

*42nd Northeast Regional Stock Assessment Workshop (42nd SAW)*

**Stock Assessment Report**  
**Part B: Expanded Multispecies**  
**Virtual Population Analysis**  
**(MSVPA-X) Stock Assessment Model**

**U.S. DEPARTMENT OF COMMERCE**  
**National Oceanic and Atmospheric Administration**  
**National Marine Fisheries Service**  
**Northeast Fisheries Science Center**  
**Woods Hole, Massachusetts**

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# Assessment Report (42nd SAW/SARC)

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## **D: EXPANDED MULTISPECIES VIRTUAL POPULATION ANALYSIS (MSVPA-X) STOCK ASSESSMENT MODEL**

### **EXECUTIVE SUMMARY**

In recent years stakeholder groups, government officials, and scientists have called for an ecosystem approach to fisheries management on both local and federal levels. While managers have traditionally relied on analytical methods to help them make informed choices on a single-species basis, few analytical tools are available to evaluate decisions at the ecosystem level. The Expanded Multispecies Virtual Population Analysis (MSVPA-X) was conceived to support to fisheries management decisions made in a multispecies context.

### **TERMS OF REFERENCE**

#### **1. Evaluate adequacy and appropriateness of model input data, including fishery-dependent data, fishery-independent data, selectivities, etc. as configured. Chapter 2**

This configuration of the MSVPA-X utilized the best available single-species assessment and diet data, attempted to fill the data gaps, and tested the model formulation and structure through sensitivity analyses. The results are presented to assess the feasibility of the MSVPA-X model. Utilization for management purposes will require updated single-species assessments, diet matrices, and other relevant information.

**Atlantic menhaden:** Atlantic menhaden are the only explicitly modeled prey species in this configuration of the MSVPA-X. The XSA is used as the single-species assessment model because it incorporates fishery independent survey data as tuning indices and is consistent with the approach used in the forward-projection single-species assessment model.

**Striped bass:** XSA is used as the single-species VPA model for striped bass, which is a predator species in this application. The XSA approach is similar to the ADAPT VPA methodology utilized in the single species striped bass stock assessment in that it utilizes tuning indices in the estimation procedures for fishery mortality rates.

**Weakfish:** The XSA model is used as the single-species VPA approach for weakfish, which is a predator species in this configuration of the MSVPA-X. A series of XSA evaluation runs were developed for the period from 1982-2000 for comparison to the ADAPT VPA and integrated catch-at-age (ICA) analysis used in the 2002 assessment document.

**Bluefish:** Due to the unavailability of catch-at-age information from a peer reviewed stock assessment during the model reference period (1982 – 2002), bluefish is included in the MSPVA-X application as a “biomass predator”. In this formulation, the predator population dynamics are not modeled. Model input requirements include a time series of total predator biomass, limited information on predator size structure, and feeding selectivity parameters. The biomass dynamics model (ASPIC) previously used to assess the bluefish stock utilized

commercial and recreational landings data. The recreational CPUE and NEFSC inshore fall survey are used as tuning indices for this approach.

**Other Prey:** To account for available non-menhaden prey, biomass estimates were developed for several “other prey” species groups that comprise important components of the predator species’ diets throughout their life history and range. “Other prey” items included in this configuration include: clupeids (Atlantic herring and threadfin herring); medium forage fish (squids and butterfish); anchovies; sciaenids (spot and croaker); macrozooplankton; benthic invertebrates; and benthic crustaceans. When available, the data and estimates from current stock assessments are utilized; however, for some “other prey” items, biomass estimates are derived using available fishery-independent, fishery-dependent and life-history data. As with the single-species assessments, the MSVPA-X will benefit from improved population estimates for all “other prey” items.

## **2. Evaluate assumptions for data gap filling when reliable data are not available (diet, biomass of prey species, feeding selectivity). Chapter 2**

An extensive review of available diet data for striped bass, weakfish, and bluefish was conducted. There is a general lack of coast wide diet data for all ages of the predator species modeled. The most spatially and temporally comprehensive data set for all three species is the Northeast Fisheries Science Center Food Habits database. However, this survey is limited to the coastal (i.e., non-estuarine) waters, is only available during spring and fall, and generally does not have large sample sizes for older fish. For each species, there are additional regional studies that provide diet information for estuarine waters and other times of the year. The MSVPA-X utilizes a thorough compilation of the available diet data.

Predation mortalities in the standard International Council for the Exploration of the Seas (ICES) MSVPA approach are calculated based upon a simplified feeding model, based on a constant ration for a predator of a given age-class and year. This constant ration does not reflect effects of food availability on feeding rates or temperature effects on predator metabolism. Food consumption rates in fish can vary strongly, particularly between seasons as a function of food availability, changing temperatures, and metabolic demands. To account for these processes, a more detailed consumption model is implemented in the MSVPA-X using the Elliot and Persson (1978) evacuation rate approach, including a modified functional relationship between food availability and predator consumption rates.

The standard MSVPA formulation assumes that predator feeding rates are independent of prey availability, resulting in a Holling type II predator-prey feeding response (Magnusson, 1995). Type II feeding responses result in depensatory dynamics in predation mortality rates, which creates a “predation pit” at low prey biomass that can result in unrealistic model dynamics such as prey extinction due to predation. In contrast, the MSVPA-X employs type III functional responses that are compensatory in nature in that the feeding rate on a particular prey item will decline at low prey abundances, and hence predation mortality pressure is released.

The feeding model also includes a “suitability index”, which is comprised of seasonal spatial overlap of predators and prey, prey type preference and prey size preference. The MSVPA-X



model employs a flexible unimodal function to describe the relationship between prey length and the proportion of the prey in the diet. The size selection index for a prey of a particular size thus corresponds to the predicted proportion of prey of that size in the predator's diet.

The selectivity model used in the MSVPA-X relies upon a rank index for prey type preference. These indices are derived from summaries of available diet composition data when they are available. For the predators considered here, there are multiple diet studies published in the literature; however, these are generally smaller scale studies focusing on particular places, seasons, and time periods.

While the MSVPA-X model is not fully spatially explicit, it is necessary to define a spatial domain and strata at regional scales to evaluate seasonal spatial overlap between predators and prey. The spatial resolution of these strata is primarily limited by available data on the spatial distribution of the species included in the model. The spatial distribution of each taxon is evaluated on a seasonal basis using landings, survey, or regional density data as appropriate. These relative spatial distributions are then used to calculate the seasonal spatial overlap (using Schoener's index) between each predator age class and each prey species.

**3. Review model formulation (overall setup, data handling, VPA calculations, assessment options, sensitivity analyses, recruitment model options, and forecast projection options) of model as configured.** Chapters 1, 3 and Appendix D1.

The Multispecies Virtual Population Analysis (MSVPA) approach was developed within International Council for the Exploration of the Seas (ICES) as a multispecies extension of cohort analysis or virtual population analysis (VPA). The approach can be viewed essentially as a series of single-species virtual population analysis models that are linked by a simple feeding model to calculate natural mortality rates. The system of linked single-species models is run iteratively until the predation mortality (M2) rates converge. Predation mortality is the portion of natural mortality of a species that is the result of predation by another species. The basic model is performed in two primary iteration loops. First, all single-species VPAs are run to calculate population size at all ages for predators and prey, then predation mortality rates are calculated for all age classes of each species based upon the simple feeding model. The single-species VPAs are run again using the calculated M2 rates, and this iteration is repeated until convergence (reviewed in Magnusson, 1995).

The MSVPA-X approach described here builds upon the framework of the standard MSVPA by incorporating a variety of single-species VPA approaches (including a "tuned" VPA), modification of the consumption model, introducing a weak Type III functional feeding response, formalizing the derivation of selectivity parameters from diet data, altering the size-selectivity model, and including predators without age-structured assessment data. These additions allow for a clearer definition of the input parameters used to model predator diets and consumption rates, and improve the MSVPA equations to reflect processes controlling feeding and predation rates.

Total biomass and spawning stock of striped bass increases over the time series. Weakfish experience fluctuations in total biomass, but a general increasing trend in spawning stock

biomass (SSB) is noted. Bluefish population biomass exhibits high abundance early in the time series (1982 – 1988), declines throughout much of the 1990s, followed by an increase in stock size in the last 3 – 4 years.

The only explicitly modeled prey species in this iteration is menhaden. Total abundance and abundance at maturity (age-2+) decline, although overall SSB has remained stable yet somewhat variable. This is in part due to an increase in weight-at-age for menhaden (ASMFC, 2004a).

#### **4. Develop research recommendations for data collection, model formulation, and model results presentation. Chapter 5**

Recommendations for data collection improvements:

- Add a bluefish age-structure/catch-at-age matrix.
- Adult index for menhaden (e.g., an aerial line transect survey) and other species.
- Obtain population weight-at-age estimates.
- Conduct a coast wide diet and abundance study (i.e., an Atlantic coast “year of the stomach”).
- Collect more diet data for all four MSVPA-X species along the entire Atlantic coast.
- Conduct stomach selectivity research for predator species to improve prey ranking matrix.
- Encourage existing fishery-independent surveys to take regular gut contents.
- Evaluate if striped bass disease (mycobacteria) is correlated with natural mortality (M1) and food availability or if disease is disrupting striped bass feeding and causing starvation.
- Estimate carrying capacity for the system to evaluate what model estimates/suggests for carrying capacity.
- Improve estimates of biomass for prey species on coast wide basis.
- Conduct a parallel comparison with ICES MSVPA model on a system that has the necessary data collected (Georges Bank or the North Sea) to identify the differences in results.
- Explore the ability to add other predators to model (birds, mammals, other fish, other systems)
- Explore the utility of implementing the Williamson spatial overlap index in the model
- Investigate type II and type III feeding responses of the MSPVPA-X species in field studies

Recommendations for the improvement of model formulation:

- Add uncertainty to model forecast and incorporate elements of Monte Carlo simulations on recruitment curves.
- Alter biomass predator bin sizes for more flexible way to vary for projection model, if necessary after conducting sensitivity analyses or until an age-structured stock assessment is developed for bluefish.
- Add ICA and production model options to retrospective.
- Develop a similar application to the “amoeba” program that allows the user to easily vary changes to model parameters.

Recommendation for the forecast component of the MSVPA-X:

- Determine the affect sensitivity of the model to the removal of all fishing pressure from system
- Insert recovery benchmarks
- Explore options for adaptive management framework with stock-recruitment options

**5. Evaluate whether or not the model and associated data are of sufficient quality to develop recommendations to management.** Chapter 4

The model has the potential to improve assessments in single-species assessments by suggesting the predation mortality rate at age (or by year, as appropriate) for explicitly modeled prey species. This has already been accomplished for menhaden in the 2003 assessment (ASMFC, 2004a). An earlier iteration of MSVPA-X produced estimates of menhaden natural mortality at age; however, menhaden population size was estimated using a separate single-species assessment model and overall natural mortality was specified within that single-species assessment.

Additionally, decision makers can be shown potential impacts of fishing and predation mortality by age class for explicitly modeled prey. Such an analysis may suggest optimum harvest strategies for both predators and prey when fisheries for both exist and are managed under the same body. Further analyses may allow for the management of prey using total mortality, rather than fishing mortality. The model may also provide insight on multiple species target biomass based on trade offs among predators and prey. The model may provide guidance for rebuilding predator stocks and the interactions between a specific predator biomass targets and the availability of prey species for other stocks of concern should that target be realized.

Based on thorough review and testing of the MSVPA –X model, the committee suggests that this formulation is capable of answering management questions about predator-prey interactions among explicitly modeled species. With clear understanding the MSVPA-X’s abilities and limitations described fully within the following assessment report, the MSVPA-X approach has the potential to provide much accessory information for fisheries managers.

**PREFACE**

The MSVPA-X is a new model developed to aid the ASMFC in better quantifying predator and prey interactions and accounting for these effects on both predator and prey populations. In developing the model, the ASMFC conducted an Internal Review of the MSVPA-X to evaluate model formulation, input data, gap filling procedures, and develop recommendations on incorporating the model and its results in Commission stock assessments for individual species. The Internal Review Panel was formed primarily of scientists involved with ASMFC multispecies projects, but also included an expert on the “standard” ICES MSVPA and two stakeholders involved with the ASMFC.

To provide SARC reviewers a framework to evaluate the model using the Terms of Reference listed below, recommendations of the ASMFC Internal Review Panel are included to preface the Terms of Reference. Although the model will be able to estimate multispecies benchmarks and

explore trophic relationships between species, the MSVPA-X is not designed to address all ecosystem level questions or local depletion issues. The ASMFC Panel was comfortable using the model for the following purposes:

- Improve single-species models for single-species population adjustments (i.e., age and year specific inclusion of M)
- Insight on multiple species benchmarks based on species trade offs
- Investigate predation mortality versus catch for important prey species by age class
- Determine the trade offs among harvesting strategies when fisheries exist for both predator and prey
- Develop short-term projections for explicitly modeled species
- Provide guidance for rebuilding predator stocks
- Evaluate change in predator management and it's effects on prey and competing predators
- Explore potential feedbacks between lack of prey, abundance of alternative prey, fishing mortality on the predator populations
- Longer projections can be performed as exploratory tool to investigate linkages among species but should not be used as a management tool
- Examine the role of predator consumption in reduced prey recruitment to the fishery

However, the Panel noted this model should not address the following issues:

- Setting reference points or harvest limits for single-species from MSVPA-X
- Estimations of absolute abundance for explicitly modeled species
- Examining local abundance or depletion
- Long-term projections are subject to the limitations of recruitment variability for the prey population and predator populations

**Atlantic States Marine Fisheries Commission MSVPA-X Multispecies Assessment  
Subcommittee/Stock Assessment Committee**

The MSVPA-X Multispecies Assessment Subcommittee presented its work to the Stock Assessment Committee on September 28, 2005:

**MSVPA-X Multispecies Assessment Subcommittee Members**

Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources  
Lance Garrison – Garrison Environmental Analysis and Research  
Robert Latour – Virginia Institute of Marine Science  
Behzad Mahmoudi – Florida Fish and Wildlife Conservation Commission  
Brandon Muffley – New Jersey Department of Environmental Protection  
Alexei Sharov – Maryland Department of Natural Resources  
Doug Vaughan – National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

**ASMFC Stock Assessment Committee members present:**

John Carmichael – Committee Chair, South Atlantic Fisheries Management Council  
Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources  
Doug Grout – New Hampshire Department of Fish and Game  
Kim McKown – New York Department of Environmental Conservation  
Brandon Muffley – New Jersey Department of Environmental Protection  
Mike Murphy – Florida Fish and Wildlife Conservation Commission  
Des Kahn – Delaware Department of Natural Resources  
Alexei Sharov – Maryland Department of Natural Resources  
Doug Vaughan - National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

Dr. Lance Garrison is acknowledged for his continued work with the MSVPA-X Assessment Subcommittee to fine tune the MSVPA-X model formulation, which he developed with Dr. Jason Link (National Marine Fisheries Service).

Appreciation is also extended to the ASMFC striped bass, Atlantic menhaden, weakfish, and bluefish Technical Committees that reviewed the input data that has been utilized in the model and the model formulation.

Special appreciation is given to the ASMFC staff dedicated to the coordinating and assisting the efforts of the ASMFC Multispecies Assessment Subcommittee in the preparation of this document to send to peer review – Patrick Kilduff, Joe Grist and Peter Mooreside. The ASMFC also appreciates the efforts of former staff Dr. Lisa Kline, Geoff White and Jeff Brust on multispecies projects.

## TABLE OF ACRONYMS

ADAPT	A VPA that incorporates one or more abundance indices
ASAP	Age Structured Assessment model
ASMFC	Atlantic States Marine Fisheries Commission
ASPIC	A Surplus Production Model Including Covariates
CFDB	Commercial fishery database
CPUE	Catch per unit effort
GIS	Geographic Information Systems
ICA	Integrated Catch-at-Age
ICES	International Council for the Exploration of the Seas
MD DNR	Maryland Department of Natural Resources
MRFSS	Marine Recreational Fisheries Statistics Survey
MSVPA	Multispecies Virtual Population Analysis
MSVPA-X	Expanded Multispecies Virtual Population Analysis
NEFSC	Northeast Fisheries Science Center
NJ DEP	New Jersey Department of Environmental Protection
NJ OTS	New Jersey Ocean Trawl Survey
SEAMAP	Southeast Area Monitoring and Assessment Program
SEFSC	Southeast Fisheries Science Center
SSB	Spawning stock biomass
SSVPA	Single species virtual population analysis
VIMS	Virginia Institute of Marine Science
VPA	Virtual population analysis
XSA	Extended Survivors Analysis
YOY	Young of year

## CONVERSION TABLE

Imperial	Metric
1 million pounds	454 metric tons (mt)
1 pound (lb.)	0.454 kilograms (kg)
1 pound (lb.)	454 grams (g)
1 ounce (oz.)	28.35 grams (g)
1 inch (in.)	2.54 centimeters (cm)
1 inch (in.)	25.4 millimeters (mm)
1 foot (ft.)	30.48 centimeters (m)
1 yard (yd.)	.914 meters (m)
1 mile	1.609 kilometers (km)
1 yard <sup>2</sup> (yd <sup>2</sup> )	0.836 meters <sup>2</sup> (m <sup>2</sup> )
1 mile <sup>2</sup>	2.59 kilometers <sup>2</sup> (km <sup>2</sup> )
1 yards <sup>3</sup> (yd <sup>3</sup> )	meter <sup>3</sup> (m <sup>3</sup> )

## LIST OF VARIABLES

Definitions of variables described in Chapter I of MSVPA-X Assessment Report.

$R_{i,a}$  - total food consumption rate in biomass for a predator  $i$  and age class  $a$

$v_{i,a}$  is a constant ration (biomass prey / biomass body weight)

$w_{i,a}$  is body weight of predator  $i$  of age  $a$ .

$C_{ia}^{ys}$  - total consumption in year,  $y$ , for a predator during a given season,  $s$  for predator  $i$ , age class  $a$ .

$SC_s$  is the mean stomach contents weight relative to predator  $i$  age  $a$  body weight in a season  $s$ ,

$D_s$  is the number of days in the season  $s$

$w_{ys}$  is the average weight-at-age for the predator  $i$  age  $a$

$N_{ys}$  is the abundance of the predator  $i$  age  $a$  during season  $s$  in year  $y$ .

$E_s^{ia}$  is the evacuation rate for a predator  $i$  and age class  $a$  in season  $s$  - the rate at which food leaves the stomach

$\overline{SC_s^{ia}}$  - an average stomach contents across years for predator  $i$ , age class  $a$ , in season  $s$

$S_{jb}^{ia}$  - suitability index" for a given prey species,  $j$ , and age class,  $b$ , for predator species,  $i$ , and age class,  $a$  is calculated as a product of spatial overlap index, general vulnerability and size selection.

$O_{ij}$  - spatial overlap index, defines similarity of spatial distribution of predator  $i$  and prey  $j$  based upon the relative abundance of predators and prey in defined areas within the model spatial domain. The index ranges between zero and 1.

$A_i$  - type selection, reflects preference for a particular species relative to all others. Type selection is entered as a proportionalized rank index, equivalent to the expected diet composition for the predator given equal prey abundances and equal prey sizes.

$S(\alpha, \beta)$  - Size selection reflects primarily capture and ingestion probabilities and is a function of relative prey to predator length.

$SB_{jb}^{ia}$  - Suitable biomass, total food available for predator  $i$  and age class  $a$

$\overline{N}_{jb}$  - the average number of prey available during the time interval, where  $\alpha$  and  $\beta$  are the beginning and end of the time period being considered expressed as a proportion of a year.

$P_{jb}^{ia}$  - The biomass of a particular prey consumed by a predator is the product of total consumption by the predator and the proportion of total suitable biomass represented by that prey type

$M2_{jb}^{ia}$  - the predation mortality rate due to the predator is the ratio of these removals to the average abundance of the prey during the time interval

$M2_{jb}$  - total predation mortality rate for a given prey species and age class is finally the sum across all predators.



## CHAPTER 1: MODEL STRUCTURE AND FORMULATION

### 1.0 BACKGROUND – THE ICES MSVPA APPROACH

The Multispecies Virtual Population Analysis (MSVPA) approach was developed within International Council for the Exploration of the Seas (ICES) as a multispecies extension of cohort analysis or virtual population analysis (VPA). The basic approach was initially described by Pope (1979) and Helgason and Gislason (1979) and later modified and described in Gislason and Helgason (1985). The approach can be viewed essentially as a series of single-species virtual population analysis (SSVPA) models that are linked by a simple feeding model to calculate natural mortality rates. The system of linked single-species models is run iteratively until the predation mortality ( $M_2$ ) rates converge. The basic model is therefore performed in two primary iteration loops. First, all single-species VPAs are run to calculate population size at all ages for predators and prey, then predation mortality rates are calculated for all age classes of each species based upon the simple feeding model. The single-species VPAs are run again using the calculated  $M_2$  rates, and this iteration is repeated until convergence (reviewed in Magnusson, 1995). The single-species VPAs for the ICES model employ the basic catch equation and VPA approach as described in Gulland (1983) using input values for terminal fishery mortality rates ( $F$ ) that are generally derived from single-species assessments.

Predator diets, and therefore prey consumption and predation mortality, are driven by feeding selectivity parameters that are assumed constant for a given predator-prey combination. Actual values of selectivity indices may be derived from a simplified feeding model. In the original formulation of the model, these indices were not well defined and the choice of selectivity parameters was arbitrary. The MSVPA approach is therefore implemented by including diet information and an additional iteration loop to solve for appropriate values of the selectivity indices. Diet data must be available for all predators and age classes in a particular year of the time series. To solve for the selectivities in the year where diet data are available, it is necessary to know the abundance (and biomass) of all prey in that year. A third iteration loop is therefore imposed where the MSVPA calculations are performed with arbitrary starting values for selectivity parameters, then the selectivities are solved for based upon diet information, and the iteration loops are repeated with the derived selectivity values until convergence. It is assumed that selectivity values are constant through time and independent of prey abundance.

The MSVPA formulation gives rise to a type-II functional feeding (Holling, 1965) response between prey abundance and predation rates. This is consistent with the interpretation that feeding selectivities are independent of prey abundance. In the case of active “switching”, where more abundant prey items are preferentially consumed and therefore selection is a function of prey abundance, a sigmoid type-III functional response would occur. While it may be desirable to explore a type-III feeding response, the solutions of the MSVPA equations become non-unique under this formulation at even moderate predation mortality rates (Hilden, 1988).

The standard MSVPA approach has been applied extensively by the ICES working group in the North Sea ecosystem. The main conclusions, as summarized in Pope (1991), are that natural mortality rates are high and variable from year to year and that predation mortality may significantly impact recruitment. In addition, changes in mesh size to increase the abundance of

older, larger fish, may result in higher predation rates and lower fishery yields. The MSVPA approach has also recently been applied to the Georges Bank fish community (Tsou and Collie, 2001) with a slightly modified expression for size selectivity and to the groundfish community of the eastern Bering Sea (Livingston and Juardo-Molina, 2000).

## 1.1 FORMULATION OF THE EXPANDED MSVPA (MSVPA-X)

The expanded MSVPA (MSVPA-X) approach described here builds upon the framework of the standard MSVPA by incorporating a variety of SSVPA approaches including a “tuned” VPA, modification of the consumption model, introducing a weak Type III functional feeding response, formalizing the derivation of selectivity parameters from diet data, altering the size-selectivity model, and including predators without age-structured assessment data. These additions allow a clearer definition of the input parameters used to model diets and consumption rates and improve the MSVPA equations to reflect processes controlling feeding and predation rates.

### 1.1.1 Single-species VPA formulation

Implementation of multiple SSVPA models allows greater flexibility in model construction to address particular data availability and the most appropriate assessment approach for each modeled species. Several forms of SSVPA are implemented in the MSVPA-X program. Some of these were included specifically to match previous assessment approaches for species considered in this application. However, for this application, all species use the XSA method.

The XSA (Shepherd, 1999) is a tuned VPA method that provides solutions for mortality rates in incomplete cohorts based upon multiple fishery-dependent and -independent abundance indices. The approach is related to the ADAPT VPA currently applied in many ASMFC single-species stock assessments. However, the ADAPT method requires extensive model building and minimization routines, resulting in a thorough statistical treatment that generally requires considerable analytical expertise and judgments of input parameters to develop the most appropriate model. While XSA does not reflect the full statistical approach of ADAPT methodology and does not require as intensive computational or model-building demands, it retains a similar theoretical basis and provides similar results. The XSA approach is therefore preferred within the MSVPA-X framework because it provides an SSVPA assessment tuned to external abundance indices that is relatively simple to execute.

The MSVPA-X implementation of XSA is identical to that described in Darby and Flatman (1994). The XSA approach includes a method described as “shrinkage to the mean F” to constrain estimates of fishery mortality rate in terminal age classes and years of the catch matrix. In general, applications not incorporating shrinkage result in unconstrained estimates of F in the last years and ages of the assessment and prevent convergence of the model. Estimates of terminal fishing mortality rates may be sensitive to values of shrinkage parameters, and the model estimates of F for a range of these parameters should be explored when implementing the XSA approach. Individual parameter descriptions are included below. For more details, please see Darby and Flatman (1994).

*CV for Shrinkage Mean:* This parameter controls the weighting applied to the shrinkage mean F. Large values result in lower weighting of the mean and therefore less constraint of terminal F values to the time series average F.

*Number of Years for the Shrinkage Mean:* In the last year of the catch matrix, estimates of F on each age class are constrained by the average F calculated over the previous N years of the assessment as determined by this parameter value.

*Number of Ages for the Shrinkage Mean:* In the terminal age class of each year of the catch matrix, the estimate of F on the last true age class is constrained by the average F over the previous N age classes as determined by this parameter value.

*Downweight Early Years:* In the calculation of shrinkage means and terminal F estimates, early years of the catch matrix are “downweighted” on the assumption that catchabilities and average F estimates in recent years are more similar to those of the terminal years. It is highly recommended that downweighting be applied when shrinkage is employed.

*Select Weighting Method:* Linear, Bisquare, and Tricubic downweighting can be applied in increasing order of the strength of the downweighting function. In the tricubic downweighting, early years of the time series have the least influence on estimates of terminal F.

### 1.1.2 Predator Consumption Model

Predation mortalities in the ICES MSVPA approach are calculated based upon a simplified feeding model developed directly from the approach described by Andersen and Ursin (1977) formulated as discrete expressions standardized to a duration of one year. Total food consumption rates in biomass for a given predator species and age class is expressed as a simple ratio of total predator weight:

$$(1.1) \quad R_{ia} = v_{ia} w_{ia}$$

where  $v_{ia}$  is a constant ratio (biomass prey / biomass body weight) and  $w_{ia}$  is predator body weight. This constant ratio therefore does not reflect effects of food availability on feeding rates or temperature effects on predator metabolism.

In reality, food consumption rates in fish can vary strongly, particularly between seasons as a function of food availability, changing temperatures, and metabolic demands. To account for these processes, a somewhat more detailed consumption model was implemented using the Elliot and Persson (1978) evacuation rate approach within the MSVPA-X equations and including a modified functional relationship between food availability and predator consumption rates.

