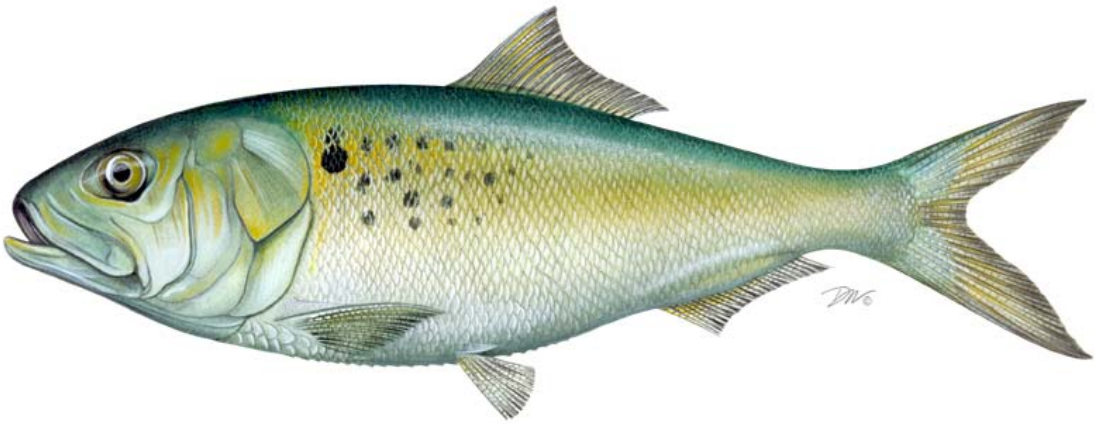
# *Atlantic Menhaden Stock Assessment Update*



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***Vision: Sustainably Managing Atlantic Coastal Fisheries***

# Atlantic States Marine Fisheries Commission

## *2017 Atlantic Menhaden Stock Assessment Update*


Prepared by the
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## Acknowledgements

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## Executive Summary

The purpose of this assessment was to update the 2015 Atlantic menhaden benchmark stock assessment (SEDAR 2015) with recent data from 2014-2016. No changes in structure or parameterization were made to the base model run. Additional sensitivity analyses were conducted.

### Landings

The Atlantic menhaden commercial fishery has two major components, a purse-seine reduction sector that harvests fish for fish meal and oil and a bait sector that supplies bait to other commercial and recreational fisheries. The first coastwide total allowable catch (TAC) on Atlantic menhaden was implemented in 2013 and since then reduction landings have ranged from 131,000 mt in 2013 to 143,500 mt in 2015. In 2016, reduction landings were 137,400 mt and accounted for approximately 76% of coastwide landings. Landings in the reduction fishery are currently at their lowest levels in the time series because only one plant remains in operation along the coast. In contrast, bait landings have increased in recent years as demand has grown because of recent limitations in other species used as bait (e.g., Atlantic herring), peaking in 2012 at 63,700 mt. In 2016, bait landings were 43,100 mt and comprised 24% of coastwide landings.

### Indices of Relative Abundance

Young of the Year (YOY) Index

The YOY index developed from 16 fishery-independent surveys shows the largest recruitments occurred during the 1970s and 1980s. Recruitment has since been lower with notable year classes in 2005, 2010, and 2016.

Age-1+ Indices

Two coastwide indices of adult abundance were developed from nine fishery independent survey data sets spanning the coast from New England to Georgia. In the most recent years, the northern adult index indicated an increase in abundance for ages-2+, while the southern adult index for the assessment indicated a slightly decreasing abundance for age-1.

### Fishing Mortality

Highly variable fishing mortalities were noted throughout the entire time series. Fishing mortality rate was reported as the geometric mean fishing mortality rate of ages-2 to -4. In the most recent decade, the geometric mean fishing mortality rate has ranged between 0.31 and 0.58. The geometric mean fishing mortality rate for 2016 was 0.51. Adding data from 2014-2016 to the assessment model resulted in higher fishing mortality rates for the entire time series compared to the 2015 benchmark assessment, although the trend remained largely the same. These changes also affected the reference points, which are calculated as the median (target) and maximum (threshold) for the 1960-2012 time series.

### Biomass

Biomass has fluctuated with time from an estimated high of over 2,288,000 mt in 1958 to a low of 567,000 mt in 2000. Biomass was estimated to have been largest during the late-1950s, with lows occurring during the mid-1990s to mid-2000s. Biomass was estimated to have been relatively stable through much of the 1970s and 1980s. The oldest age classes comprise the smallest proportion of the population, but that proportion has increased in recent years. Biomass is likely increasing at a faster rate than abundance because of the increase in the number of older fish at age and an increase in weight at age.

**Fecundity**

Population fecundity (i.e., Total Egg Production) was the measure of reproductive output used. Population fecundity (*FEC*, number of maturing ova) was highest in the early 1960s, early 1970s, and during the present decade and has generally been higher with older age classes making up a larger proportion of the *FEC.*

**Stock Status**

The current benchmarks for Atlantic menhaden are $F_{36\%}$, $F_{21\%}$, $FEC_{36\%}$, *and* $FEC_{21\%}$, which were calculated using the methods from the 2015 benchmark stock assessment. The benchmarks are calculated through spawner-per-recruit analysis using the mean values of any time-varying components (i.e., growth, maturity). Based on the current adopted benchmarks, **the Atlantic menhaden stock status is not overfished and overfishing is not occurring**. In addition, the stock is currently below the current fishing mortality target and below the current *FEC* target. The 2015 benchmark reference points for Atlantic menhaden were $F_{38\%}$, $F_{57\%}$, $FEC_{38\%}$, and $FEC_{57\%}$. Because this stock assessment update resulted in higher fishing mortality values throughout the time series due to the additional three years of data, the maximum and median *F* values were estimated higher compared to the 2015 benchmark.

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# Introduction

The purpose of this assessment was to update the 2015 Atlantic menhaden (*Brevoortia tyrannus*) benchmark stock assessment (SEDAR 2015) with recent data from 2014-2016. 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. The 2015 benchmark stock assessment for Atlantic menhaden was initiated by the Atlantic States Marine Fisheries Commission (ASMFC or Commission) Atlantic Menhaden Management Board (Board), prepared by the ASMFC Atlantic Menhaden Stock Assessment Subcommittee (SAS), and reviewed and approved by the ASMFC Atlantic Menhaden Technical Committee (TC) as part of the interstate fisheries management process.

## 1.0 Regulatory History

The first coastwide fishery management plan (FMP) for Atlantic menhaden was passed in 1981 (ASMFC 1981). The 1981 FMP did not recommend or require specific management actions, but provided a suite of options should they be needed. After the FMP was approved, a combination of additional state restrictions, establishment of local land use rules, and changing economic conditions resulted in the closure of most reduction plants north of Virginia (ASMFC 1992). In 1988, ASMFC concluded that the 1981 FMP had become obsolete and initiated a revision to the plan.

The 1992 Plan Revision included a suite of objectives to improve data collection and promote awareness of the fishery and its research needs (ASMFC 1992). Under this revision, the menhaden program was directed by the Board, which at the time was composed of up to five state directors, up to five industry representatives, one representative from the National Marine Fisheries Service, and one representative from the National Fish Meal and Oil Association.

Representation on the Board was revised in 2001 to include three representatives from each state in the management unit, including the state fisheries director, a legislator, and a governor's appointee. The reformatted Board has passed two amendments and six addenda to the 1992 FMP revision.

Amendment 1, passed in 2001, provided specific biological, social/economic, ecological, and management objectives for Atlantic menhaden. No recreational or commercial management measures were implemented as a result of Amendment 1.

Addendum I (2004) addressed biological reference points for menhaden, specified the frequency of stock assessments to be every three years, and updated the habitat section of the FMP.

Addendum II (2005) instituted a harvest cap on the reduction fishery in the Chesapeake Bay. This cap, based on average landings from 2000-2004 (see technical Addendum I), was established for the 2006 through 2010 fishing seasons. Addendum II also outlined a series of research priorities to examine the possibility of localized depletion of Atlantic menhaden in the Chesapeake Bay. They included: determining menhaden abundance in Chesapeake Bay; determining estimates of removal of menhaden by predators; exchanging of menhaden between bay and coastal systems; and conducting larval studies.

Addendum III (2006) revised the Chesapeake Bay Reduction Fishery Cap to 109,020 metric tons, which is an average of landings from 2001-2005. Implementation of the cap remained for the 2006 through 2010 fishing seasons. Addendum III also allowed a harvest underage in one year to be added to the next year's quota. As a result, the maximum cap in a given year was extended to 122,740 metric tons.

Addendum IV (2009) extended the Chesapeake Bay harvest cap three additional years (2011-2013) at the same levels as established in Addendum III.

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

Amendment 2, approved in December 2012, established a 170,800 metric ton (mt) total allowable catch (TAC) for the commercial fishery beginning in 2013. This TAC represented a 20% reduction from average landings between 2009 and 2011. The 2009-2011 time period was also used to allocate the TAC among the jurisdictions. The Amendment also established requirements for timely reporting and required states to be accountable for their respective quotas by paying back any overages the following year. The amendment included provisions that allow for the transfer of quota between jurisdictions and a bycatch allowance of 6,000 pounds per trip for non-directed fisheries that operate after a jurisdiction's quota has been landed. Further, it reduced the Chesapeake Bay reduction fishery harvest cap by 20% to 87,216 metric tons.

At its May 2015 meeting, the Board established an 187,880 mt TAC for the 2015 and 2016 fishing years. This represented a 10% increase from the 2013 and 2014 TAC. In October 2016, the Board approved a TAC of 200,000 mt for the 2017 fishing year, representing a 6.45% increase from the 2015 and 2016 fishing years.

In August 2016, the Board approved Addendum I which added flexibility to the current bycatch provision by allowing two licensed individuals to harvest up to 12,000 pounds of menhaden bycatch when working together from the same vessel using stationary multi-species gear. The intent of this Addendum was to accommodate cooperative fishing practices which traditionally take place in the Chesapeake Bay.

Amendment 3 to the Atlantic Menhaden FMP is currently under development, initiated in 2015 to address several concerns in the fishery including the adoption of ecological reference points (ERPs) and a new quota allocation scheme. The ERPs are meant to account for changes in the abundance of prey and predator species when setting overfished and overfishing thresholds for menhaden. The Board reviewed public input in February 2017 and provided guidance on management options to include in Amendment 3. Under the current timeline, the Board will consider final action on Draft Amendment 3 at the end of 2017.

In May 2013, the Board approved Technical Addendum I which established an episodic events set aside program. This program set aside 1% of the coastwide TAC for the New England States (ME, NH, MA, RI, CT) to harvest Atlantic menhaden when they occur in higher abundance than normal. In order to participate in the program, a state must reach its individual quota prior to September 1 before harvesting from the set aside. At its October 2013 meeting, the Board extended the episodic event set aside program through 2015, adding a re-allocation provision that re-allocated unused set aside as of October 31 to the coastwide states based on the same allocation percentages included in Amendment 2. At its May 2016 meeting, the Board again extended the episodic events program until final action on Amendment 3 and added New York as an eligible state to harvest under the program.

## 2.0 Life History

### 2.1 Stock Definition

Atlantic menhaden are considered a single stock. Historically there was considerable debate relative to stock structure of Atlantic menhaden on the US East Coast, with a northern and southern stock hypothesized based on meristics and morphometrics (Sutherland 1963; June 1965). Based on size-frequency information and tagging studies (Nicholson 1972 and 1978; Dryfoos et al. 1973), the Atlantic menhaden resource is believed to consist of a single unit stock or population. Recent genetic studies (Anderson 2007; Lynch et al. 2010) support the single stock hypothesis.

### 2.2 Age

In 1955, the NOAA Laboratory at Beaufort, NC, began monitoring the Atlantic menhaden purse-seine fishery for size and age composition of the catch (June and Reintjes 1959). From the outset, scales were selected as the ageing tool of choice for Atlantic menhaden due to ease of processing and reading and an age validation study confirming reliable age marks on scales (June and Roithmayer 1960). During the early decades of the Menhaden Program at the Beaufort Laboratory, scales from individual menhaden specimens were read multiple times by several readers. Since the early 1970s, only a single reader was retained on staff to age menhaden scales.

To address future plans for states to age Atlantic menhaden scales and the research recommendation to conduct an ageing workshop, the ASMFC organized and held a workshop in 2015 (ASMFC 2015). An exchange of scale samples took place and was followed with an in-person workshop to discuss the results. Depsite the fact that most participating agers were new to ageing Atlantic menhaden or had never aged the species, agreement between readers was on average 73% and increased to 95% within one year. False annuli, poor storage of samples, and damaged scales were common issues identified at the workshop. Atlantic menhaden scales were also examined at ASMFC's 2017 Quality Assurance/Quality Control Fish Ageing Workshop (ASMFC 2017). Average percent error between agers along the Atlantic coast was 15%, although many readers had no previous experiencing ageing Atlantic menhaden. When considering readers with experience ageing this species, average exact agreement was 43%, although it increased to 88% within one year.

### 2.3 Growth

Catch in numbers by year, season, and fishing area was developed for weighting corresponding sampled weights of Atlantic menhaden. This was then used to calculate the mean weight at age for fish from 1955-2016, which was used in the stock assessment for matching to landings. These "weighted" mean weights increased during the 1960s, declined dramatically during the 1970s, and remained low during most of the 1980s. Increasing mean weights were estimated during the 1990s followed by declines in mean weight to the present. Weighting by catch in numbers by year, season, and fishing area was also applied to calculate average fork lengths (mm) by age and year.

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

$$\ln W = a + b \ln FL$$

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

$$W = a(FL)^b.$$

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

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

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.

Annual estimates of length at age for the population were bias-corrected using methods in Schueller et al. (2014). Specifically, the methods correct for the absence of samples at the youngest, smallest and largest, oldest sizes and ages. The correction was done on the cohort-based annually estimated growth curves with a minimum size of 100 mm FL (unless samples had a larger minimum size) and the maximum size was set at the 99.95% size for encountered fish rounded to the nearest whole number ending in 0 or 5. In a few cases, $t_0$ was fixed at the uncorrected value. The reference age selected was age-2 as that age reflects the full distribution of sizes at the age. The corrected values of $L_\infty$ and $K$ were within the observed range of uncorrected values (Table 2.3.1). The growth curve parameters vary year to year and are influenced by both density dependent processes and the fact that each cohort experiences a different set of conditions leading to differing growth.

Annual estimates of fork length-at-age were interpolated from the annual, cohort-based von Bertalanffy growth fits with a bias correction in order to represent the population or start of the fishing year (March 1) for use in estimating population fecundity (Table 2.3.2). Annual estimates of length-at-age were interpolated based on the non-biased corrected von Bertalanffy estimates to represent the fishery or 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 2.3.3).

### 2.4 Maturity

For the 2015 benchmark stock assessment, data from the NEAMAP Southern New England/Mid-Atlantic Neashore Trawl Survey were analyzed to evaluate maturity at age. Based on the analysis and discussions among the SAS during the 2015 SEDAR benchmark assessment, it was determined that maturity is a length-based process as opposed to an age-based process. A logistic regression was fit to the maturity and length data from the commercial reduction fishery database. Fish were coded as immature or mature, as in the analysis completed on the NEAMAP data. Because the growth of Atlantic menhaden varies greatly among years, the SAS determined that maturity must also vary among years. Thus, the time-varying lengths at age for the population were used along with the logistic regression to provide time-varying maturity at age for 1955-2016 for the assessment update. Because the commercial reduction fishery had more years of data and a larger sample size, the maturity based on those data were used in the final base run model.

### 2.5 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 considered 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 the 2015 benchmark stock assessment and this update, 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). Annual fecundity at age was calculated using the Lewis et al. (1987) equation as well as the bias corrected, cohort based estimates of length at age for the population at the beginning of the fishing year (March 1; Table 2.5.1).

### 2.6 Natural Mortality

Atlantic menhaden are vulnerable to multiple sources of natural mortality (*M*) throughout their range including, but not limited to, predation, pollution, habitat degradation, toxic algal blooms, and hypoxia. Estimating the relative contribution and magnitude of these mortality sources continues to be a challenge for stock assessments especially for a short-lived forage fish like Atlantic menhaden. For the 2015 benchmark assessment, the SAS explored several methods for estimating *M* and endorsed the use of an age-varying but time-invariant approach using the methods of Lorenzen (1996) scaled to tagging estimates of natural mortality for ages 4-6. Refer to the 2015 SEDAR benchmark stock assessment report for a more detailed discussion of methods the SAS evaluated and reasoning for rejecting or accepting various methods.

### 2.7 Migration

There have been several studies examining Atlantic menhaden migration patterns (Roithmayr 1963; Dryfoos et al. 1973; Nicholson 1978; ASMFC 2004b). Adults begin migrating inshore and north in early spring following the end of the major spawning season off the Carolinas during December-February. The oldest and largest fish migrate farthest, reaching southern New England by May and the Gulf of Maine by June. Fish begin migrating south from northern areas to the Carolinas in late fall. Adults that remain in the south Atlantic region for spring and summer migrate south later in the year, reaching northern Florida by fall. During November and December, most of the adult population that summered north of Chesapeake Bay moves south of the Virginia and North Carolina capes. After winter dispersal along the south Atlantic coast, adults again begin migrating north in early spring.

## 3.0 Fishery-Dependent Data Sources

### 3.1 Commercial Reduction Fishery

SEDAR 2015 provides a description of the history of the reduction fishery for Atlantic menhaden. Briefly, coastwide participation and landings for this fishery have expanded and contracted over the years, but only one reduction factory on the US East Coast exists today – Omega Protein Inc. in Reedville, VA, which fishes with approximately seven vessels. Most of their fishing activity takes place in the Virginia portion of the Chesapeake Bay and Virginia's ocean waters, although fleets travel along the US East Coast seasonally.

#### 3.1.1 Selectivity Time Blocks or Breaks in the BAM Model

When addressing selectivity in the reduction fishery and potential time blocks or breaks, the SAS considered residual patterns in the age composition data and major changes within the fishery. With regard to the latter, the SAS adopted three time blocks for the reduction fishery in the northern region (defined as waters north of Machipongo Inlet, VA): 1955-1969, 1970-1993, and 1994-2016. The SAS also adopted three time blocks for the reduction fishery in the southern region (defined as waters south of Machipongo Inlet, VA, including Chesapeake Bay): 1955-1971, 1972-2004, and 2005-2016. These time blocks are related to changes in the reduction fishery and are decribed in detail in SEDAR 2015. In both regions, the introduction of selectivity time blocks noticeably improved the residual pattern apparent in the age composition data.

### 3.1.2 Data Collection and Survey Methods

Fishery-dependent data for the Atlantic menhaden purse-seine reduction fishery have been maintained by the Beaufort Laboratory of the National Marine Fisheries Service since 1955 and they consist of three major data sets: 1) fishery landings or catch records, 2) port samples for age and size composition of the catch, and 3) daily logbooks, or Captains Daily Fishing Reports (CDFRs). Detailed landings data for the reduction purse-seine fishery are available 1940-2016. The biostatistical data, or port samples, for length and weight at age are available from 1955 through 2016, and represent one of the longest and most complete time series of fishery data sets in the nation. The CDFRs itemize purse-seine set locations and estimated at-sea catches; vessel compliance is 100%. CDFR data for the Atlantic menhaden fleet are available for 1985-2016. Biological sampling for the menhaden purse-seine fishery is conducted over its entire range of the fishery, both temporally and geographically (Chester 1984; Chester and Waters 1985).

Historically, daily vessel unloads were reported weekly or monthly during the fishing year. In recent years (since about 2005) individual vessel unloads are available daily via email from the clerical staff at the fish factory. Landings are provided in thousands of standard fish (1,000 standard fish = 670 lbs), which are converted to kilograms.

### 3.1.3 Commercial Reduction Landings

Landings and nominal fishing effort (vessel-weeks, measured as number of weeks a vessel unloaded at least one time during the fishing year) are available since 1940 (Table 3.1.3.1). Landings rose during the 1940s, peaked during the late 1950s (>600,000 mt for five of six years; record landings of 715,200 mt in 1956), and then declined to low levels during the 1960s (from 578,600 mt in 1961 to 162,300 mt in 1969). During the 1970s the stock rebuilt (landings rose from 250,300 mt in 1971 to 375,700 mt in 1979) and then maintained intermediate levels during the 1980s. Landings during the 1990s declined from 401,100 mt in 1990 to 171,200 mt in 1999.

By 1998, the fishery had contracted to only two factories, one in Virginia and one in North Carolina. Landings dipped to 167,300 mt in 2000, rose to 233,600 mt in 2001, and then stabilized until the North Carolina reduction plant closed in 2005, leaving the sole plant along the Atlantic coast in Virginia. Between 2006 and 2012, reduction landings averaged 162,100 mt. The first coastwide TAC on Atlantic menhaden was implemented in 2013 and since that time, reduction landings have ranged from 131,000 mt in 2013 to 143,500 mt in 2015. In 2016, reduction landings were 137,400 mt and accounted for approximately 76% of coastwide landings.

### 3.1.4 Commercial Reduction Catch at Age - Methods and Intensity

Detailed sampling of the reduction fishery allows landings in biomass to be converted to landings in numbers at age. For each port/week/area caught, biostatistical sampling provides an estimate of mean weight and the age distribution of fish caught. Hence, dividing landings for that port/week/area caught by the mean weight of fish allows the numbers of fish landed to be estimated. The age proportion then allows for estimation of fish landed. Developing the catch matrix at the port/week/area caught level of stratification provides for considerably greater precision than is typical for most assessments.

*Catch At Age in Recent Years*

Since 2012, approximately 1,190 10-fish samples have been collected from the reduction fishery. Over the past three years, age-2 Atlantic menhaden have comprised on average 51% of the total numbers of fish landed in the north and 55% of the total numbers of fish landed in the south.

*Landings, Removals by Areas, and the Beaufort Assessment Model (BAM)*

In the SEDAR 2015 benchmark assessment, the Atlantic menhaden fishery is addressed in terms of a northern and a southern fishery versus solely as a reduction and a bait fishery as in the 2010 assessement (ASMFC 2010). To this end, this benchmark assessment incorporates "fleets-as-areas" components where both the bait and reduction fisheries are divided into northern and southern regions (Tables 3.1.4.1 – 3.1.4.2). By consensus, the SAS divided the northern and southern fisheries using a line that runs due east from Great Machipongo Inlet on the Eastern Shore of Virginia. Historically and for statistical reporting purposes, this has been the dividing line for the Mid-Atlantic and Chesapeake Bay areas for the Menhaden Program at the Beaufort Laboratory (June and Reintjes 1959). Nicholson (1971) noted that "Similarities in age and size composition of the catches, time and duration of fishing, and range of vessels from home port tended to set each area apart." Through about the 1970s, reduction vessels from menhaden plants in New Jersey and Delaware rarely fished below this line; conversely, reduction vessels from Chesapeake Bay rarely fished north of this line. Thus, it is a convenient line of demarcation to sort port samples and landings data for the fleet-as-areas model. Moreover, empirical data for mean lengths of port sampled fish indicated appreciable size differences between areas north and south of this line.

Landings for the bait fleets were uncomplicated as these vessels typically operate over a much smaller geographic range than the reduction fleet; therefore, it was assumed that bait removals came from the state in which the fish were landed.

#### 3.1.5 Potential Biases, Uncertainty, and Measures of Precision

The topics and data derivations for this section are unchanged and assumed the same as in the benchmark stock assessment (SEDAR 2015).

### 3.2 Commercial Bait Fishery

#### 3.2.1 Data Collection Methods

Atlantic menhaden are harvested for bait in almost all Atlantic Coast states and are used for bait in commercial (e.g., American lobster and blue crab) and sport fisheries (e.g., striped bass and bluefish). Bait harvest comes from directed bait fisheries, primarily small purse seines, pound nets, gill nets, and cast nets. Menhaden are also landed as bycatch in various food-fish fisheries, such as pound nets, haul seines, and trawls. Systems for reporting bait landings have historically been incomplete because of the nature of the fishery and its unregulated marketing. Data limitations also exist because menhaden taken as bycatch in other commercial fisheries are often reported as "bait" together with other fish species. Additionally, menhaden harvested for personal bait use or sold "over-the-side" likely go unreported. As a result, the TC has determined that even though bait landing records date back to 1955, the most reliable bait landings are available since 1985 because of recent improvements made to harvester and dealer reporting programs.

Despite problems associated with estimating menhaden bait landings, data collection has improved in many areas. Some states license directed bait fisheries and require detailed landings records. More recently, harvest data reporting requirements changed through the implementation of Amendment 2 to the Atlantic Menhaden FMP because of the need for states to monitor in-season harvest relative to their newly implemented state specific quotas. Beginning in 2013, several states went from monthly reporting to weekly or daily reporting to avoid exceeding their allocated quota.

Bait landings from 1985-2016 were compiled using state-specific landing records by gear type and represent the most accurate dataset (Table 3.2.1.1). Bait landings from 1955-1984 were compiled using the Atlantic Coastal Cooperative Statistics Program's (ACCSP) data warehouse, which houses historical data but is admittedly incomplete. More specifically, purse seine bait landings from 1955-1984 were not included because bait/reduction disposition is not available prior to 1985 so all the purse seine landings during this time period were included in the reduction landings even though a fraction of those landings may have been for bait purposes. Therefore, bait landings data from 1955-1984 are only from pound nets and "other" gears.

### 3.2.2 Commercial Bait Landings

Coastwide bait landings of Atlantic menhaden have generally increased from 1985 through 2016 (Figure 3.2.2.1). During 1985 to 1997 bait landings averaged 28,000 mt, with a high of 43,800 mt landed in 1988 and a low of 21,600 mt landed in 1986. Between 1998 and 2005, bait landings were fairly stable around 35,500 mt and then generally increased through 2016, peaking in 2012 at 63,700 mt. In 2016, bait landings were 43,100 mt and comprised 24% of coastwide landings.

*Changes from the 2015 SEDAR Benchmark Assessment*

Historic bait landings for several states have been updated from the 2015 SEDAR benchmark assessment to reflect the best available data. Prompted by incomplete or non-existent reporting in the past, several states, such as New York, have sought out historic landing reports to fill data gaps and better reflect the historic bait fishery. In addition, Florida reduction landings from 1985-1987 and Maine internal water processing landings through 1993 have been removed from the bait landings to avoid double counting in both the bait and reduction fleets. Florida reduction landings and Maine internal water processing landings are included in the reduction fleet. As a part of Amendment 3, all states have reviewed and approved their menhaden landings from 1985-2016.

### 3.2.3 Commercial Bait Catch-at-Age

Because of the limited age composition data, characterizing the age distribution of the removals by the bait fishery has been done at the region/year level, rather than port/week/area fished used for the reduction fishery. Four regions are defined as follows: (1) New England (Connecticut and north); (2) Mid-Atlantic (coastal Maryland, and Delaware through New York); (3) Chesapeake Bay (including coastal waters of Virginia); and (4) South Atlantic (North Carolina to Florida). Separate catch-at-age matrices were constructed for the northern and southern bait fisheries where the northern region included (1) and (2), while the southern region included (3) and (4). When the number of samples for a given region and year was less than 50, data were pooled across the years available and substituted for that year as described in SEDAR 2015. The resultant northern and southern catch-at-age matrices for the bait fishery are shown in Tables 3.2.3.1 and 3.2.3.2.

### 3.2.4 Potential biases, Uncertainty, and Measures of Precision

The topics and data derivations for this section are unchanged and assumed the same as in the benchmark stock assessment (SEDAR 2015).

## 3.3 Recreational Fishery

### 3.3.1 Data Collection Methods

The Marine Recreational Fisheries Statistics Survey (MRFSS, 1981-2003) and the Marine Recreational Information Program (MRIP, 2004-2016) data sets were used to derive a time series of recreational landings of Atlantic menhaden. Estimated recreational catches are reported as number/weight of fish harvested (Type A+B1) and number of fish released alive (Type B2).

### 3.3.2 Recreational Landings

The recreational landings estimates of Atlantic menhaden for the two assessment regions were combined with the bait landings and are shown in Tables 3.2.3.1 and 3.2.3.2. These estimates include an assumed 50% mortality of released fish (A+B1+0.5*B2), the same value used in the 2010 and 2015 benchmark assessments. The average recreational landings in the past ten years was estimated at 130 mt in the north and 380 mt in the south, representing less than 1% of total (combined bait and reduction) landings. Landings were highly variable with an increasing trend in recent years in both regions.

### 3.3.3 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 caught by cast net, the judgment of the data workshop participants was that a 50% release mortality rate was a reasonable value.

### 3.3.4 Recreational Catch-at-Age

Insufficient biological samples were available to develop a recreational catch-at-age matrix. As in the 2010 and 2015 benchmarks, 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.

### 3.3.5 Potential biases, Uncertainty, and Measures of Precision

The MRFSS/MRIP provides estimates of PSE (proportional standard error) as a measure of precision. The PSE values associated with MRFSS/MRIP estimates for Atlantic menhaden were substantial (>50%) in most years. Potential biases are unknown.

# 4.0 Indices of Abundance

## 4.1 Fishery-Dependent Indices

For the 2015 benchmark stock assessment, four fishery-dependent datasets (MA pound net, NJ gillnet, MD pound net, and PRFC pound net) were used to create state-specific indices of relative abundance. The fishery-dependent (FD) datasets revealed that FD indices had significant positive correlations with fishery-independent (FI) indices, within their respective regions. The FD data sets lacked both age and length data and because the FI datasets had longer time series and were generally of a higher quality (i.e., fewer issues of concern; e.g., one data set was one permit holder), all FD indices were removed from consideration in assessment models and were not updated for this report.

## 4.2 Fishery-Independent Indices

For more information on criteria used to determine which FI data sets should be developed into indices of abundance, see SEDAR 2015. For this update report, the SAS added the most recent years' data to the indices developed previously. All surveys were standardized using a generalized linear model (GLM) and the same methods as SEDAR 2015. Information on the surveys used in index development and differences in the GLM standardization from the benchmark can be found in Appendix A.

### 4.2.1 Coastwide Indices

*YOY Index (1959-2016)*

Sixteen fishery-independent young-of-the-year (YOY) survey data sets were used to create a coastwide index of recruitment for use in the base run of the Atlantic menhaden assessment model. The individual indices were combined using hierarchical modeling as described in Conn (2010). The resultant YOY index shows the largest recruitments occurring during the 1970s and 1980s (Figure 6.1.13; Table 4.2.1.1). Recruitment has since been lower but with increases in recruitment in the last three years. The CV for the index ranged from 0.37 to 1.04. This index was used to inform annual recruitment deviations in the model along with the catch at age data.

*Age-1+ Indices*

Two coastwide indices of adult abundance were developed from nine FI surveys. A northern adult index (NAD) was created using the method of Conn (2010) that included VIMS, CHESMAP, CHESFIMS, NJ, CT, and DE 16- and 30-ft trawls for the years 1980-2016 (Figure 6.1.14). A southern adult index (SAD) was created using the method of Conn (2010) that included the SEAMAP trawl survey and the GA trawl survey for the years 1990-2016 (Figure 6.1.15).

The NAD adult index for the assessment indicates an increase in abundance in the most recent years, while the SAD adult index for the assessment indicates a slightly decreasing abundance in the most recent years (Table 4.2.1.1). The CV associated with the SAD index ranged from 0.40 to 0.71, and the CV associated with the NAD index ranged from 0.29 to 0.88.

The length compositions for each of the adult indices were combined across surveys. Raw lengths in 10-mm bins from each survey by year were summed and then divided by the total number of length samples for that year. Length compositions with sample sizes over 100 (number of sets, trawls, etc.) were available continuously for 1990-2016 for the SAD and for 1988-2016 for the NAD and were used to determine selectivity of the respective indices.

## 5.0 Assessment Model

The base run from the 2015 benchmark assessment was updated. A statistical catch-at-age approach was used based on the Beaufort Assessment Model (BAM). A thorough description of the BAM model was provided in SEDAR 2015.

### 5.1 Beaufort Assessment Model (BAM)

BAM is a forward-projecting statistical catch-at-age model. The essence of such a model is to simulate a population that is projected forward in time like the population being assessed. Aspects of the fishing process (e.g., gear selectivity) are also simulated. Quantities to be estimated are systematically varied from starting values until the simulated population's characteristics match available data on the real population as closely as possible. Such data include total catch by year, observed age composition by year, observed indices of abundance, and observed length composition by year. The BAM was the forward-projecting age-structured model used in the previous Atlantic menhaden benchmark assessment (SEDAR 2015) and is being updated here.

*Treatment of Indices*

The two adult indices, SAD and NAD, were included in the base run of the BAM along with length compositions because they were deemed as accurate representations of the population over time and best available science. Age-specific selectivity schedules were estimated for each of these indices by fitting to length composition data sampled during the surveys. The SAD index selectivity was estimated as a double logistic because large fish were absent from the length samples. The NAD index selectivity was estimated as logistic because many of these surveys captured some of the largest individuals sampled by either FI or FD gears. The level of error in each index was based on the precision surrounding the annual values produced by the hierarchical method used to standardize and combine the component indices. In the BAM model, the estimates of the product of total numbers of fish at the appropriate time of the year

(May 15 for SAD and September 1 for NAD), a single catchability parameter, and the selectivity schedule were fit to the index value in that same year for each respective index. The error in both of these abundance indices was assumed to follow a lognormal distribution.

In the model the recruitment, or 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 part way through the year (June 1) and a constant catchability parameter to the computed index values. The catchability parameter for this index was blocked in order to accommodate data streams contributing to the index. Therefore, two constant catchability parameters were estimated for this index, one for 1959-1986 and one for 1987-2016. This allowed for changing spatial coverage in the index (the spatial coverage changes as survey time series were added) as well as changes due to habitat with increasing spatial coverage of the index. The error in the JAI index was assumed to follow a lognormal distribution.

*Parameterization*

The major characteristics of the model formulation were as follows:

- *Start year and terminal year:* The start year of the model was 1955, and the terminal year of the model was 2016.
- *Ages:* The model included ages 0 to 6 with age-6 being treated as a plus group.
- *Natural mortality*: The age-specific natural mortality rate was assumed constant. A Lorenzen curve was scaled such that the mortality of the older ages was that estimated in a tagging study.
- *Stock dynamics*: The standard Baranov catch equation was applied. This assumes exponential decay in cohort size because of fishing and natural mortality processes.
- *Sex ratio:* The ratio of males to females was fixed in the model at 1:1 because of the 251,330 fish sampled from the reduction fishery from 1955-1970, 49% were male and 51% were female.
- *Maturity and Fecundity*: The percent of females mature and fecundity were age and time varying, but fixed in the model. Both fecundity and maturity were based on length at age for the population at the start of the fishing year. Annual, cohort-based von Bertalanffy growth parameters ($L_\infty$, $K$, and $t_0$) were estimated with a bias correction using the fishery data. These annual growth parameters were then used to estimate mean lengths at age over time. Female fecundity at age for each year was fixed in the model and was based on a function of mean length by age for the population (Lewis and Roithmayr 1981). Lengths were also used in an estimated logistic regression function for determining maturity each year, which was fixed in the model.
- *Weights at age:* The weight-at-age during spawning and during the middle of the fishery were input into the model and were based on the overall estimates of the parameters for the weight-length equation.
- *Recruitment:* Spawning was assumed to occur on March 1 in the model; hence the spawning time in months was 0.0, as March 1 was the start date for the model. Recruitment to age-0 was estimated in the assessment model for each year with a set of annual deviation parameters, conditioned about a median recruitment, which was

estimated in log-space. The steepness value was fixed at 0.99, which allowed for the estimation of a median recruitment and estimated deviations with time. Estimated deviations were informed by age composition data and a recruitment index.

- *Fishing*: Four fisheries were explicitly modeled. Southern and northern fleets of both the reduction fishery and the bait fishery were explicitly modeled to account for differences in selectivity due to size and age based migratory patterns. Being such a small proportion of the landings in each year, recreational landings were combined with the bait fishery landings. Fishing mortality rates were estimated for each year for each fishery by estimating a mean log fishing mortality rate and annual deviations.
- *Selectivity functions – indices:* Selectivity for the recruitment index was 1.0 for age-0 and 0.0 for all other ages. Selectivities for the NAD and SAD indices were age-varying, but constant with time. The NAD index selectivity was estimated as a flat-topped logistic function, while the SAD index selectivity was estimated as a double logistic or dome-shaped function.
- *Selectivity functions - fishery*: Selectivity for each of the fishery fleets was estimated using a functional form of dome-shaped selectivity. Specifically, the selectivity for each fleet was estimated as a four parameter double logistic. Selectivity was dome-shaped for each fishery for all years 1955-2016. Selectivity for both the northern and southern commercial reduction fisheries was time-varying using time blocks. For the southern fleet, selectivity was blocked as follows 1955-1971, 1972-2004, and 2005-2016. For the northern fleet, selectivity was blocked as follows 1955-1969, 1970-1993, and 1994-2016. Time blocks were based on the contraction and changes in the fishery over time. Selectivity for the bait fishery was constant throughout the time series.
- *Discards*: Discards of Atlantic menhaden were believed to be negligible and were therefore ignored in the assessment model.
- *Abundance indices*: The model used three indices of abundance that were each modeled separately: a recruitment (age-0) index series (1959-2016; JAI), a southern adult index series (1990-2016; SAD), and a northern adult index series (1980-2016; NAD). Each index represents a composite of multiple survey datasets that were standardized/combined using the hierarchical method of Conn (2010).
- *Ageing uncertainty*: Ageing uncertainty was not included in the base run of the assessment.
- *Fitting criterion*: The fitting criterion was a total likelihood approach in which catch, the observed age compositions from each fishery, the observed length compositions from each index, and the patterns of the abundance indices were fit based on the assumed statistical error distribution and the level of assumed or measured error.
- *Biological benchmarks*: Current interim benchmarks adopted for Atlantic menhaden are SPR based benchmarks and were calculated as they were in the 2015 benchmark stock assessment.

*Weighting of Likelihoods*

The likelihood components in the BAM model include northern and southern reduction landings, northern and southern bait landings, northern and southern reduction catch-at-age, northern and southern bait catch-at-age, the NAD index, the SAD index, a recruitment index, NAD length compositions, and SAD length compositions. For each of these components, a statistical error distribution was assumed as follows:

| Likelihood Component | Error Distribution | Error Levels |
|---|---|---|
| N & S reduction landings | Lognormal | Constant CV = 0.03 |
| N & S bait landings | Lognormal | Constant CV = 0.15 (1955-1984) and Constant CV = 0.05 (1985-2016) |
| N & S reduction catch at age | Multinomial | Annual number of trips sampled |
| N & S bait catch at age | Multinomial | Annual number of trips sampled |
| NAD length compositions | Multinomial | Annual number of sampling events |
| SAD length compositions | Multinomial | Annual number of sampling events |
| NAD index | Lognormal | Annual CV values from 0.29 to 0.88 |
| SAD index | Lognormal | Annual CV values from 0.40 to 0.71 |
| Recruitment index (JAI) | Lognormal | Annual CV values from 0.37 to 1.04 |

In addition to these components, the likelihood also contained some penalty terms and prior probability distributions. The penalties were on recruitment deviations and the deviations in the initial age structure from equilibrium. The priors were on the two parameters of the descending limb of the double logistic selectivity for the SAD index and the $A_{50}$ of the descending limb of the southern commercial reduction fishery selectivity.

Iterative reweighting was used to weight the data components as they were weighted in SEDAR 40 (Francis 2011). Iterative reweighting was completed such that the standard deviation of the normalized residuals for each data component was near the value from the benchmark assessment (SEDAR 2015).

*Estimating Precision*

The BAM model was implemented using the AD Model Builder software, which allowed for easy calculation of the inverse Hessian matrix, which provides approximate precision of estimated parameters. 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 underestimates of the true precision. Instead, the BAM model employed a parametric Monte Carlo bootstrap (MCB) procedure in which the input data sources were re-sampled using the measured or assumed statistical distribution and error levels provided, as described in SEDAR 2015.

*Sensitivity Analyses*

A total of 15 sensitivity runs were completed with the BAM model. These sensitivity runs represent those involving input data, those involving changes to the model configuration, and those included as part of the retrospective analyses. Some of these runs were completed in order to explore the differences between the benchmark and update assessments.

*Sensitivity to Input Data*

Four sensitivity runs were conducted to examine various effects to changes in the input data. These runs are related to uncertainty in index choice or life history values. The following is a list of these sensitivity runs:

| Run Number | Sensitivity Examined |
|---|---|
| am-090 | Excluded the NAD index and NAD length compositions |
| am-091 | Upper CI from Lorenzen for M |
| am-092 | Lower CI from Lorenzen for M |
| am-100 | Uncorrected bait landings, as used in the 2015 benchmark stock assessment |

*Sensitivity to Model Configuration*

Five sensitivity runs were conducted to examine the effects of various model configurations. In particular, this set of runs was completed to try to assess the differences that occurred between the benchmark and update stock assessments. These runs are related to recruitment index catchability and catchability of the NAD index. The following is a list of these sensitivity runs:

| Run Number | Sensitivity Examined |
|---|---|
| am-093 | One estimated catchability for the recruitment index |
| am-076 | Fixed catchability for the NAD index (fixed at benchmark assessment value) |
| am-101 | Two catchabilities estimated for NAD index (1980-1989; 1990-2016) |
| am-102 | Two catchabilities estimated for NAD index (1980-1995; 1996-2016) |
| am-103 | Two catchabilities estimated for NAD index (1980-2006; 2007-2016) |

*Retrospective Analyses*

Retrospective analyses were completed by running the BAM model in a series of runs sequentially omitting years 2016 to 2011, as indicated below:

| Run Number | Sensitivity Examined |
|---|---|
| am-094 | Retrospective analysis with modeling ending in 2015 |
| am-095 | Retrospective analysis with modeling ending in 2014 |
| am-096 | Retrospective analysis with modeling ending in 2013 |
| am-097 | Retrospective analysis with modeling ending in 2012 |
| am-098 | Retrospective analysis with modeling ending in 2011 |
| am-099 | Retrospective analysis with modeling ending in 2010 |

*Uncertainty analyses*

Uncertainty was examined in our results in two distinct ways: sensitivity runs and by using a Monte Carlo boostrap (MCB) procedure. This parametric bootstrap procedure was run for 1,500 iterations. For some iterations, the model did not converge; where this was true, then that particular iteration was not included in the results. In addition, some iterations estimated fairly high values for $R_0$ or other parameters. Thus, some additional runs were excluded. In the end, about 13% of runs did not converge or were excluded for unrealistic parameter estimates.

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

Fishing mortality reference points for Atlantic menhaden were calculated using the same methods as the benchmark assessment (SEDAR 2015). The threshold and limit are the maximum and median geometric mean fishing mortality rates, respectively, during the years 1960-2012. The resultant reference points are $F_{36\%}$ (target) and $F_{21\%}$ (limit) based on SPR, which are a change from the 2015 benchmark stock assessment values of $F_{57\%}$ and $F_{38\%}$. These changes are due to adding additional years of data to the model. Population fecundity (*FEC*, number of maturing or ripe eggs) is the other reference point and is a measure of reproductive capacity. The reference points for reproductive output include $FEC_{36\%}$ (target) and $FEC_{21\%}$ (limit). All benchmark calculations were based upon landings weighted selectivity across all fleets and areas, *M*-at-age (which was constant), mean maturity at age, a 1:1 sex ratio, and mean fecundity-at-age from the model inputs. All means are across the time series of 1955 to 2013. Also included was the $F_{X\%}$ of the current fishing mortality rate and a plot of the biomass over time divided by the biomass at $F = 0$. Uncertainty in the benchmark estimates was provided by the bootstrap runs. For each run, the current reference points were calculated and a distribution of the benchmarks was provided.

## 6.0 Model Results

### 6.1 Goodness of Fit

Observed and model predicted removals for the northern and southern reduction and bait fisheries (1955–2016; Figures 6.1.1-6.1.4) were compared for the base model run. Reduction fishery removals, which are known fairly precisely, fit very well, as do bait fishery removals. Patterns in the annual comparisons of observed and predicted proportions of catch-at-age for the northern and southern reduction and bait fisheries (Figures 6.1.5-6.1.8) indicate a good overall model fit to the observed data. The bubble plots for the northern and southern reduction and bait fisheries (Figures 6.1.9-6.1.12) indicate that the model fit does fairly well at estimating catch-at-age during the time series. There is no patterning observed in the bubble plot that caused concern.

Observed and predicted coastwide recruitment indices were compared for the base model run (1959–2016; Figure 6.1.13). The residual pattern suggests that the recruitment index data did not fit well for relatively large year classes, especially those that occurred in the 1970s and 1980s. Visual examination of the fit suggests that the overall pattern fit reasonably well for the most recent time period with the BAM model capturing some of the lows and highs observed in the index values.

The observed and predicted NAD index (1980–2016; Figure 6.1.14) and SAD index (1990-2016; Figure 6.1.15) values fit well. The general patterns are captured. However, the model has a difficult time fitting estimates to the highest observed values in the 1980s and 2010s for the

NAD and in 1990, 2006, 2009, and 2011 for the SAD. Patterns in the annual comparisons of observed and predicted proportion NAD and SAD measurements at length for the NAD and SAD indices (Figures 6.1.16-6.1.17) indicate good fit to the observed data in some years, but problems in fitting to data in other years. Given the nature of these indices as a conglomeration of data from different state fishery-independent data sources, changing patterns in the data are expected, yet are difficult to discern with model specifications. Therefore, although the fits to the data could be better, the SAS only used the length data to get an idea of ages represented by each index, nothing more. Some of the problems include an accumulation of predicted values at larger lengths for the NAD index, a mismatch in size for given years for the SAD index, and bi-modality in the NAD index, all of which would be difficult to capture by addressing them with selectivity within the model. The bubble plots for the NAD and SAD index length compositions (Figures 6.1.18-6.1.19) show patterns, as would be expected from the annual length composition plots and are similar to the plots from the benchmark assessment.

## 6.2 Parameter Estimates

### 6.2.1 Selectivities and Catchability

Fishery removals were related to an overall level of fishing mortality and the selectivity (or availability) of Atlantic menhaden to the fishery. Model estimates of selectivity for the reduction and bait fisheries are shown graphically in Figures 6.2.1.1-6.2.1.8. Selectivity parameters were estimated for each fishery and time period as four-parameter, double-logistic models with the parameters being the ascending slope and $A_{50}$ and the descending slope and $A_{50}$ (Table 6.2.1.1).

Selectivity for the NAD index was estimated as a two-parameter logistic function as shown in Figure 6.2.1.9 and Table 6.2.1.1. Selectivity for the NAD index was used to fit the NAD length composition data and represents the ages of fish that were captured by the NAD index.

Selectivity for the SAD index was estimated as a four-parameter, double-logistic function as shown in Figure 6.2.1.10 and Table 6.2.1.1. Selectivity for the SAD index was used to fit the SAD length composition data and represents the ages of fish that were captured by the SAD index.

The base BAM model estimated a single, constant catchability parameter for the NAD and SAD abundance indices, reflecting the assumption that expected catchability for these indices is believed to be constant through time. This is a good assumption for the NAD and SAD fishery-independent indices since they are based on consistent, scientific survey collections, albeit the surveys are a mix of state surveys and do not target menhaden and because the indices used to create the NAD and SAD were standardized to account for catchability differences. Log-catchability was estimated as 0.81 (2.25 back transformed) for the NAD index with a 0.20 SE, while the log-catchability of the SAD index was -1.54 (0.21 back transformed) with a 0.08 SE. The addition of the 2014-2016 NAD index data points resulted in a large difference in the estimation of the NAD index catchability parameter when compared to the benchmark assessment. The three points had high leverage with the resultant catchability change resulting in scale differences between this update assessment and the benchmark assessment. Some sensitivity runs were included to demonstrate the impact (see below).

The base BAM model estimated two constant catchability parameters for the recruitment index using two time blocks: 1959-1986 and 1987-2016. The time blocks represent a change in the combined spatial extent of the component seine surveys that comprise the index, with the addition of several state fishery-independent surveys after 1987. Log-catchability was estimated as -2.31 (0.10 back transformed) for the first time period with a SE of 0.06, while the log-catchability of the second time period was -2.79 (0.06 back transformed) with a SE of 0.04.

#### 6.2.2 Fishing Mortality Rates

Highly variable fishing mortalities were noted throughout the entire time series and dependent upon the fishing. The highest fishing mortalities for the commercial reduction fishery in the north were in the 1950s (Figure 6.2.2.1), while the highest fishing mortality rates for the commercial reduction fishery in the south were during the 1970s to 2000s (Figure 6.2.2.2). The highest fishing mortalities for the commercial bait fishery in the north were in the 1950s and 1990s (Figure 6.2.2.3), while the highest fishing mortality rates for the commercial bait fishery in the south were during the late 1990s and 2000s (Figure 6.2.2.4).

Fishing mortality rate over time was reported as the geometric mean fishing mortality rate of ages-2 to -4 (Table 6.2.2.1; Figure 6.2.2.5). In the most recent decade, the geometric mean fishing mortality rate has ranged between 0.31 and 0.58. The geometric mean fishing mortality rate for 2016 is 0.51. The fishing mortality rate for this update assessment is higher than the fishing mortality rate from the benchmark assessment (Figure 7.2.1.3). The scale of the fishing mortality rate is different and the trend deviates in some years. To look at the difference in the scale and trend of the fishing mortality rate, the SAS and TC ran sensitivity runs (see below).

#### 6.2.3 Abundance, Fecundity, Biomass, and Recruitment Estimates

The base BAM model estimated population numbers-at-age (ages 0-6+) for 1955–2016 (Figure 6.2.3.1 and Table 6.2.3.1). From these estimates, along with growth and reproductive data, different estimates of reproductive capacity were computed. Population fecundity (i.e., Total Egg Production) was the measure of reproductive output used as in the benchmark assessment. Population fecundity (*FEC*, number of maturing ova) was highest in the early 1960s, early 1970s, and during the more recent years and has generally been higher with older age classes making up a larger proportion of the *FEC* (Figure 6.2.3.2 and Table 6.2.3.2). Fecundity for this update assessment is lower than the fecundity from the benchmark assessment (Figure 7.2.1.4). The scale of the fecundity is different and the trend deviates in some years. To look at the difference in the scale and trend of the fecundity, the SAS and TC ran sensitivity runs (see below).

Biomass has fluctuated with time from an estimated high of over 2,288,000 mt in 1958 to a low of 567,000 mt in 2000 (Figures 6.2.3.3-6.2.3.4; Table 6.2.3.3). Biomass was estimated to have been largest during the late-1950s, with lows occurring during the 1960s and mid-1990s to mid-2000s, and was relatively stable through much of the 1970s, 1980s, and 2010s. Biomass is likely increasing at a faster rate than abundance because of the increase in the number of older fish at age, which weigh more than younger individuals.

Age-0 recruits of Atlantic menhaden (Figure 6.2.3.5 and Table 6.2.3.1) were highest during the 1970s and 1980s. An extremely large year class was also predicted for 1958. More recently, larger year-classes have also been estimated in 2005, 2010, and 2016. The annual estimated recruitment values relative to the median are shown in Figure 6.2.3.6. The only recruitment parameter estimated in the model was log of $R_0$, which was estimated at 2.62 with a standard deviation of 0.024. The log of $R_0$ was estimated at a lower value with the addition of the 2014-2016 data points when compared to the benchmark stock assessment. This seemed to be related to the leverage of the 2014-2016 NAD index points and increased estimate of catchability. To explore this, the SAS and TC ran additional sensitivity runs (see below).

### 6.3 Weighting of the Data Components

The likelihood components of NAD index, SAD index, recruitment index, SAD length compositions, NAD length compositions, northern commercial reduction fishery age compositions, southern commercial reduction fishery age compositions, northern bait fishery age compositions, and southern bait fishery age compositions were all weighted such that the weights for this update were similar to the weights from the benchmark assessment (Francis 2011; SEDAR 2015).

### 6.4 Sensitivity Analyses

#### 6.4.1 Alternate model runs

The results of the sensitivity runs suggest that the base BAM model trends and stock status are somewhat robust to model choices made in the base run and data choices made by the SAS (Figures 6.4.1.1-6.4.1.11).

Sensitivity runs were completed to evaluate model robustness to decisions related to natural mortality, *M*. Fishing mortality rate varied overall for this series of runs with an increase and a decrease in *M*. Biomass and recruitment were greatly influenced by *M* with increased (upper) *M* values causing dramatically increased biomass and recruitment, which is to be expected. Only the scale of *M* was explored; time-varying *M* was not explored as a sensitivity run. Natural mortality likely varies with time given that Atlantic menhaden are a forage species and that the environment is dynamic.

Some sensitivity runs were completed to look at the effects of index choice and parameterization on model outcomes. The largest differences in model outcomes were for those runs that excluded the NAD index, had catchability fixed for the NAD index, or estimated two catchability parameters for the NAD index. When the NAD index was removed from the model, the biomass and fecundity from the 1990s forward increased dramatically and recruitment increased, while the *F* decreased. In short, the removal of the NAD index resulted in a larger population. With a loss of the NAD index, the model also lost its one logistic selectivity. The estimation of two catchabilities for the NAD index resulted in a much different scale when the break years were 2006/2007. This suggests the potential for exploring the catchability of the NAD index in the next benchmark assessment. These runs provide insight into the changes that occurred between the benchmark and update assessment. Sensitivity runs and restrospective analysis (see below) suggested that the model is sensitive to the NAD index, and in particular to the addition of three most recent data points (2014-2016). This update leads to a change in the index catchability and higher fishing mortality for most of the time series. The 2015 benchmark assessment was also sensitive to the NAD index. Thus, the NAD index is critical to determining the scaling and trend in the stock assessment, as are the decisions surrounding the configuration of the NAD index within the stock assessment model. These runs suggest further exploration of the NAD index and its components during the next assessment.

Removal of time blocks on catchability for the recruitment index had very little influence on estimates of fishing mortality, especially in the most recent time period. With one constant catchability for the recruitment index, the biomass and fecundity in the 1970s was much higher than the base run. However, both the biomass and fecundity from 1990 to the present are similar to the base run. The fit to the recruitment index was different from the base run with a poorer fit for the sensitivity run. This was expected as the additional catchability parameter would allow for better fit to the recruitment index. Overall, the behaviors observed from the sensitivity run with one catchability were as expected.

In general, a common trend in the results from 1955-2016 were seen in many of the sensitivity runs. Some sensitivity runs resulted in differing year-to-year values depending upon the data sources used and modeling choices that were made, which was expected. Some sensitivity runs did change the overall scale of the assessment. For example, changes to natural mortality scaled other model components, which is a typical stock assessment result. Overall, the final stock status was the same across all sensitivity runs except the run with lower natural mortality.

The sensitivity runs when compared to the MCB runs discussed below are generally within the bounds of uncertainty explored for this assessment. Likelihood values, SDNRs, and some of the estimated parameters (Tables 6.4.1.1-6.4.1.3) can be compared below. The output distributions from the estimated parameters from the MCBs are fairly smooth distributions, which suggests that these runs are simply the bounds on the uncertainty of the assessment given the assumptions and data inputs.

### 6.4.2 Retrospective Analyses

The retrospective was run peeling off data back to 2010 (Figures 6.4.2.1-6.4.2.11; Tables 6. 4.2.1-6.4.2.3). The fits to the indices remained consistently good with the removal of years of data. The retrospective exhibits very little change for the first of the two years peel (2015-2014). For the years before 2014, geometric mean fishing mortality for ages-2 to -4 was under predicted. Biomass and fecundity exhibit similar behaviors for the retrospective analysis as the fishing mortality rate did. However, biomass and fecundity were over predicted in the years before 2014.

There are always trade-offs in fitting data components, and those tradeoffs change with time; these trade-offs have an impact on the appearance of retrospective analyses. For example, the second catchability parameter estimated for the JAI index is consistently estimated, but the catchability for the other indices and $R_0$ are changing with respect to the number of years of data included (Table 6.4.2.3). Patterns in retrospective analysis can emerge from data trade-offs; the addition of data in a data space with no historical information can create patterns where parameter estimates are influenced and the fit to the indices is influenced.

The stock status outcome did not vary in this set of retrospective model runs. In particular, the ratio of geometric mean fishing mortality at ages-2 to -4 to the benchmarks in the terminal year showed no variation in stock status (Figures 6.4.2.8-6.4.2.9), nor did the ratio of *FEC* to the *FEC* benchmarks in the terminal year (Figures 6.4.2.10-6.4.2.11).

### 6.5 Uncertainty Analysis

Uncertainty was examined in our results in two distinct ways: sensitivity runs and by using a MCB procedure. This parametric bootstrap procedure was run for 1,500 iterations. For some iterations, the model did not converge; where this was true, then that particular iteration was not included in the results. In addition, some iterations estimated fairly high values for $R_0$ or other parameters. Thus, some additional runs were excluded. In the end, about 13% of runs did not converge or were excluded for unrealistic parameter estimates.

The resulting estimates from the MCB runs have been summarized in Figures 6.5.1-6.5.4, showing the 95% confidence region. In general, the MCB results are not symmetrical distributions about the base run results because some of the uncertainty specifications were not symmetrical. Uncertainty was large in some years, especially for biomass and fecundity. The uncertainty explored with the retrospective analysis was within the bounds of the uncertainty from the MCB runs.

## 7.0 Stock Status

### 7.1 Current Overfishing, Overfished/Depleted Definitions

The current overfishing definition is a fecundity-per-recruit threshold based on a historical performance reference point. The threshold and target were calculated, as in the benchmark assessment, as the maximum and median geometric mean fishing mortality rate for ages-2 to -4 during 1960-2012 (a period deemed sustainable). The resulting reference points for this update are a threshold of $F_{21\%}$ and a target of $F_{36\%}$. *F*-based reference points should be compared to the geometric mean fishing mortality rate for ages-2 to -4. The resultant fecundity-based overfished definition is a threshold of $FEC_{21\%}$ and a target of $FEC_{36\%}$.

The maximum spawning potential (MSP) or spawner per recruit (SPR) based reference points are intended to be interim reference points while the ASMFC's Multispecies Technical Committee develops ecological-based reference points (ERP). The ERPs will take time to develop because of the complexity of modeling the predator-prey relationships for marine species that rely on Atlantic menhaden for forage (e.g., striped bass, bluefish, and weakfish). In either case (biological or ecological reference points), the intent is to manage Atlantic menhaden at sustainable levels to support fisheries and meet predator demands by maintaining sufficient reproductive capacity to prevent stock depletion and protect against recruitment failure.

## 7.2 Stock Status Determination

### 7.2.1 Overfished and Overfishing Status

Benchmarks for Atlantic menhaden are $F_{36\%}$, $F_{21\%}$, $FEC_{36\%}$, and $FEC_{21\%}$. The benchmarks are calculated through spawner-per-recruit analysis using the mean values of any time-varying components (i.e., growth, maturity) as in the benchmark assessment (SEDAR 2015) and geometric mean fishing mortality rate at ages-2 to -4 for each year (Figure 7.2.1.1). The base BAM model benchmark estimates and terminal year stock status are indicated in Table 7.2.1.1 Based on the current adopted benchmarks, **the Atlantic menhaden stock status is not overfished and overfishing is not occurring**. In addition, the current stock is below the current fishing mortality target and below the current *FEC* target (Figure 7.2.1.2).

The stock status for this update assessment is the same as the status from the benchmark assessment (Figures 7.2.1.3 and 7.1.2.4). Because the assessment update resulted in generally higher fishing mortality values throughout the time series, the maximum and median *F* values were estimated higher than the 2015 benchmark and the resulting reference points were different from the 2015 reference points of $F_{38\%}$, $F_{57\%}$, $FEC_{38\%}$, and $FEC_{57\%}$. While the scale is different and the trend deviates in some years, during the last decade the stock status for both fishing mortality rate and fecundity has been similar. Sensitivity runs indicate that the scale and trend differences are related to the NAD index and its model configuration. However, additional analyses should be undertaken during the next benchmark assessment to address this topic.

### 7.2.2 Uncertainty

The MCB runs and sensitivity runs support the stock status determination using the benchmarks. For each MCB run, the benchmarks were calculated. The entire time series of estimates of the geometric mean fishing mortality at ages-2 to -4 over $F_{21\%}$ and $F_{36\%}$ are shown in Figures 7.2.2.1 and 7.2.2.2, which include the 95% confidence intervals for the MCB runs. The entire time series of estimates of fecundity over $FEC_{21\%}$ and $FEC_{36\%}$ are shown in Figures 7.2.2.3 and 7.2.2.4, which also include the 95% confidence intervals for the MCB runs. In addition, the retrospective runs are within the bounds of the MCB runs in Figures 7.2.2.1 – 7.2.2.4. Phase plots of base run and each MCB run versus the threshold and target benchmarks are shown in Figures 7.2.2.5 and 7.2.2.6, respectively. Densities and cumulative probability densities for each of the benchmarks are shown in Figures 7.2.2.7 -7.2.2.8. In addition, each of the sensitivity and retrospective runs, as well as most of the MCB runs, indicated the same stock status as the base run, except the lower natural mortality run, and most of the MCB runs (Tables 7.2.2.1-7.2.2.2). The history of fishing mortality rates in these figures suggests that overfishing likely occurred in the 1950s, but generally, overfishing is unlikely to be occurring at present. The history of fecundity over the time series suggests that the population was overfished as recent as the late 1990s to mid 2000s, but is not currently overfished.

The uncertainty in the terminal year stock status indicators were expressed using the results of the bootstrap runs of the base BAM model and sensitivity runs. The results indicate that the fecundity estimates for the terminal year are generally above the threshold with 5% of runs falling below 1.0 for $FEC_{21\%}$, while 61% of runs fell below 1.0 for $FEC_{36\%}$. The results for the 2016 fishing mortality rate suggests that the base run estimate is below the target and threshold with none of the bootstrap runs exceeding the threshold values in the terminal year and 10% of the boostrap runs exceeding the target values in the terminal year.

### 7.3 Plan for Development of Ecological Reference Points

In the *Ecological Reference Points for Atlantic Menhaden* report, the Biological Ecological Reference Points (BERP) Workgroup (WG) presented a suite of preliminary ecological reference point (ERP) models and ecosystem monitoring approaches for feedback as part of the 2015 Benchmark Stock Assessment for Atlantic Menhaden (SEDAR 2015, Appendix E). The BERP WG recommended the use of facilitated workshops to develop specific ecosystem and fisheries objectives to drive further development of ERPs for Atlantic menhaden. This Ecosystem Management Objectives Workshop (EMOW) contained a broad range of representation including Commissioners, stakeholder representatives, and technical representatives to provide various perspectives on Atlantic menhaden management. The EMOW identified potential ecosystem goals and objectives that were reviewed and approved by the Board. The WG then assessed the ability of each preliminary ERP model to address EMOW-identified management objectives and performance measures, and selected models accordingly.

Currently, the WG is thoroughly evaluating this suite of novel multispecies models to ensure they are able to generate ERPs which meet as many management objectives as possible. Some of the models under consideration are a Bayesian surplus production model with time-varying population growth rate which estimates the trend in total Atlantic menhaden stock biomass and fishery exploitation rate by allowing the population growth rate to fluctuate annually in response to changing environmental conditions. This approach produces dynamic, maximum sustainable yield-based ecological reference points that implicitly account for the forage services menhaden provide. Another production model that is up for consideration is a Steele-Henderson model. This type of Steele-Henderson modeling permits non-fisheries (predation and environmental) effects to be quantified and incorporated into the single species stock assessments, allowing fixed and non-equilibrium (time-varying) ecological overfishing thresholds to be established. This approach is not intended to replace more complex multispecies ecosystem assessment models, but rather to expand the scope of the single species assessments to include the separate and joint effects of fishing, predation and environmental effects at the fish community level. Finally, a multispecies statistical catch-at-age modeling framework is being considered. This model uses standard statistical catch-at-age techniques and single species models are linked using trophic calculations to provide a predator-prey feedback between the population models. The statistical framework is believed to be an improvement from the existing MSVPA because using statistical techniques may help to estimate many of the model parameters while incorporating the inherent uncertainty in the data. An external model being considered is an Ecopath with Ecosystem model, however the application of this model is for strategic planning (to explore tradeoffs) not tactical (e.g., quota setting) advice. The model is flexible and able to explore additional menhaden relevant scenarios, ERPs, and questions. This model could be used to evaluate the other models being developed.

Once these models are fully vetted, the WG will select which models will go to peer-review in 2019 along with the single-species BAM model, which has traditionally been used for menhaden management. This is an ambitious timeline, since all models will need to be evaluated in the same timeframe as a single species assessment. Additionally, the WG recommends conducting a Management Strategy Evaluation (MSE) for Atlantic menhaden during which single-species forage services reference points would be tested relative to traditional reference points and the management goals for the stock.

## 8.0 Research and Modeling Recommendations for Benchmark

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. Notes have been added for this report regarding work that has been addressed or initiated since SEDAR 2015.

<u>Annual Data Collection</u>

*Short term (next 3-6 years):*

1. Continue current level of sampling from bait fisheries, particularly in the Mid-Atlantic and New England. Analyze sampling adequacy of the reduction fishery and effectively sample areas outside of that fishery (e.g., work with industry and states to collect age structure data and biological data outside the range of the fishery). **NOTE**: Work to assess the sampling adequacy of the bait and reduction fisheries has been initiated by Genevieve Nesslage's research group at the University of Maryland Center for Environmental Science.
2. Ageing:
    a. Conduct ageing validation study (e.g., scale : otolith comparison), making sure to sample older age classes. Use archived scales to do radio isotope analysis.
    b. Ageing precision: conduct an ageing workshop to assess precision and error among readers (currently planned for January 2015). **NOTE**: A workshop was completed and described in ASMFC 2015 and Atlantic menhaden scales have been added to the annual ASMFC QA/QC Fish Ageing Workshop (ASMFC 2017) to address an ongoing need for information on ageing precision and error.
3. Conduct a comprehensive fecundity study. **NOTE**: This work has been initiated and is ongoing with Rob Latour’s research group at Virginia Institute of Marine Science.
4. Place observers on boats to collect at-sea samples from purse-seine sets, or collect samples at dockside during vessel pump-out operations (as opposed to current top of hold sampling) to address sampling adequacy.

5. Investigate relationship between fish size and school size in order to address selectivity (specifically addressing fisher behavior related to harvest of specific school sizes).
6. Investigate relationship between fish size and distance from shore (addressing selectivity).
7. Evaluate alternative fleet configurations for the removal and catch-at-age data.

*Long term (6+ years)*:

1. Develop a menhaden specific coastwide fishery-independent index of adult abundance at age. One possible methodology is an air spotter survey complemented with ground truthing for biological information (e.g., size and age composition). In all cases, a sound statistical design is essential (involving statisticians in the development and review of the design; some trial surveys may be necessary). **[Highest Priority] NOTE:** Design of a winter pelagic survey of adult Atlantic menhaden in the Mid-Atlantic has been initiated by Genevieve Nesslage's research group at the University of Maryland Center for Environmental Science.
2. Conduct studies on spatial and temporal dynamics of spawning (how often, how much of the year, batch spawning, etc.)
3. Conduct studies on productivity of estuarine environments related to recruitment. **NOTE**: Anstead et al. 2016 and 2017 used otolith chemistry to evaluate the proportional contribution of each nursery area along the US Atlantic coast for recruits for 2010-2012.
4. Investigation of environmental covariates related to recruitment. **NOTE**: Buchheister et al. 2016 evaluated coast wide recruitment patters from 1959-2013 and found the Atlantic Multidecal Oscillation was the best predictor of regional recruitment. Simpson et al. 2016 evaluated several environmental covariates for an effect on larval survival and found temperature had the greatest effect on early life survival which was more related to recruitment than larval supply.

Assessment Methodology

*Short term (3-6 year)*:

1. Conduct management strategy evaluation (MSE). **[Highest Priority] NOTE:** This work has been initiated and is ongoing with Amy Schueller's research group at the Southeast Fisheries Science Center in Beaufort, North Carolina.
2. Conduct multi-objective decision analysis (MODA). **[Highest Priority] NOTE:** This will be addressed through the ongoing BERP WG activities.
3. Continue to develop an integrated length and age based model (e.g., SS3).
4. Continue to improve methods for incorporation of natural mortality (e.g., multi-species statistical catch-at-age model). **NOTE**: This work will be addressed by McNamee's doctoral thesis (*in prep*) and through current BERP WG activities.
5. During the next benchmark stock assessment process (scheduled for 2019), the SAS recommends that the following items be considered during modeling workshops:
    a. Re-examine the methodology and surveys used for the development of the NAD index.
    b. Explore the likelihood component for the length composition data.

