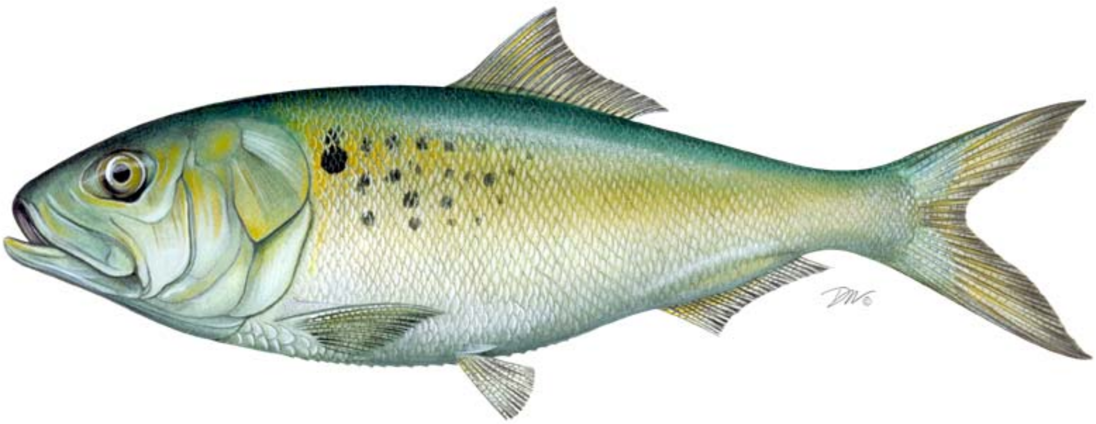
Atlantic Menhaden Stock Assessment Update



July 2012

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Atlantic States Marine Fisheries Commission

2012 Atlantic Menhaden Stock Assessment Update

Submitted to the Atlantic Menhaden Management Board
July 2012

Prepared by the
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Executive Summary

The purpose of this assessment was to update the 2010 Atlantic menhaden benchmark with recent data from 2009-2011. No changes in structure or parameterization were made to the base model run. Corrections made to data inputs were minor and are described in the body of this report. Additional sensitivity analyses and landings projections were conducted.

Updated data included reduction, bait, and recreational landings, samples of annual size and age compositions from the landings, the coastwide juvenile abundance index (JAI), and the Potomac River Fisheries Commission (PRFC) pound net index. Also, a new matrix of age- and time-varying natural mortality estimates was obtained from the 2012 update of the MSVPA-X model.

Abundance of menhaden has remained at similar levels as reported in the 2010 benchmark assessment. Total abundance in 2011 was estimated to be 7.84 billion fish. Generally low recruitment has occurred since the early 1990s. The most recent estimate for 2011 (4.03 billion) is the second lowest recruitment value for the entire time series, but is likely to be modified in the future as more data from the cohort are added to the analysis. Population fecundity (SSB, number of maturing ova) was variable across the time series, but has declined since the 1990s to a 2011 terminal year estimate of 13 trillion eggs.

Fishing mortality estimates suggest a high degree of variability, but in general the reduction fishery has experienced declining fishing mortality rates since the mid-1960s, while the bait fishery has experienced increasing fishing mortality rates since the 1980s. Reduction fishing mortality rates have risen, though, in the last two years of the assessment (2010-2011). The estimate of full fishing mortality in 2011 was 4.5.

The current overfishing definition is a fecundity-per-recruit threshold of $F_{15\%}$. The current fecundity-based overfished definition is a threshold of $SSB_{MED.T}$ (half of SSB_{MED}). Benchmarks were calculated using all years, 1955-2011. The ratio of Full F in the terminal year to the overfishing benchmark ($F_{2011}/F_{15\%}$) was greater than 1. The ratio of SSB in the terminal year to the SSB benchmark ($SSB_{2011}/SSB_{threshold}$ was greater than 1. **Therefore overfishing is occurring, but the stock is not overfished. However, the TC warns that there is a technical mismatch between the current overfishing and overfished reference points.** The TC recommends that, given the Board has adopted an $F_{15\%}$ overfishing definition, a matching overfished definition of $SSB_{15\%}$ should be adopted as well.

Retrospective pattern analysis suggested that this model is not robust to addition of new data. An underestimation of F and overestimation of SSB was evident during the 2010 benchmark stock assessment; however, these patterns became more worrisome during this update when a switch in direction of the pattern was observed such that F was overestimated and SSB was underestimated in recent years. It is unclear exactly what is causing this retrospective pattern, but it appears that some data sources have developed discordance since 2003.

Overall, the retrospective pattern and a number of other issues cast considerable doubt on the accuracy of the estimates from this update stock assessment. The TC warns that additional data analysis and modeling work are necessary to resolve these model structure and performance issues. An expedited benchmark assessment during which the TC can more fully examine many of the issues raised above is warranted. Although the Technical Committee could not come to consensus on the utility of the terminal year point estimates of F and SSB for management advice, there was consensus that the status determinations were likely robust. In other words, the ratio of $F_{2011}/F_{15\%}$ is likely greater than 1.0 (overfishing is occurring), and $SSB_{2011}/ SSB_{MED.T}$ is likely greater than 1.0 (the stock is not overfished), but the exact magnitude of these ratios could not be determined.

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1 Introduction

The purpose of this assessment was to update the 2010 Atlantic menhaden (*Brevoortia tyrannus)* benchmark (ASMFC 2010) with recent data. No changes in structure or parameterization were made to the base run. Corrections made to data inputs were minor and are described in this report. Additional sensitivity analyses and projections were conducted.

2 Regulatory History

The Commission has coordinated interstate management of Atlantic menhaden in state waters (0-3 miles) since 1981. Management authority in the exclusive economic zone (EEZ, 3-200 miles from shore) lies with NOAA Fisheries.

In 1988, the Commission initiated a revision to the FMP. The plan revision included a suite of objectives to improve data collection and promote awareness of the fishery and its research needs, including six management triggers used to annually evaluate the menhaden stock and fishery. In 2001, Amendment 1 was passed, providing specific biological, social, economic, ecological, and management objectives for the fishery.

Addendum I (2004) addressed biological reference points for menhaden, the frequency of stock assessments, and updating the habitat section currently in Amendment 1.

Addendum II instituted a harvest cap on Atlantic menhaden by the reduction fishery in Chesapeake Bay. This cap was established for the fishing seasons in 2006 through 2010. The Atlantic Menhaden Technical Committee determined the following research priorities to examine the possibility of localized depletion of Atlantic menhaden in Chesapeake Bay: determine menhaden abundance in Chesapeake Bay; determine estimates of removal of menhaden by predators; exchange of menhaden between bay and coastal systems; and larval studies (determining recruitment to the Bay).

Addendum III was initiated in response to a proposal submitted by the Commonwealth of Virginia that essentially mirrors the intent and provisions of Addendum II. It placed a five-year annual cap on reduction fishery removals from Chesapeake Bay. The cap, based on the mean landings from 2001 – 2005, was in place from 2006 through 2010. Addendum III also allowed a harvest underage in one year to be added to the next year's quota. The maximum cap in a given year is 122,740 metric tons. Though not required by the plan, other states have implemented more conservation management measures in their waters. Addendum IV (2009) extends the Chesapeake Bay harvest cap three additional years (2011-2013) at the same cap levels as established in Addendum III.

Addendum V, approved in November 2011, establishes a new F threshold and target rate (based on MSP) with the goal of increasing abundance, spawning stock biomass, and menhaden availability as a forage species.

3 Life History

3.1 Age

The seminal study on ageing Atlantic menhaden was conducted by June and Roithmayr (1960) at the NMFS Beaufort Laboratory; their specimens were collected mostly from purse-seine landings during 1952-1956. They validated rings on the scales of menhaden as reliable age marks based on timing of scale ring deposition and marginal increment analyses; accordingly, Atlantic menhaden are assigned ages based on a March 1 "birthdate". Menhaden field sampling protocols remain relatively unchanged from the 1950s. Information on precision of age estimates, paired scale:otolith (earstones) age estimates, and longevity are dealt with more thoroughly in Section 2.3 of the 2010 benchmark assessment report (ASMFC 2010).

3.2 Age

Regressions of weight (W in g) on fork length (FL in mm) for port samples of Atlantic menhaden were fit based on the natural logarithm transformation:

$$\ln W = a + b \ln FL \qquad \text{(Eq. 1);}$$

and were corrected for transformation bias (root MSE) when retransformed back to the form:

$$W = a(FL)^b \qquad \text{(Eq. 2).}$$

As in previous menhaden assessments, regressions of fork length (mm) on age (yr) were based on the von Bertalanffy growth curve:

$$FL = L_\infty(1 - \exp(-K(age - t_0))) \qquad \text{(Eq. 3).}$$

Von Bertalanffy fits were made with the size at age data aligned by cohort (year class). Because of concerns that density-dependent growth is a characteristic of the cohort, cohort-based analyses were thought to be a better approach. Attempts were made to fit the von Bertalanffy growth equation to each year class from 1947 (age-8 in 1955) to 2011 (age-0 in 2011). For most cohorts, a full range of ages were available (1955-2004). For the incomplete cohorts at the beginning of the time period (1947-1955), all fits converged, although specific parameter estimates became progressively unrealistic for the earlier years (especially 1947-1949). Similarly, incomplete cohorts for the recent time period (2005-2011) generally converged with the exception of the last two years (2010-2011).

Annual estimates of fork length at-age were interpolated from the cohort-based von Bertalanffy growth fits to represent the start of the fishing year (March 1) for use in estimating population fecundity (Table 1). Similarly, annual estimates of length-at-age were interpolated to represent the middle of the fishing year (September 1) and converted to weight-at-age (Eq. 2) for use in the statistical catch-at-age models when comparing model estimated catch to observed catch. (

Table 2, Table 3).

3.3 Fecundity

Often reproductive capacity of a stock is modeled using female weight-at-age, primarily because of lack of fecundity data. To the extent that egg production is not linearly related to female weight, indices of egg production (fecundity) are better measures of reproductive output of a stock of a given size and age structure. Additionally, fecundity better emphasizes the important contribution of older and larger individuals to population egg production. Thus in this stock assessment update (as in the most recent benchmark assessment for Atlantic menhaden [ASMFC 2010]), modeling increases in egg production with size is preferable to female biomass as a measure of reproductive ability of the stock.

Atlantic menhaden are relatively prolific spawners. Predicted fecundities are:

$$\text{number of maturing ova} = 2563 * e^{0.015*FL},$$

according to the equation derived by Lewis et al. (1987).

As in the previous benchmark assessment of Atlantic menhaden (2010; Section 2.5), the percentage of first-time spawners in the population is assumed to be 12.5% mature for age-2 fish and 85.1% mature for age-3 fish.

Most historical fecundity studies of Atlantic menhaden have concentrated on acquiring gravid females off the coast of North Carolina during the fall fishery when most age classes in the stock tend to be available (Higham and Nicholson 1964, Dietrich 1979, Lewis et al. 1987). Repeating these studies in contemporary times will be difficult relative to the acquisition of adequate number of specimens. The last menhaden factory in North Carolina, Beaufort Fisheries Inc., closed in winter 2004-05. Moreover, the North Carolina Marine Fisheries Commission recently moved to prohibit purse seining for reduction purposes 0-3 miles from the state's coastline (http://portal.ncdenr.org/web/mf/proclamation-m-25-2012). Thus, procuring specimens from traditional fall fishing grounds may be challenging. The need for additional information collection on fecundity and maturity is underlined further in Research Recommendations.

For a more thorough discussion on historical studies on fecundity of Atlantic menhaden, refer to Section 2.5 of ASMFC (2010).

3.4 Natural Mortality

Time-varying natural morality at age generated from the Expanded Multispecies VPA (MSVPA-X) was updated for this assessment through 2010. See report in Appendix 5 for details. The age-specific natural mortality rate was assumed constant over time for the years 1955-1981 and was based on the average of estimates from the MSVPA-X analysis for the years 1982-2010. The natural mortality rate for 2011 was the projected natural mortality from the MSVPA-X.

A comparison between the 2009 and 2012 model runs of total M2 estimates (summed across the 3 modeled predators) showed that overall changes to menhaden M2 were minimal between old and new runs. However, for the oldest age class (6+) large changes in the M2 were noted (see Appendix 5). While these differences are minor when compared to the overall magnitude of the predation mortality on younger ages, this difference could be a contributing factor to the ongoing retrospective problem found in the most recent menhaden update (see section 7.2.5).

4 Fishery-Dependent Data Sources

4.1 Commercial Reduction Fishery

In January 2005 the penultimate menhaden reduction factory on the US east coast, Beaufort Fisheries Inc., in Beaufort, NC, closed permanently. Since then, Omega Protein Inc. at Reedville, VA, is the sole remaining industrial processor of Atlantic menhaden on the Eastern Seaboard. The extant reduction fleet at Reedville is comprised of about ten vessels (approx. 165-200 ft in length). Most of their fishing activity is centered in the Virginia portion of Chesapeake Bay and Virginia's ocean waters; however, in summer the fleet ranges north to northern New Jersey and in fall south to Cape Hatteras, North Carolina. Occasionally, a few smaller purse-seine vessels that fish in Chesapeake Bay for menhaden for bait unload their catch at the Omega Protein factory when the bait demand is soft or when their catch is too small for the bait market.

4.1.1 Data Collection Methods

Methods of acquiring fishery-dependent data for the Atlantic menhaden purse-seine reduction fishery remain relatively unchanged since the recent benchmark stock assessment (ASMFC 2010). Briefly, landings by the reduction fleet by fishing year (March 1 through February 28 of the following year) have been maintained by the NMFS Beaufort Laboratory since 1955. Landings are reported to the Beaufort Laboratory monthly; daily vessel unloads are provided in thousands of standard fish (1,000 standard fish = 670 lbs), which are converted to kilograms.

The biostatistical data, or port samples, for length- and weight-at-age are available from 1955 through 2011, and represent one of the longest and most complete time series of fishery data sets in the nation. The NMFS employs a full-time port agent at Reedville to sample catches at dockside throughout the fishing season for age and size composition of the catch.

The Captains Daily Fishing Reports (CDFRs, or daily logbooks) itemize purse-seine set locations and estimated at-sea catch; they are mailed to the Beaufort Laboratory weekly. Vessel compliance is 100%. CDFR data for the Atlantic menhaden fleet are available for 1985-2011. Beginning in 2009, CDFR forms are optically scanned as they are received at the Beaufort Laboratory. Preliminary data on fishery removals by area are available shortly after they are scanned, facilitating timely monitoring of the "Chesapeake Bay Cap" (see Section 4.1.2 below).

4.1.2 Commercial Reduction Landings

A complete chronology of Atlantic menhaden landings, dating back through the late nineteenth century, is presented in the previous benchmark stock assessment (ASMFC 2010, Section 4.1.2). Herein, recent landings are discussed beginning in 2005. Between 2005 and 2008 (terminal year for the previous benchmark assessment) only the factory at Reedville, VA, operated. Landings ranged from 141,100 t (2008) to 174,500 t (2007), and averaged 155,000 t (Figure 1, Table 5). Reduction landings in 2008 accounted for 75% of total coastwide landings of Atlantic menhaden (bait and reduction combined), down from 80% in 2007 and 86% in 2006. During 2009 to 2011, reduction landings ranged from 143,800 t (2009) to 183,100 t (2010), and averaged 167,000 t. Reduction landings in 2011 accounted for 76% of total coastwide landings of Atlantic menhaden (bait and reduction combined), down from 81% in 2010 and 78% in 2009.

In some respects, purse-seine landings for reduction during 2008-2010 belie the recent abundance of Atlantic menhaden in lower Chesapeake Bay and vicinity. During those respective summers, and to some extent in summer 2011, fish factory managers periodically imposed daily and/or weekly landings quotas on the vessels unloading at Reedville, VA. The quotas were enacted because during many fishing weeks, catches exceeded the factory's processing capacity. The most severe restrictions occurred during the summers of 2008 and 2009 when vessels were often limited to daily landings not to exceed 700-800 thousand standard fish (approx. 213-243 t, or about one-half the capacity of their fish holds).

Beginning in 2006 and through 2013, the harvest of Atlantic menhaden for reduction in Chesapeake Bay has been 'capped' by ASMFC (Addenda III and IV to Amendment 1 of the FMP) at 109,020 t per year (with penalties for overages and credits for underages). The fishery has not exceeded the annual cap through 2011. For comparative purposes, during 1990-1999 removals of Atlantic menhaden from Chesapeake Bay by the reduction fleet averaged 145,700 t per year; during 2000-2005 removals averaged 104,400 t; and during 2006-2011 removals averaged 75,400 t.

4.1.3 Commercial Reduction Catch-at-Age

Detailed sampling of the reduction fishery permits landings in biomass to be converted to landings in numbers-at-age. Port sampling provides an estimate of mean weight and the age distribution of fish caught. Estimates of numbers of fish landed are derived by dividing weekly landings by the mean weight of fish sampled. The age proportion of the weekly port samples then allows numbers-at-age to be estimated. Developing the catch matrix at the port/week/area-caught level of stratification provides for considerably greater precision than is typical for most stock assessments.

On average, 2,631 Atlantic menhaden from the reduction fishery have been processed annually for size and age composition over the past three fishing seasons, 2009-11. In the two most recent years, age-2 Atlantic menhaden, comprising 50% (2011) and 49% (2010) of the total numbers of fish landed, have slightly outnumbered age-1 fish (42% in 2011 and 40% in 2010) in the catch-at-age matrix (Table 4). In 2009 the age composition of the coastwide landings for reduction was 1% age-0s, 48% age-1s, 31% age-2s, and 20% age-3+; in 2010, it was 2% age-0s, 40% age-1s, 49% age-2s, and 9% age-3+; and in 2011, it was 42% age-1s, 50% age-2s, and 8% age-3+. The higher proportion of age-1s in the catch in recent years suggests improved recruitment during 2009-2011 versus 2005-2008 (except for 2006 when the 2005 year class entered the fishery; 40% of the catch-at-age in numbers).

4.1.4 Potential Biases, Uncertainty, and Measures of Precision

The topics and data derivations for this section, as well as the ageing error matrix for the catch-at-age, are unchanged and assumed the same as in the benchmark stock assessment (ASMFC 2010).

4.2 Commercial Bait Fishery

4.2.1 Data Collection Methods

Commercial bait landings have been reported through a variety of state and federal reporting systems from 1985 to the present (Table 5).

4.3 Commercial Bait Landings

Coastwide bait landings of Atlantic menhaden increased during the period 1985 to 1995, declined slightly over the next decade, and grew rapidly in recent years (
Figure 2). During 1985 to 1989 bait landings averaged 30.5 thousand mt, and landings peaked at 36.3 thousand mt in 1988. During the 1990s bait landings averaged 37.8 thousand mt, with peak landings of 42.8 thousand mt in 1993. Between 2000 and 2007 average bait landings for the coast increased again to 35.8 thousand mt, with a peak of 42.8 thousand mt in 2007. Between 2008 and 2011 average landings increased more than 30% from the previous time period, to 46.7 thousand mt, peaking in 2011 at 54.8 thousand mt. Historically, the "snapper rig" (small purse seine) fishery in Chesapeake Bay and the purse-seine fishery off New Jersey have dominated the bait landings; these two fisheries account for more than 67% of the total bait harvest during 2007-2011.

In recent years (2007-2011) bait landings have averaged 28% of the total coastwide Atlantic menhaden landings (including landings for reduction; Figure 1). This is up from an average of 13% of total landings for the period 1985-2000. The relative increase of menhaden for bait as a percent of coastal landings since the late 1990s is attributed to better data collection in the Virginia 'snapper rig' bait seine fishery, the decline in coastal reduction landings because of plant closures, and increased interest in menhaden for bait purposes because of recent quota reductions for Atlantic herring, a preferred bait for the lobster fishery.

4.3.1 Commercial Bait Catch-at-Age

Biological sampling of the bait harvest for size and age continued in 2008-2011 using the target sample sizes by state and gear established in 1994 (Table 6). All age samples are processed by the NMFS Beaufort Laboratory.

4.3.2 Potential biases, Uncertainty, and Measures of Precision

Underreporting is known to occur, with the greatest sources expected to be personal use harvest and direct sales to commercial and recreational fishermen. More comprehensive reporting criteria over the years have improved bait harvest estimates, and the level of underreporting is considered to be minimal relative to the magnitude of reported landings (ASMFC 2012b).

4.3.3 Commercial Bait Catch Rates (CPUE)

Pound net landings collected by the Potomac River Fisheries Commission (PRFC) were used to develop a fishery-dependent index of relative abundance for adult menhaden. Pound nets are a stationary, presumably nonselective, fishing gear. PRFC pound nets are set in the Potomac River adjacent Chesapeake Bay; among other fishes, they catch menhaden primarily ages-1 through -3. Other than the reduction landings, these data represent the only other available information that can be used to infer changes in relative abundance of adult menhaden along the east coast of the U.S.

The updated base model index (1976-2011) was based on annual ratios of pounds of fish landed to total pound net days fished. Raw catch and effort data were available for 1976-1980 and 1988-2011. Recently, the PRFC was able to obtain and computerize more detailed data on pound net landings and effort, which allowed index values to be calculated for 1964-1975 and 1981-1987. To generate estimates of pound net landings (PN) for the missing years, a linear regression was fitted to annual PN and published landings (PB):

$$\mathrm{PN} = 219035.8 + 0.953 \cdot \mathrm{PB},$$

which had an R^2 value of 0.996 and was highly significant ($p < 0.001$, $n = 26$). During 1964–1993, there were no restrictions on the number of licenses sold to fishers operating in the Potomac River, however after 1993, the number of licenses was capped at 100 (A. C. Carpenter, PRFC, personal communication). Therefore, to generate estimates of pound net days fished (DF) for the missing years, a second linear regression was fitted to DF as a function of the number of licenses (L):

$$\mathrm{DF} = 3094.2 + 17.944 \cdot \mathrm{L},$$

which had an R^2 value of 0.485 and was significant at an α-level of 0.104 ($n = 11$). The period of overlap among DF and L and greater variability associated with the regression increases the uncertainty of the index for the reconstructed years, but not for the most years (1988–2011). This index was constructed in the same manner as those used for the and 2006 menhaden assessments, and it shows a variable trend over time with low values in 1960s-1970s, peak values in the early 1980s, and intermediate values in recent years (

Figure 3). The only difference between the benchmark and update assessment was for the years 2004-2008. These years of data were incorrect when provided to the SAS during the last benchmark assessment. However, the error did not change the overall trend of the index (

Figure 3). The corrected data were used in this update assessment.

4.4 Recreational Fishery

4.4.1 Data Collection Methods

The Marine Recreational Fisheries Statistics Survey (MRFSS) contains estimated Atlantic menhaden catches from 1981-2003 and the Marine Recreational Information Program (MRIP) contains estimated Atlantic menhaden catches from 2004-2011. These catches were downloaded from http://www.st.nmfs.noaa.gov/st1/recreational/queries/index.html using the query option.

See MRFSS/MRIP online for discussion of survey methods:
http://www.st.nmfs.noaa.gov/st1/recreational/overview/overview.html#meth

4.4.2 Biological Sampling Methods and Intensity

Insufficient biological samples were available to develop a recreational catch at age matrix. See Section 4.3.5 for a discussion of the treatment of recreational landings.

4.5 Recreational Landings

Estimated recreational catches are reported as number of fish harvested (Type A+B1) and released alive (Type B2; Table 7 and Table 8, respectively). The fundamental cell structure for estimating recreational catches is by state [Maine – Florida], mode of fishing [beach/bank, manmade, shore, private/rental, charter], fishing area [inland, ocean (<=3mi), ocean (>3mi)], and wave [six 2-month periods]. Using the same methods as the 2010 benchmark assessment, the average weight was applied by region to total harvest (A+B1+0.5*B2) in numbers to obtain harvest in weight (Table 9). To provide estimates of harvest (Type A+B1) in weight, the catch records were retained at the basic cell level for which both harvest in numbers and harvest in weights were available. These landings were then pooled by region (NE, MA, SA), and the ratio was used to obtain an average weight by region. The assumption that the size (mean weight) of the B2 caught fish was similar to that of the A+B1 fish was made.

To put these removals into perspective, reduction landings have been on the order of 170,000 mt during the last decade, bait landings around 40,000 mt during the last decade, and recreational landings on the order of 200-400 mt during the last decade. In general, the recreational landings represent less than about 1% of the combined bait and reduction landings.

Recreational landings did change during 2004-2008 from the values used in the benchmark assessment due to the switch in estimation to the new MRIP methodology (Figure 4). The change in landings was small and given that recreational landings represent less than 1% of total landings, the values provided through MRIP were used in place of the values MRFSS provided during the last benchmark assessment. The values from MRIP represent the best available estimates and starting in 2013 MRFSS estimates will no longer be provided.

4.5.1 Recreational Discards/Bycatch

To determine total harvest, an estimate of release mortality to apply to the B2 caught fish is necessary. Under the assumption that many of these recreationally caught fish were by castnet, the judgment of the data workshop participants was that a 50% release mortality rate was a reasonable value. Based on this value, the total number of fish dying due recreational fishing (A+B1+0.5*B2) is summarized in Table 10.

4.5.2 Recreational Catch Rates (CPUE)

Available recreational data was insufficient to calculate recreational catch rates.

4.5.3 Recreational Catch-at-Age

As in the benchmark, recreational landings were combined with bait landings, and the bait catch-at-age matrix was expanded to reflect these additional landings in numbers applied regionally and then combined.

4.5.4 Potential biases, Uncertainty, and Measures of Precision

Uncertainty associated with recreational landings (MRFSS/MRIP) is substantial, but probably no worse than for bait. The MRFSS/MRIP provides estimates of PSE (proportional standard error) as a measure of precision in Table 10. These values range between 15% and 40% with some exceeding 50%. Values under 20% are considered to be “good”. Potential biases are unknown.

5 Fishery-Independent Data

Fishery-independent data sources used in the benchmark and update assessments include state seine surveys that ostensibly target other species of juvenile fish, but also capture juvenile menhaden.

5.1 State seine surveys

5.1.1 Data collection

Data collected from seine surveys conducted within several states along the east coast of the U.S. were used to develop indices of relative abundance for juvenile menhaden. The primary objective of these seine surveys is to measure the recruitment strength of species other than menhaden, that is, the underlying sampling protocols were designed to target juvenile striped bass, alosines, or other fishes and species complexes. Although menhaden are a bycatch species in these surveys, the seine catch-per-haul data represent the best available information for the construction of a menhaden juvenile abundance index (JAI).

The calculation of the menhaden JAI was based on data from the following state seine surveys:

- North Carolina alosine seine survey (1972-2011)
- Virginia striped bass seine survey (1967-1973, 1980-2011)
- Maryland striped bass seine survey (1959-2011)
- Connecticut seine survey (1987-2011)
- New Jersey seine survey (1980-2011)
- New York seine survey (1986-2011)

- Rhode Island seine survey (1988-2011)

The North Carolina Alosine seine survey (Program 100S) has operated continuously from 1972-present in the Albemarle Sound and surrounding estuarine areas. The survey targets juvenile alosine fishes and sampling is conducted monthly from June through October.

The Virginia striped bass seine survey was conducted from 1967-1973 and 1980-present. The survey targets juvenile striped bass following a fixed station design, with most sampling occurring monthly from July through September and occasional collections in October and November. In 1986 the bag seine dimensions were changed from 2 m x 30.5 m x 6.4 mm to the "Maryland" style seine with the dimensions 1.2 m x 30.5 m x 6.4 mm. Rivers sampled in the southern Chesapeake Bay system include the James, Mattaponi, Pamunkey, Rappahannock, and York rivers.

The Maryland striped bass seine survey targets juvenile striped bass and has operated continuously from 1959-present. Survey stations are fixed and sampled repeatedly in three rounds in July, August, and September with a beach seine of dimensions 1.2 m x 30.5 m x 6.4 mm. Permanent stations within the northern Chesapeake Bay system are sampled in five regions: Choptank River, Head of Bay, Nanticoke River, Patuxent and Potomac River.

The New Jersey seine survey targets a variety of fishes and has operated continuously in the Delaware River from 1980-present. The sampling scheme has been modified over the years but the core survey area, sampling locations, and field time frame (June-November) have remained consistent. The current sampling protocol, which was established in 1998, consists of 32 fixed stations sampled twice a month from June through November within three distinct habitats: Area 1 – brackish tidal water; Area 2 – brackish to fresh tidal water; Area 3 – tidal freshwater. A beach seine with dimensions 1.8 m x 30.5 m x 6.4 mm is used for sampling. For the juvenile index calculation, data from Area 3 were omitted due to the rare occurrences of menhaden in tidal freshwater.

The Connecticut seine survey targets juvenile alosines in the Connecticut River and has continuously operated from 1987-present. Sampling occurs monthly from July through October with a beach seine of dimensions 2.44 m x 15.2 m x 0.5 cm. Approximately 14 hauls are taken annually in the Deep, Essex, Glastonbury, and Salmon Rivers.

The Rhode Island seine survey targets a variety of fishes in Narragansett Bay and has operated continuously from 1988-present. A total of 18 fixed stations are sampled from June through October using a beach seine with dimensions 3.05 m x 61 m.

The New York seine survey targets a variety of fishes in western Long Island Sound and has operated continuously from 1984-present. Sampling occurs with a 61 m beach seine primarily from May through October within three areas: Jamaica Bay, Little Neck Bay, and Manhasset Bay.

5.1.2 Biological Sampling

Length data (in mm) were available for the seine surveys conducted by North Carolina, Virginia, Maryland, and New Jersey; little or no length data are available for the seine surveys conducted by Connecticut, and Rhode Island.

5.1.3 Ageing Methods

For state seine surveys (North Carolina, Virginia, Maryland, New Jersey, and New York) with length data, catch-per-haul data were adjusted based on the convention cut-off sizes by month for juvenile menhaden adopted by the Atlantic menhaden Technical Committee in March 2003. Juvenile length cutoffs were defined as: June 1-June 30, 110 mm FL; July 1-August 15, 125 mm FL; and August 16-November 30, 150 mm FL.

5.1.4 Coastwide Juvenile Abundance Index

A coastwide index of juvenile menhaden abundance was developed by combining the state-specific seine data into a single dataset. As noted in the most recent menhaden stock assessment, examination of the raw catch-per-haul data for each state indicated that each data set contained a high proportion of zero catches, or alternatively, a low proportion of hauls where at least one juvenile menhaden was captured (ASMFC 2010). Zero catches can arise for many reasons, and it was reasoned that the use of an active sampling gear combined with the schooling nature of menhaden was the likely cause (Maunder and Punt 2004). Although a variety of strategies can be used to deal with zero catches, in the most recent stock assessment a delta approach was adopted where the probability of obtaining a zero catch and the catch rate, given that the catch is non-zero, were modeled separately (Maunder and Punt 2004). The general form of a delta model is:

$$\Pr(Y = y) = \begin{cases} w & y = 0 \\ (1-w)\,f(y) & \text{otherwise} \end{cases}$$

Based on analyses described in the most recent assessment report, the probability of obtaining a zero observation was modeled using the binomial distribution and the distribution used to model the non-zero catches was assumed to be lognormal (ASMFC 2010). The delta-lognormal GLM used to develop the coastwide juvenile relative abundance index included *year*, *month*, and *state* as fixed factors. All statistical analyses were conducted using the software package R, version 2.11.0 (R Development Core Team, 2010).

5.1.5 Trends

The trend of the index is generally low during the 1960s, high from the mid 1970s to mid 1980s, and low to moderate from the mid 1980s to the present (Figure 5). Over the past 20 years, noteworthy strong year-classes occurred in 1999 and 2005.

5.1.6 Potential Biases, Uncertainty, and Measures of Precision

Because of the schooling nature of Atlantic menhaden combined with the fact that these seine surveys were originally designed to measure the abundance of other species, it is possible that the menhaden catch data are not truly representative abundance.

6 Methods

In this section, one modeling approach from the last benchmark assessment was updated, the Beaufort Assessment Model (BAM). During the last benchmark assessment, BAM was recommended as the preferred assessment model.

6.1 Base Model

The Beaufort Assessment Model (BAM) used for this assessment update is a statistical catch-at-age model (Quinn and Deriso 1999) implemented with the AD Model Builder software (Fournier et al. 2012).

6.1.1 Spatial and Temporal Coverage

The BAM model is not a spatially-explicit model; rather it assumes one coastal population of Atlantic menhaden. Catches are reported by fishery and state, but are assumed to come from one population. The abundance index data for Atlantic menhaden are assumed to be measures of the coastwide population, as reflected by the age-specific selectivity vector applied to each survey. The BAM model for Atlantic menhaden employs annual time steps, modeling the years 1955-2011. The 1955 starting year reflects the first year of catch-at-age data.

6.1.2 Treatment of Indices

Two sources of information were used for abundance indices in the BAM model. Fishery-dependent PRFC pound net data were used to develop a CPUE adult abundance index. The assumed age-specific selectivity schedule was 0.25 for age-1, 1.0 for age-2, 0.25 for age-3, and 0.0 for all other ages. The level of error in this index was uncertain, thus the coefficient of variation was assumed to be 0.5. In the BAM model, the estimates of the product of total numbers of fish at the midpoint of the year, a single catchability parameter, and the selectivity schedule were fit to the PRFC pound net index value in that same year. The error in this abundance index was assumed to follow a lognormal distribution. Note that beginning in 2010, NMFS Beaufort personnel, with the assistance of PRFC staff, have acquired and "aged" port samples for PRFC pound nets (27 fish aged in 2010, 56% age-1s, 26% age-2s; 59 fish aged in 2011, 49% age-1s, 32% age-2s). As this is an assessment update, these data were not incorporated into the update data set.

The other abundance index used in the BAM model comes from a series of state-specific seine surveys. These surveys, although designed for other species, also capture primarily juvenile menhaden, primarily age-0s. In the model the juvenile abundance index (JAI) was treated as an age-0 CPUE recruitment index, by fitting the product of the model estimated annual age-0 numbers at the beginning of the year and a single catchability parameter to the computed index values. The error in the JAI index was assumed to follow a lognormal distribution.

6.1.3 Parameterization

The ADMB model code and input data file are attached as Appendices A.2 and A.3. A summary of the model equations may be found in Table 11. The formulation's major characteristics are summarized as follows:

Natural mortality: The age-specific natural mortality rate was assumed constant over time for the years 1955-1981 and was based on the average of estimates from the MSVPA-X analysis for the years 1982-2010 (MSVPA-X discussed in Section 3.4 and Appendix 5). The natural mortality rate for 2011 was the projected natural mortality from the MSVPA-X.

Stock dynamics: The standard Baranov catch equation was applied. This assumes exponential decay in population size because of fishing and natural mortality processes.

Growth/Maturity/Fecundity: Percent of females mature was fixed in the model. Female size- and fecundity-at-age varied annually.

Recruitment: Recruitment to age-0 was estimated in the assessment model for each year with a set of annual deviation parameters, conditioned about a mean and estimated in log-space.

Biological benchmarks: Biological benchmark calculation is described below in Section 6.2.

Fishing: Two commercial fisheries were modeled individually: reduction and bait. Separate fishing mortality rates and selectivity-at-age patterns were estimated for each fishery.

Selectivity functions: Selectivity was fit parametrically using a logistic model for both the reduction fishery and the bait fishery. Selectivity was assumed constant for the entire time period in the assessment model.

Discards: Discards were believed to be negligible and were therefore ignored in the assessment model.

Abundance indices: The model used two indices of abundance that were modeled separately: a juvenile (age-0) index series (1959–2011) and a pound net CPUE index series (1964–2011).

Fitting criterion: The fitting criterion was a total likelihood approach in which total catch, the observed age compositions, and the patterns of the abundance indices were fit based on the assumed statistical error distribution and the level of assumed or measured error (see Section 6.1.4 below).

6.1.4 Weighting of Likelihoods

The likelihood components in the BAM model include separate bait and reduction landings, bait and reduction catch-at-age data, a PRFC CPUE pound net index, and a seine survey-derived JAI index. For each of these components a statistical error distribution was assumed as follows:

Likelihood Component	Error Distribution	Error Levels
Reduction Landings	Lognormal	Constant CV value equal to 0.03
Bait Landings	Lognormal	Constant CV value equal to 0.15 in early years and 0.05 in later years
Reduction Catch-at-Age	Multinomial	Annual number of trips sampled ranged from 278 to 1340
Bait Catch-at-Age	Multinomial	Annual number of trips sampled ranged from 1 to 100
PFRC Pound Net Index	Lognormal	Constant CV value equal to 0.5
Seine Survey JAI Index	Lognormal	Annual CV values from 0.14 to 1.38

No additional weights were applied to the likelihood components; the measured or assumed error levels formed the basis for the relative fit among the components.

6.1.5 Estimating Precision

The BAM model was implemented in the AD Model Builder software, which allowed for easy calculation of the inverse Hessian approximated precision measures. However, in this case where some key values were fixed (e.g., natural mortality), it is believed that precision measures from the inverse Hessian matrix are probably underestimates of the true precision. Instead, a parametric bootstrap procedure was used to estimate uncertainty. Input data sources were re-sampled using the measured or assumed statistical distribution and error levels in the table above. All the data sources in the table above were re-sampled in 2,000 bootstrap iterations.

The landings, JAI index, and PRFC index were all re-sampled using multiplicative lognormal error using the *CV*s specified in the model input for each respective component. Uncertainty in the landings and indices was applied using a parametric bootstrap. The age compositions were recreated for each year by distributing the number of fish sampled for each year to each age based on the probability observed.

6.2 Sensitivity Analyses

A total of five sensitivity runs and a retrospective analysis were completed with the BAM model. Sensitivity runs are represented by those involving input data and those involving changes to the model configuration.

6.2.1 Sensitivity to Input Data

Three sensitivity runs were conducted to examine various effects to changes in the input data. The following is a list of these sensitivity runs.

Run number	Sensitivity Examined
menhad-007	Omit the JAI index data
menhad-008	Omit the PRFC pound net index data
menhad-009	Effective N for reduction and bait fishery age compositions in all years was set to the median effective N calculated for each respective fishery

A sensitivity run with the JAI index data removed was performed (menhad-007), and a sensitivity run with the PRFC pound net index data removed was completed (menhad-008). Both of these sensitivity runs were completed in order to explore the model's behavior when a data source was removed. This helps to provide information on model response to a specific data source and aids in diagnosing the apparent data conflict between the two indices in the most recent years.

Additionally, a sensitivity run was completed where the effective sample size in each year was set at the median effective sample size from the base run for each fishery. This effectively down-weighted the age composition data in order to provide information on model response to this particular data source and addressed an important concern from the benchmark stock assessment review panel.

6.2.2 Sensitivity to Model Configuration

Two sensitivity runs were conducted to examine the effects of changes in the model configuration. The following is a list of these sensitivity runs.

Run number	Sensitivity Examined
menhad-003	Assumed and estimated dome-shaped selectivity in last time period (1994-2011) for the reduction fishery; bait fishery selectivity remained logistic
menhad-006	Assumed and estimated dome-shaped selectivity in last time period (1994-2011) for both the reduction and bait fisheries

The reduction fishery has experienced major changes over its history, most notably a steady decline in number of fish plants and vessels and also a contraction of geographic coverage. Currently, one reduction plant with about ten vessels operates at Reedville, VA. This contraction of the fishery may have had some effects on the shape of the selectivity applied to the reduction fishery in recent years. A sensitivity run was completed to allow for dome-shaped selectivity in the most recent time period (1994-2011) via the inclusion of a double-logistic selectivity function for the reduction fishery (menhad-003).

In previous stock assessments for Atlantic menhaden a dome-shaped selectivity function was applied to the bait fishery. This assumption was discussed and examined during the last benchmark assessment workshop in 2010. After comparison of age data between the reduction and bait fisheries, it was decided that the two fisheries should have similarly shaped selectivity functions. Thus for consistency with that finding, a sensitivity run was completed to allow for dome-shaped selectivity in the most recent time period (1994-2011) via the inclusion of a double-logistic selectivity function for both the reduction and bait fisheries (menhad-006).

6.2.3 Retrospective Analyses

Retrospective analyses were completed by running the BAM model in a series of runs sequentially omitting years 2011 to 2001, as indicated below:

Run number	Sensitivity Examined
menhad-010	Retrospective analysis with modeling ending in 2010
menhad-011	Retrospective analysis with modeling ending in 2009
menhad-012	Retrospective analysis with modeling ending in 2008
menhad-013	Retrospective analysis with modeling ending in 2007
menhad-014	Retrospective analysis with modeling ending in 2006
menhad-015	Retrospective analysis with modeling ending in 2005
menhad-016	Retrospective analysis with modeling ending in 2004
menhad-017	Retrospective analysis with modeling ending in 2003
menhad-018	Retrospective analysis with modeling ending in 2002
menhad-019	Retrospective analysis with modeling ending in 2001
menhad-020	Retrospective analysis with modeling ending in 2000

6.3 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

Since the 2010 benchmark assessment, the Atlantic Menhaden Management Board adopted $F_{30\%}$ and $F_{15\%}$ as the menhaden management *F*-based overfishing target and threshold, respectively. *F*-based biological reference points were calculated in this update using average vectors from 1955-2011. The vectors used to calculate the *F*-based biological reference points included a vector of average fecundity, a vector of average M, and a catch weighted average selectivity vector.

The target and threshold population fecundity (SSB_{MED} and $SSB_{MED.T}$) reference points currently used for menhaden management were also calculated using the methods from the 2009 benchmark assessment. **However, the TC warns that there is a technical mismatch between the current overfishing and overfished reference points. See Appendix 3 for details concerning the mismatch and presentation of a more appropriate biomass-based reference point.**

7 Results of Base BAM Model

7.1 Goodness of Fit

Goodness-of-fit was governed in the BAM assessment model by the likelihood components in the objective function (Table 11). The relative fit among the likelihood components was governed by the error levels for each data source (see section 6.1.4). During the assessment workshop, goodness of fit was also judged for each data source through examination of the model residuals. No adjustments were made to the error levels of the data sources or to the external weights for the likelihood components. They remained fixed at the levels applied during the 2010 benchmark stock assessment.

Observed and model-predicted landings for the reduction fishery (1955–2011; Figure 6) and the bait fishery (1985–2011; Figure 7) were compared for the base model run. Reduction fishery landings, which are known fairly precisely, fit very well. The more poorly estimated bait landings show some deviations, but overall represent a good fit. Commercial reduction and commercial bait landings fit similarly during the last benchmark assessment in 2010 and this update assessment (Figure 8, Figure 9). Patterns in the annual comparisons of observed and predicted proportion catch-at-age for the reduction fishery (Figure 10) indicate a good overall model fit to the observed data. The bubble plot for the reduction fishery (Figure 11) indicates that the model fit overestimates age-0 in the most recent years. Patterns in annual comparisons of observed and predicted proportion catch-at-age for the bait fishery and associated bubble plots (Figure 12, Figure 13) indicate a good overall model fit to the observed data. Fits to the age composition data were similar between the last benchmark and current update assessment (Figure 14,

Figure 15).

Observed and predicted coastwide juvenile abundance indices were compared for the base model run (1959–2011; Figure 16). The residual pattern suggests that the JAI index data did not fit well in years prior to 1978 as compared to the most recent years. Visual examination of the fit suggests that the overall pattern fit reasonably well, with the BAM model capturing the observed index values for the low-high-low recruitment pattern suggested for the years 1959-1973, 1974-1986, and 1987-2011, respectively. Fits to the observed JAI data were very similar between the last benchmark assessment in 2010 and the current update assessment with the largest differences in fit occurring during the most recent couple of years (Figure 17).

The observed and predicted PRFC pound net CPUE index (1964–2011; Figure 18) values do not fit as well as the JAI index values. The pattern of fit is similar in that the general high-low patterns are captured, but the relative fit within the time series is better in the early years and worse in the most recent years. The model estimates smaller numbers of fish in all but one of the last 13 years compared to the relative index values. Fits to the observed PRFC data were similar between the last benchmark assessment in 2010 and the current update assessment with the largest differences in fit occurring during the early 1980s and during the most recent couple of years (Figure 19).

7.2 Parameter Estimates

7.2.1 Selectivities and Catchability

Fishing mortality was related to an overall level of fishing and the selectivity (or availability) of menhaden to the two fisheries (reduction and bait). For both fisheries time invariant, two-parameter logistic functions were applied. Model estimates of selectivity (availability) for these fisheries were compared graphically in Figure 20 and Figure 21. The results for both fisheries suggest very similar estimates of selectivity, with age-4 almost fully selected and age-5 and older fully selected. The biggest differences are in the amount of age-1 and age-2 fish that are selected. The reduction fishery selectivity estimates a higher proportion of age-1 and -2 fish available for capture compared to the bait fishery. The selectivities estimated for this update assessment were similar to the selectivities estimated during the last benchmark assessment for the commercial reduction fishery (Figure 22) and were slightly different for the commercial bait fishery with small increases in the selectivity of age 2 and 3 fish (Figure 23).

The base BAM model estimates a single, constant catchability parameter for each of the abundance indices, reflecting the assumption that catchability for these CPUE indices is believed to be constant through time. This seems to be a reasonably good assumption for the fishery-independent JAI abundance index since it is based on consistent, scientific survey collections, albeit the surveys are at fixed shore stations and ostensibly target other species. For the fishery-dependent PRFC pound net index, a sensitivity run was completed during the 2010 benchmark assessment in order to examine a random walk process in catchability. The results of the sensitivity run completed during the 2010 benchmark assessment were stable with changes in catchability for the PRFC index, and thus the constant catchability assumption was upheld.

Therefore, a sensitivity run exploring changes in selectivity was not redone for this update assessment.

7.2.2 Exploitation Rates

Total full fishing mortality rates were estimated within BAM (Figure 24, Figure 25). Highly variable fishing mortalities were noted throughout the entire time series, with a slight decline in fishing mortality from the mid-1960s to the early 1980s. Since the mid-1980s the fishing mortality rate has been quite variable, ranging between some of the highest and lowest values in the entire time series. The fishery-specific full fishing mortality rates are shown in Table 12, Figure 26, and Figure 27. The estimates suggest a high degree of variability, but in general the reduction fishery has experienced declining fishing mortality rates since the mid-1960s, while the bait fishery has experienced increasing fishing mortality rates since the 1980s (Table 12, Table 13). However, reduction fishery fishing mortality rate has risen in the last two years of the assessment (2010-2011). The total full fishing mortality rate and the fishery-specific full fishing mortality rates estimated for the update assessment were very similar to the full fishing mortality rates estimated from the 2010 benchmark assessment (Figure 28, Figure 29, Figure 30). Finally, F rates can vary substantially among age groups (Table 14). Selectivity on age-1 is small, greater on age-2, almost fully selected at age-3, and generally fully selected at older ages.

7.2.3 Abundance, Fecundity, and Recruitment Estimates

The base BAM model estimated population numbers-at-age (ages 0-8) for 1955–2011 (Table 15, Figure 31). From these estimates, along with growth and reproductive data (Section 3), different estimates of reproductive capacity were computed. Addendum 1 adopted population fecundity as the preferred measure of reproductive output. Population fecundity (SSB, number of maturing ova) was variable, but in general declined from high levels in the late 1960s, increased through the 1990s, then declined through 2011. (Table 16, Figure 32). The largest values of population fecundity were present in 1955 and 1961, resulting from two very strong recruitment events in 1951 and 1958 as noted in earlier stock assessments (Ahrenholz et al. 1987; Vaughan and Smith 1988; Vaughan et al. 2002b; ASMFC 2004). Throughout the time series, the age-3 fish produced most of the total estimated number of eggs spawned annually (Figure 33).

Age-0 recruits of Atlantic menhaden (Figure 34, Table 17) were high during the late 1950s, especially the 1958 year-class. The annual estimated recruitment values are shown in Figure 35 and were similar to recruitment values estimated during the last benchmark assessment in 2010 (Figure 36). Recruitment was generally poor during the 1960s and high during the late 1970s and early 1980s. The late 1970 and early 1980s values are comparable to the late 1950s (with the exception of the extraordinary 1958 year-class). Generally low recruitment has occurred since the early 1990s. There is a hint of a potential long-term cycle from this historical pattern of recruitment, but not enough data are present to draw any conclusions regarding the underlying cause at this point (Figure 34, Figure 35, Figure 36). The most recent estimate for 2011 is quite low and likely to be modified in the future as more data from the cohort (age-1 in 2012, age-2 in 2013, etc.) are added to the analysis. The current estimate of recruits to age-0 in 2011 (4.03 billion) is the second lowest recruitment value for the entire time series.

A plot of the model-estimated fecundity (mature ova) to the recruits at age-0 indicated a weak relationship (Figure 37). Additional discussion on dynamics of recruit per egg is presented in ASMFC (2010) section 8.2.3. Figure 37 also shows the median recruitment and fecundity-per-recruit estimates which were used to determine the benchmarks for Atlantic menhaden during the last benchmark assessment in 2010 (see ASMFC 2010 for more details).

7.3 Sensitivity Analyses

The results of the five sensitivity runs suggest that the base BAM model is stable with respect to the induced changes for three of the runs (Figure 38, Figure 39, Figure 40, Figure 41, Figure 42, Figure 43). The largest changes in population estimates relative to base model estimates resulted from sensitivity runs involving effective sample size on the age composition data and the selectivity function for both the commercial reduction and bait fisheries from 1994-2011. These changes had the greatest effects on the fishing mortality, fecundity, and biomass estimates (Figure 38, Figure 40, Figure 41), as well as for the fit to the PRFC index (Figure 43). The recruitment estimates were very similar among sensitivity runs (Figure 39), and the fits to the JAI index was also similar among sensitivity runs (Figure 42).

The negative log likelihood for the base BAM model and the sensitivity runs are in Table 19.

The resulting benchmarks appeared to be stable for three of the explored sensitivity runs. The run which included median effective sample size on the age composition data had benchmarks that were slightly different (Table 18; also see Appendix 3). The benchmarks calculated for the sensitivity runs with dome-shaped selectivity functions for the commercial fisheries from 1994-2011 were not directly comparable due to selectivity differences.

7.3.1 Retrospective Analyses

Patterns and biases in the results of a retrospective analysis over time were apparent (Figure 44-Figure 53). The fishing mortality for the terminal year of the assessment was underestimated in the 2000-2005 period and overestimated in 2006-2011, indicating presence of retrospective bias. Results indicate that the terminal full fishing mortality rate is highly variable (Figure 44 and

Figure 50) with Mohn's rho equaling 0.42 (Legault 2009). The bias in F estimates expressed as a ratio to the most recent (2011) run F estimates varied from -0.6 to 0.9 (

Figure 50). The resulting recruitment, fecundity, and biomass showed consistent biases or patterns in opposite directions (Figure 45-Figure 47 and Figure 51-Figure 53). Mohn's rho equaled 1.17 for recruitment and 1.83 for fecundity. In addition, the fits to the JAI and PRFC indices also showed biases or patterns when completing the retrospective analyses (Figure 48, Figure 49).

The magnitude of stock status outcomes varied considerably in this set of retrospective model runs. In particular, the ratios of full fishing mortality in the terminal year to $F_{15\%}$ ranged from 0.5 to 3.36, to $F_{30\%}$ ranged from 1.06 to 7.11 (Table 18). In particular, the ratios of spawning stock biomass (fecundity) in the terminal year to $SSB_{MED.T}$ ranged from 1.23 to 6.42 within this range of retrospective runs (Table 18).

The negative log likelihood for the base BAM model and the retrospective runs are in Table 20.

7.4 Uncertainty Analysis

The parametric bootstrap procedure was run for 2,000 iterations. The resulting estimates from these runs have been summarized in Figure 24, Figure 32**,** Figure 34, Table 12, Table 16, and Table 17, showing the 90% confidence region. In general the bootstrap results suggest fairly symmetrical error distributions about the base run results.

7.5 Reference Point Results - Parameter Estimates and Sensitivity

The base BAM model estimates for current benchmarks and terminal year values are listed in Table 21 for benchmark calculation. **The base BAM model estimated the current stock status as not overfished ($SSB_{2011}/SSB_{threshold}$ > 1.0) and overfishing is occurring ($F_{2011}/F_{benchmark}$ > 1.0). Note that use of an SSB reference point that is appropriately matched to the currently adopted $F_{15\%}$ would change the overfished status (see Appendix 3).**

Fecundity-per-recruit and yield-per-recruit (mt) estimates as a function of total full fishing mortality rates are shown in Figure 54 and Figure 55 for benchmarks calculated using the years 1955-2011 (see also Appendix 3). These plots are offered as a reference for comparison between fishing mortality rates. For example, using the years 1955-2011 for benchmark calculation, the terminal year full fishing mortality rate estimate (F_{2011}) of 4.50 is below $F_{6\%}$ (Figure 54). The entire time series of full fishing mortality and fecundity relative to $F_{15\%}$ and $F_{30\%}$ based benchmarks are shown in Figure 56 and Figure 57 using the years 1955-2011 for benchmark calculation.

For additional sensitivity and uncertainty analyses, see Appendix 3.

8 Stock Status

Threshold reference points are the basis for determining stock status (i.e., whether overfishing is occurring or a stock is overfished). When the fishing mortality rate (*F*) exceeds the *F*-threshold, then overfishing is occurring. When the reproductive output (measured as spawning stock biomass or population fecundity) falls below the biomass-threshold, then the stock is overfished, meaning there is insufficient mature female biomass (SSB) or egg production (population fecundity) to replenish the stock.

8.1 History of Atlantic Menhaden Reference Points

8.1.1 Amendment 1 Benchmarks

The reference points in Amendment 1, adopted in 2001, were developed from the historic spawning stock per recruit (SSB/R) relationship. As such, F_{MED} was selected as $F_{threshold}$ (representing replacement level of stock, also known as F_{REP}) and was calculated by inverting the median value of R/SSB and comparing to the SSB/R curve following the method of Sissenwine and Shepherd (1987). The spawning stock biomass corresponding to $F_{threshold}$, was calculated as a product of median recruitment and SSB/R at F_{MED}, from equilibrium YPR analysis, which became the SSB_{target}. The threshold for SSB ($SSB_{threshold}$) was calculated to account for natural mortality [(1-*M*)*SSB-target, where *M*=0.45]. In Amendment 1, the F_{target} was based on F_{MAX} (maximum fishing mortality before the process of recruitment overfishing begins).

8.1.2 Addendum 1 Benchmarks

Based on the 2003 benchmark stock assessment for Atlantic menhaden, the benchmarks were modified by the ASMFC in Addendum 1 as recommended by the Technical Committee (ASMFC 2004). The TC recommended using population fecundity (number of maturing or ripe eggs; SSB) as a more direct measure of reproductive output of the population compared to the weight of mature females. For Atlantic menhaden, older menhaden release more eggs than younger menhaden per unit of female biomass. By using the number of eggs released, more reproductive importance is given to older fish in the population than accounted for simply by female biomass. They also recommended modifications to the fishing mortality (*F*) target and threshold. The TC recommended continued use of F_{MED} to represent F_{REP} as the $F_{threshold}$, but estimated it using fecundity per recruit rather the SSB per recruit. Because the analysis calculated an F_{MAX} (target) that was greater than F_{MED} (and may be infinite), they recommended instead that F_{target} be based on the 75^{th} percentile of observed SSB/R values. This approach was consistent with the approach used for the $F_{threshold}$. For biomass (or egg) benchmarks, the TC recommended following the approach of Amendment 1.

8.1.3 Addendum V Benchmarks

Addendum V, approved in November 2011, establishes a new interim fishing mortality threshold and target (based on maximum spawning potential or MSP) with the goal of increasing abundance, spawning stock biomass, and menhaden availability as a forage species. Recognizing that development of specific multispecies reference points to achieve this management objective might take several years, the Board began the process to develop and implement interim reference points. The Technical Committee was tasked with identifying ad-hoc reference point options that would support the approved management objective until a full investigation and evaluation of multispecies reference points could be conducted. One of the options was based on the concept of maximum spawning potential (MSP), and in November 2011, Addendum V was approved which established interim fishing mortality reference points based on MSP. The interim limit and target equate to 15% and 30% MSP, respectively. Thus, fishing mortality benchmarks of $F_{15\%}$ and $F_{30\%}$ MSP were calculated based on the fecundity per recruit analysis.

Addendum V made no changes to the biomass reference points. However, the TC recommends adoption of an SSB target and threshold that is more appropriate and consistent with the $F_{15\%}$ and $F_{30\%}$ approach (see Appendix 3).

8.2 Current Overfishing, Overfished/Depleted Definitions

The current overfishing definition is a fecundity-per-recruit threshold of $F_{15\%}$ and a target of $F_{30\%}$. The current fecundity-based overfished definition is a target of SSB_{MED} and a threshold of $SSB_{MED.T}$ (half of SSB_{MED}). Benchmarks are calculated using all years, 1955-2011.

8.3 Stock Status Determination

8.3.1 Overfishing Status

Full $F/F_{15\%}$ for the terminal year was greater than 1 (Table 21; Figure 56). Hence, based on this criterion, **overfishing is occurring**. The sensitivity runs, excluding the retrospective analysis, all suggest overfishing is occurring in the terminal year (Table 18), and all of the bootstrap runs completed for the uncertainty analysis result in a stock status of overfishing is occurring (see Appendix 3). Thus, the stock status seems stable for the model changes explored and the uncertainty specified during this update assessment. However, several issues raise concern about the status of the stock relative to this benchmark. First, a retrospective pattern has continued to result in potential bias in the estimation of F in the terminal year. Second, there is relatively large variation in F among years, and overfishing was occurring in almost all of the years used in this assessment (1955-2011). With respect to the target F, the stock has never been at or below target F.

8.3.2 Overfished Status

SSB/SSB_{limit} for the terminal year was greater than 1 (Table 21;

Figure 58). Hence, based on this criterion, **the stock is not overfished**. The bootstrapped values of SSB for the most part fall into the region that is considered not to be overfished, although a small portion of the values do fall into the region that is considered to be overfished (see Appendix 3). None of the sensitivity runs suggest the stock is overfished (Table 18). Thus, the stock status seems stable for the model changes explored and the uncertainty specified during this update assessment. **Note, however, that use of an SSB reference point that is appropriately matched to the currently adopted $F_{15\%}$ would change the overfished status (see Appendix 3).**

8.3.3 Uncertainty

Uncertainty of the status of stock relative to the two benchmarks was investigated using several approaches. First, sensitivity runs were made to explore the effect on benchmarks by changes in assumptions from the base run (Table 18). While the sensitivity runs inform model behaviors, they should not be considered plausible runs. Next, sensitivity of the estimates was investigated based on a bootstrapped analysis within the BAM model (Figure 56, Figure 57, and Appendix 3). Stock status determination, based on the benchmarks as specified in Addendum I and Addendum V, seemed to be stable with respect to uncertainty.

Although the Technical Committee could not come to consensus on the utility of the terminal year point estimates of F and SSB for management advice, there was consensus that the status determinations were likely robust. In other words, the ratio of $F_{2011}/F_{15\%}$ is likely greater than 1.0 (overfishing is occurring), and $SSB_{2011}/ SSB_{MED.T}$ is likely greater than 1.0 (the stock is not overfished), but the exact magnitude of these ratios could not be determined. This statement in supported both quantitatively and qualitatively. Quantitatively, results of the sensitivity runs (albeit limited) and bootstrap analysis indicated the results of stock status were robust to uncertainty in the data and parameterization as specified in this update. Qualitatively, the 2009 benchmark stock assessment concluded that overfishing was occurring, and Addendum V reference points significantly reduced the overfishing threshold (from approximately $F_{8\%}$ to $F_{15\%}$). As harvest levels have increased since 2008 and there has been no significant increase in stock size, overfishing is still likely occurring.

9 Projections

Projections using constant landings scenarios were run in order to explore options to achieve 1) the fishing mortality threshold immediately and 2) the fishing mortality target over a range of 3, 5, and 10 years. Decisions regarding the structure and inputs for the projection analysis were discussed by the TC during a meeting on January 9, 2012. The brief documentation and methods below reflect those decisions; for further documentation see the resulting white paper (ASMFC 2012a).

9.1 Methods

Data inputs and outputs from the base run of BAM were used as the basis for all of the projections within this document. The starting conditions of the projection analysis included initial numbers-at-age, which were the estimated numbers-at-age at the end of 2011, N_a, from the bootstrap runs, which allowed for the inclusion of uncertainty. Recruitment was projected without an underlying stock-recruitment function and was based on the median recruitment from

1990-2010 estimated from the base run of BAM. Variability was incorporated into recruitment as a nonparametric bootstrap based on the annual deviations from the median in the base run of the BAM during the specified time period (1990-2010), which reflects variability in the more recent years. The median age varying natural mortality and weight vectors from 1990-2010 were projected into the future. Selectivity was constant across time for the base run of the BAM model and was thus constant in the projections. Selectivity was the weighted average selectivity from the bait and reduction fisheries.

Annual landings levels were input for the simulation and the annual fishing mortality rate, *F*, was solved for within the model. Commercial reduction and bait landings for 2012 were input as the mean of the landings from 2009-2011. Starting in 2013, management was instituted with a constant level of total landings, which was projected for several years. Total projected landings included 75, 100, 125, 150, 175, 200, and 225 thousand metric tons. Total landings were allocated such that 75% were allocated to the reduction fishery and 25% were allocated to the bait fishery. This allocation was based on the proportion of bait landings to the total coastwide landings of Atlantic menhaden for the most recent years. The allocation presented here (75:25) is for illustrative purposes only; the question of future allocations between the reduction and bait fisheries is a question that managers will need to address and provide guidance to the TC.

Each constant landings scenario was repeated 2,000 times. Outputs included the median and 5th and 95th percentiles for spawning stock size (ova), *F*, recruitment, and landings over time. Spawning stock size for each year was the sum of the number of fish at each age times the vector of median age-specific reproductive values from 1990-2010. The reproductive vector was the product of the proportion female, the maturity vector, and the median fecundity vector. Landings (1,000s mt) over time was a model input, as discussed above. Additional outputs included the probability of *F* being less than the specified target of 0.62 and less than the specified threshold of 1.34 over time given the constant landings input.

9.2 Results

As expected, the higher the landings, the lower the probability of *F* being less than the threshold and target (Table 22, Table 23). However, the range in *F* was fairly broad for a given level of constant landings (

Figure 59-Figure 72). At the low end of fixed landings considered (75,000 and 100,000 mt) the fishing mortality rapidly declines and the probability of 100% for F being below overfishing limit is achieved by the year 2016 or 2017. The rate of decline in F slows down and the range of possible F values for a given year increases as the amount of constant landings goes up. In some cases, the *F* could not be estimated or was estimated at an extremely high value, sometimes even hitting the bound of 25. In the scenarios with landings equaling 225,000 mt, the F often reached a bound, but still could not produce 225,000 mt in landings, indicating that the stock is unable to sustain this level of landings under the assumed stock productivity parameters (selected variability in recruitment, growth and natural mortality).
There is an overall general trend of rise in population fecundity through time, which varies from tenfold increase of median fecundity estimate at 75,000 mt constant landings to less than two fold increase at 225,000 mt constant annual landings.

Variability in recruitment was a major driving factor for these projections and was one of the most uncertain components of the projections. The recruitment uncertainty carried through all of the results.

9.3 Important notes to managers

These projections are only presented as an example of possible outcomes. They do not account for all possible sources of uncertainty and are primarily intended to show long term effects of constant catch policy. Furthermore, when projections are used to determine what level of landings would be appropriate to reduce overfishing, the Atlantic Menhaden Management Board needs to determine the acceptable level of risk (% probability of F being over the limit) because the projections provide an estimate of a chance for the variable to be of certain value, rather than the exact number for each year. In addition, the Atlantic Menhaden Management Board needs to decide how landings will be allocated between the reduction and bait fisheries, a decision may impact the estimated *F* for a given constant landings value.

The retrospective pattern observed during this update assessment suggests that the results from the assessment may be biased, thus projection results, which start with terminal year estimates from the assessment, may also be biased. However, the significance of such bias for projections results has not been investigated yet by the Technical Committee. If the projections are biased, then the Atlantic Menhaden Management Board should be cautious when using this for management advice, especially if providing values for quotas for the fisheries.

All results from this analysis are conditional on the assumptions made about management implementation uncertainty. Management uncertainty was assumed to be zero because no information is available for the Atlantic menhaden fishery on this type of uncertainty. If the assumption of zero uncertainty is violated, there may be effects on the projection results. The effect of management uncertainty will depend on the ability of management to maintain the limits on harvest or mortality rates within the chosen range.

It is important to note that the projections included many sources of uncertainty and their cumulative effects are represented by the wide range of possible values of F, SSB and other parameters that are illustrated on projection graphs by the upper (95% of observed values) and lower (5%) limits. It is important to keep in mind that although the general trend of expected population dynamics is generally described by the median values, the actual values for each projected year could fall anywhere in the range shown. Therefore the actual trajectory of SSB, for example, is likely to look like a series of ups and downs within the estimated range rather than a steady rise or decline as shown by the median curve.

In addition, these projections did not include structural uncertainty. Structural uncertainty means that results are conditional on the functional forms and assumptions made regarding population dynamics, selectivity, recruitment, etc. The major source of the uncertainty in the projection is recruitment. Projections were based on assumption that 1) recruitment variability for the projected period will remain similar to that observed during last two decades, and 2) there is no functional relationship between the stock size and recruitment within the range of both metrics observed during selected period. The introduction of formal stock recruitment function into the recruitment forecasting procedure may affect stock trajectories, in particular the rate of population growth when starting with low spawning biomass, but will not affect the possible range of recruitment. Another assumption adding to the overall uncertainty is the shape of the fishery-weighted selectivity over time. If allocations between the two fisheries are different in the future, the weighted selectivity vector will also be different and projection results will be affected.

10 Issues and Concerns for Management

The CIE review panel of the 2010 benchmark stock assessment raised some concerns not addressed during an update stock assessment. Therefore, several important criticisms of the 2010 benchmark stock assessment continue to apply to this update assessment. They include the following:

1. Overweighting of the age composition data.
2. Lack of spatial modeling to address changes in the fishery over time.
3. Lack of a coastwide adult abundance index.

In addition, two model performance issues mentioned during the 2010 benchmark assessment have subsequently worsened and have become a serious concern for this update, namely:

4. Poor fit to the PRFC index.
5. Strong retrospective pattern.

These unaddressed criticisms and issues make interpreting the results of this stock assessment update challenging.

In order to address Criticism 1, overweighting of the age composition data, a sensitivity run with lower sample sizes for the age composition data was completed, effectively down weighting the age composition data. This run resulted in lower F and higher SSB estimates compared to the base run; however, down weighting the age composition data did not substantially improve the model fits to the JAI or PRFC indices, suggesting that other likelihood components may also be improperly weighted and/or the indices are not truly representative of the population. The timeframe for the update assessment was insufficient to address these uncertainties. The direction and magnitude of bias in the results remains unknown.

Criticism (2) above, lack of spatial modeling, is probably the most important criticism with respect to management advice. The trend we have seen over the whole time series for the menhaden reduction fishery is one of spatial contraction of the range of the fishery and decrease in landings. Menhaden do exhibit an age/size stratification during summer in which the larger and older fish tend to migrate farther north relative to their smaller and younger counterparts that stay farther south along the Atlantic coast (Nicholson 1972; Nicholson 1978; Ahrenholz 1991). The reduction fishery operates solely out of Virginia, ranging north to New Jersey and south to Cape Hatteras; thus, the larger and older fish occurring north of about Long Island, NY, are unavailable to the reduction fishery. When this type of availability pattern occurs it is often modeled using a dome-shaped selectivity function. However, the bait fishery has had increasing catches, particularly in recent years and mostly off the New Jersey coast. While there is some suggestion of a dome-shaped selectivity in the bait fishery based in Chesapeake Bay and adjacent waters, a logistic shaped selectivity maybe more appropriate for the bait fishery in the Mid-Atlantic and New England.

The 2010 benchmark assessment review panel recommended modeling the population via a northern and southern fishery with a spatial break somewhere along the Delmarva Peninsula. The reviewers further recommended allowing for dome-shaped selectivity in the southern fishery. Because this analysis was limited to a strict update assessment, the two-area feature was not incorporated into the model at this time. However, a sensitivity run was completed allowing a freely estimated, dome-shaped selectivity curve for both the reduction and bait fisheries after 1994, when the coastwide fishery spatially contracted. Imposing a dome-shaped selectivity curve would generally reduce estimated fishing mortality rates and subsequently increase SSB, as this sensitivity run indicates; however, this particular sensitivity run produced unrealistic estimates (especially, time-series high SSB estimates) that were considered implausible by the technical committee. Although the direction of the bias is not unexpected, the magnitude of the bias is still unknown and additional work is needed during the benchmark assessment to align the spatial structure of the model with that of the stock and fishery.

Criticism (3) above, lack of a coastwide adult index of abundance, is an ongoing, serious problem for this stock assessment. As a result of not having a coastwide abundance index, we are forced to seek out more spatially limited measures of adult abundance (e.g., the PRFC pound net index). This leads to issue (4) above, the poor fit of the PRFC index. The update assessment model appears to be insensitive to the only adult index that informs the model, at least in recent years. The upward trend in the PRFC pound net index in the last few years is not matched by the model derived index and is in conflict with the trend seen in the coastwide GLM based JAI index.

An additional concern raised during the evaluation of the update stock assessment model was the presence of a strong retrospective pattern in F and SSB, issue (5) above. An underestimation of F and overestimation of SSB was evident during the 2010 benchmark stock assessment; however, these patterns became worrisome during this update when a switch in direction of the pattern was observed (such that F was overestimated and SSB underestimated in recent years), and when the pattern did not disappear with additional years of data. The strong retrospective pattern suggests that this model is not robust to addition of new data. The results suggest that terminal year fishing mortality may be overestimated and that fecundity and biomass may be underestimated. It is unclear exactly what is causing this retrospective pattern, but it appears that some data sources have developed discordance since 2003.

Overall, the five criticisms indicated above cast considerable doubt on the accuracy of the estimates from this update stock assessment. Retrospective analysis suggested that in the last 5-6 years fishing mortality and overfishing status may be biased high, while fecundity and overfished status may be biased low. Two sensitivity runs (reduced effective sample size and dome-shaped selectivity) also produced lower estimates of fishing mortality and higher estimates of fecundity than the base and other sensitivity runs. However, the base run and three sensitivity analyses produced similar estimates of recruitment, population size, biomass, fecundity, and fishing mortality across the historical time series (back to 1955), indicating these results were not affected by the changes explored in those specific sensitivity runs. Note that the sensitivity runs conducted for this update assessment were not intended to be an exhaustive array of investigations, rather a select set to identify and characterize important sources of uncertainty.

Regarding stock status, the TC notes that the overfished status reported here is based on the current $SSB_{MED.T}$ reference point adopted by the FMP. However, there is a theoretical mismatch between the $F_{15\%}$ overfishing definition recently adopted by the Board and the $SSB_{MED.T}$ in the FMP. The TC recommends that if the Board wishes to adopt an $F_{15\%}$ overfishing definition, that a matching overfished definition ($SSB_{15\%}$) be adopted as well. In addition, although MSP based reference points were identified as a viable interim option by the Technical Committee, the TC wants to point out that selected reference points were not designated to achieve a specific management goal.

Although the Technical Committee could not come to consensus on the utility of the terminal year point estimates of F and SSB for management advice, there was consensus that the status determinations were likely robust. In other words, the ratio of $F_{2011}/F_{15\%}$ is likely greater than 1.0 (overfishing is occurring), and $SSB_{2011}/SSB_{MED.T}$ is likely greater than 1.0 (the stock is not overfished), but the exact magnitude of these ratios could not be determined. This statement in supported both quantitatively and qualitatively. Quantitatively, results of the sensitivity runs (albeit limited) and bootstrap analysis indicated the results of stock status were robust to uncertainty in the data and parameterization as specified in this update. Qualitatively, the 2009 benchmark stock assessment concluded that overfishing was occurring, and Addendum V reference points significantly reduced the overfishing threshold (from approximately $F_{8\%}$ to $F_{15\%}$). As harvest levels have increased since 2008 and there has been no significant increase in stock size, overfishing is still likely occurring.

The Technical Committee concluded that projections based on the current assessment are likely biased because of 1) the observed retrospective pattern, and 2) the lack of feedback between stock size and recruitment. The observed retrospective pattern suggests that the terminal year results from the assessment, and therefore the starting values for the projection may be biased, thus projection results may also be biased. Additionally, the TC made the assumption that recruitment was constant with some variability, and thus there is no feedback from stock size to the number of recruits. The rate of increase over time presented in the projection results is therefore influenced by this assumption, as is the probability of being over the threshold and limit reference points. This assumption of constant recruitment into the future is unrealistic for an r-selected, environmentally driven species like Atlantic menhaden. The Technical Committee concluded that, given these limitations, the projection results provide information on stock response given harvest reductions but should not be used to establish harvest limits for the fishery. As an alternative to using projections to set harvest limits, the Technical Committee has compiled the default "rules" used by several regional Fishery Management Councils on how harvest limits are set in data poor situations (Appendix 4). It should be noted that, at this time, these are provided only as information for the Management Board; the Technical Committee has not had time to review these as a group to determine which (if any) would be appropriate for use in managing the Atlantic menhaden stock.

The TC warns that additional data analysis and modeling work are necessary to resolve these model performance issues. Some of the criticisms (e.g., # 3 above) cannot be addressed without additional, long-term data collection programs; others could potentially be addressed through improvements to the base assessment model. An expedited benchmark assessment during which the TC can more fully examine many of the issues raised above is warranted.

11 Research and Modeling Recommendations for Benchmark

Recommendations from the 2010 and 2012 Assessments

Many of the research and modeling recommendations from the last benchmark stock assessment remain relevant for this update stock assessment. Research recommendations are broken down into two categories: data and modeling. While all recommendations are high priority, the first recommendation is the highest priority. Each category is further broken down into recommendations that can be completed in the short term and recommendations that will require long term commitment.

<u>Annual Data Collection</u>
Long term:

1. **[Highest Priority]** Develop a coastwide fishery independent index of adult abundance at age to replace or augment the existing Potomac River pound net index in the model. Possible methodologies include an air spotter survey, or an industry-based survey with scientific observers on board collecting the data. In all cases, a sound statistical design is essential (involve statisticians in the development and review of the design; some trial surveys may be necessary). **NOTE:** An industry funded feasibility study conducted in 2011 further supported the need for this work (Sulikowski et al 2012). A subcommittee of the Menhaden Technical Committee began discussions for development of a coastwide aerial survey in 2008. At the time of this update assessment, a contract has been awarded to develop the survey design, with results expected by the end of 2012. The Technical Committee is in consensus that an index of adult abundance is the highest priority

research recommendation but recognizes that implementation of the survey will require significant levels of funding.
2. Work with industry to collect age structure data outside the range of the fishery.
3. Validate MSVPA model parameters through the development and implementation of stomach sampling program that will cover major menhaden predators along the Atlantic coast. Validation of prey preferences, size selectivity and spatial overlap is critically important to the appropriate use of MSVPA model results.

Short term:
1. Continue current level of sampling from bait fisheries, particularly in the mid-Atlantic and New England.
2. Investigate interannual maturity variability via collection of annual samples of mature fish along the Atlantic coast.
3. Recover historical tagging data from paper data sheets.
4. Continue annual sampling of menhaden from the PRFC pound net fishery to better characterize age and size structure of catch.
5. Compare age composition of PRFC catch with the age composition of the reduction bait fishery catch in Chesapeake Bay. Upon completion of comparative analysis develop most efficient and representative method of sampling for age structure.
6. Consider developing an adult index, similar to PRFC CPUE index, using MD, VA, NJ and RI pound net information.
7. Explore additional sources of information that could be used as additional indices of abundance for juvenile and adult menhaden (ichthyoplankton surveys, NEAMAP, etc.).

