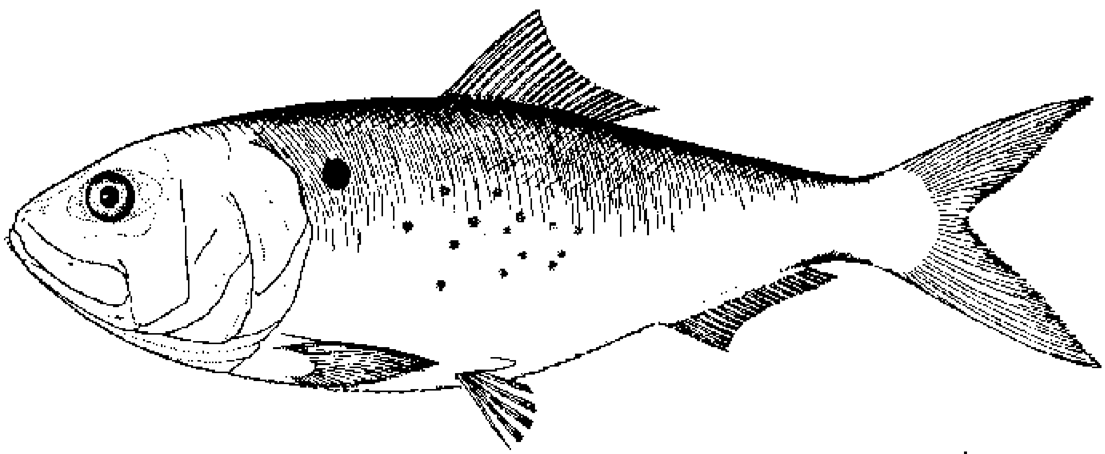
Stock Assessment Report No. 99-01 (Supplement)
of the

Atlantic States Marine Fisheries Commission

Atlantic Menhaden Stock Assessment Report for 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. In particular, the Commission appreciates the hard work of Dr. Joseph Desfosse, Geoffrey White, Dr. Douglas Vaughan, and Joseph Smith in the preparation of this stock assessment report for 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 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 Bay Laboratory), Karl Blankenship (Bay Journal), Peter Tango (Maryland Department of Natural Resources), Mike Armstrong (Masscahusetts 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 – Dr. Joseph Desfosse, Geoffrey White, Dr. Lisa Kline, Tina Berger, and Vanessa Jones.

EXECUTIVE SUMMARY

The "Atlantic Menhaden Fishery Management Plan, 1992 Revision" was prepared by the Atlantic Menhaden Advisory Committee (AMAC) under the Interstate Fisheries Management Program (ISFMP) of the Atlantic States Marine Fisheries Commission (Commission). The 1992 revision replaced the Commission's 1981 menhaden plan, which had been rendered obsolete by significant changes in the Atlantic menhaden stock and fishery.

In April, 1998, the Commission's ISFMP Policy Board called for a peer review of the Atlantic menhaden stock assessment. In addition to the stock assessment, the Peer Review Panel was tasked with addressing menhaden as a forage fish for many other coastal species, as well as evaluate the trigger mechanisms contained in the Commission's fishery management plan. This document served as the primary source document for the Peer Review Panel.

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

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 uses steam to cook the raw fish, presses to remove liquid from the cooked fish, and centrifuges to separate oil from water in the liquid fraction. The pressed fish is dried, milled and sold as fish meal. Fish oil is a significant ingredient in high quality aquaculture feeds and pet foods, as well as being used in the production of paints and cosmetics. Fish soluables, the water-fraction of the processing, are often recombined with the fish meal to form an 'enriched' meal. 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).

An explicit overfishing definition for Atlantic menhaden has not been defined. However, based on a set of six "trigger" 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.

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. 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.

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 stock assessment model. 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, Spawning Stock Biomass, and Percent Maximum Spawning Potential (%MSP). Although four larval indices were analyzed for use as tuning indices, past assessments have used a non-calibrated VPA.

Short-term losses to the Atlantic menhaden stock due to the fishery can be assessed by considering the exploitation rate, 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.

Recruits to age-1 in 1996 and 1997 resulted in values below the threshold. The other trigger that fired was the proportion of adults (age 3+) in the landings; however, this firing confirms recent poor recruitment and is not an additional source of concern. The three-year running average (1.9 billion fish) of age-1 menhaden is below the threshold. Further, there has been a downward trend in recruitment since 1985, as noted last year (AMAC 1997). Nonetheless, spawning stock has continued to grow and is at its highest level since 1962, indicating that fishing pressure is not the cause of low recruitment. In fact, there is some linkage in the historical database between very high spawning stock biomass and depressed recruitment values. Historical data collected since 1955 indicate that environmental factors are more influential in controlling menhaden recruitment success than spawning stock biomass. While the spawning stock is currently healthy, spawning stock biomass will decline over the next few years unless the trend in recruitment is reversed. There has also been a general decline in stock size (numbers and biomass) during this decade, concurrent with the decline in recruitment.

Because of company consolidation, the 1998 Virginia fleet was reduced by 35% (from 20 to 13 vessels). Processed harvest, based on an analysis of recent individual vessel performance, should be reduced by about 30% in 1998. A potential limiting factor will be the processing capacity of the remaining Virginia reduction plant.

Concern has been expressed by some members of the public for apparent reductions in the forage base in the Chesapeake Bay region. In addition to reductions in menhaden recruitment, those individuals (representing the Chesapeake Bay Acid Rain Foundation, the Sustainable Development Institute, and the Coastal Conservation Association - Maryland and Virginia) indicated that bay anchovies and silversides, which are not subject to fisheries harvest, have also declined in abundance. The status of forage species in other estuarine areas is unknown.

Based on an overall examination of stock and fishery information, AMAC concluded that there is more than sufficient Atlantic menhaden spawning stock to produce adequate recruitment. Recent poor recruitment is unrelated to fishing effort. The AMAC recommended no additional restrictions to the fishery (in 1998, ed.).

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 in 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 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 CPUE) 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 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 "trigger 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 ("fishery 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 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;**
- **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 (VA and MD 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 VA and NC 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 NC 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. NMFS 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.

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1.0 INTRODUCTION

The "Atlantic Menhaden Fishery Management Plan, 1992 Revision" was prepared by the Atlantic Menhaden Advisory Committee (AMAC) under the Interstate Fisheries Management Program (ISFMP) of the Atlantic States Marine Fisheries Commission (Commission). This revision replaced the Commission's 1981 menhaden plan, which had been rendered obsolete by significant changes in the Atlantic menhaden stock and fishery.

The original Atlantic menhaden fishery management plan (FMP) was prepared during 1976-1981 (AMMB 1981) and approved by the Atlantic States Marine Fisheries Commission (Commission) in October, 1981. This plan did not recommend any specific management measures, but provided a discussion of options, should they be needed. In 1982, the Atlantic Menhaden Management Board (AMMB) recommended seasonal limits as a means to provide long-term benefits to the fishery. The recommendation was approved by the Commission and referred to the states for implementation. Full implementation was not achieved. Changes in operation of the ISFMP, of which the menhaden program is a component, resulted in disbanding the AMMB during the mid-1980s. Oversight for the menhaden program passed to the ISFMP Policy Board, which was concerned with numerous fishery management plans (FMPs) in addition to menhaden.

A number of developments in the late 1980s greatly affected the Atlantic menhaden fishery, resulting in the need to amend the 1981 FMP. The most important of these developments included the following:

1. The Atlantic menhaden stock progressed toward recovery from a severely depressed condition during the mid 1960s-mid 1970s to the point where it was considered healthy in the early 1990s. There was an improved spawning stock biomass, good recruitment, and improved age structure. Heavy fishing continued throughout this period of recovery, although at a less intensive level.

2. Most Atlantic menhaden processing plants operating in 1981 were closed by 1988. Of 11 plants which processed menhaden along the United States Atlantic coast in 1981, only two are still in business. Closures were related to international market conditions which affect the prices of menhaden products, as well as to localized social problems involving menhaden processing plants and neighboring residential areas. Thus, the processing sector of the industry has changed significantly in the last few years.

3. In 1987, a Canadian plant began processing menhaden caught by United States vessels in the Gulf of Maine, the first direct foreign use of menhaden as a raw product.

4. In 1988, a Maine company contracted with the Soviet Union to conduct an Internal Waters Processing (IWP) venture in the Gulf of Maine under Section 306 of the Magnuson Fishery Conservation and Management Act of 1976. About 7-10 small purse-seine vessels supplied raw product to the Russian factory processing ship anchored within the internal territorial waters of the State of Maine. The IWP provisions of the Magnuson Act opened new harvesting and processing opportunities which were not considered in the original FMP.

5. Research on specialty meals for aquaculture, the use of menhaden oil for human food and medicinal products in the United States, and potential production of surimi from fresh menhaden gave promise for development of diversified products and markets for the menhaden industry.

In light of these and other social and economic developments, the Commission determined in 1988 that the 1981 menhaden FMP was no longer sufficient to guide management of the fishery and authorized preparation of a revision to the plan.

The goal of the 1992 plan revision is *To manage the menhaden fishery in a manner that is biologically, economically, and socially sound, while protecting the resource and its users*. Plan objectives include public education; continuation of the existing fishery monitoring program; improvement in collection of data on menhaden taken in directed bait fisheries, and as bycatch in other fisheries; improvement of the Captains Daily Fishing Report program; promotion of needed research on biological, economic, sociological, and habitat issues; encouragement of product research; maintenance of an adequate stock; optimal utilization of the available resource; habitat maintenance and enhancement; and utilization of the best available scientific data as the basis for coordinated management actions.

Regulatory authority over the Atlantic menhaden fishery is vested in the coastal states rather than the federal government. The vast majority of the harvest occurs in waters under state jurisdiction.

The menhaden program functions under the ISFMP, with direction provided by the Atlantic Menhaden Management Board, composed of up to five state directors, up to five industry representatives, one National Marine Fisheries Service member, and one representative from the National Fish Meal and Oil Association. In 1997, the Policy Board approved the addition of four members to the Menhaden Board, one Legislator's and one Governor's Appointee, and two public representatives. The Menhaden Board designates the members of AMAC, the technical committee which conducts the analytical activities for the program.

Members of AMAC have expertise in menhaden life history, fishing, processing, and population dynamics. Each spring, AMAC conducts three specific tasks: 1) review of the status of the stock and fishery relative to six defined "triggers" [landings, proportion of age-0 fish in the catch, proportion of adults (age 3^{+}) in the catch, recruitment to age 1, spawning stock biomass, and percent maximum spawning potential]; 2) review of state applications for allocation of menhaden for harvest under internal waters processing (IWP) arrangements as provided in Section 306 of the Magnuson Fishery Conservation and Management Act (PL 94-265); and 3) review of implementation status of the plan, including any recommendations for regulatory action.

The menhaden spawning stock is currently healthy, although there has been a decline in recruitment over the last ten years. Spawning stock biomass is currently high, but is expected to decline over the next few years unless the trend in recruitment is reversed. There has also been a general decline in the stock size (numbers and biomass) this time, concurrent with the decline in recruitment. The most recent estimates of maximum sustainable yield are about 480,000 metric tons. Research indicates that undefined environmental conditions probably are more important in determining reproductive success than spawning stock size, although there is a weak spawner-recruit relationship.

Atlantic menhaden are distributed along the Atlantic coast from Florida to Nova Scotia. Spawning occurs over much of the species' range, with a peak off North Carolina during late fall and winter. Menhaden are estuarine-dependent, utilizing coastal estuaries from Florida through southern New England as nursery areas. Young fish join the coastal migration late in their first year of life. After their first year, menhaden migrate along the Atlantic coast, with older, larger fish moving farthest north each spring and summer. Most fish migrate to the North Carolina area each fall and early winter.

Menhaden are primary consumers as adults, transforming phytoplankton into animal protein. They, in turn, serve as prey for many fish-eating fish, sea birds, and marine mammals, as do many other species of fish, including anchovies, herring, sardines, sand lance, and the young of most other fishes.

More Atlantic menhaden are landed annually along the Atlantic coast than any other fish species. Landings remained fairly consistent during 1982-91, averaging about 341,000 metric tons, but have averaged only 295,000 mt since. Landings have been considerably less than during the peak years of the fishery because of changes in fishing areas (most fishing is now in Chesapeake Bay rather than the mid-Atlantic), reduced fleet size, fewer processing facilities, increased regulatory restrictions, and smaller mean weight-at-age since the mid-1970s. Bait landings have added about 30,000 metric tons annually in recent years.

Atlantic menhaden have been harvested since colonial times, when they were used for fertilizer. Oil recovery began in the early 1800s. With introduction of the purse seine in the 1850s, large-scale fisheries were established. Oil was used for industrial purposes, and "scrap" (dried fish) was used for fertilizer. By World War II, the primary product of the industry had changed from scrap to production of high protein fish meal for poultry and swine feeds, the major contemporary uses.

Bycatch (or incidental catch) of other fishes in menhaden purse seines has been examined repeatedly since the late 1800s. Taking of non-target species is a relatively rare event, and the overall bycatch is insignificant.

During the 1980s, processing plants in the fishery declined from nine to five. In addition to two plants in Virginia and one in North Carolina, during the late 1980s and early 1990s, up to three Russian factory ships processed Atlantic menhaden caught in Maine's territorial waters. Two Canadian factories, one in New Brunswick and one in Nova Scotia, also processed menhaden from southern Maine during that period. No menhaden have been processed for reduction in the Gulf of Maine since 1993. Presently, only two plants remain on the Atlantic seaboard, one in Virginia with 13 vessels, and one in North Carolina with two vessels.

Employment in the industry presently includes about 200-250 and an equal number in the processing sector. Only 15 large vessels, up to 180 ft long, remain in the [Mid-Atlantic] fishery.

In summary, the stock is healthy, and the management system in place is adequate to meet the goal of this plan and guide the fishery for the near future. The annual AMAC review ensures that status of the stock and fishery are monitored. Should trigger values be exceeded, action will be recommended by AMAC to the Board. No regulatory action beyond those rules currently in existence are recommended at the present time.

2.0 LIFE HISTORY

2.1 Species Distribution

Atlantic menhaden are found in the continental waters of North America from Nova Scotia to central Florida. They have been taken in commercial quantities from northern Florida to southern Maine. A few individuals have been taken as far north as St. John, New Brunswick, and St. Mary Bay, Nova Scotia. The southern limit seems to be Indian River City, Florida (Hildebrand 1963). Spawning occurs in the ocean, while larvae and juveniles utilize coastal estuaries.

2.2 Migration

Adult Atlantic menhaden undergo extensive seasonal migrations north and south along the United States East Coast. Early reports of this migratory behavior were made by Roithmayr (1963) based on the decrease in the number of purse seine sets north of Cape Cod in September. Also, Reintjes (1959) observed the disappearance of fish in October north of Chesapeake Bay and their appearance off the coast of North Carolina in November. Nicholson (1971) examined latitudinal differences in length-frequency distributions of individual age groups at different times of year and described 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 summer. A study of length frequencies at the time of first annulus formation on scales (Nicholson 1972) supported the concept of a north-south migratory movement and also indicated that a great deal of mixing of fish from all areas occurs off the North Carolina coast before fish move northward in spring.

Returns of tagged Atlantic menhaden (Dryfoos et al. 1973, Nicholson 1978) have generally confirmed what was already concluded from earlier work and added some important details. 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 the 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 Chesapeake Bay moves south around Cape Hatteras.

2.3 Reproduction

Most Atlantic menhaden reach sexual maturity during their third year of life (late age 2) at lengths of 180 - 230 mm fork length (FL). Spawning occurs year-round throughout much of the species' range, with maximum spawning off the North Carolina coast during late fall and winter. Small females produce less than 100,000 eggs, while large females are capable of producing nearly 400,000 eggs.

2.3.1 Age and Size at Maturity

Some Atlantic menhaden become sexually mature during their second year (late age 1), but most do not mature until their third year (late age 2) (Higham and Nicholson 1964; Lewis et al. 1987). Spawning occurs primarily in late fall and winter (See 2.3.3). Thus, most Atlantic menhaden spawn for the first time at age 2 or 3, i.e., just before or after their third birthday (by convention, on March 1), and continue spawning every year until death. First-spawning age-3 fish have accounted for most of the stock's egg production since 1965 (Vaughan and Smith 1988). Atlantic menhaden mature at smaller sizes at the southern end of their range (180 mm FL in the south Atlantic region versus 210 mm FL in the Chesapeake Bay area and 230 mm in the north and middle Atlantic regions - Lewis et al. 1987) because of latitudinal differences in size-at-age (See 2.6) and the fact that larger fish of a given age mature earlier.

2.3.2 Fecundity

Atlantic menhaden are relatively prolific spawners. Predicted fecundities range from 38,000 eggs for a small female (180 mm FL) to 362,000 for a large female (330 mm FL) according to an equation derived by Lewis et al. (1987):

$$\text{number of eggs} = 2563 * e^{0.015*FL}.$$

This equation was derived by fitting an exponential model to length-specific fecundity data for fish collected in 1978, 1979 and 1981, as well as data reported in two earlier studies (Higham and Nicholson 1964; Dietrich 1979) for fish collected during 1956-1959 and in 1970. Fish in all three studies were collected from the North Carolina fall fishery.

2.3.3 Spawning Times and Locations

Analysis of eggs and larvae collected at various locations along the Atlantic coast during 1953-75 (e.g., Judy and Lewis 1983) generally confirmed earlier knowledge of spawning times and locations based on observations of adults with maturing or spent ovaries (e.g., Reintjes and Pacheco 1966). During December-March, most spawning-age fish congregate in offshore waters south of Cape Hatteras. Maximum spawning probably occurs at this time. Checkley et al. (1988) reported maximum spawning off North Carolina in January 1986 during periods of strong northeast winds in up-welled water near the western edge of the Gulf Stream. Spawning continues at a decreasing rate closer inshore as fish migrate north in late March. By May, most spawning is restricted to coastal waters north of Cape Hatteras. Spawning reaches a minimum in June, but continues at a low level until September north of Long Island. As mature fish migrate south in October, spawning increases from Long Island to Virginia.

The capture of a 138 mm juvenile Atlantic menhaden in an estuary on the Maine coast in October 1990 (T. Creaser, Maine Dept. Marine Resources, pers. comm.) suggests that a limited amount of spawning may occur as far north as the Gulf of Maine. Some ripening female menhaden were offloaded on to the Soviet processing ship near Portland, Maine in August and September 1991 (Steve Young, Maine Dept. Marine Resources observer on the M/V RIGA, pers. comm.). Egg and larval surveys have been entirely restricted to waters south of Cape Cod (Judy and Lewis 1983) and, thus, would not have produced any evidence for spawning in the Gulf of Maine.

2.4 Early Life History Stages

2.4.1 Eggs

Atlantic menhaden produce pelagic eggs about 1.5 mm in diameter which hatch within 2.5-2.9 days at an average temperature of 15.5EC (Hettler 1981). Embryonic development is completed in <36 hr at 20-25EC, but takes about 200 hr at 10EC (Ferraro 1980). Egg mortalities observed in the laboratory were >90% at 10EC, and 48-92% at 15, 20 and 25EC (Ferraro 1980).

2.4.2 Larvae and Juveniles

A full morphological description of Atlantic menhaden eggs and larvae is provided by Jones et al. (1978). Hettler (1984) compared Atlantic menhaden (*Brevoortia tyrannus*) larvae with gulf and yellowfin menhaden (*B. patronus* and *B. smithi*) larvae. Atlantic menhaden larvae co-occur with yellowfin menhaden larvae along the east coast of Florida to North Carolina, but not with gulf menhaden. A fourth species (*B. gunteri*) occurs exclusively in the Gulf of Mexico. Powell and Phonlor (1986) also compared early life history characteristics of Atlantic and gulf menhaden.

Yolk-sac larvae hatched at 3-4 mm standard length (SL) and maintained at 16E and 24EC began to feed at 4.5-5 mm SL (Powell and Phonlor 1986). First feeding was a function of size, not age. Larvae raised at 16EC began feeding after 5 days, while larvae raised at 24EC began feeding after only 2 days. Larvae reached 10.7 mm SL after 21 days at 20EC. Caudal and dorsal fins developed at 9 mm, and all fin rays were developed by 23 mm (Reintjes 1969). The swimbladder and acoustico-lateralis system become functional in larvae measuring approximately 20 mm (Hoss and Blaxter 1982).

Low temperatures (<3EC for >2 days) killed most larvae held in laboratory experiments (Lewis 1965, 1966), although mortality depended on acclimation temperature and the rate of thermal change. Best survival occurred at temperatures >4EC and salinities of 10-20‰.

Larvae which hatch offshore are transported shoreward and enter estuaries in the south Atlantic region after 1-3 months at sea (Reintjes 1961) at a size of 14-34 mm FL (Reintjes and Pacheco 1966). Larval migration into estuaries occurs during May-October in the north Atlantic region, October-June in the mid-Atlantic, and December-May in the south Atlantic (Reintjes and Pacheco 1966). Larval condition improved rapidly after fish entered two North Carolina inlets (Lewis and Mann 1971).

Metamorphosis to the juvenile stage occurs at about 38 mm total length (TL) during late April-May in North Carolina estuaries and later in the year farther north. Most larvae entered the White Oak estuary (North Carolina) in March and moved upstream to a fresh water-low salinity zone where they transformed into "pre-juveniles" in late March-April and then into juveniles in late April-May (Wilkens and Lewis 1971). Other studies (Weinstein 1979, Weinstein et al. 1980, Rogers et al. 1984) also show young menhaden are more abundant in shallow, low salinity (< 5‰) estuarine zones. Metamorphosis to the "pre-juvenile" stage occurs at lengths >30 mm TL and to the juvenile stage beyond 38 mm TL (Lewis et al. 1972). Metamorphosis is rarely successful outside of the low-salinity estuarine zone (Kroger et al. 1974), although Atlantic menhaden have been successfully reared from eggs to juveniles in high salinity water (Hettler 1981).

The morphological changes that occur at metamorphosis are associated with a change in feeding behavior. Larvae feed on individual zooplankters, whereas juveniles rely more heavily on filter feeding (June and Carlson 1971, Durbin and Durbin 1975). This shift in feeding behavior is associated with a loss of teeth and an increase in the number and complexity of the gill rakers through which sea water is filtered as it passes through the gills. Older larvae (25-32 mm) feed on large copepods, but only rarely on small zooplanktonic organisms (Kjelson et al. 1975). Fish larger than 40 mm FL feed primarily on phytoplankton (June and Carlson 1971), but zooplankton has also been reported as an equally important food source in juvenile Atlantic menhaden (Richards 1963, Jeffries 1975). Juveniles are capable of filtering particles as small as 7-9 microns (Friedland et al. 1984) and, thus, directly utilize the abundant small photosynthetic organisms that are not consumed by most other species of fish. Detritus derived from salt marsh cordgrass (*Spartina alterniflora*) has also been reported as a primary food source for juveniles in North Carolina salt marshes (Lewis and Peters 1984). Based on calculations incorporating feeding rates and population estimates from eight east coast estuaries, Peters and Schaaf (1981) concluded that juveniles must consume more food during estuarine residency than is available from a strictly phytoplankton-based food chain.

Young-of-the-year menhaden congregate in dense schools as they leave shallow, estuarine waters for the ocean, principally during August to November (earliest in the north Atlantic region) at lengths of 75-110 mm TL (Nicholson 1978). Many of these juveniles migrate south along the North Carolina coast as far as Florida in late fall and early winter and then redistribute northward by size as age-1 fish during the following spring and summer (Kroger and Guthrie 1973, Nicholson 1978). Larvae which enter the estuaries late in the season may remain there for an additional year and emigrate to the ocean at age 1.

Age-1 menhaden migrate north and south along the coast over a greater distance than young-of-the-year juveniles (Nicholson 1978). Abundance and distribution of juvenile Atlantic menhaden is monitored by the marine resource agencies of most Atlantic coast states under a variety of estuarine surveys using trawls and seines. According to a survey conducted by AMAC in February 1990, juvenile menhaden have been taken in recent years from Massachusetts to Georgia. (There is no survey on the Atlantic coast of Florida.) As noted above, a juvenile menhaden was taken in Maine estuarine waters in October, 1990.

Juveniles collected at 2-3 day intervals have shown growth rates of nearly 1 mm/day (Reintjes 1969). Water temperatures >33EC caused death in young-of-the-year and age-1 Atlantic menhaden (Lewis and Hettler 1968), although the time until death depended, in part, on acclimation factors. Sudden exposure to lethal temperatures, for example, caused greater mortality. Juvenile Atlantic menhaden can adjust rapidly to abrupt changes (increase or decrease) in salinity from 3.5 to 35‰ and vice-versa (Engel et al. 1987). Juveniles raised in low salinity water (5-10‰) were more active, ate more, had higher metabolic rates, and grew faster than juveniles raised in high salinity water (28-34‰) (Hettler 1976).

2.5 Adults

Adult Atlantic menhaden are strictly filter feeders, grazing on planktonic organisms. They can be observed swimming slowly in circles, in tightly packed schools, with their mouths wide open and their opercula (gill flaps) flaring. In lab experiments (Durbin and Durbin 1975), they fed on small adult copepods as well as phytoplankton. Organisms smaller than 13-16 microns (slightly larger than the minimum size reported by Friedland et al. (1984) for juveniles) were not retained in the gills. Menhaden did not feed on large zooplankton (10 mm brine shrimp) in these experiments. The filtering process is purely mechanical; particles are not selected by size (Durbin and Durbin 1975). These experiments showed that the filtering rate depended on mouth size, swimming speed, food particle concentration, and the mechanical efficiency of the gill rakers. The structure of the "branchial basket," the area underneath the opercula where the extremely fine and closely-spaced gill filaments and gill rakers are located, was described in detail by Friedland (1985).

Growth occurs primarily during the warmer months. Fish as old as age 8 were fairly common during the 1950s and early 1960s, but in more recent years, fish older than age 6 have been rare. Older (age 6) fish reach an average length of 330 mm FL and a weight of 630 g, although growth varies from year to year and is inversely density-dependent. (Growth rates are accelerated during the first year when juvenile population size is low and are reduced when juvenile population size is high.)

Natural mortality removes an estimated 30% of the exploited population at age 1 and 20% each year thereafter. Most natural mortality is probably caused by predation and disease. Another source of natural mortality is de-oxygenation of shallow inshore waters caused by the fish themselves when they form dense schools in such areas. Recently, the effects of fungal infestations and a toxic dinoflagellate have been reported to either directly cause mortality or contribute to it by weakening fish and making them more susceptible to other diseases or predation. Menhaden are preyed upon heavily by a variety of marine and estuarine fish species, marine mammals, and sea birds. Coastal pollution and habitat degradation threaten marine fish species, such as Atlantic menhaden, which spend their first year of life in estuarine waters and the rest of their life in both ocean and estuarine waters.

Adults migrate extensively along the entire United States East Coast. Following winter dispersal along the south Atlantic coast, adults begin migrating north in early spring, reaching as far north as the Gulf of Maine in June. Older and larger fish migrate farther than younger, smaller fish. The return southern migration occurs in late fall.

2.6 Growth

The growing season begins in the spring and ends in the fall as water temperatures rise above and fall below 15EC (Kroger et al. 1974). Atlantic menhaden reach lengths of about 500 mm TL and weights of over 1.5 kg (Cooper 1965). Fish as old as age 8 were fairly common in the spawning population during the 1950s and early 1960s, but fish older than age 6 have been rare in recent years (Vaughan and Smith 1988). Smith and O'Bier (1996) recently described an exceptionally large (433 mm FL; 1,551 g) Atlantic menhaden from Chesapeake Bay taken in August 1996.

Due to their greater migratory range (See section 2.2), larger fish of a given age are captured farther north than smaller fish of the same age (Nicholson 1978, Reish et al. 1985). This fact complicates any attempt to estimate overall growth for the entire stock from size-at-age data compiled from any individual area along the coast. To solve this problem, Vaughan and Smith (1988) generated weighted averages of mean lengths at age for five fishing areas along the coast and used these averages to estimate growth parameters for the 1955-1981 year classes.

Average estimates of the three parameters required by the von Bertalanffy growth equation were derived for 23 year classes during 1955-1981 and used to determine lengths at age for age 1-6 fish[1]. These estimated lengths generally describe the expected sizes for an average year class over the entire coast, ignoring variations in growth that occur over time (See below). These length estimates were then used to estimate the corresponding weights at age using the weight-length regression equation and parameter values given in Vaughan and Smith (1988).

Estimated fork lengths and weights for ages 1-6 were as follows:

Age	Fork length (mm)	Weight (g)
1	141.6	42.5
2	214.9	161.5
3	262.9	307.9
4	294.3	441.7
5	314.8	547.9
6	328.3	626.8

These estimated sizes at age are very similar to those estimated by C.E. Richards (Virginia Institute of

[1] *Growth parameters estimated by Vaughan and Smith (1988) for the 1965 and 1979-1981 year classes were biologically unrealistic and were therefore omitted when averaging values over the entire time period. Parameter estimates used to calculate lengths at ages 1-6 were:* L_{inf} *= 353.7 mm FL, K = 0.424, and* t_o *= -0.2056 years.*

Marine Science, pers. comm.) as reported in Reintjes 1969) for fish collected from the North Carolina fall fishery. They do not differentiate between male and female fish. As the fish mature, females can be expected to attain weights about 50 g heavier, on average, than males of the same age (Reintjes 1969).

There is evidence for density-dependent growth in Atlantic menhaden, at least in young fish. Comparison of annual weights at age for age-1, -2, and -3 fish and age-1^+ population size estimates for the 1955-84 period (Vaughan and Smith 1988) indicates an inverse relationship between the two parameters, suggesting that growth was accelerated during the late 1960s in response to low population size and reduced during the mid-1970s and early 1980s when population size was high. The reduction in mean weight at age 3 was particularly dramatic, declining 60% between 1976 and 1978 and remaining low through 1984. However, Reish at al. (1985) demonstrated that the growth rates of fish after recruitment in their first year of life was not correlated with abundance, but did depend on size at recruitment, indicating that fish probably recruited at smaller sizes in years of high juvenile population size and vice-versa. Thus, density-dependent effects probably occur during the estuarine nursery period. Negative correlations between the mean lengths of age 0.5 and 0.75 fish and the number of recruits at age 0.5 (Vaughan and Smith 1988) support this hypothesis. The observed decline in sizes at age in the fishery is also due in part to a shift in fishing to the south where smaller fish at a given age are found (Vaughan and Smith 1988).

2.7 Natural Mortality

The Atlantic menhaden population is subject to a high natural mortality rate. There is a somewhat reduced probability of death from natural causes when the population is being harvested. Natural mortality is also higher during the first two years of life than during subsequent years. Ahrenholz et al. (1987a) reported an annual instantaneous natural mortality rate (M) of 0.45 in the absence of fishing; this rate is equivalent to an annual reduction in population numbers of 36%. This rate is quite high compared to other pelagic marine species. Atlantic herring, for example, is characterized by an 18% annual natural mortality rate (Fogarty et al. 1989). During the 1955-1987 period, under exploitation, the annual natural mortality rate for age-1 Atlantic menhaden was 30% and, for ages 2 and older, it was 20% [see section 2.9.2 and Vaughan (1990)].

Menhaden natural mortality is probably due primarily to predation, since the fish are so abundant in coastal waters during the warmer months of the year. All large piscivorous sea mammals, birds, and fish are potential predators on Atlantic menhaden. Menhaden are preyed upon by species such as bluefish, striped bass, king mackerel, Spanish mackerel, pollock, cod, weakfish, silver hake, tunas, swordfish, bonito, tarpon, and a variety of sharks.

Other poorly understood sources of natural mortality for Atlantic menhaden are diseases and parasites. A partial list of parasites was given in Reintjes (1969), but there is no information available concerning the extent of parasitism or its possible effect on survival. Ahrenholz et al. (1987b) described the incidence of ulcerative mycosis (UM), a fungal infestation which was observed in menhaden over much of their range in 1984 and 1985 and in a more restricted area in 1986. A large fish kill in Pamlico Sound, North Carolina in November, 1984 was associated with UM, but its primary effect may be to weaken fish, making them more susceptible to other causes of mortality, such as predation, parasites, other diseases, and low dissolved oxygen concentrations. The overall impact of UM on the 1984 and 1985 year classes could not be assessed, but it was not believed to be significant (Ahrenholz et al. 1987b). However, Vaughan et al. (1986b) believed that the mortality effects of a disease or other event must be "truly catastrophic" to be detectable.

Another source of natural mortality for Atlantic menhaden (and many other species) may be "red tide." The term refers to the color of water caused by the rapid multiplication (a "bloom") of single-celled planktonic organisms called dinoflagellates, which produce a toxic compound. The toxin accumulates in the tissues of filter-feeding animals which ingest the dinoflagellate. An outbreak of red tide occurred along the coast of the Carolinas during November, 1987 - April, 1988 when Gulf Stream water containing the dinoflagellates was transported into coastal waters. Menhaden recruitment in Beaufort Inlet during this period was severely reduced (Stanley Warlen, NMFS Laboratory, Beaufort N.C., pers. comm.). A new species of toxic dinoflagellate that has recently been discovered was identified as the causative agent in a major menhaden kill in the Pamlico River, North Carolina, in May, 1991. Problems with toxic phytoplankton organisms may increase in the future since their appearance has been correlated with increasing nutrient enrichment in estuarine and coastal waters which are subject to increasing organic pollution (Smayda 1989).

An additional source of mortality are fish "kills" which occur when schools of menhaden enter enclosed inshore bodies of water in such large numbers that they consume all available oxygen and suffocate. The mean lethal dissolved oxygen concentration for menhaden has been reported to be 0.4 mg/l (Burton et al. 1980). Bluefish are known to follow (or even chase) schools of menhaden inshore, feeding on them, and may contribute to their mortality by preventing them from leaving an area before the oxygen supply is depleted. Oxygen depletion is accelerated by high water temperatures which increase the metabolic rate of the fish; at the same time, oxygen is less soluble in warm water. Menhaden which die from low oxygen stress can immediately be recognized by the red coloration on their heads caused by bursting blood capillaries. Just before death, the fish can be seen swimming very slowly in a disoriented manner just below the surface of the water. This is a common phenomenon which has been observed throughout the range of the species. Menhaden spotter pilots have reported menhaden "boiling up" from the middle of dense schools, and washing up on the beach, apparently from oxygen depletion within the school. This phenomenon was observed during December, 1979 in the ocean off Atlantic Beach, North Carolina (Michael W. Street, NC Div. of Marine Fisheries, Morehead City, NC pers. comm.). Smith (Unpubl. MS Thesis) reports on a similar event off Core Banks, NC, in December 1997. Other species are not nearly as susceptible simply because they do not enter enclosed inshore waters in such large numbers.

2.8 Ecology

Menhaden are extremely abundant in nearshore coastal waters because of their ability to directly utilize phytoplankton, which is the basic food resource in aquatic systems. Other species of marine fish are not equipped to filter such small organisms from the water. Consequently, such large populations of other species cannot be supported. Because menhaden are so abundant in nearshore coastal and estuarine waters, they are an important forage fish for a variety of larger piscivorous fishes, birds, and marine mammals. In ecological terms, menhaden occupy a very important link in the coastal marine food chain, transferring planktonic material into animal biomass. As a result of this, menhaden influence the conversion and exchange of energy and organic matter within the coastal ecosystem throughout their range (Peters and Schaaf 1981, Lewis and Peters 1984, Peters and Lewis 1984).

Because menhaden only remove planktonic organisms larger than 13-16 microns (7 microns for juveniles) from the water, the presence of large numbers of fish in a localized area could alter the composition of plankton assemblages (Durbin and Durbin 1975). Peters and Schaaf (1981) estimated that juvenile menhaden consumed 6-9% of the annual phytoplankton production in eight estuaries on the east coast, and up to 100% of the daily production in some instances.

A large school of menhaden can also deplete oxygen supplies and increase nutrient levels in the vicinity of the school. Enrichment of coastal waters by large numbers of menhaden can be expected to stimulate phytoplankton production. Oviatt et al. (1972) measured ammonia concentrations (from excretion) inside menhaden schools that were five times higher than ambient levels 4.5 km away. At the same time, chlorophyll values increased by a factor of five over the same distance, indicating the grazing effect of the fish on the phytoplankton standing crop. Oxygen values were not significantly reduced by the fish, but were much more variable inside the schools than outside them.

Also, in a study of energy and nitrogen budgets (Durbin and Durbin 1981), food consumption rates, energy expenditures, and growth efficiency were determined. Swimming speed, the duration of the daily feeding period, and the concentration of plankton in the water control the energy and nitrogen budgets for this species.

2.9 Population Dynamics

Information presented in this section is drawn primarily from Ahrenholz et al. (1987a), Vaughan and Smith (1988), and Vaughan (1990). Sampling methodology was described in Chester (1984). Early stock assessment results are summarized in Powers (1983) and Vaughan et al. (1986a). Based on tagging studies, the Atlantic menhaden fishery is believed to exploit a single stock or population of fish (Dryfoos et al. 1973, Nicholson 1978). For analytical purposes, the Atlantic menhaden fishing season for the reduction fishery extends from March 1 through the end of February of the following calendar year. Population age structure and fishing mortality rates are estimated by virtual population analysis (VPA) from the estimated catch in numbers-at-age matrix (Table 2.1) as described most recently in Vaughan (1990).

2.9.1 Abundance and Structure

Annual Atlantic menhaden population size (age 1 and older at the start of the fishing season) has ranged from 2.0 to 17.6 billion fish since 1955 (Table 2.2). Population size averaged 9.2 billion menhaden between 1955-1961 when landings were high (averaging 1,331.6 million lb or 604,000 mt), while the average was 3.2 billion menhaden between 1962-1974 when landings were low (averaging 637.1 million lb or 289,000 mt). From 1975-92 population size averaged 7.3 billion menhaden, comparing favorably to population sizes between 1955 and 1961, but landings improved by only 15% to an average of 753.1 million lb (342,000 mt). The inability of the modern fishery to regain former high levels of landings (in weight) is due primarily to reduced mean weight-at-age which occurred during the 1970s (Figure 5.3), and was caused in part by changes in fishing patterns, both geographically and seasonally. As has been noted, the migratory behavior of Atlantic menhaden results in older and larger menhaden moving farther north during spring and summer. Part of this decline is due to the shift of the center of the fishing activity southward and subsequent fishing on smaller fish at age. Part can also be explained by the inverse relationship noted between first year growth of Atlantic menhaden and year class strength (Reish et al. 1985, Ahrenholz et al. 1987a). These factors, however, do not account for all of the decline in mean weight-at-age.

The weight of Atlantic menhaden spawners (age 3 and older at the start of the fishing year) has ranged from 9,100 mt in 1966 to 360,300 mt in 1961 (Figure 7.15). High spawning stock size (averaging 208,110 mt) was the rule between 1955 and 1962, while low spawning stock size predominated from 1963 to 1974 (averaging 23,560 mt). Improvement in spawning stock size has occurred since 1975. Between 1955 and 1961, high spawning stock size produced excellent recruitment to age 1 (averaging 5.1 billion) for menhaden entering the fishable stock. Low spawning stock size, present from 1962 through 1974, produced poor recruitment (averaging 2.2 billion menhaden). However, the somewhat improved spawning stock (averaging 37,890 mt) from 1975 to 1991 produced very good to excellent recruitment (averaging 4.4 billion menhaden), comparable to that produced during the high spawning stock years (1955-61). Since 1992, recent poor recruitment (2.3 billion menhaden) has coincided with relatively high levels of spawning stock biomass (52,420 mt).

2.9.2 Fishing Mortality

Short-term losses to the Atlantic menhaden stock due to the fishery can be assessed by considering the exploitation rate (Figure 7.2), which is the fraction of the remaining stock removed by the fishery during some specified period of time (usually 1 year). Population exploitation rates (based on age-1 and older Atlantic menhaden) averaged 38% of the population removed annually by fishing during 1955 through 1990 (Table 2.2). From 1955 through 1962, when population size and landings were high, the population exploitation rate averaged 36%. During the period of low population size and landings from 1963 through 1974, the population exploitation rate averaged 43% (initially high during the mid-1960's and lower during the late 1960s and early 1970s). The population exploitation rate averaged 35% from 1975-91, when population size and landings improved significantly. For fishing years 1955 through 1990, an average of 24% of age-1 menhaden and 65% of age-2 and older menhaden were taken by the fishery annually, with 30% and 20%, respectively, being lost to natural causes annually (compared to 36% lost to natural causes annually in the absence of fishing mortality). Exploitation rates for age-0 menhaden ranged from essentially 0% to 26%.

