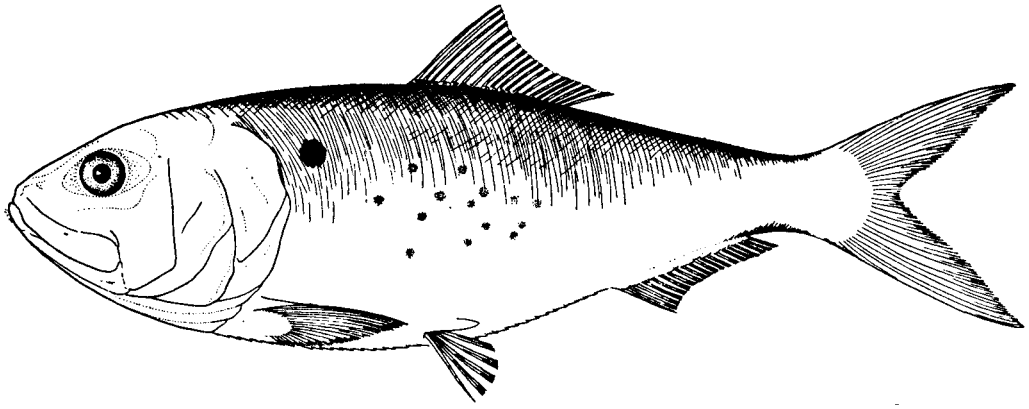
Stock Assessment Report No. 04-01
of the

Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report to Atlantic Menhaden Stock Assessment Peer Review



February 2004

Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

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Conducted on
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Preface

Summary of the Commission Peer Review Process

The Stock Assessment Peer Review Process, adopted in October 1998 by the Atlantic States Marine Fisheries Commission, was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes evaluation of input data, model development, model assumptions, scientific advice, and review of broad scientific issues, where appropriate.

The Stock Assessment Peer Review Process report outlines four options for conducting a peer review of Commission managed species. These options are, in order of priority:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC) or the Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center (SEFSC).

2. A Commission stock assessment review panel composed of 3-4 stock assessment biologists (state, federal, university) will be formed for each review. The Commission review panel will include scientists from outside the range of the species to improve objectivity.

3. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

4. An internal review of the stock assessment conducted through the Commission's existing structure (i.e. Technical Committee, Stock Assessment Committee).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species Management Board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In November 2002, the Atlantic menhaden stock assessment was prioritized for a SEDAR peer review. A review panel was convened of stock assessment biologists and representatives from the fishing community and non-government organizations. Panel members had expertise in Atlantic menhaden life history and stock assessment methods. The SEDAR review for the

Atlantic menhaden stock assessment was conducted October 6-7, 2003 in Raleigh, North Carolina.

Purpose of the Terms of Reference and Advisory Report

The Terms of Reference and Advisory Report provides summary information concerning the Atlantic menhaden stock assessment and results of the SEDAR review to evaluate the accuracy of the data and assessment methods for this species. Specific details of the assessment are documented in a supplemental report entitled Atlantic Menhaden Stock Assessment Report for Peer Review. A copy of the supplemental report can be obtained via the Commission's website at www.asmfc.org under the Atlantic Menhaden page or by contacting the Commission at (202) 289-6400.

Acknowledgments

Thanks are due to the many individuals who contributed to the Commission's Atlantic menhaden Stock Assessment Peer Review. Special thanks are extended to the Atlantic Menhaden Peer Review Panel (Dr. Steve Bobko, Old Dominion University, William Goldsborough, Chesapeake Bay Foundation, Najih Lazar, Rhode Island Division of Environmental Management Marine Fisheries Section, Dr. Tom Miller, Chesapeake Biological Laboratory, Dr. Jim Nance, NOAA Fisheries NMFS SEFSC, Dr. Paul Nitschke, NOAA Fisheries, NMFS NEFSC, Lee Paramore, North Carolina Division of Marine Fisheries, Dr. Stephen Smith, Bedford Institute of Oceanography, Dr. Elizabeth Wenner, South Carolina Department of Natural Resources, Geoffrey White, Atlantic States Marine Fisheries Commission, William T. Windley, Jr., Maryland Saltwater Sportfish Association) for their hard work in reviewing the meeting materials and providing advice on improvements to the Commission's Atlantic menhaden stock assessment. The Commission would like to extend its appreciation to the members of the Atlantic Menhaden Technical Committee and Stock Assessment Subcommittee for development of the Atlantic Menhaden Stock Assessment Report for Peer Review (Stock Assessment Peer Review Report 03-001 Supplement) and specifically to the following members for presenting this report at the Peer Review meeting: Dr. Doug Vaughan (National Marine Fisheries Service, Beaufort Laboratory), and Dr. Eric Williams (National Marine Fisheries Service, Beaufort Laboratory).

Special appreciation is given to the staff dedicated to the performance of the Peer Review and finalization of peer review reports, specifically – Dr. Lisa Kline, Dr. John Merriner, and Nancy Wallace.