*c.* Examine the age composition of the bait fishery.

*Long term (6+ years)*:

1. Develop a seasonal spatially-explicit model, once sufficient age-specific data on movement rates of menhaden are available.

## 9.0 Literature Cited


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## 10.0 Tables

**Table 2.3.1** The estimated annual, cohort-based von Bertalanffy growth curves with the bias correction as detailed in Schueller et al. (2014). Those $t_0$ values with a * indicated values were fixed at the non-bias corrected values. 2012 and 2013 did not converge.

| | | Bias corrected values | | |
|---|---|---|---|---|
| | **n** | $L_\infty$ | $K$ | $t_0$ |
| 1947 | 28 | 380.7 | 0.23 | 0.00 |
| 1948 | 101 | 335.2 | 0.69 | 0.00 |
| 1949 | 355 | 322.8 | 0.75 | -0.71 |
| 1950 | 1202 | 342.2 | 0.39 | -0.25 |
| 1951 | 6574 | 344.7 | 0.42 | 0.00 |
| 1952 | 3596 | 354.8 | 0.34 | -1.02* |
| 1953 | 9362 | 356.5 | 0.39 | -0.58 |
| 1954 | 9216 | 366.1 | 0.39 | -0.43 |
| 1955 | 18271 | 544.9 | 0.15 | -1.13 |
| 1956 | 20357 | 393.0 | 0.28 | -0.68 |
| 1957 | 9581 | 487.3 | 0.17 | -1.37 |
| 1958 | 34120 | 459.1 | 0.19 | -0.85 |
| 1959 | 6880 | 443.7 | 0.21 | -1.30* |
| 1960 | 9016 | 374.6 | 0.33 | -0.63 |
| 1961 | 8220 | 334.6 | 0.39 | -0.74 |
| 1962 | 11242 | 349.6 | 0.35 | -0.88 |
| 1963 | 9324 | 368.6 | 0.32 | -0.95 |
| 1964 | 17597 | 469.8 | 0.23 | -1.01* |
| 1965 | 17274 | 627.4 | 0.14 | -1.17* |
| 1966 | 25575 | 440.1 | 0.29 | -0.76* |
| 1967 | 13397 | 675.2 | 0.12 | -1.50* |
| 1968 | 9459 | 620.2 | 0.13 | -1.50* |
| 1969 | 11442 | 503.3 | 0.25 | -0.84* |
| 1970 | 4373 | 392.2 | 0.45 | -0.36* |
| 1971 | 7721 | 539.8 | 0.15 | -1.36 |
| 1972 | 6292 | 327.1 | 0.54 | -0.11 |
| 1973 | 6366 | 401.5 | 0.27 | -0.72* |
| 1974 | 6796 | 562.3 | 0.13 | -1.29 |
| 1975 | 8832 | 426.5 | 0.19 | -0.95* |
| 1976 | 6814 | 537.4 | 0.13 | -1.06 |
| 1977 | 7168 | 592.9 | 0.12 | -1.05 |
| 1978 | 5200 | 480.4 | 0.14 | -1.34 |
| 1979 | 9437 | 565.5 | 0.10 | -1.47* |
| 1980 | 7302 | 393.7 | 0.22 | -0.84 |
| 1981 | 13566 | 472.5 | 0.16 | -1.10 |
| 1982 | 6564 | 429.1 | 0.22 | -0.70* |
| 1983 | 9446 | 541.3 | 0.12 | -1.31 |
| 1984 | 10173 | 427.9 | 0.19 | -0.98 |
| 1985 | 8361 | 544.8 | 0.13 | -1.15 |
| 1986 | 6350 | 397.8 | 0.21 | -0.92 |
| 1987 | 4215 | 420.2 | 0.21 | -0.76* |

| | | Bias corrected values | | |
| --- | --- | --- | --- | --- |
| | n | $L_\infty$ | $K$ | $t_0$ |
| 1988 | 9608 | 384.6 | 0.29 | -0.59 |
| 1989 | 3806 | 332.8 | 0.40 | -0.56 |
| 1990 | 5668 | 393.6 | 0.26 | -0.79* |
| 1991 | 7743 | 461.4 | 0.20 | -1.25 |
| 1992 | 5775 | 626.9 | 0.13 | -1.01 |
| 1993 | 3567 | 417.4 | 0.27 | -0.82* |
| 1994 | 5693 | 405.2 | 0.35 | -0.25 |
| 1995 | 3201 | 414.8 | 0.34 | -0.16* |
| 1996 | 3329 | 455.6 | 0.23 | -0.46 |
| 1997 | 3364 | 396.3 | 0.30 | -0.46* |
| 1998 | 4574 | 426.3 | 0.24 | -1.09* |
| 1999 | 3797 | 392.5 | 0.41 | -0.26* |
| 2000 | 2182 | 325.7 | 0.62 | 0.00 |
| 2001 | 3377 | 295.2 | 0.59 | -0.47 |
| 2002 | 4238 | 363.0 | 0.35 | -0.63 |
| 2003 | 3326 | 376.3 | 0.30 | -0.83* |
| 2004 | 2293 | 367.3 | 0.36 | -0.25* |
| 2005 | 4356 | 296.1 | 0.60 | -0.19 |
| 2006 | 4009 | 302.2 | 0.55 | -0.38 |
| 2007 | 1875 | 296.3 | 0.57 | -0.43 |
| 2008 | 3544 | 402.5 | 0.22 | -1.46* |
| 2009 | 3325 | 292.1 | 0.58 | -0.46 |
| 2010 | 4171 | 302.7 | 0.48 | -0.68 |
| 2011 | 3676 | 301.6 | 0.47 | -0.72 |

**Table 2.3.2** Fork length (mm) at age on March 1 (beginning of fishing year) estimated from year class von Bertalanffy growth parameters with a bias correction. Shaded cells are the average from the three preceding estimated years.

| Year | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|
| 1955 | 155.1 | 226.3 | 263.8 | 280.2 | 298.5 | 320.7 |
| 1956 | 151.5 | 222.7 | 268.3 | 290.0 | 302.3 | 312.7 |
| 1957 | 147.3 | 207.3 | 268.6 | 296.8 | 308.6 | 316.8 |
| 1958 | 157.6 | 207.3 | 255.2 | 299.8 | 316.1 | 321.9 |
| 1959 | 138.7 | 207.7 | 252.7 | 296.3 | 321.1 | 329.2 |
| 1960 | 169.9 | 195.2 | 250.3 | 287.0 | 331.6 | 335.5 |
| 1961 | 156.4 | 221.8 | 241.8 | 286.3 | 312.9 | 361.8 |
| 1962 | 164.5 | 218.1 | 263.8 | 280.1 | 316.9 | 332.4 |
| 1963 | 169.1 | 219.5 | 262.3 | 297.9 | 311.7 | 342.8 |
| 1964 | 171.7 | 222.7 | 256.6 | 294.0 | 325.5 | 337.7 |
| 1965 | 171.0 | 225.8 | 260.3 | 281.8 | 316.8 | 347.9 |
| 1966 | 162.1 | 231.2 | 265.0 | 286.8 | 298.9 | 333.1 |
| 1967 | 175.4 | 222.0 | 279.3 | 293.4 | 305.4 | 310.4 |
| 1968 | 168.7 | 241.8 | 274.3 | 317.7 | 314.1 | 318.5 |
| 1969 | 174.3 | 223.7 | 291.6 | 319.8 | 348.3 | 329.0 |
| 1970 | 184.5 | 229.5 | 272.8 | 328.8 | 359.5 | 372.8 |
| 1971 | 179.4 | 254.5 | 277.8 | 316.5 | 356.8 | 394.0 |
| 1972 | 161.6 | 256.5 | 309.1 | 320.1 | 355.5 | 377.7 |
| 1973 | 147.3 | 214.6 | 305.7 | 351.8 | 357.2 | 390.2 |
| 1974 | 149.9 | 222.3 | 260.2 | 337.1 | 385.1 | 389.8 |
| 1975 | 141.0 | 209.8 | 266.1 | 299.4 | 357.0 | 411.0 |
| 1976 | 132.1 | 190.9 | 255.4 | 291.5 | 333.1 | 369.8 |
| 1977 | 127.7 | 183.1 | 234.9 | 290.2 | 306.4 | 362.1 |
| 1978 | 129.1 | 178.4 | 225.2 | 273.6 | 316.7 | 315.1 |
| 1979 | 134.4 | 181.5 | 222.8 | 260.0 | 307.8 | 336.9 |
| 1980 | 128.2 | 179.6 | 228.1 | 261.7 | 288.8 | 337.9 |
| 1981 | 131.0 | 171.4 | 218.9 | 269.3 | 295.8 | 312.6 |
| 1982 | 136.4 | 182.9 | 210.3 | 253.1 | 305.9 | 325.7 |
| 1983 | 132.1 | 186.6 | 224.5 | 245.4 | 282.8 | 338.4 |
| 1984 | 134.6 | 190.0 | 229.4 | 257.9 | 277.0 | 308.6 |
| 1985 | 131.4 | 182.0 | 236.6 | 265.7 | 284.7 | 305.5 |
| 1986 | 129.3 | 181.5 | 223.9 | 274.2 | 296.7 | 306.2 |
| 1987 | 133.8 | 178.5 | 223.1 | 260.9 | 304.4 | 323.0 |
| 1988 | 130.1 | 184.7 | 221.9 | 257.7 | 293.6 | 328.7 |
| 1989 | 140.4 | 185.0 | 225.7 | 260.1 | 286.4 | 322.5 |
| 1990 | 154.9 | 200.9 | 229.6 | 258.9 | 293.8 | 310.3 |
| 1991 | 147.9 | 213.8 | 246.5 | 265.7 | 285.6 | 323.5 |
| 1992 | 163.6 | 204.7 | 253.2 | 280.7 | 294.9 | 307.2 |
| 1993 | 143.2 | 216.4 | 248.4 | 279.6 | 306.5 | 318.7 |
| 1994 | 162.2 | 201.7 | 259.8 | 282.0 | 297.2 | 325.9 |
| 1995 | 142.8 | 222.6 | 253.2 | 295.5 | 307.8 | 309.0 |
| 1996 | 134.3 | 219.7 | 268.7 | 298.4 | 324.9 | 327.6 |
| 1997 | 131.9 | 214.7 | 274.1 | 303.9 | 338.2 | 349.1 |
| 1998 | 141.7 | 199.5 | 272.1 | 312.6 | 330.7 | 373.1 |

| Year | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|
| 1999 | 169.9 | 208.2 | 252.9 | 313.0 | 339.7 | 351.2 |
| 2000 | 158.2 | 225.2 | 257.4 | 295.2 | 342.2 | 358.9 |
| 2001 | 150.1 | 237.0 | 268.6 | 293.7 | 328.6 | 363.1 |
| 2002 | 170.9 | 231.1 | 289.3 | 302.6 | 320.5 | 355.1 |
| 2003 | 156.7 | 226.2 | 274.7 | 324.0 | 329.3 | 340.3 |
| 2004 | 158.1 | 217.0 | 256.9 | 298.2 | 347.1 | 350.2 |
| 2005 | 134.0 | 214.3 | 259.7 | 273.9 | 310.9 | 362.3 |
| 2006 | 151.6 | 204.8 | 256.1 | 289.9 | 283.4 | 317.7 |
| 2007 | 160.5 | 216.9 | 254.2 | 287.1 | 311.3 | 288.6 |
| 2008 | 164.8 | 220.3 | 252.6 | 288.5 | 310.1 | 326.4 |
| 2009 | 165.5 | 221.9 | 254.8 | 272.3 | 312.4 | 327.1 |
| 2010 | 166.4 | 211.3 | 254.2 | 274.8 | 283.0 | 329.1 |
| 2011 | 168.1 | 221.4 | 248.3 | 272.5 | 286.4 | 288.9 |
| 2012 | 167.0 | 219.6 | 252.4 | 278.1 | 282.8 | 293.0 |
| 2013 | 167.2 | 217.4 | 251.3 | 269.8 | 302.2 | 288.7 |
| 2014 | 167.2 | 219.5 | 248.9 | 271.0 | 279.6 | 321.6 |
| 2015 | 167.2 | 219.5 | 250.9 | 268.6 | 283.1 | 285.1 |
| 2016 | 167.2 | 219.5 | 250.9 | 269.8 | 281.0 | 290.6 |

**Table 2.3.3** Weight (g) at age on September 1 (middle of fishing year) estimated from overall weight-length parameters and annual lengths at age. Shaded cells are the average from the three preceding estimated years.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 36.7 | 126.2 | 279.1 | 397.5 | 459.9 | 533.3 | 622.6 |
| 1956 | 25.3 | 105.8 | 269.1 | 431.5 | 502.2 | 563.4 | 606.7 |
| 1957 | 43.2 | 94.0 | 232.5 | 410.6 | 545.5 | 586.4 | 634.6 |
| 1958 | 24.0 | 110.2 | 227.0 | 368.9 | 530.1 | 622.7 | 651.3 |
| 1959 | 62.8 | 77.5 | 230.6 | 367.0 | 494.1 | 622.4 | 672.2 |
| 1960 | 35.3 | 132.3 | 189.8 | 363.2 | 488.8 | 599.3 | 690.3 |
| 1961 | 51.6 | 118.9 | 254.9 | 328.0 | 489.7 | 585.0 | 683.1 |
| 1962 | 57.5 | 128.0 | 265.9 | 396.4 | 471.3 | 600.8 | 656.5 |
| 1963 | 62.0 | 140.9 | 248.2 | 407.2 | 542.2 | 606.4 | 693.4 |
| 1964 | 63.7 | 142.7 | 266.4 | 360.2 | 520.9 | 682.4 | 726.0 |
| 1965 | 52.8 | 143.7 | 270.0 | 377.5 | 450.9 | 604.4 | 810.9 |
| 1966 | 65.6 | 121.0 | 280.1 | 392.7 | 462.8 | 518.8 | 662.5 |
| 1967 | 63.8 | 158.4 | 251.0 | 426.5 | 496.4 | 523.7 | 567.4 |
| 1968 | 73.0 | 124.8 | 307.7 | 411.7 | 565.3 | 577.8 | 565.3 |
| 1969 | 75.6 | 138.4 | 243.6 | 452.7 | 587.6 | 687.3 | 638.9 |
| 1970 | 55.7 | 177.6 | 258.8 | 404.1 | 575.4 | 766.0 | 789.5 |
| 1971 | 48.4 | 167.4 | 344.6 | 411.4 | 603.0 | 671.5 | 937.8 |
| 1972 | 24.8 | 125.4 | 339.9 | 511.8 | 588.8 | 834.8 | 743.4 |
| 1973 | 40.5 | 118.0 | 263.8 | 486.2 | 658.5 | 783.1 | 1093.6 |
| 1974 | 28.6 | 104.0 | 266.0 | 414.5 | 591.5 | 777.6 | 986.9 |
| 1975 | 27.1 | 84.2 | 213.8 | 377.5 | 556.6 | 661.3 | 870.0 |
| 1976 | 18.0 | 67.4 | 186.2 | 328.0 | 445.9 | 679.7 | 705.5 |
| 1977 | 21.2 | 64.2 | 145.2 | 294.9 | 430.8 | 484.3 | 781.1 |
| 1978 | 28.9 | 68.1 | 157.4 | 240.2 | 393.5 | 516.1 | 504.9 |
| 1979 | 25.3 | 67.8 | 161.4 | 262.4 | 341.6 | 475.4 | 583.3 |
| 1980 | 22.1 | 55.7 | 141.2 | 269.1 | 361.0 | 441.2 | 539.7 |
| 1981 | 20.8 | 69.0 | 117.5 | 230.4 | 373.8 | 444.8 | 534.0 |
| 1982 | 24.9 | 71.9 | 159.3 | 202.1 | 325.7 | 466.2 | 511.8 |
| 1983 | 30.6 | 69.9 | 171.6 | 260.0 | 306.0 | 420.0 | 543.2 |
| 1984 | 23.8 | 67.7 | 157.8 | 279.9 | 354.8 | 425.0 | 508.6 |
| 1985 | 21.9 | 67.5 | 138.9 | 262.0 | 378.1 | 436.1 | 554.5 |
| 1986 | 25.5 | 65.9 | 150.3 | 228.9 | 367.8 | 458.8 | 502.1 |
| 1987 | 25.9 | 73.7 | 149.9 | 243.7 | 330.5 | 466.1 | 521.5 |
| 1988 | 27.3 | 69.0 | 160.6 | 243.7 | 333.8 | 437.1 | 552.5 |
| 1989 | 41.2 | 93.2 | 150.8 | 252.2 | 332.5 | 413.4 | 543.4 |
| 1990 | 37.5 | 114.7 | 207.7 | 246.0 | 334.3 | 409.3 | 479.9 |
| 1991 | 52.5 | 94.0 | 228.2 | 315.9 | 341.6 | 401.8 | 472.1 |
| 1992 | 30.1 | 128.3 | 192.9 | 327.1 | 401.2 | 429.6 | 454.3 |
| 1993 | 51.0 | 95.3 | 247.2 | 298.8 | 400.7 | 462.7 | 506.4 |
| 1994 | 25.2 | 122.8 | 218.5 | 358.6 | 397.3 | 451.5 | 504.8 |
| 1995 | 23.5 | 118.6 | 243.0 | 351.9 | 449.3 | 481.7 | 484.8 |
| 1996 | 18.2 | 98.5 | 286.6 | 366.4 | 473.6 | 517.7 | 550.5 |
| 1997 | 29.7 | 88.3 | 243.1 | 435.1 | 477.0 | 574.9 | 567.0 |
| 1998 | 61.1 | 94.7 | 227.0 | 388.4 | 541.6 | 568.5 | 654.4 |

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1999 | 40.3 | 134.7 | 219.5 | 363.3 | 507.8 | 610.8 | 640.7 |
| 2000 | 28.2 | 136.2 | 261.3 | 357.0 | 471.4 | 596.4 | 653.6 |
| 2001 | 55.4 | 128.0 | 291.6 | 400.2 | 484.6 | 548.7 | 658.6 |
| 2002 | 37.8 | 145.9 | 289.3 | 426.1 | 535.1 | 592.5 | 600.9 |
| 2003 | 48.1 | 116.9 | 262.8 | 414.7 | 523.7 | 656.8 | 678.6 |
| 2004 | 24.8 | 114.4 | 242.1 | 345.9 | 494.5 | 588.5 | 761.4 |
| 2005 | 35.3 | 88.3 | 224.0 | 350.8 | 397.0 | 540.9 | 629.6 |
| 2006 | 43.6 | 114.2 | 199.2 | 334.7 | 430.7 | 426.2 | 566.7 |
| 2007 | 53.7 | 129.6 | 233.0 | 303.1 | 432.7 | 484.5 | 442.5 |
| 2008 | 59.7 | 134.8 | 252.5 | 328.1 | 384.1 | 512.8 | 519.3 |
| 2009 | 53.4 | 117.6 | 245.6 | 347.3 | 392.2 | 441.6 | 575.2 |
| 2010 | 57.7 | 134.6 | 215.1 | 331.7 | 409.4 | 432.1 | 480.5 |
| 2011 | 56.9 | 132.7 | 241.5 | 324.0 | 389.7 | 447.2 | 455.8 |
| 2012 | 56.9 | 128.1 | 239.1 | 320.4 | 433.7 | 426.1 | 469.2 |
| 2013 | 56.9 | 128.1 | 231.8 | 328.5 | 371.1 | 537.1 | 448.1 |
| 2014 | 56.9 | 128.1 | 231.8 | 324.3 | 394.4 | 401.3 | 630.4 |
| 2015 | 56.9 | 128.1 | 231.8 | 324.3 | 399.2 | 439.6 | 418.9 |
| 2016 | 56.9 | 128.1 | 231.8 | 324.3 | 399.2 | 457.1 | 469.5 |

**Table 2.5.1** Fecundity (number of ova) at age on March 1 (beginning of fishing year) estimated from annual lengths.

| Year | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|
| 1955 | 26267 | 76356 | 134072 | 171499 | 225574 | 314702 |
| 1956 | 24883 | 72366 | 143502 | 198473 | 238833 | 279006 |
| 1957 | 23368 | 57467 | 144117 | 219979 | 262471 | 296958 |
| 1958 | 27254 | 57476 | 117858 | 230192 | 293759 | 320304 |
| 1959 | 20527 | 57823 | 113474 | 218295 | 316474 | 357302 |
| 1960 | 32777 | 47911 | 109417 | 189742 | 370470 | 392930 |
| 1961 | 26775 | 71349 | 96300 | 187906 | 279836 | 583275 |
| 1962 | 30235 | 67500 | 134037 | 171141 | 297215 | 375348 |
| 1963 | 32403 | 68920 | 131049 | 223455 | 274818 | 438442 |
| 1964 | 33692 | 72330 | 120396 | 210941 | 338151 | 405941 |
| 1965 | 33326 | 75794 | 127224 | 175648 | 296815 | 473099 |
| 1966 | 29143 | 82221 | 136478 | 189256 | 226831 | 379233 |
| 1967 | 35572 | 71658 | 169108 | 209101 | 250238 | 269709 |
| 1968 | 32194 | 96373 | 156906 | 300776 | 284953 | 304553 |
| 1969 | 35028 | 73488 | 203311 | 310553 | 476360 | 356683 |
| 1970 | 40785 | 80098 | 153362 | 355629 | 562879 | 687690 |
| 1971 | 37767 | 116588 | 165349 | 295467 | 540609 | 944933 |
| 1972 | 28938 | 120135 | 264616 | 312075 | 530105 | 739806 |
| 1973 | 23352 | 64090 | 251253 | 501646 | 544506 | 892560 |
| 1974 | 24271 | 71970 | 126973 | 402194 | 826354 | 886857 |
| 1975 | 21245 | 59625 | 138682 | 228571 | 542898 | 1219898 |
| 1976 | 18604 | 44895 | 118252 | 203248 | 378919 | 657341 |
| 1977 | 17400 | 39935 | 86830 | 199236 | 253960 | 585202 |
| 1978 | 17768 | 37208 | 75112 | 155318 | 296465 | 289161 |
| 1979 | 19244 | 39023 | 72427 | 126644 | 259346 | 401304 |
| 1980 | 17524 | 37913 | 78409 | 129836 | 195075 | 407546 |
| 1981 | 18298 | 33502 | 68360 | 145595 | 216542 | 278839 |
| 1982 | 19817 | 39834 | 60076 | 114123 | 252076 | 339017 |
| 1983 | 18579 | 42124 | 74366 | 101690 | 178182 | 410168 |
| 1984 | 19306 | 44310 | 79989 | 122730 | 163410 | 262470 |
| 1985 | 18410 | 39323 | 89194 | 137999 | 183470 | 250572 |
| 1986 | 17838 | 39010 | 73718 | 156641 | 219434 | 253334 |
| 1987 | 19072 | 37306 | 72816 | 128431 | 246471 | 325540 |
| 1988 | 18035 | 40898 | 71494 | 122319 | 209725 | 354998 |
| 1989 | 21041 | 41123 | 75715 | 126859 | 188243 | 323439 |
| 1990 | 26177 | 52198 | 80213 | 124490 | 210324 | 269352 |
| 1991 | 23564 | 63325 | 103370 | 137864 | 185986 | 328444 |
| 1992 | 29834 | 55250 | 114350 | 172802 | 213846 | 257181 |
| 1993 | 21955 | 65819 | 106374 | 169801 | 254310 | 305240 |
| 1994 | 29190 | 52835 | 126214 | 176012 | 221209 | 340065 |
| 1995 | 21827 | 72214 | 114326 | 215661 | 259222 | 264026 |
| 1996 | 19204 | 69223 | 144185 | 225319 | 335133 | 349075 |
| 1997 | 18541 | 64206 | 156512 | 244434 | 409063 | 481664 |
| 1998 | 21465 | 51057 | 151852 | 278590 | 365730 | 690935 |
| 1999 | 32798 | 58256 | 113812 | 280572 | 418758 | 497451 |

| Year | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|
| 2000 | 27487 | 75179 | 121790 | 214629 | 434711 | 558555 |
| 2001 | 24369 | 89659 | 144090 | 209972 | 354575 | 594044 |
| 2002 | 33274 | 82031 | 196498 | 240004 | 313961 | 527521 |
| 2003 | 26878 | 76273 | 157805 | 330756 | 358097 | 422592 |
| 2004 | 27465 | 66446 | 120859 | 224531 | 467296 | 490110 |
| 2005 | 19130 | 63834 | 126059 | 156028 | 271539 | 587754 |
| 2006 | 24912 | 55360 | 119383 | 198305 | 179784 | 300837 |
| 2007 | 28460 | 66301 | 116016 | 190006 | 273240 | 194493 |
| 2008 | 30382 | 69774 | 113395 | 194201 | 268277 | 342797 |
| 2009 | 30670 | 71500 | 117175 | 152188 | 277993 | 346570 |
| 2010 | 31077 | 61013 | 116070 | 158122 | 178830 | 356863 |
| 2011 | 31910 | 70991 | 106252 | 152698 | 188034 | 195368 |
| 2012 | 31398 | 69046 | 112949 | 166207 | 178345 | 207843 |
| 2013 | 31475 | 66874 | 111211 | 146641 | 238433 | 194730 |
| 2014 | 31475 | 68970 | 107228 | 149274 | 169818 | 318982 |
| 2015 | 31475 | 68970 | 110463 | 144125 | 179031 | 184421 |
| 2016 | 31475 | 68970 | 110463 | 146669 | 173416 | 200300 |

**Table 3.1.3.1** Total menhaden reduction landings (1000s mt) 1940-2016, divided into northern and southern reduction landings.

| Year | Landings (1000 t) | Northern landings (1000 t) | Southern landings (1000 t) |
|---|---|---|---|
| 1940 | 217.7 | | |
| 1941 | 277.9 | | |
| 1942 | 167.2 | | |
| 1943 | 237.2 | | |
| 1944 | 257.9 | | |
| 1945 | 295.9 | | |
| 1946 | 362.4 | | |
| 1947 | 378.3 | | |
| 1948 | 346.5 | | |
| 1949 | 363.8 | | |
| 1950 | 297.2 | | |
| 1951 | 361.4 | | |
| 1952 | 409.9 | | |
| 1953 | 593.2 | | |
| 1954 | 608.1 | | |
| 1955 | 644.5 | 402.7 | 241.7 |
| 1956 | 715.2 | 478.9 | 236.4 |
| 1957 | 605.6 | 389.8 | 215.8 |
| 1958 | 512.4 | 248.3 | 264.0 |
| 1959 | 662.2 | 318.4 | 343.7 |
| 1960 | 532.2 | 323.9 | 208.4 |
| 1961 | 578.6 | 334.8 | 243.9 |
| 1962 | 540.7 | 321.4 | 219.3 |
| 1963 | 348.4 | 147.5 | 200.9 |
| 1964 | 270.4 | 50.6 | 219.8 |
| 1965 | 274.6 | 58.0 | 216.6 |
| 1966 | 220.7 | 7.9 | 212.8 |
| 1967 | 194.4 | 17.2 | 177.2 |
| 1968 | 235.9 | 33.1 | 202.8 |
| 1969 | 162.3 | 15.4 | 146.9 |
| 1970 | 259.4 | 15.8 | 243.6 |
| 1971 | 250.3 | 33.4 | 216.9 |
| 1972 | 365.9 | 69.1 | 296.8 |
| 1973 | 346.9 | 90.7 | 256.2 |
| 1974 | 292.2 | 77.9 | 214.3 |
| 1975 | 250.2 | 48.4 | 201.8 |

| Year | Landings (1000 t) | Northern landings (1000 t) | Southern landings (1000 t) |
|---|---|---|---|
| 1976 | 340.5 | 86.8 | 253.7 |
| 1977 | 341.2 | 53.3 | 287.8 |
| 1978 | 344.1 | 63.5 | 280.5 |
| 1979 | 375.7 | 70.2 | 305.6 |
| 1980 | 401.5 | 83.0 | 318.5 |
| 1981 | 381.3 | 68.1 | 313.2 |
| 1982 | 382.5 | 35.1 | 347.4 |
| 1983 | 418.6 | 39.4 | 379.3 |
| 1984 | 326.3 | 35.0 | 291.3 |
| 1985 | 306.7 | 111.3 | 195.4 |
| 1986 | 238.0 | 42.6 | 195.4 |
| 1987 | 326.9 | 83.0 | 243.9 |
| 1988 | 309.3 | 73.6 | 235.6 |
| 1989 | 322.0 | 98.8 | 223.2 |
| 1990 | 401.1 | 144.1 | 257.1 |
| 1991 | 381.4 | 104.6 | 276.9 |
| 1992 | 297.6 | 99.1 | 198.5 |
| 1993 | 320.6 | 58.4 | 262.2 |
| 1994 | 260.0 | 33.4 | 226.6 |
| 1995 | 339.9 | 96.3 | 243.6 |
| 1996 | 292.9 | 61.6 | 231.4 |
| 1997 | 259.1 | 25.2 | 234.0 |
| 1998 | 245.9 | 12.3 | 233.6 |
| 1999 | 171.2 | 8.4 | 162.8 |
| 2000 | 167.3 | 43.2 | 124.1 |
| 2001 | 233.6 | 39.6 | 193.9 |
| 2002 | 174.1 | 27.2 | 146.9 |
| 2003 | 166.1 | 4.1 | 162.0 |
| 2004 | 178.5 | 25.9 | 152.6 |
| 2005 | 152.9 | 15.4 | 137.5 |
| 2006 | 157.4 | 60.1 | 97.2 |
| 2007 | 174.5 | 36.6 | 137.8 |
| 2008 | 141.1 | 39.3 | 101.8 |
| 2009 | 143.8 | 18.7 | 125.1 |
| 2010 | 183.1 | 28.7 | 154.4 |
| 2011 | 174.0 | 29.6 | 144.5 |
| 2012 | 160.6 | 23.9 | 136.7 |
| 2013 | 131.0 | 32.7 | 98.3 |
| 2014 | 131.1 | 29.9 | 101.2 |
| 2015 | 143.5 | 28.8 | 114.7 |
| 2016 | 137.4 | 45.0 | 92.4 |

**Table 3.1.4.1** Catch-at-age for the northern commercial reduction fishery from 1955-2016.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 0.000 | 0.015 | 0.471 | 0.217 | 0.253 | 0.032 | 0.012 |
| 1956 | 0.000 | 0.133 | 0.555 | 0.195 | 0.025 | 0.072 | 0.020 |
| 1957 | 0.000 | 0.270 | 0.610 | 0.051 | 0.033 | 0.017 | 0.020 |
| 1958 | 0.000 | 0.025 | 0.908 | 0.042 | 0.010 | 0.008 | 0.009 |
| 1959 | 0.000 | 0.531 | 0.291 | 0.159 | 0.009 | 0.004 | 0.007 |
| 1960 | 0.000 | 0.009 | 0.892 | 0.037 | 0.049 | 0.009 | 0.004 |
| 1961 | 0.000 | 0.003 | 0.160 | 0.803 | 0.012 | 0.018 | 0.003 |
| 1962 | 0.000 | 0.015 | 0.245 | 0.218 | 0.457 | 0.033 | 0.032 |
| 1963 | 0.000 | 0.296 | 0.438 | 0.095 | 0.068 | 0.080 | 0.023 |
| 1964 | 0.000 | 0.034 | 0.357 | 0.345 | 0.128 | 0.065 | 0.072 |
| 1965 | 0.000 | 0.160 | 0.370 | 0.373 | 0.071 | 0.013 | 0.014 |
| 1966 | 0.000 | 0.201 | 0.467 | 0.212 | 0.100 | 0.009 | 0.012 |
| 1967 | 0.000 | 0.055 | 0.296 | 0.567 | 0.072 | 0.009 | 0.000 |
| 1968 | 0.000 | 0.007 | 0.479 | 0.388 | 0.116 | 0.009 | 0.001 |
| 1969 | 0.000 | 0.001 | 0.251 | 0.594 | 0.149 | 0.005 | 0.000 |
| 1970 | 0.000 | 0.150 | 0.793 | 0.050 | 0.007 | 0.000 | 0.000 |
| 1971 | 0.000 | 0.126 | 0.288 | 0.433 | 0.137 | 0.017 | 0.000 |
| 1972 | 0.000 | 0.169 | 0.286 | 0.452 | 0.085 | 0.008 | 0.000 |
| 1973 | 0.000 | 0.021 | 0.821 | 0.133 | 0.024 | 0.001 | 0.000 |
| 1974 | 0.000 | 0.028 | 0.844 | 0.117 | 0.006 | 0.004 | 0.000 |
| 1975 | 0.000 | 0.000 | 0.798 | 0.175 | 0.025 | 0.001 | 0.000 |
| 1976 | 0.000 | 0.092 | 0.823 | 0.071 | 0.013 | 0.000 | 0.000 |
| 1977 | 0.000 | 0.022 | 0.567 | 0.326 | 0.079 | 0.006 | 0.001 |
| 1978 | 0.000 | 0.000 | 0.298 | 0.567 | 0.120 | 0.015 | 0.000 |
| 1979 | 0.000 | 0.007 | 0.579 | 0.332 | 0.076 | 0.006 | 0.000 |
| 1980 | 0.000 | 0.002 | 0.237 | 0.462 | 0.243 | 0.051 | 0.004 |
| 1981 | 0.000 | 0.001 | 0.357 | 0.357 | 0.210 | 0.070 | 0.006 |
| 1982 | 0.000 | 0.042 | 0.393 | 0.473 | 0.063 | 0.025 | 0.004 |
| 1983 | 0.000 | 0.012 | 0.826 | 0.120 | 0.037 | 0.005 | 0.000 |
| 1984 | 0.000 | 0.024 | 0.343 | 0.506 | 0.097 | 0.029 | 0.001 |
| 1985 | 0.000 | 0.020 | 0.760 | 0.089 | 0.111 | 0.017 | 0.003 |
| 1986 | 0.000 | 0.010 | 0.795 | 0.107 | 0.050 | 0.031 | 0.006 |
| 1987 | 0.000 | 0.005 | 0.652 | 0.277 | 0.058 | 0.006 | 0.002 |
| 1988 | 0.000 | 0.000 | 0.225 | 0.486 | 0.260 | 0.026 | 0.003 |
| 1989 | 0.000 | 0.081 | 0.623 | 0.173 | 0.097 | 0.025 | 0.000 |
| 1990 | 0.000 | 0.011 | 0.788 | 0.134 | 0.049 | 0.018 | 0.001 |
| 1991 | 0.000 | 0.085 | 0.430 | 0.385 | 0.072 | 0.023 | 0.005 |
| 1992 | 0.000 | 0.058 | 0.687 | 0.107 | 0.118 | 0.026 | 0.004 |
| 1993 | 0.000 | 0.045 | 0.675 | 0.226 | 0.036 | 0.017 | 0.002 |
| 1994 | 0.000 | 0.017 | 0.420 | 0.333 | 0.183 | 0.047 | 0.000 |
| 1995 | 0.000 | 0.020 | 0.567 | 0.329 | 0.079 | 0.006 | 0.000 |
| 1996 | 0.000 | 0.000 | 0.579 | 0.320 | 0.092 | 0.008 | 0.000 |
| 1997 | 0.000 | 0.000 | 0.495 | 0.293 | 0.158 | 0.055 | 0.000 |
| 1998 | 0.000 | 0.000 | 0.657 | 0.281 | 0.062 | 0.000 | 0.000 |
| 1999 | 0.000 | 0.000 | 0.389 | 0.428 | 0.168 | 0.015 | 0.000 |
| 2000 | 0.000 | 0.005 | 0.559 | 0.406 | 0.019 | 0.011 | 0.000 |

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 2001 | 0.000 | 0.000 | 0.150 | 0.796 | 0.055 | 0.000 | 0.000 |
| 2002 | 0.000 | 0.040 | 0.347 | 0.491 | 0.120 | 0.002 | 0.000 |
| 2003 | 0.000 | 0.000 | 0.474 | 0.378 | 0.139 | 0.010 | 0.000 |
| 2004 | 0.000 | 0.004 | 0.615 | 0.320 | 0.061 | 0.000 | 0.000 |
| 2005 | 0.000 | 0.000 | 0.219 | 0.605 | 0.174 | 0.002 | 0.000 |
| 2006 | 0.000 | 0.022 | 0.456 | 0.422 | 0.099 | 0.001 | 0.000 |
| 2007 | 0.000 | 0.022 | 0.761 | 0.174 | 0.041 | 0.002 | 0.000 |
| 2008 | 0.000 | 0.002 | 0.216 | 0.668 | 0.106 | 0.008 | 0.000 |
| 2009 | 0.000 | 0.123 | 0.299 | 0.463 | 0.102 | 0.013 | 0.000 |
| 2010 | 0.000 | 0.000 | 0.456 | 0.348 | 0.193 | 0.003 | 0.000 |
| 2011 | 0.000 | 0.058 | 0.726 | 0.190 | 0.023 | 0.003 | 0.000 |
| 2012 | 0.000 | 0.001 | 0.778 | 0.192 | 0.029 | 0.000 | 0.000 |
| 2013 | 0.000 | 0.028 | 0.724 | 0.233 | 0.015 | 0.000 | 0.000 |
| 2014 | 0.000 | 0.085 | 0.518 | 0.274 | 0.119 | 0.004 | 0.000 |
| 2015 | 0.000 | 0.006 | 0.593 | 0.362 | 0.038 | 0.000 | 0.000 |
| 2016 | 0.000 | 0.075 | 0.413 | 0.481 | 0.031 | 0.000 | 0.000 |

**Table 3.1.4.2** Catch-at-age for the southern commercial reduction fishery from 1955-2016.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 0.374 | 0.323 | 0.269 | 0.016 | 0.016 | 0.002 | 0.000 |
| 1956 | 0.017 | 0.885 | 0.049 | 0.018 | 0.004 | 0.022 | 0.004 |
| 1957 | 0.151 | 0.598 | 0.217 | 0.010 | 0.011 | 0.007 | 0.006 |
| 1958 | 0.059 | 0.466 | 0.443 | 0.018 | 0.005 | 0.005 | 0.004 |
| 1959 | 0.003 | 0.855 | 0.099 | 0.034 | 0.005 | 0.002 | 0.002 |
| 1960 | 0.052 | 0.192 | 0.701 | 0.018 | 0.025 | 0.008 | 0.004 |
| 1961 | 0.000 | 0.538 | 0.217 | 0.234 | 0.004 | 0.007 | 0.000 |
| 1962 | 0.040 | 0.387 | 0.491 | 0.033 | 0.044 | 0.003 | 0.002 |
| 1963 | 0.079 | 0.460 | 0.386 | 0.059 | 0.007 | 0.008 | 0.002 |
| 1964 | 0.187 | 0.433 | 0.349 | 0.028 | 0.002 | 0.000 | 0.000 |
| 1965 | 0.184 | 0.528 | 0.269 | 0.018 | 0.001 | 0.000 | 0.000 |
| 1966 | 0.265 | 0.414 | 0.299 | 0.020 | 0.001 | 0.000 | 0.000 |
| 1967 | 0.007 | 0.663 | 0.269 | 0.057 | 0.003 | 0.000 | 0.000 |
| 1968 | 0.143 | 0.349 | 0.468 | 0.037 | 0.003 | 0.000 | 0.000 |
| 1969 | 0.188 | 0.442 | 0.330 | 0.038 | 0.002 | 0.000 | 0.000 |
| 1970 | 0.016 | 0.650 | 0.309 | 0.022 | 0.003 | 0.000 | 0.000 |
| 1971 | 0.083 | 0.288 | 0.569 | 0.054 | 0.005 | 0.001 | 0.000 |
| 1972 | 0.033 | 0.618 | 0.285 | 0.061 | 0.003 | 0.000 | 0.000 |
| 1973 | 0.036 | 0.372 | 0.591 | 0.001 | 0.000 | 0.000 | 0.000 |
| 1974 | 0.196 | 0.388 | 0.413 | 0.003 | 0.000 | 0.000 | 0.000 |
| 1975 | 0.154 | 0.371 | 0.469 | 0.006 | 0.001 | 0.000 | 0.000 |
| 1976 | 0.101 | 0.572 | 0.324 | 0.003 | 0.000 | 0.000 | 0.000 |
| 1977 | 0.140 | 0.289 | 0.567 | 0.003 | 0.000 | 0.000 | 0.000 |
| 1978 | 0.158 | 0.230 | 0.558 | 0.050 | 0.003 | 0.000 | 0.000 |
| 1979 | 0.413 | 0.172 | 0.403 | 0.012 | 0.001 | 0.000 | 0.000 |
| 1980 | 0.028 | 0.476 | 0.452 | 0.038 | 0.004 | 0.001 | 0.000 |
| 1981 | 0.316 | 0.186 | 0.460 | 0.038 | 0.000 | 0.000 | 0.000 |
| 1982 | 0.038 | 0.306 | 0.558 | 0.096 | 0.001 | 0.000 | 0.000 |
| 1983 | 0.279 | 0.148 | 0.547 | 0.016 | 0.008 | 0.001 | 0.000 |
| 1984 | 0.396 | 0.311 | 0.244 | 0.040 | 0.007 | 0.002 | 0.000 |
| 1985 | 0.235 | 0.394 | 0.364 | 0.006 | 0.000 | 0.000 | 0.000 |
| 1986 | 0.056 | 0.126 | 0.797 | 0.019 | 0.002 | 0.001 | 0.000 |
| 1987 | 0.022 | 0.253 | 0.691 | 0.031 | 0.003 | 0.000 | 0.000 |
| 1988 | 0.175 | 0.146 | 0.573 | 0.099 | 0.006 | 0.001 | 0.000 |
| 1989 | 0.069 | 0.514 | 0.402 | 0.014 | 0.001 | 0.000 | 0.000 |
| 1990 | 0.190 | 0.078 | 0.697 | 0.023 | 0.010 | 0.002 | 0.000 |
| 1991 | 0.317 | 0.360 | 0.281 | 0.038 | 0.004 | 0.001 | 0.000 |
| 1992 | 0.243 | 0.428 | 0.313 | 0.014 | 0.002 | 0.000 | 0.000 |
| 1993 | 0.049 | 0.266 | 0.608 | 0.074 | 0.003 | 0.000 | 0.000 |
| 1994 | 0.064 | 0.197 | 0.609 | 0.094 | 0.035 | 0.002 | 0.000 |
| 1995 | 0.044 | 0.408 | 0.366 | 0.150 | 0.031 | 0.002 | 0.000 |
| 1996 | 0.036 | 0.226 | 0.630 | 0.092 | 0.015 | 0.001 | 0.000 |
| 1997 | 0.027 | 0.260 | 0.423 | 0.236 | 0.047 | 0.007 | 0.001 |
| 1998 | 0.073 | 0.187 | 0.535 | 0.123 | 0.073 | 0.009 | 0.001 |
| 1999 | 0.188 | 0.292 | 0.428 | 0.069 | 0.020 | 0.003 | 0.000 |
| 2000 | 0.140 | 0.205 | 0.510 | 0.127 | 0.016 | 0.002 | 0.000 |

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 2001 | 0.039 | 0.073 | 0.604 | 0.265 | 0.018 | 0.001 | 0.000 |
| 2002 | 0.242 | 0.284 | 0.321 | 0.140 | 0.012 | 0.000 | 0.000 |
| 2003 | 0.088 | 0.185 | 0.643 | 0.073 | 0.010 | 0.001 | 0.000 |
| 2004 | 0.020 | 0.234 | 0.670 | 0.060 | 0.015 | 0.001 | 0.000 |
| 2005 | 0.020 | 0.131 | 0.618 | 0.210 | 0.018 | 0.003 | 0.000 |
| 2006 | 0.016 | 0.525 | 0.378 | 0.072 | 0.008 | 0.000 | 0.000 |
| 2007 | 0.001 | 0.306 | 0.631 | 0.054 | 0.008 | 0.000 | 0.000 |
| 2008 | 0.017 | 0.115 | 0.812 | 0.053 | 0.003 | 0.000 | 0.000 |
| 2009 | 0.007 | 0.515 | 0.311 | 0.147 | 0.019 | 0.001 | 0.000 |
| 2010 | 0.017 | 0.447 | 0.494 | 0.034 | 0.008 | 0.000 | 0.000 |
| 2011 | 0.000 | 0.477 | 0.467 | 0.048 | 0.007 | 0.002 | 0.000 |
| 2012 | 0.007 | 0.183 | 0.789 | 0.020 | 0.001 | 0.000 | 0.000 |
| 2013 | 0.043 | 0.457 | 0.388 | 0.095 | 0.016 | 0.000 | 0.000 |
| 2014 | 0.007 | 0.482 | 0.377 | 0.106 | 0.026 | 0.002 | 0.000 |
| 2015 | 0.000 | 0.141 | 0.759 | 0.092 | 0.009 | 0.000 | 0.000 |
| 2016 | 0.022 | 0.303 | 0.509 | 0.160 | 0.006 | 0.000 | 0.000 |

**Table 3.2.1.1** Atlantic menhaden historical bait landings from 1950-1984 and recent bait landings (1000 mt) from 1985-2016.

| Year | Historic Bait (1000 mt) | Year | Recent Bait (1000 mt) |
|---|---|---|---|
| 1950 | 11.3 | 1985 | 26.6 |
| 1951 | 20.4 | 1986 | 21.6 |
| 1952 | 14.2 | 1987 | 25.5 |
| 1953 | 25.8 | 1988 | 43.8 |
| 1954 | 19.3 | 1989 | 31.5 |
| 1955 | 14.6 | 1990 | 28.1 |
| 1956 | 23.3 | 1991 | 29.7 |
| 1957 | 24.7 | 1992 | 33.8 |
| 1958 | 14.7 | 1993 | 23.4 |
| 1959 | 20.6 | 1994 | 25.6 |
| 1960 | 19.4 | 1995 | 28.4 |
| 1961 | 25.1 | 1996 | 21.7 |
| 1962 | 26.6 | 1997 | 24.2 |
| 1963 | 24.4 | 1998 | 38.4 |
| 1964 | 20.2 | 1999 | 34.8 |
| 1965 | 23.6 | 2000 | 33.5 |
| 1966 | 13.7 | 2001 | 35.3 |
| 1967 | 11.6 | 2002 | 36.2 |
| 1968 | 9.5 | 2003 | 33.2 |
| 1969 | 10.6 | 2004 | 34.0 |
| 1970 | 21.6 | 2005 | 38.4 |
| 1971 | 13.5 | 2006 | 27.2 |
| 1972 | 10.3 | 2007 | 42.1 |
| 1973 | 14.8 | 2008 | 47.6 |
| 1974 | 14.5 | 2009 | 39.2 |
| 1975 | 21.7 | 2010 | 42.7 |
| 1976 | 19.6 | 2011 | 52.6 |
| 1977 | 23.1 | 2012 | 63.7 |
| 1978 | 25.9 | 2013 | 37.0 |
| 1979 | 13 | 2014 | 41.6 |
| 1980 | 26.2 | 2015 | 45.8 |
| 1981 | 22.4 | 2016 | 43.1 |
| 1982 | 19.9 | | |
| 1983 | 19.1 | | |
| 1984 | 14.3 | | |

**Table 3.2.3.1** Catch-at-age for the northern commercial bait fishery (includes small amount of recreational catch).

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1985 | 0.000 | 0.000 | 0.671 | 0.180 | 0.117 | 0.025 | 0.006 |
| 1986 | 0.000 | 0.000 | 0.088 | 0.624 | 0.259 | 0.027 | 0.003 |
| 1987 | 0.000 | 0.000 | 0.087 | 0.624 | 0.259 | 0.027 | 0.003 |
| 1988 | 0.000 | 0.000 | 0.074 | 0.632 | 0.264 | 0.027 | 0.003 |
| 1989 | 0.000 | 0.000 | 0.083 | 0.627 | 0.261 | 0.027 | 0.003 |
| 1990 | 0.000 | 0.000 | 0.119 | 0.605 | 0.247 | 0.026 | 0.003 |
| 1991 | 0.000 | 0.000 | 0.153 | 0.584 | 0.234 | 0.026 | 0.003 |
| 1992 | 0.000 | 0.000 | 0.180 | 0.567 | 0.224 | 0.026 | 0.003 |
| 1993 | 0.000 | 0.000 | 0.215 | 0.546 | 0.211 | 0.025 | 0.003 |
| 1994 | 0.000 | 0.000 | 0.107 | 0.498 | 0.343 | 0.048 | 0.004 |
| 1995 | 0.000 | 0.000 | 0.086 | 0.478 | 0.434 | 0.002 | 0.000 |
| 1996 | 0.000 | 0.000 | 0.437 | 0.439 | 0.118 | 0.005 | 0.000 |
| 1997 | 0.000 | 0.000 | 0.152 | 0.326 | 0.388 | 0.116 | 0.018 |
| 1998 | 0.004 | 0.000 | 0.109 | 0.399 | 0.396 | 0.078 | 0.013 |
| 1999 | 0.005 | 0.000 | 0.149 | 0.483 | 0.311 | 0.041 | 0.010 |
| 2000 | 0.000 | 0.004 | 0.410 | 0.322 | 0.228 | 0.029 | 0.007 |
| 2001 | 0.000 | 0.000 | 0.113 | 0.734 | 0.135 | 0.014 | 0.004 |
| 2002 | 0.000 | 0.000 | 0.058 | 0.568 | 0.318 | 0.055 | 0.000 |
| 2003 | 0.000 | 0.000 | 0.127 | 0.666 | 0.197 | 0.010 | 0.000 |
| 2004 | 0.000 | 0.000 | 0.252 | 0.523 | 0.198 | 0.025 | 0.003 |
| 2005 | 0.000 | 0.000 | 0.227 | 0.538 | 0.207 | 0.025 | 0.003 |
| 2006 | 0.000 | 0.004 | 0.269 | 0.575 | 0.144 | 0.008 | 0.000 |
| 2007 | 0.000 | 0.000 | 0.386 | 0.495 | 0.110 | 0.008 | 0.002 |
| 2008 | 0.000 | 0.000 | 0.246 | 0.608 | 0.132 | 0.014 | 0.000 |
| 2009 | 0.000 | 0.000 | 0.181 | 0.616 | 0.185 | 0.017 | 0.000 |
| 2010 | 0.000 | 0.000 | 0.365 | 0.393 | 0.216 | 0.024 | 0.002 |
| 2011 | 0.000 | 0.000 | 0.142 | 0.488 | 0.325 | 0.044 | 0.000 |
| 2012 | 0.000 | 0.000 | 0.392 | 0.473 | 0.125 | 0.008 | 0.002 |
| 2013 | 0.000 | 0.000 | 0.254 | 0.563 | 0.157 | 0.026 | 0.000 |
| 2014 | 0.000 | 0.000 | 0.059 | 0.642 | 0.270 | 0.027 | 0.002 |
| 2015 | 0.000 | 0.000 | 0.059 | 0.642 | 0.270 | 0.027 | 0.002 |
| 2016 | 0.000 | 0.000 | 0.078 | 0.709 | 0.175 | 0.039 | 0.000 |

**Table 3.2.3.2** Catch-at-age for the southern commercial bait fishery (includes small amount of recreational catch).

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1985 | 0.003 | 0.176 | 0.611 | 0.172 | 0.034 | 0.003 | 0.000 |
| 1986 | 0.003 | 0.148 | 0.644 | 0.172 | 0.030 | 0.003 | 0.000 |
| 1987 | 0.003 | 0.133 | 0.678 | 0.153 | 0.031 | 0.003 | 0.000 |
| 1988 | 0.003 | 0.161 | 0.616 | 0.180 | 0.035 | 0.003 | 0.000 |
| 1989 | 0.003 | 0.148 | 0.652 | 0.164 | 0.030 | 0.003 | 0.000 |
| 1990 | 0.005 | 0.320 | 0.532 | 0.118 | 0.022 | 0.002 | 0.000 |
| 1991 | 0.002 | 0.246 | 0.607 | 0.120 | 0.022 | 0.002 | 0.000 |
| 1992 | 0.005 | 0.320 | 0.532 | 0.118 | 0.022 | 0.002 | 0.000 |
| 1993 | 0.010 | 0.397 | 0.418 | 0.144 | 0.029 | 0.003 | 0.000 |
| 1994 | 0.003 | 0.198 | 0.622 | 0.147 | 0.027 | 0.003 | 0.000 |
| 1995 | 0.000 | 0.392 | 0.374 | 0.218 | 0.017 | 0.000 | 0.000 |
| 1996 | 0.001 | 0.049 | 0.738 | 0.179 | 0.033 | 0.000 | 0.000 |
| 1997 | 0.000 | 0.083 | 0.521 | 0.303 | 0.074 | 0.012 | 0.006 |
| 1998 | 0.039 | 0.067 | 0.534 | 0.237 | 0.108 | 0.012 | 0.003 |
| 1999 | 0.000 | 0.053 | 0.722 | 0.169 | 0.049 | 0.006 | 0.000 |
| 2000 | 0.008 | 0.234 | 0.639 | 0.118 | 0.001 | 0.000 | 0.000 |
| 2001 | 0.003 | 0.061 | 0.685 | 0.235 | 0.014 | 0.003 | 0.000 |
| 2002 | 0.000 | 0.041 | 0.255 | 0.504 | 0.178 | 0.020 | 0.002 |
| 2003 | 0.006 | 0.099 | 0.752 | 0.130 | 0.013 | 0.000 | 0.000 |
| 2004 | 0.000 | 0.068 | 0.736 | 0.163 | 0.030 | 0.003 | 0.000 |
| 2005 | 0.000 | 0.015 | 0.528 | 0.430 | 0.024 | 0.003 | 0.000 |
| 2006 | 0.000 | 0.290 | 0.485 | 0.201 | 0.024 | 0.000 | 0.000 |
| 2007 | 0.000 | 0.273 | 0.688 | 0.028 | 0.011 | 0.000 | 0.000 |
| 2008 | 0.000 | 0.039 | 0.865 | 0.080 | 0.013 | 0.003 | 0.000 |
| 2009 | 0.004 | 0.264 | 0.414 | 0.288 | 0.030 | 0.000 | 0.000 |
| 2010 | 0.000 | 0.367 | 0.545 | 0.065 | 0.023 | 0.000 | 0.000 |
| 2011 | 0.000 | 0.391 | 0.514 | 0.080 | 0.015 | 0.000 | 0.000 |
| 2012 | 0.000 | 0.089 | 0.892 | 0.018 | 0.000 | 0.000 | 0.000 |
| 2013 | 0.009 | 0.612 | 0.284 | 0.091 | 0.003 | 0.000 | 0.000 |
| 2014 | 0.000 | 0.523 | 0.328 | 0.090 | 0.058 | 0.000 | 0.000 |
| 2015 | 0.000 | 0.248 | 0.702 | 0.050 | 0.000 | 0.000 | 0.000 |
| 2016 | 0.000 | 0.283 | 0.437 | 0.264 | 0.016 | 0.000 | 0.000 |

**Table 4.2.1.1** Values for each index used in the assessment and the associated CV values included in the stock assessment. Each index is scaled to its mean value.

| Year | YOY index | CV | SAD index | CV | NAD index | CV |
|---|---|---|---|---|---|---|
| 1959 | 0.69 | 0.93 | | | | |
| 1960 | 0.33 | 0.92 | | | | |
| 1961 | 0.31 | 0.94 | | | | |
| 1962 | 1.67 | 0.86 | | | | |
| 1963 | 1.02 | 1.04 | | | | |
| 1964 | 0.16 | 0.98 | | | | |
| 1965 | 0.43 | 0.88 | | | | |
| 1966 | 0.61 | 0.95 | | | | |
| 1967 | 0.81 | 0.98 | | | | |
| 1968 | 0.58 | 0.81 | | | | |
| 1969 | 0.64 | 0.75 | | | | |
| 1970 | 0.40 | 0.87 | | | | |
| 1971 | 1.64 | 0.74 | | | | |
| 1972 | 2.06 | 0.70 | | | | |
| 1973 | 1.50 | 0.86 | | | | |
| 1974 | 2.19 | 0.81 | | | | |
| 1975 | 2.99 | 0.82 | | | | |
| 1976 | 3.46 | 0.80 | | | | |
| 1977 | 2.91 | 0.82 | | | | |
| 1978 | 1.58 | 0.82 | | | | |
| 1979 | 2.46 | 0.80 | | | | |
| 1980 | 1.57 | 0.63 | | | 0.67 | 0.71 |
| 1981 | 2.38 | 0.68 | | | 0.41 | 0.80 |
| 1982 | 2.23 | 0.65 | | | 2.33 | 0.64 |
| 1983 | 1.16 | 0.69 | | | 0.85 | 0.68 |
| 1984 | 0.91 | 0.73 | | | 0.37 | 0.88 |
| 1985 | 1.71 | 0.52 | | | 0.67 | 0.74 |
| 1986 | 1.07 | 0.56 | | | 3.73 | 0.62 |
| 1987 | 0.43 | 0.55 | | | 3.45 | 0.63 |
| 1988 | 1.34 | 0.50 | | | 1.70 | 0.37 |
| 1989 | 1.34 | 0.44 | | | 1.07 | 0.39 |
| 1990 | 1.57 | 0.43 | 3.34 | 0.64 | 0.54 | 0.37 |
| 1991 | 1.14 | 0.43 | 1.08 | 0.52 | 0.65 | 0.36 |
| 1992 | 0.71 | 0.43 | 0.69 | 0.58 | 0.61 | 0.34 |
| 1993 | 0.16 | 0.48 | 0.47 | 0.58 | 0.53 | 0.42 |
| 1994 | 0.58 | 0.44 | 0.44 | 0.61 | 0.27 | 0.42 |
| 1995 | 0.36 | 0.41 | 0.14 | 0.45 | 0.48 | 0.37 |
| 1996 | 0.31 | 0.40 | 0.72 | 0.47 | 0.22 | 0.40 |
| 1997 | 0.54 | 0.39 | 0.48 | 0.53 | 0.18 | 0.36 |
| 1998 | 0.55 | 0.43 | 0.56 | 0.59 | 0.14 | 0.39 |

| Year | YOY index | CV | SAD index | CV | NAD index | CV |
|---|---|---|---|---|---|---|
| 1999 | 0.80 | 0.46 | 0.47 | 0.58 | 0.36 | 0.34 |
| 2000 | 0.71 | 0.41 | 0.77 | 0.71 | 0.25 | 0.34 |
| 2001 | 0.41 | 0.40 | 0.61 | 0.59 | 0.27 | 0.42 |
| 2002 | 0.96 | 0.41 | 0.66 | 0.57 | 0.54 | 0.36 |
| 2003 | 0.50 | 0.39 | 0.60 | 0.65 | 0.21 | 0.32 |
| 2004 | 0.63 | 0.39 | 0.45 | 0.48 | 0.31 | 0.34 |
| 2005 | 0.83 | 0.38 | 1.21 | 0.45 | 0.66 | 0.34 |
| 2006 | 0.38 | 0.38 | 3.72 | 0.45 | 0.74 | 0.31 |
| 2007 | 0.58 | 0.39 | 0.26 | 0.48 | 1.18 | 0.29 |
| 2008 | 0.41 | 0.37 | 0.44 | 0.46 | 1.20 | 0.44 |
| 2009 | 0.34 | 0.38 | 2.73 | 0.55 | 1.07 | 0.35 |
| 2010 | 0.63 | 0.39 | 0.66 | 0.42 | 0.94 | 0.31 |
| 2011 | 0.35 | 0.38 | 2.94 | 0.41 | 1.63 | 0.33 |
| 2012 | 0.24 | 0.37 | 1.00 | 0.41 | 1.42 | 0.31 |
| 2013 | 0.24 | 0.37 | 0.77 | 0.41 | 1.21 | 0.33 |
| 2014 | 0.49 | 0.37 | 0.66 | 0.48 | 2.44 | 0.31 |
| 2015 | 0.41 | 0.41 | 0.69 | 0.40 | 1.24 | 0.33 |
| 2016 | 0.62 | 0.42 | 0.42 | 0.55 | 2.50 | 0.34 |

**Table 6.2.1.1** Selectivity slope and $A_{50}$ of the ascending and descending limbs with associated SE for the bait and reduction fisheries, and the NAD and SAD indices.

| | | | Ascending Limb | | | | Descending Limb | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fishery/Index** | **Region** | **Period** | **Slope** | **SE** | **A50** | **SE** | **Slope** | **SE** | **A50** | **SE** |
| Reduction | North | 1955-1969 | 3.63 | 0.18 | 2.32 | 0.10 | 1.67 | 4.17 | 3.81 | 3.14 |
| Reduction | North | 1969-1993 | 5.31 | 0.93 | 2.13 | 0.10 | 1.49 | 1.91 | 2.83 | 1.23 |
| Reduction | North | 1994-2016 | 5.19 | 2.13 | 2.21 | 0.14 | 0.54 | 0.42 | 1.50 | 0.04 |
| Reduction | South | 1955-1971 | 3.92 | 0.24 | 1.15 | 0.05 | 2.08 | 1.25 | 1.75 | 0.02 |
| Reduction | South | 1972-2004 | 2.16 | 0.15 | 3.33 | 0.18 | 4.36 | 0.87 | -1.00 | 0.003 |
| Reduction | South | 2005-2016 | 4.80 | 1.88 | 1.36 | 0.15 | 1.44 | 0.85 | 1.50 | 0.001 |
| Bait | North | 1955-2016 | 5.71 | 2.23 | 2.47 | 0.21 | 4.27 | 3.29 | 2.19 | 0.46 |
| Bait | South | 1955-2016 | 36.21 | 28306 | 1.08 | 62.8 | 0.67 | 1.16 | 2.98 | 6.28 |
| NAD | North | | 2.42 | 5318 | 2.09 | 20.56 | NA | NA | NA | NA |
| SAD | South | | 35.0 | 0.016 | 0.13 | 0.033 | 4.08 | 0.04 | 1.75 | 0.02 |

**Table 6.2.2.1** Fishing mortality rate at age estimates from 1955-2016.

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 0.006 | 0.210 | 1.137 | 2.992 | 2.953 | 2.522 | 1.596 |
| 1956 | 0.011 | 0.369 | 3.167 | 10.457 | 10.710 | 9.069 | 5.718 |
| 1957 | 0.008 | 0.287 | 2.502 | 8.348 | 8.535 | 7.081 | 4.437 |
| 1958 | 0.008 | 0.276 | 1.358 | 3.259 | 3.160 | 2.696 | 1.707 |
| 1959 | 0.008 | 0.262 | 1.772 | 5.148 | 5.183 | 4.433 | 2.805 |
| 1960 | 0.003 | 0.087 | 0.502 | 1.372 | 1.361 | 1.142 | 0.719 |
| 1961 | 0.005 | 0.179 | 0.601 | 0.880 | 0.735 | 0.608 | 0.383 |
| 1962 | 0.009 | 0.301 | 1.078 | 1.765 | 1.537 | 1.276 | 0.804 |
| 1963 | 0.010 | 0.325 | 1.252 | 2.189 | 1.948 | 1.586 | 0.994 |
| 1964 | 0.011 | 0.349 | 1.076 | 1.281 | 0.956 | 0.703 | 0.430 |
| 1965 | 0.013 | 0.424 | 1.337 | 1.537 | 1.137 | 0.868 | 0.538 |
| 1966 | 0.014 | 0.465 | 1.229 | 0.836 | 0.354 | 0.181 | 0.101 |
| 1967 | 0.009 | 0.294 | 0.828 | 0.707 | 0.411 | 0.279 | 0.169 |
| 1968 | 0.009 | 0.302 | 0.834 | 0.741 | 0.447 | 0.326 | 0.201 |
| 1969 | 0.008 | 0.262 | 0.705 | 0.509 | 0.241 | 0.148 | 0.088 |
| 1970 | 0.010 | 0.329 | 0.922 | 0.644 | 0.274 | 0.123 | 0.051 |
| 1971 | 0.009 | 0.283 | 0.792 | 0.635 | 0.309 | 0.144 | 0.053 |
| 1972 | 0.036 | 0.309 | 2.318 | 1.498 | 0.619 | 0.350 | 0.130 |
| 1973 | 0.021 | 0.187 | 1.664 | 1.714 | 1.085 | 0.612 | 0.222 |
| 1974 | 0.017 | 0.155 | 1.371 | 1.358 | 0.841 | 0.481 | 0.177 |
| 1975 | 0.016 | 0.145 | 1.202 | 0.987 | 0.544 | 0.311 | 0.121 |
| 1976 | 0.016 | 0.139 | 1.215 | 1.162 | 0.706 | 0.408 | 0.153 |
| 1977 | 0.015 | 0.129 | 1.012 | 0.713 | 0.337 | 0.193 | 0.076 |
| 1978 | 0.014 | 0.129 | 1.007 | 0.695 | 0.322 | 0.187 | 0.075 |
| 1979 | 0.016 | 0.144 | 1.093 | 0.728 | 0.315 | 0.181 | 0.068 |
| 1980 | 0.023 | 0.205 | 1.595 | 1.101 | 0.507 | 0.296 | 0.117 |
| 1981 | 0.019 | 0.168 | 1.330 | 0.976 | 0.479 | 0.277 | 0.107 |
| 1982 | 0.023 | 0.206 | 1.506 | 0.844 | 0.281 | 0.156 | 0.063 |
| 1983 | 0.026 | 0.224 | 1.636 | 0.921 | 0.307 | 0.170 | 0.067 |
| 1984 | 0.028 | 0.244 | 1.798 | 1.052 | 0.377 | 0.209 | 0.082 |
| 1985 | 0.011 | 0.105 | 1.096 | 1.491 | 1.082 | 0.582 | 0.207 |
| 1986 | 0.008 | 0.068 | 0.545 | 0.468 | 0.266 | 0.129 | 0.045 |
| 1987 | 0.011 | 0.097 | 0.767 | 0.578 | 0.291 | 0.159 | 0.059 |
| 1988 | 0.017 | 0.156 | 1.208 | 0.827 | 0.382 | 0.204 | 0.080 |
| 1989 | 0.023 | 0.205 | 1.733 | 1.573 | 0.929 | 0.502 | 0.185 |
| 1990 | 0.013 | 0.119 | 1.237 | 1.853 | 1.387 | 0.687 | 0.229 |
| 1991 | 0.017 | 0.153 | 1.329 | 1.417 | 0.917 | 0.459 | 0.157 |
| 1992 | 0.012 | 0.111 | 1.063 | 1.449 | 1.052 | 0.500 | 0.164 |
| 1993 | 0.016 | 0.137 | 1.092 | 0.980 | 0.572 | 0.261 | 0.086 |
| 1994 | 0.015 | 0.129 | 0.972 | 0.774 | 0.396 | 0.184 | 0.100 |
| 1995 | 0.031 | 0.278 | 2.280 | 2.201 | 1.257 | 0.733 | 0.455 |
| 1996 | 0.019 | 0.174 | 1.539 | 2.152 | 1.506 | 0.707 | 0.384 |