The daily ration, R, calculated in equation 1.1 is replaced with the consumption rate (in biomass) for predator  $i$ , age class  $a$ . Total consumption in year,  $y$ , for a predator during a given season,  $s$ , is then:

$$(1.2) \quad C_{ys}^{ia} = 24E_s^{ia} \cdot \overline{SC_s^{ia}} \cdot D_s \cdot w_{ys}^{ia} \cdot \overline{N_{ys}^{ia}},$$

where  $SC_s$  is the mean stomach contents weight relative to predator body weight in a season,  $D_s$  is the number of days in the season,  $w_{ys}$  is the average weight-at-age for the predator species, and  $N_{ys}$  is the abundance of the predator age class during the time interval. The evacuation rate ( $\text{hr}^{-1}$ ) is given as:

$$(1.3) \quad E_s^{ia} = \alpha_{ia} \exp(\beta_{ia} \cdot temp_s),$$

with  $temp$  equal to seasonal temperature ( $^{\circ}\text{C}$ ) and  $\alpha$  and  $\beta$  are fitted parameters based upon laboratory feeding experiments, field studies, or other sources (Elliot and Persson 1978, Durbin *et al.* 1983). The evacuation rate (1.3) reflects the temperature dependent metabolic rates of the predator, and requires that the MSVPA-X equations be seasonally resolved. Whereas the mean stomach contents weight reflects both the size of the predator and encounter rates with suitable prey items. The evacuation rate approach for calculating predator consumption was previously implemented within MSVPA by Tsou and Collie (2001).

### 1.1.3 Functional Feeding Response

The standard MSVPA formulation assumes that predator feeding rates are independent of prey availability, resulting in a Holling type II predator-prey feeding response (Magnusson, 1995). Type II feeding responses result in depensatory dynamics in predation mortality rates. The estimated predation mortality rate on a given prey item will increase exponentially at low prey biomasses, thus creating a “predation pit” that can result in unrealistic model dynamics such as prey extinction due to predation. In contrast, type III functional responses are compensatory in nature in that the feeding rate on a particular prey item will decline at low prey abundances, and hence predation mortality pressure is released. To avoid the unrealistic dynamics resulting from the type II feeding relationship, the MSVPA-X implements a weak type III feeding response by modifying the consumption equation (Equation 1.2) to incorporate a logarithmic relationship between food availability (measured as total suitable prey biomass) and the amount of prey consumed by a predator.

Given an average stomach contents across years for predator  $i$ , age class  $a$ , in season  $s$ ,  $\overline{SC_s^{ia}}$ , as an input to the model, the stomach contents corrected for food availability in a given year,  $y$ , is calculated as:

$$(1.4) \quad SC_{ys}^{ia} = \overline{SC_s^{ia}} + \log\left(\frac{SB_{ys}^{ia}}{\overline{SB_s^{ia}}}\right) \cdot \overline{SC_s^{ia}}$$

where  $SB$  is the total suitable biomass available to the predator. The proportional stomach content weight calculated by equation 1.4 is substituted for the average value in equation 1.2 to calculate total consumption for a predator age, year, and season. The corrected stomach contents are further constrained to be  $> 10\%$  of the input average value and less than three times the input

value. These constraints avoid unrealistically small or large predator feeding rates in very extreme cases. The resulting consumption rate as a function of food availability is shown in Figure D.1.

In Figure D.1, the suitable biomass of a particular prey type is varied across a broad range while that of other prey types is held constant. The standard type II feeding response model results in an asymptote of total consumption with increasing prey biomass. In contrast, the model including a correction for food availability results in increasing predator consumption with increasing prey biomass and reduced consumption at lower prey availability relative to the standard model. The resulting predation mortality rates as a function of food availability are shown in Figure D.2.

Through most of the range of prey biomass, the two approaches result in similar predation mortality rates. However, at low prey biomasses, the standard type II model results in exponentially increasing predation mortality. The alternative model has a slower rate of increasing predation mortality, and there is a point at which predation mortality declines with further decreases in prey biomass. This approach avoids the depensatory dynamics that can result in unrealistic model predictions under the standard model.

#### 1.1.4 Feeding Selectivity Parameters

To calculate the composition of prey, a feeding model is employed that includes a “suitability index” for a given prey species,  $j$ , and age class,  $b$ , for predator species,  $i$ , and age class,  $a$ :

$$(1.5) \quad S_{jb}^{ia} = O_j^i \cdot A_j^i \cdot B_{jb}^{ia},$$

where  $O$  is a spatial overlap index,  $A$  is a measure of “general vulnerability”, and  $B$  reflects size selection (Gislason and Helgason, 1985). Each of these terms ranges between 0 and 1. In the initial formulation of the approach, the general vulnerability index was given a somewhat arbitrary definition and was taken to reflect vertical overlap between predator and prey species. The spatial overlap index was likewise developed to express the proportion of predator and prey populations that overlapped horizontally and interact with one another. However, in the original formulation these terms are not explicitly defined and were often chosen in an *ad hoc* manner. Therefore, the approach has relied upon the presence of extensive diet information for at least one year to “tune” the selectivity parameters. The MSVPA-X model more explicitly defines the parameters entering the basic selectivity equation rather than relying on the somewhat circular approach of back-calculating selectivities through an additional iteration incorporating diet information that may not be available for all species and age classes.

##### 1.1.4.1 Spatial Overlap ( $O$ )

Williamson (1993) separated the predation components into what he termed “density risk” and “prey vulnerability”. Density risk reflects the relative encounter rate of predators and prey driven by spatial overlap, while prey vulnerability reflects the combined probabilities of attack, capture, and ingestion. Density risk is expressed as a product of predator abundance and a spatial overlap

index. In this case, a similarity index is calculated based upon the relative abundance of predators and prey in defined areas within the model's spatial domain:

$$(1.6) \quad O_{ij} = 1 - 0.5 \sum_z |p_{iz} - p_{jz}|,$$

where  $p_{.z}$  is the abundance of each predator or prey in each of  $z$  spatial cells. The index ranges between 0 and 1. The spatial overlap index between predator and prey types can be calculated based upon available data across a relevant level of spatial resolution and scope. Likewise, because there are seasonal differences in spatial distribution, the spatial overlap value can be seasonally resolved in the MSVPA-X implementation. Spatial overlap indices should be developed on a seasonal basis across the entire range of the model area. Potential sources of data include fishery-independent surveys, tagging studies, and fishery landings data.

#### 1.1.4.2 Type Preference (A)

The MSVPA-X follows the general approach of the standard MSVPA and resolves feeding selectivity into two components reflecting “type” and “size” selection. However, the model follows the definitions of Chesson's (1983) electivity index in parameterizing these as opposed to the *ad hoc* definitions used in the original implementation of the MSVPA. Chesson's index is a relative index ranging from 0 to 1 that reflects the probability of selection of food type  $i$  given the presence of  $m$  food types in the environment:

$$(1.7) \quad P_i = \frac{\alpha_i n_i}{\sum_{j=1}^m n_j},$$

where  $n$  is the abundance of a given prey type in the environment. The selectivity index,  $\alpha_i$ , is the amount of food type in the diet relative to the amount in the environment scaled so that the sum of all  $\alpha_i$  is 1. This index expresses the expected diet composition of the predator if all prey were equally available in the environment (Chesson, 1983) and is calculated as:

$$(1.8) \quad \alpha_i = \frac{r_i/n_i}{\sum_{j=1}^m r_j/n_j}.$$

Under a case of random selection (no preference),  $\alpha_i = 1/m$ . This is equivalent to the selectivities form solved for in the final iteration loop of the standard MSVPA, which combines spatial overlap and size selection into a single index.

The MSVPA-X model resolves feeding selectivity, and resulting indices, into two components of type and size selection. Type selection reflects preference for a particular species relative to all others based upon ease of capture, energy content, or other factors that result in a preferred prey type. Size selection reflects primarily capture and ingestion probabilities and is a function of relative prey to predator length as opposed to weight in the standard MSVPA equations. This

formulation explicitly assumes that type selection is independent of prey size. This is consistent with several examples in the literature that suggest consistent type selection for a range of prey sizes. For example, in juvenile bluefish, fish prey were preferred over shrimp prey across a range of sizes for each type (Juanes *et al.*, 2001). To reflect changing type preferences across predator ontogeny, type selection is entered for each predator age class in the MSVPA-X implementation.

#### 1.1.4.3 Deriving Ranked Type Preferences

Type selection is entered as a proportional rank index to further reduce the data demands. Thus, for each prey type (or species), a preference rank is assigned for a given predator age class. If a prey species is not consumed by that predator age class, then it is given a rank of zero. The proportional inverse rank is calculated as:

$$(1.9) \quad A_i = \frac{m - r_i}{\sum_{j=1}^m r_j},$$

where  $m$  is the number of prey species and  $r_i$  is the preference rank for each species. The resulting proportional index is equivalent to the expected diet composition for the predator given equal prey abundances and equal prey sizes. If there is no type selection, then all prey species are given equal, tied ranks.

Developing prey type selection rankings requires reviewing available diet information for each predator. Ideally, diet studies would be available over a broad geographic area and encompass the same temporal resolution (seasons) and scale (duration) of the model runs. A suggested empirical approach for developing these input parameters from available data is as follows:

Step 1: Obtain all raw diet data and information on the scales and sampling methods of the individual studies.

Step 2: Weight individual studies by length of time series, geographical coverage, and the number of samples. Also, diet studies in which the abundance of a single prey item dominates should be examined closely. Assigning a weighting factor for spatial, temporal, and sample size differences will attempt to account for local abundance issues associated with the particular diet study.

Step 3: Generate an average seasonal diet matrix over temporal and spatial range of model to separate effect of differences in abundance.

Step 4: Develop a relative abundance/biomass matrix by season for all prey species. This would aid both when considering the influence of abundance of prey affecting selectivity and testing the difference between generalist feeding and choice of prey type.

Step 5: Calculate a electivity matrix based on diet and abundance information to develop prey type ranking.

#### 1.1.4.4 Size Preference (B)

The final component of the feeding selectivity relationship is size selectivity. Again, this is framed in terms of Chesson's index such that the size selection parameters across the size range of the prey sum to 1 and the selection parameter for a certain sized prey,  $l$ , reflects the proportion of the predator's diet that would be comprised of prey items of that size independent of type selectivity and relative abundance. The original equation from the ICES MSVPA for size selectivity does not follow this formulation and instead uses a weight ratio to determine selection for a particular prey item. The vast majority of the feeding literature indicates that the relative length of the prey is the more pertinent measure, presumably due to factors such as gape width limitations and, relative swimming speed. For example, predator-prey length ratios had a significant effect on prey capture probabilities for juvenile bluefish (Scharf *et al.*, 1998). In general, this effect results in a dome-shaped relationship between predator-prey length ratios and the capture success and is often reflected as a unimodal distribution of prey in the diets.

To effectively model this pattern, the MSVPA-X model takes a similar approach to that described in Tsou and Collie (2001) by using a flexible unimodal function to describe the relationship between prey size and the proportion of the prey in the diet. However, the MSVPA-X model uses the incomplete beta integral. The form of this function is more consistent with the formulation of Chesson's selectivity index as it integrates to 1 over the domain of predator to prey ratios being considered. The size selection index for a prey of a particular size thus corresponds to the predicted proportion of prey of that size in the predator's diet.

The beta integral is given as:

$$(1.10) \quad B(\alpha, \beta) = \int_0^1 t^{\alpha-1} (1-t)^{\beta-1} dt$$

and this is related to the incomplete beta integral as:

$$(1.11) \quad I(z; \alpha, \beta) = \int_0^z t^{\alpha-1} (1-t)^{\beta-1} dt / B(\alpha, \beta).$$

The size selection coefficient over some size range between  $x_{\min}$  and  $x_{\max}$  is calculated as:

$$(1.12) \quad S(\alpha, \beta) = I(x_{\max}; \alpha, \beta) - I(x_{\min}; \alpha, \beta).$$

In this case,  $x$  is the prey to predator length ratio. The incomplete beta function can be fit to data on the length distribution of fish prey in stomach data by maximum likelihood estimation and goodness of fit assessed with chi-square tests to derive values for the coefficients  $\alpha$  and  $\beta$ . This assumes that length distribution of prey in the diet reflects selection rather than availability, which may be a reasonable assumption in data sets of broad spatial and temporal scope. Example size selection curves for different age ranges of a fish predator using the beta function are shown in Figure D.3.

To develop size selectivity parameters, the following procedure is suggested:



Step 1: Compile data for relative length-frequency of prey items in diet by species.

Step 2: These studies should be weighted on the length of study (number of years), area covered, and number of samples to obtain average picture of prey length consumed.

Step 3: Based upon these weighted average curves, fit the beta integral to available data to derive parameters for input into the model. An Excel spreadsheet function is provided with the program distribution to allow fitting of these parameters based upon available data.

#### 1.1.4.5 Biomass Predators

One potential limitation of the previous application is that all predator species must be explicitly modeled within the standard MSVPA and must therefore have age-structured catch data and meet other assumptions of the model. While there is a capability to include “other prey” that do not correspond to these assumptions, there is no mechanism to incorporate removals by other predators for which only biomass or abundance information is available. Examples of such sources include fish species where age-structured models are unavailable or inappropriate and for species such as birds and marine mammals for which age-structured models are typically impractical. An approach to incorporate “biomass predators” that may have significant predatory impacts has been implemented in the model to overcome this limitation. These predator populations are not explicitly modeled; however, biomass and feeding information are incorporated to calculate the predation mortality rates due to these predators on explicitly modeled prey species.

Inputs for biomass predators include total predator biomass across the time frame of the model, the proportion of the predator biomass in user specified size intervals, consumption parameters, mean stomach contents, and spatial overlap and type preference parameters similar to those for standard species. In addition, one must specify the size selectivity parameters (equation 1.10;  $\alpha$  and  $\beta$ ) and the size range of the predator. Size selection by other predators is implemented in a similar manner to that for other prey. Size selectivity for a particular sized prey is integrated across the size range for a given size class of biomass predator:

$$(1.13) S = \int_{l_{\min}}^{l_{\max}} S(x/l; \alpha, \beta) dl.$$

Where  $l$  is the predator length,  $x$  is the prey length, and the function in the integral is the size selectivity function (equation 1.12). This is essentially an average value for the selectivity parameter over the range of the predator size class. Aside from this modification, the biomass predators are treated identically to other species when calculating suitable prey biomass, consumption rates, and diets.

## 1.2 CALCULATION OF PREDATION MORTALITY RATE (M2)

In addition to standard prey, an additional prey type is included in the MSVPA formulation to account for other fish prey and system biomass that is available to the predator species. As with

explicitly included fish prey (i.e., menhaden), selectivity for “other prey” is calculated using equation 1.5. However, the size selection must be calculated based upon an input size distribution for the other prey biomass. The size-selectivity function is then integrated over the size range of the other prey:

$$(1.14) \quad S_x^{ia} = O_x^i \cdot A_x^i \int B_x^{ia} \cdot BM(l)_x dl.$$

The total food available for a given predator species and age class, or “suitable biomass” is expressed as:

$$(1.15) \quad SB^{ia} = \sum_x S_x^{ia} B_x + \sum_j \sum_b S_{jb}^{ia} \cdot w_{jb} \cdot \overline{N}_{jb},$$

and,

$$SB_{jb}^{ia} = A_j^{ia} \cdot B_{jb}^{ia} \cdot O_j^{ia} \cdot w_{jb} \cdot \overline{N}_{jb}$$

which is the weighted sum of biomass,  $B_x$ , across all “other prey” types, and the sum of prey biomass ( $w_{jb} * N_{jb}$ ) across all prey species,  $j$ , and age classes,  $b$ . It is important to note that the relevant abundance is the average number of prey available during the time interval given as:

$$(1.16) \quad \overline{N}_{jb} = N(0)_{jb} \cdot \frac{\exp(-\alpha Z) - \exp(-\beta Z)}{(\beta - \alpha)Z},$$

where  $\alpha$  and  $\beta$  are the beginning and end of the time period being considered expressed as a proportion of a year.

The biomass of a particular prey consumed by a predator is the product of total consumption by the predator and the proportion of total suitable biomass represented by that prey type:

$$(1.17) \quad P_{jb}^{ia} = \frac{SB_{jb}^{ia}}{S^{ia}} \cdot C^{ia},$$

and, the predation mortality rate due to the predator is the ratio of these removals to the average abundance of the prey during the time interval:

$$(1.18) \quad MZ_{jb}^{ia} = \frac{P_{jb}^{ia}}{w_{jb} \overline{N}_{jb}}.$$

Total predation mortality rate for a given prey species and age class is finally the sum across all predators:

$$(1.19) \quad M2_{jb} = \sum_i \sum_a M2_{jb}^{ia} .$$

The model is initiated with user-entered, fixed values of M2 for each species. The SSVPA's are run and M2 values are calculated using the equations above based upon calculated biomasses and selectivity parameter inputs. The M2 values are then used in successive iterations of the model which are repeated until the M2 values do not change appreciably between iterations. The iteration loop implemented in the MSVPA-X application is shown in D.4.

### 1.3 MULTISPECIES FORECAST MODEL

MSVPA-X includes a forecast model that allows exploring potential effects of management scenarios. The forecast model includes the feeding response and consumption equations used in the historical model. A given application of a forecast model is based upon a reference MSVPA-X implemented in the project file. The forecast model is built upon the basic age-structured population model:

$$(1.20) \quad N_{t+1} = N_t \exp[-(F + M1 + M2)],$$

Population biomass is then simply:

$$(1.21) \quad B_t = N_t w_t$$

where  $w_t$  is the weight of an individual at time  $t$ . Thus, given an initial population size ( $N_0$ ), fishing mortality rate ( $F$ ), and other natural mortality rate ( $M1$ ) it is necessary to calculate both individual weight at time  $t$  and  $M2$  to project the population forward.

As shown previously, predation mortality rate is a function of prey selection, predator biomass, predator weight, and prey abundance. However, to calculate  $M2$  for a given season using the standard MSVPA-X equations, one must know the average prey and predator biomass during the season, which require estimates for the total mortality rate ( $Z$ ), and hence  $M2$ , experienced during the season. The projection model is resolved to a daily time step to avoid this problem.

At each daily time step in a given season, the size and weight of predators and prey species are calculated from input growth parameters. These terms are used to calculate feeding selectivity parameters, and the total suitable prey biomass for the daily time step is calculated based upon biomasses at the beginning of the day. Predator consumption is modeled as in the historical MSVPA-X approach. The correction for food availability is relative to the historical time series average of total suitable prey biomass from a reference MSVPA-X run.

The amount of each prey type consumed is then converted into a daily mortality rate from the total biomass consumed. This is accomplished first by converting biomass consumed to numbers consumed by dividing by prey weight. The predation mortality rate during the daily time step is then solved iteratively for total mortality,  $Z$ , using a solution of the standard catch equation:

$$(1.22) \frac{C}{N} = \frac{M2}{Z}(1 - \exp(-Z)),$$

where  $N$  is prey abundance at the beginning of the time step,  $C$  is the number consumed during the time step by all predators, and  $Z = F + M1 + M2$  where daily values for  $F$  and  $M1$  are given. The calculated mortality rates are thus used to project the predator and prey populations forward to the next day.

The model is initialized to a selected year of the reference MSVPA-X historical run. Model outputs include seasonal estimates of predation mortality, predator and prey population sizes in numbers and biomass, fisheries yields (given  $F$ ), seasonal average predator diets, total seasonal consumption, and seasonal predator size and weight-at-age. The projection model is run for each age class of each predator and prey population on an annual basis, starting from the population abundance at age estimated in the initial year of the projection. It is necessary to include a stock-recruit relationship to calculate the initial abundance of age-0 fish at the beginning of each year. This is accomplished by calculating the spawning stock biomass for each year based upon input maturity information and a stock-recruit relationship that is fit based on data from the MSVPA-X runs and selected by the user. The structure of the forecast model implementation is shown in Figure D.5. Four different stock-recruitment models are provided as options in the forecast model:

### 1.3.1 Ricker Stock-Recruit Relationship

$$(1.23) R = aS \exp(-bS)$$

This is the standard Ricker Stock-Recruit model that includes strong compensatory dynamics resulting in low recruitment success at large stock sizes. The application fits a linear transformation of the model using least-squares regression and displays model fit diagnostics.

### 1.3.2 Beverton-Holt Relationship

$$(1.24) R = \frac{aS}{b + S}$$

A linear transformation of the standard Beverton-Holt model is also fit using least squares regression.

### 1.3.3 Random from Quartiles

In cases where there is no clear relationship between spawning stock biomass (SSB) and recruitment, it may be appropriate to use a more flexible, stochastic relationship. The “random from quartiles” approach sorts SSB values from the time series into quartiles and determines the minimum and maximum recruitment observed within each SSB quartile. During the projection model, the calculated SSB is compared to the observed quartile ranges, and a value for

recruitment is randomly selected from a uniform distribution ranging between the minimum and maximum recruitment for the appropriate quartile. A weak dependence between SSB and recruitment is maintained with this approach if one exists. Recruitment values are constrained to be between the minimum and maximum values of those observed during the reference MSVPA-X run.

#### 1.3.4 Shepherd Flexible

Shepherd (1982) proposed an alternative stock-recruit relationship that has a more flexible level of compensatory dynamics than the standard Ricker curve. The Shepherd model contains a third term that determines the strength of compensatory declines in recruitment at large stock sizes.

$$(1.25) \quad R = \frac{aS}{1 + (S/B)^\gamma}$$

The model is non-linear, and therefore it is more difficult to develop a unique and reliable model fit, particularly when there is a large amount of variation in the data.

## CHAPTER 2: DATA INPUT AND MODEL PARAMETERIZATION

### 2.0 SINGLE-SPECIES ASSESSMENT DATA

This configuration of the MSVPA-X model uses data from each single-species assessment completed in 2002 and 2003, permitting a multispecies analysis through 2002. Below is a summary table of single species stock assessment models used in the MSVPA-X formulation and the current assessment model used for each species.

Species	Assessment model used in MSVPA-X	2002/2003 Assessment model	Current assessment model (2005)
Menhaden	Extended Survivors Analysis (XSA)	Forward Projecting Age Structured model	Forward Projecting Age Structured model
Striped Bass	XSA	ADAPT VPA	ADAPT VPA
Bluefish	Biomass Input	Biomass Dynamic model (ASPIC)	Statistical Catch-at-Age model (ASAP)
Weakfish	XSA	ADAPT VPA	Relative F model

### 2.1 ATLANTIC MENHADEN

#### 2.1.1 Summary of Fishery and Assessment

The Atlantic menhaden fishery consists largely of purse seine vessels targeting fish for two distinct uses. The reduction fishery typically focuses on relatively young, small fish in the estuaries and coastal waters along the U.S. Atlantic coast, particularly in Chesapeake Bay. Menhaden captured in this fishery are processed for sale as fish meal or fish oil. Purse seine vessels are also the primary component of a fishery that targets larger fish for sale as bait for crab pot and other fishing operations. There are additional small directed and bycatch based gillnet fisheries for menhaden in most states (reviewed in ASMFC, 2004a).

The reduction component of the fishery is intensively monitored, with both catch-at-age and effort data available since 1955. Fishery information on the bait component is less reliable and the catch-at-age matrix from commercial bait landings was used for 1985-2002. Biological sampling for age and size data at the reduction plants has been in place throughout the time series, but sampling of the bait fishery catches is less reliable prior to 1988. Annual size-at-age and length-weight regressions are available from 1955 to the present.

Prior to 2003, the Atlantic menhaden stock assessment used a Murphy Virtual Population Analysis approach. Terminal fishing mortality rates were estimated by a standard catch curve analysis. Population sizes in the last year of the assessment were estimated using a separable

VPA based upon the last 3-7 years of the catch-at-age matrix (Vaughn *et al.*, 2002). However, during the most recent stock assessments, a forward projecting age-structured model was applied to the Atlantic menhaden stock (ASMFC, 2004a). The model incorporated two indices of abundance: an aggregated coast wide age-0 index and a CPUE index for pound net catches. This approach also allows separate treatment of the bait and reduction fisheries, which is particularly appropriate given the different selectivity of the fisheries (reviewed in ASMFC, 2004a).

The newly applied forward-projection model results in similar trends in the Atlantic menhaden population to the previous assessment approach, though there are changes in the absolute estimates of both fishery and natural mortality rates, as well as population sizes. The stock assessment indicates that Atlantic menhaden spawning stock biomass and population fecundity are currently high relative to the population median during the last two decades, though considerably lower than peaks during the late 1950s and early 1960s. The number of recruits (age-0 and age-1) has generally been declining since reaching a peak during the early 1980s. The 2002 estimate of recruits to age-1 falls below the 25<sup>th</sup> percentile of the time series; however, this recent estimate is highly uncertain. Based primarily upon current estimates of fishing mortality rate and spawning potential, the stock assessment concludes that this population is currently not overfished.

#### 2.1.2 Fishery Catch-at-Age

Time series for predator catch-at-age matrices are restricted to the period from 1982-2002. Thus, the MSVPA-X model uses the Atlantic menhaden catch-at-age data for this period. Unlike the single-species assessment, it is not currently possible to model selectivity for the reduction and bait fisheries separately in the MSPVA-X approach. Thus, a combined catch-at-age matrix is employed including both bait and reduction fishery landings from 1985-2002. Prior to 1985, only reduction landings are included in the catch data. The method for deriving catch data is detailed in ASMFC (2004a), and data are shown in Table D.1.

#### 2.1.3 Fishery-Independent and Dependent Tuning Indices

A fishery-independent coast wide juvenile (age-0) index is available for Atlantic menhaden based upon five seine surveys conducted between North Carolina and Rhode Island. Individual state seine survey indices are derived using a lognormal generalized linear model (GLM). Correlations between surveys are then evaluated to combine individual regional surveys; for example the Virginia and Maryland surveys are highly correlated and reflect trends in Chesapeake Bay. The regional indices are then combined using an average weighting based area of the associated drainage basins. The resultant coast wide index is used as a tuning index for age-0 abundance in the single-species assessment approach used in the MSVPA-X model (Table D.2).

The forward-projection stock assessment model also uses a biomass index based upon CPUE of Potomac River pound net catches. The pound net index reflects total biomass of primarily age 1-3 Atlantic menhaden. The formulation of the MSVPA-X model requires an age-disaggregated index of abundance as opposed to biomass. Based upon the age selection model applied in the forward-projection approach and estimated weights-at-age, the CPUE (biomass) index is

converted to an age-specific index of abundance (numbers) for age classes 1-3 (Table D.3). These age-specific indices are used as tuning indices for adult abundance in the MSVPA-X application.

#### 2.1.4 Age and Growth

Size and weight-at-age derived from von Bertalanffy growth curve parameters and length-weight regression parameters are available annually since 1955 based on commercial fishery sampling (ASMFC, 2004a). However, there is a high degree of interannual variation in predicted sizes and weights-at-age, particularly in the younger age classes. In order to reduce this variability, average size and weight parameters are calculated in five-year intervals from 1982-2002. These average parameters are used to develop size and weight-at-age matrices for use in the MSVPA-X application (Table D.4, Table D.5). In the single-species assessment, the weight-at-age-0 is actually represented by age = 0.75 menhaden because fishery catches do not occur until late in the year (ASMFC, 2004a).

#### 2.1.5 Single-Species VPA Formulation

In the MSVPA-X application, XSA is used as the single-species assessment model for Atlantic menhaden because it allows including the coast wide juvenile index and the age disaggregated pound net CPUE index as tuning indices and is thus consistent with the approach used in the forward-projection assessment model. A range of XSA options were evaluated to explore the sensitivity of predicted fishing mortality rates to values of shrinkage parameters including the number of years and ages used to calculate terminal fishing mortality rates. Estimated fishing mortality on the last age class was sensitive to the number of age classes used to calculate terminal F (Figure D.6). Four age classes were used to calculate the shrinkage mean to preserve a dome-shaped fishery selection curve to be consistent with the findings of the forward-projection model. The XSA model estimated higher fishing mortality rates on older age classes than the forward-projection approach (Figure D.7). This is likely due to the fact that the reduction and bait fisheries cannot be separately analyzed in the XSA formulation. However, the trends in fishing mortality rates were similar in the two assessment approaches.

The two approaches give similar trends and estimates of total abundance when the same natural mortality vector is applied to each model. For comparison to the assessment results, the natural mortality vector estimated by the forward-projection model was applied to the XSA (age-0  $M = 4.31$ , age-1  $M = 0.98$ , age-2  $M = 0.56$ , age-3+  $M = 0.55$ ). The resulting XSA runs gave very similar results to the forward-projection model for ages 0 and 1. However, the abundance of older age classes was underestimated by the XSA in comparison to the forward-projection results, consistent with higher estimates of fishery mortality rates on these age classes. The overall magnitude and trends in abundance were similar between the two approaches (Figure D.8).