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Terms of Reference for the Atlantic Menhaden Peer Review

1. **Evaluate the adequacy and appropriateness of fishery-dependent and independent data used in the assessments (i.e. was the best available data used in the assessment).**

The commercial fisheries for Atlantic menhaden consist primarily of a directed purse seine fishery for reduction and a fishery that provides bait for other fisheries. Landings for the menhaden reduction plants have been reported since 1940 and biostatistical samples of the catches have been collected continuously since 1955. The directed bait fishery for menhaden has grown in importance in recent years and landings from 1985-2002 are included in the current model. Recreational fishermen also catch Atlantic menhaden as bait for various game fish; however, the quantities removed are believed to be minimal and are currently not quantified. By-catch of other species in these fisheries has been shown to be minimal. Fishery-independent data sources for Atlantic menhaden exist primarily as seine survey data collected by various states. In most cases, menhaden is not the target species of these surveys and thus the survey design may not be optimal for assessing the menhaden stock.

The Panel accepted the accuracy and suitability of the landings for the reduction and bait fishery. Information on the recreational fishery was minimal and omitted from the assessment model. The Panel did not believe that this was a serious issue.

The Potomac River pound net survey, which covers a limited geographical area, provided the only adult index used in the assessment. The Panel suggested that an adult abundance index would be helpful to tune the population model. There was a very strong relationship between the purse seine effort series and landings in the reduction fishery. The CPUE index derived from these data was not used in the assessment and no justification was presented in the stock assessment report. The Panel recommended the evaluation of commercial purse seine fishery effort (vessel/weeks) data as a possible index of adult abundance. As an alternative, the Panel recommended data collected in the Captain's Daily Fishing reports be evaluated for use as an adult abundance index. If the data from these reports are not useful as adult abundance indices, then the Panel recommended that the Commission explore the utility of a commercial fishery-based adult index, developed jointly with the fishermen, for future assessments.

The seine survey data included in the assessment are juvenile indices only. A composite index was developed from seine surveys conducted in North Carolina, Virginia, Connecticut, Maryland, and Rhode Island. While the North Carolina, Virginia, and Maryland surveys had similar trends, the showed different trends from those exhibited by the Connecticut and Rhode Island surveys. The surveys were weighted individually by a measure of relative productivity that dates back to the 1970s. Due to the survey weighting, the coastwide series mainly reflects the trends in the Maryland survey. However, the relative productivities of menhaden nursery areas coast wide in recent years are unknown. The Panel recommended investigation of existing studies that could assist in evaluating current productivity and development of protocols to quantify contribution of different nursery areas to the adult stock. Moreover, the Panel recommended that new research be initiated to quantify the relative contributions of different

potential nursery areas to the adult stock. The panel discussed a variety of techniques involving the use of natural tags (genetic and otolith microchemical tags) that could fulfill this need.

The stock assessment model used a new maturity vector based on the published work of Lewis et. al (1987). The Panel accepted the new maturity vector as the best available information.

In past menhaden stock assessments, a constant natural mortality rate (M) of 0.45 over all ages and years had been assumed. In the current stock assessment, different M values for each age were introduced based on results from the Commission's Multispecies VPA (MSVPA). The menhaden assessment model estimated a mortality scalar that was applied to a constant proportional mortality at age vector based on the MSVPA for 1981- 1999. The most drastic change in predicted mortality that resulted was for age-0 and age-1 menhaden, for which M's were estimated to be 4.31 and 0.98 for age-0 and age-1 fish, respectively. The Panel agreed that the change to an age-specific M was a substantial improvement over the constant M assumption. The assessment used the only quantitative information available (i.e., MSVPA M estimates). Targets should be distinguishable from the limits and represent societal goals (such as menhaden's ecological function). However, the Panel noted that it was difficult to judge whether this approach represented use of the best available data, given that the MSVPA was not available for review. The Commission is currently in the process of conducting a formal peer review of the MSVPA. The Panel questioned the validity of the assumptions that age-specific M was constant for the time period 1981-1999 and that such data could be further expanded to apply to the period from 1955- 1980. The Panel recommended that the application of results from the MSVPA to the 1955-1980 period be validated. The Panel suggested that the documentation for developing the vector of age-dependent proportional M from basic theory through use of the MSVPA be more fully developed. The Panel recommended that the MSVPA be enhanced by inclusion of all the key predators and prey in the MSVPA. The Panel recommended that assessment of key sources of predation mortality for menhaden be conducted so that temporal patterns in these sources can be determined and included in the MSVPA assessment to yield time-dependent, age-specific mortality rates.

Spawning stock biomass (SSB) was expressed as potential population fecundity estimated from fecundity at size based on studies conducted in the 1980s and earlier. The Panel accepted that the change to potential population fecundity from SSB as an index of spawning potential and recognized that the fecundity-based index will be more sensitive to changes in the underlying population structure. The Panel recommended that the fecundity-at-size estimates and maturity ogives be updated.

There have been large changes in size-at-age over the 1955-2002 period. These trends are not a problem for the model but could have an impact on future forecasts. The Panel recommended the evaluation of historical change in size (weight and length) at age using existing data (e.g., scale incremental widths).