Assessment Methodology

Long term:
1. Develop a spatially-explicit model, once sufficient age-specific data on movement rates of menhaden are available.
2. Develop multispecies statistical catch-at-age model to estimate menhaden natural mortality at age.

Short term:
1. Thoroughly explore causes of retrospective pattern in model results.
2. Explore alternative treatments of the reduction and bait fleets (e.g., spatial split, alternative selectivity configurations) in the BAM to reflect latitudinal variability in menhaden biology (larger and older fish migrating farther north during summer).
3. Review underlying data and evaluate generation of JAI and PRFC indices.
4. Perform likelihood profiling analysis to guide model selection decision-making.
5. Examine the variance assumptions and weighting factors of all the likelihood components in the model.
6. Re-evaluate menhaden natural mortality-at-age and population response to changing predator populations by updating and augmenting the MSVPA (e.g., add additional predator, prey, and diet data when available).
7. Incorporate maturity-at-age variability in the assessment model.

<u>Future Research</u>

1. Evaluate productivity of different estuaries (e.g., replicate similar methodology to Ahrenholz et al. 1987).
2. Collect age-specific data on movement rates of menhaden to develop regional abundance trends.
3. Determine selectivity of PRFC pound nets.
4. Update information on maturity, fecundity, spatial and temporal patterns of spawning and larval survivorship.
5. Investigate the effects of global climate change on distribution, movement, and behavior of menhaden.

12 Recommendations from the 2010 Peer Review Panel

The Review Panel of the last benchmark stock assessment had additional short and long term research recommendations which are detailed below. The short- and long-term recommendations are in order of priority.

Short term (improvements for the next benchmark review)

a. The Panel recommends that future model specifications include a capped effective sample size at 200, allow the gaps in the pound net index and bait fishery age composition where data are not available, modify the reduction and bait fleets to northern and southern fleets, and allow time-varying domed shaped selectivity for the southern region.
b. Fishing mortality should be calculated as full F. The N-weighted fishing mortalities relative to the N-weighted F-reference points do not provide correct interpretation with regard to overfishing.
c. The Panel has concerns about the use of F_{MED} and the fecundity associated with it as reference points. The concern is that there was no information on the relationship of the target and threshold fecundity in relation to virgin fecundity levels. Recommend examination of alternative reference points which provide more protection to SSB or fecundity than F_{MED}.
d. Examine weighting of datasets in the model. As a starting point, some experts assert that the input variance assumptions should be consistent with the estimated variance of residuals. In the base model the effective sample sizes for catch-at-age data are far too high and consequently estimates of uncertainty are too low.
e. The Panel recommends the Assessment Team's alternative use of the juvenile indices: combining relative abundance data from groups of adjacent states according to the similarity of trends in the state-specific time series; and cumulatively-combining these indices within the model. This allows for different regional patterns of recruitment to provide a stock-wide recruitment pattern.
f. Examine the timing of fisheries and indices in the model. Many of the fisheries are seasonal and need to be timed appropriately with the abundance indices. Incorrect timing may affect model fits.

Long Term

a. Develop a coast-wide adult menhaden survey. Possible methodologies include an airspotter survey, a hydro-acoustic survey, or an industry-based survey with scientific observers on board collecting the data. In all cases, a sound statistical design is essential (involve statisticians in the development and review of the design; some pilot surveys may be necessary).

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14 Tables

Table 1. Fork length (mm) at age on March 1 (beginning of fishing year) estimated from year class von Bertalanffy growth parameters.

Year	0	1	2	3	4	5	6	7	8
1955	110.6	158.6	222.1	264.5	277.7	296.5	296.1	322.1	289.7
1956	92.3	149.9	222.5	269.6	289.9	302.3	312.5	323.1	334.7
1957	119.7	138.5	211.2	265.4	298	307.9	317.4	322.6	323.3
1958	95.1	155.1	207.6	254.9	294.2	315	320.5	326.8	329
1959	140	132.9	211.8	254.2	286.1	313.6	325.2	329.4	332.6
1960	104.4	169.9	195	253.8	285.5	308.3	326.6	331.3	335.7
1961	126.2	151.9	220.5	242.5	284.9	306.7	324.2	335.3	334.9
1962	130.5	163.9	220.6	261	278.9	308	320.9	335.4	341.2
1963	136	169.4	219.5	264.7	293.4	306.7	325	330.5	343.5
1964	138.5	171.7	225.4	256.4	293.1	319.2	328	337.7	337
1965	130.8	172.4	225.9	261.1	280.7	311.3	339.9	344.3	347.1
1966	137.2	162.4	227.2	263.2	283.9	296.9	322.9	356.5	356.8
1967	143.2	176	217.1	268.2	288.9	298.5	307.6	330.4	369.7
1968	149.9	168.7	234.7	262.1	298.8	306.6	307.8	314.6	335.3
1969	144.5	175.5	216.2	274.9	299	321.7	318.8	313.7	319.3
1970	122.8	183.2	221.9	259.6	302.5	329.4	338.9	327.2	317.5
1971	123.5	173	243.1	262.8	299.1	321.4	354.3	351.7	332.9
1972	82	161.1	241.7	285.3	298.8	335.1	334.4	374.8	361.3
1973	116.7	144.6	220.9	282.8	315.1	330.5	367.9	343.2	391.7
1974	101.7	152.2	221.9	264.7	307.3	336	358.3	397.9	349.3
1975	104.3	139.1	207.5	261.8	296.9	322	350.8	382.9	425.1
1976	84.3	133.1	196.8	246.8	282.4	320.5	330.7	361.3	404.5
1977	91.1	123.4	181.9	237.6	274.7	293.1	337.7	335.9	368.6
1978	107.6	127.9	184.2	220.9	266.4	294.6	298.6	350.4	339.1
1979	104.9	134.8	186.3	227.4	252.1	286.7	308.7	301.4	359.7
1980	92.7	127.9	181	229.1	258.2	277.1	301.1	318.8	302.8
1981	88.5	129.1	170.1	218.4	260.6	280	297.1	311.2	326
1982	99	128.6	186.2	207.6	248.5	283.6	295.5	313.1	318.3
1983	110.9	131.9	190.1	227.4	241	272.9	300.5	306.5	325.9
1984	97	136	185.9	232.9	257	270.7	292.5	312.9	314.4
1985	93.3	130.3	180.2	227.1	262.7	278.3	297.1	308.4	322
1986	98.3	128.1	183.5	217.4	258.7	283.4	293.7	320.6	321.2
1987	101.2	133.7	183	222.8	248.8	282.8	297.8	304.7	341.6
1988	95.8	132.6	188.2	222.9	251.9	275.2	301.3	307.8	312.7
1989	114	140.4	184	226.5	251.7	273.3	297.5	315.5	314.8
1990	114.7	155.4	204.2	223.2	253.3	272.7	289.1	316.2	326.3

Table 1. (*continued*).

Year	0	1	2	3	4	5	6	7	8
1991	127.3	148	213.5	244.6	253.1	272.1	287.9	300.8	332
1992	101.8	164.4	200.7	249.3	270.2	276	285.3	299	309.4
1993	127.2	142.8	219.4	239.2	271.4	286.3	293.4	294.5	307
1994	84.5	162.3	206.1	256	267.2	285	296.6	306.7	301
1995	86.9	144.3	217.1	250.7	280.4	287.7	293.5	303	316.8
1996	76.3	138.1	224.6	256.1	282.2	296.6	302.6	298.6	307.1
1997	101.2	130.4	211.9	271.1	284	304.3	307.4	313.5	301.8
1998	137.3	142.3	206.7	259.4	298.1	304	319.9	314.6	321.5
1999	107.8	169.5	206.1	254	289.9	313.7	318.2	330.8	319.4
2000	87	158.9	222.3	251.5	283.5	309.4	322.7	328.3	338.6
2001	125.1	149.2	228.9	262.5	283.8	301.8	322	328	335.5
2002	108.2	170	227.6	270.5	293.2	306.9	313.2	330.1	331
2003	125	153.7	226.7	269.3	295.3	316.7	323.3	320.3	335.3
2004	91.9	159.1	216.6	257	291.4	310.1	334.5	334.9	324.7
2005	103.9	137.2	211.9	254.6	273.2	303.2	318.9	348.2	343.3
2006	113.1	151.7	201.3	249.3	277.6	281.9	309.4	324.2	358.6
2007	126.2	160.2	214.7	241.5	275.7	291.6	286.5	312.7	327.3
2008	139.4	166.8	221.6	250.4	266.6	294.5	300	289	314.5
2009	118.2	165.3	221.2	255.7	270.6	282.3	307.7	305.1	290.3
2010		171	210.4	252.6	274.7	282.1	292.1	317.1	308.2
2011			219.4	247.7	270.7	285.3	288.6	298.2	323.8

Table 2. Weight (g) at age on September 1 (middle of fishing year) estimated from annual weight-length parameters and annual lengths at age.

Year	0	1	2	3	4	5	6	7	8
1955	21.2	66.1	191.5	332.3	387.5	476.8	474.8	618.8	442.8
1956	12	55.8	194.2	356.7	448.7	511.9	568.6	631.7	706.1
1957	25.9	41.6	163.5	342.6	499.2	554.5	612.4	645.4	649.8
1958	12.4	61.2	158.6	310	494.6	618.3	654.1	697	712.8
1959	43.1	36.4	166.3	301.5	443.6	598.2	673.6	702.6	724.9
1960	15.7	79.6	126.2	303.5	449.5	580.6	703.2	737.4	770.8
1961	29.7	55.1	190	260.8	445.3	568.6	683.7	765.1	762
1962	38.3	77.2	193.1	324.1	397.6	539.8	612.8	702.6	740.3
1963	42.1	85	194.3	353.4	490.5	565.4	680.6	717.7	811.8
1964	45.9	90.8	215.1	323.4	494.2	648.1	706.2	774.5	769.1
1965	36.5	88.2	209	332.1	418.4	581.6	770.7	802.7	823.6
1966	43.5	73.5	208.7	329.8	417.4	479.5	622.8	847	849.1
1967	47	91.6	180.8	358.2	455.9	506.7	558.3	704.2	1013.1
1968	57.4	83.5	238.3	338.3	513.2	557	563.9	604.7	739.7
1969	55	101.8	197.4	422.2	550.8	694.6	674.7	641.4	678.3
1970	31.6	111	202.5	331.2	535.5	699.4	764.7	684.9	623.4
1971	32.2	90.9	259	329.3	490.3	611.9	826.2	807.4	682.1
1972	8.4	69.4	247	414.9	479.4	686.5	681.7	974.8	868.6
1973	27.5	52.9	193.1	410.7	571.3	661	917.6	742.2	1110.9
1974	16.5	58.7	192.3	334.8	535.4	709.2	868.1	1206.4	801.3
1975	17.8	44.3	157.5	329.6	490.8	634.8	833.5	1099.7	1532.6
1976	8.5	37.8	135.8	284.2	441.7	667.1	739.5	986.9	1427.3
1977	10.8	29.4	106.1	256.9	415.2	514.2	822.2	807.9	1098.2
1978	19.1	33.5	110.4	199.7	368.2	511.4	534.1	901.3	809.4
1979	17.5	39.8	115.1	221.4	310.3	473	602.7	556.9	994.5
1980	11.8	33.9	105.6	228.7	338	426.4	559.6	675	570.4
1981	9.7	33.6	83.4	190.1	340.4	431.6	524.9	611.6	712.6
1982	16.2	36.9	117.7	165.5	291.2	440.7	501.4	601.3	633.4
1983	22.3	38.3	119.6	208.9	250.4	369	498.6	530.2	642
1984	15.4	44.1	116.9	236.4	321.4	377.9	481.5	594.3	602.8
1985	13	36.8	101.2	208.4	328.1	393	482	541.5	619.8
1986	13.9	32.7	105.2	182.3	320.4	430.7	483.5	643	646.8
1987	16.6	40.1	108.1	201.4	285.3	427.8	503.5	541.5	776.6
1988	13.9	38.5	115.2	195.3	286.2	377.6	501.3	535.9	562.8
1989	21.9	43.5	105.5	208.6	295.3	386.6	510.6	619.2	615
1990	22.6	60.9	148.3	198.1	299.2	380.7	460.5	616.7	683.1

Table 2. (*continued*)

Year	0	1	2	3	4	5	6	7	8
1991	33.2	53.4	168.9	259.2	288.7	362.5	433	497	677.9
1992	15.3	71.5	135.9	272.7	353	378	420.6	488.9	546.2
1993	32.5	47	184.2	242.5	362.5	429.8	464.4	470.3	536.3
1994	8.3	69	149.5	301.5	346.5	427	485.4	541.1	509.6
1995	9.6	47.5	171.4	269.7	383.3	415.7	442.4	489.4	562.9
1996	6	41.5	201.3	308.5	422.2	496.7	530.1	507.8	556.1
1997	15.5	35.1	168.8	374.3	435.2	543.7	562.1	599	529.7
1998	41.8	46.8	154.5	319.4	498	530.2	624.2	592.1	634.2
1999	19.1	80.5	149.5	290.7	441.9	567.7	593.9	672.4	601.5
2000	9.6	65.1	188.6	279	407.9	538.4	615.2	649.6	716.2
2001	31.8	54.9	207.1	317.3	404.3	489.2	598.2	633.3	679.8
2002	21.8	87	213.1	361.6	463.1	532.3	566.7	665.6	671.3
2003	32.3	62.6	218.1	379.1	509.8	637.8	681.5	661.5	766.2
2004	12.3	67.9	177.8	303.4	449.1	545.2	690.7	693.3	629.1
2005	19.1	44.1	162.9	283	349.9	478.4	557	725.2	694.9
2006	23.5	58.3	139.8	270.4	377.3	395.4	527.5	609	831.7
2007	35	70.8	168.1	237.5	351.3	414.2	393.3	509.4	582.5
2008	46.4	79.6	187.1	270.4	326.3	440.3	465.7	416	536.9
2009	27.3	75.4	181.9	282.3	335.1	380.6	494.2	481.6	414.3
2010	26	83.3	156.8	273.9	354	383.9	427	548.9	503
2011	25.2	62.6	175.4	254.8	334.9	393.5	407.6	451.2	581

Table 3. Weight (g) at age on September 1 (middle of fishing year) estimated from annual weight-length parameters and annual lengths.

Year	0	1	2	3	4	5	6	7	8
1955	36.2	124.3	274.3	390.3	451.5	523.3	610.8	681.9	674.8
1956	25.2	105.1	267.1	428.1	498.1	558.8	601.7	633	710.4
1957	41.2	91.3	230.8	413.4	553.1	595.6	645.8	668.9	649.8
1958	22.8	109.9	231.7	382.2	555.5	655.8	686.9	719.8	728.9
1959	60.5	75.2	231.4	373.5	507.5	643.9	697.1	726.6	739.2
1960	32.2	129.6	189.6	375.4	513.3	636.2	738.3	752.7	789.3
1961	48.3	116	258.4	336.7	512.9	618.3	727.6	789.9	771.3
1962	60.1	131	267.1	394.1	466.5	591	644.3	731.1	754.8
1963	63.5	145.6	257.7	424.9	567.3	635	727.1	742.6	835.6
1964	67.1	150.4	281.1	380.3	550.2	721.1	767.2	811.7	786.5
1965	53	145.8	275.5	386.3	462.2	621.2	835.8	853.3	852.3
1966	66.8	121.9	278.1	387.7	455.6	509.7	648.2	899.7	887.3
1967	62.1	157.6	252.4	434.2	507.2	535.7	581.5	722.8	1063.5
1968	74.7	128.1	316.8	424.3	583.3	596.3	583.3	620.6	751.8
1969	83.3	152.8	268.9	500	649.2	759.4	705.9	655.1	689.9
1970	58.7	185.4	269.3	419.1	595.1	790.4	814.4	705.8	631.7
1971	50.6	169.4	341.9	406.3	589.4	654.5	905.8	844.3	695.9
1972	24.7	122.7	328.9	493.1	566.4	800	713.2	1048.6	897.8
1973	43.1	121.1	263.3	475.2	636.9	752.9	1039.3	764.4	1175.1
1974	28.7	103.4	263	408.7	582	764	968.3	1344.6	817.8
1975	27.1	84.5	214.8	379.8	560.5	666.2	877	1204.4	1682.8
1976	17.3	67.4	192.4	345.3	474.1	732.6	761.3	1023	1543.4
1977	20.2	64.4	151.3	317.3	471.6	533	878.5	821.9	1126.2
1978	28.4	68.7	163.2	252.6	420.4	556.1	543.8	944	817.6
1979	24.8	68.7	168.8	279.1	366.8	516.4	638.4	562.1	1028.2
1980	21.7	56.6	148.1	288.8	391.6	482	593.8	702.3	573.1
1981	19.5	68.2	118.8	239.7	396.9	475.8	575.8	637.1	732.7
1982	26.7	76.2	167.7	212.4	341	486.7	533.9	643	650.7
1983	31.4	70.8	171.6	258.4	303.4	414.5	534	553.5	675.8
1984	25.6	71.9	165.8	291.7	368.6	440.4	525.8	623.9	621
1985	22.6	68.4	139.3	260.6	374.2	430.8	546	579.3	641.6
1986	24.3	64.4	149.8	230.7	375.2	470.7	516.2	715.8	683
1987	26.6	75.5	153.6	249.4	338.2	476.8	533.3	566	847.6
1988	27.8	69.4	159.9	241.3	329.2	429.6	541.5	556.9	580.4
1989	39.1	91.1	150.3	256.1	341.1	427.5	567.7	657.1	632.2
1990	35.8	113.1	208.5	248.2	340.4	419.4	494	670.6	713.7

Table 3. (*continued*)

Year	0	1	2	3	4	5	6	7	8
1991	52	92.8	224.1	309.7	334.8	393.4	461.9	521.5	723.5
1992	28.3	123.1	186.4	318.7	392.3	420.5	445	512	565.8
1993	49.8	93.4	243.6	294.7	396	457.6	501.1	488.5	553.9
1994	23.5	118.8	214.3	355.7	395	450.3	504.8	572.6	523.3
1995	22.6	112.6	229.7	331.8	423.1	453.4	456.3	501.1	586.3
1996	17	96.5	288.8	371.6	483.5	529.8	564.3	517.7	564.7
1997	28.8	87.6	246.6	447	491	594.2	585.9	625.8	536
1998	60.3	93.9	227.2	390.9	547	574.4	662.1	608.2	654.1
1999	39.1	131.1	214	354.9	496.6	597.8	627.1	699.9	612.1
2000	27.1	131.5	252.7	345.5	456.5	577.9	633.4	674.5	736.3
2001	55	125.1	280.6	382.9	462.1	522	624.5	643.7	697.6
2002	40.4	149.4	290.1	422.1	526.3	581	588.9	683.6	677.6
2003	49.5	121.7	277	440.1	557.5	701.6	725.3	678	779.9
2004	25.3	113.9	238.6	339.2	482.6	572.9	738.6	722.8	638.4
2005	37.1	88.6	214.5	328.6	369.5	495.8	572.7	760.5	714.6
2006	43.8	112.5	193.7	321.5	411.2	407.1	537.6	619.3	862.4
2007	56	127.2	219.6	280.6	390.9	434.4	399.2	514.3	588
2008	61	132.7	241.3	309.7	359.7	473.5	479.2	419.4	539.6
2009	54.1	112.9	230	320.2	360.2	403.4	519.5	489.9	416
2010	52.3	137.7	205.6	309.5	378.4	399.4	442.5	568.2	508.2
2011	43.7	114.5	202	309.5	358	408	416.8	461.3	595.2

Table 4. Percent age composition of Atlantic menhaden from coastwide reduction fishery catch-at-age matrix, 2005-2011.

Year	0	1	2	3	4	5	6	7	8
2005	2	12	59	24	3	<1	-	-	-
2006	1	40	40	16	3	<1	-	-	-
2007	<1	26	65	7	1	<1	-	-	-
2008	1	9	68	18	3	<1	-	-	-
2009	1	48	31	18	3	<1	-	-	-
2010	2	40	49	7	3	<1	-	-	-
2011	-	42	50	7	1	<1	-	-	-

Table 5. Coastwide reduction and bait landings, 1940-2011.

	Reduction Fishery		Reduction Fishery	Bait Fishery
Year	Landings (1000 t)	Year	Landings (1000 t)	Landings (1000 t)
1940	217.7	1985	306.7	26.7
1941	277.9	1986	238	28
1942	167.2	1987	327	30.6
1943	237.2	1988	309.3	36.3
1944	257.9	1989	322	31
1945	295.9	1990	401.2	30.8
1946	362.4	1991	381.4	36.2
1947	378.3	1992	297.6	39
1948	346.5	1993	320.6	42.8
1949	363.8	1994	260	39.1
1950	297.2	1995	339.9	42.4
1951	361.4	1996	292.9	35.3
1952	409.9	1997	259.1	36.5
1953	593.2	1998	245.9	39.4
1954	608.1	1999	171.2	36.2
1955	641.4	2000	167.2	35.3
1956	712.1	2001	233.7	36.3
1957	602.8	2002	174	37.1
1958	510	2003	166.1	33.8
1959	659.1	2004	183.4	35.5
1960	529.8	2005	146.9	38.8
1961	575.9	2006	157.4	26.5
1962	537.7	2007	174.5	42.8
1963	346.9	2008	141.1	47.4
1964	269.2	2009	143.8	39.1
1965	273.4	2010	183.1	45.3
1966	219.6	2011	174	54.8
1967	193.5			
1968	234.8			
1969	161.6			
1970	259.4			
1971	250.3			
1972	365.9			
1973	346.9			
1974	292.2			
1975	250.2			
1976	340.5			
1977	341.1			
1978	344.1			
1979	375.7			
1980	401.5			
1981	381.3			
1982	382.4			
1983	418.6			
1984	326.3			

Table 6. Number of fish sampled from Atlantic menhaden landed for bait, 1985-2011.

	Purse Seine				Poundnet				Totals		
Year	NE	MA	CB	SA	NE	MA	CB	SA	Purse Seine	Poundnet	Grand
1985	600	0	0	170	0	0	0	30	770	30	800
1986	40	0	0	340	0	0	0	40	380	40	420
1987	0	0	0	220	0	0	0	0	220	0	220
1988	0	0	0	10	0	0	0	0	10	0	10
1989	20	0	0	10	0	0	0	0	30	0	30
1990	0	0	0	10	0	0	10	0	10	10	20
1991	0	0	0	78	0	0	0	0	78	0	78
1992	0	0	30	40	0	0	0	0	70	0	70
1993	29	0	10	130	0	0	0	0	169	0	169
1994	80	320	0	139	0	0	10	0	539	10	549
1995	130	59	96	77	0	0	0	0	362	0	362
1996	15	187	137	18	0	0	0	0	357	0	357
1997	0	110	136	67	0	0	100	0	313	100	413
1998	0	225	295	106	0	0	0	10	626	10	636
1999	0	192	299	47	0	0	0	0	538	0	538
2000	0	273	231	39	0	0	0	0	543	0	543
2001	0	677	275	10	0	0	0	0	962	0	962
2002	0	155	471	76	0	0	0	0	702	0	702
2003	0	108	309	10	0	0	0	0	427	0	427
2004	0	28	326	0	0	0	0	0	354	0	354
2005	0	4	318	0	0	0	0	0	322	0	322
2006	28	223	203	0	0	10	20	0	454	30	484
2007	122	477	374	0	190	10	80	0	973	280	1,253
2008	199	629	314	0	140	50	80	0	1,142	270	1,112
2009	27	377	481	0	40	10	110	0	885	160	1,045
2010	0	421	298	18	70	0	150	0	737	220	957
2011	0	448	327	0	0	0	260	0	775	260	1,035
Total	1,290	4,913	4,930	1,615	440	80	820	80	12,748	1,420	13,868

Table 7. Recreational harvest (Type A+B1) in numbers of Atlantic menhaden in the recreational fishery by region (New England, Middle Atlantic, and South Atlantic states), 1981-2011.

Year	MA	NE	SA	Overall
1981	117,957	248,063	77,841	443,861
1982	3,362	218,033	546,377	767,772
1983	26,033	175,877	382,531	584,441
1984	315,659	101,279	259,739	676,677
1985	266,892	227,162	101,710	595,764
1986	736,270	557,216	13,463	1,306,949
1987	365,506	463,769	142,006	971,281
1988	892,562	252,015	280,735	1,425,312
1989	192,875	258,202	182,656	633,733
1990	234,232	250,855	343,572	828,659
1991	856,362	374,938	390,179	1,621,479
1992	288,409	1,098,238	1,266,057	2,652,704
1993	268,992	354,034	84,017	707,043
1994	222,665	133,236	279,250	635,151
1995	777,497	142,589	85,272	1,005,358
1996	50,410	181,925	297,759	530,094
1997	227,652	98,781	135,071	461,504
1998	54,785	187,577	78,273	320,635
1999	742,075	54,578	289,447	1,086,100
2000	47,274	131,385	99,969	278,628
2001	147,773	17,389	985,208	1,150,370
2002	200,812	233,814	515,634	950,260
2003	217,042	21,153	1,669,518	1,907,713
2004	77,698	7,153	1,789,096	1,873,947
2005	66,226	5,547	1,467,118	1,538,891
2006	672,228	59,850	2,400,491	3,132,569
2007	298,455	480,196	1,818,868	2,597,519
2008	1,180,160	373,798	726,104	2,280,062
2009	108,563	91,556	1,307,950	1,508,069
2010	263,773	56,832	1,491,377	1,811,982
2011	560,406	22,643	1,097,325	1,680,374

Table 8. Recreational released alive (Type B2) in numbers of Atlantic menhaden in the recreational fishery by region (New England, Middle Atlantic, and South Atlantic states), 1981-2011.

Year	MA	NE	SA	Overall
1981	0	14,269	71,401	85,670
1982	9,314	0	378,801	388,115
1983	539	5,313	805,522	811,374
1984	44,582	5,435	534,245	584,262
1985	46,767	8,020	338,916	393,703
1986	30,881	3,372	97,581	131,834
1987	36,935	6,102	58,805	101,842
1988	29,641	22,082	41,840	93,563
1989	11,980	10,677	162,420	185,077
1990	43,491	27,470	108,288	179,249
1991	265,965	66,991	22,600	355,556
1992	697	96,997	22,737	120,431
1993	13,642	27,526	177,890	219,058
1994	12,424	18,771	4,117	35,312
1995	99,622	17,830	9,125	126,577
1996	2,082	3,139	391	5,612
1997	1,458	861	6,165	8,484
1998	3,209	3,628	10,219	17,056
1999	1,119	51,974	369,179	422,272
2000	57,934	0	81,727	139,661
2001	714	1,276	413,752	415,742
2002	91,225	18,221	387,996	497,442
2003	17,352	0	613,070	630,422
2004	4,326,150	52,149	387,179	4,765,478
2005	9,784	5,476	339,041	354,301
2006	270,205	114,971	1,119,853	1,505,029
2007	237,299	16,774	465,573	719,646
2008	71,499	13,107	74,687	159,293
2009	12,685	960	642,738	656,383
2010	67,672	10,161	522,416	600,249
2011	1,602	11,348	231,078	244,028

Table 9. Total catch (A+B1+0.5*B2) in weight (1,000 metric tons) of Atlantic menhaden in the recreational fishery (MRFSS/MRIP) by region (New England, Middle Atlantic, and South Atlantic states), 1981-2011.

Year	MA	NE	SA	Total
1981	0.0265	0.0798	0.0088	0.11504
1982	0.0018	0.0682	0.0567	0.12667
1983	0.0059	0.0558	0.0605	0.12225
1984	0.0759	0.0325	0.0406	0.14906
1985	0.0652	0.0723	0.0209	0.1584
1986	0.1689	0.1747	0.0048	0.34844
1987	0.0863	0.1459	0.0132	0.24543
1988	0.2039	0.0822	0.0233	0.30938
1989	0.0447	0.0824	0.0203	0.14741
1990	0.0575	0.0827	0.0307	0.17089
1991	0.2223	0.1277	0.0309	0.38094
1992	0.0649	0.3585	0.0985	0.52184
1993	0.0620	0.1150	0.0133	0.19029
1994	0.0514	0.0446	0.0217	0.1177
1995	0.1859	0.0474	0.0069	0.24019
1996	0.0116	0.0574	0.0230	0.09189
1997	0.0513	0.0310	0.0106	0.09298
1998	0.0127	0.0592	0.0064	0.07831
1999	0.1669	0.0252	0.0365	0.2286
2000	0.0171	0.0411	0.0109	0.06906
2001	0.0333	0.0056	0.0919	0.1308
2002	0.0554	0.0759	0.0547	0.18601
2003	0.0507	0.0066	0.1523	0.20964
2004	0.5035	0.0104	0.1528	0.66671
2005	0.0160	0.0026	0.1261	0.14472
2006	0.1814	0.0367	0.2282	0.44627
2007	0.0937	0.1527	0.1581	0.4046
2008	0.2732	0.1189	0.0588	0.45097
2009	0.0258	0.0288	0.1256	0.18017
2010	0.0669	0.0194	0.1351	0.22131
2011	0.1261	0.0089	0.0935	0.22844

Table 10. Total catch (A+B1+0.5*B2) in numbers of Atlantic menhaden in the recreational fishery (MRFSS/MRIP) by region (New England, Middle Atlantic, and South Atlantic states), 1981-2011.

Year	MA	NE	SA	Overall	PSE
1981	117,957	255,198	113,542	486,696	27.26
1982	8,019	218,033	735,778	961,830	35.6
1983	26,303	178,534	785,292	990,128	38.8
1984	337,950	103,997	526,862	968,808	35.2
1985	290,276	231,172	271,168	792,616	36
1986	751,711	558,902	62,254	1,372,866	33.59
1987	383,974	466,820	171,409	1,022,202	15.82
1988	907,383	263,056	301,655	1,472,094	31.19
1989	198,865	263,541	263,866	726,272	18.63
1990	255,978	264,590	397,716	918,284	14.47
1991	989,345	408,434	401,479	1,799,257	20.07
1992	288,758	1,146,737	1,277,426	2,712,920	31.12
1993	275,813	367,797	172,962	816,572	20.48
1994	228,877	142,622	281,309	652,807	18.88
1995	827,308	151,504	89,835	1,068,647	28.28
1996	51,451	183,495	297,955	532,900	48.94
1997	228,381	99,212	138,154	465,746	31.62
1998	56,390	189,391	83,383	329,163	28.82
1999	742,635	80,565	474,037	1,297,236	57.96
2000	76,241	131,385	140,833	348,459	27.95
2001	148,130	18,027	1,192,084	1,358,241	26.96
2002	246,425	242,925	709,632	1,198,981	21.27
2003	225,718	21,153	1,976,053	2,222,924	16.03
2004	2,240,773	33,228	1,982,686	4,256,686	102.14
2005	71,118	8,285	1,636,639	1,716,042	23.99
2006	807,331	117,336	2,960,418	3,885,084	18.11
2007	417,105	488,583	2,051,655	2,957,342	17.17
2008	1,215,910	380,352	763,448	2,359,709	19.21
2009	114,906	92,036	1,629,319	1,836,261	15.93
2010	297,609	61,913	1,752,585	2,112,107	13.34
2011	561,207	28,317	1,212,864	1,802,388	27.06

Table 11. General definitions, input data, population model, and negative log-likelihood components of the BAM forward-projecting statistical age-structured model used for Atlantic menhaden.

General Definitions	Symbol	Description/Definition
Year index: y = {1955,..,2011}	y	
Age index: a = {0,...,8+}	a	
Fishery index: f = {1 reduction, 2 bait}	f	
Input Data	**Symbol**	**Description/Definition**
Fishery Weight-at-age	$w^{f}_{a,y}$	Computed from size at age from fishery samples
Population Weight-at-age	$w^{p}_{a,y}$	Computed from size at age back-calculated to beginning of year
Maturity-at-age	m_a	From data workshop with recent added samples
Fecundity-at-age	$\gamma_{a,y}$	From data workshop
Observed age-0 CPUE y = {1959,...,2011}	$U_{1,y}$	Based on numbers of age-0 fish from various seine samples (selected/combined Assessment Workshop)
Observed pound net CPUE y = {1964,...,2011}	$U_{2,y}$	Based on pound net landings of menhaden per set from the Potomac River Fisheries Commission
Selectivity for U_2	s'_a	Fixed at 0.25 for a = {1, 3}, 1.0 for a = {2}, and 0 for a = {0,4,...,8+}
Coefficient of variation for U	c_U	Based on annual estimates from samples for U_1, fixed at 0.5 for U_2
Observed age compositions	$p_{f,a,y}$	Computed as percent age composition at age (a) for each year (y) and fishery (f)
Age composition sample sizes	$n_{f,y}$	Number of trips sampled in each year (y) from each fishery (f)
Observed fishery landings	$L_{f,y}$	Reported landings in weight for each year (y) from each fishery (f)
Coefficient of variation for L_f	c_{L_f}	Fixed at 0.03 for L_1 and 0.15 (early years) and 0.05 (recent years) for L_2
Observed natural mortality	$M_{a,y}$	From MSVPA-X model, constant in years 1955-1981, projected for 2011

Table 11. (c*ontinued*).

Population Model	**Symbol**	**Description/Definition**
Fishery selectivity	$s_{f,a}$	Assumed constant for all years (*y*) $s_a = \dfrac{1}{1+\exp(-\eta_1[a-\alpha_1])}$ $s_a = \left[\dfrac{1}{1+\exp(-\eta_{1,2}[a-\alpha_{1,2}])}\right]\left[1-\dfrac{1}{1+\exp(-\eta_{2,2}[a-\alpha_{2,2}])}\right]\left[\dfrac{1}{\max(s_a)}\right]$ where η's and α's are estimated parameters. The base BAM model assumed logistic selectivity for both reduction and bait fisheries.
Fishing mortality (fully selected)	$F_{f,a,y}$	$F_{f,a,y} = s_a F_{f,y}$ where $F_{f,y}$s are estimated parameters
Total mortality	$Z_{a,y}$	$Z_{a,y} = M_{a,y} + \sum_{f=1}^{2} F_{f,a,y}$
Fecundity per recruit at $F = 0$	ϕ_y	$\phi_y = \sum_{a=0}^{8+} N_{a,y} m_a \gamma_{a,y} 0.5 \Big/ N_{0,y}$ where $N_{a+1,y} = N_{a,y}\exp(-Z_{a,y})$ and $N_{8+,y} = N_{7,y}\exp(-Z_{7,y})/[1-\exp(-Z_{8+,y})]$
Population numbers Population fecundity	$N_{a,y}$ ε_y	$N_{a+1,1955} = N_{a,1955}\exp(-Z_{a,1955})$ $N_{8+,1955} = N_{7,1955}\exp(-Z_{7,1955})/[1-\exp(-Z_{8+,1955})]$ $\varepsilon_y = \sum_{a=0}^{8+} N_{a,y} m_a \gamma_a 0.5$ $N_{0,y} = R_y$ $N_{a+1,y+1} = N_{a,y}\exp(-Z_{a,y})$ $N_{A,y} = N_{A-1,y-1}\exp(-Z_{A-1,y-1}) + N_{A,y-1}\exp(-Z_{A,y-1})$ where R_y are annual recruitment parameters.

Table 11. (c*ontinued*).

Population Model (*cont.*)	**Symbol**	**Description/Definition**
Population biomass	B_y	$B_y = \sum_{a=0}^{8+} N_{a,y} w_a^p$
Predicted catch-at-age	$\hat{C}_{f,a,y}$	$\hat{C}_{f,a,y} = \frac{F_{f,a,y}}{Z_{a,y}} N_{a,y} \left[1 - \exp\left(-Z_{a,y}\right)\right]$
Predicted landings	$\hat{L}_{f,y}$	$\hat{L}_{f,y} = \sum_{a=0}^{8+} \hat{C}_{f,a,y} w_a^f$
Predicted age composition	$\hat{p}_{f,a,y}$	$\hat{p}_{f,a,y} = \hat{C}_{f,a,y} \Big/ \sum_{a=0}^{8+} \hat{C}_{f,a,y}$
Predicted age-0 CPUE	$\hat{U}_{1,y}$	$\hat{U}_{1,y} = N_{0,y} q_1$ where q_1 is a catchability parameter
Predicted pound net CPUE	$\hat{U}_{2,y}$	$\hat{U}_{2,y} = \sum_{a=0}^{8+} N_{a,y} s'_a q_2$ where q_2 is a catchability parameter
Negative Log-Likelihood	**Symbol**	**Description/Definition**
Multinomial age composition	Λ_f	$\Lambda_f = -\lambda_f n_{f,y} \sum_{a=0}^{8+} \left(p_{f,a,y} + x\right) \log\left(\hat{p}_{f,a,y} + x\right) - \left(p_{f,a,y} + x\right) \log\left(p_{f,a,y} + x\right)$ where λ_f is a preset weighting factor and x is fixed at an arbitrary value of 0.001
Lognormal indices	Λ_f	$\Lambda_f = \lambda_f \sum_y \frac{\left[\log\left(U_{f,y} + x\right) - \log\left(\hat{U}_{f,y} + x\right)\right]^2}{2c_U^2}$ where λ_f is a preset weighting factor and x is fixed at an arbitrary value of 0.001
Lognormal landings	Λ_f	$\Lambda_f = \lambda_f \sum_y \frac{\left[\log\left(L_{f,y} + x\right) - \log\left(\hat{L}_{f,y} + x\right)\right]^2}{2c_{L_f}^2}$ where λ_f is a preset weighting factor and x is fixed at an arbitrary value of 0.001

Table 12. Estimated annual total full fishing mortality rates, full fishing mortality rates for the commercial reduction fishery, and full fishing mortality rates for the commercial bait fishery from the base BAM model.

Year	full F	full F reduction	full F bait
1955	1.41	1.36	0.05
1956	2.74	2.57	0.17
1957	2.46	2.2	0.26
1958	1.54	1.44	0.1
1959	2.01	1.87	0.13
1960	0.92	0.84	0.08
1961	1.1	1.05	0.06
1962	2.14	1.98	0.16
1963	3.3	2.88	0.42
1964	4.07	3.32	0.75
1965	6.84	5.2	1.64
1966	5.29	4.27	1.02
1967	3.89	3.15	0.74
1968	3.45	3.06	0.39
1969	2.74	2.27	0.47
1970	3.19	2.43	0.76
1971	1.7	1.47	0.23
1972	3.06	2.87	0.19
1973	2.86	2.52	0.34
1974	2.85	2.51	0.34
1975	2.71	2.15	0.56
1976	3.05	2.59	0.46
1977	2.57	2.15	0.42
1978	2.49	2.09	0.4
1979	2.25	2.06	0.18
1980	2.59	2.23	0.36
1981	2.13	1.82	0.31
1982	1.64	1.45	0.19
1983	2.11	1.9	0.21
1984	2.75	2.5	0.25
1985	2.88	2.18	0.7
1986	1.43	1.07	0.36
1987	1.52	1.28	0.24
1988	2.03	1.66	0.37
1989	2.9	2.32	0.59
1990	2.46	2.02	0.45
1991	4.15	3.37	0.78
1992	3.38	2.25	1.13
1993	1.92	1.4	0.52
1994	1.26	0.97	0.29
1995	1.87	1.53	0.35
1996	1.38	1.09	0.29
1997	1.42	1.16	0.26
1998	2.17	1.67	0.49
1999	2.19	1.47	0.72
2000	1.57	1.03	0.54
2001	1.69	1.3	0.39
2002	1.8	1.3	0.51
2003	1.64	1.09	0.55
2004	1.49	1.03	0.47
2005	1.4	0.94	0.46
2006	1.68	1.26	0.42
2007	1.86	1.12	0.73
2008	1.5	0.89	0.62
2009	1.9	1.23	0.67
2010	2.81	1.68	1.13
2011	4.5	2.43	2.07

Table 13. Estimated annual total full fishing mortality rates from the base BAM model and percentiles from the bootstrap runs.

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1955	1.41	0.97	1.49	2.99
1956	2.74	1.84	3.01	5.75
1957	2.46	1.7	2.76	4.52
1958	1.54	1.08	1.68	2.91
1959	2.01	1.51	2.18	3.31
1960	0.92	0.77	0.95	1.25
1961	1.1	0.92	1.12	1.45
1962	2.14	1.75	2.23	2.96
1963	3.3	2.48	3.54	5.37
1964	4.07	3.1	4.41	6.71
1965	6.84	5.27	7.59	11.31
1966	5.29	3.67	5.96	10.09
1967	3.89	2.97	4.25	6.38
1968	3.45	2.89	3.73	4.97
1969	2.74	2.22	3.02	4.28
1970	3.19	2.53	3.49	5.06
1971	1.7	1.4	1.82	2.45
1972	3.06	2.48	3.31	4.6
1973	2.86	2.33	3.08	4.26
1974	2.85	2.2	3.1	4.57
1975	2.71	2.1	2.94	4.42
1976	3.05	2.4	3.32	4.72
1977	2.57	1.92	2.8	4.28
1978	2.49	1.73	2.74	4.59
1979	2.25	1.51	2.42	4.36
1980	2.59	1.7	2.89	4.72
1981	2.13	1.47	2.32	4.14
1982	1.64	1.17	1.79	2.83
1983	2.11	1.51	2.28	3.81
1984	2.75	1.8	3.1	5.47
1985	2.88	1.98	3.27	5.29
1986	1.43	1.07	1.55	2.39
1987	1.52	1.19	1.63	2.39
1988	2.03	1.53	2.22	3.38
1989	2.9	2.03	3.2	5.24
1990	2.46	1.83	2.66	4.2

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1991	4.15	2.75	4.65	9.1
1992	3.38	2.55	3.74	6.08
1993	1.92	1.59	2.08	2.89
1994	1.26	1.08	1.34	1.73
1995	1.87	1.65	1.99	2.49
1996	1.38	1.2	1.46	1.81
1997	1.42	1.24	1.49	1.85
1998	2.17	1.8	2.31	3.1
1999	2.19	1.72	2.36	3.36
2000	1.57	1.24	1.68	2.33
2001	1.69	1.4	1.8	2.38
2002	1.8	1.35	1.97	2.89
2003	1.64	1.23	1.78	2.78
2004	1.49	1.22	1.6	2.24
2005	1.4	1.15	1.49	1.99
2006	1.68	1.36	1.8	2.47
2007	1.86	1.46	2.01	2.88
2008	1.5	1.21	1.62	2.23
2009	1.9	1.52	2.05	2.89
2010	2.81	2.19	3.02	4.26
2011	4.5	3.09	4.85	7.81

Table 14. Estimated full fishing mortality rates at age from the base BAM model.

	Age								
Year	0	1	2	3	4	5	6	7	8
1955	0.01	0.13	0.78	1.32	1.4	1.41	1.41	1.41	1.41
1956	0.02	0.26	1.49	2.56	2.73	2.74	2.74	2.74	2.74
1957	0.02	0.22	1.3	2.3	2.45	2.46	2.46	2.46	2.46
1958	0.01	0.14	0.84	1.44	1.53	1.54	1.54	1.54	1.54
1959	0.02	0.19	1.09	1.88	2	2.01	2.01	2.01	2.01
1960	0.01	0.08	0.49	0.86	0.91	0.92	0.92	0.92	0.92
1961	0.01	0.1	0.61	1.03	1.1	1.1	1.1	1.1	1.1
1962	0.02	0.2	1.16	2	2.13	2.14	2.14	2.14	2.14
1963	0.03	0.29	1.72	3.07	3.29	3.3	3.3	3.3	3.3
1964	0.03	0.34	2.03	3.77	4.05	4.07	4.07	4.07	4.07
1965	0.05	0.53	3.27	6.31	6.81	6.84	6.84	6.84	6.84
1966	0.04	0.43	2.62	4.9	5.26	5.29	5.29	5.29	5.29
1967	0.03	0.32	1.93	3.6	3.87	3.88	3.89	3.89	3.89
1968	0.03	0.31	1.81	3.21	3.43	3.45	3.45	3.45	3.45
1969	0.02	0.23	1.38	2.54	2.73	2.74	2.74	2.74	2.74
1970	0.02	0.25	1.53	2.94	3.18	3.19	3.19	3.19	3.19
1971	0.01	0.15	0.88	1.58	1.69	1.7	1.7	1.7	1.7
1972	0.03	0.29	1.67	2.87	3.05	3.06	3.06	3.06	3.06
1973	0.02	0.25	1.5	2.66	2.85	2.86	2.86	2.86	2.86
1974	0.02	0.25	1.49	2.66	2.84	2.85	2.85	2.85	2.85
1975	0.02	0.22	1.33	2.51	2.7	2.71	2.71	2.71	2.71
1976	0.02	0.26	1.56	2.83	3.03	3.05	3.05	3.05	3.05
1977	0.02	0.22	1.3	2.38	2.55	2.56	2.57	2.57	2.57
1978	0.02	0.21	1.26	2.31	2.48	2.49	2.49	2.49	2.49
1979	0.02	0.21	1.21	2.1	2.24	2.25	2.25	2.25	2.25
1980	0.02	0.22	1.34	2.41	2.58	2.59	2.59	2.59	2.59
1981	0.02	0.18	1.09	1.98	2.11	2.12	2.13	2.13	2.13
1982	0.01	0.14	0.86	1.52	1.63	1.64	1.64	1.64	1.64
1983	0.02	0.19	1.12	1.96	2.1	2.11	2.11	2.11	2.11
1984	0.02	0.25	1.47	2.56	2.73	2.75	2.75	2.75	2.75
1985	0.02	0.22	1.37	2.66	2.87	2.88	2.88	2.88	2.88
1986	0.01	0.11	0.68	1.32	1.42	1.43	1.43	1.43	1.43
1987	0.01	0.13	0.77	1.41	1.51	1.52	1.52	1.52	1.52
1988	0.02	0.17	1.01	1.88	2.02	2.03	2.03	2.03	2.03
1989	0.02	0.23	1.43	2.69	2.89	2.9	2.9	2.9	2.9
1990	0.02	0.2	1.23	2.28	2.45	2.46	2.46	2.46	2.46

Table 14 (*continued*).

	Age								
Year	0	1	2	3	4	5	6	7	8
1991	0.03	0.34	2.06	3.84	4.13	4.15	4.15	4.15	4.15
1992	0.02	0.23	1.49	3.09	3.36	3.38	3.38	3.38	3.38
1993	0.01	0.14	0.89	1.77	1.91	1.92	1.92	1.92	1.92
1994	0.01	0.1	0.61	1.16	1.25	1.26	1.26	1.26	1.26
1995	0.01	0.15	0.93	1.73	1.86	1.87	1.87	1.87	1.87
1996	0.01	0.11	0.67	1.27	1.37	1.38	1.38	1.38	1.38
1997	0.01	0.12	0.71	1.32	1.41	1.42	1.42	1.42	1.42
1998	0.02	0.17	1.05	2	2.16	2.17	2.17	2.17	2.17
1999	0.01	0.15	0.97	2	2.18	2.19	2.19	2.19	2.19
2000	0.01	0.11	0.69	1.43	1.56	1.57	1.57	1.57	1.57
2001	0.01	0.13	0.81	1.56	1.68	1.69	1.69	1.69	1.69
2002	0.01	0.13	0.83	1.66	1.79	1.8	1.8	1.8	1.8
2003	0.01	0.11	0.72	1.5	1.63	1.64	1.64	1.64	1.64
2004	0.01	0.11	0.67	1.37	1.48	1.49	1.49	1.49	1.49
2005	0.01	0.1	0.62	1.28	1.39	1.4	1.4	1.4	1.4
2006	0.01	0.13	0.8	1.55	1.67	1.68	1.68	1.68	1.68
2007	0.01	0.12	0.78	1.69	1.85	1.86	1.86	1.86	1.86
2008	0.01	0.09	0.62	1.37	1.5	1.5	1.5	1.5	1.5
2009	0.01	0.13	0.82	1.74	1.89	1.9	1.9	1.9	1.9
2010	0.02	0.18	1.17	2.55	2.79	2.81	2.81	2.81	2.81
2011	0.02	0.26	1.77	4.07	4.48	4.5	4.5	4.5	4.5

Table 15. Estimated numbers of Atlantic menhaden (billions) at the start of the fishing year from the base BAM model..

	Age								
	0	1	2	3	4	5	6	7	8
1955	33.68	4.87	2.31	0.27	0.88	7.35E-08	2.94E-02	2.61E-09	5.21E-10
1956	33.19	10.64	1.75	0.53	0.04	1.29E-01	1.11E-08	4.55E-03	4.85E-10
1957	19.33	10.37	3.39	0.2	0.02	1.58E-03	5.17E-03	4.54E-10	1.86E-04
1958	75.38	6.06	3.42	0.47	0.01	1.19E-03	8.33E-05	2.80E-04	1.01E-05
1959	7.95	23.8	2.16	0.75	0.06	1.45E-03	1.58E-04	1.14E-05	3.96E-05
1960	15.17	2.5	8.12	0.37	0.06	5.03E-03	1.21E-04	1.35E-05	4.34E-06
1961	9.16	4.82	0.94	2.51	0.09	1.54E-02	1.24E-03	3.06E-05	4.53E-06
1962	9.22	2.9	1.78	0.26	0.5	1.74E-02	3.17E-03	2.62E-04	7.40E-06
1963	7.24	2.9	0.98	0.28	0.02	3.56E-02	1.27E-03	2.37E-04	2.01E-05
1964	8.88	2.26	0.89	0.09	0.01	4.43E-04	8.11E-04	2.96E-05	5.99E-06
1965	7.22	2.75	0.66	0.06	0	7.68E-05	4.68E-06	8.79E-06	3.86E-07
1966	9.99	2.2	0.67	0.01	0	7.59E-07	5.06E-08	3.16E-09	6.20E-09
1967	5.09	3.07	0.59	0.02	0	1.87E-07	2.37E-09	1.62E-10	3.00E-11
1968	8.18	1.58	0.92	0.04	0	6.71E-07	2.38E-09	3.09E-11	2.50E-12
1969	13.25	2.54	0.48	0.08	0	7.31E-06	1.32E-08	4.80E-11	6.74E-13
1970	6.34	4.15	0.83	0.06	0	3.80E-05	2.91E-07	5.40E-10	1.99E-12
1971	17.23	1.98	1.33	0.09	0	8.34E-05	9.66E-07	7.59E-09	1.41E-11
1972	10.91	5.44	0.7	0.28	0.01	1.98E-04	9.43E-06	1.12E-07	8.82E-10
1973	13.16	3.4	1.68	0.07	0.01	3.00E-04	5.73E-06	2.80E-07	3.35E-09
1974	17.23	4.11	1.09	0.19	0	3.10E-04	1.06E-05	2.08E-07	1.03E-08
1975	29.2	5.39	1.32	0.12	0.01	9.15E-05	1.11E-05	3.89E-07	8.00E-09
1976	23.32	9.16	1.78	0.18	0.01	3.01E-04	3.76E-06	4.66E-07	1.67E-08
1977	23.92	7.29	2.9	0.19	0.01	1.62E-04	8.81E-06	1.13E-07	1.45E-08
1978	24.42	7.5	2.41	0.4	0.01	2.71E-04	7.72E-06	4.30E-07	6.22E-09
1979	43.78	7.66	2.5	0.34	0.02	4.94E-04	1.39E-05	4.06E-07	2.29E-08
1980	28.78	13.74	2.56	0.38	0.02	1.42E-03	3.22E-05	9.29E-07	2.87E-08
1981	55.9	9.02	4.52	0.34	0.02	1.07E-03	6.57E-05	1.53E-06	4.55E-08
1982	26.73	17.58	3.09	0.76	0.03	1.37E-03	7.92E-05	4.98E-06	1.19E-07
1983	40.78	5.07	3.75	0.45	0.07	2.71E-03	1.56E-04	9.82E-06	6.32E-07
1984	55.46	8.57	1.15	0.47	0.03	4.89E-03	1.94E-04	1.19E-05	8.02E-07
1985	40.05	14.1	2.18	0.12	0.02	1.12E-03	1.91E-04	7.91E-06	5.20E-07
1986	25.33	10.69	3.74	0.24	0	6.09E-04	3.83E-05	6.84E-06	3.01E-07
1987	14.63	6.61	3.21	0.82	0.03	5.79E-04	8.91E-05	5.86E-06	1.09E-06
1988	27.56	4.23	2.16	0.68	0.11	4.26E-03	7.85E-05	1.26E-05	9.83E-07
1989	7.19	8.27	1.44	0.38	0.06	8.40E-03	3.51E-04	6.68E-06	1.16E-06
1990	13.17	2.64	2.94	0.18	0.01	1.90E-03	2.84E-04	1.24E-05	2.76E-07

Table 15 (*continued*).

	Age								
	0	1	2	3	4	5	6	7	8
1991	17.24	4.91	1	0.46	0.01	7.67E-04	1.01E-04	1.52E-05	6.80E-07
1992	13.12	6.24	1.63	0.07	0.01	1.04E-04	7.48E-06	1.00E-06	1.59E-07
1993	8.63	5.35	2.46	0.21	0	1.24E-04	2.23E-06	1.62E-07	2.52E-08
1994	14.44	3.21	2.17	0.55	0.02	1.70E-04	1.14E-05	2.08E-07	1.75E-08
1995	8.02	5.19	1.33	0.65	0.1	3.70E-03	3.04E-05	2.07E-06	4.10E-08
1996	8.53	2.61	1.99	0.29	0.07	9.80E-03	3.54E-04	2.95E-06	2.05E-07
1997	6.43	2.85	1.04	0.56	0.05	1.07E-02	1.57E-03	5.72E-05	5.10E-07
1998	9.76	2.25	1.15	0.28	0.09	7.41E-03	1.68E-03	2.47E-04	9.12E-06
1999	9.1	3.19	0.87	0.23	0.02	6.69E-03	5.47E-04	1.26E-04	1.93E-05
2000	3.72	2.91	1.27	0.18	0.02	1.64E-03	4.77E-04	3.97E-05	1.06E-05
2001	7.79	1.35	1.26	0.37	0.03	2.43E-03	2.19E-04	6.40E-05	6.74E-06
2002	12.61	2.64	0.56	0.31	0.05	3.09E-03	2.80E-04	2.56E-05	8.28E-06
2003	9.72	3.87	1.01	0.13	0.04	4.72E-03	3.19E-04	2.92E-05	3.52E-06
2004	6.32	3.34	1.52	0.26	0.02	4.32E-03	5.86E-04	4.01E-05	4.12E-06
2005	14.32	2.03	1.21	0.39	0.04	2.39E-03	6.06E-04	8.49E-05	6.40E-06
2006	9.66	4.42	0.73	0.33	0.06	5.67E-03	3.65E-04	9.51E-05	1.43E-05
2007	5.59	3.04	1.59	0.16	0.04	6.73E-03	6.34E-04	4.25E-05	1.27E-05
2008	10.48	1.83	1.14	0.37	0.02	3.52E-03	6.30E-04	6.03E-05	5.25E-06
2009	8.81	3.35	0.69	0.31	0.05	2.17E-03	4.59E-04	8.48E-05	8.82E-06
2010	7.8	2.79	1.21	0.15	0.03	4.46E-03	1.89E-04	4.07E-05	8.29E-06
2011	4.03	2.62	0.99	0.19	0.01	1.05E-03	1.61E-04	6.98E-06	1.81E-06

Table 16. Estimated annual fecundity (billions of eggs) from the base BAM model and percentiles from the bootstrap runs.

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1955	102151.8	48649.8	98848.26	157141.9
1956	61339.73	23109	58345.02	101081.1
1957	28073.84	14209.07	25770.46	48612.99
1958	36984.24	18359.35	33923.01	58891.1
1959	51319.12	24393.07	48015.01	80319.07
1960	48873.04	33337.33	46921.62	65333.29
1961	118281.3	92877.26	118000.1	142083.4
1962	67100.69	48116.77	66166.32	85069.11
1963	27508.07	18491.08	26896.42	35950.83
1964	9718.88	5862.37	9313.8	14192.22
1965	6500.38	4150.41	6165.04	8955.56
1966	3957.4	2661.5	3768.85	5451.2
1967	3944.79	1927.8	3676.76	6877.95
1968	7413.53	5385.99	7137.89	9589.47
1969	7178.88	4681.16	6684.17	9202.52
1970	7383.83	5088.57	6990.85	9390.17
1971	13549.67	9973.63	13187.58	17024.19
1972	27500.18	19877.4	26729.04	34011.74
1973	13811.02	9782.85	13046.87	17787.85
1974	16206.55	10723.4	15326.37	21403.16
1975	12407.83	7388.99	11790.34	17662.89
1976	13788.54	9000.36	13154.63	18476.19
1977	14894.24	10287.77	14152.71	19535.1
1978	18828.19	11104.93	17779.64	27092.04
1979	19243.04	9181.46	18136.14	30846.98
1980	20562.58	9445.76	19675.43	35018.24
1981	20392.96	11342.31	19120.39	32970.54
1982	28394.78	13314.49	26390.93	45259.81
1983	28999.48	17390.25	27248.84	42835.69
1984	21877.47	9770.45	20577.09	34742.87
1985	10364.88	4931.42	9558.1	18319.32
1986	16568.12	9978.18	15640.06	25024.09
1987	35104.65	21898.83	34004.96	47749.11
1988	33249.29	20879.41	31806	44780.27
1989	19935.37	10913.67	18861.16	29211.09
1990	16671.75	11201.98	16036.83	23353.8

Table 16 (*continued*).

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1991	24471.07	12843.18	23559.52	35961.12
1992	8876.69	4389.41	8239.5	15311.54
1993	18923.46	13160.5	17950.9	24087.39
1994	37219.34	28515.79	35720.27	44223.26
1995	45216.37	37036.2	43760.21	50906.05
1996	30935.49	25622.43	29729.57	34334.84
1997	45718.16	39911.09	44632.95	50281.58
1998	30711.2	24831.03	29781.09	35606.01
1999	17499.81	12465.4	16914.97	22165.58
2000	16396.6	11659.19	15888.69	21328.95
2001	29593.6	22538.97	28954.09	36708.14
2002	27754.16	20748.3	26514.49	34540.18
2003	17552.86	10453.71	16367.23	25472.7
2004	22344.43	14742.52	21627.33	29397.85
2005	27506.7	20529.04	26712.08	33690.81
2006	23007.35	17231.11	22259.63	28153.2
2007	16899.65	12620.38	16244.56	20940.34
2008	24131.03	17852.14	23431.98	30384.94
2009	22737.49	17009.56	21857.34	27757.72
2010	14567.67	10429.2	14061.59	18782.07
2011	13333.82	9382.16	13071.02	17736.5

Table 17. Estimated annual recruitment of age-0 (billions) fish from the base BAM model and percentiles from the bootstrap runs.

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1955	33.68	25.21	33.39	42.98
1956	33.19	23.38	32.81	42.65
1957	19.33	9.78	19.04	28.57
1958	75.38	64.3	76.19	87.45
1959	7.95	3.1	7.8	13.04
1960	15.17	10.84	15	19.62
1961	9.16	6.96	9.06	11.47
1962	9.22	7.45	9.13	10.9
1963	7.24	5.93	7.2	8.56
1964	8.88	7.36	8.78	10.49
1965	7.22	5.56	7.16	8.91
1966	9.99	8.43	9.94	11.42
1967	5.09	4.23	5.05	5.93
1968	8.18	6.67	8.09	9.8
1969	13.25	11.52	13.19	14.88
1970	6.34	4.74	6.25	7.82
1971	17.23	14.71	17.09	19.71
1972	10.91	8.35	10.84	13.48
1973	13.16	9.96	13.05	16.46
1974	17.23	13.65	17.01	20.91
1975	29.2	24.28	28.94	35.02
1976	23.32	17.63	23.01	29.34
1977	23.92	16.03	23.7	32.63
1978	24.42	16.83	24.1	34.25
1979	43.78	30.18	42.66	57.78
1980	28.78	17.54	28.09	40.34
1981	55.9	39.25	54.83	73.31
1982	26.73	13.79	26.28	41.53
1983	40.78	27.21	39.87	55.84
1984	55.46	40.29	54.92	70.34
1985	40.05	26.82	39.39	52.72
1986	25.33	17.44	24.93	34.4
1987	14.63	10	14.63	19.88
1988	27.56	22.26	27.36	33.01
1989	7.19	4.41	7.03	10.02
1990	13.17	9.39	13.05	17.06

Table 17 (*continued*).

Year	Base BAM model	5th percentile	50th percentile	95 percentile
1991	17.24	14.18	17.14	20.24
1992	13.12	11.12	13.05	15.16
1993	8.63	7.43	8.6	9.84
1994	14.44	13.36	14.4	15.52
1995	8.02	7.11	7.98	8.9
1996	8.53	7.49	8.52	9.65
1997	6.43	5.16	6.39	7.84
1998	9.76	7.86	9.74	11.65
1999	9.1	7.37	8.97	10.69
2000	3.72	2.73	3.66	5.08
2001	7.79	5.67	7.66	9.66
2002	12.61	9.89	12.55	15.29
2003	9.72	7.48	9.62	12.14
2004	6.32	4.9	6.29	7.87
2005	14.32	12.04	14.23	16.65
2006	9.66	7.77	9.48	11.44
2007	5.59	4.29	5.55	7.1
2008	10.48	8.57	10.5	12.46
2009	8.81	7.18	8.78	10.88
2010	7.8	6.3	7.86	10
2011	4.03	3.25	4.06	5.08

Table 18. Results from base BAM model, sensitivity runs, and retrospective analysis. Fishing mortality (F) is full F and population fecundity (SSB) is in billions of mature ova. Subscripts denote the following MED: median; MED.T: threshold associated with the median; and term: terminal year, which is 2011 for the six rows. * denotes that benchmark calculation is not directly comparable with the base run because of differences in selectivity.

Run	R_{MED}	SSB_{MED}	$SSB_{MED.T}$	SSB_{term} /$SSB_{MED.T}$	$F_{15\%}$	$F_{30\%}$	F_{term} /$F_{15\%}$	F_{term} /$F_{30\%}$
Base run	12.61	19092	9546	1.4	1.34	0.62	3.36	7.22
*cR dome-shaped selectivity	12.52	18090	9045	1.39	1.25	0.64	3.31	6.51
omit JAI	12.72	18365	9182	1.47	1.34	0.62	3.54	7.6
omit PRFC	12.61	19140	9570	1.32	1.34	0.62	3.82	8.2
median effective N	11.96	22043	11021	1.26	1.18	0.57	3.26	6.74
*cR and cB dome-shaped selectivity	14.84	23575	11787	3.67	1.09	0.65	1.51	2.52
Retrospective 2010	12.85	18337	9169	1.23	1.33	0.62	3.31	7.11
Retrospective 2009	13.09	17594	8797	1.88	1.33	0.62	2.75	5.9
Retrospective 2008	13.12	18198	9099	2.2	1.32	0.62	1.56	3.35
Retrospective 2007	13.09	17180	8590	1.48	1.31	0.61	2.3	4.93
Retrospective 2006	13.14	17679	8839	2.5	1.3	0.61	1.46	3.13
Retrospective 2005	13.26	17560	8780	4.77	1.3	0.61	0.63	1.34
Retrospective 2004	13.25	17318	8659	3.06	1.3	0.61	0.94	2
Retrospective 2003	13.26	17077	8539	2.74	1.29	0.6	0.91	1.95
Retrospective 2002	13.89	17940	8970	4.31	1.27	0.6	0.89	1.89
Retrospective 2001	14.58	18570	9285	6.42	1.26	0.6	0.5	1.06
Retrospective 2000	14.6	18266	9133	2.41	1.26	0.59	0.85	1.81

Table 19. The negative log likelihood for the base BAM model and the sensitivity runs.

Run	total	JAI	pound net	cR landings	cB landings	cR age comps	cB age comps	SR fit	SRend
Base run	2457	245	19.46	11.32	1.94	2035.4	125.6	17.7	0.83
cR dome-shaped selectivity	2398	247	19.22	10.44	1.87	1982.2	118.8	17.7	0.74
omit JAI	2191	0	19.91	11.67	1.75	2010.2	122.9	21.2	3.36
omit PRFC	2437	245	0	11.56	2	2034.1	126.4	17.7	0.84
median effective N	424	153	19.45	1.26	0.13	169.12	66.58	14.1	0.25
cR, cB dome-shaped selectivity	2337	245	26.19	8.02	2.25	1945	92.9	17.2	0.78

Table 20. The negative log likelihood for the base BAM model and the retrospective runs.

Ending year	total	JAI	pound net	cR landings	cB landings	cR age comps	cB age comps	SR fit	SRend
Base run	2457	245.3	19.46	11.32	1.94	2035.4	125.57	17.65	0.83
2010	2395	239	19.24	11.22	1.82	2002.2	103.21	17.45	0.67
2009	2357	238.4	19.31	11.15	1.77	1974.5	93.42	17.66	0.58
2008	2324	230.4	17	11.12	1.78	1954.4	91.26	17.19	0.82
2007	2275	205	16.13	10.91	1.78	1934.1	88.34	17.11	1.16
2006	2222	194.3	13.59	10.75	1.77	1902.2	79.22	17.82	2.07
2005	2192	190.2	12.69	10.52	1.77	1887.4	73.24	15.86	0.63
2004	2173	188	12.63	10.38	1.75	1872.2	71.8	15.64	0.45
2003	2144	185.1	12.43	10.17	1.71	1849.4	69.97	15.07	0
2002	2097	182.9	11.88	9.67	1.64	1809.3	65.58	15.26	0.52
2001	2055	165	12.93	9.62	1.53	1787.2	63.57	14.3	0.62
2000	2019	169.7	11.73	9.45	1.59	1753.2	59.67	13.69	0.06

Table 21. Summary of benchmarks and terminal year (2011) values estimated for the base BAM model. Fishing mortality rate is full F, and SSB is fecundity in billions of mature ova. Benchmarks were calculated using the time period 1955-2011.

Benchmarks and Terminal Year Values	Base BAM Model Estimates 1955-2011
Median Age-0 Recruits (billions)	12.61
$F_{30\%}$	0.62
$F_{15\%}$	1.34
F_{2011}	4.5
$F_{2011}/F_{30\%}$	7.22
$F_{2011}/F_{15\%}$	3.36
Target: SSB_{MED}	19,092
Threshold (Limit):	
$SSB_{MED.thresh}$	9,546
SSB_{2011}	13,334
$SSB_{2011}/SSB_{threshold}$	1.4

Table 22. The probability of the fishing mortality rate (F) being less than the THRESHOLD over time for given constant landing scenarios. Total landings are partitioned with 75% to the commercial reduction fishery and 25% to the commercial bait fishery.

Landings (1000s mt)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
75	0.00	0.09	0.86	0.99	1.00	1.00	1.00	1.00	1.00	1.00
100	0.00	0.01	0.50	0.89	0.97	1.00	1.00	1.00	1.00	1.00
125	0.00	0.00	0.19	0.58	0.81	0.92	0.97	0.99	0.99	1.00
150	0.00	0.00	0.04	0.25	0.47	0.62	0.74	0.83	0.90	0.93
175	0.00	0.00	0.01	0.06	0.16	0.27	0.36	0.44	0.51	0.57
200	0.00	0.00	0.00	0.01	0.02	0.06	0.10	0.12	0.14	0.17
225	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02

Table 23. The probability of the fishing mortality rate (F) being less than the TARGET over time for given constant landing scenarios. Total landings are partitioned with 75% to the commercial reduction fishery and 25% to the commercial bait fishery.

Landings (1000s mt)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
75	0.00	0.00	0.24	0.83	0.98	1.00	1.00	1.00	1.00	1.00
100	0.00	0.00	0.02	0.37	0.72	0.90	0.97	0.99	1.00	1.00
125	0.00	0.00	0.00	0.06	0.28	0.49	0.65	0.78	0.87	0.91
150	0.00	0.00	0.00	0.01	0.04	0.11	0.21	0.31	0.38	0.46
175	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08
200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
225	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

15 Figures

Figure 1. Annual menhaden reduction and bait landings (1,000 t), 1940-2011.

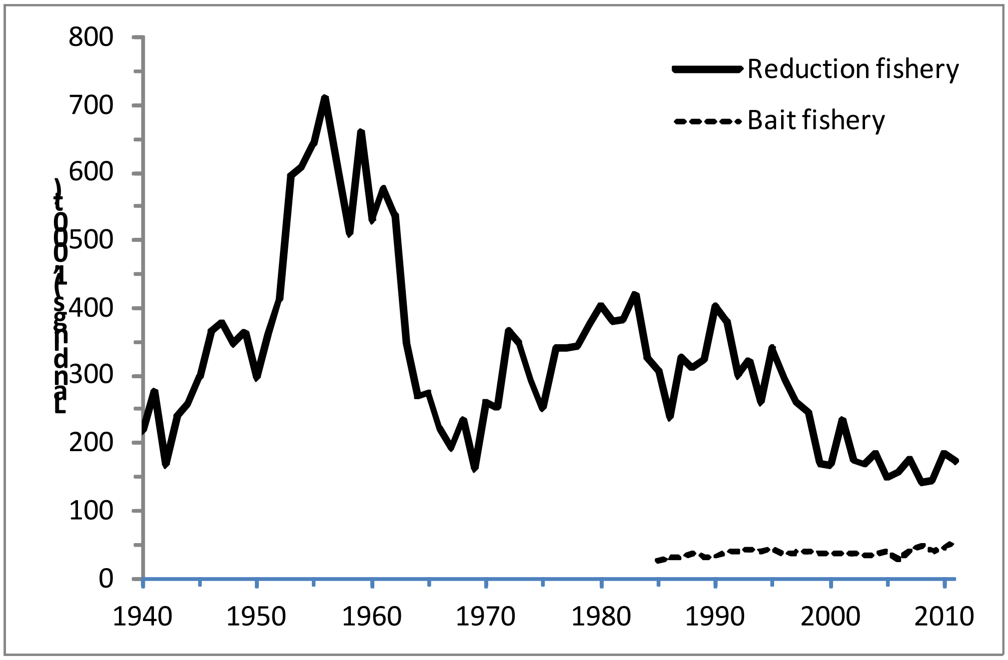


Figure 2. Annual menhaden bait landings (1,000 t), 1985-2011.

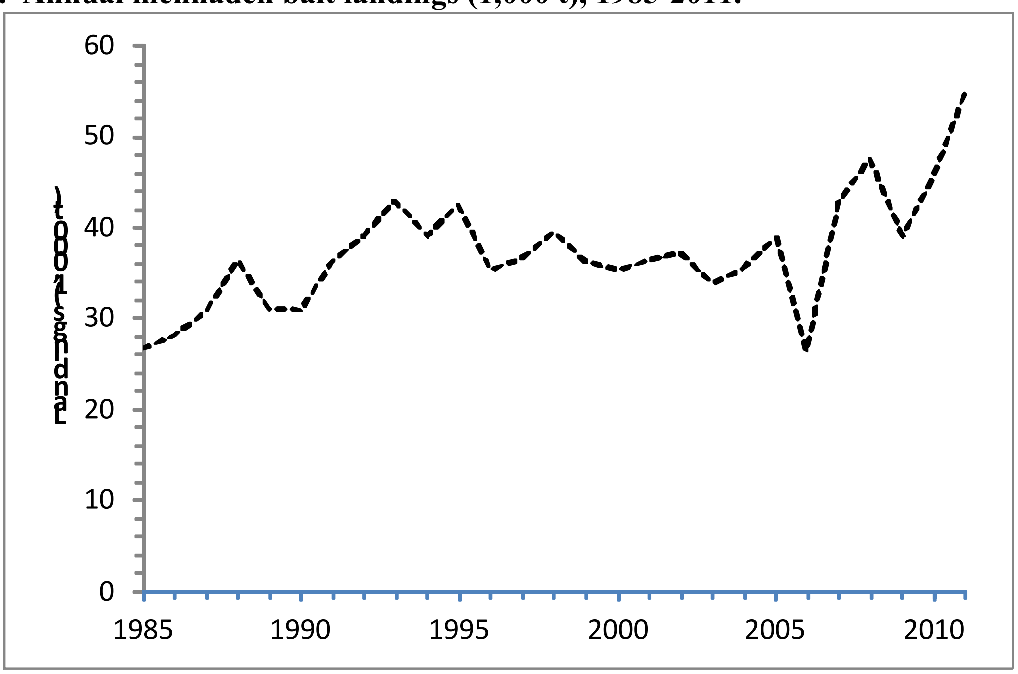
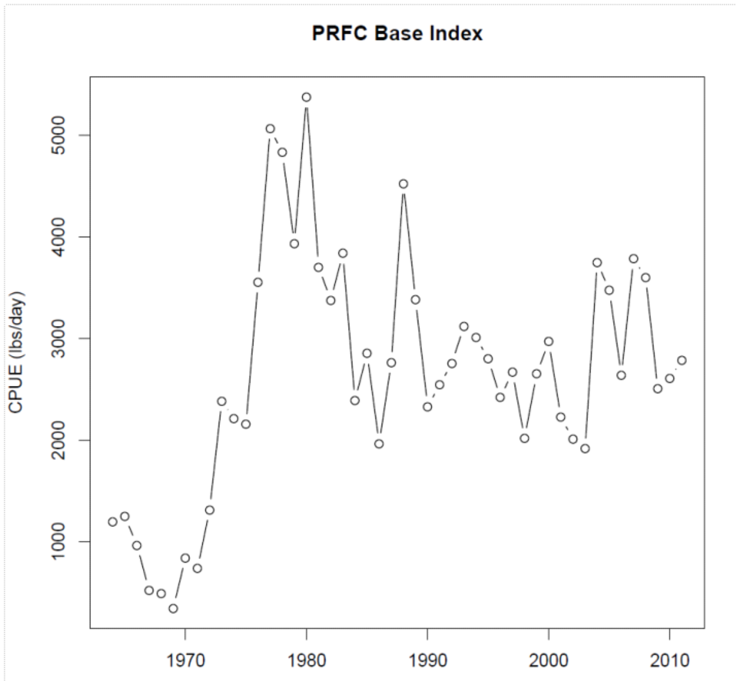


Figure 3. Top: PRFC adult Atlantic menhaden (primarily ages-1 through 3) index of relative abundance derived from annual ratios of pounds landed and pound net days fished. CPUE for the years 1964-1975 and 1981-1987 were estimated from regressions of published landings (to obtain annual landings) and licenses (to obtain total annual days fished). Bottom: Comparison of PRFC index between 2010 benchmark and 2012 update assessments; the red line represents the index used in the benchmark, 1964-2008, and the blue line indicates the updated and corrected index, 1964-2011.



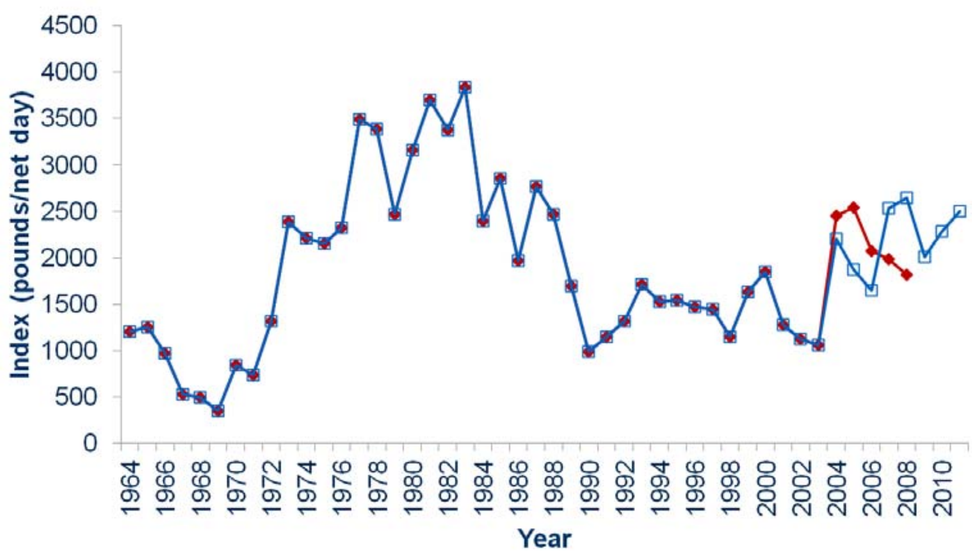


Figure 4. Recreational landings (1000s mt) from the benchmark assessment (dashed line) and for the update assessment (solid line). Differences in landings from 2004-2008 occurred because of a move from MRFSS to MRIP for those years. The current update assessment used MRFSS values from 1981-2003 and MRIP values from 2004-2011.