In the base MSVPA-X run, the XSA model using four age classes and two years to calculate the “shrinkage” mean was applied. The base natural mortality rate ( $M_1$ ) was set at 0.4 for all age classes.



The Atlantic menhaden stock assessment is scheduled to be updated in 2006 using the forward-projection assessment model.

## 2.2 STRIPED BASS

### 2.2.1 Summary of Fishery and Assessment

Striped bass commercial and recreational fisheries occur in nearshore coastal waters, estuaries, and tributaries along the U.S. Atlantic coast, particularly north of North Carolina and in the main-stem and tributaries of the Chesapeake Bay. The stock suffered very high fishing mortality and severe declines in abundance and spawning stock biomass during the late-1970s and early 1980s. Reduced fishery mortality rates during the 1980s and 1990s led to recovery of the stock. Abundance and biomass are currently high. Fishing mortality rates are below target levels for ages 4-11 fish, but exceed management targets for older age classes (ages 8-11; ASMFC, 2003).

The striped bass stock assessment is based upon catch-at-age based VPA using the ADAPT methodology and tag-recovery survival estimation. The VPA analysis is the primary tool used to provide mixed-stock estimates of fishing mortality rate. Catch-at-age matrices for the ADAPT methodology are derived from sampling of the commercial catch. Corrections are made for estimated levels of commercial discard mortality using tag-recovery rates for specific gear types and the spatial distribution of commercial fishing effort (ASMFC, 2003). Recreational harvest and discards derived from MRFSS data following standard methodologies. Length-frequency sampling was converted to catch-at-age by applying state-specific age-length keys (ASMFC, 2003).

Age-length keys for all states are derived from scales. However, there is significant concern over the accuracy of age assignments for fish over age-12 (ASMFC, 2003). To evaluate sensitivity to potential ageing errors, the most recent stock assessment evaluated the effects of designating different “plus-group” configurations including 12+, 13+, 14+, and 15+ categories in the catch-at-age matrix. Based upon this analysis, the 13+ age class was chosen as providing the most appropriate model formulation. In contrast, all previous year assessments applied a 15+ age class. Uncertainty in ageing of older fish remains a considerable challenge in the assessment of the striped bass stock.

For this analysis, we developed XSA runs for direct comparison to the 13+ ADAPT VPA used in the striped bass stock assessment. Numerous age-specific fishery-independent surveys are used as tuning indices for these approaches. The input data and configuration for the XSA and ADAPT approaches are nearly identical, allowing direct comparison of model results.

### 2.2.2 Fishery Catch-at-age

A catch-at-age matrix is available for 1982-2002. Catch data include commercial and recreational harvest and discard losses; complete details are included in the stock assessment report (ASMFC, 2003; Table D.6).

### 2.2.3 Fishery-Independent Surveys

Numerous abundance indices are available from fishery-independent and dependent surveys. Age-specific fishery-independent surveys include the Virginia pound net, Maryland gillnet survey, Connecticut trawl survey, New York ocean haul seine survey, New Jersey trawl index, Delaware trawl survey, and the NEFSC spring bottom trawl survey. Fishery-dependent indices include Massachusetts commercial CPUE, Hudson River shad fishery bycatch, and Connecticut volunteer angler CPUE. Juvenile surveys conducted in each state provide YOY indices from Maryland, Virginia, New York, and New Jersey. Yearling indices are available from New York and New Jersey.

The striped bass stock assessment subcommittee eliminates the Maryland spawning stock biomass age-2 index, the NEFSC trawl survey ages 12-15, and the Virginia Pound Net survey based on sampling and ageing concerns. The XSA analysis uses the same suite of indices as the ADAPT analysis, with the exception of age aggregated indices that cannot be used in the current implementation of the XSA.

### 2.2.4 Age and Growth

Striped bass weight-at-age is derived from several state sampling programs of commercial and recreational catch. Mean weight-at-age in the population is calculated as an average of state values weighted by the commercial catch. The weight-at-age matrix for 1982-1996 was developed for the 1997 stock assessment (NEFSC, 1998), and weights developed for 1997 were applied to 1998 and 1999. Weight-at-age for 2000-2002 were recently updated and applied in the most recent assessment (ASMFC, 2003).

Size-at-age is derived from state specific age-length keys. Seasonal average length-at-age for each state is calculated based upon available data. These state-specific estimates are then used to develop an average length-at-age vector by fitting a von Bertalanffy growth curve.

Due to uncertainties in ageing and questions about the representative nature of the annual weights-at-age derived in the striped bass assessment, the average weight-at-age is used in the base run of the MSVPA-X. Likewise, since there is no information on interannual variation in striped bass length, a single size-at-age vector is applied in the current analysis (Table D.7).

### 2.2.5 Single-Species VPA

Extended survivors analysis (XSA) is used as the single-species VPA model for striped bass in this application. The XSA approach is similar to the ADAPT methodology in that it utilizes tuning indices in the estimation procedures for fishery mortality rates. The tuning index data used in the 2003 striped bass stock assessment are used in the XSA, with the exception of age-aggregated and biomass indices. As in the ADAPT assessment, a 13+ age class is used and natural mortality set at 0.15 (ASMFC, 2003).

A series of XSA evaluation runs were conducted to evaluate sensitivity to XSA parameters and to compare results to the ADAPT assessment. Estimation of fishery mortality rates on older age

classes was sensitive to the selection of the number of age classes used to calculate the shrinkage mean  $F$  (Figure D.9). Calculating the shrinkage mean using 4 age classes most closely approximated the ADAPT results and will be used in the MSVPA-X application. The estimates of  $F$  were insensitive to other XSA parameters including the number of years used to calculate the shrinkage mean  $F$  in the last year. Trends in  $F$  were qualitatively similar for age classes 3-8 and 8-11 for the two approaches (Figure D.10). There was a tendency for the XSA to estimate slightly higher values of  $F$  relative to the ADAPT approach for older age classes during the last years of the assessment (Figure D.11). However, the selection curve and average  $F$  at-age were comparable between the two models.

The time series of estimated recruit abundance differed significantly in the last two years of the time series with ADAPT estimating much higher age-1 abundance during 2001 and 2002 compared to XSA (Figure D.11). For both assessment approaches, estimates of  $F$  and abundance for pre-recruit age classes is highly uncertain, so it is difficult to evaluate which model provides the “better” assessment. The trends and estimates of abundance for the remaining age classes are similar between the two approaches, though there is a tendency for the XSA to underestimate abundance relative to the ADAPT model (Figure D.11).

The striped bass stock assessment is updated annually and the next benchmark stock assessment is scheduled for 2007.

## 2.3 WEAKFISH

### 2.3.1 Summary of Fishery and Assessment

Weakfish are harvested commercially and recreationally along the U.S. Atlantic coast and in estuaries from Florida to the southern Gulf of Maine. Adult fish are harvested in offshore waters off of Virginia and North Carolina by gillnet and trawls. During spring and summer, gillnets and trawls are used to harvest fish in more northern coastal waters, and primarily gillnets are used in estuarine waters along the U.S. Atlantic coast. Recreational catch is concentrated in estuarine waters in the mid-Atlantic; however, there are significant recent recreational catches in southern New England states (Kahn, 2002a).

The weakfish stock biomass was generally low throughout the 1980s into the early 1990s. Fisheries regulations were put into place to restore the stock in the mid-1990s (Amendment 3 to the Interstate Fishery Management Plan for Weakfish), and estimated stock abundance and biomass has been generally increasing since at least 1990. The estimate of fishing mortality rate in the terminal year (2000) was below both the target and threshold values of  $F$  under the current FMP (Kahn, 2002a).

Kahn (2002a) applied the ADAPT VPA approach to a catch-at-age matrix derived from commercial and recreational catches through 2000. There is significant concern with the very low estimates of terminal fishing mortality and associated large population size estimates. Retrospective analyses of the ADAPT assessment indicate that the terminal  $F$  estimate may be underestimated by 100% (Kahn, 2002a). Additional concerns include the relatively limited geographic scope of biological sampling of the commercial catch, lack of data on commercial

discard mortality, and lack of information on recreational discards. The weakfish stock was assessed in 2004, but confounding signals from fishery-independent and fishery-dependent data prevented the ASMFC Weakfish Technical Committee from completing an ADAPT VPA.

An XSA analysis is applied to the weakfish stock for direct comparison to the ADAPT results. Four age disaggregated fishery-independent indices are used in both the ADAPT and XSA analyses. In addition, several indices of juvenile abundance are employed in the XSA analysis (data provided by ASMFC Weakfish Stock Assessment Subcommittee). Indices are developed for the period from 1982-2001, while the fishery catch-at-age matrix and associated data are currently available only from 1982-2000. In addition, XSA evaluation runs were compared to an integrated catch-at-age analysis (ICA) of the weakfish stock that was explored during the 2001 assessment (Kahn, 2002a).

### 2.3.2 Fishery Catch-at-age

The fishery catch-at-age matrix reflects both commercial and recreational landings, but includes discards from only the recreational fishery. Catch-at-age data are supplied either individually by state, or by estimating catch-at-age from length-frequency data and applying regional length-weight and age-length relationships as appropriate (Kahn, 2002a). The resulting catch-at-age matrix includes the period from 1982-2000 and includes age classes 1-6+ (Table D.8). For MSVPA-X evaluation runs, the catch matrix is projected forward to include 2001 and 2002 based upon fishing mortality rates and population sizes calculated through 2000.

### 2.3.3 Fishery-Independent Surveys

Four fishery-independent surveys provide age-specific indices of weakfish abundance for use in tuning the ADAPT and XSA approaches. Only surveys encompassing the region between North Carolina and Delaware are used: the New Jersey coastal trawl survey, a Delaware Bay survey, the SEAMAP fall coastal survey in North Carolina waters, and the NMFS fall inshore survey (Kahn, 2002a). In addition, several juvenile indices based upon haul seine surveys in estuarine waters are included: the VIMS haul seine (age-1), the North Carolina DMF survey (ages-1 and -2), two surveys by Maryland DNR (both age-1), and a Delaware Bay survey age-1).

### 2.3.4 Age and Growth

Size and weight-at-age are estimated from year specific von Bertalanffy parameters developed by Vaughan (unpublished data) for the period from 1990-1999 based upon otolith data (Kahn 2002b, pers. comm., D. Vaughn, SEFSC). Due to uncertainties in the methods used for length and weight analyses, the average derived weights and lengths from the 1990-1999 period are used in the MSVPA-X base run (Table D.9).

### 2.2.5 Single-Species VPA

The XSA model is used as the single-species VPA approach for weakfish. A series of XSA evaluation runs were developed for the period from 1982-2000 for comparison to the ADAPT VPA and integrated catch-at-age (ICA) analysis used in the 2002 assessment document. The

catch matrix included ages 1-6+ and the same indices were used in the XSA as in the standard assessment models. A constant natural mortality rate of 0.25 was assumed for weakfish.

The XSA for weakfish was largely insensitive to shrinkage parameters, and varying the number of years or age classes used to estimate terminal F values had little effect. The qualitative trends are similar for the ICA, XSA, and ADAPT models with the exception of the last two years of the assessment (Figure D.12). The XSA tends to underestimate fishery mortality rates on older age classes through most of the time series compared to the other two models. However, in the last two years of the assessment, the ADAPT approach estimated very low fishery mortality rates for ages 3-5 compared to the other two approaches (Figure D.13). Concern was expressed in the 2002 assessment about severe retrospective bias in the ADAPT approach and significant underestimation of F in the terminal year (Kahn 2002a). The fishing mortality rate estimates in the last two years for the XSA are more similar to those estimated by the ICA model (Figure D.13).

Abundance estimates from the three approaches diverge from one another beginning in the mid-1990s. From 1997-2000, the ICA and XSA models estimate declining abundance of older age classes, while the ADAPT estimates significant increases in the abundance of older fish during this time period (Figure D.14). For younger age classes, the ICA and XSA both predict declines during 1994-1997, while the ADAPT predicts continued increases. The ICA model indicates increases in the abundance of young weakfish during 1998-2000, while the XSA model indicates continued decline (Figure D.14).

The divergent results of the three age-structured assessment models used here likely reflect problems with the catch-at-age matrix described in the 2002 assessment. Another problem is that only two fully recruited true age classes are in the current assessment.

## 2.4 BLUEFISH

### 2.4.1 Summary of Fishery and Assessment

Bluefish landings are primarily from recreational fisheries along the U.S. Atlantic coast and in estuaries between Maine and Florida. Commercial fishery operations in coastal waters also land bluefish in several gillnet and trawl fisheries; however, the commercial landings are consistently below those of the recreational fishery (Lee, 2003). The biomass of the bluefish stock declined during the period from 1982-1992 and continued at low levels through 1998. Amendment 1 to the FMP was adopted in 1998 in an effort to rebuild the stock by 2007 through gradual reductions in fishery mortality rate. The stock assessment model results used in the MSVPA-X indicate that fishing mortality rates in the terminal year (2002) are below target levels and there have been recent increases in stock abundance.

The biomass dynamics model (ASPIC) previously used to assess the bluefish stock utilized commercial and recreational landings data. The recreational CPUE and NEFSC inshore fall survey are used as tuning indices in this approach. The stock had not been assessed using an age-structured approach, primarily due to concerns at the time, about the validity of reliable ageing. Prior to the 2005 stock assessment, the most recent age-structured assessment included catch-at-

age through 1997 (NEFSC, 1997), and at that time age-length keys were available only from North Carolina. In 2005, a forwarding projecting model (ASAP) was used to assess the bluefish stock and also determined fishing mortality to be below target levels and population abundance has been increasing since 2000. Though the peer reviewers had concerns regarding the 2005 assessment, it was accepted for management purposes (NEFSC, 2005).

Due to the unavailability of catch-at-age information from a peer reviewed stock assessment during the model reference period (1982 – 2002), bluefish is included in the MSPVA-X application as a “biomass predator”. In this formulation, the predator population dynamics are not modeled. Model input requirements include a time series of total predator biomass, limited information on predator size structure, and feeding selectivity parameters.

#### 2.4.2 Biomass Input

The time series of bluefish stock biomass from 1982-2002 is derived from the ASPIC Biomass Dynamic model used in the ASMFC stock assessment (Lee, 2003). The model uses recreational CPUE and the NEFSC inshore fall bottom trawl survey as tuning indices. Lee (2003) points out several areas of concern with this assessment model including: uncertainty as to the appropriateness of the NEFSC survey as an index of total biomass, assumptions of constant catchability in the fishery, and general concerns with the base assumptions of the simplified biomass dynamic model. The time series of total bluefish biomass is shown in Figure D.15.

#### 2.4.3 Size Structure

An analysis of bluefish diet information based upon the Northeast Fisheries Science Center Food Habits database indicated significant breaks in bluefish diets in three size classes: 10-35 cm (ages 0-1), 35-55 cm (ages 2-3), and > 55 cm (ages 4+). These three size classes were used in the MSPVA-X model to account for ontogenetic changes in feeding selectivity and consumption parameters. The proportion of the total biomass in each age class was estimated based upon the average size distribution from the previous age-structured assessment (NEFSC, 1997). The proportion of biomass calculated for each size class was: Size 1 – 0.07; Size 2 – 0.21; Size 3 – 0.71.

### 2.5 ‘OTHER PREY’ COAST WIDE BIOMASS ESTIMATES

#### 2.5.1 Benthic Invertebrates

The three primary benthic invertebrate taxa important in the diets of weakfish, bluefish, and striped bass include gammarid amphipods, isopods, and polychaetes. The benthic invertebrates, particularly gammarids, are most important in the diets of young striped bass in the Chesapeake Bay, with gammarids accounting for up to 80% of the diet during some seasons (Hartman and Brandt, 1995). Over the continental shelf, gammarids are also the primary benthic invertebrate consumed by weakfish and striped bass, typically accounting for 5-15% of the observed diet Northeast Fisheries Science Center Food Habits database. Bluefish tend to have low amounts of benthic invertebrates in their diets.

Regional density estimates for these benthic invertebrate taxa were developed from a systematic benthic sampling program of the U.S. Atlantic continental shelf described in Wigley and Theroux (1981) and Theroux and Wigley (1998). This study was a comprehensive quantitative sampling of the benthic invertebrate community conducted during the 1950s and 1960s. Sampling was conducted using quantitative grab samplers. Results in the referenced reports provide maps and taxa specific density estimates in areas consistent with the regional definitions used in the current analysis. Densities are provided as  $\text{g m}^{-2}$ , and these were converted into biomass by multiplying regional density values by area, calculated using GIS tools (Table D.10). These data are not seasonally or annually resolved; therefore, constant biomass values were used across seasons and years in the current MSVPA-X application. While these estimates of benthic invertebrate biomass are based upon data several decades old, there is no more recent broadscale estimate of benthic biomass available over the U.S. Atlantic continental shelf. The resulting total estimated biomass of benthic invertebrates is 3,357,000 mt.

The size structure of the benthic invertebrate taxa was inferred from general descriptions of the observed size ranges in these habitats. This prey type was assumed to range between 1-7 cm in body length with peak biomass occurring at 3 cm. The resulting biomass distribution input into the MSVPA-X application is shown in Figure D.16.

### 2.5.2 Macrozooplankton

Crangonid shrimps, mysids, and other large zooplankton are primary prey items for young age classes of each predator species. However, there is no systematic information available on densities or biomass of these along the mid-Atlantic coast. Monaco and Ulanowicz (1995) report total density of “mesozooplankton” in the Chesapeake, Delaware, and Narragansett Bays as part of a trophic food web model examining energy flow in these systems. The total carbon density ( $\text{mg C m}^{-2}$ ) was converted to total biomass assuming that carbon accounts for 90% of dry weight and that dry weight is 10% of live weight. These estuarine densities were averaged to generate an estimated coast wide biomass density estimate of 13.3 mt per  $\text{km}^2$ . Multiplying this value by the regional areas generated a total biomass estimate of 1,994,000 mt. An approximate length-frequency for macrozooplankton biomass based upon literature descriptions of these taxa is shown in Figure D.17.

### 2.5.3 Benthic Crustaceans

Benthic crustaceans including crabs and lobsters make up a small, but consistent, proportion of the diet of striped bass, bluefish, and weakfish. For striped bass, blue crabs have been observed to make up a significant proportion of the diet (typically 10-20%) in some seasons in estuarine habitats (Hartman and Brandt, 1995). Over the continental shelf, the Cancer crabs (rock and Jonah crabs) are observed at low levels (1-3%) in striped bass diets, and in the inshore Gulf of Maine, lobsters accounted for 20-40% of adult diets in localized studies (Nelson *et al.*, 2003). The proportion of benthic crustaceans is lower in weakfish and bluefish diets, typically ranging between 1-3%.

As important commercially exploited species, both blue crabs and lobsters are the subject of detailed assessment work along the U.S. Atlantic coast. For blue crabs, assessment documents

provide biomass estimates in 10mm size intervals for Chesapeake Bay, Delaware Bay, and North Carolina (Eggleston *et al.*, 2004; Kahn and Helser, 2005; Sharov *et al.*, 2002). The total annual biomass estimates derived from assessment data are shown in Table D.11. The average biomass of blue crabs across the time series is 85,961 mt.

Data on lobster abundance along the Atlantic coast of U.S. were obtained from the ASMFC American Lobster Stock Assessment Report (ASMFC, 2000). Absolute abundance was reported for recruits, post-recruits and total for the Gulf of Maine, Cape Cod and Long Island areas for the period of 1982-1997 (Tables D.12 and D.13). Size distribution of lobster recruits from the intertidal study in the Gulf of Maine (Cowan, 1999) was similar to the size frequency of lobsters in striped bass stomach reported by Nelson *et al.* (2003). An estimated mean weight of recruits was applied to the absolute abundance estimates to produce total biomass of recruits for each year (Table D.14).

For rock and Jonah crabs, there is no detailed assessment data from which to derive information on total biomass. However, the NEFSC bottom trawl survey samples and quantifies both species. Trawl survey estimates of seasonal (Fall and Spring) and regional catch rates (number per tow) were summarized in Stehlik *et al.* (1991). These catch rates were converted into biomass per km<sup>2</sup> (Table D.15) assuming a trawl swept-area of 0.0315 km<sup>2</sup> and a mean weight of 63g per individual as reported in Stehlik *et al.* (1991). Rock crab densities in the Chesapeake Bay were assumed to be equal to those in the mid-Atlantic coastal waters based upon the spatial distribution described in Stehlik *et al.* (1991). Regional biomass estimates based upon swept area were 2,220 mt during fall and 253 mt during spring. These are recognized to be underestimates of total biomass since the trawl does not catch crabs with 100% efficiency.

Estimates suggest that the biomass of available benthic crustaceans is dominated by blue crabs. Averaged across the time series, the total estimated biomass for these three taxa is 91,471 mt. Due to the dominance of the blue crab component, the size distribution is based upon those developed for blue crabs from assessment data. The peak biomass is in the adult size classes between 13-16 cm carapace width (Figure D.18). This size range is larger than the range of prey consumed by striped bass and other species. Therefore, the available biomass of benthic crustaceans will be in the lower portion of this size range, consistent with the findings of diet studies showing that these predators feed primarily upon juvenile crabs.

#### 2.5.4 Squid and Butterfish

Butterfish were last assessed using a forward-projection model (NEFSC, 2004). Length-frequency data for the commercial fleet are provided therein. Fishery-independent length-frequencies are available from the NEFSC fall bottom trawl survey (pers. comm., William Overholtz, NEFSC).

Northern Short-finned squid (*Illex*) were assessed in 2003 (NEFSC, 2003). This assessment uses various methods, including a fishery-independent index based on the NEFSC fall bottom trawl series, a maturation-natural mortality model, and both yield-per-recruit and egg-per-recruit models. Data on length-frequency were provided using the NEFSC fall bottom trawl survey (pers. comm., Larry Jacobson, NEFSC).



Long fin squid (*Loligo*) data are available through a peer reviewed assessment (NEFSC, 2002). *Loligo* were assessed using both a length-lased VPA and an index based assessment. Fishery-independent and dependent length-frequencies are available.

### 2.5.5 Clupeids

Clupeids (other than Atlantic menhaden) are abundant in estuaries and coastal waters along the U.S. Atlantic coast, and may constitute an important prey for each of the predators included in the MSVPA-X model. Landings were accumulated as available for four species, including Atlantic herring, Atlantic thread herring, Spanish sardine, and scads. Additionally, the MSVPA-X Assessment Subcommittee recognized the shads (American shad, hickory shad and the river herrings) as a regionally important prey item, but was unable to develop a coast wide estimate of abundance for these species due to data limitations. A coast wide assessment for American shad is scheduled for completion in 2006.

#### 2.5.5.1 Atlantic Herring

Monthly landings of Atlantic herring (mt) were obtained for 1982-2004 from the northeast commercial fishery database (CFDB) as used in a recent stock assessment for Atlantic herring (Overholtz *et al.*, 2003). Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

Length composition data representing Atlantic herring for 1982-2004 (n = 253,274) were also available from the recent stock assessment (pers. comm., Matthew Cieri, Maine DMR). These data are summarized in Table D.18.

#### 2.5.5.2 Atlantic Thread Herring

The biology of and fishery for Atlantic thread herring along the North Carolina coast is reported in Smith (1994). Monthly landings of Atlantic thread herring in North Carolina were obtained from NMFS's menhaden sampling program (pers. comm., Joseph W. Smith, SEFSC). Additional monthly landings of Atlantic thread herring from the east coast of Florida were obtained from the NMFS website for commercial landings statistics (<http://www.st.nmfs.gov/st1/commercial/index.html>). Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

Length (n = 990) and age (n = 628) compositions were also available from the NMFS menhaden sampling program (pers. comm., Joseph W. Smith, SEFSC). These data, from fish collected between 1982 and 2002, are summarized in Table D.19.

#### 2.5.5.3 Spanish Sardines and Scads

Monthly landings of Spanish sardines and scads were also obtained from the NMFS website for commercial landings statistics cited above. Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

#### 2.5.5.4 Stock Abundance

The recent assessment of the Atlantic herring stock suggested an approximate  $F = 0.05$  (age-1+ in 2002). Based on this result, and noting that the landings of Atlantic herring are several orders of magnitude larger than the aggregate of other species presented here, combined landings were divided by  $F$  to obtain an estimate of population biomass for these species in aggregate. These values are presented annually from 1982-2004 (Table D.16).

#### 2.5.6 Anchovy

Bay anchovy, *Anchoa mitchilli*, is one of the most abundant fish species in mid-Atlantic estuaries and coastal waters and is a primary prey item during some seasons and age classes for each of the predators included in the MSVPA-X model. Relatively little information is available regarding biomass and population dynamics outside of estuarine waters. However, there has been intensive study of larval dynamics, life history, and seasonal patterns in biomass inside of Chesapeake Bay (Lou and Brant, 1993; Newberger and Houde, 1995; Rilling and Houde, 1999).

##### 2.5.6.1 Estuary Biomass Estimates

Bay anchovy are a short-lived species in Chesapeake Bay, rarely are there more than three age classes in the population. During most of the year, bay anchovy biomass in the bay is relatively constant; however, during the late summer and fall following recruitment, anchovy biomass increases dramatically as age-0 fish undergo rapid growth (Newberger and Houde, 1995). Rilling and Houde (1999) estimated baywide biomass during June and July at approximately 23,000 mt. During peak densities during fall, they cite studies indicating biomass levels peaking at over 100,000 mt. Biomass levels of 23,000 mt are assumed typical of winter and spring. Biomass is assumed to increase to 100,000 mt summer (July – September) and then decline to 60,000 mt during the fall.

##### 2.5.6.2 Coastal Biomass Estimates

The New Jersey Ocean Trawl Survey (NJ OTS) database was used to develop bay anchovy biomass estimates for nearshore coastal waters. The survey started in 1989 and samples nearshore waters (3 fathom – 15 fathom isobaths) from the entrance of New York Harbor south to Delaware Bay five times a year (January, April, June, August and October). There are 15 strata – 5 strata assigned to 3 different depth regimes (inshore – 3 to 5 fathoms, mid-shore – 5 to 10 fathoms, and offshore – 10 to 15 fathoms). Station allocation and location is random and stratified by strata size. The total weight (kg) of each species is measured and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm.

The average area swept per tow ( $\text{km}^2$ ) was derived from the trawl mouth opening (wing spread x vertical opening) and the average distance covered per trawl. We then determined the average total area swept by season (**season 1** – 1 survey cruise and 30 stations, **season 2** – 2 survey cruises and 80 stations, **season 3** – 1 survey cruise and 40 stations, **season 4** – 1 survey cruise

and 40 stations) and determined the multiplying factor (area swept per season / total survey area) to develop estimates of absolute abundance and biomass. We developed a yearly, weighted (by stratum size) CPUE index (by number and biomass per tow) by season, and then multiplied that value by the number of tows within the season to determine the average total abundance or biomass caught for the season. By multiplying that value by the multiplying factor, we developed estimates of absolute abundance or biomass (mt) for that year and season. Using the mean biomass estimate for the time series (1989-2004), the total seasonal biomass estimate along the New Jersey coast was derived.

The seasonal biomass estimates and seasonal trends for bay anchovy off the New Jersey coast are different than those for Chesapeake Bay (Figure D.19). Anchovy biomass along the coast increases throughout the year and reaches its peak biomass in the fall as anchovies begin to move out of the estuaries and into the coastal waters.