2.9.3 Dynamics

In addition to the stock assessments of Atlantic menhaden already referenced, a study by Nelson et al. (1977) attempted to relate Atlantic menhaden recruitment to Ekman transport. Conceptually, it was believed that if the prevailing winds along the middle Atlantic coast of the United States were such as to create onshore currents during winter, survival of Atlantic menhaden larvae during their transport into estuarine nursery areas would be increased. Checkley et al. (1988) suggested that Atlantic menhaden "have evolved to reproduce in winter near warm boundary currents [e.g., Gulf Stream] as a result of physical conditions that permit the rapid development and shoreward drift of their eggs and larvae, with consequent high recruitment and fitness." However, the statistically-derived relationship with Ekman transport is no longer significant with the addition of more recent data (W. Schaaf, pers. comm.), and is not useful for predictive purposes.

2.9.4 Spawner-Recruit Relations and Maximum Spawning Potential

Since 1955, the contribution of age-3 spawners to the spawning stock has averaged about 76% in numbers and 66% in index of egg production (Figure 2.1). These values were exceptionally high during the 1970s (87% and 78%, respectively), but declined somewhat during the 1980s (77% and 66%, respectively), lessening the concern that recruitment failure in a single year class could have significant consequences on future year classes. When spawner and recruit data are fit to the Ricker model (Ricker 1975), a statistically significant relationship is obtained (Figure 2.2). However, considerable scatter (or unexplained variability) about the estimated spawner-recruit curve suggests that recruitment variability depends little on spawning stock size, and that environmental factors are probably more important in controlling recruitment success or failure.

Gabriel et al. (1989) developed an index of "percent maximum spawning potential" (%MSP) equal to the ratio of spawning stock biomass calculated when fishing mortality (F) is equal to that estimated or observed, divided by the spawning stock biomass calculated when F = 0 (unfished spawning stock). This ratio assumes such compensatory mechanisms as increased growth rate or earlier maturity when a fish stock is exploited. As the spawning stock size decreases relative to the unfished state, the risk of recruitment failure increases. Whether there is a threshold below which recruitment failure is certain or a gradual increase in risk of recruitment failure with decreasing spawning stock size is unknown. These ratios (Figure 2.3) are calculated under the assumption of equilibrium; that is, annual age-specific estimates of F are used to project a fixed number of recruits throughout their lifespan, and spawning stock size in biomass or index of egg production is cumulated. The index of egg production for Atlantic menhaden is based on the egg-length relation provided in Lewis et al. (1987).

From 1962-92, the percent maximum spawning potential was below 10%. Periods of both poor (less than 2 billion fish) and excellent recruitment (greater than 4.7 billion fish) have occurred, reinforcing the concept that environmental conditions are more important than spawning stock abundance in determining recruitment success or failure. Because %MSP values of 20% to 40% have been used by the Gulf of Mexico and South Atlantic Fishery Management councils in their definitions of overfishing for a number of fish stocks, these low values for Atlantic menhaden have raised some concern. On average, however, the Atlantic menhaden stock has been able to replace itself at low %MSP values. Thus, a value much lower than 20% - 40% of MSP appears to apply to Atlantic menhaden.

Recent estimates of percent MSP have been quite high, ranging from 8.4 to 14.9, from 1992-97. Recruitment of fish to age-1 though, has been below the median level of 3.4 billion during this time, and has fallen below the trigger 25^{th} percentile value of 2.2 billion the past two years.

2.9.5 Potential Yield

Yield-per-recruit (YPR) models are used to determine whether or not fish are being harvested at an age which provides maximum yield. The models can indicate if fish are being removed at too young an age, resulting in growth overfishing. This analysis shows gains and losses of YPR as a function of the fishing mortality rate and age at entry to the fishery (Figure 2.4). Overall YPR for the age at entry of 0.5 yr and F-multiple of 1.0 (existing conditions) has been generally decreasing since 1971, with an average of 78.5 g during the 1970s and 52.1 g during the 1980s (Table 2.4). The proportional contribution of younger age groups to the landings has increased, and the average size at age (as noted earlier) has decreased. Reduced growth and redirection of effort towards younger fish has contributed to the reduced levels in YPR.

Landings of Atlantic menhaden have been highly dependent on age-0 menhaden in certain fishing years (e.g., 1979, 1981, 1983, 1984, and 1985, as noted in Vaughan and Smith 1991), and most recently in 1990-92. Potential gains in YPR from increasing age at entry from age 0.5 to age 1 ranged from 0.4% in 1970 to 6.5% in 1979 and about 6.0% in 1983 and 1984 (Table 2.4). Even greater gains in YPR could be obtained by raising the age at entry to age 2 (e.g., 16.1% in 1983 and 17.7% in 1984). Such an increase is unlikely, given the current and probable future geographic distribution of fish and fishing effort.

In general, increasing the age at entry causes an increase in YPR, except for small F-multiples; e.g., F-multiple = 0.2 (Figure 2.4). Decreasing fishing mortality to F-multiple = 0.5 generally causes a decrease in yield per recruit at the current age at entry (0.5 yr), with exceptions in the 1970-1971, 1979, 1986-1987, and 1990 fishing years. Except in 1990, increasing fishing mortality to F-multiple = 2.0 causes a decrease in YPR at the current age at entry (0.5 yr). These results suggest that the age at entry should be raised to increase potential yield from the stock. However, current plant locations and fishing regulations greatly restrict the ability to obtain optimal yield per recruit.

2.9.6 MSY and Production Models

Estimates of maximum sustainable yield (MSY) are developed to obtain an approximate estimate of the production of a stock available to a fishery. As normally estimated, it assumes relatively constant environmental conditions. However, as environmental conditions change, MSY will also vary. The value of MSY depends heavily on recruitment success, which in turn, is highly dependent on environmental conditions. This level of uncertainty precludes the direct use of MSY for determining quotas for management.

Historical estimates of MSY range from 815.7 million lb (370,000 mt) to 1,234.6 million lb (560,000 mt) (Schaaf and Huntsman 1972; Schaaf 1975, 1979; Ahrenholz et al. 1987a; Vaughan and Smith 1988; Vaughan 1990). The most recent application of the generalized production model (Pella and Tomlinson 1969), which relates landings and fishing effort, suggests estimates of MSY of 1,068 million lb ± 191.8 million pounds (484,000 mt ± 87,000 mt) based on landings and adjusted fishing effort data through 1986 (Vaughan 1990). Generally high recruitment during 1975-1986 indicates potential yields from a given year class of 363.8 million lb (165,000 mt) to 1,161.8 million lb (527,000 mt) based on YPR analysis. In general, estimates of MSY exceed recent landings of Atlantic menhaden, which ranged from 524.7 million lb (238,000 mt) to 922.9 million lb (418,600 mt) since 1980, with 1997 fishing year landings of about 571.3 million lb (259,100 mt).

2.10 Probable Future Condition

Good recruitment during the mid-1970s to the mid-1980s supported landings between 661 and 881 million lb (300,000 and 400,000 mt). Poor recruitment during the 1960s and early 1970s supported landings between 441 and 661 million lb (200,000 and 300,000 mt). Most recently, landings have decreased to the levels seen in the 1960s - early 1970s. Part of this decline may be a result of the lowered recruitment but is also a result of industry consolidation and area closures, which have reduced the geographic expanse of the fishery. A precise understanding of the role of environmental conditions on menhaden recruitment is not available but would be extremely useful for predictive purposes.

3.0 FISHERY DESCRIPTION

3.1 Brief Overview of Fisheries (History of Exploitation)

Atlantic menhaden have supported one of the United States' largest fisheries since colonial times. Landings records indicate that over 18 million mt of Atlantic menhaden have been caught by fishing fleets operating from Maine to Florida since 1940.

Native Americans were the first to use menhaden, primarily for fertilizer. During the 1940s, the primary use changed to high protein animal feeds and oil production. Menhaden meal was mixed into poultry, swine, and cattle feeds as the amount used for fertilizer was decreasing. The oil was used in the manufacture of soap, linoleum, waterproof fabrics, and certain types of paint.

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. Since that time, the menhaden industry has experienced major changes in processing capacity, resource accessibility, and development of new product markets.

3.2 Fishing Vessels and Gear

The early menhaden purse seine fishery utilized sailing vessels, while coal-fired steamers were introduced after the Civil War. In the 1930s, diesel-powered vessels began to replace the steamers, although a few sailing vessels were still in use. Reintjes (1969) described modern menhaden vessels and purse seines and summarized the significant technological advancements since World War II as follows:

1946	Use of spotter aircraft. Setting on a school is now directed by the spotter pilot via radio communication with the purse boats.
1946	Use of pumps to transfer fish from the nets to the carrier vessel resulted in shorter transfer time and more fishing time.
1954	Use of synthetic net material rather than cotton twine resulted in increased net life.
1957	Use of hydraulic power blocks in the purse boats to haul in the net permitted a reduction in crew size and reduced net retrieval time. Strong synthetic net material was able to withstand the increased strain from the new haul technique.
1958	Introduction of lighter, stronger, and faster aluminum purse boats to replace wooden boats.

The refrigeration of vessel holds in the 1960s and 1970s was crucial for the industry to maintain its viability. Despite restricted access to a number of traditional grounds and a reduced fleet size, refrigerated holds enabled the fleet to maximize the harvest during peak resource availability. Refrigeration also allowed the fleet to range over a larger area and stay out longer, greatly improving the ability to catch fish when and where they are available.

Currently, commercial menhaden fishing operations utilize spotter aircraft to locate schools of menhaden and direct vessels to the fish. When a school is located, two purse boats with a net stretched between them are deployed. The purse boats encircle the school and close the net to form a purse or bag. The net is then retrieved to concentrate the catch and the mother ship comes along-side and pumps the catch into refrigerated holds. Individual sets can vary from 10 to more than 100 mt, and large vessels can carry 400-600 mt of refrigerated fish. The small vessels used in the Gulf of Maine are not refrigerated and utilize a single purse boat.

Over the years, vessels participating in the Atlantic menhaden purse seine fishery have varied considerably in size, fishing methods, gear type, and intensity of effort. During the early 1960s, the commercial menhaden fleet experienced significant changes as larger, faster vessels replaced outdated models. Today, the 15 vessels operating in NC and VA range from 166 ft (51 m) to 200 ft (61 m) in length. Typical menhaden vessels generally carry two purse boats approximately 39 ft (13 m) in length. A few small vessels have only one purse boat and are called "snapper rigs." These small boats have the ability to fish in shallow areas not available to the larger vessels. The catches of the snapper rigs (a very small fraction of the total) are mostly sold for bait (sport fishery, crab pots, etc.) with minor quantities processed into meal, oil, and solubles.

The typical purse seine net has a bar mesh of 3/4 in (1.9 cm) to 7/8 in (2.2 cm). The net length ranges from about 1,000 ft (305 m) to about 1,400 ft (427 m) and the depth from about 65 ft (20 m) to about 90 ft (27 m).

The commercial menhaden fleet operating in the North Atlantic region underwent considerable changes during the late 1980's and early 1990's, including the introduction of two conventional menhaden steamers, addition of a number of small menhaden boats active in other fisheries during the off-season, and the development of a menhaden IWP venture with up to three Russian processing ships. In 1987, two New England-based menhaden vessels began to fish the Gulf of Maine area, landing the catch at a Canadian processing plant. Another Canadian factory in Nova Scotia processed menhaden in 1992 and 1993. No menhaden have been processed in the North Atlantic since the summer of 1993.

Up to three IWP ventures operated within Maine's coastal waters from 1988-93. Under state jurisdiction, a foreign vessel was permitted to process menhaden caught by US vessels into fish meal and oil during the 1988-93 fishing seasons. The Gulf of Maine Atlantic menhaden fleet included about 20 purse seine vessels and carriers serving the reduction and lobster bait markets. These vessels include some that are seasonal (boats active in other fisheries during the off-season), as well as vessels specifically built and rigged for purse seine fisheries (both menhaden and Atlantic herring). The majority of the vessels are based in Maine, but some operate out of the Boston area. Several of the catcher boats can hold their catch for direct transfer to the foreign processing vessel. Smaller catcher boats normally pump the fish from the seine onto a carrier vessel for later transfer to the processing vessel.

During the 1990 season, the mid-Atlantic fleet, based in Virginia was composed of 20 vessels, and the south Atlantic fleet, based in North Carolina, consisted of one large vessel and two smaller vessels, each using two purse boats. One of the smaller vessels, however, fished exclusively for bait. An additional 3-4 large vessels from Virginia and/or the Gulf of Mexico fished in the south Atlantic during the fall fishery. Due to company consolidation in 1997, there are presently 13 vessels in the mid-Atlantic fleet (at Reedville, VA) and two vessels in the south Atlantic (at Beaufort, NC).

Historically, the total number of vessels fishing for menhaden was generally related to the availability of the resource. Greer (1915) reported 147 vessels in 1912. During 1955-1959, about 115-130 vessels fished during the summer season, while 30-60 participated in the North Carolina fall fishery. As the resource declined during the 1960s, fleet size decreased more than 50%. Through the 1970s, approximately 40 vessels fished during the summer season, while nearly 20 were active in the fall fishery. During 1980-1990, 16-33 vessels fished the summer season, and the level of effort in the fall fishery ranged from a low of 3 vessels in 1986 to a maximum of 25 (Table 3.1).

Changes in fleet size in recent years are attributable to a number of factors. Reductions in effort during the mid-1980s were related largely to world commodity markets and economic considerations. Addition of vessels participating in the Gulf of Maine IWP ventures reflected resource availability in Maine. Reduction of the Chesapeake fleet by several vessels was accompanied by improved operating efficiency. Vessels from the Gulf of Mexico fishery were added to the Atlantic fleet for the fall fishery in order to maximize harvest when weather and fish migratory behavior provided opportunities for large catches. In November 1997, Omega Protein purchased its competitor in Reedville, AMPRO Fisheries. For the 1998 fishing season, Omega dismantled the AMPRO factory and reduced the Virginia reduction fleet from 20 to 13 vessels.

All fifteen vessels in the menhaden fleet currently utilize refrigerated fish holds, compared to only 60% of the fleet in 1980 (Table 3.1). Refrigeration enables vessels to deliver better quality raw material and serves to increase vessel range and extend time on the fishing grounds. This ability to maximize peak resource availability was critical in the 1970s and 1980s for the maintenance of the industry in the face of restricted access to traditional grounds and a reduced number of vessels landing at fewer plants.

Average hold capacity of menhaden vessels in the summer fishery declined from 1,101,000 standard fish (737,670 lb or 334.6 mt) in 1980, to 997,000 standard fish (667,990 lb or 303 mt) in 1990, a decrease of 9.4% (Table 3.1). The total hold capacity of the fifteen vessel menhaden fleet is well below that in the late 1950s.

During peak landing years (1953-1962), an average of 112 vessels with a mean vessel capacity of about 678,000 standard fish (representing a total fleet capacity of approximately 76,000,000 standard fish) supplied the industry (Nicholson 1971). The fleet landed daily catches at 20 menhaden reduction plants from New York to Florida. In comparison, the 1990 fleet of 33 vessels, which operated within a more restrictive and regulated environment, landed their catch at five plants, including the foreign processing vessel. As previously noted, the current fleet of fifteen vessels unloads menhaden at only two ports, Reedville, VA and Beaufort, NC.

3.3 Fishing and Landing Areas

In 1991, Chesapeake Bay, including the mid-Atlantic area, accounted for about 74% of the menhaden landings. The North Atlantic area contributed most of the balance of the landings, while the south Atlantic area contributed the remainder. The catch was landed at shoreside processing plants in Beaufort, North Carolina.; Reedville, Virginia. (2 plants); and Blacks Harbour, N.B., Canada. A Russian factory ship anchored at various locations within the territorial waters of southern Maine also processed menhaden under an IWP arrangement.

The Chesapeake Bay area (including the mid-Atlantic area) accounted for about 77% of the Atlantic menhaden landings in 1990 and about 73% during the 1980-1990 period (Table 3.2. and Figure 3.1). Plants in the north and south Atlantic areas, including one plant active during the fall fishery, generally handled about 27% of the annual landings. Three processing plants located in Virginia and North Carolina normally process about 90% of the harvest (Figure 3.1). The data in Table 3.2 illustrate the recent year-to-year variations in regional landings.

As no menhaden landings for reduction have occurred in New England since the summer of 1993, landings of Atlantic menhaden for reduction have been made exclusively by the Virginia and North Carolina menhaden vessels at Reedville and Beaufort. Between 1994 to 1997, the reduction factories at Reedville unloaded an average 88.9% of the Atlantic menhaden catch for reduction; the remainder was unloaded at Beaufort.

Recently, Smith (in review) summarized catch estimates of menhaden vessel captains in the Virginia and North Carolina fleets (excluding New England vessels) from Captains Daily Fishing Reports (CDFR’s) from 1985-96. On average over the twelve year study period, 52% of the catch by the Virginia and North Carolina fleets came from the Virginia portion of Chesapeake Bay, 17% was caught in North Carolina coastal waters, 16% in Virginia ocean waters, and 15% in ocean waters of Rhode Island, New York, New Jersey, Delaware, and Maryland and Delaware Bay combined.

3.4 Fishing Seasons

The directed menhaden purse seine fishery for reduction is seasonal. The presence of menhaden schools is dependent on the temperature of coastal waters. Two fairly distinct fishing seasons occur, the "summer fishery" and the "fall fishery". The summer fishery begins in April with the appearance of schools of menhaden off the North Carolina coast. The fish migrate northward, appearing off southern New England in May-June. The fishery in the Gulf of Maine may extend into early October although menhaden may not appear in the Gulf of Maine in some years. Menhaden stratify by age along their migration route as smaller, younger fish remain in the southern area, while larger, older fish travel farther to the north. Peak landings occur during June-September (Table 3.3).

The fall fishery begins about 1 November with the appearance of migratory fish moving south. In early fall, a southward migration is initiated by cooling ocean temperatures. By late November-early December, most of the fish are found between Cape Hatteras and Cape Fear, North Carolina. Menhaden vessels based in Beaufort, North Carolina and Reedville, Virginia harvest these fish during the fall fishery. Fishing may continue into January (and sometimes February), but is highly weather-dependent. Menhaden leave the nearshore coastal fishing grounds in January, probably dispersing in ocean waters off the south Atlantic states.

3.5 Incidental Catches

Incidental bycatch of other finfish species in menhaden purse seines has been a topic of interest for many years to the commercial and recreational fishing industry, as well as the scientific community (Smith 1896; Christmas et al. 1960; Oviatt 1977). Numerous past studies have shown that there is

little or no bycatch in the menhaden purse seine fishery. Some states restrict bycatch to 1% or less of the total catch on a vessel by regulation (see Section 3.7).

A study of bycatch of other species in the menhaden fishery was recently completed through funding provided by the Federal Saltonstall-Kennedy grant program (Austin et al. 1994). The Virginia Institute of Marine Science received funding to study bycatch levels of finfish, turtles, and marine mammals in the Atlantic menhaden fishery. Results from that study indicate that bycatch in the 1992 Atlantic menhaden reduction fishery was minimal, comprising about 0.04% by number. The maximum percentage bycatch occurred in August (0.14%) and was lowest in September (0.002%). Among important recreational species, bluefish accounted for the largest bycatch, 1,206 fish (0.0075% of the total menhaden catch). No marine mammals, sea turtles, or other protected species were killed, captured, entangled or observed during sampling. A concurrent study was conducted by LSU for the Gulf of Mexico menhaden fishery as well.

Additional data are available are from the Gulf of Maine IWP fishery. Every catch unloaded onto the processing vessel was inspected by a state observer. In 1991, a total of 93 fish were taken as bycatch along with about 60,000,000 menhaden (David Stevenson, Maine Department of Marine Resources, pers. comm.).

3.6 Commercial Reduction and Bait Fishing Activities

3.6.1 Reduction Fishery

Atlantic menhaden have supported one of the United State's largest fisheries since colonial times. Menhaden have repeatedly been listed as one the nation's most important commercial species in terms of quantity. Total menhaden landings (Gulf of Mexico and Atlantic) in calendar year 1996 were 1,800 million lb (816,467 mt) valued at $94.2 million (NMFS 1997). Atlantic menhaden landings in 1996 (calendar year) totaled 672 million lb (304,813 mt) with an estimated ex-vessel value of $39.7 million (NMFS 1997). Landings records indicate that over 18 million mt of Atlantic menhaden have been caught by fishing fleets operating from Maine to Florida since 1940.

Native Americans may have used menhaden for fertilizer before the European settlement of North America. Colonists soon recognized the value of whole menhaden for fertilizer, and local seine fisheries gradually developed from New York to Maine. Farmers applied 6,000 to 8,000 fish per acre (Harrison

1931). The use of whole fish as fertilizer continued into the nineteenth century. Union soldiers returning home from North Carolina and Virginia after the Civil War provided anecdotal reports on the abundance of menhaden in Chesapeake Bay and coastal North Carolina, sparking interest in a southern fishery, which soon developed.

The menhaden oil industry began in Rhode Island in 1811 (Frye 1978). It has grown steadily with significant mechanization, including 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. Numerous small factories were located along the coasts of the northeastern states. However, their supply was limited to fish that could be captured by the traditional shore-based seines. In 1845, the purse seine was introduced, and an adequate supply of raw material was no longer a problem. By 1870, the industry had expanded southward, with several plants in the Chesapeake Bay and North Carolina areas (Whitehurst 1973).

The industry gradually developed during the late 1800s and early 1900s and was described in considerable detail prior to World War I by Greer (1915). During this period the number of factories and vessels varied with the supply of menhaden. The principal use for the scrap was fertilizer, with different companies each producing their own formulation. A small amount of scrap was used to feed cattle and chickens.

Menhaden's primary use changed from fertilizer to animal feed during the period following World War I. Harrison (1931) described the uses of menhaden during the late 1920s as follows: "... much is being used in mixed feeds for poultry, swine, and cattle and the amount going to fertilizer is steadily decreasing. Menhaden oil is used primarily in the manufacture of soap, linoleum, water proof fabrics, and certain types of paints."

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. Since that time the menhaden industry has experienced major changes in processing capacity, resource accessibility, and access to new product markets.

Nine menhaden reduction plants on the Atlantic coast closed permanently during the 1980s while two new operations began (Table 3.4). In 1990, five reduction plants with 37 vessels processed Atlantic menhaden for fish meal and oil. In the United States, land-based plants are currently located at Beaufort, North Carolina and Reedville, Virginia. An IWP venture operated in Maine state waters from 1988-92. Menhaden have also been caught off the coast of Maine and transported to a reduction plant in Blacks Harbour, New Brunswick, Canada (Vaughan 1990).

Since preparation of the 1981 Atlantic menhaden FMP (AMMB 1981), there have been numerous regulatory changes affecting the menhaden fishery, such as season limits, area closures, and changes in license fees. In some state waters, a prohibition on commercial menhaden fishing operations using purse seines has been implemented (See section 3.7.1).

In calendar year 1991, 304,813 mt of Atlantic menhaden, with an ex-vessel value of $39.7 million, were landed at three processing facilities along the Atlantic coast (NMFS 1997).

3.6.2 Bait Fishery

Information on the harvest and use of menhaden for bait is difficult to obtain because of the nature of the bait fisheries and data collection systems. Harvest comes from directed fisheries, primarily small purse seines, pound nets, and gill nets, and bycatch in various food-fish fisheries, such as pound nets, haul seines, and trawls. Menhaden are taken for bait in almost all Atlantic coast states and are used for bait in crab pots, lobster pots, and hook and line fisheries (both sport and commercial). A specialized use involves live menhaden as bait for coastal pelagic species in the south Atlantic area.

Annual landings of Atlantic menhaden for bait along the Atlantic coast average about 65.5 million lb (about 29,700 mt). Bait landings in 1996 (23,300 mt) accounted for 8% of the total Atlantic menhaden landings of 292,900 mt.

Closure of reduction plants in New England and the mid-Atlantic may have influenced growth in the bait fishery, making more product available for the lobster and crab pot fisheries, as well as bait and chum for sport fishermen. Additionally, the passage of a net ban in Florida in November 1994 reduced the availability of bait and chum in that state, which opened up new markets for menhaden bait caught in Virginia and the mid-Atlantic states. The appearance of growth in the Atlantic coast bait fishery (Table 3.5) must be tempered by the knowledge that reporting systems for bait landings, particularly for Atlantic menhaden, have historically been incomplete, at best. In most cases, recent landings estimates are more accurate, but for some states, bait landings continue to be underestimated. The nature of the fishery and its unregulated marketing are causes of the under-reporting problem. There are some well-documented, large-scale, directed bait fisheries for menhaden using gears such as purse seines, pound nets, and gill nets. There are also many smaller-scale directed bait fisheries and bycatch fisheries supplying large quantities of bait with few, if any reporting requirements. Menhaden taken as bycatch in other commercial fisheries is often reported as "bait" together with other fish species. The "over-the-side" sale of menhaden for bait among commercial fishermen is under-reported (often unreported). Common practices, such as utilizing menhaden for bait or chum in sportfishing tournaments is difficult to estimate when quantity sales are made to individual marinas and fishing clubs.

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. Catch-per-unit-of-effort (CPUE) data, pounds caught per hour set and pounds caught per yard of net set are also reported for directed gill net fisheries in some states. Average bait landings by region for the principal gears are shown in Table 3.6.

3.6.2.1 New England

In the New England region, Maine and Rhode Island purse seine vessels account for the majority of the recorded landings. Ocean trap nets are also used in Rhode Island and Maine, while stop seines are used only in Maine. In New Hampshire and Connecticut, smaller directed gill net fisheries are well-regulated and monitored. The bulk of menhaden landings for bait in New England is utilized in the coastal lobster fishery.

3.6.2.2 Mid-Atlantic

New Jersey dominates current mid-Atlantic landings. Reports of catch by fishing area are required by New Jersey under its recently implemented licensing of bait purse seine vessels. Pound nets contribute significantly to bait landings in New York and New Jersey. Delaware closely regulates its directed gill net fishery, obtaining detailed catch/effort data each year.

3.6.2.3 Chesapeake Bay

In the Chesapeake Bay region, pound nets account for the majority of menhaden landings in Maryland and the Potomac River. Virginia snapper rigs (small purse seiners) provide landings records, but menhaden taken in other fisheries are combined with other finfish bait species in landings reports. Therefore, only total landings data are available. Most of the catch is used in the blue crab pot fishery.

3.6.2.4 South Atlantic

Part of North Carolina's landings are reported directly, while the rest are estimated from fishery-dependent sampling. The principal use in North Carolina is in the blue crab pot fishery. South Carolina and Georgia have no directed menhaden fisheries; shrimp trawl bycatch and cast netting supply menhaden to crab potters and sport fishermen in those states. Florida's east coast had substantial menhaden landings for bait from gill nets and purse seines prior to the implementation of a net ban in 1994.

Appendix A.3 contains each state's menhaden bait landings by gear for each year recorded since 1985.

3.6.3. Domestic Processing Activities and Products

Menhaden reduction plants, through a process of heating, separating, and drying, produce fish meal, fish oil, and fish solubles from fresh menhaden. Meal is a valuable ingredient in poultry and livestock feeds because of its high protein content (at least 60%). The broiler industry is currently the largest user of menhaden meal, followed by the turkey, swine, pet food, and ruminant industries. The aquaculture industry has recently demonstrated an increased demand for fish meal.

Menhaden oil has been used for many years as an edible oil in Europe. The oil is refined and used extensively in cooking oils and margarine. In 1989, the United States Food and Drug Administration (FDA) concluded that fully and partially hydrogenated menhaden oil is a safe ingredient for human consumption. In 1990, the FDA proposed an amendment, based on an industry petition, to the standard of identity for margarine to permit the use of marine oils. It was approved in 1997 and could provide a significant new market for omega-3 rich menhaden oil.

Solubles are the aqueous liquid component remaining after oil removal. In general, most meal producers add the soluble component to the meal to create a product termed "full meal." The use of solubles as an export product is limited because most companies in the feed industry are not equipped with the necessary storage tanks, pumps, and meters to handle a liquid product.

The world fish meal industry is in the process of adopting low temperature meal technology, a process which yields significantly higher protein content than previous technologies and produces feed components particularly valuable to aquaculturists. Investment in these new processes represents an opportunity for the U.S. industry to broaden its market base and add value to its products. Public sector support, in the form of research on markets, technology development, and new products, will be a key factor in maintaining the domestic menhaden industry's global competitive status into the next century.

3.7 Management

3.7.1 Regulatory Measures

Major changes have occurred in the Atlantic menhaden industry since the completion of the 1981 menhaden FMP (AMMB 1981). The Atlantic fishery became relatively more important, due in part, to the continued improvement of the Atlantic menhaden population and the overall decrease in Gulf of Mexico landings. However, state government regulatory actions, local government land use rules, and changing economic conditions combined have resulted in plant closures (Table 3.4). During the mid-1980s, historical low prices occurred for fish meal, while oil prices fell to lows during 1987 and 1989-90 (Table 3.7). Menhaden companies have either gone out of business or have adapted with internal restructuring, as well as adopting new organizational procedures and technology. An IWP fishery operated in Maine waters from 1988-93, which maintained the menhaden fishing industry in that area. Controversy over operation of menhaden boats in coastal waters has caused the closure of some states' waters and restricted access in others. Currently, New Hampshire, New York, Connecticut, New Jersey, Maine, Rhode Island, Virginia, and North Carolina have established seasons for menhaden purse seine fishing. A summary of current (1992) state laws and regulations pertaining to the Atlantic menhaden fishery is presented in Table 3.8. The summary includes information on licensing, closed seasons and areas, special conditions, and penalties for violations.

3.7.2 Regulatory Trend

Since 1981, a number of areas along the Atlantic coast have closed to menhaden purse seine fishing. These closures were not recommended in the 1981 FMP, nor were they based on the biological condition of the stock. Combined with national and international economic factors, the closures have affected the viability of the Atlantic menhaden industry in spite of improved stock conditions. Some states have closed specific riverine, estuarine, or near-shore ocean areas to menhaden purse seine fishing (FMP). Other states have more general area closures, such as in New Jersey where menhaden purse seine fishing for reduction is not allowed within 1.2 mi (1.9 km) of shore. Menhaden purse seine fishing is not allowed at all in the state waters of South Carolina, Maryland, and Delaware. State officials have often responded to pressure groups by restricting purse seine fishing access to traditional fishing grounds as conflicts have developed. Such decisions have generally not been based on sound biological or economic data.

3.7.3 Conflict and Competition in the Menhaden Fishery

Management of coastal fisheries is inherently controversial because of the wide range of interests involved and the need to protect critical habitat. Conflict occurs when the activity of a group or individual interferes, either in reality or perception, with the activities of another group or individual to such an extent that one party seeks dominance over the other. Competition takes place in fisheries when groups or individuals seek the same resource using different methods or try to utilize the same space for their activities, with neither party seeking dominance (Maiolo 1981). Both competition and conflict occur, depending on one's view, among the purse seine fishery, other fisheries, and other users of coastal resources.

As use of public waters, especially in the estuary and near-shore ocean areas, has grown, competition for space has increased, escalating spatial competition to conflict in some areas. In most states, various areas are closed to menhaden purse seining to separate purse seiners from other commercial gears, such as crab and lobster pots or pound nets; to separate commercial from sport fishing activities; or to protect other uses of the coastal zone. Today's menhaden fleet is greatly reduced in number of vessels from that of the past, but most of the vessels are quite large and operate during the peak tourist and sport fishing seasons (Summer-Fall) in areas where marine sportfishing is concentrated. Most conflicts have occurred in North Carolina, Virginia, Delaware, New Jersey, and New York.

The natural behavior of menhaden generates spatial competition. Menhaden are not randomly distributed; they form dense schools in limited areas at any given time during the fishing season, principally in estuarine and near-shore ocean waters. For purse seine vessels to harvest them, the vessels must go to the fish, often bringing these large vessels into areas near tourist facilities or with concentrations of sport fishermen. The mere sight of menhaden vessels sometimes elicits telephone calls expressing concern to state agencies.

Menhaden serve as a forage fish for sport fish, such as striped bass (Versar, Inc. 1990), bluefish (Wilk 1977), weakfish (Merriner 1975), and king mackerel (Saloman and Naughton 1983). Because menhaden occupy this ecological role, some anglers insist that menhaden be abundantly available as prey for fishes higher in the food chain. The above studies all show that the noted game fish consume many other food items besides menhaden. In addition, especially in the south Atlantic area, sport fishermen harvest live menhaden for bait to use in the "slow trolling" method of fishing, which is quite selective for large king mackerel.

A misconception frequently cited by anglers is that menhaden purse seines "entrap all fish within a large chunk of water. Anything bigger than a few inches is rounded up, and pulled alongside ..." the menhaden vessels (Richard 1989). Studies on the menhaden bycatch issue have been conducted since the late 1800s (Smith 1896) to more recent times (Knapp 1950; Baughman 1950; Christmas et al. 1960; Gunter 1964; White and Lane 1968; Ganz 1975; Oviatt 1977; Guillory and Hutton 1982, Austin et al. 1994). Bycatches have been extremely low, generally zero or much less than 1%, with thousands of sets examined over the years. Most of the bycatch in the historical studies has been of species of little importance to anglers, such as alewife, mullet, threadfin shad, and sea catfish. States which allow menhaden purse seine fishing generally have a limit on bycatch; for example, a 1% bycatch of foodfish is allowed in Virginia (by weight) and North Carolina (by number).

No studies have shown that the menhaden purse seine fishery has any significant biological effect on any other species or fishery. Yet, conflicts have developed from misconceptions concerning the competition and a lack of acceptance of scientific evidence demonstrated by many years of research. It can be concluded that existing competition between the menhaden fishery and other fisheries is principally for space rather than for menhaden.

In an effort to reduce conflicts, the menhaden industry has instituted an education program for other fishermen, management agencies, and the general public. These efforts include taking interested persons on their vessels to observe fishing activities. Individual menhaden companies follow internal codes of conduct for their fishing operations which clearly demonstrate the industry's concern with other fisheries and water-based activities. Areas addressed include cooperation with management agencies, adherence to water quality standards, and courtesy in vessel operations.

4.0 HABITAT DESCRIPTION

4.1 Condition of Habitat

Of primary importance is the fact that Atlantic menhaden are estuarine-dependent. Following oceanic spawning, menhaden larvae enter the coastal estuaries where they transform into juveniles. They utilize the estuary from low salinity headwaters to high salinity areas near inlets as nursery areas for most of their first year.

Prior to passage of coastal protection laws, principally during the 1970s, wetlands were viewed as wastelands, and dredging and filling was encouraged. Large areas of productive habitat were permanently altered, eliminating their value for fisheries production. Since implementation of coastal habitat protection programs, however, very little of the remaining Atlantic coastal wetlands has been lost. Productivity of the remaining coastal wetlands continues to be compromised, however, by pollution from towns and cities, industry, and run-off from urban surfaces, agriculture, and silviculture. Under current habitat management programs, most Atlantic coast estuaries remain fairly productive. The general migration of the U.S. population to the coastal zone will place increasing stress on estuaries, and protection programs will have to be strengthened.

4.2 Habitat Protection Programs

The federal Coastal Zone Management Act provides a framework under which individual coastal states have developed their own coastal habitat protection programs. In general, wholesale dredging and filling are not allowed. Individual development projects are subject to state and federal review and permit limitations. Every Atlantic coast state has a coastal habitat protection program in place (ASMFC 1992, Table 11.27). These protection programs have greatly reduced the loss of vital coastal habitat to dredging and filling since the mid-1970s. Virtually all proposals affecting coastal habitat are now reviewed by a variety of local, state, and federal agencies, and wholesale destruction of coastal wetlands is rare. Many important estuarine habitats are now protected as part of various wildlife refuges, national and state parks, and public and private nature preserves. In addition, a federal permit program is conducted by the U.S. Army Corps of Engineers, generally in cooperation with the state programs. Every state also conducts water quality protection programs under the federal Clean Water Act. National Pollution Discharge Elimination System permits are required for point-source discharges. Unfortunately, these programs provide much less control over non-point pollution, especially that originating from agricultural and silvicultural activities.

4.3 Physical Description of Habitat

Atlantic menhaden occupy a wide variety of habitats during their life history. Adult Atlantic menhaden spawn in continental shelf waters. Larvae enter estuaries and transform into juveniles, utilizing coastal estuaries as nursery areas before migrating to coastal waters in the fall. They make extensive north-south migrations in the near-shore ocean.

4.3.1 Gulf of Maine

The Gulf of Maine is a semi-enclosed sea of 36,300 mi^2 (90,700 km^2) bordered on the east, north and west by the coasts of Nova Scotia, New Brunswick, and the New England states. To the south, the Gulf is open to the North Atlantic Ocean. Below about 165 ft (50 m) depth, however, Georges Bank forms a southern boundary for the Gulf. The interior of the Gulf of Maine is characterized by five major deep basins (>600 ft, 200 m) which are separated by irregular topography that includes shallow ridges, banks, and ledges. Water flows in and out of the Bay of Fundy around Grand Manan Island. Major tributary rivers are the St. John in New Brunswick; St. Croix, Penobscot, Kennebec, Androscoggin, and Saco in Maine; and Merrimack in Massachusetts.

The predominantly rocky coast north of Portland, Maine is characterized by steep terrain and bathymetry, with numerous islands, embayments, pocket beaches, and relatively small estuaries. Tidal marshes and mud flats occur along the margins of these estuaries. Farther south, the coastline is more uniform with few sizable bays, inlets, or islands, but with many small coves. Extensive tidal marshes, mud flats, and sandy beaches along this portion of the coast are gently sloped. Marshes exist along the open coast and within the coves and estuaries.

The surface circulation of the Gulf of Maine is generally counterclockwise, with an offshore flow at

Cape Cod which joins the clockwise gyre on the northern edge of Georges Bank. The counterclockwise gyre in the Gulf is more pronounced in the spring when river runoff adds to the southwesterly flowing coastal current. Surface currents reach velocities of 1.5 knots (80 cm sec) in eastern Maine and the Bay of Fundy region under the influence of extreme tides (up to 30 ft, 9 m) and gradually diminish to 0.2 knots (10- 20 cm sec) in Massachusetts Bay where tidal amplitude is about 10 ft (3 m).

There is great seasonal variation in sea surface temperature in the Gulf, ranging from 4EC in March throughout the Gulf to 18EC in the western Gulf and 14EC in the eastern Gulf in August. The salinity of the surface layer also varies seasonally, with minimum values in the west occurring during summer, from the accumulated spring river runoff, and during winter in the east under the influence of runoff from the St. Lawrence River (from the previous spring). With the seasonal temperature and salinity changes, the density stratification in the upper water column also exhibits a seasonal cycle. From well mixed, vertically uniform conditions in winter, stratification develops through the spring and reaches a maximum in the summer. Stratification is more pronounced in the southwestern portion of the Gulf where tidal mixing is diminished.

4.3.2 Middle Atlantic Region (Cape Cod, Mass. to Cape Hatteras, N.C.)

The coastal zone of the middle Atlantic states varies from a glaciated coastline in southern New England to the flat and swampy coastal plain of North Carolina. Along the coastal plain, the beaches of the barrier islands are wide, gently sloped, and sandy, with gradually deepening offshore waters. The area is characterized by a series of sounds, broad estuaries, large river basins (e.g., Connecticut, Hudson, Delaware, and Susquehanna), and barrier islands. Conspicuous estuarine features are Narragansett Bay (Rhode Island), Long Island Sound and Hudson River (New York), Delaware Bay (New Jersey and Delaware), Chesapeake Bay (Maryland and Virginia) (the largest estuary in the U.S.), and the nearly continuous band of estuaries behind barrier islands along southern Long Island, New Jersey, Delaware, Maryland, Virginia, and North Carolina. The complex estuary of Currituck, Albemarle, and Pamlico sounds behind the Outer Banks of North Carolina (covering an area of 2,500 square miles) is an important feature of the region. Coastal marshes border small estuaries in Narragansett Bay and much of the glaciated coast from Cape Cod to Long Island Sound. Nearly continuous marshes occur along the shores of the estuaries behind the barrier islands and around Delaware Bay.

At Cape Hatteras, the Shelf extends seaward approximately 20 mi (33 km), and widens gradually northward to about 68 mi (113 km) off New Jersey and Rhode Island where it is intersected by numerous underwater canyons. Surface circulation north of Cape Hatteras is generally southwesterly during all seasons, although this may be interrupted by coastal indrafting and some reversal of flow at the northern and southern extremities of the area. Speeds of the drift north of Cape Hatteras are on the order of six miles (km) per day. There may be a shoreward component to this drift during the warm half of the year and an offshore component during the cold half. The western edge of the Gulf Stream meanders in and out off Cape Hatteras, sometimes coming within 12 mi (20 km) of the shore, but becomes less discrete and veers to the northeast north of the Cape. Surface currents as high as 4 knots (200 cm/sec) have been measured in the Gulf Stream off Cape Hatteras.

