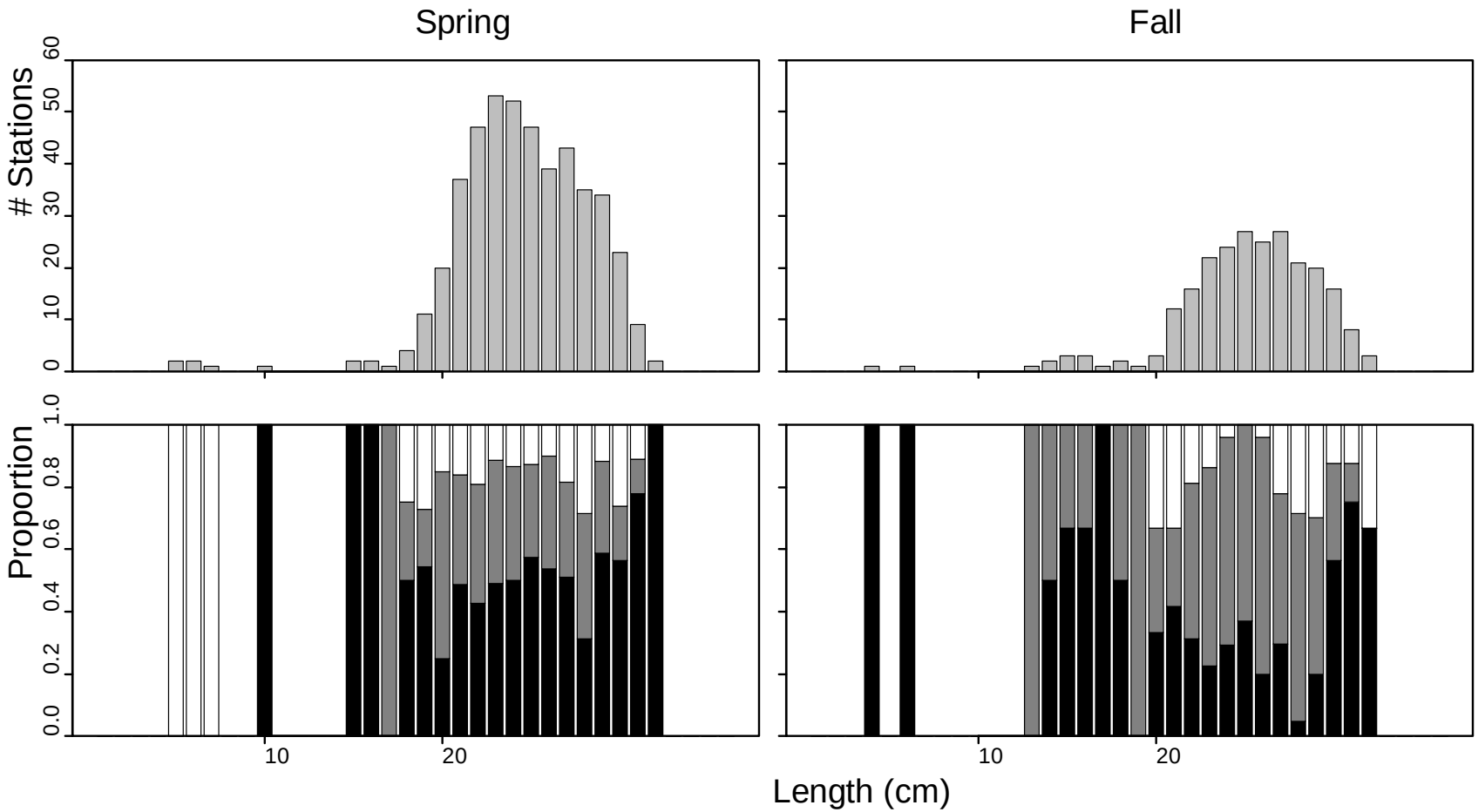


Figure 4. Total number of fish captured at each station (both vessels combined) at length (top) and proportions captured by the *Albatross IV* (white) and *Henry B. Bigelow* (gray) (bottom) for data collected from stations during the spring (left) and fall (right) surveys in 2008.

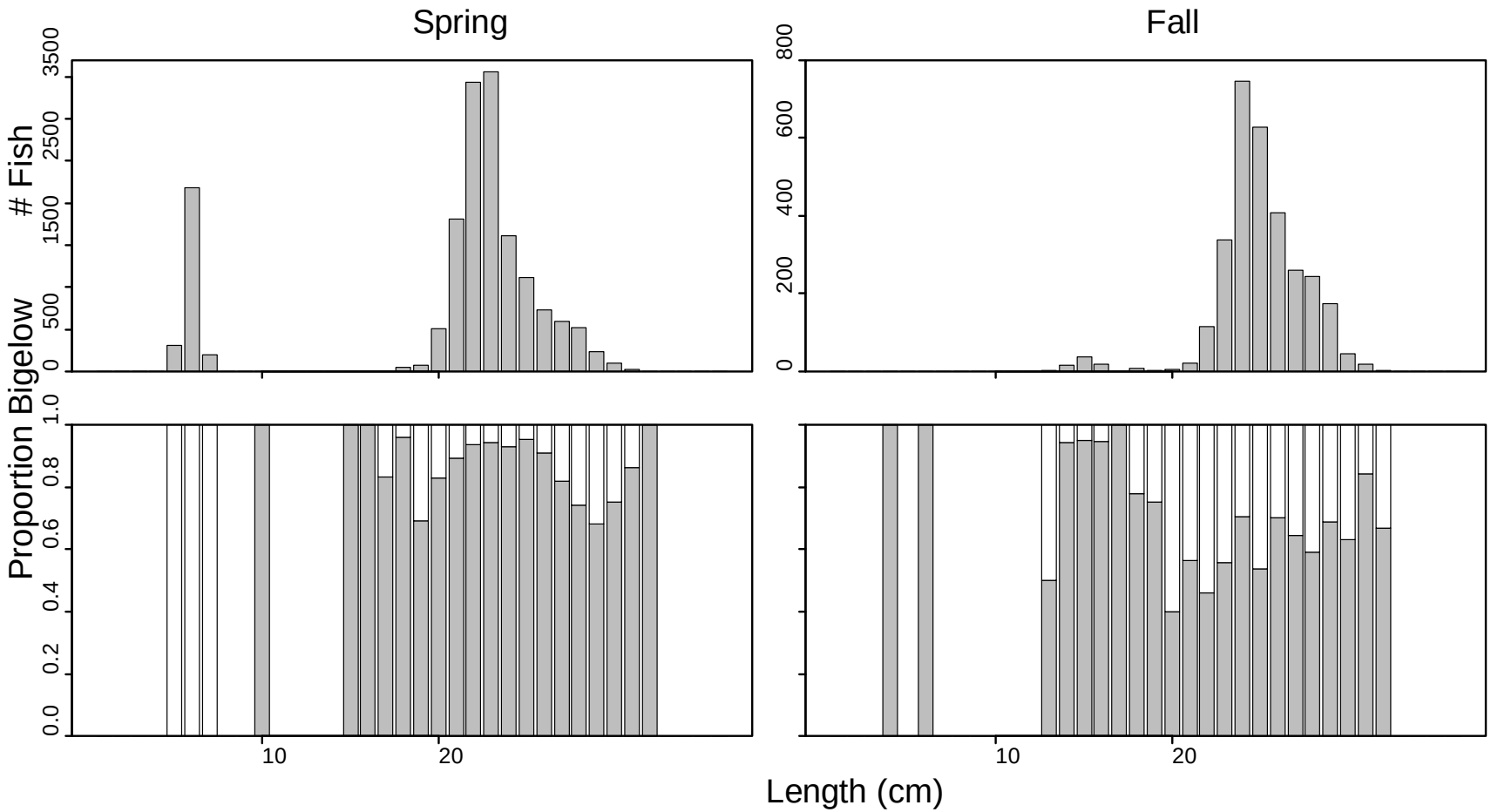


Figure 5. Predicted relative catch efficiency from the best performing model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected at all stations in 2008 for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

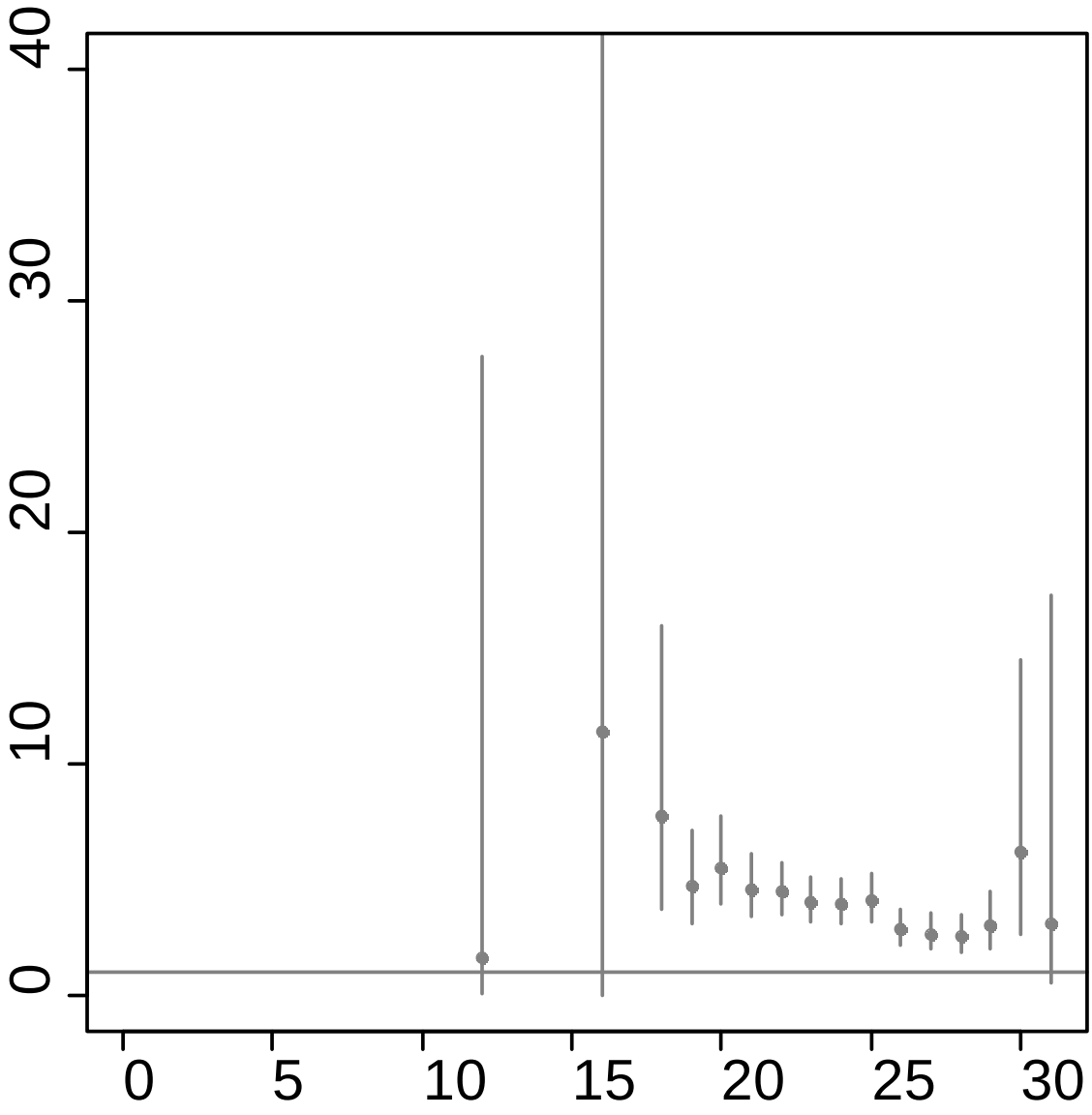


Figure 6. Predicted beta-binomial dispersion parameter from the best performing model (red) and 95% confidence intervals (dashed lines) and predicted dispersion parameter by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected at all stations in 2008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