#### 2.5.6.4 Estuary Time Series Index

Data from the New Jersey Department of Environmental Protection (NJ DEP) Delaware River seine survey, Virginia Institute of Marine Science (VIMS) trawl survey, VIMS seine survey, Maryland Department of Natural Resources seine survey, Maryland DNR coastal bay seine survey and Delaware Department of Natural Resources and Environmental Control Delaware Bay juvenile trawl survey were used to develop a yearly *estuary* bay anchovy index. We first developed separate Chesapeake Bay and Delaware Bay indices using the appropriate surveys. We z-transformed (+ 2) the annual CPUE indices in order to normalize and standardize the data. The Chesapeake Bay indices are highly correlated and all surveys show a clear decline in anchovy abundance (Figure D.20); the Delaware Bay indices are not correlated and are much more variable and neither survey shows a clear trend in abundance (Figure D.21). To create one index for the Chesapeake Bay, we weighted the surveys according to length of time series, number of samples, and the spatial and temporal range of the survey – the surveys had the following weighting factors: VIMS seine – 0.3, VIMS trawl – 0.3, MD DNR seine – 0.3 and MD DNR coastal bay – 0.1. The same procedure was followed to develop the Delaware Bay index, with both surveys assigned a weighting factor of 0.5. In order to combine the two surveys into one grand estuary index that would be applied to other estuary waters along the Atlantic coast, we re-weighted the two surveys in reference to each other by their total area (km<sup>2</sup>) – Chesapeake index weighting, 0.788 and Delaware index, 0.212. Figure D.22 shows the combined Chesapeake Bay index, the combined Delaware Bay index and the combined *estuary* index.

#### 2.5.6.5 Coastal Time Series Index

Data from the NJ OTS and the Southeast Area Monitoring and Assessment Program (SEAMAP) survey were used to develop the yearly *coastal* bay anchovy index. As with the estuary indices to normalize and standardize the surveys, we z-transformed (+3) the annual CPUE values. The surveys were not significantly correlated but both show a decrease in anchovy abundance over the course of the time series – NJ OTS 1989 – 2004, SEAMAP 1990 – 2004 (Figure D.23). In order to combine the two indices and develop one coast wide annual index, we weighted each z-transformed index. Weighting factors were estimated by comparing the survey area sampled, time series length, number of samples collected and the temporal range of the surveys. For this

case both the NJ OTS and the SEAMAP survey were assigned a weighting factor of 0.5. Those values were then added to derive the single annual *coastal* index value (Figure D.23).

#### 2.5.6.6 Time series of Seasonal Density and Biomass Estimates

Estuaries: The seasonal estuary biomass estimates developed by Rilling and Houde (1999) were determined from data collected in 1993. Since we developed a single seasonal biomass estimate, we used 1993 as the ‘reference year’ and scaled the annual (1982 – 2002) estuary indices to the 1993 index to determine the annual seasonal biomass estimates. We first determined the annual seasonal densities (biomass km<sup>-2</sup>) for each of the estuaries along the coast – Buzzards Bay, Long Island Sound, Hudson River Estuary, Delaware Bay, Chesapeake Bay, Neuse River and Pamlico Sound (GIS tools were used to determine estuary and coastal water area – km<sup>2</sup>). We assumed the density inside Chesapeake Bay is similar to that in other estuaries, but applied the appropriate scaled index value to the appropriate estuary to develop the season densities (ex. formula: {season biomass \* scaled index value} / area). The calculated seasonal densities were then multiplied by the respective estuaries total area (km<sup>2</sup>) to determine the annual seasonal biomass estimates for each estuary. We then summed all of the individual estuary estimates to determine the total estuary bay anchovy biomass.

Coast: A similar procedure was followed with the coastal estimates. For consistency with the estuary estimates, we scaled the annual coastal estimates to the 1993 reference year to determine the annual seasonal biomass estimates (Note: from 1982 through 1988, coastal biomass estimates are constant and are equivalent to the 1993 reference year because the coastal surveys used in this analysis began in 1989). We determined the annual seasonal densities (biomass km<sup>-2</sup>) for the New Jersey coast and the remaining coastal waters (out to 10 nautical miles from shore) and assumed the density along the Jersey coast was similar to that along other parts of the coast and applied the appropriate scaled index value to develop the seasonal densities. As with the estuarine estimates, the calculated densities were multiplied by the corresponding coastal total area and then all of the coastal areas were summed to get the total coastal bay anchovy biomass.

The total estuary and coastal estimates were then summed to develop the overall annual seasonal bay anchovy biomass (Table D.20).

The length-frequency of bay anchovy is summarized in Newberger and Houde (1995) and length-frequency data from the New Jersey Ocean Trawl Survey show a similar size range.

## 2.6 DIET SELECTIVITY INDICES

The selectivity model used in the MSVPA-X relies upon a rank index for prey type preference. These indices are derived from summaries of available diet composition data when they are available. For the predators considered here, there are multiple diet studies published in the literature; however, these are generally smaller scale studies focusing on particular places, seasons, and time periods. The most spatially and temporally comprehensive data set for all three species is the Northeast Fisheries Science Center Food Habits database. However, this survey is limited to the coastal (i.e., non-estuarine) waters, is only available during spring and fall, and generally does not have large sample sizes for older fish. For each species, there are additional

regional studies that provide diet information for estuarine waters and/or other times of the year. A compilation of regional studies and NEFSC Food Habits database was used to develop overall rank indices of type preference for each predator species and age class.

The strategy used to develop type indices for each predator is outlined as follows:

- 1) For each region, summarize available data to develop an average diet for each season and age class.
- 2) Calculate the seasonal biomass of each prey type in the region based upon the estimated biomass and spatial distribution of each prey type (used in the spatial overlap analyses).
- 3) Calculate a quantitative electivity index as the ratio between the proportion of the prey in the diet versus the proportion of the prey biomass, and normalize so that these electivity values sum to one. This is equivalent to calculating Chesson's electivity index.
- 4) For each predator age and prey type, calculate the average of this quantitative index weighting by the proportion of the predator biomass in each region. Thus, the average selectivity will therefore reflect data from the region(s) containing the majority of each predator's biomass.
- 5) Rank the resulting overall values, and use these as the rank type-preference index in the model. The rank indices reduce the effects of poor estimation of biomasses in each region that may result in biases in the quantitative indices.

As an example of the data used to derive these indices, we present the diet information for striped bass from Chesapeake Bay. There are a number of primary sources of diet information in the published literature for striped bass (Table D.21) encompassing all of the regions, age classes, and seasons used in the current application. For early age classes of striped bass, the most comprehensive available data set is from Hartman and Brandt (1995). This study includes fish sampled across most of the Chesapeake Bay including the main-stem and tributaries. Samples were collected during the early 1990s and across most months. The seasonal diet compositions used for age classes 0, 1-2, and 3-5 based upon this study are shown in Figure D.24. Generally, age-0 fish fed primarily upon benthic invertebrates during the early part of the year and anchovies and macrozooplankton during the later part of the year. Age 1-2 and 3-5 fish were more piscivorous, and their diets were dominated by menhaden except for season 2 when sciaenids were more important (Figure D.24a).

The samples collected in Hartman and Brandt (1995) did not include older age classes. Therefore, diet information for older fish was taken from Walter and Austin (2003) using samples collected during 2000-2001 across most of the Chesapeake Bay and most seasons. The seasonal patterns for both age groups are similar with medium forage fish (made up primarily of *Alosa* spp.) comprising the majority of the large fish diets during the early part of the year and menhaden and sciaenids during the later part of the year (Figure D.25). Benthic crustaceans (primarily blue crabs) were also an important component of the diet for age 6-7 fish during the spring (Figure D.25a).

The proportion of total biomass in the Chesapeake Bay by prey type is shown in Figure D.26. These seasonal values are derived from information on the seasonal spatial distribution of each taxon and the estimated total biomass of each. It is important to note that the “medium forage fish” category does not well represent the biomass of that prey type in the Chesapeake Bay since biomass estimates for *Alosa* spp. and other small fish were not available. Based upon the available data, anchovies represent the majority of the prey biomass in the Chesapeake Bay in all seasons.

Quantitative values for Chesson’s electivity index were calculated as the ratio between the proportion of each prey in the diet and the proportion of total prey biomass in the region. The seasonal values for each striped bass age class and prey type are shown in Table D.22. A similar analysis was conducted for all other regions using the data sources listed in Table D.21. These quantitative scores were then averaged across regions and seasons weighed by the biomass of each age class of striped bass. These averages were ranked to provide the indices input into the MSVPA-X application shown in Table D.23.

In contrast to striped bass, there are very few references for regional and seasonal diet composition for weakfish. Hartman and Brandt (1995) is the primary data source for the Chesapeake Bay, while diet information for the remainder of the study is limited to the Northeast Fisheries Science Center Food Habits database (Table D.24). Based upon this somewhat incomplete picture of weakfish diets, the resulting type preference ranks are shown in Table D.25.

The primary data source for bluefish diets is also Hartman and Brandt (1995) for the Chesapeake Bay and the NEFSC food habits database for larger fish in the remaining regions (Table D.26). The NEFSC food habits data are also described in Buckel *et al.* (1999). There are a number of additional studies (Buckel *et al.*, 1999, Juanes *et al.*, 2001, Buckel and Conover, 1992), primarily in the New England region, examining the diets of age-0 bluefish and these were also incorporated into the current analysis. The resulting type preference ranks are shown in Table D.27.

## 2.7 SPATIAL OVERLAP INDICES

### 2.7.1 Model Spatial Domain

While the MSVPA-X model is not fully spatially explicit, it is necessary to define a spatial domain and strata at regional scales to evaluate seasonal spatial overlap between predators and prey. The spatial resolution of these strata is primarily limited by available data on the spatial distribution of the species included in the model. Ideally, a broad scale scientific survey would capture all predator and prey species at a relatively high spatial resolution. However, this is rarely the case, and in particular spatial data on invertebrate and small fish prey are typically limited.

The spatial domain for the current model application was developed based upon the known spatial distribution of the four primary species. Five regional strata were defined (Figure D.27,

Table D.28) ranging from North Carolina to the Gulf of Maine. The offshore extent of the model was defined as 20 nautical miles from shore for coastal strata. Georges Bank (defined by the 200m isobath) was included in the Gulf of Maine (GM) stratum. These strata areas are used to expand the densities of invertebrate and other prey to total biomass. In the case of data from the NMFS bottom trawl survey, stations were assigned to strata based upon their reported latitude and longitude locations.

Commercial and recreational landings data were used to evaluate the spatial distribution of several species. While landings data are subject to several biases, there is no comprehensive regional survey providing spatial distribution data for the larger predators. The NMFS bottom trawl survey provides some data; however, it is inefficient at catching these larger more pelagic predators, does not sample nearshore waters, and does not include sampling in Chesapeake Bay. The bottom trawl survey is also limited to primarily the fall and spring seasons. Landings data therefore provide the best available measure of the relative spatial distribution of the predators included in this model.

Landings data were matched to the regional strata based upon the reported state (Table D.28). Landings data were downloaded for the period from 1982-2002 (where available) from the NMFS website (<http://www.st.nmfs.gov/st1/commercial/index.html>) by state, month, and area (inland versus offshore). For the recreational (MRFSS) data, the two-month “waves” were divided evenly into monthly landings so as to define the seasonal totals. For Virginia and Maryland, nearly all commercial and recreational landings are from the Chesapeake Bay region. The total landings were thus calculated for each season and region

The spatial distribution of each taxon was evaluated on a seasonal basis using landings, survey, or regional density data as appropriate. These relative spatial distributions were then used to calculate the seasonal spatial overlap (using Schoener’s index) between each predator age class and each prey species.

### 2.7.2 Striped Bass

The seasonal spatial distribution of striped bass based on landings data is shown in Figure D.28. During the winter months (season 1), striped bass is concentrated in the southern portion of the range, particularly in North Carolina and Chesapeake Bay. During spring, the landings increased in the northern portion of the area, and this trend continued through season 3 where the majority of landings are concentrated in the New England and Gulf of Maine strata. During the fall months, the landings were highest in the mid-Atlantic and Chesapeake Bay regions as the stock moves south (Figure D.28). These spatial patterns in the total biomass were converted into age-specific spatial distribution based upon the observed age-structure of the catch within each region (Figure D.29).

### 2.7.3 Weakfish

Weakfish seasonal distribution patterns were similar to those observed for striped bass; however, weakfish did not occur as far north during the spring and summer (Figure D.30). In the winter, weakfish landings primarily occurred in the North Carolina region. The weakfish stock

progressed north during the spring and summer with landings concentrated in the mid-Atlantic region, and occurring in the Gulf of Maine area only during the summer months. During fall, the stock again moved south and was concentrated in the mid-Atlantic and Chesapeake Bay areas. The regional age structure of the catch is shown in Figure D.31 and was used to calculate age-specific seasonal spatial distribution of the stock.

#### 2.7.4 Bluefish

The spatial distribution of the bluefish stock showed a similar seasonal progression to that of the other predator species (Figure D.32). During the winter, the landings were concentrated in the North Carolina and mid-Atlantic regions. Landings increased in the northern regions during spring. In summer and fall, the landings were highest in the southern New England stratum. Unlike weakfish and striped bass, there are no available data on the regional age structure from commercial landings; therefore, the spatial distribution of different size classes used were derived from the NMFS bottom trawl survey. The spring bottom trawl survey was used as the proxy for the winter and spring seasons while the fall survey was used for the summer and fall. The relative mean catch per tow in each region for each season (Figure D.33) was used to calculate the seasonal spatial distribution of each size class.

#### 2.7.5 Menhaden

The seasonal spatial distribution of Atlantic menhaden was derived from the time series of purse seine landings. The relative distribution of landings of ages 0-2 menhaden were used since this size range is the primary component of predator diets. Menhaden landings occurred exclusively in the North Carolina region during winter months. During spring, landings were concentrated in the mid-Atlantic region and southern New England. In the summer, landings are concentrated in the Chesapeake Bay and then again in the North Carolina and Chesapeake Bay in the fall (Figure D.34).

#### 2.7.6 Other Fish Prey

For medium forage fish (primarily butterfish and squid) and herrings (primarily Atlantic herring), seasonal spatial distribution was derived from the mean catch per tow in each region from NMFS bottom trawl survey data. Since the survey does not sample inside the Chesapeake Bay, stations from offshore waters of Virginia and Maryland were used as a proxy. The spring survey was used as a proxy for seasons 1 and 2, and the fall survey for seasons 3 and 4. The relative distribution of medium forage species was highest in the North Carolina and Gulf of Maine regions during the colder seasons (Seasons 1 and 2), and highest in the Gulf of Maine for summer and fall (Figure D.35a). The herrings were distributed throughout the region during the colder months, but were highest in the Gulf of Maine. In the warmer months, nearly all of the clupeid biomass was in the Gulf of Maine region (Figure D.35b).

The spatial distribution of the sciaenids (croaker and spot) was derived from commercial landings data, similar to the approach used for the predator species. Sciaenid landings were concentrated in the North Carolina region during the winter, then further north in the Chesapeake



Bay region during spring and summer, and again in North Carolina during the fall (Figure D.35c).

#### 2.7.7 Anchovy and Invertebrate Prey

For the remaining other prey there was no seasonal data on spatial distribution available. Therefore, the regional spatial distributions are constant across seasons. For the benthic invertebrates, crustaceans, and macrozooplankton the relative spatial distribution is based upon the regional densities used to develop biomass estimates (see Section 2.5, Figure D.36). For anchovy, there is no coast wide measure of relative abundance. Therefore, arbitrary values were used centering the majority of the biomass in the North Carolina and Chesapeake Bay regions (Figure D.36).

#### 2.7.8 Spatial Overlap Indices

The seasonal and age-specific relative distribution of biomasses was used to calculate spatial overlap values for each predator age class and prey type. These values are input into the MSVPA-X model as a component of the feeding selectivity equations (Tables D.29-D.31).

## CHAPTER 3: MODEL PERFORMANCE AND SENSITIVITY ANALYSES

### 3.0 SUMMARY

The information below summarizes the base run configuration of the MSVPA-X that was used to evaluate model performance and sensitivity for the ‘retrospective’ MSVPA-X (See Sections 3.1 and 3.2). Section 3.3 reviews the set-up of the MSVPA-X forecast module. The results of the base run for the retrospective MSVPA-X are presented in Section 3.4. The sensitivity of the MSVPA-X to changes in input is presented in this Appendix (D1). Several analyses were conducted to evaluate the sensitivity of the MSVPA-X to changes in input parameters. Specifically, sensitivity of the model to changes in M1, prey type selectivity, prey size selectivity, predator weight-at-age, gastric evacuation rate parameters, predator and prey spatial overlap, and the addition and deletion of ‘other prey’ items are presented. An examination into the retrospective bias of the model in terminal year estimates is presented. A test of the forecast model is also presented that investigates the ability of MSVPA-X to reproduce past observations.

### 3.1 SINGLE-SPECIES CONFIGURATIONS

The following table details the MSVPA-X input data for each species (i.e., Atlantic menhaden, striped bass, weakfish, and bluefish) for the model’s base run configuration. The input data can also be reviewed in the MSVPA-X executable by opening the project file “BaseRun\_07Sept\_05.prj” and then opening “Open Species” listed in the options under File. Note that the options for bluefish are limited to feeding (consumption and prey size-selectivity parameters, as well as, the proportion of biomass in each size class) and biomass (time series of biomass estimates from the single-species assessment), as it is currently modeled as a “biomass predator”. The data input for explicitly modeled species includes catch-at-age, weight-at-age, size-at-age, maturity, and options regarding the single-species virtual population analysis. Feeding parameters (consumption and prey size-selectivity) for explicitly modeled species are entered under the MSVPA configuration (Section 3.2).

	Menhaden	Striped Bass	Weakfish	Bluefish
Catch-at-age	Stock Ass.	Stock Ass.	Stock Ass.	NA**
Weight-at-age	5 yr avg.	Constant	Constant	NA
Size-at-age	5 yr avg.	Constant	Constant	NA
Maturity schedule				
Age-0	0.00	0.00	0.00	
Age-1	0.00	0.00	0.90	
Age-2	0.118	0.00	1.00	
Age-3	0.864	0.00	1.00	
Age-4	1.00	0.04	1.00	
Age-5	1.00	0.13	1.00	
Age-6*	1.00	0.45	1.00	
Age-7	NA	0.89	NA	
Age-8	NA	0.94	NA	
Age-9 – 13+	NA	1.00	NA	

Single-species VPA Configuration	XSA	XSA	XSA
Apply shrinkage to the mean	Yes	Yes	Yes
CV for shrinkage mean	0.50	0.70	0.70
Number of years for shrinkage mean	4	3	3
Number of ages for shrinkage mean	3	3	2
Down weight early years	Yes	Yes	Yes
Weighting method	Tricubic	Tricubic	Tricubic
Earliest year for weighting	1982	1982	1982
M1	0.40	0.15	0.25
M2	0.00	0.00	0.00
Age-specific Natural Mortality Rates	No	No	No

\* indicates the plus group for menhaden and weakfish (age-6).

\*\* data for bluefish biomass time series is from the stock assessment (Lee, 2003); for details on bluefish feeding parameter data, see Table D.32.

### 3.2 MSVPA-X CONFIGURATION

This section details the steps and information used to configure the MSVPA-X for the base run. The MSVPA-X configuration process allows the model user to define the predator species (“Full MSVPA” or “Biomass Predator”) and prey species (“Full MSVPA”), the time frame and seasonality, add “Other Prey” species, prey type and preference of predators, predator-prey spatial overlap, predator consumption rates, predator seasonal gut fullness, and the type of single-species VPA used for each species. The following subsections provide the examples of the information used in the base run MSVPA configuration. Full details of the input data can be reviewed in the MSVPA-X executable by opening the project file “BaseRun\_07Sept\_05.prj” and then opening “Open MSVPA” listed in the options under File and navigating through the set-up options.

#### 3.2.1 New MSVPA Configuration

Full MSVPA Species	Striped bass, weakfish
Prey only MSVPA Species	Menhaden
Biomass Predator	Bluefish

#### 3.2.2 Enter time frame for MSVPA

Years	1982-2002
Number of Seasons	4
Season 1 Length (days)	92
Season 2 Length (days)	91
Season 3 Length (days)	91

Season 4 Length (days)	91
Seasonal Spatial Overlap	Yes
Model Predator Growth	No
Annual Temperature Variation	Yes (Table D.33)

### 3.2.3 Enter Other Prey Data

See Chapter 2 for full descriptions on methods and data used for each “other prey” species or group (anchovy, benthic crustaceans, benthic invertebrates, clupeids, macrozooplankton, medium forage fish, and sciaenids). The minimum and maximum size and parameters for each “Other Prey” item are listed in Table D.34. Biomass estimates for each “other prey” species by year and season are entered in this field.

### 3.2.4 Enter Prey Preferences

Prey preferences for each predator, by age, are entered in this field using the quantitative ranking methodology covered in Section 2.6. Predators cannot eat one another nor is there cannibalism, so, for each predator, the other predators are given a preference of 0 and the preferred prey item gets a ranking of 1. Ties in preference are entered as an average of the tied rank positions (e.g., if sciaenids and menhaden were tied for third in prey type preference, they would each receive a ranking of 3.5 which is the average of the third and fourth positions occupied in the matrix). Table D.35 contains the quantitative prey preference ranks for weakfish by age.

### 3.2.5 Enter Spatial Overlap Data

This field allows the user to define the seasonal spatial overlap between predators and prey. Again, since predators cannot eat one another and there is no cannibalism, each predator is given a rank of 0. See Section 2.7 for further details on the methods used to develop the quantitative spatial overlap indices. Table D.36 contains the quantitative spatial overlap rankings during season 1 for weakfish by age.

### 3.2.6 Enter Size Preference and Consumption Parameters

The parameters for prey size preference and consumption of each predator are entered in this field (Table D.37). For striped bass, parameters are entered for three age ranges (0-4, 5-9, and 10-13+), but for weakfish and bluefish age aggregated parameters are used. If higher resolution data were available then it would be possible to have age-specific values for each predator.

### 3.2.7 Enter Seasonal Mean Gut Fullness

In this field, mean gut fullness is entered for each predator by age or size class.

### 3.2.8 Select SSVPA for each species

For this configuration, the type of VPA used for each species (menhaden, striped bass and weakfish) was the XSA.

### 3.3 FORECAST MODULE

This section reviews the base configuration for the forecast module of the MSVPA-X. To run the forecast module, the ‘retrospective’ MSVPA-X configuration on which the forecast will be based must be selected. Then the user can select the year to start the projection and number of years to run the forecast module. Additional required inputs include von Bertalanffy parameters, length and weight relationships, and stock-recruitment relationships for each of the explicitly modeled species. Options for implementing the forecast module include: selecting fishery removal methods (catch versus fishing mortality), variable fishing mortality, other predator biomass, other prey biomass, and recruitment success. Each scenario can be saved. The MSVPA-X Assessment Subcommittee cautions against projections of greater than five years, as long-term projections are constrained to the stock-recruitment relationship of short-lived prey species.

#### 3.3.1 Configure a Forecast Model

This entry screen allows the user to enter a name for the forecast and select an MSVPA configuration, the initial year of forecast, the number of years forecasted, and whether or not to model predator growth based on prey availability.

#### 3.3.2 Enter von Bertalanffy Parameters

Parameters for the von Bertalanffy growth curve and the length-weight relationship for each explicitly modeled species are entered in this screen.

#### 3.3.3 Stock-Recruit Parameters

Spawning stock biomass and recruit abundance data are entered for each explicitly modeled species for each year of the ‘retrospective’ MSVPA-X analysis. The user can select among the Ricker, Beverton-Holt, random from quartiles, and the Shepherd flexible methods to determine the stock-recruitment relationship for each species in the forecast.

#### 3.3.4 Configure Forecast Scenarios

This is the final input screen before executing the forecast run. The user selects the method for modeling fishery removals, either catch limits in numbers or fishing mortality rate. The user can also opt to enter variable fishing mortality rates, other predator biomass, other prey biomass, and recruitment success.

### 3.4 BASE RUN RESULTS

#### 3.4.1 Population sizes

The results of the MSPA-X Base run for explicitly modeled predators are given in Figures D.37 (total biomass) and D.38 (SSB). Biomass by size class for bluefish, the biomass input predator, is given in Figure D.40. Total biomass and SSB of striped bass increases over the time series.

Weakfish experience fluctuations in total biomass, but a general increasing trend in SSB is noted. It is notable that weakfish results from this iteration of the MSVPA-X differ from the most recent single-species assessment (See Chapter 2). Bluefish population biomass exhibits high abundance early in the time series (1982 – 1988), declines throughout much of the 1990s, followed by an increase in stock size in the last 3 – 4 years.

The only explicitly modeled prey species in this iteration is menhaden. Abundance and biomass trends are shown in Figures D.40 and D.41. Total abundance and abundance at maturity (age-2+) decline, although overall SSB has remained stable yet somewhat variable (Figure D.41). This can be explained in part by an increase in weight-at-age for menhaden (ASMFC, 2004a).

Menhaden total biomass is expressed in relation to other important prey items in Figure D.42. While menhaden and anchovy biomass decline, biomass estimates of other prey species are either stable (medium forage fish and sciaenids) or dramatically increasing (clupeids). The dramatic increase in clupeid biomass is in part due to the increase of Atlantic herring. Estimated current stock size for this stock is given elsewhere; but is thought to be approximately  $1.8 \times 10^6$  mt SSB (Overholtz *et al.*, 2003). The increase in this stock has implications for both consumption by prey type and location (discussed below). It should be recognized that with the exception of menhaden, prey items in this iteration of the MSVPA are included as biomass inputs and are not explicitly modeled.

### 3.4.2 Diet composition

Average predicted diet compositions, across the available time series and seasons, are given for striped bass, weakfish, and bluefish (Figures D.43-D.45 respectively) by age (or size). In general, all predators are predicted to feed mainly on macrozooplankton and benthic invertebrates at younger ages or size classes. The diet composition for intermediate ages shifts to dominance by medium forage fish and anchovies. At older age classes, clupeids and menhaden dominate as many predators become more piscivorous.

One exception to the overall trend above is the prevalence of benthic crustaceans in the diet of striped bass at intermediate ages (ages 5-8). Nelson *et al.* (2003) suggest that as striped bass age, they tend to move farther north during the summer feeding period. Given this change in behavior and the lack of smaller menhaden in the prey field in this area, it is not unreasonable that striped bass in northern areas are predicted to feed more on benthic food sources than on menhaden and clupeids. At the oldest age classes (9-13+), however, type preferences apparently overcome availability, as clupeids tend to dominate the diet for the oldest striped bass. A similar result is seen in bluefish, but is lacking for weakfish; an expected result given that weakfish do not migrate as far north as the other predators.

### 3.4.3 Consumption and prey availabilities

Estimates of modeled consumption expressed as total biomass, for each important prey item by year are given in Figures D.46-D.48 for striped bass, weakfish, and bluefish (respectively). Striped bass increased consumption of all prey items during the time series, an expected result given their increasing abundance. Recent results suggest a decrease in benthic invertebrate

consumption, which is attributed to expansion of the striped bass population to older ages (Figure D.46; comments in section 3.4.1 above). Recent increases in consumption of both clupeids and menhaden may be the result of the expanding in age structure seen in striped bass.

Weakfish consumption exhibits no overall trend. Consumption of menhaden, benthic invertebrates, and anchovies is highly variable, but may show signs of recent increases in consumption by this stock.

Estimated consumption of fish prey by bluefish increases over time, particularly for the clupeids. While menhaden consumption is well below historical levels, clupeid consumption is at a historic high. The MSVPA-X Assessment Subcommittee suggests that this consumption rate may be the product of strong overlap between bluefish and clupeids in Northern areas and the recent increase in clupeid availability, and therefore cautions that clupeid consumption may be overestimated.

For explicitly modeled species, food availability can be tied to both natural mortality and growth rates in future iterations of the MSVPA-X; however, such is not possible at this time without additional data on the relationship between food availability and survivability of the explicitly modeled predator species. Overall, the prey available to striped bass has remained fairly constant across the temporal framework for the MSVPA-X (Figure D.49). The relative food availability for weakfish declines in relation to the decline in availability of their major prey, menhaden (Figure D.50).