Hydrographic conditions in the mid-Atlantic region vary seasonally due to river runoff and warming in spring and cooling in winter. The water column becomes increasingly stratified in the summer and homogeneous in the winter due to fall-winter cooling of surface waters. In winter, the mean range of sea surface temperatures is 0E - 7EC off Cape Cod and 1E - 14EC off Cape Charles (at the southern end of the Delmarva Peninsula); in summer, the mean range is 15E - 21EC off Cape Cod and 20E - 27EC off Cape Charles. The tidal range averages slightly over 3 ft (1 m) on Cape Cod, decreasing to the west. Within Long Island Sound and along the south shore of Long Island, tide ranges gradually increase, reaching 6 ft (2 m) at the head of the Sound and in the New York Bight. South of the Bight, tide ranges decrease gradually to slightly over 3 ft (1 m) at Cape Hatteras.

The waters of the coastal middle Atlantic region have a complex and seasonally dependent circulation pattern. Seasonally varying winds and irregularities in the coastline result in the formation of a complex system of local eddies and gyres. Surface currents tend to be strongest during the peak river discharge period in late spring and during periods of highest winds in the winter. In late summer, when winds are light and estuarine discharge is minimal, currents tend to be sluggish, and the water column is generally stratified.

4.3.3 South Atlantic Region

The south Atlantic coastal zone extends in a large oceanic bight from Cape Hatteras south to Biscayne Bay and the Florida Keys. North of Florida it is bordered by a coastal plain that stretches inland for a hundred miles and a broad continental shelf that reaches into the ocean for nearly an equal distance. This broad shelf tapers down to a very narrow and precipitous shelf off the southeastern coast of Florida. The irregular coastline of North Carolina, South Carolina, Georgia, and eastern Florida is generally endowed with extensive bays and estuarine waters, bordered by nutrient-rich marshlands. Barrier beaches and dunes protect much of the shoreline. Along much of the southern coast from central South Carolina to northern Florida estuarine salt-marsh is prominent. Most of the east coast of Florida varies little in general form. Sand beaches with dunes are sporadically interrupted by mangrove swamps and low banks of earth and rock.

The movements of oceanic waters along the South Atlantic coast have not been well defined. The surface currents, countercurrents, and eddies are all affected by environmental factors, particularly by winds. The Gulf Stream flows along the coast at 6-7 miles per hour (10-11 km/hr). It is nearest the coast off southern Florida and gradually moves away from the coast as it flows northward. A gyral current that flows southward inshore of the Gulf Stream exists for most of the year north of Cape Canaveral.

Sea surface temperatures during the winter increase southward from Cape Hatteras to Fort Lauderdale, Florida, with mean minimums ranging from 2E to 20EC and maximums ranging from 17E to 26EC. In the summer, the increases are more gradual, ranging north to south from minimums of 21E to 27EC to maximums of 28E to 30EC. Mean sea-surface salinity is generally in the range of 34 to 36 ppt year round. Mean tidal range is just over 3 ft (1 m) at Cape Hatteras and increases gradually to about 6-7 ft (2 m) along the Georgia coast. Tides decrease south of Cape Canaveral to 3 ft (1 m) at Fort Lauderdale.

4.4 Habitat Areas of Particular Concern

Almost all of the estuarine and nearshore waters along the Atlantic coast from Florida to Nova Scotia, serve as important habitat for juvenile and/or adult Atlantic menhaden. Spawning occurs in oceanic waters along the Continental Shelf as well as in sounds and bays in the northern extent of their range (Judy and Lewis 1983). Larvae are carried by inshore currents into estuaries from May to October in the New England area, from October to June in the mid-Atlantic area, and from December to May in the south Atlantic area (Reintjes and Pacheco 1966). After entering the estuary, larvae congregate in large concentrations near the upstream limits of the tidal zone, where they undergo metamorphosis into juveniles (June and Chamberlin 1959). As juvenile menhaden grow and develop, they form dense schools and range throughout the lower salinity portions of the estuary; eventually migrating to the ocean in late fall-winter.

Pollution and habitat degradation threaten the coastal menhaden population, particularly during the estuarine residency of larvae and juveniles. Concern has been expressed (Ahrenholz et al. 1987b) that the outbreaks of ulcerative mycosis in the 1980s may have been symptomatic of deteriorating water quality in estuarine waters along the east coast. The growth of the human population and increasing industrialization in the coastal zone are expected to further reduce water quality unless steps are taken to ameliorate their effect on the environment (Cross et al. 1985). Other potential threats to the coastal menhaden population are posed by offshore dumping of sewage sludge, dredge spoil, and industrial wastes, as well as oil spills. Stout et al. (1981) showed that overall levels of chlorinated hydrocarbons in menhaden products have declined since the late 1960s. Warlen et al. (1977) showed that DDT was taken up by menhaden as a result of their feeding on plankton and detritus.

Many factors in the estuarine environment affect the behavior and well-being of menhaden. The combined influence of weather, tides, and river flow can expose estuarine fish to rapid changes in temperature and salinity. It has been reported that salinity affects menhaden temperature tolerance, activity and metabolic levels, and growth (Lewis 1966, Hettler 1976). Factors such as waves, currents, turbidity, and dissolved oxygen levels can impact the suitability of the habitat, as well as the distribution of fish and their feeding behavior (Reintjes and Pacheco 1966). However, the most important factors affecting natural mortality in Atlantic menhaden are considered to be predators, parasites and fluctuating environmental conditions (Reish et al. 1985).

It is clearly evident that estuarine and coastal areas along the Atlantic coast provide essential habitat for most life stages of Atlantic menhaden. However, an increasing number of people live near the coast, which precipitates associated industrial and municipal expansion, thus, accelerating competition for use of the same habitats. Consequently, estuarine and coastal habitats have been significantly reduced and continue to be stressed adversely by dredging, filling, coastal construction, energy plant development, pollution, waste disposal, and other human-related activities.

Estuaries of the mid-Atlantic and south Atlantic states provide almost all of the nursery areas utilized by Atlantic menhaden at the present time. Areas such as Chesapeake Bay and the Albemarle-Pamlico system are especially susceptible to pollution because they are generally shallow, have a high total volume relative to freshwater inflow, low tidal exchange, and a long retention time. Most tributaries of these systems originate in the Coastal Plain and have relatively little freshwater flow to remove pollutants. Shorelines of most estuarine areas are becoming increasingly developed, even with existing habitat protection programs. Thus, the specific habitats of greatest long-term importance to the menhaden stock and fishery are increasingly at risk.

5.0 DATA SOURCES

Atlantic menhaden landings have been reported from processing plants since 1940 and have been sampled for length, weight, and age since 1955 according to a two-stage cluster sampling design in which fish were sampled weekly from each port where menhaden were processed (Nicholson 1975, Chester 1984, Smith et al. 1987). The frequency of fishery samples and the consolidated nature of the fishery provide an extremely reliable 41-year series of catch at age, ages 0-6+, for estimation of abundance and mortality through VPA (Cadrin and Vaughan 1997). Unfortunately, no independent indices of relative abundance are available to calibrate abundance estimates for the last year of catch:

commercial catch per unit of effort is a biased index because commercial catchability is inversely related to abundance (Schaaf 1975, Ahrenholz et al. 1987a, Vaughan and Smith 1988, Atran and Loesch, 1995) and fishery-independent survey indices are not correlated with abundance (Ahrenholz et al. 1989). In the absence of reliable abundance indices, and therefore of a formal statistical estimator for year-class abundance in the last year of the VPA, ad hoc estimation rules have been used to approximate abundance (Cadrin and Vaughan 1997).

5.1 Commercial Data

The commercial fishery for menhaden consists of a purse seine reduction fishery, which accounts for approximately 90% of the landings, and a bait fishery which exists as a mixed species aggregate bycatch of pound nets, gill nets, and trawl nets, as well as a live bait market. Data used in this analysis are from the Atlantic menhaden reduction fishery and include landings information from 1940 through 1997, fishing effort from 1941 through 1997, and estimated landings in numbers by age (from NMFS biostatistical port sampling) from 1955 through 1997. Data from the bait fishery is limited, therefore landings by the bait fishery have been conservatively estimated at 10% of the total Atlantic harvest for the period 1985-1997.

5.1.1 Commercial Landings

As noted in Ahrenholz et al. (1987a) some fishing on Atlantic menhaden has occurred since colonial times, but the purse seine fishery for reduction began in New England about 1850. Landings and nominal effort (measured as number of weeks a vessel unloaded during the fishing year, vessel-weeks) are available since 1940 (Figure 5.1). Landings rose during the 1940's (from 167,000 to 376,000 mt), peaking during the 1950's (high of 712,000 mt in 1956), and then declined to low levels during the 1960's (from 576,000 mt in 1961 to 162,000 mt in 1969). During the 1970's 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 when meal prices were very low to 402,000 mt in 1981). Landings during the 1990's have varied between 259,000 mt in 1997 and 401,000 mt in 1990. It has been demonstrated, in general, for purse seine fisheries that catch-per-effort and nominal fishing effort are poor measures of population abundance and fishing mortality, respectively (Clark and Mangel 1979). However, there was an approximate linear relationship between landings and fishing effort during this time period (Figure 5.2). Thus, at a rough level, reduction in nominal effort does equate approximately with reduction in landings.

The number of processing plants has declined from more than 20 during the late 1950's to 3 plants during the last four years (1994-1997) (Table 3.4). Only 2 plants are operating in 1998, one in Reedville, Virginia, and another in North Carolina. Similarly, the number of purse seine vessels in the reduction fishery has declined from more than 130 vessels during the 1950's to 20-23 vessels during the period of 1994-1997. In 1998, fifteen vessels were active (Smith et al. 1998), reducing effort by approximately 30%.

Recently, AMAC began summarizing available data on bait landings and instituted a pilot study to sample Atlantic menhaden landings from the bait fisheries along the U.S. East Coast (AMAC 1997). The current levels of bait landings are conservatively estimated at 10% of the total Atlantic harvest on an annual basis for the period of 1985 through 1997 (Table 5.1)

5.1.2 Commercial Discards / Bycatch

Data are not available for the amount of menhaden discarded by other fisheries, however, there are reports of the bycatch of other species within the menhaden fishery. During the 1992 fishing season, bycatch in the menhaden purse-seine net fishery in the Chesapeake Bay was below one percent of menhaden landings, both by numbers of fish (Austin et al. 1994) and by weight of fish (Kirkley1995). However, the number of net sets in which bycatch exceeded one percent did increase when analyzed by weight of fish, rather than numbers of fish and marine invertebrates. Further, Kirkley (1995) noted that the sampling performed in 1992 was conducted at the prevailing resource conditions at that time, and does not assess bycatch relative to a wide range of resource conditions. Obviously, changes in the abundance of striped bass, bluefish, or other species could cause a change in bycatch relative to menhaden, or alter the composition of the bycatch (Kirkley 1995).

5.1.3 Commercial Catch Rates

Catch-per-unit effort was not analyzed because of the general problem of using effort data from a purse seine fishery (Clark and Mangel 1979); that is, effort is not a valid measure of fishing mortality, nor is catch-per-unit effort a valid measure of stock abundance for pelagic schooling species, such as menhaden.

5.1.4 Commercial Mean Weight-at-Age

Mean weight at age of individual Atlantic menhaden were generally high during the late 1950's (when stock abundance was high) and the 1960's (when stock abundance declined to low levels) (Figure 5.3). However, during the early 1970's, the mean weight at age declined sharply, and remained low until the late 1980's. Recently, the mean weight at age has risen to levels approaching those of the late 1950's and 1960's.

Interestingly, exceptionally large Atlantic menhaden were encountered in Chesapeake Bay during summer 1996 (one individual was 423 mm FL, weighing 1.55 kg, and aged by scales to be 7 years old) (Smith and O'Bier 1996). The existence of this school of large, old menhaden suggests a broadening of the older age classes, usually associated with rebuilding of a stock.

5.1.5 Commercial Catch-at-Age

Because of limited age composition data currently available, bait landings were separated into the four geographic areas historically defined for the reduction fishery (New England, 1; Middle Atlantic, 2; Chesapeake Bay, 3; and South Atlantic, 4). Age structure from the reduction fishery for June through September by year and area was used to expand the bait landings in numbers at age for inclusion in the Atlantic menhaden catch-at-age matrix. Hence, catch-at-age estimates from the reduction fishery for the period 1985-97 (Table 5.2) are combined with catch-at-age estimates from the bait fishery (Table 5.3) to create a combined catch-at-age matrix (Table 5.4)

5.1.6 Commercial Catch-at-Age by Area

Age composition of fish in the 1997 reduction landings coastwide (numbers of individual fish) was age-0 (2.5%), age-1 (24.7%), age-2 (42.9%), age-3 (23.8%), and age-4+ (6.1%). Age-2 fish made up 39.8% of the South Atlantic catch, and 43.9% of the Chesapeake Bay harvest, which includes coastal Virginia waters from Chincoteague, VA to Avon, NC. Landings from the Mid-Atlantic area were age-2 (53.1%), age-3 (27.7%), and age-4+ (19.3%). No landings were made in the Gulf of Maine during 1997.

5.2 Recreational Data

A recreational bait fishery exists, yet no data is available to quantify the menhaden removed by this fishery, therefore it is not included in this report.

5.2.1 Recreational Landings

Data not available

5.2.2 Recreational Discards

Data not available

5.2.3 Recreational Catch Rates

Data not available

5.2.4 Recreational Catch-at-Age

Data not available

5.3 Fishery-Independent Survey Data

Sampling for juvenile Atlantic menhaden began in 1955, and in the 1970's sampling activities culminated in extensive coastwide trawl surveys conducted through 1978 (Ahrenholz et al. 1989). A four-stream survey (2 streams in North Carolina and 2 streams in Virginia) was continued through 1986. Ahrenholz et al. (1989) found no significant correlations between the relative juvenile abundance estimates and fishery-dependent estimates of year class strength. However, recent investigation with extant data sets suggest there may be some hope. Several potential indices are discussed below.

5.3.1 Striped Bass Seine Surveys

Maryland Department of Natural Resources (MD DNR) and the Virginia Institute of Marine Science (VIMS) conduct extensive annual striped bass seine surveys in their respective state waters and tributaries to Chesapeake Bay (primarily June through September). Among other fish species, Atlantic menhaden catch per effort (CPE) has recently been made available. A generalized least squares model (GLM) was developed for 1987-1997 from the Maryland seine survey data for Atlantic menhaden (provided by Donald Cosden, Tidewater Administration, Annapolis, MD). The model used ln(C+1) as the dependent variable, and year, month nested in year, and site as independent variables. Variance explained (R^2) was 0.35, highly significant (Pr > F is 0.0001) with sample size of n=2,310. Re-transforming the annual predicted means (LSMEANS), correcting for transformation bias using mean squared error, provides an annual index of Atlantic Menhaden juveniles for the Maryland portion of the Chesapeake Bay. A similar index of juvenile Atlantic menhaden abundance for tributaries to the Virginia portion of the Chesapeake Bay was provided by VIMS (Dr. Herb Austin) based on samples from the lower portion of the rivers where Atlantic menhaden are found. These indices are compared to 1-year lagged estimates of recruits to age-1 menhaden (Figure 5.4)

5.3.2 Beaufort Bridge Larval Index

An index of larval Atlantic menhaden catch-per-effort sampled at a bridge near the NMFS Beaufort

Laboratory since 1986 has been compared with lagged recruits to age 1, as part of the South Atlantic Bight Recruitment Experiment (SABRE), with some success. This index of larval catch-per-effort (CPE), developed by Dr. Stan Warlen (NMFS Beaufort, NC), was compared to 1-year lagged estimates of recruits to age-1 menhaden (Figure 5.5)

5.3.3 SEAMAP Indices

The SEAMAP (Southeast Area Monitoring and Assessment Program) South Atlantic Shallow Water Trawl Survey data was provided through Dr. Charles Wenner. Trawl sampling was conducted from coastal North Carolina (primarily south of Cape Fear River) to northern Florida, during three seasons: Spring (April-May), Summer (July-August), and Fall (September-October). Length data indicate that spring caught menhaden are mostly 120-150 mm FL, summer caught menhaden are 110-170 mm FL, and fall caught menhaden are 130-200 mm. These size ranges indicate a mix of age-0 and age-1 menhaden. A similar GLM was developed for these data by season. Again, ln(C+1) was the dependent variable, while the independent variables were year, region, and year*region. R^2 ranged from 0.11 for the spring model (n=1,031), 0.16 for the summer model (n=775), and 0.22 for the fall model (n=941). All models were highly significant (Pr > F is 0.0001). The re-transformed LSMEAN annual values provide indices of juvenile abundances that are compared to 1-year lagged estimated of recruits to age-1 menhaden (Figure 5.6). There are several problems with using these indices: 1) they are offshore, 2) have short time frames with reduced contrast, and 3) the sizes indicate several ages. The third problem may actually be a plus, since it is difficult to use calibrated VPA's on a single age, which was the original intent of investigating the utility of juvenile indices.

5.3.4 Inter-correlations

Correlations among these indices and with lagged recruits to age-1 menhaden was performed. Only the striped bass indices were statistically correlated with recruits (Maryland index at " = 0.001 and Virginia index at " = 0.097). The Beaufort Bridge larval index was no longer significantly correlated with lagged recruits to age-1 menhaden, and was largely driven (high leverage) by the first two years of the data series (1988-89). Inter-correlations among the indices was intended to test for coherency among them. The Maryland and Virginia seine indices were well correlated (" = 0.020), the Maryland seine index was marginally significantly correlated with the Beaufort Bridge larval index (" = 0.090), and the Virginia seine index was well correlated with the SEAMAP spring index (" = 0.031). Several correlations were just above " = 0.1, Virginia seine index and SEAMAP summer index (0.105), and SEAMAP spring and summer indices (0.128). The AMAC has recommended, through the Commission Management and Science Committee, that power plant impingement data be investigated for a number of marine fish species as a source of calibration indices in VPA tuning. Difficulties in detecting reductions in highly variable biological data have been investigated by Vaughan and Van Winkle (1982) and Vaughan et al. (1986b).

5.3.5 Sampling Intensity

See above descriptions

5.3.6 Mean Weights-at-Age

No fishery independent data available.

5.3.7 Stock Abundance

No fishery independent data available.

5.3.8 Biomass Indices

No fishery independent data available.

5.4 Uncertainties / Precision Estimates

5.4.1 Separable VPA Comparison

Comparative application of separable virtual population analysis (as described in Cadrin and Vaughan 1997) were made with the catch at age matrices in section 5.1.5 (with and without bait landings included) for fishing years 1985-97 and ages 0-5. The results are compared for three variables: 1) Exploitation rate for ages 1-5 (Figure 5.7), 2) recruits to age-1 (Figure 5.8), and 3) mid-year total biomass (ages1-5) (Figure 5.9).

Inclusion of bait landing in the catch matrix suggest slightly lower exploitation rates, somewhat higher estimates of recruits to age-1, and higher estimates of mid-year total biomass. Temporal trends in these estimates are very similar, with and without bait landings included. The differences in the estimates are relatively small.

6.0 RETROSPECTIVE ANALYSES

The Atlantic Menhaden FMP (ASMFC 1992) established six trigger variables to represent different biological aspects that review the status of the Atlantic menhaden stock. The estimated variables are compared to pre-selected warning values (Table 6.1)

Three trigger variables are available soon after the fishing season ends. The first trigger variable is taken directly from the reported landings. The second and third trigger variables (the proportions of age-0's and age-3+ in landings, respectively) are estimated following the computation of catch in numbers at age using the landings and bio-statistical data sets.

Three trigger variables are obtained from virtual population analysis (VPA), recruits to age-1, spawning stock biomass, and percent of maximum spawning potential. VPA results have less accuracy associated with the most recent (1997) estimates, especially the trigger variable for recruits to age-1. To better understand uncertainty in the most recent estimates of these trigger variables from VPAs, an excerpt of a detailed application of retrospective analysis by Cadrin and Vaughan (1997) is presented below.

“The error in estimates of abundance is progressively less in previous years than in the last year of the VPA, provided that catch at age and natural mortality (M) are well estimated and fishing mortality (F) is at least moderate (Jones 1961, Tomlinson 1970, Pope 1972, Ulltang 1977, Megrey 1989). As stated in the menhaden fishery management plan, “trigger estimates for recent years from VPA are subject to large uncertainty, while estimates 2 to 3 years old are more reliable” (ASMFC 1992). Consistency in successive stock assessments can be evaluated by using “historical analysis,” which compares estimates from the most recent assessment with contemporary estimates from prior stock assessments (Sinclair et al. 1985), but historical assessments of the menhaden stock were not conducted with a common estimation rule. Consistency of the current estimation rule can be evaluated by using “retrospective analysis," which recreates a historical series of VPA's with a single estimation rule (Sinclair et al. 1990)."

6.1 Historical Methods

Three Atlantic menhaden management variables derived from VPA (age-1 abundance [R], spawning stock biomass [SSB], and percent maximum spawning potential [%MSP]) were compared among ten reported stock assessments (Table 6.2). The number of historical estimates of each variable differed because some reports did not document all three population estimates.

Consistency of successive stock assessments was measured by comparing historical estimates with revised estimates (from the 1995 VPA), which are more reliable. Inconsistency may result from historical estimation error or inaccurate estimates for prior years in the current VPA (Sinclair et al. 1990). The population thresholds used to define overfishing are subject to some uncertainty because they are also VPA estimates; but they are converged estimates, which are much more certain than current estimates. In comparing current VPA estimates with these overfishing thresholds for an annual assessment of stock status, converged and current estimates are assumed to be consistent. Estimates in the last year (Y_t), and backcalculated years (Y_{t-1}, Y_{t-2}, etc.) were compared with the time series of estimates derived in 1995. Differences between historical estimates and revised estimates were calculated as follows:

$$^{a}R_{t,t+k} = R_{t,t+k} - R_{t,\,1995},$$

where $R_{t,1995}$ = the most recent estimate of recruitment in year t;
$R_{t,t+k}$ = recruitment in year t as estimated when t+k was the last year in the assessment; and
k = is the retrospective lag between year t and the last year of the historical VPA.

For example, $R_{1990,\,1993}$ is the 1993 estimate of 1990 recruitment, which has a three-year retrospective lag (i.e. k = 3). When k = 0, $R_{t,t}$ is an estimate of recruitment for the last year in an assessment and is referred to as a terminal estimate. Historical differences in SSB and %MSP were similarly calculated:

$$SSB_{t,t+k} = SSB_{t,t+k} - SSB_{t,\,1995}$$
$$^{a}\%MSP_{t,t+k} = \%MSP_{t,t+k} - \%MSP_{t,\,1995}.$$

Root mean square (RMS) difference was used as a measure of dispersion of historical estimates from converged estimates for the additive properties of mean square difference. Sample sizes for historical differences were low, because of the limited number of historical stock assessments, but the following retrospective analyses have greater sample size for estimating RMS difference (n>30).

6.2 Retrospective Comparisons

Retrospective analysis was performed in two stages to investigate consistency of both elements of the estimation rule: 1) estimation of fully recruited F by ad hoc methods and 2) estimation of partial recruitment to the fishery at ages 0 and 1 by separable VPA (SVPA; Pope and Shepherd 1982). Both analytical stages assumed that menhaden were fully recruited to the fishery at age 2 and that M was 0.45 for all ages, over the entire time period.

Fully recruited F was approximated by using three alternative ad hoc methods for the first element of the analysis. Conventional catch curves (Beverton and Holt 1957, Ricker 1975, Gulland 1983) and modified catch curves (Chapman and Robson 1960, Robson and Chapman 1961) were used to estimate mortality of the age-5 cohort over the four terminal years of the catch record (i.e. ages 2-5). These two catch-curve methods assumed that F in the current year was similar to F experienced by that cohort over the previous three years. The third ad hoc method, log catch ratios (Ricker 1975, Gulland 1983), derived fully recruited F from the negative log ratio of age-3^+ abundance in the terminal year to age-2^+ abundance in the previous year and assumed that F in the last year was similar to F the previous year. All three ad hoc methods assume that menhaden are fully recruited and equally available to the fishery at age-2^+, which was confirmed through inspection of backcalculated F from the 1995 VPA.

The second element of the assessment, estimation of partial recruitment, was performed by using SVPA on a fixed number of years. For example, a retrospective series of 5-year SVPA's was produced with the following algorithm.

Step 1	SVPA was run on an initial time series of catch-at-age data (e.g. 1995-60) with the appropriate estimate of fully recruited F in the terminal year.
Step 2	Catch data in the starting year (e.g. 1955) were deleted, and catch data from a new terminal year (e.g. 1961) were appended.
Step 3	SVPA was rerun on the revised time series with the appropriate estimate of fully recruited F in the new terminal year.

Steps 2 and 3 were repeated until 1995 was the terminal year.

Significance of retrospective bias was tested with a conventional t-ratio test (H_0: mean difference = 0). Normality was tested by using the Shapiro and Wilk (1965) method. Results of t-ratio tests were confirmed by using nonparametric chi-square and sign tests. Dispersion of retrospective estimates from converged estimates was compared among alternative assessment rules by using RMS of retrospective differences. Retrospective estimates of fully recruited F in terminal years were compared with backcalculated estimates of fully recruited F from the 1995 VPA, as the average of ages 2-5 (weighted by abundance), to derive retrospective differences:

$$ªF_{t,t} = F_{t,t} - F_{t,\ 1995}.$$

Note that there is no k subscript, as there were in the formulae for historical comparisons, because all retrospective estimates of fully recruited F were for terminal years (i.e k = 0). The relative retrospective difference ($ªF_{t,t}/F_{t,\ 1995}$.) was also calculated to remove the magnitude of the estimate from estimates of general inconsistency.

Backcalculated estimates of fully recruited F from the 1995 VPA were used in terminal years to compare retrospective inconsistency of SVPA settings without including retrospective inconsistency from ad hoc estimates of terminal F. The fixed number of years in each series of retrospective SVPA's was varied from three to ten years by using the algorithm described for the five-year example above. Retrospective consistency was compared among the eight series of retrospective SVPA's according to RMS difference of age-1 F estimates. Full recruitment of age-2 and oldest age (6^+) menhaden was confirmed through inspection of backcalculated F at age from the 1995 VPA and was not adjusted for retrospective comparison.

Final SVPA runs were performed with seven years of catch-at-age and catch-curve estimates of terminal F to emulate more realistic inconsistency and describe the general magnitude and direction of retrospective differences. Retrospective estimates of R were derived directly from SVPA terminal estimates of age-1 abundance. SSB was estimated from terminal SVPA estimates of age-3^+ abundance and estimated weight at age of spawners. Percent MSP was calculated according to egg production per recruit (Vaughan 1990, ASMFC 1992). Retrospective differences and relative differences of management variable estimates were log transformed [e.g. log e (R+ constant)] to test bias, and geometric mean square was used to estimate mean square difference because differences had skewed distributions.

7.0 ASSESSMENT RESULTS

7.1 Mortality

7.1.1 Natural Mortality

Natural mortality rates (M) are often difficult to estimate for many fish populations, thus life history analogies often are used in assessments (e.g., weakfish, black sea bass, red snapper, etc.). However, natural mortality has been directly estimated for Atlantic menhaden through an extensive long-term tagging program (Ahrenholz et al. 1991). An initial estimate of M was made by Schaaf and Huntsman (1972) by relating fishing mortality and fishing effort (M=0.37). However, the extensive tagging studies suggested much higher levels for natural mortality: preliminary analyses by Dryfoos et al. (1973) suggested m = 0.52, while Reish et al. (1986) obtained M = 0.50 (averaged over ages 2 and older). The current estimate of M, equal to 0.45, is based on the mid-point of the range of estimates (Ahrenholz et al. 1991), and has been used routinely in Atlantic menhaden stock analyses published in peer-reviewed literature (e.g., Ahrenholz et al. 1987, Vaughan and Smith 1988, Vaughan 1993, Cadrin and Vaughan 1997). For comparison, one of the most commonly used life history appoaches based on maximum age (Hoenig 1983), suggests an M of 0.44 for Atlantic menhaden; this estimate is based on a maximum age of 10 for the species (450,000 specimens aged since 1955). The age-10 Atlantic menhaden were obtained during 1955-1964 when the spawning stock was very robust from two extraordinarily large year classes in the 1950's.

Values attributed to M parenthetically in Section 11.2.3.3. of the Atlantic Menhaden Fishery Management Plan (FMP) (ASMFC 1992) are incorrect, because M = 0.45 was used throughout both Section 11.3.2 and Vaughan (1990). However, some clarification of the difference between instantaneous natural mortality rate (M) and expectation of natural death (v) is needed (Ricker 1975). For a type 2 fishery (natural and fishing mortality operating concurrently), the expectation of natural death is related to the instantaneous natural mortality rate as follows:

$$v = MA/Z,$$

where

$$A = (1-\exp(-Z)), \text{ and}$$

$$Z = M + F.$$

The variable ‘A’ is the actual total mortality rate (proportion dying from all causes), and F and Z are instantaneous fishing and total mortality rates. Instantaneous rates are preferred in fishery science because they are additive (Z = M+F); while proportions are not. The variable ‘A’ does not equal u+v, where ‘u’ is the exploitation rate (u=FA/Z, or proportion dying due to fishing), and ‘v’ is the proportion dying due to natural causes. Hence, while M may be constant (as typically assumed in almost all stock assessments), v varies with fishing mortality. In the case of Atlantic menhaden, with M fixed at 0.45, u (for ages 1-8) has varied between 0.29 and 0.51, and v has varied between 0.25 and 0.30 during the period 1955-1997, with lower values of v associated with higher values of u (Figure 7.1). Age-specific estimates of v range from 0.27 to 0.35 for age-1 menhaden, and 0.16 to 0.25 for age-2 menhaden. Recent higher values for v suggest that a greater proportion of Atlantic menhaden are dying naturally, possibly through consumption by predatory species.

7.1.2 Total Mortality

Total mortality is not directly analyzed. However, total mortality (Z) is calculated internal to the VPA analysis, but has the natural mortality (M) subtracted from Z to obtain fishing mortality (F). Reorganizing the equation above, Z-M=F, and the estimates of fishing mortality are used in the stock assessment.

7.2 Estimates of Stock Size and Fishing Mortality

7.2.1 VPA Calibration

Unfortunately, no independent indices of relative abundance are available to calibrate abundance estimates for the last year of catch: commercial catch per unit of effort is a biased index because commercial catchability is inversely related to abundance (Schaaf 1975, Ahrenholz et al. 1987a, Vaughan and Smith 1988, Atran and Loesch, 1995) and fishery-independent survey indices are not correlated with abundance (Ahrenholz et al. 1989). In the absence of reliable abundance indices, and therefore of a formal statistical estimator for year-class abundance in the last year of the VPA, ad hoc estimation rules have been used to approximate abundance (Cadrin and Vaughan 1997).

7.2.2 Model Results

7.2.2.1 Exploitation rates

Temporal trends in exploitation for juveniles (age 0) have been highly variable, depending both on availability and weather (Figure 7.2). Recent values have been low (as indicated by low values of age 0 menhaden in the landings - trigger variable # 2, see discussion of Management Option 7 in Vaughan and Merriner, 1991). A combination of low mortality and good winter weather during the late 1970's and early 1980's resulted in good recruitment. Exploitation rates on older fish (ages 1-8) have declined over the period 1965 through 1997, with high values occurring during the mid-1960's when stock size was low. This decline, statistically significant at " = 0.002, is partly driven by

decline in fishing mortality on age-1 menhaden, although there are significant declines in fishing mortality on age-2 and age 3-8 menhaden.

7.2.2.2 Population size

Recruitment to age-1 and total population biomass (ages 1-8 at mid-year) are estimated using the Murphy (1965) virtual population analysis approach (Vaughan et al. 1986a, Ahrenholz et al. 1987a, Vaughan and Smith 1988, Vaughan 1990, 1993) (Figure 7.3). Recruitment of Atlantic menhaden to age 1 was high during the late 1950's, with the record recruitment estimated at 15.1 billion recruits in 1959 (from the 1958 year class). Recruitment was generally poor during the 1960's (below 2 billion recruits to age 1), showing recovery during the 1970's to levels comparable to the late 1950's (with of course the exception of the 1958 year class). Preliminary estimates for recruits to age 1 in 1996 and 1997 are below 2 billion menhaden (the warning level for trigger variable #4). Total population biomass was very high in the late 1950's, declined precipitously in the 1960's, and recovered during the 1970's. With the recent poor recruitment, total population biomass (and numbers of fish) has declined somewhat in the most recent years (Figure 7.4). Most of this decline is with young fish, ages 1-2, a direct consequence of the recent poor year classes.

7.2.2.3 Maximum Spawning Potential

Maximum spawning potential (also referred to as static SPR), is inversely related to fishing mortality rate. Although generally calculated as a ratio of spawning stock biomass per recruit, it is more properly related to an index of egg production (Figure 7.5). Trigger #6 (%MSP) for Atlantic menhaden is calculated based on such an index of egg production, and provides lower estimates of %MSP than that based on mature female biomass. Although highly variable, generally higher values of this trigger variable are associated with two temporal periods (1955-61 and 1992-97). Higher values are generally associated with better stock condition (lower fishing mortality). Although the Councils and Commissions have mostly adopted values of 20-40% SPR for definitions of overfishing, these were developed primarily for top predators (generally longer lived with delayed age of first maturity). Atlantic menhaden have only exceeded 20% once during the period 1955-97 (24.1% in 1960), when F was low due to the sheer size of the 1958 year class as age-2 menhaden upon which the reduction fishery has historically exploited. Historical estimates of SPR between 10% and 20% have occurred in 1955, 1958, 1961, 1993, 1994, and 1996. Additionally, Atlantic menhaden have demonstrated that they can produce good to excellent recruitment from much lower values of SPR, especially during the mid to late 1970's and early 1980's when the population was rebuilding (Vaughan 1998).

7.2.3 Precision of Estimates of F & SSB & Fmsy & Bmsy

Management variable estimates from past stock assessments were generally consistent throughout most of the time series, except for the last two years of each assessment, when some historical estimates deviated from revised estimates from the 1995 VPA (Figure 7.6). Terminal estimates of age-1 abundance were greater than revised estimates for five assessments and less than revised estimates for three assessments, but positive historical differences (i.e. historical estimate > revised estimate) were greater. For example, in 1992, recruitment was estimated to be 3.4 billion greater than the 1995 estimate of 1992 recruitment. Estimates converged to within 160 million recruits of 1995 VPA estimates, when the retrospective lag (k) was greater than one year.

Only five terminal estimates of SSB and %MSP were available, including 1995 estimates. Two historical estimates of SSB were greater than revised estimates and two were less than revised estimates. Historical estimates of SSB converged to within 1,500 t of 1995 VPA estimates when k>1 year.

Historical estimates of %MSP were greater than revised estimates for three assessments and less than revised estimates for two assessments. The 1992 estimate of 1991 %MSP (i.e. backcalculated one year) was 3.6, but subsequent estimates of 1991 %MSP were below the overfishing threshold of 3 %MSP. Therefore, an overfishing trigger fired, but it was not detected until two years later. Estimates of %MSP converged to within 0.6 of 1995 VPA estimates when k>1.

7.2.4 Retrospective and Sensitivity Analyses

Conventional catch curves produced the most consistent estimates of fully recruited F among the three ad hoc methods used. Retrospective differences from catch-curve estimates in terminal years ranged from -1.12 to 0.92 (Figure 7.7). The RMS difference was 0.51 and the RMS relative difference was 33% (n = 36). The mean retrospective difference in fully recruited F was not significantly different from zero. Therefore, although terminal estimates were imprecise, they were not biased. Retrospective differences in catch-curve estimates were negatively correlated with backcalculated F from the 1995 VPA (r = - 0.62) (i.e. when F was low, catch-curve estimates were generally greater than revised estimates; when F was high, catch-curve F was generally less than the revised estimate). Retrospective differences in fully recruited F produced opposite inconsistencies in SSB and %MSP. For example, in 1993, catch-curve F was greater than the revised F (Figure 7.7), and initial VPA estimates of SSB and %MSP were less than revised estimates (Figure 7.6). Alternative methods of estimating fully recruited F produce even greater inconsistency. The RMS retrospective difference from modified catch curves was 0.60 (49% relative difference), and log catch ratios produced a RMS difference of 0.61 (52% relative difference) (n = 36 for both methods).

Retrospective differences in estimates of age-1 F from SVPA ranged from -0.59 to 0.45 for all retrospective SVPA's and were not significantly different from zero (n = 31 for each series). RMS difference was minimized when seven years of catch-at-age data were used and increased regularly as the number of years deviated from seven (Figure 7.8). The RMS retrospective difference for estimates of age-1 F was 0.13 (33% relative difference) with backcalculated values of fully recruited F and increased to 0.18 (45% relative difference) with catch-curve estimates (Figure 7.9).

Retrospective differences in age-1 abundance ranged from -2.4 billion to 11.5 billion individuals in terminal years (Figure 7.10). There was no significant bias in log-transformed differences, and the RMS difference was 1.2 billion recruits (n = 34). The RMS relative difference for estimates of age-1 abundance was 46%.

Retrospective differences in terminal SSB estimates ranged from -72,000 mt to 448,000 mt (Figure 7.11). The large positive differences in 1962 and 1963 SSB were primarily due to large negative differences in fully recruited F (Figure 7.7). Log-transformed retrospective differences were not significantly biased, and the RMS difference was 9,000 mt SSB (n =34). The RMS relative difference for estimates of SSB was 33%. Retrospective differences in %MSP ranged from -5.5 to 19.5 in terminal years (Figure 7.12).

The RMS difference was 4.7 %MSP, and there was no significant bias in log-transformed differences (n = 34). The RMS relative difference for estimates of %MSP was 106%, because inconsistencies were larger than the estimated level of %MSP. Retrospective differences in %MSP were negatively correlated with retrospective differences in fully recruited F (r = - 0.79).

7.2.5 Significance of the 1951 and 1958 year classes

The purpose of this section is to explore the effect that two apparently rare, but very high, recruitment years have on the interpretation of the current status of the Atlantic menhaden stock. In development of estimates for the six trigger variables, recruits to age 1 (R1) is estimated for 1955 through 1997, with the usual warning that estimates in the most recent years have greater uncertainty associated with them (Cadrin and Vaughan 1997). The estimate of R1 for the 1958 year class (age 1 in 1959) is 15.1 billion menhaden, considerably larger than that estimated for any other year for which data are available (7.3 billion age-1 menhaden in 1957 is the next highest). The median value for recruits is 3.1 billion age-1 menhaden for the period 1955-1997, and the average value is 3.7 billion age-1 menhaden (skewed upwards from the median by the 1958 year class). The interquartile range (representing the middle 50% of the estimated values) varies between 2.2 and 4.7 billion age-1 menhaden. This range would suggest what might be considered ‘moderate’ values of recruitment. Values of recruits above 4.7 billion age-1 menhaden are ‘very good’ to ‘excellent’.

7.2.5.1 Estimating the 1951 Year Class

The relatively high population estimate for age-4 menhaden in 1955 suggested that the 1951 year class (age-1 in 1952) may have been at least as strong as the 1958 year class. Mean age-specific F for ages 1-3 during 1955-1959 were applied for the respective ages in the back calculations (F1 = 0.398, F2 = 1.164, and F3 = 0.693). Back calculated recruits to age-1 menhaden for 1952-1954 augment those directly estimated from the VPA (Figure 7.13).

7.2.5.2 Reconstructed Landings and Spawning Stock Biomass

If a ‘more normal’ recruitment to age-1 from those two year classes is assumed (based on mean estimated recruits to age-1 for 1955-1958), then projecting these recruits through the cohort’s life span (using estimated fishing mortality rates) would allow estimation of landings and spawning stock biomass under these altered hypothetical conditions. Actual landings were compared to the hypothetical landings (smaller recruits to age-1 in 1952 and 1959), suggesting that some of the high landings obtained in the mid 1950's would still have been available without the two extremely strong year classes (1951 and 1958), although the landings in the late 1950's and early 1960's would have been much less under hypothetical conditions (Figure 7.14).

Peak values of spawning stock biomass (above 300,000 mt) were only attainable because of these strong year classes, although spawning stock biomass between 100,000 to 200,000 mt would have been present and still be the highest in the time series (Figure 7.15). The estimate for spawning stock biomass in 1997 (keeping in mind the retrospective problem), is very similar in biomass to that of 1958 compared to 89,000 mt in 1997). Further, the smallest spawning stock biomass estimated during the latter half of the 1950's produced the largest year class during this period.

