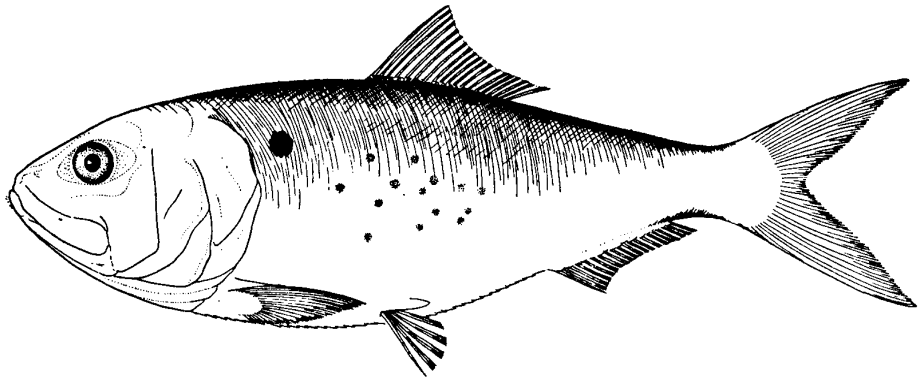
Stock Assessment Report No. 99-01
of the

# Atlantic States Marine Fisheries Commission

*Terms of Reference & Advisory Report*
*for the Atlantic Menhaden Stock Assessment Peer Review*



February 1999

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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).

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 June 1997, the horseshoe crab and Atlantic menhaden stock assessments were prioritized for an external peer review. An external review panel was formed of four stock assessment biologists with expertise in menhaden life history, stock assessment techniques, and multispecies interactions. The external peer review for the Atlantic menhaden stock assessment was conducted November 16 - 18, 1998 in Baltimore, Maryland.

## 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 external peer 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. To obtain these supplemental documents please contact 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. Richard Condrey, Louisiana State University; Dr. Kevin Friedland, University of Massachusetts, National Oceanic and Atmospheric Administration Cooperative Marine Education and Research Program; Dr. David Secor, University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory; Dr. Behzad Mamoudi, Florida Department of Environmental Protection) for their hard work in reviewing the meeting materials and providing advice on improvements to the Commission=s Atlantic menhaden stock assessment and fishery management. Many other people provided support to this peer review, including: Dr. Douglas Vaughan and Mr. Joseph Smith (National Marine Fisheries Service) who presented the stock assessment materials to the panel; and Ellen Cosby (Virginia Marine Resources Commission) and Michael Street (North Carolina Division of Marine Fisheries) who provided information on behalf of the Atlantic Menhaden Advisory Committee.

The Commission would also like to thank the many people who attended the peer review and presented their individual viewpoints on the status of the menhaden assessment and fishery, including: Sara Gottlieb (New Mexico Heritage Program), Alexei Sharov (Maryland Department of Natural Resources), Niels Moore (National Fisheries Institute), Jule Wheatly (Beaufort Fisheries, Inc.), Sherman Baynard (Centerville, Maryland), Bill Goldsborough (ASMFC Commissioner), Gary B. Bolon (Cape May, New Jersey), James Price (Easton, Maryland), Phil Jones (Maryland Department of Natural Resources), Harley Speir (Maryland Department of Natural Resources), Pat Augustine (ASMFC Commissioner), Fred Frillici (ASMFC Commissioner proxy), Claire Buchanan (ICPRB), Joe Mihursky (Chesapeake Biological Laboratory), Karl Blankenship (Bay Journal), Peter Tango (Maryland Department of Natural Resources), Mike Armstrong (Massachusetts Division of Marine Fisheries), John Merriner (National Marine Fisheries Service), Everett B. Mills (Westport, Massachusetts), Charles Williams (Reedville, Virginia).

Special appreciation is given to the staff dedicated to the performance of the Peer Review and finalization of peer review reports, specifically B Dr. Joseph Desfosse, Geoffrey White, Dr. Lisa Kline, Tina Berger, and Vanessa Jones.