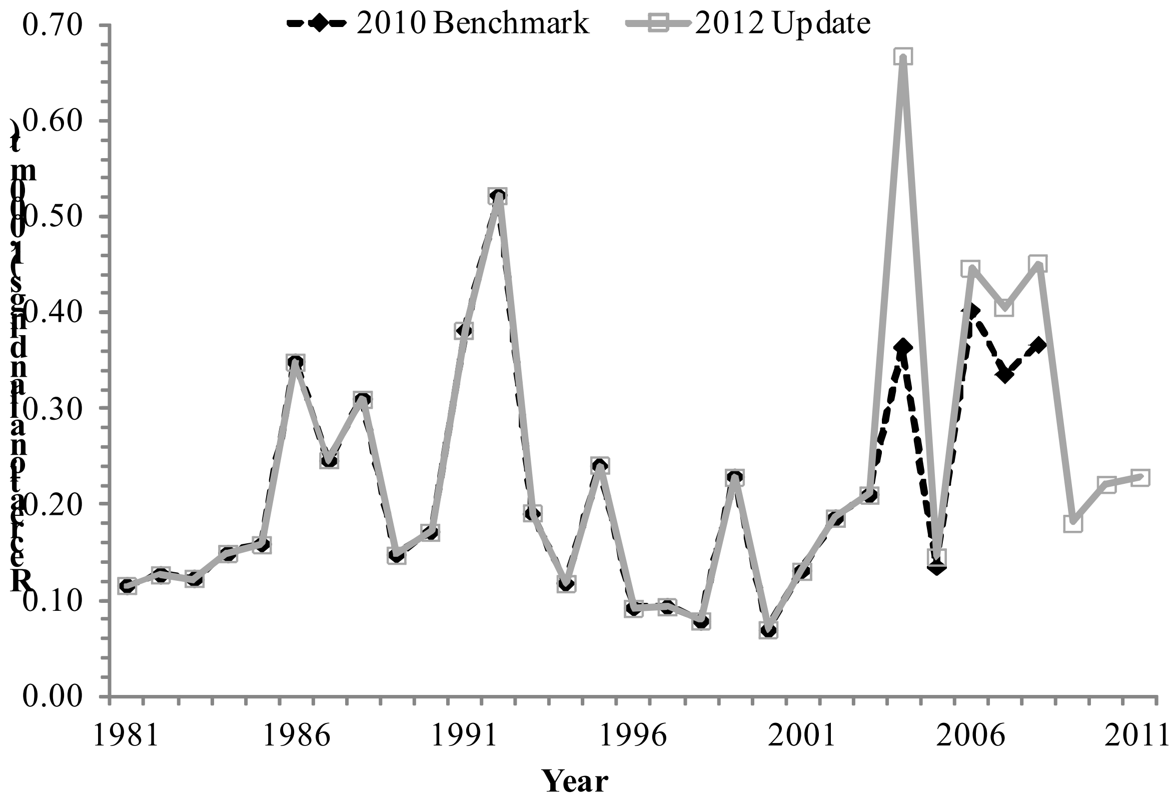


Figure 5. Coastwide juvenile abundance index (black line) based on the delta-lognormal GLM with fixed factors year, month, and state fitted to seine catch-per-haul data for 1959-2011 from all states combined. Coefficients of variations (CV; grey line) were calculated from jackknifed derived SEs.

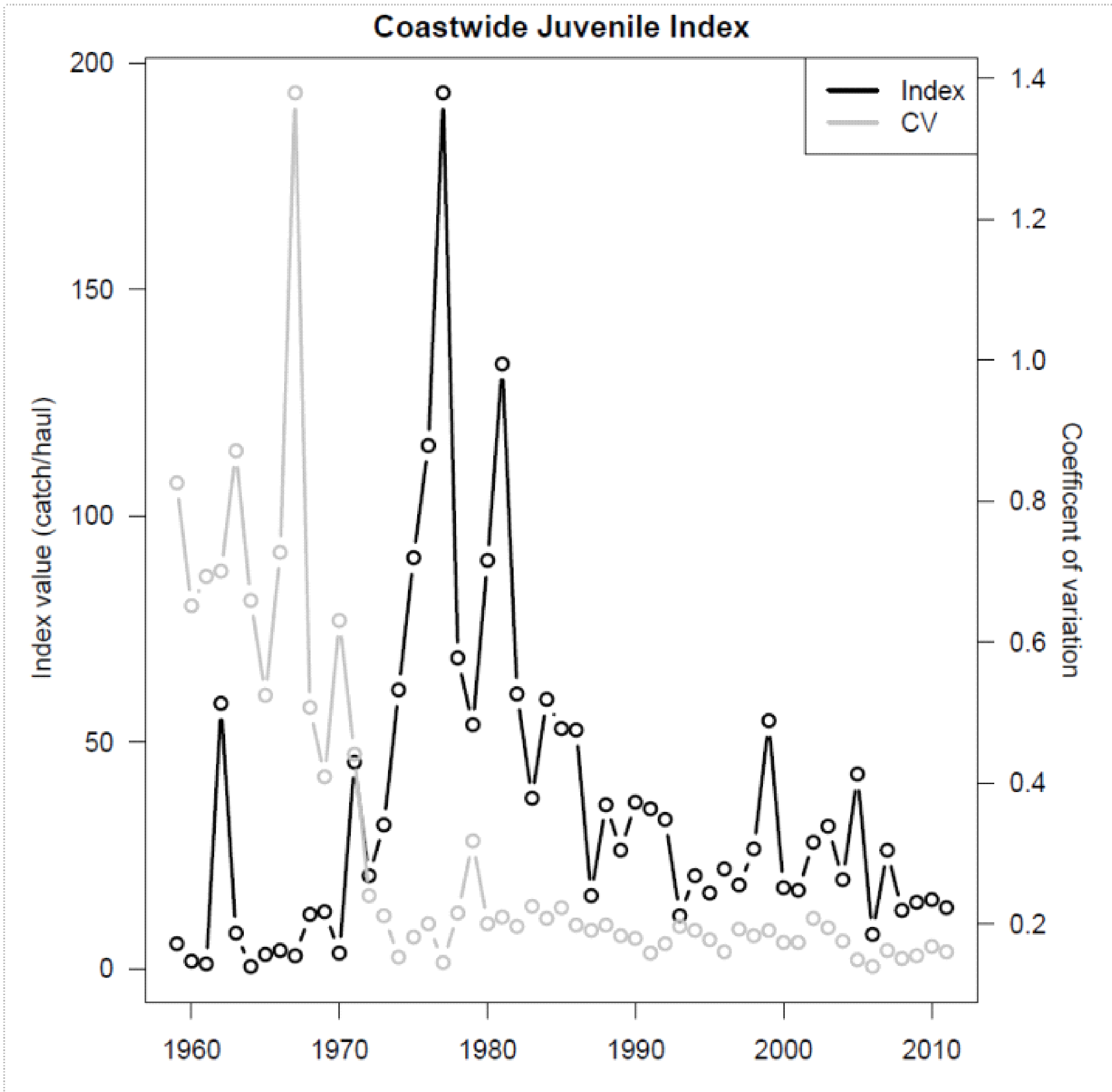


Figure 6. Observed (open circles) and predicted (connected points) landings in 1,000 metric tons of Atlantic menhaden by the commercial reduction fishery from the base BAM model.

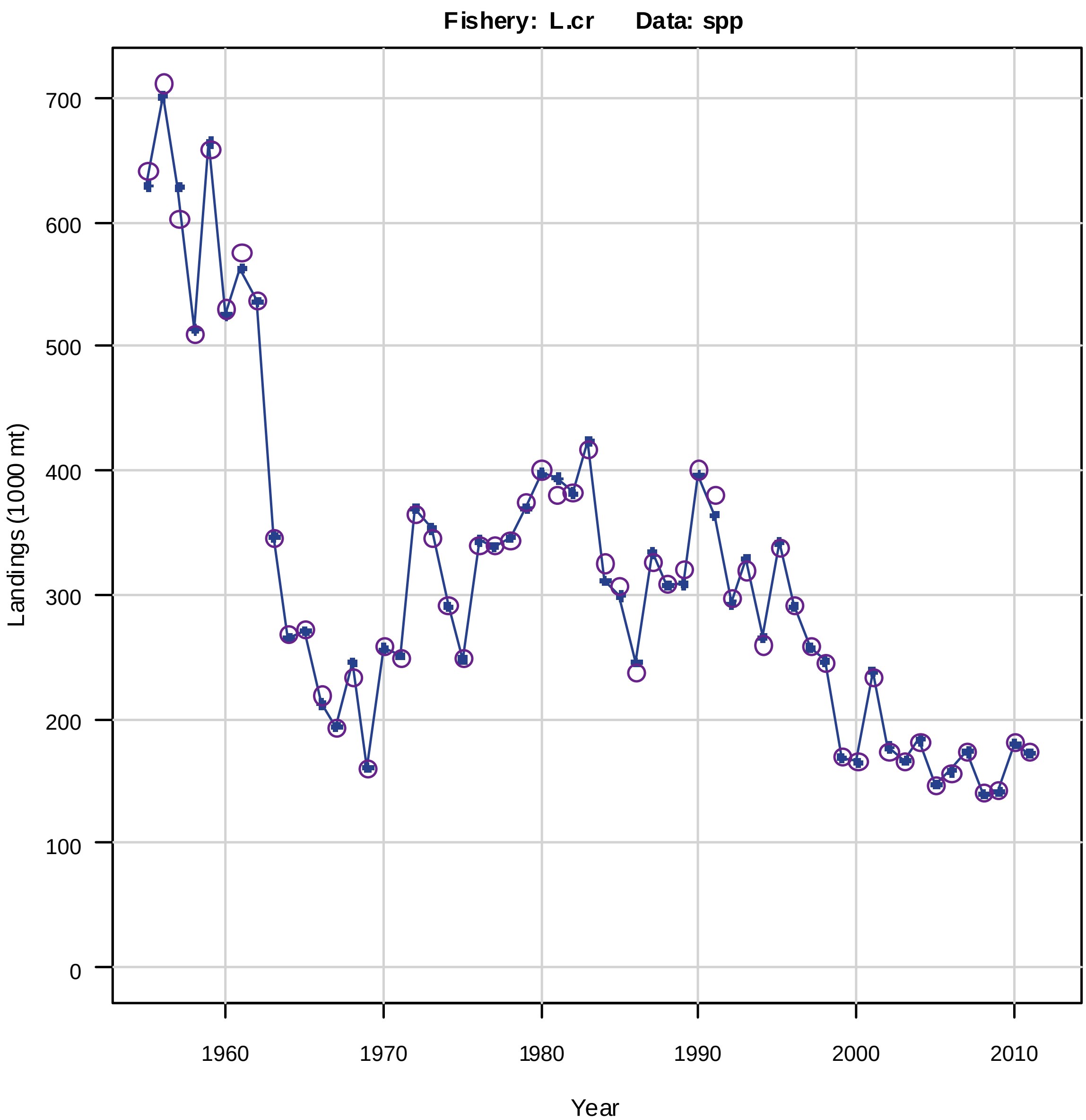


Figure 7. Observed (open circles) and predicted (connected points) landings in 1000 metric tons of Atlantic menhaden by the bait fishery from the base BAM model.

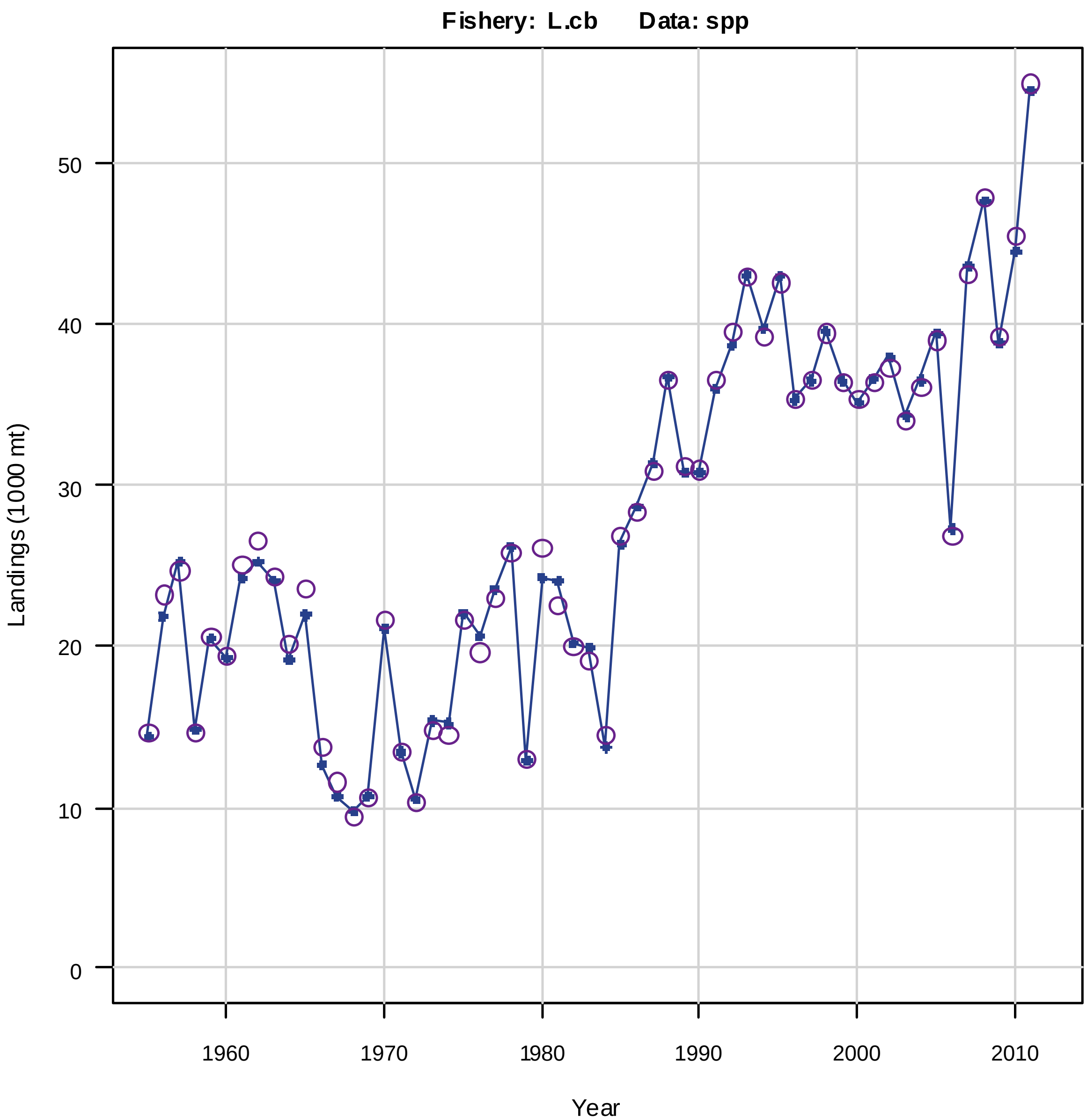


Figure 8. Observed (open circles) and predicted (connected points) landings in 1,000 metric tons of Atlantic menhaden by the commercial reduction fishery from the base BAM model for the 2010 benchmark assessment (red) and the current update assessment (blue).

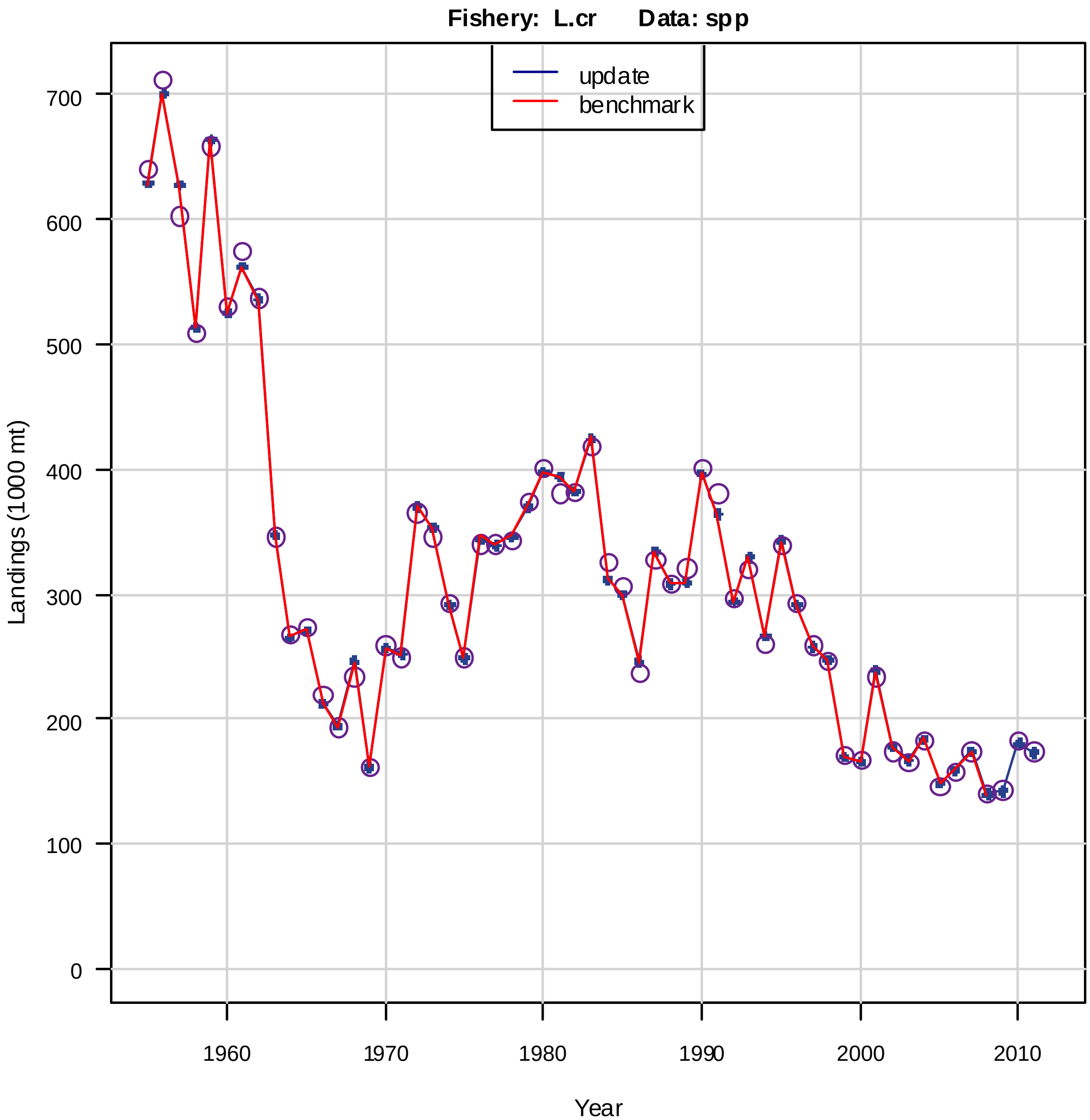


Figure 9. Observed (open circles) and predicted (connected points) landings in 1,000 metric tons of Atlantic menhaden by the commercial bait fishery from the base BAM model for the 2010 benchmark assessment (red) and the current update assessment (blue).

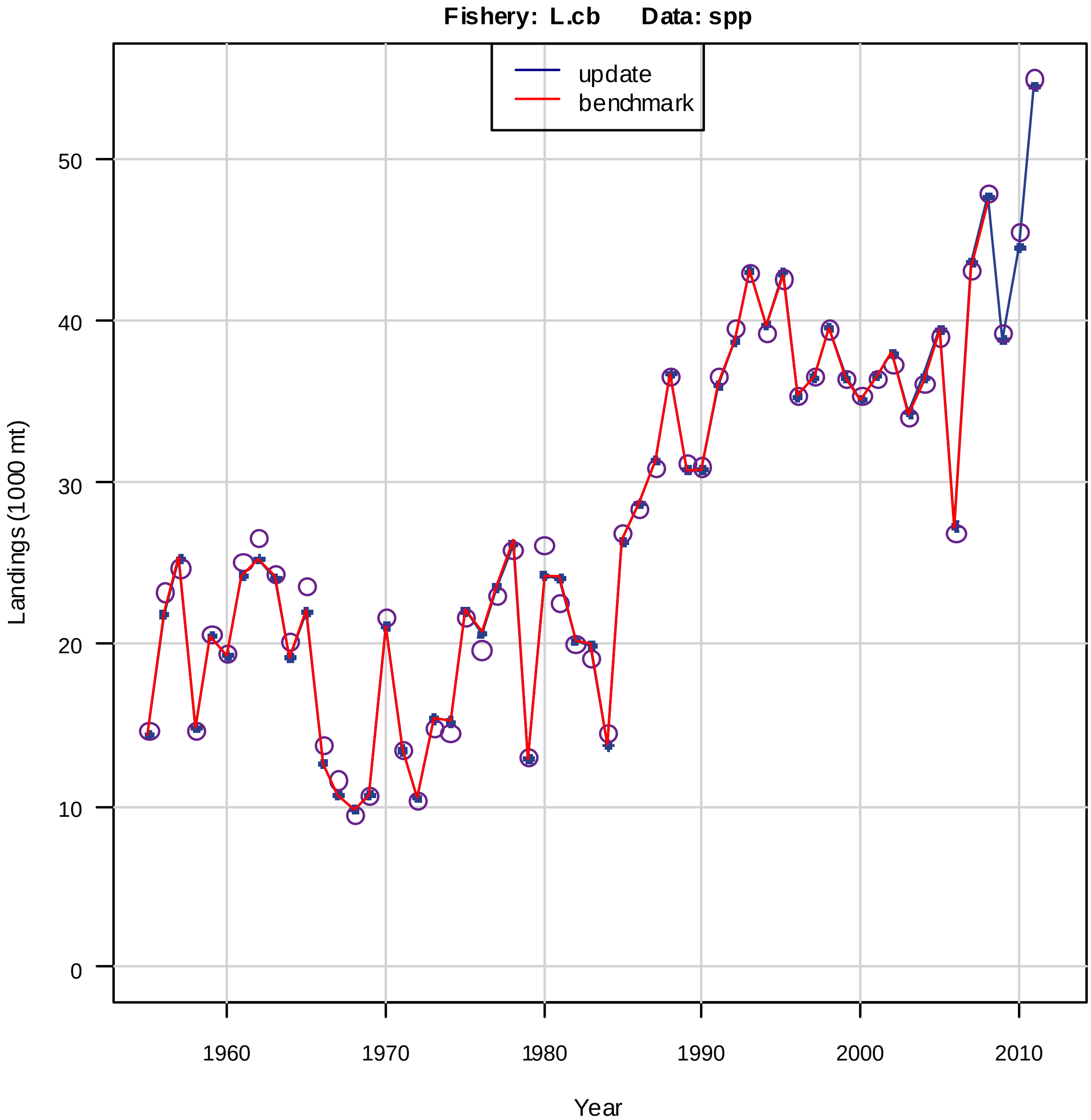


Figure 10. Annual observed (open circles) and predicted (connected points) proportions at age for Atlantic menhaden from the commercial reduction fishery from the base BAM model. The number of trips sampled (N) is indicated for each year.

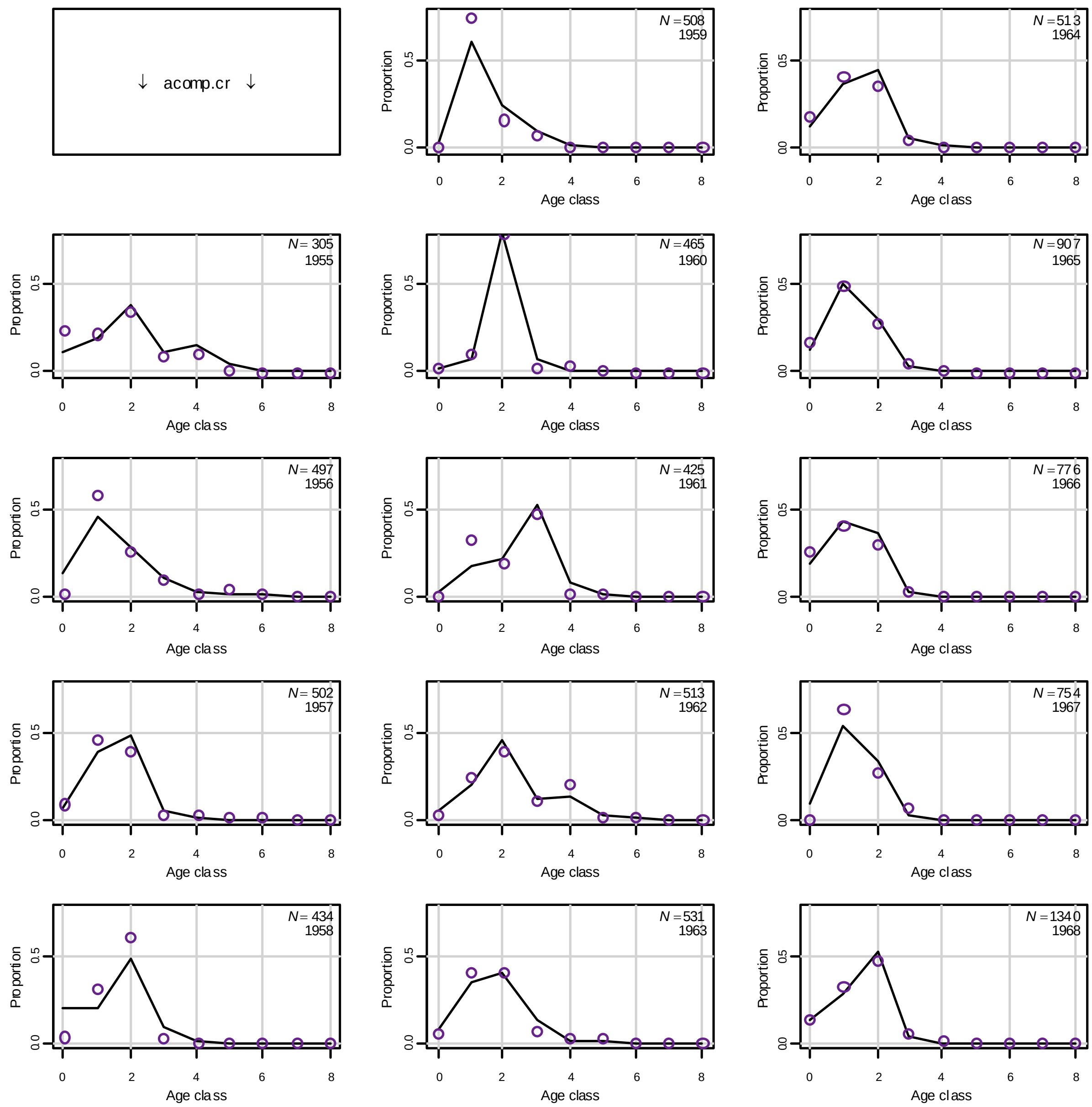


Figure 10. (*continued*).

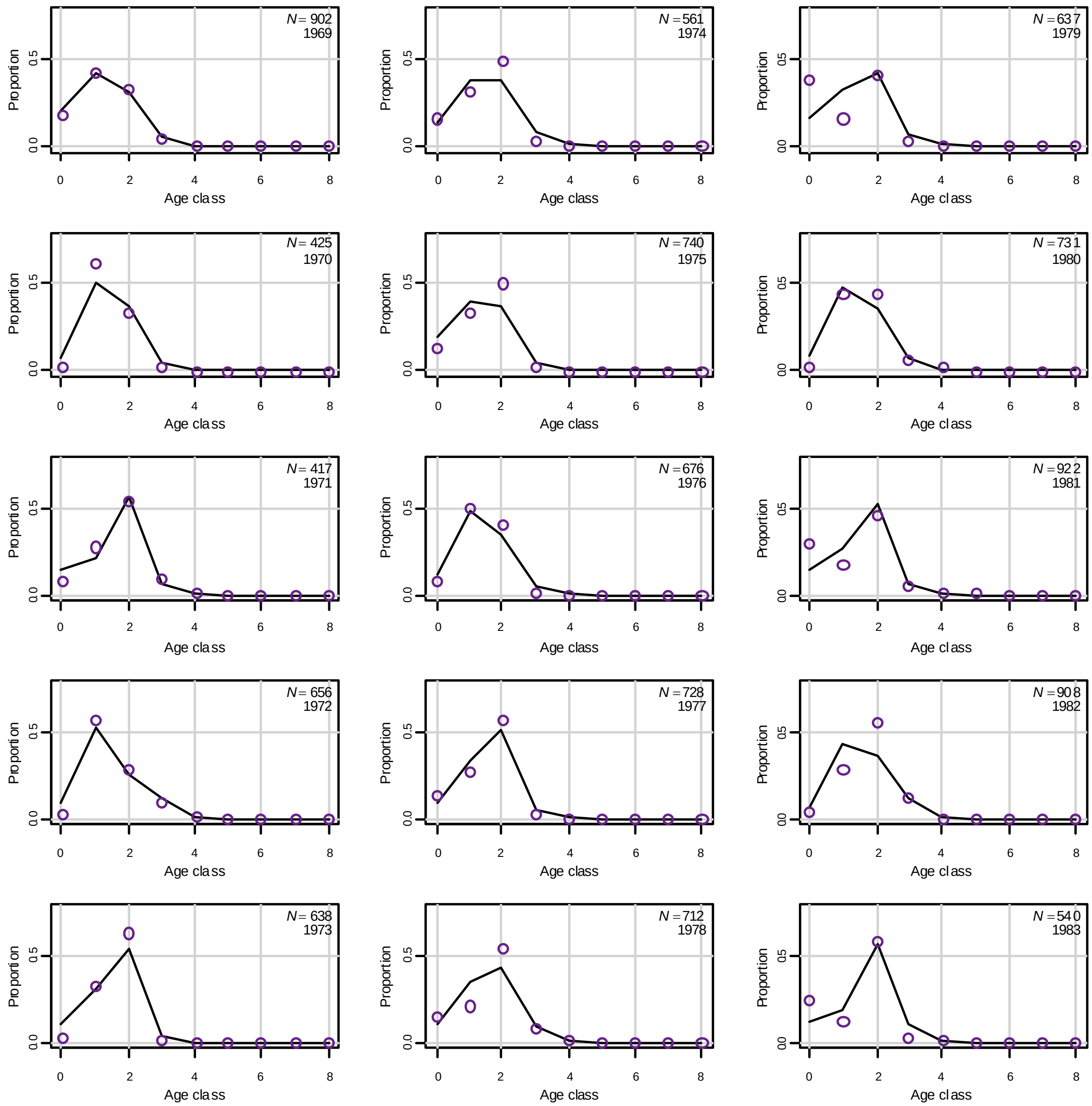


Figure 10. (*continued*).

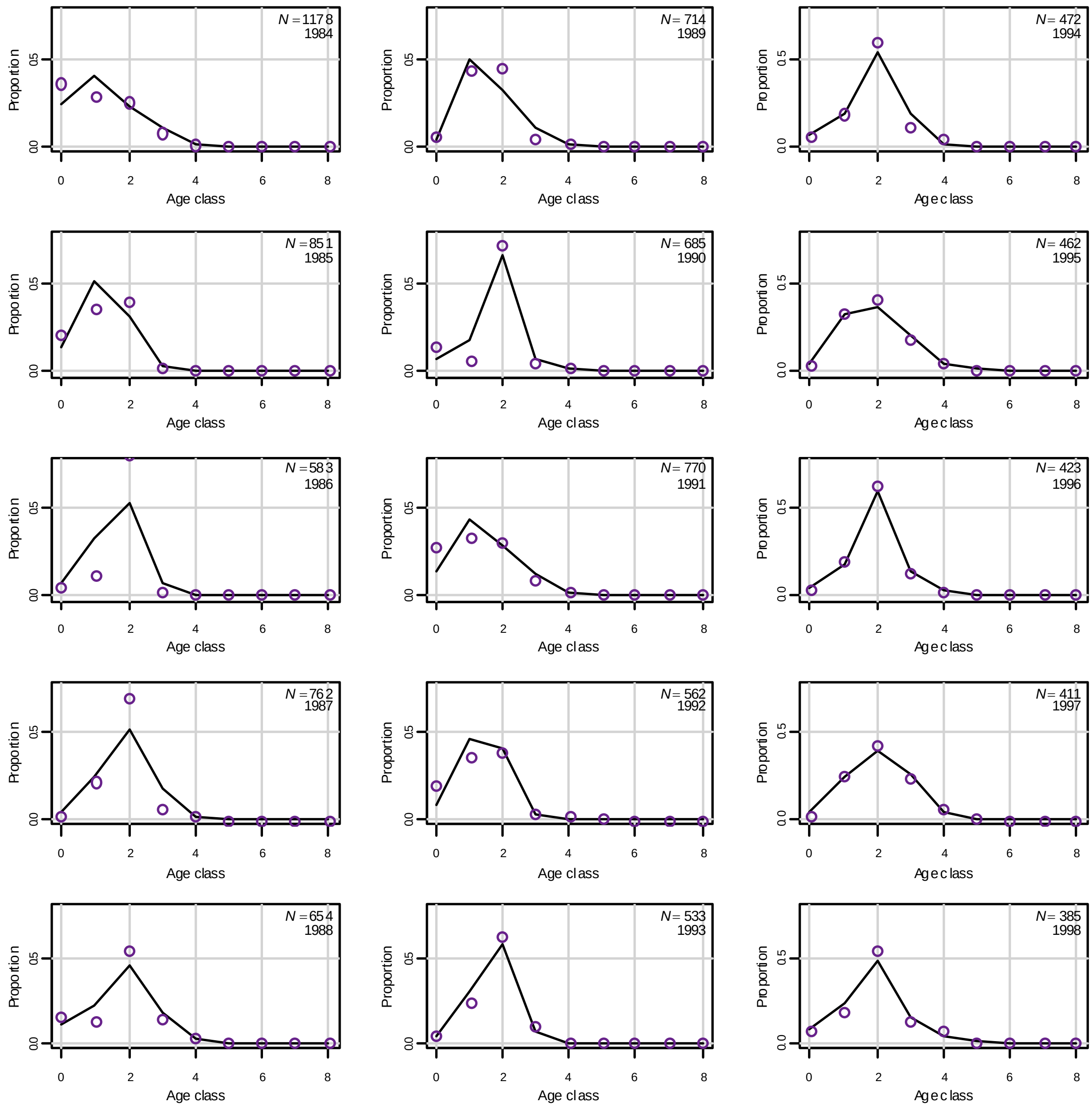


Figure 10. (*continued*).

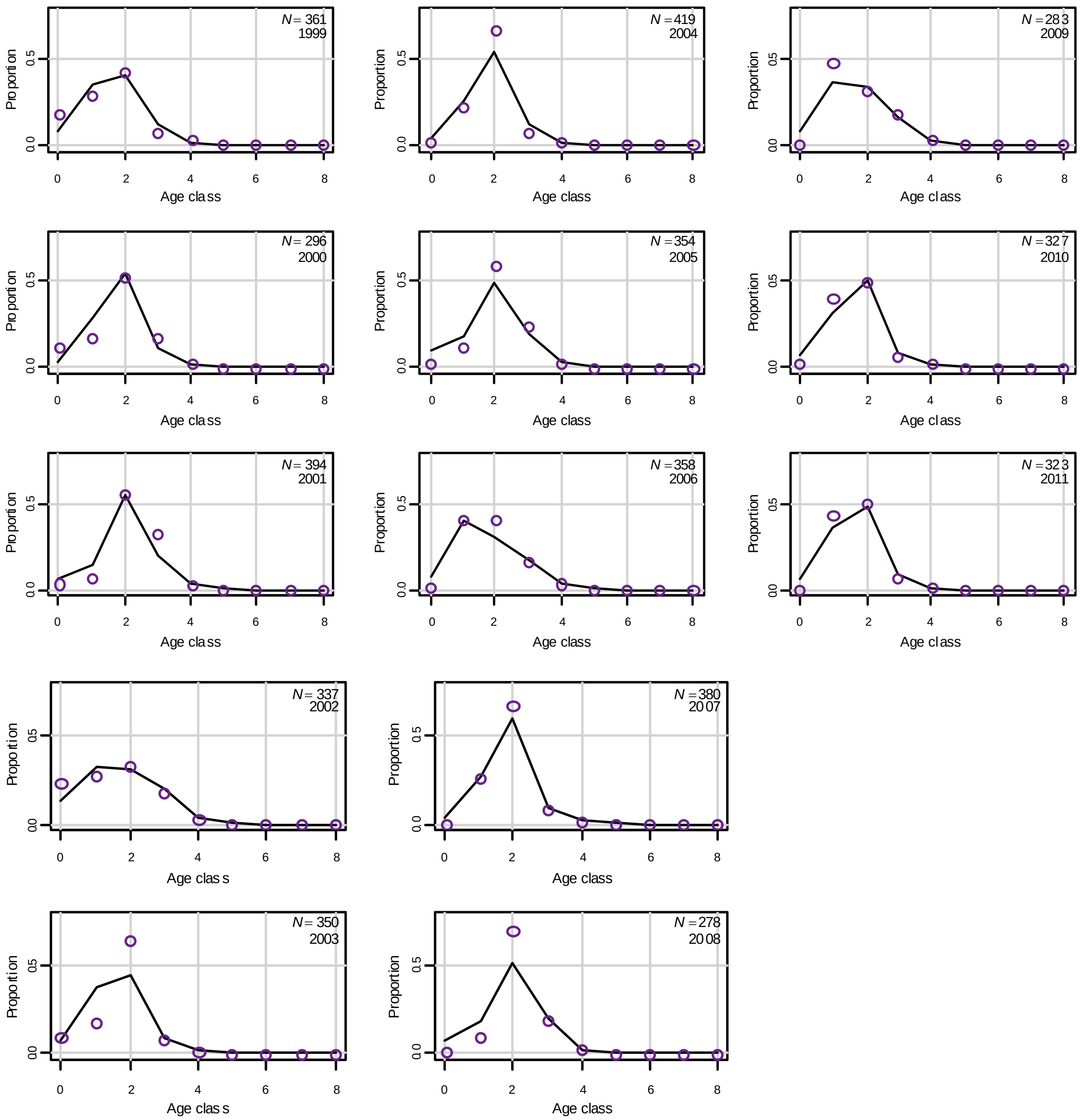


Figure 11. Bubble plot of Atlantic menhaden commercial reduction fishery catch-at-age residuals from the base BAM model. Area of circles is relative to the size of the residual and blue (dark) circles indicate an overestimate by the BAM model.

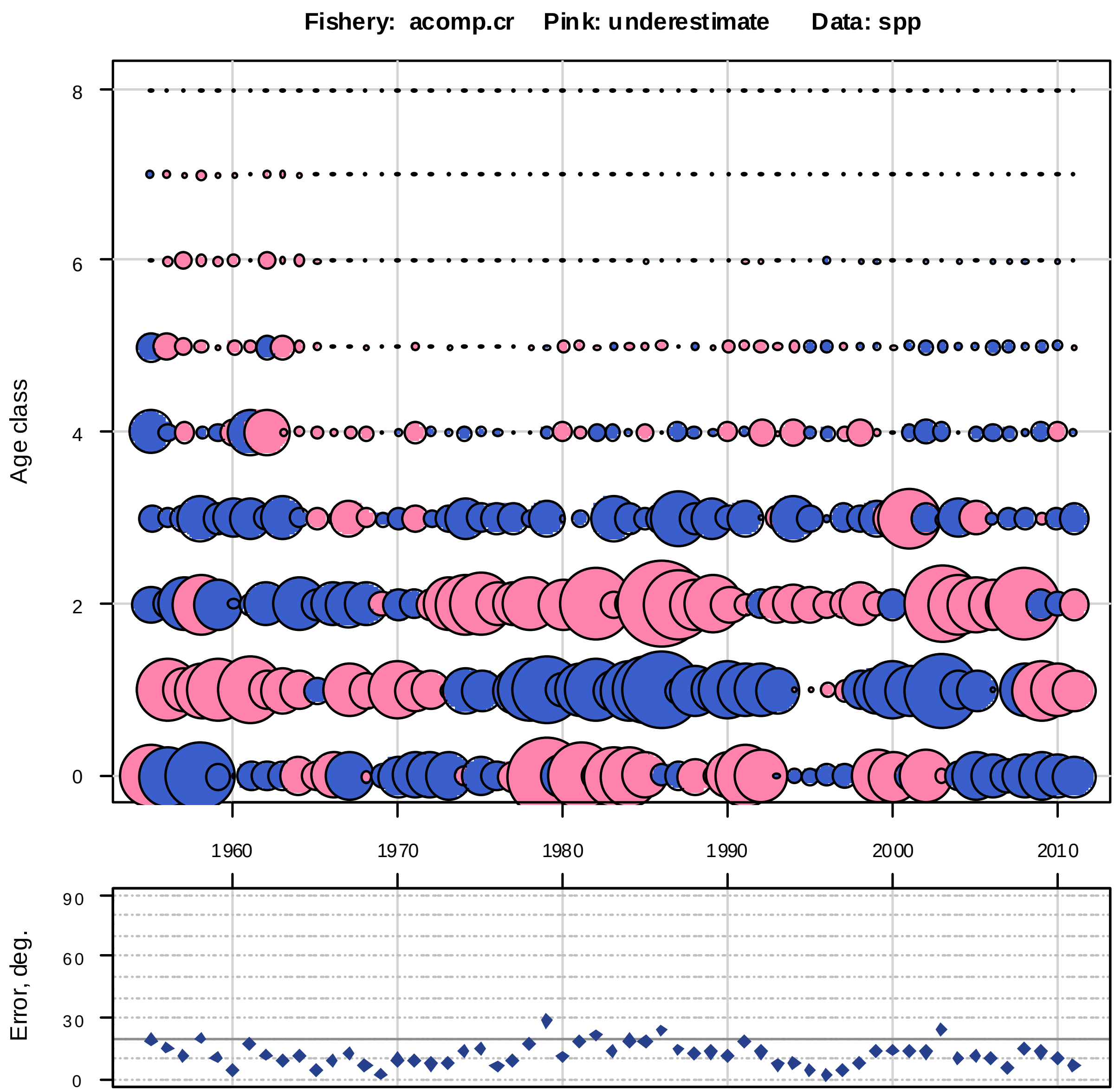


Figure 12. Annual observed (open circles) and predicted (connected points) proportions at age for Atlantic menhaden from the bait fishery from the base BAM model. The number of trips sampled (N) is indicated for each year.

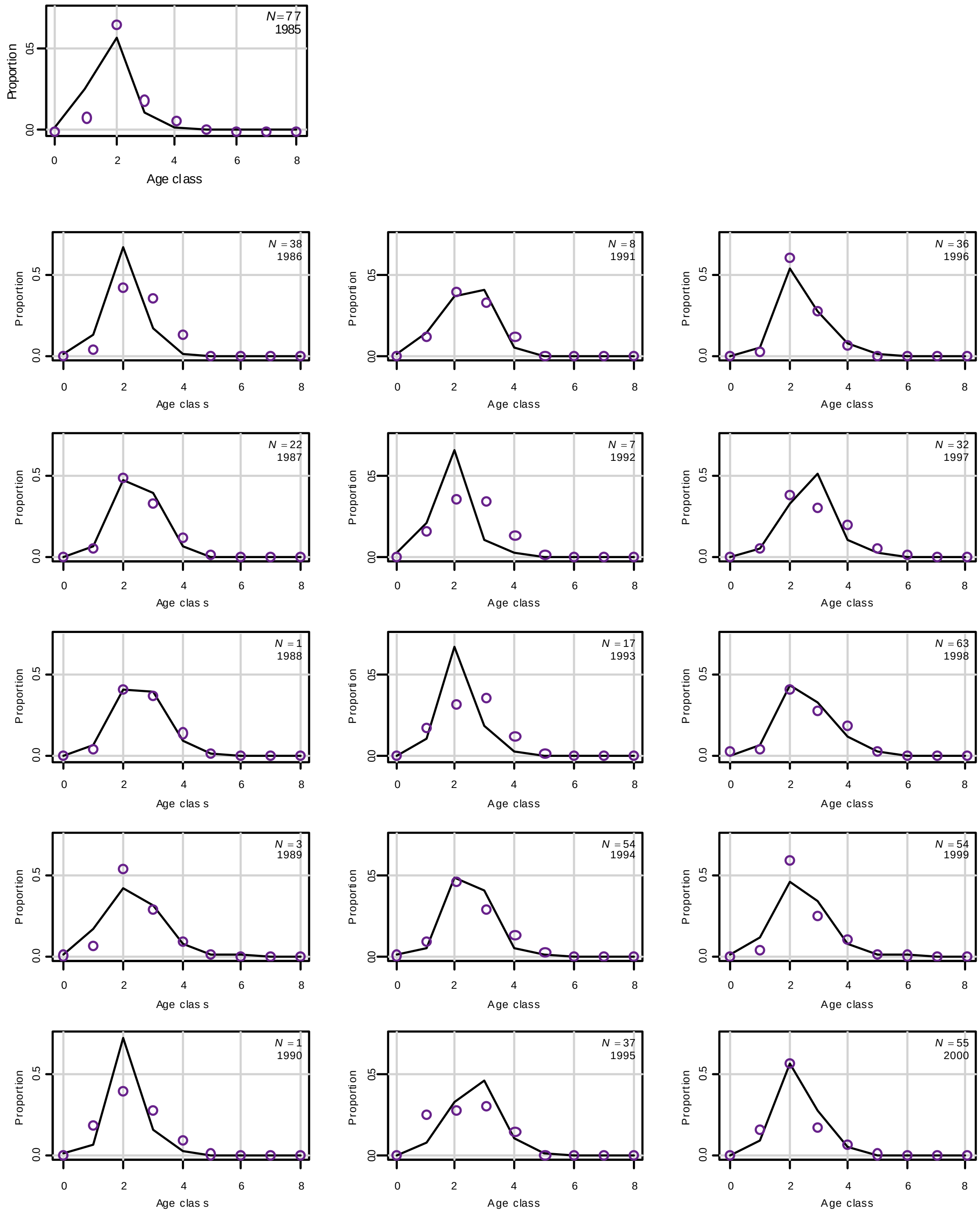


Figure 12. (*continued*).

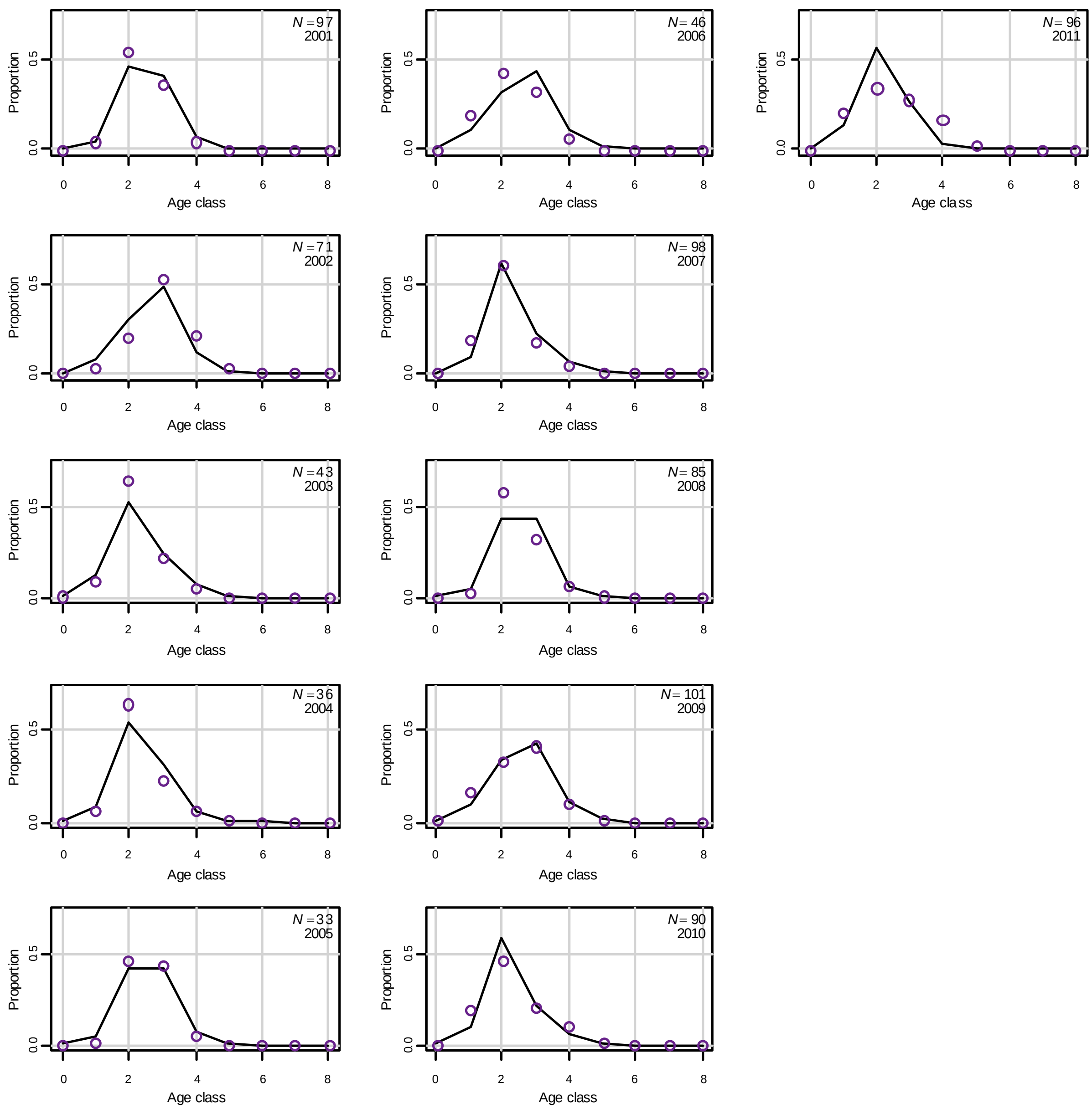


Figure 13. Bubble plot of Atlantic menhaden bait fishery catch-at-age residuals from the base BAM model. Area of circles is relative to the size of the residual and blue (dark) circles indicate an overestimate by the BAM model.

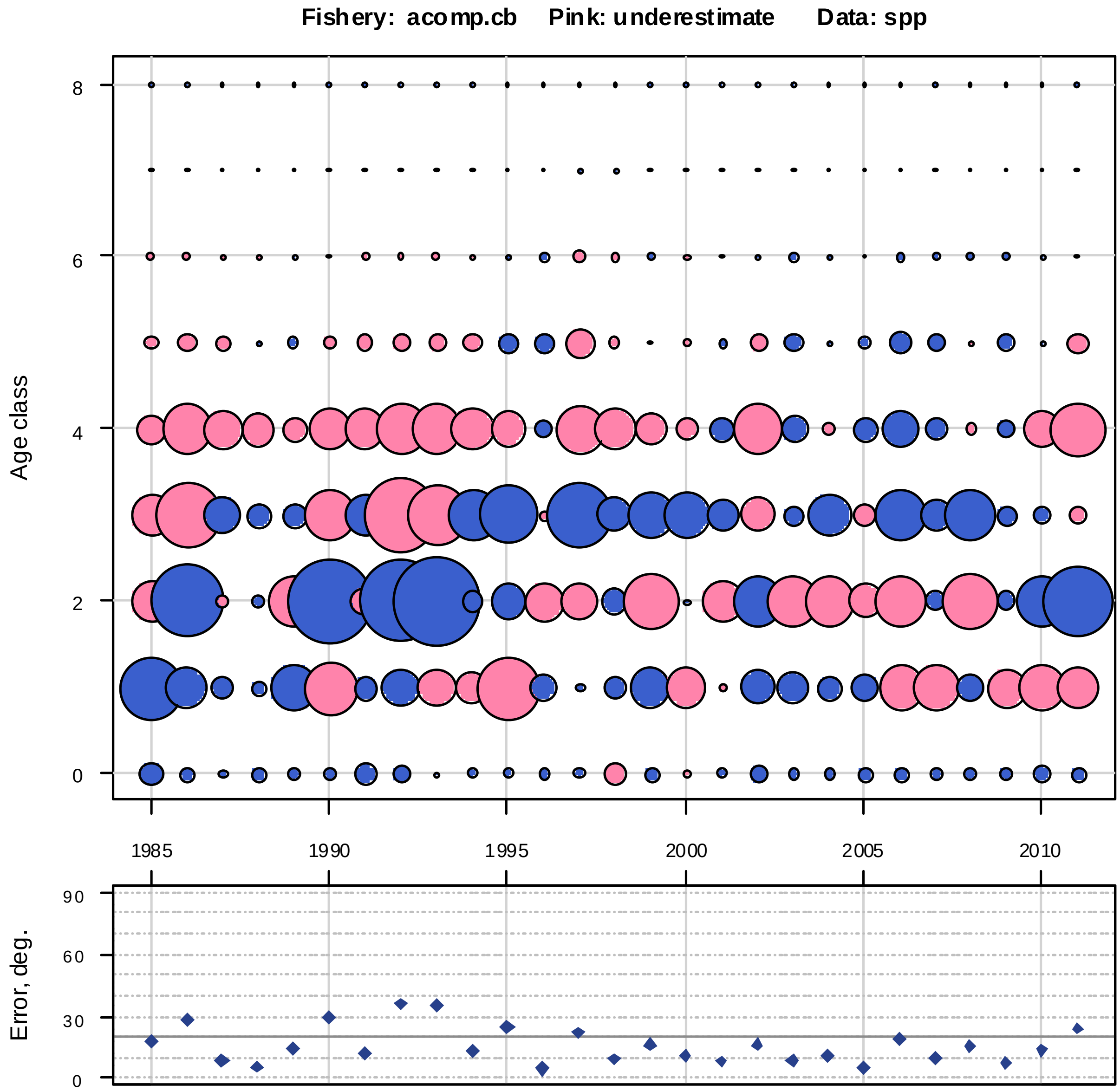


Figure 14. Annual observed (open circles) and predicted (lines) proportions at age for Atlantic menhaden from the commercial reduction fishery from the base BAM model for the last benchmark assessment (red) and the current update assessment (black). The number of trips sampled (*N*) is indicated for each year.

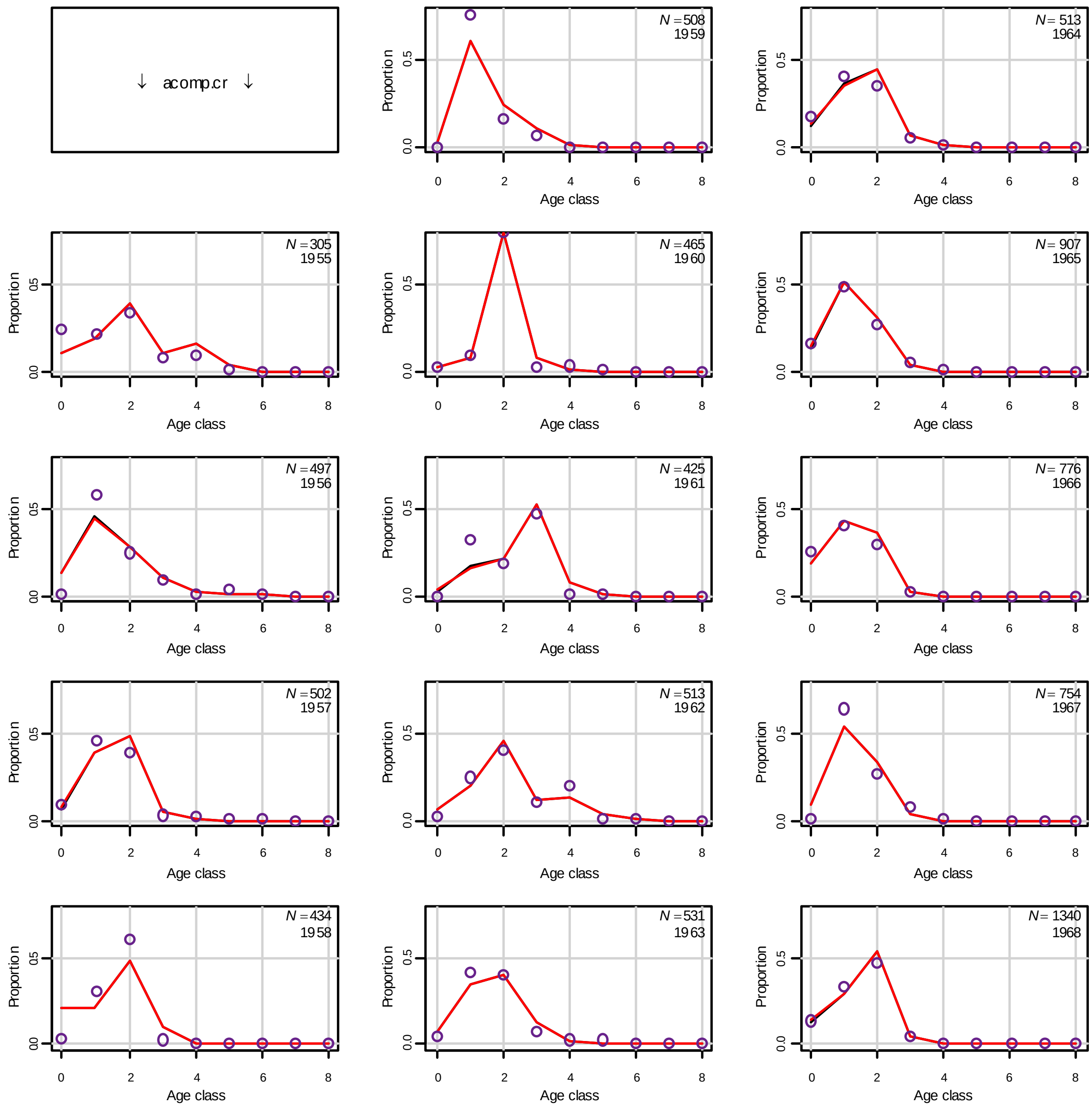


Figure 14. (*continued*).

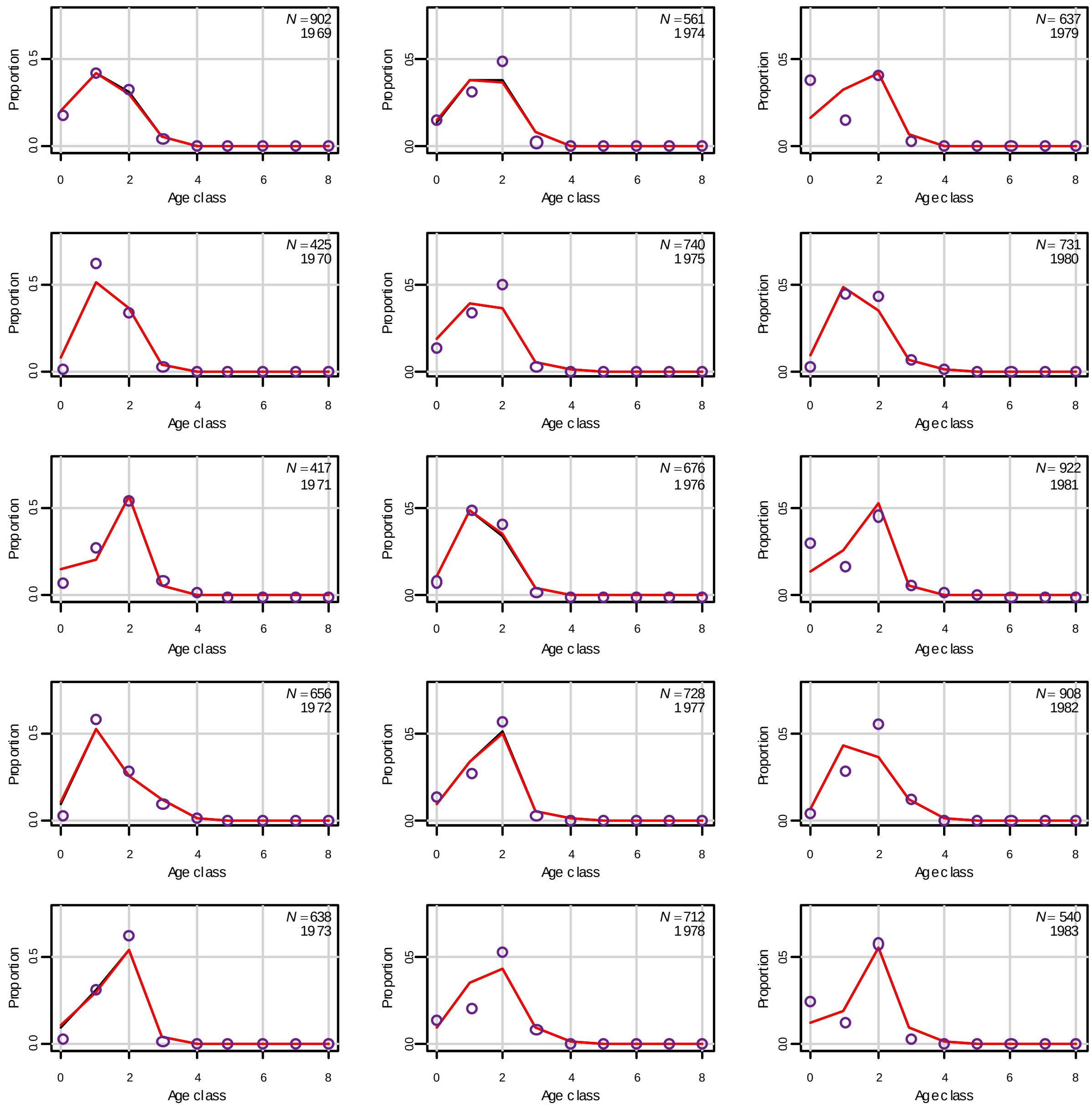


Figure 14. (*continued*).

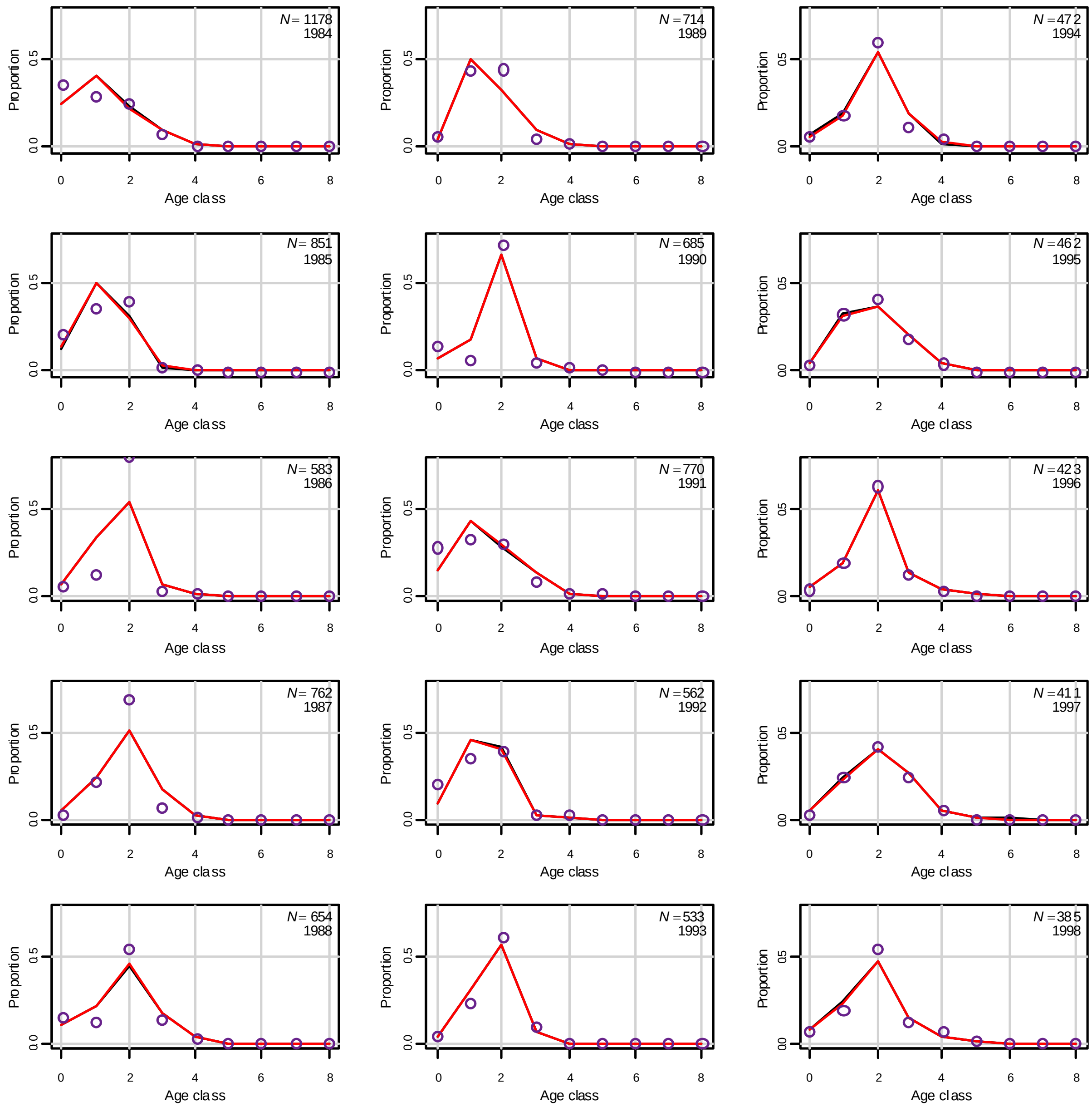


Figure 14. (*continued*).

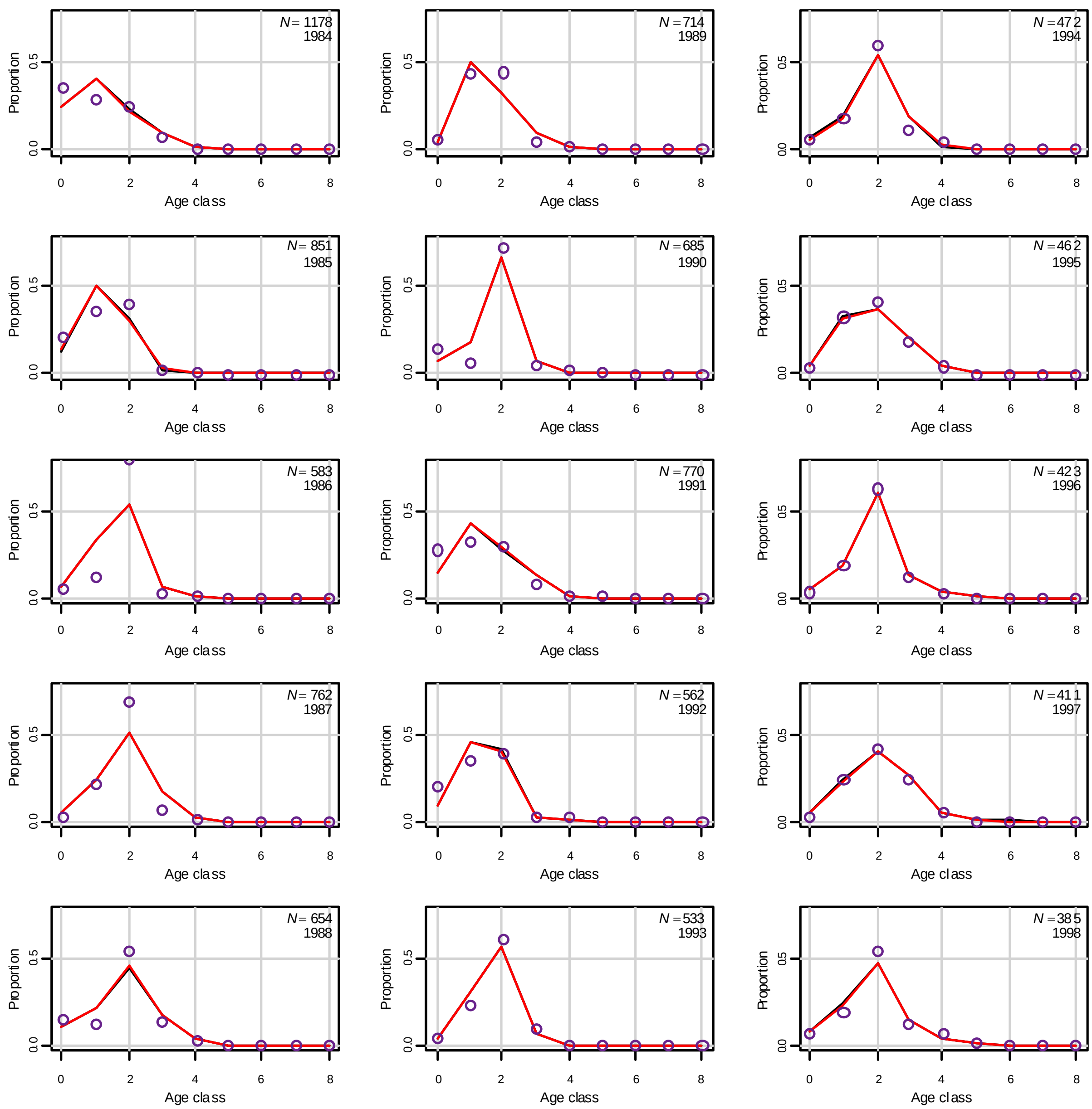


Figure 14. (*continued*).

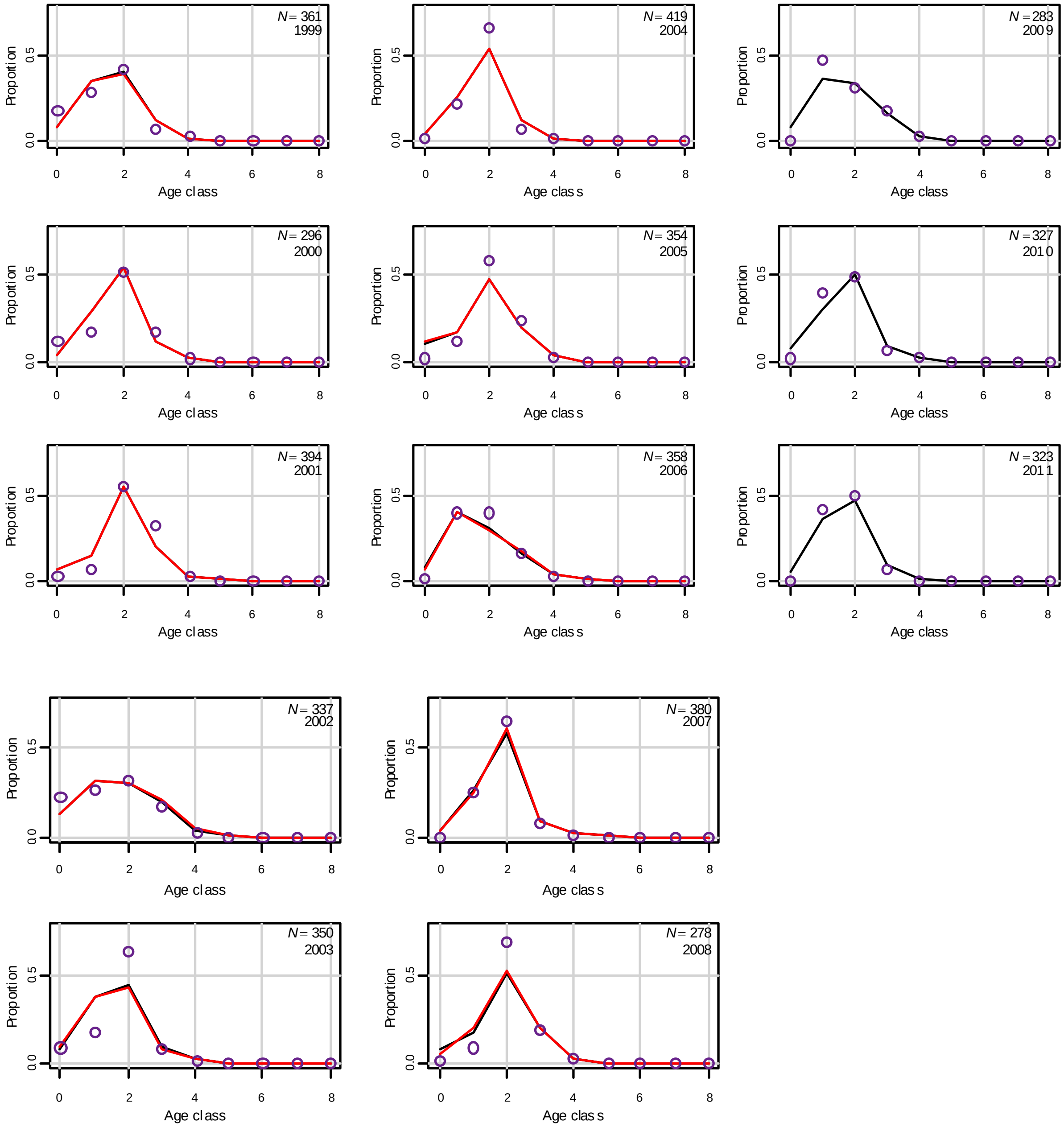


Figure 15. Annual observed (open circles) and predicted (lines) proportions at age for Atlantic menhaden from the commercial bait fishery from the base BAM model for the last benchmark assessment (red) and the current update assessment (black). The number of trips sampled (*N*) is indicated for each year.

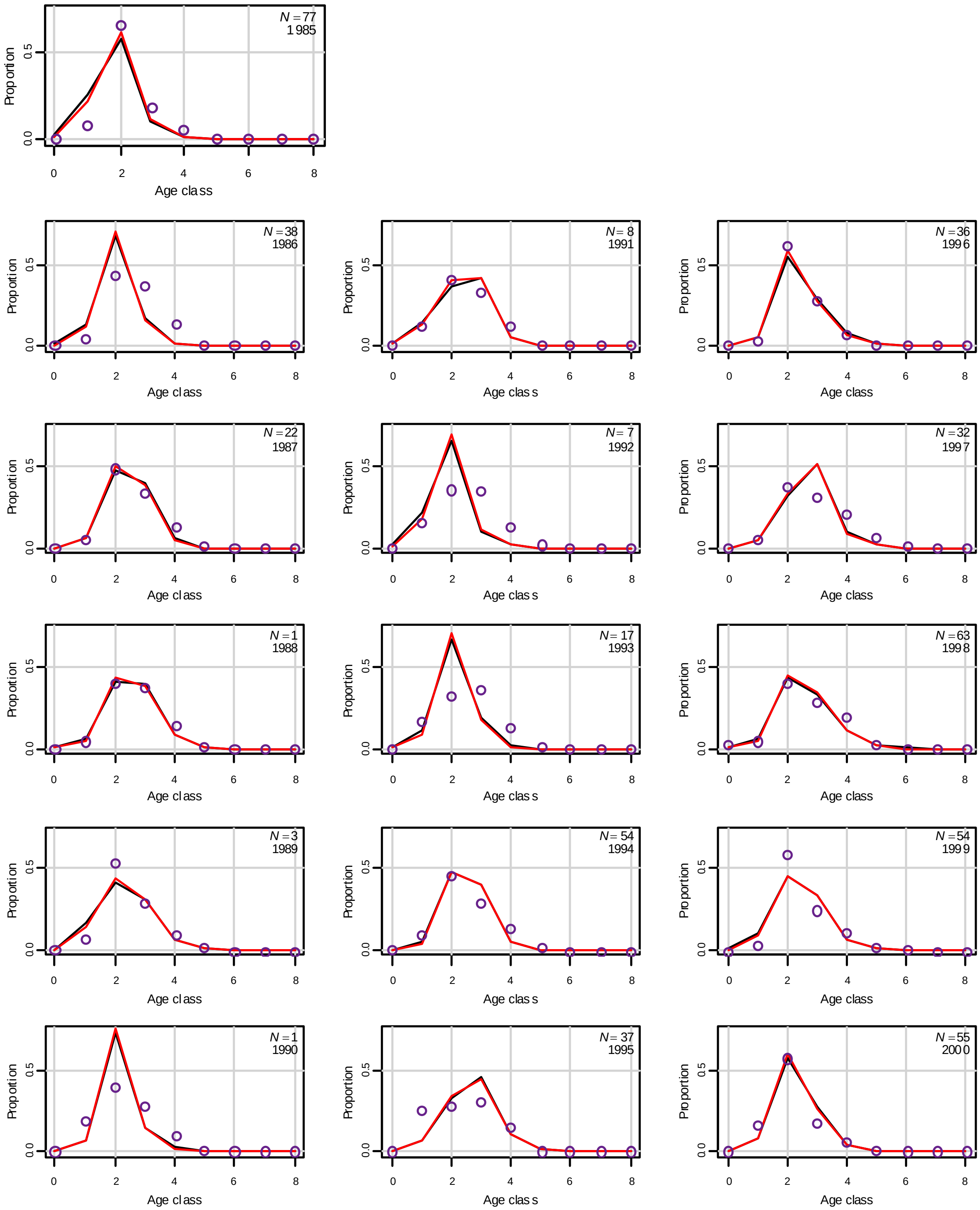


Figure 15. (*continued*).