7.2.6 Spawner-Recruit Relationship and Survival

This section further investigates aspects of recruitment to age-1 and spawning stock biomass. Assuming that spawning stock biomass is proportional to eggs produced, survival (S) is defined as

the ratio of recruits to age-1 (R_1) to spawning stock biomass (SSB). Survival from spawning stock biomass to recruitment to age-1 can be indexed for 1955-1996 by:

$$S_0 = R_1/SSB.$$

The pattern of survival shows generally low survival during the late 1950's and early 1960's (generally high SSB), with the exception of the 1958 year class (Figure 7.16). Particularly high survival is noted during the mid 1970's when the menhaden stock was rebuilding. Only in the last few years is low survival again noted, on par with the 1950's and early 1960's.

7.2.6.1 Ricker Spawner-Recruit Curve

Weak dependancy of recruits to age-1 on spawning stock biomass for Atlantic menhaden has been noted (e.g. Ahrenholz et al. 1987a, Vaughan and Smith 1988). However, the spawner-recruit data can be fit to the Ricker (1975) spawner recruit curve (with and without the 1958 year class) (Figure 7.17). Parameter estimates for the Ricker curve are:

R = "P*exp(-$P)

where R (as millions of age-1 menhaden) is recruits and P is spawning stock biomass (as thousands of mt of age 3-8 mature females). The parameters " and $ are estimated by nonlinear regression techniques. Although the mathematical curve shown has poor explanatory powers, the nonlinear parameter ($) is significantly different from 0 (i.e. the asymptotic 95% confidence interval does not include zero).

Estimates for the full data set are (asymptotic standard error in parentheses): " = 130.2 (23.2) and $ = 0.0087 (0.0017). Similarly, estimates for the data set with the 1958 year class excluded are: " = 121.7 (19.6) and $ = 0.0093 (0.0017). Spawning stock that produces theoretical maximum recruitment occurs at P = 1/$, or 114,900 mt with the full data set and 107,500 mt with the 1958 year class excluded. However, the maximum recruits to age-1 menhaden that would be produced by these spawning stocks are 5.5 and 4.8 billion age-1 menhaden recruits, respectively. Expected survival (SE) can be calculated from the predicted R1 from historical estimates of SSB (Figure 7.18). Survival during the late 1950's may be low because spawning stock was above that which produce maximal recruitment.

Myers et al. (1994) suggest that the spawning stock biomass that produces one-half maximum recruitment may serve as a biological reference point (possible trigger warning level) for a stock. Based on the fitted Ricker curve (all data), the value for Atlantic menhaden is estimated at 26,700 mt. Although this value is above the current trigger warning value for Atlantic menhaden (17,000 mt), it is still well below recent estimated values of spawning stock biomass (15,700 MT in 1986 was the last time a value lower than either of the above trigger values occurred).

The statistical properties of recruits to age-1 Atlantic menhaden are summarized for different ranges of spawning stock biomass (Table 7.1). In addition to mean values, nonparametric statistics are calculated that are less sensitive to non-normal (highly skewed) distribution of R_1 due to the remarkable strength of the 1958 year class. These statistics include the median (or 50th percentile), 25th and 75th percentiles. The interquartile range, defined by the 25th and 75th percentiles, is a nonparametric analog to variance. Although the mean value of R_1 trends upward with increasing minimum spawning stock biomass, this is due to the reduced sample size and increasing effect of the recruits to age-1 in 1959 (1958 year class). It does not demonstrate an increased likelihood of improved recruitment. In fact, no trend is evident in the median value (though it actually declines insignificantly for the highest range presented for SSB) or lower limit of the interquartile range (25th percentile) of R1. There is some indication of improvement in the upper limit of the interquartile range (75th percentile) with increasing spawning stock biomass at or above its historic median level (40,400 mt).

7.2.6.2 Relative Survival

Relative Survival (S_R) was calculated such that it adjusted observed survival by dividing by predicted survival (based on Ricker spawner-recruit curve) and rescaling to 0 by subtracting 1 ($S_R = 0$ at $S_0 = S_E$):

$$S_R = (S_0/S_E) - 1.$$

Estimates of relative survival suggest that the period from 1955 through 1997 was very noisy (in a statistical sense) with two periods of particular interest (Figure 7.19). The period from 1973-1977 was characterized by better than expected survival to age-1. There appear to be two periods with at least four consecutive years of worse than expected (negative) relative survival: 1 (1962-1965 and 2) 1993-1996. Because spawning stock biomass has been filtered out of these calculations, environmental conditions such as increased predation, decreased available food, or other physical driving variables (e.g.

Ekman transport, river flows, pollutants, etc.) probably contribute to the recent decline in recruitment.

7.2.7 Event Tree Projections of R_1 and SSB

With the recent acquisition of AMPRO, Inc., by Omega Protein (formerly Zapata Protein), 7 of 20 vessels active in the Virginia fleet will not fish during the 1998 fishing year (representing about 71% of the average landings for 1994-1997 based on years fished). The purpose of the following projections (simulations) was to evaluate the potential long-term impact of this reduced fishing effort on the health of the Atlantic menhaden stock. Recent trigger reports (Vaughan 1997, 1998) to the Atlantic Menhaden Advisory Committee raise concern over the low estimates of recruitment to age-1. This is one of three trigger variables estimated by VPA, and therefore subject to retrospective problems (Cadrin and Vaughan 1997). In this section, the results from Atlantic menhaden population projections are compared for varying levels of fishing mortality using the simulation approach described in Vaughan (1993). The varying levels of fishing mortality used in the projections represent different levels of fishing hypothesized for the Virginia reduction fleet. Projections are based on recent four-year history (100% Virginia fishing mortality for the recent period 1994-1997), three intermediate levels to represent reduced fishing by the Virginia fleet (70%, 80% and 90% of fishing mortality associated with the Virginia fleet during 1994-1997), and no fishing by the Virginia fleet (0% of F associated with the Virginia fleet for the period 1994-1997).

7.2.7.1 Projection Approach

The Atlantic menhaden population is projected for 25 years using the event tree approach for the spawner-recruit relationship. Conditional probabilities of recruitment to age 0 given spawning stock biomass were estimated directly from the historical estimates of spawning stock biomass (1955-1996) and subsequent recruits to age-0 (1956-1997) were obtained from VPA (Murphy approach estimates without calibration to fishery independent estimates of population abundance) (Table 7.2). Fishing mortality was obtained from the mean estimates of age-specific F for the period 1994-1997 (When only Virginia and North Carolina plants have been active in the reduction fishery) from the most recent Murphy-based VPA. Estimates of F associated with the Virginia fleet were estimated from the proportion of landings in numbers at age from the Virginia plants relative to the coastwide estimates (Virginia and North Carolina plants combined during 1994-1997). Estimates of age-specific F were then calculated to reflect anywhere from 0% to 100% of the landings at the Virginia plants. These estimates of F form the basis of the projections (Table 7.3).

Projection years are for 1996 through 2020 (25 years). Natural mortality (M=0.45/yr) was assumed constant for the duration of the projections. As noted in Ahrenholz et al. (1987a), estimates of M varied in the early literature on Atlantic menhaden between M=0.37 (Schaaf and Huntsman 1972), M=0.52 from preliminary tag-recovery analysis (Dryfoos et al. 1973), and M=0.50 from a more extensive tag-recovery analysis (Reish et al. 1985). The mean of the range (M=0.45) has ben used routinely in Atlantic menhaden assessments beginning with Ahrenholz et al. (1987a). As noted by Ahrenholz et al. (1991), the long-term tagging studies on Atlantic menhaden have made "major contributions to our knowledge of the biology and population dynamics of both the Atlantic and gulf menhaden." Almost 438,000 juvenile Atlantic menhaden were tagged coastwide between 1970 and 1986. The population age structure for 1995 as estimated by VPA was used as the initial age structure for the projections. Parameters from annual von Bertalanffy growth equations and weight-length relations were averaged for the most recent five (5) year period (1993-1997), and they were used to represent growth for the population projections.

7.2.7.2 Projection Results

The 25 year projections are repeated 100 times with underlying error (estimated from historical data), and the annual median and interquartile range are plotted for the fourth and fifth triggers (Figures 7.20-7.24) for the event tree simulation approach. Because F is directly related to % MSP, % MSP is not simulated in these projections. These projections are for comparison only, and are not intended as predictions of future trends. The projections suggest no significant difference in recruitment to age 1 whether there is no fishing by the Virginia reduction fleet or at the mean level for 1994-1997. On the other hand, spawning stock biomass will be considerably higher when no fishing by the Virginia fleet occurs compared to the mean level for 1994-1997. Intermediate levels of spawning stock biomass are obtained for reduced levels of fishing by the Virginia reduction fleet.

This event tree approach suggests that recruitment and spawning stock biomass are mostly decoupled (at least for the historic range of observed SSB and recruitment), and that only changing environmental conditions can assure improved recruitment.

7.2.8 Environmental Relationships

Two general areas of environmental relationships are discussed briefly in this section as they may relate to recruitment success or failure of Atlantic menhaden. These include species interactions (e.g., predator-prey relationships) and physical factors (e.g., temperature, river inflow, etc.).

7.2.8.1 Predator-Prey

Predator-prey relationships of Atlantic menhaden with those that feed upon them and that which they feed upon will effect the dynamics of the Atlantic menhaden stock. The recent resurgence of striped bass to historically high levels, in particular, could lead to decreased survival by juvenile menhaden.

Striped bass seine CPE (Maryland and Virginia) were compared with Atlantic menhaden survival (R1/SSB) (Figure 7.25). Next, estimates of striped bass recruits to age-1 and population size (ages 1-15) were also compared to Atlantic menhaden survival (Figure 7.26). Whether there is a cause and effect between these species, as might be suggested by these figures, is difficult to ascertain. Statistical analysis may only demonstrate relationships among variables, and not cause and effect between them. Other predatory species, such as bluefish and weakfish, are also undergoing changes in their populations. Results of the most recent assessment on weakfish presented to the SARC (NEFSC 1998) suggest a strong increase in recruitment beginning with low values about 1990. Other important prey species, such as bay anchovy, shad, and river herring also appear to be either in decline or at low levels (Miller et al. 1996). There are no fisheries on bay anchovy, which is an important forage species for striped bass.

Speculations may also be made concerning food availability for Atlantic menhaden both coastwide and within the Chesapeake Bay. It would be of great use if a time series of such data were available for statistical comparison.

7.2.8.2 Physical Factors

Similarly, changes in weather patterns and introduction of pollutants can have significant effects on the survival of larval Atlantic menhaden. Govoni (1997) has demonstrated an inverse relationship between changes in Mississippi River flow with changes in gulf menhaden recruitment to age-0. River inflow to the Chesapeake Bay data (measured at the fall line for selected rivers including the Susquehanna, Choptank, Patuxent, and Potomac rivers in the Maryland portion and Rappahannock, James, Pamunkey, Mattaponi, and Appomattox rivers in the Virginia portion) were obtained and compared to lagged Atlantic menhaden recruits to age-1 (Figure 7.27). Unlike gulf menhaden, this relationship was not statistically significant. An approximated break out of contribution of recruits by large geographic areas to the coastal stock is 15% from north of the Chesapeake Bay, 40% from the Chesapeake Bay, 35% from North Carolina Bays north of the Cape Fear River, and 10% from south of the Cape Fear River (D. Ahrenholz, pers. Comm.). Hence, one of several reasons that this relationship is not demonstrable statistically is the relative contribution of Chesapeake Bay to the stock.

Similar comparisons were made with winter indices (Nov.-Mar.) Of the El Nino (3.4 anomaly), the North Atlantic sea surface temperature (SST, for the region between 5E and 20E North latitude of the Atlantic Ocean), and the North Atlantic Oscillation (Hurrell 1995, 1996). Inter-correlations among these physical factors were explored with respect to recruits to age-1 menhaden (Table 7.4), but other than inter-correlations found among the physical factors (both direct and based on differencing) none were found to be correlated with Atlantic Menhaden recruitment. That does not mean that these variables do no contribute to early survival of juvenile Atlantic menhaden, but that any effect they may have is sufficiently obscured by confounding factors that no clear signal can be determined.

8.0 BIOLOGICAL REFERENCE POINTS

8.1 Overfishing Definition

An explicit overfishing definition for Atlantic menhaden has not been defined. However, based on a set of six “trigger” 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.

These data types were selected for their importance as indicators of the existing condition of the stock and fishery, relative ease of measurement, and clarity of meaning within the community of those fishing industry representatives and state and federal fishery management personnel concerned with management of the Atlantic menhaden fishery. The six variables are considered as thresholds which, when met, call for specific AMMB/AMAC 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 AMMB/AMAC in determining appropriate responses.

When AMAC meets each spring, data relative to each trigger will be evaluated, along with other available information. Should the AMAC determine that one or more triggers have been reached, but ancillary information does not indicate that significant stock or fishery problems exist, the AMAC will advise the AMMB that fishing restrictions are not recommended. If, however, the AMAC analyses indicate substantive problems within the stock or fishery, the AMAC report to AMMB will recommend regulatory actions to address the problems. The AMMB will consider the AMAC report and forward its recommendations to the ISFMP Policy Board and the Commission, which has the statutory responsibility to make recommendations to the states. The ISFMP Policy Board or the Commission will forward specific requirements and/or recommendations to the states in time for implementation by the next fishing season. The process is illustrated in Figure 6.1.

As part of its annual review, AMAC will consider implementation status of regulatory measures which may be developed and recommended under this management process. The AMAC report will include an evaluation of state actions to implement regulations recommended by the Commission to the states.

Whenever a state considers implementation of rules for the menhaden fishery which do not result from the AMAC/AMMB review process, those rules should be submitted to the Commission for review and comment. Such review should foster greater interstate cooperation and more effective management of the resource.

8.2 Atlantic Menhaden Stock and Fishery Triggers

The following six triggers or warning variables were selected to represent landings and key biological aspects of the Atlantic menhaden stock that would indicate its condition (Table 6.1). All of the data for the triggers are derived from the menhaden purse seine reduction fishery. The AMAC will evaluate data relative to each trigger at its annual meeting. In the committee's discussions, all six triggers and any relevant ancillary information will be considered. The committee will forward its findings and recommendations to the AMMB.

Estimates of the first variable, landings in weight, are available within a week after the end of the fishing season (end of February). Estimates of the second and third variables [proportion of age-0 and adult (age 3+) menhaden in the landings, respectively] are available from estimated catch-at-age data a few months later, after processing fish samples for size and ageing scales at Beaufort. However, these triggers are subject to the potential for "false firings" because values beyond the thresholds do not necessarily imply that something is wrong with the Atlantic menhaden stock. Ancillary information (such as weather, new rules, economic conditions) is important to judge whether exceeding any of these triggers requires some recommendation from the committee for initiation of management actions to rectify the apparent problem.

Estimates of the last three variables are obtained from virtual population analysis (VPA) on estimated catch-at-age data, and can be completed within a few weeks of availability of such data. These triggers are also subject to false firings, but for a different reason than the first three triggers. Trigger estimates for recent years from VPA are subject to large uncertainty, while estimates more than 2 to 3 years old are more reliable. This situation exists because of the convergence properties of back-calculations. If the estimates are considered to be reliable, then firing of any of these triggers suggests a problem in the Atlantic menhaden stock, which must be addressed by the AMMB and AMAC.

Generally, the 25^{th} or 75^{th} percentile of the historical data from 1965 through 1990 was used to select the particular trigger value for each variable. The value of the third trigger is based on historical data from 1955 through 1990, because the scenario of concern (recruitment overfishing) occurred in 1960-1961. The first, fourth, fifth, and sixth variables are triggered if the respective values fall below the 25^{th} percentile (or similar value). The second variable is triggered if the respective value exceeds the 75^{th} percentile. The third variable is triggered at about twice the 75^{th} percentile; this trigger was last fired during the stock collapse of the early 1960s.

8.2.1 Landings in Weight (Trigger #1, Figure 8.2)

Landings were selected because they could be an indicator of a change in stock abundance. An awareness of whether economic conditions have affected fishing activity, as occurred in 1986 when a major plant closed, would be important ancillary information. Catch-per-unit effort was not selected because of the general problem of using effort from a purse seine fishery (Clark and Mangel 1979); that is, effort is not a valid measure of fishing mortality, nor is catch-per-unit effort a valid measure of stock abundance for pelagic schooling species, such as menhaden. This trigger fires if landings fall below 250,000 mt.

8.2.2 Proportion of Age-0 Menhaden in Landings (Trigger #2, Figure 8.3)

The proportion of age-0 menhaden in the landings was selected because of two concerns. First, very high harvest of the youngest fish, in general, reduces potential yields based on a yield-per-recruit or growth overfishing argument. The number of fish in a population declines with increasing age due to both natural and fishing mortality, while weight of an individual fish increases with age. Initial growth is rapid and then tends to level off. Population biomass, represented by the product of numbers and weight, typically increases during the period of rapid growth, peaks, and then declines as growth levels off. Growth overfishing refers to the catching of fish at ages significantly below the age where biomass peaks. Second, very high harvest of the youngest fish in years of poor recruitment, although they may be readily available for harvest due to good weather or other factors, may reduce subsequent spawning stock biomass. This threshold is reached if more than 25% of the menhaden harvested (by number) are age-0 fish.

8.2.3 Proportion of Adults in Landings (Trigger #3, Figure 8.4)

The proportion of adult (age 3+) menhaden in the landings was also selected because of two concerns. First, short-term reduction in adult spawning stock may be indicated. This approach addresses the concern of recruitment overfishing, which can occur if the spawning stock is insufficient to produce adequate numbers of recruits to the stock. Although the relationship between spawning stock and subsequent recruits for menhaden is weak, as spawning stock is reduced the probability of poor recruitment increases. Second, large landings of adults relative to subadults may indicate lack of availability of subadults (i.e., recruitment failure), as occurred in 1961 and 1962. This trigger is reached if more than 25% of the menhaden in the catch (by number) are age 3 and older.

8.2.4 Recruits to Age-1 (Trigger #4, Figure 8.5)

The estimates of recruits to age-1 was selected because it indicates directly what will be available to the fishery, especially one year later at age-2, the age class upon which the fishery largely depends. The problem with using this variable, as indicated above, is the great uncertainty with estimating recruitment for the most recent years. A major concern with this variable is that several poor recruitment years may occur consecutively. Such a situation, coupled with high fishing mortality, will subsequently result in reduced spawning stock biomass, and potential recruitment overfishing. An estimate of less than 2 billion age-1 menhaden will cause this trigger to fire.

8.2.5 Spawning Stock Biomass (Trigger #5, Figure 8.6)

Estimates of female spawning stock biomass were selected to represent the availability of spawners in sufficient quantity to produce adequate recruitment. Although the relationship between menhaden spawning stock biomass and subsequent recruits is poor, it is generally understood and accepted that the probability of poor recruitment will increase when spawning stock biomass falls to some low level. What that low level might be is poorly known for menhaden and generally unknown for most fish stocks. Again, the most recent estimates (1-2 yr) of spawning stock biomass must be viewed with uncertainty. A spawning stock biomass below 17,000 mt will cause this trigger to fire.

8.2.6 Percent Maximum Spawning Potential (Trigger #6, Figure 8.7)

Estimates of percent maximum spawning potential (%MSP), based on fishing mortality rates estimated in the VPA, are widely used by the regional fishery management councils to define overfishing (e.g., recruitment overfishing). This index is equal to the ratio of spawning stock biomass at the current fishing mortality rate (F), divided by the spawning stock biomass calculated when F is equal to 0 (unfished spawning stock). As the spawning stock size decreases relative to the unfished state, the risk of recruitment failure increases. Whether there is a threshold below which recruitment failure is certain or a gradual increase in risk of recruitment failure with decreasing spawning stock size is unknown. These ratios are calculated under the assumption of equilibrium; that is, annual age-specific estimates of F are used to project a fixed number of recruits throughout their lifespan, and spawning stock size in biomass or index of egg production is cumulated. The index of egg production for Atlantic menhaden is based on the egg-length relation provided in Lewis et al. (1987). These estimates compare equilibrium female spawning stock biomass with and without fishing mortality. These estimates are useful for determining whether fishing mortality is too high to permit adequate survival of recruits to spawning age. As above, recent estimates of fishing mortality from the virtual population analysis are quite uncertain. This trigger will fire if the %MSP falls below 3%.

8.3 Abundance, MSY, and Present Condition

Although landings have generally recovered from the depressed levels of the 1970's, they have not returned to the levels attained during the late 1950's when they averaged 1,377.9 million pounds (lb) (625,000 mt) during the 1955-1959 fishing years (Smith et al. 1987). During the 1980's, the mean population was about 7.3 billion fish, compared to less than 5.6 billion during the 1970's, and less than 3.9 billion during the 1960's (Vaughan 1990). Although the mean population for the 1980's is only slightly smaller than that for the 1950's (8.1 billion fish during 1955-58, excluding 1959), recent landings in weight have been considerably less (a mean of 381,400 mt for the 1980's -vs- 616,600 mt for 1955-58). The fact that landings (in weight) have declined since the 1950s while the population (in numbers) had nearly recovered in the early 1990s to its previous size resulted from changes that have occurred in geographic and seasonal fishing patterns and smaller mean weight at age.

Estimates of MSY of 1,068.1 million lb ± 191.8 million lb (484,000 mt ± 87,000 mt) at a mean F of 0.54/yr (34% annual exploitation rate) were obtained from a generalized production model for the 1955-1986 period (Vaughan 1990). Levels of landings (in weight) equaling those of the 1950s are unlikely to be attained over an extended period given the present structure of the fishery. However, during the 1980s, landings averaged 753.1 million lb (342,000 mt), with a mean F averaging 1.15/yr (57% annual exploitation rate). Although this pattern of fishing might suggest that greater landings would be available with less effort, plant location and geographic restrictions on fishing limit, to a considerable degree, the ability of the fishery to attain landings comparable to those of the late 1950s.

Historical MSY estimates since the early 1970s have shown no trends, ranging between 815.7 million lb (370,000 mt) and 1,256.6 million lb (470,000 mt). Sufficient recruitment to attain MSY has been available since 1975. With considerable variation about the fitted spawner-recruit curves, it appears that managing the fishery to maintain large numbers of spawners in order to provide a large fishable stock, would prove ineffective. This situation prevails because environmental conditions appear to outweigh spawning stock size in affecting subsequent recruitment (suggested by considerable scatter in the spawner-recruit relation and both low and high recruitment concurrent with low spawning stock size). However, the Ricker spawner-recruit relationships are marginally significant, and age-3 spawners are of great importance to the spawning stock. Thus, further increasing the number of spawners (age-3 and older) may guard against a possible stock collapse brought on by heavy fishing during a period of poor recruitment.

The modern purse-seine fishery for Atlantic menhaden has a high dependency on pre-spawners (age-2 and younger fish), so large fluctuations in year-to-year availability and catches are to be expected. To enhance the stability of the resource and fishery, it is desirable that a wide range of age classes contribute significantly to the fishery. Whether landings greater than 1 billion lb (454,000 mt) are attainable is questionable because of changes in plant locations and fishing patterns.

9.0 RECOMMENDATIONS AND FINDINGS

Under the 1992 Revision of the Commission Atlantic Menhaden Fishery Management Plan (FMP), adopted in September 1992, management of the fishery is subject to an annual review. This review is conducted each spring by the Atlantic Menhaden Advisory Committee (AMAC), focusing on three topics:

1. Condition of the stock and fishery as determined by analysis of data for the six triggers in the FMP and ancillary information,

2. Allocation of menhaden for harvest under Internal Waters Processing (IWP) requests, and

3. Implementation of the FMP relative to other areas of concern, including state management actions which may affect the fishery.

The annual AMAC report to the Atlantic Menhaden Management Board (AMMB) considers each of the above topics and contains specific recommendations relative to each area of concern.

9.1 Current Condition of the Stock and Fishery

Catch in numbers and weight of Atlantic menhaden are summarized in Table 2.1, and Murphy VPA estimates of population size are summarized in Table 2.5. The 1992 FMP established six trigger variables to represent different biological aspects that review the status of the Atlantic menhaden stock (Table 6.1; Figures 8.2-8.7). The estimated variables are compared to preselected warning values. Two trigger values in 1997 fell below their thresholds.

Three trigger variables are available soon after the fishing season ends. The first trigger variable is taken directly from the reported landings. The second and third trigger variables are estimated following computation of catch in numbers at age using the landings and biostatistical data sets.

Three trigger variables are obtained from virtual population analysis (VPA) and have less accuracy associated with the most recent (1997) estimates, especially the trigger variable for recruits to age-1. To better understand uncertainty in the most recent estimates these trigger variables from VPAs, a detailed application of retrospective analysis to Atlantic menhaden is presented in Cadrin and Vaughan (1997).

9.1.1 Landings in Weight

The estimated landings for 1997 of 259,140 mt does not exceed (fall below) the trigger value of 250,000 mt. Landings for Atlantic menhaden decreased from 1996 (292,900 mt) by about 12%. Cool and windy weather during May and early June resulted in poor early season catches of Atlantic menhaden in Chesapeake Bay; however, by mid-June, the weather moderated and catches improved (Smith et al. 1998). High landings (1990-91) from the Gulf of Maine were supported largely by the strong 1988 year class; landings have not been recorded from that area for several years.

Late in 1997, Ampro Fisheries in Reedville, VA was purchased by Zapata Protein (now Omega Protein). Omega Protein will operate a fleet of 13 purse seine vessels at the one remaining processing plant in Reedville, VA in 1998. This will result in a significant reduction in effort in 1998, because there were 20 vessels working out of two Virginia plants in 1997.

9.1.2 Proportion of age-0's in Landings

The estimated value of 2.5% age-0 menhaden in the landings in 1997 does not exceed the trigger value of 25%, and is below the 25th percentile for 1965-90.

9.1.3 Proportion of Adults (age 3+) in Landings

The estimated value of 29.9% adult menhaden in the landings in 1997 does exceed the trigger value of 25%, This trigger value indicates that recent recruitment is poor, since older menhaden now represent a greater proportion of the landings.

9.1.4 Recruits to age-1

The estimate for 1997 of 1.4 billion age-1 menhaden does exceed (fall below) the trigger value of 2.0 billion age-1 menhaden. The recent three-year running average of 1.9 billion age-1 menhaden is also below the trigger value. Note that the initial estimate of 1.1 billion age-1 menhaden for 1996 has risen slightly to 1.4 billion age-1 menhaden with an additional year of data from the 1995 cohort. Also, the estimate of age-1 menhaden in 1994 (1993 cohort) is now estimated at 2.4 billion age-1 menhaden (the initial estimate of this trigger in the 1995 Annual report was 1.7 billion age-1 menhaden, below the trigger threshold). In addition to the poor recruitment to age-1 in 1996 (1995 cohort), population estimates for age-2 in 1997 remain low.

9.1.5 Spawning Stock Biomass

The estimate for 1997 of 89,000 mt does not exceed (fall below) the trigger value of 17,000 mt, and is above the median of 26,700 mt for 1965-90. The recent three-year running average is quite high at 73,000 mt. The initial estimate for 1997 is the largest value estimated since 1962, and is similar to the spawning stock biomass estimate for 1958 (88,700 mt), which produced the largest number of age-1 recruits (15.1 billion age-1 menhaden) on record.

9.1.6 Percent Maximum Spawning Potential

The estimate for 1997 of 8.5% does not exceed (fall below) the trigger value of 3%. This trigger variable compares the weight of mature females in the stock with fishing mortality as estimated from the VPA to the weight of mature females that would be in the stock with no fishing mortality (same number of recruits). Various life history parameters (natural mortality, growth, and maturity schedule) are assumed the same between the two scenarios. The recent three-year running average is at 10.6%, which exceeds all values during the 1965-90 period

9.1.7 Conclusion

Recruits to age-1 in 1996 and 1997 resulted in values below the threshold. The other trigger that fired was the proportion of adults (age 3+) in the landings; however, this firing confirms recent poor recruitment and is not an additional source of concern. The three-year running average (1.9 billion fish) of age-1 menhaden is below the threshold. Further, there has been a downward trend in recruitment since 1985, as noted last year (AMAC 1997). Nonetheless, spawning stock has continued to grow and is at its highest level since 1962, indicating that fishing pressure is not the cause of low recruitment. In fact, there is some linkage in the historical database between very high spawning stock biomass and depressed recruitment values (Vaughan 1997). Historical data collected since 1955 indicate that environmental factors have more influence in controlling menhaden recruitment success than spawning stock biomass (see section 7.2.8). While the spawning stock is currently healthy, spawning stock biomass will decline over the next few years, unless the trend in recruitment is reversed. There has been a general decline in the stock size (numbers and biomass) during this decade, concurrent with the decline in recruitment.

Because of company consolidation, the 1998 Virginia fleet will be reduced by 35% (from 20 to 13 vessels). Processed harvest, based on an analysis of recent individual vessel performance, will be reduced by about 30% in 1998. A potential limiting factor will be the processing capacity of the remaining Virginia reduction plant.

Concern has been expressed by some members of the public for apparent reductions in the forage base in the Chesapeake Bay region. In addition to reductions in menhaden recruitment, those individuals (representing the Chesapeake Bay Acid Rain Foundation, the Sustainable Development Institute, and the Coastal Conservation Association - Maryland and Virginia) indicated that bay anchovies and silversides, which are not subject to fisheries harvest, have also declined in abundance. The status of forage species in other estuarine areas is unknown. The AMAC shares this concern.

Based on an overall examination of stock and fishery information, AMAC concludes that there is more than sufficient Atlantic menhaden spawning stock to produce adequate recruitment. Recent poor recruitment is unrelated to fishing effort. The AMAC recommends no additional restrictions to the fishery (in 1998, ed.).

9.2 Sampling Issues

Port sampling and landings data from the Atlantic menhaden fishery form the foundation of the trigger estimation set forth in the Atlantic menhaden FMP. The AMAC recommends that the NMFS Beaufort Laboratory continue to collect and maintain these data sets. Captains Daily Fishing Reports (CDFR) are daily deck logs that are extremely useful in resolving questions of catch and distance from shore. CDFRs are also used by some ‘snapper’ rigs. The AMAC recommends that the NMFS Beaufort Laboratory continue to maintain and collect CDFR data sets. The AMAC also recommends that CDFR’s (or its equivalent) be used by all purse seine vessels fishing for Atlantic menhaden for bait or reduction.

9.3 IWP Allocation

No written requests for an IWP allocation for the 1998-99 fishing season were received prior to the spring AMAC meeting. Subsequent to that meeting, a request was received by the Commission. No action has been taken since.

9.4 State Management Actions

No proposals affecting the Atlantic menhaden fishery were introduced through either management agencies or legislative systems in Maine, Massachusetts, or Virginia since AMAC’s last meeting in October 1997. The two-year moratorium on large menhaden vessels in Connecticut waters continues. Little progress is apparent in Maryland concerning preparation of a state fishery management plan.

In New Jersey, a bill was introduced and referred to a legislative committee. This bill proposes that bait seiners be prohibited from fishing within two miles of the coast and reduction fishery vessels be restricted to working in waters at least three miles out from shore. It also proposes that bait seining be prohibited in Sandy Hook and Raritan Bays. This bill is supported by some sport fishing interests. The New Jersey Marine Fisheries Council (NJMFC) has attempted to bring representatives of differing factors together for discussions on several occassions. Unfortunately, the proponents of the bill have declined to participate. The NJMFC has written to the legislature requesting that the bill not be allowed out of committee , and that the existing management system be allowed to do its job. Specific problems to be addressed by the bill have not ben defined. The bill's supporters have not adequately identified the conflict between the sport fishermen and the menhaden industry.

Interest in new area restrictions for purse seine fishing has resurfaced in North Carolina. All of the beach town governments in Brunswick County, the southernmost county in the state, have passed resolutions favoring restrictions. Representatives of the town of Southern Shores, along the northern coast, are expected to officially ask the North Carolina Marine Fisheries Commission to move the menhaden purse seine fishery 1.5 miles offshore during summer and 0.5 miles off the beach during fall, as is already done in some nearby areas. In 1995 and 1997, the Commission declined to act on identical requests by Southern Shores.

9.5 Projections

See section 7.2.

9.6 Research Recommendations

9.6.1 General

The Atlantic menhaden "Fact Sheet" will undergo another revision and should be published during the 1998 fishing season. University researchers are urged to evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year abundance. This issue is being addressed by the Commission Management and Science Committee which will then forward a report to the ISFMP Policy Board. An external peer-review of the menhaden assessment and management program was recommended by the ISFMP Policy Board during the Commission's Spring Meeting in June, 1998. This review is scheduled to be conducted in late 1998.

9.6.2 Regulatory Recommendations

Because the stock is considered healthy, there are no recommendations from AMAC or the Atlantic Menhaden Plan Review Team for additional restrictions on the fishery.

9.6.3 Amendments

No amendments to the current plan are in development. AMAC has recommended that an addendum be prepared during 1999 which would address the following issues: 1) reformatting the current FMP to follow the current approved ISFMP outline; 2) update the Habitat section; and 3) to evaluate the trigger levels in light of recent changes in the fishery.

9.6.4 Research and Monitoring Recommendations

Evaluate effects of selected environmental factors on growth, survival and abundance of juvenile and adult Atlantic menhaden (1).

Develop and test methods for estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques (1).

Determine how loss/degradation of critical estuarine and nearshore habitat affects growth, survival and abundance of juvenile and adult Atlantic menhaden abundance (1).

Monitor landings, size, age, gear and harvest area in the reduction and bait fisheries, and determine age composition by area (1).

Study the ecological role of menhaden (predator/prey relationship, nutrient enrichment, oxygen depletion, etc.) in major Atlantic coast embayments and estuaries (1).

Evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year abundance (2).

Determine the effects of fish diseases (such as ulcerative mycosis and toxic dinoflagellates) on the menhaden stock (3).

Evaluate the effects of regulations on the fishery, the participants and the stock (3).

Monitor fish kills along the Atlantic coast and use the NMFS Beaufort Laboratory as a repository for these reports (4).

Develop bycatch studies of menhaden by other fisheries (5).

Periodically monitor the economic structure and sociological characteristics of the menhaden reduction industry (6).

Identified Management Issues
Make annual prediction for the Atlantic coast fishery.

Analyze vessel catch records.

Completed
Analyze Captains Daily Fishing Reports to improve estimates of catch matrix for VPA and in relating temporal-spatial distributions to environmental conditions. **(Vaughan, D.S. 1997. Trigger Variables for Atlantic Menhaden, unpubl. report for 1996 fishery)**

9.7 Minority Opinion

9.7.1 Description of Opinions

9.7.2 Justification of Why Not Adopted

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11.0 TABLES

Table 2.1. Estimated Atlantic menhaden landings in numbers by age (in millions) and weight of total landings (in thousands of metric tons), 1955-1997.

Year	Numbers at age							Total numbers	Total weight
	0	1	2	3	4	5	6-8		
1955	761.0	674.1	1057.7	267.3	307.2	38.1	13.0	3118.4	641.4
1956	36.4	2073.3	902.7	319.6	44.8	150.7	37.4	3564.8	712.1
1957	299.6	1600.0	1361.8	96.7	70.8	40.5	42.3	3511.7	602.8
1958	106.1	858.2	1635.3	72.0	17.3	15.9	14.4	2719.2	510.0
1959	11.4	4038.7	851.3	388.3	33.4	11.9	18.7	5353.6	659.1
1960	72.2	281.0	2208.6	76.4	102.2	23.8	11.0	2775.1	529.8
1961	0.2	832.4	503.6	1209.6	19.2	29.4	3.9	2598.3	575.9
1962	51.6	514.1	834.5	217.3	423.4	30.8	28.3	2099.9	537.7
1963	96.9	724.2	709.2	122.5	45.0	52.4	14.3	1764.5	346.9
1964	302.6	704.0	605.0	83.5	17.9	7.8	8.3	1729.1	269.2
1965	259.1	745.2	421.4	77.8	12.2	1.8	2.0	1519.5	273.4
1966	349.5	550.8	404.1	31.7	3.9	0.4	0.3	1340.6	219.6
1967	7.0	633.2	265.7	72.8	5.1	0.5	0.0	984.2	193.5
1968	154.3	377.4	539.0	65.7	10.7	1.0	0.1	1148.0	234.8
1969	158.1	372.3	284.3	47.8	5.4	0.1	0.0	868.2	161.6
1970	21.4	870.8	473.9	32.6	4.0	0.1	0.0	1403.0	259.4
1971	72.8	263.3	524.3	88.3	17.8	2.5	0.0	969.1	250.3
1972	50.2	981.3	488.5	173.1	19.1	1.9	0.0	1713.9	365.9
1973	56.0	588.5	1152.9	38.6	7.0	0.3	0.0	1843.4	346.9
1974	315.6	636.7	986.0	48.6	2.5	1.4	0.0	1990.6	292.2
1975	298.6	720.0	1086.5	50.2	6.6	0.2	0.1	2162.3	250.2
1976	274.2	1612.0	1341.1	48.0	8.0	0.3	0.0	3283.5	340.5
1977	484.6	1004.5	2081.8	83.5	17.8	1.4	0.1	3673.7	341.1
1978	457.4	664.1	1670.9	258.1	31.2	3.5	0.0	3085.2	344.1
1979	1492.5	623.1	1603.3	127.9	21.8	1.5	0.1	3870.1	375.7
1980	88.3	1478.1	1458.2	222.7	69.2	14.4	1.4	3332.3	401.5
1981	1187.6	698.7	1811.5	222.2	47.5	15.4	1.3	3984.0	381.3
1982	114.1	919.4	1739.5	379.7	16.3	5.8	0.9	3175.7	382.4
1983	964.4	517.2	2293.1	114.3	47.4	5.0	0.7	3942.1	418.6
1984	1294.2	1024.2	892.1	271.5	50.3	15.2	0.5	3548.0	326.3
1985	637.2	1075.8	1224.6	44.1	35.6	6.2	1.7	3025.3	306.7
1986	98.4	224.2	1523.1	49.1	10.5	6.1	1.1	1912.4	238.0
1987	42.9	504.7	1587.7	151.9	25.2	2.2	0.7	2315.2	327.0
1988	338.8	282.7	1157.6	301.4	69.8	7.1	0.3	2158.0	309.3
1989	149.7	1154.6	1158.5	108.4	47.5	11.6	0.2	2630.0	322.0
1990	308.1	132.8	1553.1	109.0	42.2	12.7	0.4	2157.9	401.2
1991	881.8	1033.9	946.1	254.0	37.9	10.7	2.0	3166.6	381.4
1992	399.6	727.2	195.4	66.1	51.3	10.9	1.4	2052.5	297.6
1993	67.9	379.0	983.1	148.9	10.9	3.9	0.3	1594.0	320.6
1994	88.6	274.5	888.9	165.1	67.2	7.5	0.2	1492.1	260.0
1995	56.8	533.6	671.9	309.1	67.5	4.4	0.0	1643.3	339.9
1996	33.7	209.1	679.1	138.9	29.0	2.0	0.0	1091.9	292.9
1997	25.1	246.7	428.0	237.4	51.4	8.7	1.2	998.5	262.7

Table 2.2. Annual estimates of Atlantic menhaden population size (age 1-8 at start of fishing year), numbers landed (age 1 to maximum age observed), exploitation rates (u, ratio of catch to population numbers for ages 1-8), and instantaneous fishing mortality rate F (yr1, weighted mean of F for ages 1-8 from VPA), for fishing years, 1955-1990.

Fishing year	Population size (millions)	Numbers landed (millions)	u	F
1955	6967.6	2357.4	0.34	0.63
1956	8298.0	3528.5	0.43	0.83
1957	9823.3	3212.1	0.33	0.89
1958	7123.0	2613.1	0.37	0.69
1959	17627.0	5342.2	0.30	0.55
1960	9309.4	2702.9	0.29	0.50
1961	6843.4	2598.1	0.38	0.71
1962	4587.1	2048.3	0.45	1.19
1963	3603.0	1667.6	0.46	1.15
1964	2770.6	1426.5	0.51	1.20
1965	2594.0	1260.4	0.49	1.23
1966	2071.7	991.2	0.48	0.98
1967	2496.8	977.2	0.39	0.79
1968	2024.7	993.7	0.49	1.39
1969	2222.7	710.0	0.32	0.82
1970	3443.4	1381.5	0.40	0.79
1971	2463.1	896.2	0.36	0.87
1972	4318.1	1663.8	0.39	1.17
1973	4179.4	1787.4	0.43	1.81
1974	4325.7	1675.1	0.39	1.54
1975	5243.6	1863.7	0.36	1.43
1976	8738.5	3009.3	0.34	1.06
1977	8399.8	3189.1	0.38	1.15
1978	7622.6	2627.8	0.34	1.21
1979	7080.5	2377.7	0.34	1.07
1980	9350.3	3244.1	0.35	0.95
1981	8152.4	2796.4	0.34	1.02
1982	9419.3	3061.6	0.33	1.27
1983	6134.8	2977.7	0.49	1.37
1984	5449.6	2253.8	0.41	1.28
1985	6744.6	2388.1	0.35	1.26
1986	7051.8	1818.9	0.26	1.28
1987	6574.6	2366.1	0.36	0.99
1988	5695.6	1882.3	0.33	1.27
1989	8854.3	2680.6	0.30	0.79
1990	5541.5	1881.7	0.34	0.82

Table 2.3. Estimated number of spawning Atlantic menhaden (age 3-8 females) that produced the given year

class, estimated egg production from the spawning stock, and estimated numbers of recruits to age-1 by year class, 1955-97.