2. **Evaluate the adequacy, appropriateness and application of models used to assess these species and to estimate population benchmarks.**

A new forward-projecting statistical catch-at-age model was used as the assessment tool for Atlantic menhaden in 2003. Previous stock assessment analyses of Atlantic menhaden have used untuned virtual population analysis (VPA) methods. The Panel approved of the use of this new model to assess Atlantic coast menhaden stocks. The model uses weighted likelihoods for the major time series of data in the model to adjust population rates so that the overall model likelihood is minimized. Briefly, the likelihood components express the probability of observing the data given model parameters. The Panel agreed that the weightings used in the model appropriately reflected the degrees of belief in the different time series input to the model. The Panel noted that the weightings chosen for the model force a high degree of agreement between observed and predicted catches. The model fit the juvenile abundance indices fairly well, but fit the bait fishery and the Potomac River pound net index less well. No consensus was reached to explain the discrepancies in index fits. The Panel noted that the forward projection model did not exhibit any retrospective patterns. However, strong retrospective patterns typically seen in a VPA would not be expected in a forward projection model.

The menhaden stock assessment model presented assumed a unit stock. The Panel recommended that stock structure be assessed using natural tags such as otolith microchemistry and/or genetic markers. This research should seek to elucidate the potential for stock structure and the potential presence of latitudinal or other spatial variability in the stock.

The Panel noted the higher Ms on age-0 and age-1 menhaden assumed for this model resulted in much larger population sizes for those ages than in previous assessments. This does not have an impact on stock status because these population increases are removed due to high M values prior to their full recruitment to the fishery. Consequently, estimated Ms for the adult animals (age-2+) are similar to those assumed for model runs assuming constant M across all age groups. The Panel recommended that the constant pattern of M at age over time should be re-evaluated for each assessment, and that the best available estimates be used. This concern is particularly relevant should the model be used to project the population into the future.

Both a Ricker and a Beverton-Holt stock-recruitment model were used to relate recruits to spawning stock biomass. There was very little difference between model results using these two different relationships. The Panel noted that at present the lack of difference is not of concern, but the structure of the stock recruitment relationship could become an issue in a rebuilding situation.

The Panel requested a sensitivity analysis to evaluate the impact of the large 1958 year class on the estimates. This involved re-running the Ricker base model with data from 1965 to the present (as compared to 1955 to the present). Re-running the model for this time frame resulted in truncation of the reduction landings, reduction age compositions, and composite juvenile index. Overall, the magnitude and trends in the population did not change. The Panel was encouraged by these results.

The Panel noted that the model resulted in patterns in residuals of numbers at age for commercial catch. The Panel recommended investigation of the source of this pattern in the residuals that should include the potential roles of whether the selectivity model, spatial changes in fishing pattern, or fish distribution are causing this observed residual pattern.

The Panel also noted that it was difficult to distinguish degrees of belief in alternative models. The Panel recommended the development of measures (goodness of fit/complexity) to screen multiple models.

The control plot determination of overfishing/overfished was based on point estimates only. Variances were directly available from the model output. However, these variances were based on the underlying Hessian matrix, and accordingly are believed to be underestimates. The Panel recommended the development of uncertainty measures or risk analysis for future control plots such as through bootstrap analysis involving resampling of the input distributions.

3. Evaluate the adequacy and appropriateness of the Technical Committee's recommendations of current stock status based on biological reference points.

The technical committee presented F-based and biomass-based reference points that together define the conditions of overfishing and overfished. In past assessments, the target fishing mortality was based on Fmax and SSB was used as the biomass measure. In this assessment, SSB has been replaced with population fecundity (number of maturing or ripe ova as a function of fish size). The Panel agreed that this change represents an improved measure of reproductive capacity. F_{MED} continues to be used to represent F_{REP} as the *F*-threshold. However, in the current forward projection model, Fmax was infinite, possibly due to varying M at age and other aspects of the model. Therefore, the *F*-target is based on the 75^{th} percentile of fecundity/R_0 . The Panel noted that the proposed F-target, though arbitrary, was not capricious and yielded a target that was sufficiently lower than the threshold so that deviations of F from the target will not result in overfishing. The Panel agreed with the definition of these new benchmarks. Based on these benchmarks the menhaden stock in 2002 is considered not overfished and overfishing is not occurring. The Panel accepted the conclusion on stock status on a coastwide basis.

The Panel noted the lack of any clear relationship between estimates of F and stock spawning potential apparent in the control plots. This will become of concern should the population be assessed as overfished and/or overfishing is occurring as it suggests that management action to control F may have little impact on population abundance and spawning potential.

The stock assessment document referred to the ecological role of menhaden, although no new data or analyses were presented. Nevertheless, there was considerable discussion at the meeting about the need for information on the role of menhaden as a forage fish for other species such as bluefish, striped bass, marine mammals, and birds. Some participants expressed frustration with the lack of ecosystem-based information in the stock assessment. In particular, there was concern that while the stock assessment tracked status on a coastwide basis it would not detect localized depletion and reduced ecological function that could occur when the fishery is concentrated in one part of the coast. The terms of reference for this panel were limited to evaluating the data, model and stock status for the menhaden fishery. The previous stock

assessment for this stock in 1999 did include a term of reference directed toward understanding the ecological role menhaden. At that time, the panel concluded that "until management had specified an allocation goal for menhaden as a forage fish or filter feeder, it will not be possible to develop a reference point to conserve menhaden's ecological function". The current Panel recommends that management objectives be established before it can be determined what kind of scientific information will be useful for ecosystem-based management decisions.