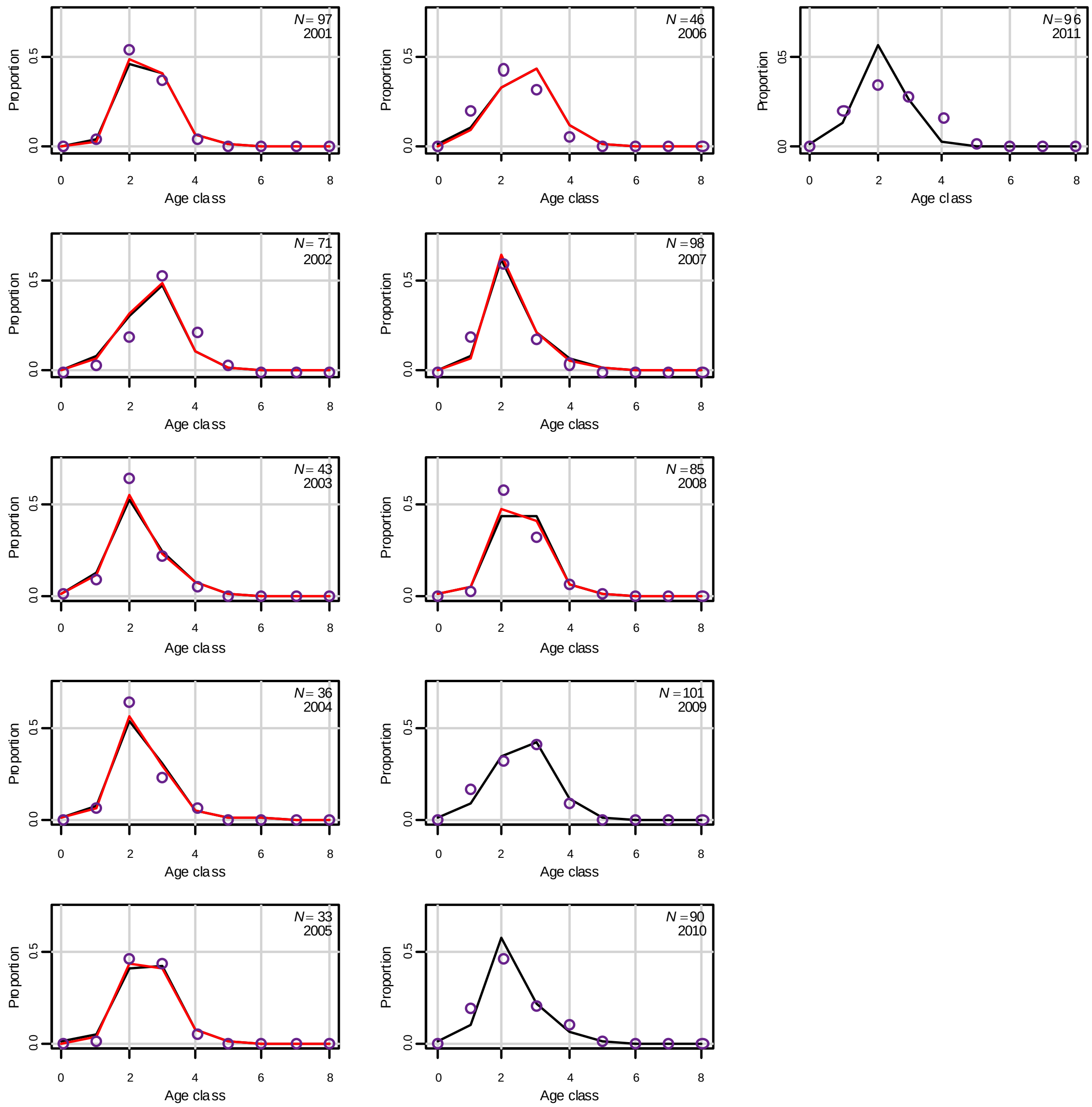


Figure 16. Observed (open circles) and predicted (connected points) juvenile abundance index values for Atlantic menhaden from the base BAM model. Bottom panel indicates pattern and magnitude of log-transformed residuals of model fit.

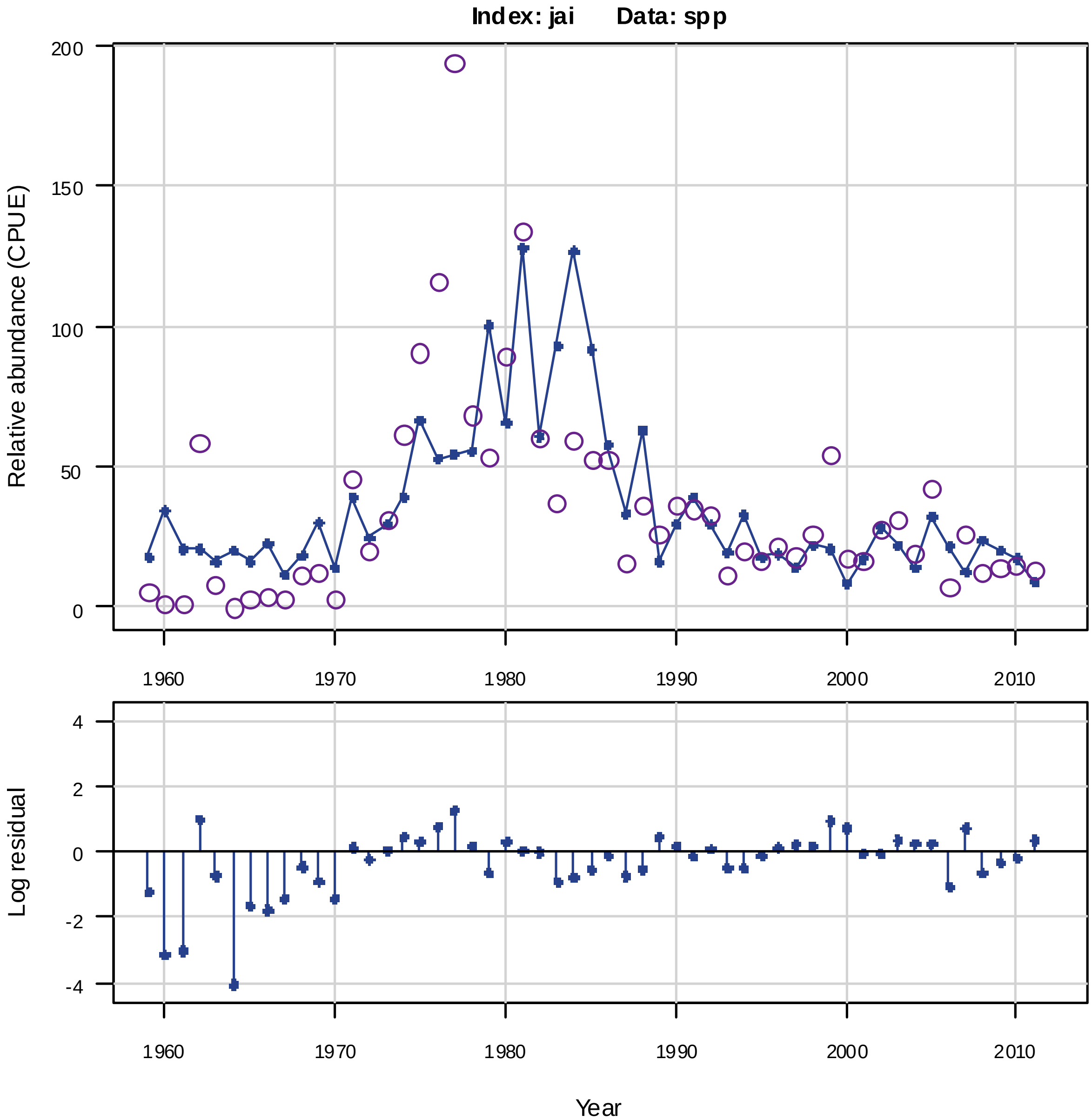


Figure 17. Observed (open circles) and predicted (connected points) juvenile abundance index values for Atlantic menhaden from the base BAM model for the benchmark assessment from 2010 (red) and this update assessment (blue).

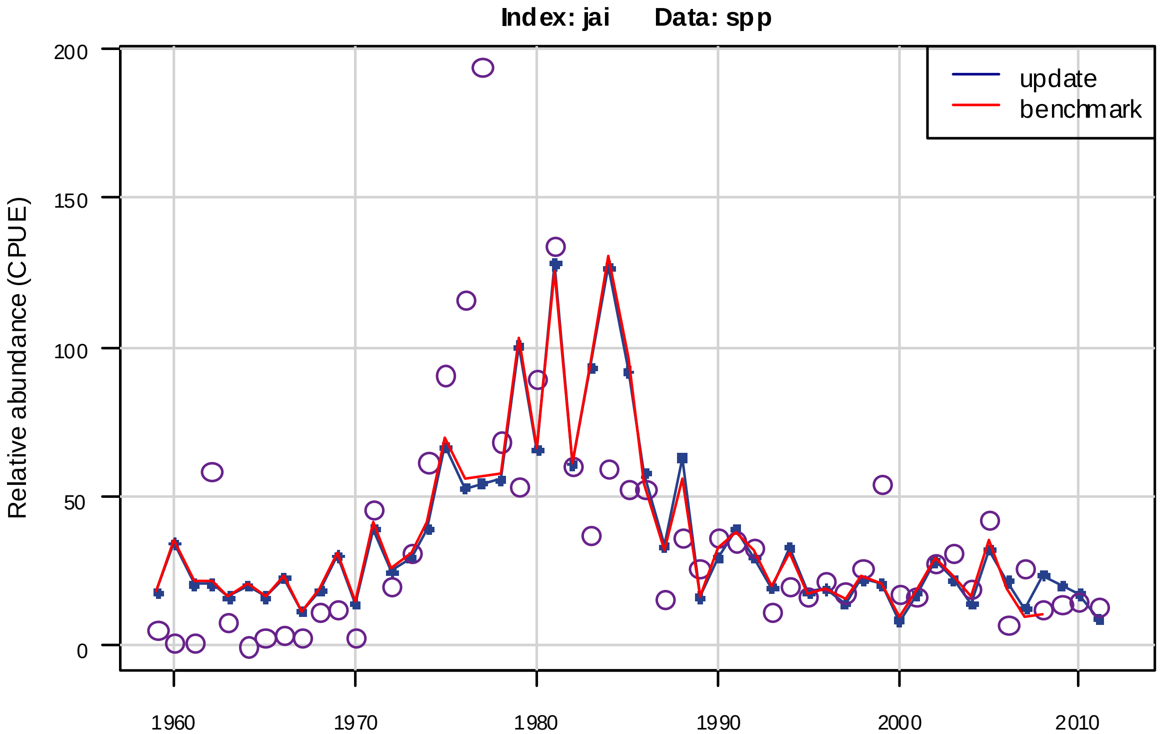


Figure 18. Observed (open circles) and predicted (connected points) PRFC pound net CPUE index values for Atlantic menhaden from the base BAM model. Bottom panel indicates pattern and magnitude of log-transformed residuals of model fit.

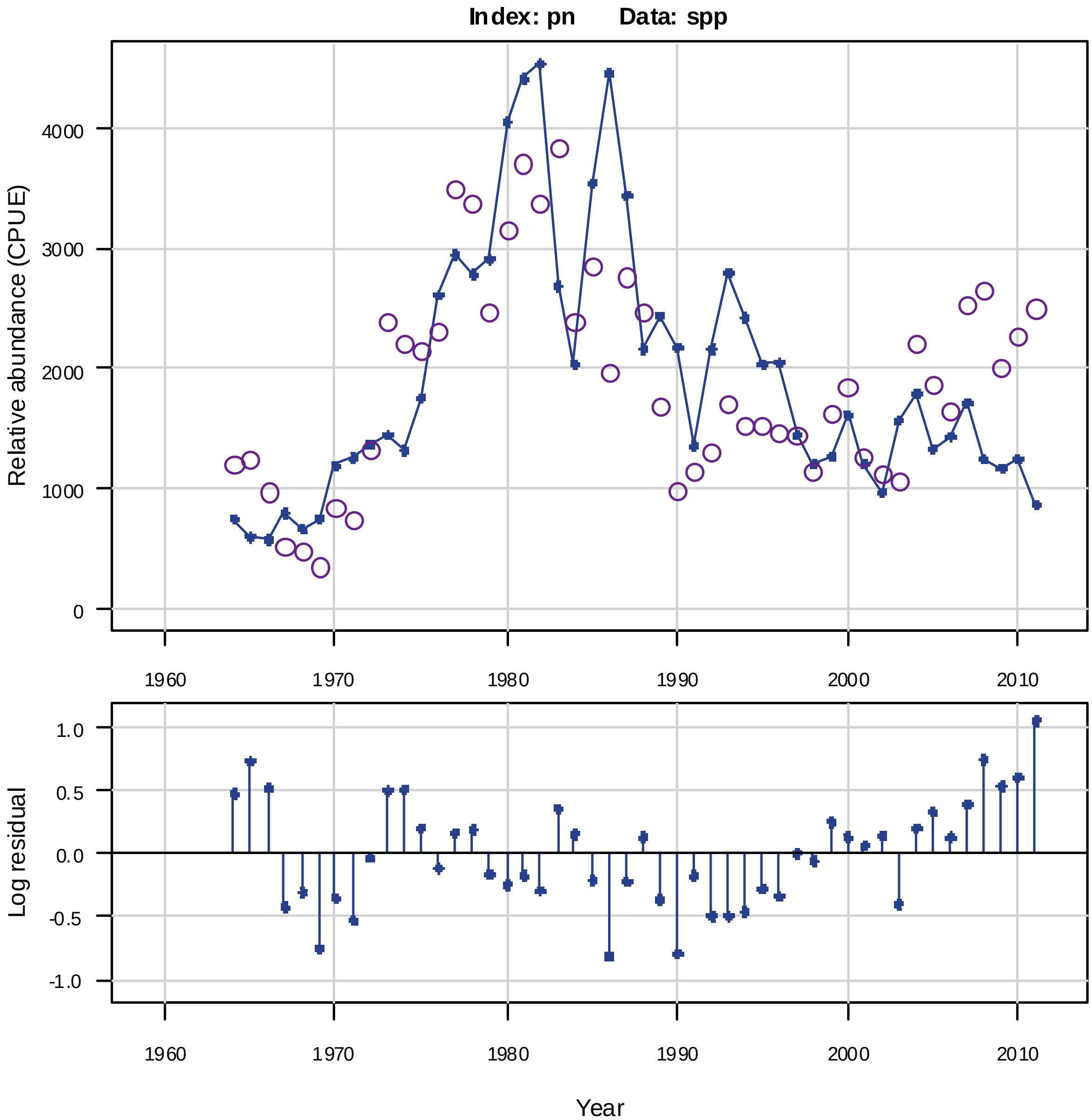


Figure 19. Observed (open circles) and predicted (connected points) PRFC pound net CPUE index values for Atlantic menhaden from the base BAM model for the benchmark assessment from 2010 (red) and this update assessment (blue).

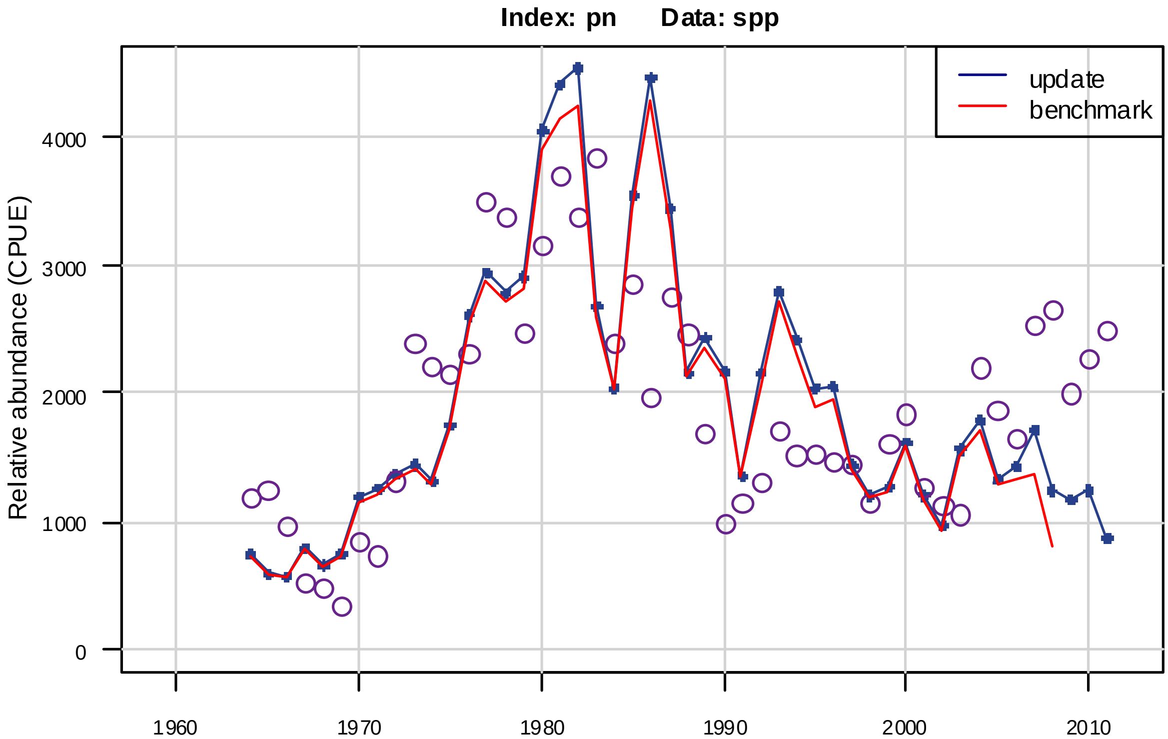


Figure 20. Estimated age-specific selectivity pattern for the Atlantic menhaden commercial reduction fishery from the base BAM model.

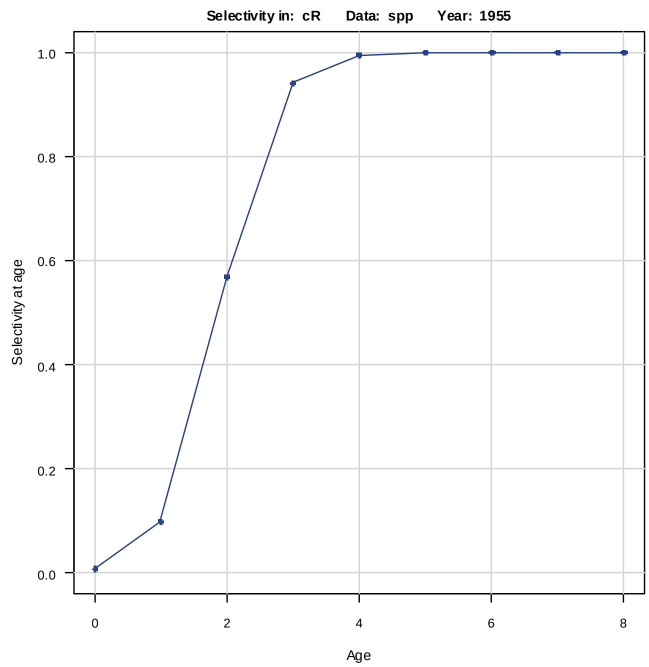


Figure 21. Estimated age-specific selectivity pattern for the Atlantic menhaden bait fishery from the base BAM model.

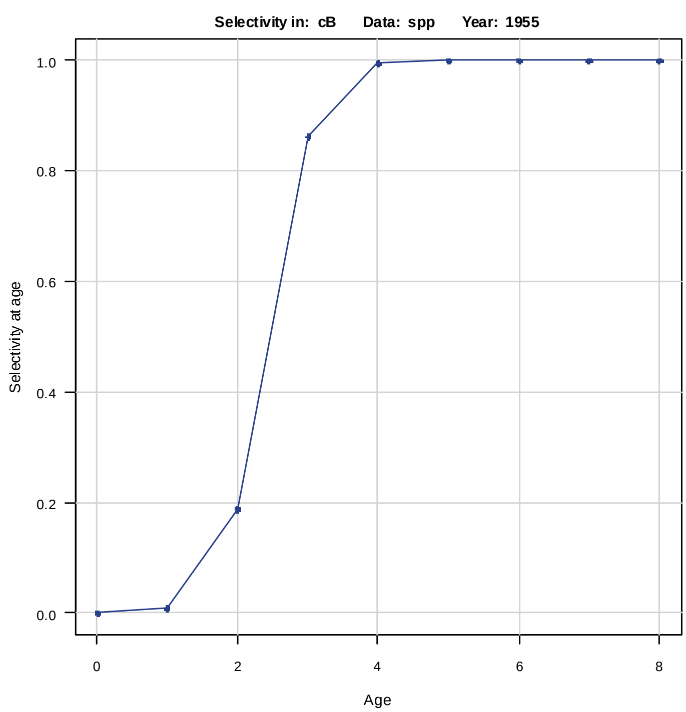


Figure 22. Estimated age-specific selectivity pattern for the Atlantic menhaden commercial reduction fishery from the base BAM model for the update assessment (blue) and the 2010 benchmark assessment (red).

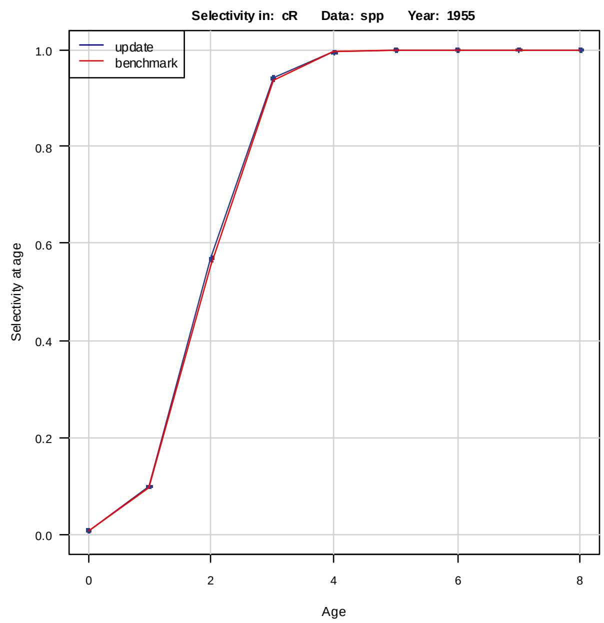


Figure 23. Estimated age-specific selectivity pattern for the Atlantic menhaden bait fishery from the base BAM model for the update assessment (blue) and the 2010 benchmark assessment (red).

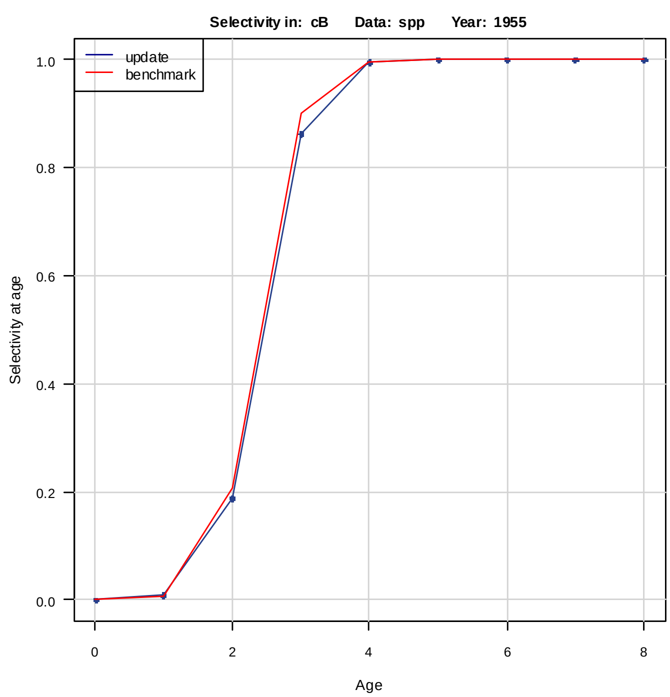


Figure 24. Estimated annual full fishing mortality rate from the base BAM model (connected points). Shaded area represents the 90% confidence interval of the bootstrap runs.

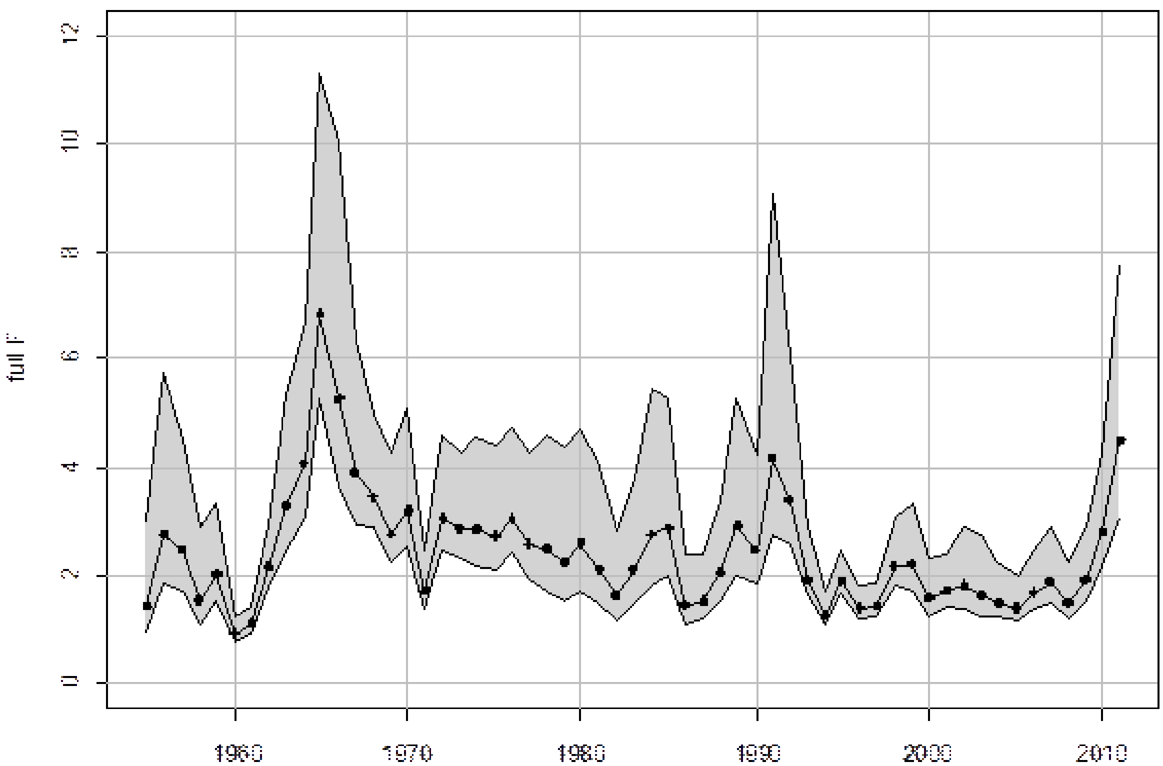


Figure 25. Estimated annual full fishing mortality rate from the base BAM model (connected points).

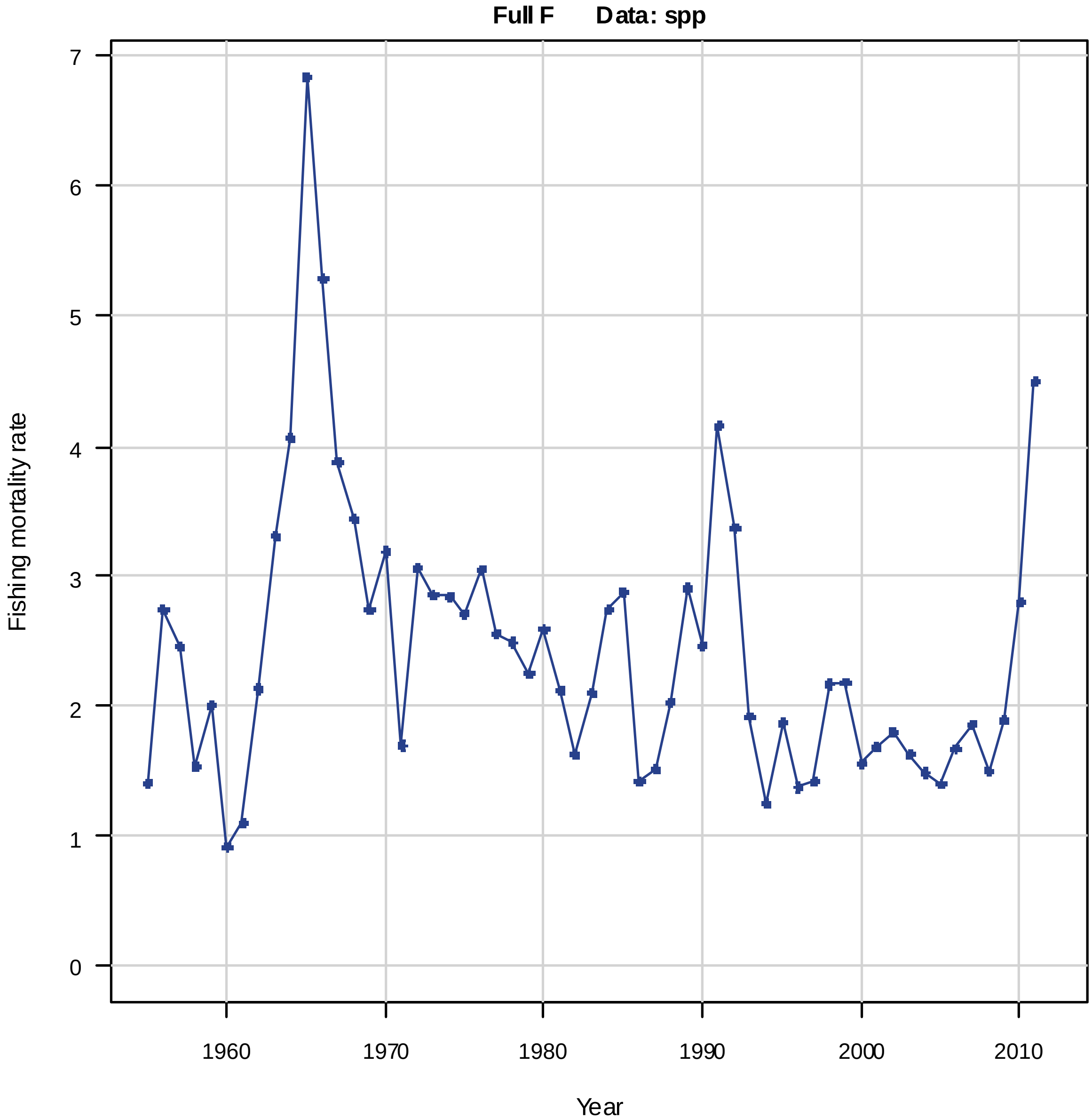


Figure 26. Estimated annual full fishing mortality rates for the commercial reduction fishery from the base BAM model.

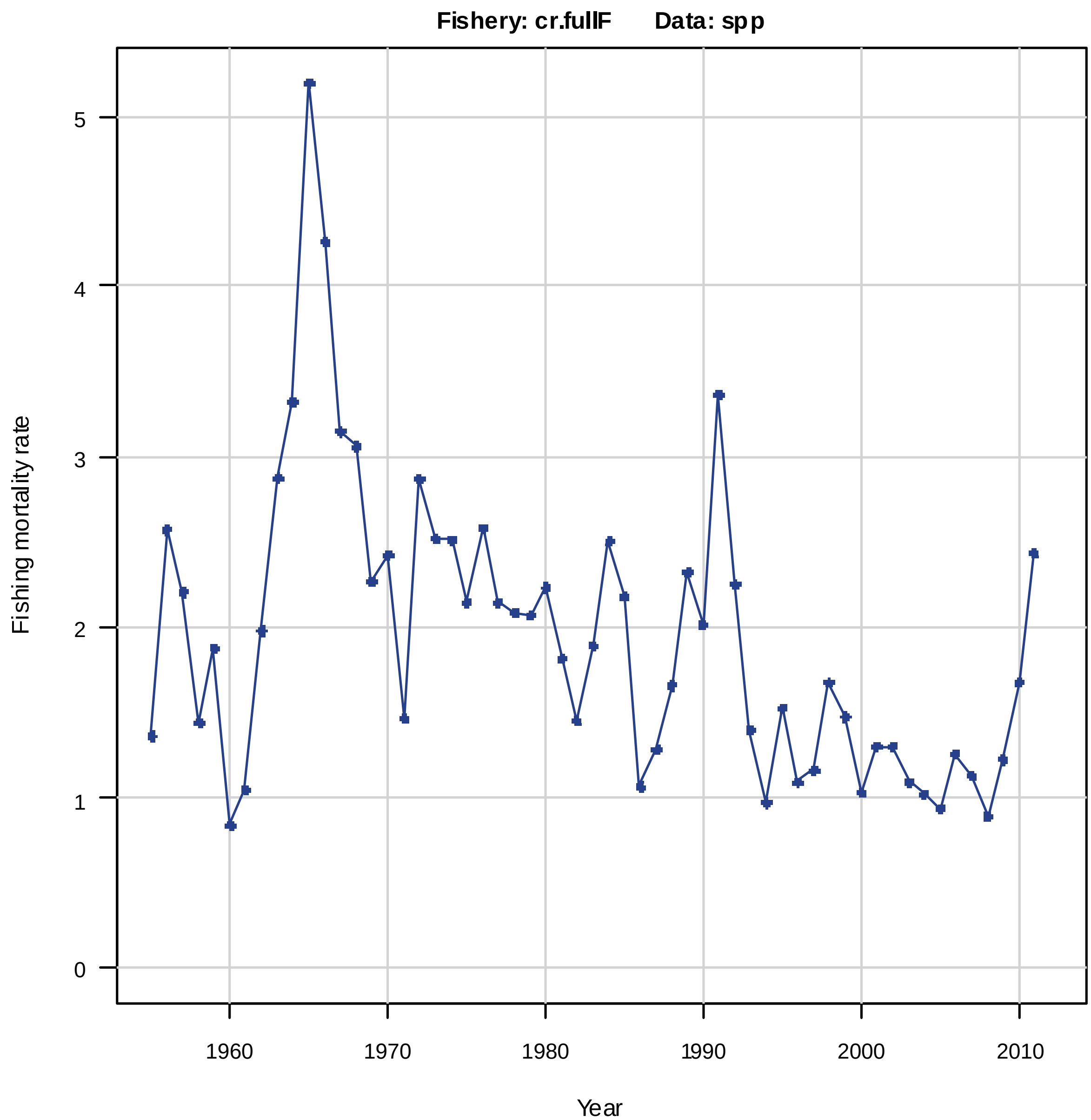


Figure 27. Estimated annual full fishing mortality rates for the bait fishery from the base BAM model.

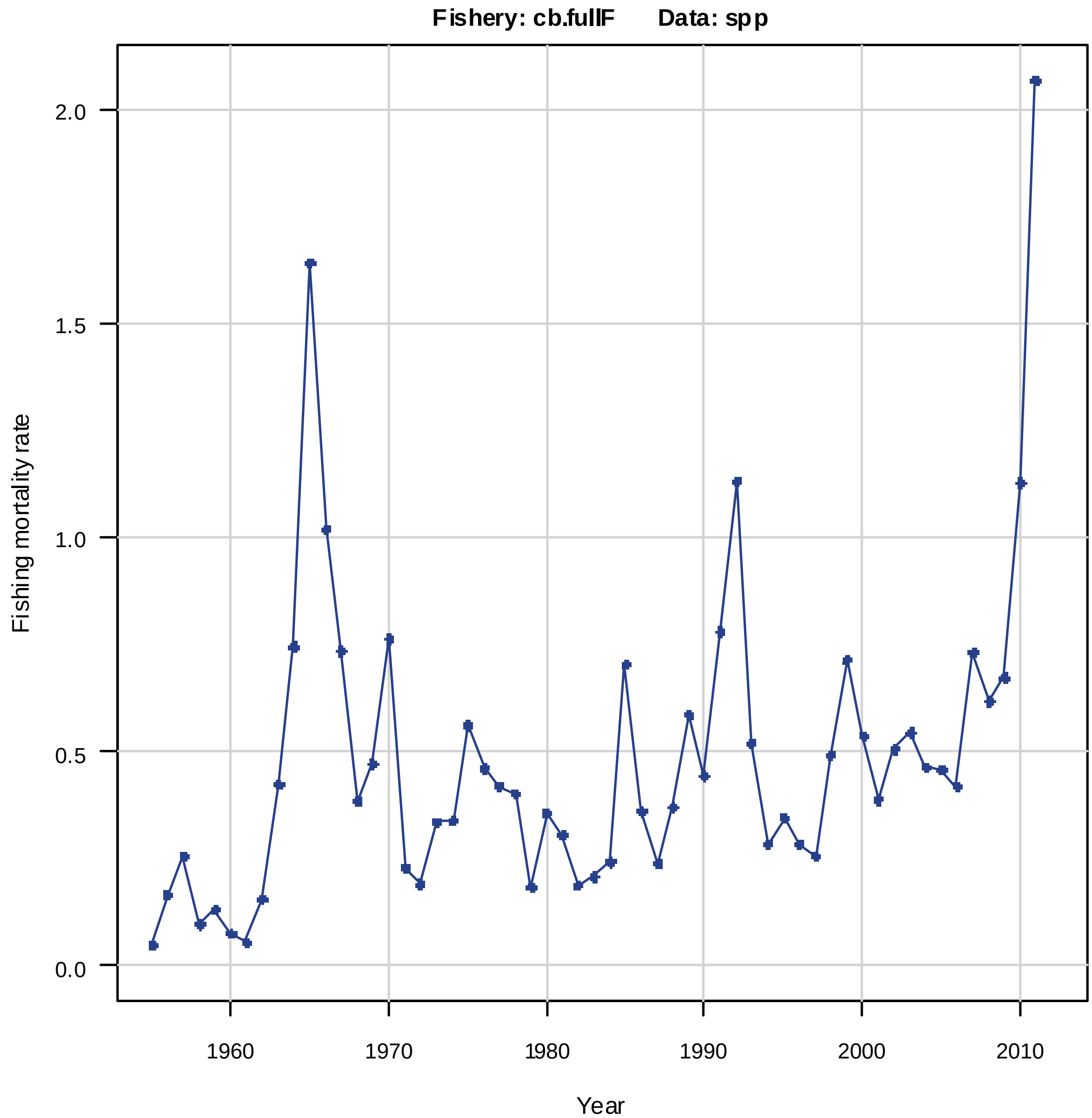


Figure 28. Estimated annual full fishing mortality rates, full F, for combined reduction and bait fisheries from the base BAM model for this update assessment (blue) and the 2010 benchmark assessment (red).

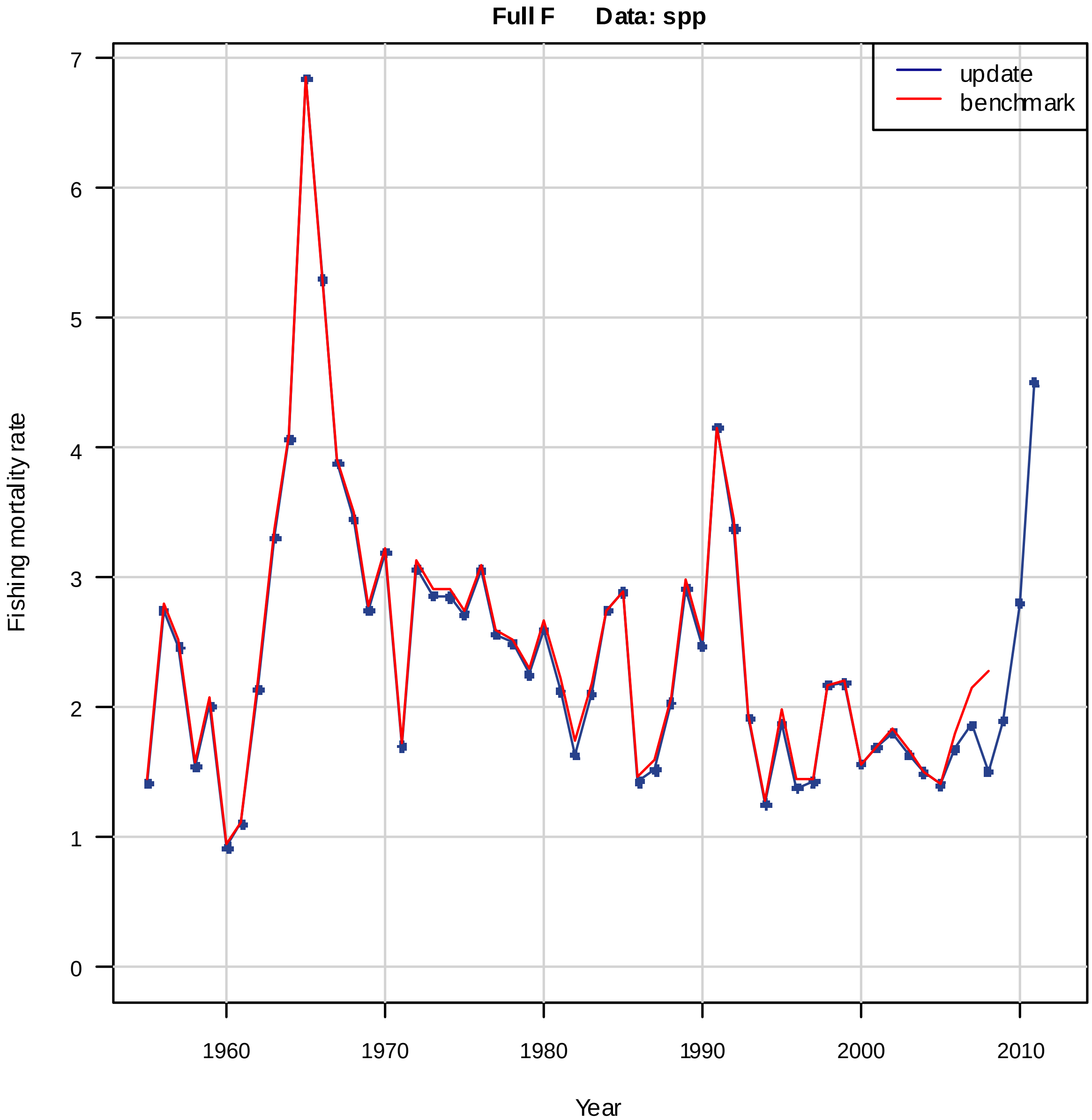


Figure 29. Estimated annual full fishing mortality rates for the commercial reduction fishery from the base BAM model for this update assessment (blue) and the 2010 benchmark assessment (red).

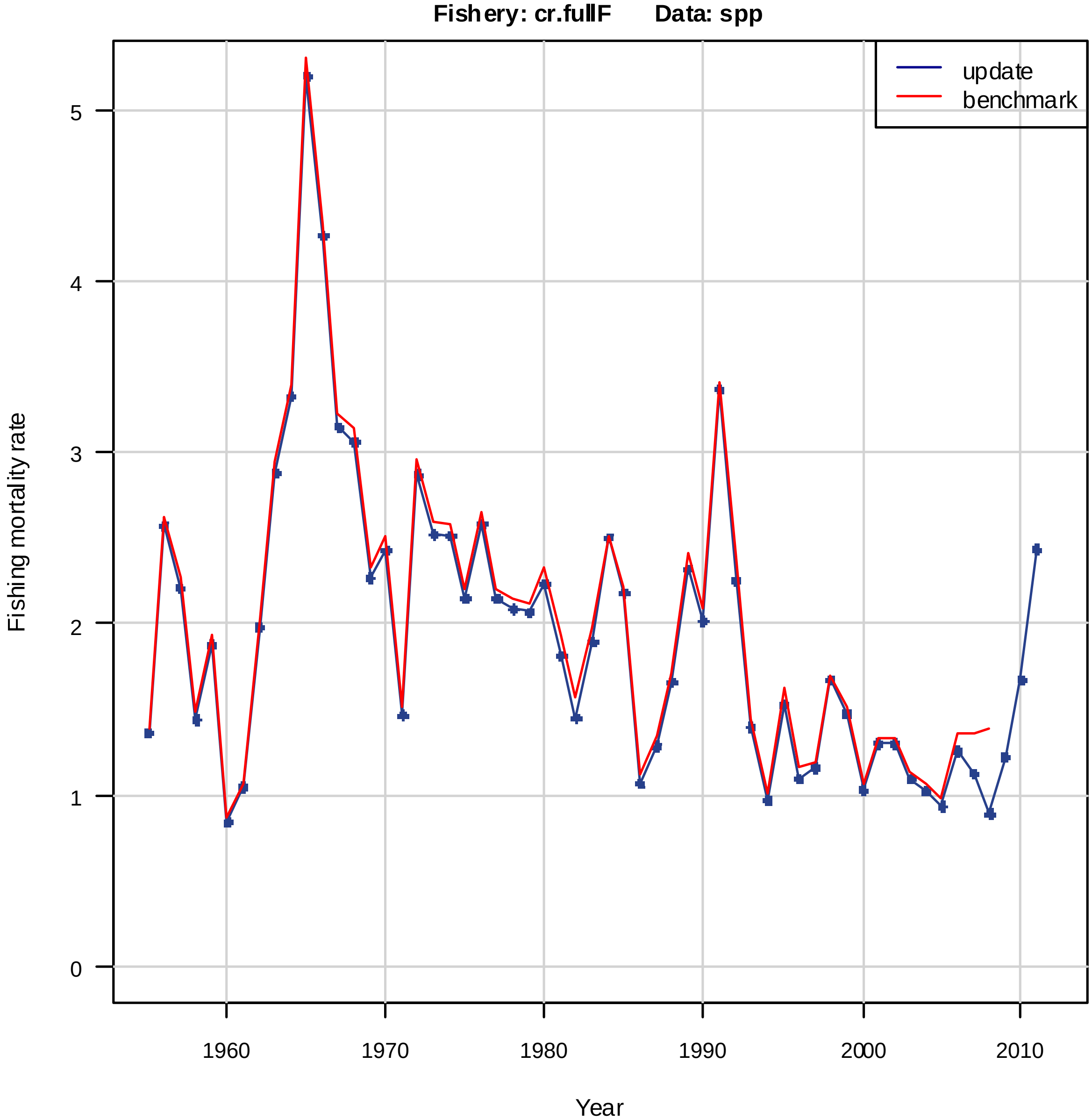


Figure 30. Estimated annual full fishing mortality rates for the bait fishery from the base BAM model for this update assessment (blue) and the 2010 benchmark assessment (red).

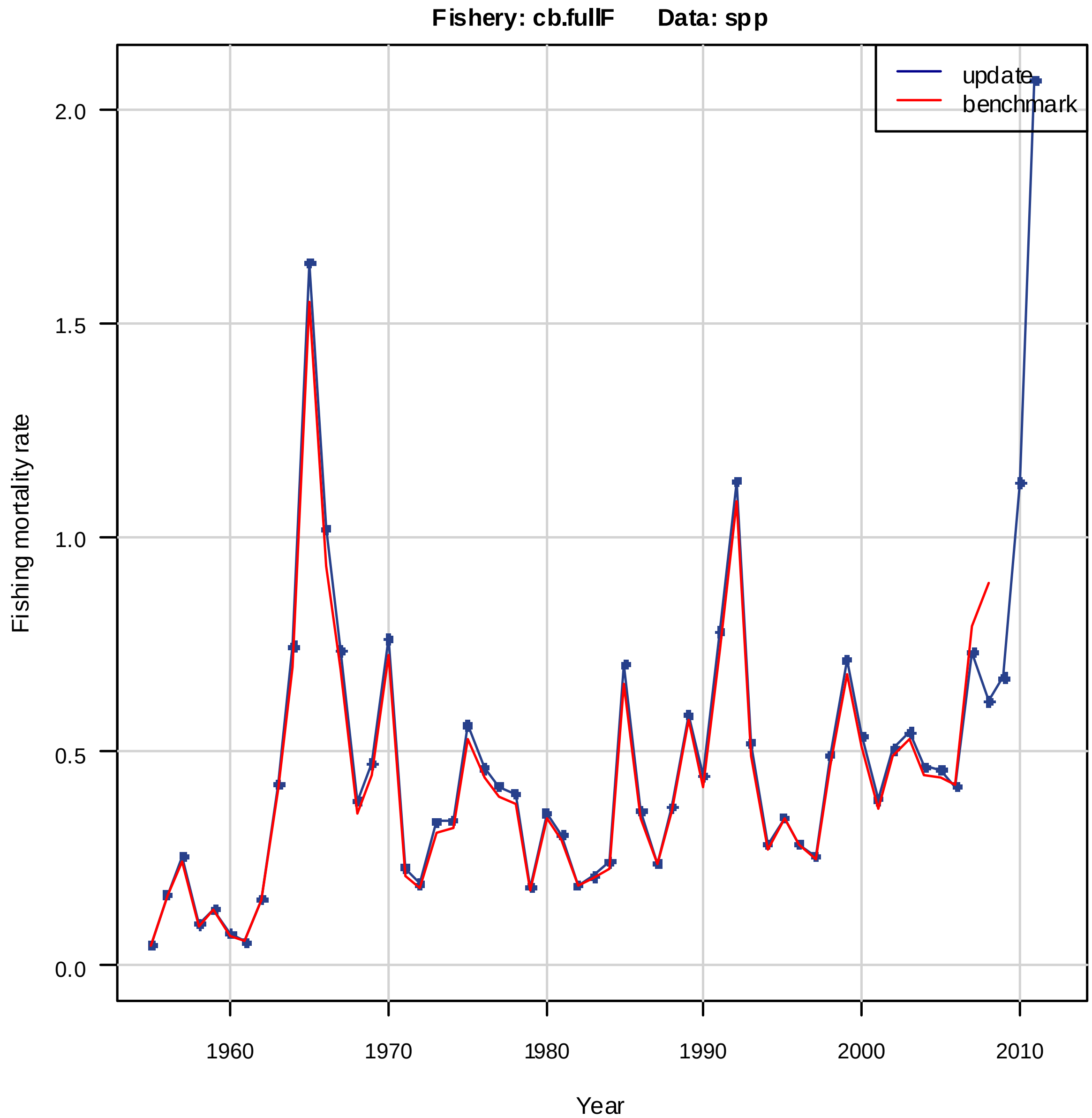


Figure 31. Estimated numbers at age of Atlantic menhaden (billions) at the start of the fishing year from the base BAM model.

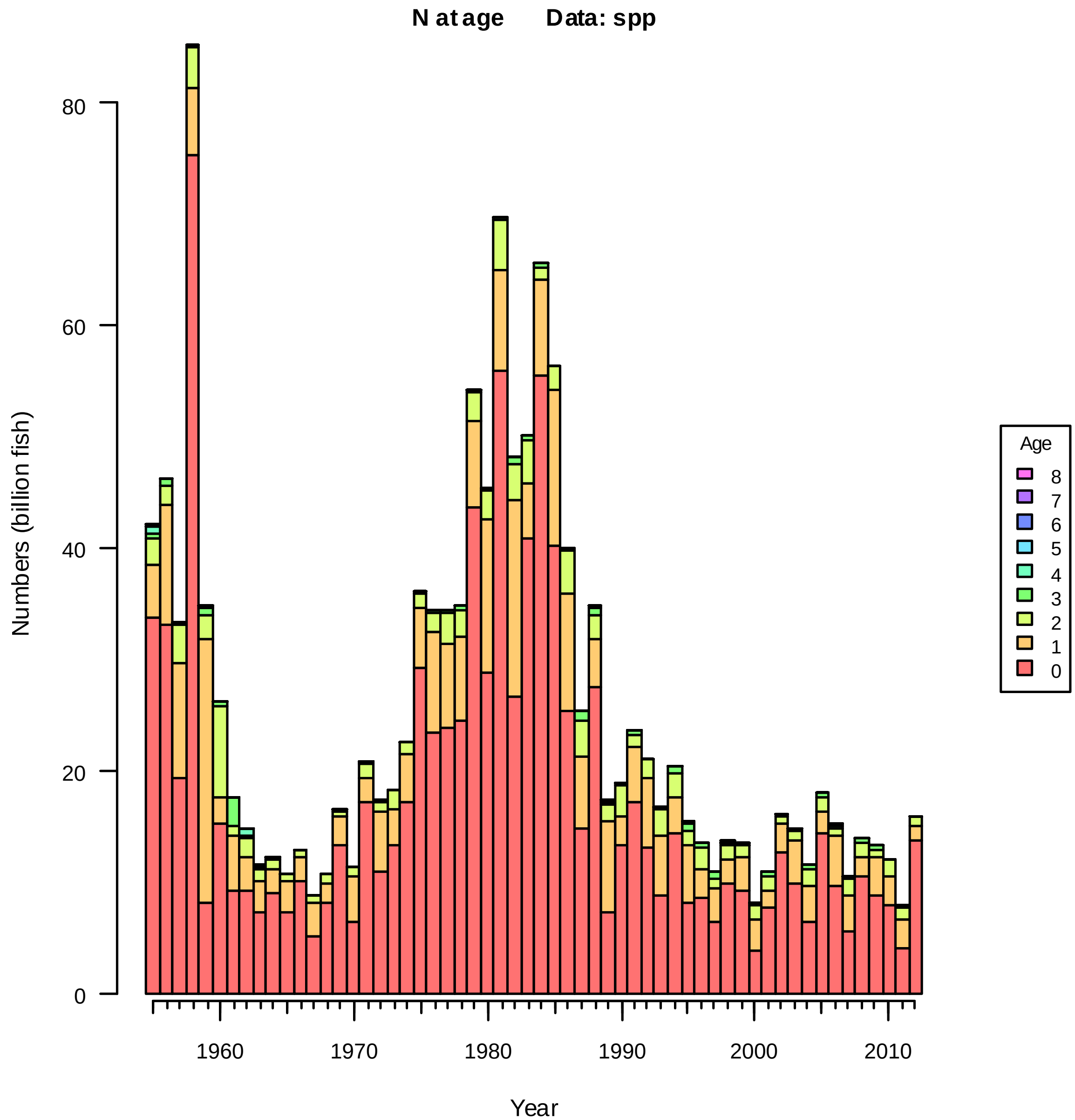


Figure 32. Estimated annual fecundity (billions of eggs) from the base BAM model (connected points). Shaded area represents the 90% confidence interval of the bootstrap runs.

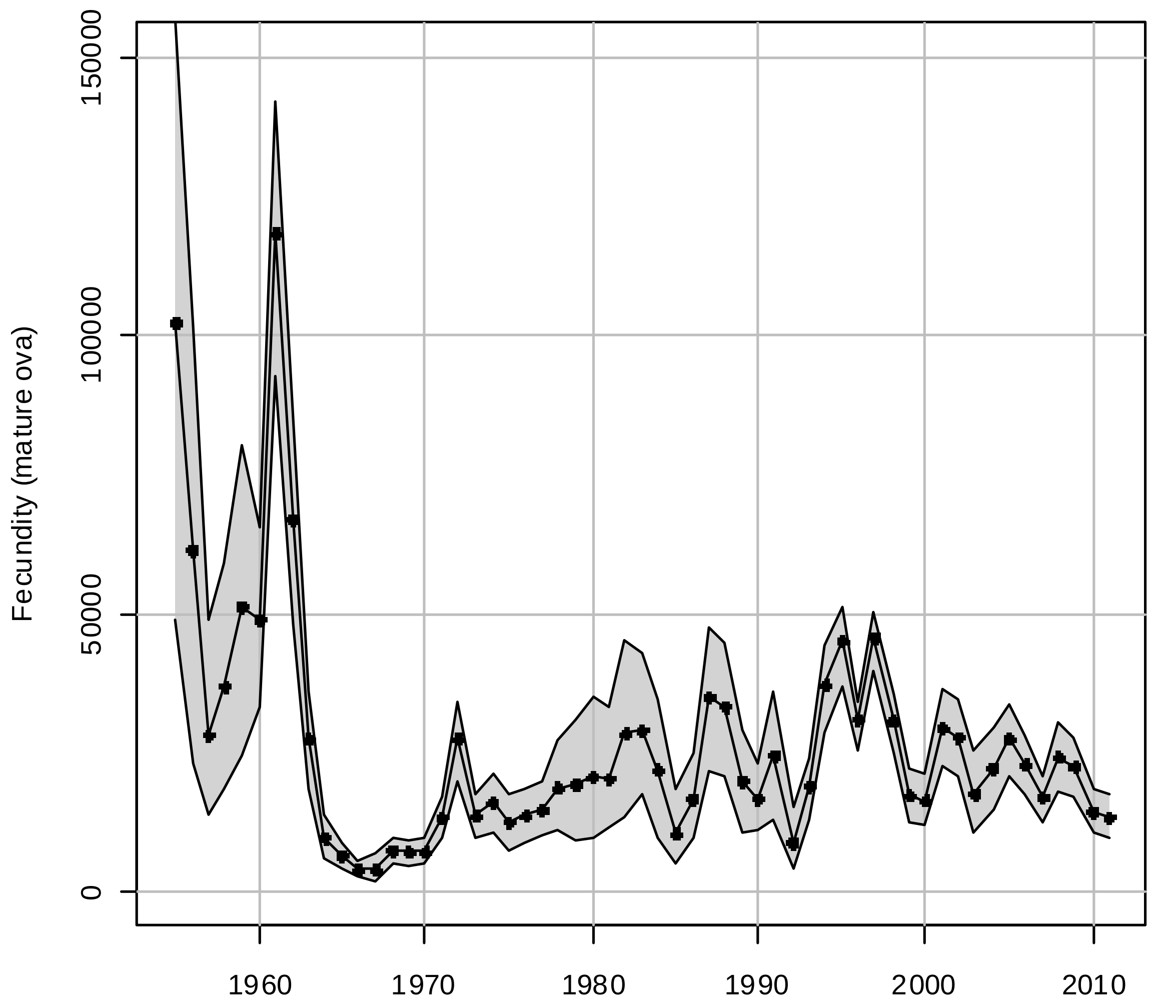


Figure 33. Estimated total fecundity (billions of mature ova) at age of Atlantic menhaden at the start of the fishing year from the base BAM model.

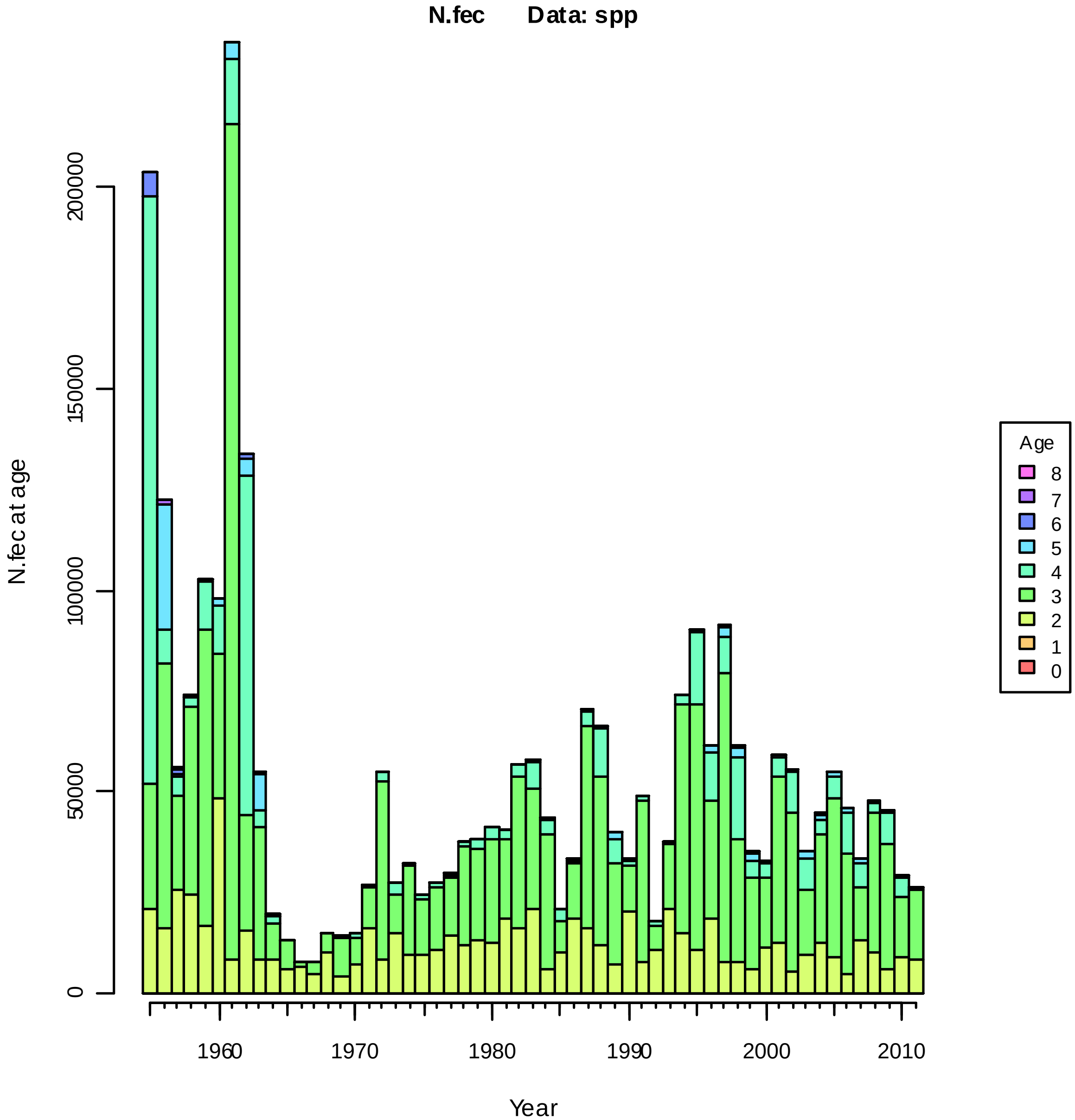


Figure 34. Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). Shaded area represents the 90% confidence interval of the bootstrap runs.

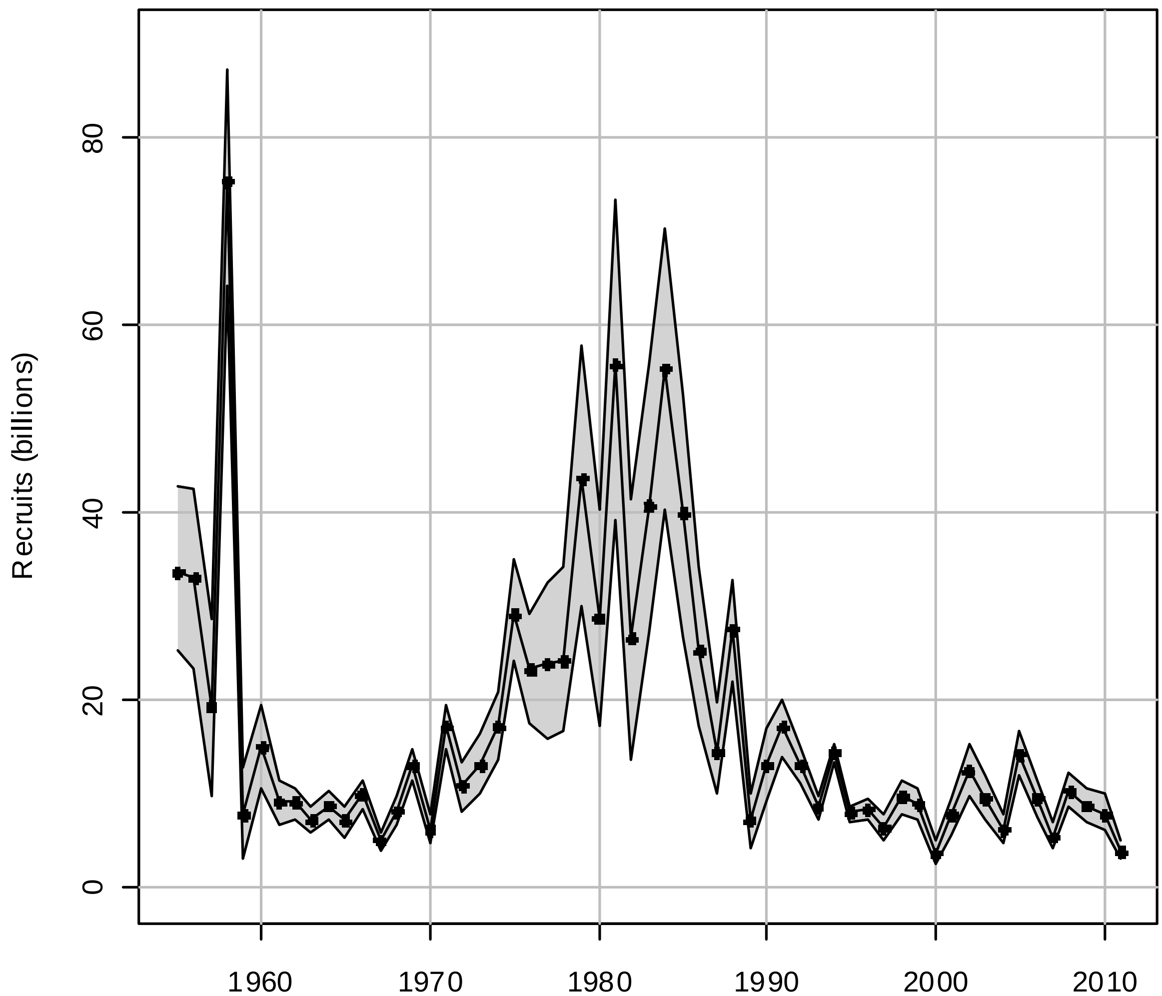


Figure 35. Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). The recruitment estimate for 2012 shown in this figure is a projection based on the long term geometric mean.

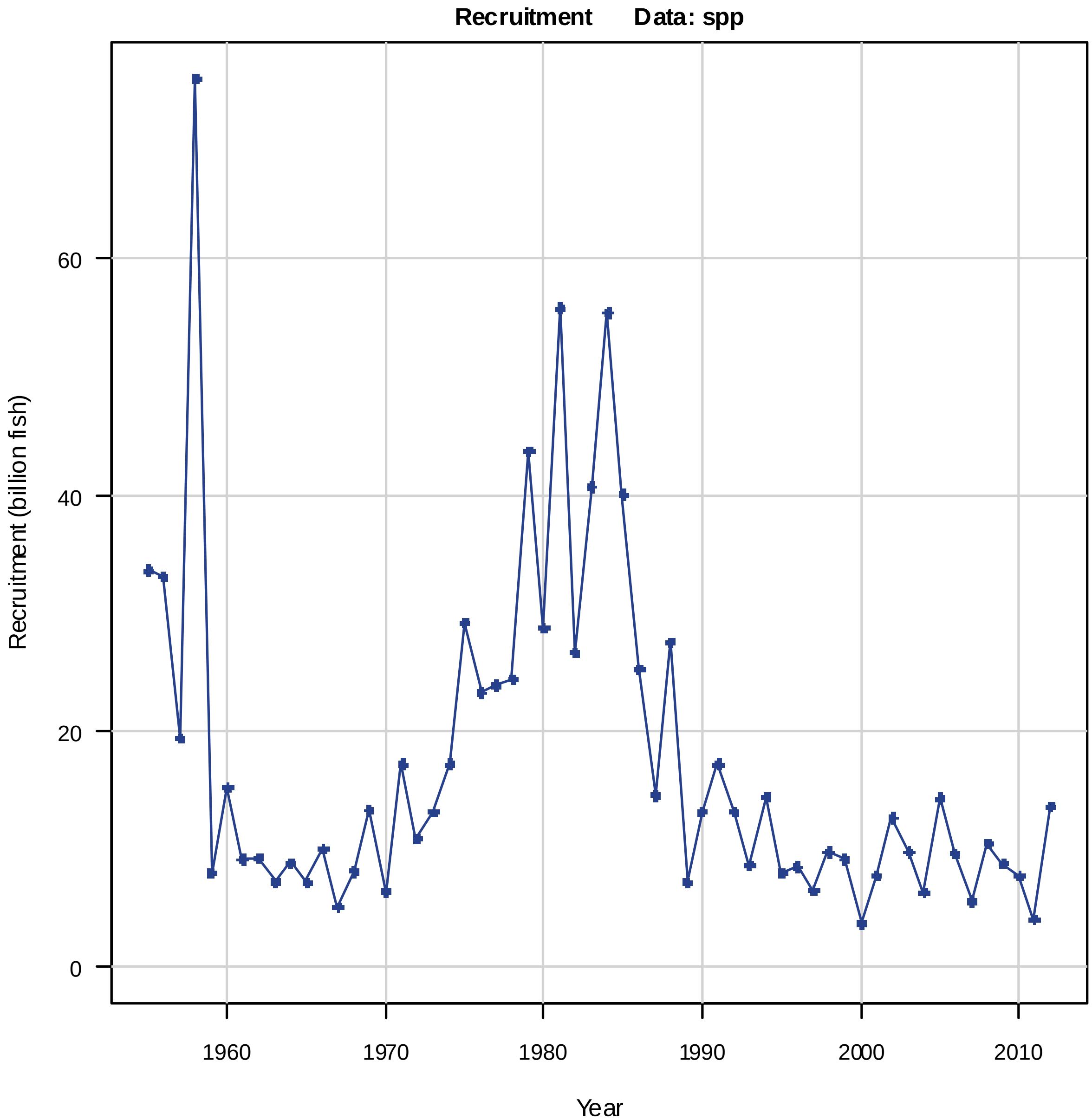


Figure 36. Estimated annual recruitment to age-0 (billions) from the base BAM model for the update assessment (blue) and for the last benchmark assessment in 2010 (red). The recruitment estimate for 2012 (blue) and 2009 (red) shown in this figure are projections based on the long term geometric mean.

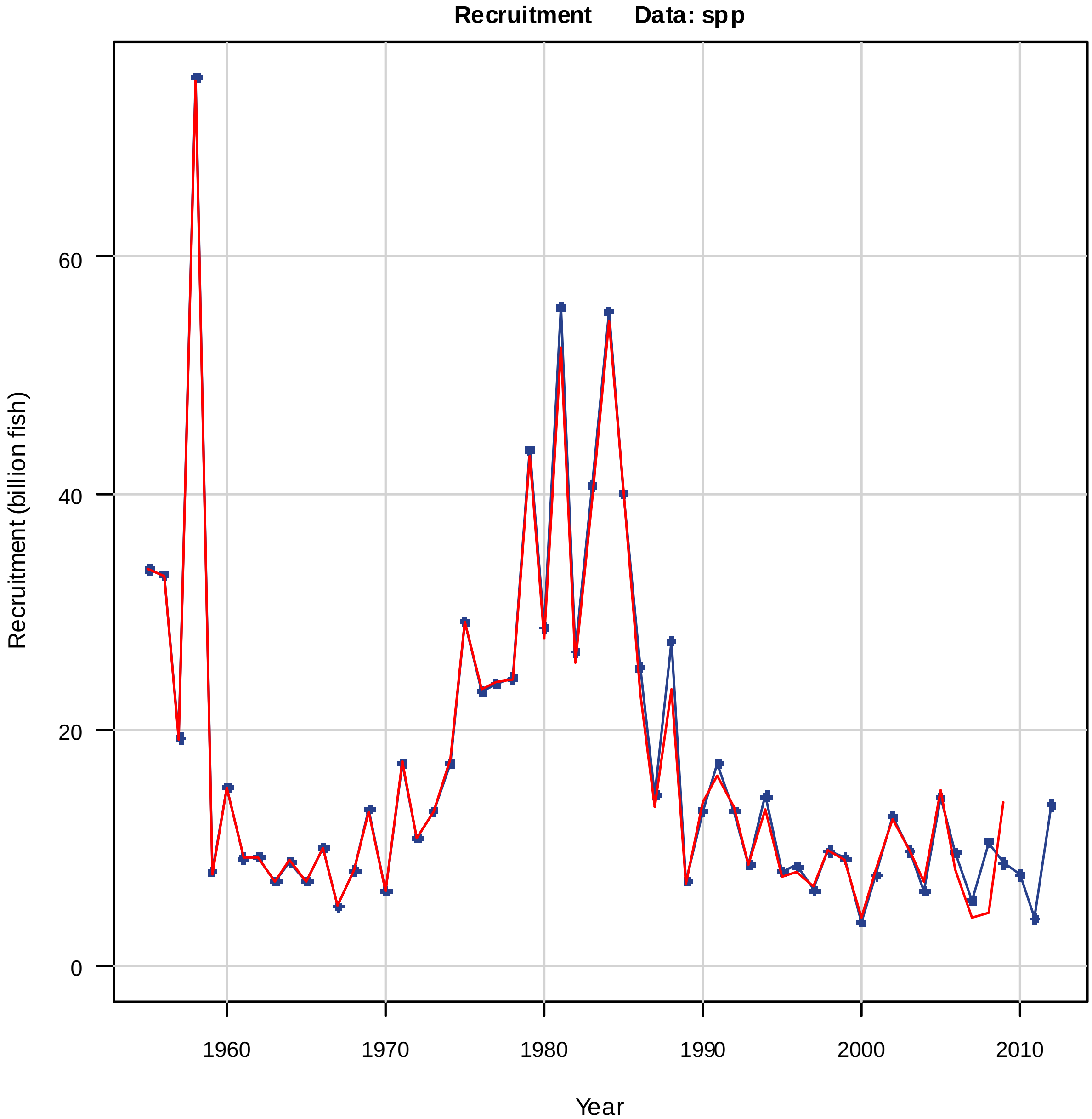


Figure 37. Estimated spawning stock (billions of mature ova) and recruitment (billions of age-0 fish) from the base BAM model (points). Lines indicate the median recruitment (horizontal) and the 50th and 75th percentile of spawners-per-recruit.