Year class	Spawners		Eggs (trillions)	Recruits to age-1 (millions)
	Number (millions)	Weight (100 mt)		
1955	795.40	326.97	152.59	5680.4
1956	587.20	258.65	124.11	7243.8
1957	282.25	133.24	65.88	3324.1
1958	215.75	88.73	42.50	15103.1
1959	537.40	173.67	77.18	2216.1
1960	306.95	123.32	57.48	3008.7
1961	1321.35	360.29	152.88	2228.3
1962	544.75	200.02	91.15	2232.9
1963	175.60	65.25	30.31	1741.2
1964	84.25	30.83	14.09	1910.1
1965	58.75	20.81	9.32	1373.6
1966	28.15	9.09	3.99	1933.5
1967	56.45	20.94	9.43	1184.8
1968	49.60	16.79	7.42	1681.7
1969	39.45	14.1	6.29	2572.3
1970	45.10	16.21	7.27	1330.5
1971	84.25	28.04	12.55	3435.1
1972	120.35	47.96	22.11	2691.5
1973	31.00	12.52	5.88	2994.4
1974	37.95	12.09	5.33	3745.2
1975	43.80	13.64	5.91	6801.3
1976	56.75	15.57	6.54	5125.1
1977	99.35	25.63	10.68	4691.0
1978	225.60	44.53	18.09	4213.8
1979	198.80	40.44	16.33	6648.1
1980	252.60	57.96	23.80	4671.0
1981	198.80	42.45	17.49	6352.2
1982	316.00	48.66	19.57	2444.5
1983	177.70	35.73	14.42	3788.6
1984	253.50	15.22	22.41	4995.5
1985	75.20	18.82	7.87	4459.5
1986	78.60	15.80	6.51	3377.2
1987	198.75	37.48	15.07	2985.6
1988	306.20	59.19	23.84	5520.8
1989	177.80	38.29	15.56	2217.0
1990	161.05	35.25	14.41	3540.1
1991	238.25	59.57	24.54	3547.8
1992	106.75	29.77	12.57	3259.8
1993	108.00	39.31	16.01	2355.6
1994	218.30	62.89	26.54	2947.8
1995	275.25	75.05	31.58	1416.5
1996	186.70	55.09	23.51	1357.9
1997	258.10	89.01	39.47	-----

Table 2.4. Yield-per-recruit (g) for age at entry of 0.5 yr and F-multiple of 1 for Atlantic menhaden for

each fishing year from 1970 through 1990, and for mean conditions for the 1970s and 1980s. Percent gains/ losses are presented for increasing ages at entry (1.0 and 2.0 yr) and two F-multiples (0.5 and 2.0).

		Age at entry (y)		F-multiple	
		%			
Fishing year	Y/R (grams)	1.0	2.0	0.5	2.0
1970	89.7	0.4	8.7	-4.0	-6.4
1971	100.5	0.6	8.4	-2.7	-5.5
1972	99.5	0.5	15.5	6.7	-12.7
1973	90.4	0.6	14.3	8.7	-13.9
1974	85.7	2.2	13.5	7.2	-12.0
1975	79.9	1.1	10.3	7.4	-11.4
1976	69.7	1.6	14.1	1.9	-12.6
1977	58.2	2.7	15.6	9.4	-16.7
1978	53.7	2.6	9.1	7.6	-11.5
1979	52.7	6.5	12.7	-3.0	-10.4
1980	53.9	0.6	14.3	3.9	-13.2
1981	50.5	5.3	13.5	10.1	-17.4
1982	51.6	1.4	7.4	4.5	-7.4
1983	51.5	6.0	16.1	4.2	-12.9
1984	51.3	6.1	17.7	8.1	-14.1
1985	52.0	4.3	13.7	4.8	-12.7
1986	56.2	0.9	3.6	-4.1	-5.5
1987	51.5	0.4	6.9	-2.3	-8.6
1988	53.9	1.9	6.2	2.5	-7.8
1989	50.8	2.1	10.3	1.7	-10.0
1990	63.0	0.6	3.1	-12.4	+1.6
			Mean conditions		
1970s	78.5	1.8	12.6	4.7	-11.7
1980s	52.1	2.9	11.2	4.0	-11.5

Table 2.5. Estimated Atlantic menhaden population size in numbers by age (in millions) from Murphy Virtual Population Analysis, 1955-1997. Estimates of population size at age 0 should be interpreted with care, because natural mortality at this age is poorly known.

Year	0	1	2	3	4	5	6	7	8
1955	7962.2	3091.4	2285.4	619.6	813.4	116.4	32.1	7.3	2.0
1956	9112.6	5680.4	1443.2	644.3	189.1	280.9	44.6	12.3	3.2
1957	4496.7	7243.4	2015.0	239.1	166.0	85.6	64.2	6.9	2.7
1958	19031.2	3324.1	3367.4	265.0	77.7	51.2	23.5	12.9	1.2
1959	2787.9	15103.1	1449.3	893.3	112.8	36.1	20.3	7.9	4.4
1960	3848.3	2216.1	6479.4	278.5	270.5	45.9	13.8	3.6	1.6
1961	2790.7	3008.7	1192.0	2417.1	118.0	93.3	11.1	2.7	0.5
1962	2853.9	2228.3	1269.3	371.7	615.0	60.2	36.7	4.8	1.1
1963	2288.8	2232.9	1018.9	182.5	72.2	75.8	14.9	5.0	0.8
1964	2729.0	1741.2	860.9	120.3	24.5	12.1	9.2	1.7	0.7
1965	1997.5	1910.1	566.4	98.0	14.4	2.3	1.8	0.9	0.1
1966	2810.5	1373.6	641.8	49.6	5.7	0.4	0.2	0.3	0.1
1967	1491.5	1933.5	450.4	104.4	7.7	0.7	0.0	0.0	0.1
1968	2278.0	1184.8	740.7	85.7	12.3	1.1	0.1	0.0	0.0
1969	3397.8	1681.7	462.1	72.4	6.3	0.2	0.0	0.0	0.0
1970	1690.1	2572.3	780.8	79.8	10.3	0.1	0.0	0.0	0.0
1971	4383.0	1330.5	964.0	139.4	25.7	3.4	0.0	0.0	0.0
1972	3426.4	3435.1	642.2	215.0	22.3	3.1	0.3	0.0	0.0
1973	3812.5	2691.5	1425.9	49.6	11.0	0.6	0.6	0.2	0.0
1974	5042.4	2994.4	1255.4	70.2	3.3	1.8	0.1	0.4	0.1
1975	0850.7	3745.2	1410.8	78.4	8.5	0.3	0.1	0.1	0.2
1976	6724.6	6801.3	1823.7	100.8	12.2	0.5	0.0	0.0	0.0
1977	6414.9	5125.1	3076.0	169.4	27.4	1.8	0.1	0.0	0.0
1978	5787.0	4691.0	2480.4	402.9	44.1	4.1	0.1	0.0	0.0
1979	9987.1	4213.8	2469.1	329.9	62.6	4.9	0.1	0.1	0.0
1980	5948.1	6648.1	2197.0	368.8	111.4	23.0	2.0	0.0	0.0
1981	9277.0	4671.0	3082.0	306.7	66.6	18.7	3.8	0.2	0.0
1982	3188.8	6352.2	2429.4	591.8	30.6	7.2	0.8	1.5	0.1
1983	5817.9	2444.5	3328.2	255.6	91.6	7.0	0.4	0.1	0.7
1984	7695.8	3788.6	1153.8	408.8	75.0	22.2	0.8	0.1	0.1
1985	6295.0	4995.5	1616.5	80.5	56.9	10.1	2.8	0.1	0.0
1986	4339.5	4459.5	2342.9	127.8	17.7	9.4	1.7	0.5	0.1
1987	3788.0	3377.2	2666.6	348.6	43.5	3.4	1.4	0.3	0.3
1988	7291.4	2985.6	1757.1	497.4	105.3	8.6	0.5	0.4	0.2
1989	2943.3	5520.6	1678.0	251.0	89.2	14.8	0.4	0.1	0.1
1990	4777.2	2217.0	2477.9	224.0	76.5	20.6	0.9	0.1	0.0
1991	5424.0	3540.1	1308.8	391.3	64.6	16.6	3.8	0.2	0.0
1992	4427.6	3547.8	1452.1	132.0	65.0	12.9	2.6	0.9	0.1
1993	3025.8	3259.8	1692.6	319.9	33.6	5.1	0.6	0.6	0.2
1994	3790.7	2355.6	1780.3	333.2	89.6	12.9	0.4	0.1	0.4
1995	1837.1	2947.8	1285.7	454.3	86.0	7.5	2.5	0.1	0.1
1996	1738.2	1416.5	1461.0	306.6	58.4	5.4	1.4	1.6	0.0
1997	1947.0	1357.9	738.8	409.7	88.7	15.1	1.8	0.9	0.0

Table 3.1. Numbers of menhaden processing plants, aircraft, vessels, vessel hold capacity (standard fish), and percent fleet refrigeration for the Atlantic menhaden fishery, 1972-1990. (One standard fish = 0.667 lb)[1].

	Summer fishery[2]						Fall fishery[3]				
					Hold capacity (1000)					Hold capacity (1000)	
Year	Number of plants	Number of aircraft	Number of vessels	Percent refrigerated	Total	Mean	Number of aircraft	Number of vessels	Percent refrigerated	Total	Mean
1972	7	23	35	29	29,085	831	15	15	40	14,285	952
1973	7	24	39	44	34,960	896	15	16	44	13,360	835
1974	7	26	41	49	38,160	931	16	18	39	13,710	762
1975	7	27	43	51	42,710	993	18	23	48	19,860	863
1976	7	26	41	56	40,560	989	17	20	60	18,260	913
1977	7	28	43	65	48,125	1119	17	18	67	18,275	1015
1978	7	28	38	66	44,350	1167	11	17	65	19,550	1150
1979	7	29	39	67	44,550	1142	11	18	67	21,500	1194
1980	7	29	40	60	44,020	1101	11	19	58	21,820	1148
1981	7	29	40	63	40,450	1011	13	18	61	21,150	1175
1982	6	23	30	60	31,350	1045	10	16	69	19,150	1197
1983	6	20	31	61	33,750	1089	11	17	71	19,950	1174
1984	5	20	30	63	33,150	1105	9	12	67	14,850	1238
1985	5	17	23	83	29,500	1283	2	4	25	2,850	713
1986	5	8	16	75	15,900	994	2	3	33	2,300	767
1987	6	11	19	84	21,100	1110	2	3	33	2,300	767
1988	6	15	27	74	28,400	1052	2	6	83	8,700	1450
1989	5	17	32	53	31,400	981	15	25	83	32,600	1300
1990	5	17	33	53	32,900	997	15	23	90	31,500	1432

[1] In attempting to compute total number of vessels active during the fishing year, summer and fall fishing vessel tallies are not additive.

[2] Includes only vessels that fished regularly during the summer fishery; does not include vessels added to the Virginia fleet during October and November or vessels fishing exclusively for the New Brunswick, Canada plant.

[3] The fall fishery is defined through 1988, as all vessels unloading fish in North Carolina after the start of the fall fishery on 1 November. In 1989 and 1990, the fall fishery includes activities of vessels landing at Reedville, Va. because those vessels fished intensively along the North Carolina coast to south of Cape Hatteras.

Table 3.2. Atlantic menhaden landings (1,000 metric tons) and percent contribution of total landings by region, 1980-97.

Year	North Atlantic	%	Chesapeake Bay	%	South Atlantic	%	Total
1980	29.6	7.4	282.8	70.4	89.1	22.2	401.5
1981	21.8	5.7	215.9	56.6	143.6	37.7	381.3
1982	35.1	9.2	258.0	67.5	89.4	23.3	382.4
1983	39.4	9.4	279.6	66.8	99.7	23.8	418.6
1984	35.0	10.7	203.6	62.4	87.7	26.9	326.3
1985	14.3	4.7	273.4	89.2	19.0	6.1	306.7
1986	10.0	4.2	197.7	83.1	30.4	12.7	238.0
1987	25.9	7.9	276.1	84.5	24.9	7.6	326.9
1988	39.8	12.9	236.3	76.4	33.2	10.7	309.3
1989	38.2	11.9	256.9	79.8	27.0	8.3	322.0
1990	58.2	14.5	308.9	77.0	34.7	8.5	401.8
1991	51.3	13.5	282.9	74.2	47.3	12.4	381.4
1992	27.8	9.3	249.5	83.8	20.4	6.8	297.6
1993	10.3	3.2	281.9	87.9	28.4	8.8	320.6
1994	0	0	227.9	87.6	32.1	12.4	260.0
1995	0	0	313.0	92.1	26.9	7.9	339.9
1996	0	0	261.8	89.4	31.1	10.6	292.9
1997	0	0	223.6	86.3	35.6	13.7	259.1
Mean (1980-97)	24.3	7.3	257.2	77.6	50.0	15.1	331.5

Table 3.3. Atlantic menhaden landings by month (metric tons) for fishing seasons 1980-1990.

	Year										
Month	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Mar	0	0	0	0	0	0	713	0	0	0	0
Apr	173	2,223	795	554	7	0	1,060	751	0	0	0
May	37,220	19,681	34,151	23,487	12,436	24,608	17,616	12,822	13,318	24,779	34,848
Jun	59,785	61,551	76,315	62,627	38,590	60,690	35,384	46,139	32,507	48,372	51,345
Jul	77,666	90,029	76,220	74,646	56,487	58,213	48,306	68,636	43,381	54,182	64,612
Aug	82,954	61,299	69,010	82,705	65,820	57,377	42,229	53,336	63,711	71,862	72,314
Sep	66,588	45,601	59,164	62,212	45,254	41,907	46,235	61,532	69,471	49,544	65,574
Oct	34,213	28,151	34,072	20,979	30,079	35,319	34,052	35,248	23,215	29,728	47,749
Nov	15,630	41,679	4,953	26,288	14,623	6,363	5,404	34,506	23,588	14,274	29,108
Dec	30,092	31,097	27,755	49,405	34,031	20,345	6,538	12,588	37,045	27,336	30,206
Jan	3,287	0	25	15,732	26,397	1,017	465	1,317	3,057	1,938	5,402
Feb	0	0	0	0	2,571	824	0	21	0	0	0
Total*	409,588	383,291	382,460	418,634	326,296	306,662	239,633	326,894	309,293	322,014	401,159

* Total may not agree with data in other tables due to rounding.

Table 3.4. Years of activity for individual Atlantic menhaden reduction plants.

Year/plant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Total Plants	Number Vessels
1955	!	!	!	!	!	!		!		!	!	!	!		!	!	!	!	!	!	!	!	!	!	!	!											23	150
1956	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!												24	149
1957	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!											25	144
1958	!	!	!	!	!			!	!	!	!	!	!	!	!	!	!	!		!	!		!	!	!	!											22	130
1959	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!		!	!		!	!	!	!											23	144
1960	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!		!			!		!												20	115
1961	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!		!			!		!												20	117
1962	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!			!			!		!												19	112
1963	!	!	!	!	!			!	!	!	!	!	!	!	!	!	!	!		!																	17	112
1964	!	!	!	!	!	!		!	!	!	!	!	!	!	!	!	!	!		!																	18	111
1965	!	!		!	!			!		!	!	!	!	!		!	!	!	!	!							!	!									17	84
1966	!	!		!	!		!	!	!	!	!	!	!	!	!	!	!		!	!							!	!	!								20	76
1967		!		!			!	!	!	!	!	!	!	!	!	!	!		!	!							!	!	!								18	64
1968	!	!		!			!			!	!	!	!	!	!	!	!		!	!							!	!	!								17	59
1969	!	!		!			!			!		!	!	!	!	!	!			!							!	!	!								15	51
1970		!					!			!		!	!	!	!	!	!			!			!		!		!	!	!								15	54
1971		!					!			!		!	!	!	!	!	!			!			!		!		!	!									14	51
1972		!					!			!			!	!			!			!			!		!		!	!									11	51
1973		!					!			!			!	!			!			!		!	!		!			!									11	58
1974		!					!			!			!	!			!			!			!		!			!									10	63
1975		!					!			!			!	!			!			!		!	!		!			!		!							12	61
1976		!					!			!			!	!			!			!			!		!			!		!							11	62
1977		!					!			!			!	!			!			!		!	!		!			!		!							12	64
1978		!					!			!			!	!			!			!		!	!		!			!		!							12	53
1979		!					!			!			!	!			!			!		!	!		!			!		!							12	54
1980							!			!			!	!			!			!		!	!					!		!							11	51
1981							!			!			!	!			!			!		!	!					!		!							11	57
1982							!			!			!	!			!			!		!	!					!		!							10	47
1983							!			!			!	!			!			!			!					!		!							9	41
1984							!			!			!	!						!			!					!		!							8	38
1985							!			!			!							!								!		!							6	24
1986							!			!			!							!								!		!							6	16
1987							!			!			!							!										!		!					6	23
1988							!			!			!																	!		!	!				6	30
1989							!			!			!																			!	!				5	37
1990							!			!			!																			!	!				5	35
1991							!			!			!																			!	!				5	37
1992							!			!			!																			!	!	!	!	!	8	37
1993							!			!			!																			!	!		!	!	7	31
1994							!			!			!																								3	20
1995							!			!			!																								3	20
1996							!			!			!																								3	21
1997							!			!			!																								3	23
1998										!			!																								2	15

Table 3.4. (Continued)

Port	Plant	Name	Location
3	1	Atlantic Processing Co.	Amagansett, NY
4	2	J. Howard Smith (Seacoast Products)	Port Monmouth, NJ
4	3	Fish Products Co.	Tuckerton, NJ
8	4	New Jersey Menhaden Products Co.	Wildwood, NJ
0	5	Fish Products Co. (Seacoast Products Co.)	Lewes, DE
0	6	Consolidated Fisheries	Lewes, DE
5	7	AMPRO (Standard Products Co.)	Reedville, VA
5	8	McNeal-Edwards (Standard Products Co.)	Reedville, VA
5	9	Menhaden Co. (Standard Products Co.)	Reedville, VA
5	10	Omega Protein (Zapata haynie Co.)	Reedville, VA
5	11	Standard Products Co.	White Stone, VA
6	12	Fish Meal Co.	Beaufort, NC
6	13	Beaufort Fisheries, Inc.	Beaufort, NC
6	14	Standard Products Co.	Beaufort, NC
6	15	Standard Products Co.	Morehead City, NC
6	16	Haynie Products, Inc.	Morehead City, NC
7	17	Standard Products Co.	Southport, NC
7	18	Southport Fisheries Menhaden	Southport, NC
9	19	Quinn Menhaden Fisheries, Inc.	Fernandina Beach, FL
9	20	Nassau Oil and Fertilizer Co.	Fernandina Beach, FL
9	21	Mayport Fisheries	Mayport, FL
1	22	Maine Marine Products (Pine State Products)	Portland, ME
2	23	Lipman Marine Products (Gloucester Marine Protien)	Glucester, MA
2	24	Gloucester Dehydration Co.	Gloucester, MA
11	25	Point Judith By Products Co.	Point Judith, RI
9	26	Quinn Fisheries	Younges Island, SC
5	27	Haynie Products (Cockerall's Ice & Seafood)	Reedville, VA
6	28	Sea and Sound Processing Co.	Beaufort, NC
12	29	Cape Charles Processing Co.	Cape Charles, VA
13	30	Sea Pro, Inc.	Rockland, ME
	31		
15	32	Conner Bros.	New Brunswick, Cananda
14	33	Riga (IWP)	Maine
14	34	Vares (IWP)	Maine
14	35	Dauria (IWP)	Maine
15	36	Comeau	Nova Scotia, Canada

Table 3.7. Annual unit values and unit values adjusted for inflation for menhaden products in the United States, 1980-1990.

	Meal		Oil		Solubles	
Year	Mean price[1] per short ton	Adjusted price[2] per short ton	Mean price[1] per pound	Adjusted price[2] per pound	Mean price[1] per short ton	Adjusted price[2] per short ton
1980	$376	$428	$0.19	$0.21	$103	$117
1981	387	403	0.18	0.19	114	119
1982	331	331	0.15	0.15	10	100
1983	353	348	0.17	0.16	98	96
1984	311	300	0.16	0.16	120	116
1985	239	228	0.15	0.14	117	112
1986	247	239	0.13	0.13	118	115
1987	315	299	0.12	0.11	137	130
1988	452	418	0.20	0.18	130	121
1989	384	338	0.11	0.09	153	134
1990	346	290	0.10	0.09	152	127

Source: U.S. Department of Commerce. 1981-1991. Fisheries of the United States. National Marine Fisheries Service. Current Fishery Statistics 8200, 8300, 8320, 8360, 8380, 8385, 8700, 8800, 8900, 9000.

[1] Mean prices were calculated as total value divided by total production. Prices are FOB processing plant.

[2] Prices were adjusted for inflation by dividing average prices by the Producer Price Index for finished goods (base year = 1982).

Table 3.8. State statutes and rules governing the Atlantic menhaden fishery, as of September 1992.

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
MAINE						
Department of Marine Resources	12 M.R.S.A. Sections 6171, 6171-A, 6191 and 6192	Commissioner may adopt or amend regulations upon advice and consent of the Advisory Council. Limitations: method, time, number, weight, length or location. When a condition endangering marine species exists, Commissioner may adopt emergency rules with no public hearing or Council approval required. An emergency rule may be in effect no more than 90 days.	None specifically for menhaden NRC - $334 RC - $89	June 1 to December 31 in certain areas; otherwise, no season.	1) No setting of purse seine within 1500 ft. of any stop seine. 2) No setting of seine within 2000 ft. of the mouth of any weir. Chapter 34 special permit Damariscotta and St. George rivers--in certain areas. No purse seining in Kennebec and upper Sheepscot rivers. Boats transporting are limited to 30,590 lb, must be measured, plainly marked and sealed by State sealer.	Possible suspension of permit or where specific penalties are not provided. Fine up to $1000 and/or imprisonment for one year.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
NEW HAMPSHIRE						
Fish and Game Department	R.S.A. 211.65 Division of Marine Fisheries created R.S.A. 206.1 Commission created R.S.A. 206.10. Powers and Duties of Director R.S.A. 211.62. Authority to regulate taking, inspections, and processing of marine species.	The Director may make rules and regulations. Methods: size, number, quantity, areas, and manner of their taking.	None specifically for menhaden. NRC - $200.50 (or equal to non-resident fee in operators' home state) RC - $25.50 Inland Netter Permit-free (required to take finfish by net or trap in Great Bay and Hampton/ Seabrook estuaries.)	May 15 to October 10.	State waters closed to mobile gear April 16-December 14. Gill nets in Great Bay estuary system 2-7/8" maximum mesh size.	General penalty misdemeanor.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
MASSACHUSETTS Division of Marine Fisheries Marine Fisheries Advisory Commission	Mass. Ann. Laws 2.5, SA; Chapter 130	The Division may promulgate regula-tions with approval of Marine Advisory Commission. Method: taking fish, size, seasons and hours, and opening and closing of areas.	Boats: 100'--$260; 60'-99'--$195; up to 59'--$130. This permit is valid for taking, landing, and selling finfish, and may be endorsed for shellfish. A special permit ($20) is required for regulated fisheries.	No season.	Special permits are issued for areas designated as a regulated fishery area or as an inshore permit area. Specific regulations may apply by individual area.	Violators are subject to fines from $10 to $5000, imprison-ment not more than 1 year, or both.
RHODE ISLAND Division of Fish and Wildlife	Title 20-3-1 General Laws of Rhode Island Title 42 Chapter 17	Marine Fisheries Council may promul-gate regulations: Manner of taking fish, size of fish, seasons and hours, numbers and quantities and opening and closing of areas. 1)Required to make monthly reports to Department. 2) Equipment must be registered.	Vessels to 50'-$100; 50' to 99'-$125; 99' or more $10 per linear foot.	May 1 to October 1.	Numerous areas within Narragansett Bay and Mt. Hope Bay are restricted if landings exceed 1,000,000 pounds per day.	Fine up to $500 and one year suspension of license. Fine from $500 to $700, imprisonment not more than 30 days, or both.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
CONNECTICUT Department of Environmental Protection	C.G.S. Section 26.3	Promulgate regulations for the management and protection of fishery resources.	Purse seine--$500.	Third Monday in May through third Friday of October.	Closed area: Buoy to buoy line from Byram River to Stonington. Sec. 26-154a.	Fine up to and not exceeding $500 or imprisonment not more than 50 days, or both.
NEW YORK Department of Environmental Conservation	N.Y.E.C.L. Sections 13-0333, 13-0343	None specifically for menhaden; all rules are statutory.	Vessel-30 gross tons (gt) or less--$25; 30-100 gt--$200; 100-150 gt--$500; 150-200 gt--$750; over 200 gt--$1000. Licenses expire Dec. 31 following date of issue.	Third Monday in May to third Friday in October. Purse seine fishing is not allowed on weekends or legal holidays May 1 through September 15.	Buoy to buoy line in western half of Long Island Sound. All waters of New York Harbor and tributaries closed to all net fishing. Menhaden fishing prohibited within 1/2 mile of ocean beach from Rockaway Pt. to East Rockaway Inlet.	General civil penalty of $60 plus $25 per fish. Specific civil penalties from $250 to $1000 for each offense of Section 13-0333. General criminal penalty of fine up to $250 and/or up to 15 days imprisonment.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
NEW JERSEY						
Division of Fish, Game and Wildlife	New Jersey Stat. Ann. Title 23:3-51, 3.52.	Division cooperates with other states, interstate and Federal departments and agencies to develop programs and policies for the conservation and protection of natural resources.	R - Vessels: 30-100 gt--$125; 100-150 gt--$250; 150-175 gt--$400; 175-200 gt--$550; 200 + gt--$900; 20 tons or less used for taking menhaden for bait purposes only--$20. NR - Vessels: 30-100 gt--$ 450; 100-150 gt--$ 700; 150-175 gt--$1000; 175-200 gt--$1150; 200 + gt--$1500. Residents who lease vessels from out of state shall pay fees same as NR. License applications for bait purposes will only be accepted between January 1 and March 1 of any year.	Third Monday in May through third Friday in October.	Purse seine fishing for purposes other than bait restricted to the Atlantic Ocean not closer than 1.2 nautical miles of the shore, jetties or fishing piers. Purse seine fishing for bait purposes only restricted to the Atlantic Ocean and Delaware Bay not closer than 0.6 nautical miles and in Raritan Bay and Sandy Hook Bay not closer than 0.3 nautical miles of the shore, jetties or fishing piers. No fishing on Saturdays, Sundays or legal holidays. Fishing allowed only between sunrise and sunset. Fishing for bait purposes requires monthly reporting of fish harvested.	Violations are misdemeanors--$1000 for each offense.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
DELAWARE Division of Fish and Wildlife	Title 7, Section 903	Division has authority to protect, conserve and propagate the fisheries resources of State.	None.	No open season.	Purse seine fishing not allowed in state waters.	Violations are regarded as misdemeanors. $2500- fine for first offense; $5000 each offense thereafter.
MARYLAND Tidewater Administration	M.D.N.R. Section 1-101, 4-202	Regulations may include, but are not limited to, provisions enlarging, extending, restricting, or prohibiting the taking or catching of these resources.	None issued for purse seines; gill nets and pound nets used in Bay, up to 200 yards of gill nets--$50.	No open season.	Commercial menhaden fishery prohibited from use of purse seines in Maryland waters. Pound net locations are regulated laterally.	Violations are misdemeanors. Fine from $100 to $1000; violators shall be imprisoned until such fines and costs are paid.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
VIRGINIA Marine Resources Commission	Code of Virginia, Chapter 4. Use of purse nets for taking menhaden, Sections 28.2-400 to 28.2-411.	Commission has authority to protect, conserve and promote the seafood and marine resources of the Commonwealth.	R - Vessels: A) Sail vessel: purse nets of not more than 400 meshes deep--$21.50; B) Sail vessel: more than 400 meshes--$75; C) Power boat or steam vessel: under 70 gt--$3 per gt, max. $150; over 70 gt--$5 per gt, max. $600; and D) Power boat or steam vessel less than 20hp--$37.50. NR - applicants required to submit affidavit.	First Monday of May through third Friday of November in the Chesapeake Bay and tributaries. In waters east of the Chesapeake Bay Bridge Tunnel within 3 miles, season is first Monday of May to Friday before Christmas. For vessels under 70 gt taking only bait--season is first Monday of March through third Friday of November.	Selected smaller tributaries to Chesapeake Bay and major rivers are closed above designated lines. Mesh size not less than 1-3/4" stretched. Unlawful for purse seines to take food fish in excess of 1 percent of the total catch.	All violations are misdemeanors. Upon conviction, violators shall be fined up to $1000 and/or imprisonment up to 12 months.

Table 3.8. (Continued)

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
NORTH CAROLINA						
Marine Fisheries Commission Division of Marine Fisheries	North Carolina General Statutes. See G.S. 113-152 113-156 113-163 113-182 113-185 113-186 143B-289.3 143B-289.4	Marine Fisheries Commission power specifically includes the promulgation of rules and regulations implementing the provisions of Chapter 113 of the General Statutes. Commission can restrict gear, area, season, size and quantity and can delegate authority for management by Proclamation (Administrative order).	License must have name of man in command. Mother ship: $2 per ton, gt, customhouse measurements and no license is required for a purse boat used in connection with a licensed mothership. NR License fee--$200.	May 15-January 15 within 1 mile of shore. Year 'round beyond 1 mile. Director may open season by proclamation during April 1-May 14 with restrictions. No purse seine fishing between sunrise and sunset on Memorial Day, Fourth of July, Labor Day or weekends from Memorial Day through Labor Day.	Various estuarine and ocean areas restricted. Buying or selling menhaden for reduction must be done by a measure of 22,000 cubic inches for every 1000 fish. Specific regulation prohibiting fishing applies to Wrightsville Beach. No fishing in the ocean within 750 ft. of a marked ocean pier. Unlawful for purse seines to take foodfish in excess of 1 percent of the total amount of fish on board.	Violations of marine fisheries regulations are misdemeanors punishable by fine of $50 to $250 for the first offense and $100 to $500 for any offense thereafter, and/or imprisonment for up to 30 days.

Table 3.8. (Continued).

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
SOUTH CAROLINA Wildlife and Marine Resources Commission	S.C. Code Section 50-17-440	Statutory authority only.	None.	No open season.	Purse seine fishing not allowed in state waters.	Violations are misdemeanors punishable by fine up to $200 or imprisonment for up to 30 days. Any nets and catch are subject to confiscation.
GEORGIA Department of Natural Resources	Official Code of Georgia, Section 27-4-114; 27-4-130.	Commissioner of Natural Resources may open and close the saltwaters to allow or disallow the use of certain equipment in accordance with sound principles of wildlife research and management (O.C.G.A. 27-4-130).	Personal- RC - $10 NRC - $100.25 Purse boats: 18' or less--$50; over 18'--$50 plus $3 per foot. Other boats: 18' or less--$5; over 18'--$5 plus $.50 per foot or fraction thereof; NRC-License fee--$25.	Set administratively by Commissioner of Department of Natural Resources.	1000 ft. restricted area from shore for Jekyll Island, St. Simons Island, Sea Island, Tybee Island. No purse seines inside rivers, creeks and sounds.	Variable, civil or misdemeanor criminal prosecutions.

Table 3.8. (Continued).

State delegation of authority	Legislative authority	Regulatory/ administrative authority	Licenses*	Open season	Special areas and conditions	Penalties
FLORIDA Marine Fisheries Commission	Title 46	All rules and regulations under the Florida Marine Fisheries Commission.	Purse seine--$25 NR--$25 Purse boat--$31 Carrier vessel--$76 Dealer classification--$10 Wholesale dealer: R--$100 NR--$150 Alien--$500	No closed season.	No menhaden by purse seine along designated areas of west coast. All fishing by nets (except small cast nets) prohibited in Broward County.	Violations of Chapter 370-up to $500 fine and/or imprisonment of 1 year. Other sections specify seizure of fishing gear, vessels, catch and vehicles.

* Terms used: NR = non resident
R = resident
NRC = non resident commercial
RC = resident commercial

Table 5.1. Comparison of landings (1000 mt) by the bait and reduction fisheries for Atlantic menhaden.

Year	Reduction	Bait	(%)	Total
1985	306.7	26.7	(8.0)	333.4
1986	238.0	28.0	(10.5)	266.0
1987	326.9	60.6	(8.6)	357.5
1988	309.3	36.3	(10.5)	345.6
1989	322.0	30.9	(8.8)	352.9
1990	401.2	30.7	(7.1)	431.9
1991	381.4	36.2	(8.7)	417.6
1992	297.6	38.7	(11.5)	336.3
1993	320.6	35.1	(9.9)	355.7
1994	260.0	28.1	(9.8)	288.1
1995	339.9	31.1	(8.4)	371.0
1996	292.9	23.3	(7.4)	316.2
1997	259.1	31.3[a]	(10.8)	290.4

[a] Average bait landings for 1985-96.

Table 5.2. Catch in numbers at age for the Atlantic menhaden reduction landings (in millions).

Year	N0	N1	N2	N3	N4	N5	N6-8
1985	637.2	1075.9	1224.6	44.1	35.6	6.2	1.7
1986	98.4	224.2	1523.1	49.1	10.5	6.1	1.1
1987	42.9	504.7	1587.7	151.9	25.2	2.2	0.7
1988	338.8	282.7	1157.6	301.4	69.8	7.1	0.6
1989	149.7	1154.6	1158.5	108.4	47.5	11.6	0.2
1990	308.1	132.8	1553.1	109.0	42.2	12.3	0.4
1991	881.8	1033.9	946.1	254.0	37.9	10.7	2.2
1992	399.6	727.2	795.4	66.1	51.3	10.9	1.9
1993	67.9	379.0	983.1	148.9	10.9	3.9	0.3
1994	88.6	274.5	888.9	165.1	67.2	7.5	0.2
1995	56.8	533.6	671.9	309.1	67.5	4.4	0.0
1996	33.7	209.1	679.1	138.9	29.0	2.0	0.0
1997	25.1	246.7	428.0	237.4	51.4	8.7	1.2

Table 5.3. Catch in numbers at age for the Atlantic menhaden bait landings (in millions).

Year	N0	N1	N2	N3	N4	N5	N6-8
1985	0.6	48.4	83.6	5.0	5.2	0.8	0.1
1986	0.0	8.5	68.3	19.1	12.2	8.0	1.4
1987	0.3	16.2	73.0	32.6	9.9	0.9	0.4
1988	0.6	4.9	55.7	42.7	26.0	2.2	0.3
1989	0.5	64.3	61.4	16.6	11.3	3.0	0.1
1990	0.6	5.1	78.8	12.1	4.9	1.8	0.1
1991	6.2	26.9	47.9	43.8	8.8	2.8	0.6
1992	0.0	34.7	74.3	14.6	20.2	4.6	0.8
1993	0.6	9.9	65.6	23.6	5.6	3.8	0.4
1994	0.0	5.2	34.6	18.7	9.6	1.9	0.0
1995	0.1	17.8	48.4	27.3	8.1	0.4	0.0
1996	0.0	0.6	36.4	15.1	4.1	0.4	0.0
1997	0.0	0.6	29.4	14.3	4.9	1.4	0.0

Table 5.4. Catch in numbers at age for the Atlantic menhaden reduction and bait landings (in millions).

Year	N0	N1	N2	N3	N4	N5	N6-8
1985	637.8	1124.2	1308.3	49.1	40.8	7.0	1.8
1986	98.4	232.7	1597.5	68.2	22.7	14.0	2.4
1987	43.2	520.9	1660.7	184.5	35.1	3.1	1.0
1988	339.4	287.6	1213.4	344.1	95.8	9.3	0.9
1989	150.2	1218.8	1219.9	125.0	58.8	14.6	0.3
1990	308.7	137.9	1631.9	121.1	47.1	14.2	0.5
1991	888.0	1060.9	994.0	297.8	46.8	13.5	2.8
1992	399.6	761.9	869.8	80.6	71.5	15.4	2.7
1993	68.6	388.9	1048.6	172.5	16.6	7.7	0.7
1994	88.7	279.7	923.5	183.8	76.9	9.5	0.2
1995	56.9	551.4	720.2	336.4	75.6	4.7	0.0
1996	33.7	209.8	715.5	154.1	33.1	2.4	0.0
1997	25.1	247.3	457.4	251.7	56.3	10.1	1.3

Table 6.1 Annual estimated values of six Atlantic menhaden triggers. (Boldface indicates years in which respective trigger would have been exceeded.).

Year	Landings[a]	PO[b]	P3+[c]	Recruits[d]	SSB[e]	MSP[f]
1940	179.0	-	-	-	-	-
1941	283.1	-	-	-	-	-
1942	167.4	-	-	-	-	-
1943	215.0	-	-	-	-	-
1944	243.5	-	-	-	-	-
1945	285.6	-	-	-	-	-
1946	351.8	-	-	-	-	-
1947	376.4	-	-	-	-	-
1948	341.3	-	-	-	-	-
1949	363.4	-	-	-	-	-
			-	-	-	-
1950	311.2	-	-	-	-	-
1951	351.2	-	-	-	-	-
1952	423.6	-	-	-	-	-
1953	589.2	-	-	-	-	-
1954	617.9	-	-	-	-	-
1955	644.5	24.4	20.1	3.1	327.0	13.8
1956	715.4	1.0	15.5	5.7	258.7	6.6
1957	605.6	8.5	7.1	7.3	133.2	6.7
1958	512.4	3.9	4.4	3.3	88.7	16.1
1959	662.2	0.2	8.4	15.1	173.7	8.6
1960	532.2	2.6	7.7	2.2	123.3	24.1
1961	578.6	0.0	**48.6**	3.0	360.3	13.3
1962	541.6	2.5	**33.3**	2.2	200.0	4.9
1963	348.4	5.5	13.3	2.2	65.3	3.1
1964	270.4	17.5	6.8	**1.7**	30.8	**2.4**
1965	274.6	17.1	6.2	**1.9**	20.8	**1.7**
1966	**220.5**	**26.1**	2.7	**1.4**	**9.1**	3.3
1967	**194.4**	0.7	8.0	**1.9**	20.9	5.5
1968	**235.9**	13.4	6.7	**1.2**	**16.8**	**2.1**
1969	**162.3**	18.2	6.2	**1.7**	**14.1**	5.4
1970	259.4	1.5	2.6	2.6	**16.2**	6.6
1971	250.3	7.5	11.2	**1.3**	28.1	6.6
1972	365.9	2.9	11.3	3.4	48.0	**2.0**
1973	346.9	3.0	2.5	2.7	**12.5**	**1.3**
1974	292.2	15.9	2.6	3.0	**12.1**	**1.5**
1975	250.2	13.8	2.6	3.7	**13.6**	**1.9**
1976	340.5	8.4	1.7	6.8	**15.6**	2.8
1977	341.2	13.2	2.8	5.1	25.6	4.3
1978	344.1	14.8	9.5	4.7	44.5	3.7
1979	375.7	**38.6**	3.9	4.2	40.4	6.4

Table 6.1. (Continued)

Year	Landings[a]	PO[b]	P3+[c]	Recruits[d]	SSB[e]	MSP[f]
1980	401.5	2.6	9.2	6.7	58.0	4.6
1981	381.3	**29.8**	7.2	4.7	42.4	5.0
1982	382.5	3.6	12.7	6.4	48.8	3.1
1983	418.6	24.5	4.2	2.5	35.8	3.8
1984	326.3	**36.5**	9.5	3.8	55.3	**1.7**
1985	306.7	21.1	2.9	5.0	18.8	**2.5**
1986	**238.0**	5.1	3.5	4.5	**15.7**	7.5
1987	326.9	1.9	7.8	3.4	37.5	7.8
1988	309.3	15.7	17.6	3.0	58.9	5.1
1989	322.0	5.7	6.4	5.5	38.3	5.2
1990	401.2	14.3	7.6	2.2	35.3	7.7
1991	381.4	**27.8**	9.6	3.5	59.6	**2.8**
1992	297.6	19.5	6.3	3.5	29.8	8.6
1993	320.6	4.3	10.3	3.3	39.3	10.2
1994	260.0	5.9	16.1	2.4	62.9	13.0
1995	339.9	3.5	23.2	2.9	75.0	8.4
1996	292.9	3.1	15.6	**1.4**	55.1	14.9
1997	259.1	2.5	**29.9**	**1.4**	89.0	8.5
Median[g]	324.1	13.6	7.1	3.4	26.9	4.1
25%	250.3	3.6	3.7	2.2	15.7	2.1
75%	365.9	18.2	10.3	4.7	42.4	5.5
Trigger	<250.0	>25.0	>25.0	<2.0	<17.0	<3.0

[a] Landings in thousands of metric tons.
[b] Percent by numbers of age 0's in landings.
[c] Percent by numbers of adults (ages 3+) in landings.
[d] Estimated numbers of recruits to age 1 in billions.
[e] Estimated mature female biomass (spawning stock biomass or SSB) in thousands of metric tons.
[f] Estimated equilibrium maximum spawning potential based on egg production (for estimated F vs F=0) in percent (includes F at age 0).
[g] Median, 25th, and 75th percentiles based on fishing years from 1965 through 1990, except for P3+ which is based on fishing years 1955 through 1990.