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**Terms of Reference for the**
**Atlantic Menhaden Peer Review**

**1. Review Atlantic menhaden assessment methodology and model including, but not limited to, the following:**

**a. evaluate the sources of data used in the assessment;**
**b. evaluate the extent of retrospective bias in the analysis;**
**c. identify and evaluate other potential sources of mortality.**

The choice of the Murphy Virtual Population Analysis (VPA) and Separable Virtual Population Analysis (SVPA) methods for assessment of the Atlantic menhaden stock are reasonable given the available data. The catch-at-age matrix was constructed based on comprehensive biostatistical port sampling (1955-1997) with sufficient temporal and spatial resolution. Specific suggestions with regard to modeling and input parameters include:

a. The sampling rate, samples per catch, should be examined to determine whether sampling is inefficiently high. The potential of measuring reproductive parameters by biosamplers should be pursued.

b. The current estimate of natural mortality (M), equal to 0.45, is based on the mid-point of the range of estimates from tagging studies conducted during 1966 through 1987. The Panel recommends further analysis to assess the sensitivity of spawning stock biomass (SSB) and recruitment estimates to age-specific values of M. For instance, recent increases in striped bass abundance, a key predator on menhaden, may have caused increased mortality on age 0 and 1 menhaden. The Panel recommends evaluating the feasibility of multispecies assessment as a means to assign and partition mortality rates.

c. Various fishery-independent (i.e., juvenile indices available from Maryland and Virginia) and fishery-dependent (i.e., pound net catch-per-unit effort) data sets were reviewed. The Panel suggests that these data sources be evaluated as potential tuning indices to calibrate abundance estimates generated by the VPA for the most recent years and also be used as independent data to verify estimates from the VPA analyses and other models.

d. The Panel believes that the lack of data on spawning frequency and lack of more recent information on size/age at maturity have increased the level of uncertainties associated with estimates of SSB. This level of uncertainty may have an effect on measurements of spawning potential and population resiliency. The Panel recommends monitoring of

reproductive parameters in landings (see 1.a recommendation) and computation of SSB based upon current weight-at-age, maturity schedules, and weight-fecundity relationships.

e. The Panel recommends that yield-per-recruit analysis, spawning stock biomass-per-recruit and estimates of biological reference points ($F_{0.1}$, $F_{threshold}$, $F_{max}$) be developed for future assessments.

g. The Panel believes that there are insufficient data to support selection of a Ricker spawner-recruit relationship at this time due to violation of the underlying assumptions of the Ricker curve and recommends alternative models be investigated.

h. A retrospective analysis was performed to investigate estimation of (1) fully recruited fishing mortality (F) by ad hoc methods, as referenced in the Atlantic Menhaden Stock Assessment Report for Peer Review; and (2) estimation of partial recruitment to the fishery at age 0 and 1 by separable VPA. This assessment shows that although there was some retrospective error in the assessment, it was unbiased. However, the exercise does underscore the absence of an assessment of model precision for the VPA. The Panel recommends investigating the precision of the VPA results and management trigger variables using error estimates associated with the catch at age data and catch curve analyses.

**2. Review the trigger mechanisms used to monitor the menhaden stock and fishery. In particular, evaluate:**

**a. whether the triggers accurately represent the condition and characteristics of the stock;**

**b. whether the levels at which the triggers are set are appropriate to maintain adequate stock conditions in light of the specific life history characteristics of Atlantic menhaden.**

Six trigger variables, derived from the VPA and directly from catch data, are used to monitor and evaluate the Atlantic menhaden resource. These variables are intended to provide an assessment of fishery impacts by monitoring changes in stock size and recruitment. This could be risky because in a schooling search fishery, such as the Atlantic menhaden fishery, it is possible to maintain high levels of catch while the stock abundance and recruitment are being depleted. Therefore, there is a need to include trigger mechanisms that are based on fishery-independent data and/or manage this fishery based on the traditional reference points such as $F_{0.1}$, $F_{max}$, and others. The concept of Atrigger variables@ is commonly used in fishery management; however, in the menhaden assessment

and management process, neither individually or collectively do any of these variables trigger a specific management action. As such, the Panel suggests these variables or others that may emerge in future assessments be referred to as biological reference points or variables that are used to evaluate stock status. Further, in the future these stock status variables can become triggers if implemented through the management process.