4. Develop recommendations for future research for improving data collection and the assessment.

1. Issue: There is no adult abundance index to tune the population model.
   - Evaluate commercial purse seine fishery effort (vessel/weeks) series as a possible tuning index in the model. Evaluate any measure of effort contained in this or other data series.
   - Evaluate the data collected in the Captain's Daily Fishing reports for an adult abundance index. If these data are not useful, explore the utility of a commercial fishery-based adult index, developed jointly with the fishermen, for future assessments.

2. Issue: Recent relative productivities of menhaden nursery areas coast wide are unknown.
   - Investigate if there are any existing studies that could assist in evaluating current productivity.
   - Develop protocols to quantify contribution of different nursery areas to the adult stock.

3. Issue: M-at-age is an improvement over constant M assumption. However, there is concern that not all key sources of mortality have been accounted for and little is known about the temporal patterns of mortality.
   - Identify key sources of non-fishing mortality for menhaden.
   - Enhance the coverage of the MSVPA to more predator and prey species.
   - Determine if there are temporal patterns in these sources.
   - Validate assumptions about applying results from MSVPA to the 1955-1980 period.

4. Issue: There have been large changes in size-at-age over the 1955-2002 period. These trends are not a problem for the model but could have an impact on forecasts.
   - Evaluate historical change in size (weight and length) at age using existing data (e.g., scale incremental widths).

5. Issue: There are patterns in residuals of numbers at age for commercial catch estimated by the model.
   - Investigate if the selectivity model is causing this pattern.
   - Look at spatial changes in fishing pattern as well as fish distribution.

6. Issue: Current fecundity estimates are from studies in the 1980's and earlier.
   - Update the fecundity-at-size estimates and maturity ogives.

7. Issue: Cannot address local depletion questions with the current model.

- Investigate methods to determine the proportion of the stock that may reside in a particular area in any one season and whether regional reference points can be developed to address local depletion.
- Extend these methods to track changes in distribution over time.

8. Issue: Control plot determination of overfishing/overfished is based on point estimates only.
   - Develop uncertainty measures or risk analysis for control plots.

9. Issue: It is difficult to distinguish between results of different models and model assumptions.
   - Develop measures (goodness of fit/complexity) to screen multiple models.

10. Issue: The assessment model assumes a unit stock.
- Test this assumption using otolith microchemistry and/or genetic markers.

Atlantic Menhaden Advisory Report

Status of Stocks

Based on the 2003 assessment, the 2002 population fecundity estimate of menhaden is above the threshold and fishing mortality rate is below the threshold (Figure 1). Therefore, the Atlantic menhaden stock in 2002 is considered not overfished and overfishing is not occurring on a coastwide basis.

Stock Identification and Distribution

The Atlantic menhaden resource is believed to consist of a single unit stock or population, based on tagging studies. Adult Atlantic menhaden undergo extensive seasonal migrations north and south along the U.S. east coast. There is a cyclic north-south movement with the largest and oldest fish proceeding farthest north such that the population stratifies itself by age and size along the coast during the summer. A great deal of mixing of fish from all areas occurs off the North Carolina coast before fish move northward in spring. Adults begin migrating inshore and north in early spring following the end of the major spawning season off the North Carolina coast during December –February. The oldest and largest fish migrate farthest, reaching the Gulf of Maine in May and June. Adults that remain in the south Atlantic region for spring and summer migrate south later in the year, reaching northern Florida by fall. Fish begin migrating south from northern areas to the Carolinas in late fall. During November, most of the adult population that summered north of the Chesapeake Bay moves south around Cape Hatteras.

Management Unit

The management unit for Atlantic menhaden is the entire Atlantic coast and fishery and stock parameters are evaluated on a coastwide scale.

Landings

The commercial fisheries for Atlantic menhaden consist primarily of directed purse seine fisheries for reduction and bait and are nearly the exclusive sources of fishery-dependent data for the stock. Landings for the menhaden reduction plants have been reported since 1940. The directed bait fishery for menhaden has grown in importance in recent years and landings from 1985-2002 are included in the current model. Recreational fishermen also catch Atlantic menhaden as bait for various game fish; however, the quantities removed are believed to be minimal and are currently not quantified.

Reduction fishery landings rose during the 1940s (from 167,000 to 376,000 tons), peaked during the 1950s (high of 712,000 t in 1956), and then declined to low levels during the 1960s (from 576,000 t in 1961 to 162,000 t in 1969). During the 1970s the stock rebuilt (landings rose from 250,000 t in 1971 to 376,000 t in 1979) and then maintained intermediate levels during the 1980s (varying between 238,000 t in 1986 to 418,600 t in 1983). Landings during the 1990s declined from about 400,000 t in 1990 to 171,200 t in 1999 (Figure 2).

In recent years, purse seine fisheries for bait have operated primarily in North Carolina, Virginia, and New Jersey. Bait fishery landings were over 18,000 t in Virginia and close to 15,000 t in New Jersey (Figure 3).

Data and Assessment

Data used in the Atlantic menhaden stock assessment include landings from the reduction fishery from 1955 to the present and bait fisheries landings for 1985-2002. Biostatistical samples of the catches since 1955 were used for age estimation. Fishery-independent data sources were obtained from seine survey data collected by various states where menhaden are not the target species.