#### 3.4.4 Menhaden Predation mortality (M2)

Menhaden exhibit significant changes in predation mortality by age (Figure D.51-D.54). Age-0 menhaden M2 fluctuated, but it generally increases over time as the weakfish population increases. Likewise, M2 on age-1, 2, and 3 menhaden increases as predation by both striped bass and bluefish increases, as a result of both changes in the size- and age-structure of these predators and potential overlap with menhaden in recent years.

Overall, these results suggest that predation mortality increases as predator stocks rebound. This increase is not limited to younger age classes, as it extends to older menhaden than previously assumed. However, the scale of the graphs presented cannot be ignored. It should be recognized that size-at-age drives these interactions. For example, declining predator growth and an increase in prey size-at-age will dramatically affect the outcomes of this iteration. Overall, the M2 by included predators are mostly affecting age-0 to age-2 menhaden. For menhaden above age-2, M2 appears inconsequential.

## CHAPTER 4: MODEL UTILITY FOR MANAGEMENT PURPOSES

Within the past few years many stakeholder groups, government officials, and scientists have called for an ecosystem approach to fisheries management on both the local and federal level. However, while managers have traditionally relied on analytical methods to help them make informed choices, few analytical tools are available to evaluate decisions at the ecosystem level. This MSVPA-X model was conceived to provide support to decision makers to enable them to make informed decisions in a multispecies context. This analysis is similar to most models used in fishery science in that it relies on past performance. The committee suggests that this iteration of the MSVPA-X has management utility while providing important caveats in interpretation.

The committee notes that this model is not designed for setting reference points or harvest limits for single-species. Additionally, the model intentionally encompasses a broad geographic range and therefore examination of local abundance or depletion is not possible. The MSVPA-X was conceived, in part, to provide accessory information and not to replace the single-species assessments already in place. Moreover, this formulation employs the XSA method for ease of calculation. Although every effort is made to develop configurations that reflect the single-species assessment results, results for individual species in the MSVPA-X framework may not correspond exactly to the outputs from the single-species assessments as peer reviewed.

The MSVPA-X, in principle, may examine prey availability and then tie that availability to both growth rates and its effects on the predator species by age class. However, until survivability of any given year-class, or predator stock, is examined relative to prey availability, such calculations are not possible. Further, the effects of prey availability on growth and recruitment of the predator species have been left out of the base run, so that this review examines the interactions among predators and prey without the confounding effect of predator growth.

As mentioned earlier, the MSVPA-X includes a forecast module that provides modelers the unique ability to explore the potential effects of various recruitment success, fishing patterns or pressure, and the availability of “other prey” items on the changes in stock size and dynamics of explicitly modeled species. Example projection scenarios provided here utilize “status quo” fishing mortality rates for fully modeled predator and prey stocks. Fishing mortality, stock size of “other” prey items, and their availability to the predators are all fixed in time and space by the user and are not part of the dynamic model structure. Any projections are subjected to the limitations of the recruited prey species. While longer-term projections are desirable to examine management objectives for longer-lived predator stocks, this iteration relies on the modeled recruitment. Therefore, it is subject to the limitations of our ability to predict recruitment for the explicit prey and predator species, and our abilities in this area are admittedly poor for various reasons. Due to their short life spans and environmentally driven recruitment, forage species may depart radically from their predicted population sizes making long-term predictions highly variable. Moreover, such departures could cascade to affect prey population sizes by season and, consequently affect growth and recruitment of the predator stocks. This, in turn, may affect prey availability for all predator species.



It is made clear that while the “other prey” items are included in this iteration of the MSVPA-X, and represent the best estimates available, they are not explicitly modeled and are instead primarily inputs into this analysis. Further, they are grouped by “type” to reflect guild functions within the prey field and in their respective ecosystems. Consequently, model outputs defining consumption of these should be used with caution. Resulting population sizes of these “other prey” items in this analysis should not be used for management. Decision makers are pointed to the single-species assessments, where available, for the “other prey” items instead.

With that said, the model has the potential to improve assessments in single-species assessments by suggesting the natural mortality rate at age (or by year, as appropriate) for explicitly modeled prey species. This has already been accomplished for menhaden in the 2003 assessment (ASMFC, 2004a). An earlier iteration of MSVPA-X produced the estimates of menhaden natural mortality at age; however, menhaden population size was estimated using a separate single-species assessment model and overall natural mortality was specified within that single-species assessment.

Additionally, decision makers can be shown potential impacts of fishing and predation mortality by age class for explicitly modeled prey. Such an analysis may suggest optimum harvest strategies for both predators and prey when fisheries for both exist and are managed under the same body. Further analyses may allow for the management of prey using total mortality, rather than fishing mortality. The model may also provide insight on multiple species target biomass based on trade offs among predators and prey. The model may provide additional guidance for rebuilding predator stocks by allowing the investigation of the interactions of specific predator biomass targets and the availability of prey species for other modeled predator stocks should that target be realized.

The seasonal resolution in this model may provide an insight as to when an explicitly modeled prey stock could be important for a given predator. MSVPA may pinpoint specific seasons when particular prey items are important for particular predators and how different predators may affect each other. However, seasonal importance is primarily defined by the modeler by specifying spatial overlap and type preference. Indirect interactions between predators can be examined primarily in the forecasting module that is also derived seasonally.

MSVPA-X may help decision makers determine appropriate size and bag limits for a given predator species. The model indicates that changing a predator’s age structure may affect prey species under certain régimes. Changes in bag limits and selectivities for a predator species may therefore affect prey availability, consumption, and prey availability for other species. Such analyses will require further modeling outside of the MSVPA-X, but are not inconceivable.

Competition and cannibalism are not explicitly modeled within this iteration of the MSVPA-X; these components can be incorporated explicitly at a later date. Nonetheless, competition is implied within the MSVPA. Changes in a predator’s total consumption can affect availability of that prey to other predators. Such changes may become more pronounced if competition and cannibalism are introduced. While growth of the predator stocks based on prey availability was not investigated in the presented analysis, the model does provide an option to perform this function.

The projection portion of the MSVPA-X provides ample opportunities to explore many different scenarios, which may be useful in both the moderate and long-term. While the committee cautions against the use of long-term projections using this iteration, even short-term projections have the capability to enhance management decisions. Changes in predator stock sizes and age structure, changes in prey recruitment success or failure, changes in management for both predators and prey, and changes in spatial and temporal overlap among modeled stocks can now be examined using an analytical approach. Moreover, such changes can be examined in light of both predators and prey.

Based on thorough review and testing of the MSVPA –X model, the committee suggests that this formulation is capable of answering management questions about predator-prey interactions among explicitly modeled species. With clear understanding the MSVPA-X’s abilities and limitations described above, the MSVPA-X approach has the potential to provide much accessory information for fisheries managers.

## CHAPTER 5: ASMFC RESEARCH RECOMMENDATIONS

### 5.0 SINGLE-SPECIES ASSESSMENTS

As the MSVPA assessment depends heavily on the quality of data from single-species stock assessments, completion of existing research recommendations for single-species assessments will improve the utility of the MSVPA-X (See Appendix D2. Single-species Research Recommendations). In future MSVPA-X assessments, the most recently updated and peer reviewed single-species stock assessments will be used in the MSVPA-X.

### 5.1 MULTISPECIES RECOMMENDATIONS FROM ASMFC INTERNAL PEER REVIEW

#### 5.1.1 Model Formulation

##### Short-term

These short-term research recommendations from the ASMFC Internal Review have been completed:

- Document how parameters are estimated within model with a flow chart to present the order of the estimation process.
- Add option to permit partitioning of biomass (vary size-structure of biomass predators) predators in forecast projections.
- Add option to input a recruitment vector in the forecast projection model.
- Add option to input catch as opposed to F into forecast projection model to simulate quota management approaches.

##### Long-term

The following long-term research recommendations from the MSVPA-X Internal Peer Review still remain:

- Add uncertainty to model forecast and incorporate elements of Monte Carlo simulations on recruitment curves.
- Alter biomass predator bin sizes for more flexible way to vary for projection model.
- Add ICA and production model options to retrospective.
- Develop a similar application to the “amoeba” program that allows the user to easily vary changes in model parameters.

#### 5.1.2 Data

##### Short-term research recommendations

Updated diet data were obtained from several of the sources cited in the MSVPA (pers. comm., Jeff Buckel, North Carolina State University; pers. comm., Anthony Overton, East Carolina University; pers. comm., Wilson Laney U.S. Fish and Wildlife Service; pers. comm., Chris

Bonzek Virginia Institute of Marine Science; pers. comm., Joe Smith, SEFSC); however, some of the data could be obtained or had not been updated from earlier compilation efforts.

New ‘Other Prey’ species were added to the model. The full suite of ‘Other Prey’ includes:

1. Sciaenids (spot, croaker)
2. Small Forage Fish (anchovy, silversides, and sand lance)
3. Medium Forage Fish (butterfish, squid, mullets)
4. Clupeids (Atlantic herring, thread herring, and others)
5. Benthic invertebrates (worms)
6. Benthic crustaceans (lobsters, blue crabs, jonah crabs, calico crabs)
7. Macrozooplankton (shrimps, mysids, amphipods)

A reasonable estimate of coast wide abundance could not be estimated for the *Alosa* spp. group and was not included in the “other prey” categories. A coast wide assessment of American shad is currently underway and may provide additional information that can be used to develop an abundance estimate. The shad assessment will be done on a river system specific basis and the quality of shad abundance data for Atlantic coast river systems is highly variable and may preclude development of a coast wide abundance estimate.

A coastal bay anchovy abundance estimate was developed using data from the New Jersey Ocean Trawl Survey along with a number of other fishery independent surveys – MD seine survey, MD coastal bay survey, VIMS seine and trawl surveys, DE trawl survey, NJ Delaware River seine survey and the SEAMAP survey.

New prey type selectivity ranks and spatial overlap indices were developed following quantitative algorithms.

#### Long-term

Two long-term recommendations from the ASMFC MSVPA-X Internal Review regarding data improvement have been addressed. Collection of diet data for adults of all three MSVPA-X predator species for the winter season off of Cape Hatteras, North Carolina has been initiated between the SEAMAP Cooperative Winter Tagging Cruise and VIMS Chesapeake Trophic Interaction Laboratory Services. In addition, an age-structured stock assessment model (ASAP) has been developed and peer reviewed for the coastwide bluefish stock (ASMFC, 2005).

The other long-term research recommendations remain:

- If not achieved before SARC review, add a bluefish age-structure/catch-at-age matrix.
- Adult index for menhaden (e.g., an aerial line transect survey) and other species.
- Obtain population weight-at-age estimates.
- Conduct a coast wide diet and abundance study (i.e., an Atlantic coast “year of the stomach”).
- Collect more diet data for all three MSVPA-X predator species along the entire Atlantic coast, especially for nearshore sites, during all seasons.
- Conduct stomach selectivity research for predator species to improve prey ranking matrix.
- Encourage existing fishery-independent surveys to take regular gut contents.

- Evaluate if striped bass disease (mycobacteria) is correlated with natural mortality (M1) and food availability or if disease is disrupting striped bass feeding and causing starvation. The panel noted that if disease affects striped bass feeding in recent years, then using historical striped bass diet data might bias striped bass consumption in the model output.
- Estimate carrying capacity for the system to evaluate what model estimates/suggests for carrying capacity.
- Improve estimates of biomass for prey species on coast wide basis.
- Conduct a parallel comparison with ICES MSVPA model on a system that has the necessary data collected (Georges Bank or the North Sea) to identify the differences in results.
- Explore the ability to add other predators to model (birds, mammals, other fish, other systems).
- Explore the utility of implementing the Williamson spatial overlap index in the model.
- Investigate type II and type III feeding responses of the MSPVPA-X species in field studies.

### 5.1.3 Recommendations for Base Run & Sensitivity Analyses

The recommendations from the MSVPA-X Internal Peer Review regarding the tasks to necessary to develop a base run, conduct sensitivity analyses in the retrospective model, and to test the forward projecting model were addressed and covered in detail earlier in this report (see Chapters 1, 2, and 3 for additional information).

### 5.1.4 Recommendations for Forecast Projection Module (Still under development)

- Determine the affect and sensitivity of the model to the removal of all fishing pressure from system
- Insert recovery benchmarks
- Explore options for adaptive management framework with stock-recruitment options

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## TABLES

Table D.1. Catch at age of Atlantic menhaden (millions) from 1982-2002. The period from 1985-2002 includes combined landings from the reduction and bait components of the fishery (ASMFC, 2004a).

Year	Age						
	0	1	2	3	4	5	6+
1982	114.1	919.4	1739.6	379.7	16.3	5.8	0.8
1983	964.4	517.2	2293.1	114.3	47.4	5.0	0.2
1984	1294.2	1024.2	892.1	271.5	50.3	15.2	0.5
1985	637.6	1088.7	1254.4	72.2	49.1	7.5	1.9
1986	98.7	237.0	1547.8	81.0	28.4	7.2	1.3
1987	43.2	518.4	1615.8	186.3	43.9	3.5	1.0
1988	339.2	297.7	1186.7	343.6	94.2	8.5	0.9
1989	150.1	1172.6	1194.0	141.3	64.0	13.0	0.5
1990	308.5	153.5	1589.4	141.7	59.2	13.6	0.7
1991	882.2	1051.9	982.0	294.1	59.3	12.3	2.5
1992	400.1	744.5	834.6	108.3	72.8	12.7	2.3
1993	68.3	391.4	1015.1	187.4	30.7	5.5	0.6
1994	88.8	289.1	911.0	194.6	86.9	10.4	0.4
1995	56.9	559.1	703.0	347.0	87.0	4.5	0.1
1996	33.8	211.8	716.5	159.3	34.0	2.2	0.1
1997	25.2	251.6	456.9	263.0	63.4	12.0	1.8
1998	75.4	189.2	578.5	157.2	96.1	13.0	1.5
1999	194.1	305.1	508.5	114.8	42.0	5.5	0.8
2000	78.1	127.4	399.7	133.2	21.9	3.3	0.3
2001	23.1	46.1	398.9	266.9	22.9	1.5	0.3
2002	178.2	216.5	296.6	179.9	26.5	1.4	0.2

Table D.2. Coastwide age-0 menhaden CPUE index in state seine surveys (ASMFC, 2004a).

	<b>Age</b>
<b>Year</b>	<b>0</b>
1982	5.005
1983	4.554
1984	5.189
1985	4.936
1986	4.962
1987	3.743
1988	4.774
1989	4.150
1990	4.298
1991	4.271
1992	3.285
1993	2.585
1994	3.118
1995	2.765
1996	2.572
1997	2.817
1998	2.938
1999	2.662
2000	2.308
2001	3.021
2002	2.481

Table D.3. Potomac River pound net CPUE indices for Atlantic menhaden. The aggregated biomass index (ASMFC, 2004a) was disaggregated by applying a selectivity curve (0.25 - age 1, 1.0 - age 2, 0.25- age 3) and converting catch in pounds to numbers based upon annual weight-at age-data.

Year	Age		
	1	2	3
1982	885.0	1773.8	270.9
1983	825.3	1550.1	237.7
1984	555.4	966.2	147.5
1985	574.7	976.5	147.7
1986	477.9	853.5	128.6
1987	780.2	1487.5	228.4
1988	822.8	1464.3	220.7
1989	386.3	772.6	120.5
1990	172.5	352.9	62.1
1991	223.9	477.7	81.9
1992	237.3	452.0	78.3
1993	336.7	743.4	131.4
1994	284.4	486.8	78.1
1995	248.8	443.3	75.5
1996	183.9	288.4	46.9
1997	202.4	347.0	55.8
1998	124.4	249.6	40.0
1999	158.9	292.4	46.9
2000	162.8	275.2	46.1
2001	78.4	163.2	29.1
2002	82.1	153.9	27.4

Table D.4. Size-at-age of Atlantic menhaden (mm) from 1982-2002 calculated from five-year averages of annual von Bertalanffy growth curve parameters (ASMFC, 2004a)

Year	Age						
	0	1	2	3	4	5	6
1982	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1983	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1984	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1985	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1986	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1987	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1988	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1989	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1990	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1991	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1992	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1993	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1994	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1995	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1996	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1997	66.51	163.94	227.16	268.19	294.81	312.09	323.30
1998	66.51	163.94	227.16	268.19	294.81	312.09	323.30
1999	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2000	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2001	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2002	66.51	163.94	227.16	268.19	294.81	312.09	323.30

Table D.5. Weight-at-age of Atlantic menhaden (g) from 1982-2002 calculated from five-year averages of annual length-weight regression parameters (ASMFC, 2004a)

Year	Age						
	0	1	2	3	4	5	6
1982	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1983	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1984	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1985	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1986	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1987	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1988	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1989	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1990	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1991	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1992	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1993	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1994	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1995	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1996	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1997	5.18	93.27	265.27	451.61	611.63	734.09	821.99
1998	5.18	93.27	265.27	451.61	611.63	734.09	821.99
1999	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2000	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2001	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2002	5.18	93.27	265.27	451.61	611.63	734.09	821.99

Table D.6. Commercial and recreational catch at age matrix for striped bass (ASMFC, 2003).

Year	Age												
	1	2	3	4	5	6	7	8	9	10	11	12	13+
1982	1.810	105.555	256.699	220.835	58.429	19.180	24.213	16.802	11.692	10.593	11.017	13.668	15.671
1983	3.625	110.327	178.236	193.141	150.019	39.286	18.713	4.125	2.895	3.709	4.581	5.644	13.548
1984	5.563	542.751	302.698	82.425	60.374	51.680	18.280	4.668	2.117	2.078	0.693	0.336	11.139
1985	1.311	72.529	101.959	40.483	58.703	43.106	43.522	17.283	6.351	3.404	1.043	0.827	10.321
1986	11.332	21.009	63.841	132.875	49.899	31.972	20.367	23.997	9.191	5.260	3.355	1.564	10.116
1987	1.368	10.915	37.629	51.422	67.260	25.041	13.204	6.490	6.384	2.982	1.448	1.968	12.916
1988	2.566	30.882	41.755	63.222	107.100	97.917	40.598	24.411	13.995	5.773	3.676	3.251	9.560
1989	0.729	35.994	79.665	68.244	104.896	95.437	45.645	21.026	10.423	3.758	3.234	1.965	8.848
1990	2.123	46.231	124.469	187.830	173.215	165.168	104.079	67.781	20.695	7.256	5.061	3.507	13.671
1991	1.792	72.836	145.252	208.716	161.950	101.438	91.311	82.920	58.757	24.090	14.173	2.755	22.330
1992	2.914	45.769	199.651	189.212	177.132	109.523	62.419	67.781	58.384	44.782	9.301	4.070	15.942
1993	0.287	69.633	185.306	327.330	288.512	185.379	86.551	67.337	82.587	76.145	41.133	9.327	17.457
1994	5.665	145.422	348.825	290.641	367.749	232.389	135.432	86.698	99.882	80.962	36.013	22.302	14.625
1995	3.838	426.821	459.079	447.829	391.341	470.669	204.809	190.869	151.640	88.555	52.246	16.455	14.908
1996	0.465	92.673	639.954	634.993	533.768	457.572	436.529	208.439	140.109	67.719	42.043	44.663	20.621
1997	2.533	285.466	486.449	850.321	615.973	593.847	405.508	372.316	200.317	120.479	59.642	29.987	24.850
1998	26.421	183.404	485.409	706.672	1125.019	510.938	280.434	265.002	215.493	113.842	95.070	45.172	65.493
1999	9.210	116.452	433.400	656.249	651.804	714.112	336.562	226.801	193.497	138.519	97.623	45.054	45.696
2000	37.977	323.977	419.860	989.188	1021.208	780.437	738.105	311.870	160.636	141.488	59.631	29.301	30.751
2001	34.741	161.922	431.514	605.354	830.556	696.646	576.745	480.387	205.831	119.546	102.964	49.634	47.952
2002	25.189	213.284	306.307	462.780	569.670	741.606	514.862	355.018	276.601	106.444	87.934	48.450	61.888

Table D.7 Weight (kg) and size at age (cm) of striped bass estimated from a von Bertalanffy curve fit to state specific length at age data. von Bertalanffy parameters are:  $L_{inf} = 158.4$ ,  $k = 0.075$ ,  $T_0 = -0.9855$ .

<b>Age</b>	<b>Weight (kg)</b>	<b>Length (cm)</b>
0	0.078	11.29
1	0.156	21.92
2	0.756	31.78
3	1.274	40.93
4	2.079	49.41
5	2.719	57.29
6	3.66	64.6
7	4.79	71.37
8	5.657	77.66
9	6.528	83.50
10	7.912	88.91
11	9.116	93.93
12	10.24	98.59
13+	11.712	102.91



Table D.8. Catch-at-age of weakfish (thousands of fish) from 1982-2000 (Kahn, 2002a).

Year	Age					
	1	2	3	4	5	6+
1982	7893	11794	5419	2774	720	639
1983	6431	12100	5702	2775	567	424
1984	7533	13892	6437	3040	483	254
1985	12790	10690	3134	1165	212	55
1986	17032	15000	4815	1816	262	52
1987	14976	13533	4254	1478	144	11
1988	6952	15443	10456	6058	1042	69
1989	2246	4796	4307	2918	625	84
1990	8895	4537	2012	1200	590	89
1991	9104	5460	2686	1355	459	56
1992	4306	5682	2176	1252	527	65
1993	3769	5770	2126	1133	400	48
1994	3166	2876	3001	1362	199	38
1995	3471	3095	3379	1574	196	54
1996	1482	2053	4073	2955	1334	98
1997	970	1553	2563	5037	1469	397
1998	835	1709	3535	1904	2827	871
1999	805	1148	2076	3058	702	1123
2000	934	1046	1663	1754	1822	466

Table D.9. Weight (kg) and size (cm) at age for weakfish at the beginning of each year based on annual Von Bertalanffy growth curves and length-weight regressions (Kahn, 2002a).

<b>Age</b>	<b>Weight (kg)</b>	<b>Length (cm)</b>
0	0.027	5.3
1	0.111	17.3
2	0.255	26.0
3	0.480	33.3
4	0.755	39.6
5	1.057	44.9
6+	1.368	49.5

Table D.10. Regional densities (gm-2) of benthic invertebrate taxa provided in Wigley and Theroux (1981) and Theroux and Wigley (1998).

Taxon	Georges Bank/ Gulf of Maine (Area = 84,006 km <sup>2</sup> )	Southern New England (Area = 14,805 km <sup>2</sup> )	Mid-Atlantic (Area = 17,203 km <sup>2</sup> )	Chesapeake Bay (Area = 7,913 km <sup>2</sup> )	North Carolina (Area = 26,455 km <sup>2</sup> )
Gammarids	5.9	5.51	4.7	4.7	4.7
Isopoda	0.94	0.95	0.94	0.95	0.35
Polychaetes	8.2	39.1	22.2	22.2	22.2
Total Biomass (000 Metric Tons)	1,263	674	479	220	720

Table D.11. Estimated total biomass (mt) of blue crabs based upon stock assessment documents.

<b>Year</b>	<b>DE Bay</b>	<b>Chesapeake Bay</b>	<b>North Carolina</b>	<b>Total Biomass (mt)</b>
1982	11,142.22	40,156.55	34,988.2	86287.0
1983	3,548.14	42,130.65	31,724.5	77403.3
1984	4,640.41	34,264.70	29,821.5	68726.6
1985	13,233.29	33,405.84	27,053.0	73692.2
1986	25,147.32	35,408.78	21,670.4	82226.5
1987	8,136.74	32,636.71	29,575.8	70349.3
1988	12,883.98	33,787.20	32,479.7	79150.9
1989	17,796.26	37,676.11	89,149.5	144621.9
1990	34,994.84	38,568.56	35,230.4	108793.8
1991	6,795.04	53,278.71	81,223.2	141297.0
1992	19,848.34	38,230.46	31,149.7	89228.5
1993	19,946.08	41,868.20	40,069.5	101883.8
1994	29,721.50	24,629.33	31,635.8	85986.6
1995	38,529.63	20,025.25	28,425.7	86980.6
1996	13,773.82	26,916.03	23,517.2	64207.0
1997	17,238.11	18,884.66	43,653.4	79776.2
1998	44,001.66	23,560.38	32,089.8	99651.8
1999	22,642.30	12,525.48	30,418.0	65585.8
2000	33,719.37	15,024.27	23,052.5	71796.1
2001	29,954.37	13,546.09	20,050.8	63551.2
2002	15,330.24	16,822.63	31,839.5	63992.4

Table D.12. Absolute abundance (millions) of recruit and postrecruit lobster in the Gulf of Maine.

Year	Recruits	Postrecruits	Total
1982	27.57	9.19	36.76
1983	32.28	13.86	46.14
1984	15.24	22.37	37.61
1985	31.89	15.5	47.39
1986	27.71	22.06	49.77
1987	14.01	23.99	38
1988	33.51	14.25	47.76
1989	37.04	20.98	58.02
1990	41.67	26.5	68.17
1991	30.18	29.02	59.2
1992	34.33	23.91	58.24
1993	38.76	27.4	66.16
1994	71.55	31.02	102.57
1995	44.85	54.45	99.3
1996	70.23	53.11	123.34
1997	54.49	59.54	114.03

Table D.13. Absolute abundance (millions) of recruit and postrecruit lobster in the Cape Cod and Long Island areas.

Year	Recruits	Postrecruits	Total
1982	1.58	1.998	3.578
1983	1.696	1.547	3.243
1984	2.54	1.309	3.849
1985	1.681	1.437	3.118
1986	3.481	0.969	4.45
1987	1.222	2.282	3.504
1988	1.855	1.511	3.366
1989	3.928	0.85	4.778
1990	3.914	1.536	5.45
1991	1.455	2.283	3.738
1992	3.383	1.743	5.126
1993	1.466	2.217	3.683
1994	2.791	0.672	3.463
1995	3.451	1.387	4.838
1996	6.171	2.719	8.89
1997	6.18	4.789	10.969

Table D.14. Estimated biomass (mt) of lobster recruits.

Year	Gulf of Maine	Cape Cod and LI	Total
1982	1,582.0	90.7	1,672.6
1983	1,852.2	97.3	1,949.5
1984	874.5	145.7	1,020.2
1985	1,829.8	96.5	1,926.3
1986	1,590.0	199.7	1,789.7
1987	803.9	70.1	874.0
1988	1,922.8	106.4	2,029.2
1989	2,125.4	225.4	2,350.7
1990	2,391.0	224.6	2,615.6
1991	1,731.7	83.5	1,815.2
1992	1,969.9	194.1	2,164.0
1993	2,224.0	84.1	2,308.2
1994	4,105.5	160.1	4,265.7
1995	2,573.5	198.0	2,771.5
1996	4,029.8	354.1	4,383.9
1997	3,126.6	354.6	3,481.2
average	2,170.8	167.8	2,338.6

Table D.15. Seasonal and regional trawl survey catch per tow reported in Stehlik *et al.* (1991).

Taxon	Georges Bank/ Gulf of Maine (Area = 84,006 km <sup>2</sup> )	Southern New England (Area = 14,805 km <sup>2</sup> )	Mid-Atlantic (Area = 17,203 km <sup>2</sup> )	Chesapeake Bay (Area = 7,913 km <sup>2</sup> )	North Carolina (Area = 26,455 km <sup>2</sup> )
Rock Crab (Spring)	2.24	22.34	22.34	22.34	0
Rock Crab (Fall)	0.84	1.15	1.15	1.15	0
Jonah (Spring)	0.33	0.08	0.08	0	0
Jonah (Fall)	0.29	0.09	0.09	0	0



Table D.16. Annual landings (mt) summarized by clupeid species and total from sources identified in text. Abundance (mt) is estimated from total annual landings by dividing by F (0.05) as described in text.