The Panel reviewed the efficacy of the currently defined biological reference points (Afishery triggers@), with the specific goal of assessing whether they accurately represent stock condition. The first three reference points are derived directly from catch data. These reference points may be reflective of size and condition of the stock, but are influenced to some unknown degree by the behavior of the fishery. Thus, reference points 1 though 3 are potentially misleading reference points of true trends in stock condition. These triggers are also redundant of the information on stock size provided by the VPA since they are both dependent upon catch data. The VPA model explicitly accounts for the effect of fishing; thus stock size estimates from the VPA are less likely to be biased by the changes in catch patterns associated with decisions made by the fishery. The Panel recommends that the catch-based reference points (triggers 1 through 3) be dropped from the assessment because of the inherent risk of misinterpreting stock trends.

Two of the reference points (triggers 4 and 5) are stock size estimates from the VPA representing the most accurate estimates of stock abundance and providing useful reference points on stock condition. The Panel suggests variables 4 and 5 be retained in the advisory process but believes their use could be enhanced in two ways. First, if procedures to estimate precision of the VPA can be developed, the resulting data on precision of stock size estimates should be carried over into the evaluation of reference points so that risk can be characterized in the management process. Second, more explicit assessment of age-structure should be pursued to monitor recruitment into the spawning stock and safeguard against age truncation.

The final reference point used in the assessment is the percent maximum spawning potential (%MSP). Although %MSP reference points are widely used in Atlantic coast fishery management plans, with the redefinition of overfishing for federally-managed marine species under the Sustainable Fisheries Act, %MSP reference points have been replaced by a fishing control rule based on maximum sustainable yield (MSY) and rebuilding harvest strategies. The control rule consists of a framework of management actions that link management goals to biological reference points. In addition, the Panel was not convinced that the 3%MSP reference level for menhaden is sufficient for sustainable production of this stock. Therefore, the Panel suggests this reference point be dropped from the assessment and a fishing control rule be developed for the menhaden fishery.

The Panel suggests that other mortality rate and SSB based reference points be developed that would provide the basis for a control rule for menhaden fisheries management. These reference points should include a target fishing mortality rate associated with MSY of the

stock and other rates specified during periods of stock rebuilding. Likewise, there should be a biomass level where fishing would cease in order to avoid stock collapse and long term damage to the ecosystem.

Atlantic menhaden recruit to the fishery at age-1 and only begin to spawn two years later. Therefore, menhaden are subjected to fishing pressure prior to formulation of any abundance index or management actions to protect incoming fish prior to spawning. This poses a special problem for managers concerned about the management of year classes entering the population. The Panel suggests the development of a predictive reference point and a protocol to estimate the size of the incoming year class so that harvest levels on age 1 fish can be calibrated. This reference point could be based on some fishery independent measure of abundance of age-0 fish resident in the principal nursery areas for menhaden.

**3. Evaluate the status of the Atlantic menhaden stock. In addition, evaluate:**

**a. the extent of any local impacts which may be a result of changes in fishing patterns over the last 30-40 years; and**

**b. reports of local depletion of menhaden in Chesapeake Bay and northeastern Florida waters.**

Indicators of recruitment from the VPA and fishery independent data from Maryland and Virginia show consistent declining trends from 1990 to the present (Figures 1 and 2). Levels of current recruitment are in the lower quartiles of historical times series for these indices. Potential causes of declines in abundance of 1-year old menhaden may include reduced spawning stock biomass, unfavorable oceanographic or juvenile nursery conditions, and predation on larval and juvenile menhaden. Results of the VPA suggest that low recruitment is not necessarily the result of reduced spawning stock, since recent estimates of spawning stock biomass are relatively high (Figure 3). Recruitment time series (Virginia and Maryland juvenile seine survey data, and VPA recruitment indices) show strong autocorrelation (Figure 2), indicating that recruitment may be affected by decadal scale changes. Because recruitment in any given year is autocorrelated with recruitment in adjacent years, the current trend of declining recruitment is likely to persist in the near future. The consistent decline in recruitment over the last eight years should result in declining population abundance and spawning stock in the coming years.