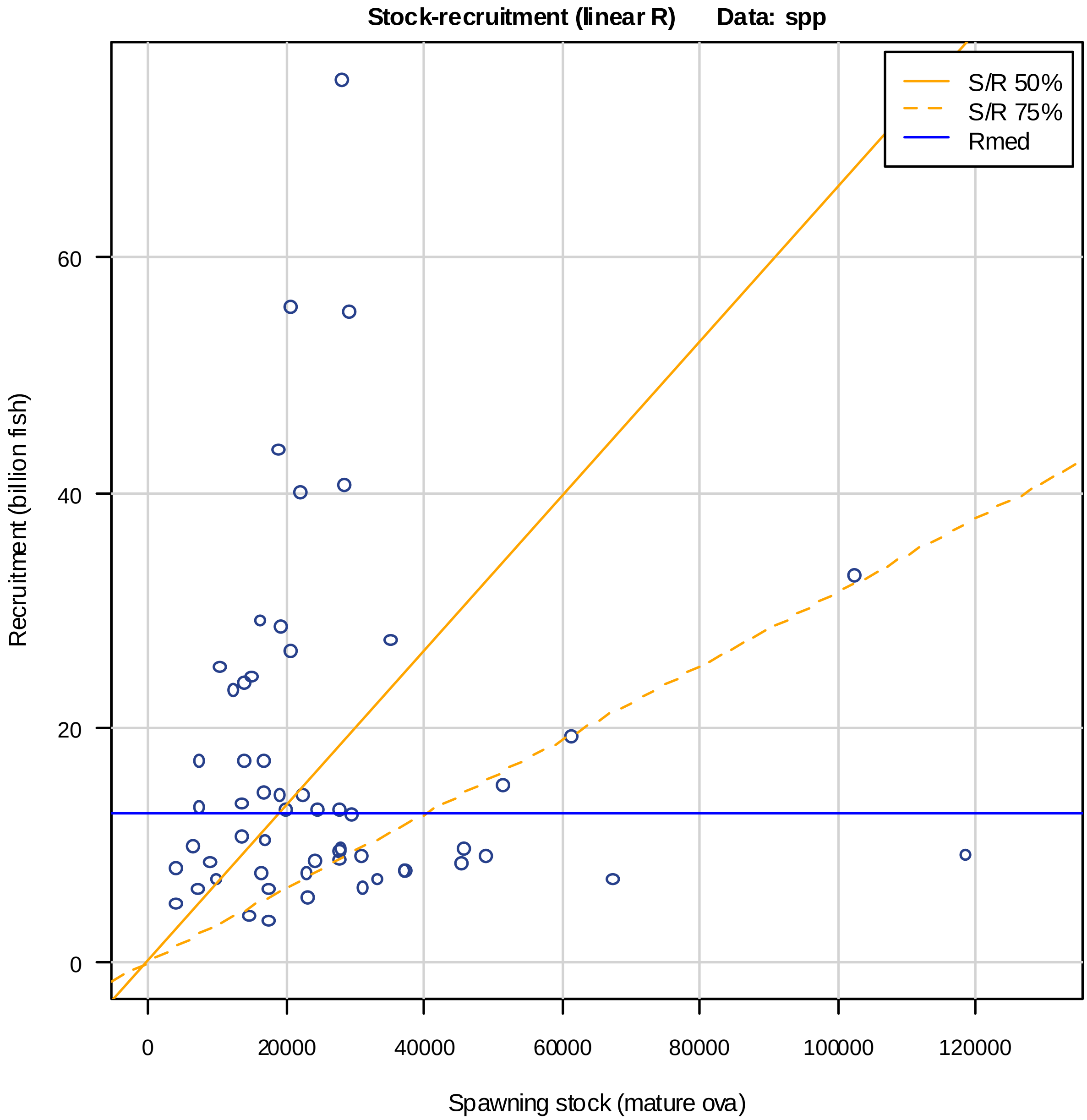


Figure 38. Estimated annual full fishing mortality rates from the base BAM model (connected open circles) and various sensitivity runs.

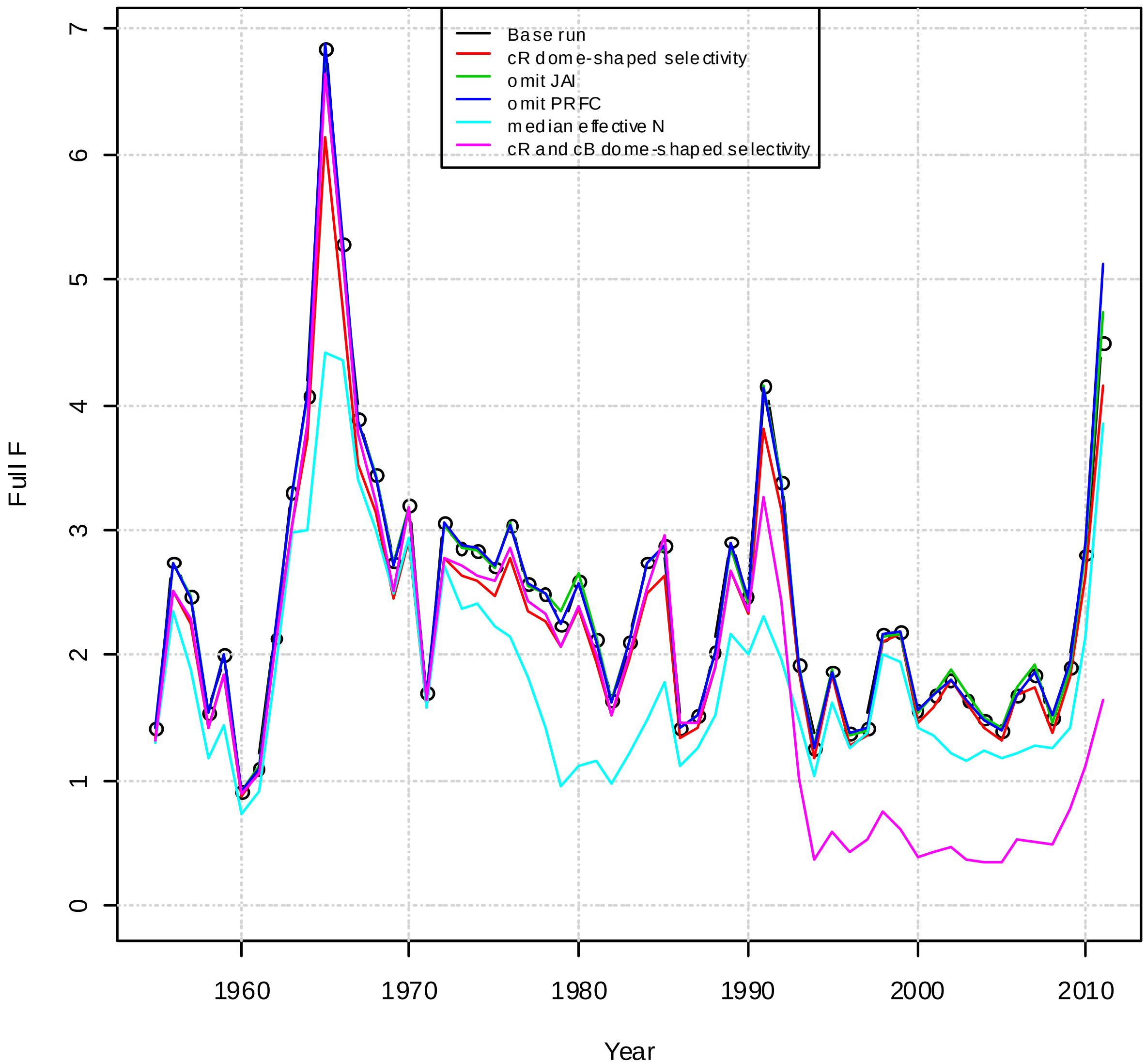


Figure 39. Estimated annual recruitment of age-0 fish (billions) from the base BAM model (connected open circles) and various sensitivity runs.

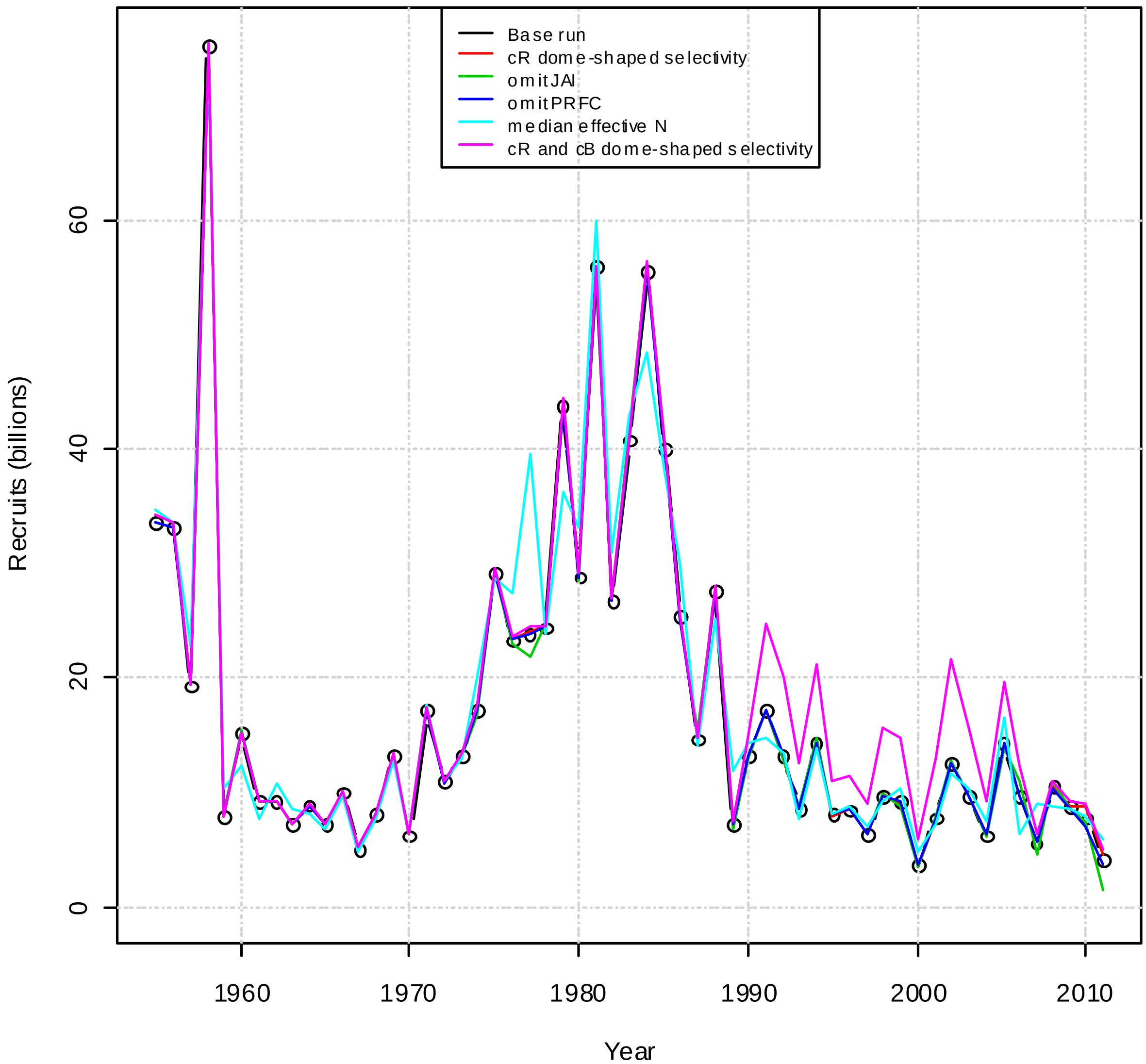


Figure 40. Estimated annual fecundity (billions of mature eggs) from the base BAM model (connected open circles) and various sensitivity runs.

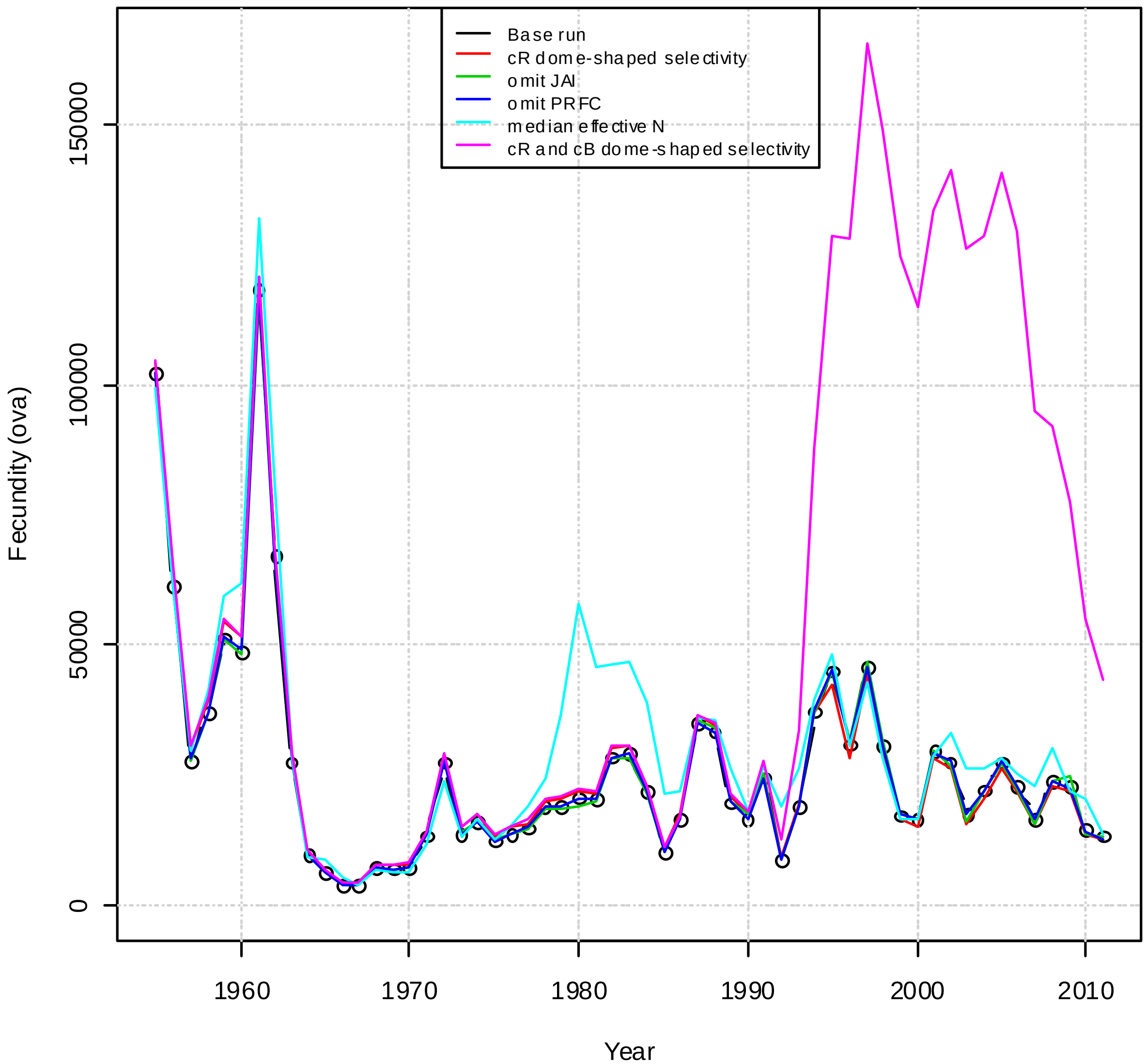


Figure 41. Estimated annual biomass (1,000 mt) from the base BAM model (connected open circles) and various sensitivity runs.

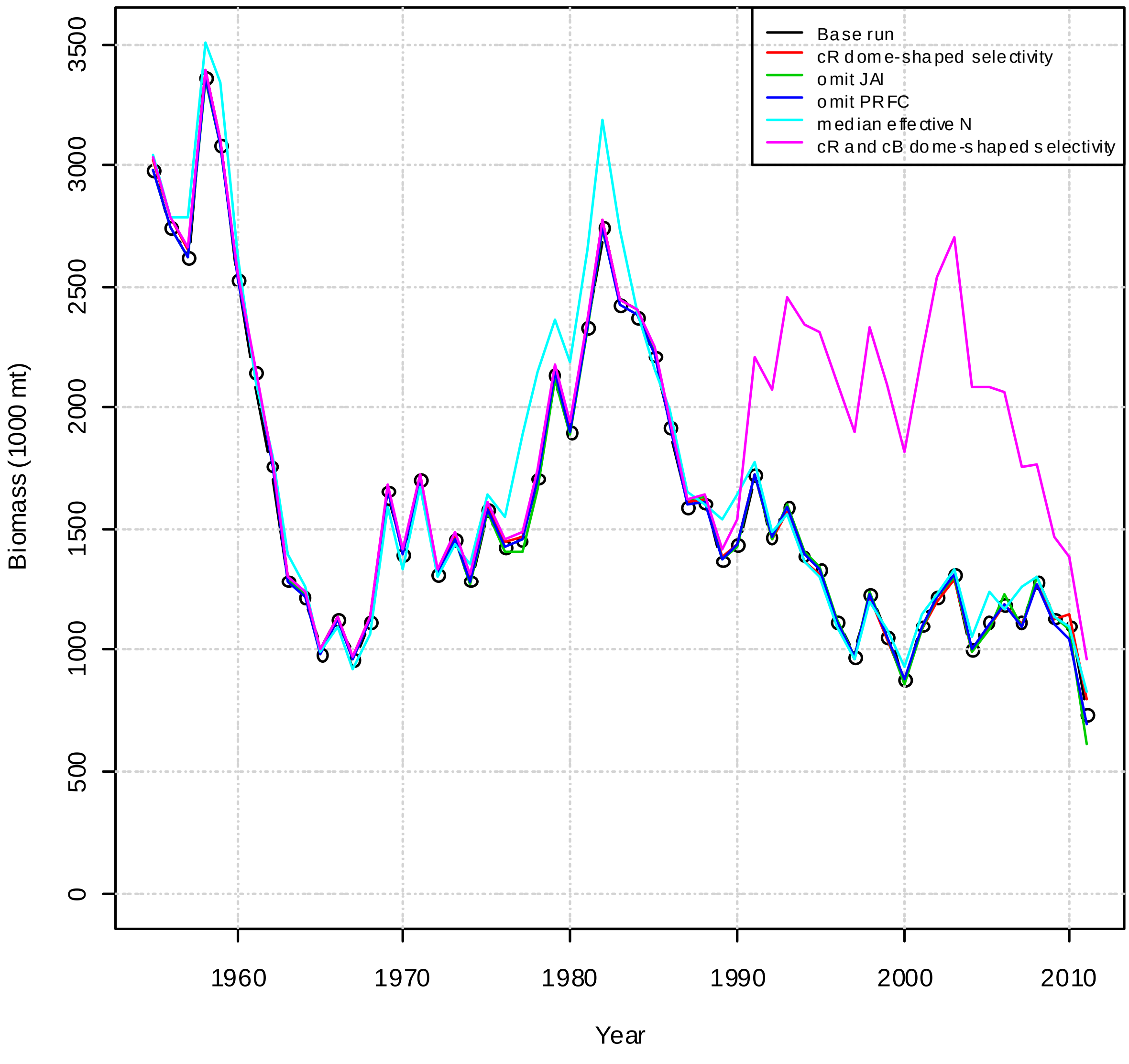


Figure 42. Fit to the observed juvenile abundance index from the base BAM model and various sensitivity runs. The open points are the observed values.

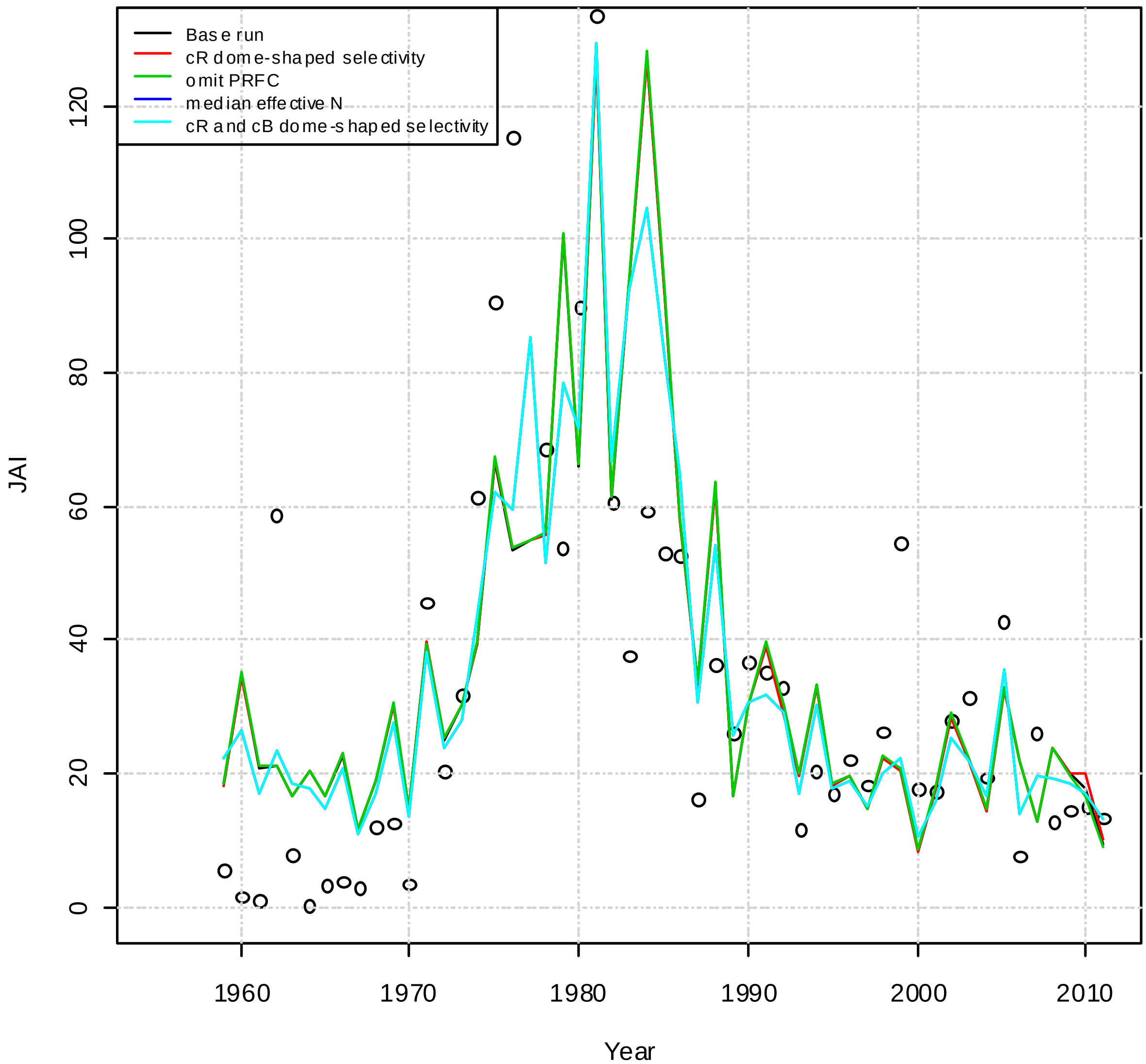


Figure 43. Fit to the observed pound net index from the base BAM model and various sensitivity runs. The open points are the observed values.

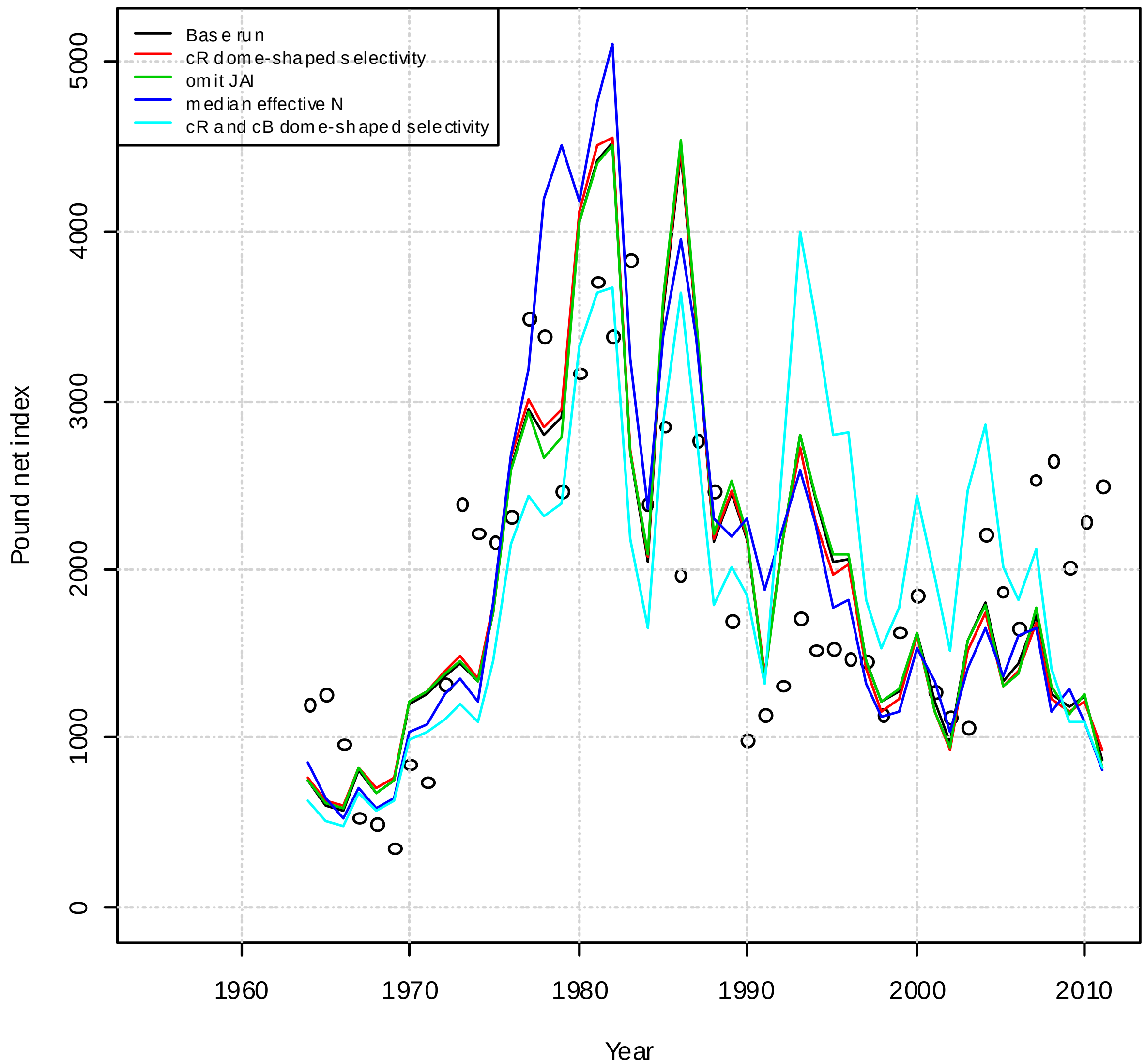


Figure 44. Estimated annual full fishing mortality rates from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

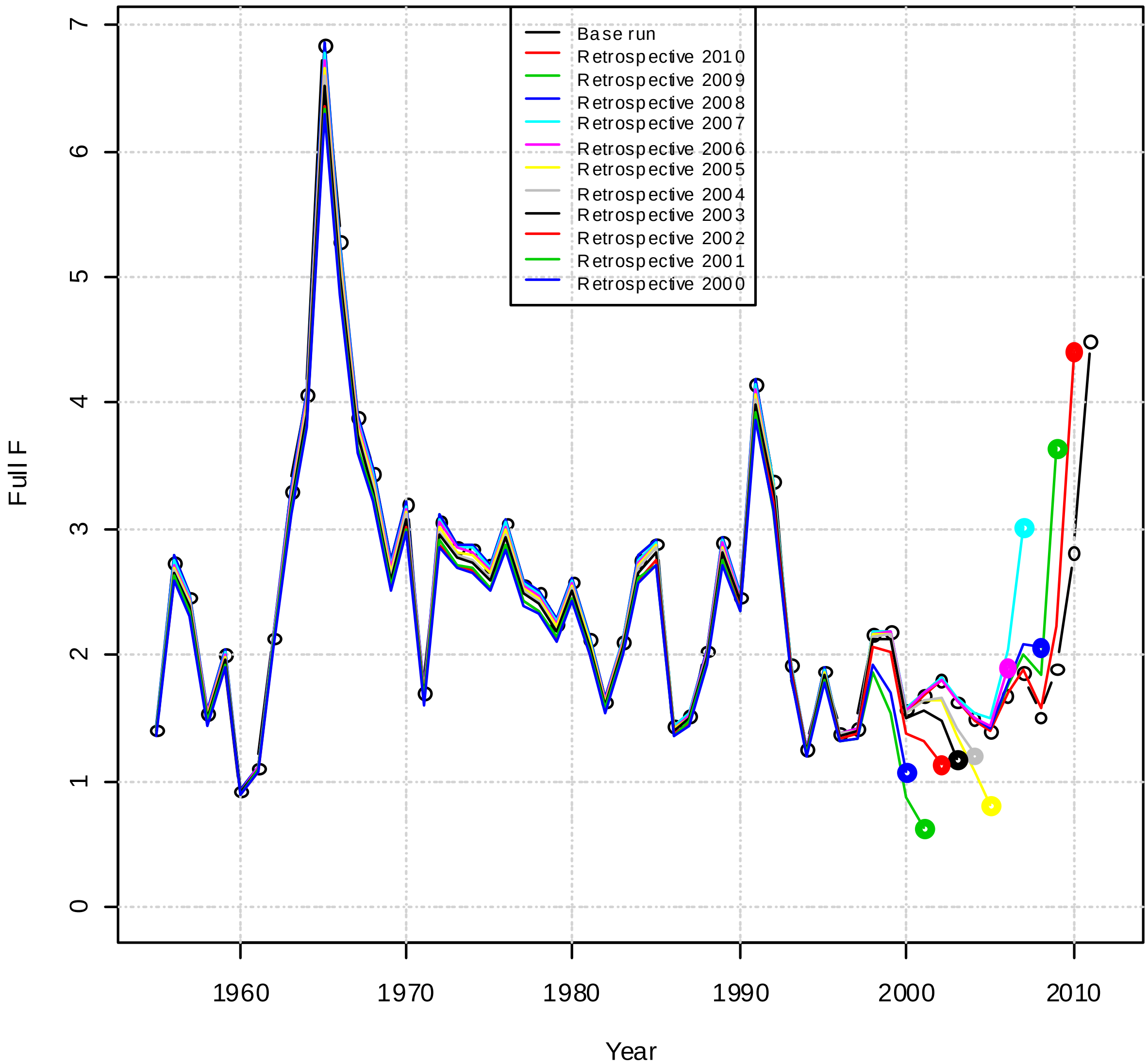


Figure 45. Estimated annual recruitment of age-0 fish (billions) from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

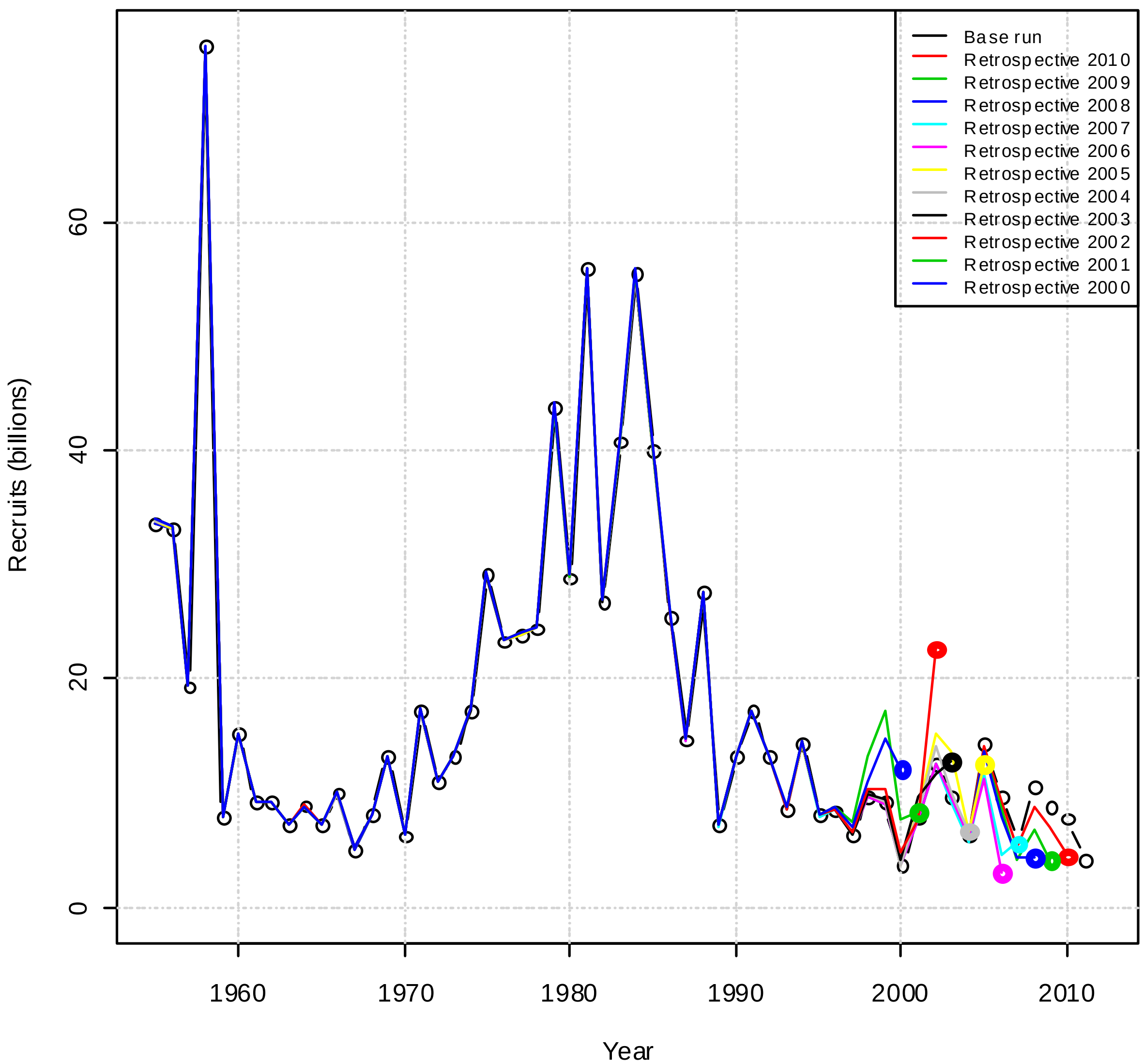


Figure 46. Estimated annual population fecundity (billions of mature ova) from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

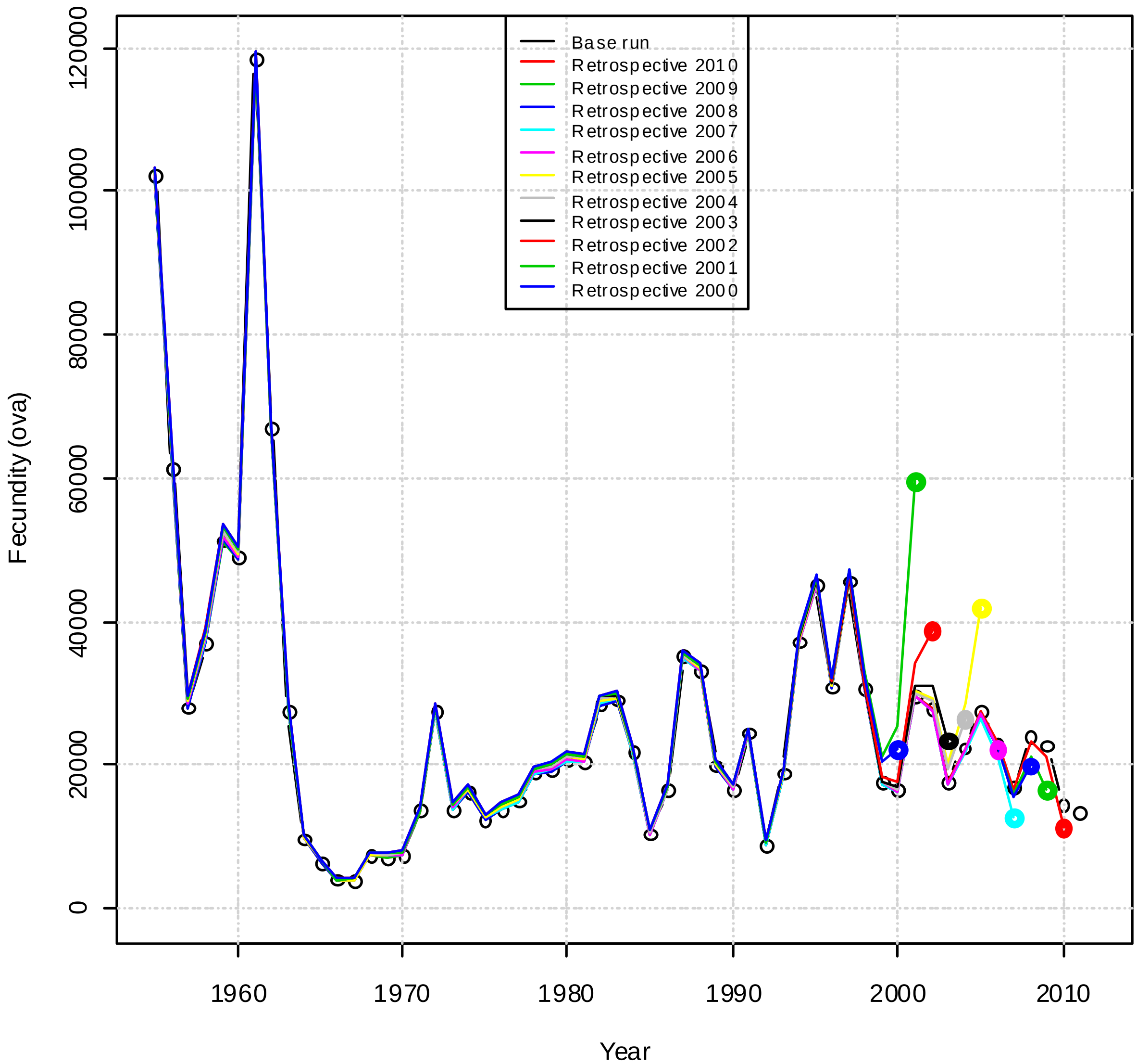


Figure 47. Estimated annual population biomass (1,000s mt) from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

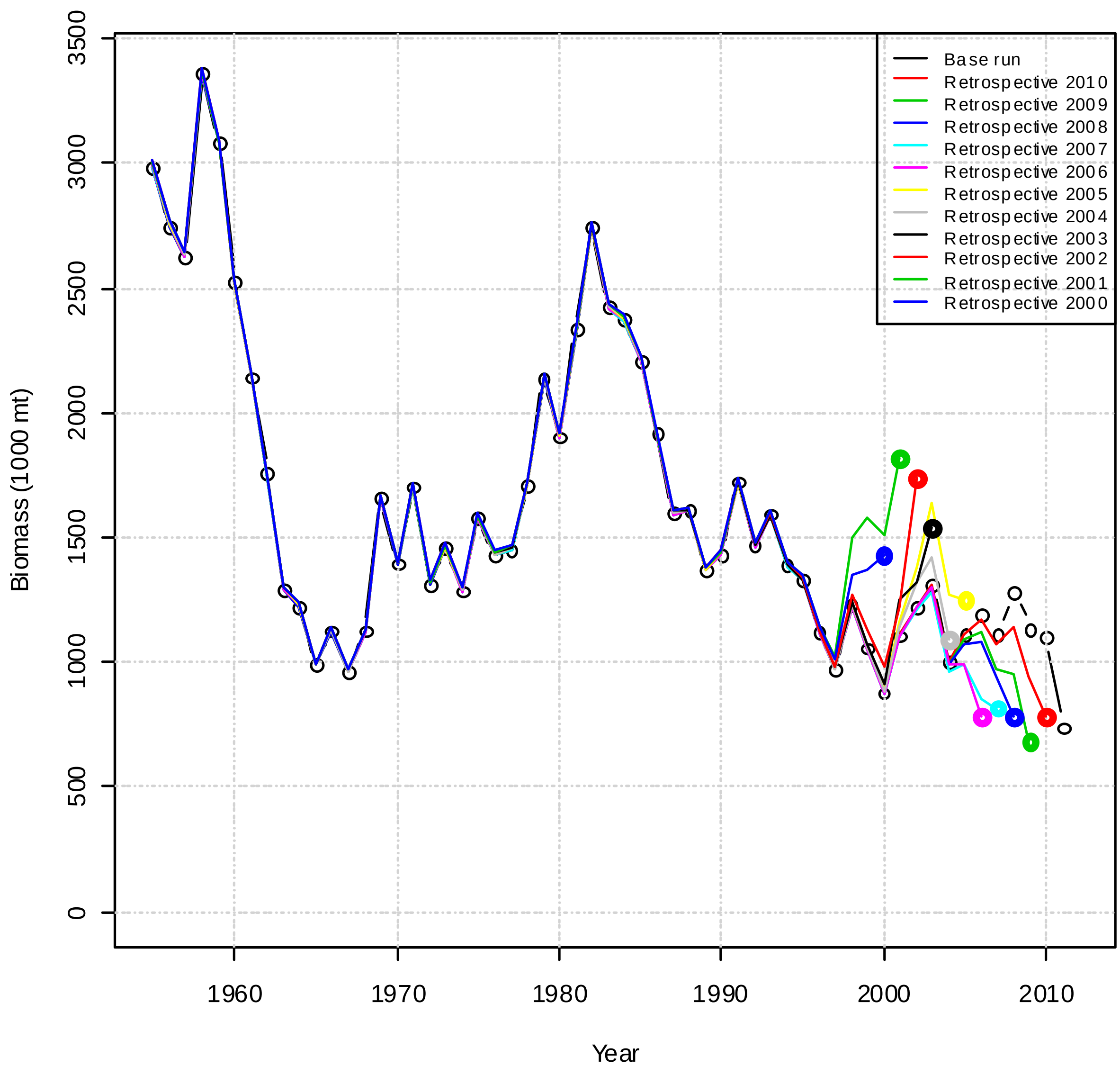


Figure 48. Fit to the JAI index from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

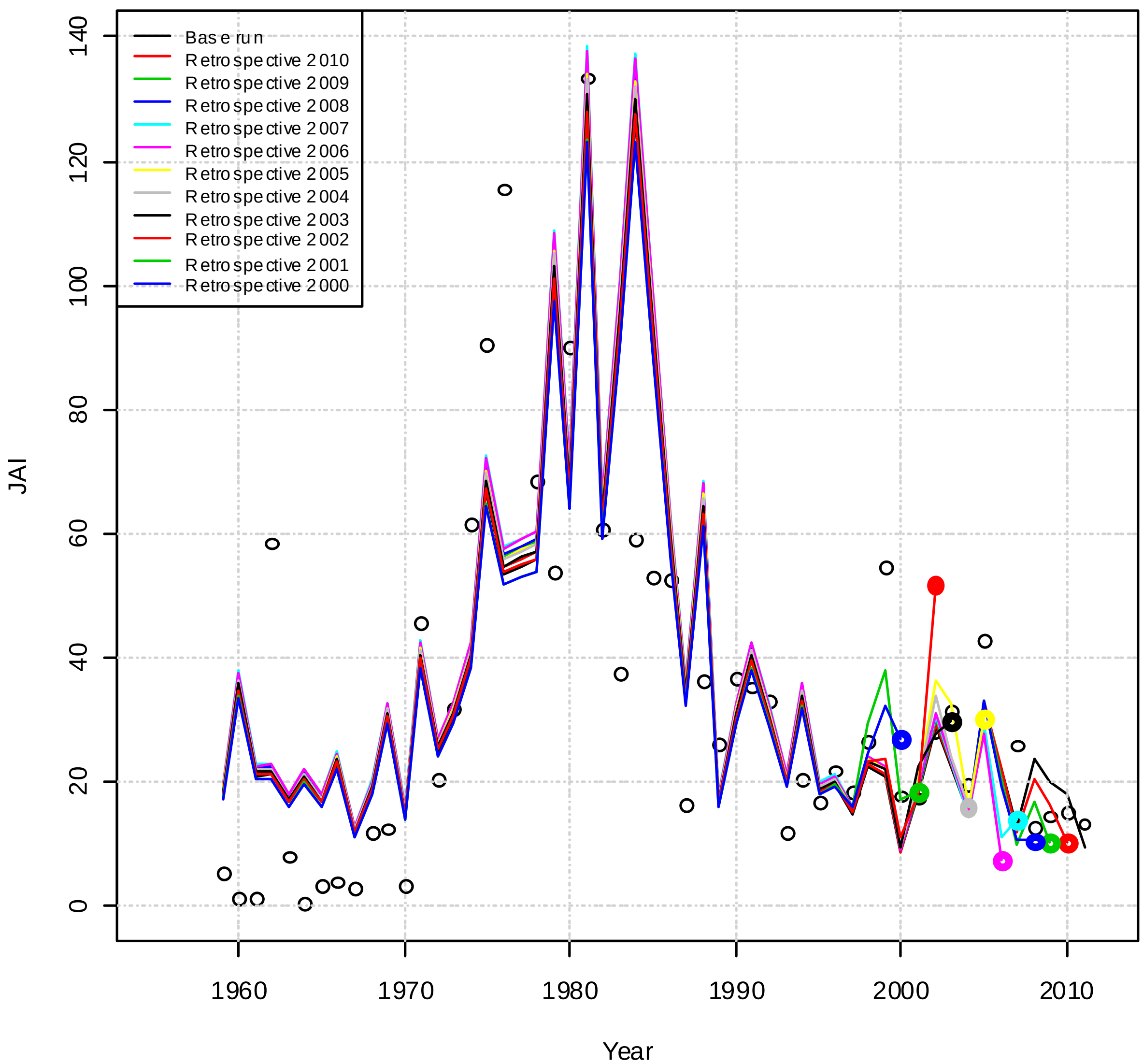


Figure 49. Fit to the pound net index from the base BAM model (connected open circles) and retrospective analysis runs. The last year of data used in the model run is indicated in the legend.

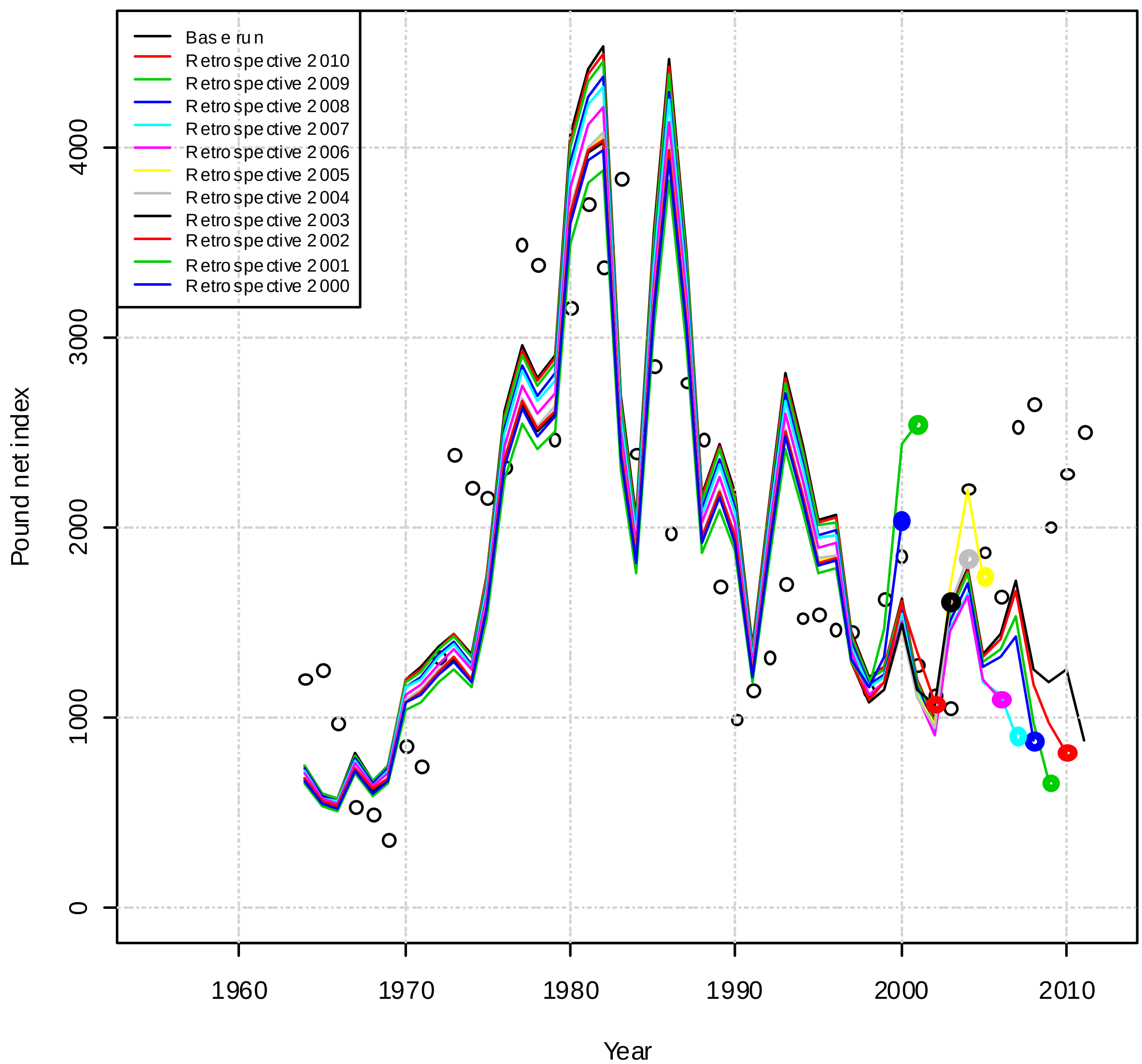


Figure 50. Relative change in full F from the base BAM model with a terminal year of 2011 compared to the retrospective analysis runs. The last year of data used in the model run is the year indicated on the x-axis.

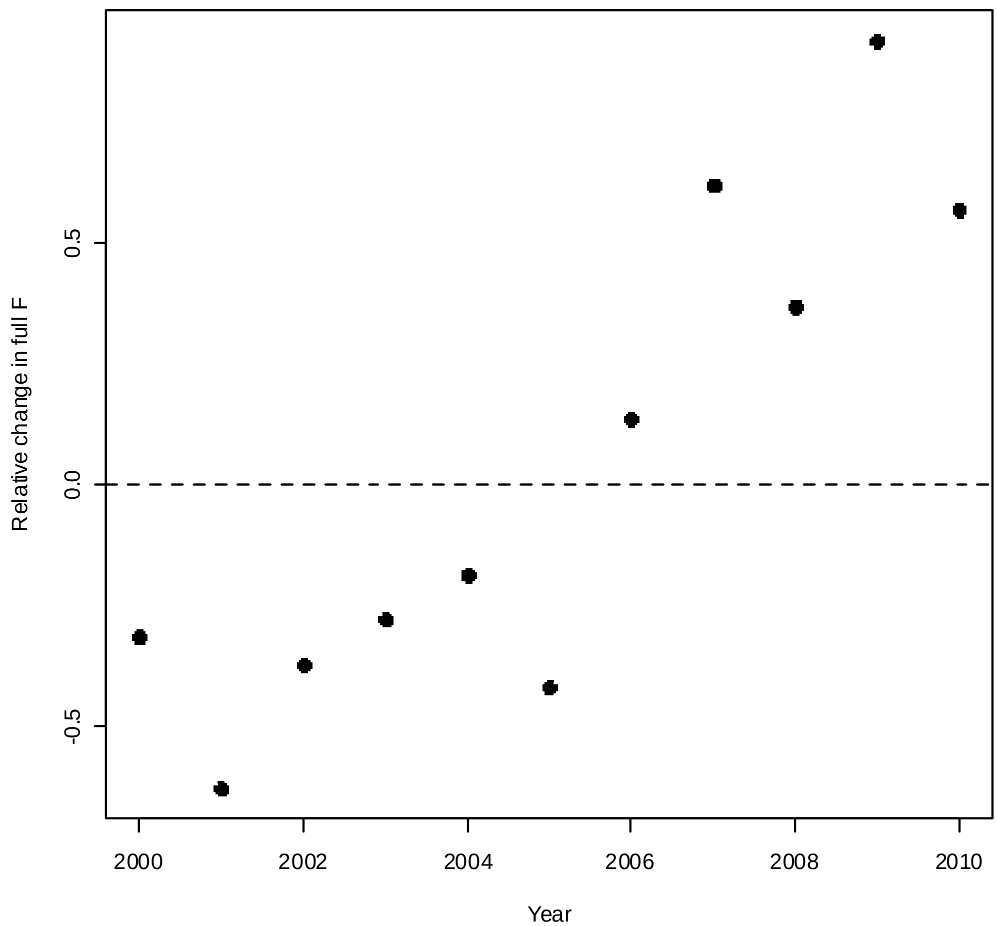


Figure 51. Relative change in recruitment from the base BAM model with a terminal year of 2011 compared to the retrospective analysis runs. The last year of data used in the model run is the year indicated on the x-axis.

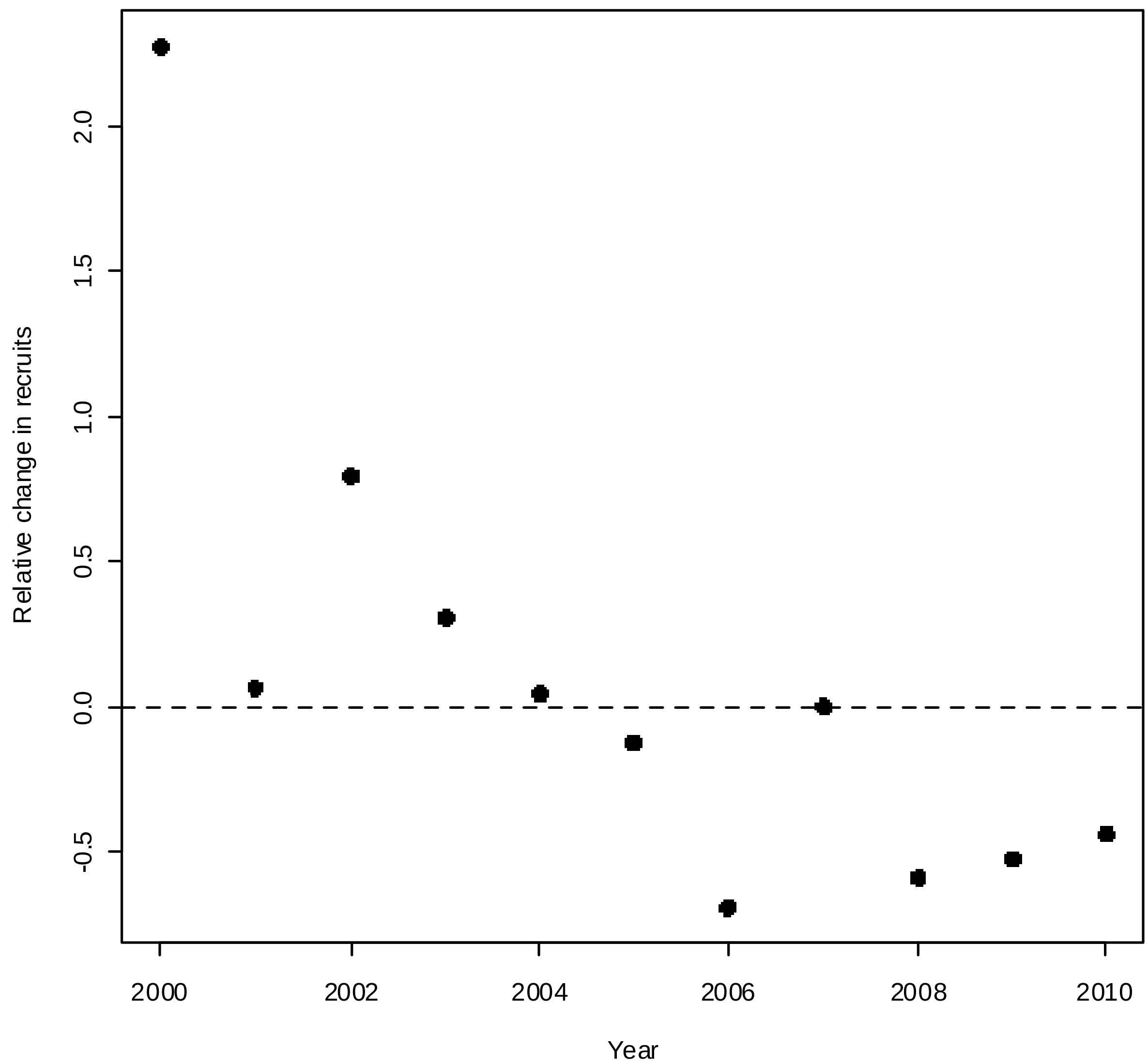


Figure 52. Relative change in fecundity from the base BAM model with a terminal year of 2011 compared to the retrospective analysis runs. The last year of data used in the model run is the year indicated on the x-axis.

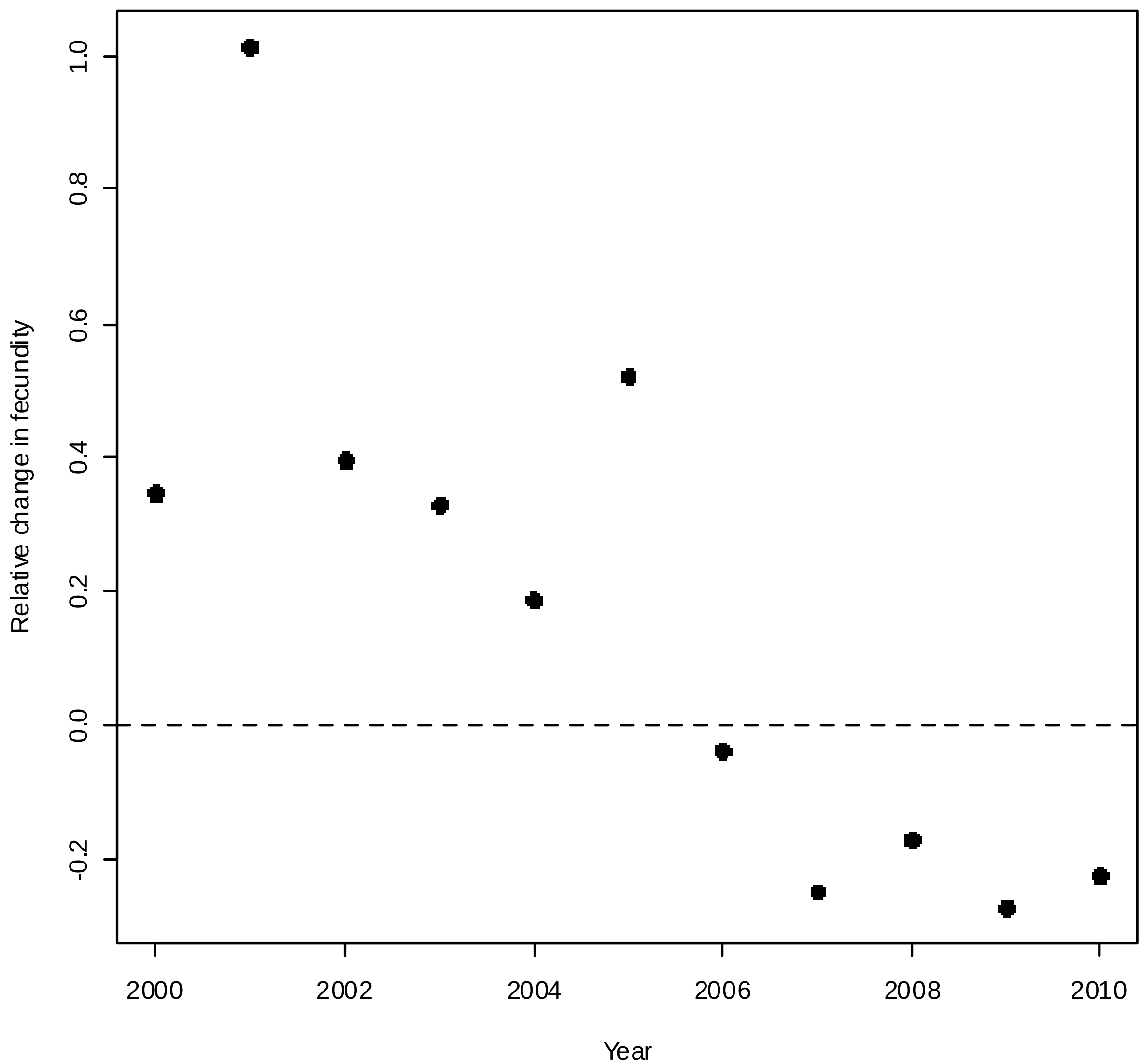


Figure 53. Relative change in biomass from the base BAM model with a terminal year of 2011 compared to the retrospective analysis runs. The last year of data used in the model run is the year indicated on the x-axis.

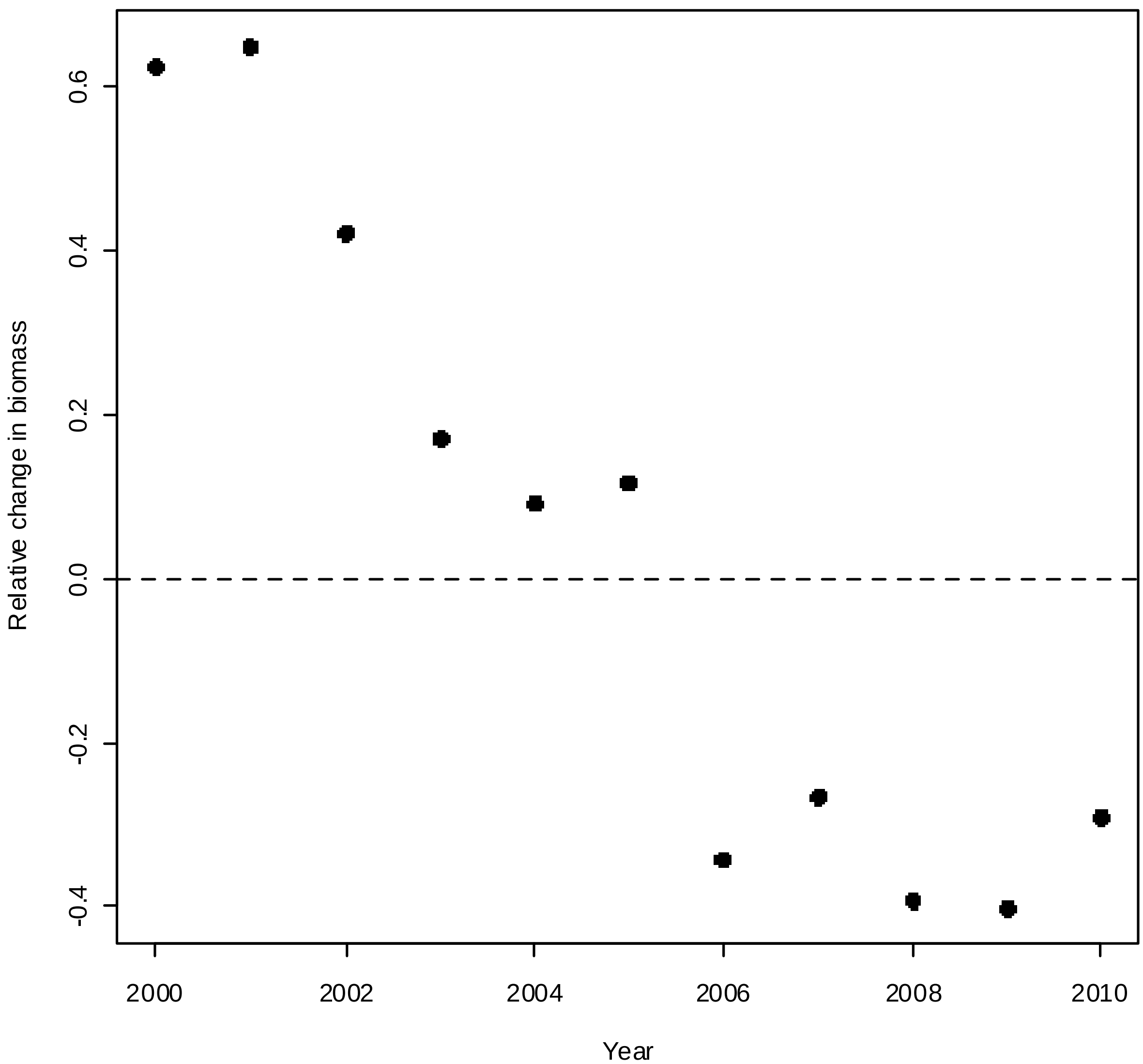


Figure 54. Estimates of the proportional (re-scaled to max of 1.0) fecundity-per-recruit as a function of the total full fishing mortality rate from the base BAM model using the years 1955-2011 for benchmark calculations.

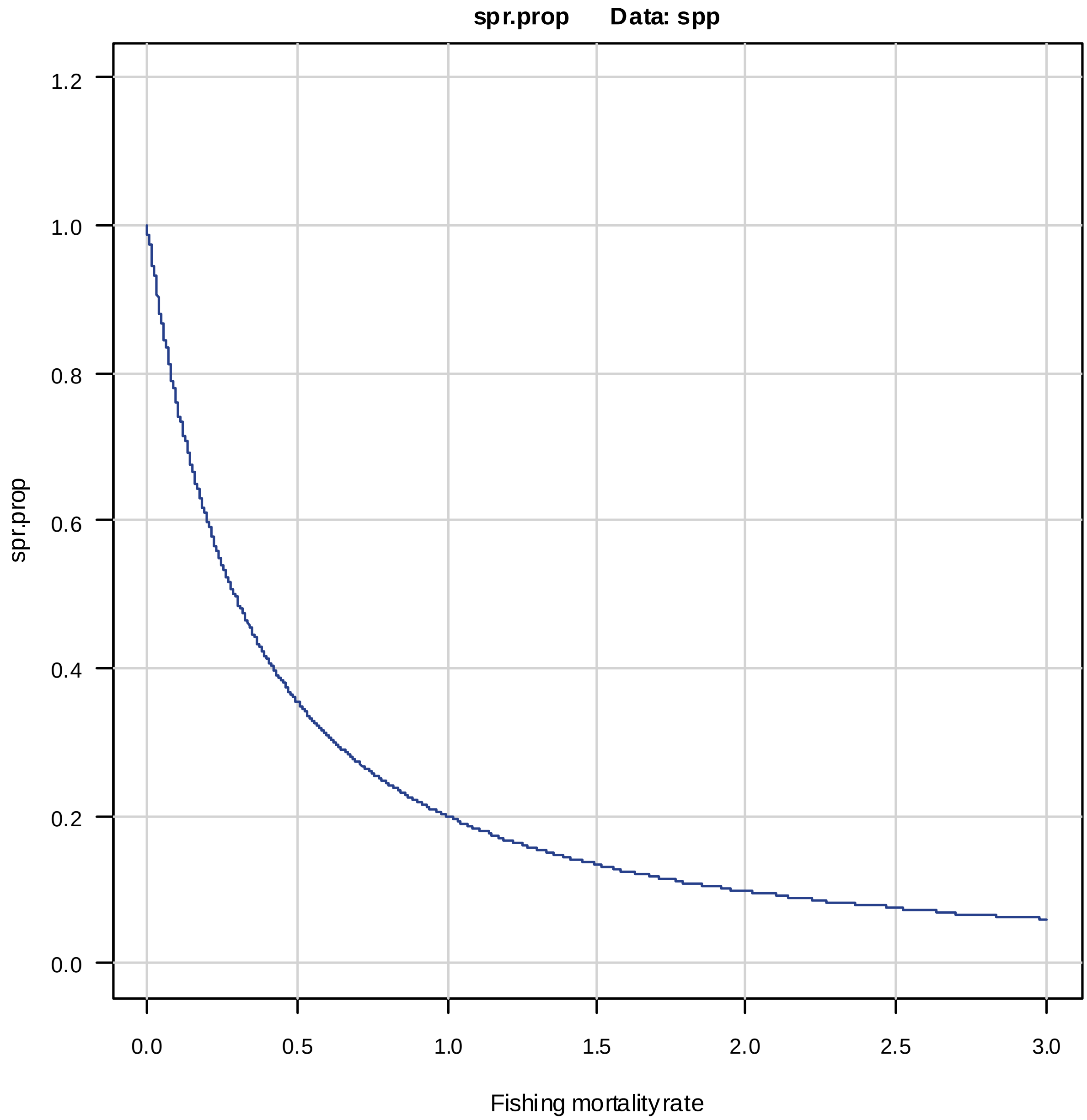


Figure 55. Estimates of the yield-per-recruit (mt/million) as a function of the total full fishing mortality rate from the base BAM model using the years 1955-2011 for benchmark calculations.

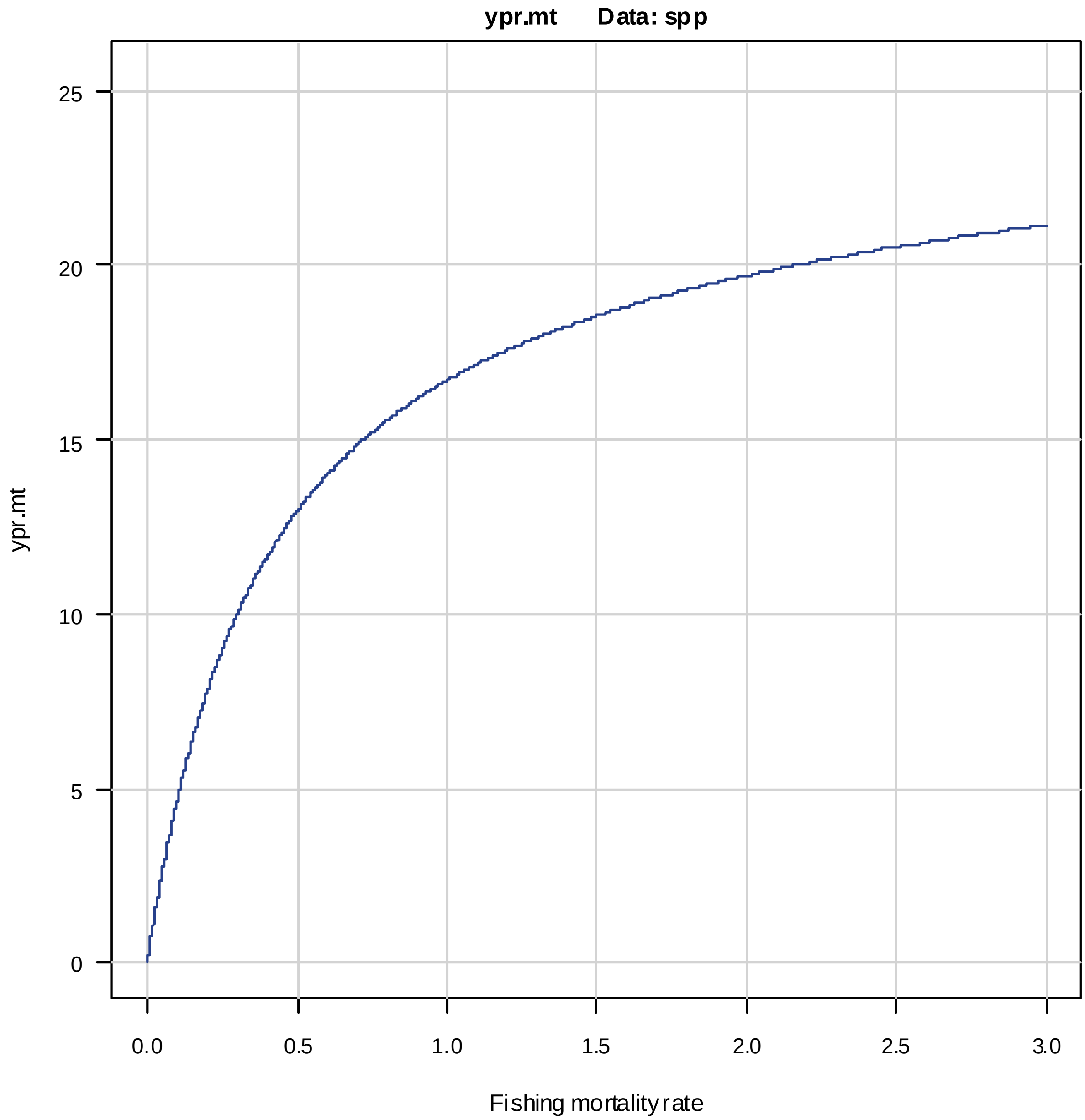


Figure 56. Estimates of the total full fishing mortality rate relative to the F15% benchmark (fishing limit value) from the base BAM model (connected points) using benchmarks calculated over 1955-2011. Shaded area represents the 90% confidence interval of the bootstrap runs.

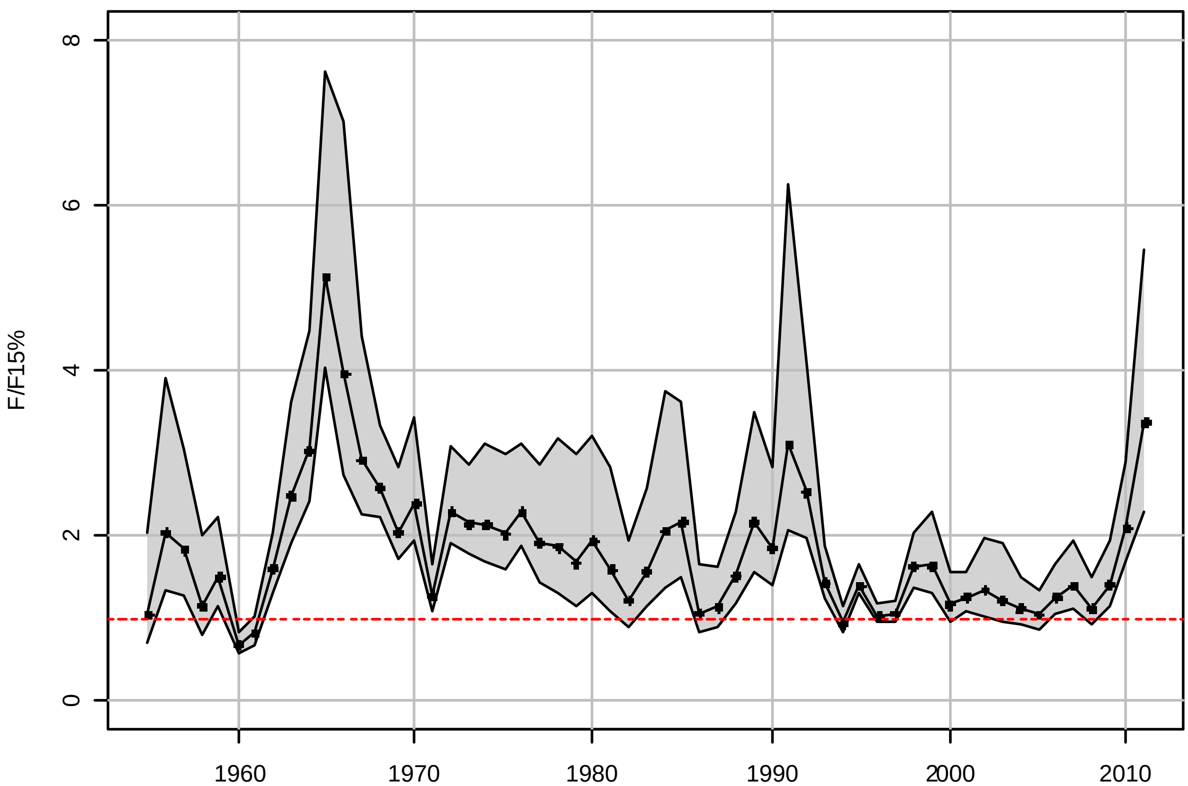


Figure 57. Estimates of the total full fishing mortality rate relative to the F30% benchmark (fishing target) from the base BAM model (connected points) using benchmarks calculated over 1955-2011. Shaded area represents the 90% confidence interval of the bootstap runs.