<b>Year</b>	<b>HERRING, ATLANTIC</b>	<b>HERRING, ATLANTIC THREAD</b>	<b>SARDINE, SPANISH</b>	<b>SCADS</b>	<b>Grand Total</b>	<b>Abundance</b>
1982	44447.8	38.2			44486.0	889719.8
1983	33229.9	1370.0			34599.9	691998.0
1984	46659.7	1526.4	8.3		48194.4	963888.3
1985	33352.3	1529.1			34881.4	697628.0
1986	40219.4	108.6	1.7	36.4	40366.1	807322.8
1987	49957.2	421.1	1.6	95.3	50475.2	1009503.0
1988	53617.4	563.8	2.1	161.6	54345.0	1086899.3
1989	55842.1	1.5	13.2	125.7	55982.5	1119649.4
1990	55573.5	2584.2	65.9	49.0	58272.6	1165452.3
1991	80165.4	1726.6	14.3	0.1	81906.3	1638126.9
1992	92748.5	2168.8	81.1		94998.4	1899968.5
1993	77056.3	3101.1	48.0	5.4	80210.9	1604217.2
1994	64255.6	3557.3	55.9	3.3	67872.2	1357443.1
1995	106304.9	3961.0	32.9	10.4	110309.2	2206183.1
1996	119118.7	2997.7	90.9	31.5	122238.8	2444775.1
1997	111144.1	6305.0	151.9	55.9	117656.8	2353136.1
1998	99510.0	1397.4	150.2	52.8	101110.5	2022209.1
1999	110265.2	381.3	168.6	42.5	110857.6	2217151.6
2000	106173.1	1931.2	3.2	0.1	108107.6	2162152.8
2001	124260.0	268.5	12.3	0.1	124540.9	2490818.6
2002	93123.9	1249.5	7.5	0.3	94381.2	1887624.3
2003	103781.1	14.4	27.7		103823.2	2076463.4
2004	87324.2				87324.2	1746483.2
<b>Grand Total</b>	<b>1788130.4</b>	<b>37202.6</b>	<b>937.3</b>	<b>670.4</b>	<b>1826940.7</b>	

Table D.17. Seasonal landings (mt) summarized by species and overall proportion by season. Season define by 3-month periods (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec).

<b>Season</b>	<b>HERRING, ATLANTIC</b>	<b>HERRING, ATLANTIC THREAD</b>	<b>SARDINE, SPANISH</b>	<b>SCADS</b>	<b>Grand Total</b>	<b>Proportion</b>
1	305798.19	177.4	19	4.1	305998.7	0.168
2	284549.13	514.8	73	36.6	285173.5	0.156
3	733470.37	35296.1	113.4	9	768888.9	0.421
4	464312.71	21.2	2.5	0.8	464337.2	0.255
<b>Grand Total</b>	1788130.4	36009.5	207.9	50.5	1824398.3	1.000

Table D.18. Length composition of Atlantic herring summarized from data for 1982-2004 (pers. comm., Matthew Cieri, Maine DMR).

<b>Total Length (mm)</b>	<b>Frequency</b>	<b>Proportion</b>
<230	253	0.001
230-250	10131	0.040
250-270	40524	0.160
270-290	73449	0.290
290-310	78515	0.310
310-330	37991	0.150
330-350	10131	0.040
350-370	1266	0.005
370-390	253	0.001
Total	252514	1.00

Table D.19. Length and age composition of Atlantic thread herring summarized from data collected between 1982-2002 (pers.comm., Joe W. Smith, SEFSC).

<b>Fork Length (mm)</b>	<b>Frequency</b>	<b>Proportion</b>
120-129	1	0.001
130-139	11	0.011
140-149	95	0.096
150-159	225	0.227
160-169	296	0.299
170-179	249	0.252
180-189	100	0.101
190-199	11	0.011
200-209	2	0.002
Total	990	1.000

<b>Age (yr)</b>	<b>Frequency</b>	<b>Proportion</b>
1	1	0.002
2	11	0.018
3	95	0.151
4	225	0.358
5	296	0.471
	628	0.634

Table D.20. Time series of bay anchovy biomass estimates (mt) for Atlantic coast estuaries and coastal waters and combined during season 2 (spring) and 3 (summer).

Season 2				Season 3			
Year	Estuaries	Coast	Total	Year	Estuaries	Coast	Total
1982	45,754.0	136,810.2	182,564.2	1982	198,930.6	555,016.7	753,947.3
1983	48,283.4	136,810.2	185,093.6	1983	209,927.8	555,016.7	764,944.5
1984	50,454.2	136,810.2	187,264.3	1984	219,366.0	555,016.7	774,382.7
1985	61,795.4	136,810.2	198,605.6	1985	268,675.8	555,016.7	823,692.5
1986	58,527.7	136,810.2	195,337.9	1986	254,468.2	555,016.7	809,484.9
1987	50,706.5	136,810.2	187,516.6	1987	220,462.9	555,016.7	775,479.6
1988	33,382.2	136,810.2	170,192.3	1988	145,139.8	555,016.7	700,156.6
1989	70,142.2	103,160.9	173,303.1	1989	304,966.1	418,507.0	723,473.1
1990	41,061.1	124,354.2	165,415.3	1990	178,526.4	504,484.9	683,011.4
1991	67,817.3	98,229.5	166,046.8	1991	294,857.8	398,501.1	693,358.9
1992	70,667.3	133,228.6	203,895.9	1992	307,249.2	540,486.9	847,736.2
1993	62,564.6	136,810.2	199,374.8	1993	272,020.2	555,016.7	827,036.9
1994	48,157.1	89,310.4	137,467.6	1994	209,378.8	362,318.0	571,696.8
1995	50,924.8	120,611.6	171,536.5	1995	221,412.2	489,301.9	710,714.1
1996	36,013.9	109,687.8	145,701.7	1996	156,582.0	444,985.8	601,567.8
1997	43,518.0	90,873.9	134,391.9	1997	189,208.9	368,660.7	557,869.6
1998	42,997.8	73,458.3	116,456.1	1998	186,946.9	298,008.6	484,955.5
1999	49,790.1	92,748.7	142,538.7	1999	216,478.5	376,266.3	592,744.8
2000	59,745.8	88,964.0	148,709.8	2000	259,764.5	360,912.5	620,677.0
2001	36,354.7	68,741.1	105,095.8	2001	158,064.0	278,871.6	436,935.6
2002	29,202.1	80,801.1	110,003.2	2002	126,965.5	327,796.9	454,762.4
<b>Mean</b>	50,374.3	112,792.9	163,167.2	<b>Mean</b>	219,018.7	457,582.7	676,601.3

Table D.21. References for regional diet composition data for striped bass.

<b>Reference</b>	<b>Region</b>	<b>Age Classes</b>	<b>Seasons</b>
Hartman & Brandt 1995a	Chesapeake Bay	0, 1-2, 3-5	1-4
Walter & Austin 2003	Chesapeake Bay	6+	1-4
Walter <i>et al.</i> 2003	Chesapeake Bay	1-3, 4-7, 8+	1-4
Cooper 1998	North Carolina	0	3-4
Walter <i>et al.</i> 2003	North Carolina	1-3, 4-7, 8+	1-4
NEFSC-Food Habits Database	North Carolina	4-7, 8+	2
NEFSC-Food Habits Database	Mid-Atlantic	1-3, 4-7	2
Walter <i>et al.</i> 2003	New England	1-3, 4-7, 8+	1-4
NEFSC-Food Habits Database	New England	1-3, 4-7, 8+	2,4
Nelson et al. 2003	Gulf of Maine	4-7, 8+	3

Table D.22. Quantitative electivity values for striped bass in Chesapeake Bay.

<b>Age Class</b>	<b>Season</b>	<b>Anch.</b>	<b>Invert.</b>	<b>Crust.</b>	<b>Macro-zooplankton</b>	<b>Med. Forage</b>	<b>Menhaden</b>	<b>Sciaenids</b>
Age 0	1	0.0000	0.9896	0.0000	0.0104	0.0000		0.0000
Age 0	2	0.0000	0.9896	0.0000	0.0104	0.0000	0.0000	0.0000
Age 0	3	0.0181	0.0283	0.0272	0.1265	0.7999	0.0000	0.0000
Age 0	4	0.4020	0.0279	0.1870	0.3831	0.0000	0.0000	0.0000
Age 1-2	1	0.0378	0.3401	0.0000	0.0811	0.4066		0.1345
Age 1-2	2	0.0070	0.0421	0.0324	0.0406	0.2807	0.0000	0.5972
Age 1-2	3	0.0355	0.0067	0.7533	0.1437	0.0000	0.0447	0.0161
Age 1-2	4	0.0230	0.0026	0.0582	0.0764	0.0000	0.4669	0.3728
Age 3-5	1	0.0017	0.0002	0.0000	0.0000	0.9765		0.0216
Age 3-5	2	0.0018	0.0658	0.0302	0.0004	0.4388	0.0082	0.4547
Age 3-5	3	0.0404	0.2180	0.0769	0.0000	0.4682	0.1965	0.0000
Age 3-5	4	0.0005	0.0000	0.0191	0.0027	0.0982	0.8796	0.0000
Age 6-7	1	0.0016	0.0007	0.0021	0.0000	0.9748		0.0208
Age 6-7	2	0.0000	0.0005	0.0323	0.0000	0.9319	0.0096	0.0257
Age 6-7	3	0.0043	0.0036	0.9653	0.0000	0.0143	0.0125	0.0000
Age 6-7	4	0.0020	0.0012	0.0089	0.0000	0.4021	0.0423	0.5434
Age 8+	1	0.0000	0.0000	0.0004	0.0000	0.9996		0.0000
Age 8+	2	0.0000	0.0000	0.0239	0.0000	0.9475	0.0067	0.0218
Age 8+	3	0.0000	0.0000	0.0047	0.0000	0.9301	0.0652	0.0000
Age 8+	4	0.0114	0.0058	0.0175	0.0000	0.4505	0.0744	0.4403

Table D.23. Ranked type preference values for Striped Bass used as inputs in the MSVPA-X application.

Age	Anchovies	Inverts.	Crust.	Herrings	Macro - zooplankton	Medium Forage	Menhaden	Sciaenids
0	0	1	0	0	2	0	0	0
1	7	5	1	0	6	4	3	2
2	7	5	1	0	6	4	3	2
3	6	3	4	0	7	1	2	5
4	7	5	3	6	8	1	2	4
5	6	5	3	8	7	1	2	4
6	5	8	3	7	6	1	2	4
7	6	7	2	5	0	1	4	3
8	6	7	2	5	0	1	4	3
9	6	7	2	4	0	1	5	3
10	6	7	2	4	0	1	5	3
11	6	7	2	3	0	1	5	4
12	6	7	2	3	0	1	5	4
13+	6	7	2	3	0	1	5	4

Table D.24. Available references for diet information for weakfish.

<b>Reference</b>	<b>Region</b>	<b>Age Classes</b>	<b>Seasons</b>
Hartman & Brandt 1995a	Chesapeake Bay	0, 1, 2-3	2-4
Merriner 1975	North Carolina	0-5	3-4
NEFSC-Food Habits Database	North Carolina	1-2, 3+	2, 4
NEFSC-Food Habits Database	Mid-Atlantic	1-2, 3+	4
NEFSC-Food Habits Database	New England	1-2, 3+	4



Table D.25. Type preference ranks derived from available diet information for weakfish.

<b>Age</b>	<b>Anchovies</b>	<b>Inverts.</b>	<b>Crust.</b>	<b>Herrings</b>	<b>Macro - zooplankton</b>	<b>Medium Forage</b>	<b>Menhaden</b>	<b>Sciaenids</b>
0	3	2	0	0	1	0	0	0
1	2	7	6	0	5	4	1	3
2	4	6	5	0	7	3	1	2
3	6	8	5	2	7	4	3	1
4	6	8	4	2	7	5	3	1
5	6	8	4	2	7	5	1	3
6+	5	8	4	2	7	6	3	1

Table D.26. Available references for diet information for bluefish.

<b>Reference</b>	<b>Region</b>	<b>Size Classes</b>	<b>Seasons</b>
Hartman & Brandt 1993a	Chesapeake Bay	1-3	3
NEFSC-Food Habits Database	North Carolina	1-3	2, 4
NEFSC-Food Habits Database	Mid-Atlantic	1-3	2,4
NEFSC-Food Habits Database	New England	1-3	2,4
Buckel and Conover 1999	New England	1	3
Juanes <i>et al.</i> 2001	New England	1	3
NEFSC-Food Habits Database	Gulf of Maine	1-3	2,4

Table D.27. Type preference ranks derived from available diet information for bluefish.

<b>Size</b>	<b>Anchovies</b>	<b>Inverts.</b>	<b>Crust.</b>	<b>Herrings</b>	<b>Macro - zooplankton</b>	<b>Medium Forage</b>	<b>Menhaden</b>	<b>Sciaenids</b>
1	2	6	5	7	8	1	4	3
2	7	8	6	2	5	1	4	3
3	6	7	4	3	8	1	5	2

Table D.28. Surface area and states included in strata used for spatial analyses.

<b>Region</b>	<b>Area (km<sup>2</sup>)</b>	<b>States</b>
North Carolina	26,455	North Carolina
Chesapeake Bay	7,912	Virginia and Maryland
Mid-Atlantic	17,202	Offshore VA and MD, New Jersey, Delaware
Southern New England	14,805	New York, Connecticut, Rhode Island
Gulf of Maine	84,006	Massachusetts, Maine

Table D.29. Seasonal spatial overlap values for weakfish.

Season	Prey	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
1	Menhaden	0.9282	0.9631	0.9725	0.9733	0.8853	0.9091
1	Anchovy	0.3718	0.3369	0.3275	0.3267	0.4147	0.3909
1	Crustaceans	0.4617	0.4267	0.4173	0.4165	0.4781	0.4480
1	Inverts	0.2808	0.2515	0.2421	0.2413	0.3293	0.3055
1	Herrings	0.0965	0.0792	0.0698	0.0690	0.1570	0.1332
1	Macrozooplankton	0.2291	0.2128	0.2034	0.2027	0.2906	0.2669
1	Medium Forage Fish	0.4083	0.3734	0.3640	0.3632	0.4512	0.4274
1	Sciaenids	0.9742	0.9370	0.9237	0.9208	0.9296	0.9171
2	Menhaden	0.8512	0.7579	0.5577	0.5275	0.2941	0.2162
2	Anchovy	0.6476	0.8507	0.6712	0.6461	0.4321	0.3543
2	Crustaceans	0.5811	0.8129	0.6999	0.6577	0.4245	0.3467
2	Inverts	0.3132	0.4238	0.4365	0.4537	0.3749	0.3888
2	Herrings	0.1418	0.2378	0.2505	0.2677	0.3495	0.3690
2	Macrozooplankton	0.2744	0.3439	0.3567	0.3738	0.3197	0.3172
2	Medium Forage Fish	0.3394	0.4997	0.4909	0.5030	0.3699	0.3282
2	Sciaenids	0.9109	0.5792	0.3878	0.3506	0.1825	0.1046
3	Menhaden	0.8709	0.6039	0.4012	0.3656	0.2282	0.1750
3	Anchovy	0.5898	0.7067	0.5040	0.4899	0.3525	0.2993
3	Crustaceans	0.5234	0.6805	0.5216	0.4823	0.3449	0.2916
3	Inverts	0.2554	0.3265	0.3266	0.3514	0.3899	0.3872
3	Herrings	0.0001	0.0018	0.0023	0.0028	0.0048	0.0054
3	Macrozooplankton	0.2425	0.2853	0.2854	0.3103	0.2859	0.2621
3	Medium Forage Fish	0.2864	0.3987	0.3988	0.4236	0.4155	0.3623
3	Sciaenids	0.9456	0.5902	0.3643	0.3244	0.1851	0.1312
4	Menhaden	0.7381	0.7341	0.5476	0.5082	0.2459	0.1814
4	Anchovy	0.7310	0.8516	0.6965	0.6757	0.4299	0.3654
4	Crustaceans	0.6646	0.8923	0.7239	0.6846	0.4222	0.3577
4	Inverts	0.3278	0.4239	0.4378	0.4564	0.4072	0.4151
4	Herrings	0.0001	0.0012	0.0018	0.0019	0.0020	0.0021
4	Macrozooplankton	0.2762	0.3440	0.3580	0.3765	0.3376	0.3282
4	Medium Forage Fish	0.3501	0.4874	0.5013	0.5199	0.4794	0.4284
4	Sciaenids	0.6308	0.6817	0.5344	0.4950	0.2325	0.1680

Table D.30. Seasonal spatial overlap values for bluefish.

Season	Prey	Size1	Size2	Size3
1	Menhaden	0.9939	0.6707	0.9125
1	Anchovy	0.3062	0.5934	0.3875
1	Crustaceans	0.3960	0.7119	0.4773
1	Inverts	0.2208	0.4361	0.3021
1	Herrings	0.0484	0.2501	0.1298
1	Macrozooplankton	0.1821	0.3563	0.2635
1	Medium Forage Fish	0.3427	0.5871	0.4240
1	Sciaenids	0.9052	0.7520	0.9249
2	Menhaden	0.3910	0.2996	0.4760
2	Anchovy	0.4258	0.4874	0.6796
2	Crustaceans	0.4965	0.4639	0.6678
2	Inverts	0.3404	0.5770	0.6676
2	Herrings	0.1681	0.5635	0.4816
2	Macrozooplankton	0.3017	0.4333	0.5063
2	Medium Forage Fish	0.4623	0.4836	0.6801
2	Sciaenids	0.1731	0.1880	0.2381
3	Menhaden	0.3968	0.1972	0.1755
3	Anchovy	0.4183	0.3430	0.3213
3	Crustaceans	0.3820	0.3195	0.2780
3	Inverts	0.3788	0.4477	0.6644
3	Herrings	0.0000	0.0674	0.3035
3	Macrozooplankton	0.2633	0.3170	0.5337
3	Medium Forage Fish	0.3381	0.4172	0.6339
3	Sciaenids	0.3665	0.1285	0.1068
4	Menhaden	0.6096	0.1629	0.1110
4	Anchovy	0.5065	0.3637	0.3325
4	Crustaceans	0.5601	0.3560	0.3090
4	Inverts	0.4608	0.4572	0.5456
4	Herrings	0.0000	0.0410	0.1767
4	Macrozooplankton	0.3067	0.3265	0.4149
4	Medium Forage Fish	0.4114	0.4267	0.5151
4	Sciaenids	0.5966	0.1373	0.0854

Table D.31. Seasonal spatial overlap values for striped bass.

Season	Prey	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13+
1	Menhaden	0.0000	0.0000	0.0000	0.0162	0.0000	0.0069	0.0528	0.1593	0.4259	0.6320	0.5773	0.4656	0.4241
1	Anchovy	0.4504	0.4504	0.5084	0.5340	0.5140	0.5140	0.5500	0.6725	0.7392	0.6680	0.7227	0.7326	0.7210
1	Crustaceans	0.3840	0.3840	0.4420	0.4675	0.4476	0.4476	0.4835	0.6061	0.7626	0.7550	0.7542	0.7560	0.7444
1	Inverts	0.1160	0.1160	0.1740	0.1996	0.1796	0.1796	0.2156	0.3381	0.3194	0.3117	0.3110	0.3128	0.3012
1	Herrings	0.1040	0.1040	0.1620	0.1876	0.1676	0.1676	0.1931	0.2091	0.1351	0.1274	0.1267	0.1285	0.1169
1	Macrozooplankton	0.1031	0.1031	0.1611	0.1835	0.1666	0.1667	0.2026	0.3251	0.2678	0.2601	0.2593	0.2611	0.2496
1	Medium Forage Fish	0.1422	0.1422	0.2002	0.2258	0.2058	0.2058	0.2418	0.3643	0.4675	0.4598	0.4591	0.4609	0.4493
1	Sciaenids	0.0976	0.0976	0.0976	0.1138	0.0976	0.1045	0.1504	0.2569	0.5235	0.7296	0.6749	0.5632	0.5217
2	Menhaden	0.6901	0.6901	0.5251	0.4473	0.3716	0.3035	0.3072	0.2578	0.3707	0.4219	0.3480	0.3176	0.3371
2	Anchovy	0.6000	0.6000	0.6568	0.6351	0.5594	0.4913	0.4922	0.4305	0.4772	0.5397	0.4276	0.3919	0.4114
2	Crustaceans	0.5622	0.5622	0.6032	0.6117	0.5360	0.4506	0.4401	0.3785	0.4252	0.4876	0.3755	0.3399	0.3593
2	Inverts	0.2082	0.2082	0.2869	0.4569	0.5314	0.6669	0.6466	0.7828	0.7346	0.8981	0.8413	0.7959	0.7781
2	Herrings	0.1945	0.1945	0.2732	0.4432	0.6270	0.7927	0.7757	0.8799	0.8279	0.7862	0.8586	0.8848	0.7930
2	Macrozooplankton	0.1671	0.1671	0.2458	0.4157	0.3877	0.5233	0.5029	0.6392	0.6149	0.8174	0.7706	0.6966	0.7571
2	Medium Forage Fish	0.2490	0.2490	0.3277	0.4791	0.4380	0.5735	0.5532	0.6794	0.6266	0.7951	0.7048	0.6594	0.6416
2	Sciaenids	0.6695	0.6695	0.4325	0.3357	0.2600	0.1919	0.1956	0.1462	0.2591	0.3093	0.2364	0.2117	0.2522
3	Menhaden	0.7783	0.7783	0.6347	0.4725	0.3655	0.2758	0.2707	0.2198	0.2628	0.2920	0.2218	0.2054	0.2211
3	Anchovy	0.6000	0.6000	0.6636	0.6183	0.4559	0.3188	0.3137	0.2628	0.3058	0.3350	0.2648	0.2484	0.2641
3	Crustaceans	0.5555	0.5555	0.6100	0.5949	0.4038	0.2667	0.2616	0.2107	0.2538	0.2829	0.2127	0.1964	0.2121
3	Inverts	0.2082	0.2082	0.3893	0.6619	0.6113	0.7169	0.6756	0.7202	0.7236	0.7719	0.7242	0.7036	0.6968
3	Herrings	0.0001	0.0001	0.1694	0.3111	0.2040	0.3666	0.3285	0.4800	0.3749	0.5615	0.5533	0.5049	0.5994
3	Macrozooplankton	0.1671	0.1671	0.3482	0.5771	0.4676	0.6015	0.5601	0.7066	0.6081	0.8388	0.7840	0.7149	0.7636
3	Medium Forage Fish	0.2804	0.2804	0.4615	0.7212	0.5726	0.6762	0.6349	0.6765	0.6829	0.7394	0.6785	0.6621	0.6643
3	Sciaenids	0.8413	0.8413	0.5809	0.4038	0.2968	0.2188	0.2137	0.1628	0.2058	0.2350	0.1648	0.1484	0.1641
4	Menhaden	0.4607	0.4607	0.4720	0.4916	0.4857	0.4752	0.4785	0.4310	0.6106	0.7224	0.6433	0.5938	0.6866
4	Anchovy	0.6000	0.6000	0.6113	0.6762	0.6673	0.6912	0.6895	0.6525	0.7811	0.8607	0.8013	0.7394	0.7935
4	Crustaceans	0.5622	0.5622	0.5736	0.6023	0.5933	0.6121	0.6253	0.6291	0.7140	0.8582	0.7492	0.6873	0.6750
4	Inverts	0.2082	0.2082	0.2195	0.2844	0.4264	0.4556	0.4637	0.5235	0.6320	0.6125	0.6975	0.6579	0.6499
4	Herrings	0.0001	0.0001	0.0097	0.0222	0.0191	0.0464	0.0413	0.0733	0.0465	0.0660	0.0816	0.0787	0.0948
4	Macrozooplankton	0.1671	0.1671	0.1784	0.2433	0.2828	0.3120	0.3200	0.3798	0.4860	0.5055	0.5212	0.5182	0.5126
4	Medium Forage Fish	0.2804	0.2804	0.2917	0.3566	0.4269	0.4561	0.4642	0.5240	0.6030	0.6587	0.6481	0.6172	0.6124
4	Sciaenids	0.3526	0.3526	0.3527	0.3587	0.3527	0.3546	0.3678	0.3956	0.5509	0.6967	0.6176	0.5432	0.5536

Table D.32. Single-species feeding parameter input for the biomass predator bluefish by size class. The proportion of biomass attributed to each size class is also presented.

<b>Parameter\Size Class</b>	<b>10-30cm</b>	<b>30-60cm</b>	<b>60-90cm</b>
<b>Evacuation <math>\alpha</math></b>	0.004	0.004	0.004
<b>Evacuation <math>\beta</math></b>	0.115	0.115	0.115
<b>Size Preference <math>\alpha</math></b>	8.65	8.65	8
<b>Size Preference <math>\beta</math></b>	25	25	25
<b>Proportion of Biomass</b>	0.025	0.265	0.71



Table D.33. Annual temperatures by season used in base run configuration in the MSVPA.

<b>Year</b>	<b>Season 1</b>	<b>Season 2</b>	<b>Season 3</b>	<b>Season 4</b>
1982	12.04	15.6	21.69	13.77
1983	12.04	15.87	21.65	13.73
1984	12.04	15.87	21.78	13.75
1985	12.1	16.13	22.3	14
1986	12.12	16.34	22.25	14.36
1987	12.2	15.87	22.59	13.48
1988	12.02	16.19	21.61	13.83
1989	12.39	16.28	22.42	13.4
1990	12.56	16.08	22.56	14.9
1991	12.83	17.53	22.73	14.16
1992	12.47	14.36	21.25	13.65
1993	12.22	16.32	22.24	13.39
1994	12.1	15.62	21.38	14.62
1995	12.44	15.9	22.57	13.66
1996	11.58	15.23	21.64	13.26
1997	12.54	14.53	21.85	13.73
1998	12.91	15.88	22.54	14.73
1999	12.47	15.67	22.63	14.71
2000	12.5	15.57	21.78	13.89
2001	12.19	15.98	22.31	14.82
2002	12.95	16.2	23.19	14.14

Table D.34. Base run configuration for ‘Other Prey’ minimum and maximum length and size ( $\alpha$  and  $\beta$ ) parameters.

<b>Other Prey</b>	<b>Min Length (cm)</b>	<b>Max Length (cm)</b>	<b><math>\alpha</math></b>	<b><math>\beta</math></b>
Bay Anchovy	2	11	12.45	9.69
Benthic Crust	1	21	6.54	3.35
Benthic Invert	1	6	3.29	3.32
Clupeids	7	39	4.87	3.46
Macrozoopl.	1	4	4.74	2.73
Med. For. Fish	1	27	1.15	2.52
Sciaenids	9	24	13.1	5.84

Table D.35. Quantitative prey preference rankings for weakfish by age as used in the base run configuration of the MSVPA-X model.

	<b>Age-0</b>	<b>Age-1</b>	<b>Age-2</b>	<b>Age-3</b>	<b>Age-4</b>	<b>Age-5</b>	<b>Age-6</b>
Striped Bass	0	0	0	0	0	0	0
<b>Weakfish</b>	0	0	0	0	0	0	0
<b>Menhaden</b>	4	1	1	3	3	1	3
<b>Bay Anchovy</b>	3	2	4	6	6	6	5
<b>Benthic Crust.</b>	0	6	5	5	4	4	4
<b>Benthic Invert.</b>	2	7	6	8	8	8	8
<b>Clupeids</b>	0	0	0	2	2	2	2
<b>Macrozoopl.</b>	1	5	7	7	7	7	7
<b>Medium Forage</b>	0	4	3	4	5	5	6
<b>Sciaenids</b>	0	3	2	1	1	3	1

Table D.36. Spatial overlap indices for weakfish by age as used in the base run configuration of the MSVPA-X model.