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1997 | 0.025 | 0.226 | 1.743 | 1.520 | 0.853 | 0.362 | 0.182 |
| 1998 | 0.027 | 0.244 | 1.830 | 1.450 | 0.769 | 0.288 | 0.128 |
| 1999 | 0.018 | 0.167 | 1.287 | 1.117 | 0.646 | 0.235 | 0.100 |
| 2000 | 0.011 | 0.100 | 0.920 | 1.252 | 0.871 | 0.435 | 0.246 |
| 2001 | 0.016 | 0.140 | 1.120 | 0.996 | 0.555 | 0.293 | 0.171 |
| 2002 | 0.016 | 0.142 | 1.133 | 0.923 | 0.492 | 0.254 | 0.146 |
| 2003 | 0.017 | 0.156 | 1.165 | 0.709 | 0.290 | 0.123 | 0.061 |
| 2004 | 0.011 | 0.097 | 0.792 | 0.751 | 0.446 | 0.218 | 0.121 |
| 2005 | 0.001 | 0.114 | 0.708 | 0.641 | 0.381 | 0.166 | 0.082 |
| 2006 | 0.001 | 0.071 | 0.543 | 0.803 | 0.566 | 0.314 | 0.187 |
| 2007 | 0.001 | 0.070 | 0.466 | 0.606 | 0.422 | 0.184 | 0.093 |
| 2008 | 0.001 | 0.060 | 0.411 | 0.533 | 0.372 | 0.165 | 0.084 |
| 2009 | 0.001 | 0.077 | 0.474 | 0.473 | 0.295 | 0.118 | 0.055 |
| 2010 | 0.001 | 0.097 | 0.591 | 0.657 | 0.428 | 0.167 | 0.076 |
| 2011 | 0.001 | 0.086 | 0.549 | 0.721 | 0.509 | 0.192 | 0.084 |
| 2012 | 0.001 | 0.058 | 0.387 | 0.619 | 0.474 | 0.157 | 0.059 |
| 2013 | 0.000 | 0.051 | 0.327 | 0.379 | 0.251 | 0.111 | 0.057 |
| 2014 | 0.001 | 0.066 | 0.422 | 0.454 | 0.293 | 0.129 | 0.065 |
| 2015 | 0.001 | 0.076 | 0.489 | 0.579 | 0.392 | 0.159 | 0.075 |
| 2016 | 0.001 | 0.062 | 0.436 | 0.654 | 0.478 | 0.210 | 0.107 |

**Table 6.2.3.1** Numbers at age in billions of fish estimated from the base run of the BAM model for 1955-2016.

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 26.735 | 4.348 | 2.744 | 0.540 | 0.000 | 0.000 | 0.000 |
| 1956 | 28.328 | 8.668 | 1.553 | 0.460 | 0.015 | 0.000 | 0.000 |
| 1957 | 13.599 | 9.142 | 2.640 | 0.034 | 0.000 | 0.000 | 0.000 |
| 1958 | 79.353 | 4.400 | 3.021 | 0.113 | 0.000 | 0.000 | 0.000 |
| 1959 | 11.646 | 25.675 | 1.470 | 0.405 | 0.002 | 0.000 | 0.000 |
| 1960 | 10.263 | 3.770 | 8.701 | 0.130 | 0.001 | 0.000 | 0.000 |
| 1961 | 10.195 | 3.340 | 1.522 | 2.749 | 0.019 | 0.000 | 0.000 |
| 1962 | 11.644 | 3.308 | 1.230 | 0.436 | 0.645 | 0.005 | 0.000 |
| 1963 | 8.836 | 3.764 | 1.078 | 0.218 | 0.042 | 0.082 | 0.001 |
| 1964 | 8.499 | 2.855 | 1.198 | 0.161 | 0.014 | 0.004 | 0.010 |
| 1965 | 7.807 | 2.744 | 0.887 | 0.213 | 0.025 | 0.003 | 0.005 |
| 1966 | 11.312 | 2.515 | 0.791 | 0.122 | 0.026 | 0.005 | 0.003 |
| 1967 | 6.542 | 3.639 | 0.695 | 0.121 | 0.030 | 0.011 | 0.004 |
| 1968 | 8.446 | 2.116 | 1.195 | 0.159 | 0.034 | 0.012 | 0.007 |
| 1969 | 11.488 | 2.730 | 0.689 | 0.271 | 0.043 | 0.013 | 0.009 |
| 1970 | 5.429 | 3.718 | 0.926 | 0.178 | 0.092 | 0.020 | 0.012 |
| 1971 | 15.225 | 1.754 | 1.179 | 0.192 | 0.053 | 0.042 | 0.018 |
| 1972 | 12.029 | 4.925 | 0.582 | 0.279 | 0.058 | 0.023 | 0.032 |
| 1973 | 12.452 | 3.788 | 1.592 | 0.030 | 0.035 | 0.018 | 0.027 |
| 1974 | 19.646 | 3.978 | 1.384 | 0.157 | 0.003 | 0.007 | 0.020 |
| 1975 | 30.335 | 6.299 | 1.500 | 0.184 | 0.023 | 0.001 | 0.013 |
| 1976 | 25.286 | 9.740 | 2.401 | 0.235 | 0.039 | 0.008 | 0.007 |
| 1977 | 24.619 | 8.123 | 3.734 | 0.372 | 0.042 | 0.011 | 0.007 |
| 1978 | 20.840 | 7.917 | 3.144 | 0.709 | 0.103 | 0.018 | 0.010 |
| 1979 | 37.572 | 6.702 | 3.066 | 0.600 | 0.200 | 0.044 | 0.014 |
| 1980 | 22.123 | 12.059 | 2.556 | 0.537 | 0.164 | 0.087 | 0.031 |
| 1981 | 25.994 | 7.054 | 4.328 | 0.271 | 0.101 | 0.059 | 0.056 |
| 1982 | 14.911 | 8.322 | 2.626 | 0.597 | 0.058 | 0.037 | 0.058 |
| 1983 | 29.858 | 4.752 | 2.982 | 0.304 | 0.145 | 0.026 | 0.053 |
| 1984 | 32.063 | 9.496 | 1.672 | 0.303 | 0.068 | 0.064 | 0.044 |
| 1985 | 25.474 | 10.174 | 3.275 | 0.145 | 0.060 | 0.028 | 0.056 |
| 1986 | 16.898 | 8.217 | 4.034 | 0.571 | 0.018 | 0.012 | 0.038 |
| 1987 | 11.039 | 5.471 | 3.382 | 1.221 | 0.202 | 0.008 | 0.029 |
| 1988 | 25.323 | 3.562 | 2.186 | 0.820 | 0.387 | 0.090 | 0.021 |
| 1989 | 15.925 | 8.119 | 1.342 | 0.341 | 0.203 | 0.157 | 0.057 |
| 1990 | 18.112 | 5.078 | 2.912 | 0.124 | 0.040 | 0.048 | 0.087 |
| 1991 | 14.965 | 5.832 | 1.986 | 0.441 | 0.011 | 0.006 | 0.057 |
| 1992 | 15.980 | 4.799 | 2.204 | 0.274 | 0.060 | 0.003 | 0.033 |
| 1993 | 6.622 | 5.150 | 1.892 | 0.397 | 0.036 | 0.013 | 0.018 |
| 1994 | 13.688 | 2.127 | 1.978 | 0.331 | 0.084 | 0.012 | 0.016 |
| 1995 | 10.592 | 4.402 | 0.824 | 0.391 | 0.086 | 0.034 | 0.015 |

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1996 | 11.178 | 3.350 | 1.468 | 0.044 | 0.024 | 0.015 | 0.016 |
| 1997 | 9.913 | 3.577 | 1.240 | 0.164 | 0.003 | 0.003 | 0.011 |
| 1998 | 9.354 | 3.154 | 1.256 | 0.113 | 0.020 | 0.001 | 0.007 |
| 1999 | 9.796 | 2.970 | 1.089 | 0.105 | 0.015 | 0.006 | 0.004 |
| 2000 | 6.730 | 3.138 | 1.107 | 0.157 | 0.019 | 0.005 | 0.005 |
| 2001 | 6.825 | 2.172 | 1.250 | 0.230 | 0.025 | 0.005 | 0.004 |
| 2002 | 13.005 | 2.193 | 0.832 | 0.213 | 0.048 | 0.009 | 0.004 |
| 2003 | 10.276 | 4.177 | 0.837 | 0.140 | 0.048 | 0.017 | 0.006 |
| 2004 | 11.003 | 3.296 | 1.574 | 0.136 | 0.039 | 0.021 | 0.013 |
| 2005 | 16.032 | 3.552 | 1.318 | 0.372 | 0.036 | 0.015 | 0.018 |
| 2006 | 9.593 | 5.225 | 1.397 | 0.339 | 0.111 | 0.015 | 0.018 |
| 2007 | 9.756 | 3.128 | 2.143 | 0.423 | 0.086 | 0.037 | 0.016 |
| 2008 | 12.369 | 3.181 | 1.285 | 0.702 | 0.131 | 0.033 | 0.028 |
| 2009 | 9.561 | 4.033 | 1.319 | 0.445 | 0.233 | 0.054 | 0.033 |
| 2010 | 18.654 | 3.117 | 1.644 | 0.429 | 0.157 | 0.103 | 0.048 |
| 2011 | 11.411 | 6.081 | 1.246 | 0.475 | 0.126 | 0.061 | 0.081 |
| 2012 | 8.517 | 3.720 | 2.457 | 0.376 | 0.131 | 0.045 | 0.076 |
| 2013 | 9.936 | 2.777 | 1.546 | 0.872 | 0.114 | 0.048 | 0.068 |
| 2014 | 10.791 | 3.240 | 1.163 | 0.582 | 0.338 | 0.053 | 0.066 |
| 2015 | 8.781 | 3.519 | 1.336 | 0.398 | 0.209 | 0.150 | 0.066 |
| 2016 | 13.363 | 2.863 | 1.436 | 0.428 | 0.126 | 0.084 | 0.116 |

**Table 6.2.3.2** Fecundity at age in billions of eggs during 1955-2016.

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1955 | 0 | 3997 | 73328 | 33639 | 6 | 0 | 0 |
| 1956 | 0 | 6470 | 37082 | 31334 | 1490 | 0 | 0 |
| 1957 | 0 | 5341 | 37163 | 2339 | 1 | 0 | 0 |
| 1958 | 0 | 4796 | 42541 | 5989 | 1 | 0 | 0 |
| 1959 | 0 | 7905 | 20820 | 20472 | 263 | 0 | 0 |
| 1960 | 0 | 8650 | 72952 | 6279 | 124 | 2 | 0 |
| 1961 | 0 | 3577 | 35282 | 109844 | 1722 | 28 | 0 |
| 1962 | 0 | 5501 | 25313 | 27155 | 53504 | 785 | 13 |
| 1963 | 0 | 7929 | 23408 | 13305 | 4665 | 11211 | 202 |
| 1964 | 0 | 7214 | 28587 | 8816 | 1430 | 604 | 2120 |
| 1965 | 0 | 6401 | 23197 | 12471 | 2153 | 465 | 1248 |
| 1966 | 0 | 3664 | 24386 | 7805 | 2404 | 541 | 515 |
| 1967 | 0 | 11002 | 16444 | 9909 | 3055 | 1341 | 528 |
| 1968 | 0 | 4427 | 47781 | 11941 | 5017 | 1657 | 1061 |
| 1969 | 0 | 7651 | 16953 | 26979 | 6633 | 3052 | 1552 |
| 1970 | 0 | 18198 | 27062 | 13081 | 16370 | 5618 | 3999 |
| 1971 | 0 | 6624 | 61831 | 15251 | 7722 | 11250 | 8288 |
| 1972 | 0 | 7126 | 31830 | 36484 | 8984 | 6109 | 11893 |
| 1973 | 0 | 2211 | 29076 | 3723 | 8832 | 5018 | 12191 |
| 1974 | 0 | 2897 | 32878 | 9196 | 613 | 2923 | 8691 |
| 1975 | 0 | 2677 | 23259 | 11962 | 2590 | 212 | 7813 |
| 1976 | 0 | 2718 | 16169 | 12529 | 3851 | 1497 | 2423 |
| 1977 | 0 | 1413 | 17150 | 12589 | 4065 | 1426 | 2078 |
| 1978 | 0 | 1407 | 11114 | 18367 | 7680 | 2594 | 1395 |
| 1979 | 0 | 1935 | 13161 | 14333 | 11650 | 5700 | 2906 |
| 1980 | 0 | 2113 | 9691 | 15145 | 9889 | 8297 | 6287 |
| 1981 | 0 | 1291 | 10876 | 5738 | 6976 | 6226 | 7751 |
| 1982 | 0 | 2474 | 12030 | 9330 | 2930 | 4637 | 9863 |
| 1983 | 0 | 1324 | 16332 | 7688 | 6276 | 2239 | 10889 |
| 1984 | 0 | 2750 | 10745 | 8857 | 3822 | 4982 | 5712 |
| 1985 | 0 | 1873 | 14167 | 5096 | 3886 | 2483 | 6987 |
| 1986 | 0 | 1466 | 17309 | 14321 | 1384 | 1311 | 4742 |
| 1987 | 0 | 1565 | 11985 | 29796 | 11951 | 1024 | 4687 |
| 1988 | 0 | 642 | 10729 | 19058 | 21558 | 9235 | 3752 |
| 1989 | 0 | 3417 | 6898 | 8903 | 11838 | 14494 | 9143 |
| 1990 | 0 | 4653 | 31159 | 3625 | 2289 | 4909 | 11573 |
| 1991 | 0 | 3436 | 35208 | 19615 | 711 | 541 | 9402 |
| 1992 | 0 | 7874 | 27394 | 13968 | 5070 | 273 | 4146 |
| 1993 | 0 | 2261 | 36742 | 18390 | 3000 | 1580 | 2729 |
| 1994 | 0 | 3105 | 21942 | 19238 | 7200 | 1339 | 2741 |
| 1995 | 0 | 1921 | 19633 | 19877 | 9128 | 4331 | 1986 |
| 1996 | 0 | 965 | 32003 | 3014 | 2728 | 2447 | 2758 |

| Ages | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 1997 | 0 | 995 | 22684 | 12350 | 350 | 660 | 2656 |
| 1998 | 0 | 1354 | 12509 | 8169 | 2803 | 134 | 2436 |
| 1999 | 0 | 6819 | 15854 | 5331 | 2086 | 1173 | 1038 |
| 2000 | 0 | 3450 | 28708 | 8697 | 2049 | 1017 | 1402 |
| 2001 | 0 | 1588 | 44837 | 15755 | 2610 | 859 | 1267 |
| 2002 | 0 | 5107 | 25590 | 20510 | 5713 | 1360 | 1165 |
| 2003 | 0 | 4491 | 22357 | 10599 | 7914 | 3130 | 1360 |
| 2004 | 0 | 3621 | 31381 | 7499 | 4328 | 4974 | 3215 |
| 2005 | 0 | 1019 | 23972 | 21593 | 2726 | 1992 | 5164 |
| 2006 | 0 | 3905 | 17782 | 18410 | 10774 | 1289 | 2625 |
| 2007 | 0 | 4006 | 42630 | 22109 | 7994 | 5060 | 1486 |
| 2008 | 0 | 5316 | 28684 | 35443 | 12430 | 4446 | 4745 |
| 2009 | 0 | 6804 | 30650 | 23450 | 16859 | 7370 | 5712 |
| 2010 | 0 | 5812 | 26584 | 22392 | 11892 | 8954 | 8596 |
| 2011 | 0 | 12612 | 28746 | 21970 | 9115 | 5595 | 7714 |
| 2012 | 0 | 7008 | 53446 | 18876 | 10425 | 3884 | 7766 |
| 2013 | 0 | 5245 | 31008 | 42647 | 7965 | 5709 | 6467 |
| 2014 | 0 | 6120 | 24064 | 27462 | 23931 | 4446 | 10294 |
| 2015 | 0 | 6645 | 27645 | 19350 | 14312 | 13270 | 6000 |
| 2016 | 0 | 5406 | 29713 | 20790 | 8793 | 7212 | 11571 |

**Table 6.2.3.3** Biomass of Atlantic menhaden (1000s mt) by age from 1959 to 2016.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ | Total |
|---|---|---|---|---|---|---|---|---|
| 1955 | 745.9 | 271.7 | 566.6 | 181.0 | 0.0 | 0.0 | 0.0 | 1765 |
| 1956 | 603.4 | 503.6 | 304.8 | 162.8 | 6.9 | 0.0 | 0.0 | 1582 |
| 1957 | 477.3 | 485.4 | 413.4 | 12.1 | 0.0 | 0.0 | 0.0 | 1388 |
| 1958 | 1491.8 | 289.0 | 473.1 | 34.1 | 0.0 | 0.0 | 0.0 | 2288 |
| 1959 | 521.7 | 1127.1 | 231.5 | 118.7 | 1.2 | 0.0 | 0.0 | 2000 |
| 1960 | 262.7 | 314.4 | 1125.9 | 37.0 | 0.6 | 0.0 | 0.0 | 1741 |
| 1961 | 346.6 | 214.4 | 294.7 | 699.5 | 8.1 | 0.1 | 0.0 | 1564 |
| 1962 | 462.3 | 249.1 | 225.9 | 146.1 | 261.4 | 3.2 | 0.0 | 1348 |
| 1963 | 377.3 | 309.4 | 202.1 | 71.9 | 20.8 | 46.9 | 0.7 | 1029 |
| 1964 | 345.9 | 246.4 | 235.0 | 49.5 | 6.5 | 2.3 | 7.7 | 893 |
| 1965 | 270.9 | 233.5 | 181.9 | 68.5 | 10.5 | 1.9 | 4.2 | 771 |
| 1966 | 446.8 | 180.6 | 174.8 | 41.4 | 11.3 | 2.4 | 1.9 | 859 |
| 1967 | 287.2 | 335.5 | 135.3 | 48.5 | 14.0 | 5.8 | 2.2 | 828 |
| 1968 | 416.4 | 172.4 | 304.3 | 60.2 | 20.4 | 6.8 | 4.3 | 985 |
| 1969 | 548.0 | 247.1 | 137.2 | 124.7 | 26.4 | 10.4 | 5.9 | 1099 |
| 1970 | 174.3 | 402.3 | 199.8 | 66.3 | 62.0 | 17.8 | 11.7 | 934 |
| 1971 | 570.9 | 173.6 | 352.8 | 75.9 | 31.5 | 36.3 | 20.9 | 1262 |
| 1972 | 141.9 | 350.7 | 178.7 | 154.3 | 35.6 | 19.9 | 33.6 | 915 |
| 1973 | 287.6 | 201.1 | 277.9 | 16.0 | 29.4 | 16.1 | 31.6 | 860 |
| 1974 | 457.8 | 223.2 | 270.4 | 50.6 | 2.2 | 7.9 | 22.6 | 1035 |
| 1975 | 515.7 | 291.0 | 243.8 | 63.3 | 11.5 | 0.7 | 17.5 | 1143 |
| 1976 | 391.9 | 366.2 | 289.3 | 71.3 | 17.8 | 5.5 | 7.2 | 1149 |
| 1977 | 389.0 | 274.6 | 394.4 | 86.3 | 18.9 | 6.1 | 6.5 | 1176 |
| 1978 | 431.4 | 277.1 | 305.6 | 144.1 | 38.8 | 10.6 | 5.7 | 1213 |
| 1979 | 680.0 | 266.1 | 315.2 | 117.8 | 64.1 | 24.3 | 10.5 | 1478 |
| 1980 | 349.5 | 412.4 | 254.1 | 113.5 | 53.6 | 38.8 | 22.7 | 1245 |
| 1981 | 517.3 | 258.9 | 370.9 | 50.3 | 36.1 | 28.3 | 32.2 | 1294 |
| 1982 | 217.7 | 346.2 | 276.5 | 97.8 | 17.0 | 19.9 | 38.0 | 1013 |
| 1983 | 603.1 | 178.7 | 334.6 | 61.2 | 38.7 | 10.8 | 39.2 | 1266 |
| 1984 | 545.1 | 378.9 | 198.7 | 65.4 | 21.4 | 24.9 | 24.2 | 1258 |
| 1985 | 428.0 | 376.4 | 339.6 | 34.4 | 20.6 | 11.9 | 30.1 | 1241 |
| 1986 | 297.4 | 289.2 | 414.7 | 114.2 | 7.0 | 5.9 | 20.3 | 1149 |
| 1987 | 161.2 | 214.5 | 329.7 | 241.2 | 65.6 | 4.4 | 18.3 | 1035 |
| 1988 | 433.0 | 127.5 | 237.2 | 159.2 | 120.7 | 42.3 | 14.2 | 1134 |
| 1989 | 390.2 | 370.2 | 146.5 | 69.8 | 65.1 | 68.4 | 35.8 | 1146 |
| 1990 | 420.2 | 316.4 | 412.6 | 26.8 | 12.6 | 22.5 | 48.7 | 1260 |
| 1991 | 576.1 | 313.8 | 342.5 | 119.4 | 3.8 | 2.6 | 36.6 | 1395 |
| 1992 | 346.8 | 355.1 | 331.4 | 80.9 | 24.7 | 1.2 | 17.7 | 1158 |
| 1993 | 210.6 | 249.8 | 339.1 | 110.2 | 14.7 | 6.8 | 11.0 | 942 |
| 1994 | 169.7 | 153.2 | 284.0 | 105.9 | 34.9 | 6.0 | 10.6 | 764 |
| 1995 | 90.0 | 211.7 | 161.4 | 115.1 | 41.5 | 18.4 | 8.4 | 647 |
| 1996 | 133.0 | 132.6 | 276.2 | 15.6 | 12.1 | 9.5 | 10.5 | 590 |

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6+ | Total |
|---|---|---|---|---|---|---|---|---|
| 1997 | 154.6 | 133.8 | 216.8 | 62.3 | 1.5 | 2.4 | 9.0 | 580 |
| 1998 | 392.9 | 147.9 | 174.0 | 41.9 | 11.7 | 0.5 | 7.1 | 776 |
| 1999 | 177.3 | 247.7 | 172.8 | 30.9 | 8.7 | 4.2 | 3.5 | 645 |
| 2000 | 66.6 | 208.7 | 225.2 | 48.7 | 9.3 | 3.6 | 4.5 | 567 |
| 2001 | 234.1 | 122.5 | 298.8 | 81.8 | 12.0 | 3.3 | 3.9 | 756 |
| 2002 | 339.4 | 186.2 | 183.5 | 95.7 | 24.9 | 5.4 | 3.8 | 839 |
| 2003 | 308.3 | 269.4 | 172.8 | 53.3 | 30.8 | 11.8 | 4.8 | 851 |
| 2004 | 113.3 | 218.8 | 284.8 | 42.1 | 19.2 | 17.0 | 10.8 | 706 |
| 2005 | 258.1 | 139.6 | 229.1 | 118.9 | 13.8 | 8.4 | 16.1 | 784 |
| 2006 | 237.9 | 303.6 | 210.5 | 103.5 | 50.1 | 6.2 | 10.6 | 922 |
| 2007 | 282.0 | 217.7 | 386.9 | 126.3 | 37.6 | 21.2 | 7.0 | 1079 |
| 2008 | 541.8 | 241.1 | 243.6 | 205.5 | 58.2 | 18.7 | 18.2 | 1327 |
| 2009 | 297.3 | 309.4 | 256.0 | 133.7 | 86.5 | 30.7 | 21.8 | 1135 |
| 2010 | 690.2 | 243.1 | 273.4 | 127.9 | 59.8 | 43.3 | 32.5 | 1470 |
| 2011 | 422.2 | 490.1 | 240.2 | 131.7 | 46.7 | 26.4 | 36.0 | 1393 |
| 2012 | 291.3 | 293.9 | 461.2 | 109.5 | 51.8 | 18.8 | 35.7 | 1262 |
| 2013 | 339.8 | 220.3 | 281.3 | 250.9 | 41.2 | 24.9 | 30.2 | 1189 |
| 2014 | 369.1 | 257.0 | 218.1 | 162.5 | 123.3 | 21.3 | 41.4 | 1193 |
| 2015 | 300.3 | 279.0 | 250.5 | 114.0 | 74.3 | 62.8 | 28.5 | 1109 |
| 2016 | 457.0 | 227.0 | 269.3 | 122.5 | 45.5 | 34.4 | 52.6 | 1208 |

**Table 6.4.1.1** Likelihood components for the base run and all sensitivity runs.

| Run | total | unwgt | cRn L | cRs L | cBn L | cBs L | SAD lenc | NAD lenc | cRn agec | cRs agec | cBn agec | cBs agec | SAD | NAD | JAI | priors | SRfit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base run | -4314 | -4299 | 0.14 | 1.46 | 0.05 | 0.07 | -1470 | -1348 | -605 | -548 | -295 | -303 | 57.9 | 67.6 | 143.0 | -11.3 | -7.4 |
| Am-076 | -4286 | -4281 | 0.07 | 0.62 | 0.02 | 0.03 | -1471 | -1346 | -607 | -546 | -295 | -303 | 47.7 | 96.7 | 142.1 | 1.6 | -8.3 |
| Am-089 | -3129 | -3113 | 0.02 | 0.10 | 0.00 | 0.01 | -1471 | 0 | -610 | -546 | -296 | -309 | 60.1 | 0.0 | 58.4 | -11.3 | -7.1 |
| Am-090 | -4298 | -4282 | 0.15 | 0.76 | 0.10 | 0.06 | -1470 | -1348 | -604 | -545 | -292 | -305 | 50.5 | 81.4 | 148.7 | -11.3 | -7.3 |
| Am-091 | -4312 | -4299 | 0.13 | 1.94 | 0.05 | 0.08 | -1470 | -1346 | -604 | -548 | -294 | -302 | 63.3 | 67.1 | 131.1 | -11.3 | -6.4 |
| Am-092 | -4289 | -4272 | 0.12 | 1.62 | 0.06 | 0.08 | -1470 | -1347 | -602 | -544 | -295 | -303 | 57.9 | 73.0 | 156.3 | -11.3 | -8.5 |
| Am-100 | -4286 | -4281 | 0.07 | 0.62 | 0.02 | 0.03 | -1471 | -1346 | -607 | -546 | -295 | -303 | 47.65 | 96.73 | 142.07 | 1.56 | -8.3 |
| Am-101 | -3129 | -3113 | 0.02 | 0.10 | 0.00 | 0.01 | -1471 | 0 | -610 | -546 | -296 | -309 | 60.11 | 0.0 | 58.4 | -11.3 | -7.1 |
| Am-102 | -4298 | -4282 | 0.15 | 0.76 | 0.10 | 0.06 | -1470 | -1348 | -604 | -545 | -292 | -305 | 50.54 | 81.4 | 148.7 | -11.3 | -7.3 |
| Am-103 | -4312 | -4299 | 0.13 | 1.94 | 0.05 | 0.08 | -1470 | -1346 | -604 | -548 | -294 | -302 | 63.29 | 67.1 | 131.1 | -11.3 | -6.4 |

**Table 6.4.1.2** Standard deviation of the normalized residuals for the base run and each sensitivity run.

| Run | SAD lenc | NAD lenc | cRn agec | cRs agec | cBn agec | cBs agec | SAD | NAD | JAI |
|---|---|---|---|---|---|---|---|---|---|
| Base run | 0.35 | 0.41 | 1.08 | 1.28 | 1.18 | 1.15 | 2.11 | 1.94 | 2.24 |
| Am-076 | 0.37 | 0.35 | 1.06 | 1.32 | 1.07 | 1.13 | 1.91 | 2.32 | 2.23 |
| Am-089 | 0.26 | | 1.03 | 1.33 | 0.96 | 0.98 | 2.15 | | 1.43 |
| Am-090 | 0.37 | 0.36 | 1.12 | 1.34 | 1.13 | 1.13 | 1.97 | 2.13 | 2.28 |
| Am-091 | 0.34 | 0.41 | 1.10 | 1.27 | 1.23 | 1.17 | 2.21 | 1.93 | 2.15 |
| Am-092 | 0.35 | 0.41 | 1.08 | 1.32 | 1.17 | 1.14 | 2.11 | 2.01 | 2.33 |
| Am-100 | 0.37 | 0.35 | 1.06 | 1.32 | 1.07 | 1.13 | 1.91 | 2.32 | 2.23 |
| Am-101 | 0.26 | 0.21 | 1.03 | 1.33 | 0.96 | 0.98 | 2.15 | 5.03 | 1.43 |
| Am-102 | 0.37 | 0.36 | 1.12 | 1.34 | 1.13 | 1.13 | 1.97 | 2.13 | 2.28 |
| Am-103 | 0.34 | 0.41 | 1.1 | 1.27 | 1.23 | 1.17 | 2.21 | 1.93 | 2.15 |

**Table 6.4.1.3** Estimated $R_0$ and index catchabilities (*q*) from each of the sensitivity runs.

| Run | $R_0$ | *q* NAD | *q2 NAD* | *q* SAD | $q_1$ JAI | $q_2$ JAI |
|---|---|---|---|---|---|---|
| Base run | 13.78 | 2.25 | | 0.21 | 0.10 | 0.06 |
| Am-076 | 16.65 | 0.58 | | 0.19 | 0.08 | 0.05 |
| Am-089 | 22.83 | | | 0.10 | 0.07 | 0.03 |
| Am-090 | 63.33 | 6.79 | | 0.10 | 0.03 | 0.02 |
| Am-091 | 6.85 | 2.10 | | 0.31 | 0.18 | 0.12 |
| Am-092 | 14.35 | 2.21 | | 0.22 | 0.07 | |
| Am-100 | 13.82 | 2.25 | | 0.21 | 0.1 | 0.06 |
| Am-101 | 14.1 | 3.19 | 1.42 | 0.2 | 0.1 | 0.06 |
| Am-102 | 13.48 | 2.58 | 2.98 | 0.22 | 0.1 | 0.06 |
| Am-103 | 33.9 | 0.04 | 0.18 | 0.11 | 0.03 | 0.03 |

**Table 6.4.2.1** Likelihood components for the base run and retrospective analyses.

| Run | total | unwgt | cRn L | cRs L | cBn L | cBs L | SAD lenc | NAD lenc | cRn agec | cRs agec | cBn agec | cBs agec | SAD | NAD | JAI | priors | SRfit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base run | -4314 | -4299 | 0.14 | 1.46 | 0.05 | 0.07 | -1470 | -1348 | -605 | -548 | -295 | -303 | 57.9 | 67.6 | 143.0 | -11.3 | -7.4 |
| End year 2015 | -4195 | -4181 | 0.11 | 1.19 | 0.03 | 0.05 | -1416 | -1300 | -595 | -536 | -288 | -292 | 56.4 | 63.1 | 126.8 | -11.3 | -6.4 |
| End year 2014 | -4059 | -4046 | 0.10 | 1.10 | 0.03 | 0.05 | -1362 | -1253 | -584 | -528 | -280 | -282 | 57.2 | 64.3 | 120.9 | -11.3 | -5.6 |
| End year 2013 | -3942 | -3928 | 0.06 | 0.66 | 0.01 | 0.03 | -1309 | -1206 | -575 | -517 | -271 | -275 | 55.0 | 65.2 | 105.5 | -11.3 | -4.9 |
| End year 2012 | -3811 | -3798 | 0.06 | 0.58 | 0.01 | 0.02 | -1255 | -1160 | -565 | -509 | -262 | -270 | 51.9 | 68.3 | 102.8 | -11.3 | -5.0 |
| End year 2011 | -3674 | -3659 | 0.05 | 0.53 | 0.01 | 0.02 | -1201 | -1114 | -553 | -497 | -253 | -259 | 53.0 | 68.0 | 95.9 | -11.3 | -5.7 |
| End year 2010 | -3561 | -3547 | 0.03 | 0.28 | 0.00 | 0.01 | -1149 | -1068 | -545 | -484 | -243 | -249 | 44.1 | 64.1 | 82.5 | -11.3 | -4.7 |

**Table 6.4.2.2** Standard deviation of the normalized residuals for the base run and each retrospective run.

| Run | SAD lenc | NAD lenc | cRn agec | cRs agec | cBn agec | cBs agec | SAD | NAD | JAI |
|---|---|---|---|---|---|---|---|---|---|
| Base run | 0.35 | 0.41 | 1.08 | 1.28 | 1.18 | 1.15 | 2.11 | 1.94 | 2.24 |
| Retrospective 2015 | 0.36 | 0.38 | 1.09 | 1.30 | 1.14 | 1.16 | 2.12 | 1.90 | 2.13 |
| Retrospective 2014 | 0.34 | 0.38 | 1.10 | 1.30 | 1.14 | 1.17 | 2.18 | 1.94 | 2.10 |
| Retrospective 2013 | 0.33 | 0.36 | 1.09 | 1.34 | 1.09 | 1.09 | 2.19 | 1.99 | 1.98 |
| Retrospective 2012 | 0.33 | 0.35 | 1.09 | 1.34 | 1.10 | 1.01 | 2.17 | 2.07 | 1.97 |
| Retrospective 2011 | 0.33 | 0.35 | 1.10 | 1.36 | 1.09 | 1.00 | 2.25 | 2.09 | 1.92 |
| Retrospective 2010 | 0.29 | 0.35 | 1.12 | 1.40 | 1.05 | 1.00 | 2.10 | 2.07 | 1.80 |

**Table 6.4.2.3** Estimated $R_0$ and index catchabilities ($q$) from the retrospective analysis.

| Run | $R_0$ | $q$ NAD | $q$ SAD | $q_1$ JAI | $q_2$ JAI |
|---|---|---|---|---|---|
| Base run | 13.78 | 2.25 | 0.21 | 0.10 | 0.06 |
| Retrospective 2015 | 14.08 | 1.72 | 0.21 | 0.10 | 0.06 |
| Retrospective 2014 | 14.29 | 1.56 | 0.21 | 0.09 | 0.06 |
| Retrospective 2013 | 15.67 | 0.77 | 0.19 | 0.08 | 0.06 |
| Retrospective 2012 | 16.24 | 0.64 | 0.18 | 0.08 | 0.06 |
| Retrospective 2011 | 16.74 | 0.61 | 0.17 | 0.08 | 0.05 |
| Retrospective 2010 | 19.15 | 0.31 | 0.14 | 0.07 | 0.05 |

**Table 7.2.1.1** Fishing mortality and fecundity benchmarks (targets and thresholds) along with terminal year values from the base run of the BAM. Fecundity (FEC) is in billions of eggs.

| Reference Points | Benchmark | Current value |
|---|---|---|
| $F_{21\%\ (threshold)}$ | 1.85 | 0.51 |
| $F_{36\%\ (target)}$ | 0.80 | 0.51 |
| $FEC_{21\%\ (threshold)}$ | 57,295 | 83,486 |
| $FEC_{36\%\ (target)}$ | 99,467 | 83,486 |

**Table 7.2.2.1** Benchmarks calculated for the base run and each sensitivity run along with the 2016 values relative to the benchmark values. Values with a dash (–) indicate an extreme scenario that hit a bound on the maximum level of F.

| Run | $F_{21\%}$ | $F_{36\%}$ | $FEC_{21\%}$ | $FEC_{36\%}$ | $F_{2016}/F_{21\%}$ | $F_{2016}/F_{36\%}$ | $FEC_{2016}/FEC_{21\%}$ | $FEC_{2016}/FEC_{36\%}$ |
|---|---|---|---|---|---|---|---|---|
| Base run | 1.85 | 0.80 | 57295 | 99467 | 0.28 | 0.64 | 1.46 | 0.84 |
| Am-076 | 1.56 | 0.74 | 69203 | 120183 | 0.19 | 0.41 | 2.16 | 1.25 |
| Am-089 | 1.63 | 0.82 | 94892 | 164784 | 0.12 | 0.23 | 2.32 | 1.33 |
| Am-090 | - | 4.18 | - | 69829 | - | 0.13 | - | 1.29 |
| Am-091 | 0.91 | 0.51 | 93196 | 161886 | 0.58 | 1.05 | 0.90 | 0.52 |
| Am-092 | 1.84 | 0.80 | 59670 | 103555 | 0.30 | 0.69 | 1.32 | 0.76 |
| Am-100 | 1.85 | 0.81 | 57443 | 99725 | 0.28 | 0.64 | 1.46 | 0.84 |
| Am-101 | 1.68 | 0.76 | 58614 | 101784 | 0.26 | 0.57 | 1.75 | 1.01 |
| Am-102 | 1.93 | 0.81 | 56046 | 97269 | 0.30 | 0.70 | 1.34 | 0.77 |
| Am-103 | 1.64 | 0.82 | 140904 | 244652 | 0.09 | 0.18 | 1.88 | 1.08 |

**Table 7.2.2.2** Benchmarks calculated for the base run and each retrospective run.

| Run | $F_{21\%}$ | $F_{36\%}$ | $FEC_{21\%}$ | $FEC_{36\%}$ |
|---|---|---|---|---|
| Base run | 1.85 | 0.80 | 57295 | 99467 |
| Retrospective 2015 | 1.58 | 0.72 | 58539 | 101622 |
| Retrospective 2014 | 1.51 | 0.70 | 59411 | 103141 |
| Retrospective 2013 | 1.54 | 0.73 | 65141 | 113104 |
| Retrospective 2012 | 1.54 | 0.74 | 67485 | 117189 |
| Retrospective 2011 | 1.57 | 0.78 | 69580 | 120834 |
| Retrospective 2010 | 1.57 | 0.79 | 79593 | 138203 |

## 12.0 Figures

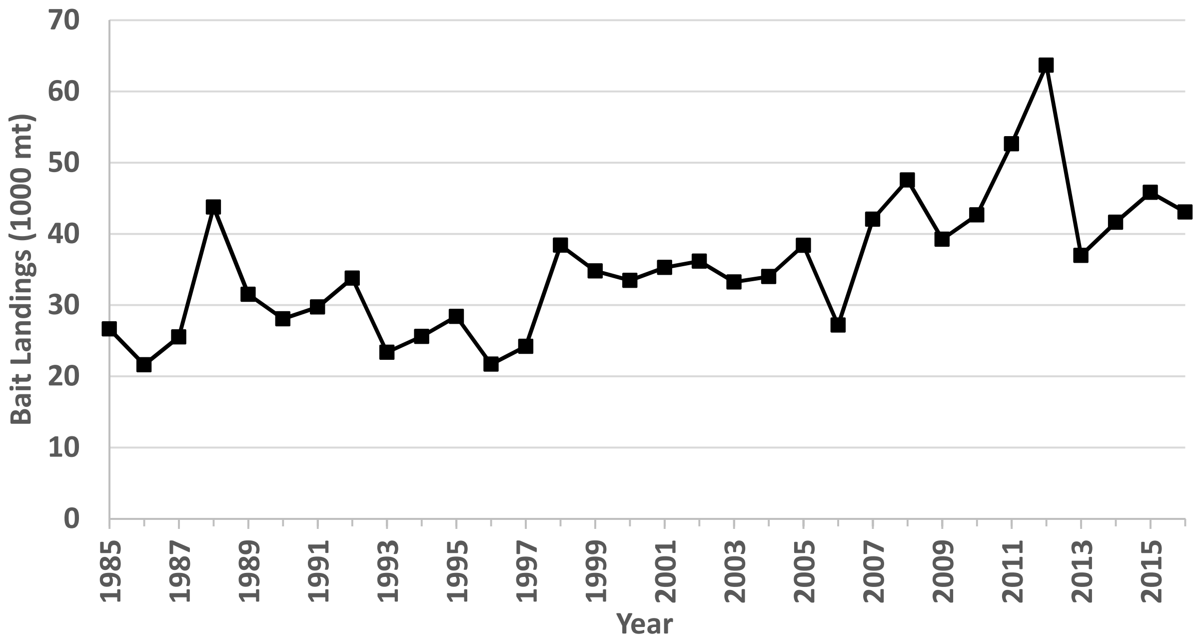



**Figure 3.2.2.1.** Atlantic menhaden bait landings (1000s mt) from 1985 to 2016.

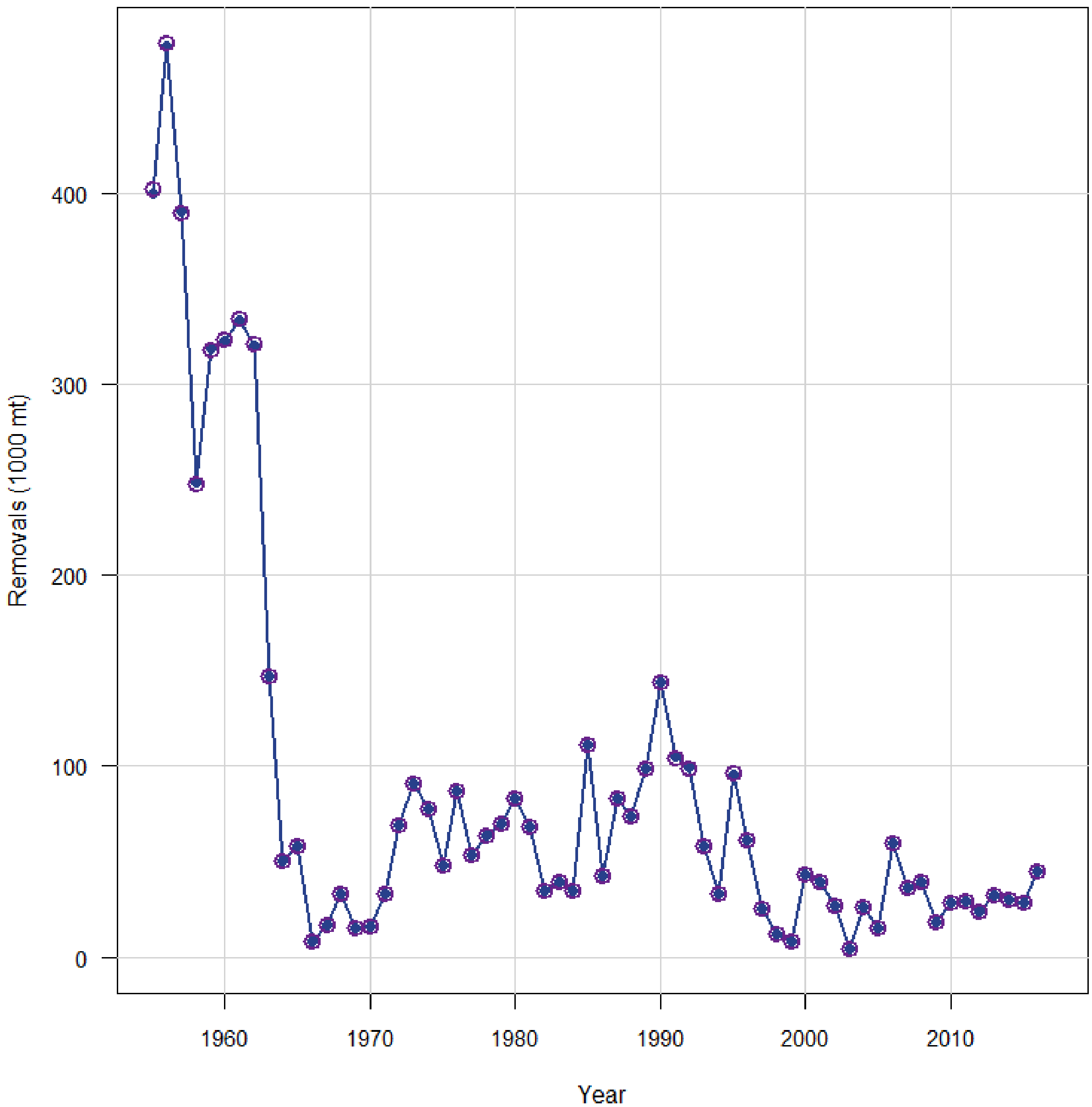



**Figure 6.1.1.** Observed and predicted removals of Atlantic menhaden from 1955-2016 from north of Virginia Eastern Shore by the commercial reduction fishery.

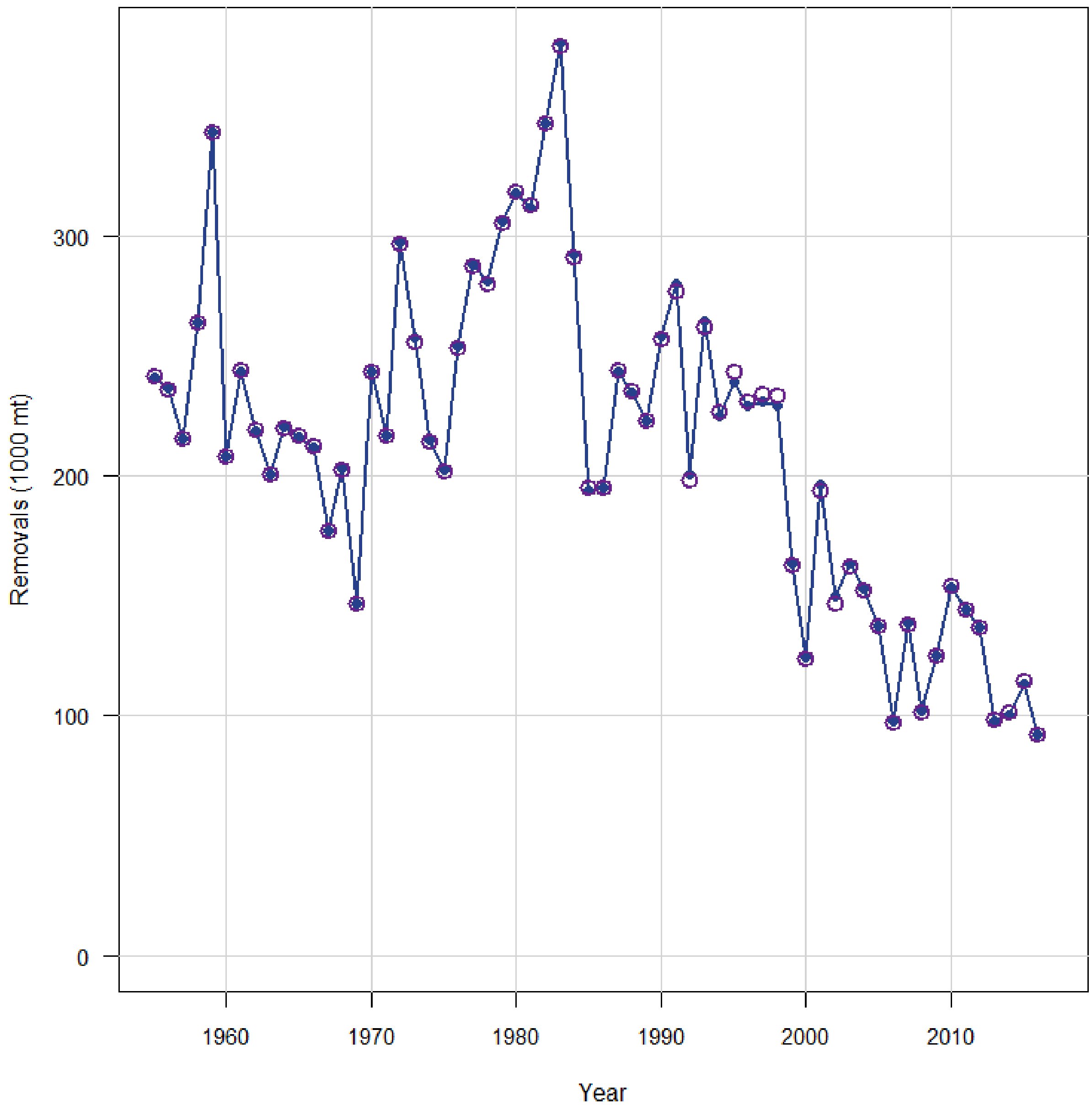



**Figure 6.1.2.** Observed and predicted removals of Atlantic menhaden from 1955-2016 from Virginia Eastern Shore and south by the commercial reduction fishery.

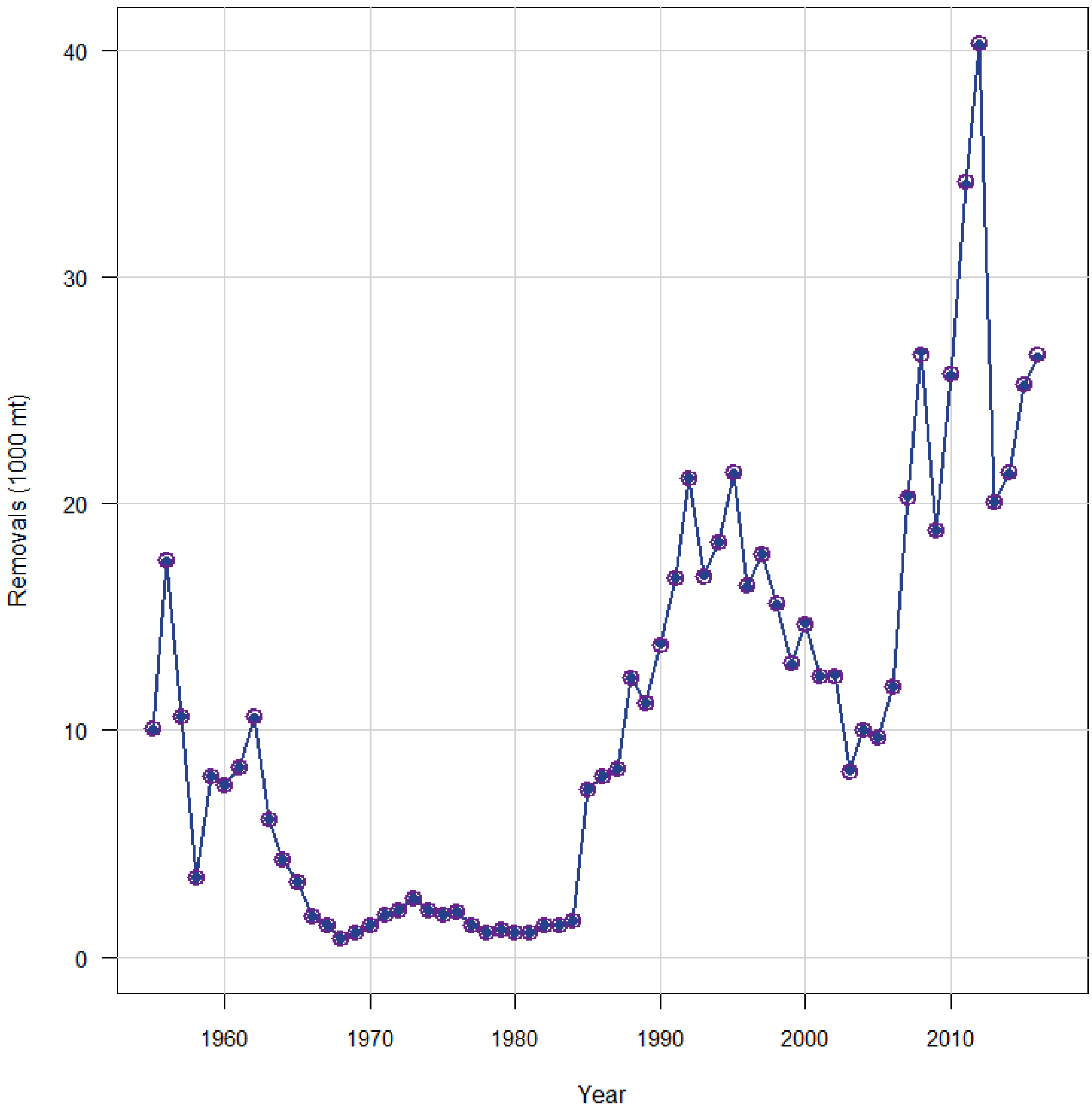



**Figure 6.1.3.** Observed and predicted removals of Atlantic menhaden from 1955-2016 from north of Virginia Eastern Shore by the commercial bait fishery.

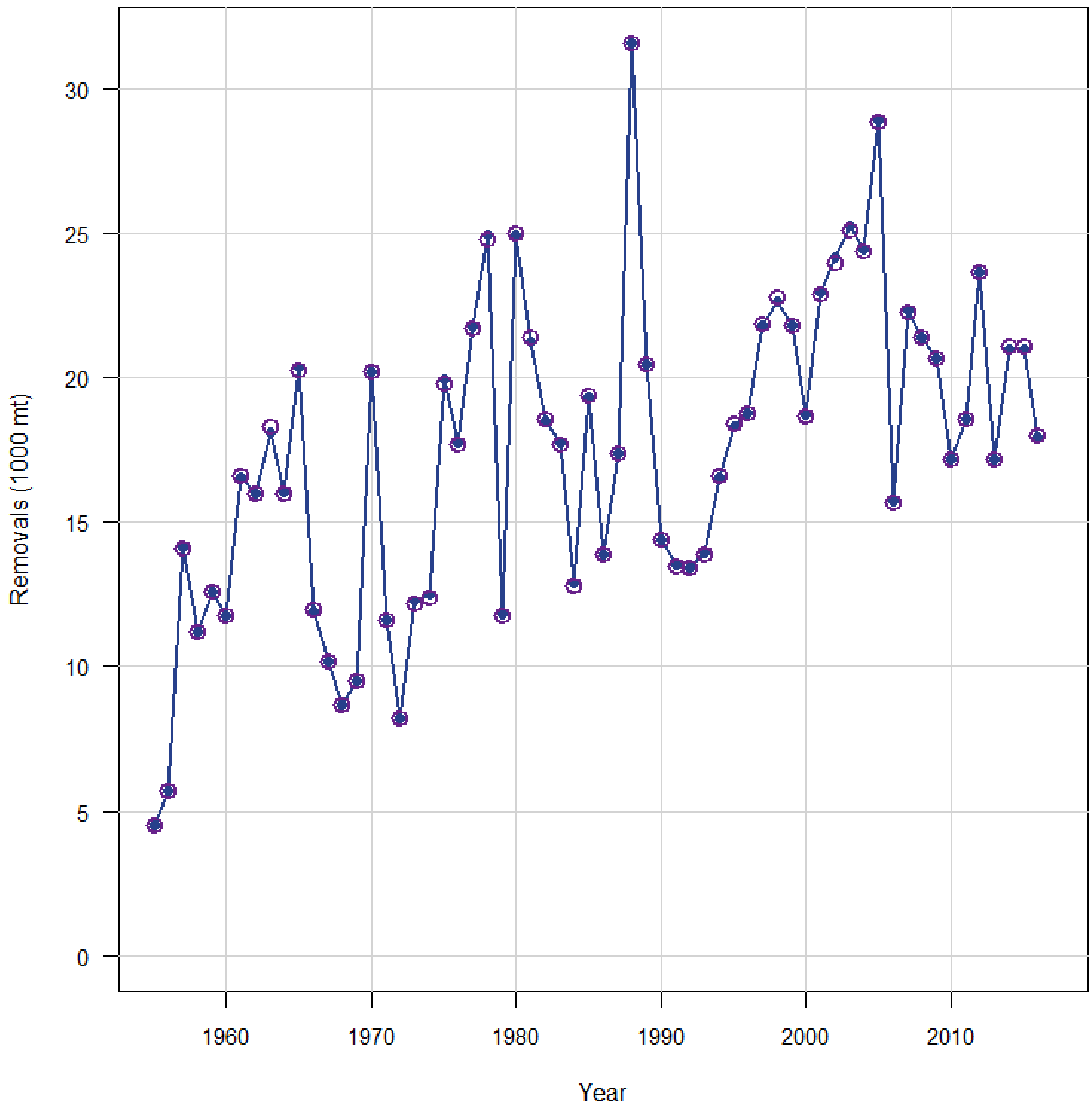



**Figure 6.1.4.** Observed and predicted removals of Atlantic menhaden from 1955-2016 from Virginia Eastern Shore and south by the commercial bait fishery.

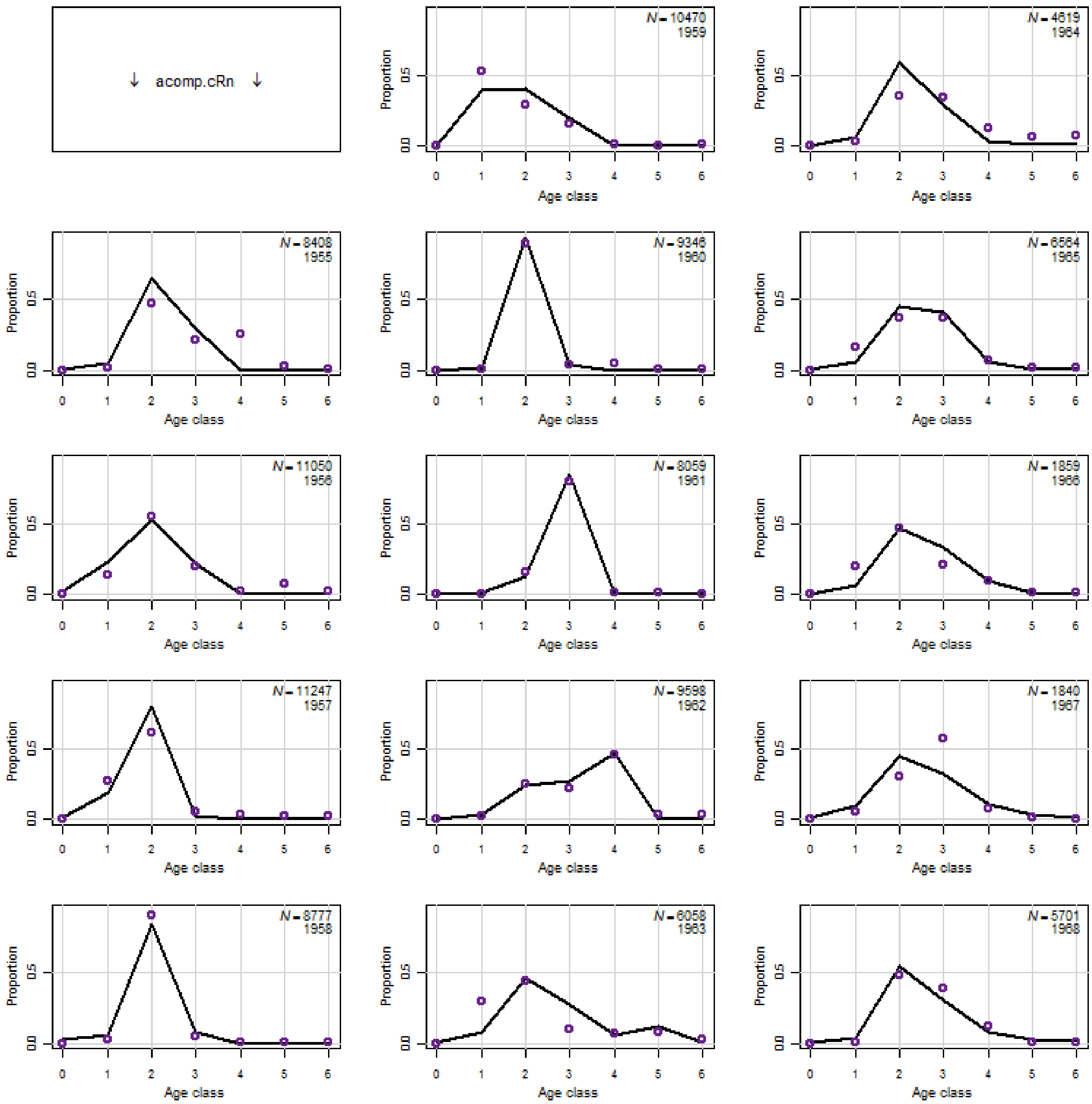



**Figure 6.1.5.** Annual observed and predicted catch-at-age of Atlantic menhaden from 1955-2016 from north of Virginia Eastern Shore by the commercial reduction fishery.

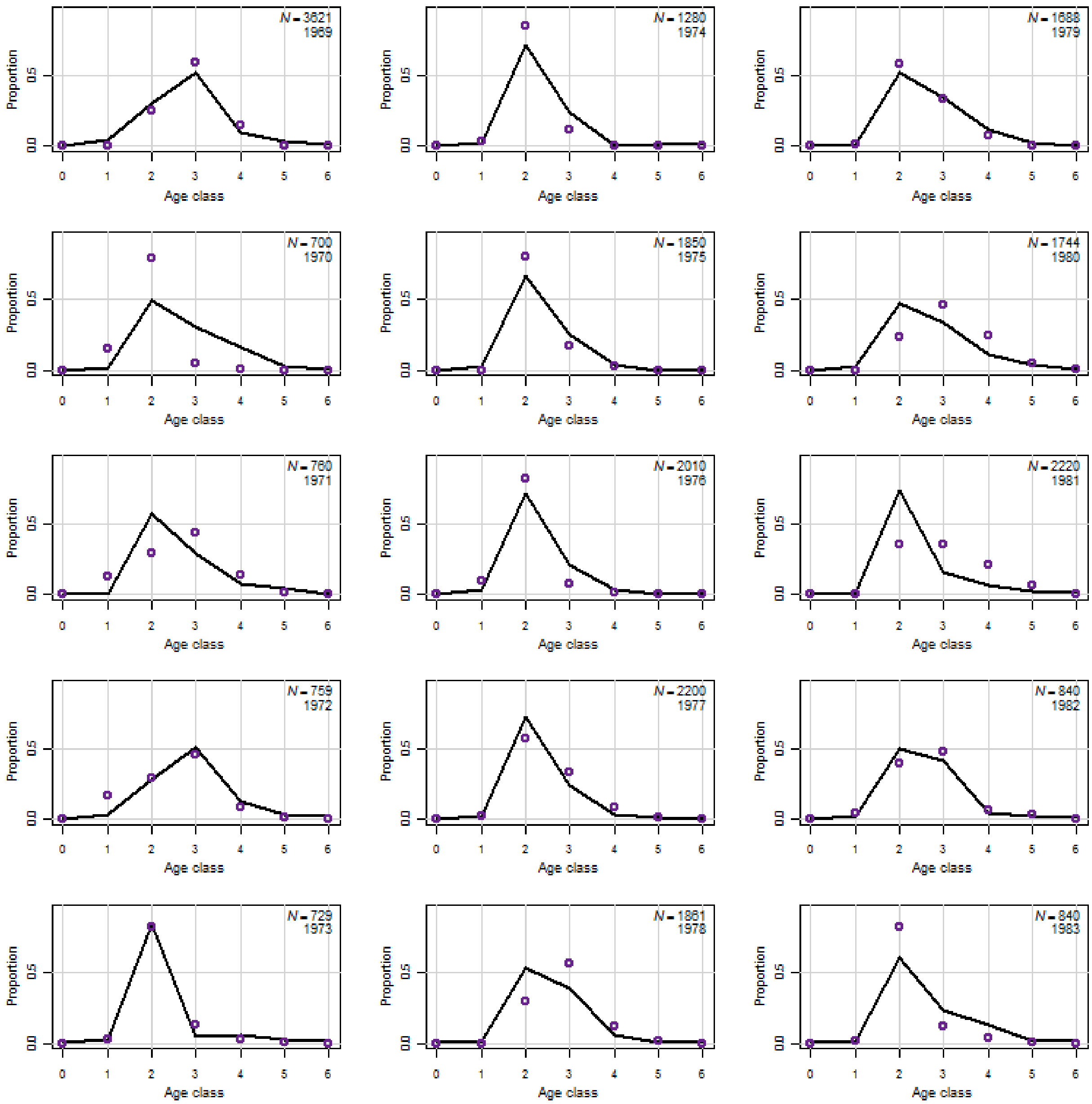
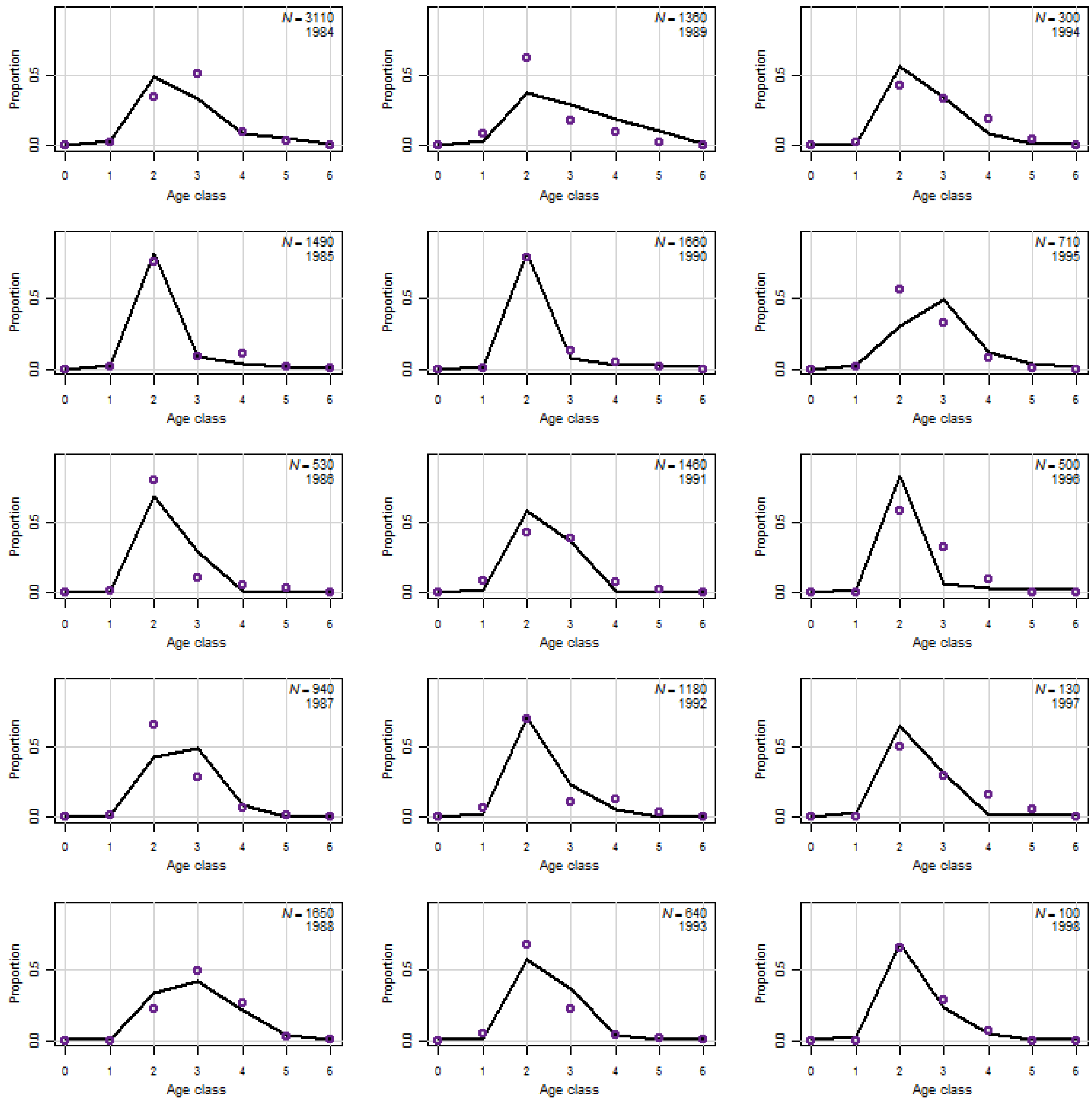



**Figure 6.1.5.** ***Continued*.**

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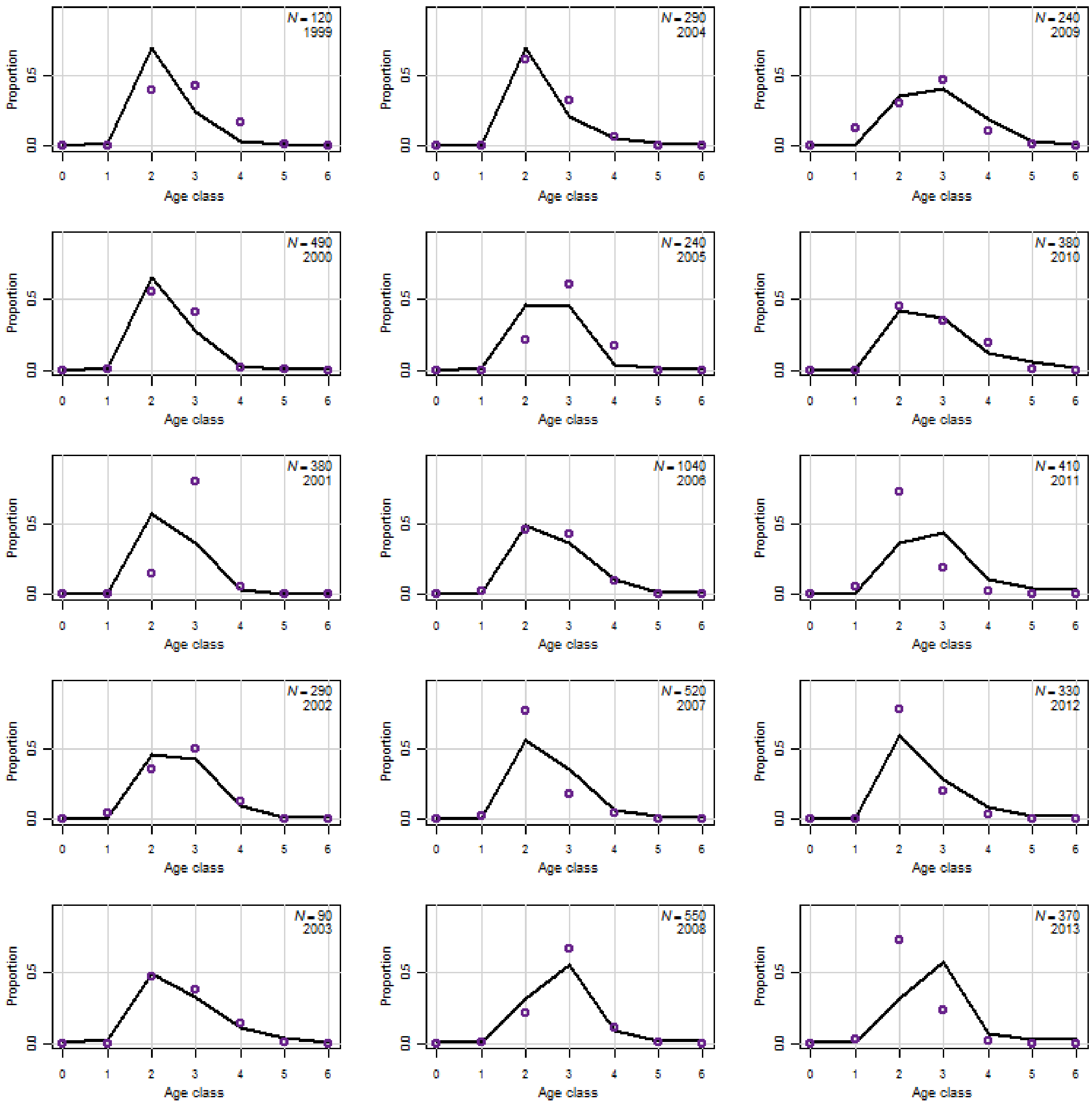



**Figure 6.1.5.** ***Continued*.**


**Figure 6.1.5. *Continued*.**

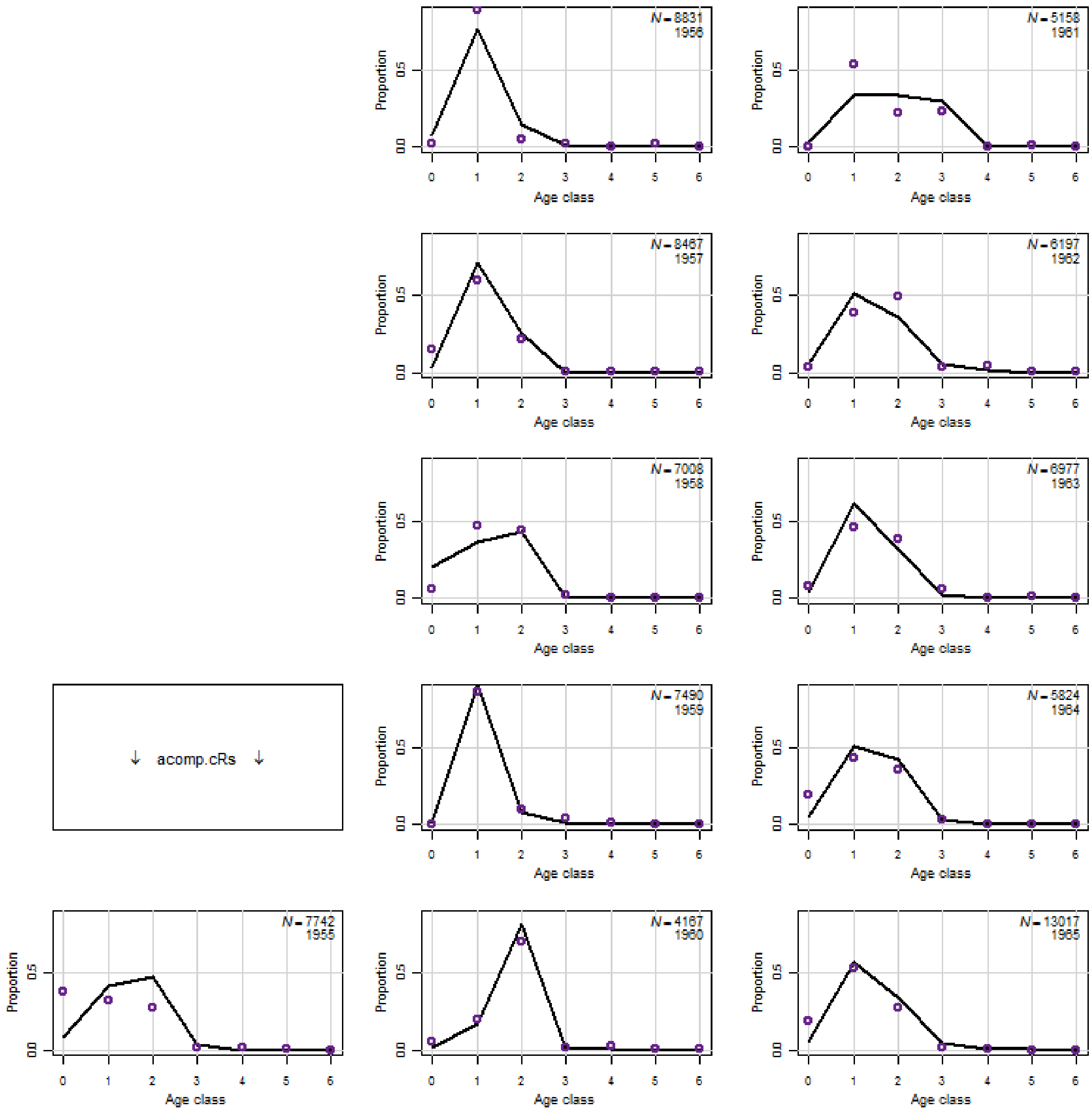
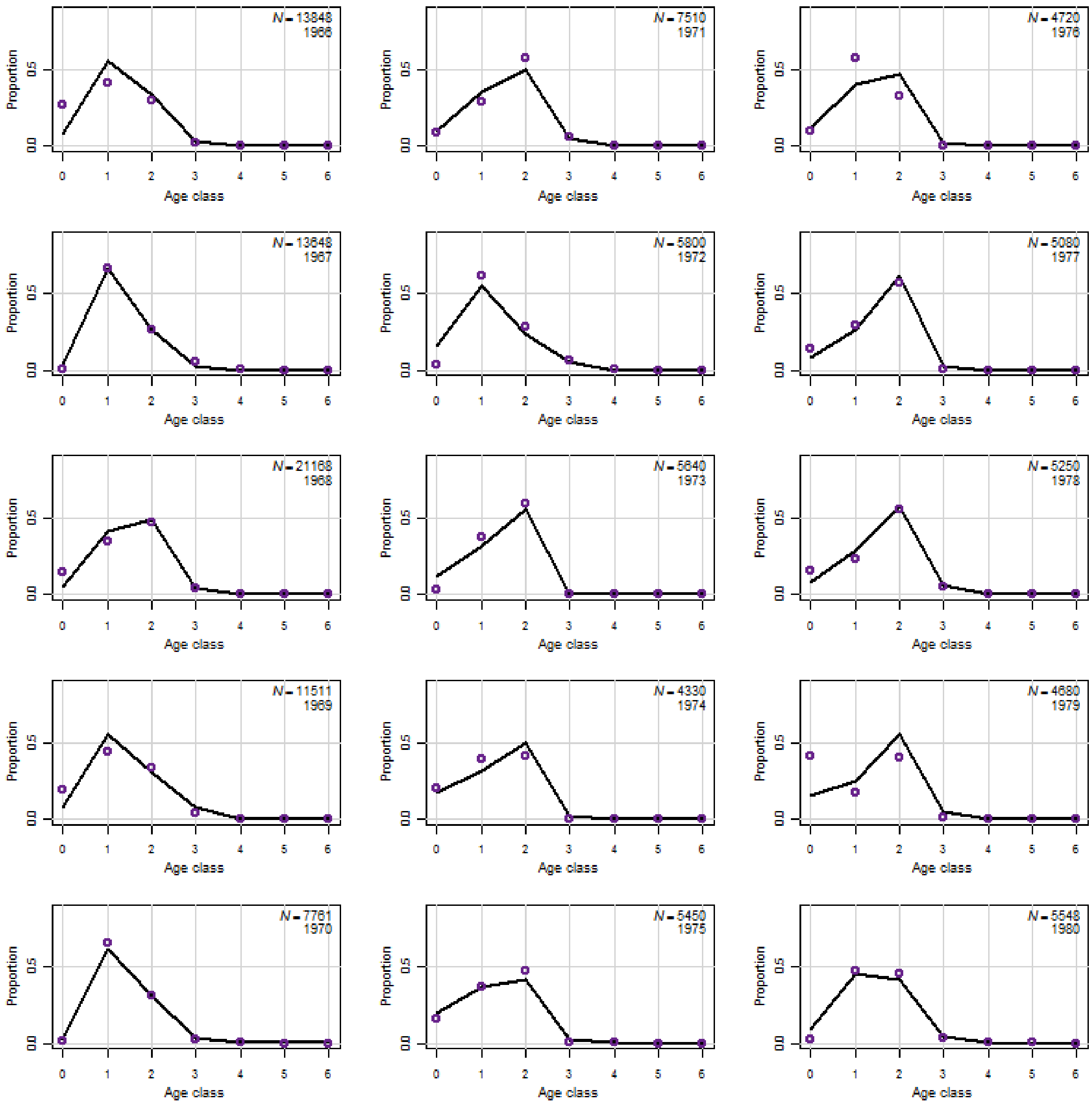



**Figure 6.1.6.** Annual observed and predicted catch-at-age of Atlantic menhaden from 1955-2016 from Virginia Eastern Shore and south by the commercial reduction fishery.