A new forward-projecting statistical catch-at-age model was used as the assessment tool for Atlantic menhaden in 2003. Previous stock assessment analyses of Atlantic menhaden have used untuned virtual population analysis (VPA) methods. The essence of forward-projecting age-structured models is to simulate a population that is projected forward in time like the population being assessed. Quantities to be estimated are systematically varied from starting values until the simulated population's characteristics statistically match available data on the real population as closely as possible. Natural mortality rate (M) was estimated from the Commission's Multispecies Virtual Population Analysis (MSVPA) as an age-specific rate.

Biological Reference Points

Biological reference points for Atlantic menhaden are F-based and biomass-based reference points that together define the conditions of overfishing and overfished. In this assessment, Spawning Stock Biomass (SSB) has been replaced with population fecundity (number of maturing or ripe ova as a function of fish size). F_{MED} continues to be used to represent F_{REP} as the *F*-threshold. However, in the current forward projection model, F_{max} was infinite, possibly due to varying M at age and other aspects of the model. Therefore, the *F*-target is based on the 75^{th} percentile of fecundity/R_0. This ratio times the median recruit (age-0) is the biomass threshold.

Fishing Mortality

Fishing mortality is related to an overall level of fishing and the selectivity (or availability) of menhaden to the two fisheries (reduction and bait). Fishing mortality rates on ages-2 to -8 (referred to as full F) were calculated as the weighted average of age-specific Fs for ages-2 to -8, weighted by population number at age. Highest fishing mortality was noted in the mid-1960s during a period of poor recruitment, when the menhaden population declined dramatically and subsequently many reduction plants were shut down. Since the mid-1960s, fishing mortality has declined, such that it has generally been below 1.0 for the last 11 years. The historical time period 1955-2002 produced a median F of 1.04 with interquartile range between 0.83 and 1.27. The estimate of fishing mortality rate for 2002 of 0.79 was below the 25th percentile of the historical estimates (Figure 4).

Recruitment

Recruits of Atlantic menhaden to age-0 (Figure 5) and age-1 (Figure 6) were high during the late 1950s, especially the 1958 year class. Recruitment was generally poor during the 1960s, with values below the 25th percentile for the recruitment time series. High recruitment occurred during the 1970s to levels above the 75th percentile. Moderate to high recruitment occurred during the 1980s, with generally low recruitment since the mid-1990s. The current estimate of recruits to age-0 in 2002 (406.8 billion for the Ricker model; 402.7 billion for the Beverton-Holt model) is between the median and 75th percentiles, while the current estimate of recruits to age-1 in 2002 (2.5 billion for both the Ricker and Beverton-Holt models) falls below the 25th percentile.

Spawning Stock Biomass

Spawning stock biomass (SSB, weight of mature female biomass at start of fishing year) was high in the late 1950s and early 1960s, low in the late 1960s, and generally increasing in recent years (Figure 7). Historically high levels of spawning stock biomass (greater than the 75th percentile) occurred during 1955-1956, 1958-1962, 1987-1988, 1994-1995 and 1997. The estimate for spawning stock biomass in 2002 was 91,900 t, or between the median and 75th percentile.

Similarly, population fecundity (number of maturing or ripe ova) followed a similar pattern to spawning stock biomass (Figure 8). The historical time period 1955-2002 produced a median population fecundity of 30.1×10^{12} ova with interquartile range between 23.2×10^{12} and 48.6×10^{12}. Historically high levels of population fecundity (greater than the 75th percentile) occurred during 1955-1956, 1958-1962, 1988, and 1994-1997. The estimate for population fecundity in 2002 was 40.6×10^{12}, again between the median and the 75th percentile.

Bycatch

Studies have shown that there is little bycatch in the menhaden purse seine fishery. Some states restrict bycatch on a vessel to 1% or less of the total catch by regulation.

Sources of Information

Atlantic States Marine Fisheries Commission. 2003. Atlantic Menhaden Stock Assessment Report for Peer Review. ASMFC Stock Assessment Report No. 03-01 (Supplemental). Washington, DC.

Figure 1. Control plot for Atlantic menhaden from base Ricker model (solid square is value for 2002). Results were very similar using the Beverton-Holt model.