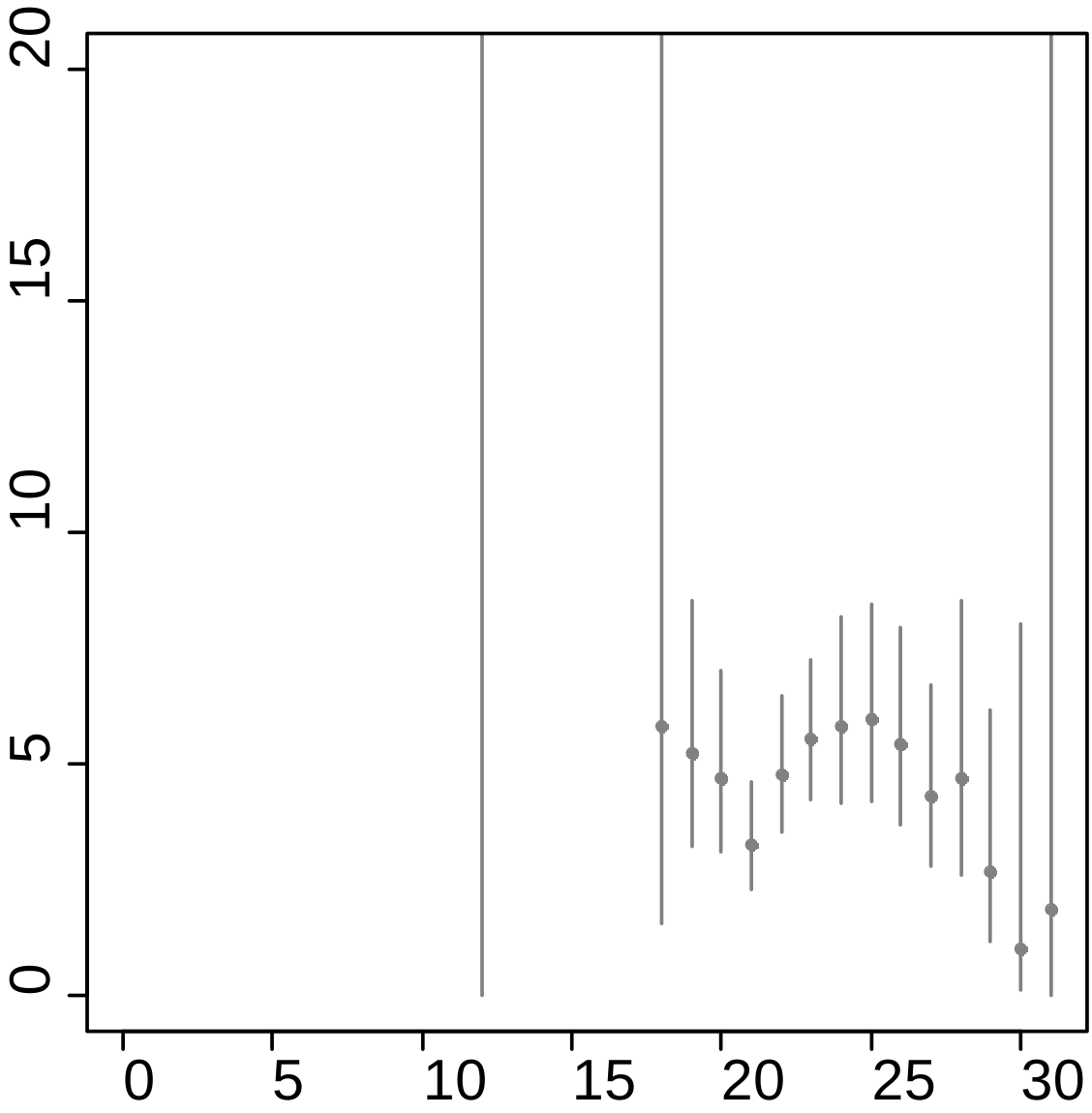


Figure 7. Randomized quantile residuals of the best performing model (as measured by AICc, see Table 1) in relation to the predicted number captured by the *Henry B. Bigelow* (left), the total number of fish captured at a station (middle), and their normal quantiles (right). Results are based on data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

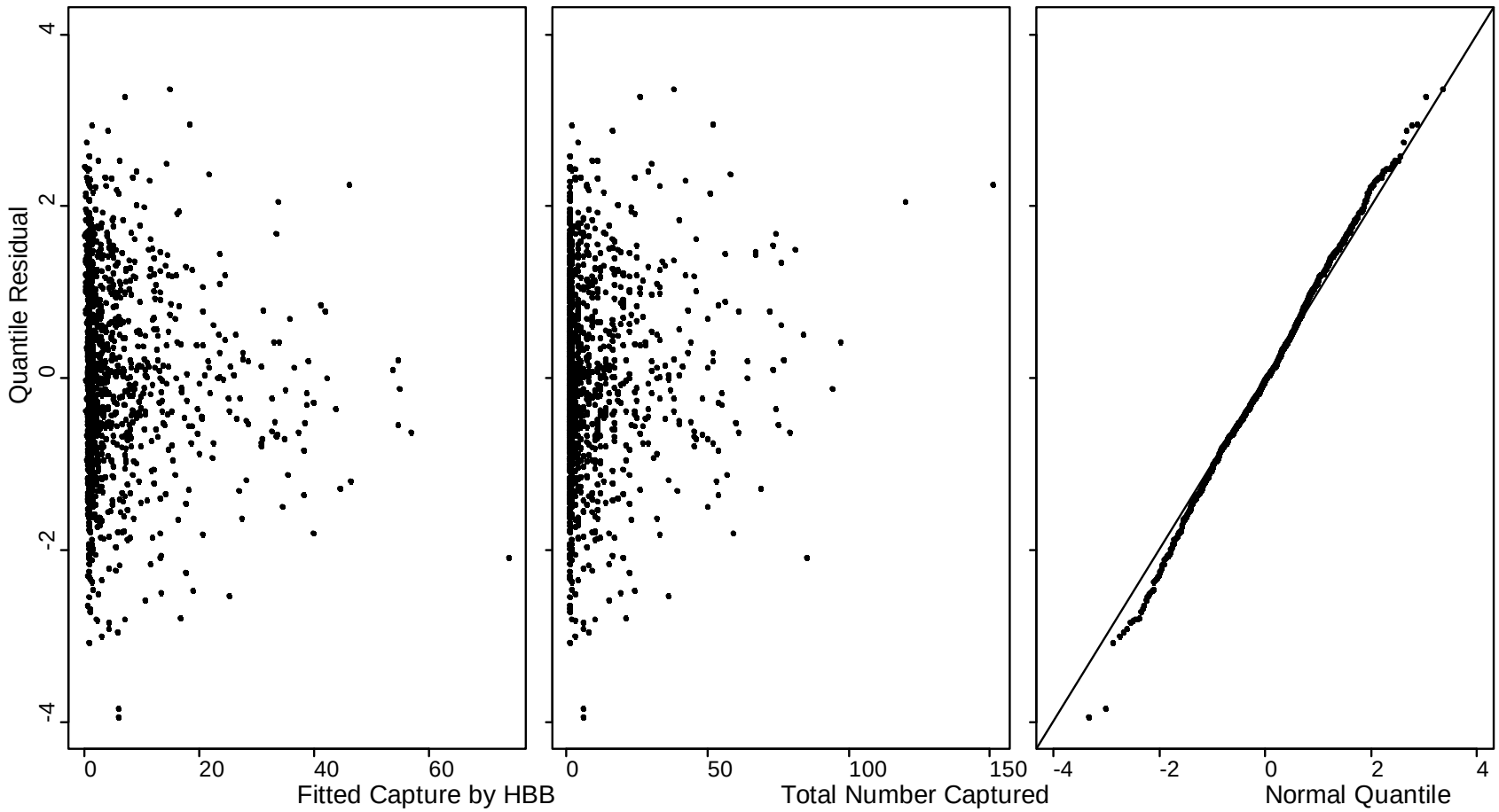


Figure 8. Predicted relative catch efficiency (left) and proportion captured by *Henry B. Bigelow* (right) from the best performing model and the best thin-plate regression spline smoother (Rank 50 with respect to AIC_c). Results are based on data collected across all stations in 2008 for fish at least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

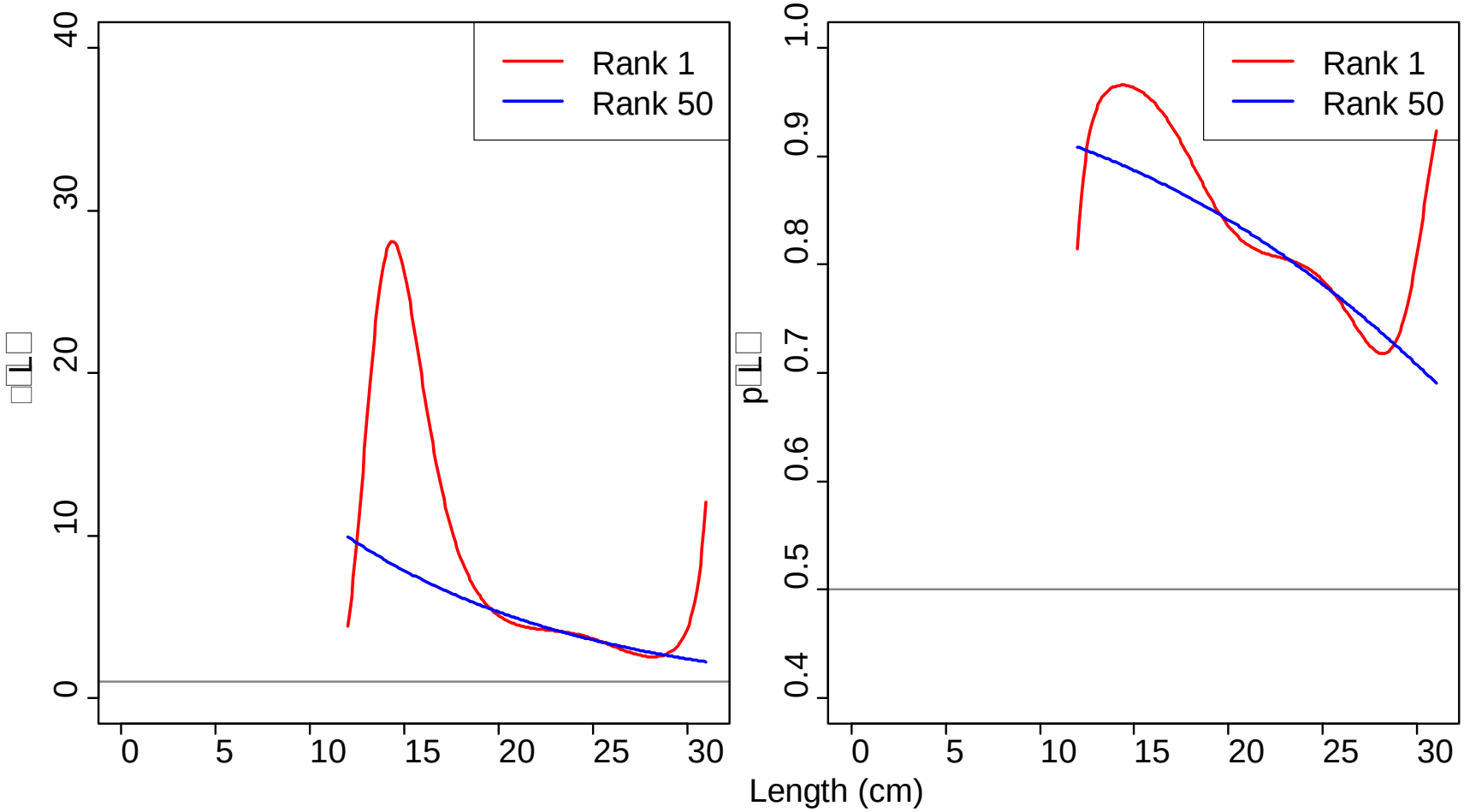


Figure 9. Predicted relative catch efficiency from the best performing orthogonal polynomial (without gamma assumption) model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based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