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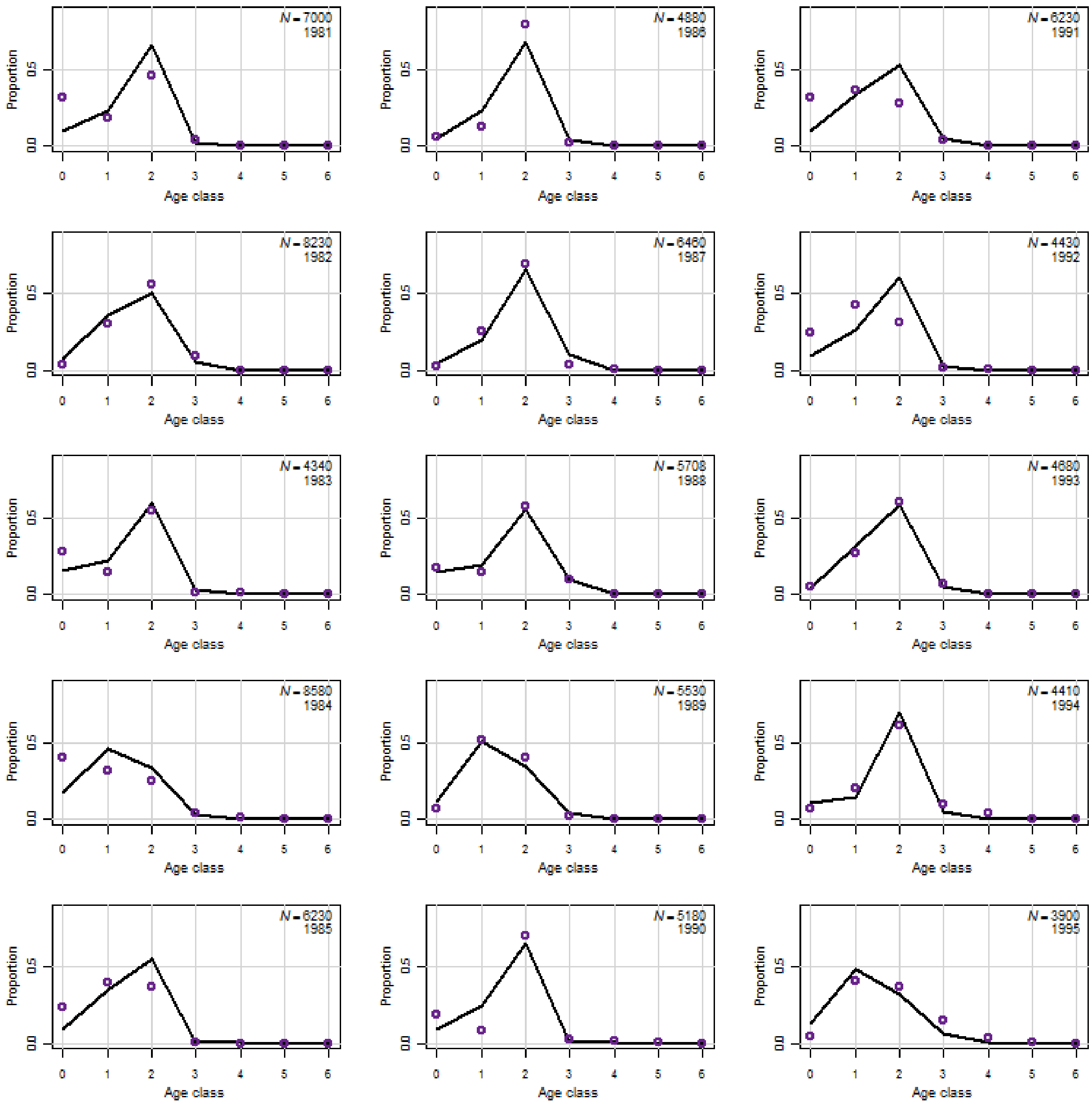


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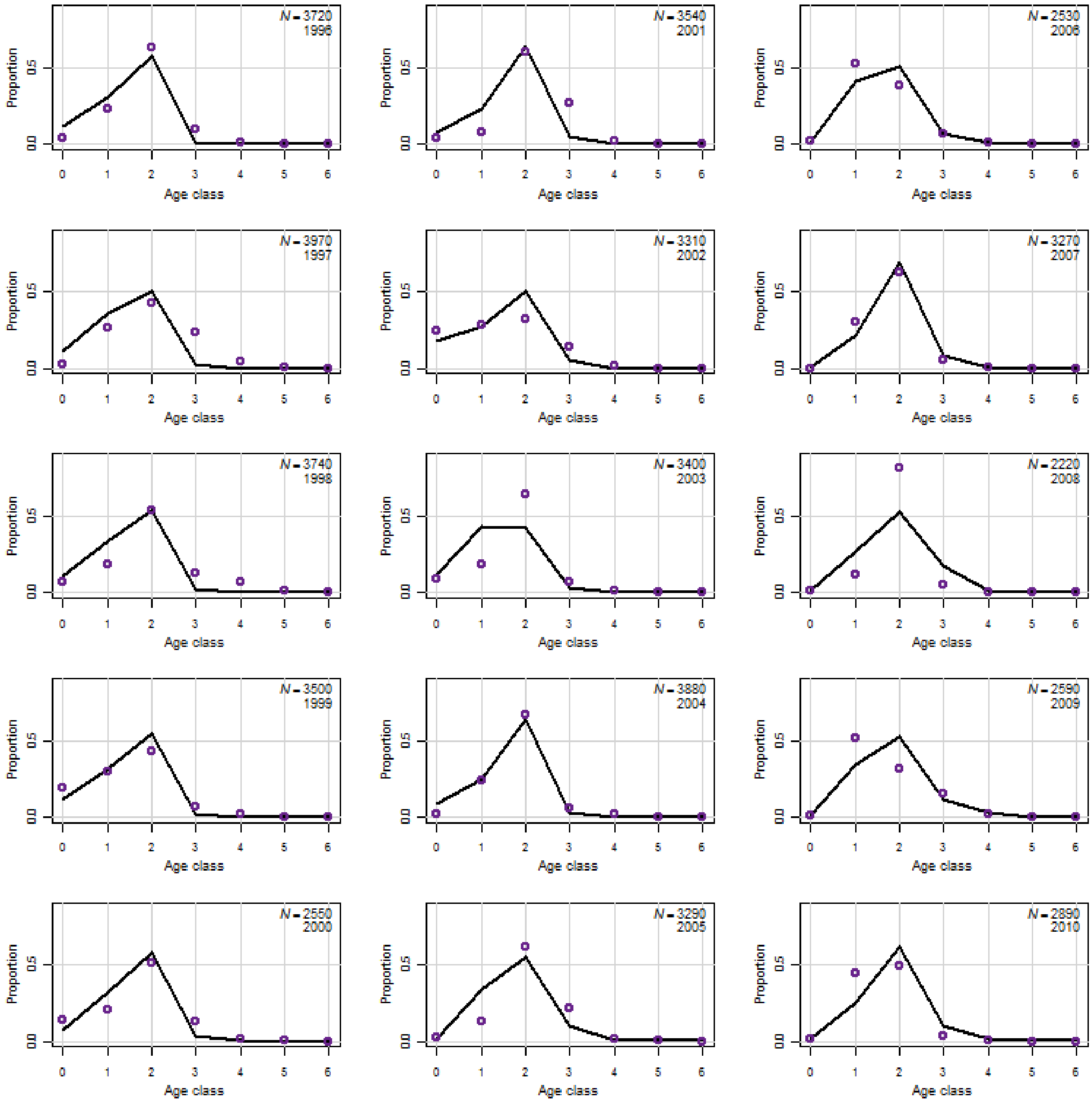


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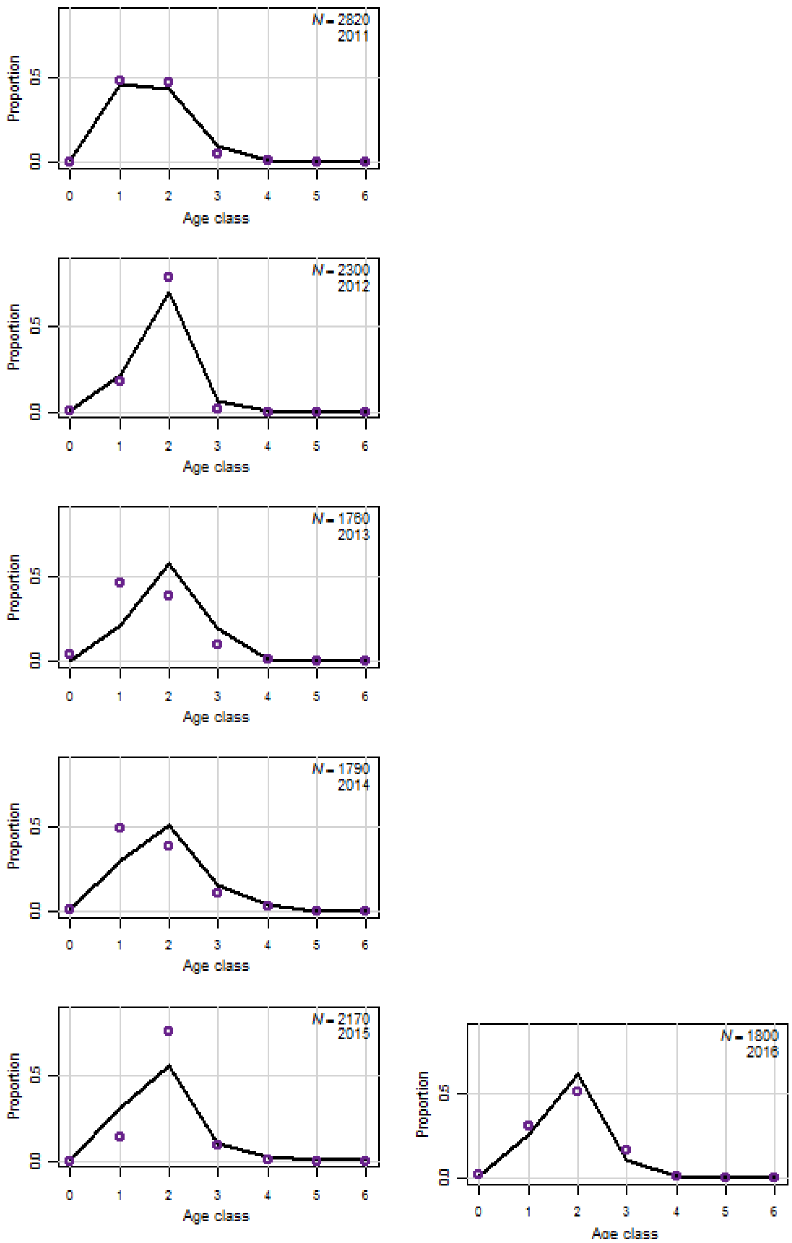


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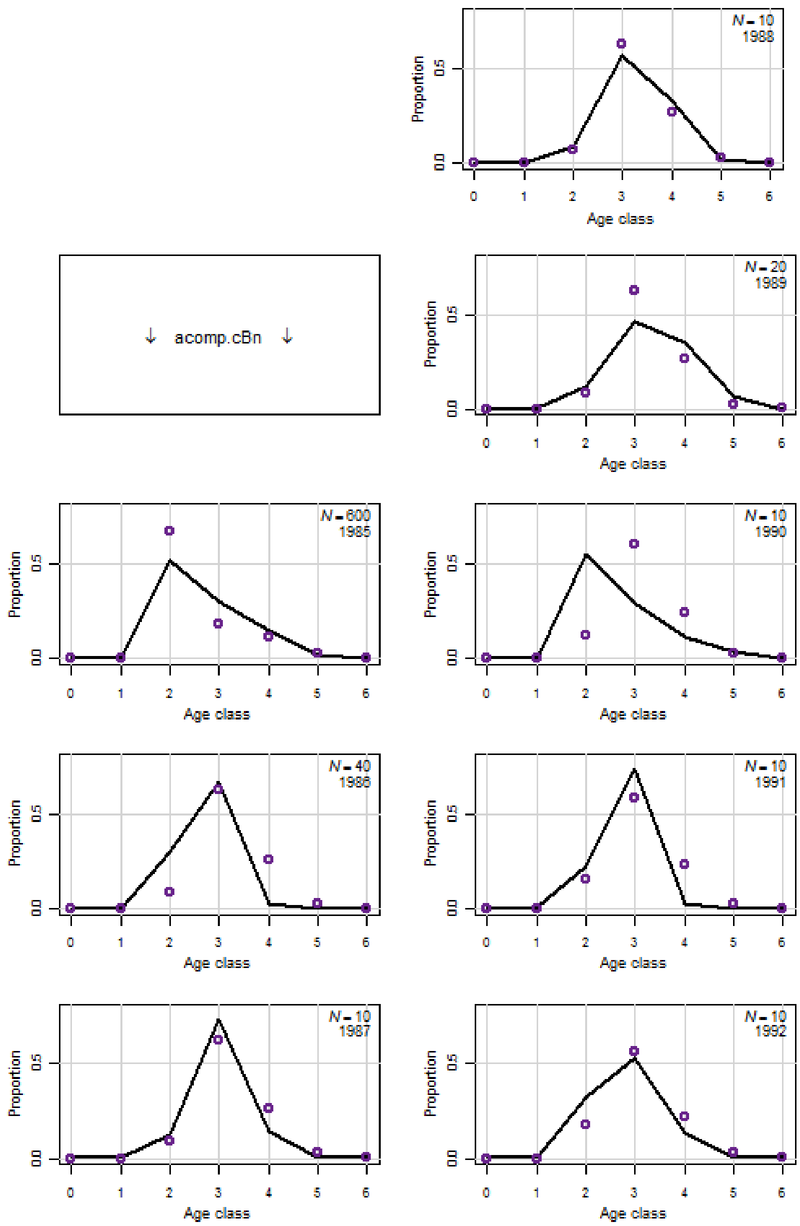
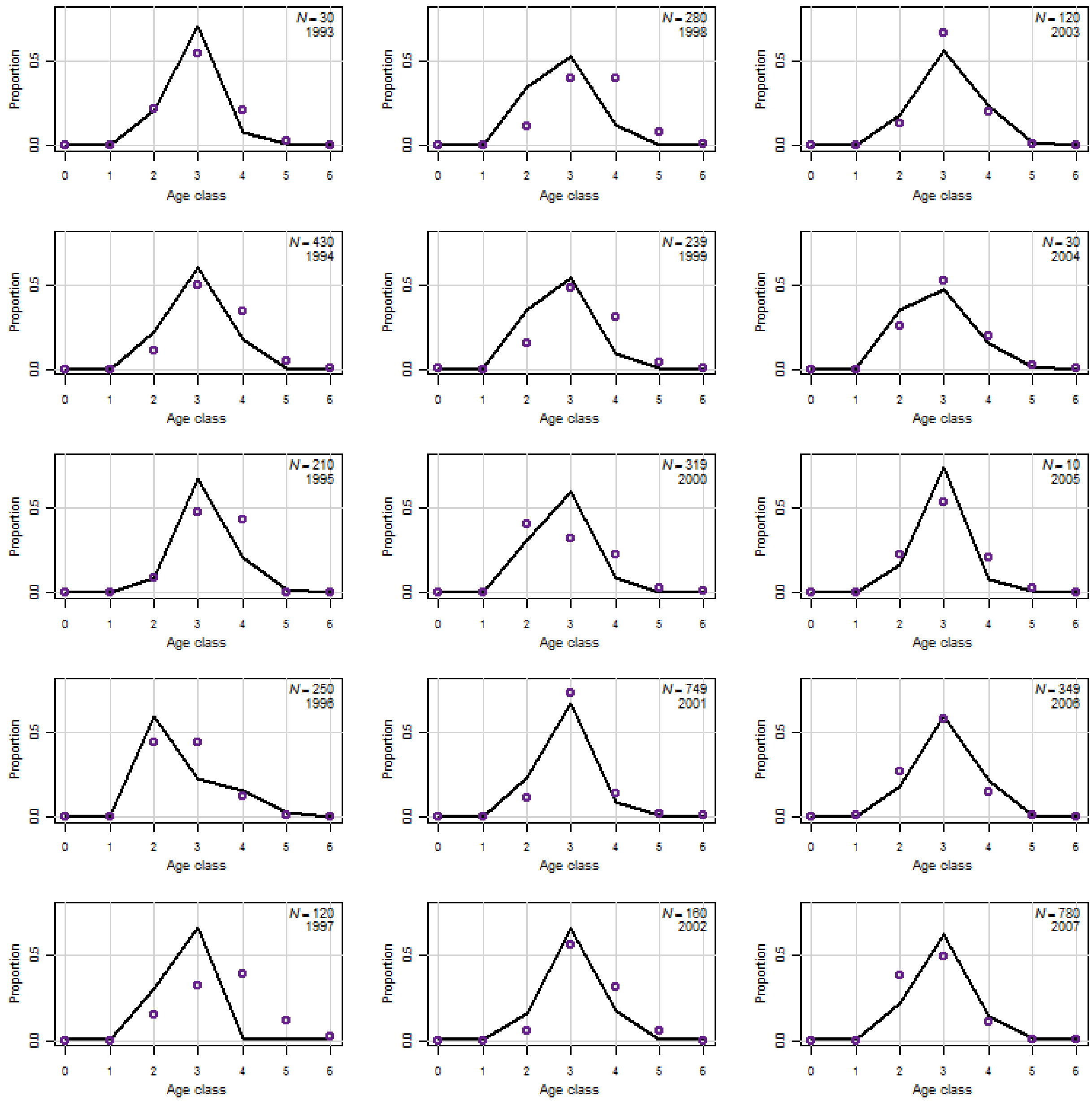



**Figure 6.1.7.** Annual observed and predicted catch-at-age of Atlantic menhaden from 1985-2016 from north of Virginia Eastern Shore by the commercial bait fishery.

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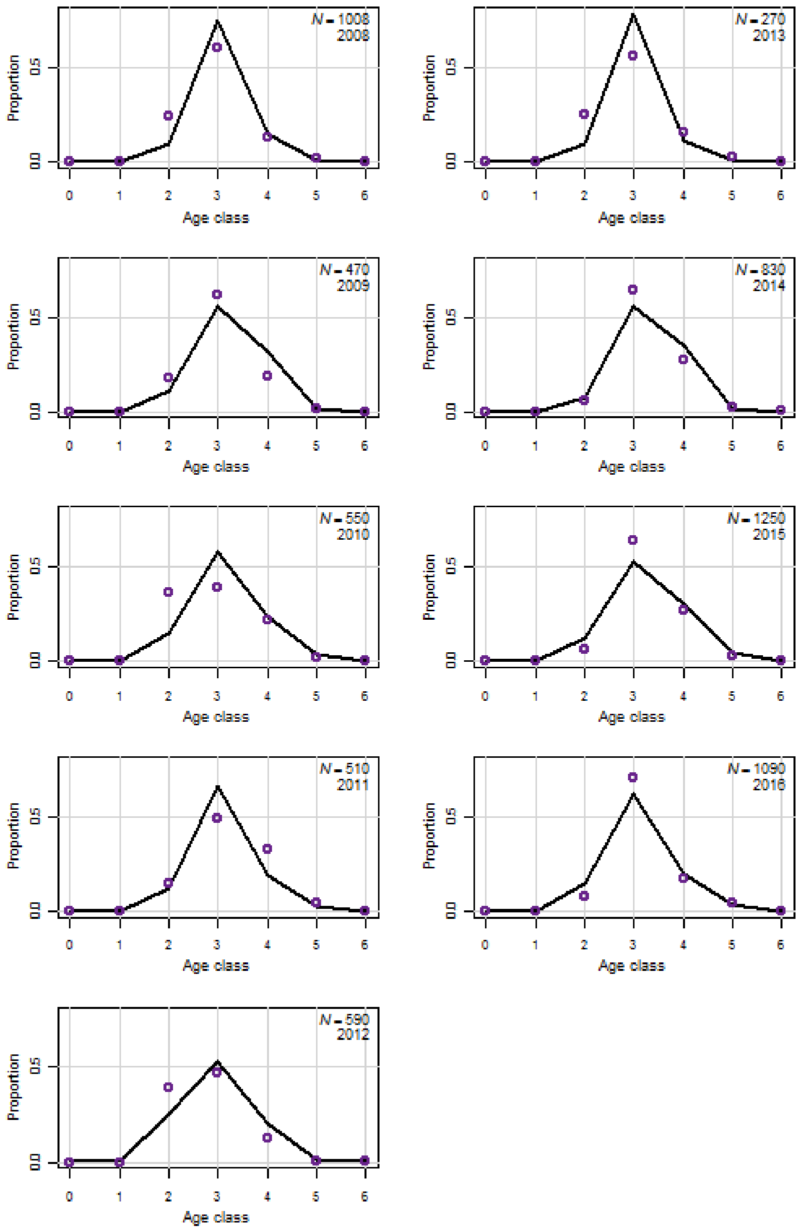


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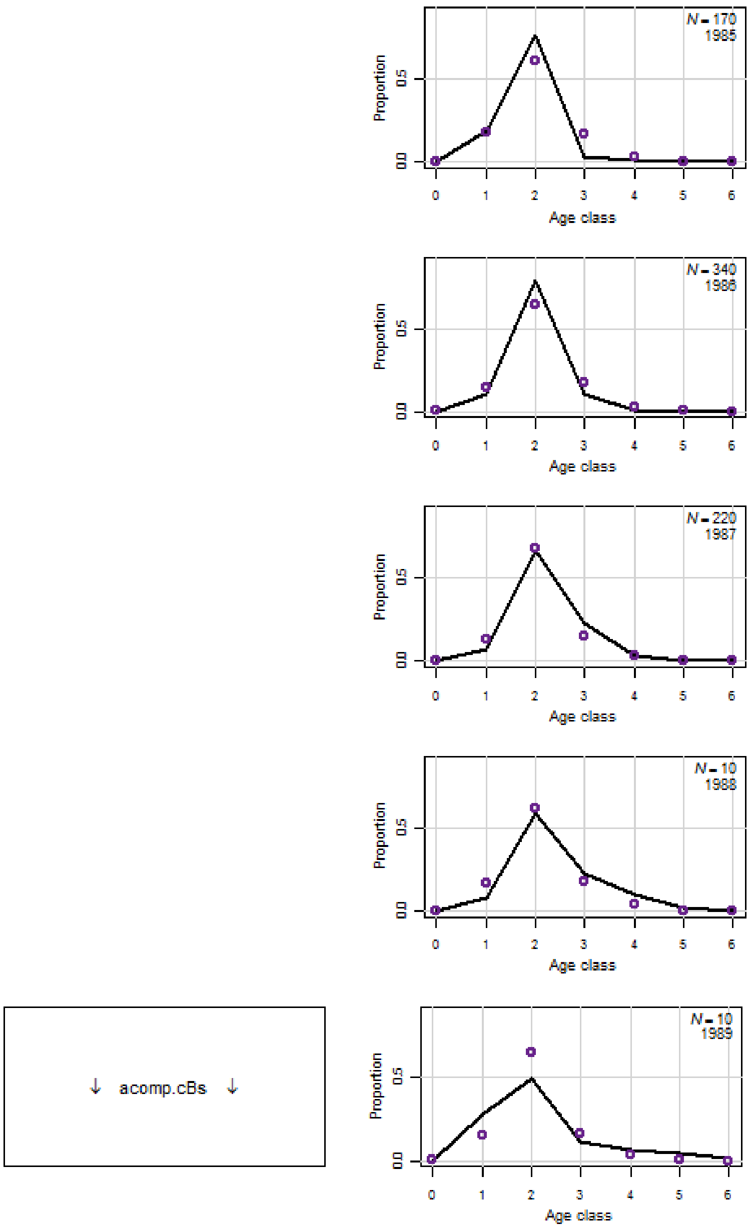
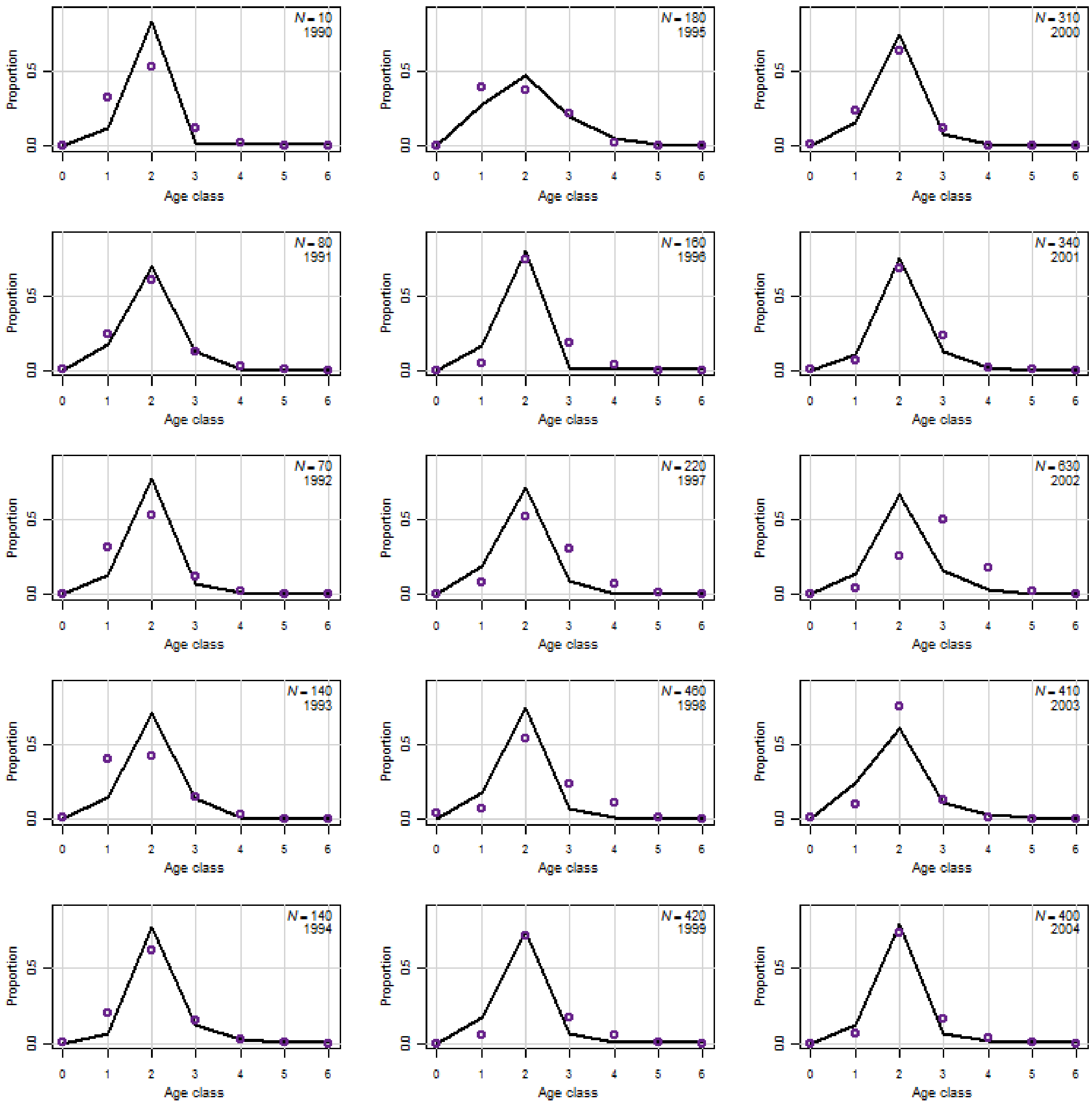



**Figure 6.1.8.** Annual observed and predicted catch-at-age of Atlantic menhaden from 1985-2016 from Virginia Eastern Shore and south by the commercial bait fishery.

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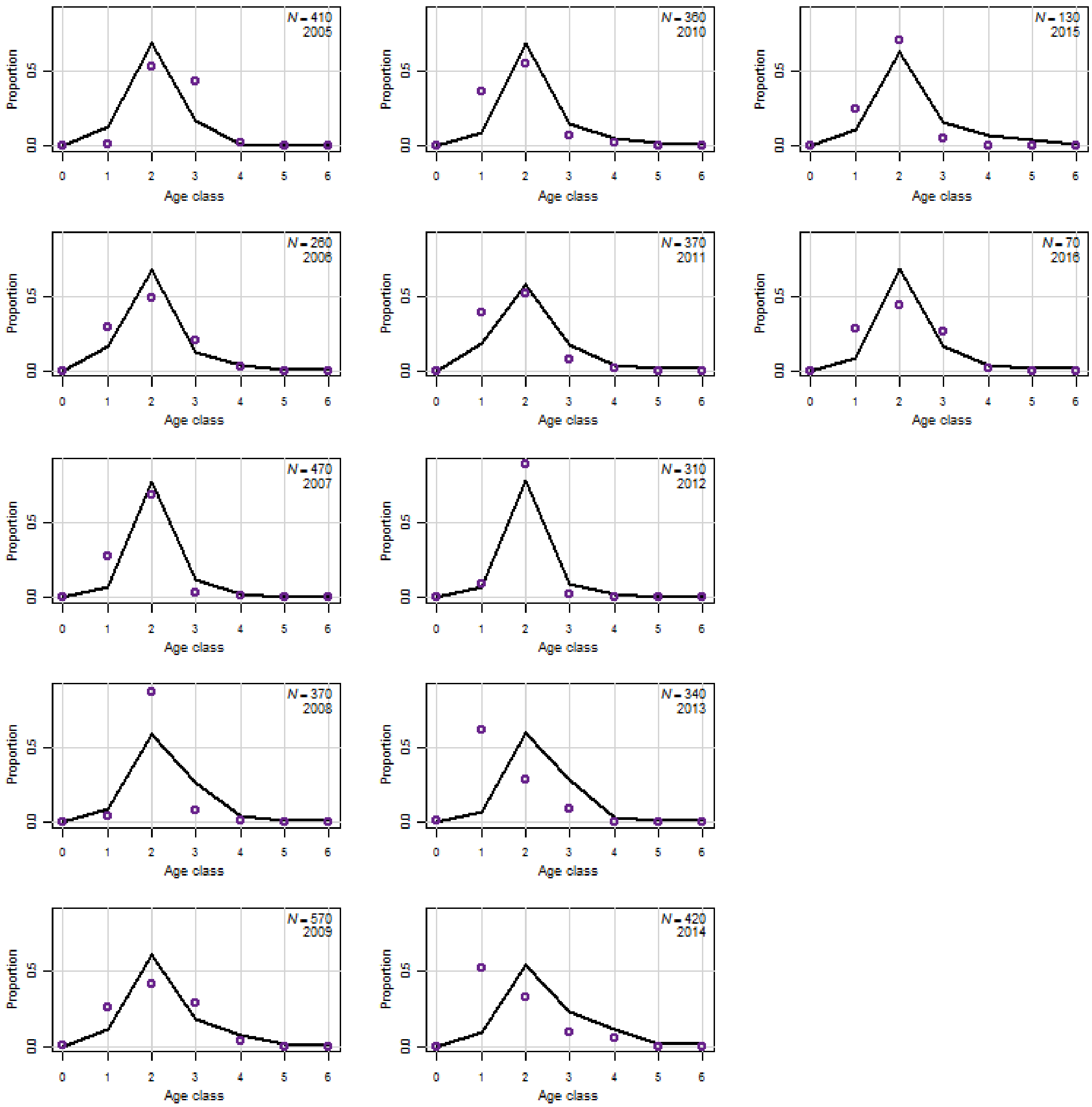


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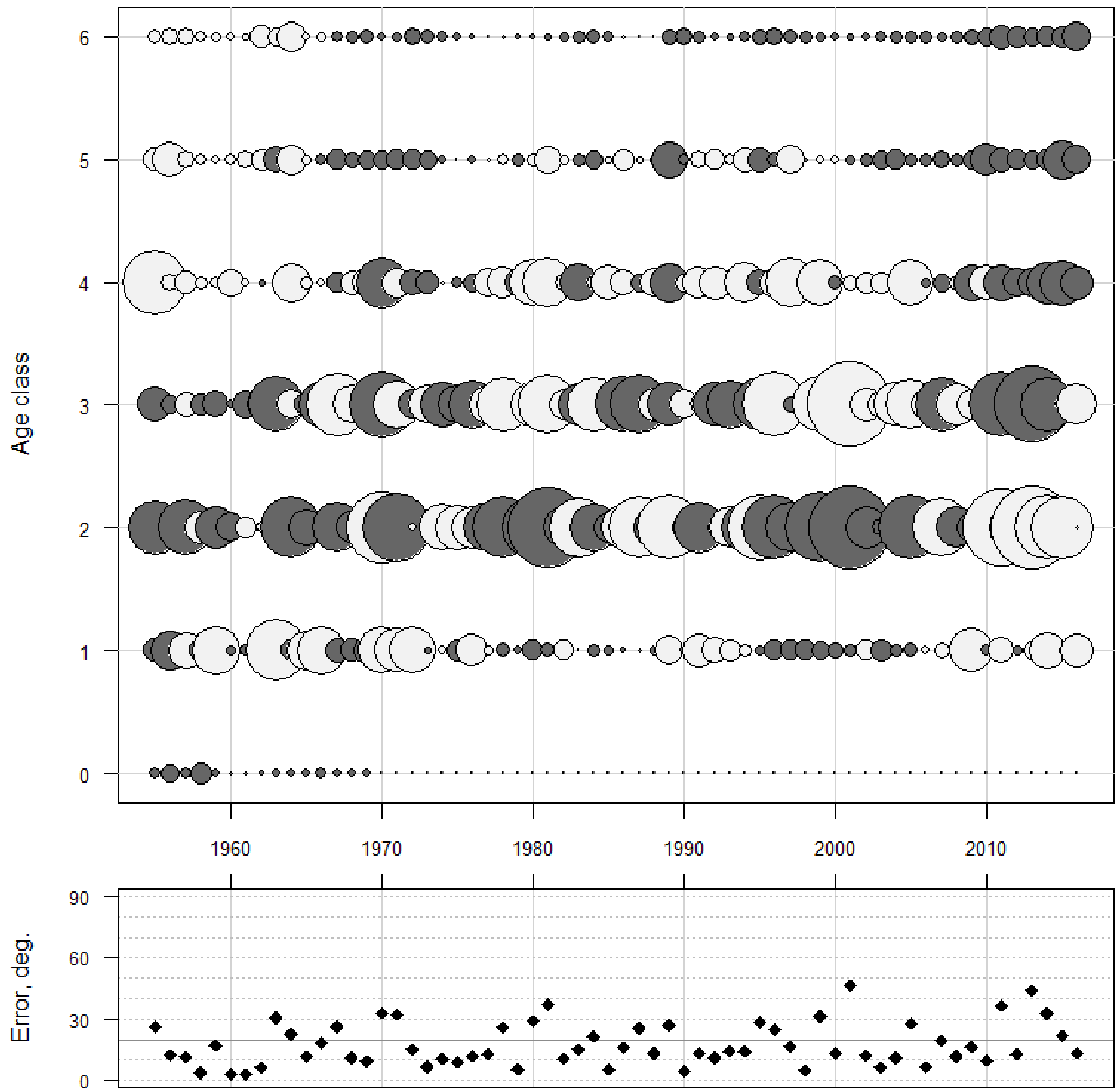
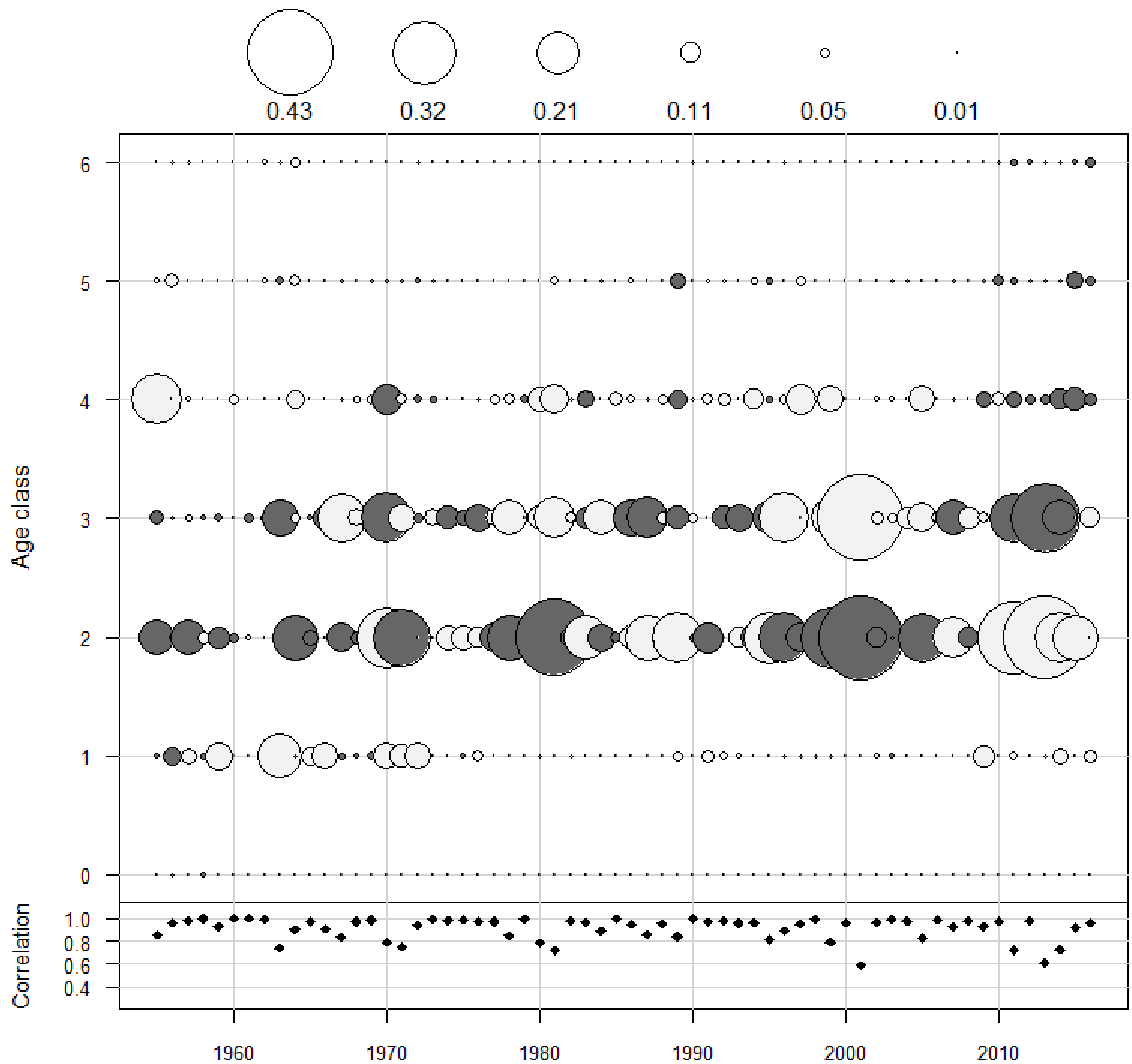



**Figure 6.1.9.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted catch-at-age for Atlantic menhaden from 1955-2016 from north of Virginia Eastern Shore by the commercial reduction fishery. The error degrees in the upper panel represents a composite fit by year across ages, while in the lower plot contains correlations between years.

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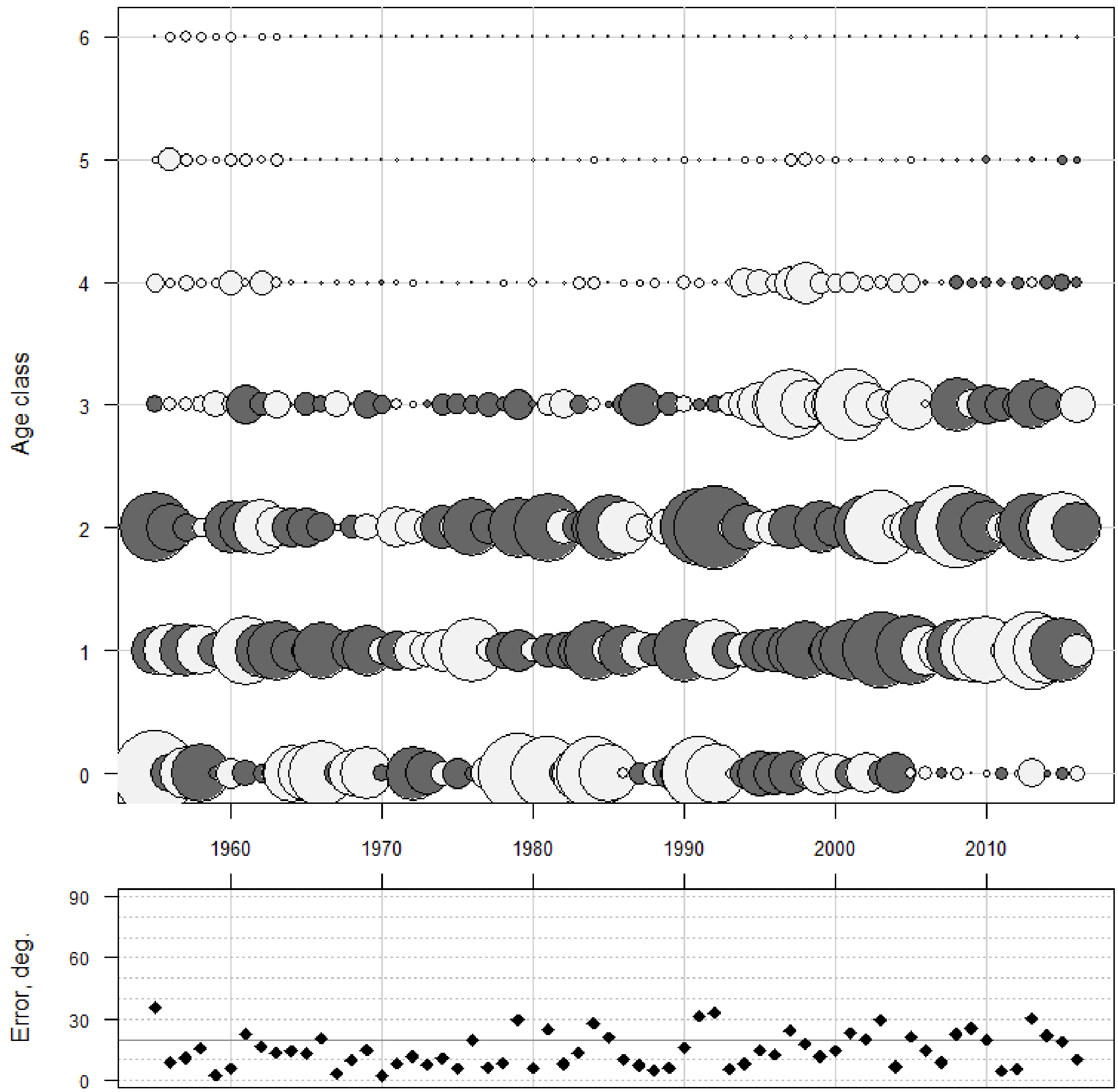
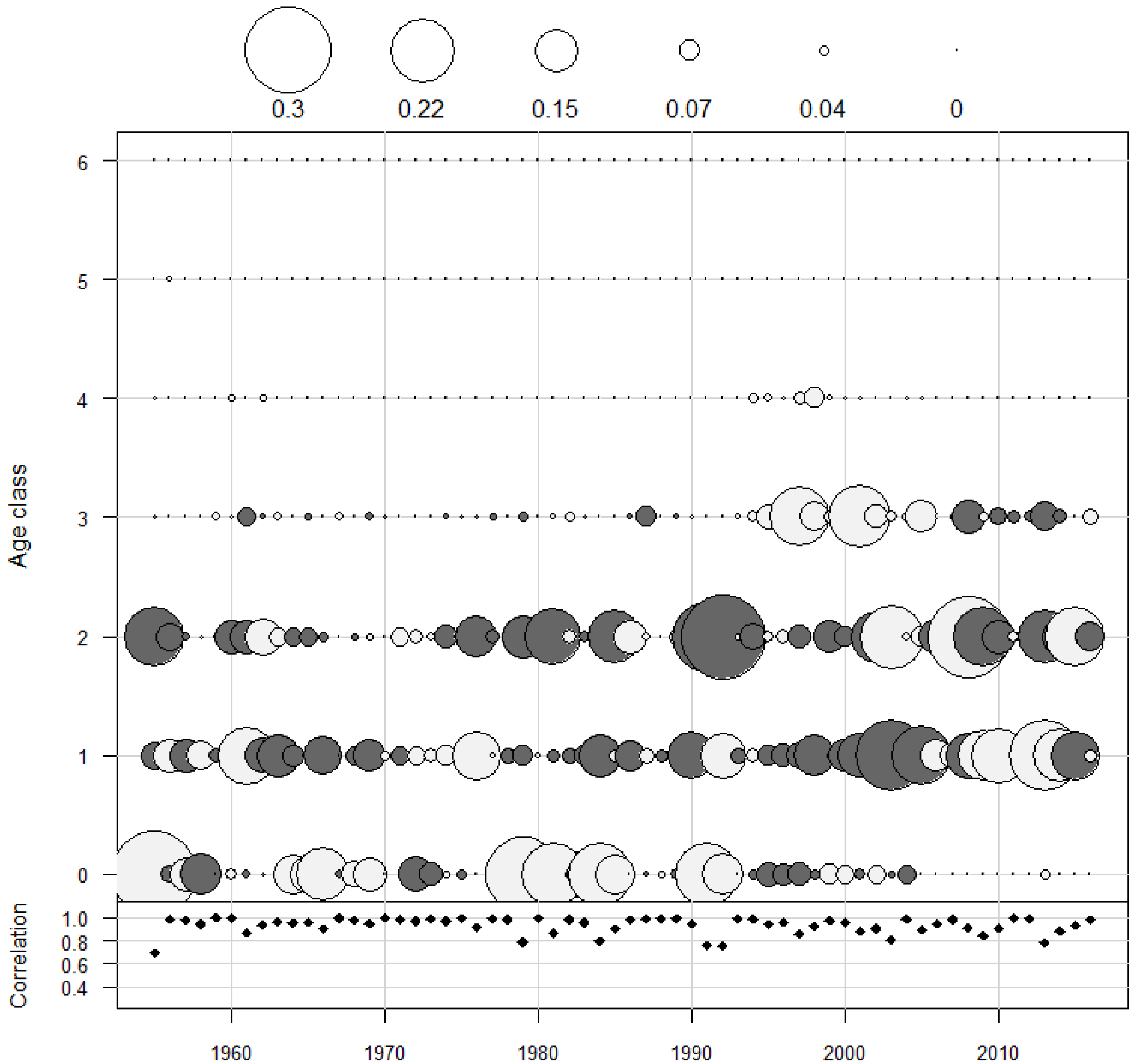



**Figure 6.1.10.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted catch-at-age for Atlantic menhaden from 1955-2016 from Virginia Eastern Shore and south by the commercial reduction fishery. The error degrees in the upper panel represents a composite fit by year across ages, while in the lower plot contains correlations between years.

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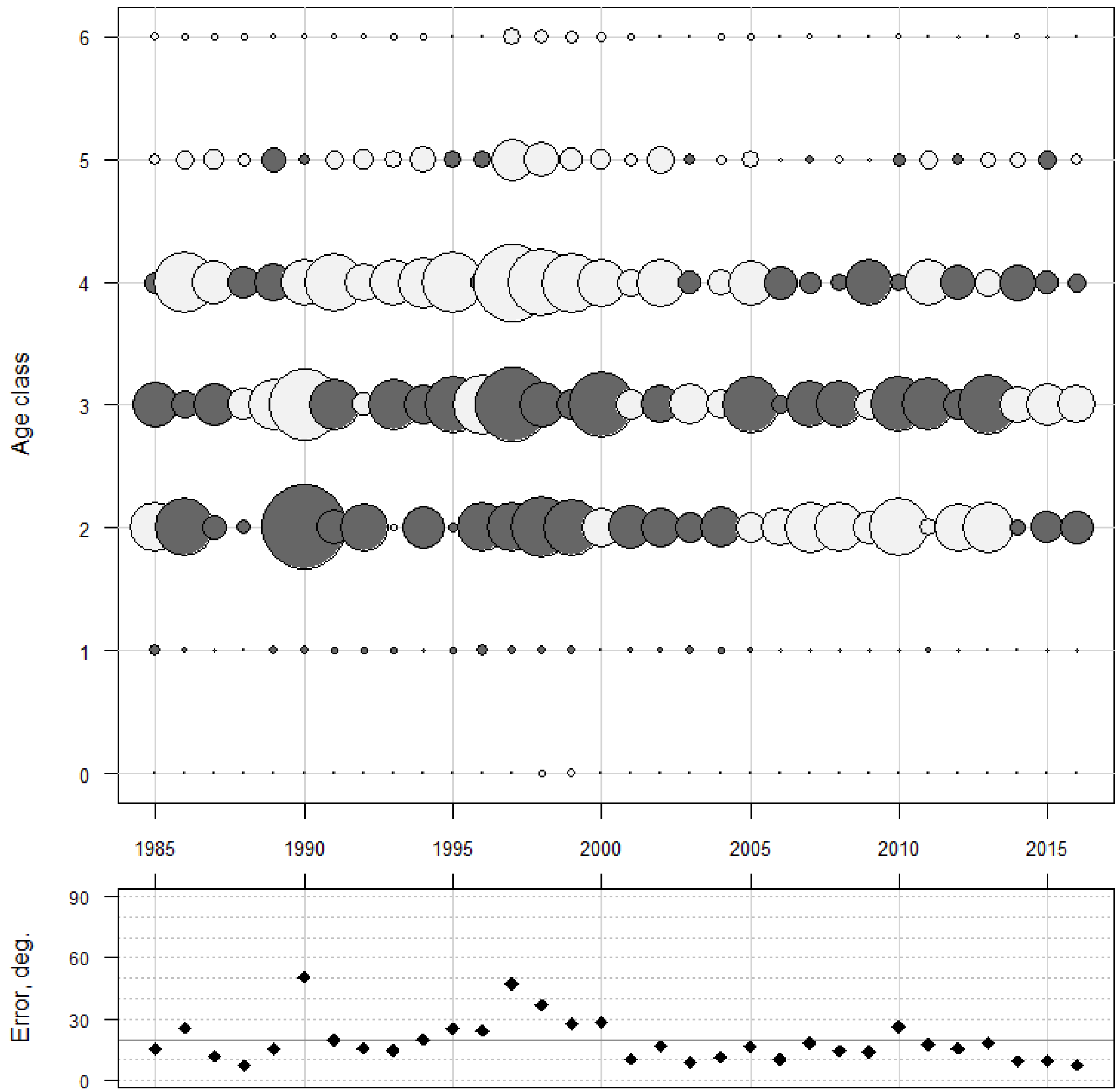



**Figure 6.1.11.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted catch-at-age for Atlantic menhaden from 1985-2016 from north of Virginia Eastern Shore by the commercial bait fishery. The error degrees in the upper panel represents a composite fit by year across ages, while in the lower plot contains correlations between years.

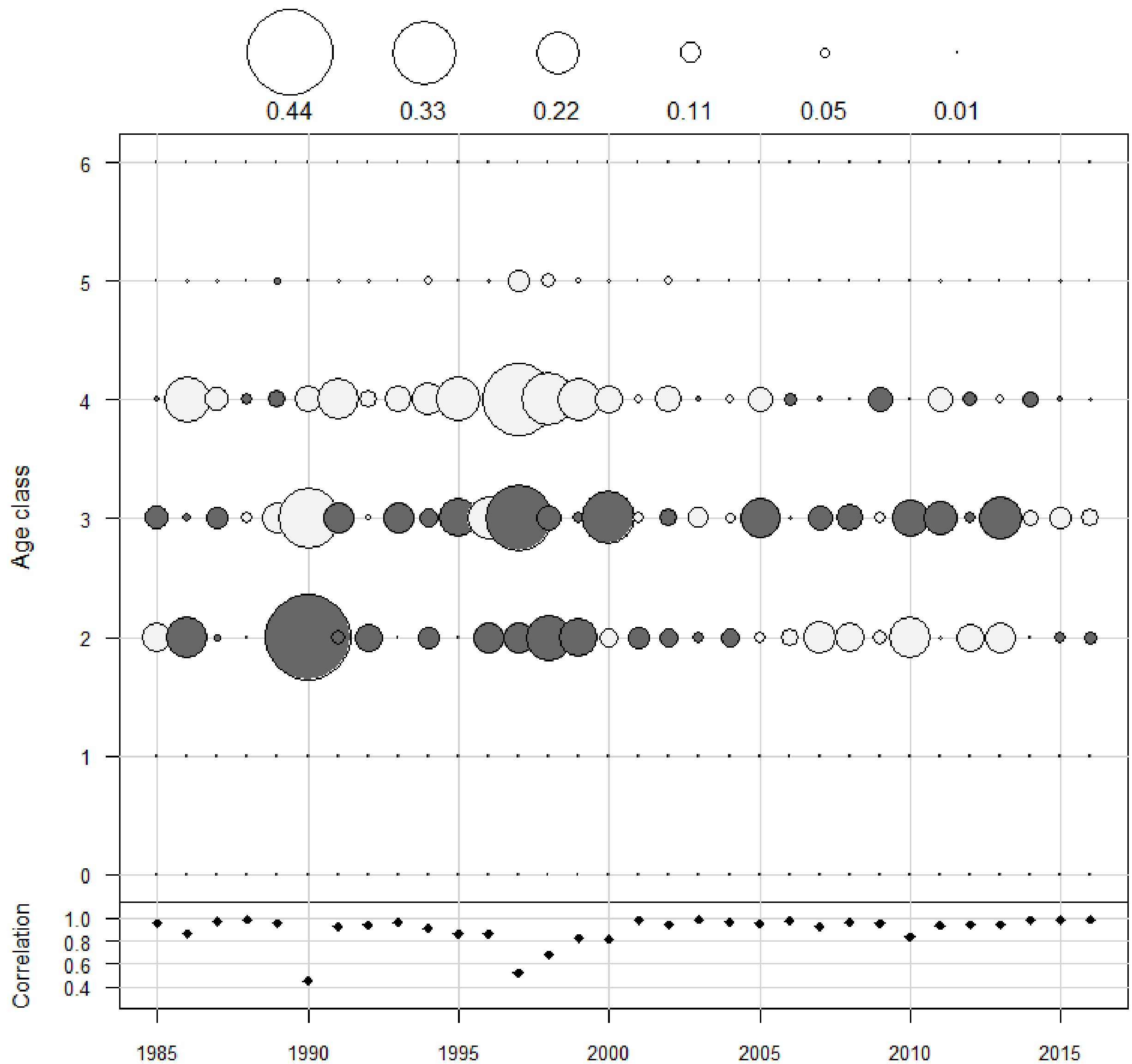



**Figure 6.1.11.** ***Continued.***

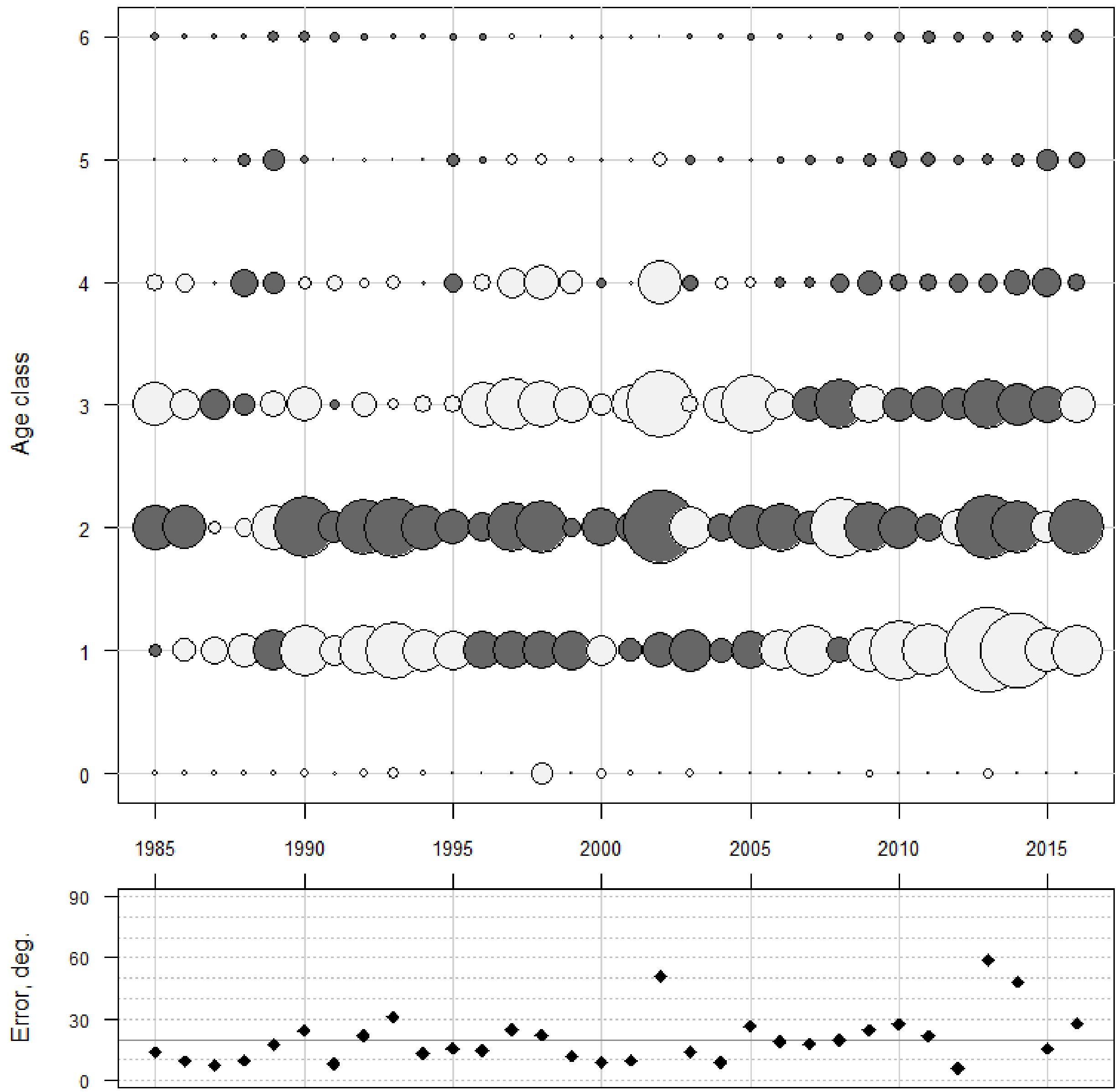



**Figure 6.1.12.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted catch-at-age for Atlantic menhaden from 1985-2016 from Virginia Eastern Shore and south by the commercial bait fishery. The error degrees in the upper panel represents a composite fit by year across ages, while in the lower plot contains correlations between years.