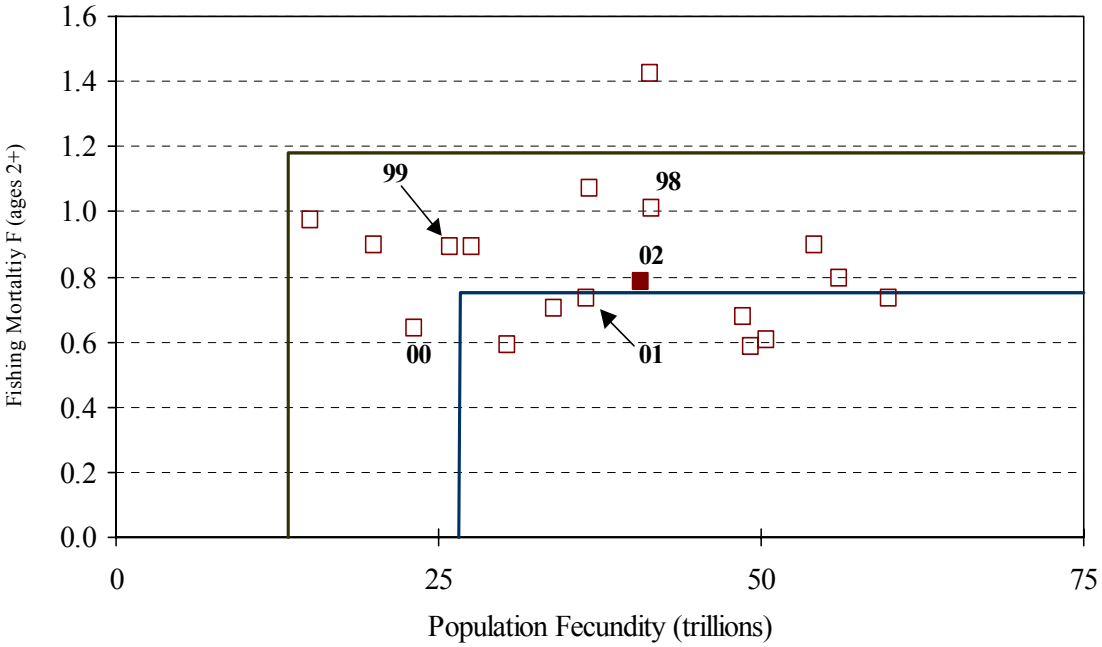

Figure 2. Landings and nominal effort from the reduction purse seine fishery for Atlantic menhaden, 1955-2002.

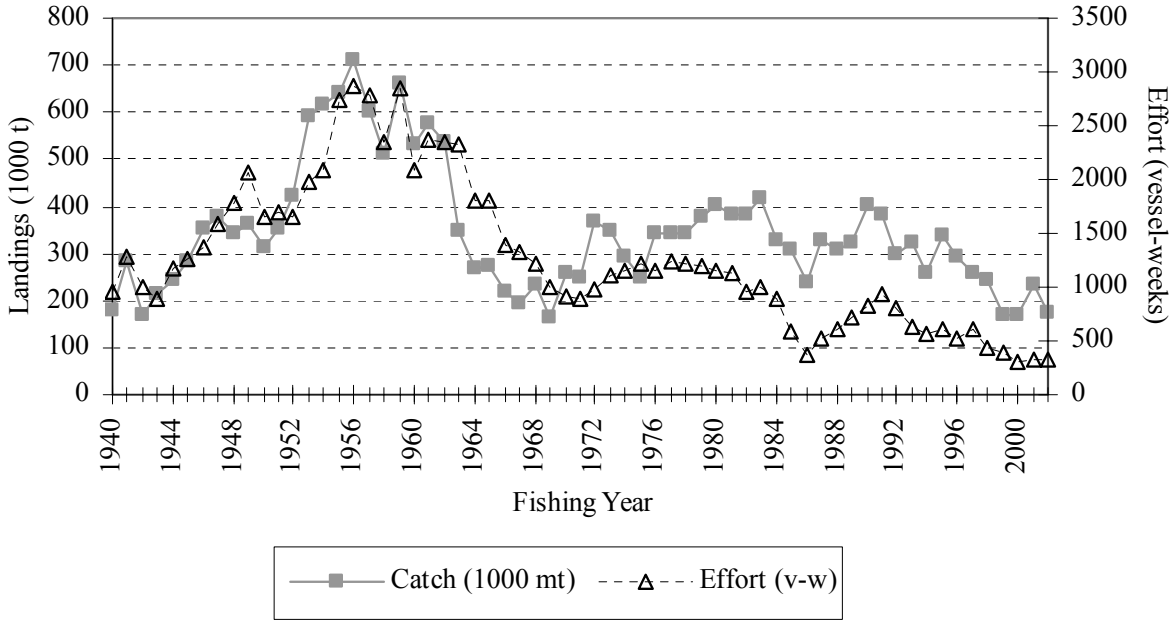

Figure 3. Mean landings by state from the bait fishery for Atlantic menhaden, 1998-2002.