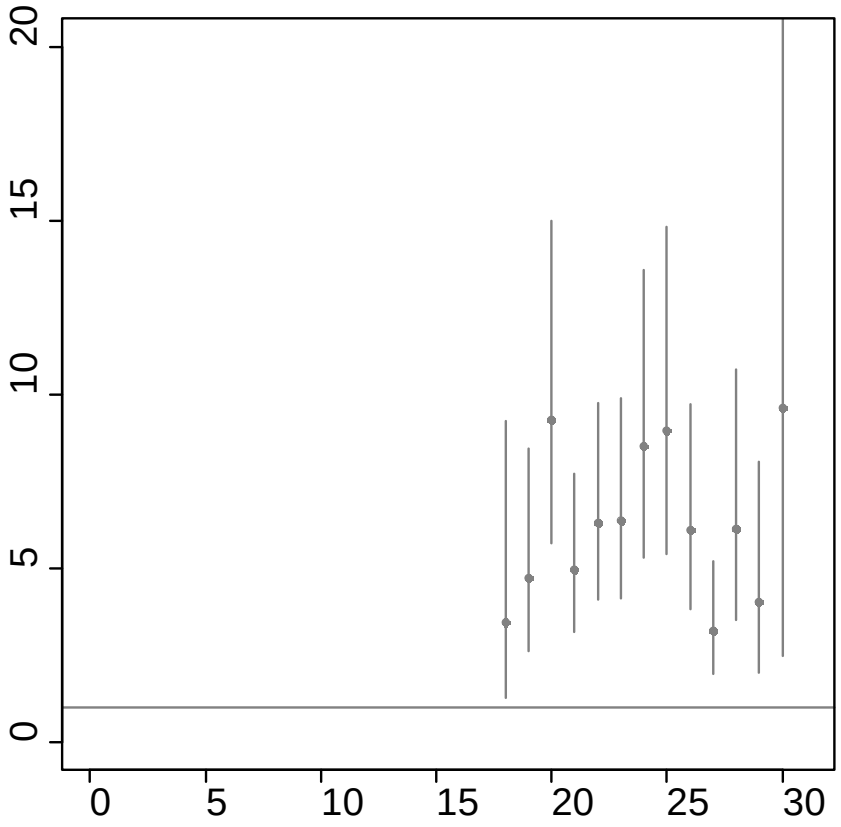


Figure 10. Predicted dispersion parameter from the best performing orthogonal polynomial model (red) and 95% confidence intervals (dashed lines) and predicted relative catch efficiency by length class (gray) with 95% confidence intervals (vertical lines). Results are based on data collected from stations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

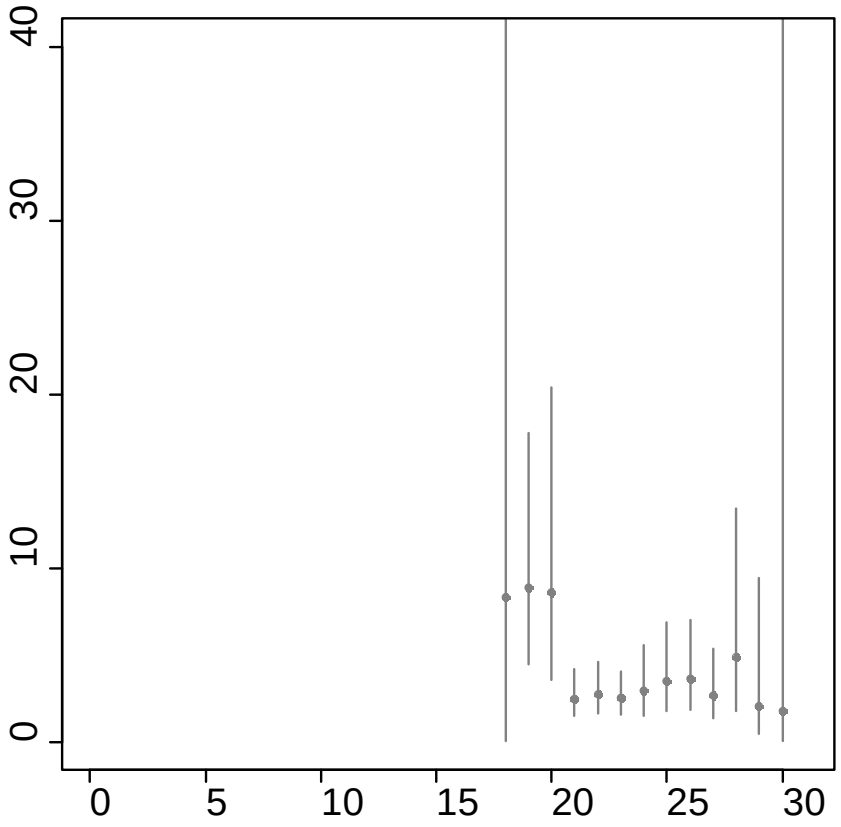


Figure 11. Randomized quantile residuals of the best performing (as measured by AICc) in relation to the predicted number captured by the *Henry B. Bigelow* (left), the total number of fish captured at a station (middle), and their normal quantiles (right). Results are based on data collected from stations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

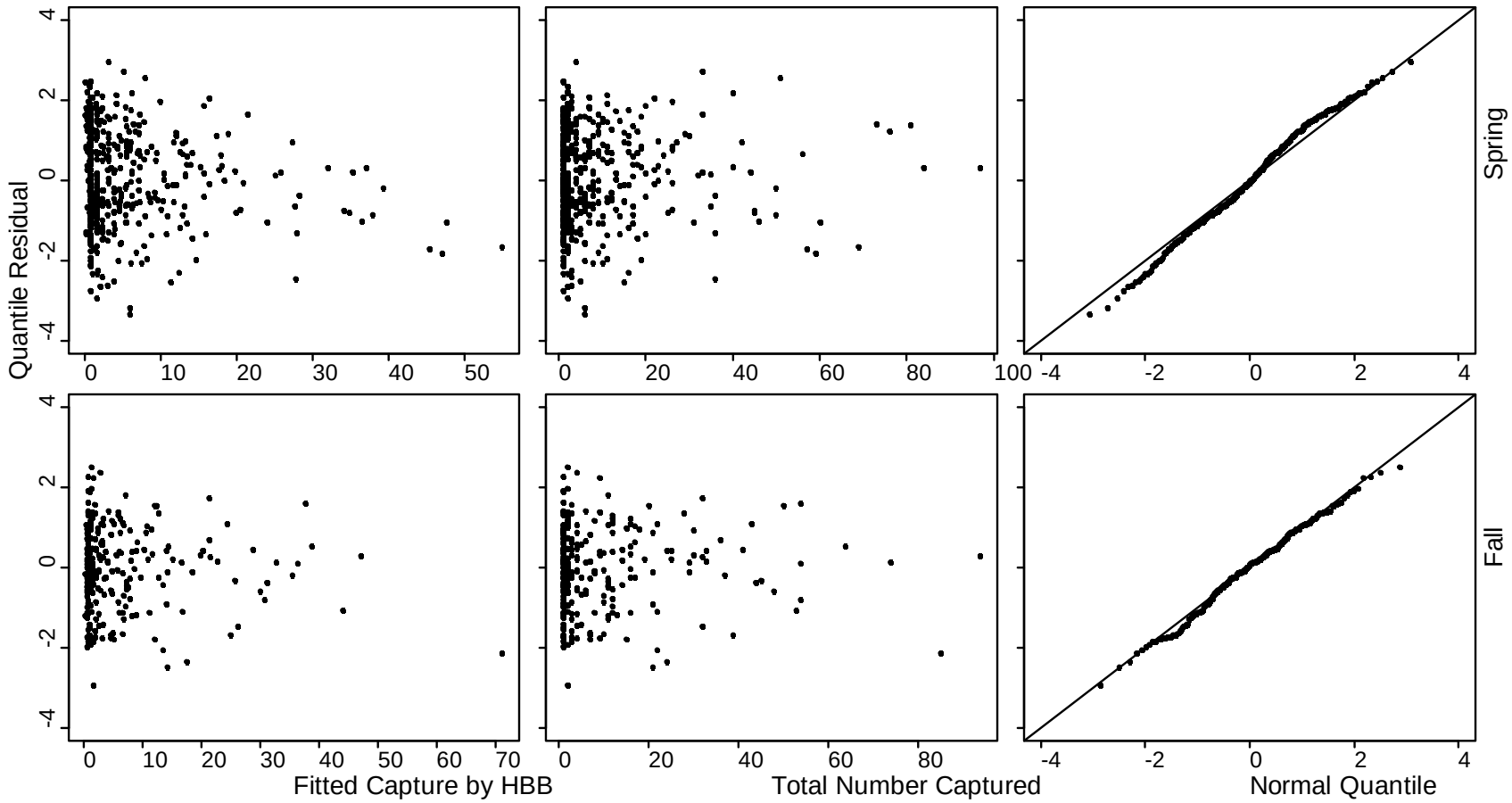
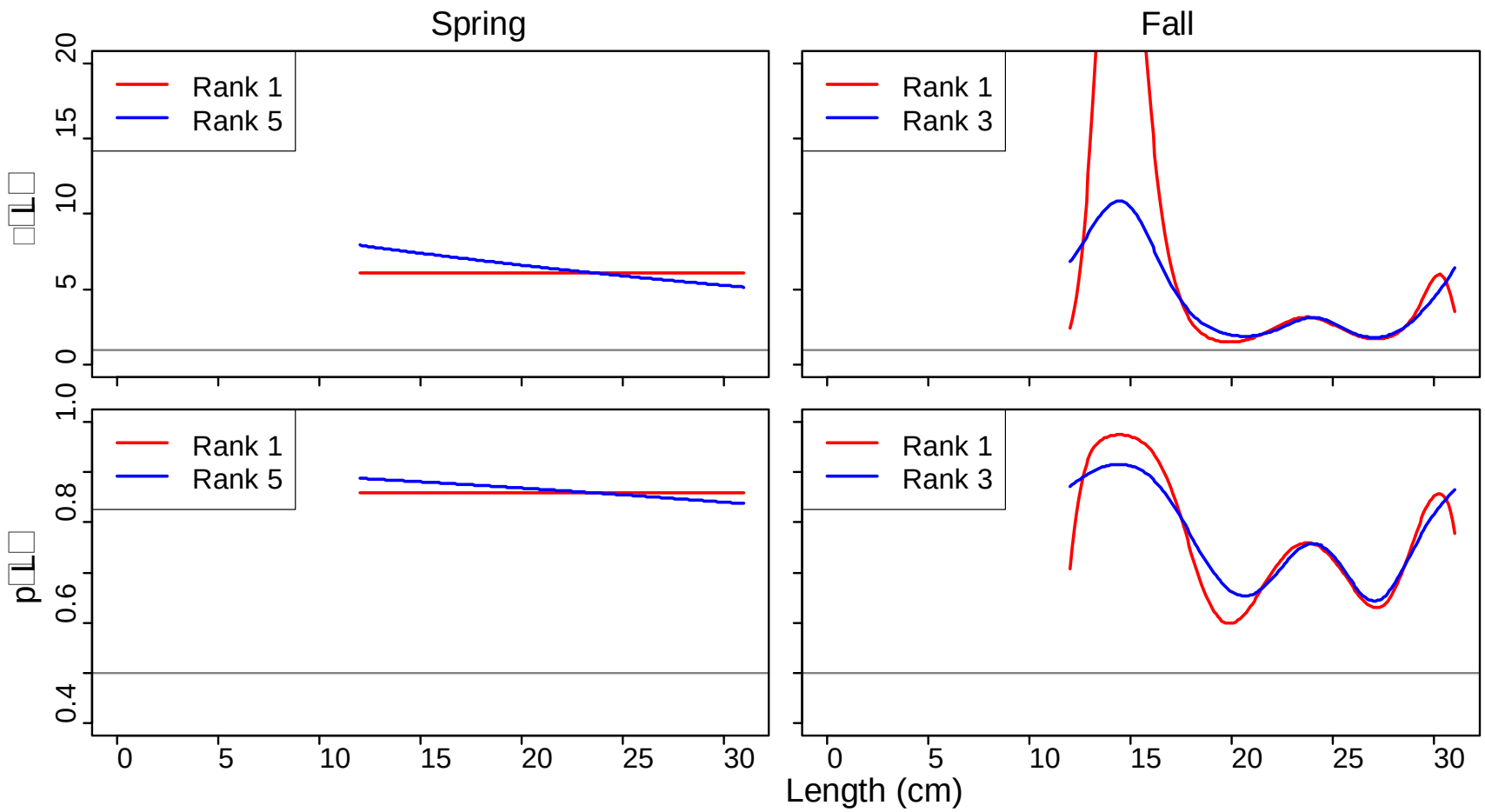


Figure 12. Predicted relative catch efficiency (top) and proportion captured by *Henry B. Bigelow* (bottom) from the best performing model (orthogonal polynomials, rank 1) and the best thin-plate spline smoother (Rank 12 for spring data, 11 for fall data) for data collected from stations during the spring (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:

Jonathan Hare[1], James Churchill[2], David Richardson[1], Michael Jech[1], Jonathan Deroba[1], and Harvey Walsh[1]
[1] - Northeast Fisheries Science Center
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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.