Table 6.2. Age-based stock assessments of Atlantic menhaden. Y_t indicates the terminal year of the VPA.

Y_t	Source
1976	AMMB, 1981; Powers, 1983
1981	Vaughan et al., 1986; Ahrenholz et al., 1987
1984	AMMB, 1986; Vaughan and Smith, 1988
1988	Vaughan, 1990; Vaughan and Merriner, 1991
1990	AMAC, 1992 (p. 40-50); Vaughan, 1993
1992	AMAC, 1992 (p. 17-30)
1993	Vaughan, 1994[1]
1994	Vaughan, 1995[1]
1995	Vaughan, 1996[1]

[1] Vaughan, D.S. Trigger variables for Atlantic menhaden. Natl. Mar. Fish. Serv., NOAA, Unpubl. AMAC reports.

Table 7.1. Statistical properties of recruits to age-1 Atlantic menhaden (R_1, in billions) dependent on the spawning stock biomass (SSB, in mt) that produced them.

Range of SSB (mt)	Recruits to Age-1 (billions)				
				Percentiles	
	n	Mean	Median	25th	75th
All	43	3.7	3.1	2.2	4.7
Greater than:					
17,000[a]	33	3.8	3.3	2.2	4.7
26,700[b]	29	3.9	3.3	2.2	4.7
40,400[c]	21	4.3	3.3	2.2	5.5
88,000[d]	8	5.1	3.1	2.2	6.5
Less than:					
17,000	10	3.3	3.1	1.9	3.7
26,700	14	3.2	3.1	1.7	4.5
40,400	23	3.2	3.1	1.9	3.8
88,000	35	3.3	3.1	1.9	4.5

[a] Current warning level for trigger #5 (SSB)
[b] SSB that produces one-half maximum R_1
[c] Median SSB for period 1955-97
[d] Minimum SSB during 1955-62 (period of historically high levels of SSB)

Table 7.2. Conditional probabilities of recruitment to age-0 from spawning stock biomass based on interquartile stratifications (based on interquartile range for 1955-97) used in population projections.

Spawning Stock Biomass	Recruits to Age-0[a]		
	Low (< 2.81)	Middle (2.81 - 6.29)	High (>6.29)
Low (< 20.8)	0.20	0.50	0.30
Middle (20.8 - 62.9)	0.19	0.57	0.24
High (> 62.9)	0.36	0.36	0.27

[a] Recruits to age-0 in billions and spawning stock biomass in thousands of metric tons (mt).

Table 7.3. Mean fishing mortality (F) for the period 1994-97 for North Carolina and percent of Virginia port landings from Murphy virtual population analysis. Also, maximum spawning potential (or static SPR) is given for each F associated with percent of Virginia port landings.

Age	F				
	0% VA	70% VA	80% VA	90% VA	100% VA
0	0.022	0.024	0.024	0.024	0.025
1	0.063	0.170	0.185	0.200	0.216
2	0.186	0.737	0.815	0.894	0.973
3	0.075	0.804	0.908	1.013	1.117
4	0.103	1.157	1.307	1.458	1.609
5	0.070	0.749	0.846	0.943	1.040
6	0.055	0.541	0.611	0.680	0.750
7	0.0	0.0	0.0	0.0	0.0
8+	0.0	0.0	0.0	0.0	0.0
%MSP	67.4	16.2	14.5	12.7	11.1

Table 7.4. Probability associated with inter-correlations among environmental indices and recruits to age-1 (NS = not significant for " = 0.1).

Environmental Indices	RF	N3.4	NA SST	NAO	R_1
			Direct Comparisons		
RF	-	NS	NS	0.057	NS
N3.4		-	0.080	NS	NS
NA SST			-	0.005	NS
NAO				-	NS
R_1					-
			Comparisons of Lagged Differences		
RF	-	0.089	NS	0.035	NS
N3.4		-	0.069	NS	NS
NA SST			-	0.034	NS
NAO				-	NS
R_1					-

Note: RF = flow, N3.4 = El Nino 3.4 anomaly, NA SST = North Atlantic Sea Surface Temperature, NAO = North Atlantic Oscillation, and R_1 = recruits to age-1 menhaden.

12.0 FIGURES

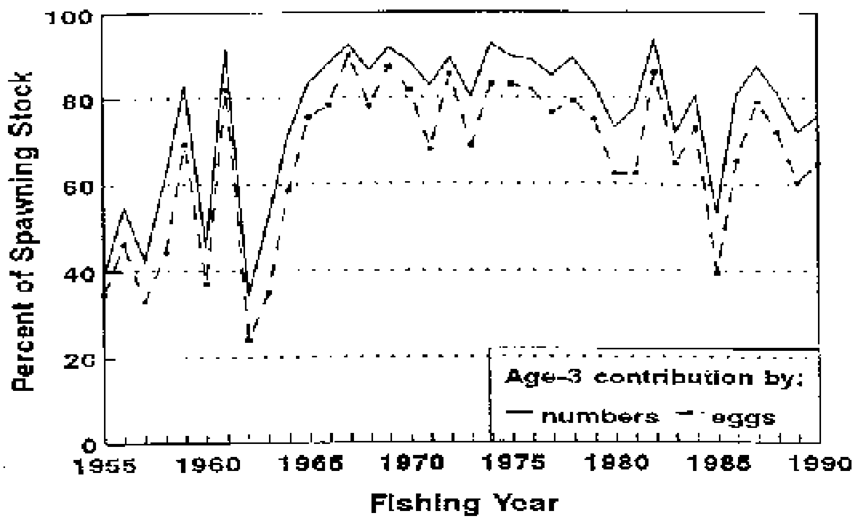


Figure 2.1. Contribution of age-3 spawners to total spawning stock (numbers) and to total egg production (eggs) of Atlantic menhaden for fishing years 1955-1990.

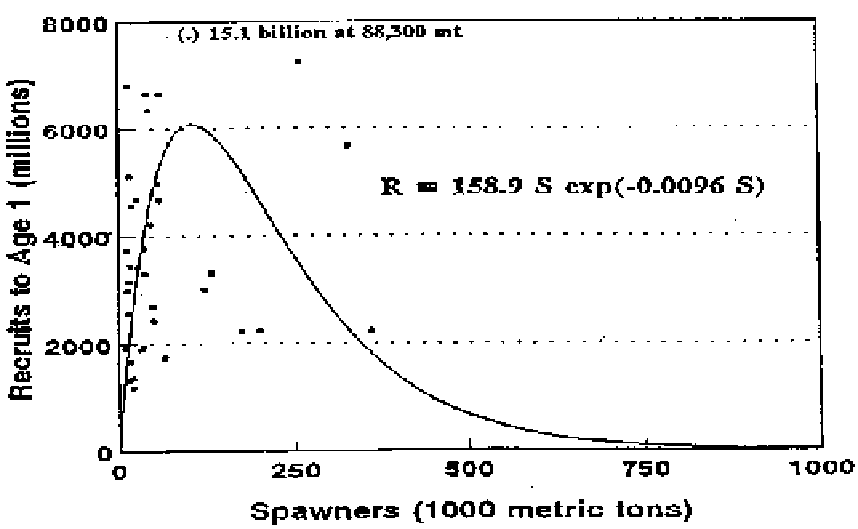


Figure 2.2. Numbers of Atlantic menhaden recruits (R) plotted against numbers of spawners (S) for year classes, 1955-1989. Curve represents the fitted Ricker function [$R = \alpha S \exp(-\beta S)$].

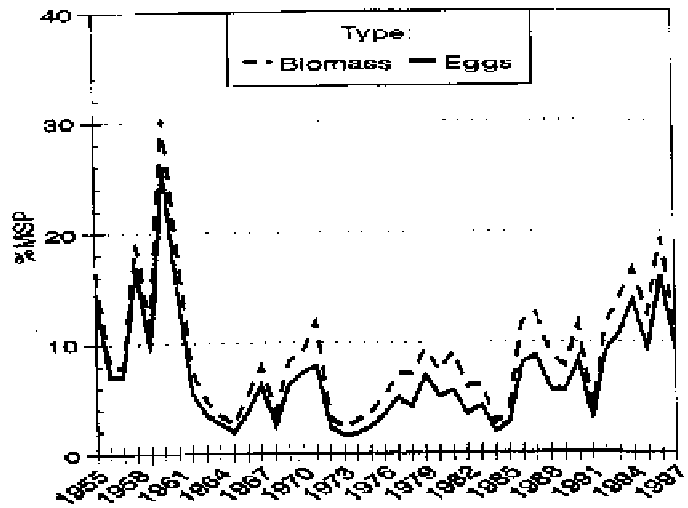


Figure 2.3. Equilibrium spawning stock ratio in biomass and index of egg production for Atlantic menhaden for fishing years, 1955-1990.

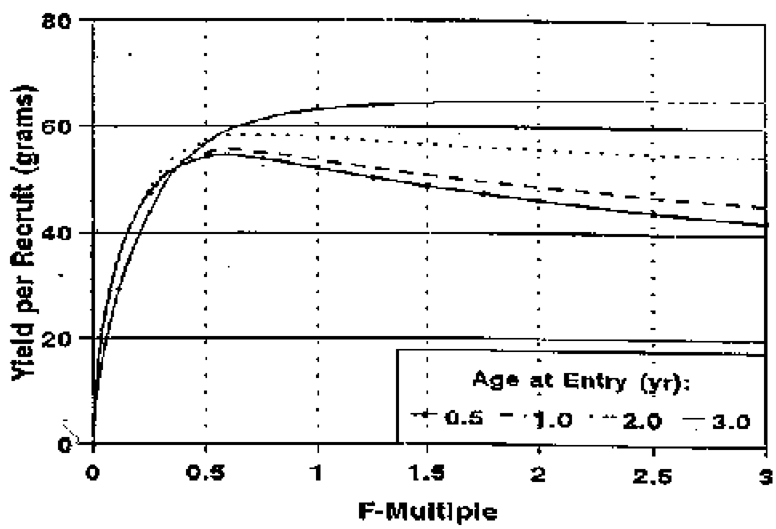


Figure 2.4. Yield-per-recruit analysis for Atlantic menhaden using average growth and fishing mortality values for the 1980-1990 fishing years.

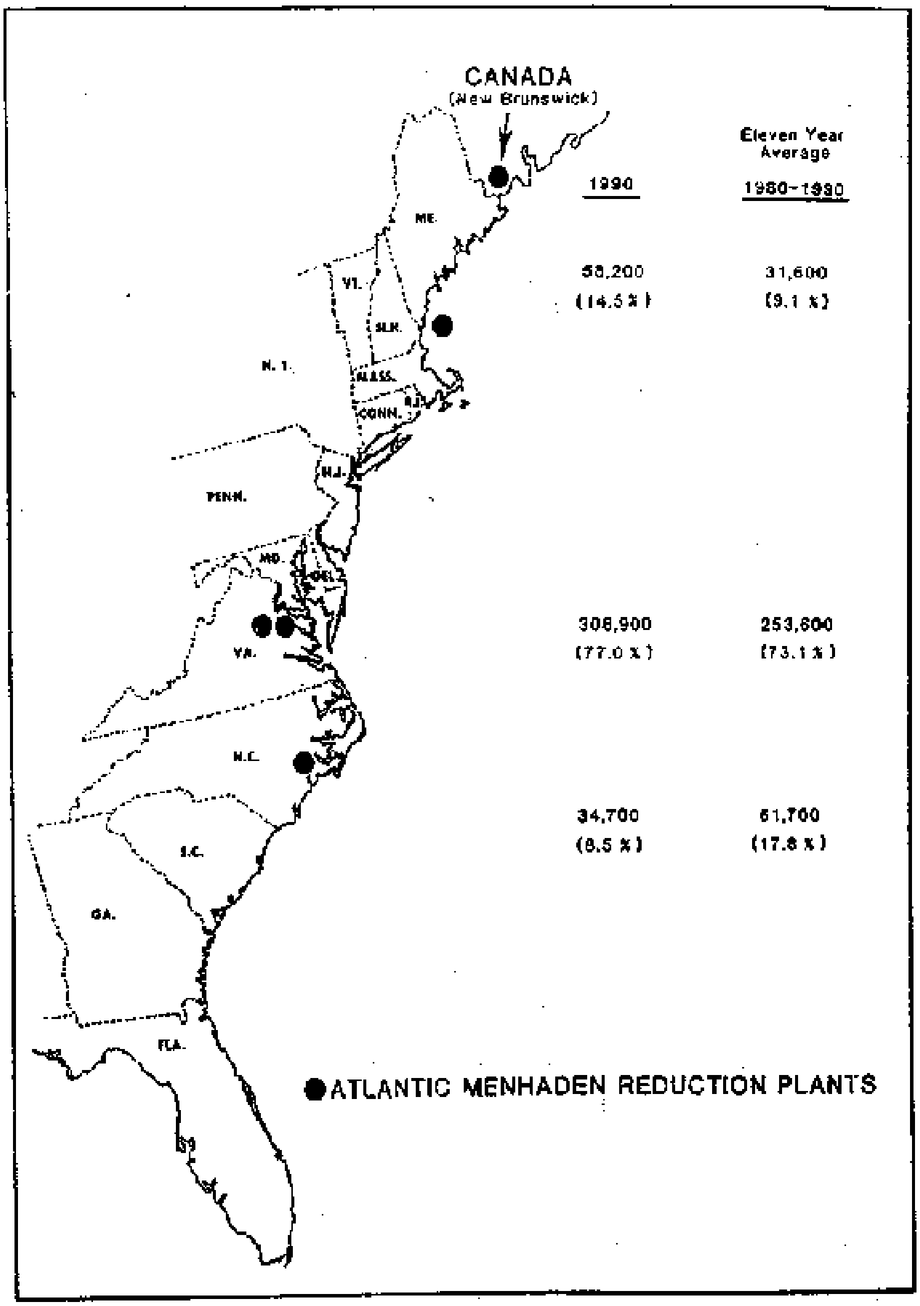


Figure 3.1. Locations of Atlantic menhaden processing plants and purse seine landings (mt) for reduction, 1990.

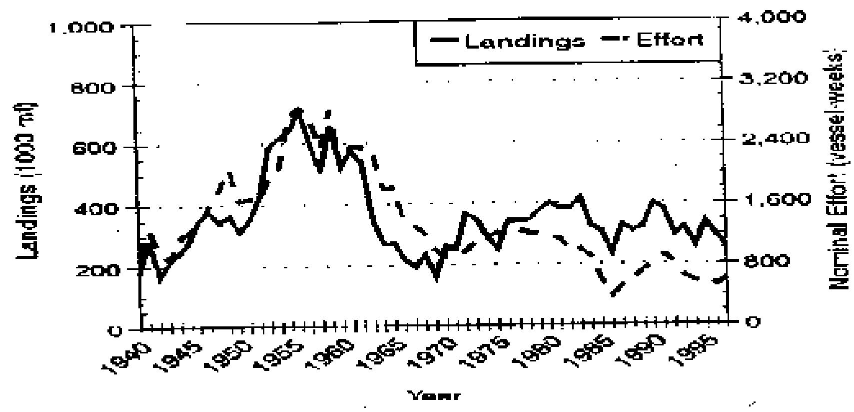


Figure 5.1. Atlantic menhaden landings and nominal effort.

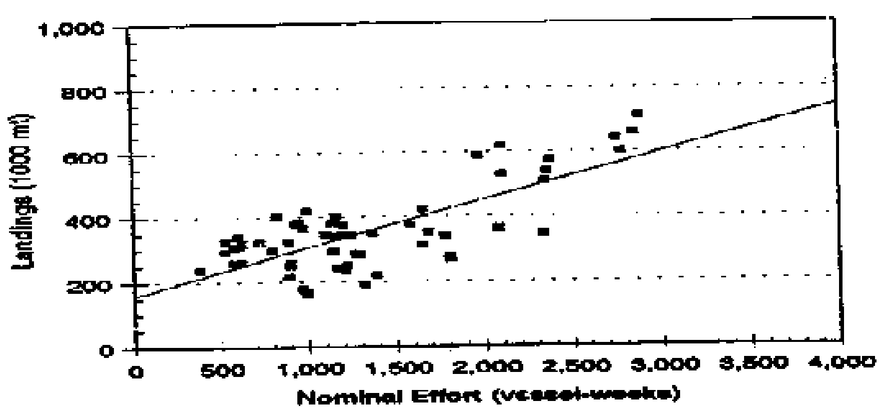


Figure 5.2. Atlantic menhaden landings vs nominal effort.

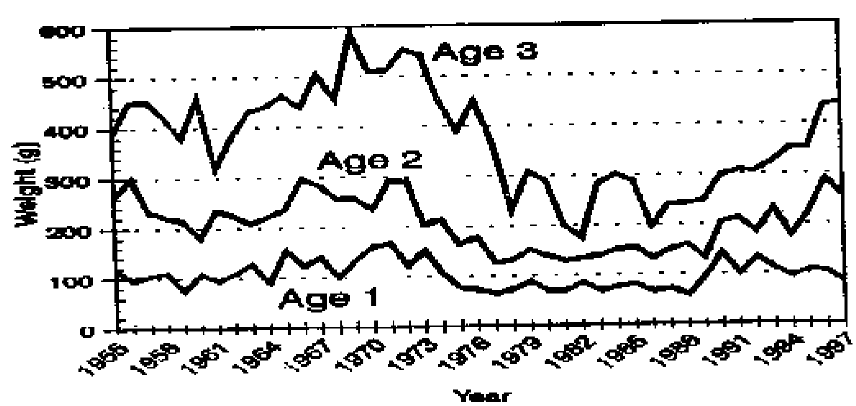


Figure 5.3. Mean weight at age for Atlantic menhaden.

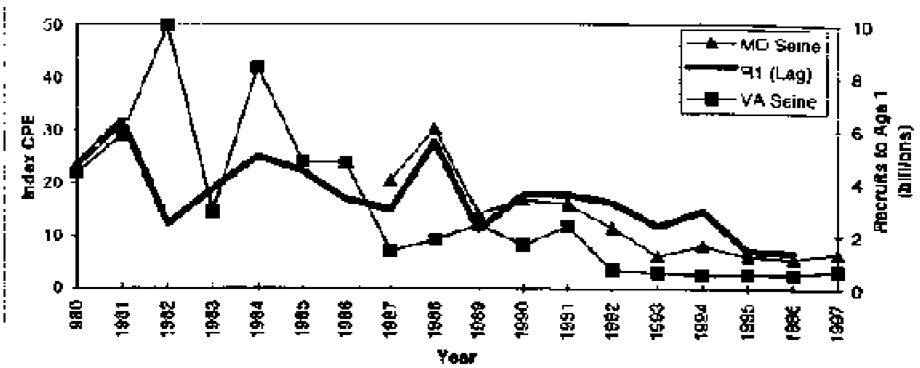


Figure 5.4. Chesapeake Bay seine survey CPE vs. lagged age-1 menhaden recruits.

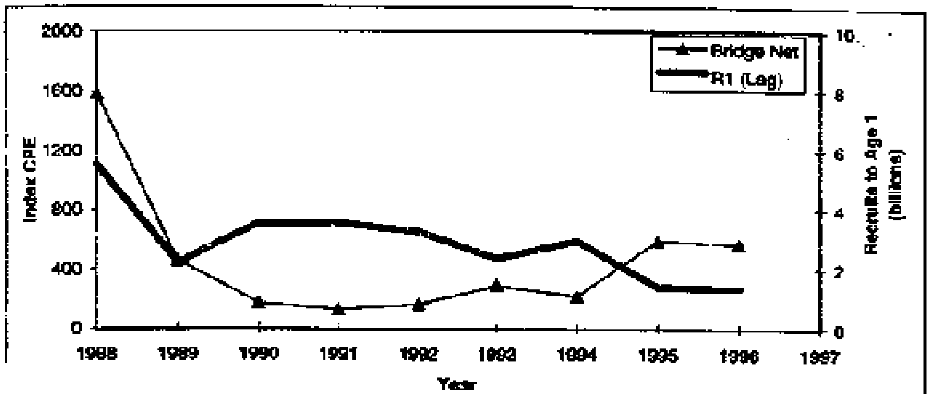


Figure 5.5. Bridge net larval index vs lagged age-1 menhaden recruits.

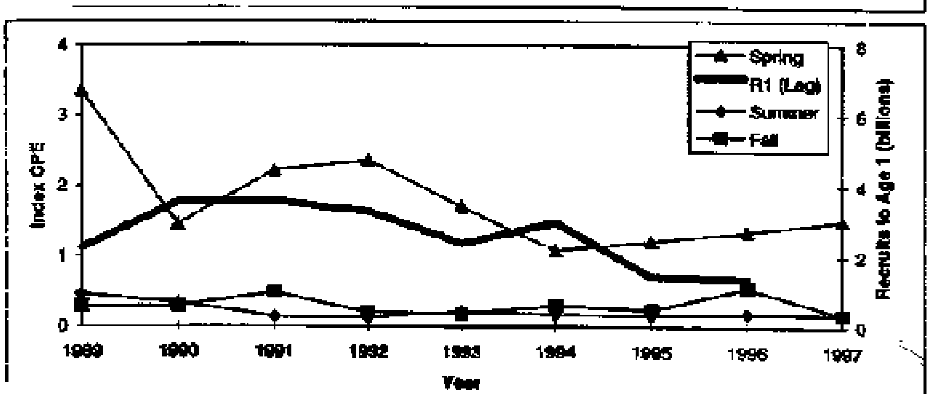


Figure 5.6. SEAMAP indices vs lagged age-1 menhaden recruits.

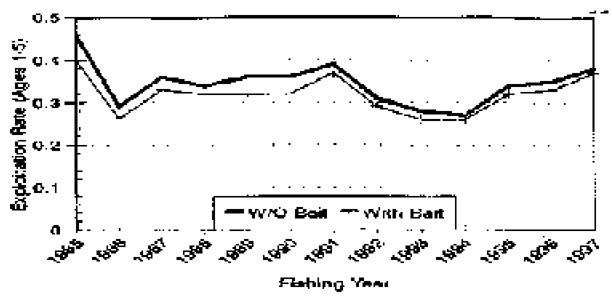


Figure 5.7. Exploitation rate (age 1-5) using Atlantic menhaden catch-at-age with and without bait landings.

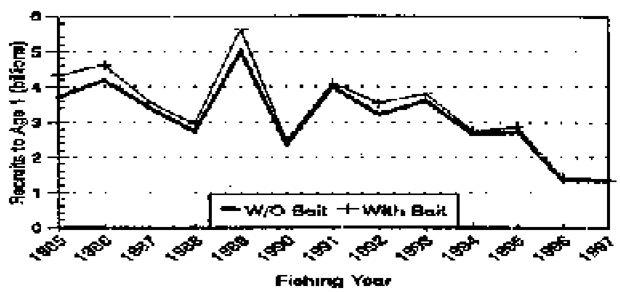


Figure 5.8. Recruits to age-1 Atlantic menhaden using catch-at-age with and without bait landings.

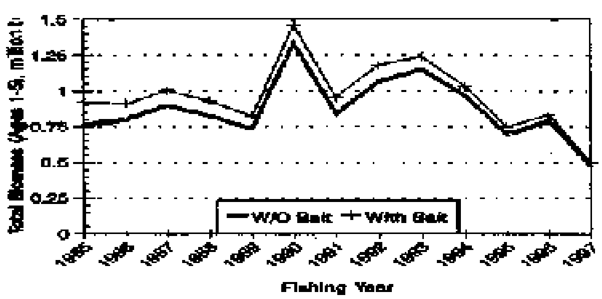


Figure 5.9. Total biomass (age 1-5) using Atlantic menhaden catch-at-age with and without bait landings.

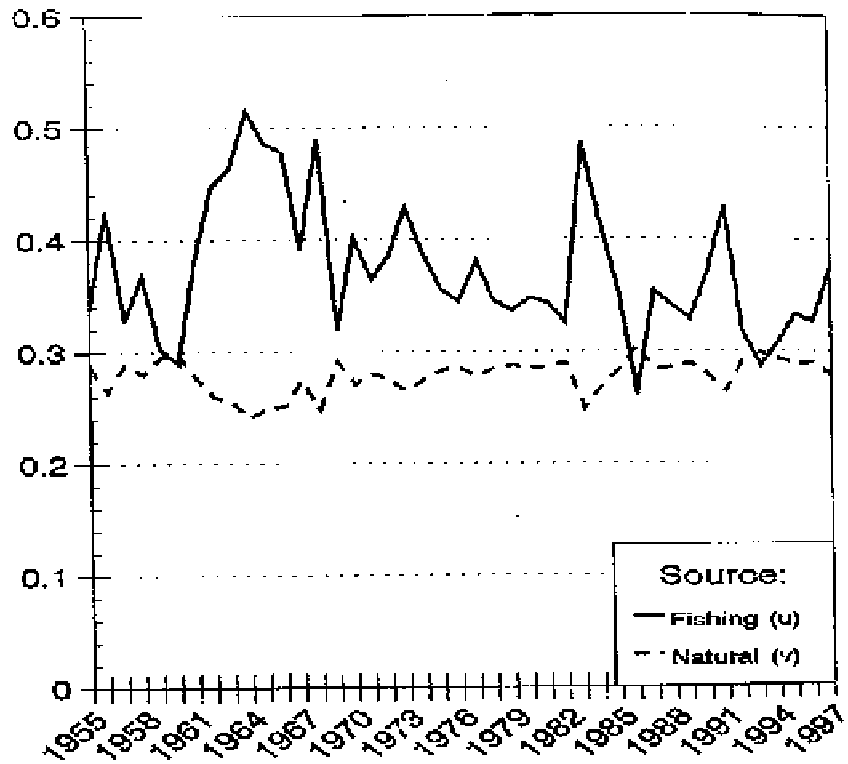


Figure 7.1. Exploitation rate (u) and expectation of natural death (v) for Atlantic menhaden

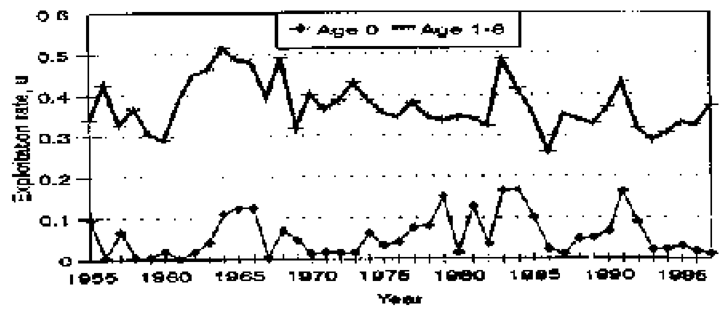


Figure 7.2. Exploitation rates (u) for age 0 and age 1-8 Atlantic menhaden.

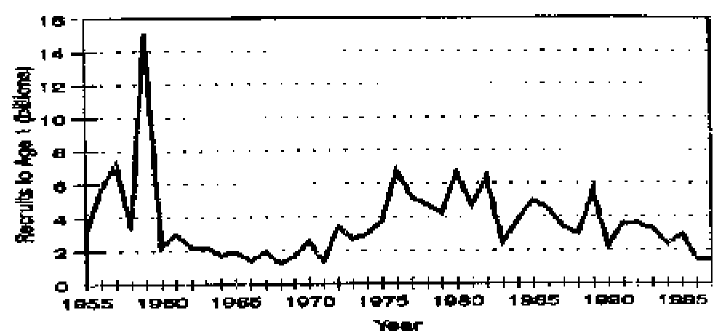


Figure 7.3. Recruits to age-1 Atlantic menhaden.

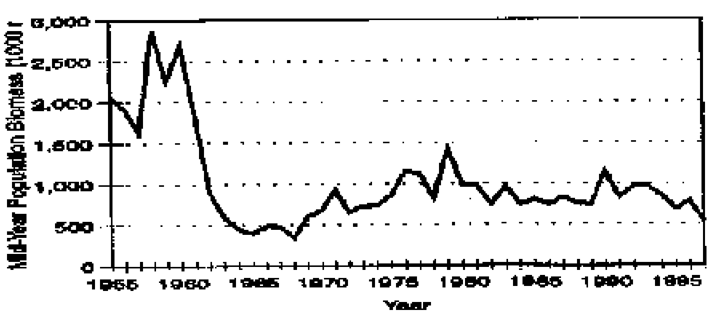


Figure 7.4. Total population biomass (ages 1-8) or Atlantic menhaden.

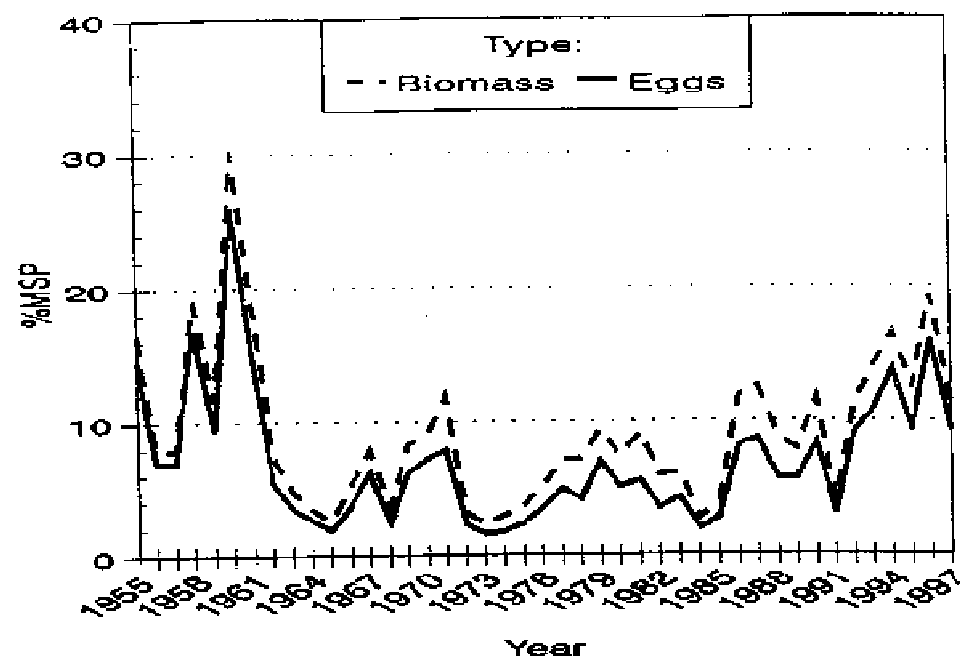


Figure 7.5. Annual static SPR (or %MSP) for Atlantic menhaden.

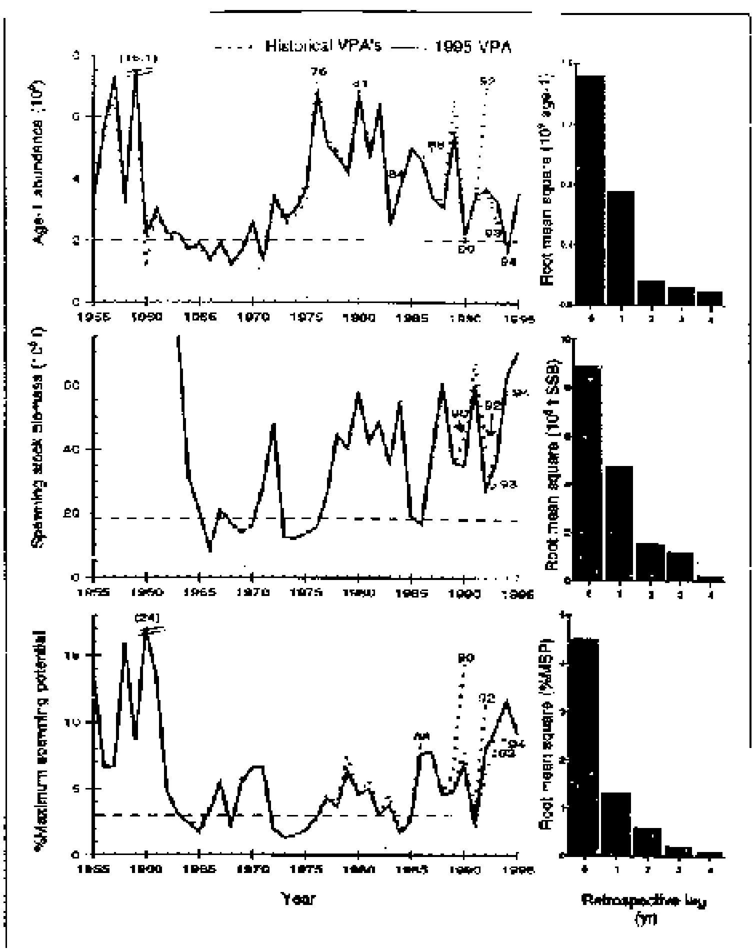


Figure 7.6. Comparison of historical estimates of Atlantic menhaden recruitment, spawning stock biomass, and percent maximum spawning potential. In the left charts, terminal years of historical stock assessments are labeled at the end of each series, overfishing thresholds are indicated by broken horizontal lines, and values in parentheses are not plotted. Convergence of estimates is illustrated by reduction in root mean square of historical differences over time in the charts on the right.

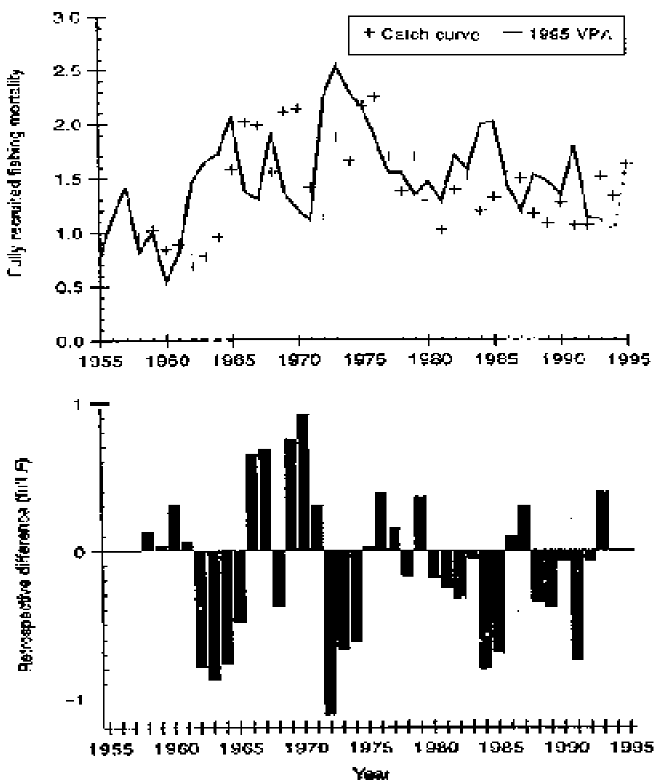


Figure 7.7. Retrospective catch-curve estimates of Atlantic menhaden fishing mortality and backcalculated estimates from the 1995 VPA (above) and retrospective differences (below). The broken line in the upper chart indicates provisional estimates.

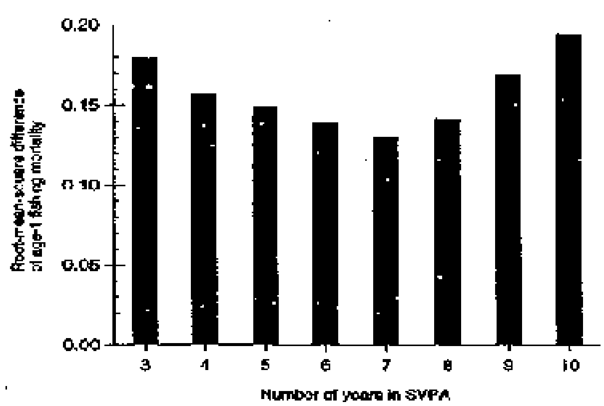


Figure 7.8. Root-mean-square retrospective difference of fishing mortality estimates for age-1 Atlantic menhaden from SVPA's with three to ten years of catch at age.

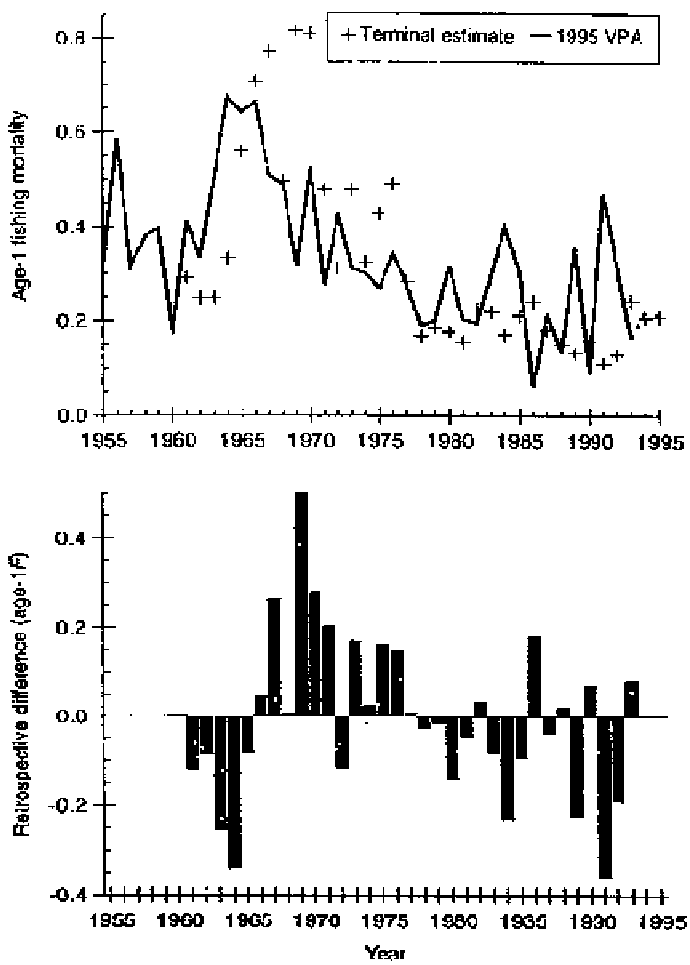


Figure 7.9. Estimates of fishing mortality for age-1 Atlantic menhaden from the 1995 VPA and terminal estimates from retrospective SVPA's (above) and retrospective differences (below). The broken line in the upper chart indicates provisional estimates.

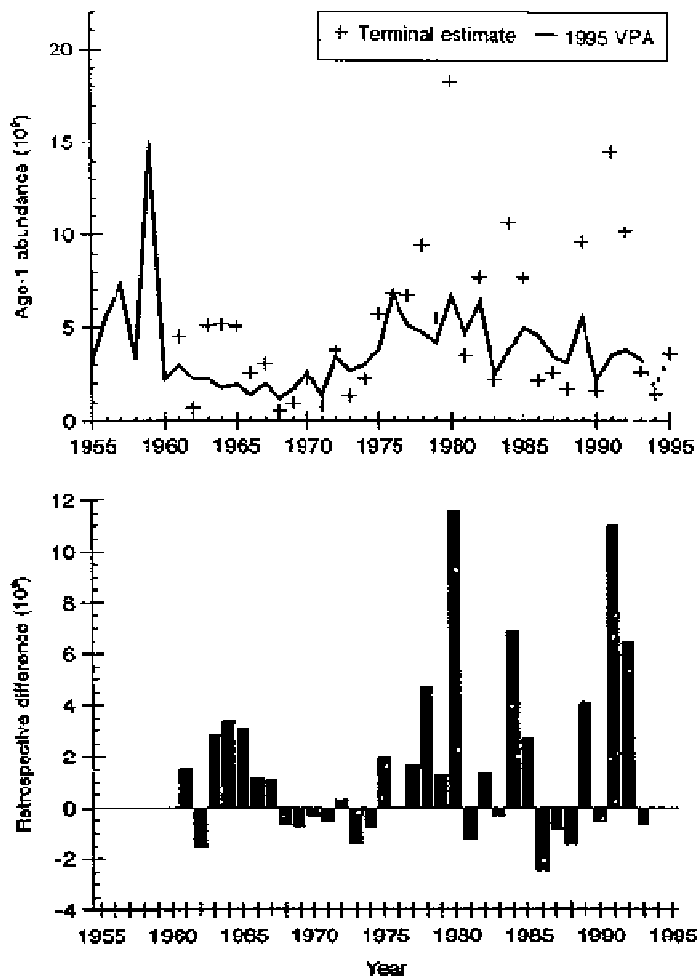


Figure 7.10. Estimates of Atlantic menhaden recruitment from the 1995 VPA and terminal estimates from retrospective SVPA's (above) and retrospective differences (below). The broken line in the upper chart indicates provisional estimates.