Evidence from fisheries dependent sources strongly suggest that the stock range has contracted from the northern and southern extent of its range in the last few years. Stock contraction to regions south of Long Island and possibly north of northeastern Florida has coincided with a regional shift which has concentrated reduction fishery effort in Virginia and North Carolina waters, with greater than 80% of the reduction landings occurring in the Chesapeake Bay and mid-Atlantic region. Contractions in stock range and the reduction fishery may be an indication of possible future declines in population abundance.

The Panel did not receive any direct evidence of local depletion of menhaden in Chesapeake Bay and Florida waters. However, most effort is directed on components of the stock which utilize the Chesapeake Bay and North Carolina waters as feeding grounds during summer and fall. Therefore, on a seasonal basis, local exploitation rates are expected to exceed those estimated from the VPA for these regions. These local depletions may or may not be subsidized in subsequent years by menhaden from other less exploited regions.

**4. Evaluate the ecological significance of menhaden as both a forage fish for other species and as a consumer (of phytoplankton). Evaluate whether the current triggers account for the role of menhaden as a forage fish and filter-feeder. If appropriate, suggest additional trigger(s) or reference points which could reflect this role.**

No comprehensive analysis of the ecological role of menhaden was included in the stock assessment report. Evidence in the literature and new data presented to the Panel strongly support the important role of Atlantic menhaden in: (1) ecosystem phytoplankton and nutrient dynamics, and (2) as a forage base for piscivores (e.g., bluefish, weakfish, and striped bass). These aspects will be further addressed by the Commission workshop on multispecies interactions being planned for 1999. Specific issues related to menhaden management that should be addressed during this workshop include: (1) evaluate the relationship between menhaden juvenile recruitment and piscivore abundances, (2) develop a multispecies approach to estimate and allocate natural mortality, and (3) evaluate competition between forage fish and piscivore fisheries.

The current triggers do not address the role of menhaden as forage or filter feeders. A reference point responsive to menhaden as a forage species would be one which maximizes population abundance taking into regard the allocation of fish between F and M. Until management has specified an allocation and goals for menhaden as a forage fish, it is not possible to specifically develop a reference point to address this issue.

The reference point for menhaden as a filter feeder would have to take into account a model of the mass balance of the target material being filtered (e.g., phytoplankton, zooplankton, nitrogen). Considerations would include filtering rates of the target material by menhaden, and removal of menhaden from the ecosystem by emigration and harvest. Until management has 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 ecological function.

**5. Review management and research recommendations, and identify any new management and research needs.**

The Atlantic Menhaden Advisory Committee (AMAC) made no recommendations for changes in regulation of the menhaden fisheries in 1998. The Panel believes that this inaction was inappropriate based on the following: (1) indications of recruitment declines and stock contraction, and (2) lack of clear relationships between management indicators, actions, and evaluation of efficacy of management actions in the current management framework. A voluntary reduction in the fleet from 22 to 15 vessels occurred in 1998 which was expected to reduce effort and potentially contribute to reduced landings. However, due to uncertainties in estimation of natural mortality it may not be possible to evaluate the effect of fleet reduction on exploitation rate. The trigger-based management system has not served the function of guiding regulatory actions in the menhaden fishery. The detailed information on stock status afforded by the VPA has not been utilized to full advantage in guiding management.

Management Needs:

The Panel recommends the development of a quota based management system for Atlantic menhaden. The annual total allowable catch should be allocated by season and fishing areas. Fishing levels should be determined by a fishing control rule that can respond to changes in relevant biological reference points. The fishing control rule should specify fishing levels at high and low stock size based upon reproductive schedules. See Terms of Reference #2 and #4 for further recommendations on the fishing control rule.

The Panel recommends that biological reference points based upon recruitment and spawning stock status be developed. These references points should result in risk-averse management decisions which preserve spawning stock and increase the likelihood of favorable recruitment. Dynamic pool (yield-per-recruit) and surplus production models should be used in addition to the VPA to establish threshold F values which consider the need for stock rebuilding (e.g. SSB per recruit), increased yield to the fishery (e.g. yield per recruit, surplus production), and the ecological role of menhaden (allocation of natural mortality versus fishing mortality).