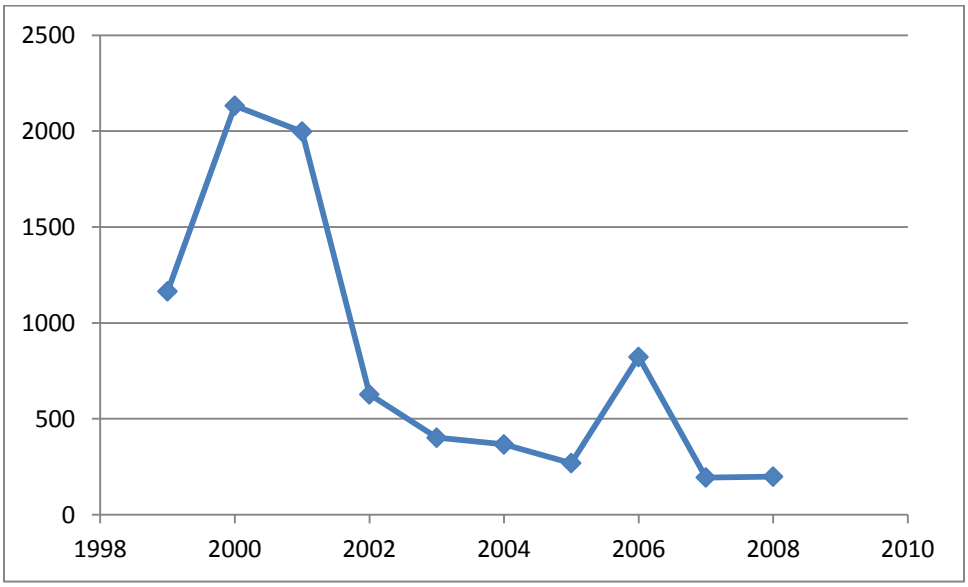


Figure 2. Spatial coverage of the acoustic survey with the systematic parallel sampling design.

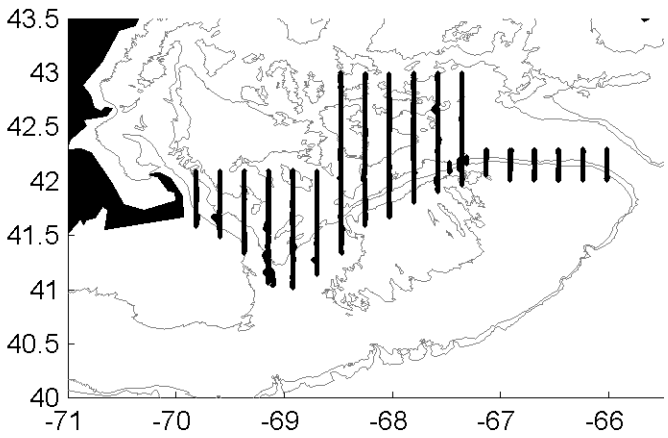


Figure 3. Distribution of small larval herring (< 9 mm) from the October and November ECOMON surveys for 1999-2010. Red x's indicate sampling locations where no small larvae were collected. Circle diameter is proportional to the square root of abundance. The larval distribution is a function of spawning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

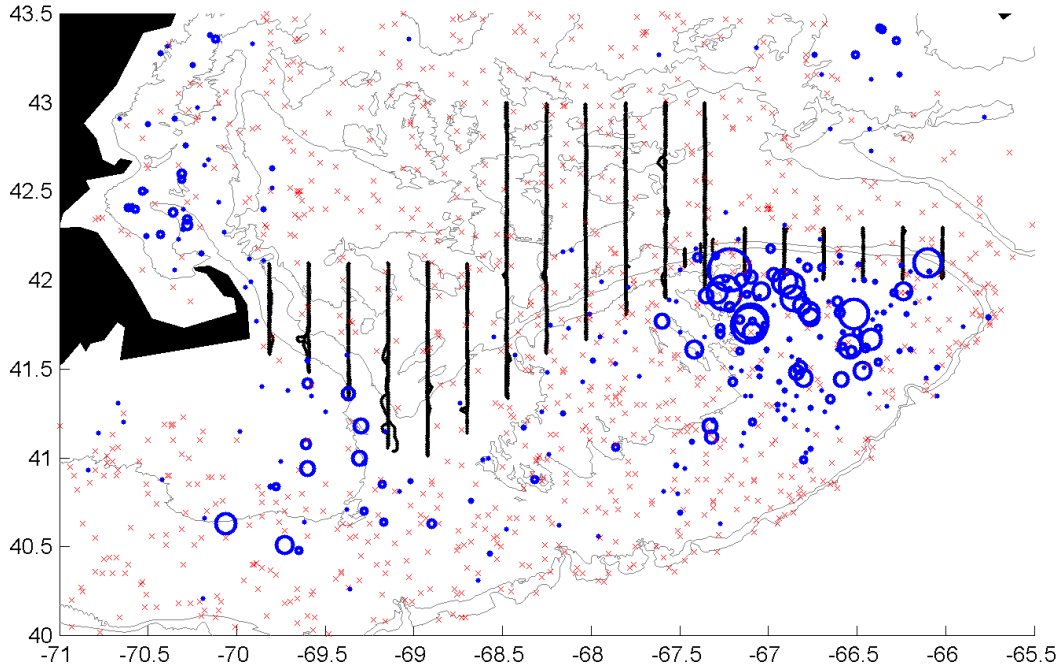


Figure 4. Predicted locations of herring egg hatching (circles) and measured abundances of herring on the acoustic survey (surface) for the years 1999-2009. The egg hatching locations are estimated using a larval transport model and the observed abundances of larval Atlantic herring at age; results are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

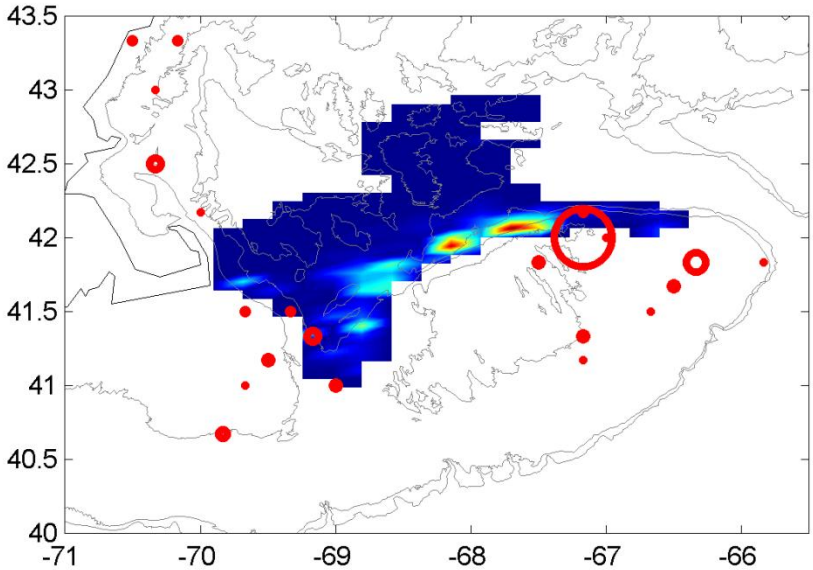


Figure 5. Estimated timing of mean hatch day of larval herring and average longitude of recently hatched larval herring on Georges Bank. Mean hatch day was determined on an annual basis using the approach used to develop a larval index in Richardson et al (2010). A two parameter normal distribution of 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.

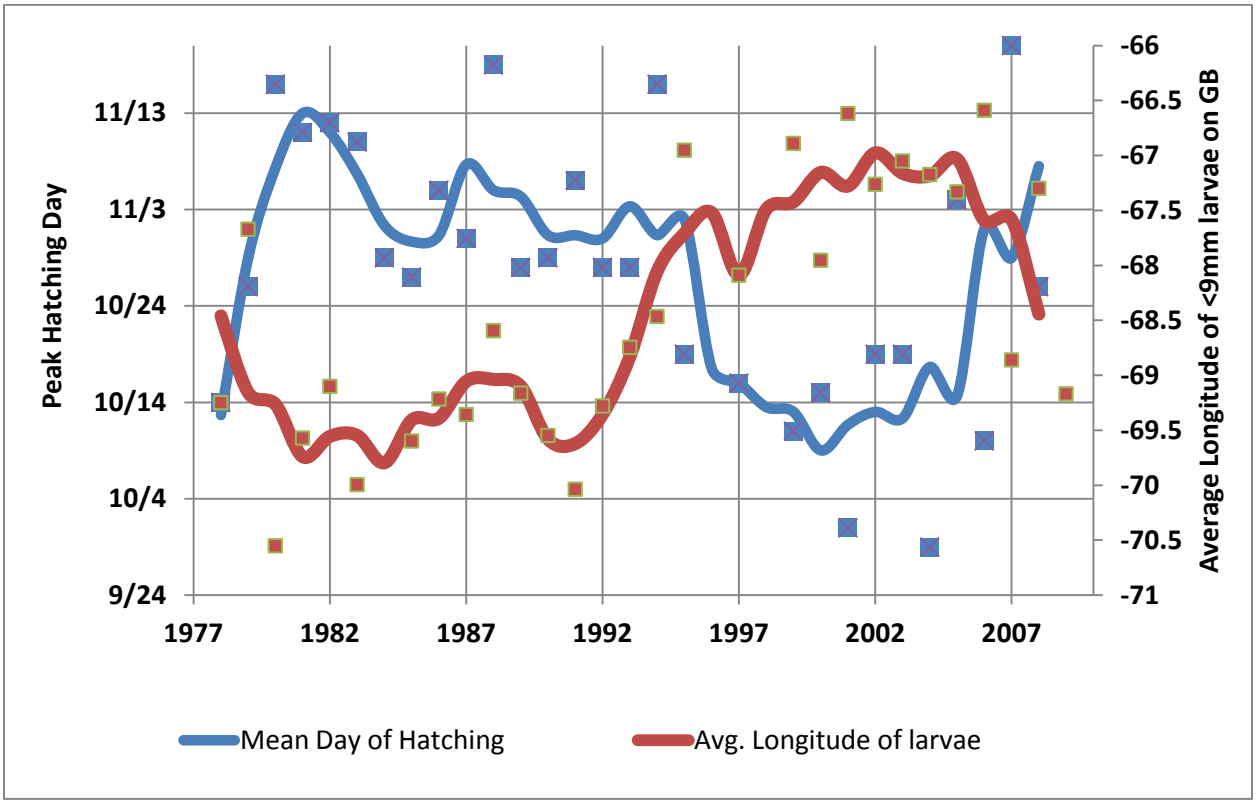


Figure 6. Same as figure 5, but with a focus on the 1999-2009 period of the acoustic survey.