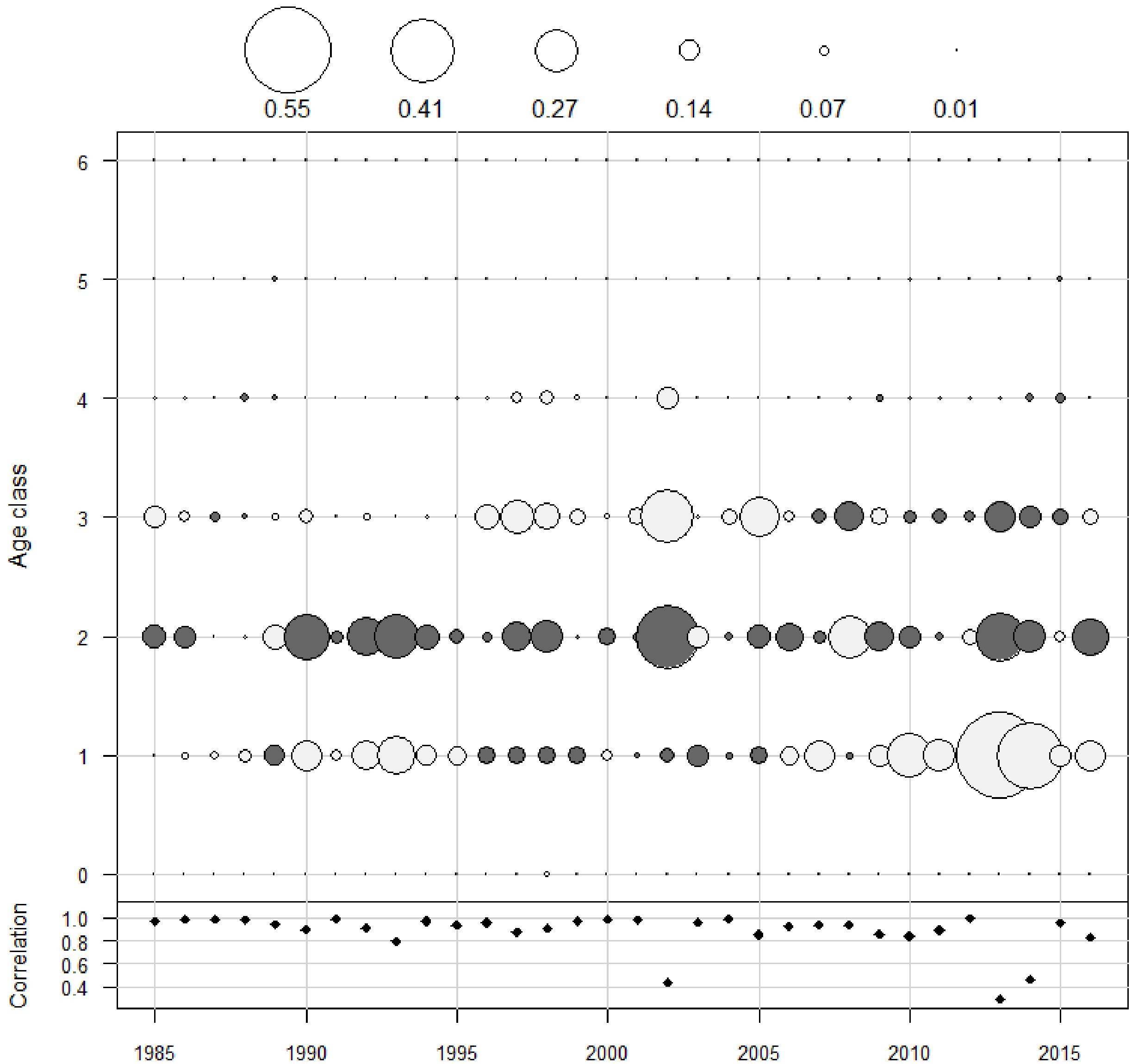



**Figure 6.1.12.** ***Continued.***

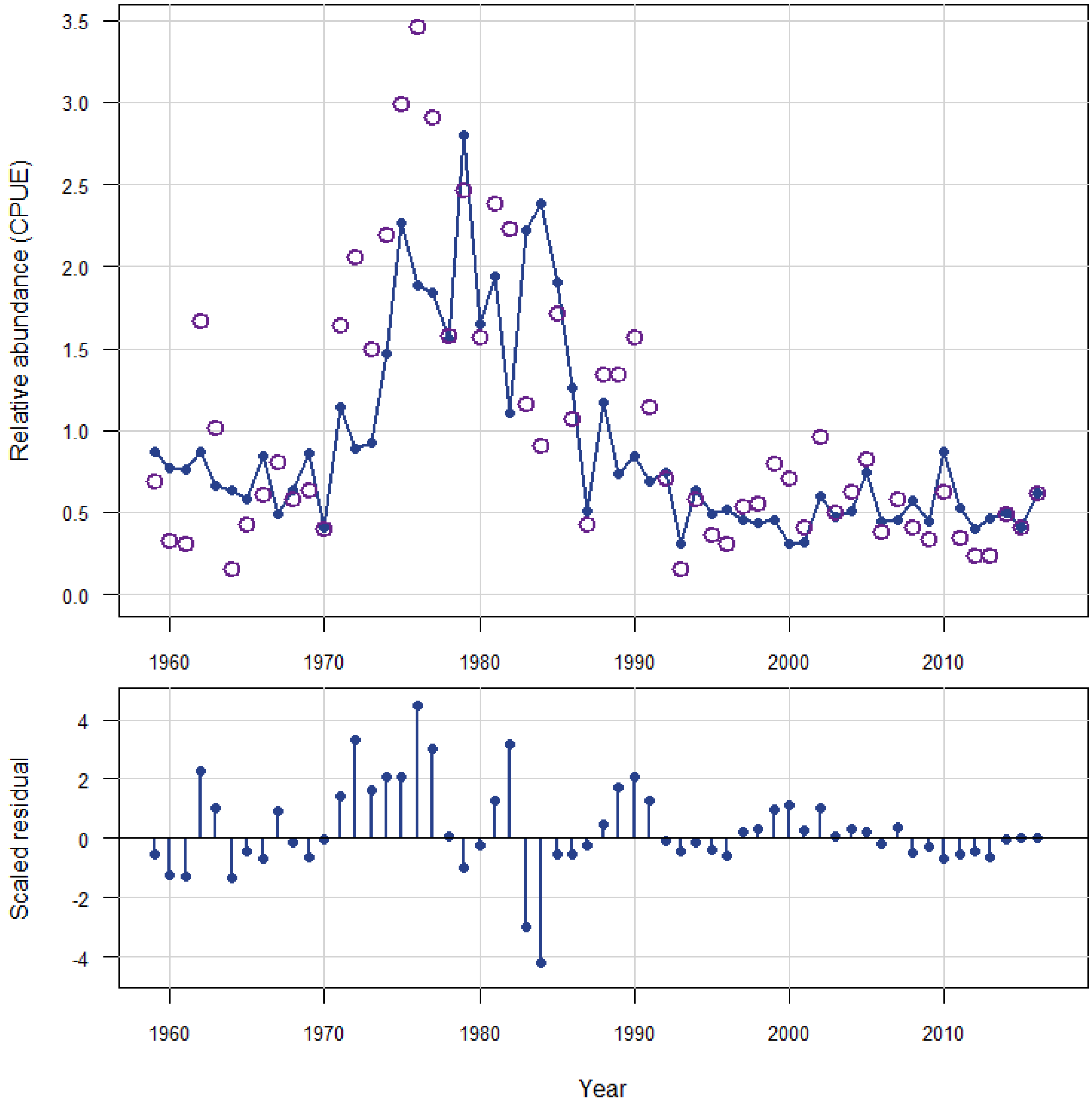



**Figure 6.1.13.** The observed and predicted recruitment index for 1959-2016 comprised of a series of state surveys.

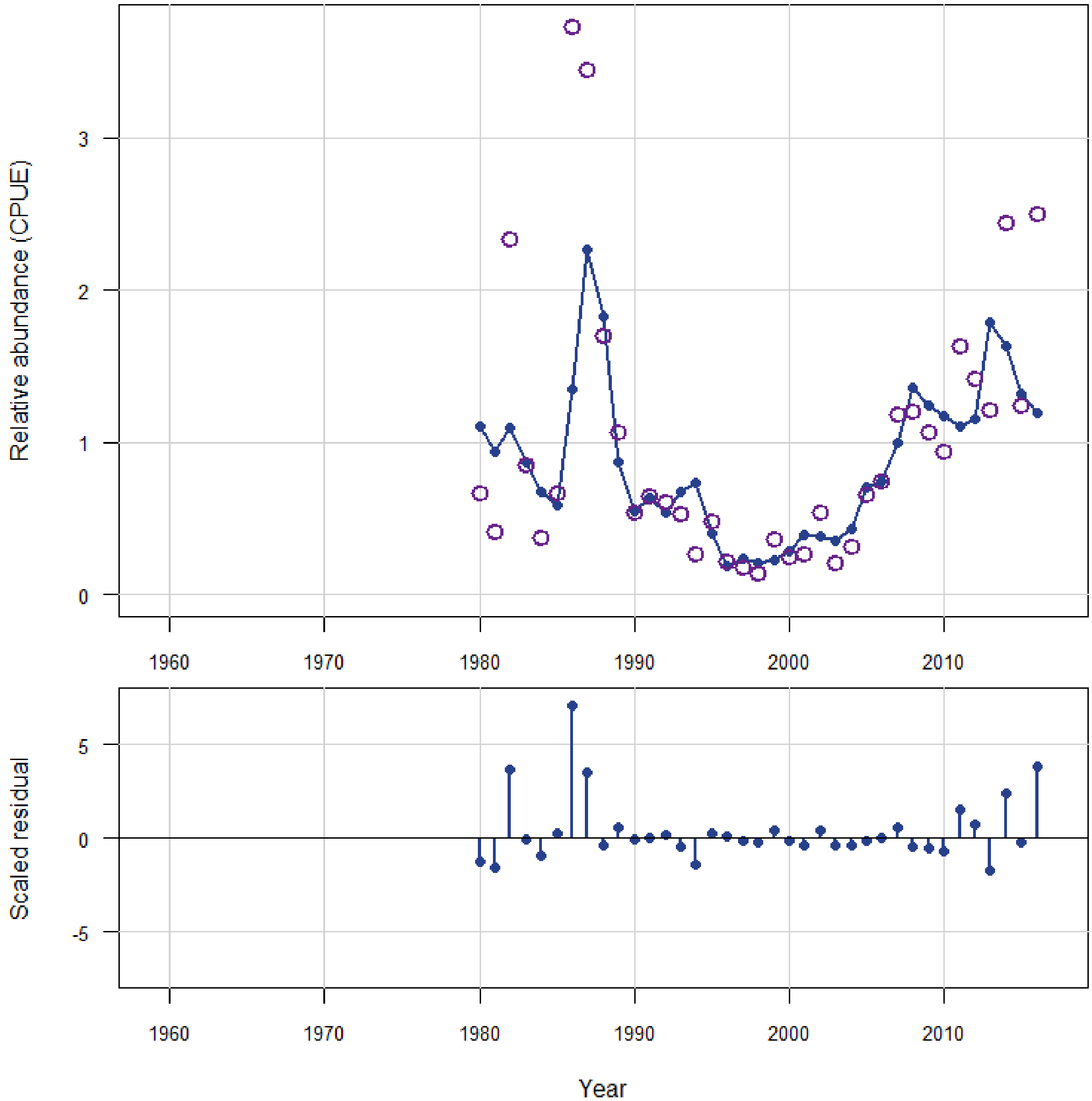



**Figure 6.1.14.** The observed and predicted NAD index for 1980-2016 comprised of a series of state trawl surveys in the northern region.

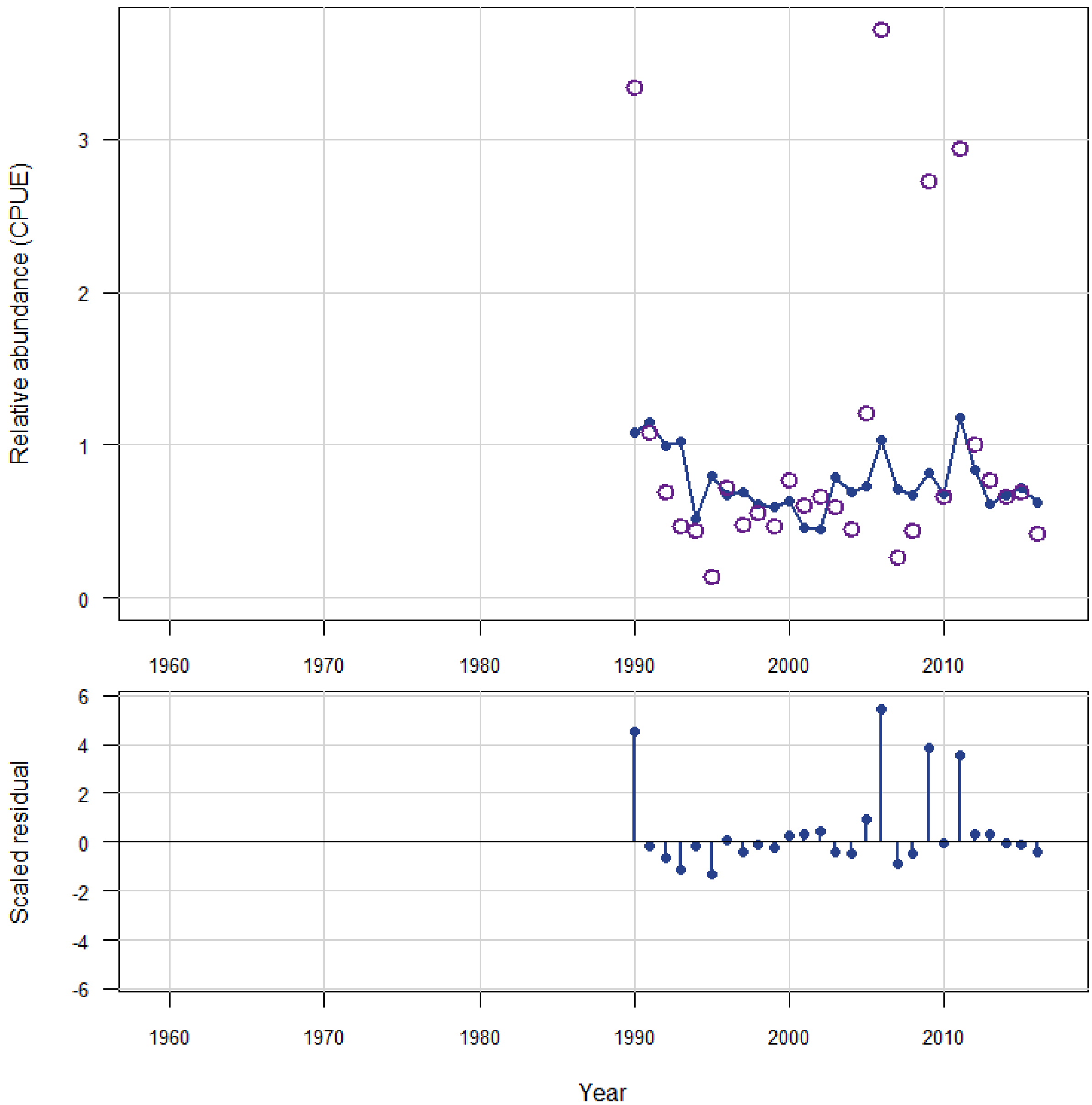



**Figure 6.1.15.** The observed and predicted SAD index for 1990-2016 comprised of two state trawl surveys in the southern region.

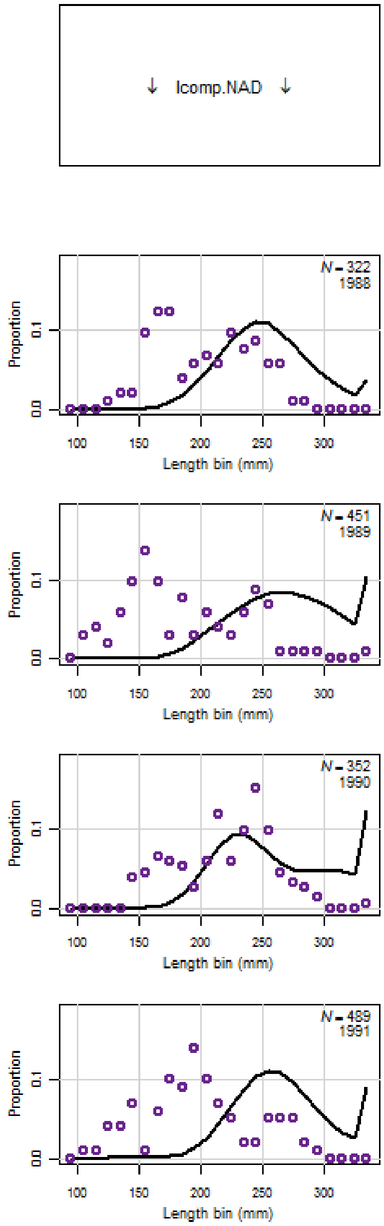



**Figure 6.1.16.** Annual observed and predicted length measurements of Atlantic menhaden from 1986-2016 for the NAD index.

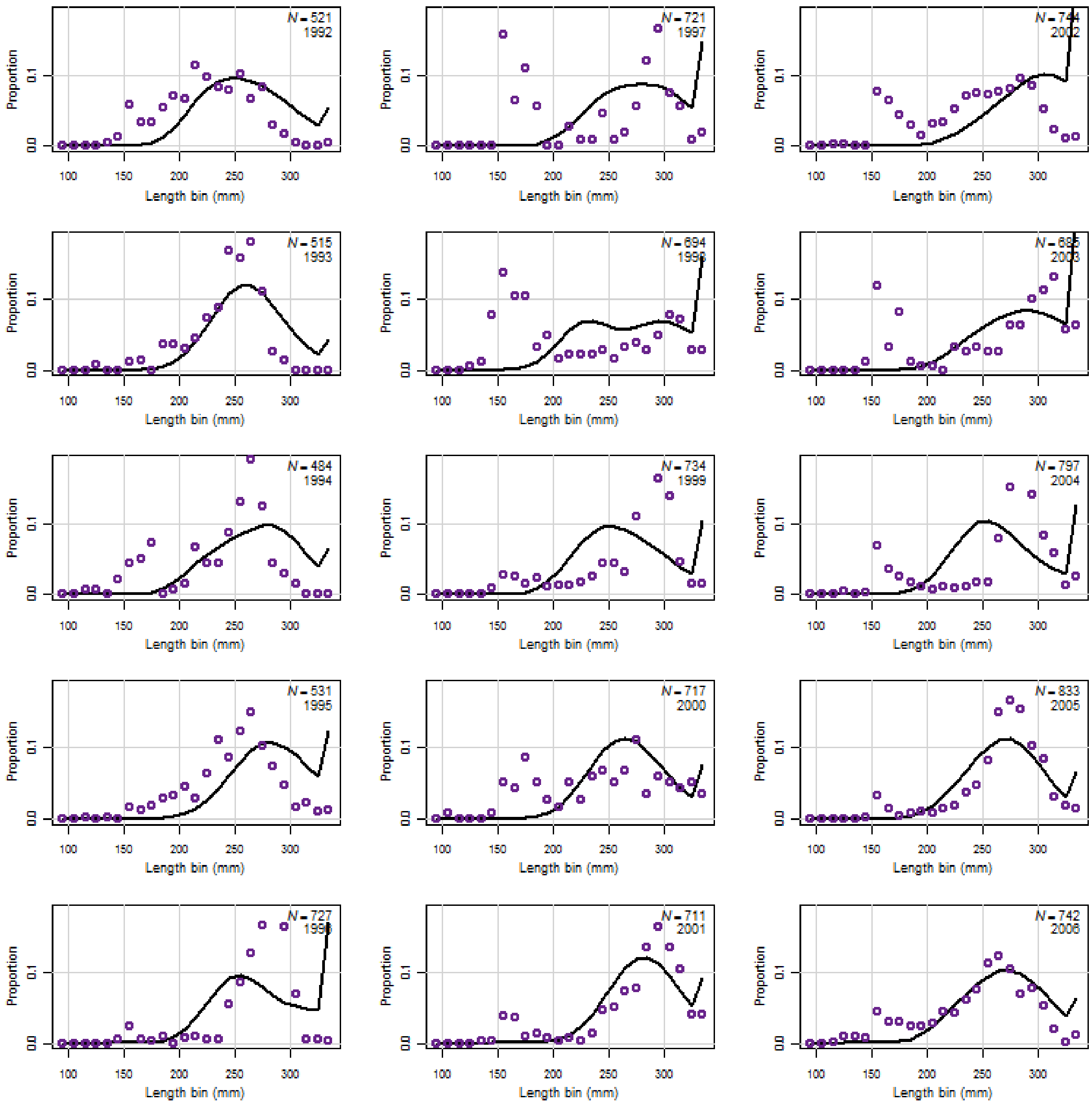
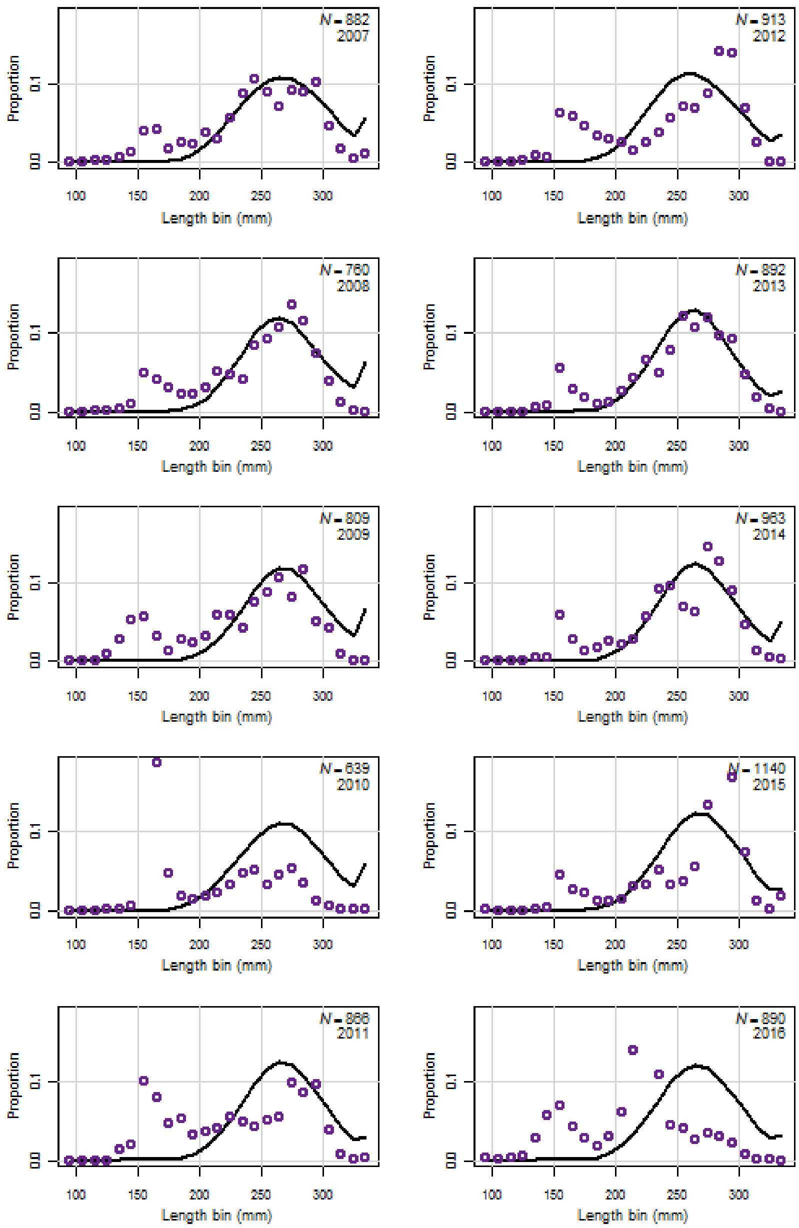



**Figure 6.1.16.** ***Continued.***



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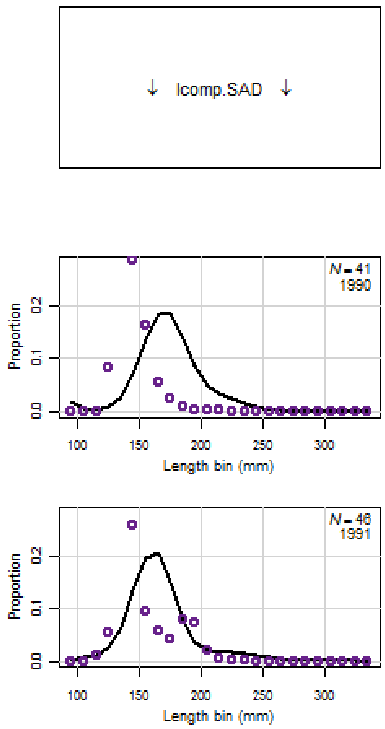
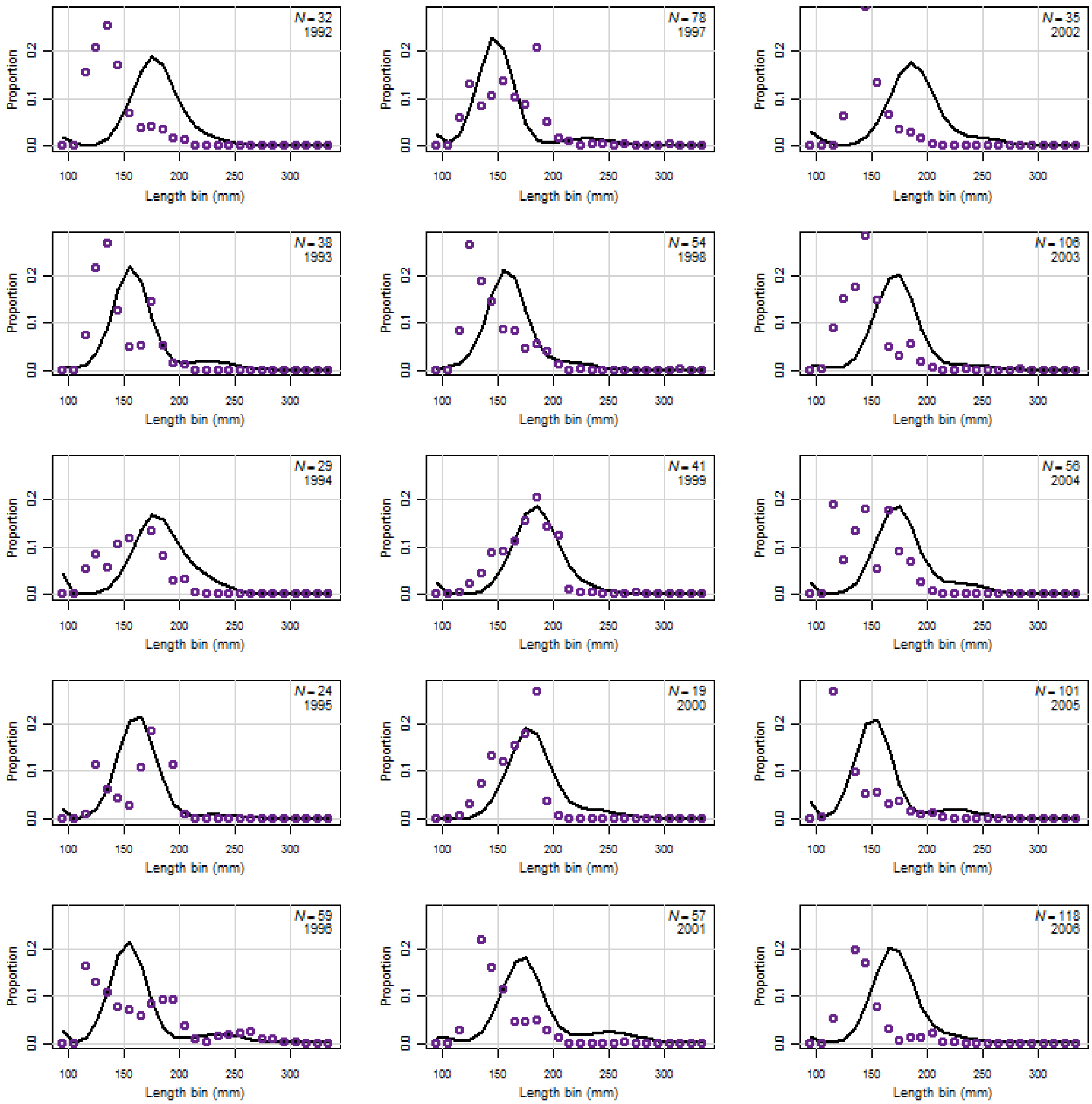



**Figure 6.1.17.** Annual observed and predicted length measurements of Atlantic menhaden from 1990-2016 for the SAD index.

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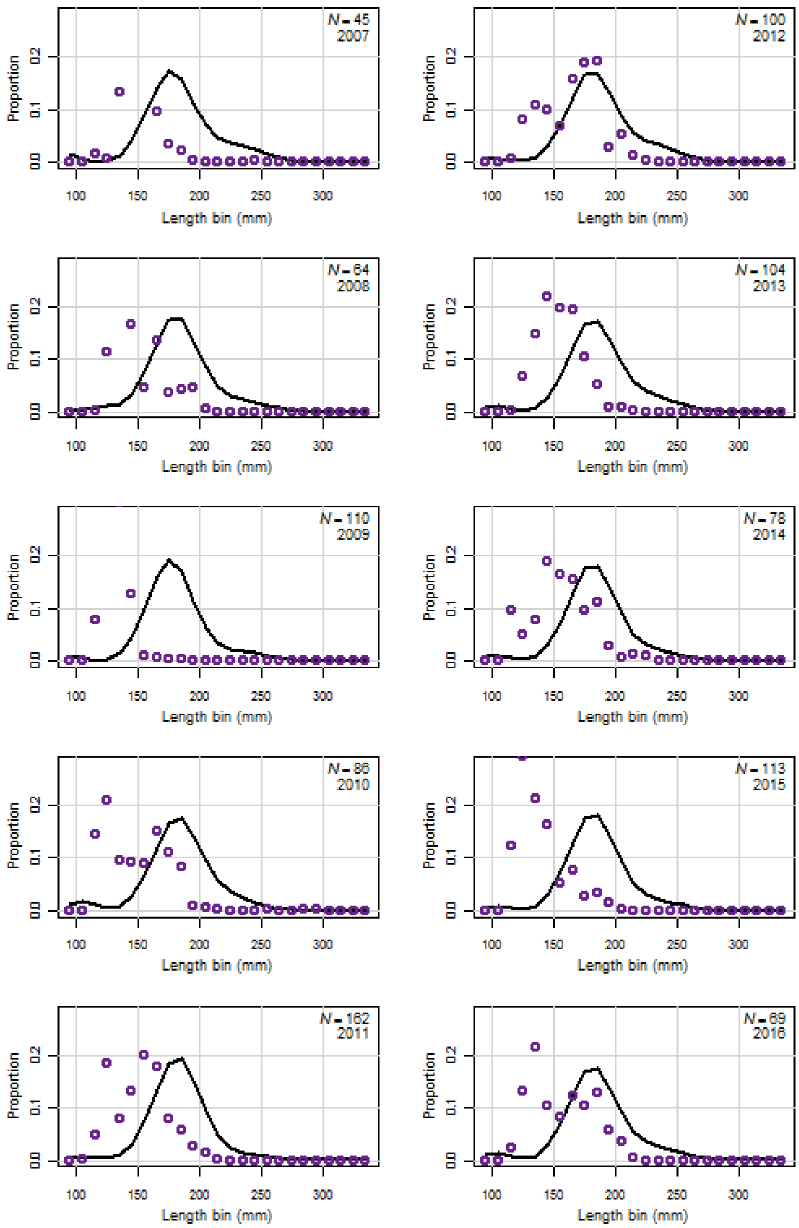


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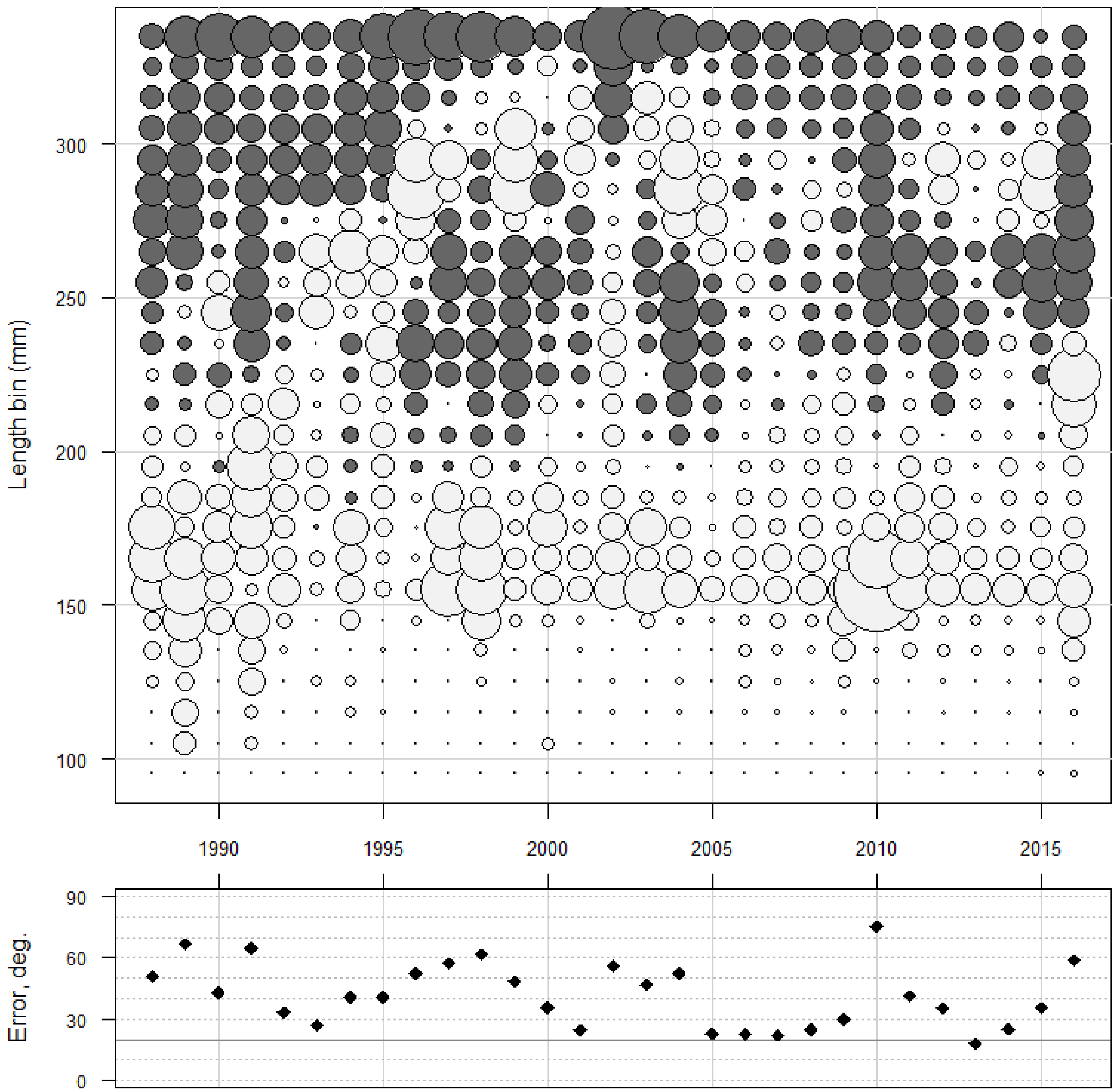



**Figure 6.1.18.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted lengths for Atlantic menhaden from 1986-2016 from the NAD. The error degrees in the upper panel represents a composite fit by year across lengths, while in the lower plot contains correlations between years.

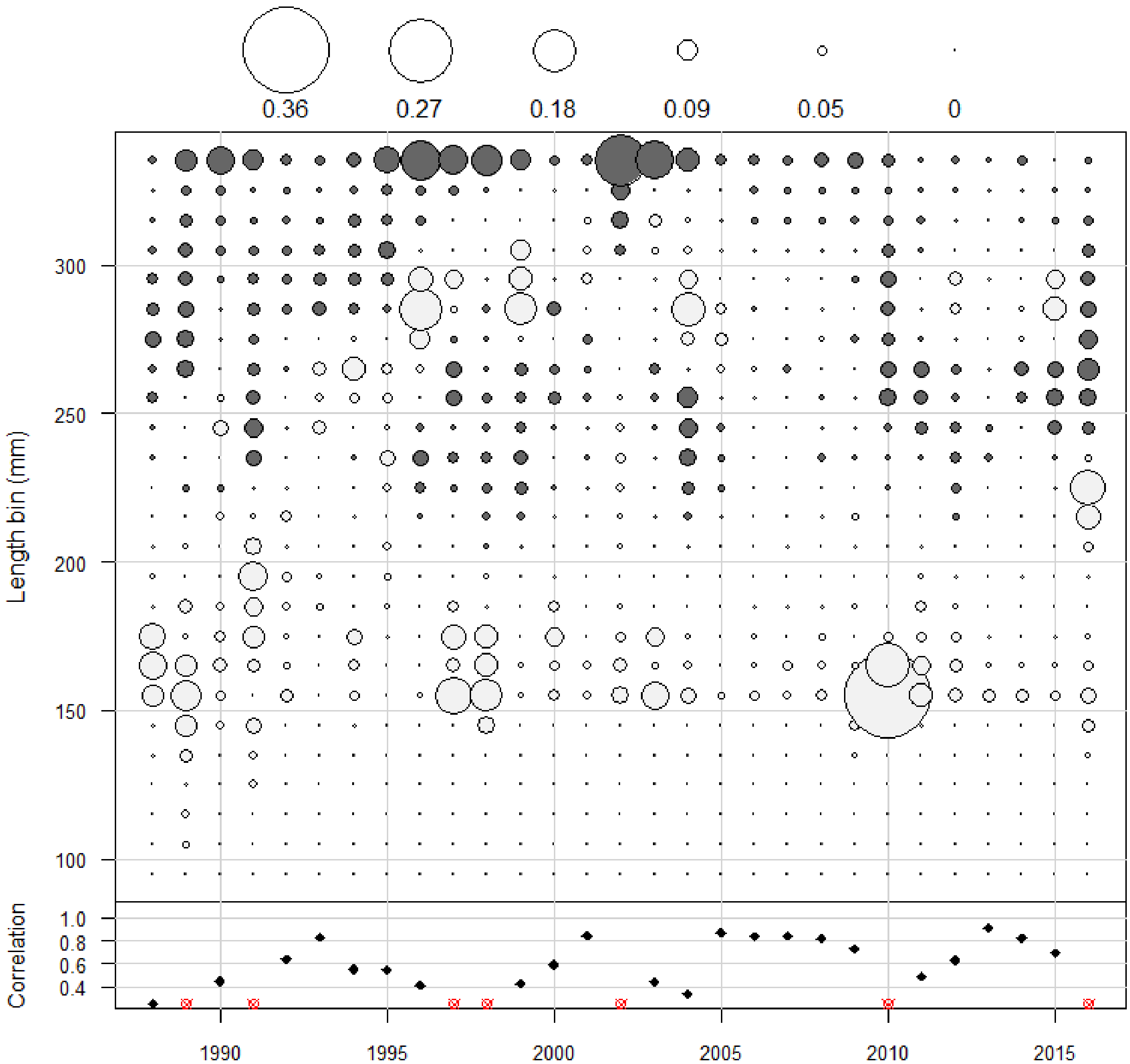



**Figure 6.1.18.** ***Continued.***

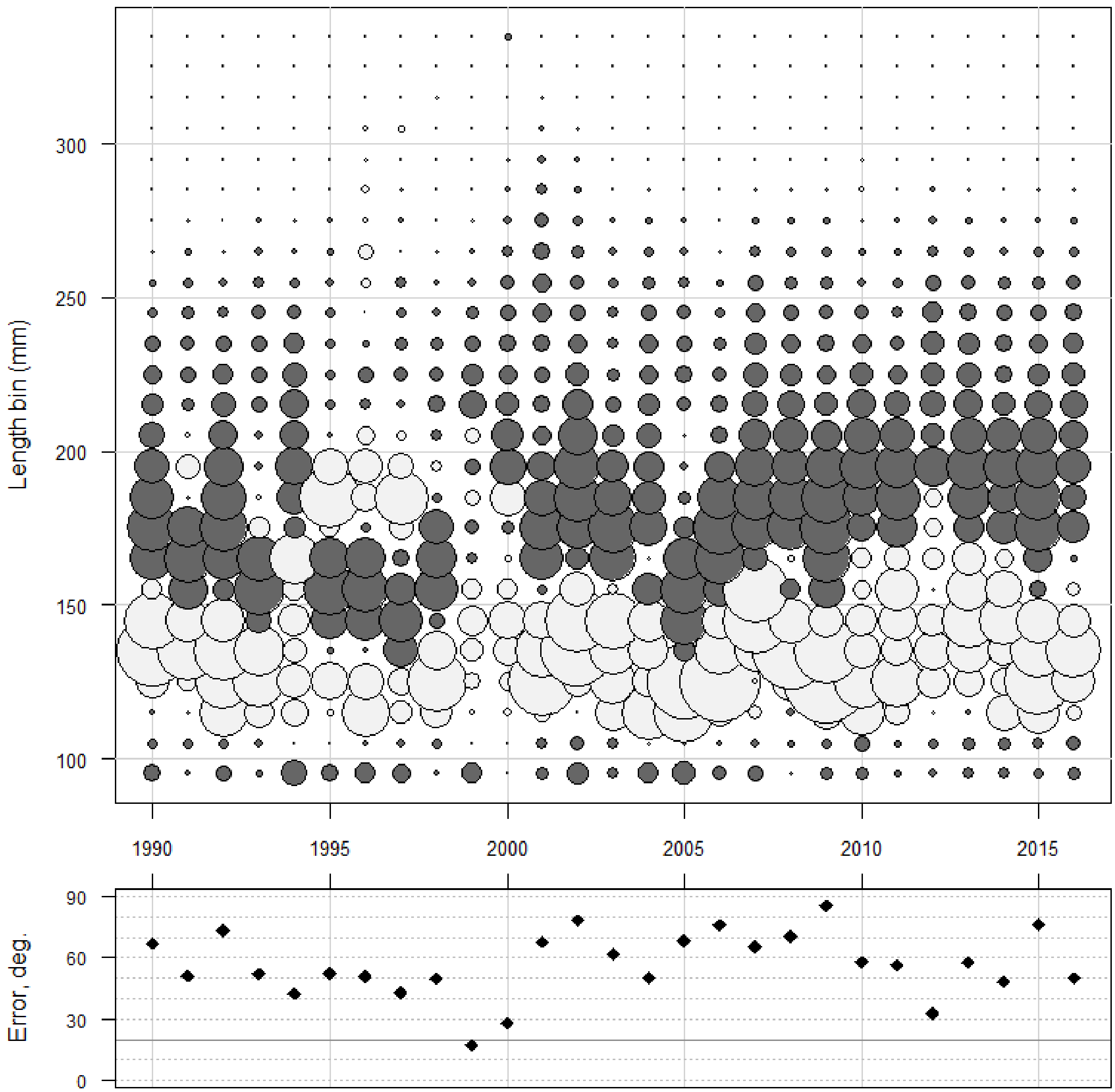



**Figure 6.1.19.** Relative (above) and absolute (next page) bubble plots of the residuals of the predicted lengths for Atlantic menhaden from 1990-2016 from the SAD. The error degrees in the upper panel represents a composite fit by year across lengths, while in the lower plot contains correlations between years.