The Panel believes that future stock assessments would benefit from a greater diversity of scientific participants and input. This should result in increased sources of auxiliary data to support stock assessments, fine tuning of the assessment, and corroboration of stock assessment findings. Increased scientific input is also needed to address menhaden=s critical ecological role. To facilitate increased scientific input, the Panel recommends that the current mixed advisory-scientific committee (AMAC) be dissolved and reconstituted into separate technical and advisory committees.

Research Needs:

The Panel supports the research needs identified in the Atlantic Menhaden Stock Assessment Report for Peer Review and would like to emphasize the following three research needs from that report:

1. Evaluate effects of selected environmental factors and predation on recruitment of Atlantic menhaden into the spawning stock.

2. Develop and test methods for estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques.

3. Monitor landings, size, gear, and harvest area in the reduction and bait fisheries, and determine age composition by area.

The Panel would also like to recommend the following additional research needs (not in order of priority):

- Growth back-calculation studies should be pursued to investigate historical trends in growth rate. The National Marine Fisheries Service has an extensive dataset on scale growth increments which should be utilized for this purpose.

- Monte Carlo simulations should be conducted to evaluate precision of the VPA.

- The feasibility of estimating year class strength using biologically stratified sampling design should be evaluated. These efforts could be supported by process studies linking plankton production to abundance of young menhaden.

- Alternative measures of effort, including spotter pilot logbooks, trip length, or other variables, should be evaluated. Spotter pilot logbooks should be evaluated for spotter plane search time, GPS coordinates, and estimates of school sizes observed by the pilots.

**Advisory Report for the**
**Atlantic Menhaden Peer Review**

## State of Stock

Indicators of recruitment from the VPA and fishery independent data from Maryland and Virginia show consistent declining trends from 1990 to the present (Figures 1 and 2). Levels of current recruitment are in the lower quartiles of historical times series for these indices. Potential causes of declines in abundance of 1-year old menhaden may include reduced spawning stock biomass, unfavorable oceanographic or juvenile nursery conditions, and predation on larval and juvenile menhaden. Results of the VPA suggest that low recruitment is not necessarily the result of reduced spawning stock, since recent estimates of spawning stock biomass are relatively high (Figure 3). Recruitment time series (Virginia and Maryland juvenile seine survey data, and VPA recruitment indices) show strong autocorrelation (Figure 2), indicating that recruitment may be affected by decadal scale changes. Because recruitment in any given year is autocorrelated with recruitment in adjacent years, the current trend of declining recruitment is likely to persist in the near future. The consistent decline in recruitment over the last eight years should result in declining population abundance and spawning stock in the coming years. Evidence from fisheries dependent sources strongly suggest that the stock range has contracted from the northern and southern extent of its range in the last few years.

## Management Advice

The Panel recommends the development of a quota based management system for Atlantic menhaden. The annual total allowable catch should be allocated by season and fishing areas. Fishing levels should be determined by a fishing control rule that can respond to changes in relevant biological reference points. The fishing control rule should include specification of fishing levels at high and low stock size and consideration of the nature of menhaden life history (i.e., measures to control harvest by age). See Terms of Reference #2 and #4 for further recommendations on the fishing control rule.

The Panel recommends that biological reference points based upon recruitment and spawning stock status be developed. These references points should result in risk-averse management decisions which preserve spawning stock and increase the likelihood of favorable recruitment. Alternative stock assessments such as dynamic pool (yield-per-recruit) and surplus production models should be used in addition to the VPA to establish threshold F values which consider the need for stock rebuilding (e.g. SSB per recruit), increased yield to the fishery (e.g. yield per recruit, surplus production), and the ecological role of menhaden (allocation of natural mortality versus fishing mortality).

The Panel believes that future stock assessments would benefit from a greater diversity of scientific participants and input. This should result in increased sources of auxiliary data to

support stock assessments, fine tuning of the assessment, and corroboration of stock assessment findings. Increased scientific input is also needed to address menhaden=s critical ecological role. To facilitate increased scientific input, the Panel recommends that the current mixed advisory-scientific committee (AMAC) be dissolve and reconstituted into separate technical and advisory committees.