	<b>Age-0</b>	<b>Age-1</b>	<b>Age-2</b>	<b>Age-3</b>	<b>Age-4</b>	<b>Age-5</b>	<b>Age-6</b>
<b>Striped Bass</b>	0	0	0	0	0	0	0
<b>Weakfish</b>	0	0	0	0	0	0	0
<b>Menhaden</b>	0.9282	0.9282	0.9631	0.9725	0.9733	0.8853	0.9091
<b>Bay Anchovy</b>	0.3718	0.3718	0.3369	0.3275	0.3267	0.4147	0.3909
<b>Benthic Crust.</b>	0.4617	0.4617	0.4267	0.4173	0.4165	0.4781	0.448
<b>Benthic Invert.</b>	0.2808	0.2808	0.2515	0.2421	0.2413	0.3293	0.3055
<b>Clupeids</b>	0.0965	0.0965	0.0792	0.0698	0.069	0.157	0.1332
<b>Macrozoopl.</b>	0.2291	0.2291	0.2128	0.2034	0.2027	0.2906	0.2669
<b>Medium Forage</b>	0.4083	0.4083	0.3734	0.364	0.3632	0.4512	0.4274
<b>Scianieds</b>	0.9742	0.9742	0.937	0.9237	0.9208	0.9296	0.9171

Table D.37. Predator evacuation and prey size preference parameter values for the base run.

<b>Species (ages)</b>	<b>Evacuation <math>\alpha</math></b>	<b>Evacuation <math>\beta</math></b>	<b>Size Preference <math>\alpha</math></b>	<b>Size Preference <math>\beta</math></b>
Striped Bass (0-4)	0.004	0.115	2.98	11.244
Striped Bass (5-9)	0.004	0.115	9.1	35.2
Striped Bass (10-13+)	0.004	0.115	13.9	51.2
Weakfish	0.004	0.115	10.1	25.5
Bluefish	0.004	0.115	10.1	25.5

## FIGURES

Figure D.1. Predator consumption related to food availability.

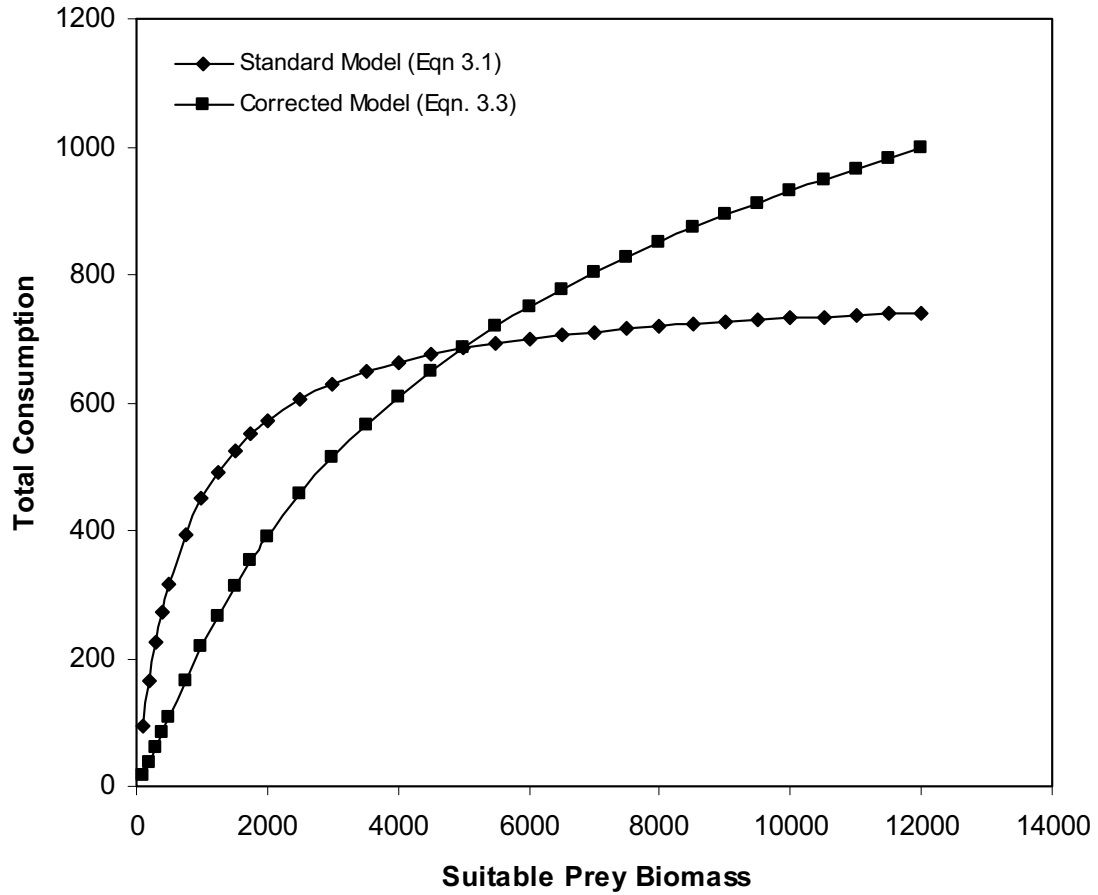


Figure D.2. Predator mortality rate related to food availability.

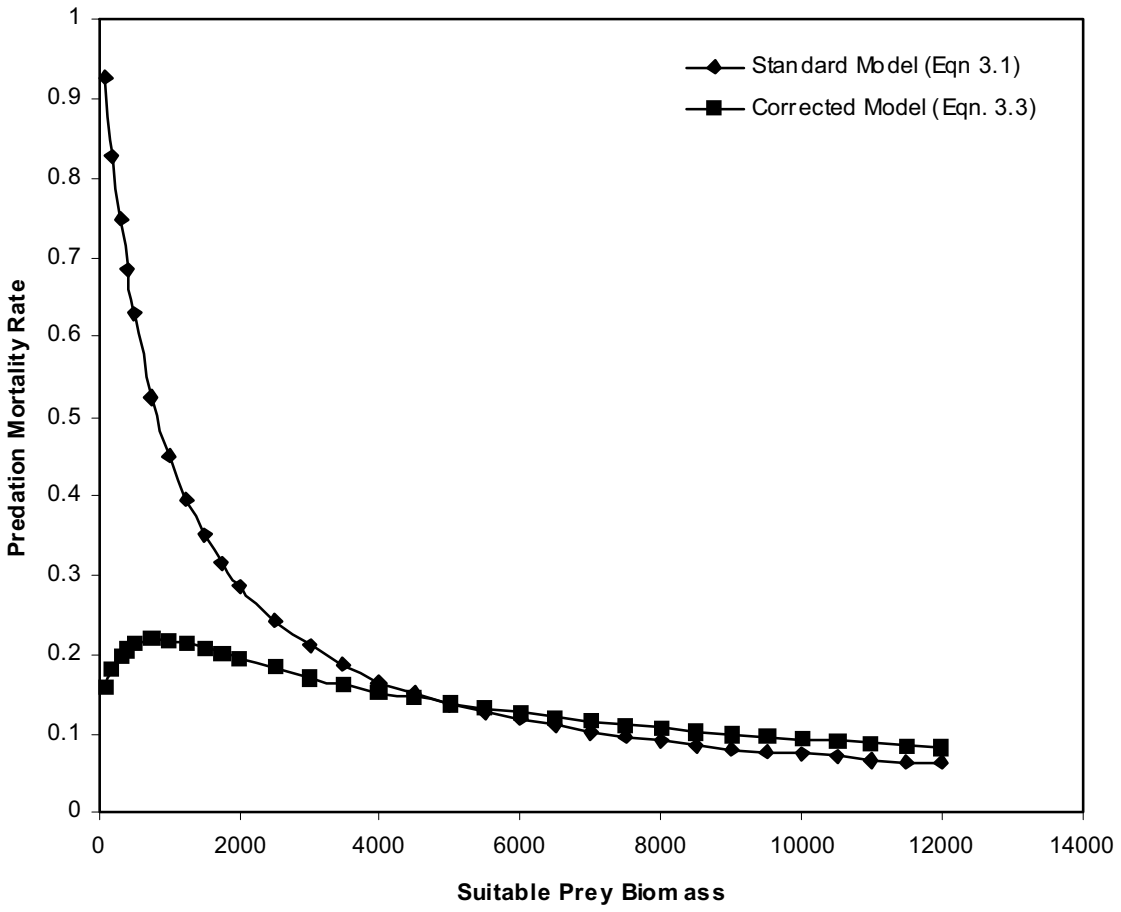


Figure D.3. Prey size selection curves.

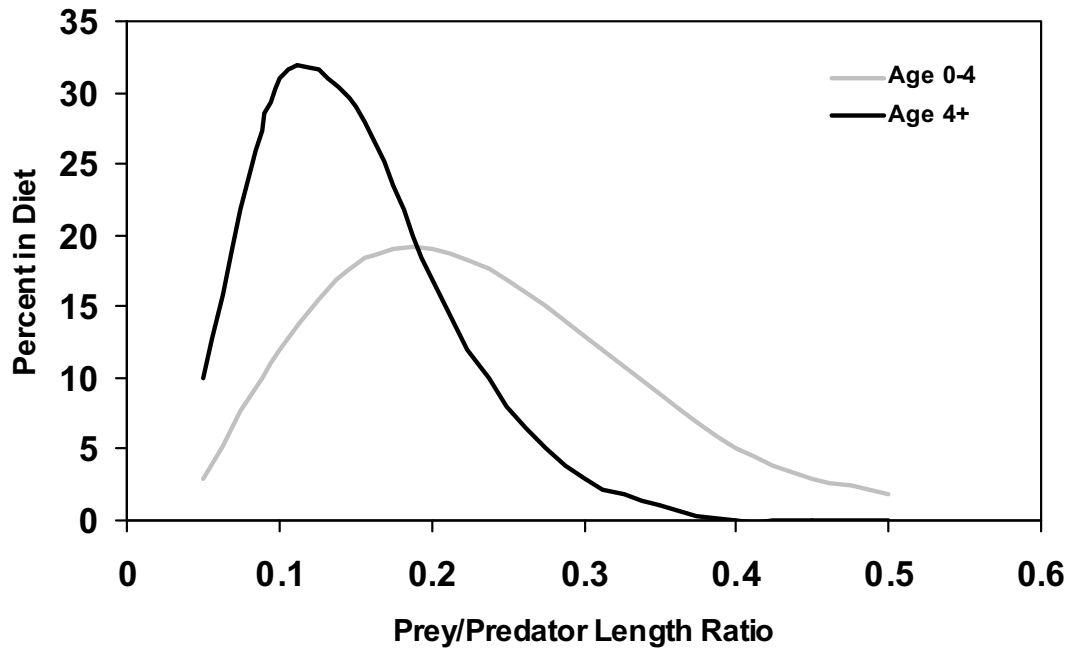




Figure D.4. MSVPA-X Implementation flow chart.

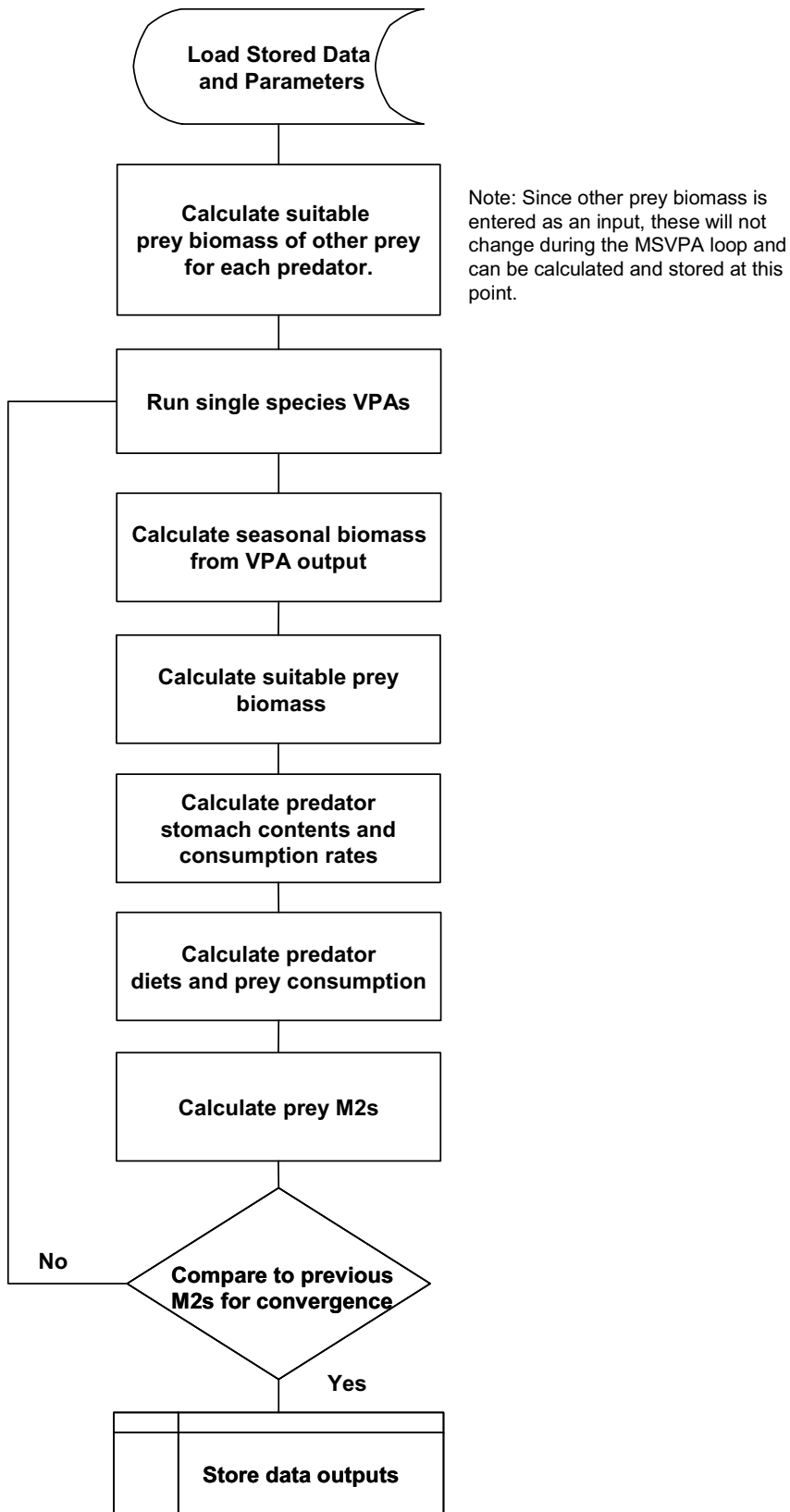


Figure D.5. Forecast model implementation flow chart.

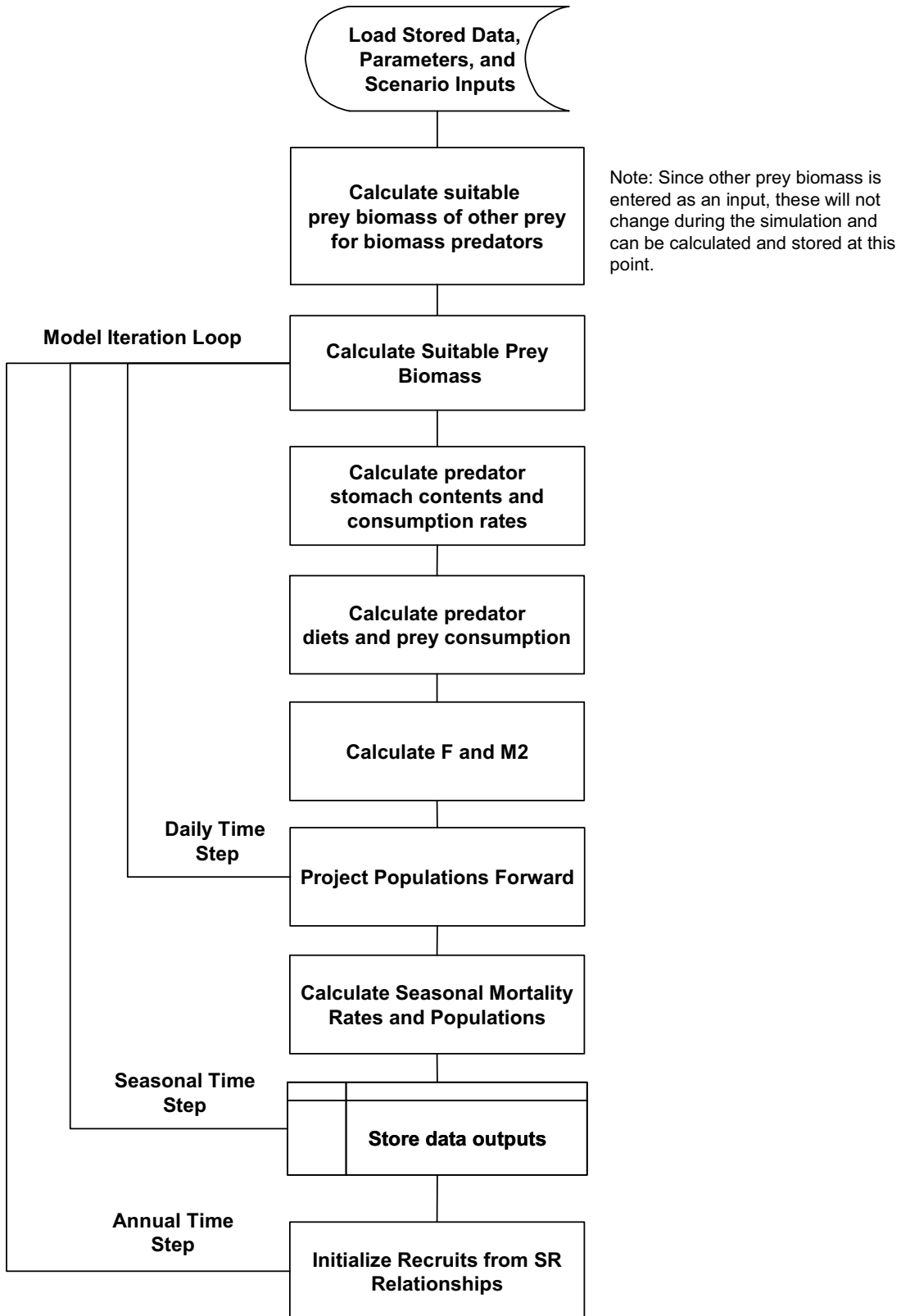


Figure D.6. Estimated average fishing mortality rate at age during 2000-2002 for Atlantic menhaden in evaluation runs assessing sensitivity to the number of age classes used to calculate shrinkage means.

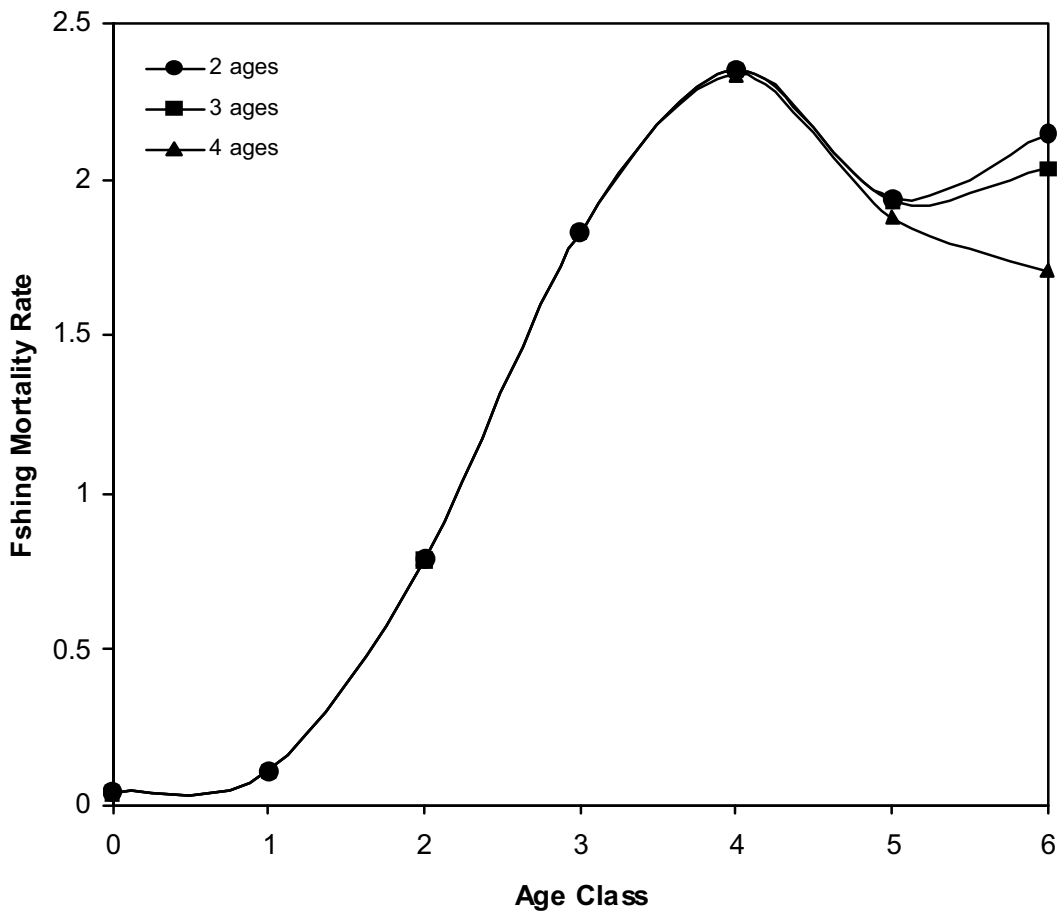


Figure D.7. Average fishery mortality rate on age classes 2+ menhaden estimated by the forward projection model and evaluation runs using Extended Survivors Analysis (XSA).

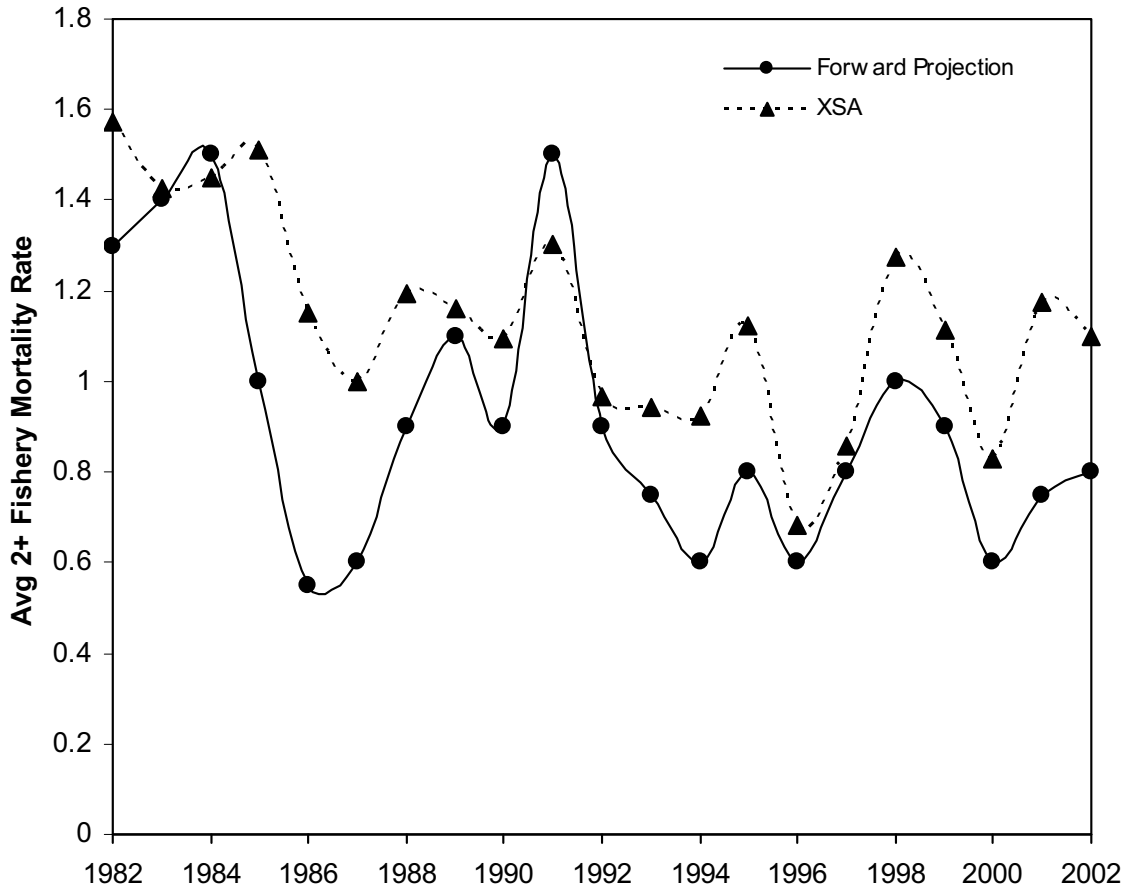


Figure D.8. Estimated abundance of (a) age-0, (b) age-1, and (c) age-3+ Atlantic menhaden in evaluation runs of the forward projection model and XSA.

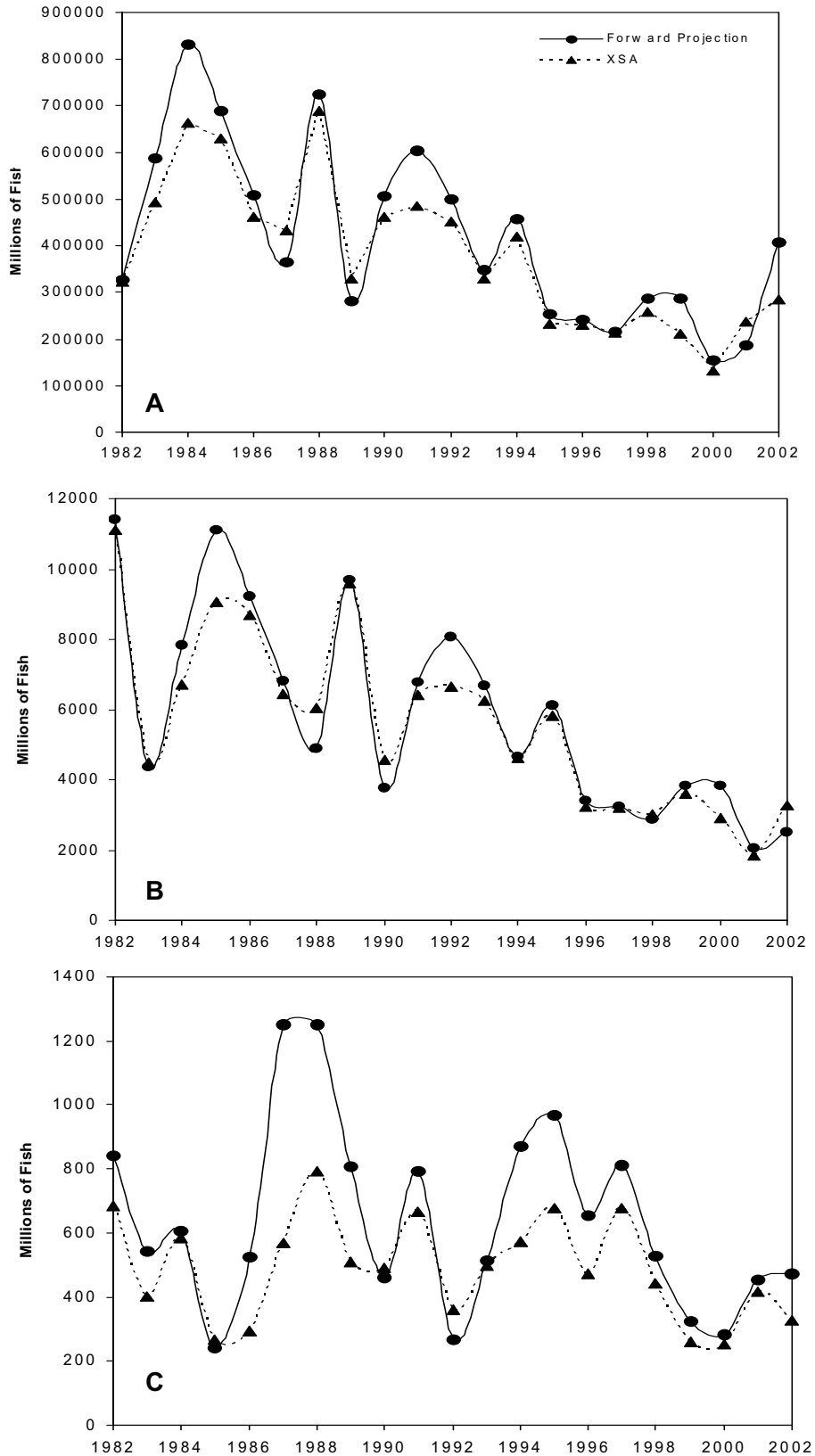


Figure D.9. Average fishery mortality rates for ages (A) 8-11 and (B) 3-8 for striped bass estimated from XSA evaluation runs. The ADAPT time series represents average F from the striped bass stock assessment (ASMFC, 2003).