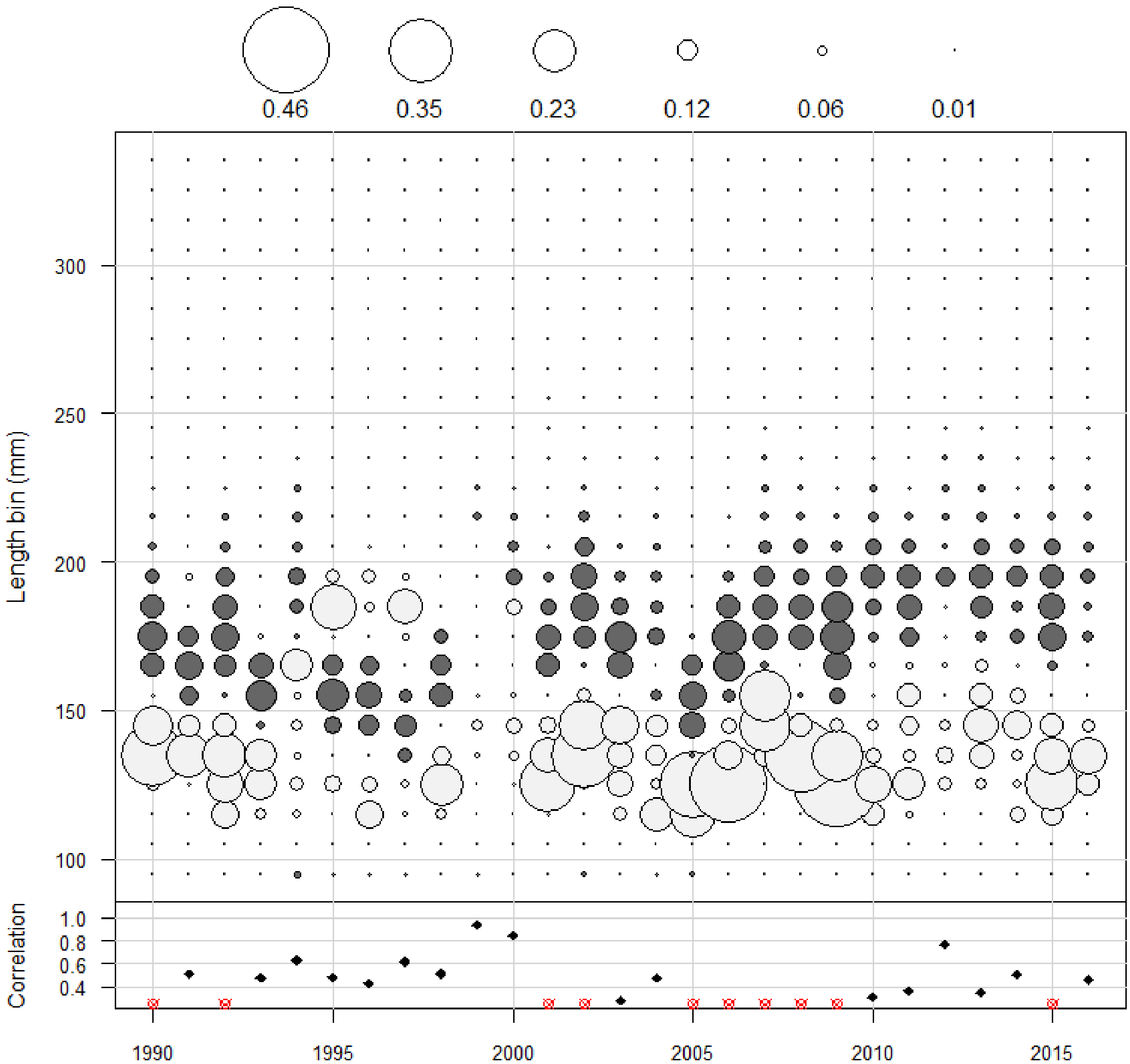



**Figure 6.1.19.** ***Continued.***

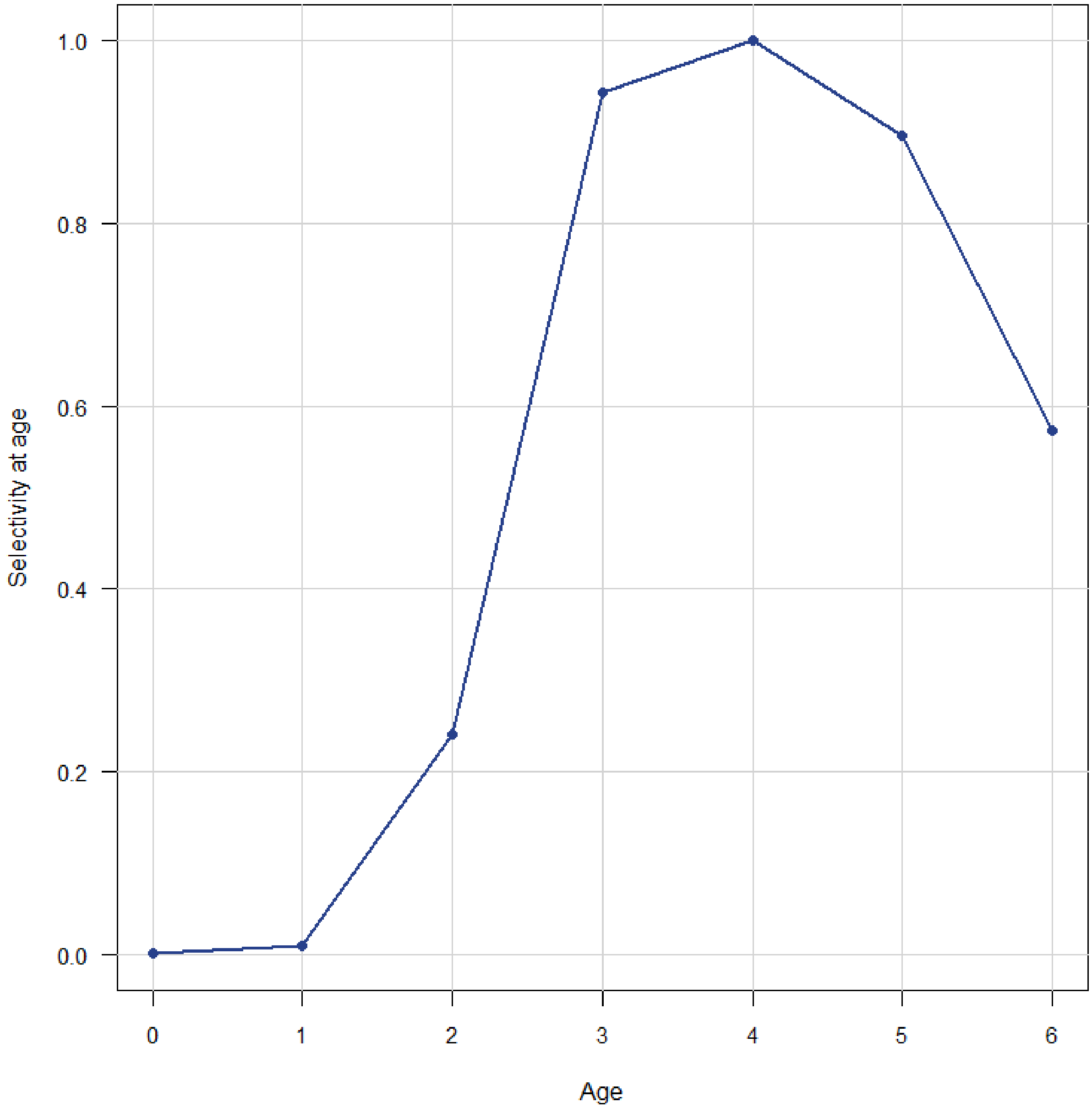


**Figure 6.2.1.1.** Selectivity for the northern commercial reduction fleet for 1955-1969.

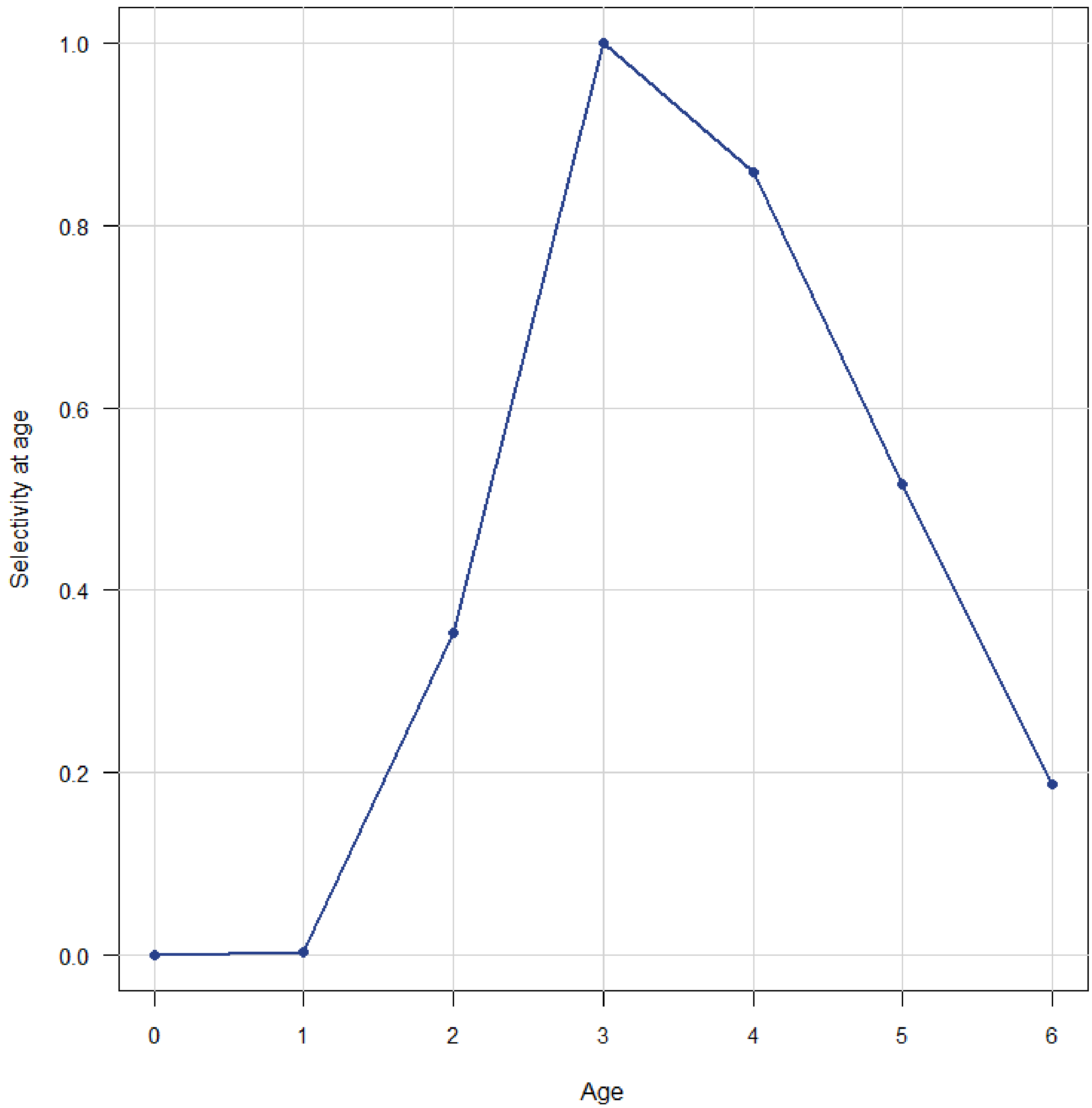



**Figure 6.2.1.2.** Selectivity for the northern commercial reduction fleet for 1970-1993.

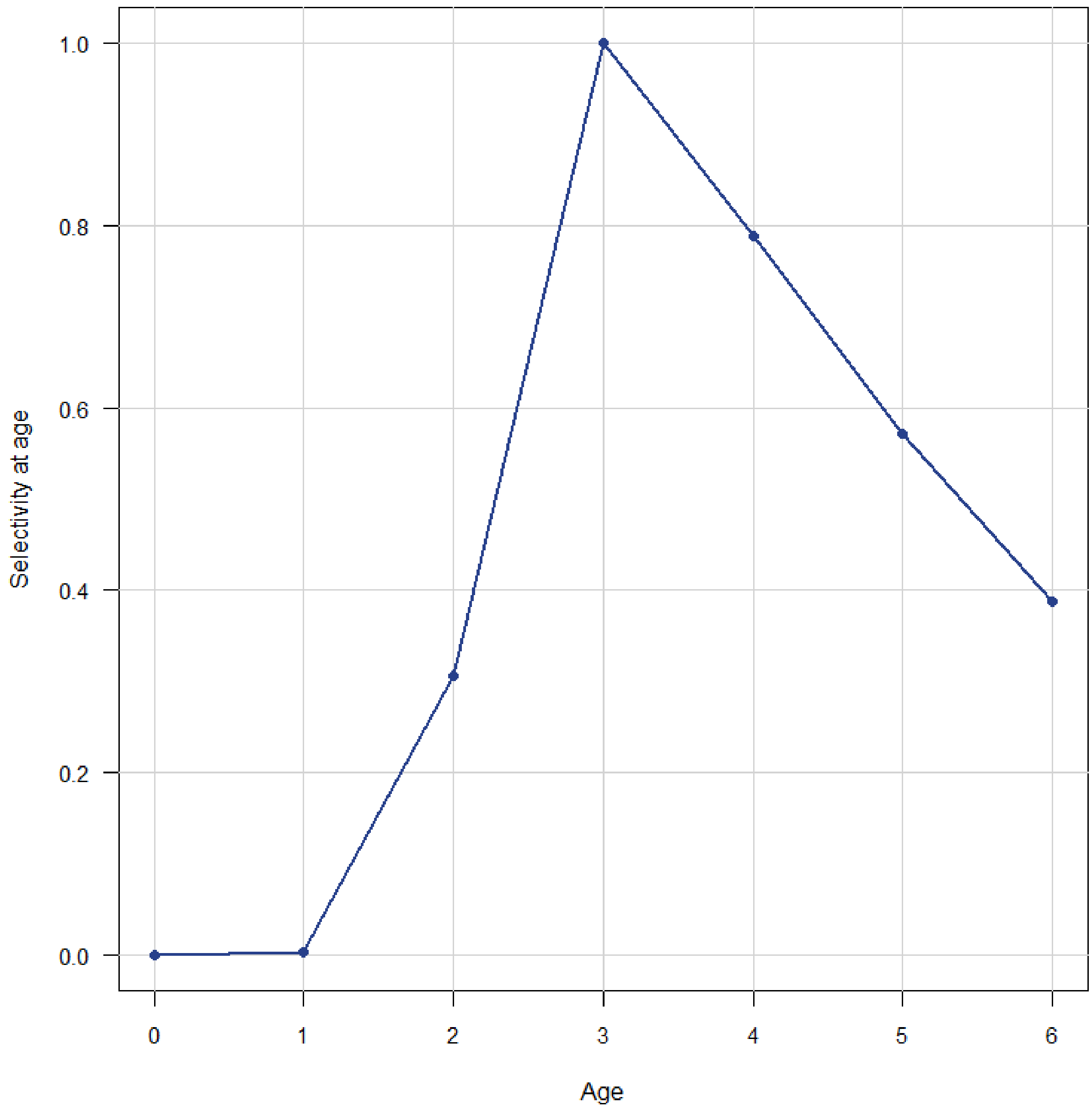



**Figure 6.2.1.3.** Selectivity for the northern commercial reduction fleet for 1994-2016.

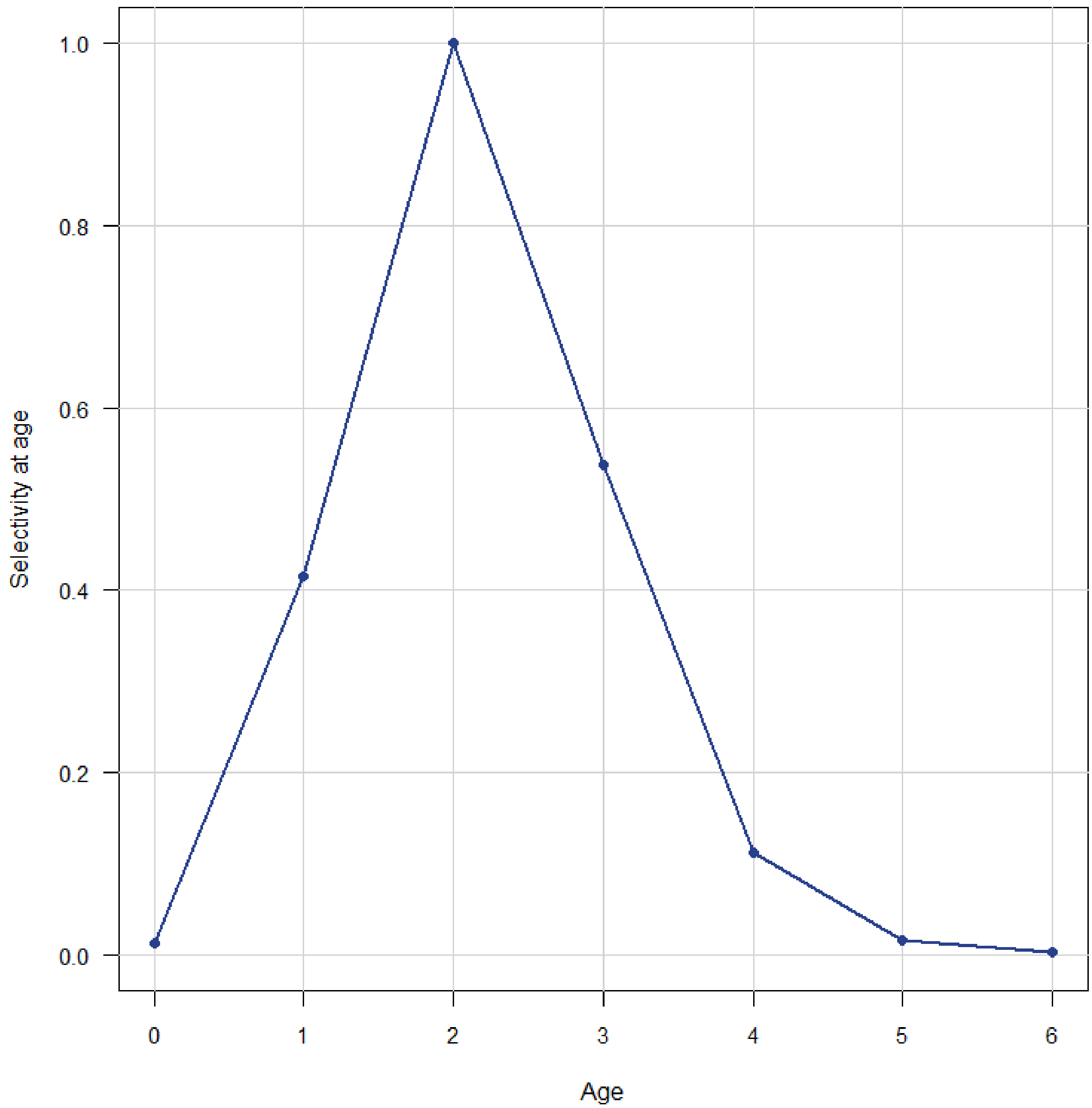



**Figure 6.2.1.4.** Selectivity for the southern commercial reduction fleet for 1955-1971.

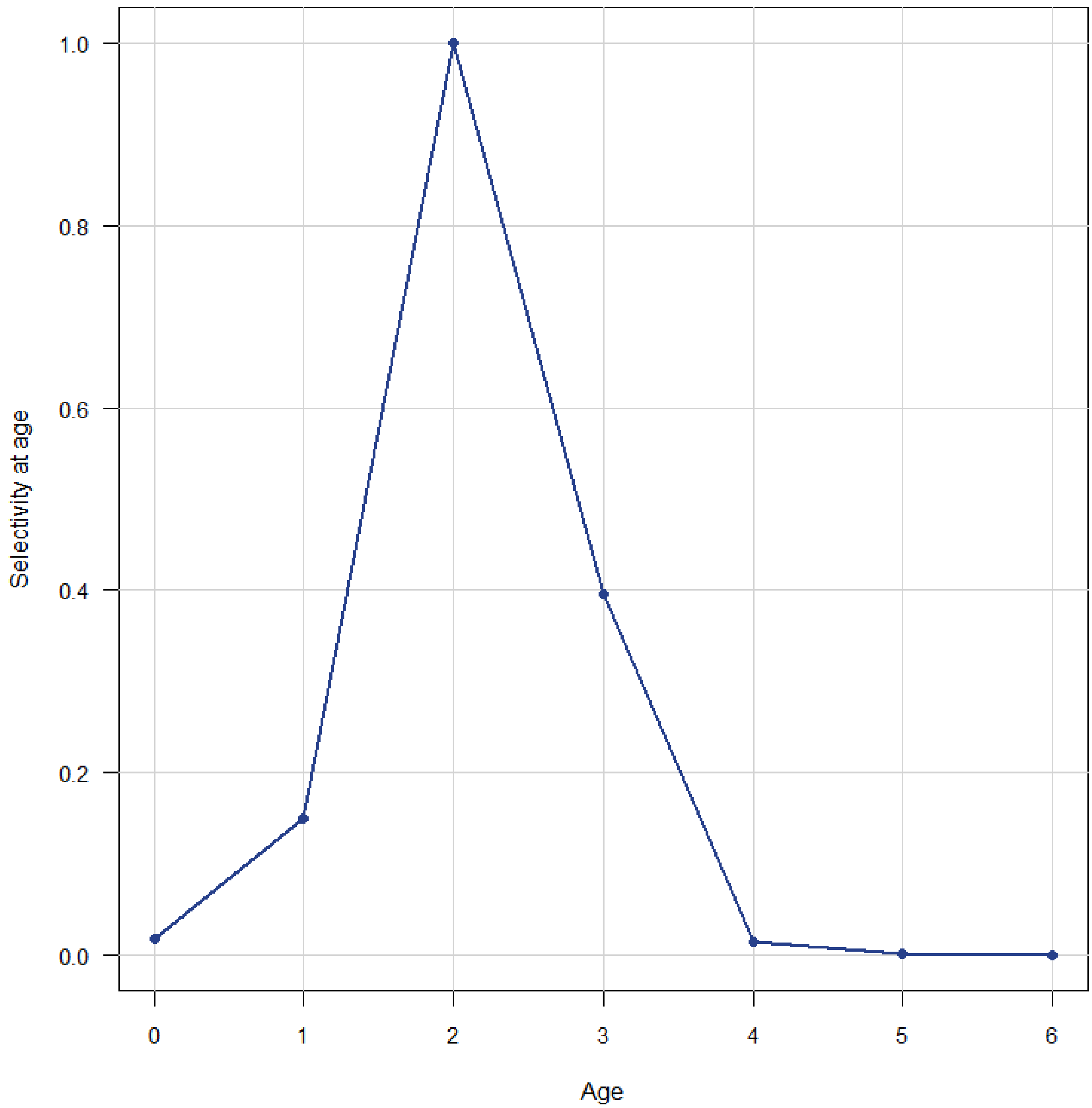



**Figure 6.2.1.5.** Selectivity for the southern commercial reduction fleet for 1972-2004.

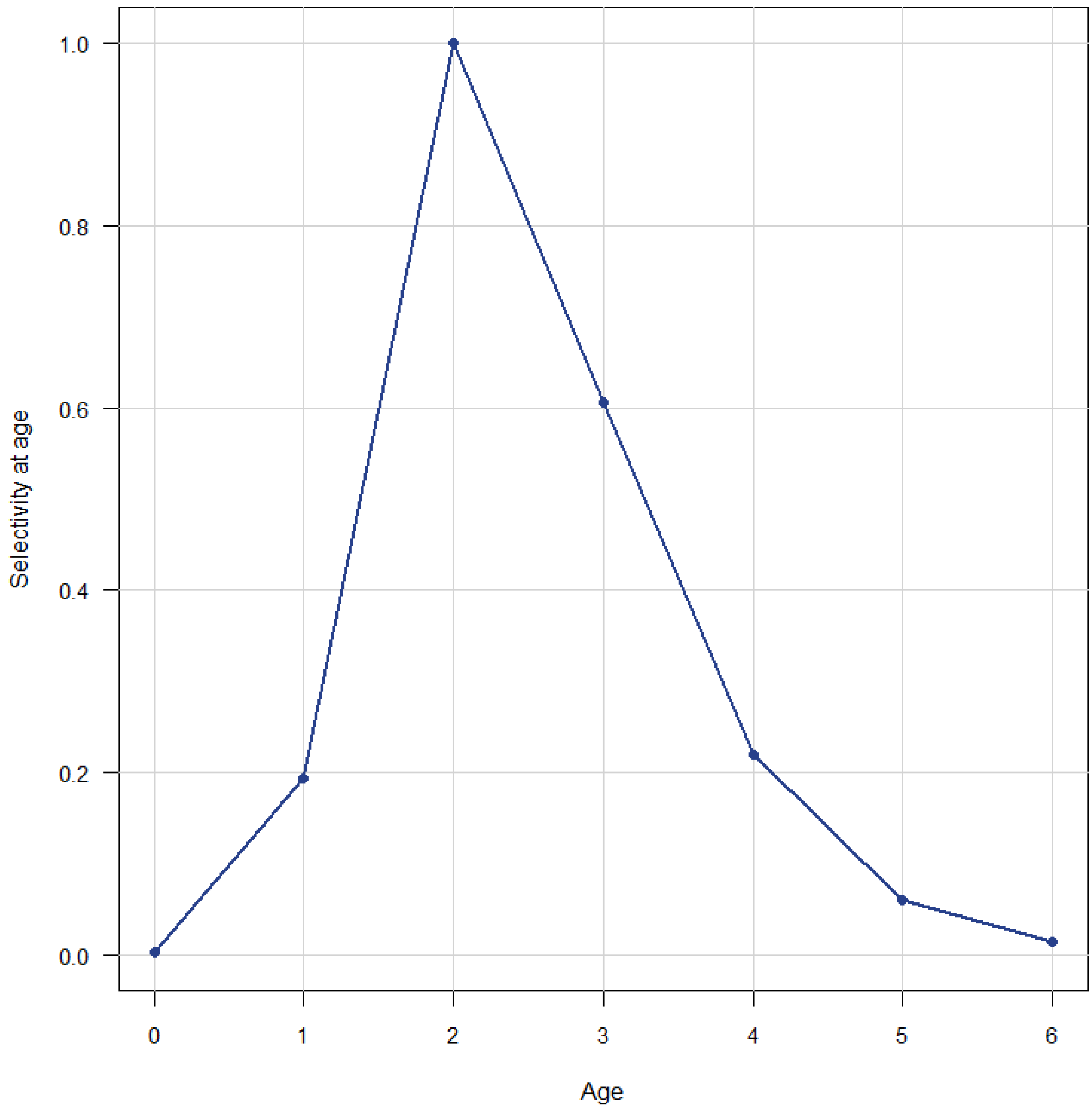



**Figure 6.2.1.6.** Selectivity for the southern commercial reduction fleet for 2005-2016.

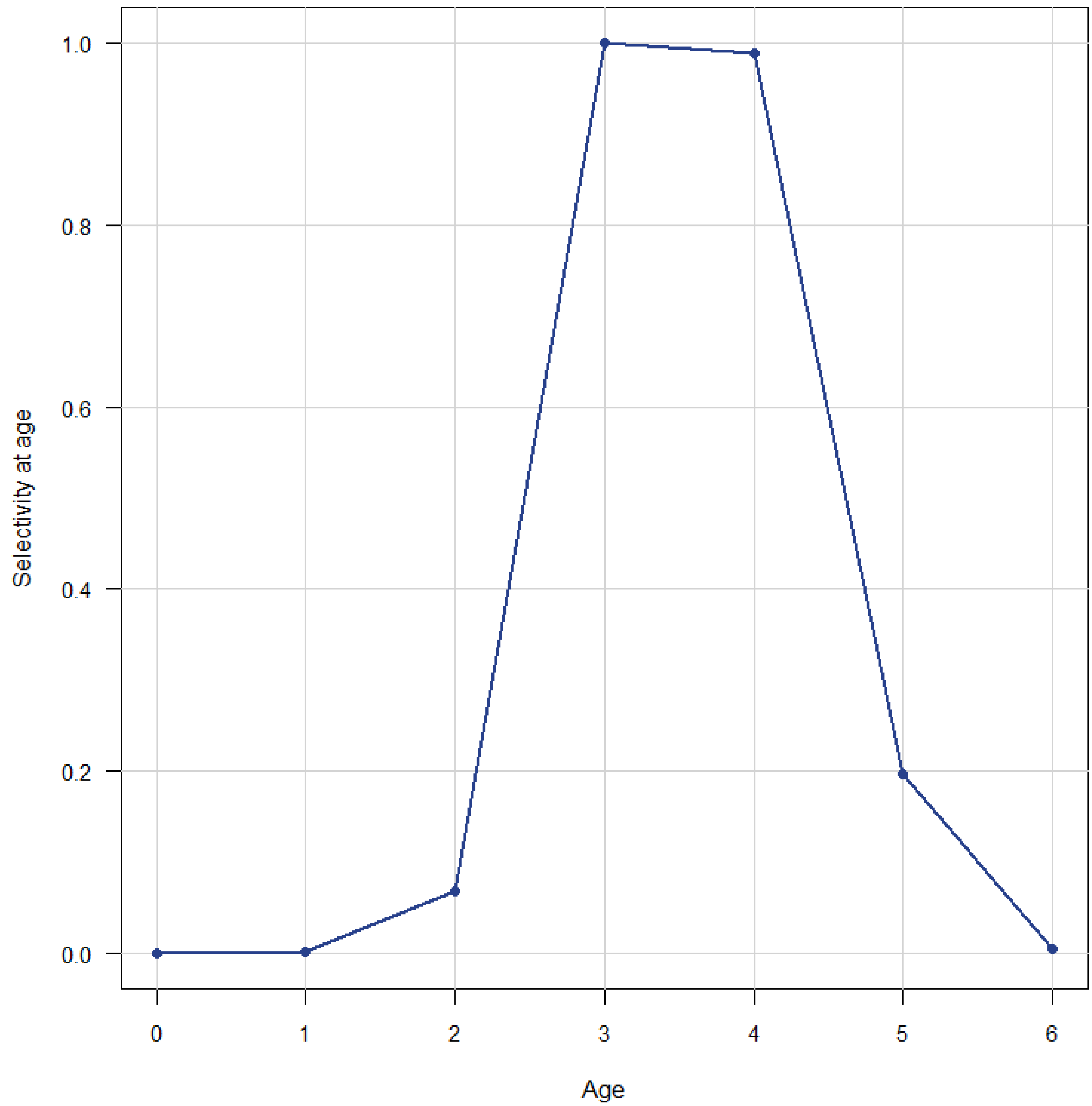



**Figure 6.2.1.7.** Selectivity for the northern commercial bait fleet for 1955-2016.

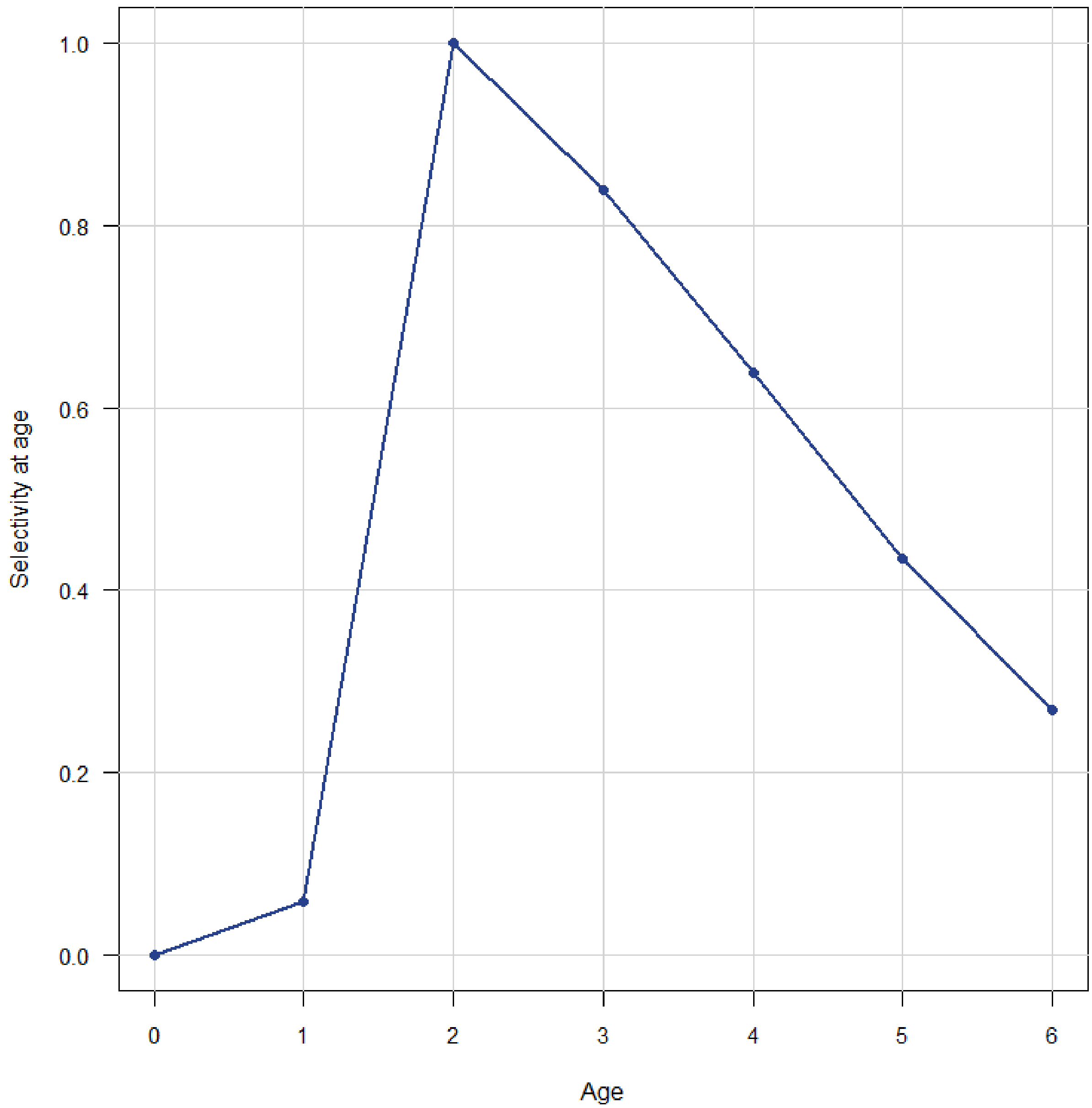


**Figure 6.2.1.8.** Selectivity for the southern commercial bait fleet for 1955-2016.

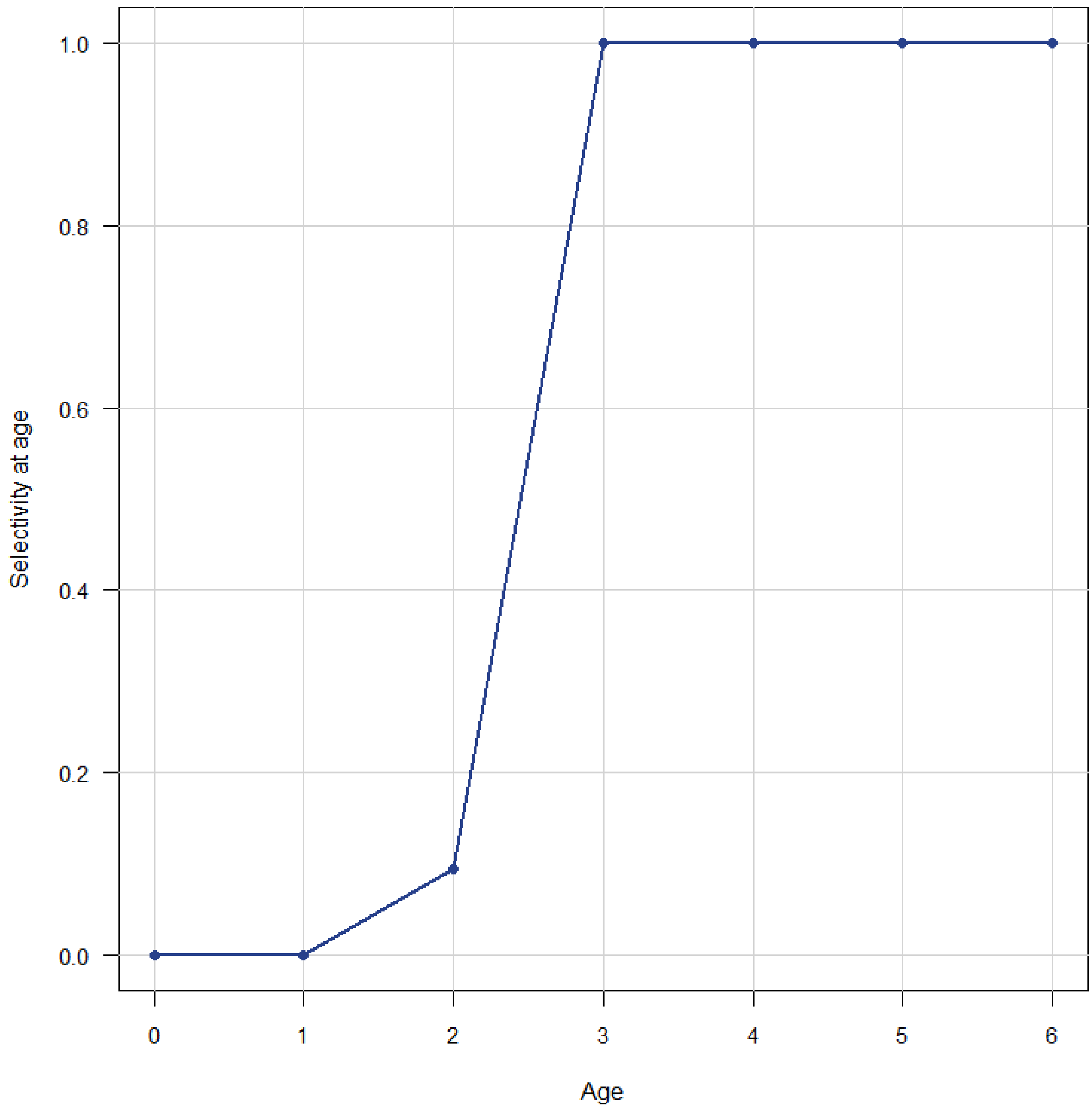



**Figure 6.2.1.9.** Selectivity for the NAD index for 1980-2016.

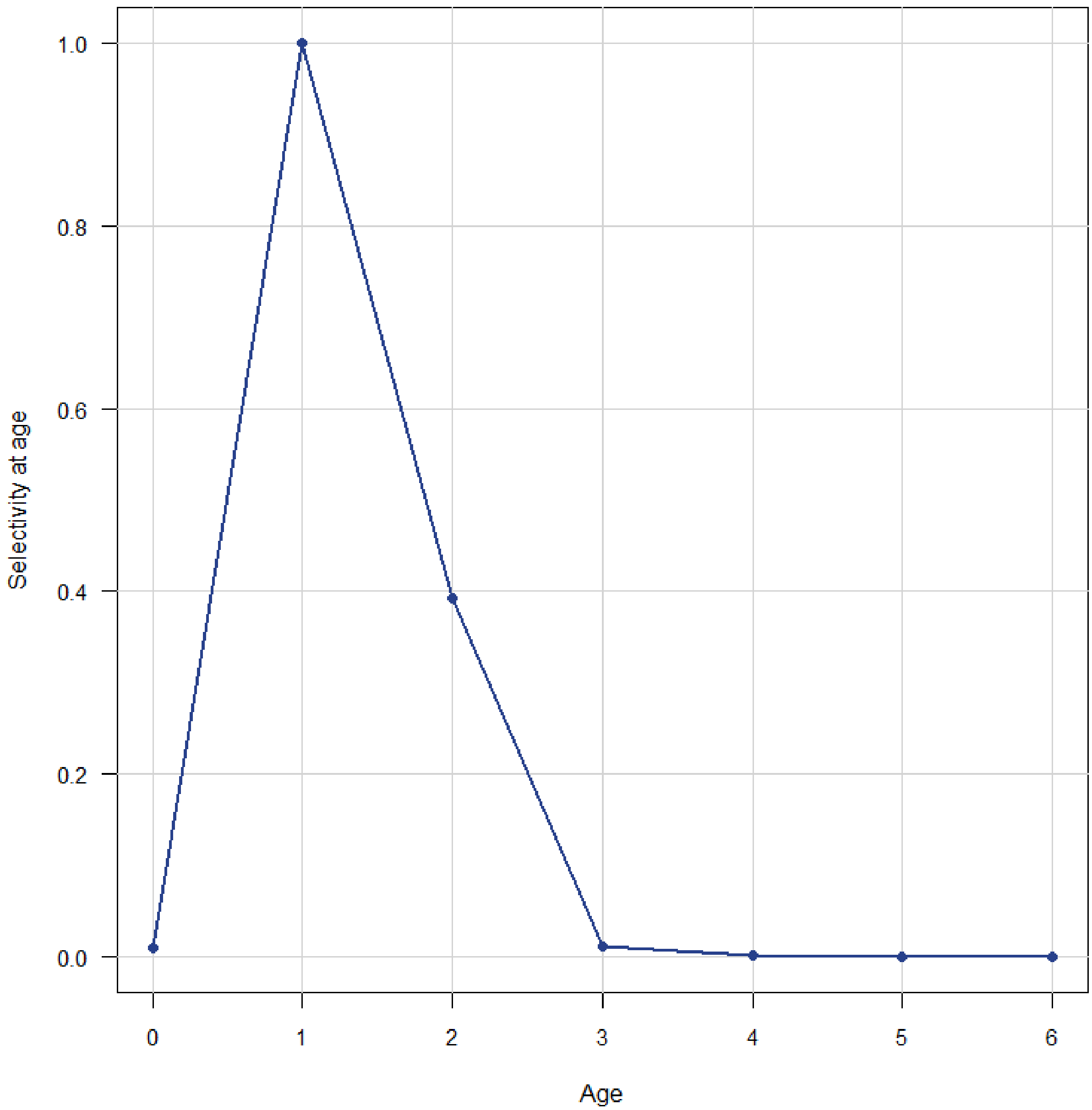



**Figure 6.2.1.10.** Selectivity for the SAD index for 1990-2016.

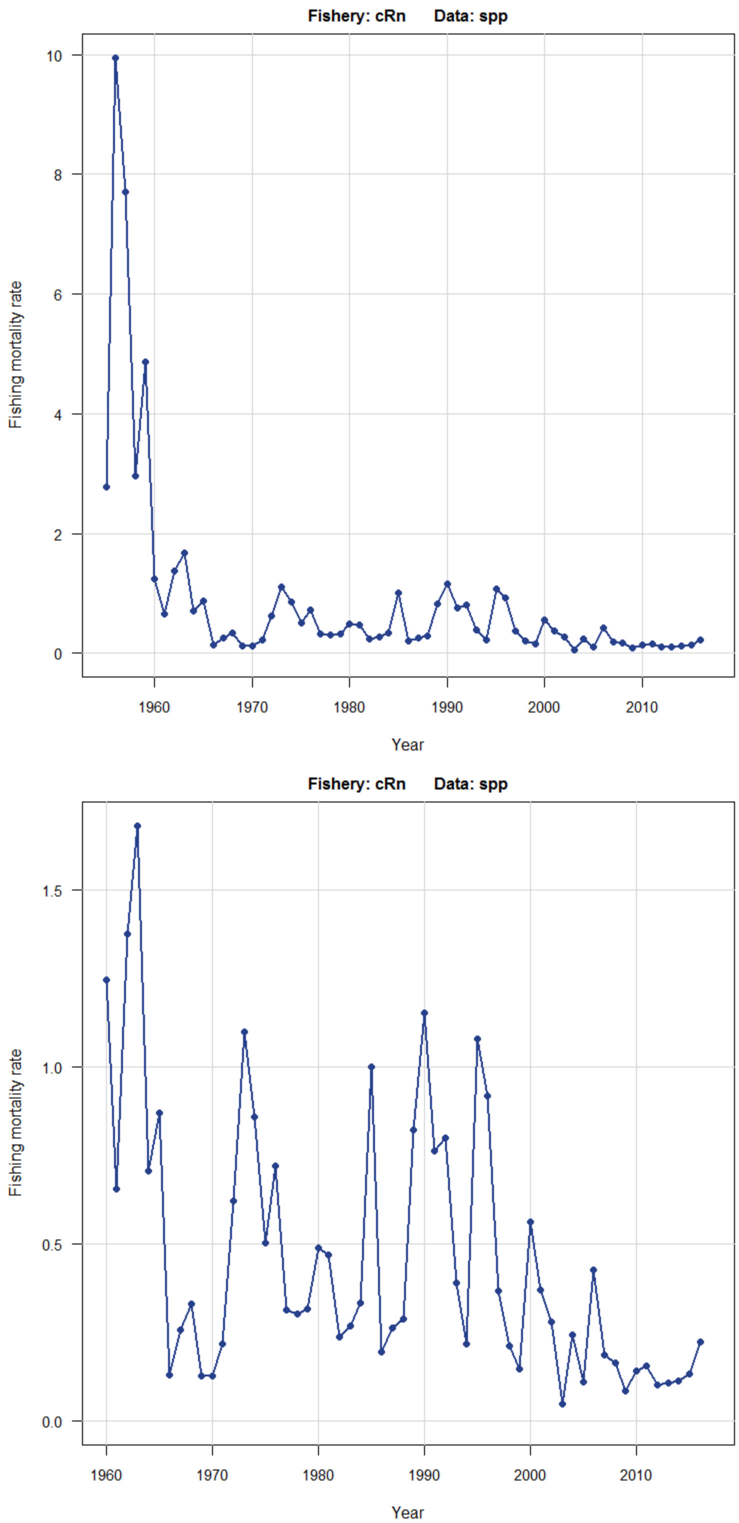



**Figure 6.2.2.1.** Full fishing mortality rate for the northern commercial reduction fishery from 1955-2016 (upper panel) and truncated to 1960-2016 (lower panel).

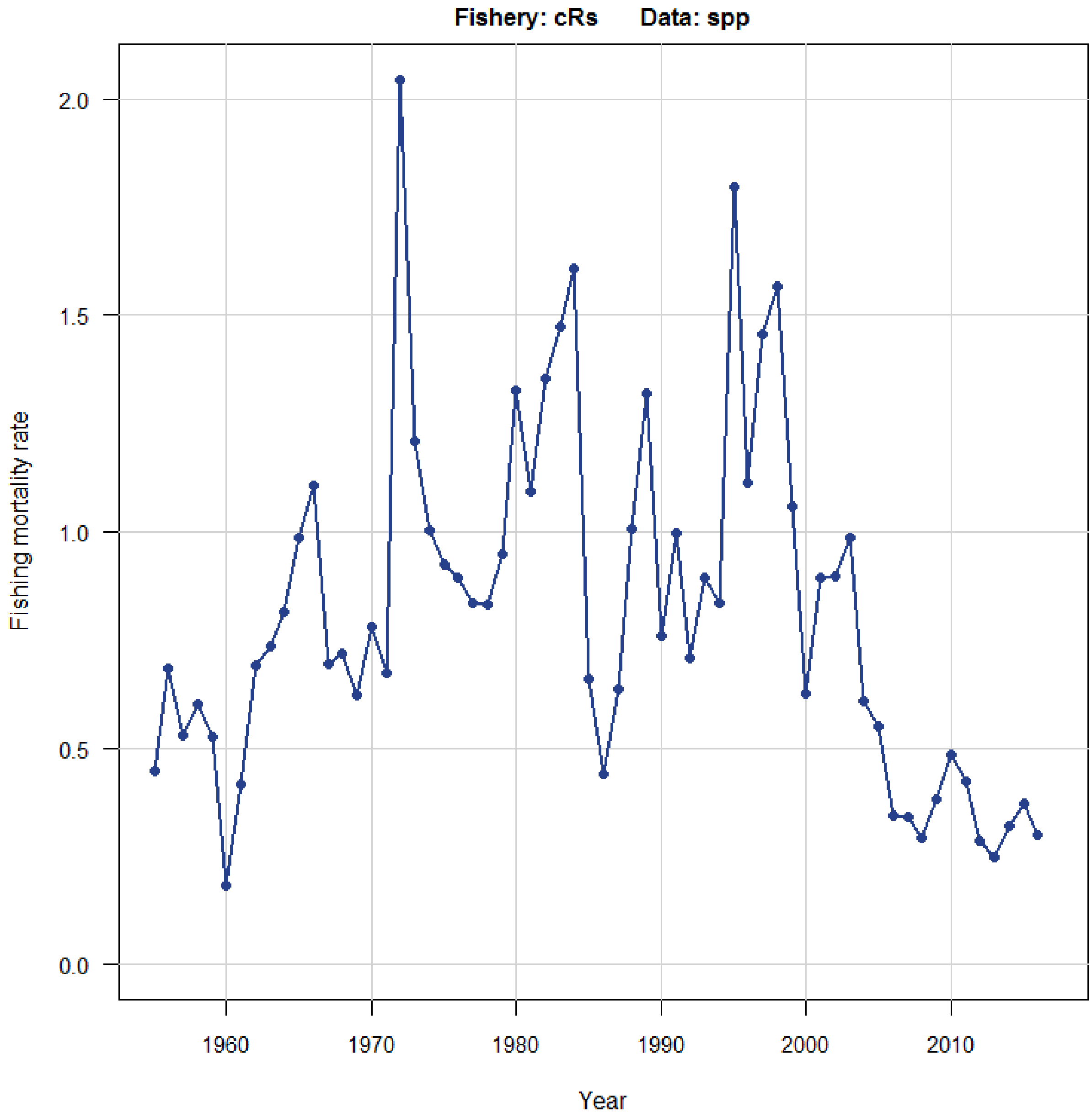



**Figure 6.2.2.2.** Full fishing mortality rate for the southern commercial reduction fishery from 1955-2016.

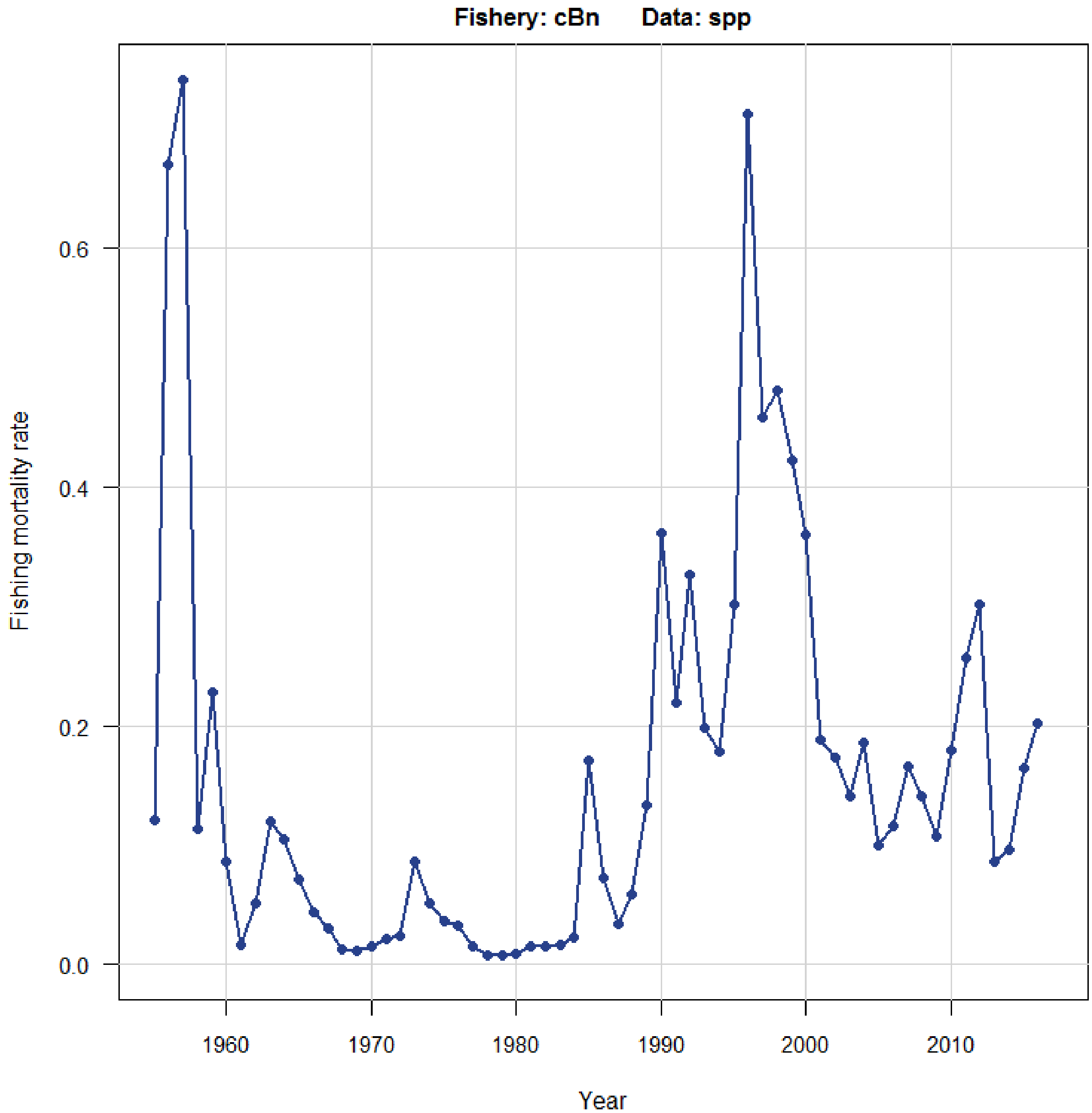



**Figure 6.2.2.3.** Full fishing mortality rate for the northern commercial bait fishery from 1955-2016.

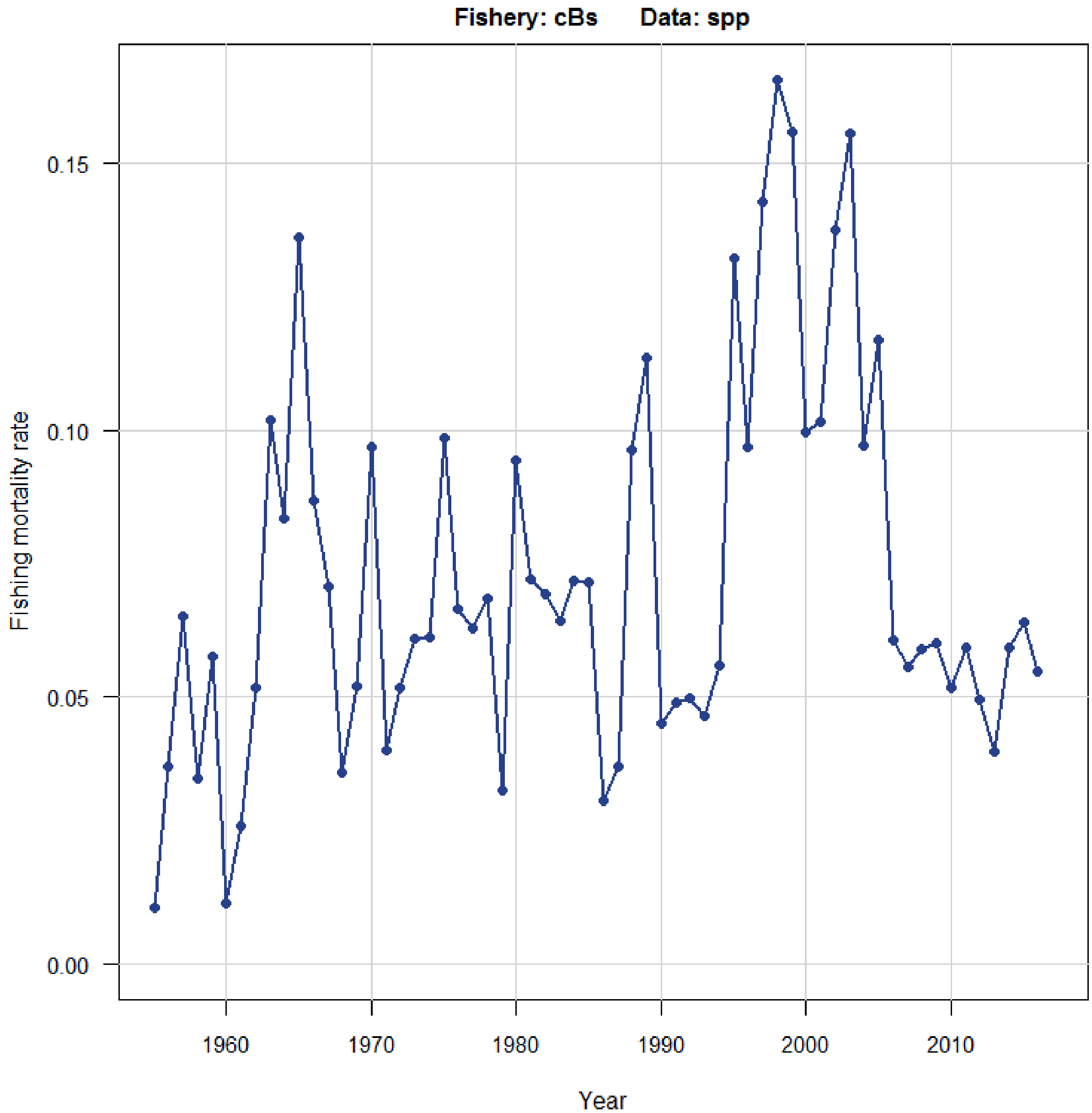



**Figure 6.2.2.4.** Full fishing mortality rate for the southern commercial bait fishery from 1955-2016.

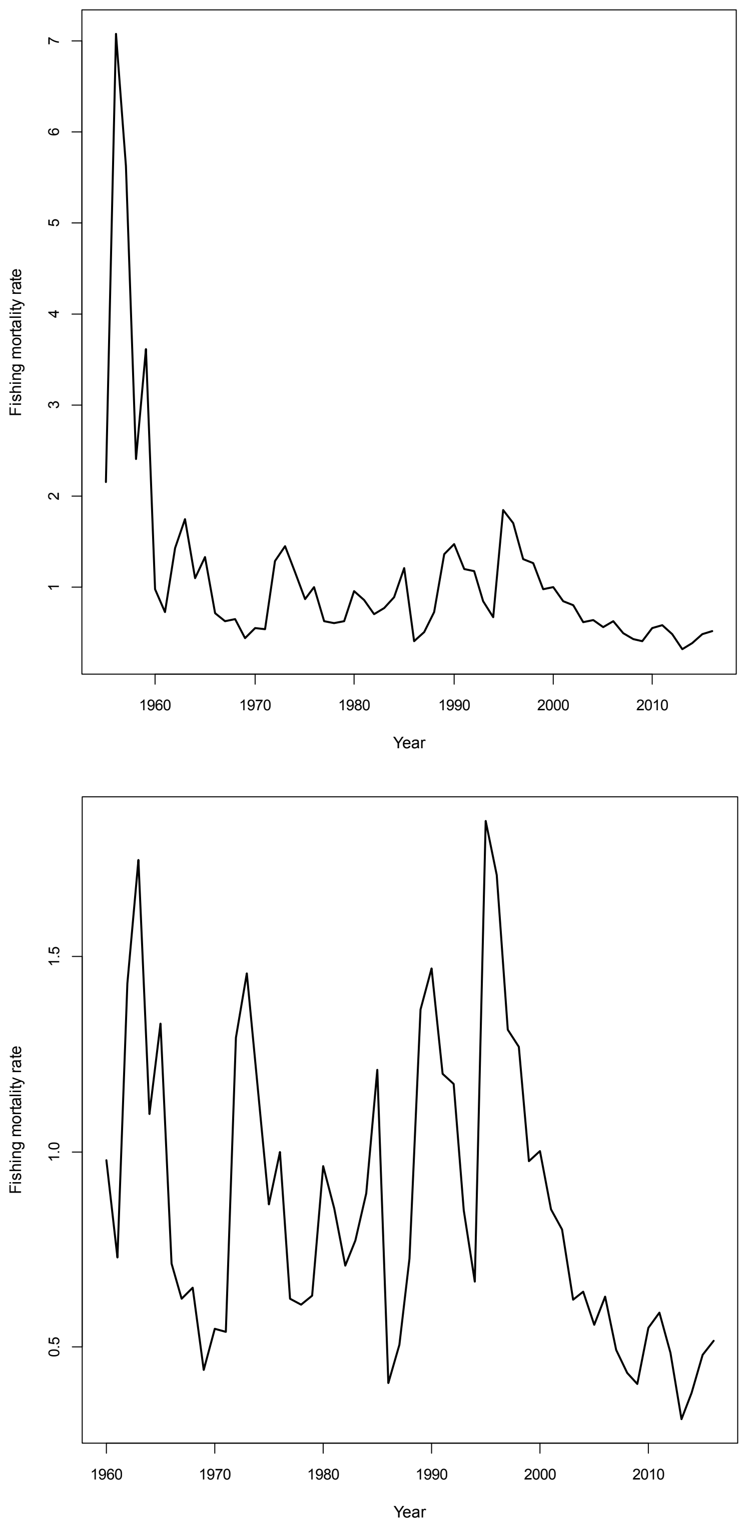



**Figure 6.2.2.5.** Geometic mean *F* across ages 2 to 4 over the time course of the fishery from 1955-2016 (upper panel) and truncated to 1960-2016 (lower panel).

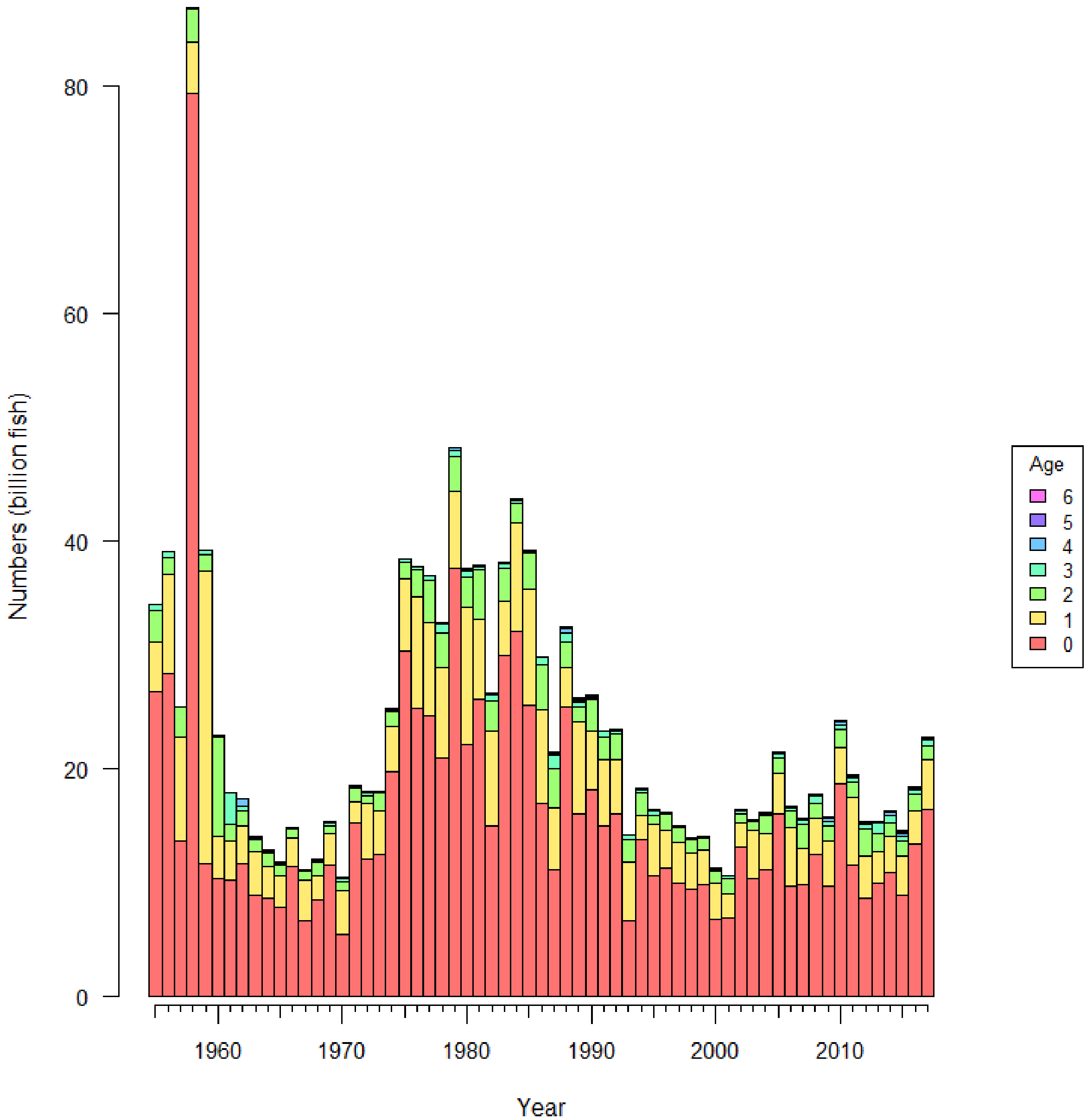



**Figure 6.2.3.1.** Numbers at age (above) and proportion of numbers at age (next page) estimated from the base run of the BAM for ages 0-6+ during the time period 1955-2016.

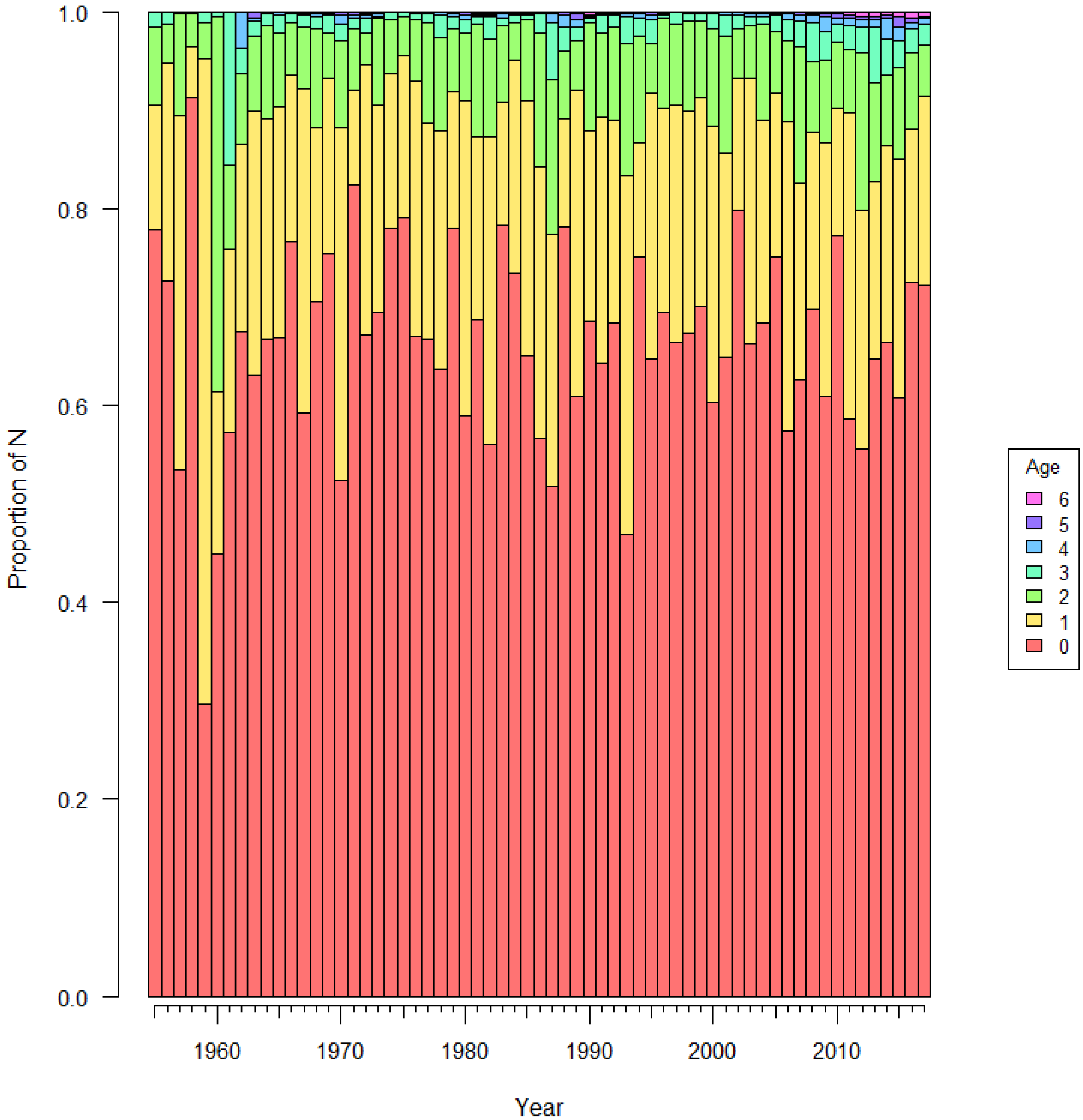



**Figure 6.2.3.1.** ***Continued.***

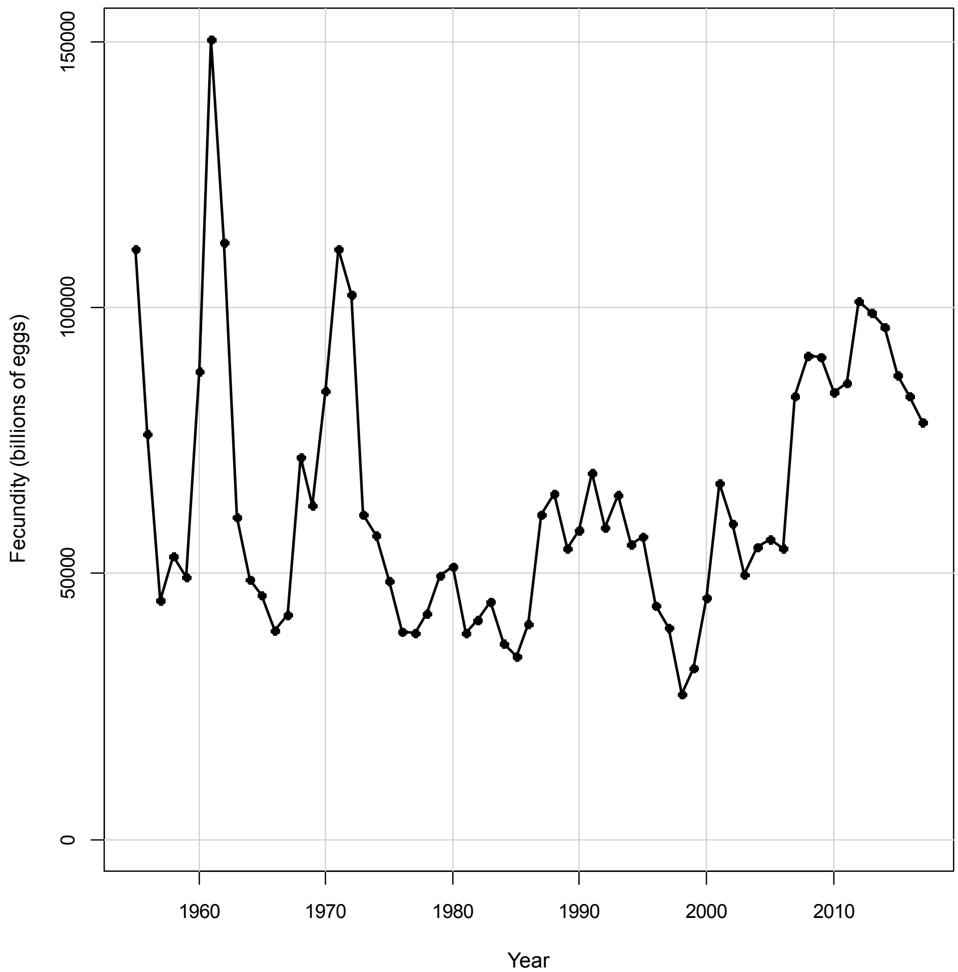



**Figure 6.2.3.2.** Fecundity in billions of eggs from 1955-2017, with the last year being a projection based on 2016 mortality.

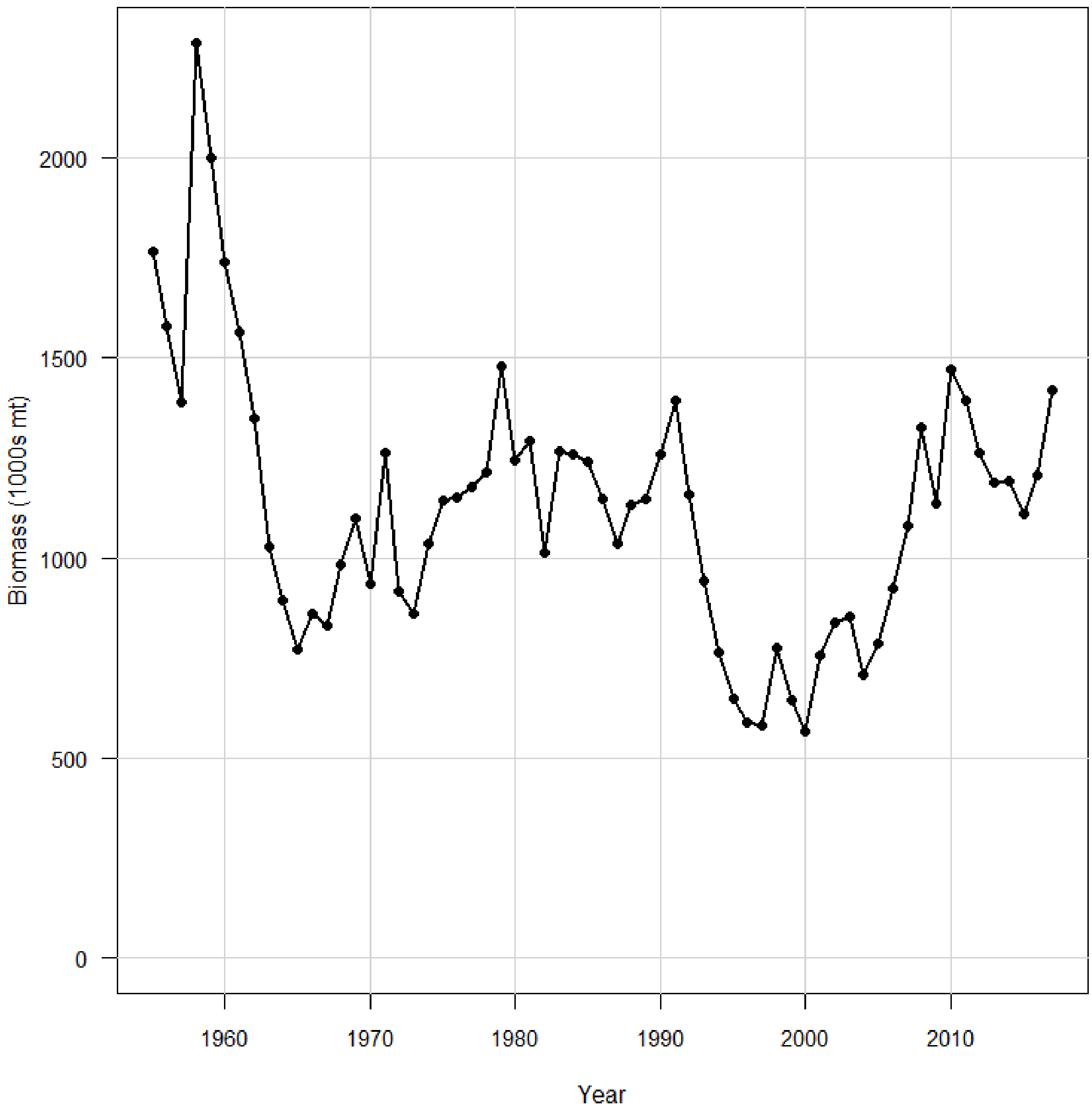



**Figure 6.2.3.3.** Biomass (above) and proportion of biomass at age (next page) over time as predicted from the base run of the BAM for Atlantic menhaden, with the last year being a projection based on 2016 mortality.

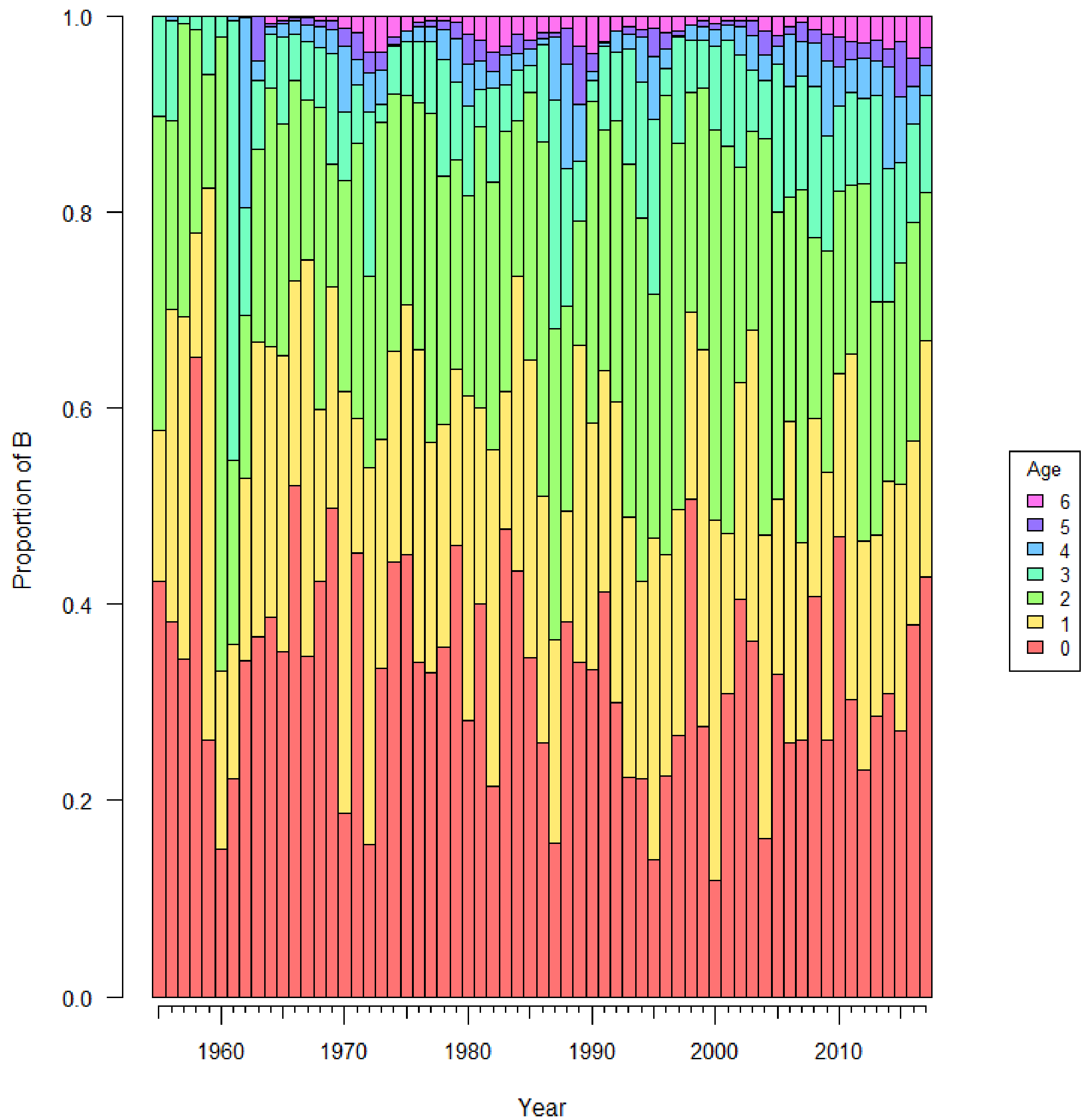



**Figure 6.2.3.3.** ***Continued.***

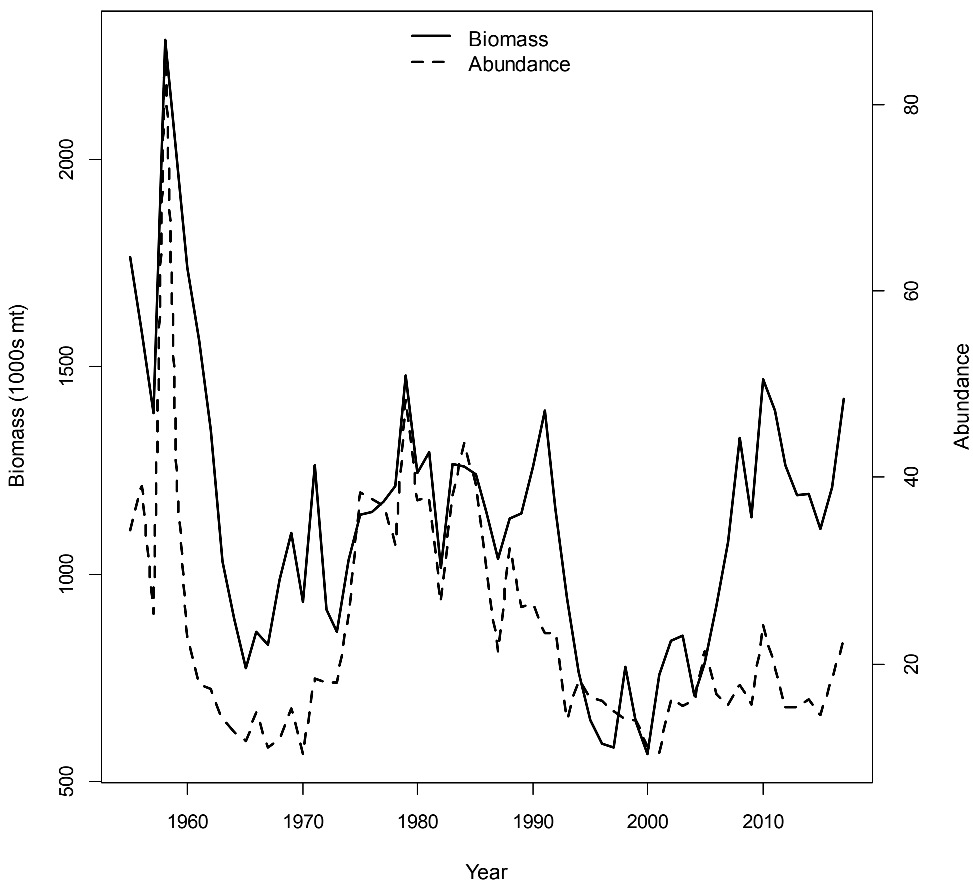


**Figure 6.2.3.4.** Biomass (1000s mt) and abundance over time for Atlantic menhaden from 1959-2016.

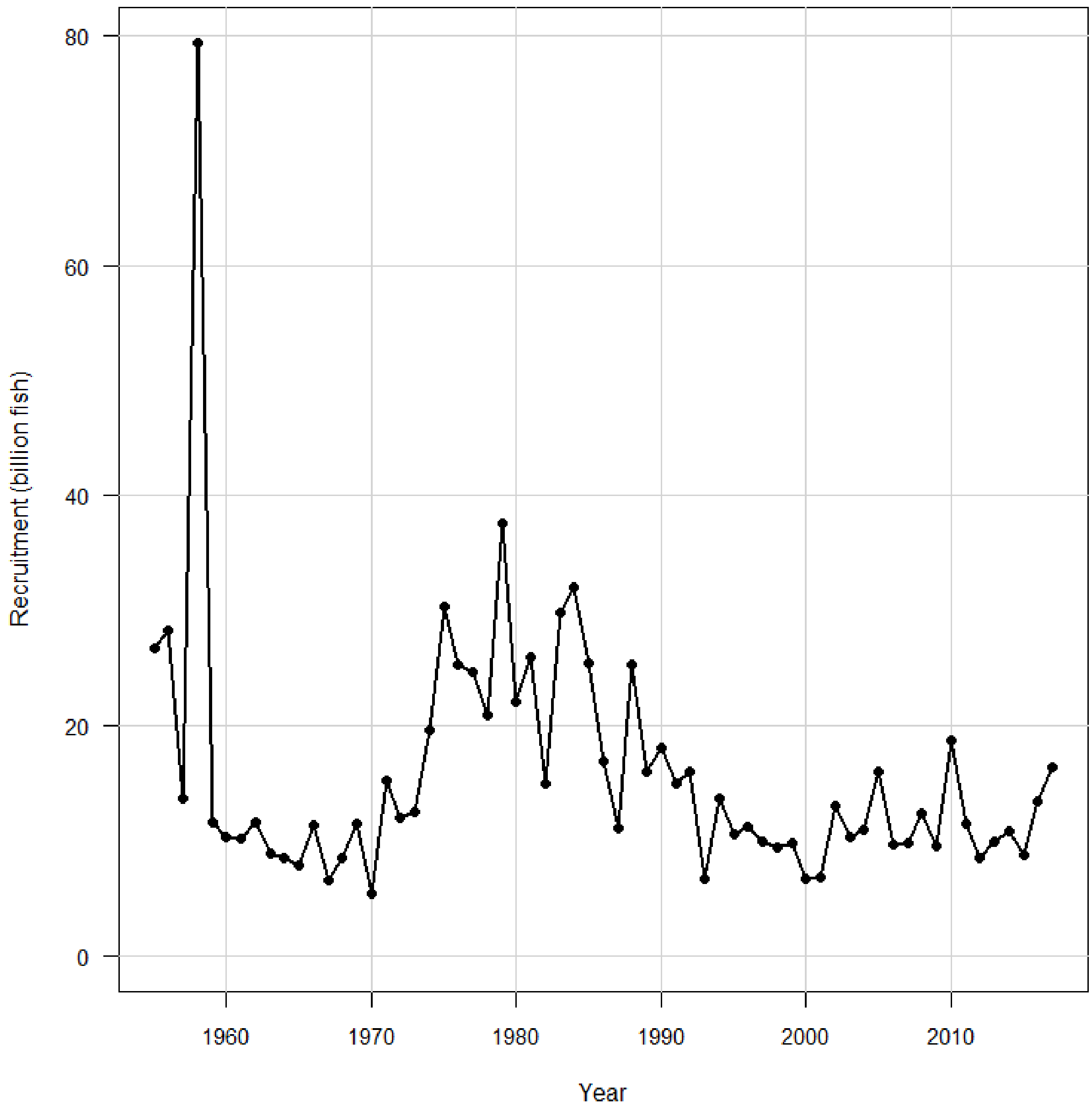



**Figure 6.2.3.5.** Number of recruits in billions of fish predicted from the base run of BAM for 1955-2017, with the last year being a projection based on 2016 mortality.

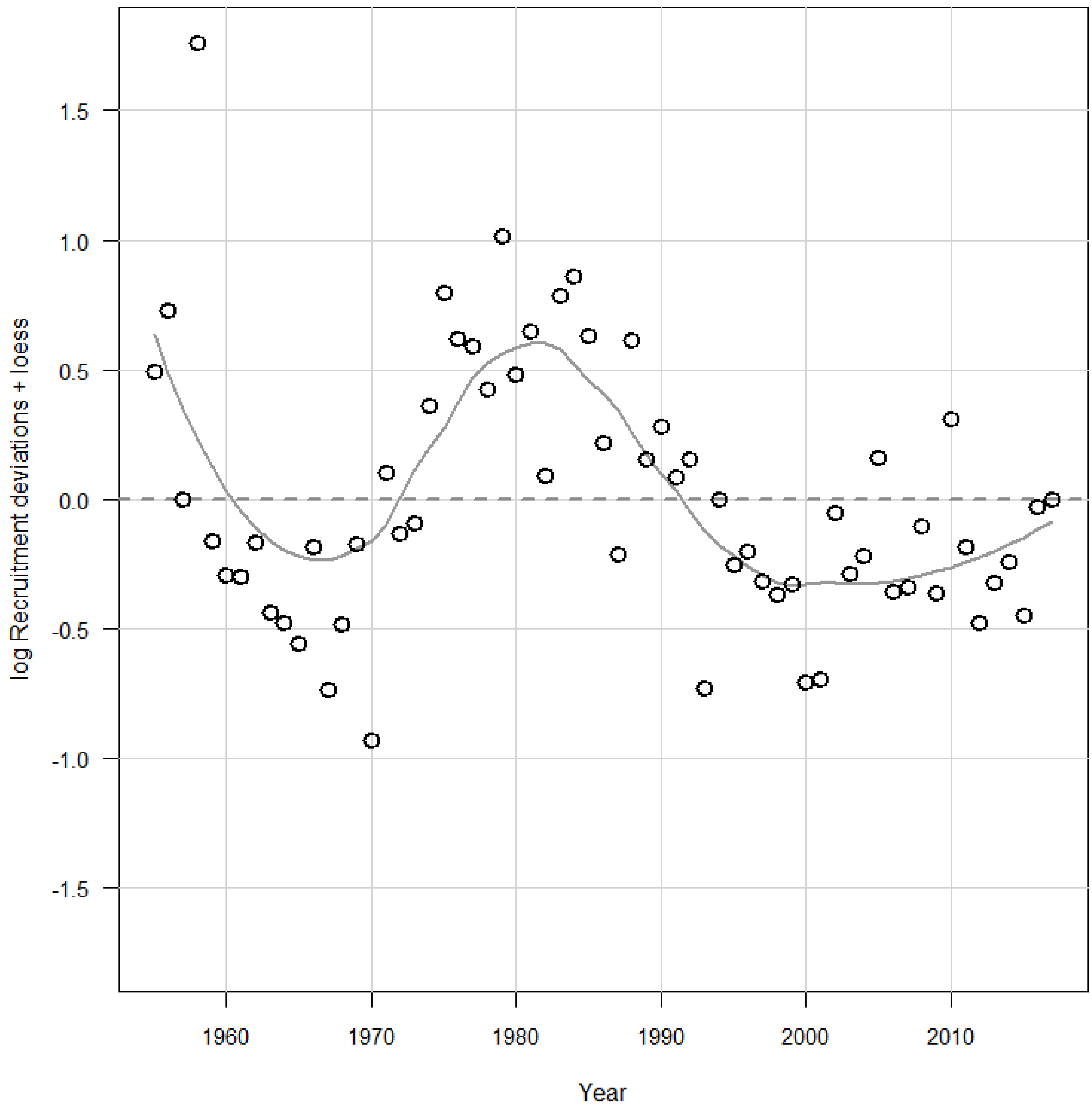



**Figure 6.2.3.6.** Deviations in log recruitment from 1955-2017 with a loess smoother, with the last year being a projection based on 2016 mortality.