**Stock Identification and Distribution**

Atlantic menhaden are found in the continental waters of North America from Nova Scotia to central Florida. Spawning occurs in the ocean, while larvae and juveniles utilize coastal estuaries. Atlantic menhaden undergo extensive seasonal migrations north and south along the United States east coast. Based on tagging studies, the Atlantic menhaden fishery is believed to exploit a single stock or population of fish.

**Management Unit**

The management unit for Atlantic menhaden is the Atlantic coastal and estuarine waters from Maine through Florida.

**Fishery Description**

Atlantic menhaden have supported one of the United States= largest fisheries since colonial times. Native Americans were the first to harvest menhaden, primarily as fertilizer. During the 1940s, the primary use associated with harvest changed to high protein animal feeds and oil production. Following World War II, the industry grew rapidly, reaching peak production during 1953-62. Sharp declines in landings thereafter resulted in factory closings and fleet reductions through the 1960s and into the early 1970s. In 1955, 24 reduction plants operated on the Atlantic coast, with a decline to only two plants in 1998. Since the 1970s, the menhaden industry has experienced major changes in fishery efficiency, processing capacity, resource accessibility, and development of new product markets.

The Atlantic menhaden fishery consists of two components -- the reduction fishery and the bait fishery. The reduction fishery includes boilers for rendering raw fish and presses for removing oil. Oil was initially used for fuel and industrial processes, while the remaining solids (scrap) were used for fertilizer. Menhaden are taken as bait in almost all Atlantic coast states and are used for bait in crab pots, lobster pots, and hook-and-line fisheries (both recreational and commercial).

**Landings**

Landings and nominal effort for the reduction fishery (measured as number of weeks a vessel unloaded during the fishing year, vessel-weeks) are available since 1940 (Figure 4). Landings rose during the 1940s (from 167,000 to 367,000 mt), peaking during the 1950s (high of 712,00 mt in 1956), and then declined to low levels during the 1960s (from 576,000 mt in 1961 to 162,000 mt in 1969). During the 1970s the stock rebuilt (landings rose from 250,000 mt in 1971 to 376,000 mt in 1979), and then maintained intermediate levels during the 1980s (varying between 238,000 mt in 1986 to 402,000 mt in 1981). Landings during the 1990s have varied between 259,000 mt in 1997 and 401,000 mt in 1990.

The current levels of bait landings are conservatively estimated at 10% of the total Atlantic harvest on an annual basis for the period 1985 through 1997 (Table1 - copy Table 5.1).

**Data and Assessment**

Landings of the reduction fishery have been reported from processing plants and sampled each week for length, weight and age since 1955. Landings of the Atlantic menhaden bait fishery have been summarized for the period 1985-1997. A constant natural mortality rate (M) of 0.45, measured from tagging studies, was used in the VPA assessment. A catch-at-age matrix was compiled from reduction and bait fisheries data. Landings data, catch-at-age matrix, and natural mortality rate were used as inputs to a Murphy VPA analysis to estimate the number of recruits to age-1, SSB, and %MSP. Although four larval indices were analyzed for use as tuning indices, past assessments have used a non-calibrated VPA. See Term of Reference #1 for more details and Panel recommendations.

**Biological Reference Points**

An explicit overfishing definition for Atlantic menhaden has not been defined. However, based on a set of six Atrigger@ variables, stock status is evaluated annually. Three of these variables are taken directly from the reduction fishery landings and three are generated from a VPA. The six variables are considered as thresholds which, when met, call for specific management board consideration of probable causes for reaching that point and determination of whether or not regulatory action is warranted. Ancillary information will also be evaluated by the Atlantic Menhaden Management Board in determining appropriate responses. See Term of Reference #3 for more details and Panel recommendations.

**Fishing Mortality**

Short-term losses to the Atlantic menhaden stock due to the fishery can be assessed by considering the exploitation rate (Figure 5), which is the fraction of the remaining stock removed by the fishery during some specified period of time (usually 1 year). For the period

1955 through 1997, the exploitation rate for age 1-8 menhaden has remained stable at approximately 0.3 to 0.5.