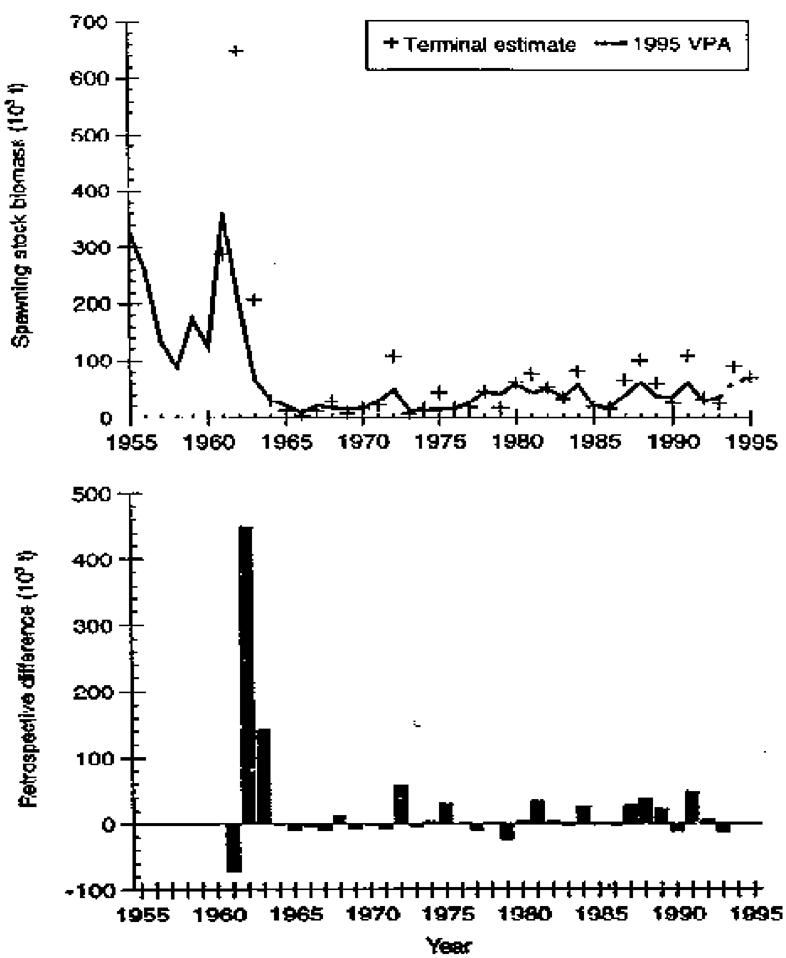


Figure 7.11. Estimates of spawning stock biomass of Atlantic menhaden derived from the 1995 VPA and terminal estimates from retrospective SVPA's (above) and retrospective differences (below). The broken line in the upper chart indicates provisional estimates.

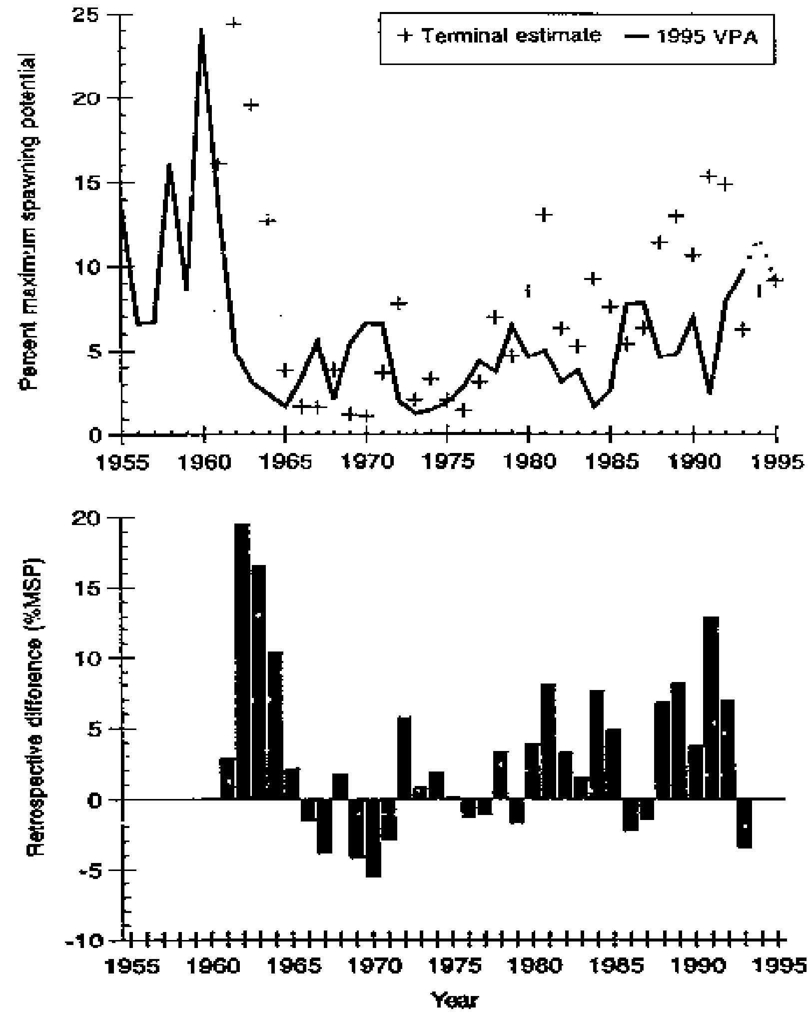


Figure 7.12. **Estimates of percent maximum spawning potential of Atlantic menhaden derived from the 1995 VPA and terminal estimates from retrospective SVPA's (above) and retrospective differences (below). The broken line in the upper chart indicates provisional estimates.**

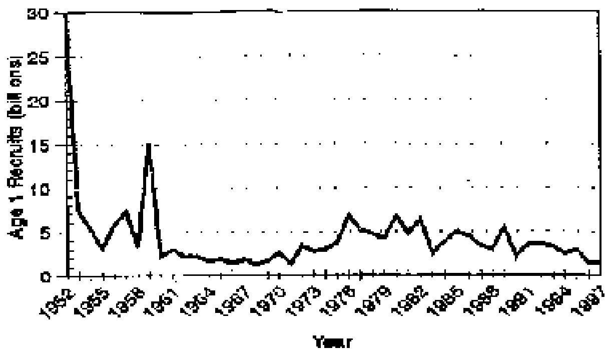


Figure 7.13. Recruit to age1 Atlantic menhaden, extended for 1952-1954.

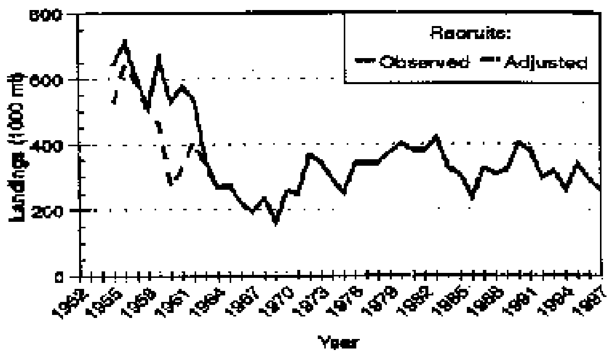


Figure 7.14. Comparison of Atlantic menhaden landings with and without recruit adjustment.

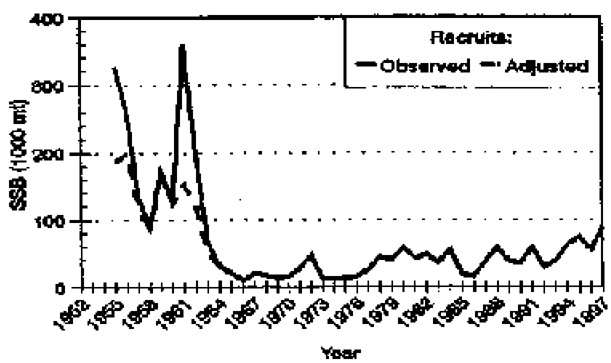


Figure 7.15. Comparison of Atlantic menhaden spawning stock biomass with and without recruit adjustment.

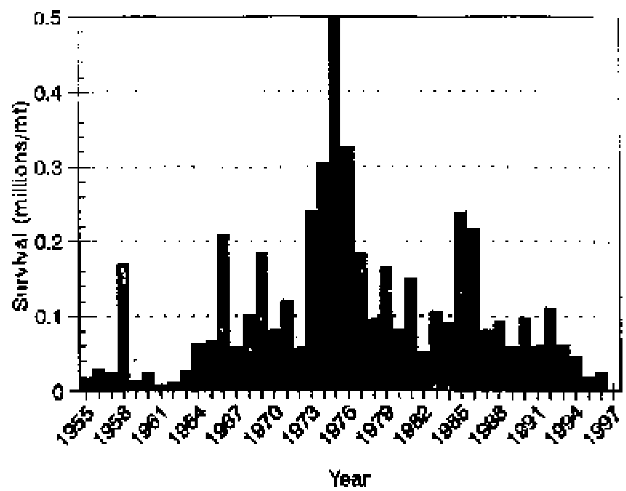


Figure 7.16. Observed survival to age-1 Atlantic menhaden.

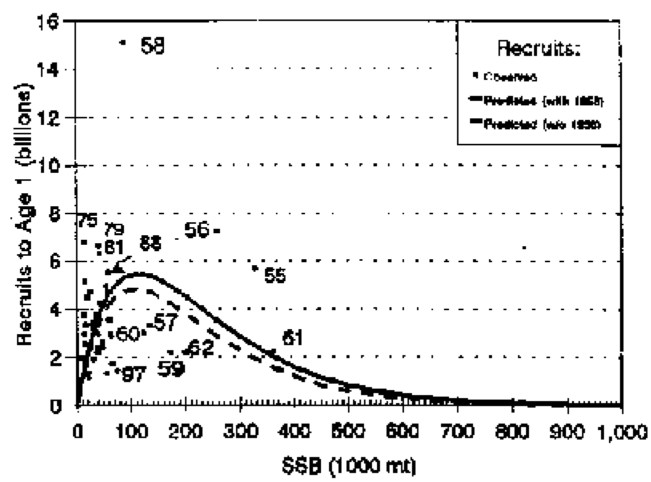


Figure 7.17. Observed and Ricker model estimates of age-1 Atlantic menhaden (model estimated with and without 1958 year class).

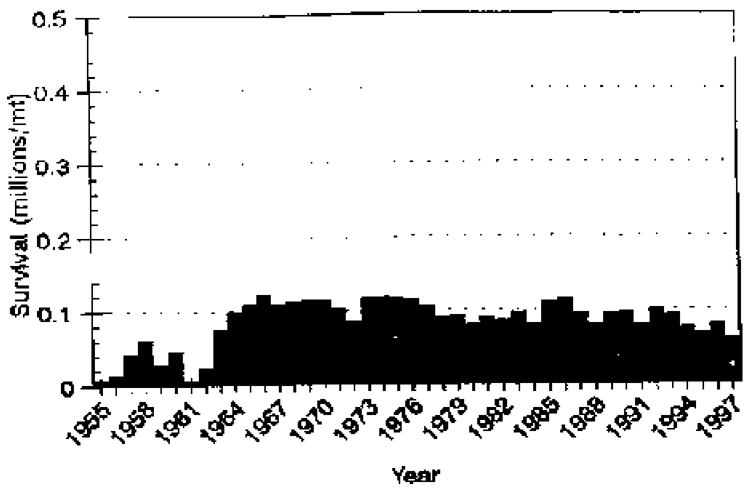


Figure 7.18. Predicted survival to age-1 Atlantic menhaden from Ricker curve.

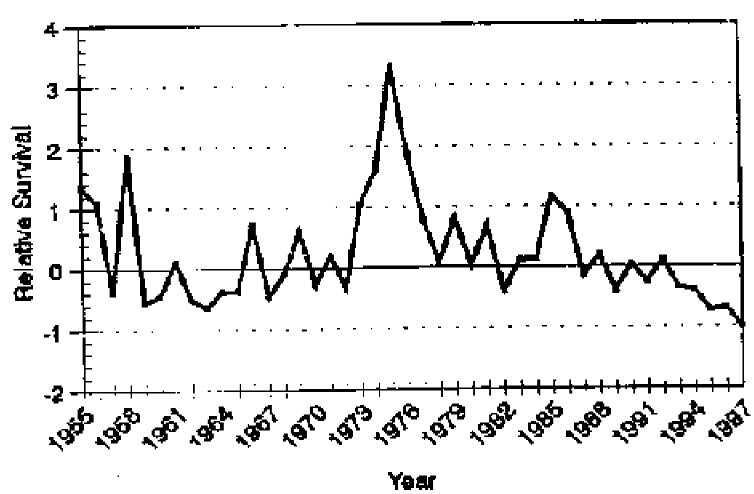


Figure 7.19. Relative survival to age-1 Atlantic menhaden from Ricker curve.

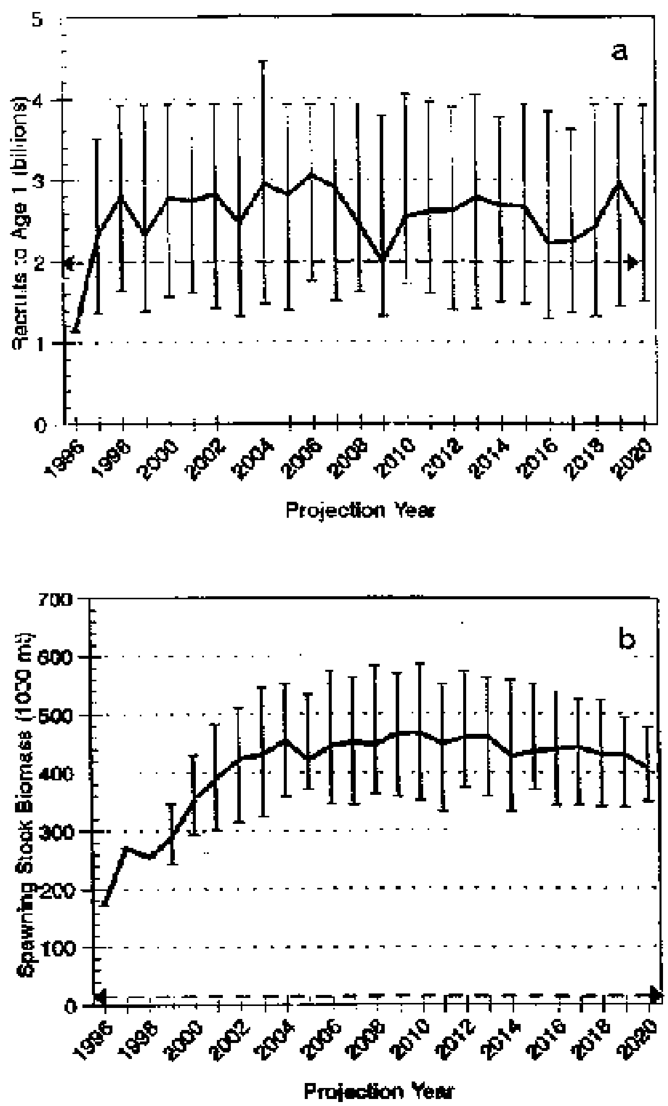


Figure 7.20. Projected values for 0% landings in Virginia of (a) recruits to age-1, and (b) spawning stock biomass of Atlantic menhaden (interquartile range displayed).

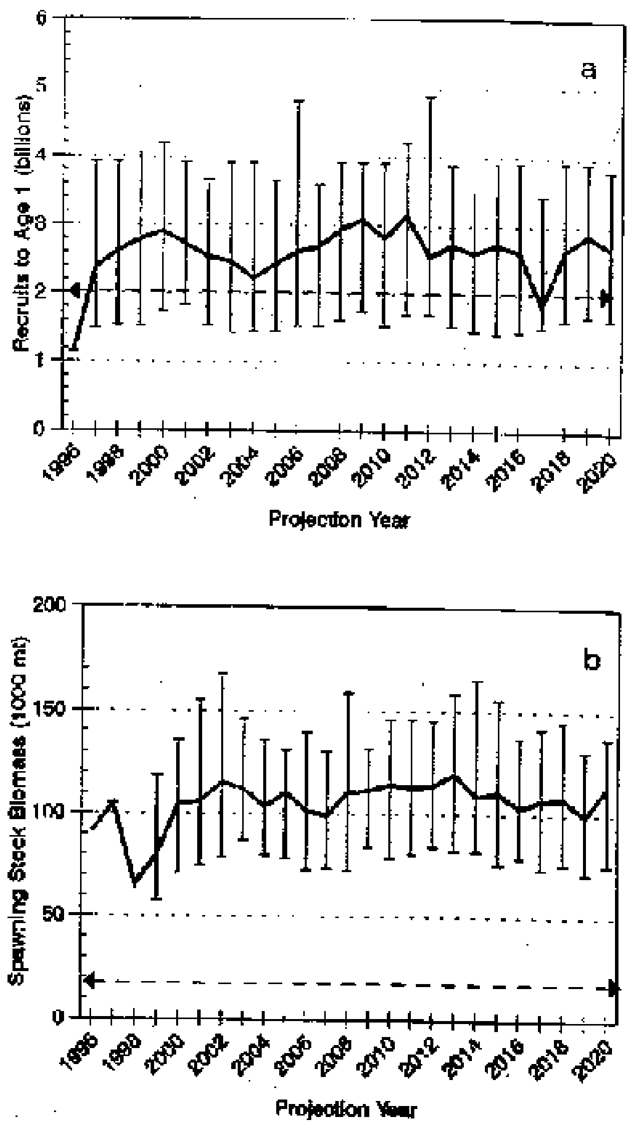


Figure 7.21. Projected values for 70% landings in Virginia of (a) recruits to age-1, and (b) spawning stock biomass of Atlantic menhaden (interquartile range displayed).

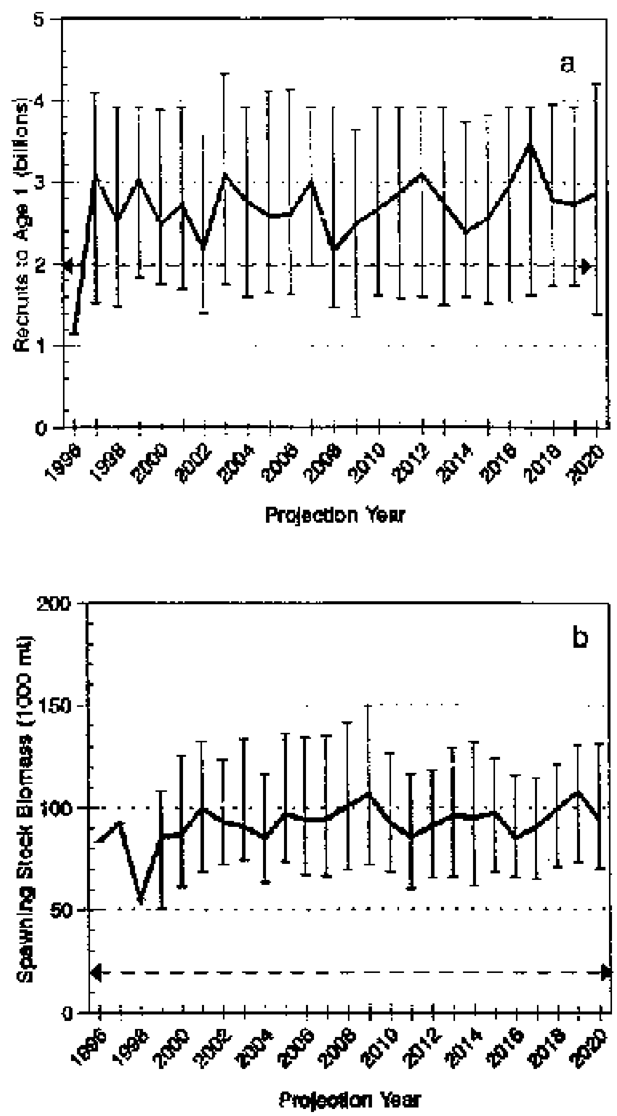


Figure 7.22. Projected values for 80% landings in Virginia of (a) recruits to age-1, and (b) spawning stock biomass of Atlantic menhaden (interquartile range displayed).

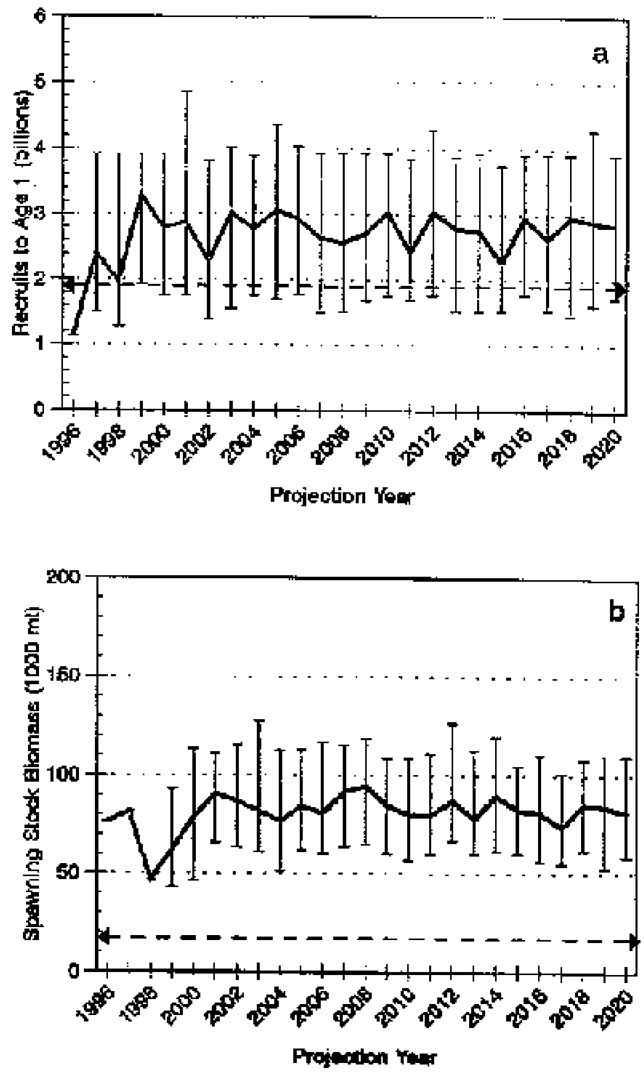


Figure 7.23. Projected values for 90% landings in Virginia of (a) recruits to age-1, and (b) spawning stock biomass of Atlantic menhaden (interquartile range displayed).

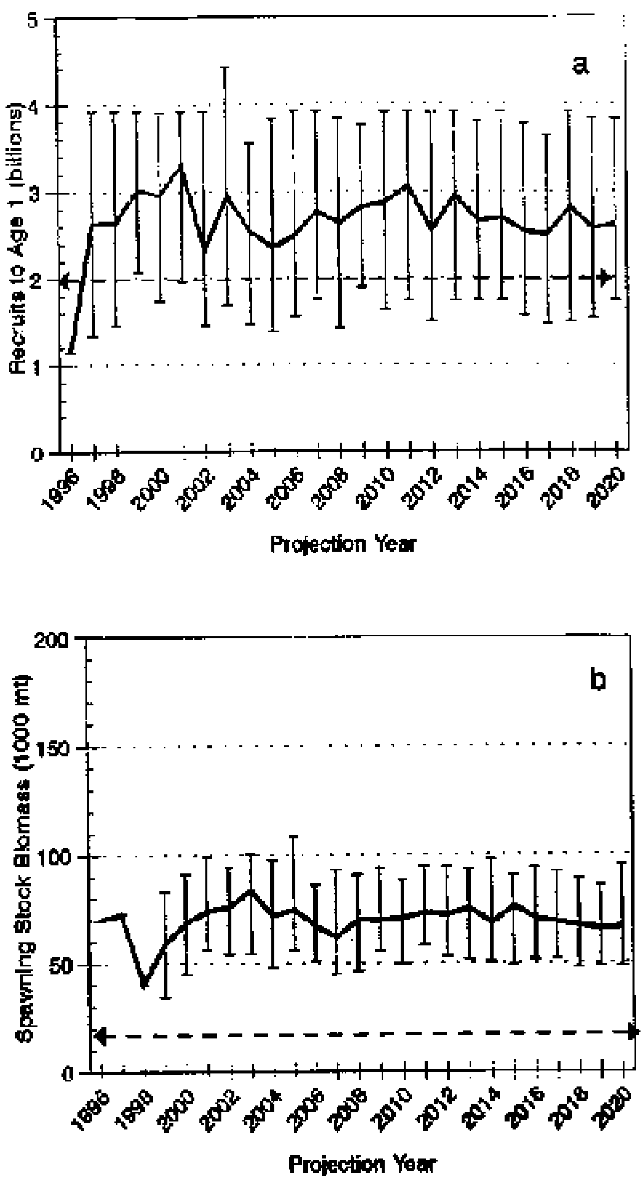


Figure 7.24. Projected values for 100% landings in Virginia of (a) recruits to age-1, and (b) spawning stock biomass of Atlantic menhaden (interquartile range displayed).

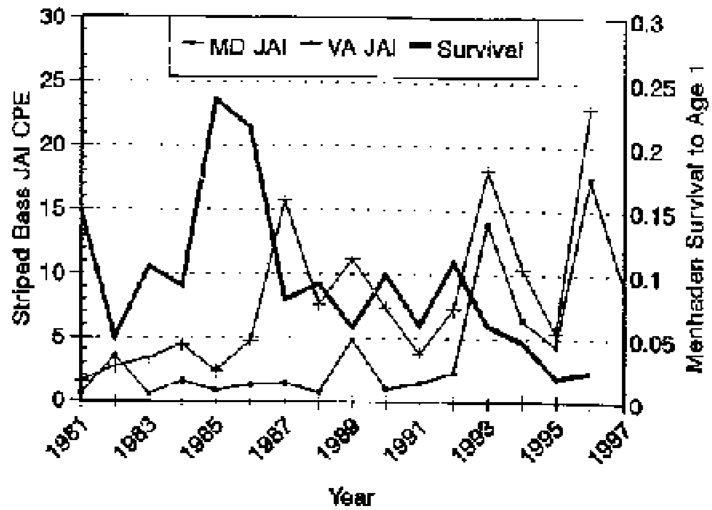


Figure 7.25. Striped bass juvenile abundance indices (MD & VA) vs survival to age-1 menhaden.

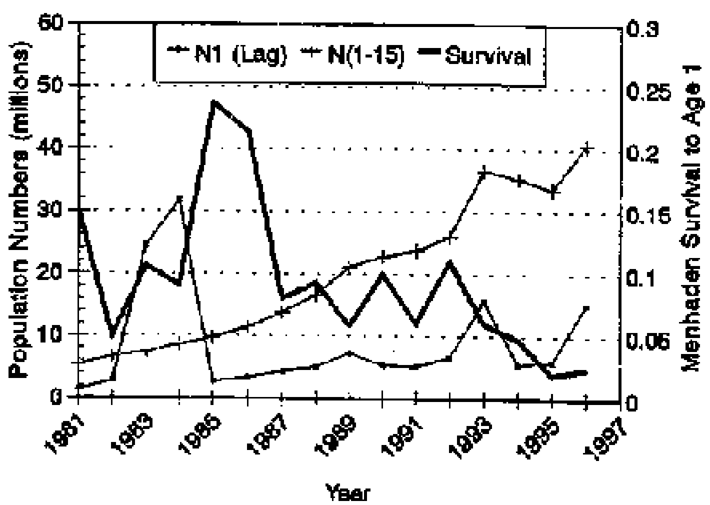


Figure 7.26. Striped bass VPA population numbers vs survival to age-1 menhaden.

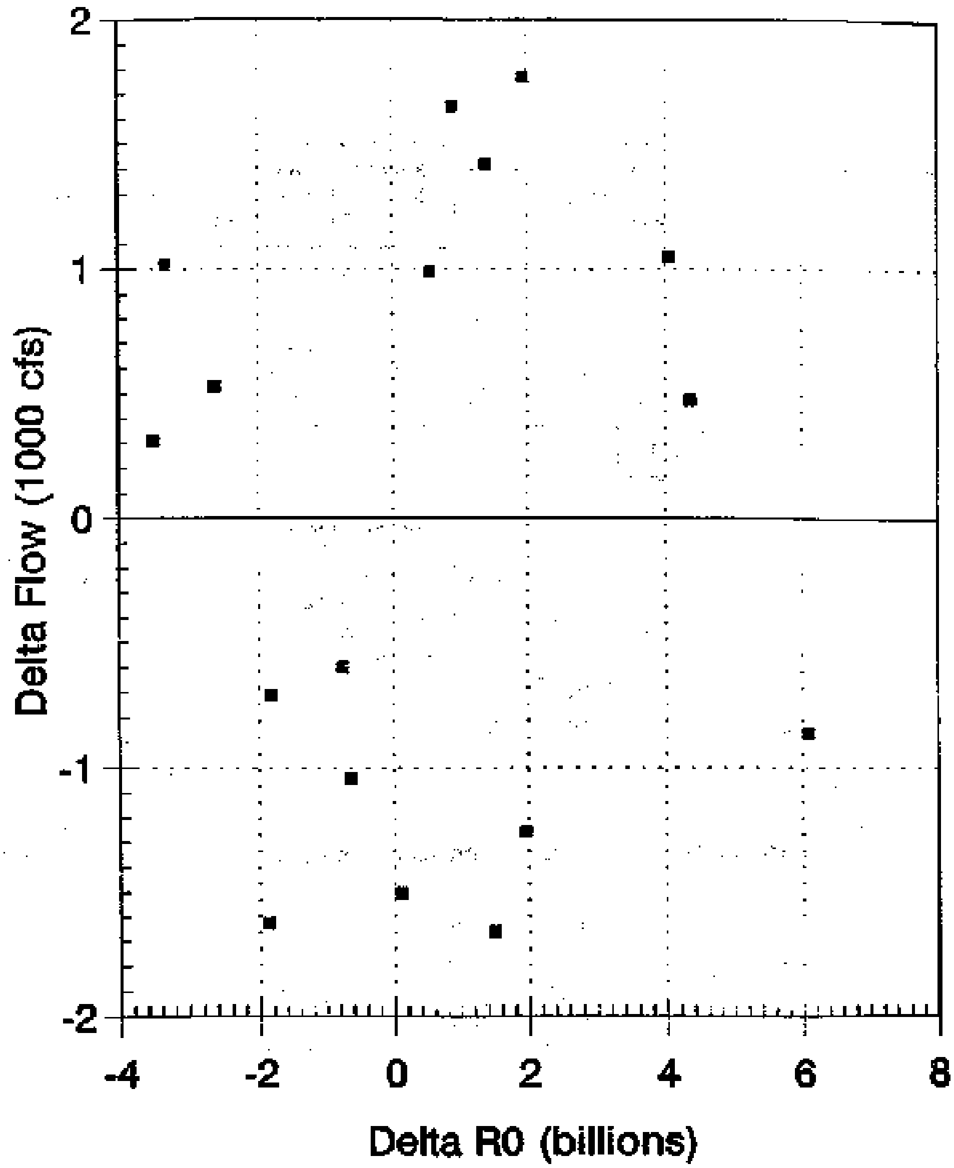


Figure 7.27. Delta Chesapeake Bay river inflow vs delta recruits to age-0 menhaden.

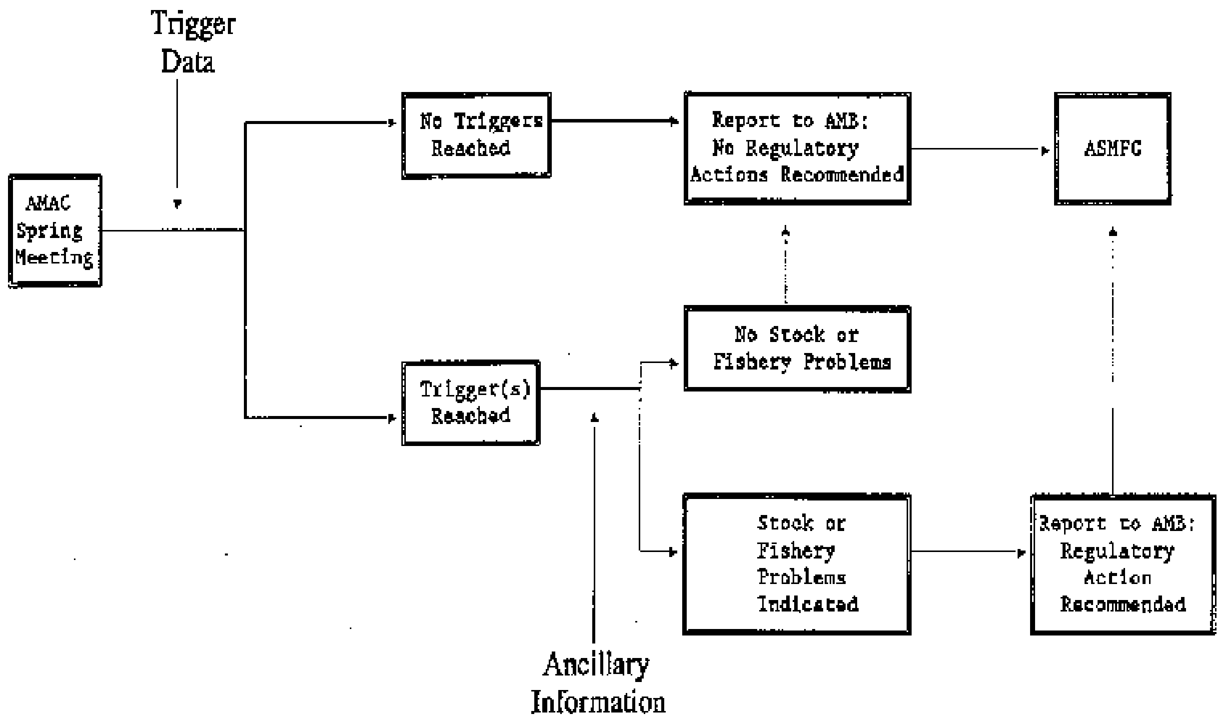


Figure 8.1. Diagram of annual review of menhaden stock and fishery condition process.

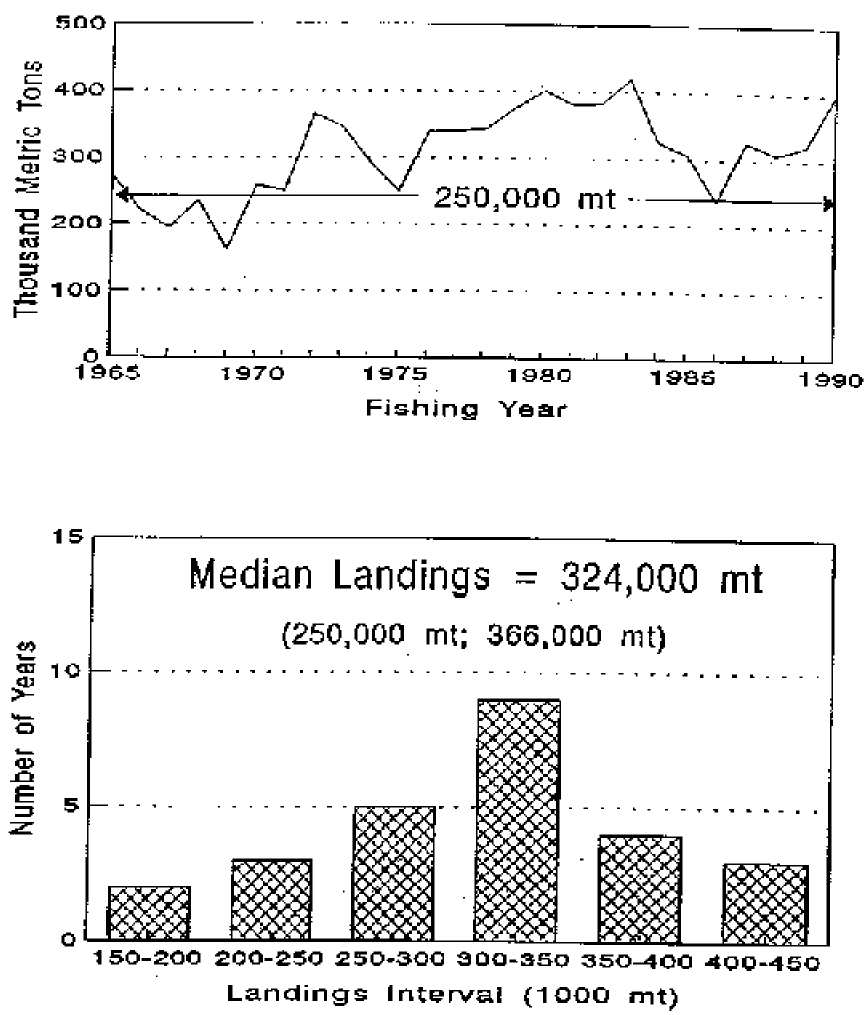


Figure 8.2 **Trigger #1 <250,000 mt, Atlantic menhaden landings, temporal trend, 1965-1990**

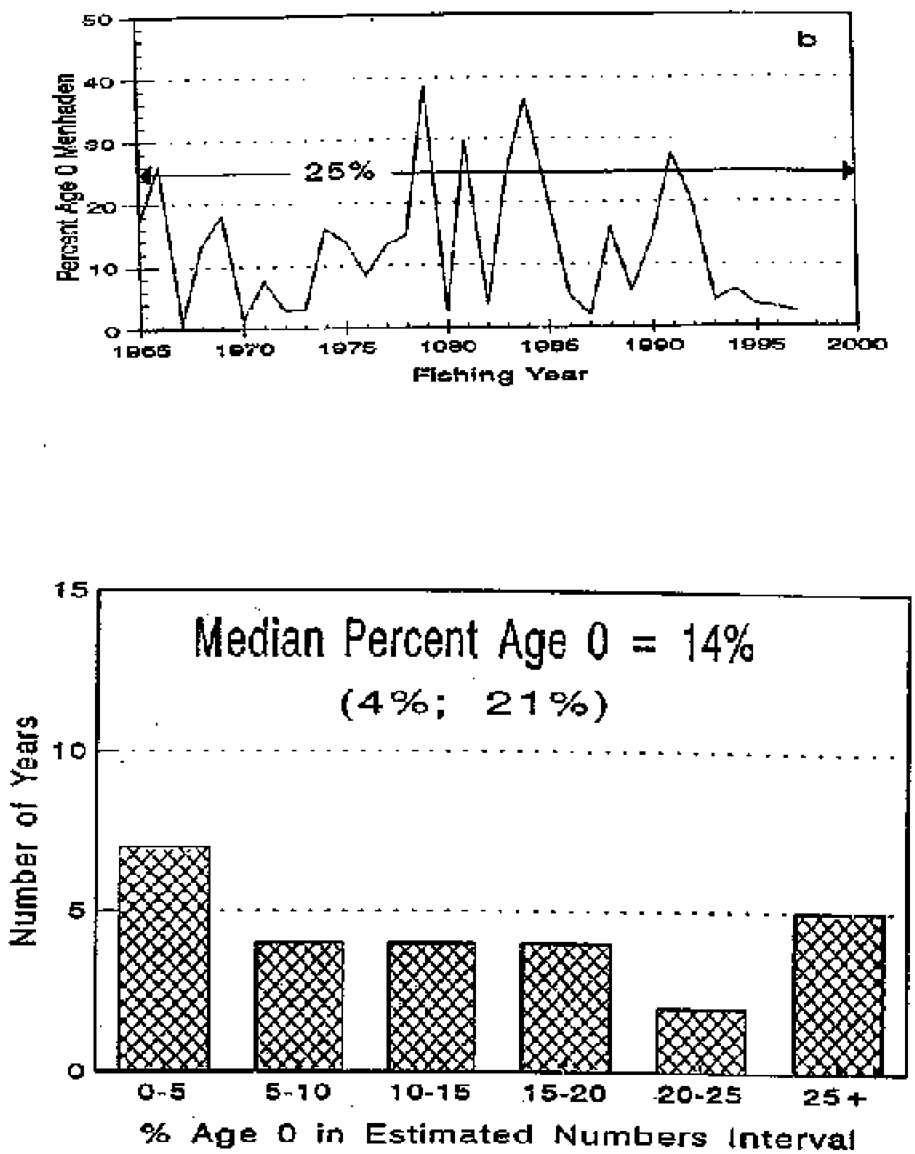
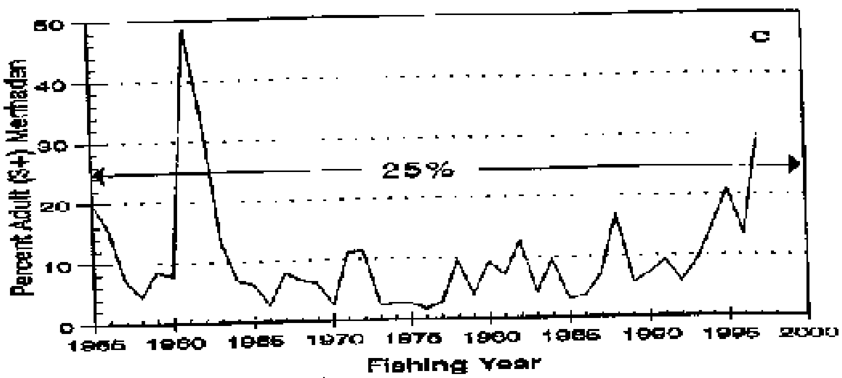


Figure 8.3. **Trigger #2 >25%, Atlantic menhaden percent age 0 in landings, temporal trend, 1965-1990.**



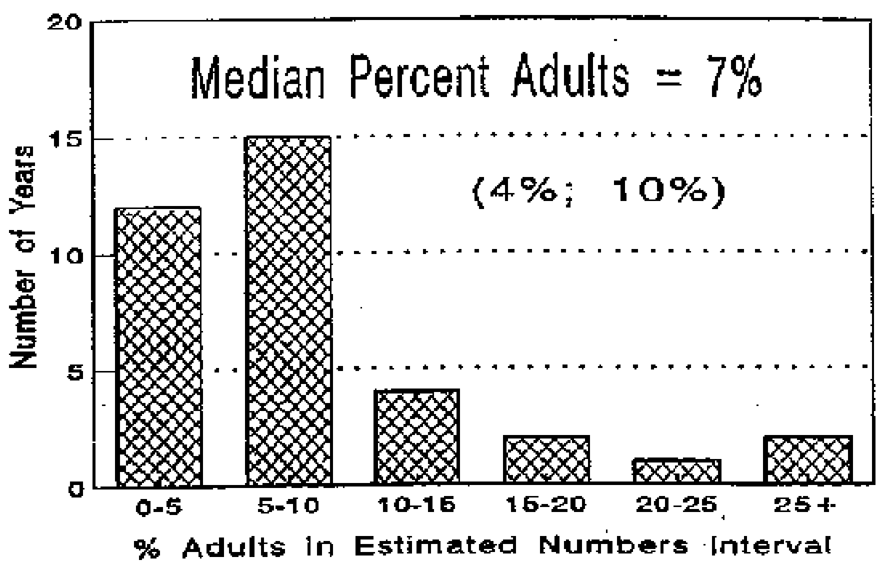


Figure 8.4. Trigger #3 >25%, Atlantic menhaden percent of adults in landings, temporal trend, 1955-1990.