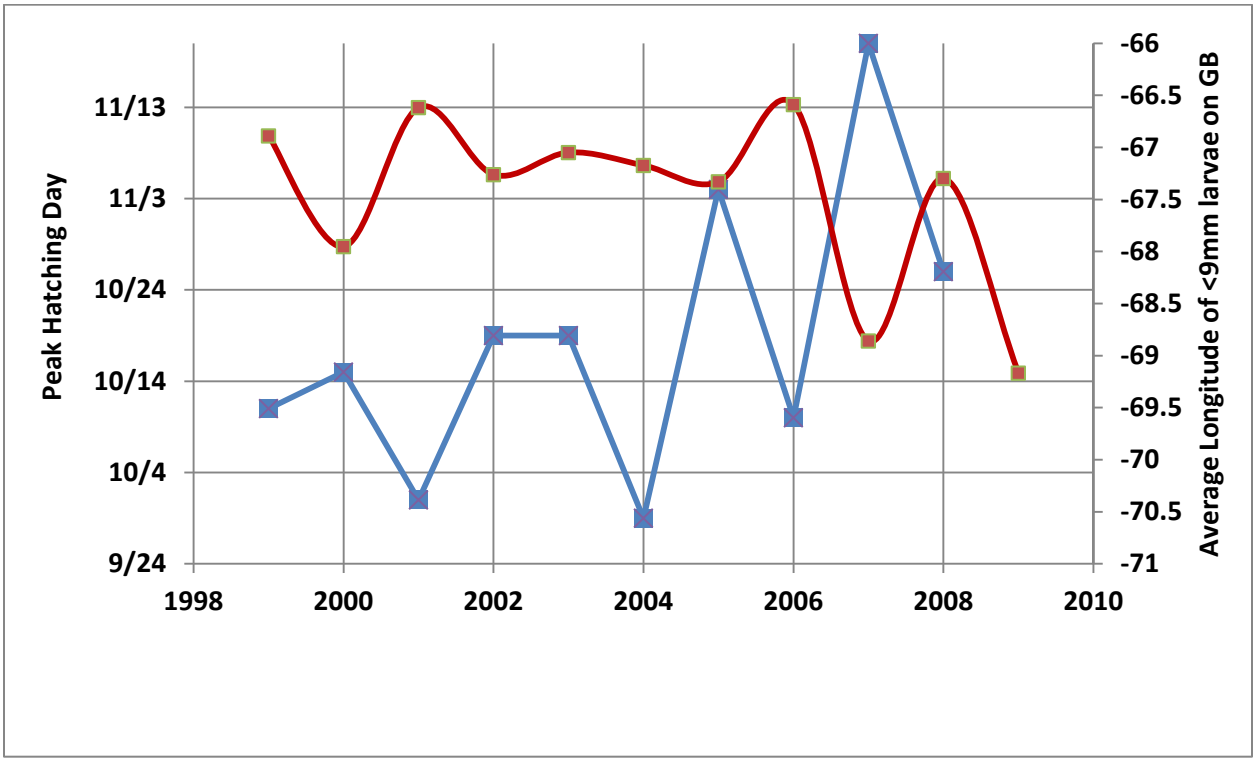
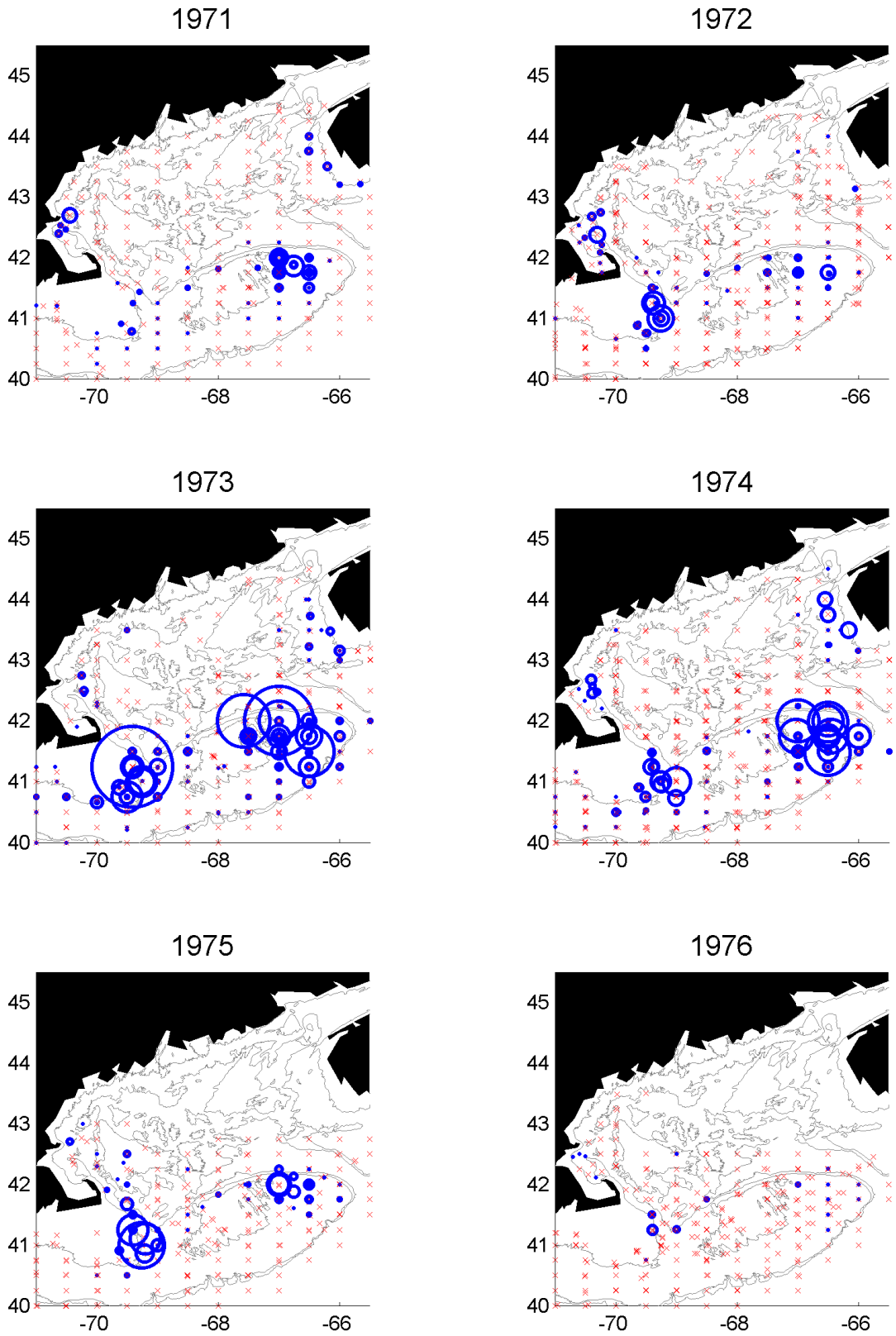
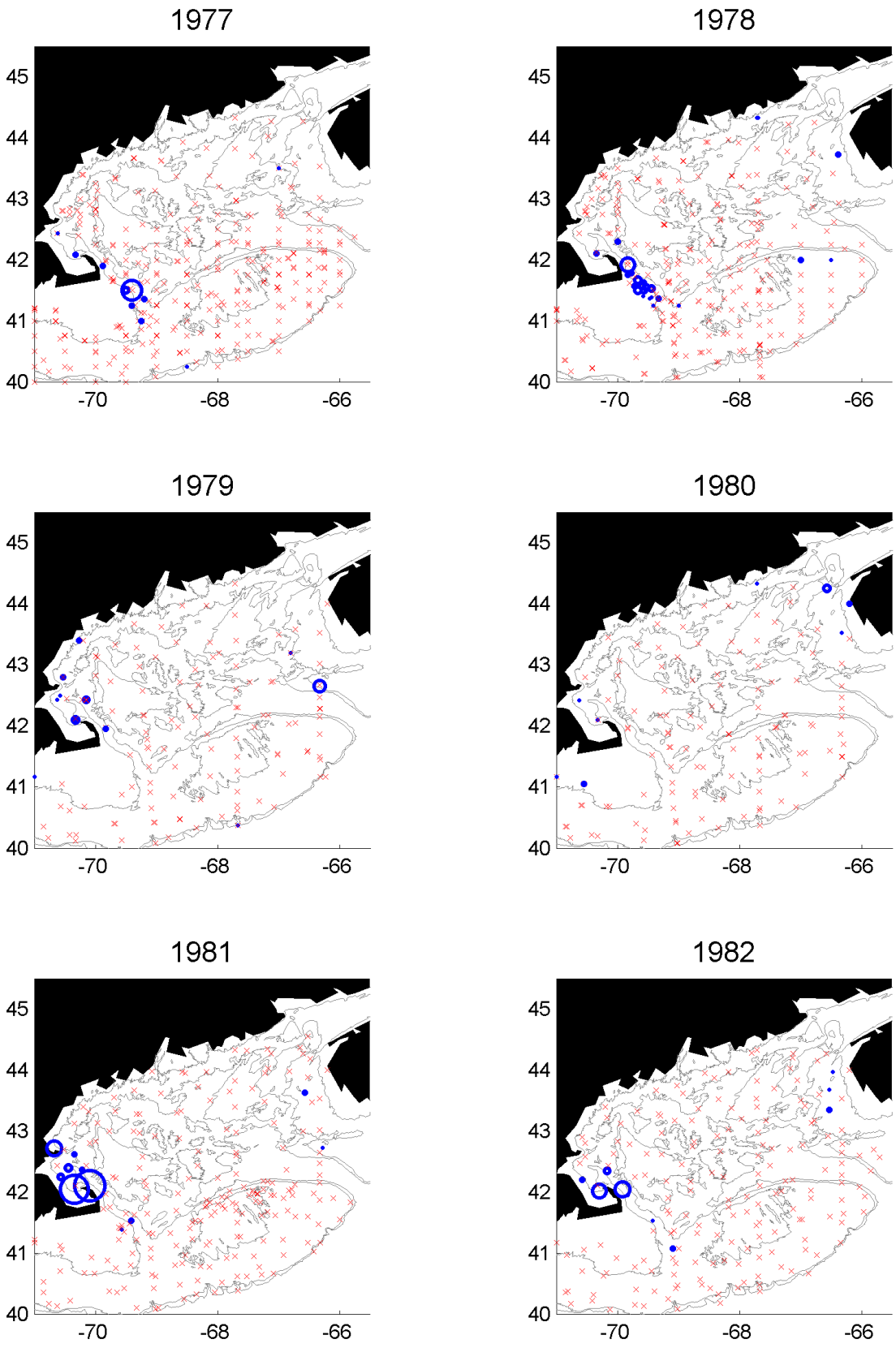


Figure 6 Annual distribution of small larvae (<9mm) during sampling in Oct-Dec.