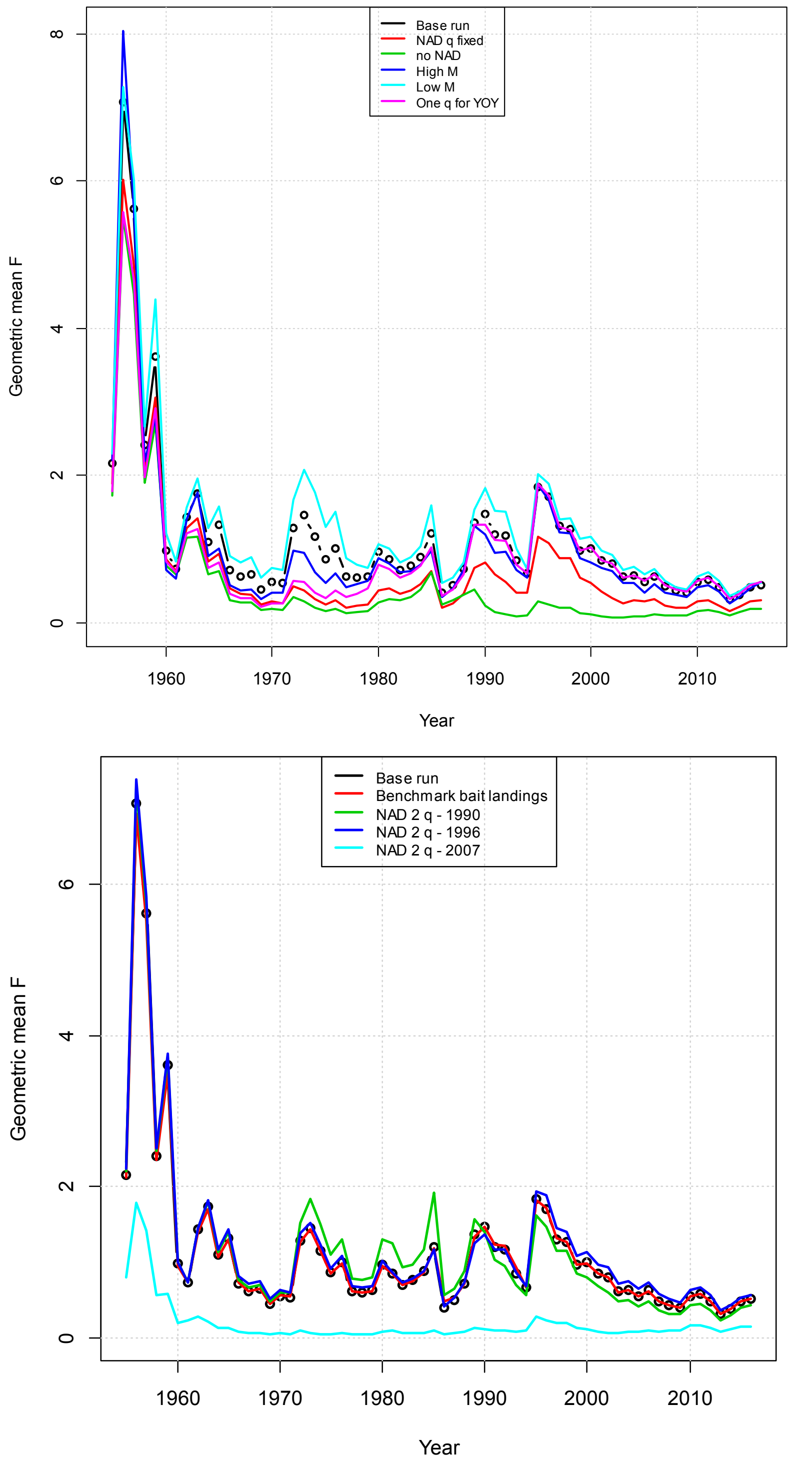
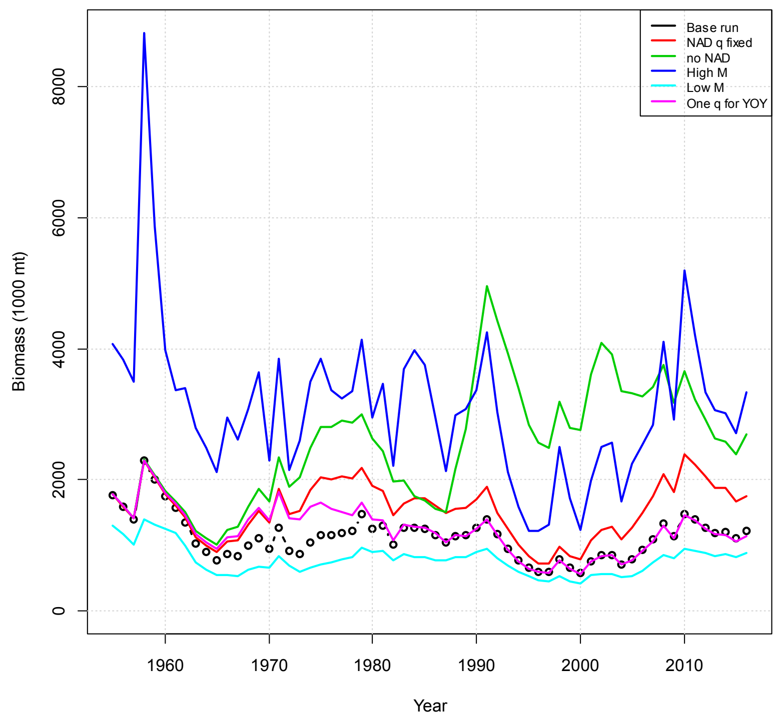



**Figure 6.4.1.1** Geometric mean of *F* for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.



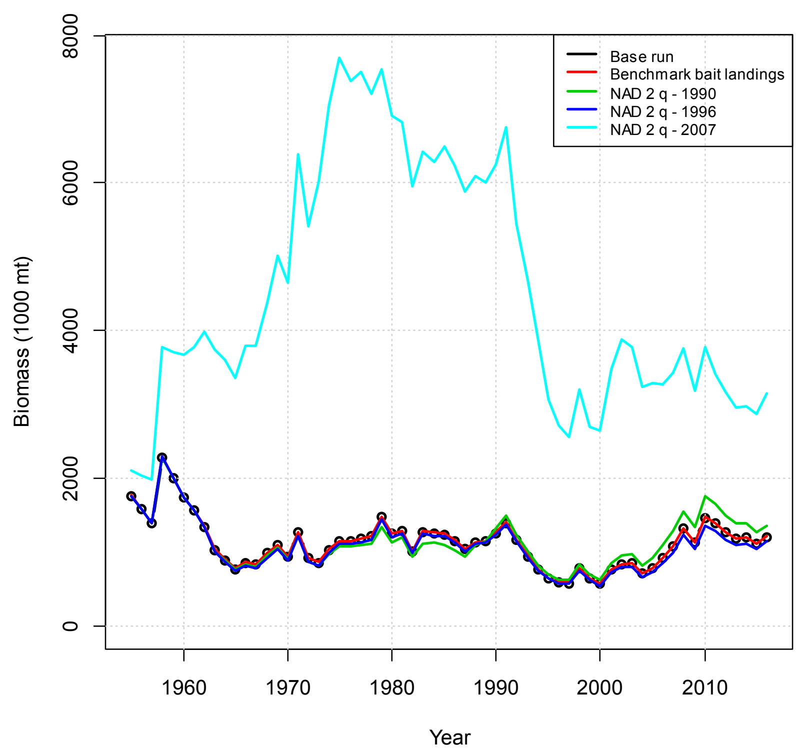




**Figure 6.4.1.2** Age-1+ biomass in 1000 mt for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

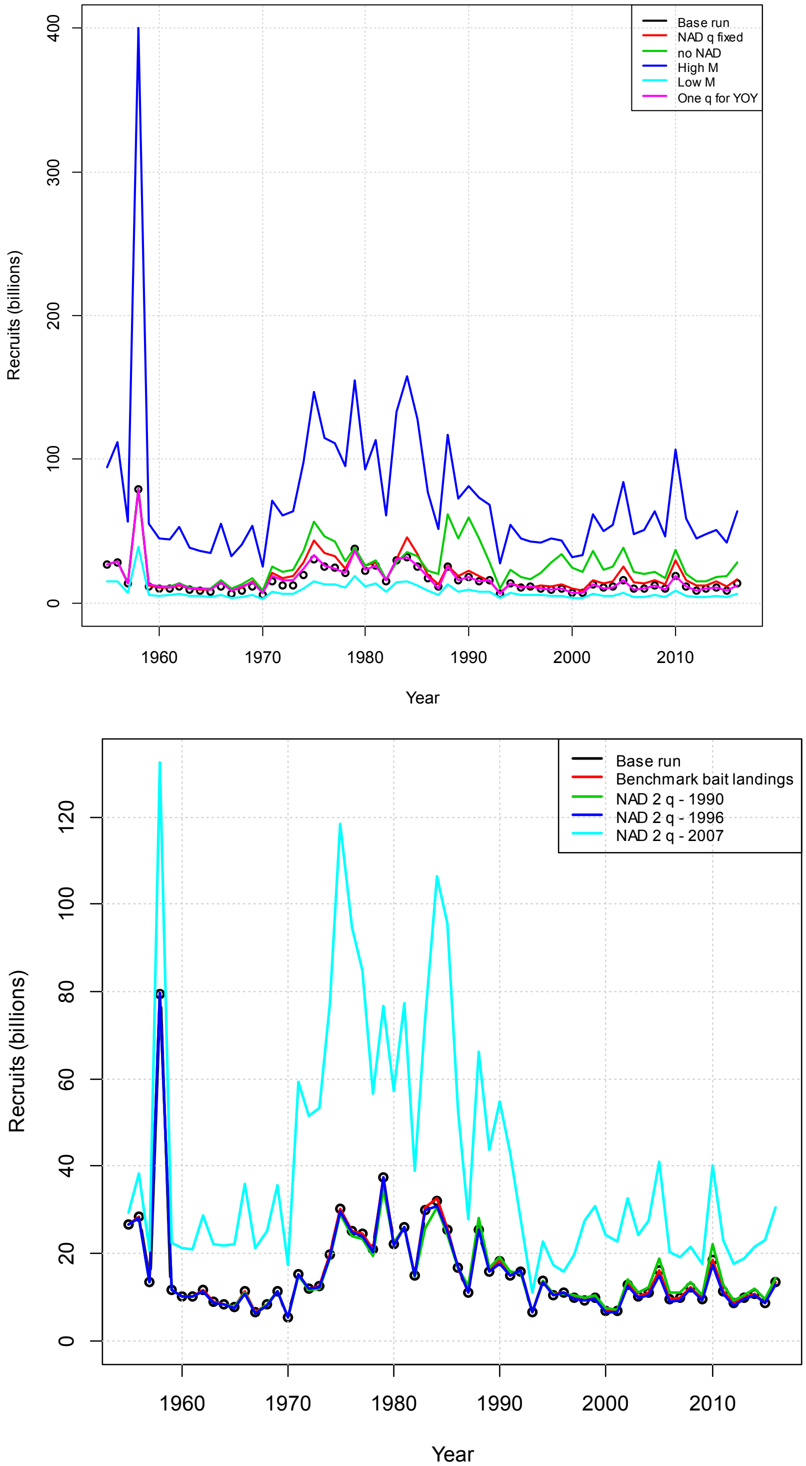



**Figure 6.4.1.3** Recruitment over time for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

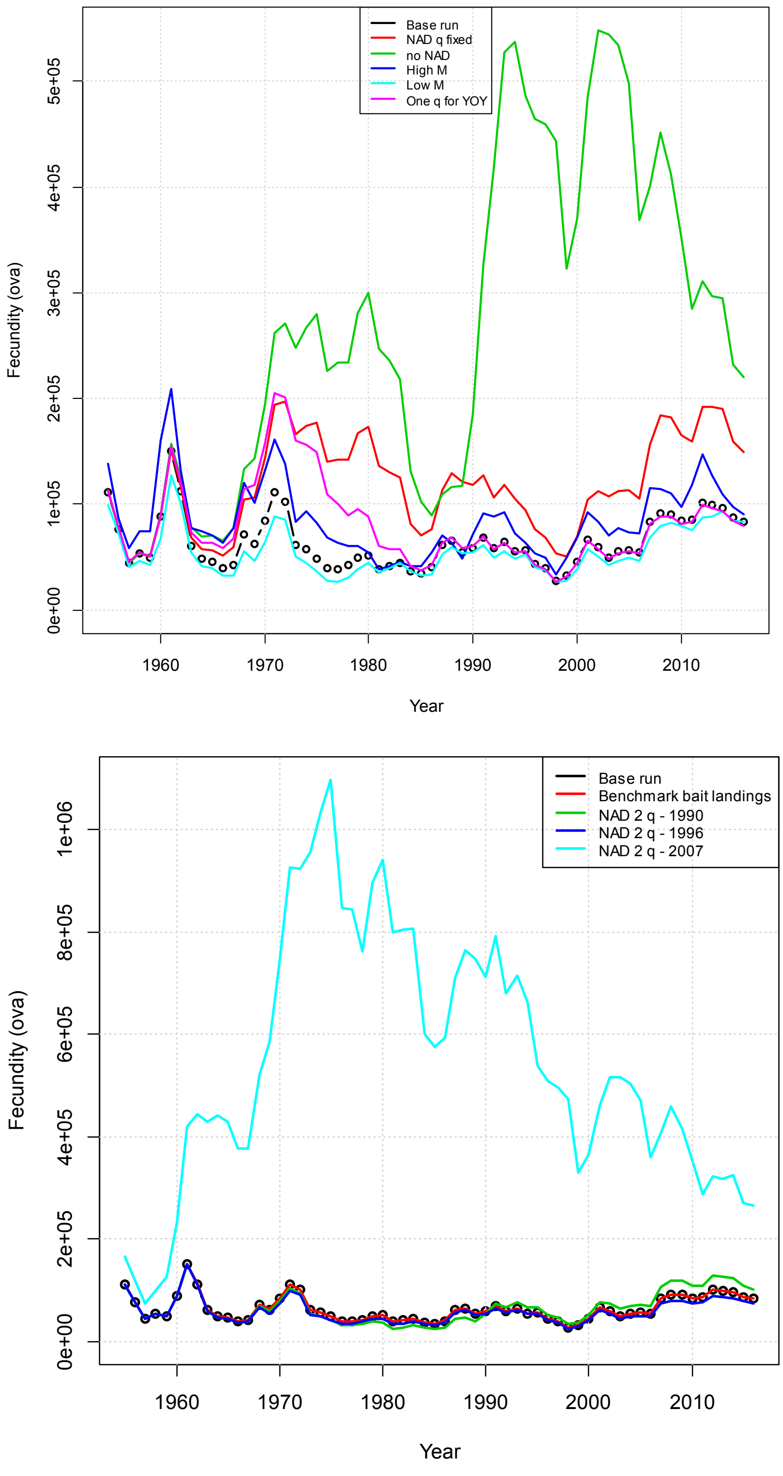
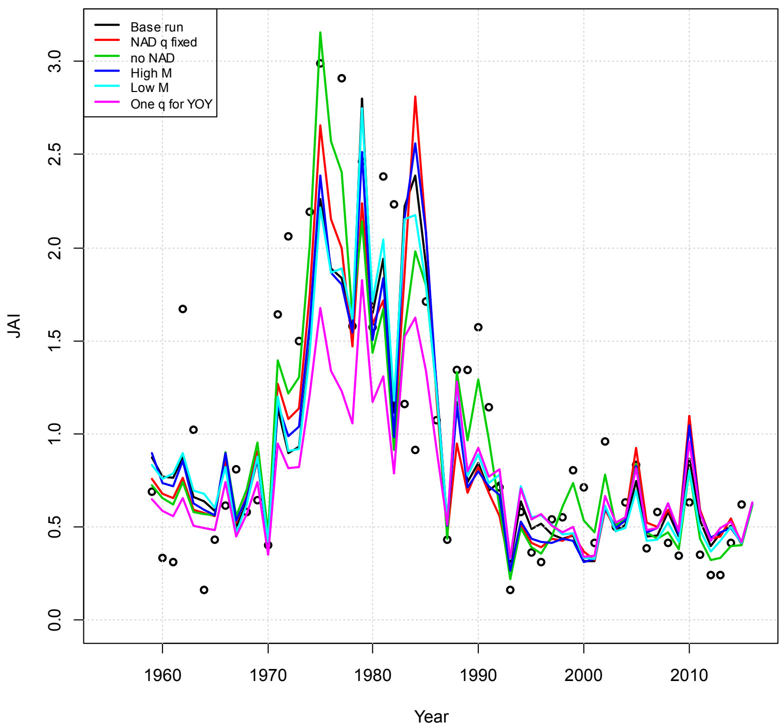



**Figure 6.4.1.4** Fecundity over time for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.



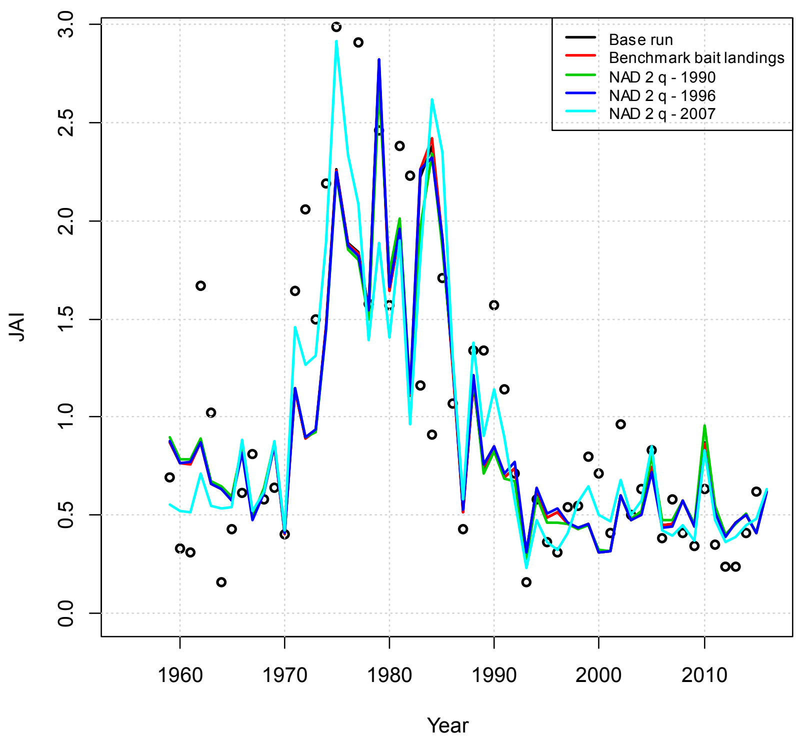
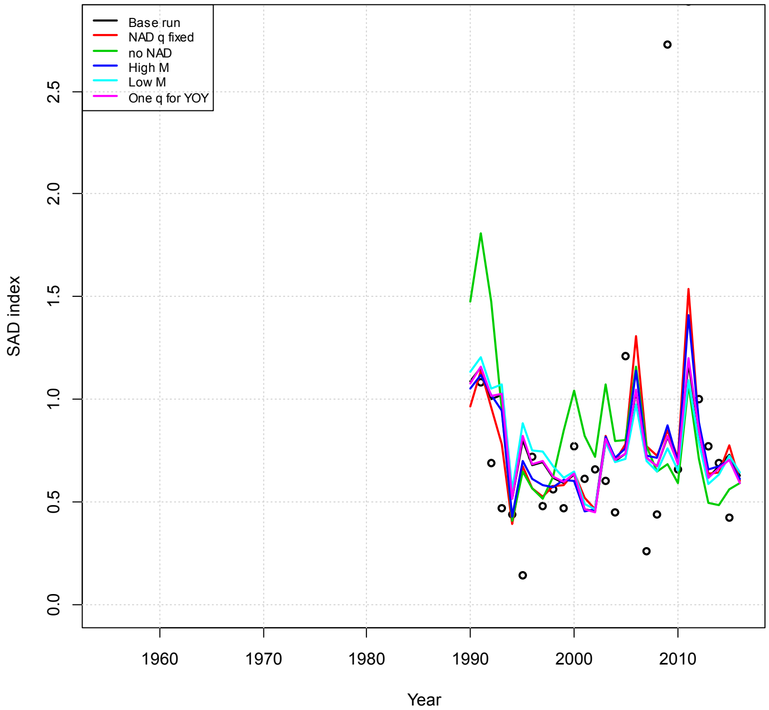




**Figure 6.4.1.5** Fit to the recruitment index for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.



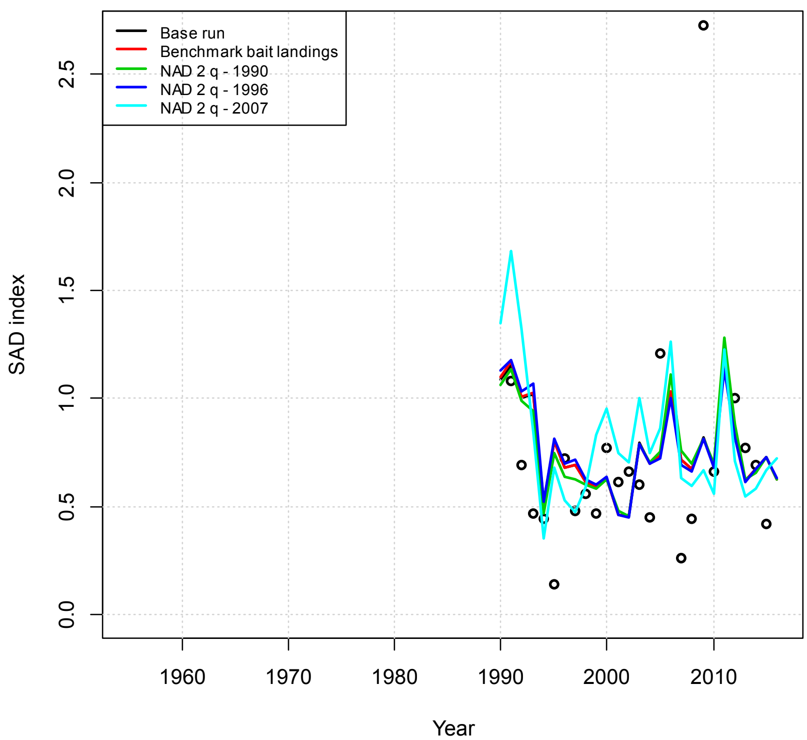




**Figure 6.4.1.6** Fit to the SAD index for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

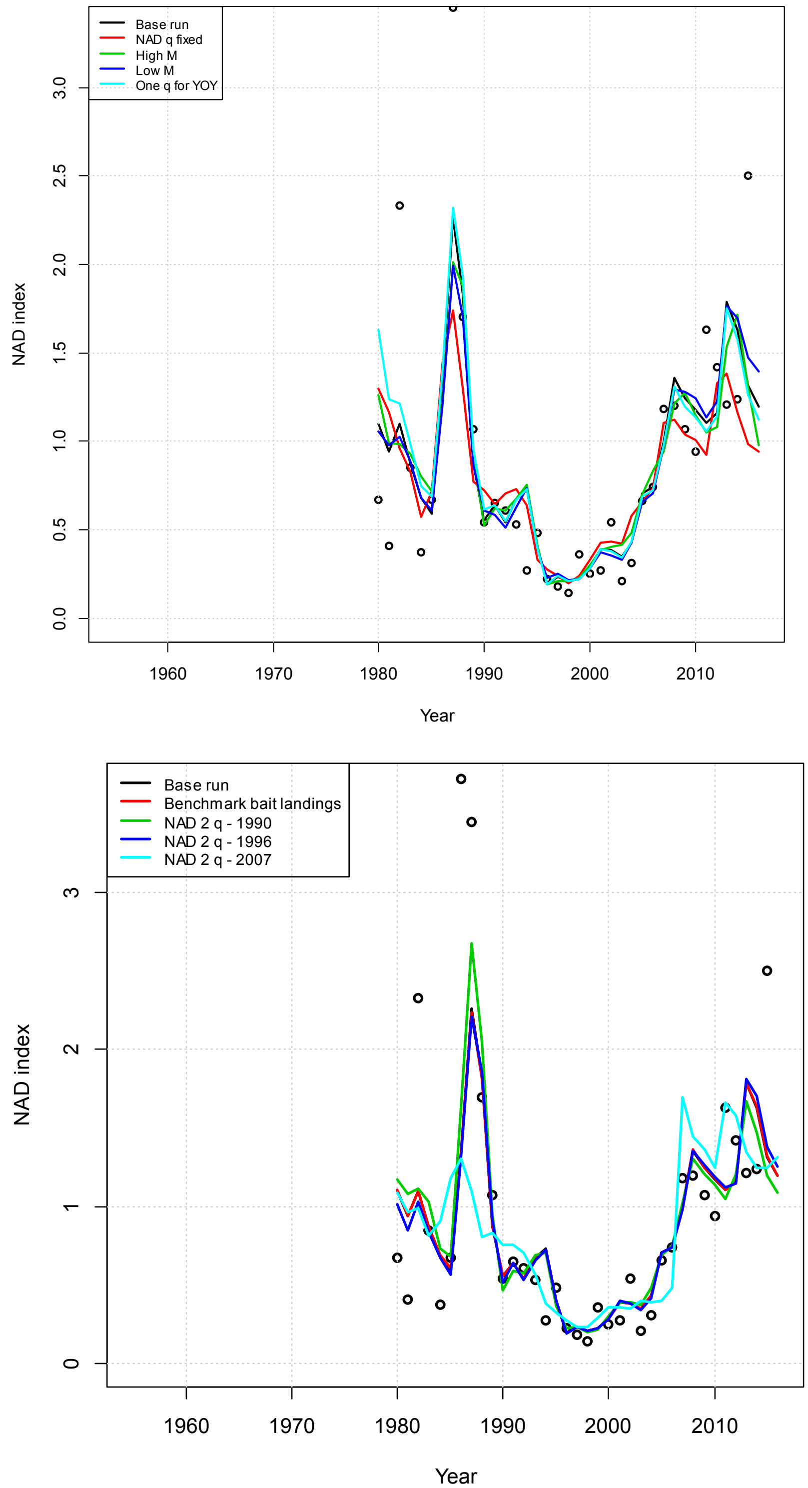



**Figure 6.4.1.7** Fit to the NAD index for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

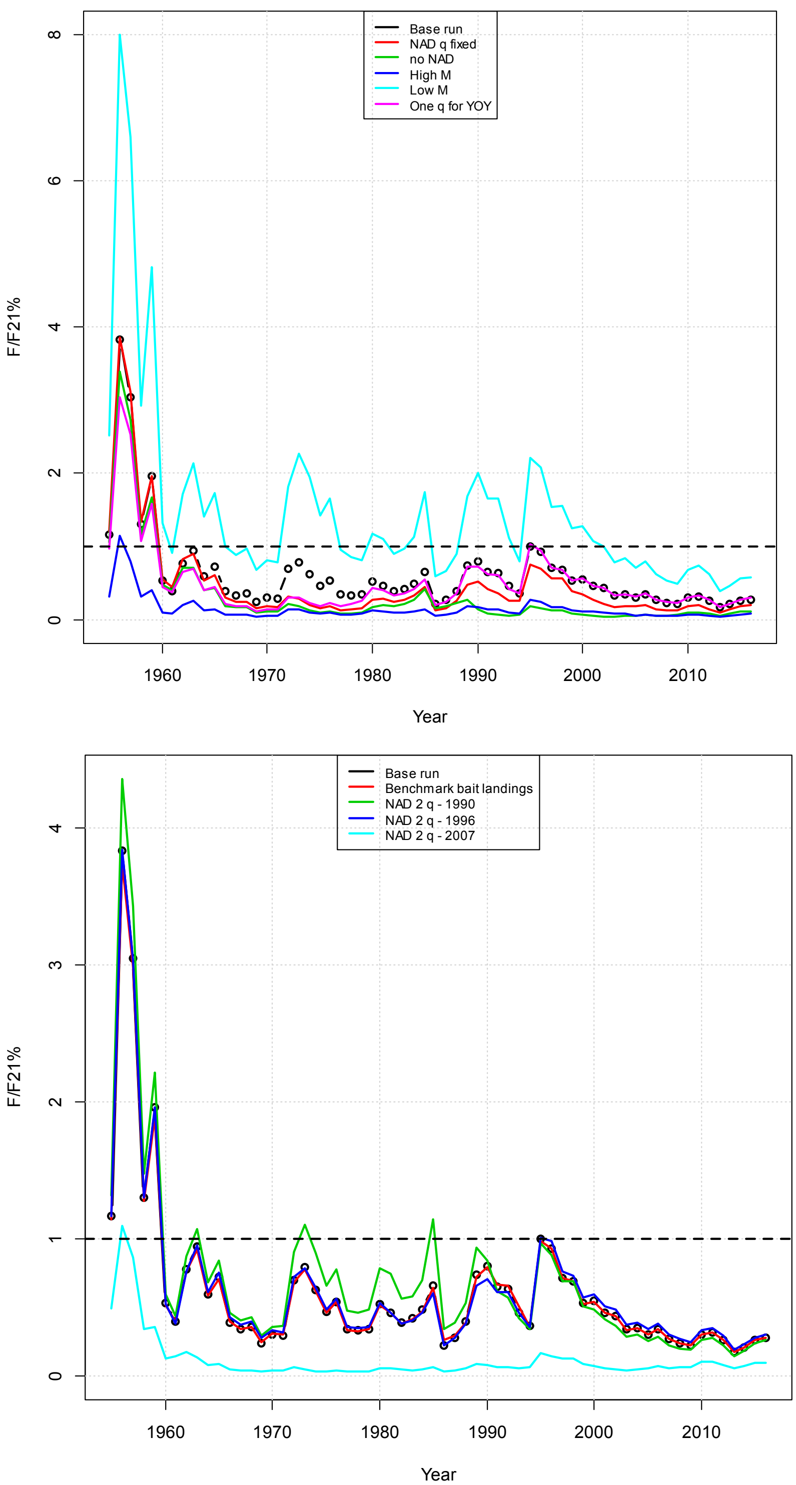
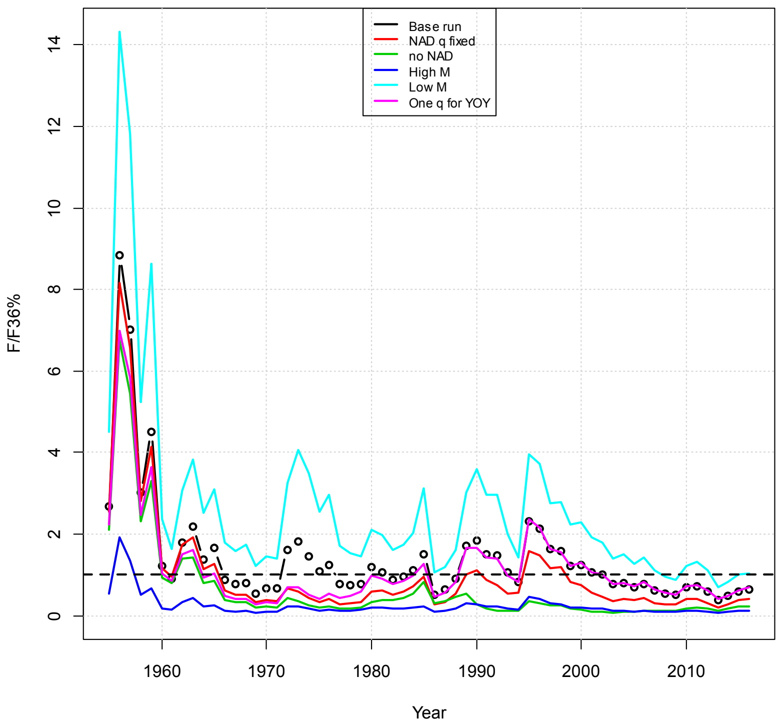



**Figure 6.4.1.8** Full *F* over $F_{21\%}$ for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.



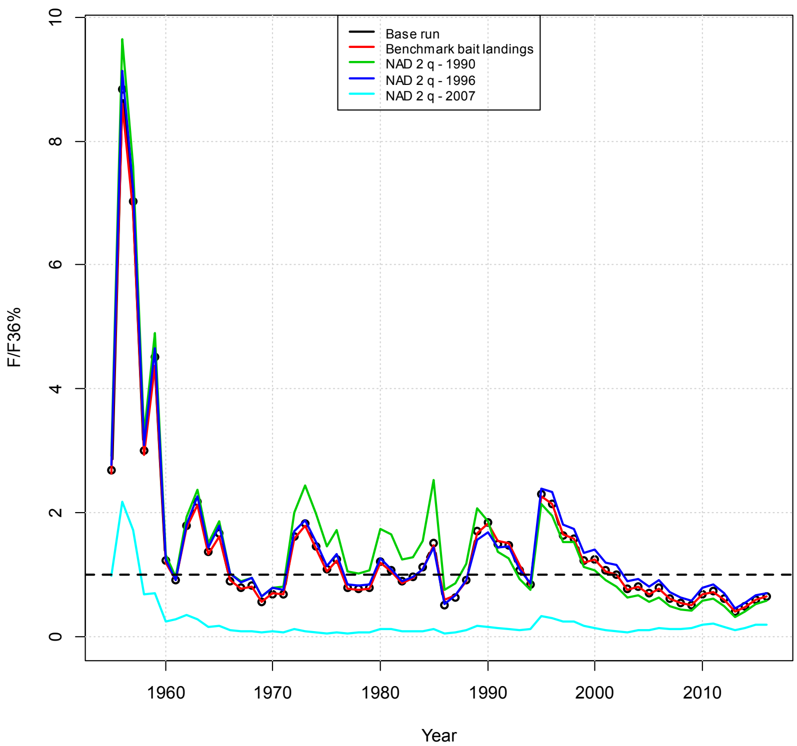




**Figure 6.4.1.9** Full *F* over $F_{36\%}$ for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

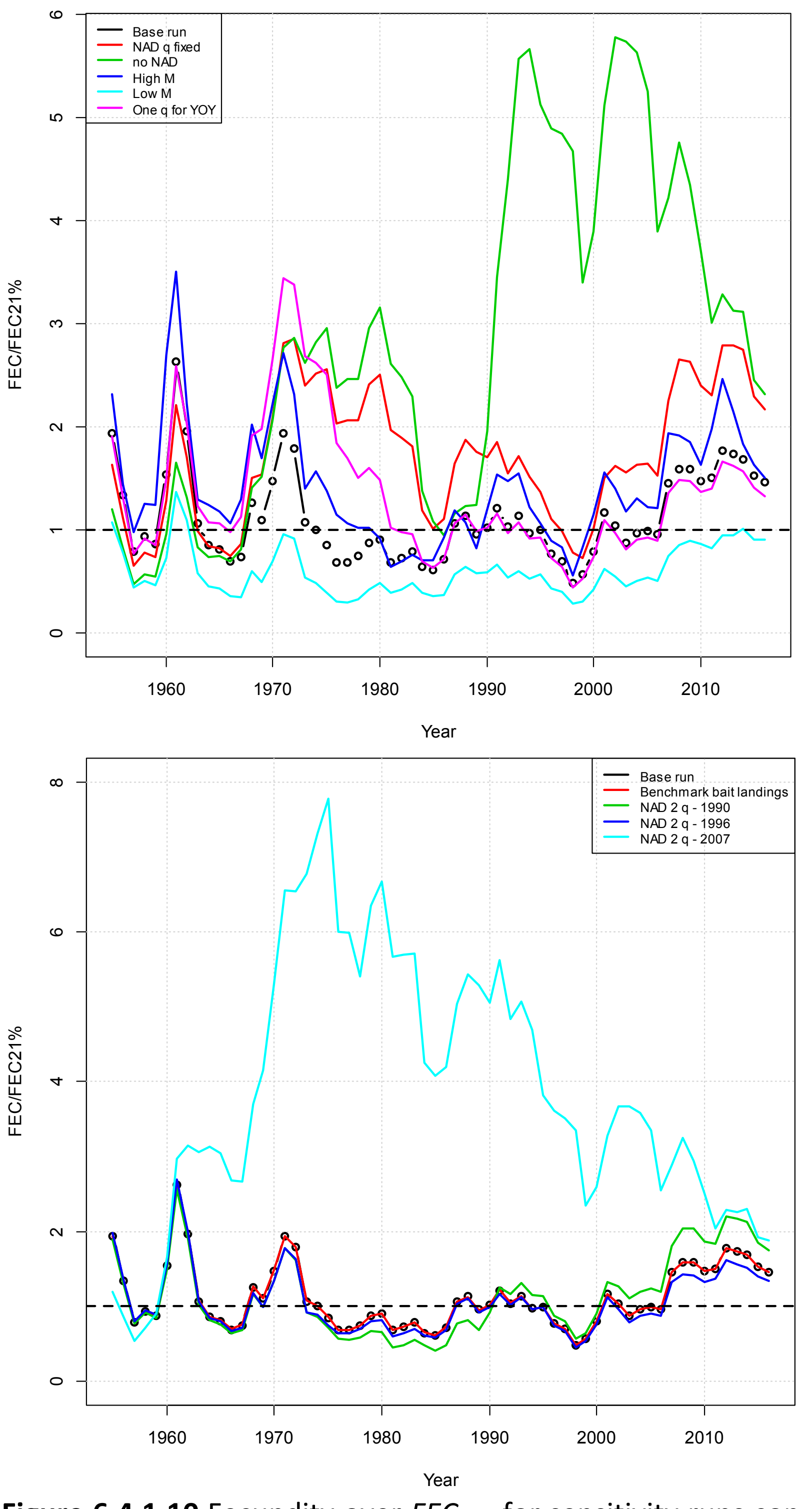



**Figure 6.4.1.10** Fecundity over *$FEC_{21\%}$* for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

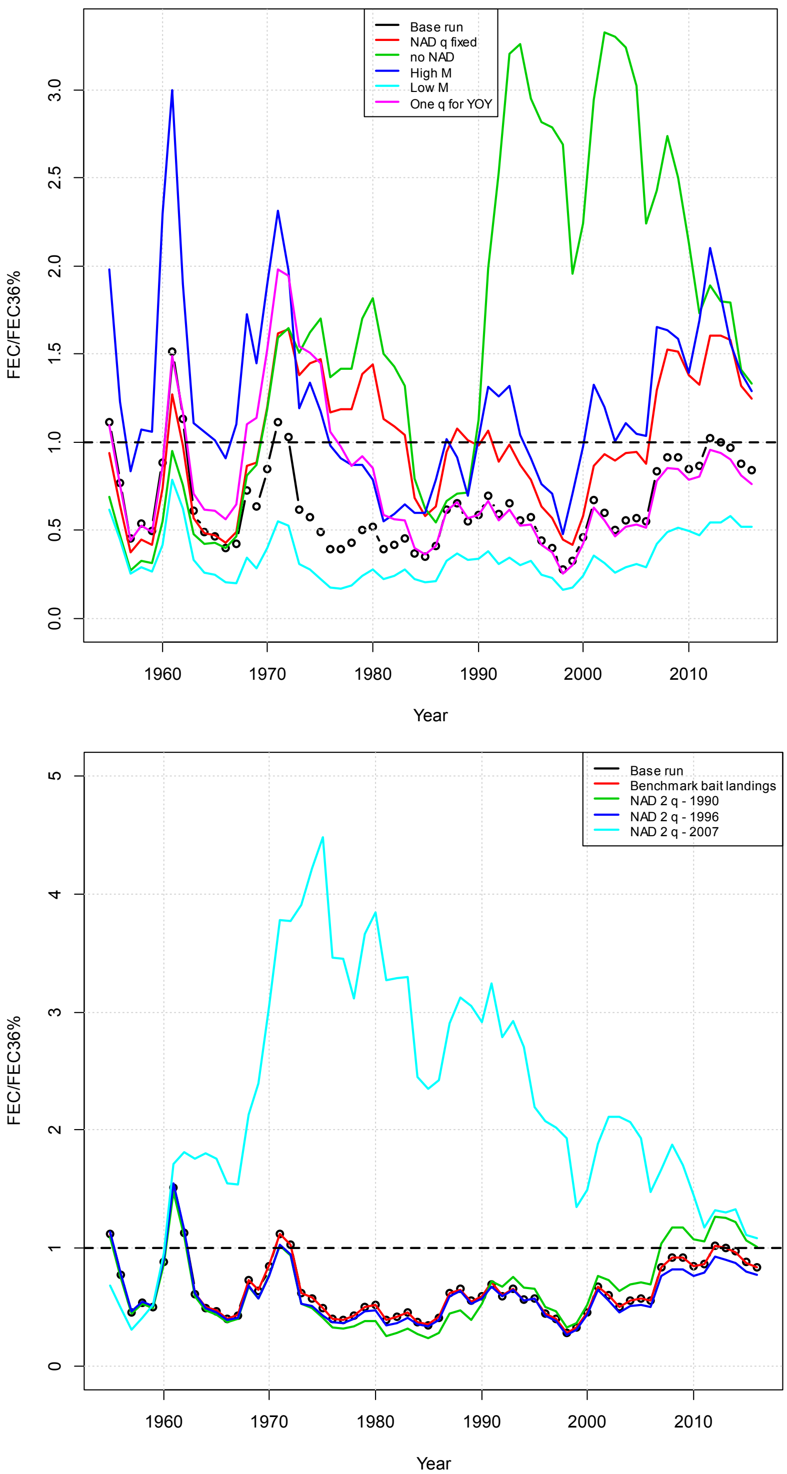



**Figure 6.4.1.11** Fecundity over *$FEC_{36\%}$* for sensitivity runs considering differences in growth and life history parameters and differences in indices and catchability in the assessment model.

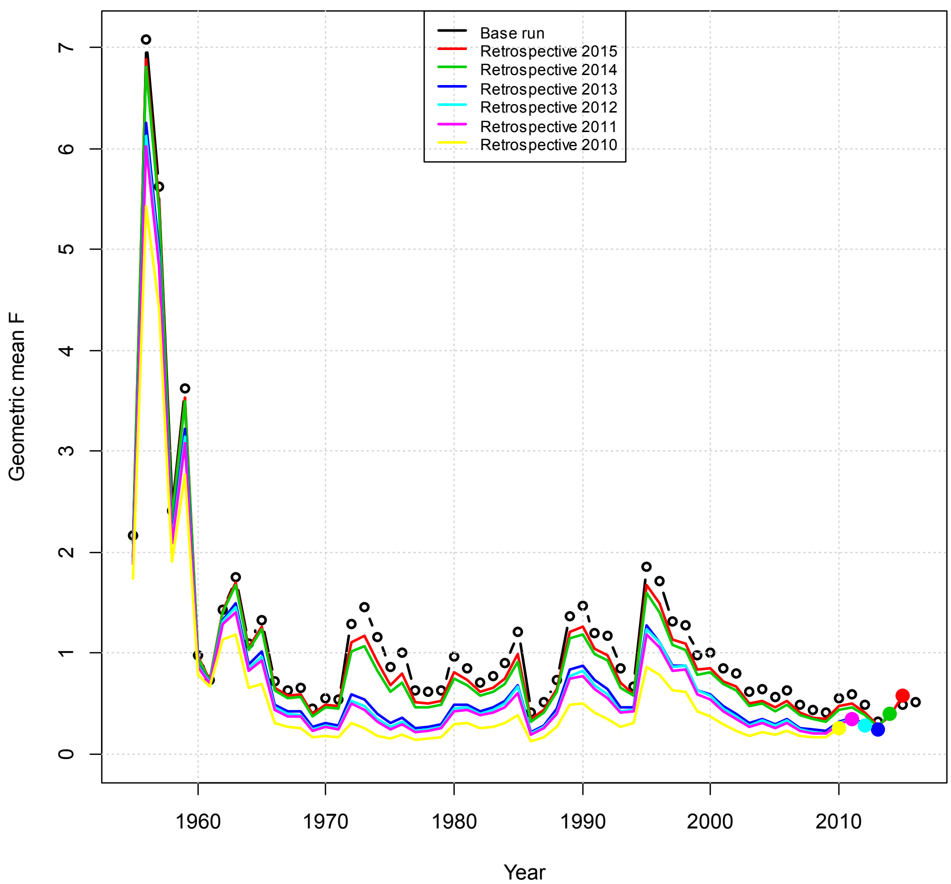



**Figure 6.4.2.1** Fishing mortality over time for the retrospective analysis of the assessment model.

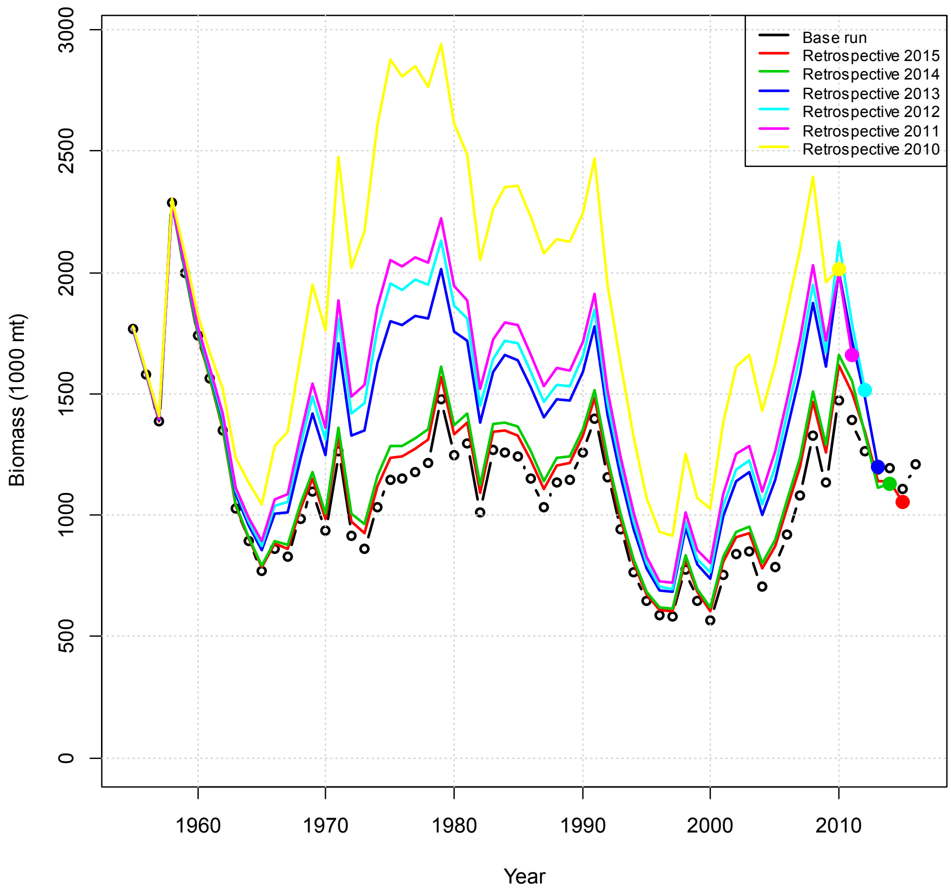



**Figure 6.4.2.2** Age-1+ biomass in 1000s mt over time for the retrospective analysis of the assessment model.

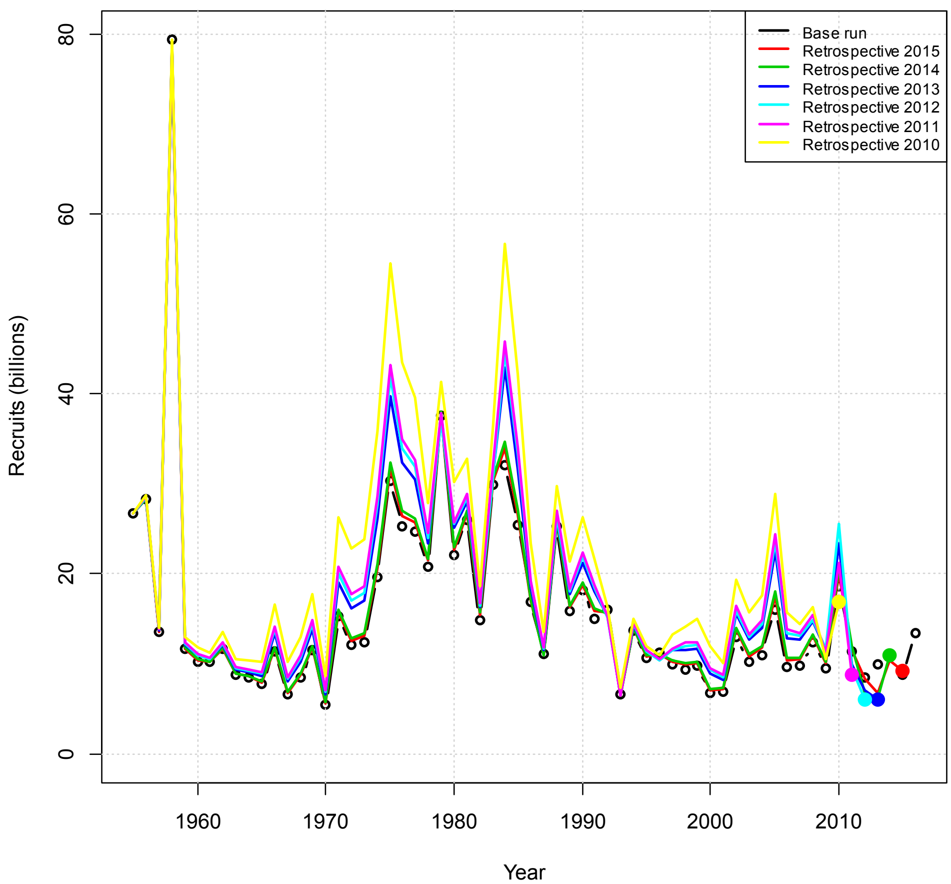



**Figure 6.4.2.3** Recruitment over time for the retrospective analysis of the assessment model.

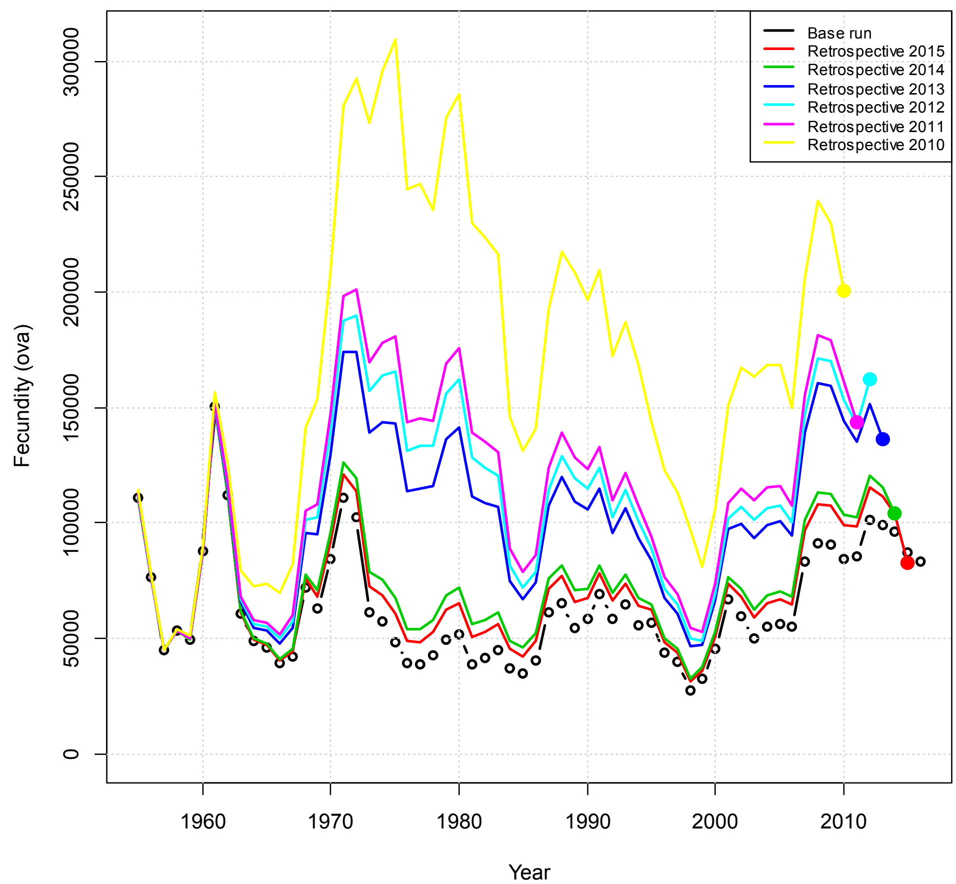



**Figure 6.4.2.4** Fecundity over time for the retrospective analysis of the assessment model.

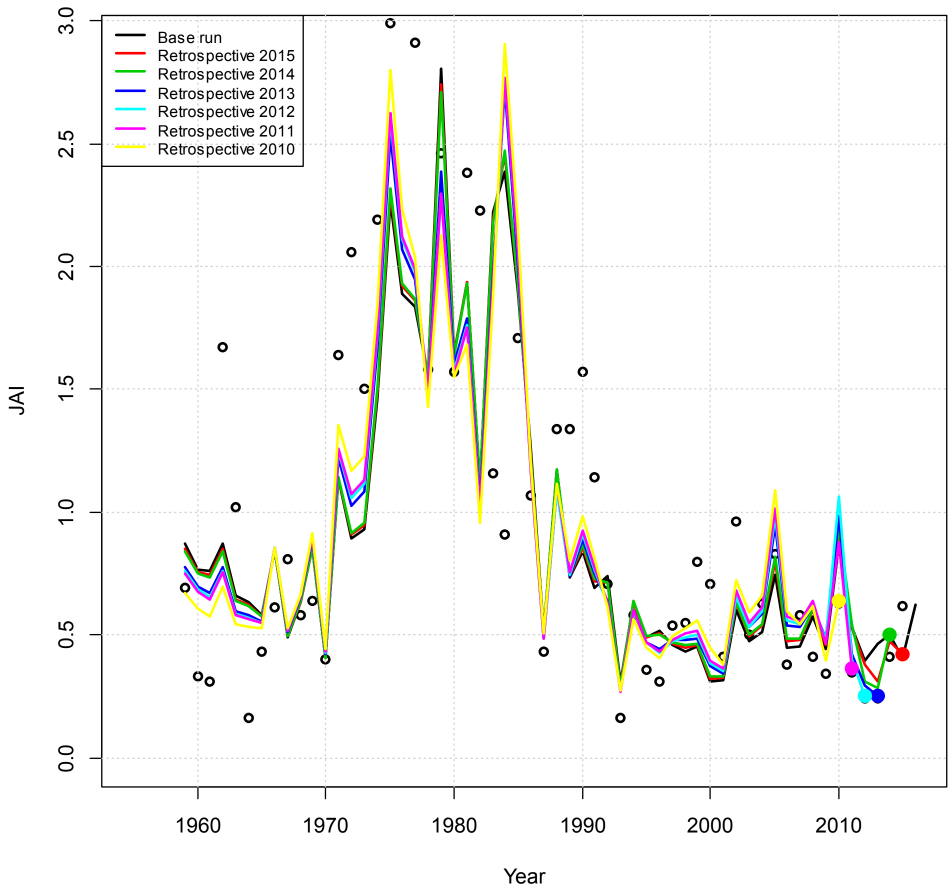



**Figure 6.4.2.5** Fit to the JAI index over time for the retrospective analysis of the assessment model.

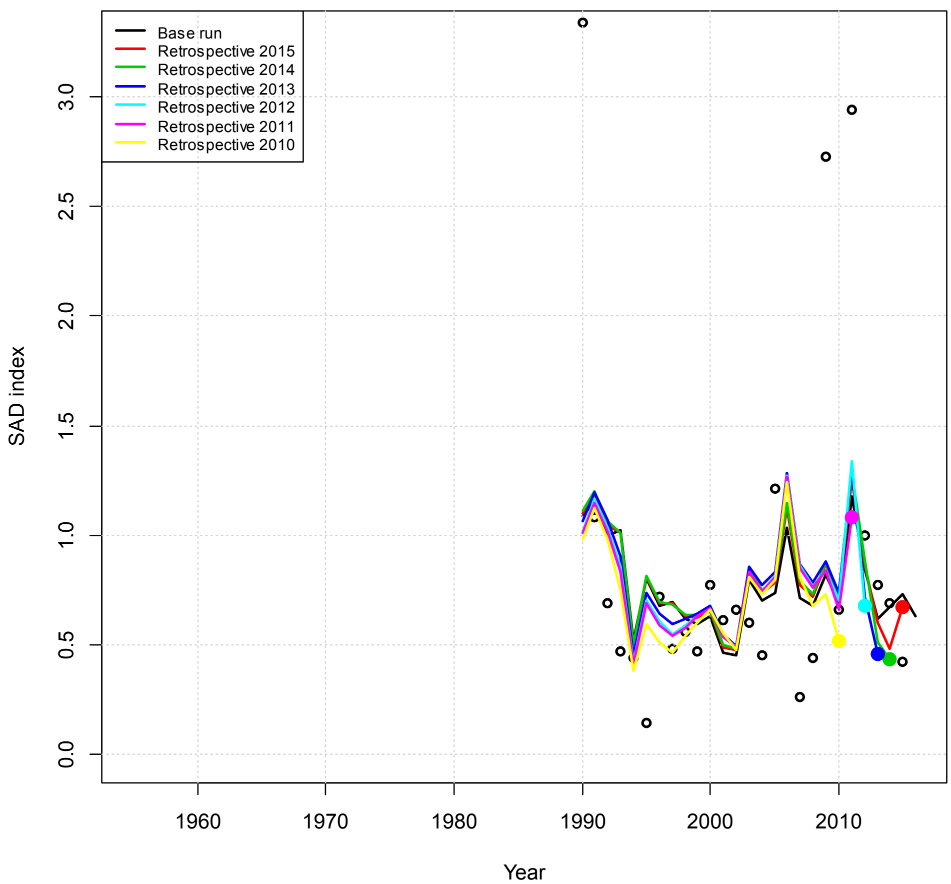



**Figure 6.4.2.6** Fit to the SAD index over time for the retrospective analysis of the assessment model.

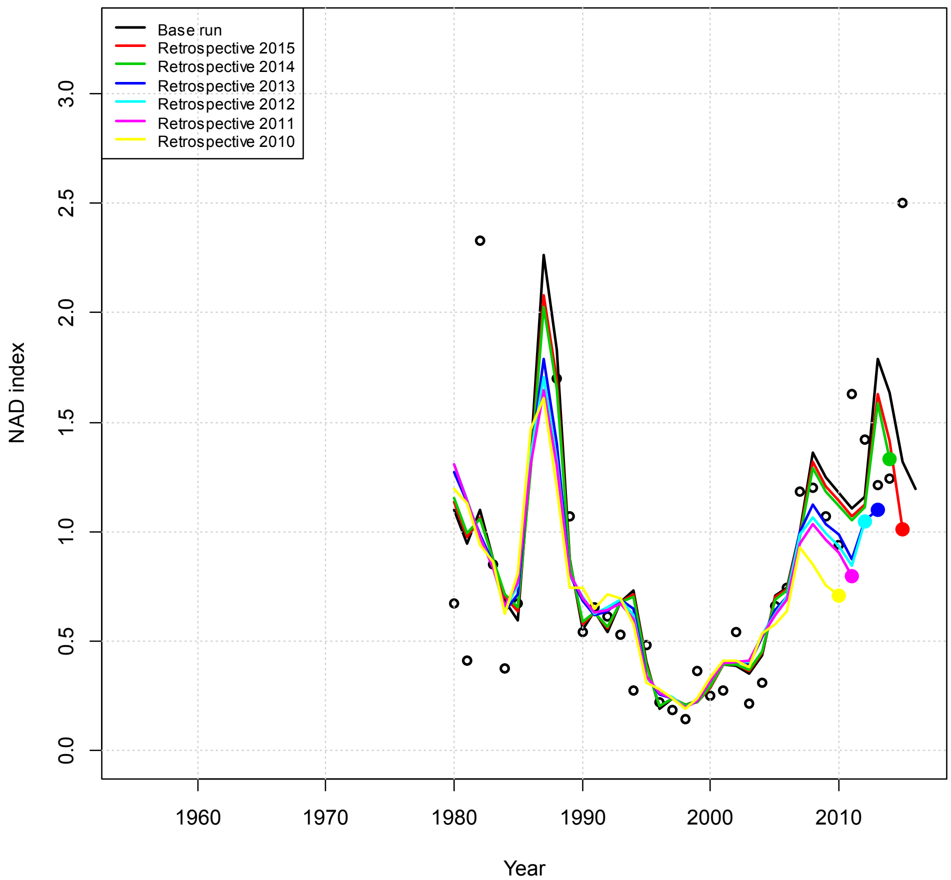



**Figure 6.4.2.7** Fit to the NAD index over time for the retrospective analysis of the assessment model.

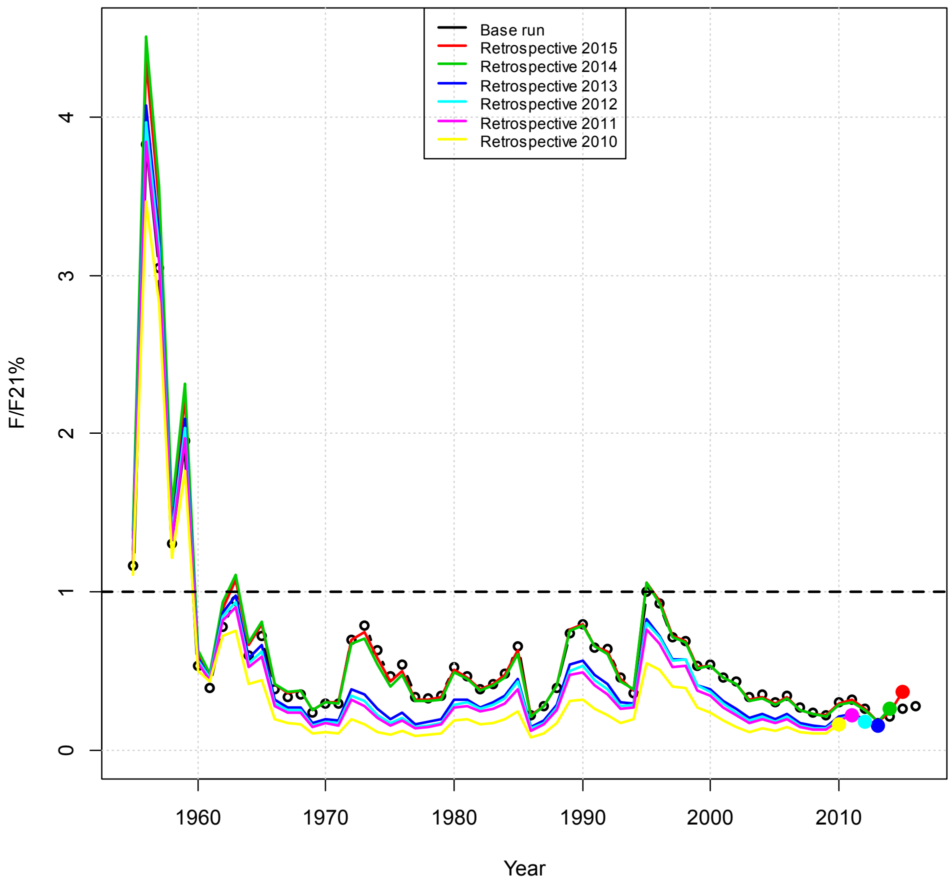



**Figure 6.4.2.8** Fishing mortality rate over $F_{21\%}$ for the retrospective analysis of the assessment model.

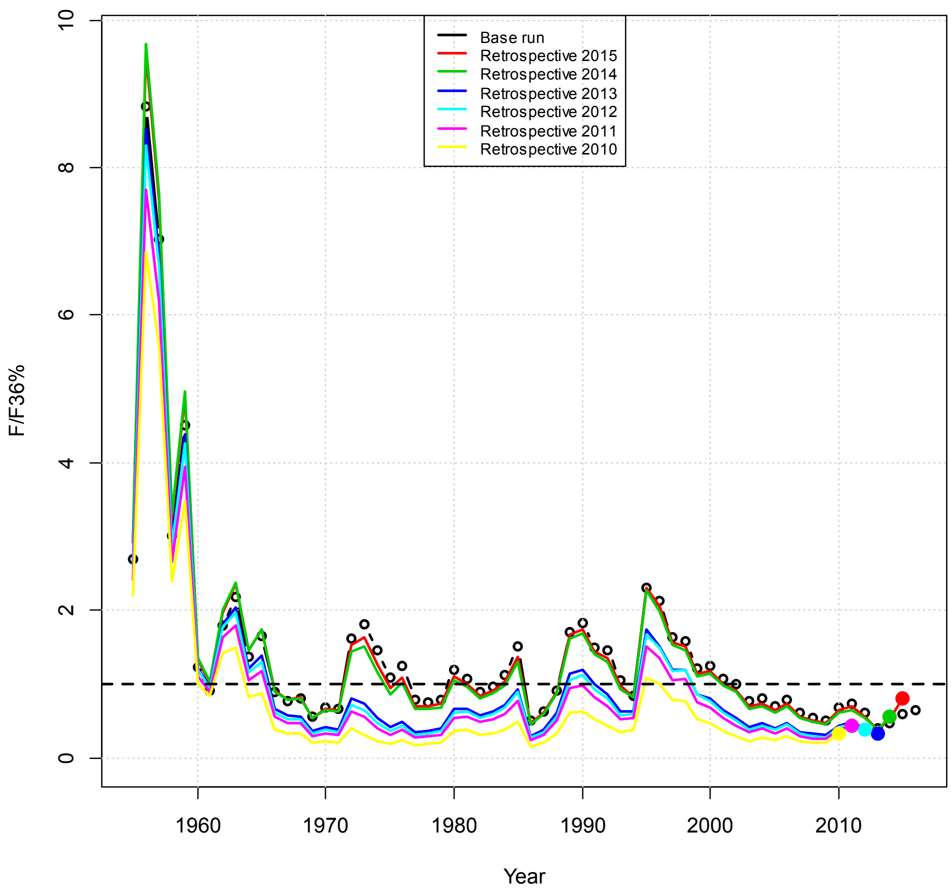



**Figure 6.4.2.9** Fishing mortality rate over $F_{36\%}$ for the retrospective analysis of the assessment model.

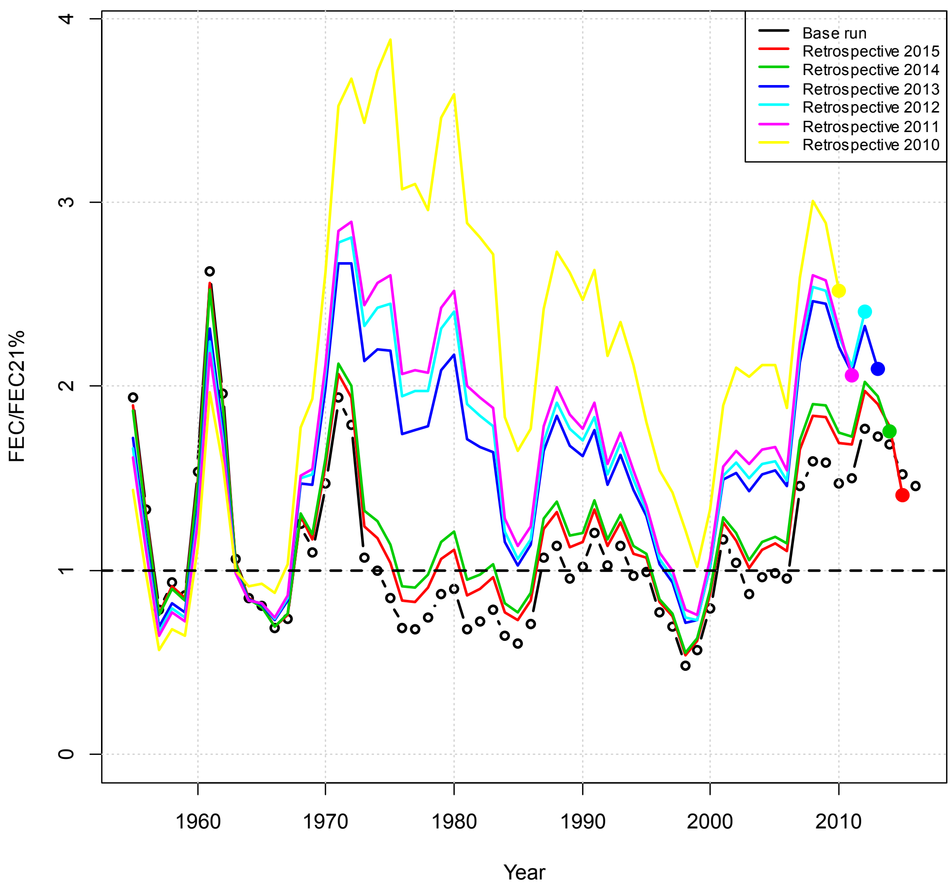



**Figure 6.4.2.10** Fecundity over $FEC_{21\%}$ for the retrospective analysis of the assessment model.

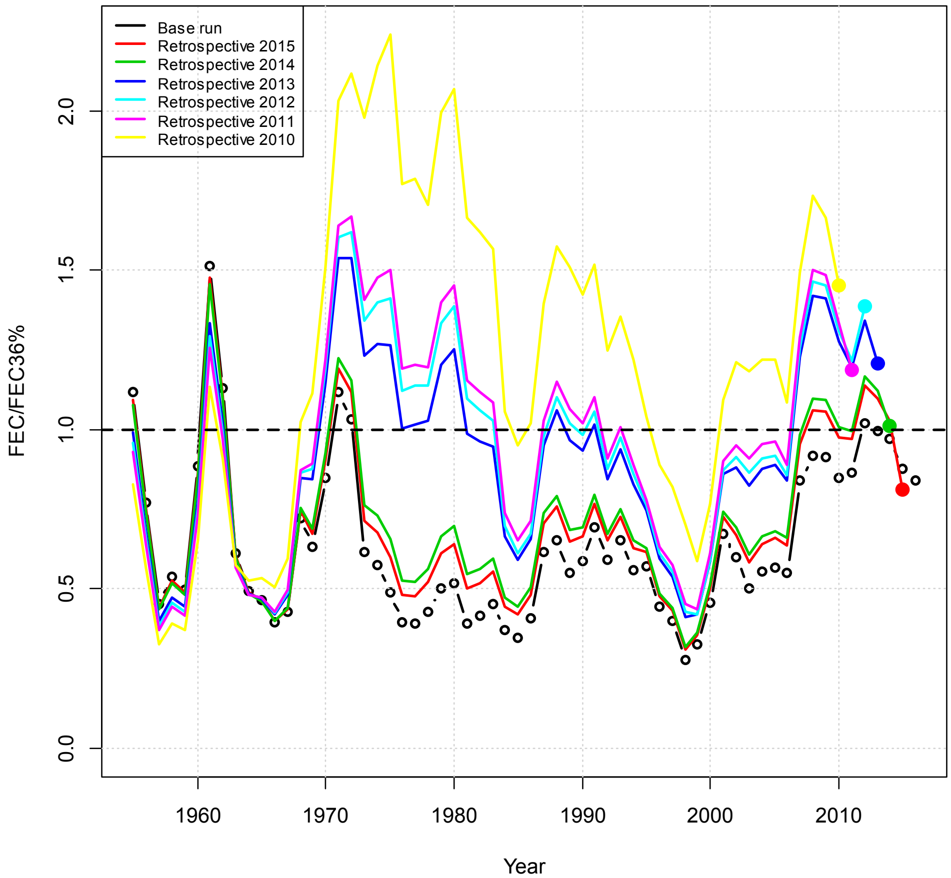



**Figure 6.4.2.11** Fecundity over $FEC_{36\%}$ for the retrospective analysis of the assessment model.

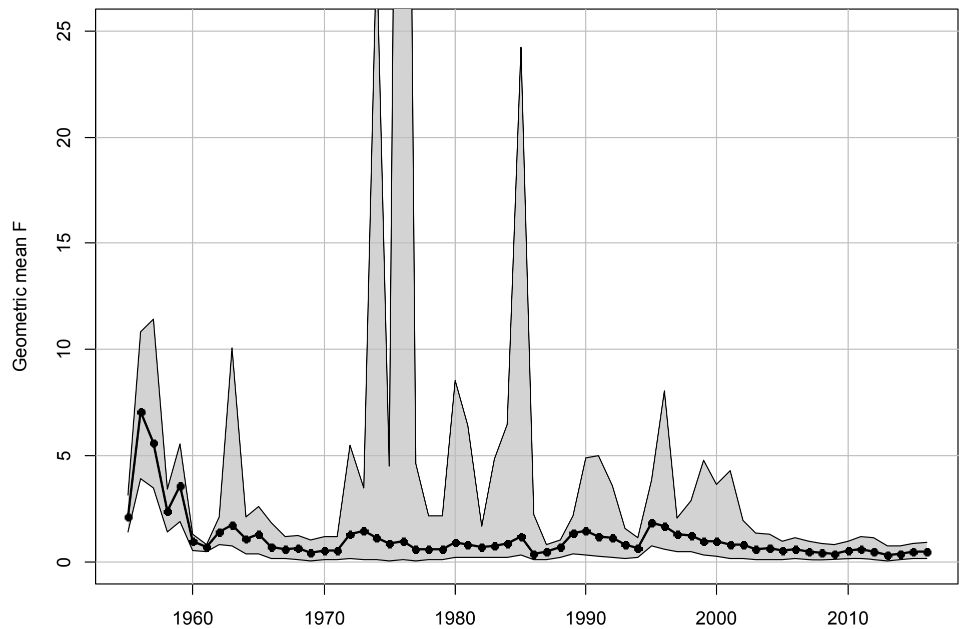



**Figure 6.5.1.** Geometric mean fishing mortality at ages-2 to -4 over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run.