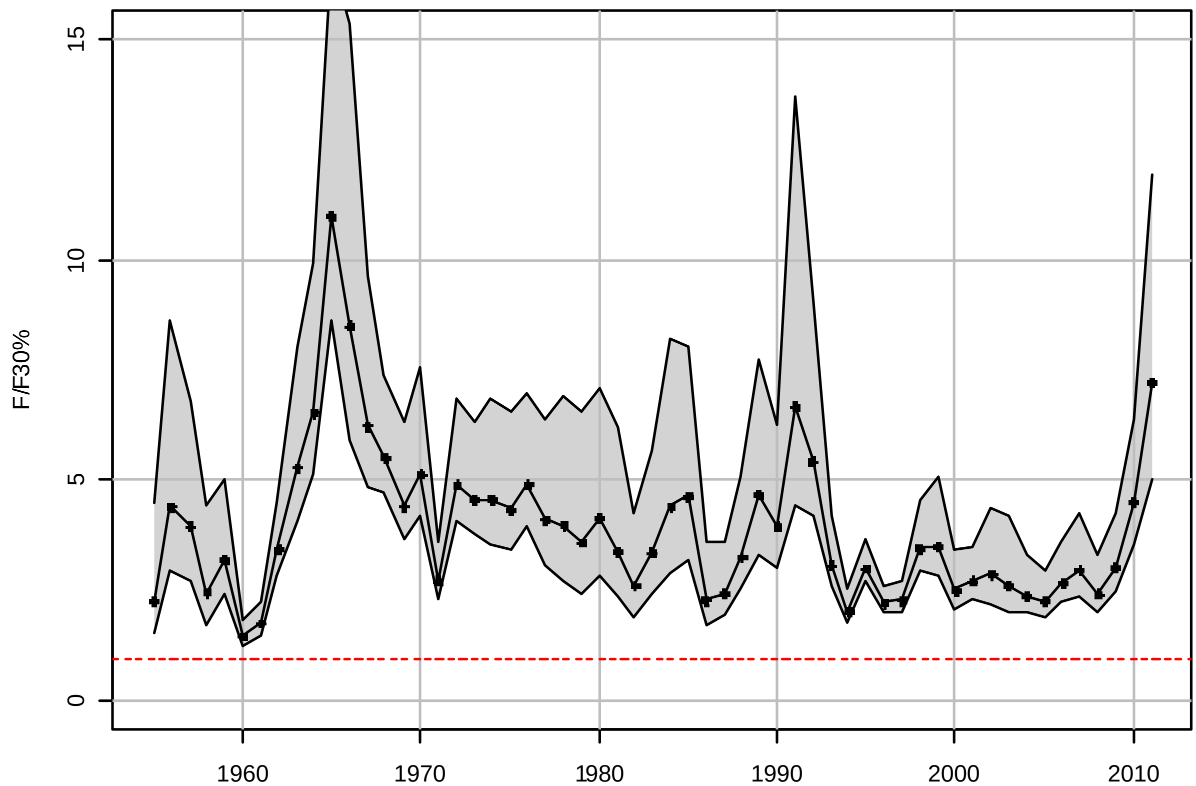


Figure 58. Annual fecundity compared to target and limit (threshold).

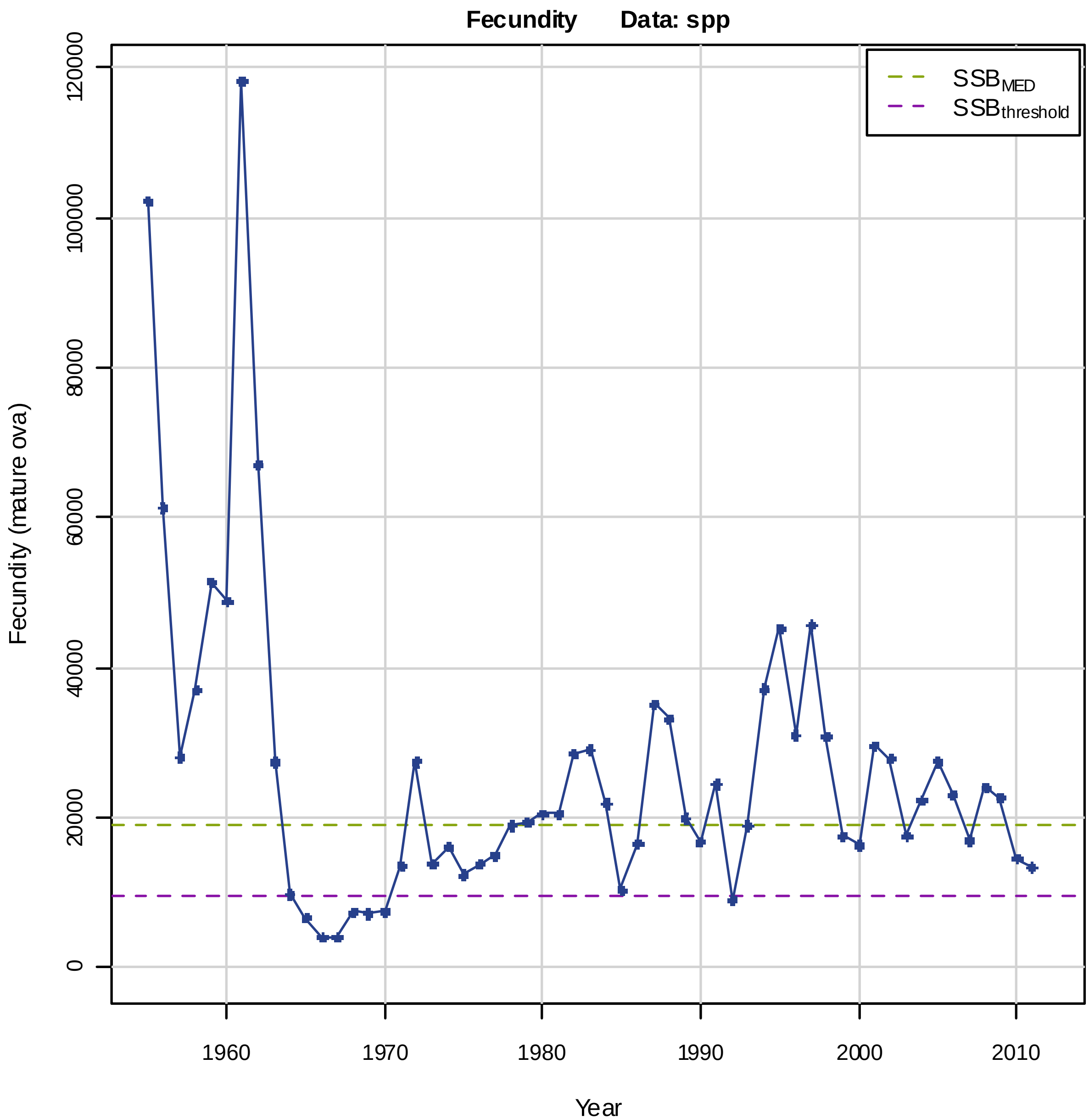


Figure 59. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 75,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

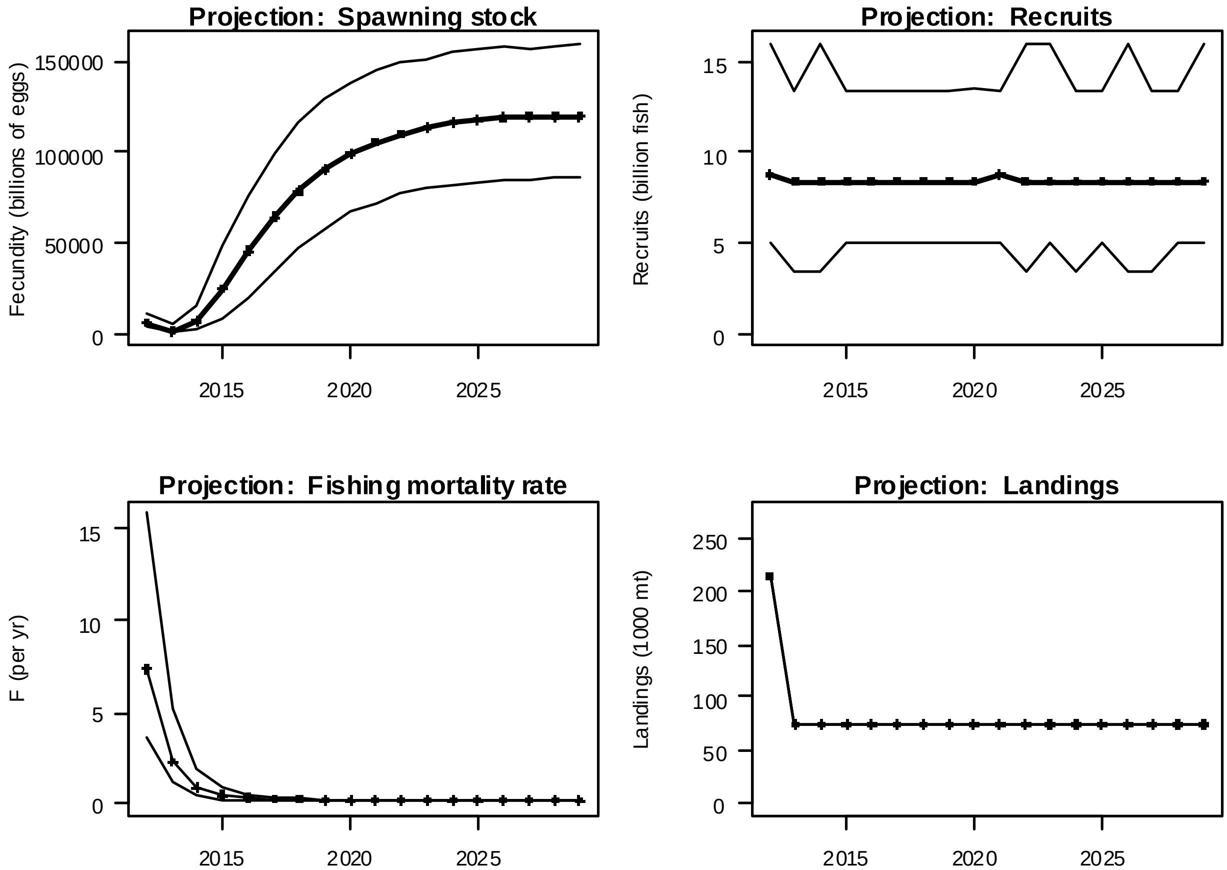


Figure 60. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 75,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denote the target.

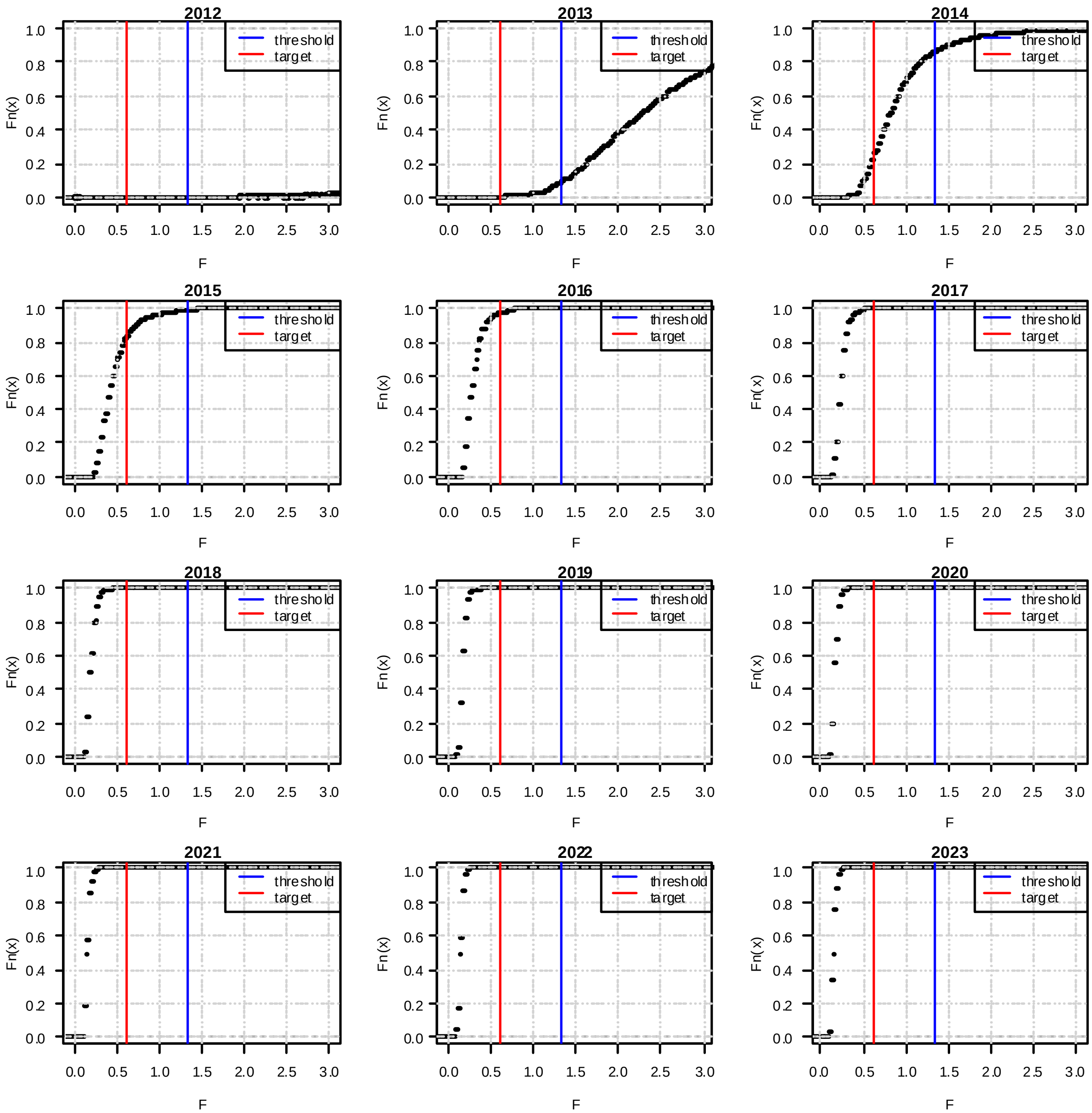


Figure 61. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 100,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

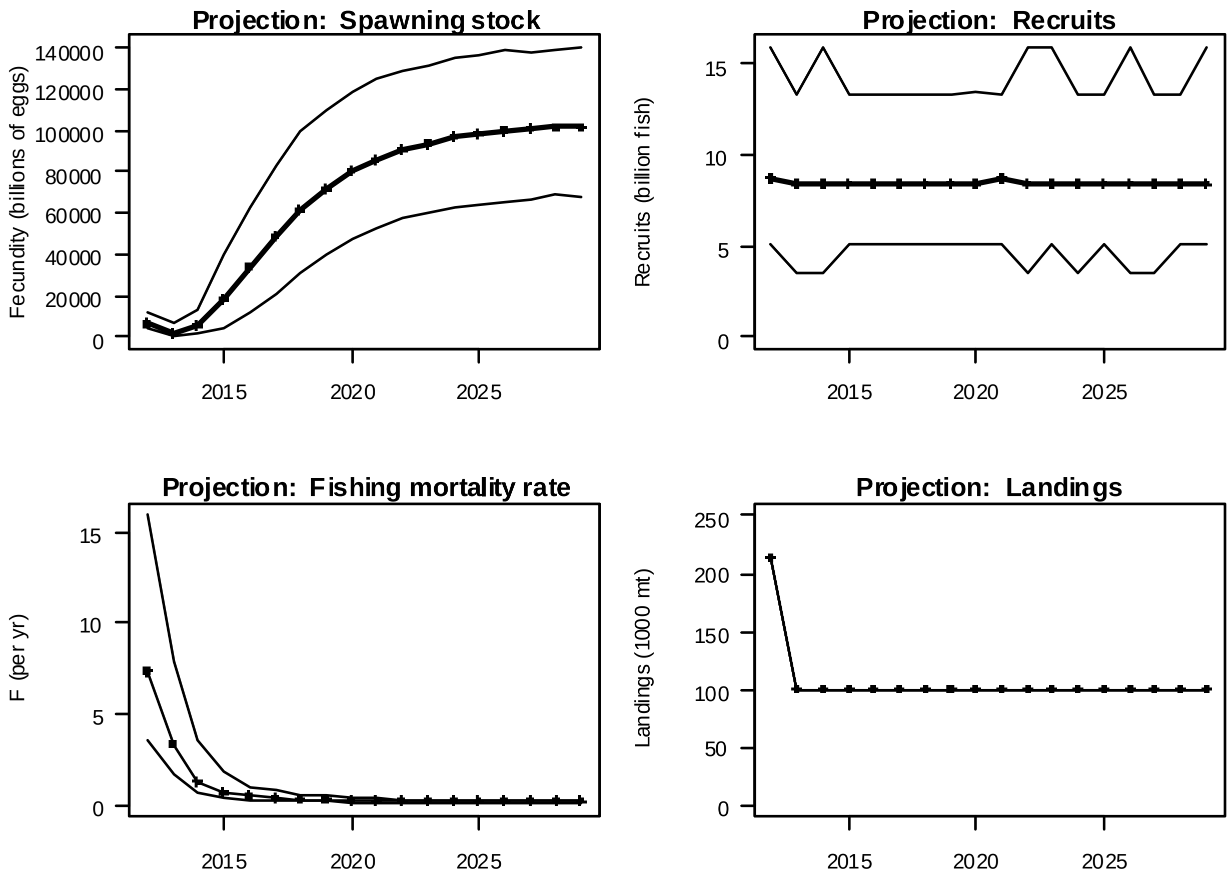


Figure 62. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 100,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.

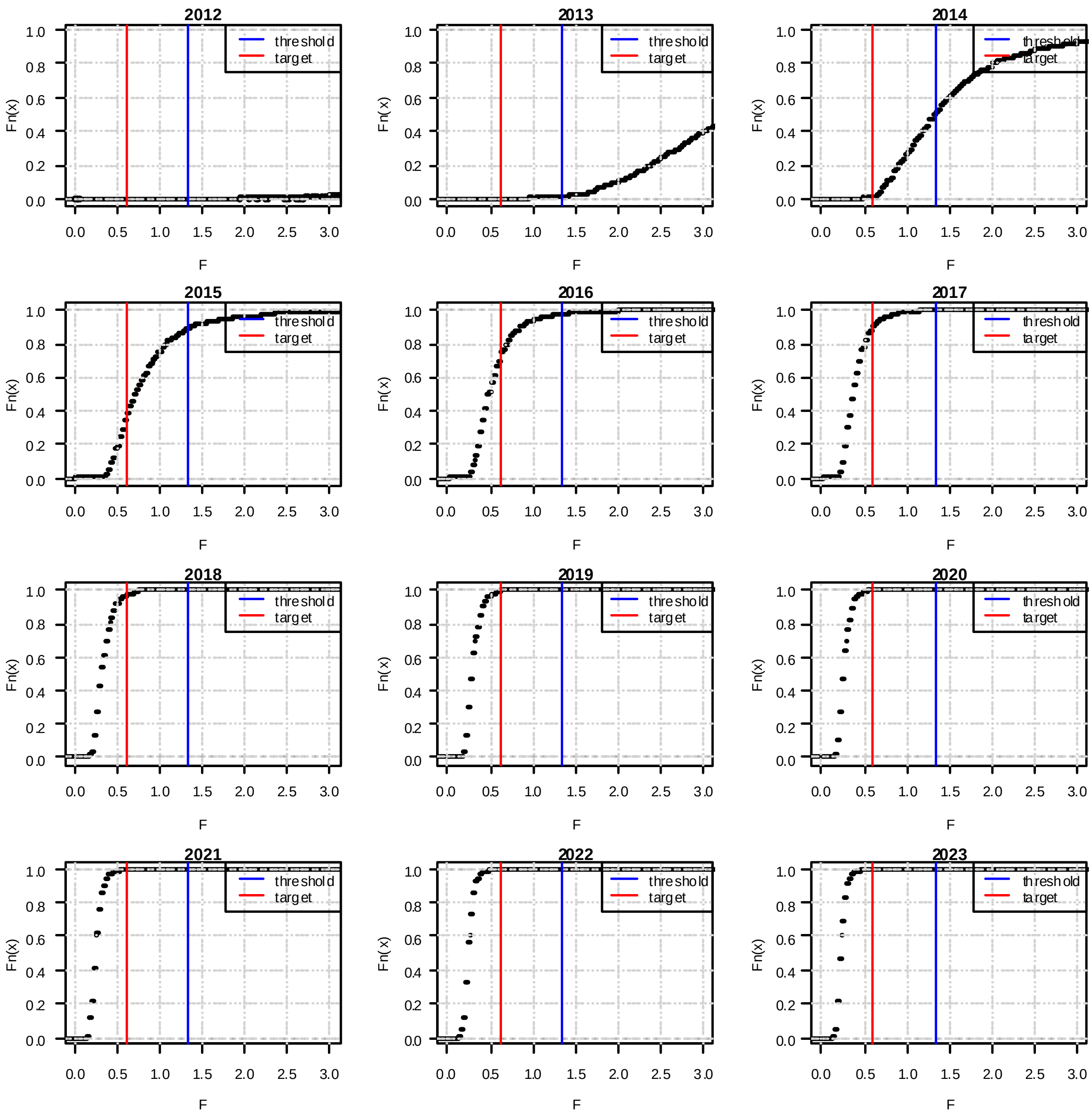


Figure 63. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 125,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

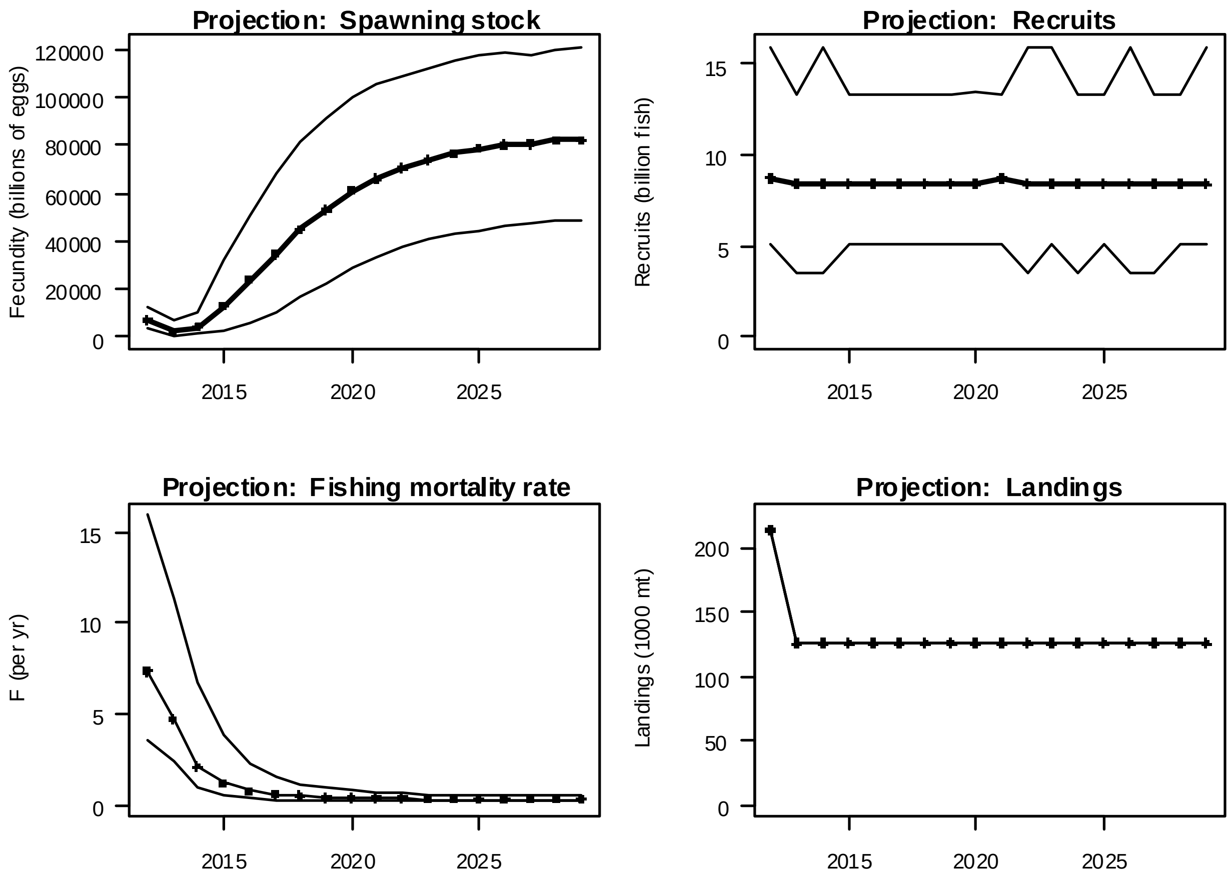


Figure 64. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 125,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.

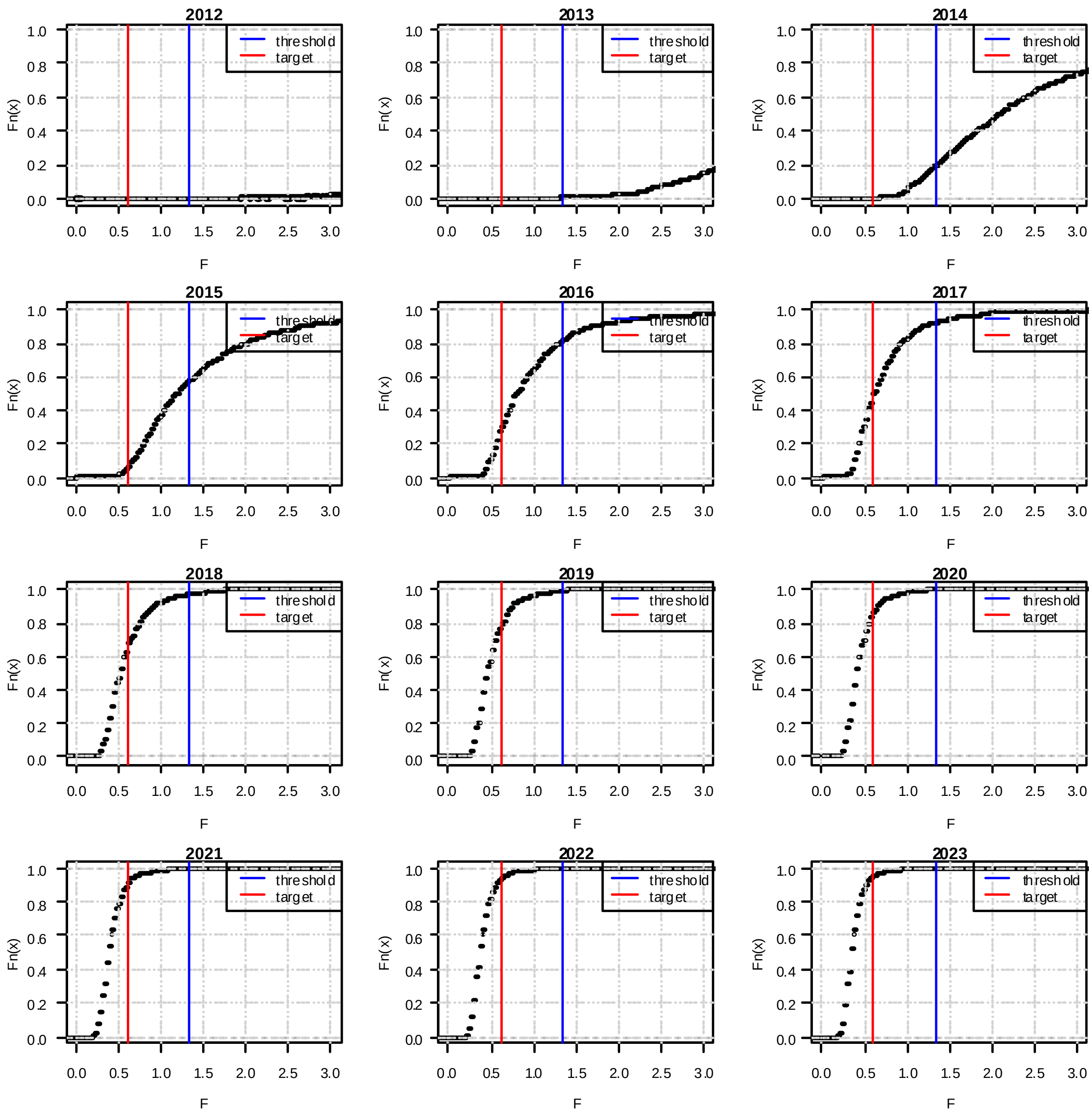


Figure 65. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 150,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

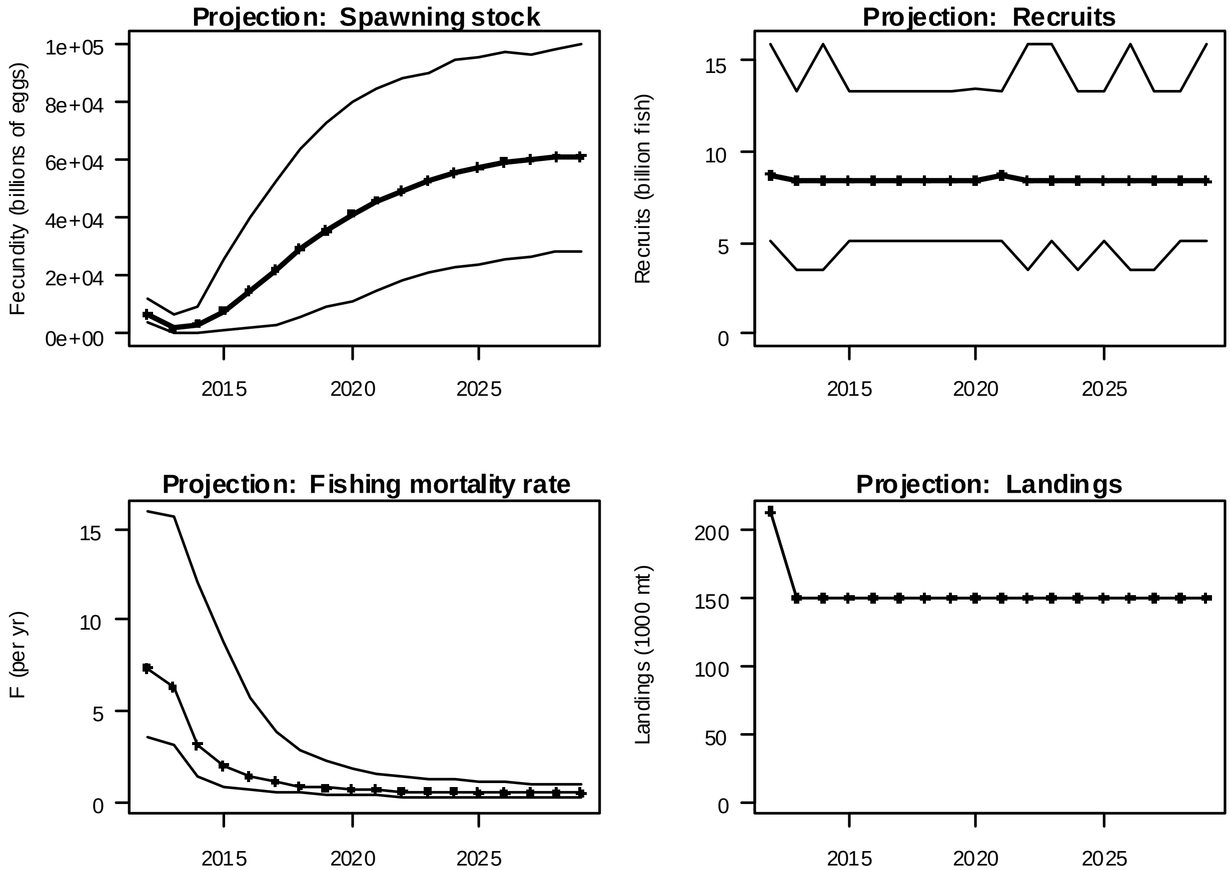


Figure 66. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 150,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.

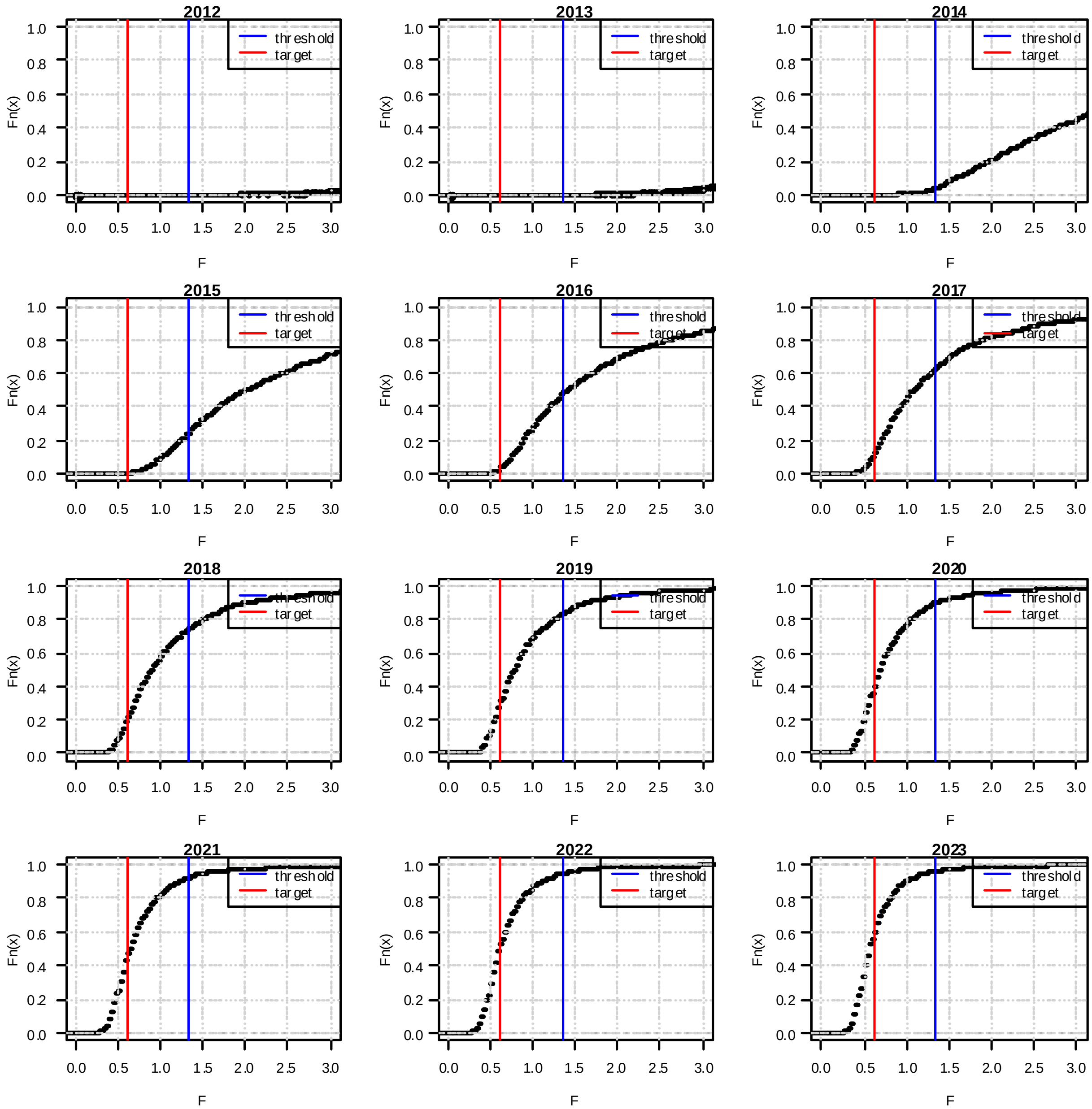


Figure 67. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 175,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

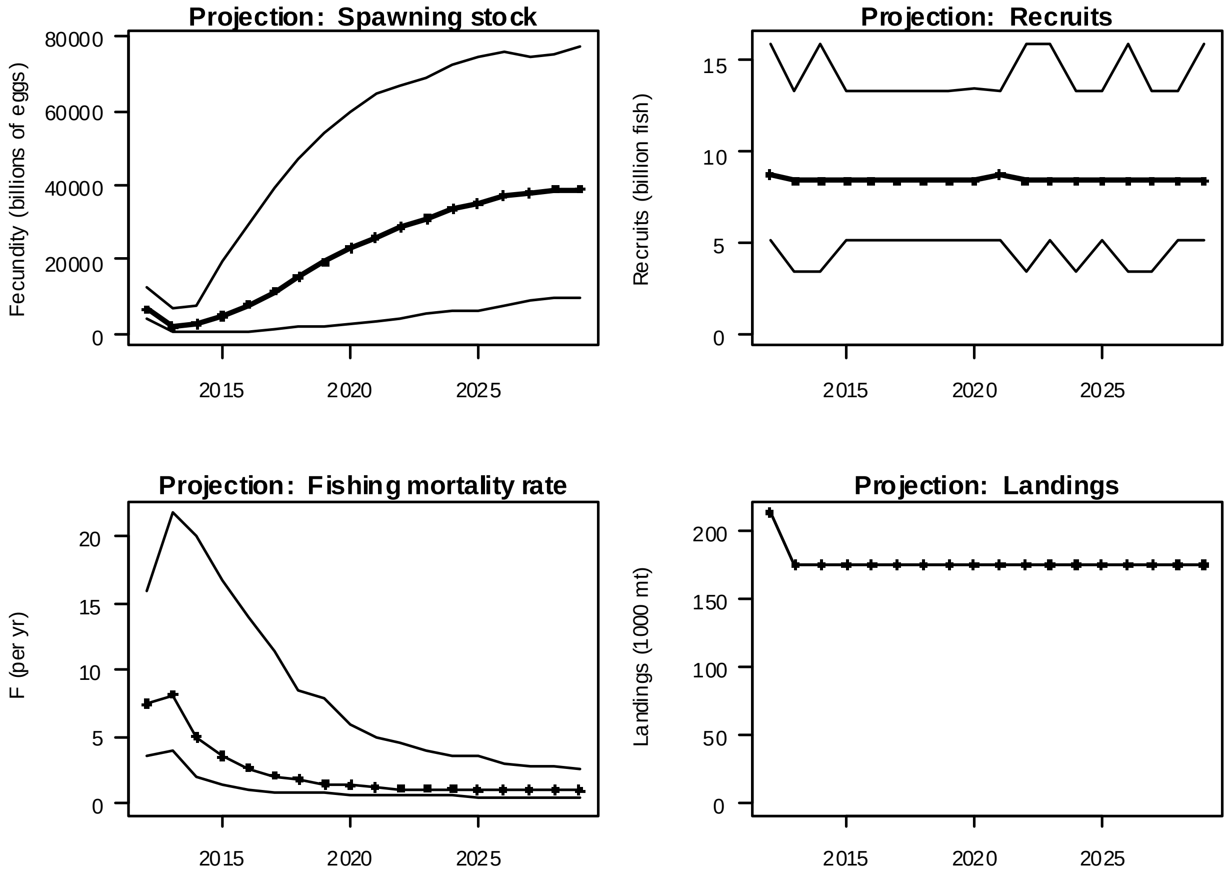


Figure 68. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 175,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.

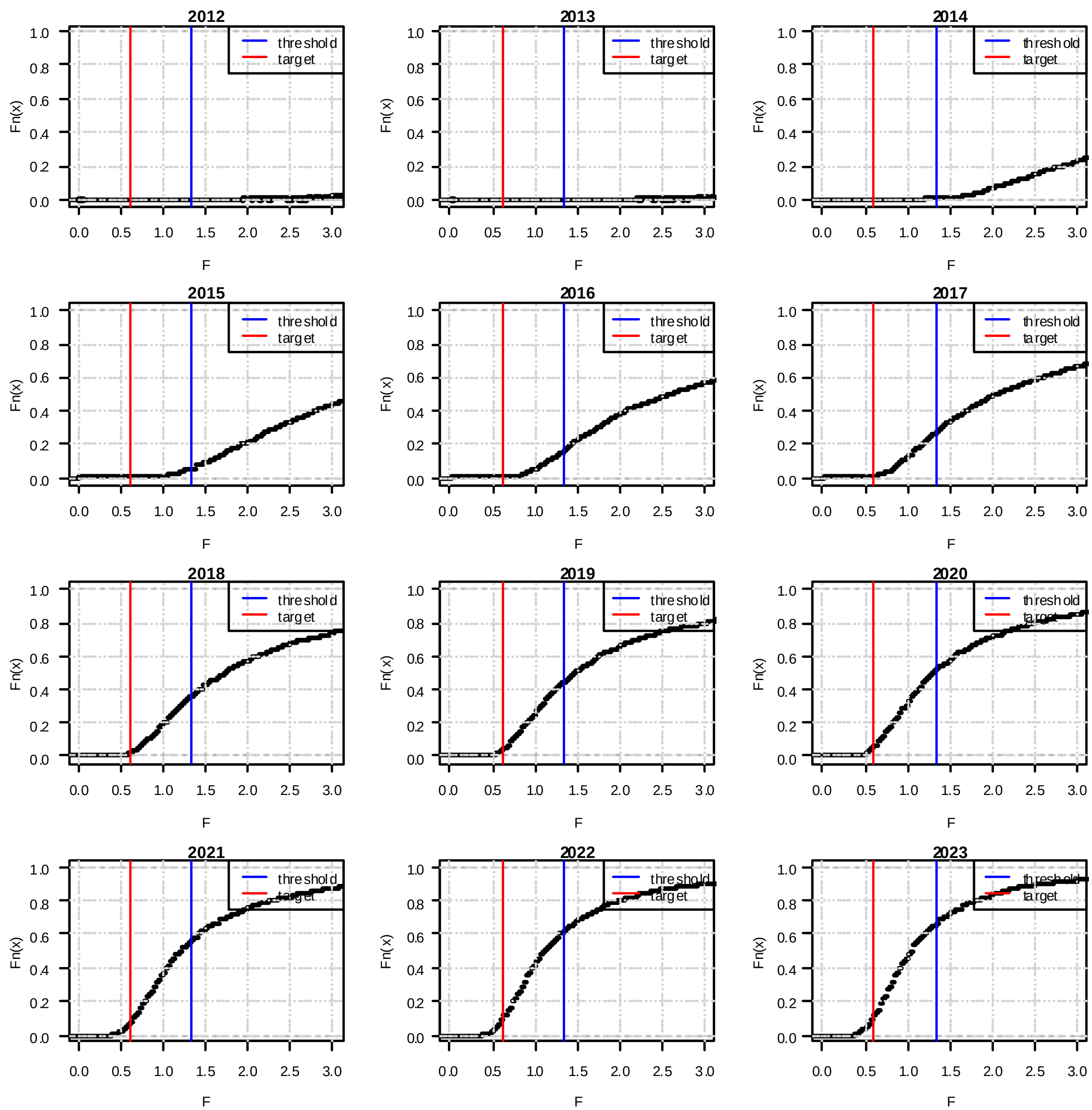


Figure 69. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 200,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

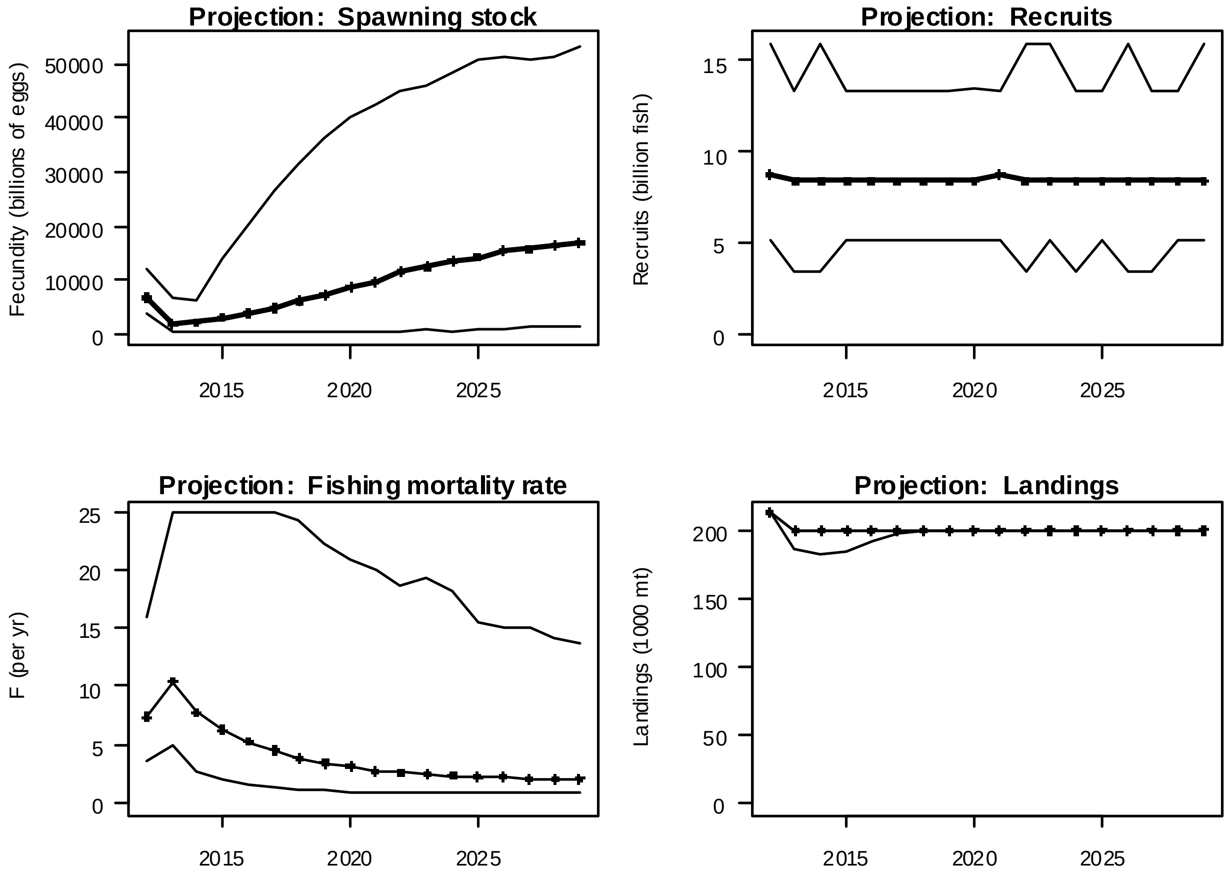


Figure 70. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 200,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.

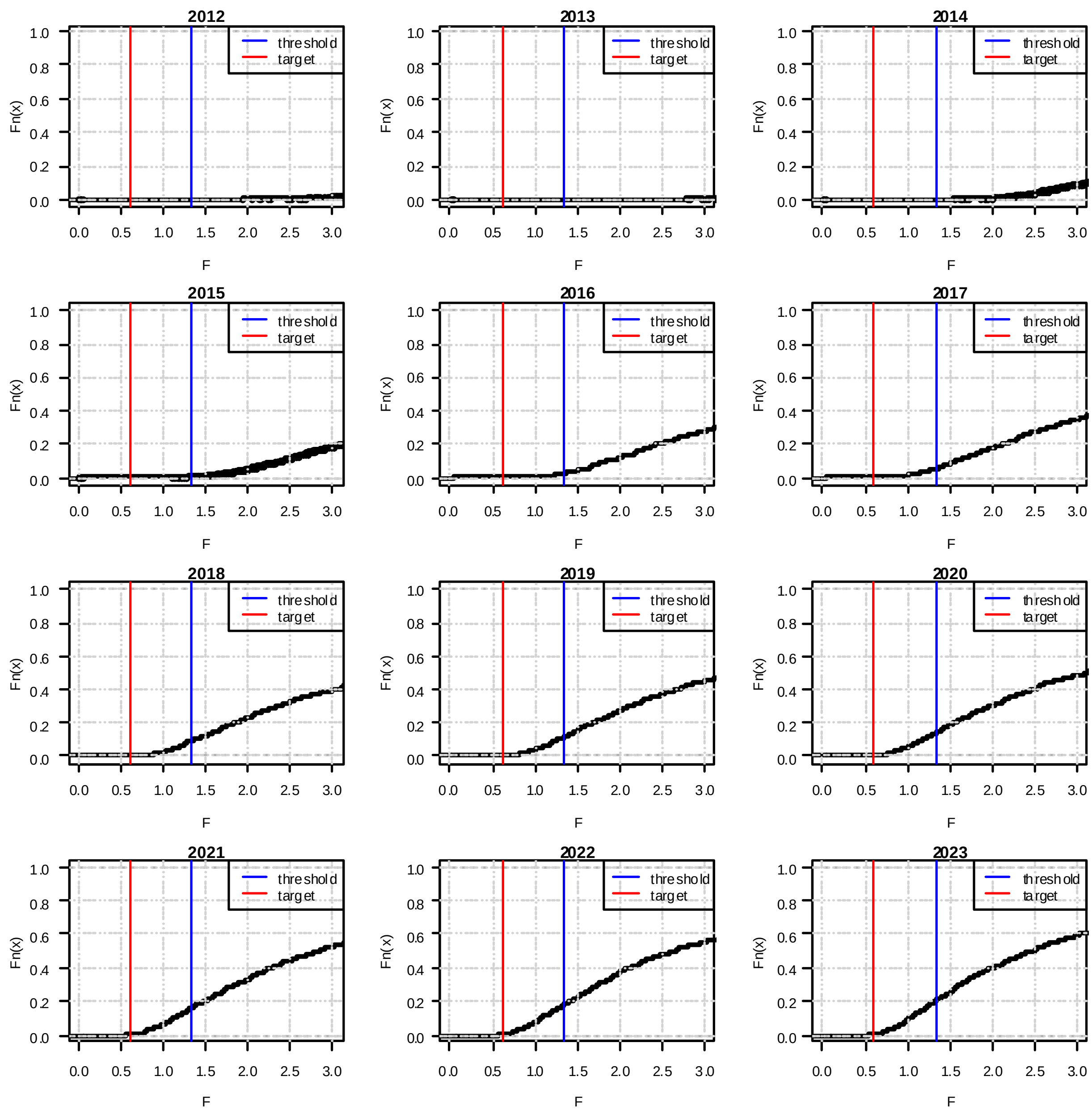


Figure 71. Fecundity, recruits, fishing mortality (F), and landings over time based on constant landings of 225,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery.

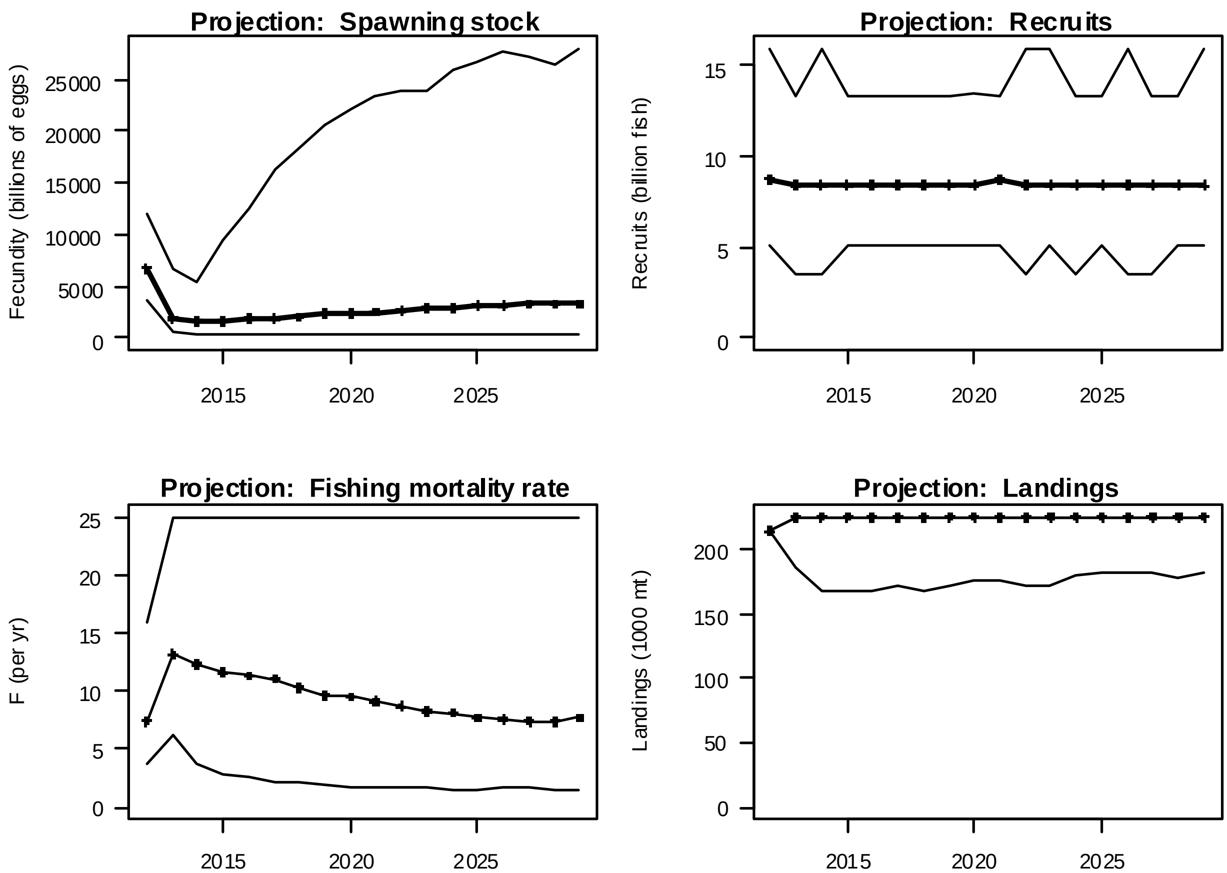
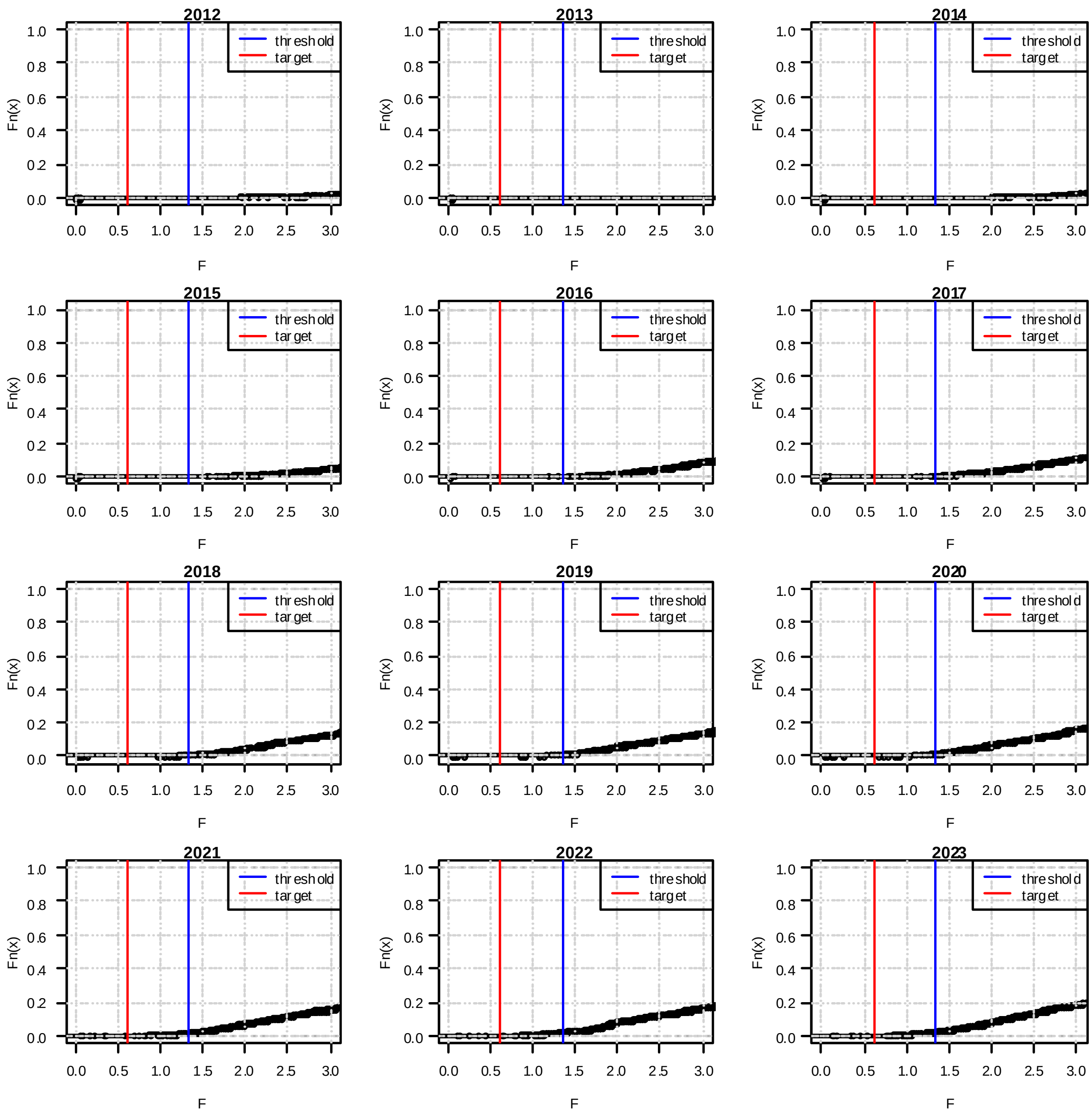


Figure 72. Cumulative distribution of fishing mortality rates for 2012 to 2023 based on constant landings of 225,000 mt with 25% allocated to the bait fishery and 75% allocated to the reduction fishery. The blue line denotes the threshold and the red line denotes the target, and where the lines cross the distribution is the probability that the given landings will be below a specified *F* in that year.



16 Appendix 1 – BAM dat file

```
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
## Data Input File
## ASMFC Assessment: Atlantic Menhaden
##
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

#starting and ending year of model
1955
2011
#Starting year to estimate recruitment deviation from S-R curve
1955
#3 phases of constraints on recruitment deviations: allows possible heavier constraint in early
and late period, with lighter constraint in the middle
#ending years of recruitment constraint phases
1956
2009
#4 periods of changing selectivity for reduction fishery: yr1-1963, 1964-1975, 1976-1993, 1994-
2011
#ending years of regulation period
1963
1975
1993

#starting and ending years to use for benchmark calculations
1955
2011

#Number of ages (last age is plus group)
9
##vector of agebins, last is a plus group
0 1 2 3 4 5 6 7 8

#max value of F used in spr and msy calculations
3.0
#number of iterations in spr calculations
30001
#number of iterations in msy calculations
30001
#Number years at end of time series over which to average sector Fs, for weighted selectivities
57
#multiplicative bias correction of recruitment (may set to 1.0 for none or negative to compute
from recruitment variance)
-1.0
```

```
#number yrs to exclude at end of time series for computing bias correction (end rec devs may
have extra constraint)
0

##time-invariant vector of % maturity-at-age for females (ages 0-8+)
0	0	0.125	0.851	1	1	1	1	1
##time-invariant vector of % maturity-at-age for males (ages 0-8+)
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
#time-variant vector of proportion female (ages 0-8+)
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
#time of year (as fraction) for spawning: mid-April=115d/365d
0.0
#age-dependent natural mortality at age
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455

#age-independent natural mortality (used only to compute MSST=(1-M)SSBmsy)
0.45
#age and year specific natural mortality
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
1.140	0.889	0.683	0.574	0.519	0.482	0.455	0.455	0.455
```

1.650	1.400	1.067	0.814	0.655	0.539	0.451	0.451	0.451
1.543	1.293	0.969	0.746	0.619	0.532	0.462	0.462	0.462
1.347	1.118	0.829	0.650	0.556	0.494	0.452	0.452	0.452
1.301	1.106	0.831	0.651	0.555	0.490	0.448	0.448	0.448
1.334	1.093	0.843	0.667	0.565	0.493	0.447	0.447	0.447
1.228	0.988	0.775	0.625	0.538	0.478	0.435	0.435	0.435
1.189	0.909	0.724	0.596	0.521	0.466	0.432	0.432	0.432
0.982	0.799	0.655	0.568	0.517	0.484	0.440	0.440	0.440
0.968	0.766	0.614	0.539	0.501	0.475	0.460	0.460	0.460
0.985	0.765	0.614	0.540	0.503	0.480	0.455	0.455	0.455
0.877	0.698	0.568	0.508	0.480	0.462	0.450	0.450	0.450
0.978	0.761	0.598	0.523	0.488	0.465	0.448	0.448	0.448
1.015	0.783	0.597	0.519	0.485	0.466	0.448	0.448	0.448
1.108	0.802	0.602	0.524	0.492	0.474	0.460	0.460	0.460
1.088	0.815	0.590	0.507	0.474	0.455	0.444	0.444	0.444
1.040	0.786	0.586	0.498	0.460	0.437	0.426	0.426	0.426
1.102	0.784	0.588	0.502	0.463	0.440	0.421	0.421	0.421
1.127	0.771	0.577	0.502	0.470	0.453	0.434	0.434	0.434
1.005	0.730	0.553	0.491	0.466	0.452	0.442	0.442	0.442
1.069	0.756	0.578	0.512	0.484	0.470	0.455	0.455	0.455
1.168	0.832	0.607	0.523	0.489	0.468	0.459	0.459	0.459
1.059	0.821	0.617	0.522	0.478	0.450	0.436	0.436	0.436
1.129	0.910	0.685	0.567	0.509	0.473	0.442	0.442	0.442
1.168	0.922	0.689	0.572	0.515	0.478	0.453	0.453	0.453
1.144	0.895	0.697	0.595	0.543	0.512	0.472	0.472	0.472
1.108	0.860	0.671	0.583	0.540	0.512	0.495	0.495	0.495
1.132	0.878	0.692	0.603	0.559	0.533	0.501	0.501	0.501
1.138	0.891	0.699	0.609	0.566	0.539	0.523	0.523	0.523
1.074	0.862	0.689	0.596	0.547	0.516	0.493	0.493	0.493
1.027	1.017	0.769	0.619	0.544	0.505	0.484	0.484	0.484

##Spawner-recruit parameters
#switch for S-R function to use Ricker (1) or Beverton-Holt (2)
2
#steepness (fixed or initial guess)
0.99
#standard error of steepness (from meta-analysis)
0.2
#log_R0 - log virgin recruitment
2.7
R autocorrelation
0.0

##--><>--><>--><>-- Weight-at-age in the fishery (g) --><>--><>--><>--><>--><>--><>--><>-
-><>

36.2	124.3	274.3	390.3	451.5	523.3	610.8	681.9	674.8
25.2	105.1	267.1	428.1	498.1	558.8	601.7	633.0	710.4
41.2	91.3	230.8	413.4	553.1	595.6	645.8	668.9	649.8
22.8	109.9	231.7	382.2	555.5	655.8	686.9	719.8	728.9
60.5	75.2	231.4	373.5	507.5	643.9	697.1	726.6	739.2
32.2	129.6	189.6	375.4	513.3	636.2	738.3	752.7	789.3
48.3	116.0	258.4	336.7	512.9	618.3	727.6	789.9	771.3
60.1	131.0	267.1	394.1	466.5	591.0	644.3	731.1	754.8
63.5	145.6	257.7	424.9	567.3	635.0	727.1	742.6	835.6
67.1	150.4	281.1	380.3	550.2	721.1	767.2	811.7	786.5
53.0	145.8	275.5	386.3	462.2	621.2	835.8	853.3	852.3
66.8	121.9	278.1	387.7	455.6	509.7	648.2	899.7	887.3
62.1	157.6	252.4	434.2	507.2	535.7	581.5	722.8	1063.5
74.7	128.1	316.8	424.3	583.3	596.3	583.3	620.6	751.8
83.3	152.8	268.9	500.0	649.2	759.4	705.9	655.1	689.9
58.7	185.4	269.3	419.1	595.1	790.4	814.4	705.8	631.7
50.6	169.4	341.9	406.3	589.4	654.5	905.8	844.3	695.9
24.7	122.7	328.9	493.1	566.4	800.0	713.2	1048.6	897.8
43.1	121.1	263.3	475.2	636.9	752.9	1039.3	764.4	1175.1
28.7	103.4	263.0	408.7	582.0	764.0	968.3	1344.6	817.8
27.1	84.5	214.8	379.8	560.5	666.2	877.0	1204.4	1682.8
17.3	67.4	192.4	345.3	474.1	732.6	761.3	1023.0	1543.4
20.2	64.4	151.3	317.3	471.6	533.0	878.5	821.9	1126.2
28.4	68.7	163.2	252.6	420.4	556.1	543.8	944.0	817.6
24.8	68.7	168.8	279.1	366.8	516.4	638.4	562.1	1028.2
21.7	56.6	148.1	288.8	391.6	482.0	593.8	702.3	573.1
19.5	68.2	118.8	239.7	396.9	475.8	575.8	637.1	732.7
26.7	76.2	167.7	212.4	341.0	486.7	533.9	643.0	650.7
31.4	70.8	171.6	258.4	303.4	414.5	534.0	553.5	675.8
25.6	71.9	165.8	291.7	368.6	440.4	525.8	623.9	621.0
22.6	68.4	139.3	260.6	374.2	430.8	546.0	579.3	641.6
24.3	64.4	149.8	230.7	375.2	470.7	516.2	715.8	683.0
26.6	75.5	153.6	249.4	338.2	476.8	533.3	566.0	847.6
27.8	69.4	159.9	241.3	329.2	429.6	541.5	556.9	580.4
39.1	91.1	150.3	256.1	341.1	427.5	567.7	657.1	632.2
35.8	113.1	208.5	248.2	340.4	419.4	494.0	670.6	713.7
52.0	92.8	224.1	309.7	334.8	393.4	461.9	521.5	723.5
28.3	123.1	186.4	318.7	392.3	420.5	445.0	512.0	565.8
49.8	93.4	243.6	294.7	396.0	457.6	501.1	488.5	553.9
23.5	118.8	214.3	355.7	395.0	450.3	504.8	572.6	523.3
22.6	112.6	229.7	331.8	423.1	453.4	456.3	501.1	586.3
17.0	96.5	288.8	371.6	483.5	529.8	564.3	517.7	564.7
28.8	87.6	246.6	447.0	491.0	594.2	585.9	625.8	536.0

60.3	93.9	227.2	390.9	547.0	574.4	662.1	608.2	654.1
39.1	131.1	214.0	354.9	496.6	597.8	627.1	699.9	612.1
27.1	131.5	252.7	345.5	456.5	577.9	633.4	674.5	736.3
55.0	125.1	280.6	382.9	462.1	522.0	624.5	643.7	697.6
40.4	149.4	290.1	422.1	526.3	581.0	588.9	683.6	677.6
49.5	121.7	277.0	440.1	557.5	701.6	725.3	678.0	779.9
25.3	113.9	238.6	339.2	482.6	572.9	738.6	722.8	638.4
37.1	88.6	214.5	328.6	369.5	495.8	572.7	760.5	714.6
43.8	112.5	193.7	321.5	411.2	407.1	537.6	619.3	862.4
56.0	127.2	219.6	280.6	390.9	434.4	399.2	514.3	588.0
61.0	132.7	241.3	309.7	359.7	473.5	479.2	419.4	539.6
54.1	112.9	230.0	320.2	360.2	403.4	519.5	489.9	416.0
52.3	137.7	205.6	309.5	378.4	399.4	442.5	568.2	508.2
43.7	114.5	202.0	309.5	358.0	408.0	416.8	461.3	595.2

##--><>--><>--><>-- Weight-at-age for the spawning population - start of year (g) --><>--><>--><>--><>

21.2	66.1	191.5	332.3	387.5	476.8	474.8	618.8	442.8
12.0	55.8	194.2	356.7	448.7	511.9	568.6	631.7	706.1
25.9	41.6	163.5	342.6	499.2	554.5	612.4	645.4	649.8
12.4	61.2	158.6	310.0	494.6	618.3	654.1	697.0	712.8
43.1	36.4	166.3	301.5	443.6	598.2	673.6	702.6	724.9
15.7	79.6	126.2	303.5	449.5	580.6	703.2	737.4	770.8
29.7	55.1	190.0	260.8	445.3	568.6	683.7	765.1	762.0
38.3	77.2	193.1	324.1	397.6	539.8	612.8	702.6	740.3
42.1	85.0	194.3	353.4	490.5	565.4	680.6	717.7	811.8
45.9	90.8	215.1	323.4	494.2	648.1	706.2	774.5	769.1
36.5	88.2	209.0	332.1	418.4	581.6	770.7	802.7	823.6
43.5	73.5	208.7	329.8	417.4	479.5	622.8	847.0	849.1
47.0	91.6	180.8	358.2	455.9	506.7	558.3	704.2	1013.1
57.4	83.5	238.3	338.3	513.2	557.0	563.9	604.7	739.7
55.0	101.8	197.4	422.2	550.8	694.6	674.7	641.4	678.3
31.6	111.0	202.5	331.2	535.5	699.4	764.7	684.9	623.4
32.2	90.9	259.0	329.3	490.3	611.9	826.2	807.4	682.1
8.4	69.4	247.0	414.9	479.4	686.5	681.7	974.8	868.6
27.5	52.9	193.1	410.7	571.3	661.0	917.6	742.2	1110.9
16.5	58.7	192.3	334.8	535.4	709.2	868.1	1206.4	801.3
17.8	44.3	157.5	329.6	490.8	634.8	833.5	1099.7	1532.6
8.5	37.8	135.8	284.2	441.7	667.1	739.5	986.9	1427.3
10.8	29.4	106.1	256.9	415.2	514.2	822.2	807.9	1098.2
19.1	33.5	110.4	199.7	368.2	511.4	534.1	901.3	809.4
17.5	39.8	115.1	221.4	310.3	473.0	602.7	556.9	994.5
11.8	33.9	105.6	228.7	338.0	426.4	559.6	675.0	570.4
9.7	33.6	83.4	190.1	340.4	431.6	524.9	611.6	712.6

16.2	36.9	117.7	165.5	291.2	440.7	501.4	601.3	633.4
22.3	38.3	119.6	208.9	250.4	369.0	498.6	530.2	642.0
15.4	44.1	116.9	236.4	321.4	377.9	481.5	594.3	602.8
13.0	36.8	101.2	208.4	328.1	393.0	482.0	541.5	619.8
13.9	32.7	105.2	182.3	320.4	430.7	483.5	643.0	646.8
16.6	40.1	108.1	201.4	285.3	427.8	503.5	541.5	776.6
13.9	38.5	115.2	195.3	286.2	377.6	501.3	535.9	562.8
21.9	43.5	105.5	208.6	295.3	386.6	510.6	619.2	615.0
22.6	60.9	148.3	198.1	299.2	380.7	460.5	616.7	683.1
33.2	53.4	168.9	259.2	288.7	362.5	433.0	497.0	677.9
15.3	71.5	135.9	272.7	353.0	378.0	420.6	488.9	546.2
32.5	47.0	184.2	242.5	362.5	429.8	464.4	470.3	536.3
8.3	69.0	149.5	301.5	346.5	427.0	485.4	541.1	509.6
9.6	47.5	171.4	269.7	383.3	415.7	442.4	489.4	562.9
6.0	41.5	201.3	308.5	422.2	496.7	530.1	507.8	556.1
15.5	35.1	168.8	374.3	435.2	543.7	562.1	599.0	529.7
41.8	46.8	154.5	319.4	498.0	530.2	624.2	592.1	634.2
19.1	80.5	149.5	290.7	441.9	567.7	593.9	672.4	601.5
9.6	65.1	188.6	279.0	407.9	538.4	615.2	649.6	716.2
31.8	54.9	207.1	317.3	404.3	489.2	598.2	633.3	679.8
21.8	87.0	213.1	361.6	463.1	532.3	566.7	665.6	671.3
32.3	62.6	218.1	379.1	509.8	637.8	681.5	661.5	766.2
12.3	67.9	177.8	303.4	449.1	545.2	690.7	693.3	629.1
19.1	44.1	162.9	283.0	349.9	478.4	557.0	725.2	694.9
23.5	58.3	139.8	270.4	377.3	395.4	527.5	609.0	831.7
35.0	70.8	168.1	237.5	351.3	414.2	393.3	509.4	582.5
46.4	79.6	187.1	270.4	326.3	440.3	465.7	416.0	536.9
27.3	75.4	181.9	282.3	335.1	380.6	494.2	481.6	414.3
26.0	83.3	156.8	273.9	354.0	383.9	427.0	548.9	503.0
25.2	62.6	175.4	254.8	334.9	393.5	407.6	451.2	581.0

##--><>--><>--><>-- Fecundity-at-age - not adjusted for maturity (g) --><>--><>--><>--><>

13463	27660	71747	135469	165103	219032	217740	321215	197636
10233	24296	72102	146296	198365	238715	278272	326059	387985
15428	20472	60931	137238	224019	259559	299712	323917	327225
10666	26237	57710	117364	211476	289036	313736	344903	356689
20917	18821	61418	116011	187290	282759	336617	358600	376132
12263	32755	47772	115336	185702	261358	343690	368737	394034

17011	25036	70012	97435	183960	254960	331452	391833	389392
18151	29948	70150	128512	168105	259983	315659	392635	427908
19711	32553	68999	135948	208853	255173	335926	364507	443039
20457	33674	75370	119892	207922	307939	351183	406166	401612
18237	34048	75932	128808	172836	273148	420039	448402	467517
20068	29310	77431	132904	181346	220185	325457	538380	540608
21964	35909	66557	143144	195394	225602	258464	364216	656569
24285	32187	86618	130604	226649	254766	259346	287397	391507
22385	35628	65678	158388	227292	319609	305825	283479	308310
16182	40033	71523	125826	239545	358396	413289	346808	300046
16345	34342	98269	132074	227586	318080	521103	500891	378173
8763	28730	96288	185087	226597	390623	386319	708822	578342
14754	22426	70424	178248	289225	364405	639178	441371	912764
11782	25141	71533	135920	257501	396200	553580	1001315	483573
12253	20637	57577	130162	220146	320777	494628	799846	1507572
9077	18868	49093	103812	177278	313545	365766	578387	1105788
10058	16325	39217	90510	157887	207920	406384	395594	645832
12879	17450	40638	70425	139391	212757	225751	491521	414559
12366	19345	41904	77701	112508	189067	263044	235543	565097
10294	17459	38722	79681	123164	163676	234456	305897	240762
9663	17774	32855	67809	127673	170870	220932	272912	340566
11321	17653	41867	57673	106595	180427	215633	280868	303798
13532	18542	44385	77593	95158	153582	232534	254408	340344
10981	19719	41641	84316	121001	148589	206248	280104	286135
10385	18098	38260	77328	131778	166631	220916	261679	321083
11194	17507	40211	66869	124164	179809	209812	314420	317127
11694	19044	39900	72507	107028	178377	223223	247684	430450
10781	18729	43140	72525	112059	159064	235350	259482	279125
14167	21067	40486	76556	111879	154549	222090	290944	288137
14328	26370	54852	72906	114475	153221	195960	294199	342191