**Recruitment / Spawning Stock**

Indicators of recruitment from the VPA and fishery independent data from Maryland and Virginia show consistent declining trends from 1990 to the present. Levels of current recruitment are in the lower quartiles of historical time series for these indices. The VPA assessment suggests that low recruitment is not necessarily the result of reduced spawning stock, since recent SSB is estimated to be relatively high. See Term of Reference #3 for more details and Panel recommendations.

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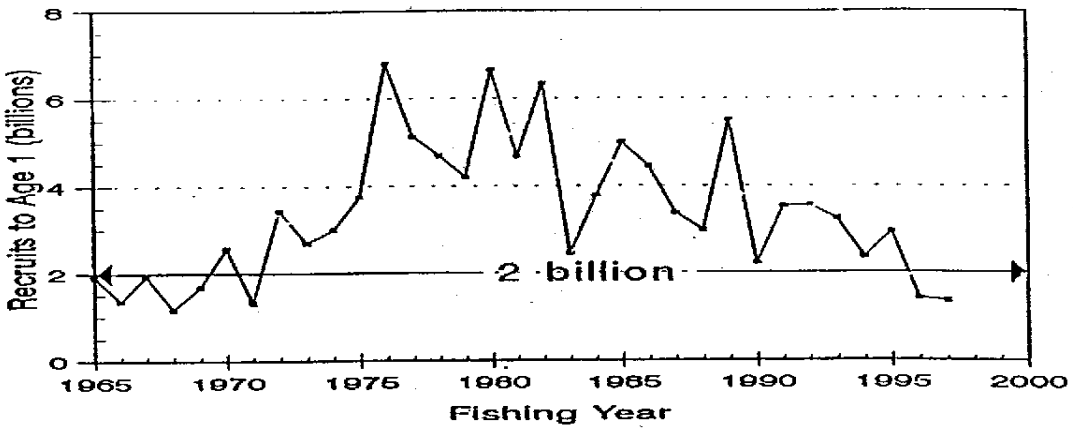