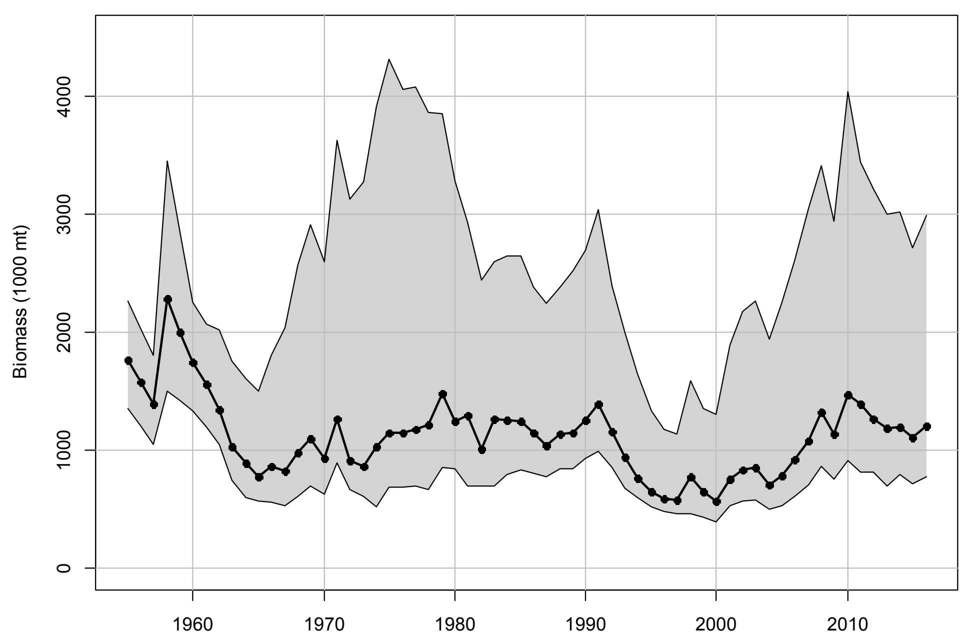



**Figure 6.5.2.** Age-1+ biomass in 1000s mt over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run.

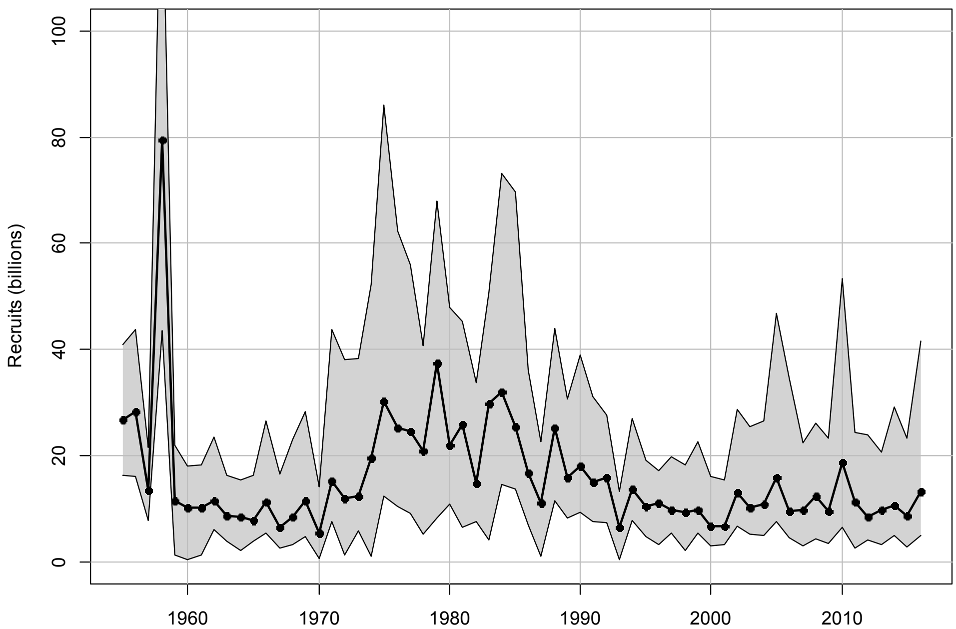



**Figure 6.5.3.** Recruitment over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run.

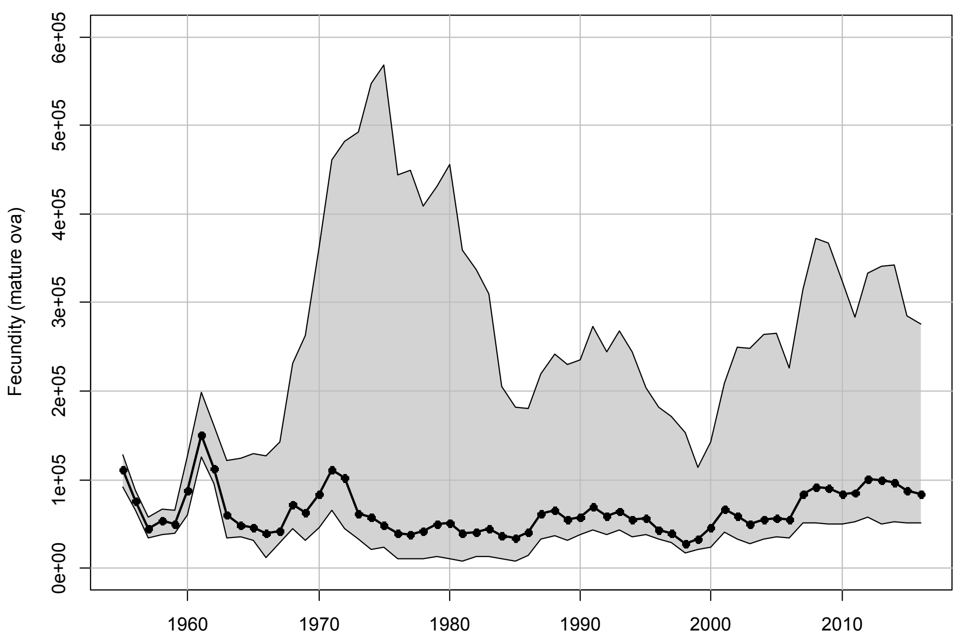



**Figure 6.5.4.** Fecundity over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run.

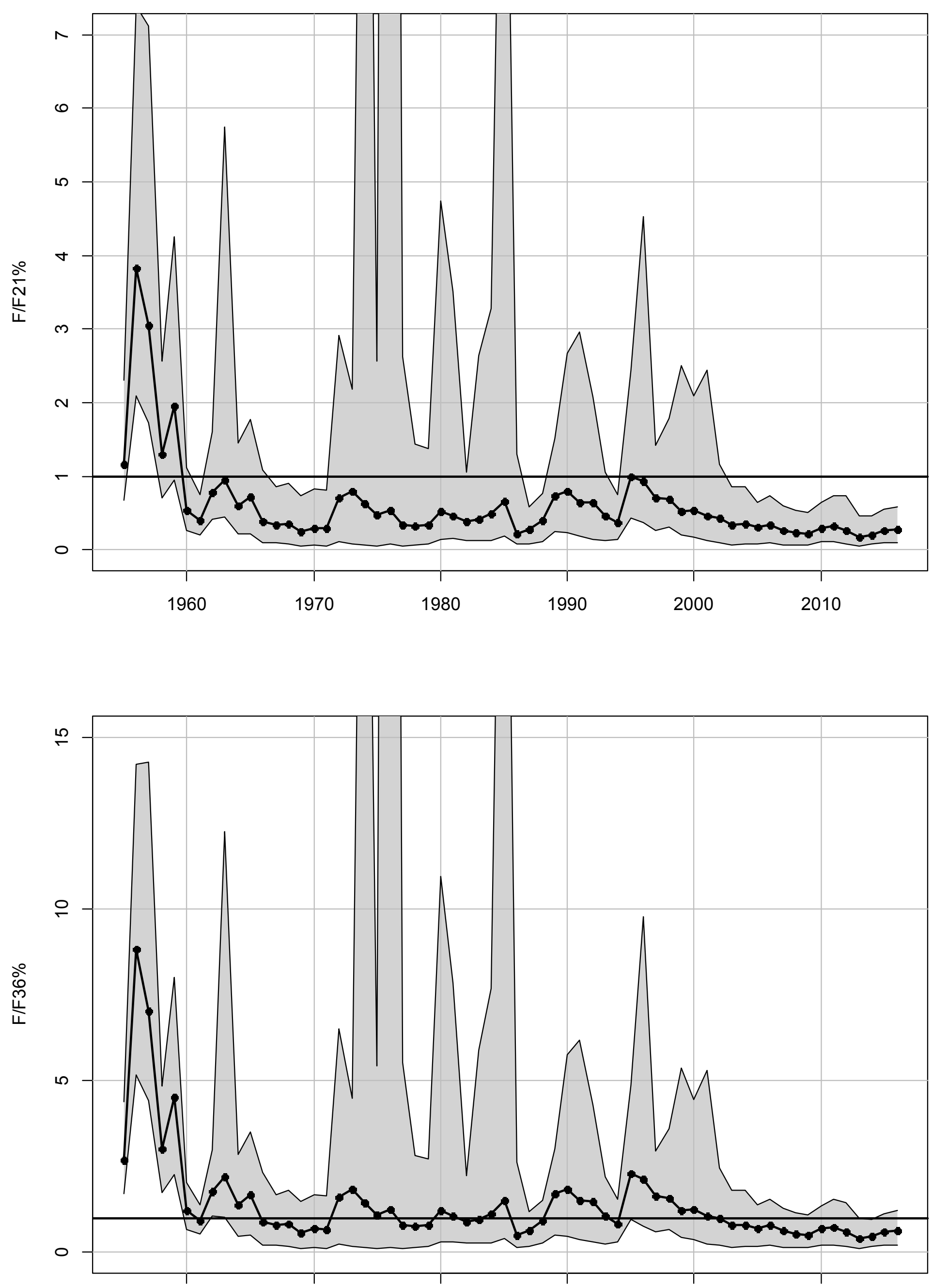



**Figure 7.2.1.1** Geometric mean fishing mortality at ages-2 to -4 over time compared to the recommended SPR benchmarks based on the minimum and median $F_{X\%}$ during the time period 1960-2012.

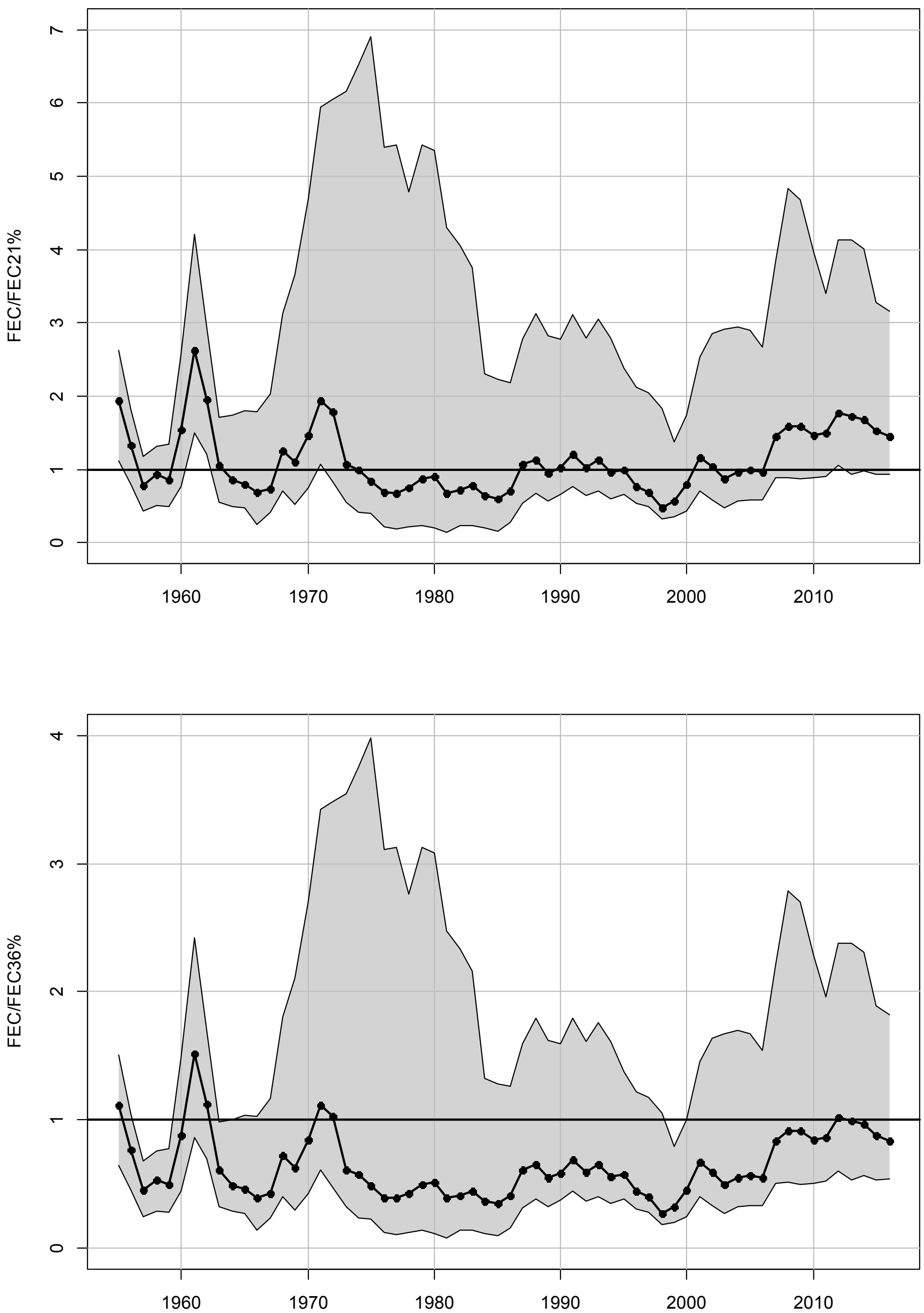



**Figure 7.2.1.2.** Fecundity over time compared to the recommended fecundity based benchmarks associated with the SPR benchmarks based on the minimum and median $F_{X\%}$ during the time period 1960-2012.

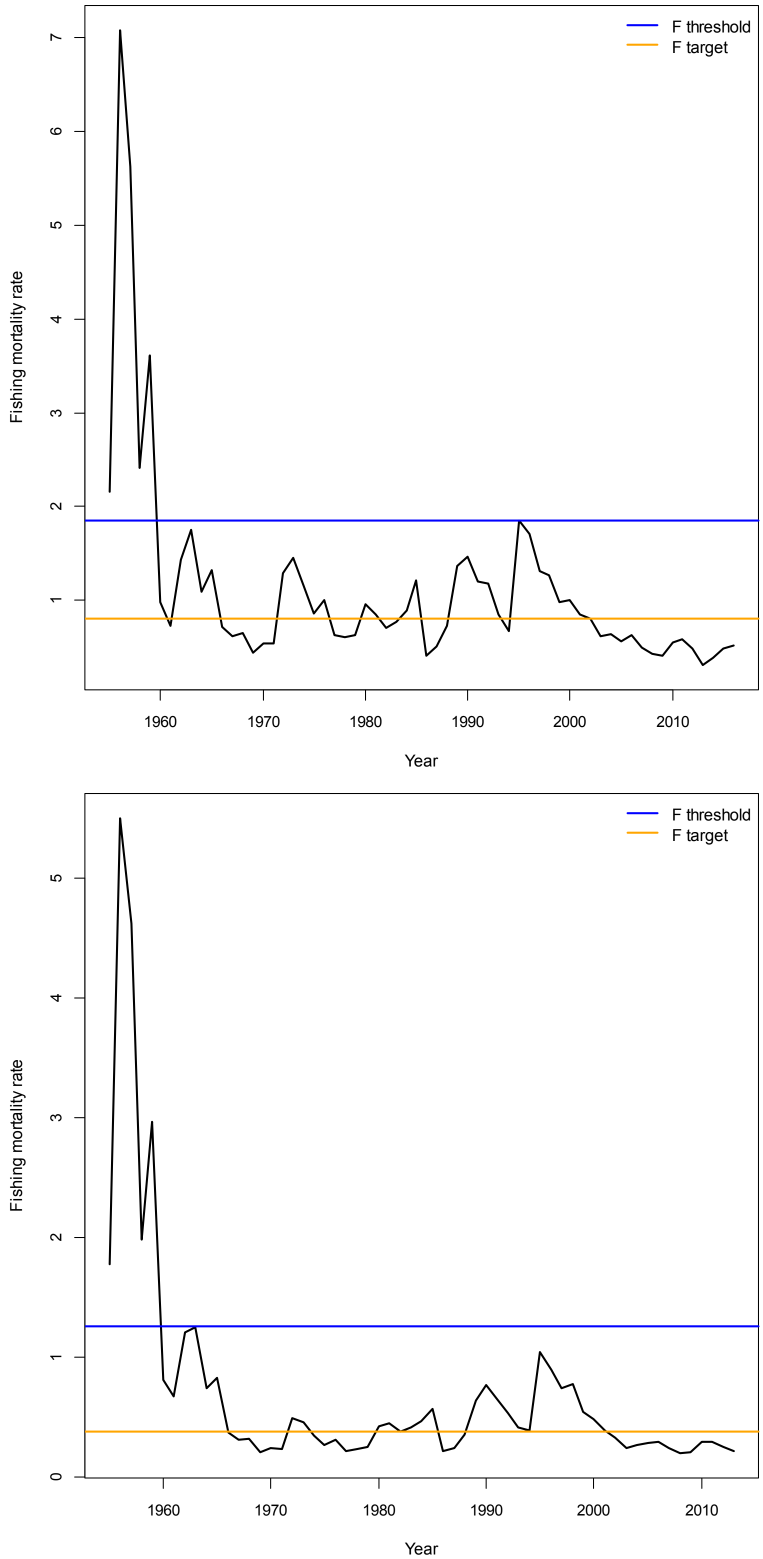
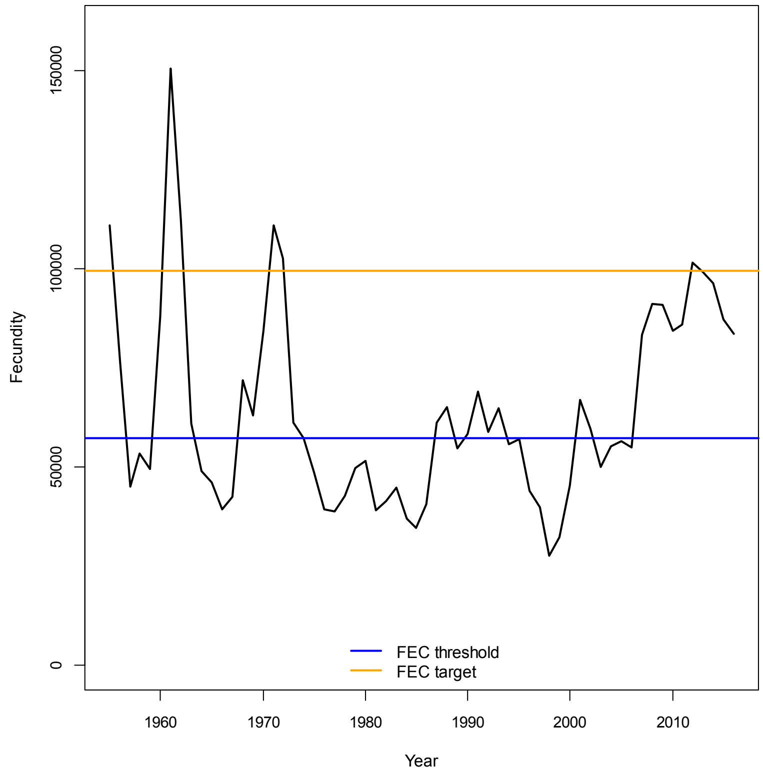



**Figure 7.2.1.3** Update (above) and benchmark (below) geometric mean fishing mortality rate for ages-2 to 4 over time with the fishing mortality rate reference points indicated as horizontal lines.



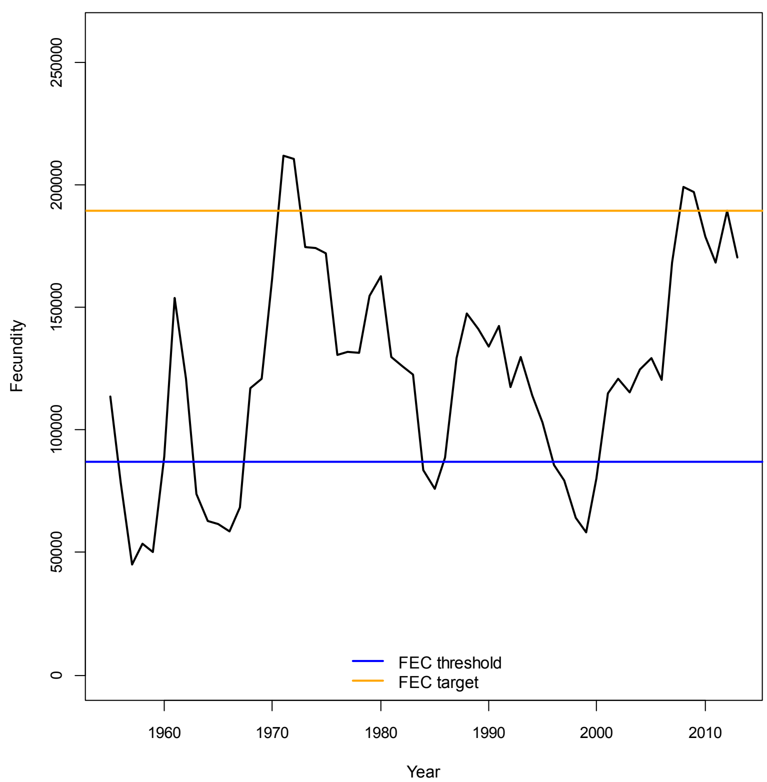




**Figure 7.2.1.4** Update (above) and benchmark (below) fecundity over time with the fecundity reference points indicated as horizontal lines.

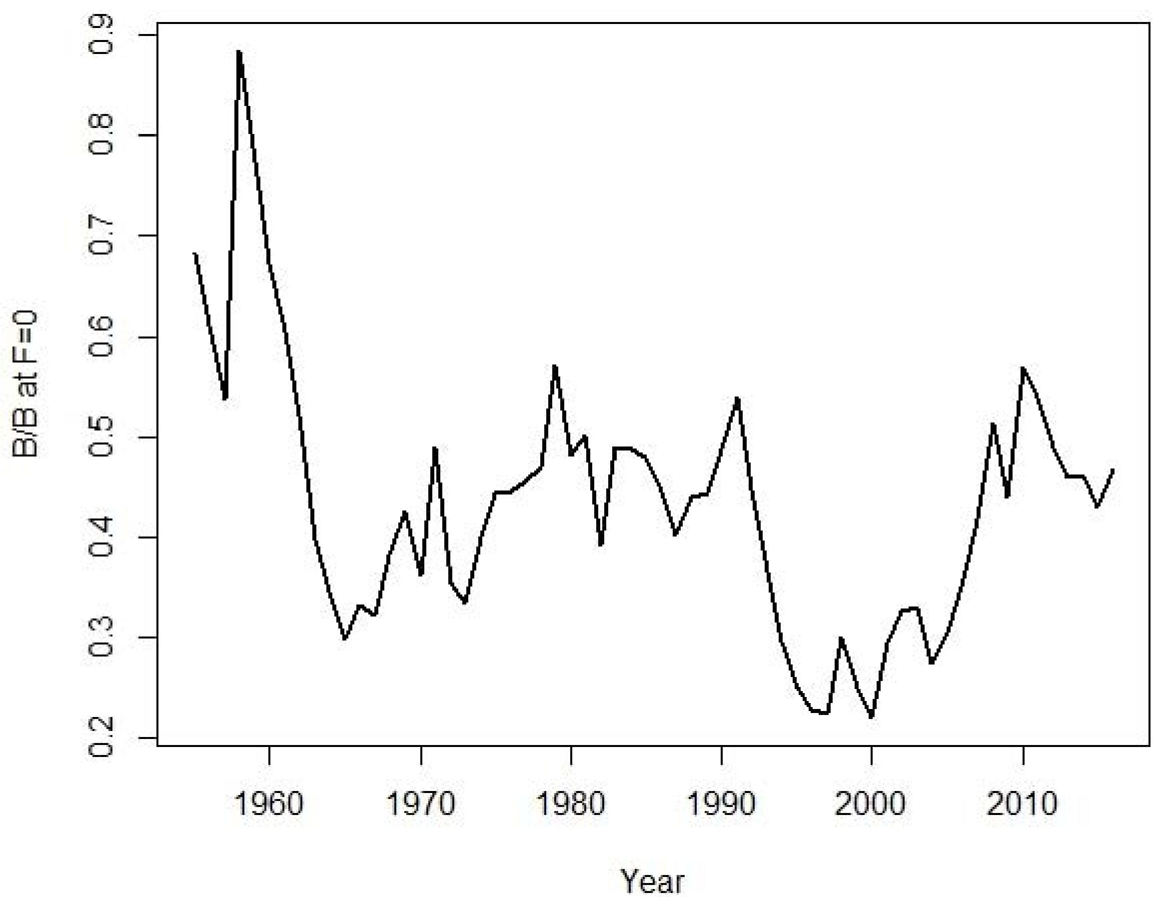



**Figure 7.2.1.5.** Biomass over time divided by the biomass at *F* = 0.

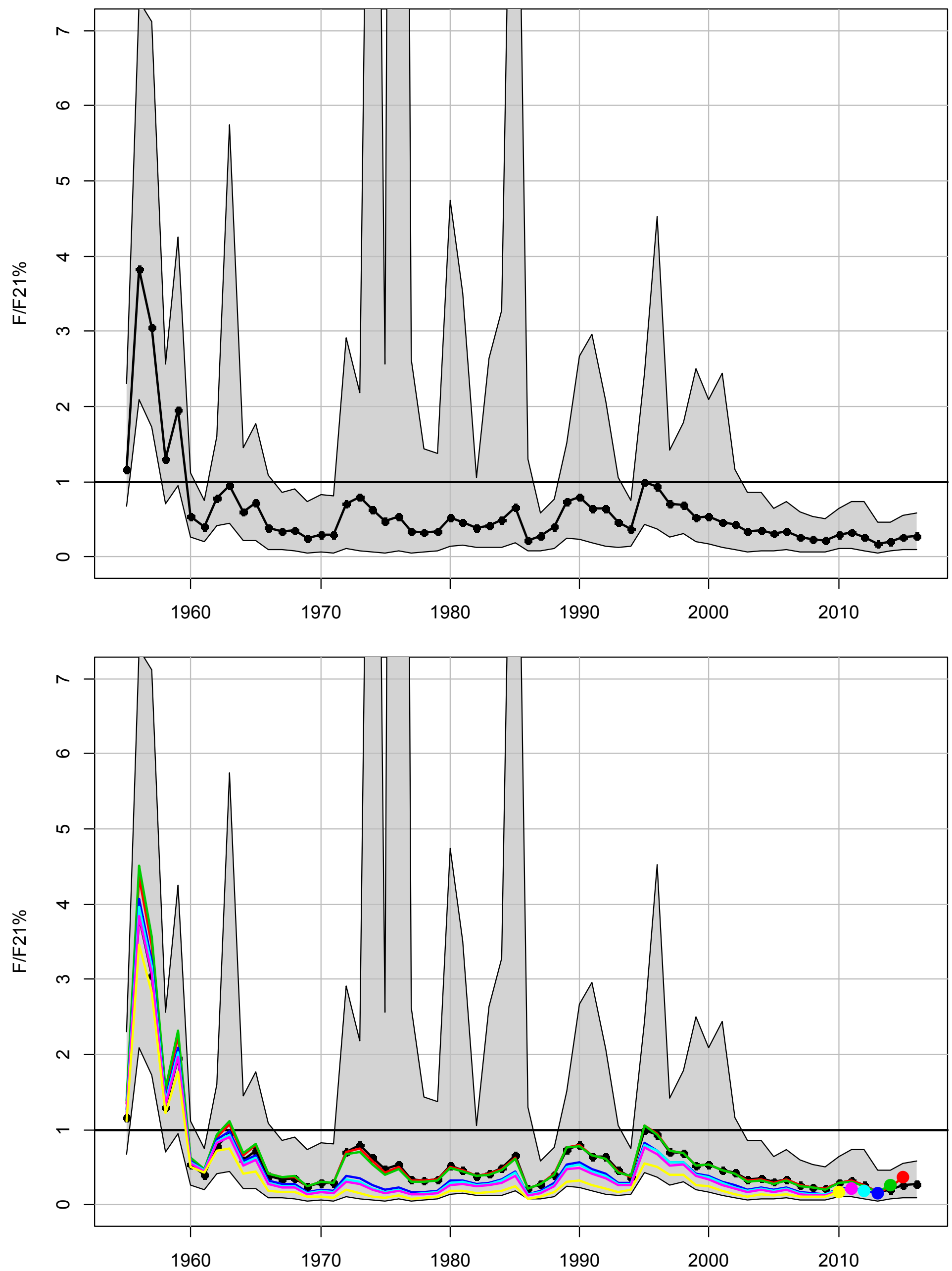



**Figure 7.2.2.1.** Geometric mean fishing mortality at ages-2 to 4 over $F_{21\%}$ over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run. In lower panel, the retrospective analysis is overlaid on the MCB analysis.

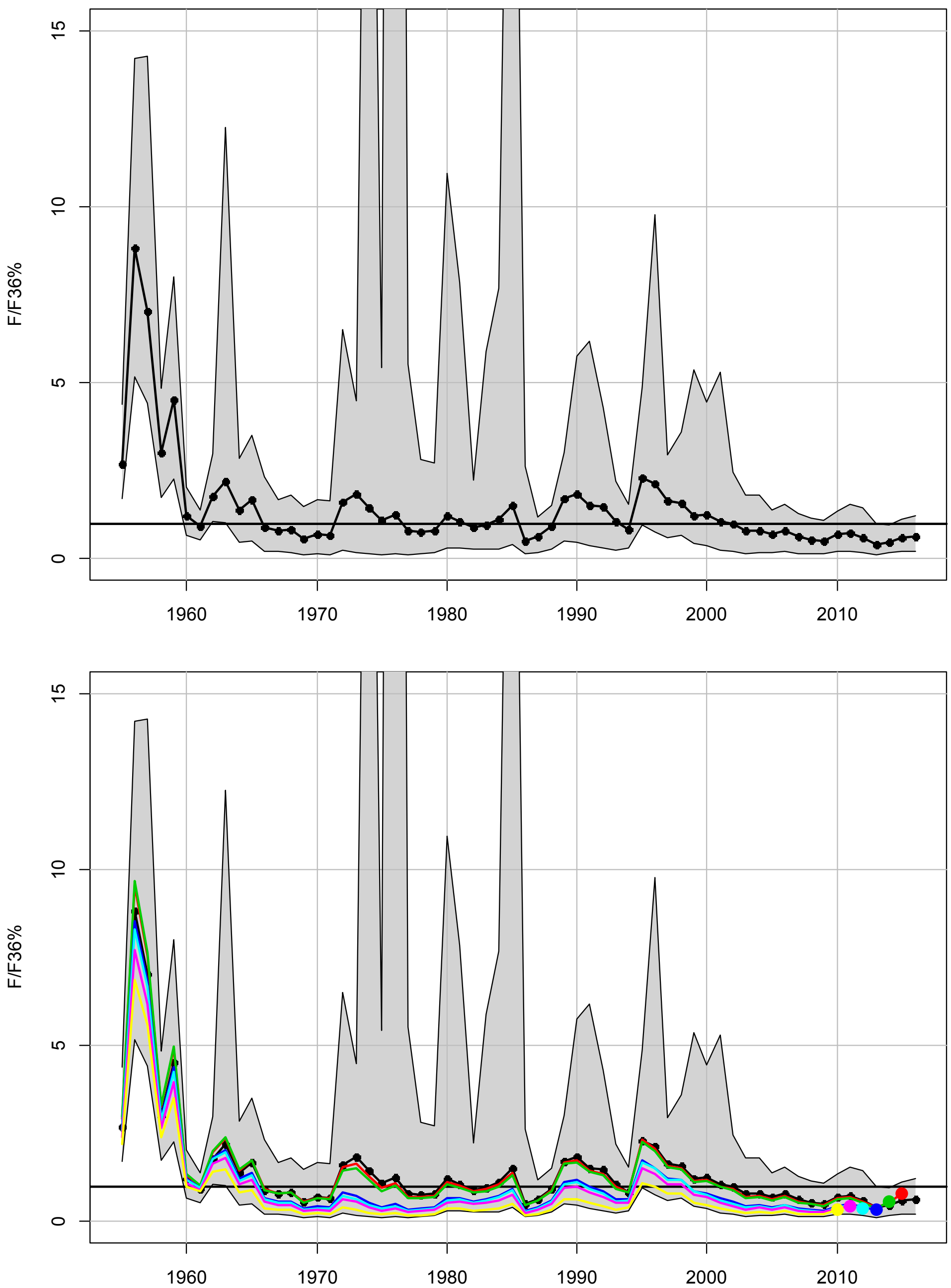



**Figure 7.2.2.2.** Geometric mean fishing mortality at ages-2 to 4 over $F_{36\%}$ over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run. In lower panel, the retrospective analysis is overlaid on the MCB analysis.

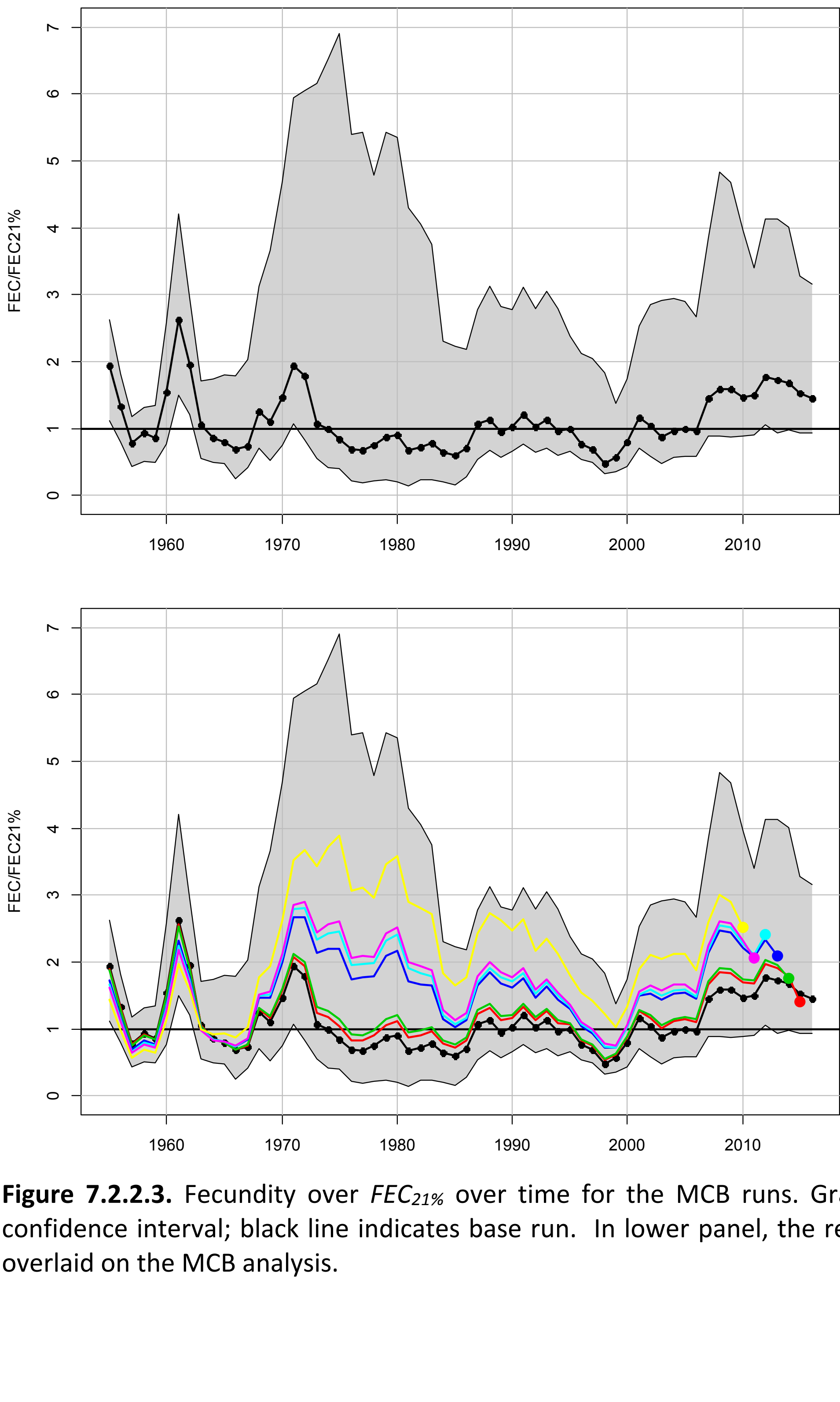



**Figure 7.2.2.3.** Fecundity over $FEC_{21\%}$ over time for the MCB runs. Gray area indicates 95% confidence interval; black line indicates base run. In lower panel, the retrospective analysis is overlaid on the MCB analysis.

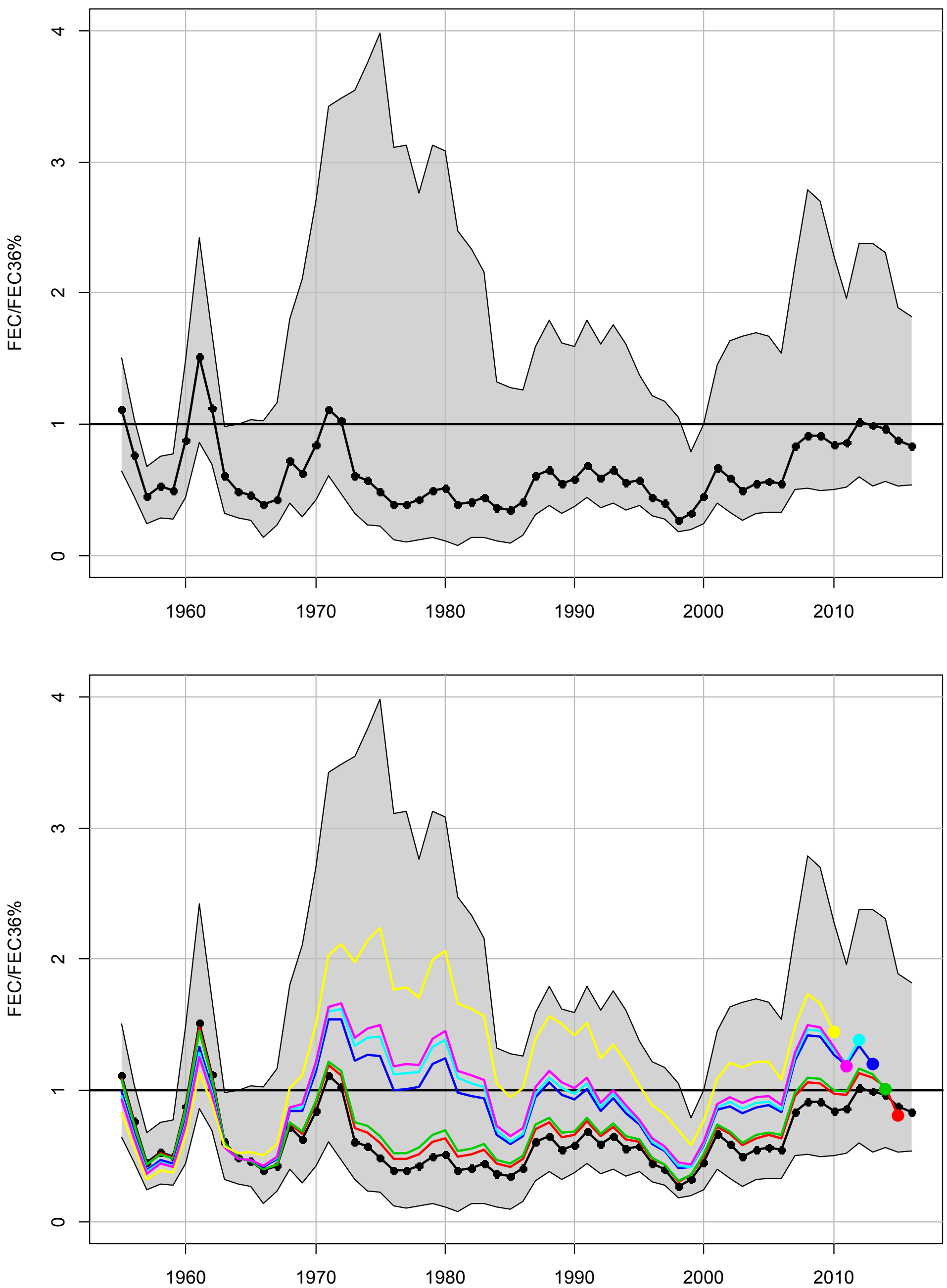



**Figure 7.2.2.4.** Fecundity over $FEC_{36\%}$ over time for the MCB runs. Gray area indicates 95% confidence interval; black lines indicates base run. In lower panel, the retrospective analysis is overlaid on the MCB analysis.

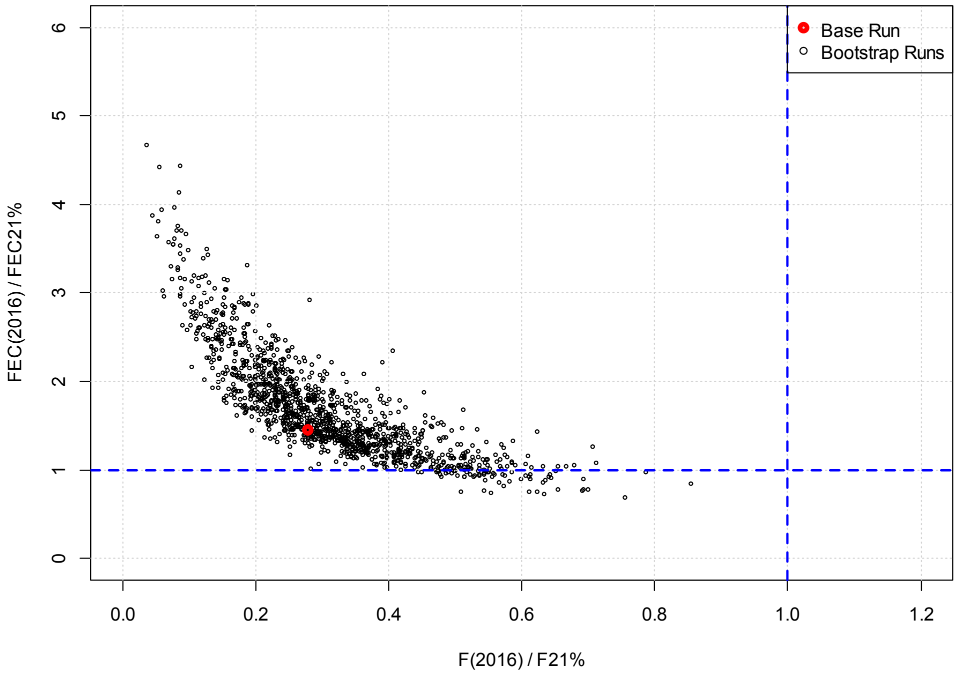



**Figure 7.2.2.5.** Plot of the terminal year geometric mean fishing mortality at ages-2 to 4 and the terminal year fecundity relative to their respective threshold benchmarks for the base run and each bootstrap run.

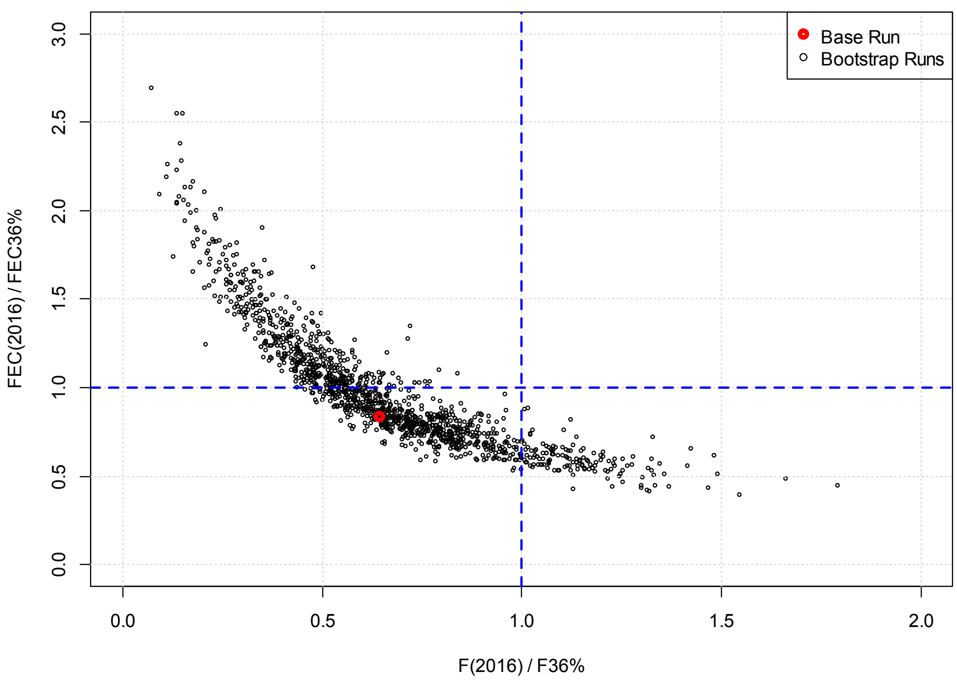
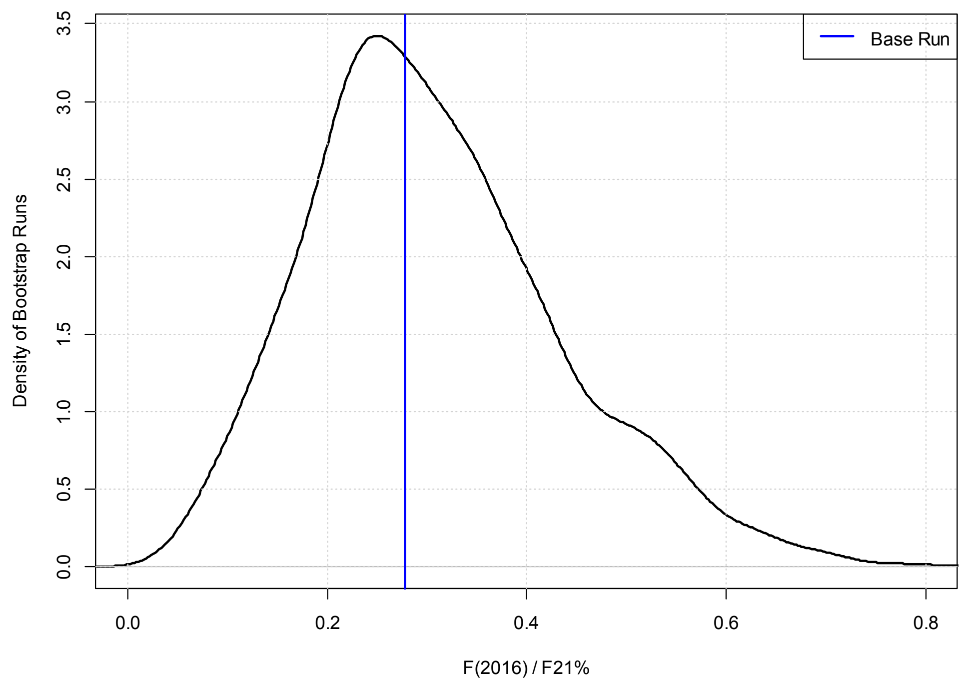



**Figure 7.2.2.6.** Plot of the terminal year geometric mean fishing mortality at ages-2 to 4 and the terminal year fecundity relative to their respective target benchmarks for the base run and each bootstrap run.



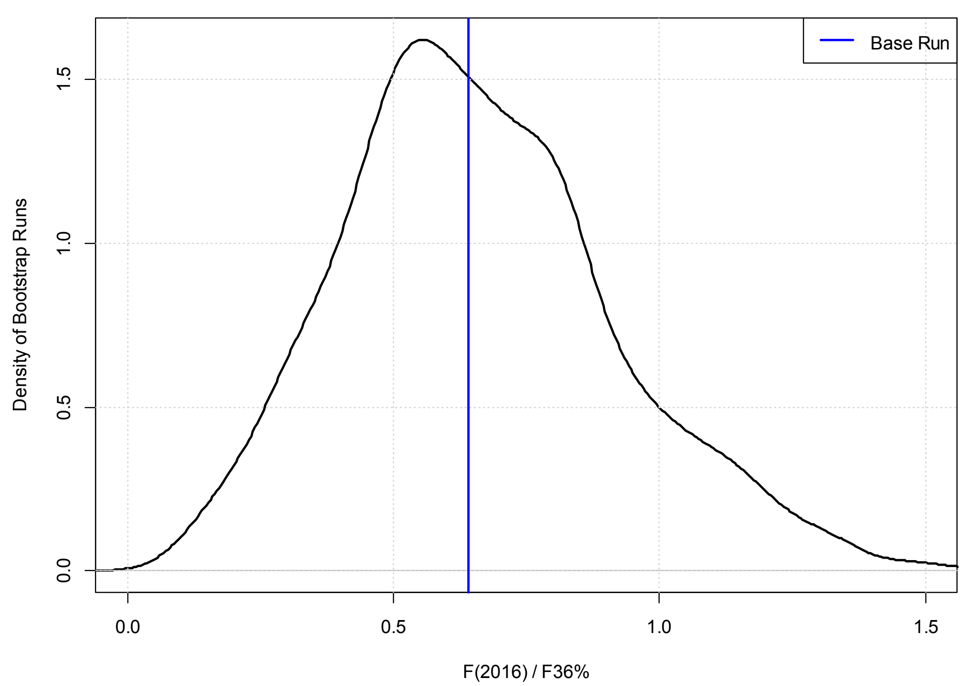
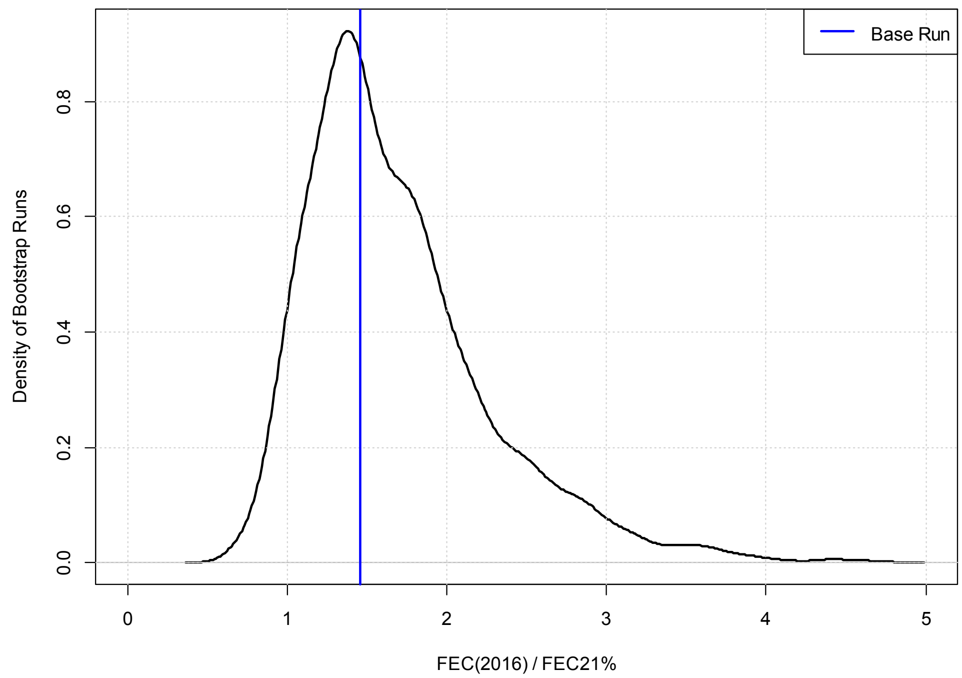




**Figure 7.2.2.7.** Density plots for terminal year geometric mean fishing mortality at ages-2 to 4 over the $F_{21\%}$ threshold (above) and $F_{36\%}$ target (below) benchmarks across the base run and MCB runs.



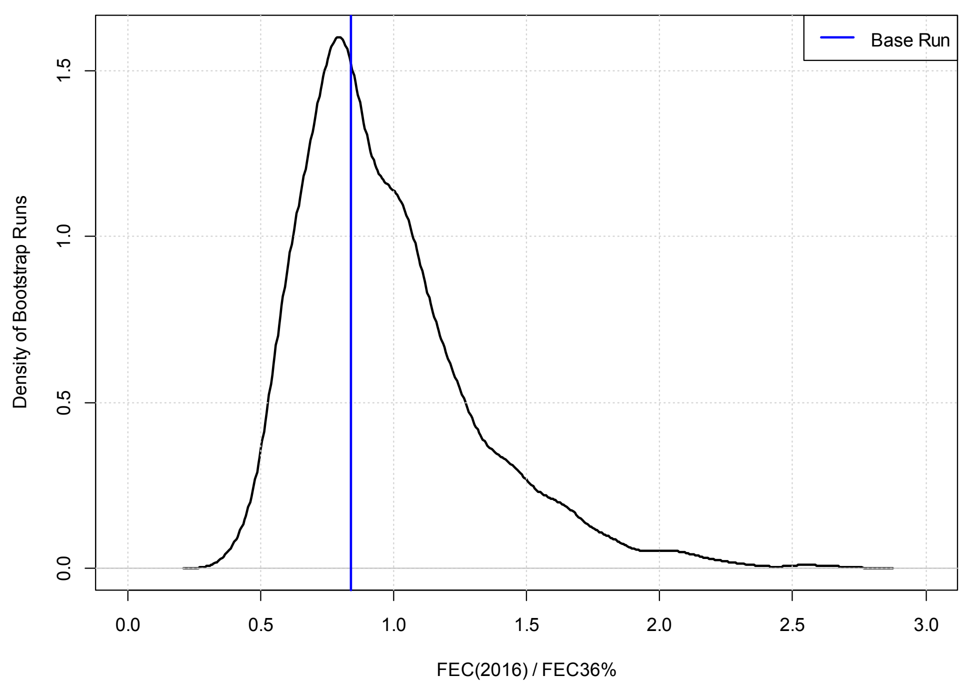




**Figure 7.2.2.8.** Density plots for terminal year fecundity over the *$FEC_{21\%}$* threshold (above) and *$FEC_{36\%}$* target (below) benchmarks across the base run and MCB runs.

## 13.0 Appendix A. Standardization of Abundance Indices for Atlantic Menhaden

Three indices of abundance for Atlantic menhaden were developed from several surveys and used in the most recent benchmark stock assessment (SEDAR 2015). Below is a description of the GLM standardization of each of the surveys and any changes or notes in the survey or model structure for this report.

**Rhode Island Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, bottom temperature, and depth as categorical factors was compared with nested submodels using AIC. The model that included year and bottom temperature was selected because it produced the lowest AIC (% deviance = 41). The model was unchanged from the previous benchmark assessment and updated through 2016.

**Connecticut Long Island Sound Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, stratum, month, starting depth of the tow, surface temperature, bottom temperature, surface salinity, bottom salinity, and season was compared with nested submodels using AIC. The model that included year, and depth was selected because it produced the lowest AIC and good model diagnostics. The model formula was unchanged from the previous benchmark assessment, but the use of the standard glm model was a departure from the previously selected model (zero inflated negative binomial model) from the benchmark assessment.

*Adult Index:* A full model that predicted catch as a linear function of year, stratum, month, starting depth of the tow, surface temperature, bottom temperature, surface salinity, bottom salinity, and season was compared with nested submodels using AIC. The model that included year and stratum was selected because it produced the lowest AIC and good model diagnostics. The model was changed from the previous benchmark assessment, which had year and season as effects.

**Connecticut River Seine Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, month, and site was compared with nested submodels using AIC. The same model parameterization as the previous assessment for binomial (year+month+site) and lognormal (year+month) components was used.

**Connecticut Thames Seine Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, month, and site was compared with nested submodels using AIC. The same model parameterization as the previous assessment (year+month+site) for both the binomial and lognormal components was used.

**New York Peconic Bay Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, depth, and bottom salinity was compared with nested submodels using AIC. The model including year, depth, and bottom salinity factors was selected because it produced the lowest AIC (% deviance = 32). While data was supplied for the update assessment, adding the 2014-2016 data resulted in an unstable model with convergence issues and unreasonable estimated values. This could not be resolved and therefore this index was not updated with the last 3 years of data (2014-2016), although values from the previous benchmark were included in the update.

**New York Western Long Island Seine Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, month, region, temperature, and salinity was compared with nested submodels using AIC. Relative to the previous assessment, the covariate dissolved oxygen was eliminated from consideration because of missing values, particularly early in the time series. This decision probably should have been made during the previous assessment because data filtering to complete dissolved oxygen led to the elimination of data for 1997. Slightly different parameterizations were therefore supported for the binomial (year+month+region+temp+salinity) and lognormal (year+month+region+temp) components. The estimated index and CV for 1988 differs considerably from that of the previous assessment. Since dissolved oxygen was no longer considered, more data records were retained for analysis, including a single catch of 30,000 fish which created a much higher index value. This haul also contributed to the extremely high bootstrapped CV value for that year.

**New Jersey Ocean Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, station, stratum, vessel, month, starting depth of the tow, bottom temperature, bottom salinity, and bottom dissolved oxygen was compared with nested submodels using AIC. Additionally, a zero inflated negative binomial model was also run for comparison. The zero inflated model that included year, bottom temperature, and bottom salinity was selected because it produced the lowest AIC and good model diagnostics. The choice of zero inflated over standard glm was made from the outcome of the vuongs non nested hypothesis test. The model formula was unchanged from the previous benchmark assessment, but the use of the zero inflated model was a departure from the previously selected model from the benchmark assessment.
*Adult Index:* A full model that predicted catch as a linear function of year, station, stratum, vessel, month, starting depth of the tow, bottom temperature, bottom salinity, and bottom dissolved oxygen was compared with nested submodels using AIC. The model that included year, bottom temperature, and bottom salinity was selected because it produced the lowest AIC and good model diagnostics. The model was unchanged from the previous benchmark assessment.

**New Jersey Juvenile Striped Bass Seine Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, month, river, salinity, and dissolved oxygen was compared with nested submodels using AIC. For the previous assessment both model components were parameterized the same (year+month+river+sal+DO), however, for the update assessment, the supported binomial model differed slightly (year+month+river+DO) while the lognormal model remained the same.

**Delaware Inland Bays Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, sea surface temperature, and surface salinity was compared with nested submodels using AIC. The full model was selected because it produced the lowest AIC (% deviance = 42). The model was unchanged from the previous benchmark assessment and updated through 2016.

**Delaware 16 ft Trawl Survey**

*Age0 index*: A full model that predicted catch as a linear function of year, station, month, starting depth of the tow, surface temperature, surface salinity, surface dissolved oxygen, and tide was compared with nested submodels using AIC. The model that included year, surface temperature, surface salinity, and tide was selected because it produced the lowest AIC and good model diagnostics. The model was changed from the previous benchmark assessment, which only had year and temperature as effects.

*Adult index*: A full model that predicted catch as a linear function of year, station, month, starting depth of the tow, surface temperature, surface salinity, surface dissolved oxygen, and tide was compared with nested submodels using AIC. The model that included year, surface temperature, surface salinity, and tide was selected because it produced the lowest AIC and good model diagnostics. The model was changed from the previous benchmark assessment, which only had year, surface temperature, and surface salinity as effects.

**Delaware 30 ft Trawl Survey**

*Adult index*: A full model that predicted catch as a linear function of year, month, and station as categorical factors was compared with nested submodels using AIC. The model that included year and month was selected because it produced the lowest AIC. The model was unchanged from the previous benchmark assessment and updated through 2016.

**Maryland Coastal Bays Trawl Survey**

*Age0 Index:* A full model that predicted catch as a linear function of year, surface salinity, and sea surface temperature was compared with nested submodels and the submodel that included year and salinity was selected because it produced the lowest AIC (% deviance = 32). The model was unchanged from the previous benchmark assessment and updated through 2016.

**Maryland Juvenile Striped Bass Seine Survey**

*Age0 index*: A full model that predicted catch as a linear function of year, month, and region was compared with nested submodels using AIC. The same model parameterization as previous assessment (year+month+region) for both the binomial and lognormal components was used.

**ChesFIMS Trawl Survey**

*Adult index*: A full ZINB that predicted catch as a function of the categorical variables year and season was compared with nested submodels using AIC. For the 2015 benchmark stock assessment, a reduced model that removed the covariate season from the count model of the ZINB was selected because it produced the lowest AIC. This index was not updated through 2016 and remained unchanged from the benchmark assessment.

**ChesMMAP Trawl Survey**

*Adult index*: A full ZINB model that predicted catch as a function of the categorical variables year, stratum and cruise, and the continuous variable area swept was compared with nested submodels using AIC. For the 2015 benchmark stock assessment and this update, a reduced model that removed the covariate year from the negative binomial count sub-model was selected because it produced the lowest AIC.

**Virginia Striped Bass Seine Survey**

*Age0 index*: A full model that predicted catch as a linear function of year, month, river, salinity, and temerpature was compared with nested submodels using AIC. Same model parameterization as previous assessment (year+month+river+sal+temp) for both the binomial and lognormal components. Models were fitted with and without 2016 data due to gear change and no calibration coefficients. Troy Tuckey (VIMS) discovered that a gear changed occurred in 1999 and indications thus far are that there is not catchability differences for YOY striped bass, but potential changes for menhaden have not been evaluated.

**VIMS Juvenile Fish Trawl Survey**

*Age0 index:* Models that predicted catch as a linear function of year, river system and either bottom salinity, bottom temperature, depth, or dissolved oxygen were compared using AIC. The model that included year and depth was selected because it produced the lowest AIC and no convergence problems (% deviance = 36). The model is unchanged from the most recent benchmark assessment and updated through 2016.

*Adult index:* A full model that predicted catch as a linear function of year, river system, bottom salinity, bottom temperature, depth, or dissolved oxygen was compared with nested submodels using AIC. The model with year, river system, bottom salinity, bottom temperature, and depth selected because it produced the lowest AIC (% deviance=18). The model is unchanged from the most recent benchmark assessment and updated through 2016.

**South Carolina Electrofishing Survey**

*Age0 index*: A full ZINB model that predicted catch as a function of the categorical variables year, month, tidal stage, and stratum, and the continuous variables depth, salinity duration, and water temperature was compared with nested submodels using AIC. In both the 2015 benchmark assessment and the 2017 update, a reduced model that removed the covariates month, tidal stage, depth, duration and water temperature from the negative binomial count sub-model and the covariates depth duration and water temperature from the binomial sub-model was selected because it produced the lowest AIC.

**Georgia Ecological Monitoring Trawl Survey**

*Age0 index*: A full model that predicted catch as a linear function of year, surface salinity, tow duration, depth, and sea surface temperature was compared with nested submodels. The submodel that included year, tow duration, temperature, and salinity was selected because it produced the lowest AIC. The model was unchanged from the latest benchmark assessment and updated through 2016.

*Adult index:* A full model that predicted catch as a linear function of year, surface salinity, tow duration, depth, and sea surface temperature was compared with nested submodels. The submodel that included year, temperature, salinity, tow duration, and depth was selected because it produced the lowest AIC. For the 2015 benchmark assessment, year, temperature, and salinity was selected so the model is slightly changed for the update.

**SEAMAP-SA Coastal Trawl Survey**

*Adult index:* A full ZINB that predicted catch as a function of the categorical variables year, season, and strata and continuous variables water temperature and salinity was compared with nested submodels using AIC. A reduced model that removed the covariate salinity from the count model of the ZINB was selected because it produced the lowest AIC. The model is unchanged from the most recent benchmark assessment and updated through 2016.