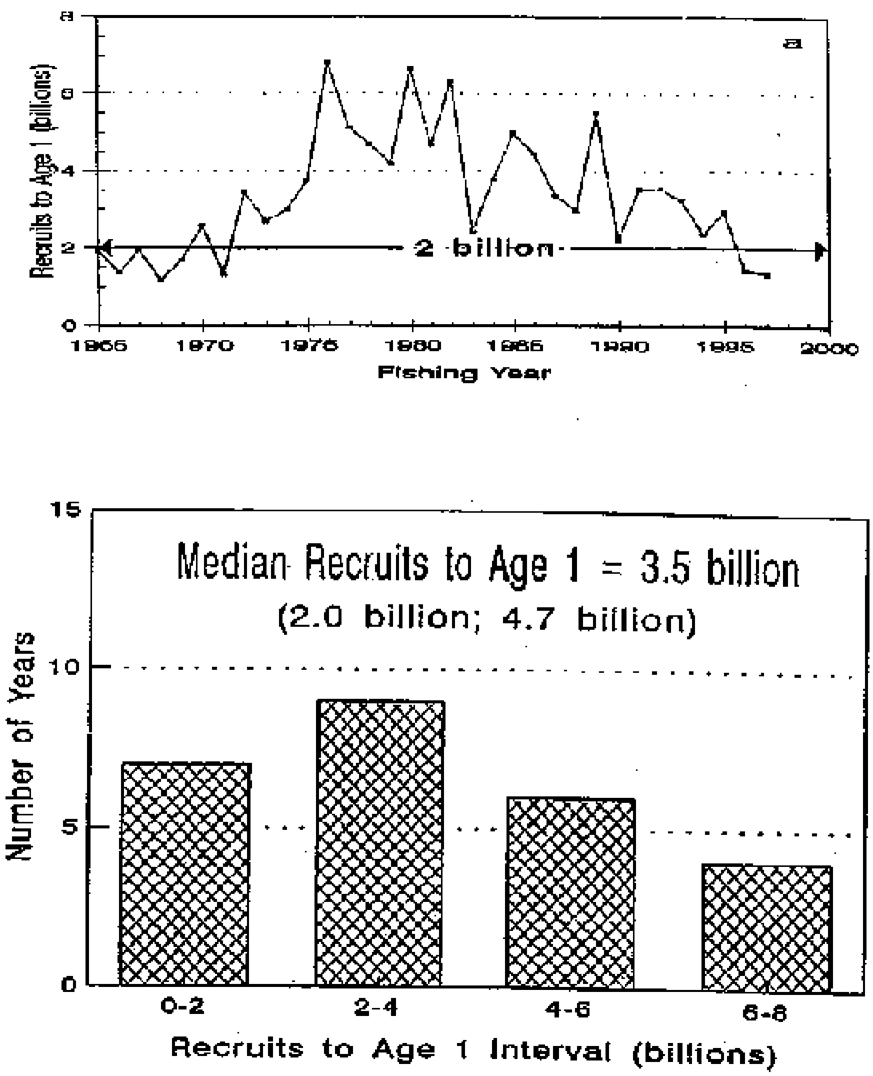
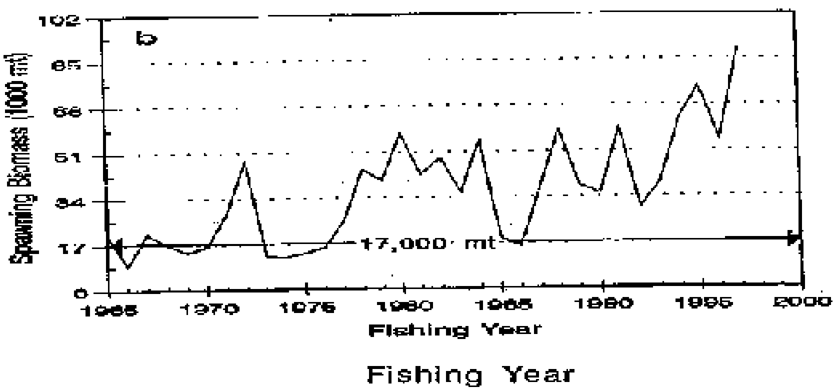


Figure 8.5. Trigger #4 <2 billion, Atlantic menhaden recruits to age-1, temporal trend, 1965-1990.



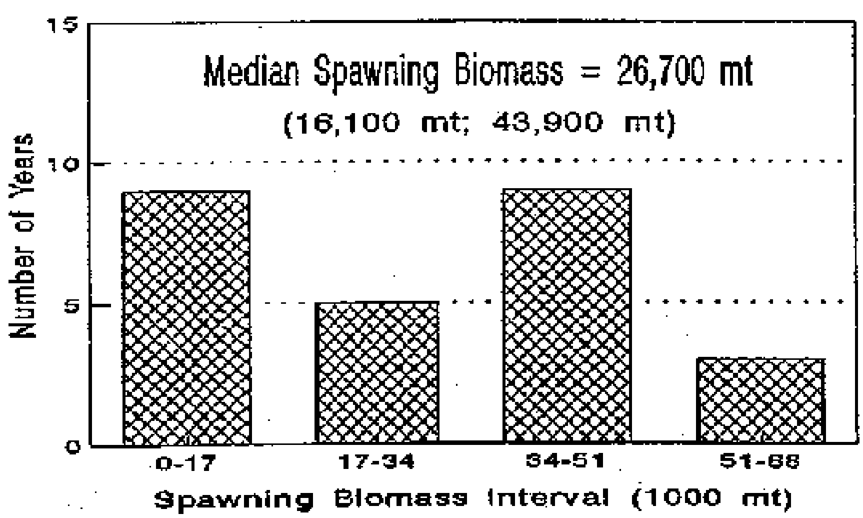


Figure 8.6. Trigger #5 <17,000 mt, Atlantic menhaden female spawning biomass, temporal trend, 1965-1990.

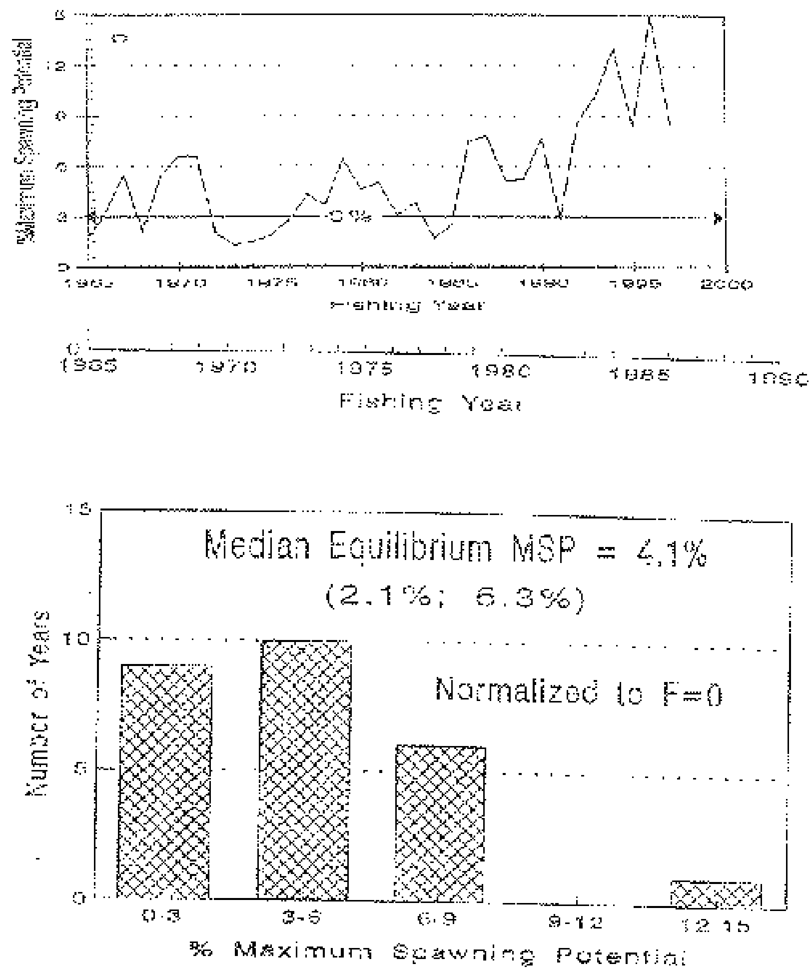


Figure 8.7 Trigger #6 <3%, Atlantic menhaden percent MSP, temporal trend, 1965-1990.

13.0 APPENDICES

A.1 DESCRIPTION OF SOCIOECONOMIC CHARACTERISTICS OF THE FISHERY

A.1.1 Domestic Harvesting Sector

The purse seine reduction fishery employs about 500-550 fishermen from North Carolina to Maine, serving on about 33 vessels. Most of the crew members come from the area near the processing plants. Many fishermen are members of families with long-term involvement in the menhaden fishery, often with relatives in the harvesting and processing sectors. The large, full-time menhaden vessels utilized in Virginia and North Carolina fish with 14-16 man crews, while the small vessels which fish seasonally in Maine for the IWP have crews of about 4-6 fishermen. Almost all vessels in North Carolina and Virginia are owned by the processing companies. However, several independent vessels have fished under contracts with one of the Virginia companies in recent years. All of the Gulf of Maine vessels are independently owned.

Almost all of the purse seine vessels in North Carolina and Virginia have refrigerated holds, while most of the Gulf of Maine vessels do not. Some of the larger vessels can hold two million or more standard fish, over 600 mt. Most of the small Gulf of Maine vessels can carry 80-150 mt at a time.

Up to 17 spotter aircraft have been used to locate fish for the industry in recent years. Some of the pilots are company employees, and some aircraft are owned by the companies, while other spotter pilots and their airplanes work under contracts with the menhaden companies.

All of the Gulf of Maine fishermen are Caucasian, while about 75-80% of the crewmembers in North Carolina and Virginia are African-Americans. Menhaden fishing is the principal occupation of the Virginia and North Carolina crewmembers. In contrast, the northern fishermen participate in other fisheries, such as groundfish trawling, outside the menhaden season or when menhaden are not available.

A.1.2 Domestic Processing Sector

Two of the three domestic menhaden processing plants are located in Reedville, Va. The other facility is in Beaufort, N.C. Employment at these three plants in 1990 was about 300-350, including support staff (maintenance, net-mending, etc.). Similar to vessel crews, many processing employees are members of families with long-standing ties to the industry. In Virginia, about 60% of the shoreside personnel are Caucasian, and 40% are African-American. About two-thirds of North Carolina processing workers are African-American, while the remainder are Caucasian.

A.1.3 Foreign Processing Sector

A single shore-based plant in Blacks Harbour, New Brunswick, Canada processes approximately 20,000 mt of menhaden annually. The plant operates with two large, Maine-registered menhaden purse seine vessels and a single spotter aircraft. All of the crew is white, while the processing employees (40-50 persons) are mostly white, along with a few Asians. The fishing season extends from early June to mid-September. The meal produced is utilized domestically, while oil is exported to foreign markets.

The Russian factory processing ship participating in the IWP in Maine has a crew of about 200, all of whom are Russian. About 160 persons work in the processing sector, while the rest of the crew operates the vessel. All of the meal and oil produced is shipped back to Russia.

A.1.4 International Trade

The U.S. menhaden industry faces competition in the world commodity markets. At the same time, expansion of the global economy offers opportunities for new products, market expansion, and greater economic impact.

The majority of domestic meal production is marketed within the United States. Nonetheless, that market responds to international forces including commodity prices, global weather trends, currency fluctuations, and the relative strength of the domestic economy.

Currently, the menhaden industry participates internationally in three areas: export of raw material to Canada, IWP operations, and export of menhaden oil.

A.1.4.1 Export of Raw Material to Canada

Since 1987, the largest vessels in the New England menhaden fleet have delivered fish to a processing plant in Canada. In 1991, two boats, owned and operated by fishermen long active in the New England menhaden fishery, participated in this activity.

A.1.4.2 Internal Waters Processing

Since 1988, an IWP project organized by Resource Trading Company of Portland, Maine, utilizing a Russian processing ship, has provided a market opportunity for traditional Maine menhaden fishermen. Operating under an IWP permit issued by the Governor of Maine pursuant to the Magnuson Act, the M/V RIGA has annually processed 20,000-35,000 mt during the June-October menhaden season. With a capacity of 500 mt per day, the RIGA takes fish from a fleet of up to a dozen U.S. catchers and carriers and processes it into fish meal and oil for transport back to Russia.

The significance of this project is that it has maintained an American menhaden harvesting capacity in New England even though the region's domestic processing sector disappeared. As a result, those considering future investment in domestic processing will not face the difficult hurdles of refinancing the harvesting sector and recovering lost harvesting expertise.

A.1.4.3 Export of Menhaden Oil

Nearly all U.S. menhaden oil is exported to Europe for both food and industrial uses. This trade is vulnerable to supplies of competing fish and vegetable oils and to the standing of U.S. currency. European processing of this oil into added-value products represents an economic opportunity lost by the United States due to restrictive regulations on the domestic use of menhaden oil.

To assess the future impact of international forces on the domestic menhaden industry one can simply observe that the world's population is projected to rise from a current 5.25 billion to 6.0 billion by the year 2000 and to add another billion persons by 2010. The world economy will continue to demand every ounce of protein possible from its marine resources, not only for livestock and poultry feed, but also for the burgeoning aquaculture industry.

A.2 DESCRIPTION OF BUSINESSES, MARKETS, AND ORGANIZATIONS ASSOCIATED WITH THE FISHERY

A.2.1 Relationship Among Harvesting and Processing Sectors

The menhaden industry in Virginia and North Carolina is vertically integrated, with the processing companies owning the vessels, processing the catch, and selling the products. In contrast, the processing companies in the Gulf of Maine annually contract with vessel owners for the services of their vessels.

A.2.2 Fishery Cooperatives or Associations

The National Fish Meal and Oil Association (NFMOA) is an active division of the National Fisheries Institute, the largest fisheries trade association in the United States, which represents over 1,000 fishery-related businesses. The objectives of the NFMOA are to promote fishery products through research, education, and trade show efforts; to cooperate with state and federal agencies to ensure wise use of the fishery resource to maintain the highest continued yield; and to improve its products. Membership of NFMOA generally includes the menhaden fishing and processing companies, businesses which utilize menhaden products, and others concerned with the industry.

A.2.3 Labor Organizations

The Reedville Fishermen's Association is the only known labor organization formed specifically to represent menhaden fishermen. The Association was organized in 1988 among the vessel personnel of one of the two companies based in Reedville, Virginia. The Association became a local affiliate of a national labor union (United Food and Commercial Workers) during 1992.

A.2.4 Foreign Investment in the Domestic Fishery

There is no known foreign investment in the domestic Atlantic menhaden fishery.

A.3 ATLANTIC MENHADEN BAIT LANDINGS BY STATE AND GEAR TYPE, 1985-95

Table A3.1 Menhaden bait landings (pounds) in Maine, by gear, 1985-97.

Year	Stop Seine	Purse Seine	Pots & Traps	Total (lbs)	Total (mt)
1985		1,891,383		1,891,383	857.9
1986		16,250,100		16,250,100	7,371.0
1987		14,361,840		14,361,840	6,514.5
1988		19,685,728		19,685,728	8,929.4
1989		380,000	619	380,619	172.6
1990	852,000	4,892,597		5,744,597	2,605.7
1991		13,893,963		13,893,963	6,302.3
1992		10,980,056		10,980,056	4,980.5
1993		19,101,041		19,101,041	8,664.2
1994	0	0		0	0
1995	0	0		0	0
1996	0	0	0	0	0
1997	0	0	0	0	0

Concerted effort was expended by NMFS reporting specialists in 1991 to record menhaden bait landings. Thus, the 1991 estimate is given with a high level of confidence. All estimates prior to 1991 are based on incomplete information. Unique gear type in Maine within recent years is the stop seine, a long net which has traditionally been used in Maine to harvest juvenile Atlantic herring. The menhaden bait fishery takes place in the summer, with the majority of the catch in July and August (75% of the catch in 1991).

Table A3.2 Menhaden bait landings (pounds) in New Hampshire, by gear, 1987-97.

Year	Gill Net	Cast Net	Other	Total (lbs)	Total (mt)
1987	4,099			4,099	1.9
1988	5,141		6	5,147	2.3
1989	5,424			5,424	2.5
1990	6,044			6,044	2.7
1991	11,849		141	11,990	5.4
1992	10,164		3	10,167	4.6
1993	3,710			3,710	1.7
1994	1,000	27		1,027	0.47
1995	1,538		52	1,590	0.72
1996	32	41		73	0.03
1997				0	0

Atlantic menhaden landings from New Hampshire coastal inland gill netting have been recorded only since 1987. These data were collected from coastal inland netting reports from Great Bay and tributaries and a portion of the Piscataqua River. The bait fishery is primarily a gill net fishery using fixed position 24-hour sets, average net length from 70 to 117 feet. Gill net fishing effort is recorded in hours, ranging from 1,370 hours (13 gill nets) in 1988 to 2,518 hours (11 gill nets) in 1989. Cast nets (8" diameter x 1" mesh) and a dip net (18" diameter) were used in 1991.

Table A3.3 Menhaden bait landings (pounds) in Massachusetts, by gear, 1985-97.

Year	Gill Net	Purse Seine	Pound Net	Fish Trap	Total (lbs)	Total (mt)
1985	3,625	3,036,000			3,039,625	1,378.8
1986		3,411,000			3,411,000	1,547.2
1987	1,775	1,213,400			1,215,175	551.2
1988	1,125	8,039,195		7,000	8,047,320	3,650.2
1989		1,454,350		5,052	1,459,402	662.0
1990		1,700,200		9,405	1,709,605	775.5
1991		12,783,000		15,310	12,798,310	5,805.3
1992		13,490,990		8,460	13,499,450	6,123.3
1993		1,210,000		1,569	1,211,569	549.6
1994		348,000		3,251	351,251	159.3
1995		2,902,823		7,790	2,910,613	1,320.2
1996			8,500		8,500	3.9
1997						

Massachusetts has a small but significant menhaden purse seine fishery for bait, used primarily in the coastal lobster fishery. In 1990, the fishery was concentrated in Boston Harbor, where 12 permits were issued, five of which were actively fished. Two additional seiners worked the North Shore of Massachusetts, while a third worked from Cape Cod into Rhode Island waters. The number of active permits declined from seven in 1993 to four in 1995 due to poor availability of menhaden in Massachusetts coastal waters.

Table A3.4 Menhaden bait landings (pounds) in Rhode Island, by gear, 1985-97.

Year	Trap	Purse Seine	Total (lbs)	Total (mt)
1985	840,020	7,548,026	8,388,046	3,804.8
1986	619,187	9,770,000	10,389,187	4,712.5
1987	609,294	12,999,930	13,609,224	6,173.1
1988	409,437	15,174,000	15,583,437	7,068.6
1989	285,975	18,747,198	19,033,173	8,633.4
1990	372,155	16,730,495	17,102,650	7,757.7
1991	80,375	5,010,000	5,090,375	2,309.0
1992	84,859	2,764,500	2,849,359	1,292.5
1993	342,800	4,803,480	5,146,280	2,334.3
1994	46,000	487,800	533,800	242.1
1995	102,815	5,770,500	5,873,315	2,664.1
1996	802		802	0.4
1997				

Menhaden are taken as bait in Rhode Island in a directed small vessel purse seine fishery, and as a bycatch in other fisheries, primarily with floating fish traps. These data are collected by port agents through the Department of Environmental Management/NMFS Cooperative Statistics Program. Since 1984 all menhaden landings for Rhode Island have been used for bait.

Table A3.5 Menhaden bait landings (pounds) in Connecticut, by gear, 1981-97.

Year	Hook & Line	Gill Net	Trawl	Other	Total (lbs)	Total (mt)
1981	3,059	136,864	11,426		151,349	68.7
1982	426	167,570	3,090		171,086	77.6
1983		125,400	2,400	1,500	129,300	58.7
1984	200	185,600	100	1,000	186,900	84.8
1985	1,700	231,600		1,500	234,800	106.5
1986	2,600	176,700	100	75,000	254,400	115.4
1987	800	55,500	100	38,500	94,900	43.0
1988	1,000	172,900	300	1,000	175,200	79.5
1989	1,300	128,700	500	18,000	148,500	67.4
1990	1,615	86,621	470	8,000	96,706	43.9
1991	1,600	86,700		8,000	96,300	43.7
1992	1,300	87,800		2,100	91,200	41.4
1993	71,855	80,020	807,002		958,877	434.9
1994	460	57,568		2,100	60,128	27.3
1995		15,000		5,000*	20,000	9.1
1996		76,392		6,459	82,851	37.6
1997		71,609		720	72,329	32.8

* Pound Net

Menhaden are taken as bait in Connecticut primarily by gill net. Smaller landings come from snag hook and line, otter trawl, pound net, seine, and fyke and dip net fishermen. Landings data originate from annual reports required of holders of a Commercial Finfish License. It is estimated that at least 90% of the landings are used as lobster bait, with the remainder used for bluefish bait by hook and line fishermen. The “other” category for gear type includes pound net, seine, fyke net, and dip net to maintain confidentiality of landings.

Table A3.6 Menhaden bait landings (pounds) in New York, by gear, 1981-97.

Year	Pound Net	Common Seine	Gill Net	Trawl	Total (lbs)	Total (mt)
1981					533,200	241.9
1982					394,300	178.9
1983					216,300	98.1
1984					692,500	314.1
1985					901,800	409.1
1986	307,385		58,500		365,885	166.0
1987	57,020	3,000	118,317		178,337	80.9
1988	2,900	433,380	38,918		475,198	215.5
1989	15,020	231,790	42,330	3,110	292,250	132.6
1990	86,960	221,400	92,150		400,510	181.7
1991	86,620	117,775	430,805	3,550	638,750	289.7
1992	9,650	170,000	262,500	2,950	445,100	201.9
1993	71,855	80,020	807,002		958,877	434.9
1994	600	86,900	811,916		899,416	408.0
1995			1,087,978		1,087,978	493.5
1996	200		10,795	140	11,135	5.1
1997			670		670	0.3

Atlantic menhaden are taken as bait in New York for the recreational finfish and crab fisheries and for the commercial American lobster and crab fisheries. How reported catches are divided for use by each of those fisheries is not known. A restricted gill net fishery were probably under-reported for 1981 until 1990. Best estimates indicate this fishery takes between 50,000 and 100,000 pounds annually. There are other gill net landings in which menhaden are a bycatch. Most of the haul seine catches are the result of a directed fishery supplying wholesale and retail bait dealers. All pound net menhaden landings are bycatch. Large purse seiners do sporadically take menhaden from New York waters, but, they are landed (and recorded) out of state. All reported menhaden landings in New York are for bait (including chum) purposes.

Table A3.7 Menhaden bait landings (pounds) in New Jersey, by gear, 1982-97.

Year	Pound Net	Gill Net	Purse Seine	Trawl	Other	Total (lbs)	Total (mt)
1982	1,112,351	199,526	325,480			1,637,357	742.7
1983	588,433	129,091	863,930			1,581,454	717.3
1984	1,194,037	327,555	719,440	1,080		2,242,112	1,017.0
1985	1,561,771	314,923	969,800	33,272		2,879,766	1,306.3
1986	1,380,707	259,990	797,388	15,508		2,453,593	1,112.9
1987	1,510,028	363,979	663,350	25,806		2,563,163	1,162.6
1988	889,967	419,863	667,934	6,281		1,984,045	899.96
1989	1,581,755	297,865	956,231	18,510		2,854,361	1,294.7
1990	1,098,126	176,347	7,761,439	5,547		9,041,459	4,101.2
1991	828,615	335,208	15,427,136	6,443		16,597,402	7,528.5
1992	1,773,468	334,124	25,348,814	14,500		27,470,906	12,460.7
1993	1,088,803	455,305	26,727,648	4,790	20,195	28,296,741	12,835.3
1994	365,385	273,525	37,524,924	5,375	6,992	38,176,201	17,316.6
1995	858,832	406,460	35,280,491	26,534	190	36,572,507	16,589.2
1996	118,800	708,417	33,755,346	933,938	225	35,516,726	16,110.3
1997		225,923	37,628,655	102,486	3,665	37,960,729	17,218.9

Historically, menhaden bait landings came largely from Sandy Hok Bay pound nets, purse seine vessels, a variety of gill nets (set, drift and runabout) and the otter trawl fishery as bycatch. Recent regulations created a separate menhaden bait license for purse seine vessels, allowed them to come closer to shore in major bays and along the coast, and created a mandatory reporting system (daily catch area fished). Six such licenses were issued in 1990 for six purse seine vessels, 31 to 67 ft. long. Purse seine landings now dominate menhaden bait landings in New Jersey (86% in 1990 and 93% in 1991) while other gear landings remain at their historic levels.

Table A3.8 Menhaden bait landings (pounds) in Delaware, by gear, 1982-97.

Year	Gill Net	Other	Total (lbs)	Total (mt)
1982			58,300	26.4
1983			41,000	18.6
1984			208,000	94.3
1985	176,135		176,135	79.9
1986	19,821	260	20,081	9.1
1987	22,034		22,034	10.0
1988	127,713		127,713	57.9
1989	104,382		104,382	47.3
1990	167,116	3	167,119	75.8
1991	277,148	1,626	278,774	126.5
1992	105,518	200	105,718	48.0
1993	163,686	366	164,052	74.4
1994	78,672		78,672	35.7
1995	101,312	76	101,388	46.0
1996	99,983	80	100,063	45.4
1997	55,733		55,733	25.3

Since 1985, the Delaware menhaden bait fishery has been primarily a gill net fishery (staked or anchored and drifting) with the catch used for crab bait. Prior to 1985, NMFS obtained landings data directly from the fishermen. Reporting is required of all licensed gill net fishermen. Effort data have been obtained since 1985 as pounds of menhaden landed per yard of gill net fished (‘85, 0.69; ‘86, 0.08; ‘87, 0.10; ‘88, 0.63; ‘89, 0.56; ‘90, 0.60; and ‘91, 1.01). Landings in April and May account for the majority of the catch.

Table A3.9 Menhaden bait landings (pounds) in Maryland, by gear, 1981-97.

Year	Pound Net	Long Haul Seine	Gill Net	Fish Pot	Fyke Net	Other	Total (lbs)	Total (mt)
1981	5,261,549	8,970	78,132	300	104		5,349,055	2,426.3
1982	5,119,839			57	1,359		5,190,816	2,354.5
1983	3,369,791	50			2,576		3,534,724	1,603.3
1984	1,650,623	59,440		100	20,420		2,002,405	908.3
1985	2,034,749			30,870	7,515		2,157,406	978.6
1986	2,198,060	12			3,185	22	2,262,891	1,026.4
1987	2,243,887			7,080	16,448	55,197	2,367,378	1,073.8
1988	2,059,701			30	15,626	38,794	2,242,480	1,017.2
1989	3,715,820				2,630	5,080	3,778,616	1,714.0
1990	1,602,438				655		1,662,275	754.0
1991	2,949,000			20,000	595	25,760	3,126,345	1,418.1
1992	1,624,533			10	80,089	400	1,777,088	806.1
1993	1,750,114				1,475	2,300	1,806,638	819.5
1994	2,336,220				41,830	9,921	2,575,135	1,168.1
1995	5,401,700						5,401,700	2,450.2
1996	3,713,620	50		300	2,502	610	3,906,808	1,772.1
1997	3,297,418				4,170		3,457,237	1,568.2

Over 90% of the commercial menhaden landings are taken by pound nets within the Maryland portion of Chesapeake Bay. Menhaden are primarily used as bait for the blue crab pot fishery and are a major source of chum for charter boat and sport fishermen. Catch statistics are collected through monthly harvest reports by the fishermen. Landings data include Maryland tributaries of the Potomac River but not the Potomac mainstem. Other gear types include trawl and hook and line.

Table A3.10 Menhaden bait landings (pounds) in Virginia, by gear, 1981-97.

Year	Gill Net	Snapper Rig	Pound Net	Haul Seine	Otter Trawl	Other*	Total (lbs)	Total (mt)
1981	250,589	9,710,805	21,209,653	465			31,171,512	14,139.3
1982	324		21,966,452		53,210		22,019,986	9,988.2
1983	10,809		24,471,744				24,482,553	11,105.2
1984	36,540		14,489,426		1,340		14,527,306	6,589.5
1985	50,674		17,269,831				17,320,505	7,856.5
1986	35,081		9,816,378	33,786		66	9,885,311	4,483.9
1987	14,132		14,216,087	88,408			14,318,627	6,494.9
1988	87,104		11,596,293	293,343			11,976,740	5,432.6
1989	6,210	12,738,922	11,487,918	180		77,200	24,310,430	11,027.1
1990	7,453	12,113,763	5,716,821	386,149			18,224,186	8,266.4
1991	167,455	8,610,878	5,708,905				14,487,238	6,571.4
1992	23,712	11,165,380	5,044,888				16,233,980	7,363.7
1993	58,442		7,119,652	1,471		480	7,180,045	3,256.8
1994	146,371		5,517,147	1,100		7	5,664,625	2,569.5
1995	170,437		5,970,076				6,140,513	2,785.3
1996	126,131		5,218,437	4,600	49,720		5,398,888	2,448.9
1997	107,734		5,163,705	3,294	6,300	750	5,281,783	2,395.8

*Other gear types include fyke net, crab pots and traps, eel and fish pots.

Menhaden bait landings in Virginia have been reported by the fishermen since 1993, under the mandatory reporting program. Prior to 1993, landings were collected by technicians from the buyers or processors. The snapper rigs (small purse seine boats) are not required to report their catch under the current mandatory reporting system. Menhaden landed for bait taken by other gear (pound net and gill net) are often reported as “bait” collectively with other species of fish. Consequently, the complete picture of menhaden bait landings in Virginia cannot be shown because the menhaden poundage cannot be extracted from the generic bait category.

Table A3.11 Menhaden bait landings (pounds) for Potomac River Fisheries Commission, by gear, 1981-97.

Year	Pound Net	Gill Net	Haul Seine	Fyke Net	Landed in MD	Landed in VA	Total (lbs)	Total (mt)
1981	20,364,817	7,048			4,150,488	16,216,377	20,371,865	9,240.6
1982	17,988,067	1,367			3,764,705	14,224,729	17,989,434	8,160.0
1983	20,820,224	721			2,857,187	17,963,758	20,820,945	9,444.3
1984	13,111,057	840	9,700		3,244,254	9,877,343	13,121,597	5,951.9
1985	16,768,303	586			3,213,502	13,555,387	16,768,889	7,606.3
1986	10,946,547	25,426			2,548,105	8,423,868	10,971,973	4,976.9
1987	13,119,905	590			3,381,323	9,739,172	13,120,495	5,951.4
1988	13,231,030	338			4,342,213	8,889,155	13,231,368	6,001.7
1989	8,333,994		180		2,072,144	6,262,030	8,334,174	3,780.4
1990	4,523,776				903,355	3,620,421	4,523,776	2,052.0
1991	5,376,223				1,431,142	3,945,081	5,376,223	2,438.6
1992	5,061,295	270			752,796	4,308,769	5,061,565	2,295.9
1993	7,868,456	5	15,540		1,247,141	6,636,860	7,884,001	3,576.2
1994	6,680,785	26		126	1,239,923	5,441,014	6,680,937	3,030.5
1995	7,002,818				1,671,619	5,331,199	7,002,818	3,176.5
1996	5,111,370			53	1,844,756	3,266,677	5,111,423	2,318.5
1997	5,757,060	70	22	218	1,715,759	4,041,611	5,757,370	2,611.5

Commercial menhaden landings come from four gear types; however, pound net catches account for the majority of the catch. Only 2-10% of the Virginia landings go for industrial use; the rest is used for bait.

Table A3.12 Menhaden bait landings (pounds) in North Carolina, by gear, 1981-97.

Year	Pound Net	Long Haul Seine	Gill Net	Purse Seine	Trawl	Other	Total (lbs)	Total (mt)
1981						8,000	8,000	3.6
1982	1,017,178	1,782,672					2,799,850	1,270.0
1983	433,817	2,167,933	1,000				2,602,750	1,180.6
1984	283,380	1,023,969		791,000			2,098,349	951.8
1985	267,814	723,123	12,833	2,911,830			3,915,600	1,776.1
1986	311,886	626,384		3,566,771			4,505,041	2,043.5
1987	412,737	728,164	1,754	3,186,810			4,329,465	1,963.8
1988	1,772,250	1,309,122	10,174	2,244,205	734		5,336,485	2,420.6
1989	1,443,546	990,838	59,370	3,613,493	48,568		6,155,815	2,792.3
1990	584,540	1,744,304	14,989	3,989,610	400		6,333,843	2,873.0
1991	320,600	812,134	269,920	3,258,084	308,940		4,969,678	2,254.2
1992	1,235,939	753,050	215,756	1,891,052			4,095,797	1,857.8
1993	485,450	603,516	32,858	931,550			2,053,374	931.4
1994[1]	777,804	219,188	37,472[2]	3,981,910	2,864[3]	586,632	5,605,870	2,542.8
1995[1]	455,765	117,736	40,458[2]	1,866,580	705[3]	310,941	2,792,185	1,266.5
1996[1]	253,186	60,462	98,927[2]	86,859		502,588	903,095	409.6
1997[1]	393,181	240,372	69,258[2]	1,521,757	300[3]	1,020,439	3,175,749	1,440.5

[1] Figures reflect trip ticket data only. Most menhaden is recorded in the "general bait" category. Biological sampling of the fishery for bait composition has not been analyzed to adjust the figures.
[2] Includes anchor, drift, and runaround gill nets.
[3] Includes shrimp and fish trawl.

Menhaden are taken as bait in North Carolina in a directed small vessel purse seine fishery and as bycatch in other fisheries, principally with pound nets and long haul seines. Preceding 1994, purse seine data were collected from participating dealers through the North Carolina Division of Marine Fisheries (NCDMF)/NMFS Cooperative Statistics Program. Values for other gears were derived from a combination of data from the statistics program and bycatch calculated from biological sampling of unculled catches from various commercial gears. The 1994 to present data were collected through NCDMF's Trip Ticket Program.

Table A3.13 Menhaden bait landings (pounds) in South Carolina, by gear, 1983-97.

Year	Trawl	Total (lbs)	Total (mt)
1983	34,000	34,000	15.4
1984	CONFIDENTIAL		
1985	7,938	7,938	3.6
1986	1,546	1,546	0.7
1987	3,934	3,934	1.8
1988	CONFIDENTIAL		
1989	0	0	0.0
1990	0	0	0.0
1991	0	0	0.0
1992	CONFIDENTIAL		
1993		0	0.0
1994	0	0	0.0
1995	0	0	0.0
1996	0	0	0.0
1997	0	0	0.0

There are no directed fisheries for Atlantic menhaden in South Carolina. Recorded landings of menhaden for bait represent a bycatch from the shrimp trawl fishery. These menhaden, as well as frozen menhaden obtained from North Carolina, serve as bait in the blue crab fishery.

Menhaden bait landings in Georgia, 1981-1997.

There is no directed commercial fishery for menhaden in Georgia. However, the demand for menhaden to be used for live bait in the recreational fishery, especially king mackerel tournaments, is at an all time high. These recreational anglers use large cast nets (up to 12' in diameter) to capture menhaden for their personal use. Few, if any, individuals are involved in the sale of menhaden for bait purposes. Since cast nets and saltwater anglers are unlicensed, the extent of this harvest is unknown. Menhaden are also taken as bycatch in the shrimp trawl fishery. While most are discarded at sea, a small quantity is landed and sold for bait in the crab pot fishery.

Table A3.14 Menhaden bait landings (pounds) in Florida, by gear, 1982-97.

Year	Long Haul Seine	Gill Net	Purse Seine	Cast Net	Other	Total (lbs)	Total (mt)
1982		413,299				413,299	187.5
1983		1,150,426				1,150,426	521.8
1984	947	1,036,021				1,036,968	470.4
1985	23,859	1,067,826				1,091,685	495.2
1986	30,298	842,686				872,984	396.0
1987	11,849	1,297,636				1,309,485	594.0
1988		1,017,904	53			1,017,957	461.7
1989	8,026	1,248,275	116,179			1,372,480	622.6
1990		1,499,414	1,136,116	956		2,636,486	1,195.9
1991		970,624	1,490,012	27,132	5,063	2,492,831	1,130.7
1992	8,600	2,104,951	590,441	41,825	667	2,746,484	1,245.8
1993	4,296	1,369,400	1,148,915	59,905	2,251	2,584,767	1,172.4
1994						1,387,012	629.1
1995						660,272	299.5
1996	77	5,164	20,000	245,071	1,759	272,071	123.4
1997		223		8,336	399,933	408,492	185.3

Historically, gill netting accounted for the majority of Florida east coast menhaden landings for bait. Recently, there has been an increase in purse seining for bait menhaden. All data are collected from licensed wholesale dealers and reported through a detailed trip ticket program to the Florida Department of Natural Resources' Marine Fisheries Information System.