17301 23607 63019 100508 114209 151802 192481 233508 372828
11794 30181 52052 107864 147453 160861 185035 227120 265781
17271 21825 68848 92673 150265 187929 208910 212599 256089
9100 29252 56433 119239 141157 184363 219109 255020 234350
9443 22337 66500 110187 171898 191874 209152 241463 296939
8052 20339 74449 119511 176526 219312 240032 226078 256774
11702 18123 61582 149569 181602 246020 257940 282628 237196
20099 21649 56881 125462 224089 244805 310820 287369 318397
12914 32600 56379 115806 198170 283248 302967 366460 308808
9448 27803 71927 111449 180157 265805 324435 352755 411527
16749 24031 79355 131544 181048 237106 320982 350990 393221
12987 32813 77921 148231 208483 255753 281249 362328 367363
16723 25692 76840 145560 215084 296236 327068 312738 391655
10172 27874 65996 121075 202863 268489 387280 389664 334063
12172 20064 61521 116790 154373 241983 306415 475127 441406
13970 24940 52516 107766 164962 175774 265745 331510 555314
17011 28337 64217 95875 160275 203292 188400 279302 347428
20748 31291 71159 109691 139713 212289 230685 195515 286783
15094 30613 70713 118748 148526 176822 259034 249020 199427
2563 33330 60171 113248 157875 176326 204895 298233 260813
2563 2563 68863 105264 148654 184971 194311 224680 329526

##--><>--><>--><>-- Juvenile Abundance Index from seine surveys --><>--><>--><>--><>--><>
##Switch to use single index (=1) or let model combine indices (not equal to 1)

1
##Starting and ending years of time series, respectively
1959
2011
##Observed CPUE (numbers) and CV vectors, respectively
5.491734867 1.534904649 1.076431123 58.49198267 7.981097225 0.35919016
3.247040557 3.961176354 2.935460962 11.99799361 12.59130939 3.527680041
45.66921052 20.408 31.768 61.500 90.67782902 115.4876118 193.2720334
68.54676898 53.83551253 90.01464586 133.6273607 60.73340475 37.55812116
59.35820177 52.88549569 52.74099064 16.23705165 36.27840019 26.12079688
36.6717888 35.33512979 32.96361429 11.81244874 20.45342909 16.78943714
21.99224431 18.40753229 26.40169637 54.66091353 17.9452847 17.27377949
27.99333855 31.4852824 19.51574823 42.83586482 7.670375404 26.03329246
12.78954984 14.57326323 15.08972551 13.39590218
0.825771029 0.65102718 0.693498008 0.700055169 0.870469319 0.659286488
0.524139237 0.727360555 1.378414886 0.506140876 0.408322838 0.630359596
0.440986753 0.239 0.212 0.152 0.181651923 0.19898857 0.145517735
0.215161259 0.316513403 0.200730196 0.21002599 0.196650846 0.224923611
0.206726223 0.222313732 0.197158985 0.189717662 0.19791558 0.182516329
0.17930702 0.157287034 0.172143806 0.195243429 0.190494429 0.178044763
0.160901394 0.192580693 0.183430456 0.189749333 0.17337474 0.174111664
0.207722682 0.19491029 0.176160697 0.148973832 0.138549198 0.162734644
0.150567815 0.154886058 0.168381506 0.16091767

##--><>--><>--><>-- Juvenile Abundance Indices (4 groups) from seine surveys --><>--><>--
><>--><>--><>
##Series 1 Observed CPUE (numbers) and CV vectors, respectively
##must have zeros in place of missing values and all series must be the same length as single index above
##this is the first pca which includes NC, VA, MD, and NJ
11.22236324 3.810815272 2.454395881 145.4116619 19.21190751 0.912880198
7.664551774 9.709131271 4.816096224 9.54805575 10.71565941 3.670002203
46.52267774 8.385763603 8.675398659 13.60809331 21.68499099 36.03533635
47.9972427 20.79606107 33.69199196 35.77239409 61.4170975 22.18331719
14.95832472 33.94508329 30.450203 29.14765001 13.96951388 31.89998324
19.30337276 29.16463299 22.80238979 14.14661101 6.509984223 15.17569029
14.6478255 10.19497052 12.87027351 8.41088298 22.94038778 5.249502305
6.175214786 5.740289035 9.774880827 4.209639331 25.32354302 5.24906146
5.965354555 5.903325195 5.790499148 11.64416909 7.347340044
0.827327143 0.624641534 0.689540863 0.68186415 0.857998483 0.644916586
0.507367753 0.725246191 1.324318264 0.49092314 0.403332086 0.584119269
0.437848642 0.247553927 0.218169417 0.150318895 0.183799148 0.208396777
0.140888537 0.209386317 0.331029776 0.203209149 0.218999882 0.208750268
0.237426726 0.222041593 0.235828175 0.208853941 0.193845915 0.230292034
0.207729318 0.208286098 0.166036424 0.174472623 0.211501457 0.219711709

0.200614413 0.1783482 0.222785647 0.20710356 0.205126879 0.177415462
0.221658495 0.206586884 0.200632268 0.172754398 0.160026835 0.164505125
0.161476058 0.148338709 0.151362405 0.176032138 0.16434461
##Series 2 Observed CPUE (numbers) and CV vectors, respectively
##this is the second pca which includes NY, RI, and CT
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
12.83630273 0 50.74708419 2.817741794 21.37008409 30.32209573
38.44188855 68.16488424 205.1397687 21.77823001 31.73125384 9.207271953
71.13961393 52.90854248 194.8673195 249.3451522 120.4190692 99.1709621
416.0385222 273.5613528 182.0206876 52.72150685 11.85976458 273.9825802
6.25279857 35.40534735 3.243542377 4.977913035
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0.717595862 0 0.864701992 0.475363734 0.505377615 0.504660343
0.479697559 0.499317118 0.485946106 0.534964142 0.497585705 0.444626636
0.437916177 0.502891836 0.451746654 0.488411478 0.439086388 0.414100414
0.460747837 0.467153269 0.461933647 0.454053612 0.397312665 0.434577534
0.631797479 0.571418097 0.467509485 0.481292493
##Series 3 Observed CPUE (numbers) and CV vectors, respectively
##Not updated...
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 62.6893134 259.2783574
51.8810532 12.2443508 30.9959456 14.1435884 2.3832303 1.5905358
5.8567029 8.145969 13.1786803 7.4515134 6.3196687 1.2897558
10.3979867 13.436357 3.5883454 8.64925 3.8668316 26.4074946
2.6622985 1.089944 2.0327237 1.9672035 0.3815253 12.2755695
1.6988698 1.4698375 1.1856853 5 5 5
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0.6100114 0.7673876
0.4563601 0.5643986 0.3666978 0.3004134 0.5151165 0.3213347
0.3180115 0.2841494 0.2579026 0.2837902 0.2688518 0.4544062
0.3454617 0.2981172 0.3135442 0.321363 0.2960134 0.3096394
0.2708529 0.3130682 0.3179908 0.3103309 0.3233245 0.258085
0.2679273 0.2771044 0.2998046 0.3 0.3 0.3
##Series 4 Observed CPUE (numbers) and CV vectors, respectively
##Not updated...
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 5.798786 36.682552 114.432077 88.413428
457.305185 720.60668 125.110058 76.98277 31.049442 270.940064
252.012355 1990.351097 180.398169 586.980987 234.406695 881.609674
1533.95439 557.335098 27.657342 7.583182 452.320643 23.885976
25 25 25

```
0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0.484021	0.4013174	0.4930011	0.5355576
	0.5371519	0.5340335	0.4895519	0.575322	0.5688208	0.5077108
	0.5219801	0.4456174	0.5576982	0.6027831	0.4460296	0.6735579
	0.578154	0.56118	0.5660324	0.5055432	0.5770563	0.747471
0.5	0.5	0.5

##--><>--><>--><>-- PRFC pound net index --><>--><>--><>--><>--><>--><>--><>--><>--
><>
##Starting and ending years of time series, respectively
1964
2011
##Observed CPUE (numbers) and CV vectors, respectively
1200.034827	1253.47176	968.6025307	526.5643746	491.3551115	350.0381583
	844.3270832	738.4494723	1318.00342	2388.332307	2213.956559	2156.071384
	2320.080977	3493.875143	3384.639318	2470.892705	3164.768854	3703.970913
	3379.37838	3837.60589	2392.945932	2854.073898	1967.828042	2765.947626
	2465.256195	1692.525183	986.646892	1148.029682	1315.305353	1710.162139
	1524.597216	1538.066769	1467.940839	1448.316981	1144.909144	1626.076021
	1845.551788	1277.655637	1120.800936	1055.591783	2205.259804	1872.553586
	1643.624096	2534.952645	2646.751512	2008.635962	2283.734811	2498.894641
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
#0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

##--><>--><>--><>-- Commercial Reduction fishery --><>--><>--><>--><>--><>--><>--><>
#Starting and ending years of landings time series, respectively
1955
2011
##Observed landings (1000 mt) and assumed CVs
641.4	712.1	602.8	510	659.1	529.8	575.9	537.7	346.9	269.2	273.4	219.6
	193.5	234.8	161.6	259.4	250.3	365.9	346.9	292.2	250.2	340.5	341.1	344.1
	375.7	401.5	381.3	382.4	418.6	326.3	306.7	238	327	309.3	322	401.2
	381.4	297.6	320.6	260	339.9	292.9	259.1	245.9	171.2	167.2	233.7	174
166.1	183.4	146.9	157.4	174.5	141.1	143.8	183.1	174
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
```

0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
0.03 0.03 0.03 0.03
##Number and vector of years of age compositions for hook and line fishery
57
1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967
1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
2004 2005 2006 2007 2008 2009 2010 2011
##sample sizes of age comps by year (first row observed N, second row effective N: effective may be set to observed)
15009 17963 18389 14303 17938 12783 12898 15458 12716 10286 18955 15486 14653
25888 14858 8239 8118 6198 6348 5361 7262 6401 7266 7025 6231
7046 8870 8552 11279 11594 8507 5826 7548 7349 6374 6790 7614
5440 5348 4862 4504 4275 3982 3688 3468 3068 4102 3654 3108
3759 3102 3300 3759 3204 2461 2710 2721
305 497 502 434 508 465 425 513 531 513 907 776 754
1340 902 425 417 656 638 561 740 676 728 712 637
731 922 908 540 1178 851 583 762 654 714 685 770
562 533 472 462 423 411 385 361 296 394 337 350
419 354 358 380 278 283 327 323
#age composition samples (year,age)
0.244021051 0.216174805 0.339151289 0.085737126 0.098527746 0.01219106
0.003397508 0.00059956 0.000199853
0.010187608 0.581584368 0.253242777 0.089628681 0.012581417 0.042253521
0.008072148 0.00189278 0.0005567
0.085322747 0.455598456 0.387786177 0.02757083 0.020175105 0.011528631
0.010495405 0.001196367 0.000326282
0.039012795 0.315598126 0.601412291 0.026497937 0.006362302 0.005872894
0.003355939 0.0018178 0.000139831
0.002118526 0.754418242 0.159000948 0.072531639 0.006244076 0.002230027
0.002285778 0.00083626 0.000334504
0.025971994 0.101228194 0.795900806 0.027536572 0.036845811 0.00852695
0.002894469 0.000860518 0.000234687
7.75374E-05 0.320384586 0.19384353 0.46553462 0.007366054 0.011320462
0.001085524 0.00031015 7.75374E-05
0.02458274 0.244857032 0.397399405 0.103441584 0.201643162 0.014620261
0.011709147 0.001423211 0.000323457
0.054895792 0.410460087 0.401966182 0.069445537 0.025481715 0.02965002
0.005898545 0.001887534 0.000314589
0.174995139 0.407155357 0.349893059 0.048318102 0.010402489 0.004569318
0.003791561 0.000777756 0.000194439
0.170509101 0.49042469 0.277341071 0.051173833 0.008018992 0.0012134
0.000791348 0.000474809 5.27565E-05

0.260687072	0.410887253	0.301433553	0.02363425	0.00290585	0.000258298	6.45745E-05	6.45745E-05	0
0.007029757	0.643393393	0.26992902	0.073983074	0.005187005	0.00047775	0	0	0
0.134386588	0.328723733	0.469483931	0.057207973	0.009309333	0.000849815	3.86279E-05	0	0
0.182124108	0.428859873	0.327500337	0.055054516	0.006259254	0.000201911	0	0	0
0.015293118	0.620706396	0.337783712	0.023303799	0.002912975	0.000121374	0	0	0
0.075141661	0.271741808	0.541019956	0.091155457	0.018354274	0.002586844	0	0	0
0.029202969	0.572442723	0.284930623	0.101000323	0.011132623	0.001129397	0	0	0
0.030403277	0.31931317	0.625393825	0.020951481	0.003780718	0.00015753	0	0	0
0.158552509	0.319903003	0.495243425	0.02443574	0.001305727	0.000746129	0	0	0
0.138116221	0.332966125	0.502478656	0.023271826	0.003029468	0.000137703	0	0	0
0.083580691	0.490860803	0.408373692	0.014685205	0.002343384	0.000156226	0	0	0
0.131865107	0.273503097	0.566689608	0.022711631	0.004817619	0.000412939	0	0	0
0.148327402	0.215231317	0.541637011	0.083701068	0.010106762	0.00113879	0	0	0
0.385714286	0.160995185	0.414285714	0.033065811	0.005617978	0.000321027	0	0	0
0.026539881	0.443514051	0.437553222	0.066846438	0.020720976	0.004257735	0.000425773	0	0
0.298049825	0.175402999	0.454627438	0.055799797	0.011949047	0.003832713	0.000338181	0	0
0.035898036	0.289522919	0.547708138	0.11950421	0.005144995	0.001870907	0.000116932	0.000116932	0
0.244613884	0.131217306	0.581700505	0.028991932	0.012057807	0.001241245	8.86603E-05	0	8.86603E-05
0.364757633	0.288683802	0.25142315	0.076505089	0.014145248	0.004312575	0.000172503	0	0
0.210625294	0.35554772	0.404795487	0.014574518	0.011753644	0.002115656	0.000587682	0	0
0.051493306	0.117233093	0.796429797	0.025575009	0.005492619	0.003261243	0.000514933	0	0
0.018550417	0.217967404	0.685835431	0.065588976	0.010865244	0.000927521	0.000265006	0	0

0.157028167	0.131038236	0.53639951	0.139610831	0.032385359	0.00326575	0.000136073	0.000136073	0
0.056941176	0.438901961	0.440313725	0.041254902	0.018039216	0.004392157	0.000156863	0	0
0.142709867	0.061561119	0.719734904	0.050515464	0.019587629	0.005743741	0.000147275	0	0
0.278434463	0.326503809	0.2987917	0.080246914	0.011951668	0.003414762	0.000656685	0	0
0.194669118	0.354227941	0.3875	0.032169118	0.025	0.005330882	0.000735294	0.000183824	0
0.04262479	0.237801458	0.616563844	0.093475416	0.006917181	0.002430361	0.000186951	0	0
0.059440559	0.184080625	0.595639654	0.110654052	0.045043192	0.005141917	0.000205677	0	0
0.034635879	0.32482238	0.40874778	0.188055062	0.0410746	0.002664298	0	0	0
0.030877193	0.191578947	0.621988304	0.127251462	0.026432749	0.001871345	0	0	0
0.025364139	0.247865394	0.426418885	0.238322451	0.051732798	0.009040683	0.00125565	0	0
0.072396963	0.18356833	0.536605206	0.12527115	0.072396963	0.008947939	0.000813449	0	0
0.183626405	0.28509657	0.426635918	0.077543961	0.023637936	0.003170943	0.000288268	0	0
0.118318123	0.173728814	0.518252934	0.170143416	0.016949153	0.002933507	0	0	0
0.034365099	0.065074336	0.552035096	0.325127955	0.022422618	0.000974896	0	0	0
0.22194855	0.263546798	0.323481117	0.169129721	0.02134647	0.000547345	0	0	0
0.086872587	0.182754183	0.640604891	0.076898327	0.011261261	0.001287001	0.00032175	0	0
0.018355946	0.21867518	0.666666667	0.077414206	0.017823889	0.000798085	0	0	0
0.018703644	0.121573686	0.590454692	0.237665269	0.028700419	0.00290229	0	0	0
0.012121212	0.396363636	0.398181818	0.161212121	0.031212121	0.000606061	0	0	0
0.001330141	0.256451184	0.653099229	0.074487896	0.013833466	0.000798085	0	0	0
0.013732834	0.09082397	0.683832709	0.184769039	0.025280899	0.001872659	0	0	0
0.005941539	0.477313524	0.310089318	0.177185978	0.026978785	0.002490856	0.000000000	0.000000000	0.000000000

```
0.015130872   0.400268268   0.489815526   0.066563349   0.027669655   0.000552330
        0.000000000   0.000000000   0.000000000
0.000000000   0.423873050   0.499423133   0.065985197   0.008974268   0.001744352
        0.000000000   0.000000000   0.000000000

##--><>--><>--><>-- Commercial Bait fishery --><>--><>--><>--><>--><>--><>--><>
#Starting and ending years of landings time series, respectively
1955
2011
##Observed landings (1000 mt) and assumed CVs (includes MRFSS landings)
14.638849     23.252443     24.706525     14.688427     20.584228     19.443850
        25.067948     26.579637     24.390235     20.233646     23.619581     13.722410
        11.610436     9.460088      10.607452     21.642142     13.471437     10.348269
        14.768668     14.539331     21.691221     19.628598     23.091326     25.865743
        13.019076     26.114873     22.553758     19.988213     19.187072     14.480761
        26.819892     28.327247     30.875023     36.559491     31.167033     30.969148
        36.610655     39.566498     42.989747     39.252885     42.626679     35.402869
        36.625869     39.444272     36.424157     35.371754     36.436071     37.242311
        34.056661     36.135930     38.977165     26.900390     43.205670     47.823131
        39.285798     45.478444     54.984197
0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15
        0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15    0.15
        0.15    0.15    0.15    0.15    0.15    0.05    0.05    0.05    0.05    0.05    0.05    0.05
        0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
        0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
#0.20   0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20
        0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20
        0.20    0.20    0.20    0.20    0.20    0.10    0.10    0.10    0.10    0.10    0.10    0.10
        0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10
        0.10    0.10    0.10    0.10    0.10    0.10    0.10    0.10
##Number and vector of years of age compositions for bait fishery
27
1985    1986    1987    1988    1989    1990    1991    1992    1993    1994    1995    1996    1997
        1998    1999    2000    2001    2002    2003    2004    2005    2006    2007    2008    2009
2010    2011
##sample sizes of age comps by year  (first row observed N, second row effective N: effective
may be set to observed)
770     380     220     10      30      10      78      70      169     539     362     357     313
        626     538     543     962     702     427     354     322     454     973     842     1005
899     955
77      38      22      1       3       1       8       7       17      54      37      36      32
        63      54      55      97      71      43      36      33      46      98      85      101     90
96
#age composition samples (year,age)
0.003   0.085   0.651   0.187   0.062   0.010   0.002   0.000   0.000
```

```
0.002   0.054   0.430   0.365   0.135   0.013   0.002   0.000   0.000
0.002   0.048   0.481   0.332   0.124   0.012   0.001   0.000   0.000
0.002   0.051   0.411   0.377   0.144   0.014   0.002   0.000   0.000
0.002   0.069   0.531   0.291   0.096   0.010   0.001   0.000   0.000
0.004   0.198   0.396   0.286   0.104   0.010   0.001   0.000   0.000
0.001   0.121   0.405   0.333   0.125   0.013   0.002   0.000   0.000
0.003   0.151   0.356   0.346   0.129   0.014   0.002   0.000   0.000
0.005   0.173   0.317   0.359   0.129   0.014   0.002   0.000   0.000
0.002   0.096   0.463   0.282   0.136   0.019   0.001   0.000   0.000
0.000   0.255   0.275   0.310   0.160   0.000   0.000   0.000   0.000
0.000   0.029   0.615   0.285   0.068   0.002   0.000   0.000   0.000
0.000   0.049   0.380   0.308   0.198   0.054   0.011   0.000   0.000
0.029   0.046   0.408   0.286   0.193   0.031   0.006   0.000   0.000
0.001   0.041   0.589   0.242   0.111   0.014   0.002   0.000   0.000
0.006   0.163   0.570   0.179   0.071   0.009   0.002   0.000   0.000
0.002   0.046   0.538   0.363   0.044   0.006   0.001   0.000   0.000
0.000   0.029   0.197   0.522   0.220   0.031   0.001   0.000   0.000
0.005   0.084   0.645   0.221   0.044   0.002   0.000   0.000   0.000
0.000   0.058   0.649   0.227   0.058   0.007   0.001   0.000   0.000
0.000   0.014   0.472   0.448   0.058   0.007   0.001   0.000   0.000
0.000   0.196   0.427   0.314   0.060   0.002   0.000   0.000   0.000
0.000   0.187   0.594   0.175   0.041   0.002   0.001   0.000   0.000
0.000   0.021   0.582   0.322   0.067   0.008   0.000   0.000   0.000
0.002   0.162   0.327   0.411   0.091   0.007   0.000   0.000   0.000
0.000   0.200   0.465   0.212   0.111   0.011   0.001   0.000   0.000
0.000   0.204   0.337   0.275   0.163   0.021   0.000   0.000   0.000


##################Parameter values and initial
guesses########################################################################
#######
###Selectivity parameters.
###Initial guess must be within boundaries.
# Initial guesses initialized near solutions from preliminary model runs
# age at size limits (12, 20 inches)= 1.42, 3.62
# zero in slope2 provides logistic selectivity

1.4 #selpar_L50_cR
3.3 #selpar_slope_cR
6.0 #selpar_L502_cR
0.0  #selpar_slope2_cR

2.2 #selpar_L50_cB
3.9 #selpar_slope_cB
6.5 #selpar_L502_cB
```

0.0 #selpar_slope2_cB

1.14 #selpar_L50_cPN
7.62 #selpar_slope_cPN
1.72 #selpar_L502_cPN
7.77 #selpar_slope2_cPN

##################Likelihood Component Weighting##
##Weights in objective fcn
1.0 #landings
1.0 #age comps
1.0 #JAI index
1.0 #PN index
1.0 #S-R residuals
0.0 #constraint on early recruitment deviations
1.0 #constraint on ending recruitment deviations
0.0 #penalty if F exceeds 3.0 (reduced by factor of 10 each phase, not applied in final phase of optimization)
0.0 #weight on tuning F (penalty not applied in final phase of optimization)
1.0 #weight for penalty to keep JAI combination weights summing to 1.0

##
##log catchabilities (initial guesses)
-1.8 #JAI survey
6.4 #PN survey

#exponent for JAI cpue index
1.0

#JAI combination weights
0.25
0.25
0.25
0.25

#rate increase switch: Integer value (choose estimation phase, negative value turns it off)
-1
##annual positive rate of increase on all fishery dependent q due to technology creep
0.0
DD q switch: Integer value (choose estimation phase, negative value turns it off)
-1

```
##density dependent catchability exponent, value of zero is density independent, est range is (0.1,0.9)
0.0
##SE of density dependent catchability exponent (0.128 provides 95% CI in range 0.5)
0.128
#Age to begin counting D-D q (should be age near full exploitation)
2
#Random walk switch:Integer value (choose estimation phase, negative value turns it off)
-3
#Variance (sd^2) of fishery dependent random walk catchabilities (0.03 is near the sd=0.17 of Wilberg and Bence
0.03

##log mean F (initial guesses)
0.2          #commercial reduction
-1.2         #commercial bait
#Initialization F as a proportion of  first few assessment years (set to 1.0 without evidence otherwise)
1.0

#Tuning F (not applied in last phase of optimization)
1.5
#Year for tuning F
2011

#threshold sample sizes (greater than or equal to) for age comps
1.0 #cR
1.0 #cB

#switch to turn priors on off (-1 = off, 1 = on)
-1

##########################################################################################
#####################################
#Ageing error matrix (columns are true age 1-20, rows are ages as read for age comps)
#1	0	0	0	0	0	0	0	0
#0	1	0	0	0	0	0	0	0
#0	0	1	0	0	0	0	0	0
#0	0	0	1	0	0	0	0	0
#0	0	0	0	1	0	0	0	0
#0	0	0	0	0	1	0	0	0
#0	0	0	0	0	0	1	0	0
#0	0	0	0	0	0	0	1	0
#0	0	0	0	0	0	0	0	1
```

```
0.989574885  0.010425115  3.41132E-08  8.71309E-12  4.9779E-12  3.69962E-10
     1.06845E-07  1.57149E-05  0.000623385
0.010425115  0.979149769  0.036041469  2.7224E-05  5.8031E-07  8.37634E-07
     1.08755E-05  0.000198104  0.001951093
2.07379E-12  0.010425115  0.927916994  0.089249633  0.001764541  0.000311433
     0.000471017  0.001762145  0.006387882
0  2.07379E-12  0.036041469  0.821446286  0.163648594  0.019751402  0.008711424
     0.010519756  0.017424063
0  0  3.41132E-08  0.089249633  0.669172569  0.226878066  0.069393527
     0.042182061  0.039598326
0  0  0  2.7224E-05  0.163648594  0.506116523  0.24003818  0.113684332
     0.074981978
0  0  0  8.71314E-12  0.001764541  0.226878066  0.362749737  0.206038939
     0.118305185
0  0  0  0  5.8031E-07  0.019751402  0.24003818  0.251197896
     0.155534864
0  0  0  0  4.97791E-12  0.000312271  0.078586951  0.374401052
     0.585193224

##########################################################################################
##########################################999 #end of data file flag
```

17 Appendix 2 – BAM code

```
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##
//##  ASMFC Assessment: Atlantic Menhaden, October 2009
//##
//##  Erik Williams, NMFS, Beaufort Lab
//##  Erik.Williams@noaa.gov
//##
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

DATA_SECTION
//Create ascii file for output
//!!CLASS ofstream report1("menhadresults.rep",ios::out);  //create file for output

!!cout << "Starting Atlantic Menhaden Assessment Model" << endl;

// Starting and ending year of the model (year data starts)
init_int styr;
init_int endyr;

//Starting year to estimate recruitment deviation from S-R curve
init_int styr_rec_dev;
!!cout << styr_rec_dev <<endl;
//possible 3 phases of constraints on recruitment deviations
init_int endyr_rec_phase1;
init_int endyr_rec_phase2;

//3 periods of size regs: styr-83 no restrictions, 1984-91 12-inch TL, 1992-08 20-in TL
init_int endyr_period1;
init_int endyr_period2;
init_int endyr_period3;

//starting and ending years to use for benchmark calculations
init_int styr_bench;
init_int endyr_bench;

//Total number of ages
init_int nages;

// Vector of ages for age bins
init_ivector agebins(1,nages);

//number assessment years
```

```
number nyrs;
number nyrs_rec;
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   nyrs=endyr-styr+1.;
   nyrs_rec=endyr-styr_rec_dev+1.;
 END_CALCS

//Max F used in spr and msy calcs
init_number max_F_spr_msy;
//Total number of iterations for spr calcs
init_int n_iter_spr;
//Total number of iterations for msy calcs
init_int n_iter_msy;
//Number years at end of time series over which to average sector F's, for weighted selectivities
init_int selpar_n_yrs_wgted;
//bias correction (set to 1.0 for no bias correction or a negative value to compute from rec
variance)
init_number set_BiasCor;
//exclude these years from end of time series for computing bias correction
init_number BiasCor_exclude_yrs;

//Female maturity and proportion female at age
init_vector maturity_f_obs(1,nages);            //proportion females mature at age
init_vector maturity_m_obs(1,nages);            //proportion males mature at age
init_vector prop_f_obs(1,nages);                //proportion female at age

init_number spawn_time_frac; //time of year of peak spawning, as a fraction of the year
// Natural mortality
init_vector set_M(1,nages); //age-dependent: used in model
init_number set_M_constant; //age-independent: used only for MSST
init_matrix set_M_mat(styr,endyr,1,nages); //age and year specific M
//Spawner-recruit parameters (Initial guesses or fixed values)
init_number set_SR_switch;
init_number set_steep;
init_number set_steep_se;
init_number set_log_R0;
init_number set_R_autocorr;

//-->><>-->><>-->><>-- Weight-at-age in the fishery (g) -->><>-->><>-->><>-->><>-->><>-->><>-->><>--
><>
init_matrix wgt_fish_g(styr,endyr,1,nages);

//-->><>-->><>-->><>-- Weight-at-age for the spawning population - start of year (g) -->><>-->><>--
><>-->><>
```

```
init_matrix wgt_spawn_g(styr,endyr,1,nages);

//--><>--><>--><>-- Fecundity-at-age - not adjusted for maturity (g) --><>--><>--><>--><>
init_matrix fec_eggs(styr,endyr,1,nages);

//--><>--><>--><>-- Juvenile Abundance Index from seine surveys --><>--><>--><>--><>--
><>
init_int JAI_cpue_switch;
//CPUE
init_int styr_JAI_cpue;
init_int endyr_JAI_cpue;
init_vector obs_JAI_cpue(styr_JAI_cpue,endyr_JAI_cpue);   //Observed CPUE
init_vector JAI_cpue_cv(styr_JAI_cpue,endyr_JAI_cpue);    //CV of cpue

//--><>--><>--><>-- Juvenile Abundance Indices from seine surveys --><>--><>--><>--><>--
><>
//CPUE, must have zeros in place of missing values
init_vector obs_JAI1_cpue(styr_JAI_cpue,endyr_JAI_cpue);   //Observed CPUE 1
init_vector JAI1_cpue_cv(styr_JAI_cpue,endyr_JAI_cpue);    //CV of cpue 1
init_vector obs_JAI2_cpue(styr_JAI_cpue,endyr_JAI_cpue);   //Observed CPUE 2
init_vector JAI2_cpue_cv(styr_JAI_cpue,endyr_JAI_cpue);    //CV of cpue 2
init_vector obs_JAI3_cpue(styr_JAI_cpue,endyr_JAI_cpue);   //Observed CPUE 3
init_vector JAI3_cpue_cv(styr_JAI_cpue,endyr_JAI_cpue);    //CV of cpue 3
init_vector obs_JAI4_cpue(styr_JAI_cpue,endyr_JAI_cpue);   //Observed CPUE 4
init_vector JAI4_cpue_cv(styr_JAI_cpue,endyr_JAI_cpue);    //CV of cpue 4

//--><>--><>--><>-- PRFC pound net index --><>--><>--><>--><>--><>--><>--><>--><>--
><>
//CPUE
init_int styr_PN_cpue;
init_int endyr_PN_cpue;
init_vector obs_PN_cpue(styr_PN_cpue,endyr_PN_cpue);   //Observed CPUE
init_vector PN_cpue_cv(styr_PN_cpue,endyr_PN_cpue);    //cv of cpue

//--><>--><>--><>-- Commercial Reduction fishery --><>--><>--><>--><>--><>--><>--><>
// Landings  (1000 mt)
init_int styr_cR_L;
init_int endyr_cR_L;
init_vector obs_cR_L(styr_cR_L,endyr_cR_L); //vector of observed landings by year
init_vector cR_L_cv(styr_cR_L,endyr_cR_L);    //vector of CV of landings by year

// Age Compositions
init_int nyr_cR_agec;
init_ivector yrs_cR_agec(1,nyr_cR_agec);
init_vector nsamp_cR_agec(1,nyr_cR_agec);
```

```
init_vector neff_cR_agec(1,nyr_cR_agec);
init_matrix obs_cR_agec(1,nyr_cR_agec,1,nages);

//-->><>-->><>-->><>-- Commercial Bait fishery -->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>
// Landings (1000 mt)
init_int styr_cB_L;
init_int endyr_cB_L;
init_vector obs_cB_L(styr_cB_L,endyr_cB_L);
init_vector cB_L_cv(styr_cB_L,endyr_cB_L);    //vector of CV of landings by year

// Age compositions
init_int nyr_cB_agec;
init_ivector yrs_cB_agec(1,nyr_cB_agec);
init_vector nsamp_cB_agec(1,nyr_cB_agec);
init_vector neff_cB_agec(1,nyr_cB_agec);
init_matrix obs_cB_agec(1,nyr_cB_agec,1,nages);

//#########################################################################################
#
//#####################Parameter values and initial guesses
#######################################
//Initial guesses of estimated selectivity parameters
init_number set_selpar_L50_cR;
init_number set_selpar_slope_cR;
init_number set_selpar_L502_cR;
init_number set_selpar_slope2_cR;

init_number set_selpar_L50_cB;
init_number set_selpar_slope_cB;
init_number set_selpar_L502_cB;
init_number set_selpar_slope2_cB;

init_number set_selpar_L50_PN;
init_number set_selpar_slope_PN;
init_number set_selpar_L502_PN;
init_number set_selpar_slope2_PN;

//--weights for likelihood components------------------------------------------------------------------------------------
--------
init_number set_w_L;
init_number set_w_ac;
init_number set_w_I_JAI;
init_number set_w_I_PN;
init_number set_w_rec;           //for fitting S-R curve
init_number set_w_rec_early;       //additional constraint on early years recruitment
```

init_number set_w_rec_end; //additional constraint on ending years recruitment
init_number set_w_fullF; //penalty for any Fapex>3(removed in final phase of optimization)
init_number set_w_Ftune; //weight applied to tuning F (removed in final phase of optimization)
init_number set_w_JAI_wgts; //weight for penalty to keep JAI combination weights summing to 1.0

////--index catchability--
init_number set_logq_JAI; //catchability coefficient (log) for MARMAP RVC
init_number set_logq_PN; //catchability coefficient (log) for MARMAP CVT

init_number set_JAI_exp; //exponent for cpue index

//--JAI index combination weights---
init_number set_wgt_JAI1;
init_number set_wgt_JAI2;
init_number set_wgt_JAI3;
init_number set_wgt_JAI4;

//rate of increase on q
init_int set_q_rate_phase; //value sets estimation phase of rate increase, negative value turns it off
init_number set_q_rate;
//density dependence on fishery q's
init_int set_q_DD_phase; //value sets estimation phase of random walk, negative value turns it off
init_number set_q_DD_beta; //value of 0.0 is density indepenent
init_number set_q_DD_beta_se;
init_int set_q_DD_stage; //age to begin counting biomass, should be near full exploitation

//random walk on fishery q's
init_int set_q_RW_phase; //value sets estimation phase of random walk, negative value turns it off
init_number set_q_RW_PN_var; //assumed variance of RW q

////--F's--------------------------------
init_number set_log_avg_F_cR;
init_number set_log_avg_F_cB;
init_number set_F_init_ratio; //defines initialization F as a ratio of that from first several yrs of assessment

//Tune Fapex (tuning removed in final year of optimization)
init_number set_Ftune;

```
init_int set_Ftune_yr;

//threshold sample sizes for age comps
init_number minSS_cR_agec;
init_number minSS_cB_agec;

//switch to turn priors on off (-1 = off, 1 = on)
init_number switch_prior;

//ageing error matrix (columns are true ages, rows are ages as read for age comps)
init_matrix age_error(1,nages,1,nages);

// #######Indexing integers for year(iyear), age(iage) ###############
int iyear;
int iage;
int ff;
int quant_whole;

number sqrt2pi;
number g2mt;                    //conversion of grams to metric tons
number g2kg;                    //conversion of grams to kg
number g2klb;                   //conversion of grams to 1000 lb
number mt2klb;                  //conversion of metric tons to 1000 lb
number mt2lb;                   //conversion of metric tons to lb
number dzero;                   //small additive constant to prevent division by zero

init_number end_of_data_file;
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   if(end_of_data_file!=999)
   {
     for(iyear=1; iyear<=1000; iyear++)
     {
       cout << "*** WARNING: Data File NOT READ CORRECTLY ****" << endl;
       cout << "" <<endl;
     }
   }
   else
   {
    cout << "Data File read correctly" << endl;
   }
 END_CALCS

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>--><>--><>
```

```
PARAMETER_SECTION
//////-----------------------------------------------------------------------------------------

  matrix wgt_fish_kg(styr,endyr,1,nages);
  matrix wgt_fish_mt(styr,endyr,1,nages);
  matrix wgt_spawn_kg(styr,endyr,1,nages);
  matrix wgt_spawn_mt(styr,endyr,1,nages);

  matrix wgt_cR_mt(styr,endyr,1,nages);      //wgt of cR landings in 1000 mt
  matrix wgt_cB_mt(styr,endyr,1,nages);      //wgt of cB landings in 1000 mt

  matrix pred_cR_agec(1,nyr_cR_agec,1,nages);
  matrix ErrorFree_cR_agec(1,nyr_cR_agec,1,nages); //age comps prior to applying ageing error
matrix
  matrix pred_cB_agec(1,nyr_cB_agec,1,nages);
  matrix ErrorFree_cB_agec(1,nyr_cB_agec,1,nages);

  //nsamp_X_allyr vectors used only for R output of comps with nonconsecutive yrs, given
sample size cutoffs
  vector nsamp_cR_agec_allyr(styr,endyr);
  vector nsamp_cB_agec_allyr(styr,endyr);

//effective sample size applied in multinomial distributions
  vector neff_cR_agec_allyr(styr,endyr);
  vector neff_cB_agec_allyr(styr,endyr);

//Computed effective sample size for output (not used in fitting)
  vector neff_cR_agec_allyr_out(styr,endyr);
  vector neff_cB_agec_allyr_out(styr,endyr);

//-----Population-------------------------------------------------------------------------------
  matrix N(styr,endyr+1,1,nages);          //Population numbers by year and age at start of yr
  matrix N_mdyr(styr,endyr,1,nages);        //Population numbers by year and age at mdpt of yr:
used for comps and cpue
  matrix N_spawn(styr,endyr,1,nages);        //Population numbers by year and age at peaking
spawning: used for SSB
  init_bounded_vector log_Nage_dev(2,nages,-5,5,1); //log deviations on initial abundance at age
  //vector log_Nage_dev(2,nages);
  vector log_Nage_dev_output(1,nages);             //used in output. equals zero for first age
  matrix B(styr,endyr+1,1,nages);          //Population biomass by year and age at start of yr
  vector totB(styr,endyr+1);              //Total biomass by year
  vector totN(styr,endyr+1);              //Total abundance by year
  vector SSB(styr,endyr);                ///Total spawning biomass by year
  vector rec(styr,endyr+1);              //Recruits by year
```

```
  vector pred_SPR(styr,endyr);            //spawning biomass-per-recruit (lagged) for Fmed calcs
  vector prop_f(1,nages);                //Proportion female by age
  vector maturity_f(1,nages);              //Proportion of female mature at age
  vector maturity_m(1,nages);              //Proportion of female mature at age
  matrix reprod(styr,endyr,1,nages);
  vector wgted_reprod(1,nages);            //average reprod in last few years
//
////---Stock-Recruit Function (Beverton-Holt, steepness parameterization)----------
  init_bounded_number log_R0(1,10,1);      //log(virgin Recruitment)
  //number log_R0;
  number R0;                              //virgin recruitment
  init_bounded_number steep(0.21,0.99,-3);   //steepness
//  number steep;  //uncomment to fix steepness, comment line directly above
  init_bounded_dev_vector log_rec_dev(styr_rec_dev,endyr,-5,5,1); //log recruitment deviations
  //vector log_rec_dev(styr_rec_dev,endyr);
  vector log_rec_dev_output(styr,endyr+1);           //used in output. equals zero except for yrs in
log_rec_dev
  number var_rec_dev;                    //variance of log recruitment deviations
                                      //Estimate from yrs with unconstrainted S-R(XXXX-XXXX)
  number BiasCor;                        //Bias correction in equilibrium recruits
  init_bounded_number R_autocorr(-1.0,1.0,2);  //autocorrelation in SR
  number S0;                             //equal to spr_F0*R0 = virgin SSB
  number B0;                             //equal to bpr_F0*R0 = virgin B
  number R1;                             //Recruits in styr
  number R_virgin;                         //unfished recruitment with bias correction
  vector SdS0(styr,endyr);                 //SSB / virgin SSB

////---Selectivity-------------------------------------------------------------------

//Commercial reduction-----------------------------------------------
  matrix sel_cR(styr,endyr,1,nages);
  init_bounded_number selpar_slope_cR1(0.5,10.0,1); //period 1
  init_bounded_number selpar_L50_cR1(0.5,4.0,1);
  init_bounded_number selpar_slope2_cR1(0.0,10.0,-1); //period 1
  init_bounded_number selpar_L502_cR1(0.0,6.0,-1);
  vector sel_cR1_vec(1,nages);

  init_bounded_number selpar_slope_cR2(0.5,10.0,-2); //period 2
  init_bounded_number selpar_L50_cR2(0.5,4.0,-2);
  init_bounded_number selpar_slope2_cR2(0.0,10.0,-3); //period 2
  init_bounded_number selpar_L502_cR2(0.0,6.0,-3);
  vector sel_cR2_vec(1,nages);

  init_bounded_number selpar_slope_cR3(0.5,10.0,-2); //period 3
  init_bounded_number selpar_L50_cR3(0.5,4.0,-2);
```

```
  init_bounded_number selpar_slope2_cR3(0.0,10.0,-3); //period 3
  init_bounded_number selpar_L502_cR3(0.0,6.0,-3);
  vector sel_cR3_vec(1,nages);

  init_bounded_number selpar_slope_cR4(0.5,10.0,-2); //period 4
  init_bounded_number selpar_L50_cR4(0.5,4.0,-2);
  init_bounded_number selpar_slope2_cR4(0.0,10.0,-3); //period 4
  init_bounded_number selpar_L502_cR4(0.0,6.0,-3);
  vector sel_cR4_vec(1,nages);

//Commercial bait-----------------------------------------------
  matrix sel_cB(styr,endyr,1,nages);
  init_bounded_number selpar_slope_cB(0.5,10.0,1);
  init_bounded_number selpar_L50_cB(0.5,4.0,1);
  init_bounded_number selpar_slope2_cB(0.5,10.0,-1);
  init_bounded_number selpar_L502_cB(0.0,6.0,-1);
  vector sel_cB_vec(1,nages);

//Commercial bait-----------------------------------------------
  matrix sel_PN(styr,endyr,1,nages);
  number selpar_slope_PN; //period 1
  number selpar_L50_PN;
  number selpar_slope2_PN; //period 1
  number selpar_L502_PN;
  vector sel_PN_vec(1,nages);

  //effort-weighted, recent selectivities
  vector sel_wgted_L(1,nages);  //toward landings
  vector sel_wgted_tot(1,nages);//toward Z

//-------CPUE Predictions--------------------------------
  vector obs_JAI_cpue_final(styr_JAI_cpue,endyr_JAI_cpue);     //used to store cpue used in
likelihood fit
  vector JAI_cpue_cv_final(styr_JAI_cpue,endyr_JAI_cpue);
  vector pred_JAI_cpue(styr_JAI_cpue,endyr_JAI_cpue);          //predicted JAI U
  vector N_JAI(styr_JAI_cpue,endyr_JAI_cpue);          //used to compute JAI index
  vector pred_PN_cpue(styr_PN_cpue,endyr_PN_cpue);          //predicted PN U
  matrix N_PN(styr_PN_cpue,endyr_PN_cpue,1,nages);          //used to compute PN index

//------Index exponent---------------------------------
  init_bounded_number JAI_exp(0.01,1.0,-3);

//------Index combination weights---------------------------------
  init_bounded_number wgt_JAI1(0.001,1.0,-3);
  init_bounded_number wgt_JAI2(0.001,1.0,-3);
```

```
  init_bounded_number wgt_JAI3(0.001,1.0,-3);
  init_bounded_number wgt_JAI4(0.001,1.0,-3);
  number JAI_wgt_sum_constraint;

////---Catchability (CPUE q's)----------------------------------------------------------
  init_bounded_number log_q_JAI(-10,10,1);
  init_bounded_number log_q_PN(-10,10,1);
  init_bounded_number q_rate(0.001,0.1,set_q_rate_phase);
  //number q_rate;
  vector q_rate_fcn_PN(styr_PN_cpue,endyr_PN_cpue);        //increase due to technology creep
(saturates in 2003)

  init_bounded_number q_DD_beta(0.1,0.9,set_q_DD_phase);
  //number q_DD_beta;
  vector q_DD_fcn(styr,endyr);    //density dependent function as a multiple of q (scaled a la
Katsukawa and Matsuda. 2003)
  number B0_q_DD;                //B0 of ages q_DD_age plus
  vector B_q_DD(styr,endyr);      //annual biomass of ages q_DD_age plus

  init_bounded_vector q_RW_log_dev_PN(styr_PN_cpue,endyr_PN_cpue-1,-
3.0,3.0,set_q_RW_phase);
  vector q_PN(styr_PN_cpue,endyr_PN_cpue);

//---Landings in numbers (total or 1000 fish) and in wgt (klb)------------------------------------------
-------
  matrix L_cR_num(styr,endyr,1,nages);            //landings (numbers) at age
  matrix L_cR_mt(styr,endyr,1,nages);            //landings (1000 mt) at age
  vector pred_cR_L_knum(styr,endyr); //yearly landings in 1000 fish summed over ages
  vector pred_cR_L_mt(styr,endyr);  //yearly landings in 1000 mt summed over ages

  matrix L_cB_num(styr,endyr,1,nages);             //landings (numbers) at age
  matrix L_cB_mt(styr,endyr,1,nages);             //landings (1000 mt) at age
  vector pred_cB_L_knum(styr,endyr);      //yearly landings in 1000 fish summed over ages
  vector pred_cB_L_mt(styr,endyr);       //yearly landings in 1000 mt summed over ages

  matrix L_total_num(styr,endyr,1,nages);               //total landings in number at age
  matrix L_total_mt(styr,endyr,1,nages);               //landings in 1000 mt at age
  vector L_total_knum_yr(styr,endyr);                  //total landings in 1000 fish by yr summed
over ages
  vector L_total_mt_yr(styr,endyr);                   //total landings (1000 mt) by yr summed over
ages

////---Fmed calcs-------------------------------------------------------------------------
  number quant_decimal;
  number quant_diff;
```

```
  number quant_result;

  number R_med;                               //median recruitment for chosen benchmark years
  vector R_temp(styr_bench,endyr_bench);
  vector R_sort(styr_bench,endyr_bench);
  number SPR_med;                             //median SSB/R (R = SSB year+1) for chosen SSB years
  number SPR_75th;
  vector SPR_temp(styr_bench,endyr_bench);
  vector SPR_sort(styr_bench,endyr_bench);
  number SSB_med;                             //SSB corresponding to SSB/R median and R median
  number SSB_med_thresh;                      //SSB threshold
  vector SPR_diff(1,n_iter_spr);
  number SPR_diff_min;
  number F_med;                               //Fmed benchmark
  number F_med_target;
  number F_med_age2plus;                      //Fmed benchmark
  number F_med_target_age2plus;
  number L_med;

////---MSY calcs---------------------------------------------------------------------------
  number F_cR_prop;       //proportion of F_sum attributable to reduction, last
X=selpar_n_yrs_wgted yrs, used for avg body weights
  number F_cB_prop;       //proportion of F_sum attributable to bait, last X yrs
  number F_temp_sum;      //sum of geom mean Fsum's in last X yrs, used to compute
F_fishery_prop

  vector F_end(1,nages);
  vector F_end_L(1,nages);
  number F_end_apex;

  number SSB_msy_out;           //SSB (total mature biomass) at msy
  number F_msy_out;             //F at msy
  number msy_mt_out;            //max sustainable yield (1000 mt)
  number msy_knum_out;          //max sustainable yield (1000 fish)
  number B_msy_out;             //total biomass at MSY
  number R_msy_out;             //equilibrium recruitment at F=Fmsy
  number spr_msy_out;           //spr at F=Fmsy

  vector N_age_msy(1,nages);         //numbers at age for MSY calculations: beginning of yr
  vector N_age_msy_mdyr(1,nages);    //numbers at age for MSY calculations: mdpt of yr
  vector L_age_msy(1,nages);         //catch at age for MSY calculations
  vector Z_age_msy(1,nages);         //total mortality at age for MSY calculations
  vector F_L_age_msy(1,nages);       //fishing mortality landings (not discards) at age for MSY
calculations
  vector F_msy(1,n_iter_msy);        //values of full F to be used in equilibrium calculations
```

```
  vector spr_msy(1,n_iter_msy);      //reproductive capacity-per-recruit values corresponding to F
values in F_msy
  vector R_eq(1,n_iter_msy);        //equilibrium recruitment values corresponding to F values in
F_msy
  vector L_eq_mt(1,n_iter_msy);     //equilibrium landings(1000 mt) values corresponding to F
values in F_msy
  vector L_eq_knum(1,n_iter_msy);     //equilibrium landings(1000 fish) values corresponding to
F values in F_msy
  vector SSB_eq(1,n_iter_msy);       //equilibrium reproductive capacity values corresponding to
F values in F_msy
  vector B_eq(1,n_iter_msy);        //equilibrium biomass values corresponding to F values in
F_msy

  vector FdF_msy(styr,endyr);
  vector SdSSB_msy(styr,endyr);
  number SdSSB_msy_end;
  number FdF_msy_end;

  vector wgt_wgted_L_mt(1,nages);  //fishery-weighted average weight at age of landings
  number wgt_wgted_L_denom;        //used in intermediate calculations

  number iter_inc_msy;             //increments used to compute msy, equals 1/(n_iter_msy-1)

////--------Mortality------------------------------------------------------------------
  vector M(1,nages);                       //age-dependent natural mortality
  number M_constant;                       //age-indpendent: used only for MSST
  matrix M_mat(styr,endyr,1,nages);
  vector wgted_M(1,nages);                  //weighted M vector for last few years
  matrix F(styr,endyr,1,nages);
  vector Fsum(styr,endyr);                 //Full fishing mortality rate by year
  vector Fapex(styr,endyr);                 //Max across ages, fishing mortality rate by year (may
differ from Fsum bc of dome-shaped sel
  matrix Z(styr,endyr,1,nages);

  vector E(styr,endyr);                   //Exploitation rate
  vector F_age2plus(styr,endyr);           //population weighted age 2+ F
  vector F_cR_age2plus(styr,endyr);           //population weighted age 2+ F
  vector F_cB_age2plus(styr,endyr);           //population weighted age 2+ F

  init_bounded_number log_avg_F_cR(-5,2.0,1);
  init_bounded_dev_vector log_F_dev_cR(styr_cR_L,endyr_cR_L,-10.0,5.0,2);
  matrix F_cR(styr,endyr,1,nages);
  vector F_cR_out(styr,endyr); //used for intermediate calculations in fcn get_mortality
  number log_F_dev_init_cR;
  number log_F_dev_end_cR;
```

```
  init_bounded_number log_avg_F_cB(-10,0.0,1);
  init_bounded_dev_vector log_F_dev_cB(styr_cB_L,endyr_cB_L,-10.0,5.0,2);
  matrix F_cB(styr,endyr,1,nages);
  vector F_cB_out(styr,endyr); //used for intermediate calculations in fcn get_mortality
  number log_F_dev_init_cB;
  number log_F_dev_end_cB;

  init_bounded_number F_init_ratio(0.05,2.0,-1);

//---Per-recruit stuff----------------------------------------------------------------------------------
  vector N_age_spr(1,nages);         //numbers at age for SPR calculations: beginning of year
  vector N_age_spr_mdyr(1,nages);    //numbers at age for SPR calculations: midyear
  vector L_age_spr(1,nages);         //catch at age for SPR calculations
  vector Z_age_spr(1,nages);         //total mortality at age for SPR calculations
  vector spr_static(styr,endyr);     //vector of static SPR values by year
  vector F_L_age_spr(1,nages);       //fishing mortality of landings (not discards) at age for SPR
calculations
  vector F_spr(1,n_iter_spr);        //values of full F to be used in per-recruit calculations
  vector F_spr_age2plus(1,n_iter_spr);  //values of F age2+ to be used in per-recruit calculations
  vector spr_spr(1,n_iter_spr);      //reproductive capacity-per-recruit values corresponding to F
values in F_spr
  vector L_spr(1,n_iter_spr);        //landings(mt)-per-recruit (ypr) values corresponding to F
values in F_spr

  vector N_spr_F0(1,nages);          //Used to compute spr at F=0: at time of peak spawning
  vector N_bpr_F0(1,nages);          //Used to compute bpr at F=0: at start of year
  vector N_spr_initial(1,nages);     //Initial spawners per recruit at age given initial F
  vector N_initial_eq(1,nages);      //Initial equilibrium abundance at age
  vector F_initial(1,nages);         //initial F at age
  vector Z_initial(1,nages);         //initial Z at age
  number spr_initial;                //initial spawners per recruit
  vector spr_F0(styr,endyr);         //Spawning biomass per recruit at F=0
  vector bpr_F0(styr,endyr);         //Biomass per recruit at F=0
  number wgted_spr_F0;

  number iter_inc_spr;               //increments used to compute msy, equals
max_F_spr_msy/(n_iter_spr-1)


////-------Objective function components-----------------------------------------------------------------------
--------
  number w_L;
  number w_ac;
  number w_I_JAI;
```

```
  number w_I_PN;
  number w_rec;
  number w_rec_early;
  number w_rec_end;
  number w_fullF;
  number w_Ftune;
  number w_JAI_wgts;

  number f_JAI_cpue;
  number f_PN_cpue;

  number f_cR_L;
  number f_cB_L;

  number f_cR_agec;
  number f_cB_agec;

  number f_PN_RW_cpue; //random walk component of indices

  //Penalties and constraints. Not all are used.
  number f_rec_dev;              //weight on recruitment deviations to fit S-R curve
  number f_rec_dev_early;        //extra weight on deviations in first recruitment stanza
  number f_rec_dev_end;          //extra weight on deviations in first recruitment stanza
  number f_Ftune;                //penalty for tuning F in Ftune yr.  Not applied in final optimization
phase.
  number f_fullF_constraint;     //penalty for Fapex>X
  number f_JAI_wgts;

  number f_priors;               //prior information on parameters

  objective_function_value fval;
  number fval_unwgt;

//--Dummy variables ----
  number denom;                  //denominator used in some calculations
  number numer;                  //numerator used in some calculations
  vector temp_agevec(1,nages);
  number dum1;

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
INITIALIZATION_SECTION


//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
```

```
//##-->>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
GLOBALS_SECTION
  #include "admodel.h"          // Include AD class definitions
  #include "admb2r.cpp"    // Include S-compatible output functions (needs preceding)

//##-->>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
RUNTIME_SECTION
 maximum_function_evaluations 1000, 4000,8000, 10000;
 convergence_criteria 1e-2, 1e-5,1e-6, 1e-7;

//##-->>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##-->>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
PRELIMINARY_CALCS_SECTION

// Set values of fixed parameters or set initial guess of estimated parameters
  M=set_M;
  M_constant=set_M_constant;
  M_mat=set_M_mat;
  steep=set_steep;
  R_autocorr=set_R_autocorr;

  log_q_JAI=set_logq_JAI;
  log_q_PN=set_logq_PN;

  JAI_exp=set_JAI_exp;

  wgt_JAI1=set_wgt_JAI1;
  wgt_JAI2=set_wgt_JAI2;
  wgt_JAI3=set_wgt_JAI3;
  wgt_JAI4=set_wgt_JAI4;

  q_rate=set_q_rate;
  q_rate_fcn_PN=1.0;
  q_DD_beta=set_q_DD_beta;
  q_DD_fcn=1.0;
  q_RW_log_dev_PN.initialize();

  if (set_q_rate_phase<0 & q_rate!=0.0)
  {
     for (iyear=styr_PN_cpue; iyear<=endyr_PN_cpue; iyear++)
     {   if (iyear>styr_PN_cpue & iyear <=2003)
         {//q_rate_fcn_cL(iyear)=(1.0+q_rate)*q_rate_fcn_cL(iyear-1); //compound
            q_rate_fcn_PN(iyear)=(1.0+(iyear-
styr_PN_cpue)*q_rate)*q_rate_fcn_PN(styr_PN_cpue);  //linear
         }
```

```
        if (iyear>2003) {q_rate_fcn_PN(iyear)=q_rate_fcn_PN(iyear-1);}
    }
} //end q_rate conditional

w_L=set_w_L;
w_ac=set_w_ac;
w_I_JAI=set_w_I_JAI;
w_I_PN=set_w_I_PN;
w_rec=set_w_rec;
w_fullF=set_w_fullF;
w_rec_early=set_w_rec_early;
w_rec_end=set_w_rec_end;
w_Ftune=set_w_Ftune;
w_JAI_wgts=set_w_JAI_wgts;

log_avg_F_cR=set_log_avg_F_cR;
log_avg_F_cB=set_log_avg_F_cB;
F_init_ratio=set_F_init_ratio;

log_R0=set_log_R0;

selpar_L50_cR1=set_selpar_L50_cR;
selpar_slope_cR1=set_selpar_slope_cR;
selpar_L502_cR1=set_selpar_L502_cR;
selpar_slope2_cR1=set_selpar_slope2_cR;

selpar_L50_cR2=set_selpar_L50_cR;
selpar_slope_cR2=set_selpar_slope_cR;
selpar_L502_cR2=set_selpar_L502_cR;
selpar_slope2_cR2=set_selpar_slope2_cR;

selpar_L50_cR3=set_selpar_L50_cR;
selpar_slope_cR3=set_selpar_slope_cR;
selpar_L502_cR3=set_selpar_L502_cR;
selpar_slope2_cR3=set_selpar_slope2_cR;

selpar_L50_cR4=set_selpar_L50_cR;
selpar_slope_cR4=set_selpar_slope_cR;
selpar_L502_cR4=set_selpar_L502_cR;
selpar_slope2_cR4=set_selpar_slope2_cR;

selpar_L50_cB=set_selpar_L50_cB;
selpar_slope_cB=set_selpar_slope_cB;
selpar_L502_cB=set_selpar_L502_cB;
selpar_slope2_cB=set_selpar_slope2_cB;
```

```
 selpar_L50_PN=set_selpar_L50_PN;
 selpar_slope_PN=set_selpar_slope_PN;
 selpar_L502_PN=set_selpar_L502_PN;
 selpar_slope2_PN=set_selpar_slope2_PN;

 sqrt2pi=sqrt(2.*3.14159265);
 //g2mt=0.000001;         //conversion of grams to metric tons
 g2mt=1.0;
 g2kg=0.001;            //conversion of grams to kg
 mt2klb=2.20462;        //conversion of metric tons to 1000 lb
 mt2lb=mt2klb*1000.0;   //conversion of metric tons to lb
 g2klb=g2mt*mt2klb;     //conversion of grams to 1000 lb
 dzero=0.00001;         //additive constant to prevent division by zero

 SSB_msy_out=0.0;

 iter_inc_msy=max_F_spr_msy/(n_iter_msy-1);
 iter_inc_spr=max_F_spr_msy/(n_iter_spr-1);

 maturity_f=maturity_f_obs;
 maturity_m=maturity_m_obs;
 prop_f=prop_f_obs;

//Fill in sample sizes of comps sampled in nonconsec yrs.
//Used primarily for output in R object

     nsamp_cR_agec_allyr=missing;
     nsamp_cB_agec_allyr=missing;

     neff_cR_agec_allyr=missing;
     neff_cB_agec_allyr=missing;

     for (iyear=1; iyear<=nyr_cR_agec; iyear++)
       {
        if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
         {
          nsamp_cR_agec_allyr(yrs_cR_agec(iyear))=nsamp_cR_agec(iyear);
          neff_cR_agec_allyr(yrs_cR_agec(iyear))=neff_cR_agec(iyear);
         }
       }
     for (iyear=1; iyear<=nyr_cB_agec; iyear++)
       {
        if (nsamp_cB_agec(iyear)>=minSS_cB_agec)
         {
```

```
      nsamp_cB_agec_allyr(yrs_cB_agec(iyear))=nsamp_cB_agec(iyear);
      neff_cB_agec_allyr(yrs_cB_agec(iyear))=neff_cB_agec(iyear);
     }
    }

//fill in Fs for msy and per-recruit analyses
 F_msy(1)=0.0;
 for (ff=2;ff<=n_iter_msy;ff++)
 {
  F_msy(ff)=F_msy(ff-1)+iter_inc_msy;
 }
 F_spr(1)=0.0;
 for (ff=2;ff<=n_iter_spr;ff++)
 {
  F_spr(ff)=F_spr(ff-1)+iter_inc_spr;
 }

//fill in F's, Catch matrices, and log rec dev with zero's
 F_cR.initialize();
 L_cR_num.initialize();
 F_cB.initialize();
 L_cB_num.initialize();

 F_cR_out.initialize();
 F_cB_out.initialize();

 L_total_knum_yr.initialize();
 L_total_mt_yr.initialize();

 log_rec_dev_output.initialize();
 log_Nage_dev_output.initialize();
 log_rec_dev.initialize();
 log_Nage_dev.initialize();


//##-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>
//##-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>
TOP_OF_MAIN_SECTION
 arrmblsize=20000000;
 gradient_structure::set_MAX_NVAR_OFFSET(1600);
 gradient_structure::set_GRADSTACK_BUFFER_SIZE(2000000);
 gradient_structure::set_CMPDIF_BUFFER_SIZE(2000000);
 gradient_structure::set_NUM_DEPENDENT_VARIABLES(500);
```

```
//>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
PROCEDURE_SECTION

 R0=mfexp(log_R0);

 //cout<<"start"<<endl;
 get_weight_at_age();
 get_reprod();
 get_weight_at_age_landings();
 //cout<< "got weight at age of landings"<<endl;
 get_spr_F0();
 //cout << "got F0 spr" << endl;
 get_selectivity();
 //cout << "got selectivity" << endl;
 get_mortality();
 //cout << "got mortalities" << endl;
 get_bias_corr();
 //cout<< "got recruitment bias correction" << endl;
 get_numbers_at_age();
 //cout << "got numbers at age" << endl;
 get_landings_numbers();
 //cout << "got catch at age" << endl;
 get_landings_wgt();
 //cout << "got landings" << endl;
 get_catchability_fcns();
 //cout << "got catchability_fcns" << endl;
 get_indices();
 //cout << "got indices" << endl;
 get_age_comps();
 //cout<< "got age comps"<< endl;
 evaluate_objective_function();
 //cout << "objective function calculations complete" << endl;

FUNCTION get_weight_at_age
  //compute mean length (mm) and weight (whole) at age
    wgt_fish_kg=g2kg*wgt_fish_g;                    //wgt in kilograms
    wgt_fish_mt=g2mt*wgt_fish_g;                    //mt of whole wgt: g2mt converts g to
mt
    wgt_spawn_kg=g2kg*wgt_spawn_g;                  //wgt in kilograms
    wgt_spawn_mt=g2mt*wgt_spawn_g;                  //mt of whole wgt: g2mt converts g
to mt

FUNCTION get_reprod
```

```
 //product of stuff going into reproductive capacity calcs
 for (iyear=styr; iyear<=endyr; iyear++)
 {
   //reprod(iyear)=elem_prod((elem_prod(prop_f,maturity_f)+elem_prod((1.0-
prop_f),maturity_m)),wgt_spawn_mt(iyear));
   //reprod(iyear)=elem_prod((elem_prod(prop_f,maturity_f)+elem_prod((1.0-
prop_f),maturity_m)),fec_eggs(iyear));
   reprod(iyear)=elem_prod(elem_prod(prop_f,maturity_f),fec_eggs(iyear));
 }

 //compute average natural mortality
 wgted_M=M_mat(endyr)*0.0;
 for(iyear=(endyr-selpar_n_yrs_wgted+1); iyear<=endyr; iyear++)
 {
  wgted_M+=M_mat(iyear);
 }
 wgted_M=wgted_M/selpar_n_yrs_wgted;

 //average reprod for last few years for eq calculations
 wgted_reprod=reprod(endyr)*0.0;
 for(iyear=(endyr-selpar_n_yrs_wgted+1); iyear<=endyr; iyear++)
 {
  wgted_reprod+=reprod(iyear);
 }
 wgted_reprod=wgted_reprod/selpar_n_yrs_wgted;

FUNCTION get_weight_at_age_landings

 wgt_cR_mt=wgt_fish_mt;
 wgt_cB_mt=wgt_fish_mt;

FUNCTION get_spr_F0

 for (iyear=styr; iyear<=endyr; iyear++)
 {
   //at mdyr, apply half this yr's mortality, half next yr's
   N_spr_F0(1)=1.0*mfexp(-1.0*M_mat(iyear,1)*spawn_time_frac); //at peak spawning time
   N_bpr_F0(1)=1.0;      //at start of year
   for (iage=2; iage<=nages; iage++)
   {
    //N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(M(iage-1)));
    dum1=M_mat(iyear,iage-1)*(1.0-spawn_time_frac) + M_mat(iyear,iage)*spawn_time_frac;
    N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(dum1));
    N_bpr_F0(iage)=N_bpr_F0(iage-1)*mfexp(-1.0*(M_mat(iyear,iage-1)));
   }
```

```
  N_spr_F0(nages)=N_spr_F0(nages)/(1.0-mfexp(-1.0*M_mat(iyear,nages))); //plus group (sum
of geometric series)
  N_bpr_F0(nages)=N_bpr_F0(nages)/(1.0-mfexp(-1.0*M_mat(iyear,nages)));

  spr_F0(iyear)=sum(elem_prod(N_spr_F0,reprod(iyear)));
  bpr_F0(iyear)=sum(elem_prod(N_bpr_F0,wgt_spawn_mt(iyear)));
 }

 N_spr_F0(1)=1.0*mfexp(-1.0*wgted_M(1)*spawn_time_frac); //at peak spawning time
 for (iage=2; iage<=nages; iage++)
 {
  dum1=wgted_M(iage-1)*(1.0-spawn_time_frac) + wgted_M(iage)*spawn_time_frac;
  N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(dum1));
 }
 N_spr_F0(nages)=N_spr_F0(nages)/(1.0-mfexp(-1.0*wgted_M(nages))); //plus group (sum of
geometric series
 wgted_spr_F0=sum(elem_prod(N_spr_F0,wgted_reprod));

FUNCTION get_selectivity

//// ------- compute landings selectivities by period

 for (iage=1; iage<=nages; iage++)
 {
   sel_cR1_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_cR1*(double(agebins(iage))-
            selpar_L50_cR1))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_cR1*
            (double(agebins(iage))-(selpar_L50_cR1+selpar_L502_cR1)))))); //double logistic

   sel_cR2_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_cR2*(double(agebins(iage))-
            selpar_L50_cR2))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_cR2*
            (double(agebins(iage))-(selpar_L50_cR2+selpar_L502_cR2)))))); //double logistic

   sel_cR3_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_cR3*(double(agebins(iage))-
            selpar_L50_cR3))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_cR3*
            (double(agebins(iage))-(selpar_L50_cR3+selpar_L502_cR3)))))); //double logistic

   sel_cR4_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_cR4*(double(agebins(iage))-
            selpar_L50_cR4))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_cR4*
            (double(agebins(iage))-(selpar_L50_cR4+selpar_L502_cR4)))))); //double logistic

   sel_cB_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_cB*(double(agebins(iage))-
            selpar_L50_cB))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_cB*
            (double(agebins(iage))-(selpar_L50_cB+selpar_L502_cB)))))); //double logistic

   sel_PN_vec(iage)=(1./(1.+mfexp(-1.*selpar_slope_PN*(double(agebins(iage))-
```

```
                    selpar_L50_PN))))*(1.-(1./(1.+mfexp(-1.*selpar_slope2_PN*
                    (double(agebins(iage))-(selpar_L50_PN+selpar_L502_PN)))))); //double logistic
  }
  sel_cR1_vec=sel_cR1_vec/max(sel_cR1_vec); //re-normalize double logistic
  sel_cR2_vec=sel_cR2_vec/max(sel_cR2_vec); //re-normalize double logistic
  sel_cR3_vec=sel_cR3_vec/max(sel_cR3_vec); //re-normalize double logistic
  sel_cR4_vec=sel_cR4_vec/max(sel_cR4_vec); //re-normalize double logistic
  sel_cB_vec=sel_cB_vec/max(sel_cB_vec); //re-normalize double logistic
  sel_PN_vec=sel_PN_vec/max(sel_PN_vec); //re-normalize double logistic

//-----------fill in years--------------------------------------------

  for (iyear=styr; iyear<=endyr; iyear++)
  {  //time-invariant selectivities
    sel_cB(iyear)=sel_cB_vec;
    sel_PN(iyear)=sel_PN_vec;
  }
  //Period 1:
  for (iyear=styr; iyear<=endyr_period1; iyear++)
  {
    sel_cR(iyear)=sel_cR1_vec;
  }

  //Period 2:
  for (iyear=endyr_period1+1; iyear<=endyr_period2; iyear++)
  {
    //sel_cR(iyear)=sel_cR2_vec;
    sel_cR(iyear)=sel_cR1_vec;
  }

  //Period 3
  for (iyear=endyr_period2+1; iyear<=endyr_period3; iyear++)
  {
    //sel_cR(iyear)=sel_cR3_vec;
    sel_cR(iyear)=sel_cR1_vec;
  }

  //Period 4
  for (iyear=endyr_period3+1; iyear<=endyr; iyear++)
  {
    //sel_cR(iyear)=sel_cR4_vec;
    sel_cR(iyear)=sel_cR1_vec;
  }

FUNCTION get_mortality
```

```
  Fsum.initialize();
  Fapex.initialize();
  F.initialize();
  ////initialization F is avg of first 3 yrs of observed landings
  log_F_dev_init_cR=sum(log_F_dev_cR(styr_cR_L,(styr_cR_L+2)))/3.0;
  log_F_dev_init_cB=sum(log_F_dev_cB(styr_cB_L,(styr_cB_L+2)))/3.0;

  for (iyear=styr; iyear<=endyr; iyear++)
  {
   //-------------
   if(iyear>=styr_cR_L & iyear<=endyr_cR_L)
     {F_cR_out(iyear)=mfexp(log_avg_F_cR+log_F_dev_cR(iyear));}
   if (iyear<styr_cR_L)
     {F_cR_out(iyear)=mfexp(log_avg_F_cR+log_F_dev_init_cR);}
   F_cR(iyear)=sel_cR(iyear)*F_cR_out(iyear);
   Fsum(iyear)+=F_cR_out(iyear);

   //-------------
   if(iyear>=styr_cB_L & iyear<=endyr_cB_L)
       {F_cB_out(iyear)=mfexp(log_avg_F_cB+log_F_dev_cB(iyear));}
   if (iyear<styr_cB_L)
     {F_cB_out(iyear)=mfexp(log_avg_F_cB+log_F_dev_init_cB);}
   F_cB(iyear)=sel_cB(iyear)*F_cB_out(iyear);
   Fsum(iyear)+=F_cB_out(iyear);

   //Total F at age
   F(iyear)=F_cR(iyear); //first in additive series (NO +=)
   F(iyear)+=F_cB(iyear);

   Fapex(iyear)=max(F(iyear));
   Z(iyear)=M_mat(iyear)+F(iyear);
  }  //end iyear

FUNCTION get_bias_corr
  //may exclude last BiasCor_exclude_yrs yrs bc constrained or lack info to estimate
  var_rec_dev=norm2(log_rec_dev(styr_rec_dev,(endyr-BiasCor_exclude_yrs))-
            sum(log_rec_dev(styr_rec_dev,(endyr-BiasCor_exclude_yrs)))
            /(nyrs_rec-BiasCor_exclude_yrs))/(nyrs_rec-BiasCor_exclude_yrs-1.0);
  if (set_BiasCor <= 0.0) {BiasCor=mfexp(var_rec_dev/2.0);}   //bias correction
  else {BiasCor=set_BiasCor;}


FUNCTION get_numbers_at_age
//Initialization
  S0=spr_F0(styr)*R0;
```

```
  if(set_SR_switch>1) //Beverton-Holt
  {
    R_virgin=(R0/((5.0*steep-1.0)*spr_F0(styr)))*
             (BiasCor*4.0*steep*spr_F0(styr)-spr_F0(styr)*(1.0-steep));
  }
  if(set_SR_switch<2) //Ricker
  {
    R_virgin=R0/spr_F0(styr)*(1+log(BiasCor*spr_F0(styr))/steep);
  }
  B0=bpr_F0(styr)*R_virgin;

  temp_agevec=wgt_fish_mt(styr);

B0_q_DD=R_virgin*sum(elem_prod(N_bpr_F0(set_q_DD_stage,nages),temp_agevec(set_q_D
D_stage,nages)));

  F_initial=sel_cR(styr)*mfexp(log_avg_F_cR+log_F_dev_init_cR)+
          sel_cB(styr)*mfexp(log_avg_F_cB+log_F_dev_init_cB);
  Z_initial=M+F_init_ratio*F_initial;

//Initial equilibrium age structure
  N_spr_initial(1)=1.0*mfexp(-1.0*Z_initial(1)*spawn_time_frac); //at peak spawning time;
  for (iage=2; iage<=nages; iage++)
    {
      N_spr_initial(iage)=N_spr_initial(iage-1)*
              mfexp(-1.0*(Z_initial(iage-1)*(1.0-spawn_time_frac) +
Z_initial(iage)*spawn_time_frac));
    }
  N_spr_initial(nages)=N_spr_initial(nages)/(1.0-mfexp(-1.0*Z_initial(nages))); //plus group
//    N_spr_F_init_mdyr(1,(nages-1))=elem_prod(N_spr_initial(1,(nages-1)),
//                              mfexp((-1.*(M(nages-1)+ F_initial))/2.0));

  spr_initial=sum(elem_prod(N_spr_initial,reprod(styr)));

  if(set_SR_switch>1) //Beverton-Holt
  {
    if (styr=styr_rec_dev) {R1=(R0/((5.0*steep-1.0)*spr_initial))*
             (4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep));} //without bias correction (deviation
added later)
    else {R1=(R0/((5.0*steep-1.0)*spr_initial))*
             (BiasCor*4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep));} //with bias correction
  }
  if(set_SR_switch<2) //Ricker
  {
```

```
   if (styr=styr_rec_dev) {R1=R0/spr_initial*(1+log(BiasCor*spr_initial)/steep);} //without bias
correction (deviation added later)
   else {R1=R0/spr_initial*(1+log(BiasCor*spr_initial)/steep);} //with bias correction
  }

  if(R1<0.0) {R1=1.0;} //Avoid negative popn sizes during search algorithm


//Compute equilibrium age structure for first year
  N_initial_eq(1)=R1;
  for (iage=2; iage<=nages; iage++)
  {
   N_initial_eq(iage)=N_initial_eq(iage-1)*
     mfexp(-1.0*(Z_initial(iage-1)*(1.0-spawn_time_frac) + Z_initial(iage)*spawn_time_frac));
  }
  //plus group calculation
  N_initial_eq(nages)=N_initial_eq(nages)/(1.0-mfexp(-1.0*Z_initial(nages))); //plus group

//Add deviations to initial equilibrium N
  N(styr)(2,nages)=elem_prod(N_initial_eq(2,nages),mfexp(log_Nage_dev));

  if (styr=styr_rec_dev) {N(styr,1)=N_initial_eq(1)*mfexp(log_rec_dev(styr_rec_dev));}
  else {N(styr,1)=N_initial_eq(1);}

  N_mdyr(styr)(1,nages)=elem_prod(N(styr)(1,nages),(mfexp(-1.*(Z_initial(1,nages))*0.5)));
//mid year
  N_spawn(styr)(1,nages)=elem_prod(N(styr)(1,nages),(mfexp(-
1.*(Z_initial(1,nages))*spawn_time_frac))); //peak spawning time

  SSB(styr)=sum(elem_prod(N_spawn(styr),reprod(styr)));

  temp_agevec=wgt_fish_mt(styr);

B_q_DD(styr)=sum(elem_prod(N(styr)(set_q_DD_stage,nages),temp_agevec(set_q_DD_stage,n
ages)));

//Rest of years
  for (iyear=styr; iyear<endyr; iyear++)
  {
   if(iyear<(styr_rec_dev-1)) //recruitment follows S-R curve exactly
   {
      //add dzero to avoid log(zero)
      if(set_SR_switch>1) //Beverton-Holt
      {
       N(iyear+1,1)=BiasCor*mfexp(log(((0.8*R0*steep*SSB(iyear))/(0.2*R0*spr_F0(iyear)*
```

```
        (1.0-steep)+(steep-0.2)*SSB(iyear)))+dzero));
      }
      if(set_SR_switch<2) //Ricker
      {
       N(iyear+1,1)=mfexp(log(BiasCor*SSB(iyear)/spr_F0(iyear)*mfexp(steep*(1-
SSB(iyear)/(R0*spr_F0(iyear))))+dzero));
      }
      N(iyear+1)(2,nages)=++elem_prod(N(iyear)(1,nages-1),(mfexp(-1.*Z(iyear)(1,nages-1))));
      N(iyear+1,nages)+=N(iyear,nages)*mfexp(-1.*Z(iyear,nages));//plus group
      N_mdyr(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*0.5))); //mid year
      N_spawn(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*spawn_time_frac))); //peak spawning time
      SSB(iyear+1)=sum(elem_prod(N_spawn(iyear+1),reprod(iyear+1)));
      temp_agevec=wgt_fish_mt(iyear+1);

B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),temp_agevec(set_q_DD
_stage,nages)));

    }
    else   //recruitment follows S-R curve with lognormal deviation
    {
      //add dzero to avoid log(zero)
      if(set_SR_switch>1) //Beverton-Holt
      {
       N(iyear+1,1)=mfexp(log(((0.8*R0*steep*SSB(iyear))/(0.2*R0*spr_F0(iyear)*
        (1.0-steep)+(steep-0.2)*SSB(iyear)))+dzero)+log_rec_dev(iyear+1));
      }
      if(set_SR_switch<2) //Ricker
      {
       N(iyear+1,1)=mfexp(log(SSB(iyear)/spr_F0(iyear)*mfexp(steep*(1-
SSB(iyear)/(R0*spr_F0(iyear))))+dzero)+log_rec_dev(iyear+1));
      }
      N(iyear+1)(2,nages)=++elem_prod(N(iyear)(1,nages-1),(mfexp(-1.*Z(iyear)(1,nages-1))));
      N(iyear+1,nages)+=N(iyear,nages)*mfexp(-1.*Z(iyear,nages));//plus group
      N_mdyr(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*0.5))); //mid year
      N_spawn(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*spawn_time_frac))); //peak spawning time
      SSB(iyear+1)=sum(elem_prod(N_spawn(iyear+1),reprod(iyear+1)));
      temp_agevec=wgt_fish_mt(iyear+1);

B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),temp_agevec(set_q_DD
_stage,nages)));
    }
```

```
 }


   //last year (projection) has no recruitment variability
   if(set_SR_switch>1) //Beverton-Holt
   {
     N(endyr+1,1)=mfexp(log(((0.8*R0*steep*SSB(endyr))/(0.2*R0*spr_F0(endyr)*
            (1.0-steep)+(steep-0.2)*SSB(endyr)))+dzero));
   }
   if(set_SR_switch<2) //Ricker
   {
     N(endyr+1,1)=mfexp(log(SSB(iyear)/spr_F0(iyear)*mfexp(steep*(1-
SSB(iyear)/(R0*spr_F0(iyear))))+dzero));
   }
   N(endyr+1)(2,nages)=++elem_prod(N(endyr)(1,nages-1),(mfexp(-1.*Z(endyr)(1,nages-1))));
   N(endyr+1,nages)+=N(endyr,nages)*mfexp(-1.*Z(endyr,nages));//plus group
   //SSB(endyr+1)=sum(elem_prod(N(endyr+1),reprod));


//Time series of interest
 rec=column(N,1);
 SdS0=SSB/S0;
 for (iyear=styr; iyear<=endyr; iyear++)
 {
   pred_SPR(iyear)=SSB(iyear)/rec(iyear+1);
 }

FUNCTION get_landings_numbers //Baranov catch eqn
 for (iyear=styr; iyear<=endyr; iyear++)
 {
   for (iage=1; iage<=nages; iage++)
   {
     L_cR_num(iyear,iage)=N(iyear,iage)*F_cR(iyear,iage)*
       (1.-mfexp(-1.*Z(iyear,iage)))/Z(iyear,iage);
     L_cB_num(iyear,iage)=N(iyear,iage)*F_cB(iyear,iage)*
       (1.-mfexp(-1.*Z(iyear,iage)))/Z(iyear,iage);
   }

   pred_cR_L_knum(iyear)=sum(L_cR_num(iyear));
   pred_cB_L_knum(iyear)=sum(L_cB_num(iyear));
 }

FUNCTION get_landings_wgt

////---Predicted landings------------------------
```

```
 for (iyear=styr; iyear<=endyr; iyear++)
 {
  L_cR_mt(iyear)=elem_prod(L_cR_num(iyear),wgt_cR_mt(iyear));     //in 1000 mt
  L_cB_mt(iyear)=elem_prod(L_cB_num(iyear),wgt_cB_mt(iyear));     //in 1000 mt

  pred_cR_L_mt(iyear)=sum(L_cR_mt(iyear));
  pred_cB_L_mt(iyear)=sum(L_cB_mt(iyear));
 }

FUNCTION get_catchability_fcns
 //Get rate increase if estimated, otherwise fixed above
 if (set_q_rate_phase>0.0)
 {
    for (iyear=styr_PN_cpue; iyear<=endyr_PN_cpue; iyear++)
    {   if (iyear>styr_PN_cpue & iyear <=2003)
        {//q_rate_fcn_cL(iyear)=(1.0+q_rate)*q_rate_fcn_cL(iyear-1); //compound
          q_rate_fcn_PN(iyear)=(1.0+(iyear-
styr_PN_cpue)*q_rate)*q_rate_fcn_PN(styr_PN_cpue);  //linear
        }
        if (iyear>2003) {q_rate_fcn_PN(iyear)=q_rate_fcn_PN(iyear-1);}
    }
 } //end q_rate conditional

 //Get density dependence scalar (=1.0 if density independent model is used)
 if (q_DD_beta>0.0)
 {
  B_q_DD+=dzero;
  for (iyear=styr;iyear<=endyr;iyear++)
     {q_DD_fcn(iyear)=pow(B0_q_DD,q_DD_beta)*pow(B_q_DD(iyear),-q_DD_beta);}
      //{q_DD_fcn(iyear)=1.0+4.0/(1.0+mfexp(0.75*(B_q_DD(iyear)-0.1*B0_q_DD))); }
 }

FUNCTION get_indices
//---Predicted CPUEs------------------------
 //combined JAI index
 if(JAI_cpue_switch==1)
 {
  obs_JAI_cpue_final=pow(obs_JAI_cpue,JAI_exp);
  JAI_cpue_cv_final=JAI_cpue_cv;
 }
 else
 {

obs_JAI_cpue_final=(obs_JAI1_cpue*wgt_JAI1+obs_JAI2_cpue*wgt_JAI2+obs_JAI3_cpue*w
gt_JAI3+obs_JAI4_cpue*wgt_JAI4)
```

```
                    /(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4);
   obs_JAI_cpue_final=pow(obs_JAI_cpue_final,JAI_exp);

JAI_cpue_cv_final=(JAI1_cpue_cv*wgt_JAI1+JAI2_cpue_cv*wgt_JAI2+JAI3_cpue_cv*wgt_J
AI3+JAI4_cpue_cv*wgt_JAI4)
                    /(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4);
  }

 //JAI survey
  for (iyear=styr_JAI_cpue; iyear<=endyr_JAI_cpue; iyear++)
  {   //index in number units
     N_JAI(iyear)=N(iyear,1);
     pred_JAI_cpue(iyear)=mfexp(log_q_JAI)*N_JAI(iyear);
  }

 //PN index
  for (iyear=styr_PN_cpue; iyear<=endyr_PN_cpue; iyear++)
  {   //index in number units
     N_PN(iyear)=elem_prod(N_mdyr(iyear),sel_PN(iyear));
     pred_PN_cpue(iyear)=mfexp(log_q_PN)*sum(N_PN(iyear));
  }

FUNCTION get_age_comps

 //Commercial reduction
  for (iyear=1;iyear<=nyr_cR_agec;iyear++)
  {
   ErrorFree_cR_agec(iyear)=L_cR_num(yrs_cR_agec(iyear))/
                     sum(L_cR_num(yrs_cR_agec(iyear)));
   pred_cR_agec(iyear)=age_error*ErrorFree_cR_agec(iyear);
  }

 //Commercial bait
  for (iyear=1;iyear<=nyr_cB_agec;iyear++)
  {
   ErrorFree_cB_agec(iyear)=L_cB_num(yrs_cB_agec(iyear))/
                     sum(L_cB_num(yrs_cB_agec(iyear)));
   pred_cB_agec(iyear)=age_error*ErrorFree_cB_agec(iyear);
  }

////-------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
FUNCTION get_weighted_current
  F_temp_sum=0.0;
  F_temp_sum+=mfexp((selpar_n_yrs_wgted*log_avg_F_cR+
```

```
      sum(log_F_dev_cR((endyr-selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted);
  F_temp_sum+=mfexp((selpar_n_yrs_wgted*log_avg_F_cB+
      sum(log_F_dev_cB((endyr-selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted);

  F_cR_prop=mfexp((selpar_n_yrs_wgted*log_avg_F_cR+
      sum(log_F_dev_cR((endyr-
selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted)/F_temp_sum;
  F_cB_prop=mfexp((selpar_n_yrs_wgted*log_avg_F_cB+
      sum(log_F_dev_cB((endyr-
selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted)/F_temp_sum;

  log_F_dev_end_cR=sum(log_F_dev_cR((endyr-
selpar_n_yrs_wgted+1),endyr))/selpar_n_yrs_wgted;
  log_F_dev_end_cB=sum(log_F_dev_cB((endyr-
selpar_n_yrs_wgted+1),endyr))/selpar_n_yrs_wgted;

  F_end_L=sel_cR(endyr)*mfexp(log_avg_F_cR+log_F_dev_end_cR)+
        sel_cB(endyr)*mfexp(log_avg_F_cB+log_F_dev_end_cB);

  F_end=F_end_L;
  F_end_apex=max(F_end);

  sel_wgted_tot=F_end/F_end_apex;
  sel_wgted_L=elem_prod(sel_wgted_tot, elem_div(F_end_L,F_end));

  wgt_wgted_L_denom=F_cR_prop+F_cB_prop;
  wgt_wgted_L_mt=F_cR_prop/wgt_wgted_L_denom*wgt_cR_mt(endyr)+
           F_cB_prop/wgt_wgted_L_denom*wgt_cB_mt(endyr);

FUNCTION get_msy

  //compute values as functions of F
  for(ff=1; ff<=n_iter_msy; ff++)
  {
   //uses fishery-weighted F's
   Z_age_msy=0.0;
   F_L_age_msy=0.0;

   F_L_age_msy=F_msy(ff)*sel_wgted_L;
   Z_age_msy=wgted_M+F_L_age_msy;

   N_age_msy(1)=1.0;
   for (iage=2; iage<=nages; iage++)
   {
    N_age_msy(iage)=N_age_msy(iage-1)*mfexp(-1.*Z_age_msy(iage-1));
```

```
  }
  N_age_msy(nages)=N_age_msy(nages)/(1.0-mfexp(-1.*Z_age_msy(nages)));
  N_age_msy_mdyr(1,(nages-1))=elem_prod(N_age_msy(1,(nages-1)),
                         mfexp((-1.*Z_age_msy(1,(nages-1)))*spawn_time_frac));
  N_age_msy_mdyr(nages)=(N_age_msy_mdyr(nages-1)*
                   (mfexp(-1.*(Z_age_msy(nages-1)*(1.0-spawn_time_frac) +
                         Z_age_msy(nages)*spawn_time_frac) )))
                   /(1.0-mfexp(-1.*Z_age_msy(nages)));

  spr_msy(ff)=sum(elem_prod(N_age_msy_mdyr,wgted_reprod));


  //Compute equilibrium values of R (including bias correction), SSB and Yield at each F
  if(set_SR_switch>1) //Beverton-Holt
  {
   R_eq(ff)=(R0/((5.0*steep-1.0)*spr_msy(ff)))*
           (BiasCor*4.0*steep*spr_msy(ff)-wgted_spr_F0*(1.0-steep));
  }
  if(set_SR_switch<2) //Ricker
  {
   R_eq(ff)=R0/spr_msy(ff)*(1+log(BiasCor*spr_msy(ff))/steep);
  }
  if (R_eq(ff)<dzero) {R_eq(ff)=dzero;}
  N_age_msy*=R_eq(ff);
  N_age_msy_mdyr*=R_eq(ff);

  for (iage=1; iage<=nages; iage++)
  {
   L_age_msy(iage)=N_age_msy(iage)*(F_L_age_msy(iage)/Z_age_msy(iage))*
              (1.-mfexp(-1.*Z_age_msy(iage)));
  }


  SSB_eq(ff)=sum(elem_prod(N_age_msy_mdyr,wgted_reprod));
  B_eq(ff)=sum(elem_prod(N_age_msy,wgt_fish_mt(endyr)));
  L_eq_mt(ff)=sum(elem_prod(L_age_msy,wgt_wgted_L_mt));
  L_eq_knum(ff)=sum(L_age_msy);
}

msy_mt_out=max(L_eq_mt);

for(ff=1; ff<=n_iter_msy; ff++)
{
 if(L_eq_mt(ff) == msy_mt_out)
   {
```

```
      SSB_msy_out=SSB_eq(ff);
      B_msy_out=B_eq(ff);
      R_msy_out=R_eq(ff);
      msy_knum_out=L_eq_knum(ff);
      F_msy_out=F_msy(ff);
      spr_msy_out=spr_msy(ff);
    }
  }

//----------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
FUNCTION get_miscellaneous_stuff

  //compute total landings- and discards-at-age in 1000 fish and klb
  L_total_num.initialize();
  L_total_mt.initialize();

  L_total_num=(L_cR_num+L_cB_num); //catch in number fish
  L_total_mt=L_cR_mt+L_cB_mt;   //landings in klb whole weight

  for(iyear=styr; iyear<=endyr; iyear++)
  {
      L_total_mt_yr(iyear)=sum(L_total_mt(iyear));
      L_total_knum_yr(iyear)=sum(L_total_num(iyear));

      B(iyear)=elem_prod(N(iyear),wgt_fish_mt(iyear));
      totN(iyear)=sum(N(iyear));
      totB(iyear)=sum(B(iyear));
  }
  B(endyr+1)=elem_prod(N(endyr+1),wgt_fish_mt(endyr));
  totN(endyr+1)=sum(N(endyr+1));
  totB(endyr+1)=sum(B(endyr+1));

//  steep_sd=steep;
//  fullF_sd=Fsum;

  if(F_msy_out>0)
    {
     FdF_msy=Fapex/F_msy_out;
     FdF_msy_end=FdF_msy(endyr);
    }
  if(SSB_msy_out>0)
    {
     SdSSB_msy=SSB/SSB_msy_out;
     SdSSB_msy_end=SdSSB_msy(endyr);
```

```
   }

  //fill in log recruitment deviations for yrs they are nonzero
  for(iyear=styr_rec_dev; iyear<=endyr; iyear++)
  {
   log_rec_dev_output(iyear)=log_rec_dev(iyear);
  }
  //fill in log Nage deviations for ages they are nonzero (ages2+)
  for(iage=2; iage<=nages; iage++)
  {
   log_Nage_dev_output(iage)=log_Nage_dev(iage);
  }

  //Compute the exploitation rate for ages 1+ and pop wgtd F for ages 2+
   for(iyear=styr; iyear<=endyr; iyear++)
   {

E(iyear)=sum(L_cR_num(iyear)(2,nages)+L_cB_num(iyear)(2,nages))/sum(N(iyear)(2,nages));

F_age2plus(iyear)=((F_cB(iyear)(3,nages)+F_cR(iyear)(3,nages))*N(iyear)(3,nages))/sum(N(iye
ar)(3,nages));
     F_cR_age2plus(iyear)=(F_cR(iyear)(3,nages)*N(iyear)(3,nages))/sum(N(iyear)(3,nages));
     F_cB_age2plus(iyear)=(F_cB(iyear)(3,nages)*N(iyear)(3,nages))/sum(N(iyear)(3,nages));
   }


//----------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
FUNCTION get_per_recruit_stuff

 //static per-recruit stuff

 for(iyear=styr; iyear<=endyr; iyear++)
 {
   N_age_spr(1)=1.0;
   for(iage=2; iage<=nages; iage++)
   {
     N_age_spr(iage)=N_age_spr(iage-1)*mfexp(-1.*Z(iyear,iage-1));
   }
   N_age_spr(nages)=N_age_spr(nages)/(1.0-mfexp(-1.*Z(iyear,nages)));
   N_age_spr_mdyr(1,(nages-1))=elem_prod(N_age_spr(1,(nages-1)),
                      mfexp(-1.*Z(iyear)(1,(nages-1))*spawn_time_frac));
   N_age_spr_mdyr(nages)=(N_age_spr_mdyr(nages-1)*
                  (mfexp(-1.*(Z(iyear)(nages-1)*(1.0-spawn_time_frac) +
Z(iyear)(nages)*spawn_time_frac) )))
```

```
                    /(1.0-mfexp(-1.*Z(iyear)(nages)));
    spr_static(iyear)=sum(elem_prod(N_age_spr_mdyr,reprod(iyear)))/spr_F0(iyear);
  }


  cout << "sel_wgted_L = " << sel_wgted_L  << endl;
  cout << "wgted_M     = " << wgted_M  << endl;
  cout << "wgted_reprod = "  << wgted_reprod << endl;
  cout << "wgt_wgted_L_mt = " << wgt_wgted_L_mt << endl;

  //compute SSB/R and YPR as functions of F
  for(ff=1; ff<=n_iter_spr; ff++)
  {
    //uses fishery-weighted F's, same as in MSY calculations
    Z_age_spr=0.0;
    F_L_age_spr=0.0;

    F_L_age_spr=F_spr(ff)*sel_wgted_L;

    Z_age_spr=wgted_M+F_L_age_spr;

    N_age_spr(1)=1.0;
    for (iage=2; iage<=nages; iage++)
    {
      N_age_spr(iage)=N_age_spr(iage-1)*mfexp(-1.*Z_age_spr(iage-1));
    }
    N_age_spr(nages)=N_age_spr(nages)/(1-mfexp(-1.*Z_age_spr(nages)));
    N_age_spr_mdyr(1,(nages-1))=elem_prod(N_age_spr(1,(nages-1)),
                              mfexp((-1.*Z_age_spr(1,(nages-1)))*spawn_time_frac));
    N_age_spr_mdyr(nages)=(N_age_spr_mdyr(nages-1)*
                    (mfexp(-1.*(Z_age_spr(nages-1)*(1.0-spawn_time_frac) +
Z_age_spr(nages)*spawn_time_frac) )))
                    /(1.0-mfexp(-1.*Z_age_spr(nages)));
    F_spr_age2plus(ff)=F_L_age_spr(3,nages)*N_age_spr(3,nages)/sum(N_age_spr(3,nages));
    spr_spr(ff)=sum(elem_prod(N_age_spr,wgted_reprod));
    L_spr(ff)=0.0;
    for (iage=1; iage<=nages; iage++)
    {
      L_age_spr(iage)=N_age_spr(iage)*(F_L_age_spr(iage)/Z_age_spr(iage))*
                  (1.-mfexp(-1.*Z_age_spr(iage)));
      L_spr(ff)+=L_age_spr(iage)*wgt_wgted_L_mt(iage); //in mt
    }
  }

FUNCTION get_effective_sample_sizes
```

```
    neff_cR_agec_allyr_out=missing;
    neff_cB_agec_allyr_out=missing;

    for (iyear=1; iyear<=nyr_cR_agec; iyear++)
      {if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
        { numer=sum( elem_prod(pred_cR_agec(iyear),(1.0-pred_cR_agec(iyear))) );
         denom=sum( square(obs_cR_agec(iyear)-pred_cR_agec(iyear)) );
          if (denom>0.0) {neff_cR_agec_allyr_out(yrs_cR_agec(iyear))=numer/denom;}
          else {neff_cR_agec_allyr_out(yrs_cR_agec(iyear))=-missing;}
        } else {neff_cR_agec_allyr_out(yrs_cR_agec(iyear))=-99;}
      }

    for (iyear=1; iyear<=nyr_cB_agec; iyear++)
      {if (nsamp_cB_agec(iyear)>=minSS_cB_agec)
        { numer=sum( elem_prod(pred_cB_agec(iyear),(1.0-pred_cB_agec(iyear))) );
         denom=sum( square(obs_cB_agec(iyear)-pred_cB_agec(iyear)) );
          if (denom>0.0) {neff_cB_agec_allyr_out(yrs_cB_agec(iyear))=numer/denom;}
          else {neff_cB_agec_allyr_out(yrs_cB_agec(iyear))=-missing;}
        } else {neff_cB_agec_allyr_out(yrs_cB_agec(iyear))=-99;}
      }
//---------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------

FUNCTION get_Fmed_benchmarks

 //sorting function for recruitment and SPR values (slow algorithm, but works)
 R_temp=rec(styr_bench,endyr_bench);
 SPR_temp=pred_SPR(styr_bench,endyr_bench);
 for(int jyear=endyr_bench; jyear>=styr_bench; jyear--)
 {
  R_sort(jyear)=max(R_temp);
  SPR_sort(jyear)=max(SPR_temp);
  for(iyear=styr_bench; iyear<=endyr_bench; iyear++)
  {
   if(R_temp(iyear)==R_sort(jyear))
   {
    R_temp(iyear)=0.0;
   }
   if(SPR_temp(iyear)==SPR_sort(jyear))
   {
    SPR_temp(iyear)=0.0;
   }
  }
 }
```

```
// compute the quantile using quant_whole (declared in the data section)
// which computes the floor integer of a decimal number
//median
quant_decimal=(endyr_bench-styr_bench)*0.5;
quant_whole=(endyr_bench-styr_bench)*0.5;
quant_diff=quant_decimal-quant_whole;
R_med=R_sort(styr_bench+quant_whole)*(1-
quant_diff)+R_sort(styr_bench+quant_whole+1)*(quant_diff);
SPR_med=SPR_sort(styr_bench+quant_whole)*(1-
quant_diff)+SPR_sort(styr_bench+quant_whole+1)*(quant_diff);
//cout << "quant_decimal = " << quant_decimal << endl;
//cout << "quant_whole = " << quant_whole << endl;
//cout << "quant_diff = " << quant_diff << endl;
//cout << "result = " << quant_whole*(1-quant_diff)+(quant_whole+1)*quant_diff << endl;
//cout << "R_med = " << R_med << endl;
//cout << "R_sort = " << R_sort << endl;
//cout << "R = " << R_temp << endl;

//75th quantile
quant_decimal=(endyr_bench-styr_bench)*0.75;
quant_whole=(endyr_bench-styr_bench)*0.75;
quant_diff=quant_decimal-quant_whole;
SPR_75th=SPR_sort(styr_bench+quant_whole)*(1-
quant_diff)+SPR_sort(styr_bench+quant_whole+1)*(quant_diff);
//cout << "quant_decimal = " << quant_decimal << endl;
//cout << "quant_whole = " << quant_whole << endl;
//cout << "quant_diff = " << quant_diff << endl;
//cout << "result = " << quant_whole*(1-quant_diff)+(quant_whole+1)*quant_diff << endl;

//find F that matches SPR_med = F_med
SPR_diff=square(spr_spr-SPR_med);
SPR_diff_min=min(SPR_diff);
for(ff=1; ff<=n_iter_spr; ff++)
{
 if(SPR_diff(ff)==SPR_diff_min)
 {
  F_med=F_spr(ff);
  F_med_age2plus=F_spr_age2plus(ff);
  L_med=L_spr(ff)*R_med;
 }
}
SSB_med=SPR_med*R_med;
SSB_med_thresh=SSB_med*0.5;
```

```
  //get the target that corresponds to Fmed, based on 75th quantile of SPR scatter
  SPR_diff=square(spr_spr-SPR_75th);
  SPR_diff_min=min(SPR_diff);
  for(ff=1; ff<=n_iter_spr; ff++)
  {
   if(SPR_diff(ff)==SPR_diff_min)
   {
    F_med_target=F_spr(ff);
    F_med_target_age2plus=F_spr_age2plus(ff);
   }
  }

FUNCTION evaluate_objective_function
  fval=0.0;
  fval_unwgt=0.0;

////---likelihoods---------------------------

////---Indices-------------------------------
  f_JAI_cpue=0.0;
  for (iyear=styr_JAI_cpue; iyear<=endyr_JAI_cpue; iyear++)
  {
   f_JAI_cpue+=square(log((pred_JAI_cpue(iyear)+dzero)/
      (obs_JAI_cpue_final(iyear)+dzero)))/(2.0*log(1.0+square(JAI_cpue_cv_final(iyear))));
  }
  fval+=w_I_JAI*f_JAI_cpue;
  fval_unwgt+=f_JAI_cpue;

  f_PN_cpue=0.0;
  for (iyear=styr_PN_cpue; iyear<=endyr_PN_cpue; iyear++)
  {
   f_PN_cpue+=square(log((pred_PN_cpue(iyear)+dzero)/
      (obs_PN_cpue(iyear)+dzero)))/(2.0*log(1.0+square(PN_cpue_cv(iyear))));
  }
  fval+=w_I_PN*f_PN_cpue;
  fval_unwgt+=f_PN_cpue;

////---Landings-------------------------------

  f_cR_L=0.0; //in 1000 mt
  for (iyear=styr_cR_L; iyear<=endyr_cR_L; iyear++)
  {
    f_cR_L+=square(log((pred_cR_L_mt(iyear)+dzero)/
     (obs_cR_L(iyear)+dzero)))/(2.0*log(1.0+square(cR_L_cv(iyear))));
  }
```

```
 fval+=w_L*f_cR_L;
 fval_unwgt+=f_cR_L;

 f_cB_L=0.0; //in 1000 mt
 for (iyear=styr_cB_L; iyear<=endyr_cB_L; iyear++)
 {
  f_cB_L+=square(log((pred_cB_L_mt(iyear)+dzero)/
     (obs_cB_L(iyear)+dzero)))/(2.0*log(1.0+square(cB_L_cv(iyear))));
 }
 fval+=w_L*f_cB_L;
 fval_unwgt+=f_cB_L;

//////---Age comps-------------------------------
 f_cR_agec=0.0;
 for (iyear=1; iyear<=nyr_cR_agec; iyear++)
 {
  if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
   {
  f_cR_agec-=neff_cR_agec(iyear)*
         sum(elem_prod((obs_cR_agec(iyear)+dzero),
           log(elem_div((pred_cR_agec(iyear)+dzero),
             (obs_cR_agec(iyear)+dzero)))));
  }
 }
 fval+=w_ac*f_cR_agec;
 fval_unwgt+=f_cR_agec;


 f_cB_agec=0.0;
 for (iyear=1; iyear<=nyr_cB_agec; iyear++)
 {
  if (nsamp_cB_agec(iyear)>=minSS_cB_agec)
   {
  f_cB_agec-=neff_cB_agec(iyear)*
         sum(elem_prod((obs_cB_agec(iyear)+dzero),
           log(elem_div((pred_cB_agec(iyear)+dzero),
             (obs_cB_agec(iyear)+dzero)))));
  }
 }
 fval+=w_ac*f_cB_agec;
 fval_unwgt+=f_cB_agec;

////-----------Constraints and penalties--------------------------------
 f_rec_dev=0.0;
 f_rec_dev=norm2(log_rec_dev);
```

```
f_rec_dev=pow(log_rec_dev(styr_rec_dev),2);
for(iyear=(styr_rec_dev+1); iyear<=endyr; iyear++)
{f_rec_dev+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
fval+=w_rec*f_rec_dev;


f_rec_dev_early=0.0; //possible extra constraint on early rec deviations
if (styr_rec_dev<endyr_rec_phase1)
  {
   f_rec_dev_early=pow(log_rec_dev(styr_rec_dev),2);
   for(iyear=(styr_rec_dev+1); iyear<=endyr_rec_phase1; iyear++)
   {f_rec_dev_early+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
  }
fval+=w_rec_early*f_rec_dev_early;

f_rec_dev_end=0.0; //possible extra constraint on ending rec deviations
if (endyr_rec_phase2<endyr)
  {
   for(iyear=(endyr_rec_phase2+1); iyear<=endyr; iyear++)
   {f_rec_dev_end+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
  }
fval+=w_rec_end*f_rec_dev_end;

f_Ftune=0.0;
if (!last_phase()) {f_Ftune=square(Fapex(set_Ftune_yr)-set_Ftune);}
fval+=w_Ftune*f_Ftune;

//code below contingent on four phases
f_fullF_constraint=0.0;
if (!last_phase())
{for (iyear=styr; iyear<=endyr; iyear++)
    {if (Fapex(iyear)>3.0){f_fullF_constraint+=mfexp(Fapex(iyear)-3.0);}}
 if (current_phase()==1) {w_fullF=set_w_fullF;}
 if (current_phase()==2) {w_fullF=set_w_fullF/10.0;}
 if (current_phase()==3) {w_fullF=set_w_fullF/100.0;}
}

fval+=w_fullF*f_fullF_constraint;

//Random walk components of fishery dependent indices
f_PN_RW_cpue=0.0;
for (iyear=styr_PN_cpue; iyear<endyr_PN_cpue; iyear++)
   {f_PN_RW_cpue+=square(q_RW_log_dev_PN(iyear))/(2.0*set_q_RW_PN_var);}
fval+=f_PN_RW_cpue;
```

```
  //JAI combination weights penalty to sum to 1.0
  f_JAI_wgts=0.0;
  f_JAI_wgts=square(1.0-(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4));
  fval+=w_JAI_wgts*f_JAI_wgts;

  f_priors=0.0;
  f_priors=norm2(log_Nage_dev);
  f_priors+=square(steep-set_steep)/square(set_steep_se);
  f_priors+=square(R_autocorr-set_R_autocorr);
  f_priors+=square(q_DD_beta-set_q_DD_beta)/square(set_q_DD_beta_se);

  if(switch_prior==1)
  {
   fval+=f_priors;
  }
  //cout << "fval = " << fval << "  fval_unwgt = " << fval_unwgt << endl;


REPORT_SECTION

  //cout<<"start report"<<endl;
  get_weighted_current();
  //cout<<"got weighted"<<endl;
  get_msy();
  //cout<<"got msy"<<endl;
  get_miscellaneous_stuff();
  //cout<<"got misc stuff"<<endl;
  get_per_recruit_stuff();
  //cout<<"got per recruit"<<endl;
  get_effective_sample_sizes();
  get_Fmed_benchmarks();

  //><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>--><>--><>--><>
  report << "Likelihood " << "Value " << "Weight" << endl;
  report << "JAI_index " << f_JAI_cpue << " " << w_I_JAI << endl;
  report << "PN_index " << f_PN_cpue << " " << w_I_PN << endl;
  report << "reduction_agec " << f_cR_agec << " " << w_ac << endl;
  report << "L_reduction " << f_cR_L << " " << w_L << endl;
  report << "bait_agec " << f_cB_agec << " " << w_ac << endl;
  report << "L_bait " << f_cB_L << " " << w_L << endl;
  report << "R_dev " << f_rec_dev << " " << w_rec << endl;
  report << "R_dev_early " << f_rec_dev_early << " " << w_rec_early << endl;
  report << "R_dev_end " << f_rec_dev_end << " " << w_rec_end << endl;
  report << "F_tune " << f_Ftune << " " << w_Ftune << endl;
```

```
 report << "fullF_constraint " << f_fullF_constraint << " " << w_fullF << endl;
 report << "priors " << f_priors << " " << switch_prior << endl;
 report << "TotalLikelihood " << fval << endl;
 report << "UnwgtLikelihood " << fval_unwgt << endl;
 report << "Error levels in model" << endl;
 report << "JAI_cv " << JAI_cpue_cv << endl;
 report << "PN_cv " << PN_cpue_cv << endl;
 report << "L_reduction_cv " << cR_L_cv << endl;
 report << "L_bait_cv " << cB_L_cv << endl;
 report << "NaturalMortality Vector" << endl;
 report << "Age " << agebins << endl;
 report << "M_vector " << M << endl;
 report << "NaturalMortality Matrix " << endl;
 report << "Year " << agebins << endl;
 for(iyear=styr; iyear<=endyr; iyear++)
 {
  report << iyear << " " << M_mat(iyear) << endl;
 }
 report << "Steepness " << steep << endl;
 report << "R0 " << R0 << endl;
 report << "Recruits" << endl;
 report << "Year";
 for(iyear=styr; iyear<=endyr; iyear++)
 {
  report << " " << iyear;
 }
 report << endl;
 report << "Age-0_recruits " << column(N,1) << endl;
 report << "Age-1_recruits " << column(N,2) << endl;
 report << "SSB" << endl;
 report << "Year";
 for(iyear=styr; iyear<=endyr; iyear++)
 {
  report << " " << iyear;
 }
 report << endl;
 report << "FEC " << SSB << endl;
 //report << "SSB " << FEC << endl;
 report << "Lagged_R " << column(N,1)(styr+1,endyr) << endl;

//    cout<< mfexp(log_len_cv)<<endl;
//  report << "TotalLikelihood " << fval << endl;
 #include "menhad_make_Robject012.cxx"   // write the S-compatible report
```