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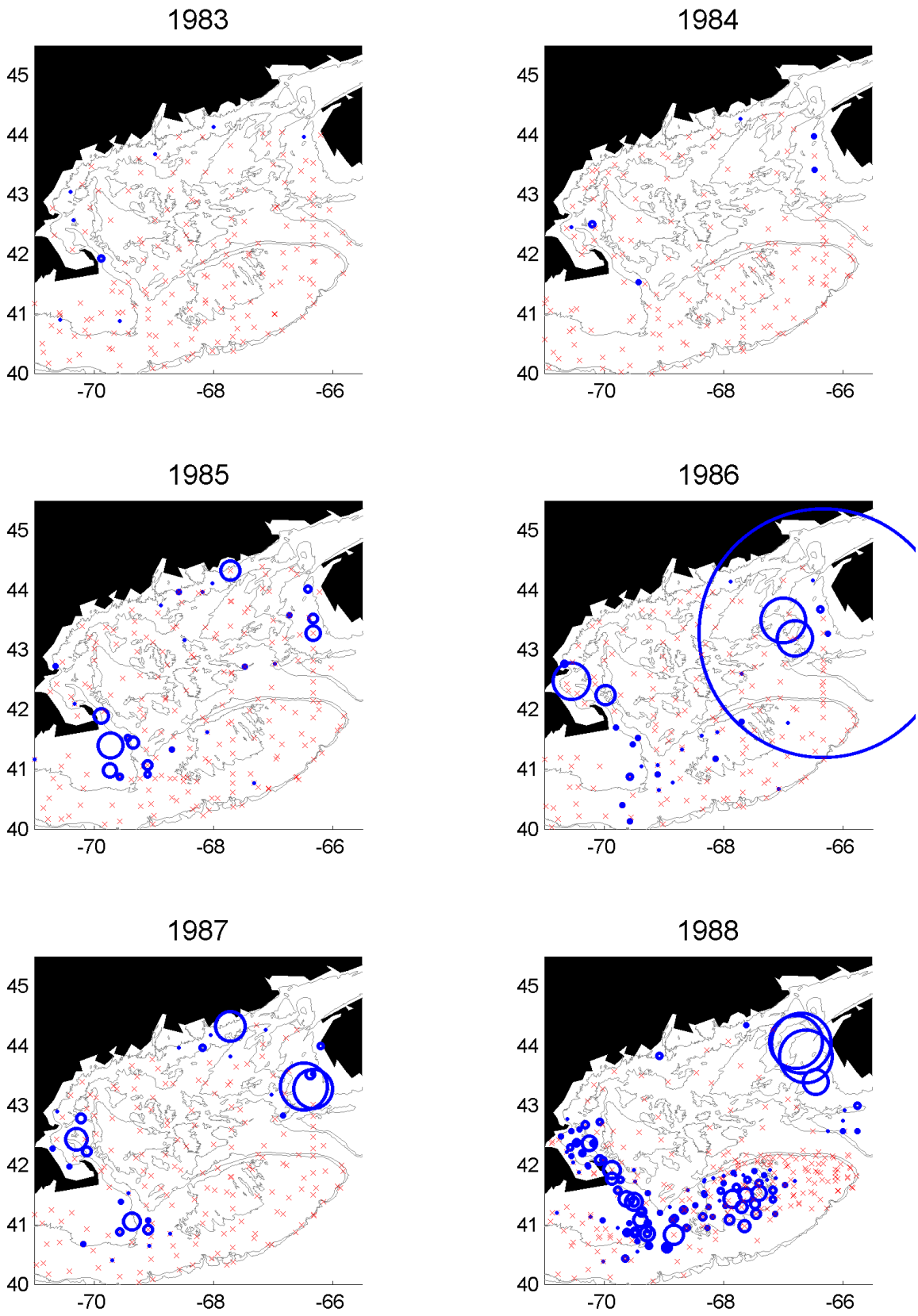
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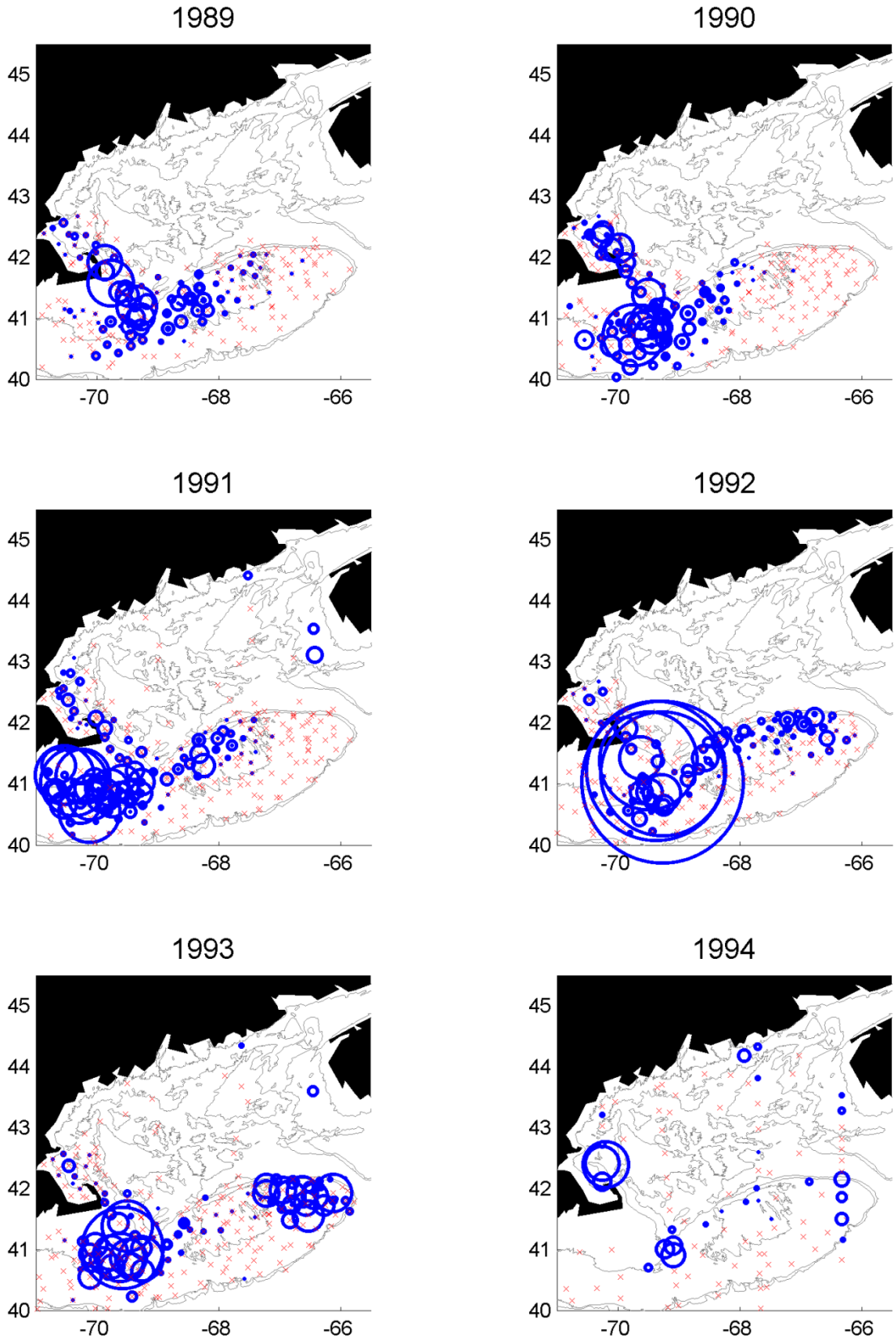
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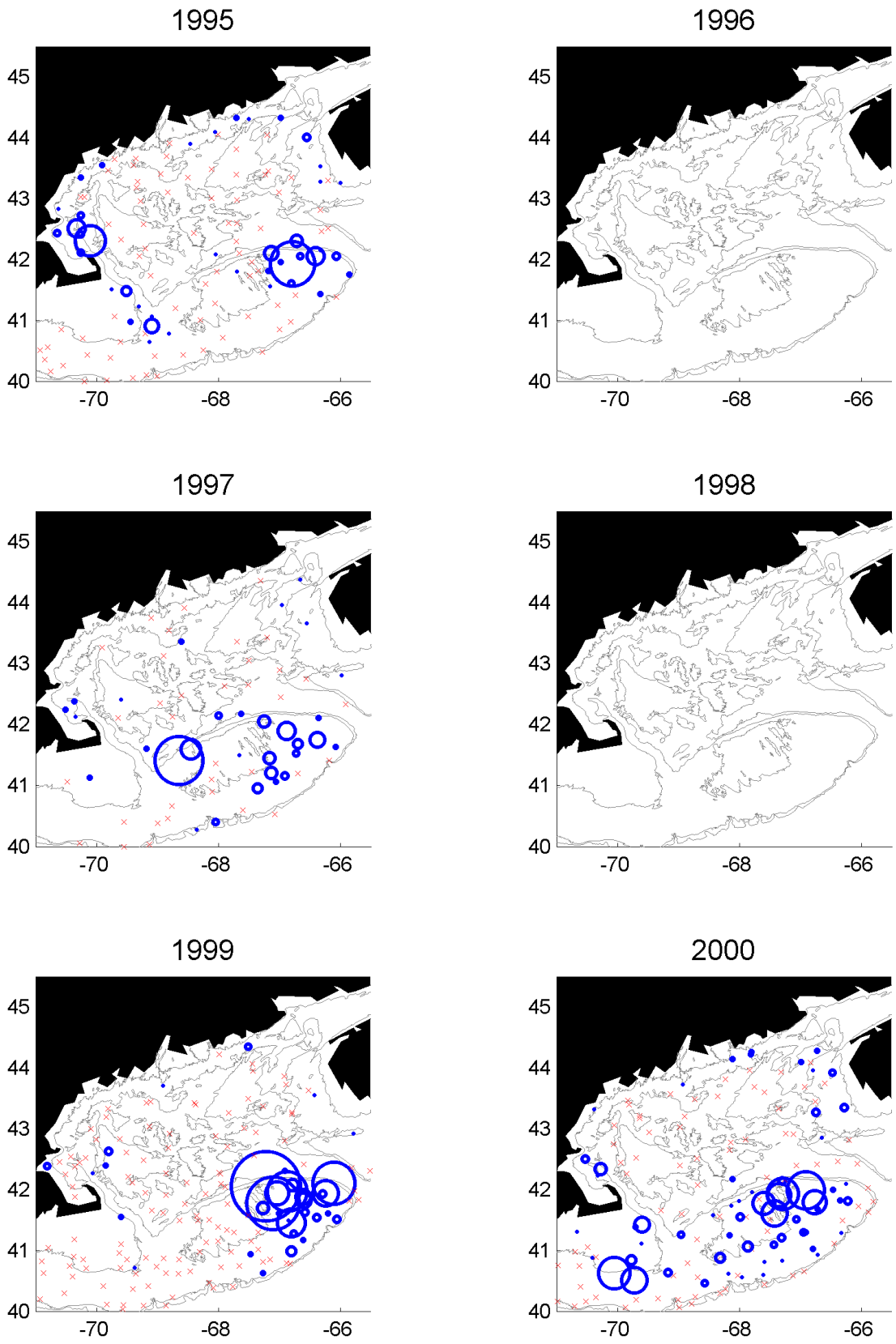
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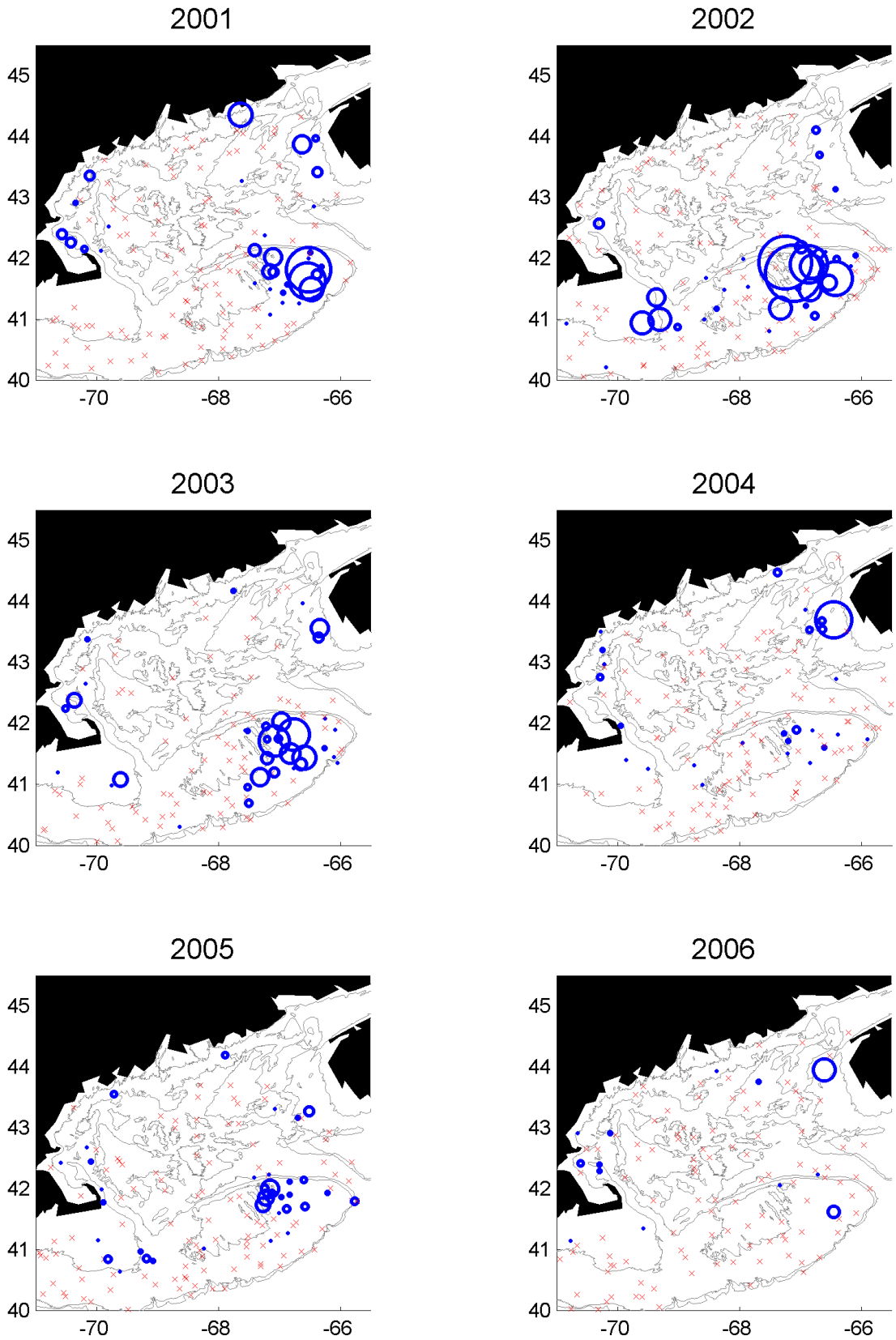
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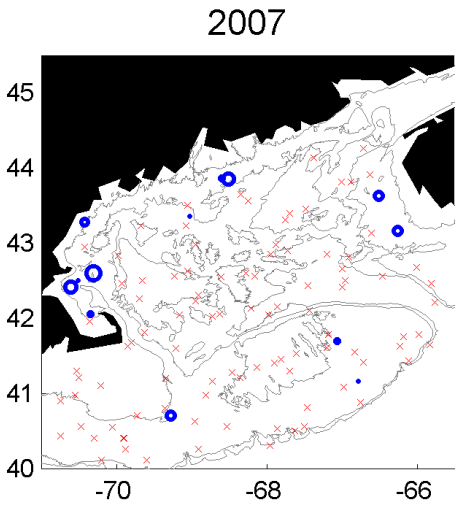
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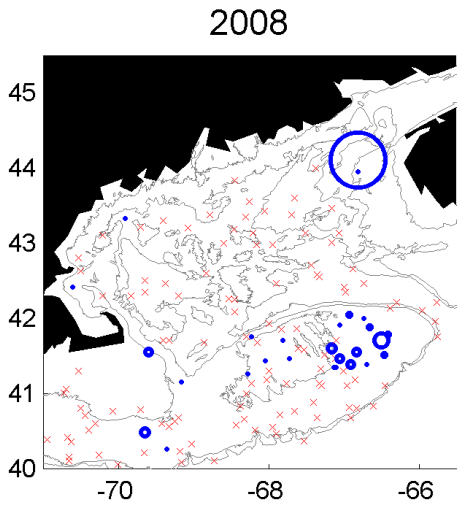
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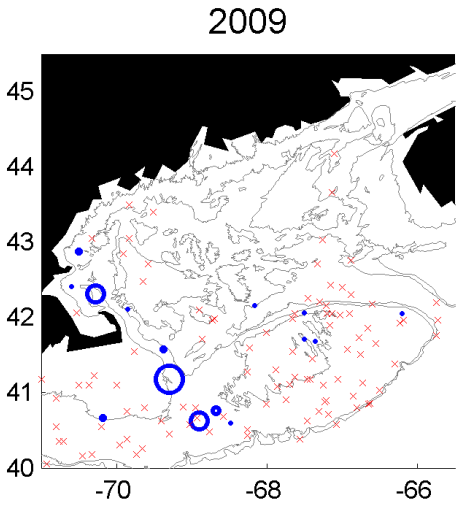
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An implementation of ASAP that allows modeling of environmental covariate effects on stock-recruit parameters and application to Atlantic herring

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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_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.