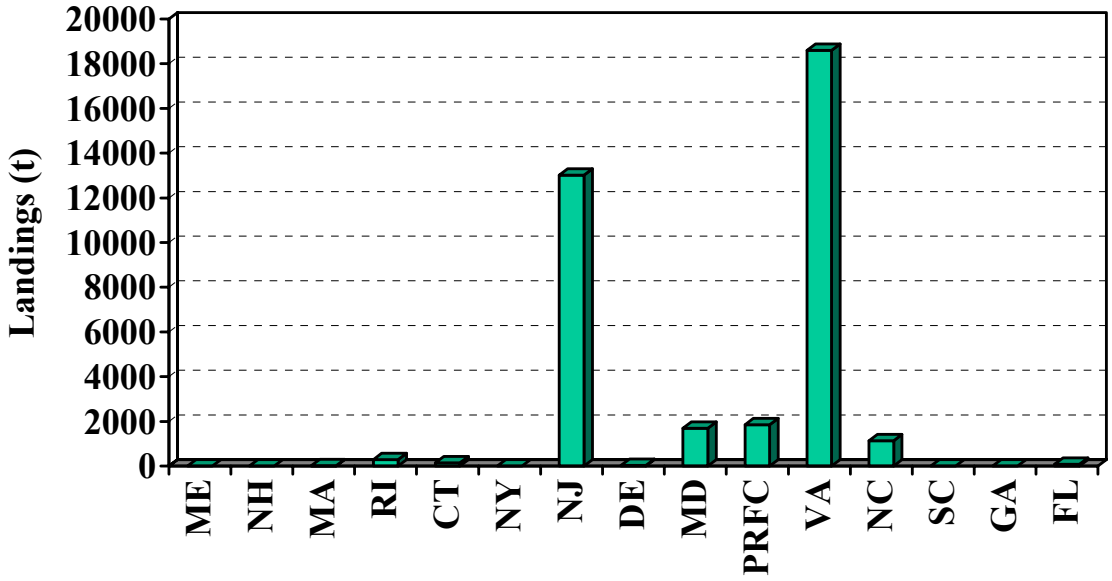

Figure 4. Atlantic menhaden fishing mortality rate, *F* (ages 2+) plus/minus 2 standard errors from Ricker model. Horizontal lines represent target (dashed) and threshold (solid).

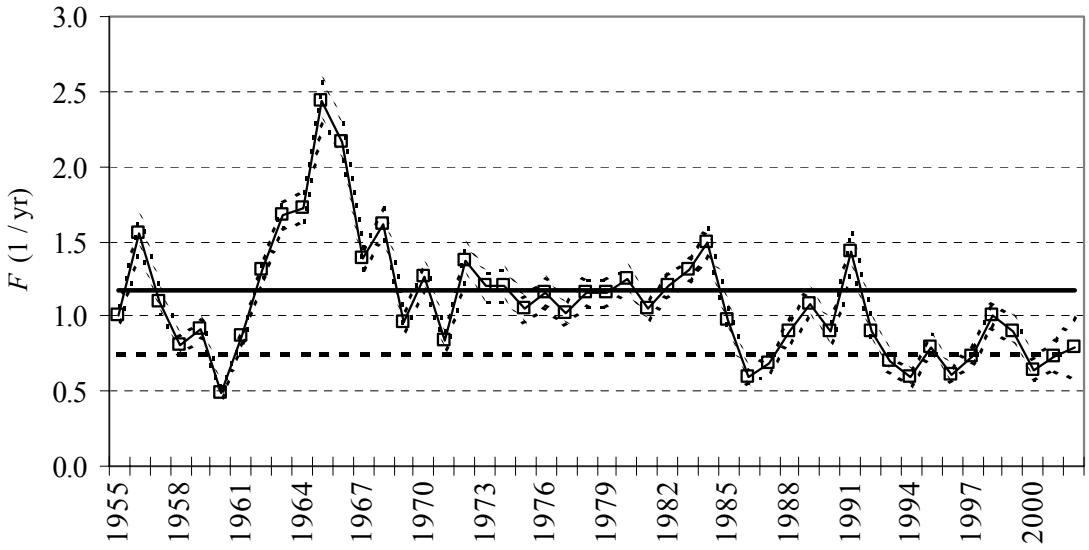

Figure 5. Atlantic menhaden recruitment to age-0 for both spawner-recruit models.

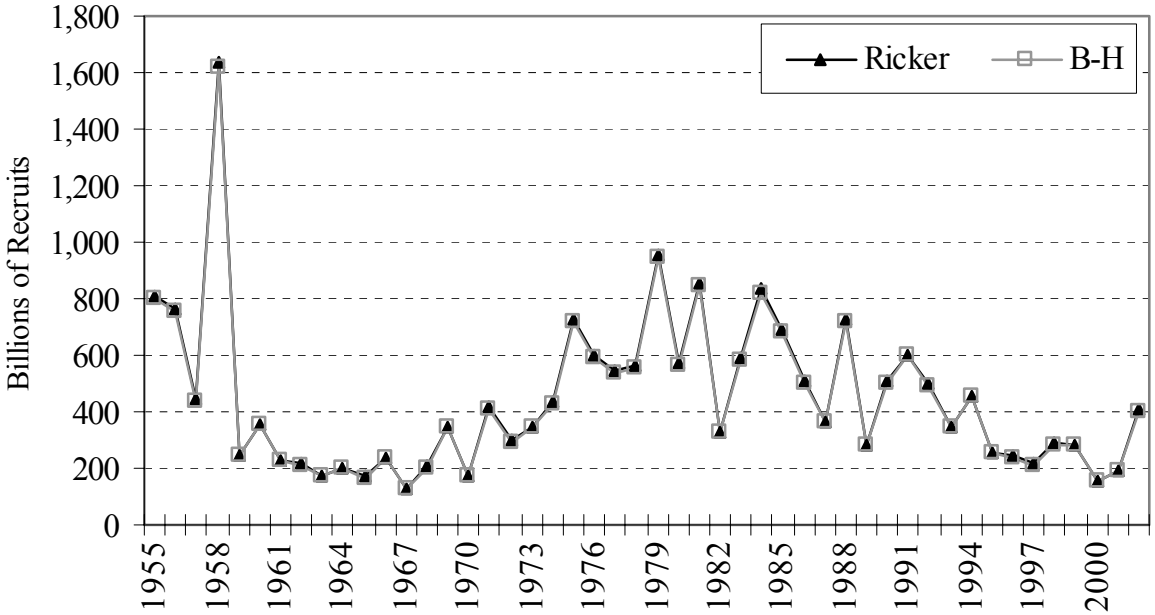

Figure 6. Atlantic menhaden recruitment to age-1 for both spawner-recruit models.