18 Appendix 3. Concerns and additional analyses regarding reference points

Statement of the problem

The current overfished definition in the Atlantic menhaden FMP is SSB_{MED} as a target and 50% of SSB_{MED} as a threshold. Since the 2010 benchmark assessment, the Atlantic Menhaden Management Board adopted $F_{30\%}$ and $F_{15\%}$ as the menhaden management F-based overfishing target and threshold, respectively. The target and threshold population fecundity (SSB_{MED}) reference point currently used for menhaden management is presented in the body of this report using the methods from the 2009 benchmark assessment. **However, the TC warns that there is a technical mismatch between the current overfishing and overfished reference points. Logically, $SSB_{15\%}$ and $SSB_{30\%}$ (threshold and target, respectively) should be adopted if the Board wishes to define overfishing using $F_{30\%}$ and $F_{15\%}$ benchmarks.** Additional calculations and sensitivity runs were performed to estimate $SSB_{30\%}$ and $SSB_{15\%}$ and compare those estimates with other reference points – see below. Note SSB in this report implies fecundity, or mature ova.

Notes on methods

$SSB_{30\%}$ and $SSB_{15\%}$ reference points associated with $F_{30\%}$ and $F_{15\%}$ were calculated using the same vectors of average fecundity, M, and catch-weighted selectivity in addition to a value of median recruitment using the years 1955-2011. The uncertainty in the terminal year stock status indicators is expressed using the results of the 2,000 bootstrap runs of the base BAM model.

F-based biological reference points in the main body of this update report were calculated using average vectors from 1955-2011. The TC requested several analyses examining the reference points calculated across a shorter, more recent time period as a sensitivity analysis. The vectors used to calculate the F-based biological reference points included a vector of average fecundity, a vector of average M, and a catch weighted average selectivity vector.

Note F_{MED} is no longer being used for management, but is provided in Table 24 for continuity comparison with the 2010 assessment.

Supplemental results

Estimates of $SSB_{30\%}$ and $SSB_{15\%}$ and some exploration of the sensitivity of these results to model configuration are presented in Table 24 and Table 25. **If $SSB_{15\%}$ were adopted for management, the stock would be overfished.** The retrospective analysis, which re-estimates benchmarks annually, demonstrates that overfishing has been occurring during six of the last 12 years (Table 24) and that the population was overfished during nine of the last 12 years when using fecundity-per-recruit based benchmarks.

The entire time series of $SSB_{30\%}$ and $SSB_{15\%}$ and associated bootstrap confidence intervals are shown in **Figure 73** and **Figure 74** using the years 1955-2011 for benchmark calculation. Phase plots of the last ten years of fecundity-per-recruit-based estimates are shown in Figure 75 using the years 1955-2011 for benchmark calculation. The results based on fecundity-per-recruit based benchmarks indicate that the fecundity estimates for the terminal year are all below the threshold (limit) using the years 1955-2011 (**Figure 76**).

Sensitivity to reference time period
Fecundity-per-recruit and yield-per-recruit (mt) estimates as a function of total full fishing mortality rates are shown in **Figure 77** and **Figure 78Figure 78** for benchmarks calculated using the years 1990-2011. These plots are offered as a reference for comparison between fishing mortality rates. For example, using the years 1990-2011 for benchmark calculation, the terminal year full fishing mortality rate estimate (F_{2011}) of 4.50 is below $F_{7\%}$.

The entire time series of $SSB_{30\%}$ and $SSB_{15\%}$ and associated bootstrap confidence intervals are shown in **Figure 79** and **Figure 80** using the years 1990-2011 for benchmark calculation. Phase plots of the last ten years of estimates are shown in **Figure 81** using the years 1990-2011 for benchmark calculation. The results based on fecundity-per-recruit based benchmarks indicate that the fecundity estimates for the terminal year are all below the threshold (limit) using the years 1955-2011 (**Figure 82**).

Appendix 3 – Tables

Table 24. Results from base BAM model, sensitivity runs, and retrospective analysis. Median recruitment to age-0 (billions) is labeled as R_{MED}, fishing mortality (F) is full F, and population fecundity (SSB) is in billions of mature ova. Subscripts denote the following MED: median; MED.T: threshold associated with the median; and term: terminal year, which is 2011 for the six rows. * denotes that benchmark calculation is not directly comparable with the base run because of differences in selectivity.

Run	R_{MED}	F_{MED}	$F_{MED.T}$	SSB_{MED}	$SSB_{MED.T}$	F_{term} /F_{MED}	SSB_{term} /$SSB_{MED.T}$	$F_{15\%}$	$F_{30\%}$	$SSSB_{15\%}$	$SSB_{30\%}$	F_{term} /$F_{15\%}$	F_{term} /$F_{30\%}$	SSB_{term} /$SSB_{15\%}$	SSB_{term} /$SSB_{30\%}$
Base run	12.61	2.06	1.02	19092	9546	1.83	1.4	1.34	0.62	30551	61100	3.36	7.22	0.44	0.22
*cR dome-shaped selectivity	12.52	1.95	0.97	18090	9045	1.77	1.39	1.25	0.64	30326	60650	3.31	6.51	0.41	0.21
omit JAI	12.72	2.15	0.97	18365	9182	1.88	1.47	1.34	0.62	30809	61618	3.54	7.6	0.44	0.22
omit PRFC	12.61	2.06	1.02	19140	9570	2.07	1.32	1.34	0.62	30561	61123	3.82	8.2	0.41	0.21
median effective N	11.96	1.51	0.85	22043	11021	2.07	1.26	1.18	0.57	28993	57989	3.26	6.74	0.48	0.24
*cR and cB dome-shaped selectivity	14.84	1.4	0.33	23575	11787	1.04	3.67	1.09	0.65	35953	71906	1.51	2.52	1.2	0.6
Retrospective 2010	12.85	2.17	0.96	18337	9169	1.71	1.23	1.33	0.62	31342	62686	3.31	7.11	0.36	0.18
Retrospective 2009	13.09	2.29	0.99	17594	8797	1.71	1.88	1.33	0.62	32014	64027	2.75	5.9	0.52	0.26
Retrospective 2008	13.12	2.23	0.96	18198	9099	0.9	2.2	1.32	0.62	32300	64599	1.56	3.35	0.62	0.31
Retrospective 2007	13.09	2.32	0.95	17180	8590	1.09	1.48	1.31	0.61	32406	64812	2.3	4.93	0.39	0.2
Retrospective 2006	13.14	2.27	0.99	17679	8839	0.95	2.5	1.3	0.61	32627	65251	1.46	3.13	0.68	0.34
Retrospective 2005	13.26	2.29	1.02	17560	8780	0.37	4.77	1.3	0.61	33006	66008	0.63	1.34	1.27	0.63
Retrospective 2004	13.25	2.3	1	17318	8659	0.49	3.06	1.3	0.61	33009	66020	0.94	2	0.8	0.4
Retrospective 2003	13.26	2.32	0.98	17077	8539	0.47	2.74	1.29	0.6	32983	65963	0.91	1.95	0.71	0.35
Retrospective 2002	13.89	2.26	0.98	17940	8970	0.58	4.31	1.27	0.6	34252	68498	0.89	1.89	1.13	0.56
Retrospective 2001	14.58	2.26	0.97	18570	9285	0.29	6.42	1.26	0.6	35757	71518	0.5	1.06	1.67	0.83
Retrospective 2000	14.6	2.26	0.97	18266	9133	0.43	2.41	1.26	0.59	35483	70970	0.85	1.81	0.62	0.31

Table 25. Summary of benchmarks and terminal year (2011) values estimated for the base BAM model. Fishing mortality rate is full F, and SSB is fecundity in billions of mature ova. The benchmarks were calculated using two time periods: 1955-2011 and 1990-2011.

Benchmarks and Terminal Year Values	Base BAM Model Estimates 1955-2011	Base BAM Model Estimates 1990-2011
Median Age-0 Recruits (billions)	12.61	8.96
Threshold (Limit): F_{MED}	2.06	1.51
Target: $F_{MED.target}$	1.02	1.04
$F_{30\%}$	0.62	0.7
$F_{15\%}$	1.34	1.53
F_{2011}	4.5	4.5
F_{2011}/F_{MED}	1.83	2.5
$F_{2011}/F_{30\%}$	7.22	6.43
$F_{2011}/F_{15\%}$	3.36	2.94
Target: SSB_{MED}	19,092	25,186
Threshold (Limit): $SSB_{MED.thresh}$	9,546	12,593
$SSB_{30\%}$	61,100	49,537
$SSB_{15\%}$	30,551	24,767
SSB_{2011}	13,334	13,334
$SSB_{2011}/SSB_{threshold}$	1.4	1.05
$SSB_{2011}/SSB_{30\%}$	0.22	0.27
$SSB_{2011}/SSB_{15\%}$	0.44	0.54

Appendix 3 - Figures

Figure 73. Estimates of the population fecundity (SSB) relative to the limit SSB15% from the base BAM model (connected points) using benchmarks calculated over 1955-2011. Shaded area represents the 90% confidence interval of the bootstrap runs.

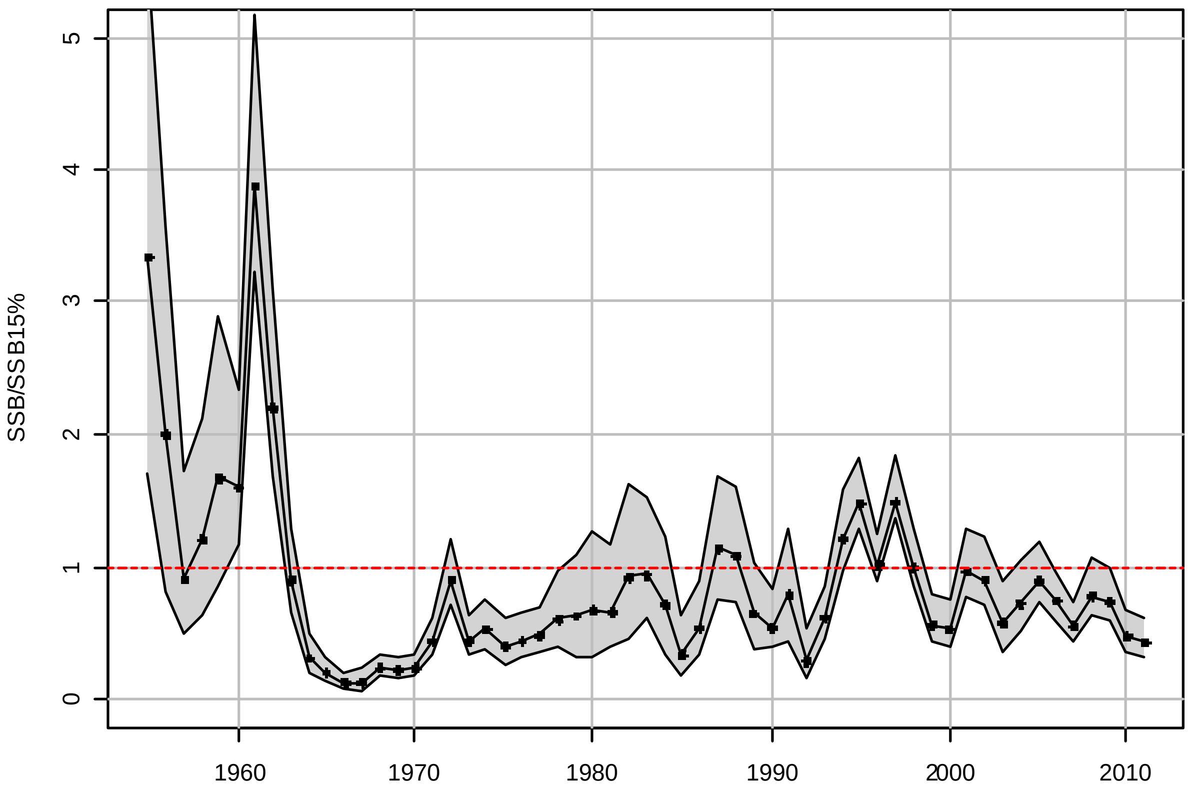


Figure 74. Estimates of the population fecundity (SSB) relative to the target SSB30% from the base BAM model (connected points) using benchmarks calculated over 1955-2011. Shaded area represents the 90% confidence interval of the bootstrap runs.

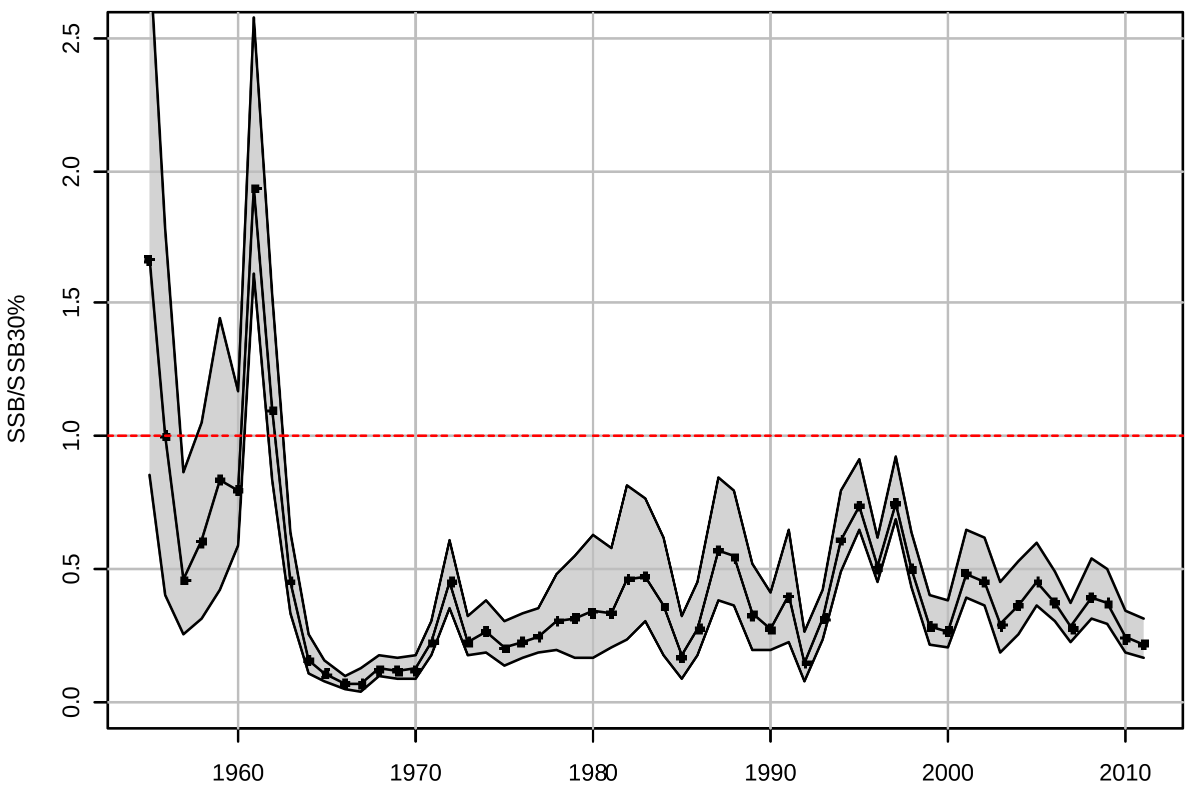


Figure 75. Phase plot of recent estimates of the population fecundity (mature ova in billions) and total full fishing mortality rate from the base BAM model with fecundity-per-recruit based benchmarks calculated using the years 1955-2011. Solid vertical and horizontal lines indicate the targets and limits for each respective axis. Double digit number in circles indicates the year of the point estimate (e.g. 08 = 2008).

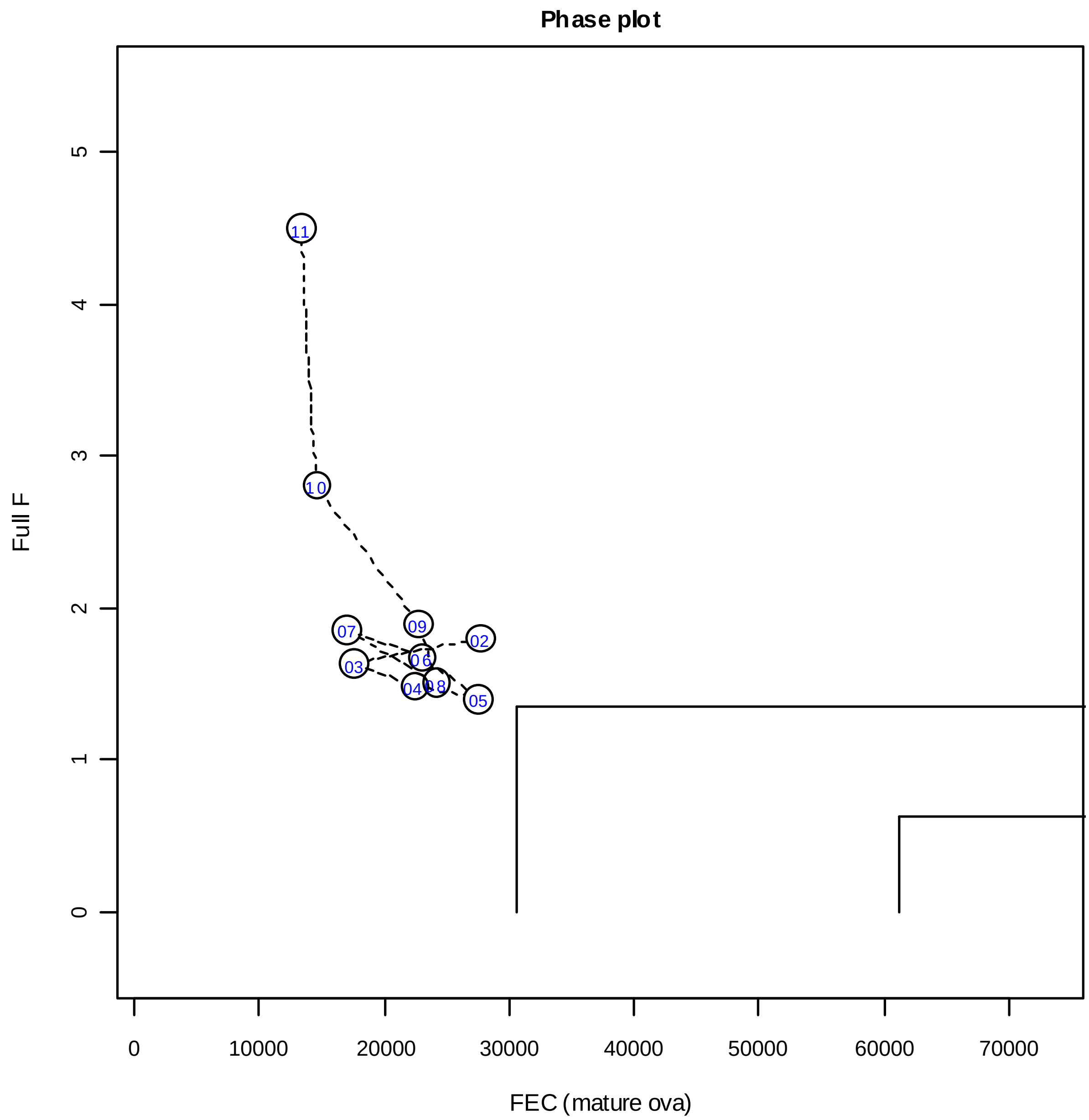


Figure 76. Scatter plot of the 2011 estimates relative to the F15% benchmarks (limits) from the 2,000 bootstrap estimates from the base BAM model. All years 1955-2011 were used to calculate the benchmarks.

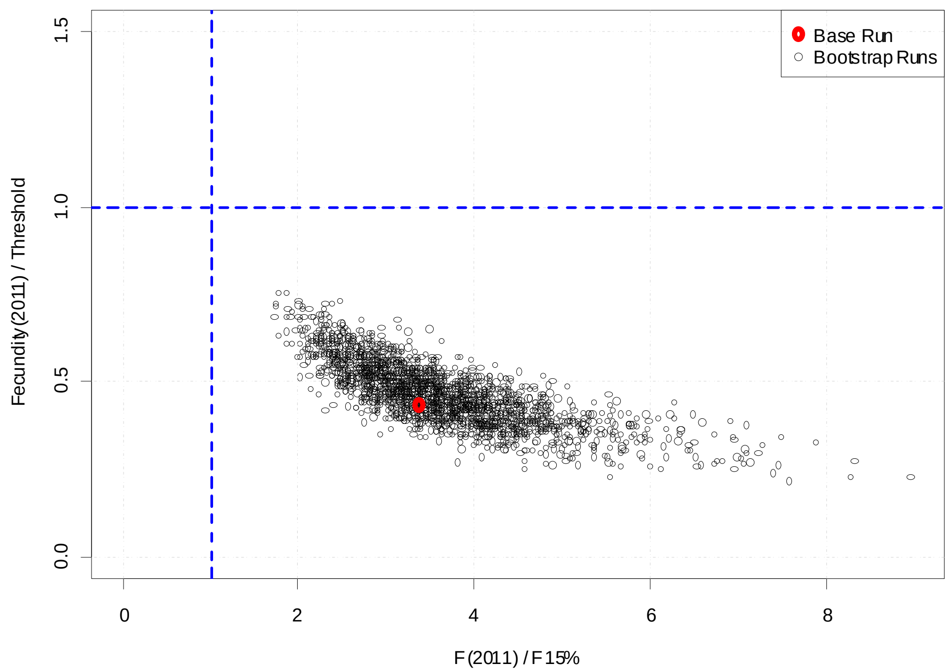


Figure 77. Estimates of the proportional (re-scaled to max of 1.0) fecundity-per-recruit as a function of the total full fishing mortality rate from the base BAM model using the years 1990-2011 for benchmark calculations.

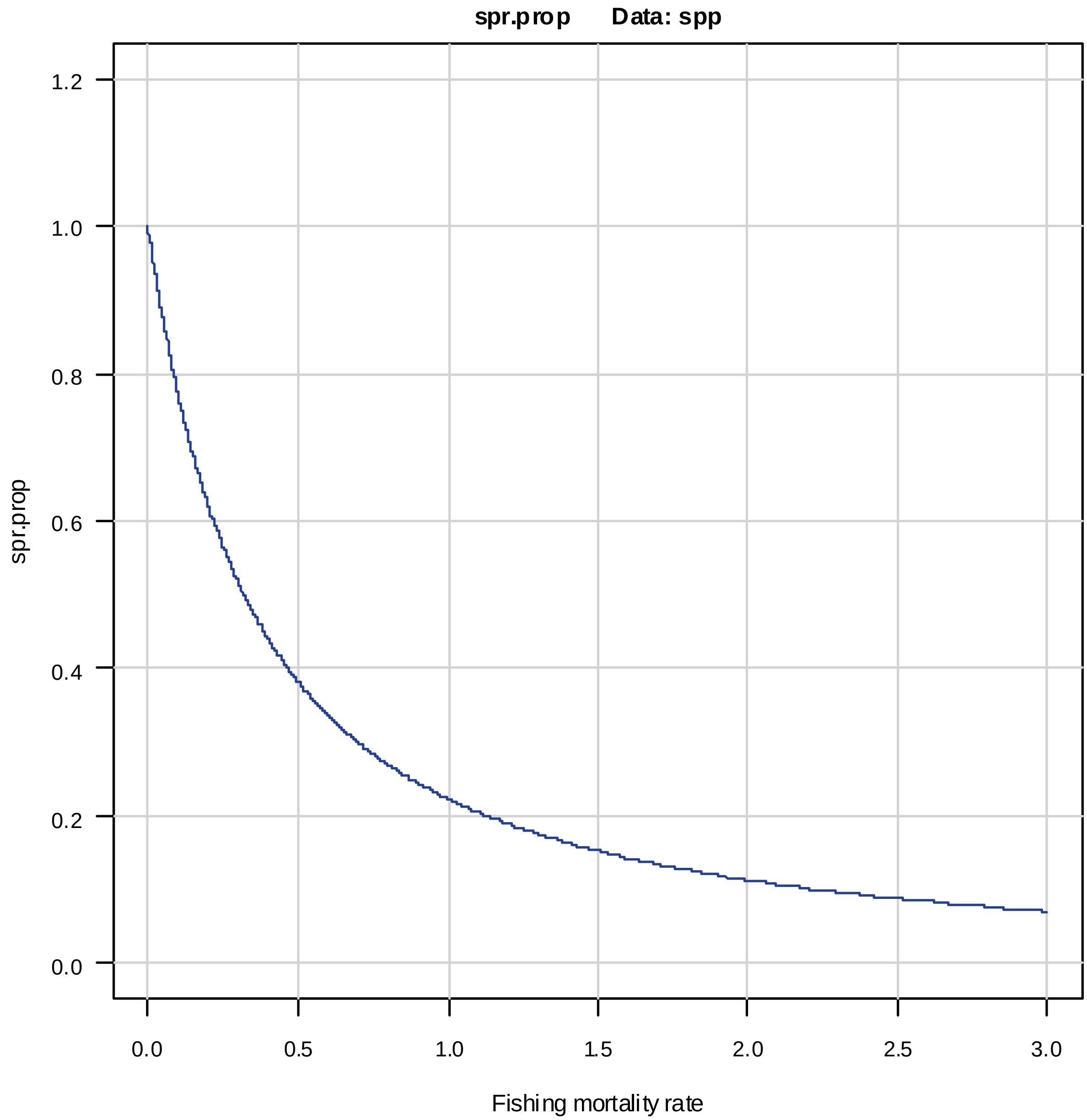


Figure 78. Estimates of the yield-per-recruit (mt/million) as a function of the total full fishing mortality rate from the base BAM model using the years 1990-2011 for benchmark calculations.

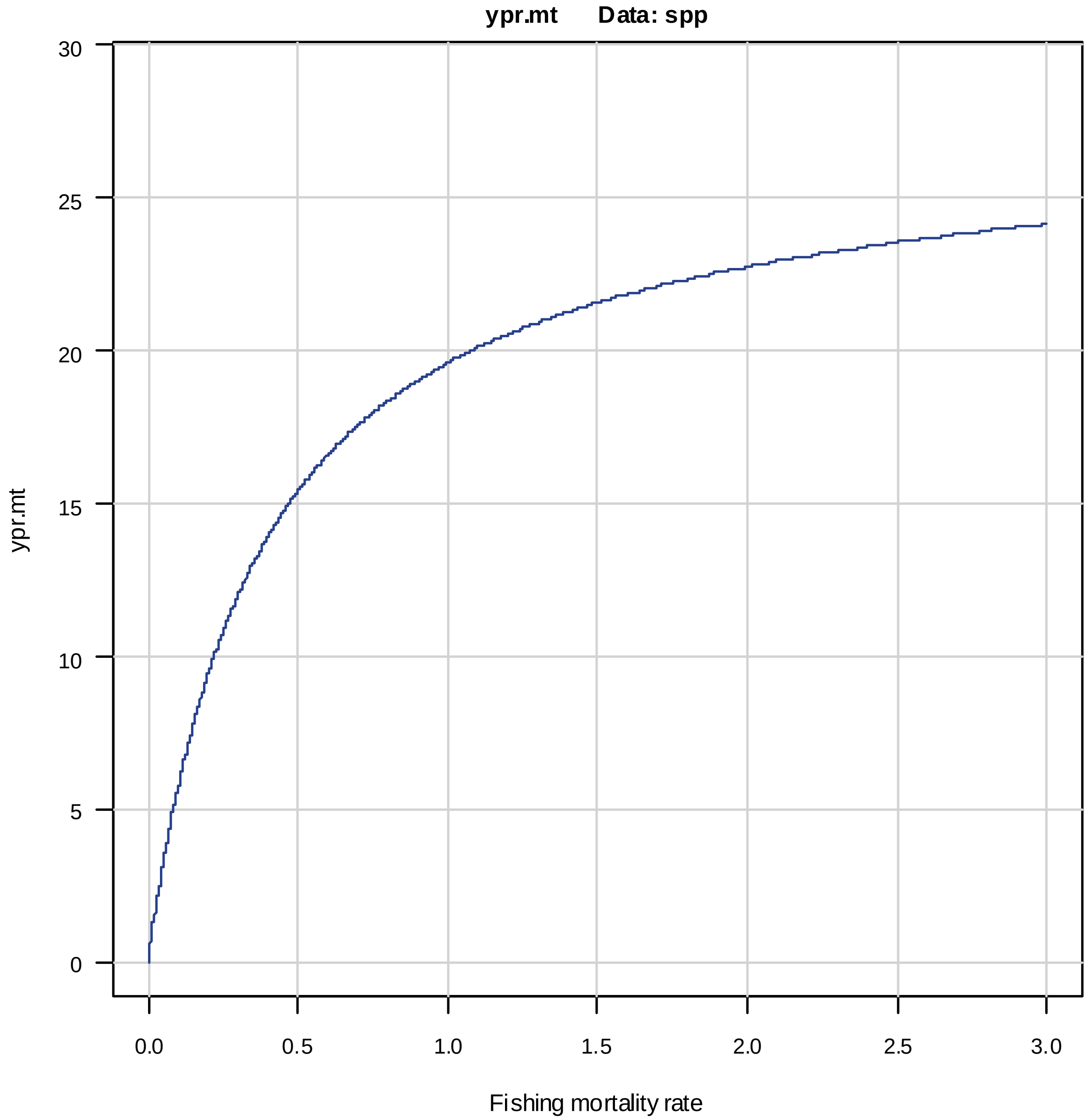


Figure 79. Estimates of the total full fishing mortality rate relative to the F15% benchmark (fishing limit value) from the base BAM model (connected points) using benchmarks calculated over 1990-2011. Shaded area represents the 90% confidence interval of the bootstrap runs.

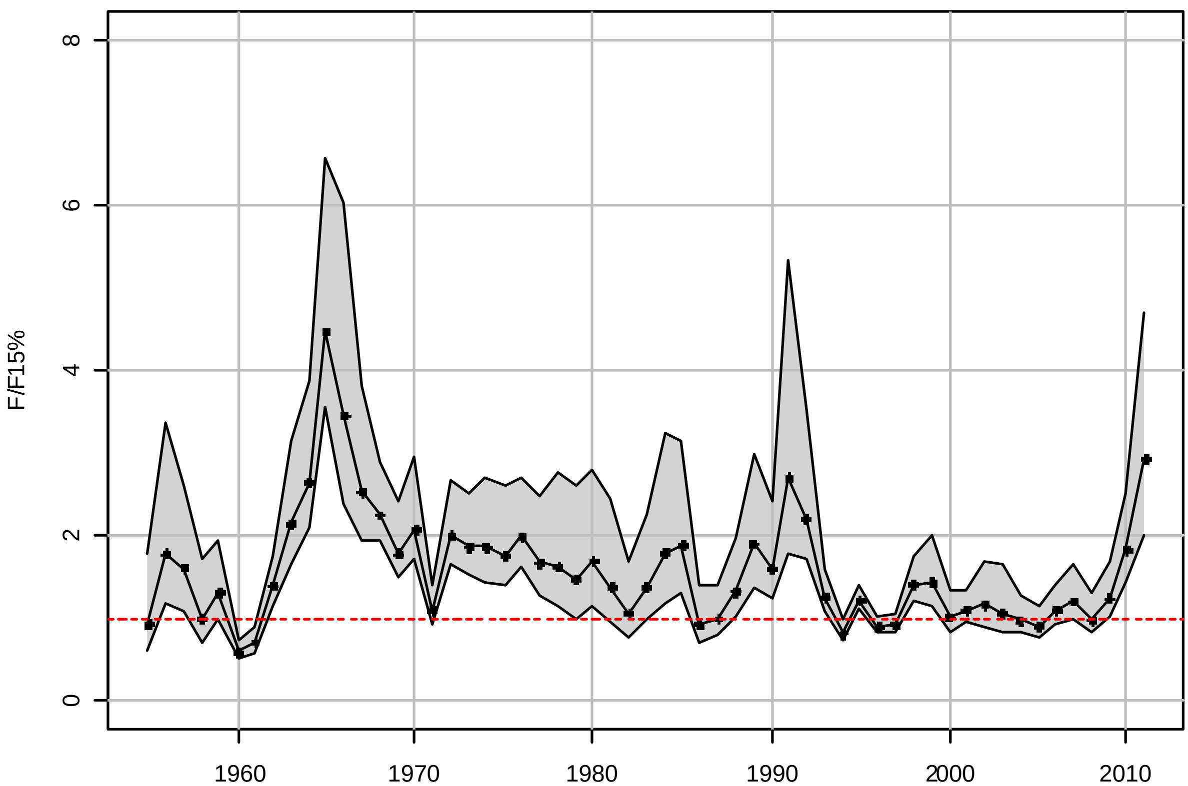


Figure 80. Estimates of the population fecundity (SSB) relative to the target SSB30% from the base BAM model (connected points) using benchmarks calculated over 1990-2011. Shaded area represents the 90% confidence interval of the bootstrap runs.

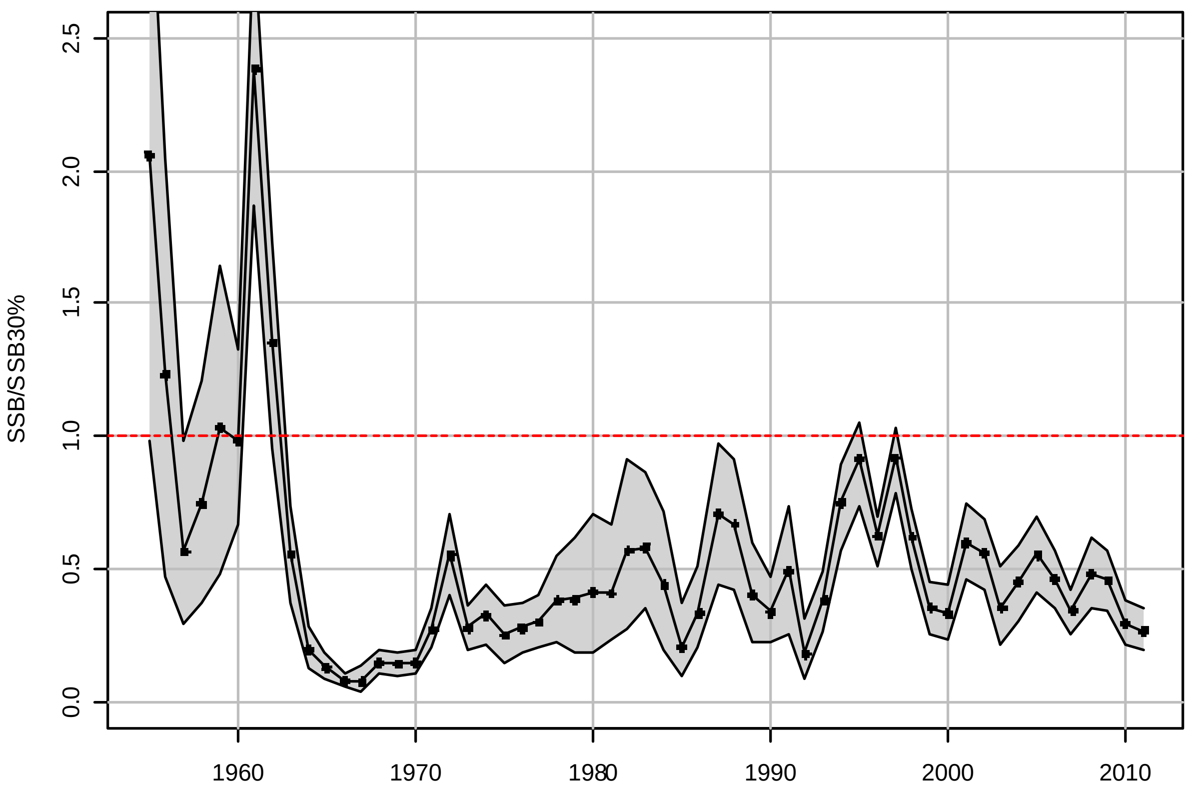


Figure 81. Phase plot of recent estimates of the population fecundity (mature ova in billions) and total full fishing mortality rate from the base BAM model with fecundity-per-recruit based benchmarks calculated using the years 1990-2011. Solid vertical and horizontal lines indicate the targets and limits for each respective axis. Double digit number in circles indicates the year of the point estimate (e.g. 08 = 2008).

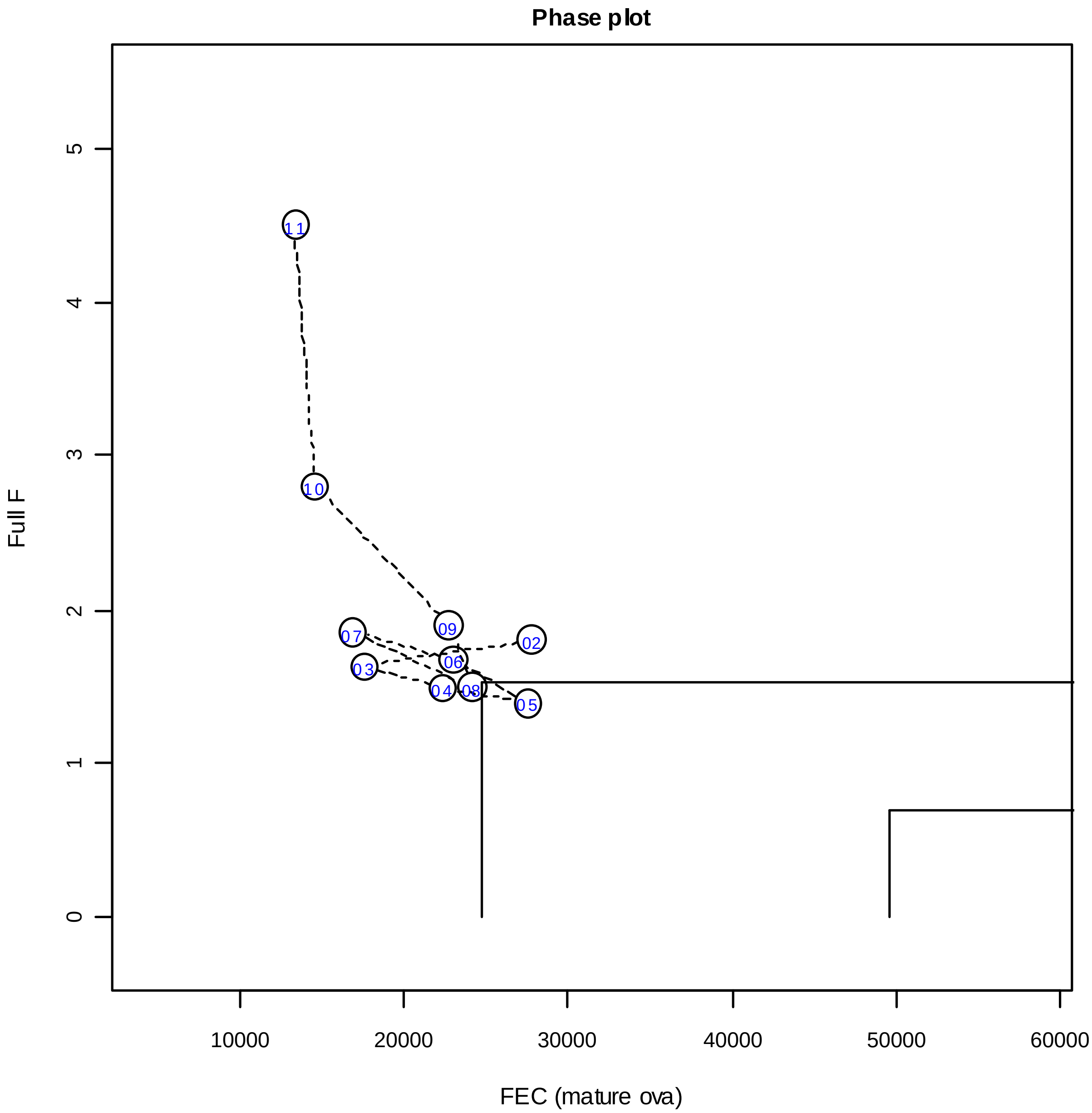
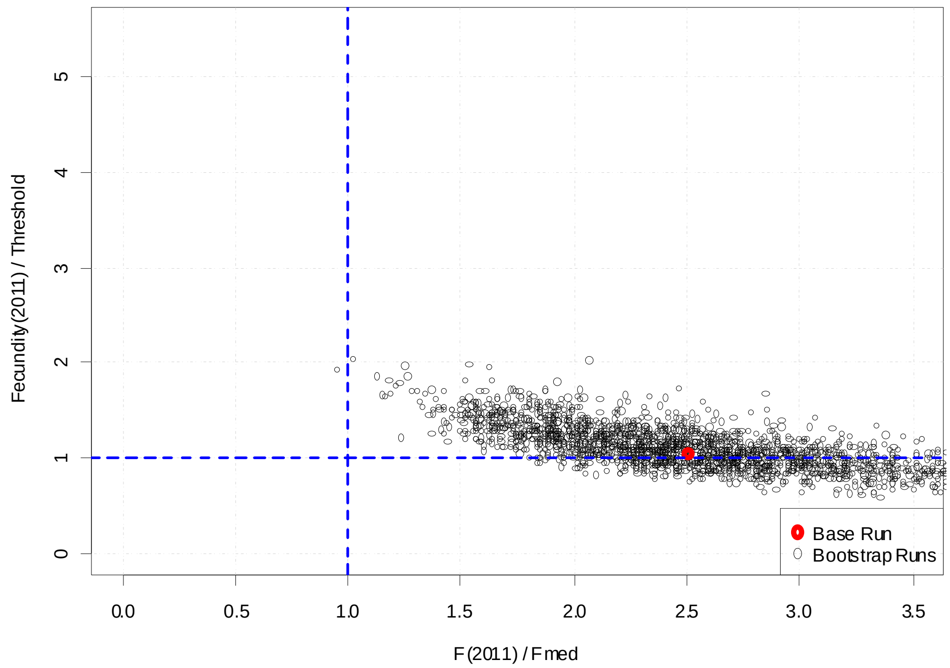


Figure 82. Scatter plot of the 2011 estimates relative to the FMED benchmarks (limits) from the 2,000 bootstrap estimates from the base BAM model using truncated years 1990-2011 (lower panel) to calculate benchmarks.



19 Appendix 4. Alternative approaches to set harvest limits in data poor situations

Table 26. Summary of ad-hoc "rules" used by Fishery Management Councils to set harvest limits in data poor situations.

Council	Species group	Multiplier	Comments
New England	Atlantic herring	1	Not OF, OF not occurring
New England	Red crab	1	Based on stock status
Carribean		0.85	Used to set ABC and ACL
New England	Groundfish	0.75	
Pacific		0.75	Used to set ABC
Pacific	Groundfish	0.5	Used to set OY
Pacific	Coastal pelagics	0.25	Used to set ABC

Table 27. Estimated harvest levels (thousand MT) for a range of uncertainty correction factors.

Probability of reducing overfishing

0%

Average	Multiplier					
	1	0.9	0.8	0.75	0.5	0.25
3-year	213.5	192.2	170.8	160.2	106.8	53.4
5-year	209.5	188.5	167.6	157.1	104.7	52.4

20 Appendix 5. 2012 Update of the Expanded Multispecies Virtual Population Analysis