**Figure 1.** Atlantic menhaden recruits to age-1, temporal trend, 1965-1990.

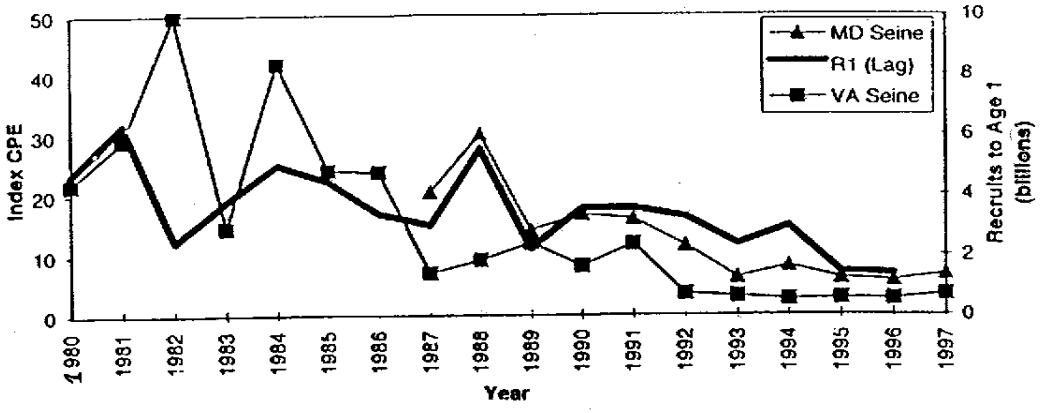


**Figure 2.** Chesapeake Bay seine survey CPE vs. lagged age-1 menhaden recruits.

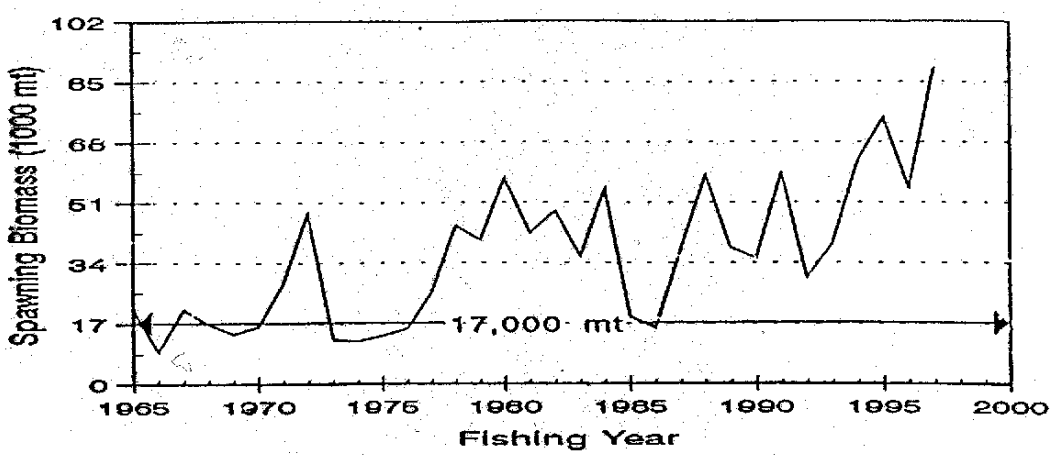


**Figure 3.** Atlantic menhaden female spawning biomass, temporal trend, 1965-1990.

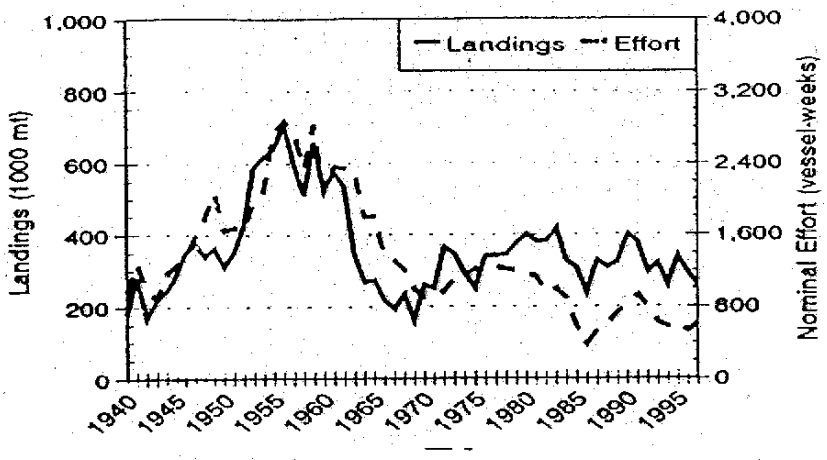


**Figure 4.** Atlantic menhaden landings and nominal effort, 1940-1998.

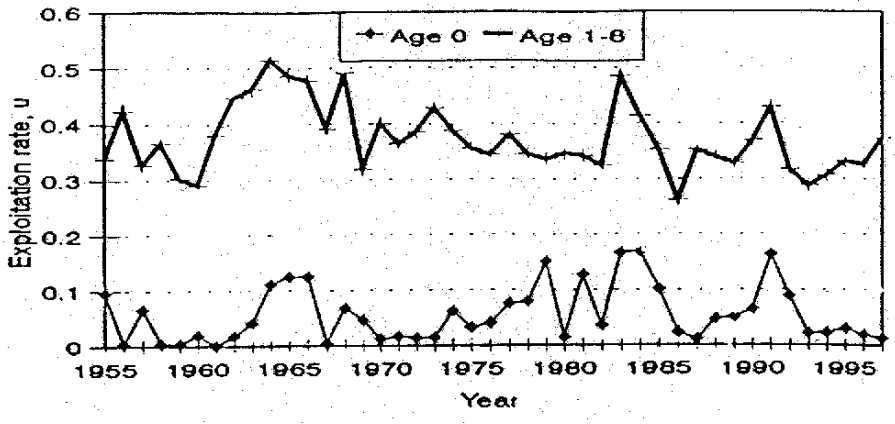


**Figure 5.** Exploitation rates for age 0 and age 1-8 Atlantic menhaden, 1955-1998.