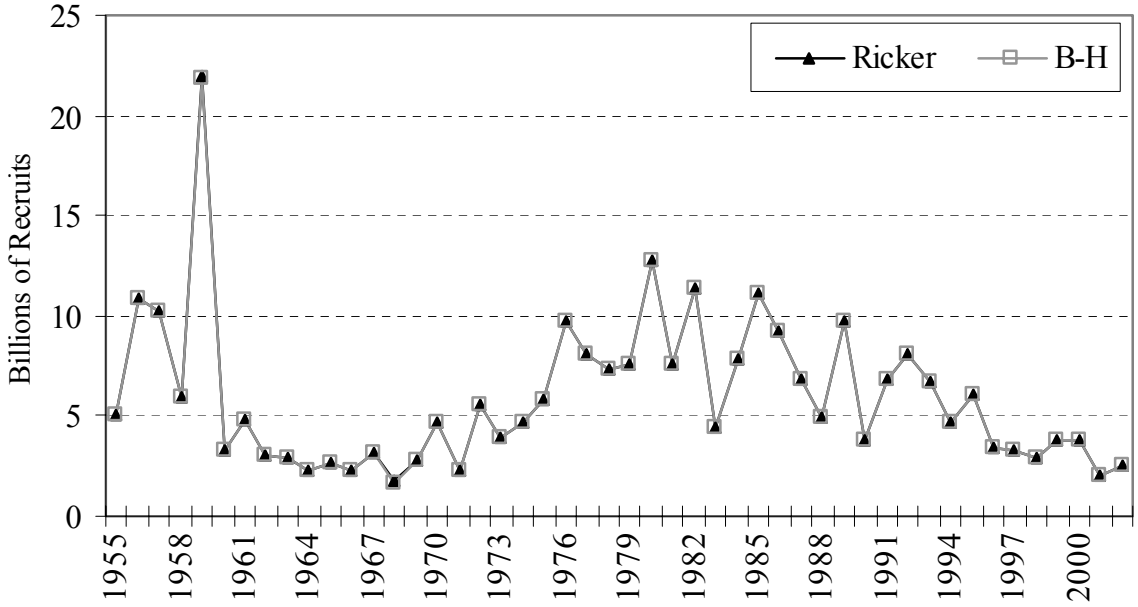

Figure 7. Atlantic menhaden spawning stock biomass (SSB) plus/minus 2 standard errors from Ricker model. Horizontal lines represent target (dashed) and threshold (solid) from Amendment 1.

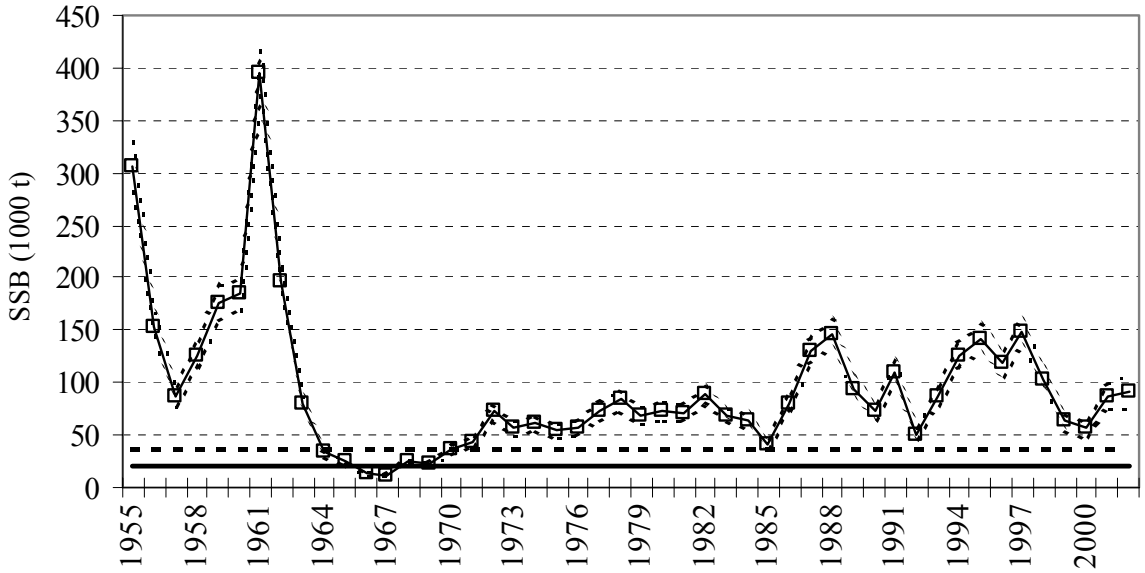

Figure 8. Atlantic menhaden population fecundity (# maturing ova) plus/minus 2 standard errors from Ricker model. Horizontal lines represent target (dashed) and threshold (solid).