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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% **2006** expanded total

3 yr avg. = 27% 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

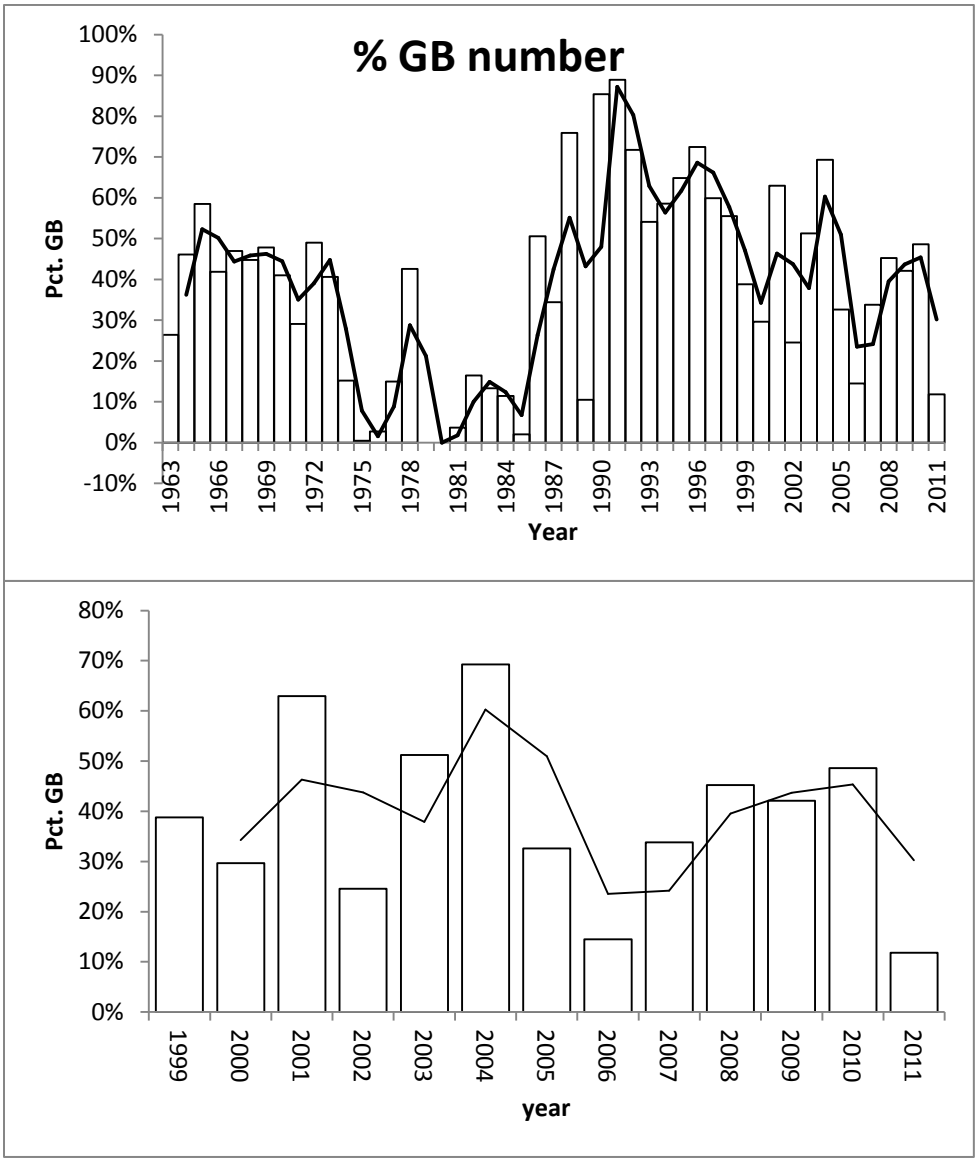

Figure 1. Proportion of herring abundance (>= 15 cm) on Georges Bank from NEFSC bottom trawl survey.

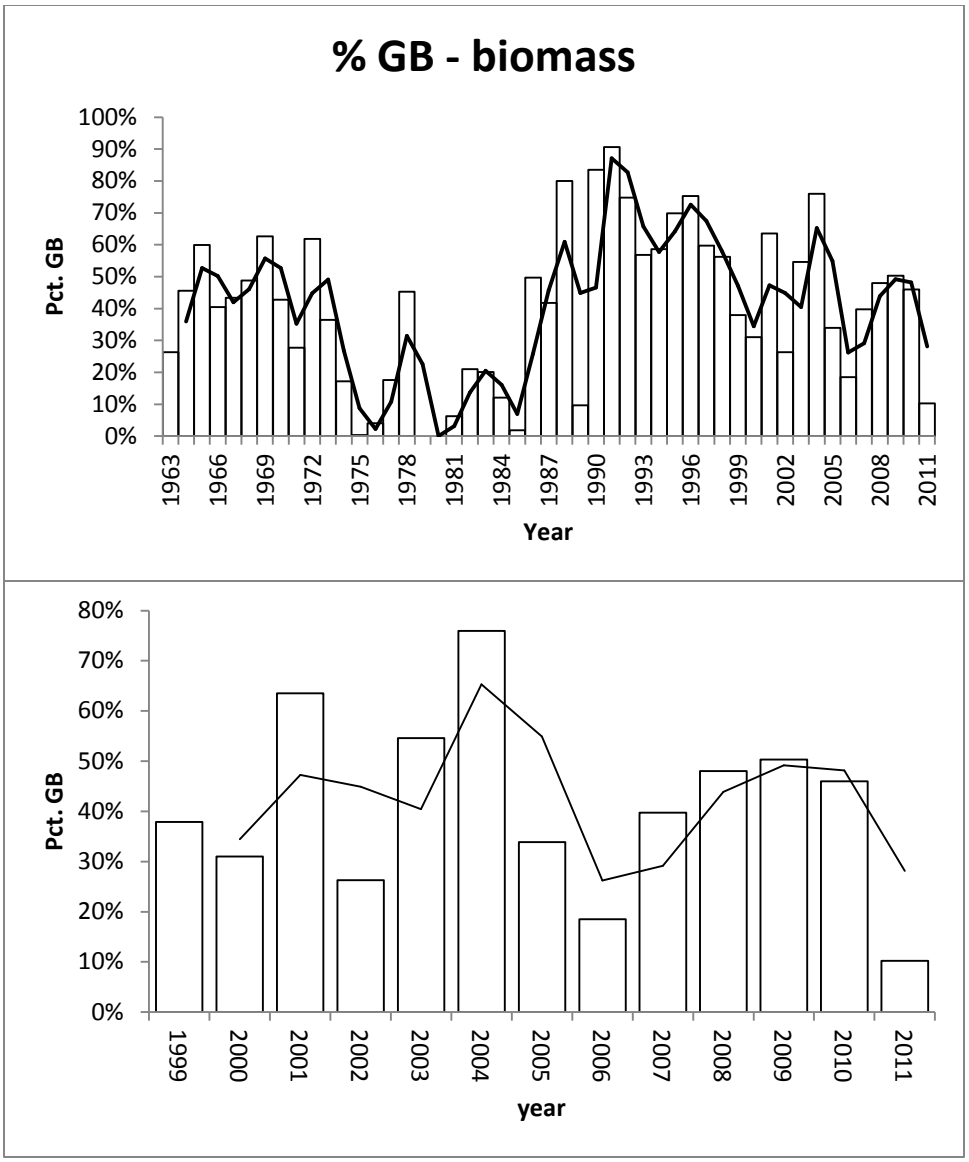

Figure 1. Proportion of herring biomass (>= 15 cm) on Georges Bank from NEFSC bottom trawl survey.

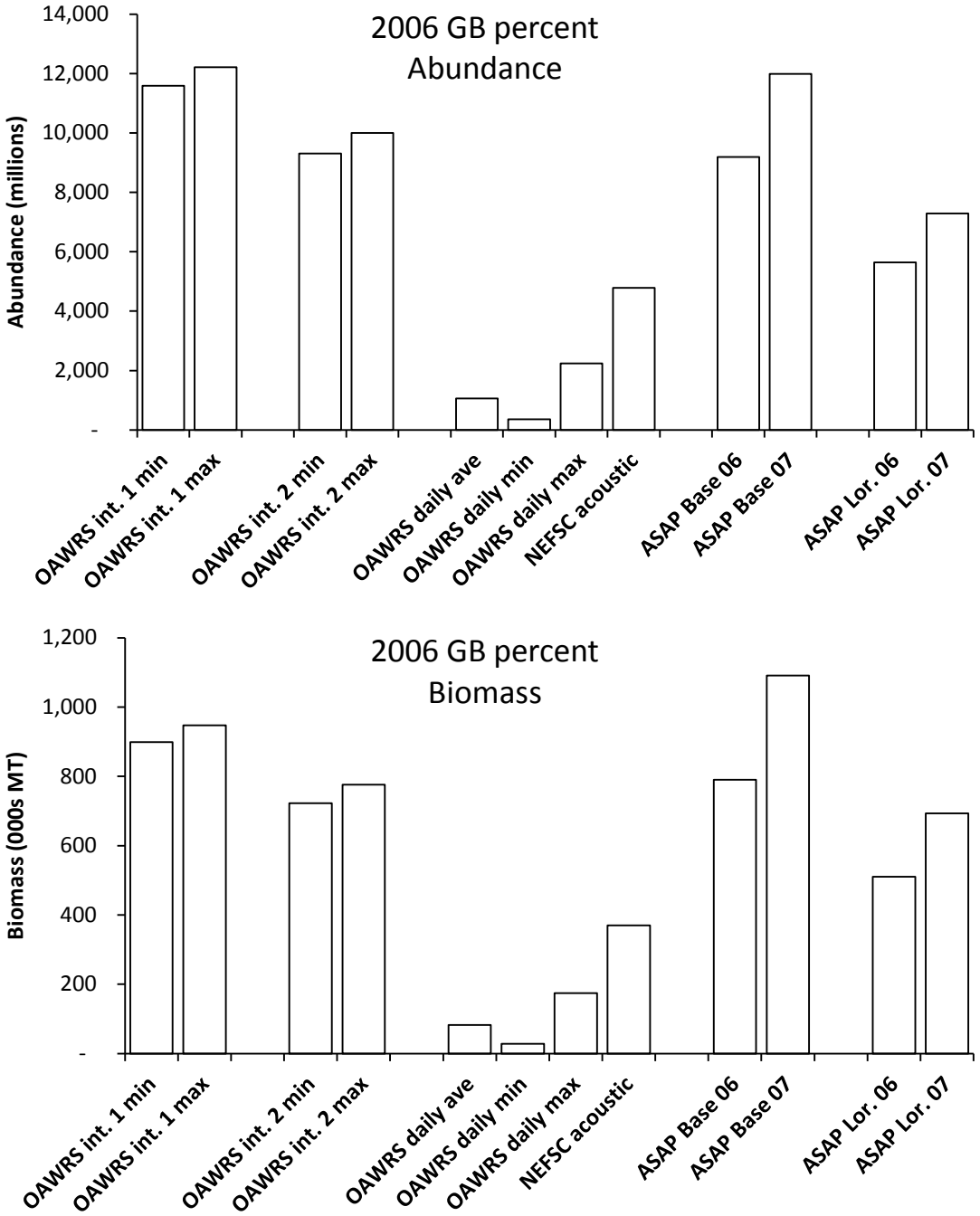

Figure 3. Comparison of abundance and biomass among methods based on 2006 survey ratio.

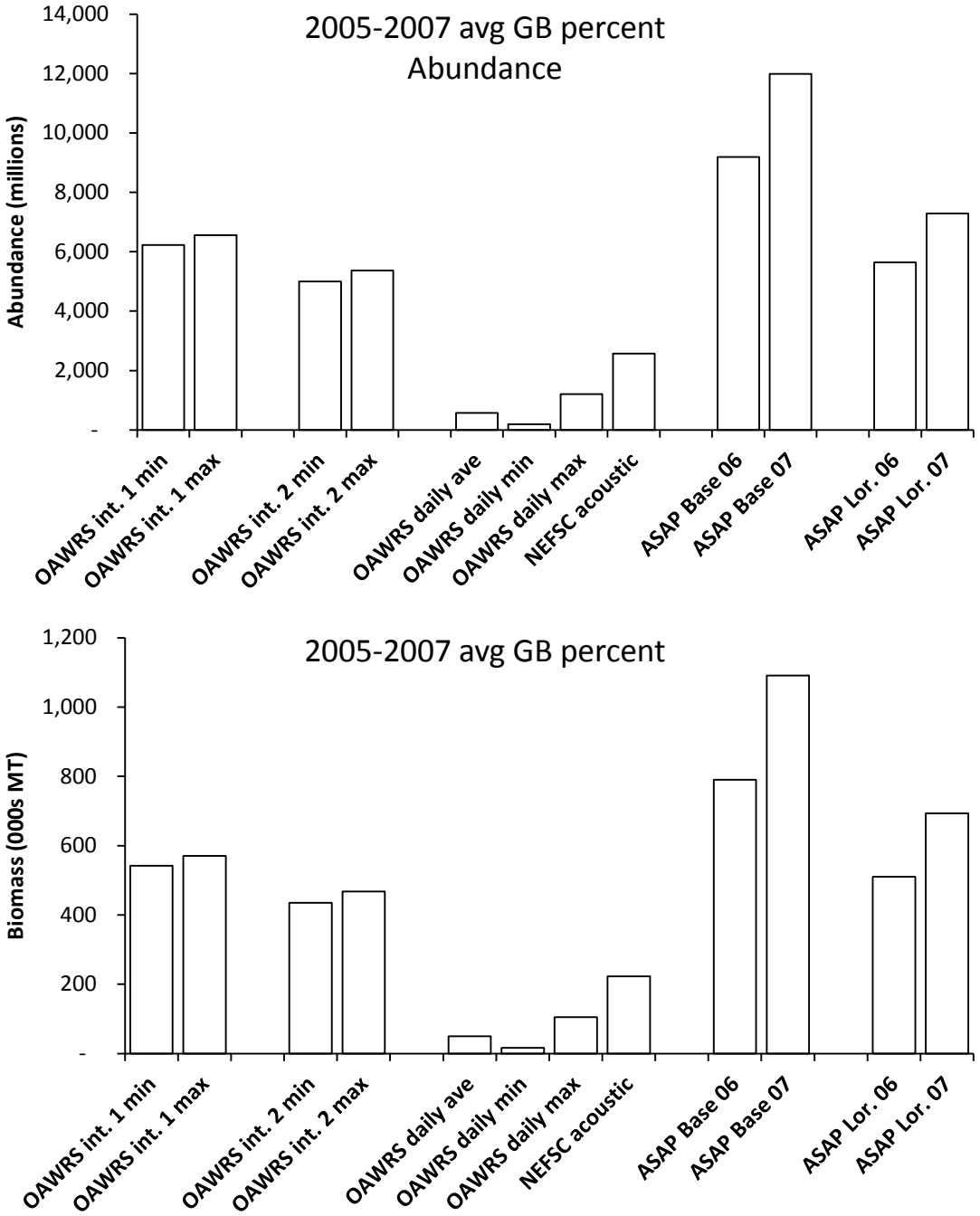

Figure 4. Comparison of abundance and biomass among methods based on 2005-2007 survey ratio.

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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Chu, C.Y.C., Hung-Ken Chien, and R.D. Lee. 2008. Explaining the optimality of U-shaped age-specific mortality. Theoretical Population Biology 73(2): 171-180.

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Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49: 627-647.

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).

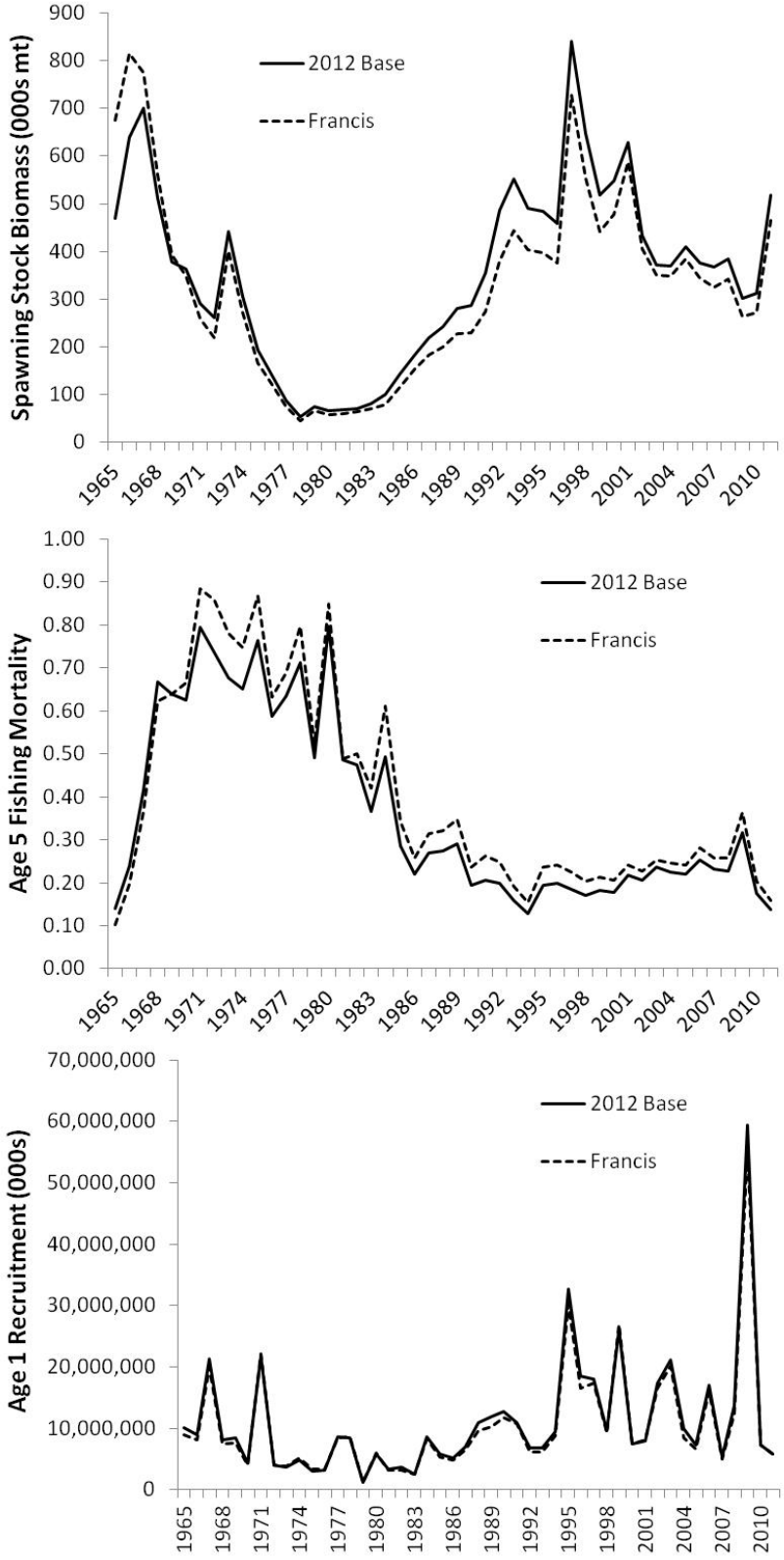

Figure 2. Time series estimates of spawning stock biomass, fishing mortality, and recruitment for the base model and a model without age variation in natural mortality.

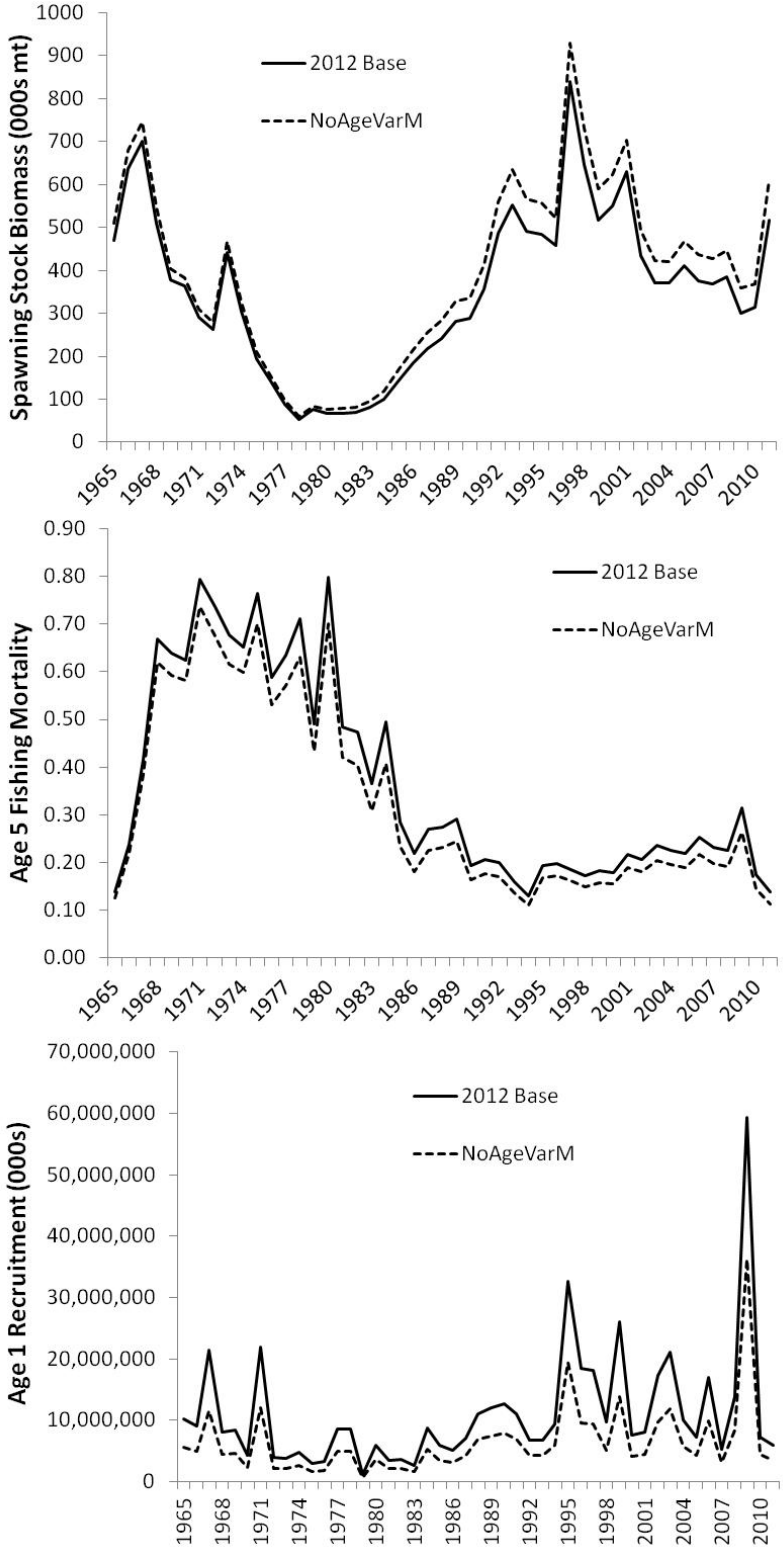

Table 1.—Negative log likelihood values for various data sources, the Mohn's rho for spawning stock biomass (SSB) estimated as the average of a 7-year peel, and the ratio of the geometric means for levels of implied consumption from each run (Imp.) to estimated consumption (Est.) for two time periods, 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