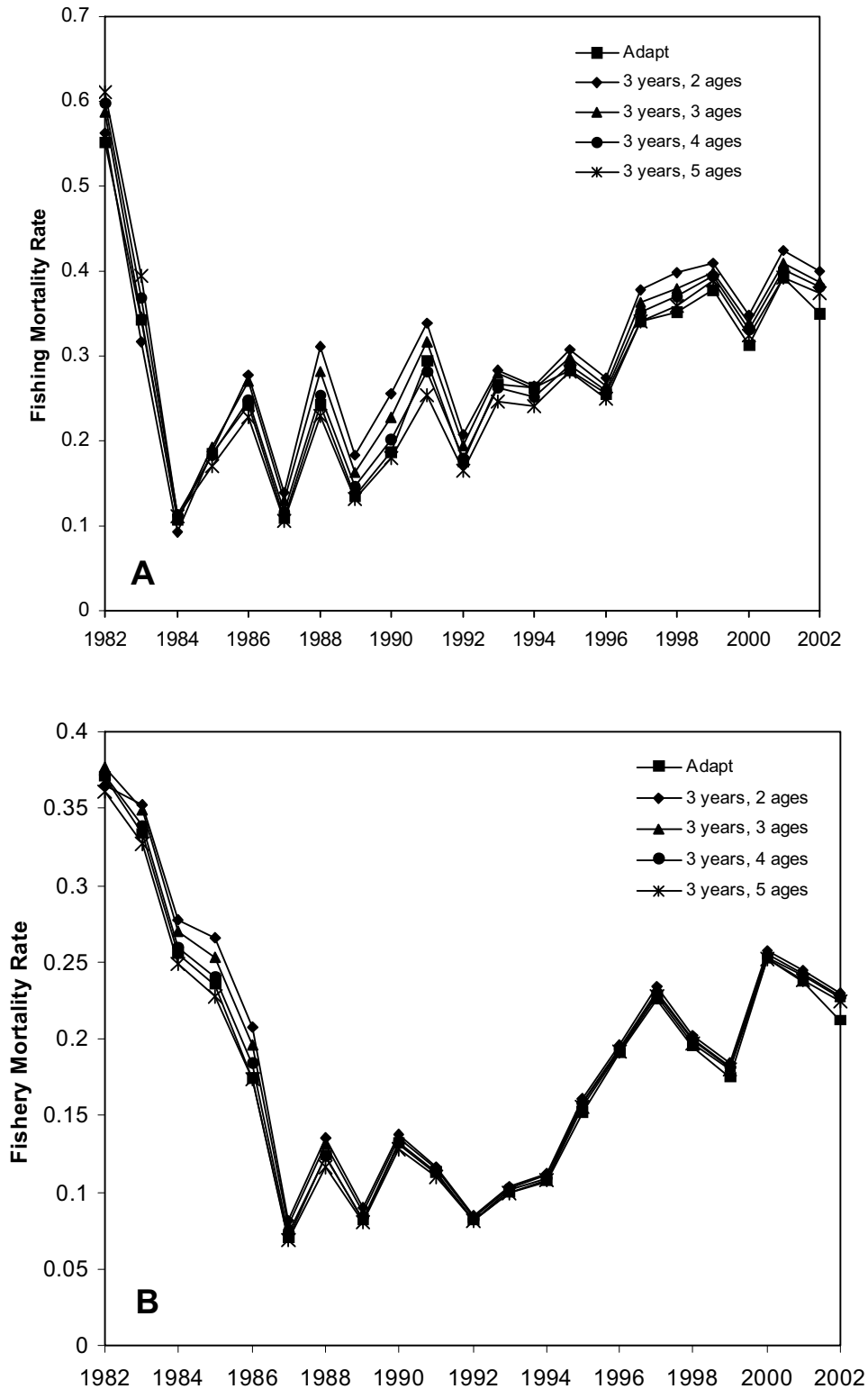


Figure D.10. Average fishery mortality rates during 2000-2002 by age class for the XSA evaluation run. The ADAPT time series represents output from the striped bass stock assessment (ASMFC, 2003).

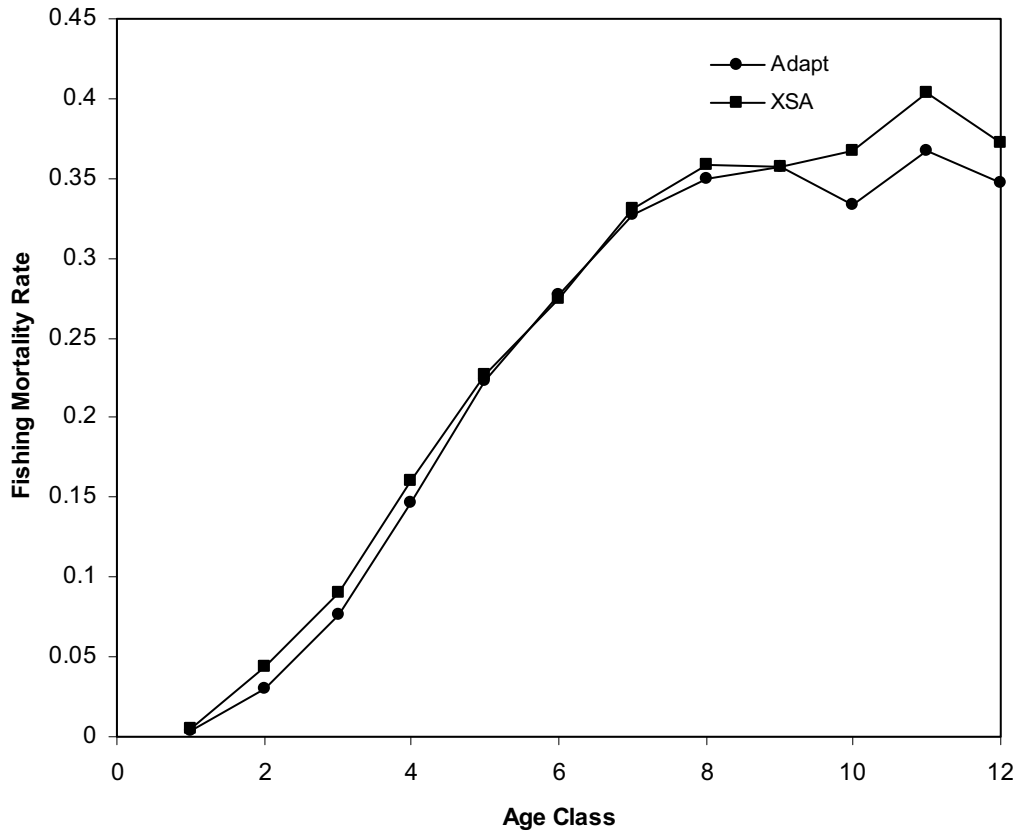


Figure D.11. Total abundance of striped bass age class 1 (A), ages 3-8 (B), and ages 8-11 (C) estimates from XSA evaluation runs. The ADAPT time series represents output from the striped bass stock assessment (ASMFC, 2003).

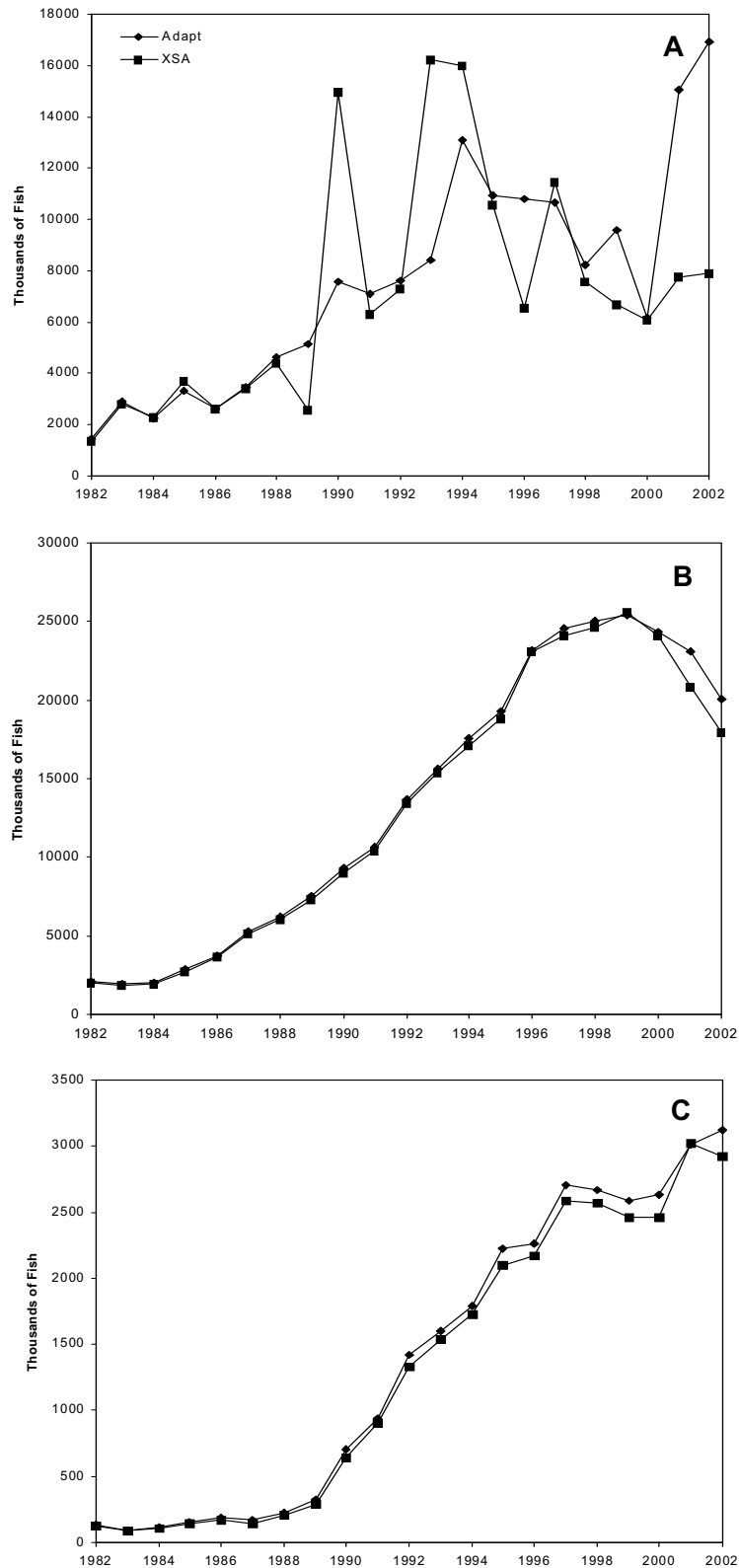




Figure D.12. Average age 4 and 5 fishing mortality rates for weakfish estimated by evaluation runs of the extended survivors analysis. Results from the ADAPT VPA assessment for weakfish (Kahn, 2002a) and an integrated catch at age (ICA) analysis are shown.

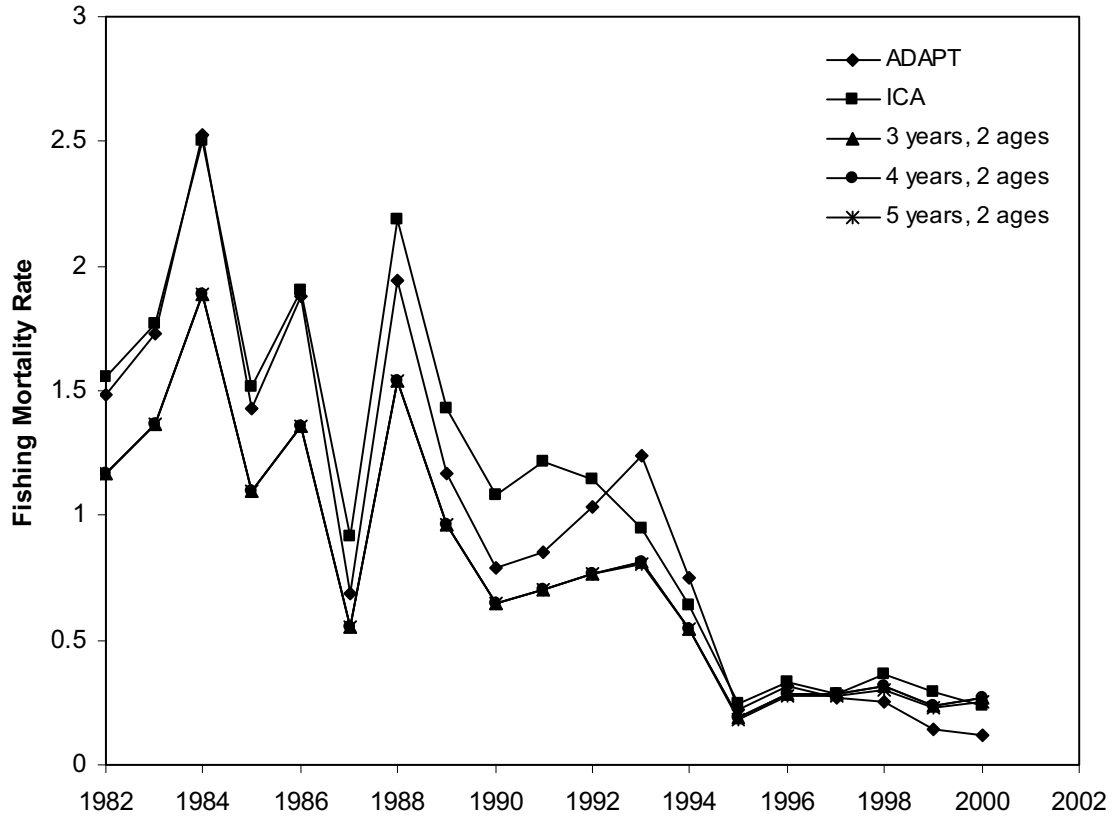


Figure D.13. Average fishing mortality rates by age class during 1998-2000 for weakfish estimated by evaluation runs of the extended survivors analysis. Results from the ADAPT VPA assessment for weakfish (Kahn, 2002a) and an integrated catch-at-age (ICA) analysis are shown.

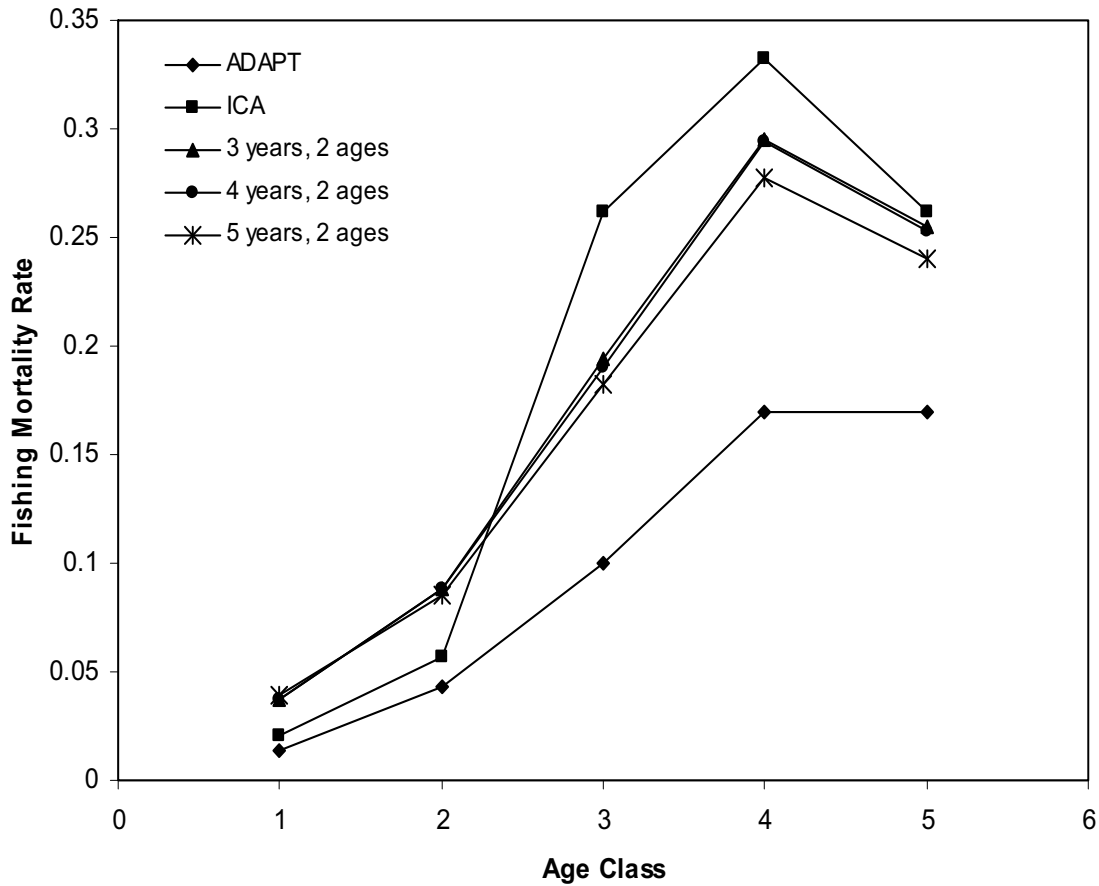


Figure D.14. Abundance of (A) ages 4-6+ and (B) ages 1-3 weakfish as estimated by XSA, ADAPT and ICA.

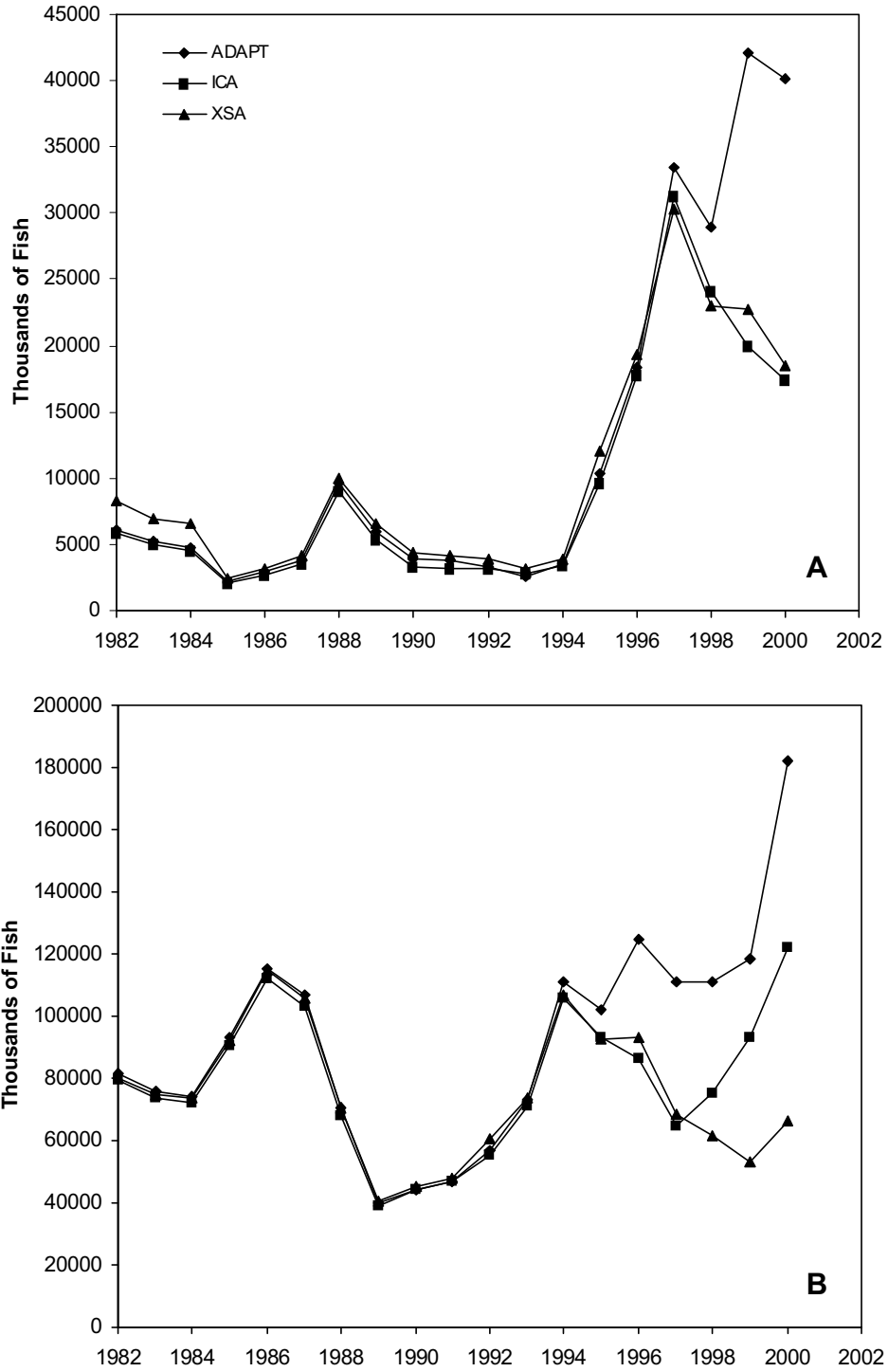


Figure D.15. Total biomass (000 mt) of the bluefish stock from 1982-2002 estimated by the ASPIC biomass-dynamic model (Lee, 2003).

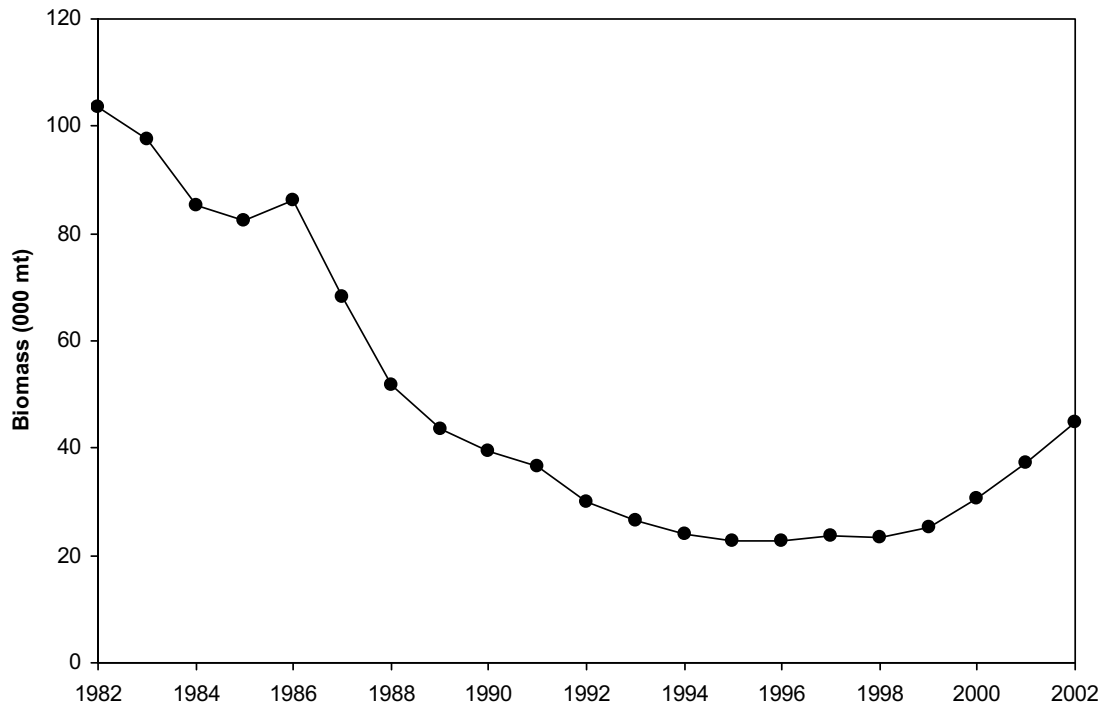


Figure D.16. Assumed biomass size distribution of the benthic invertebrate prey category.

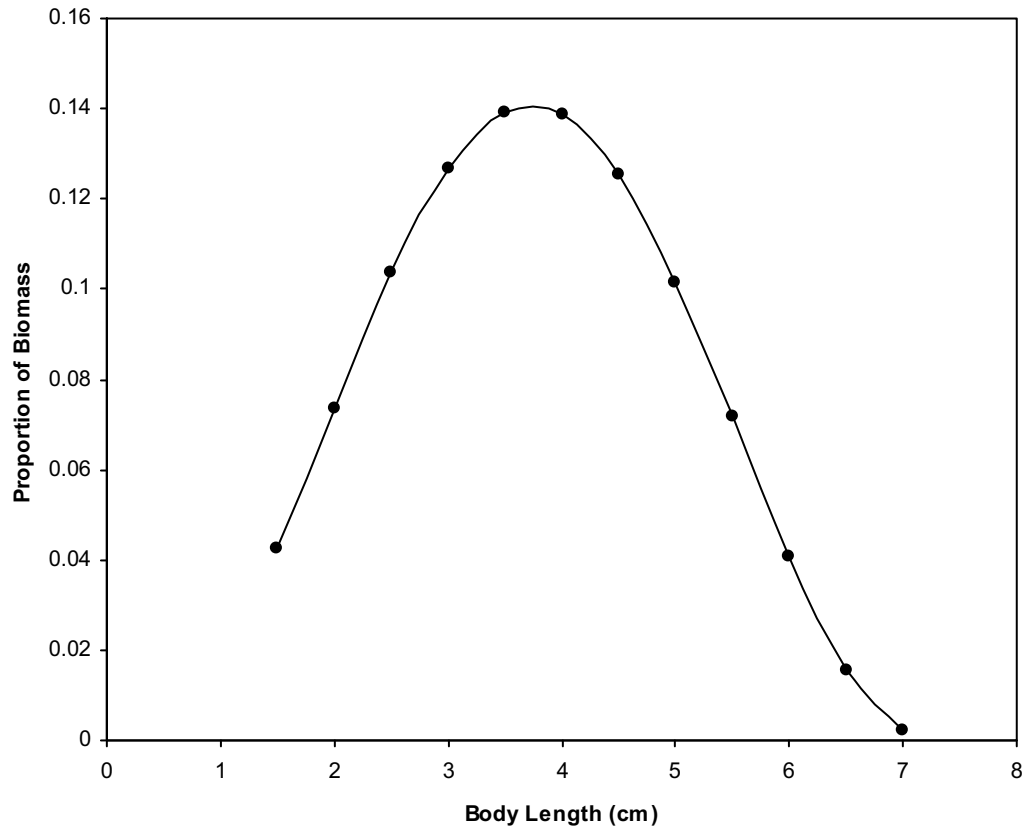


Figure D.17. Assumed biomass size distribution of the macrozooplankton prey category.

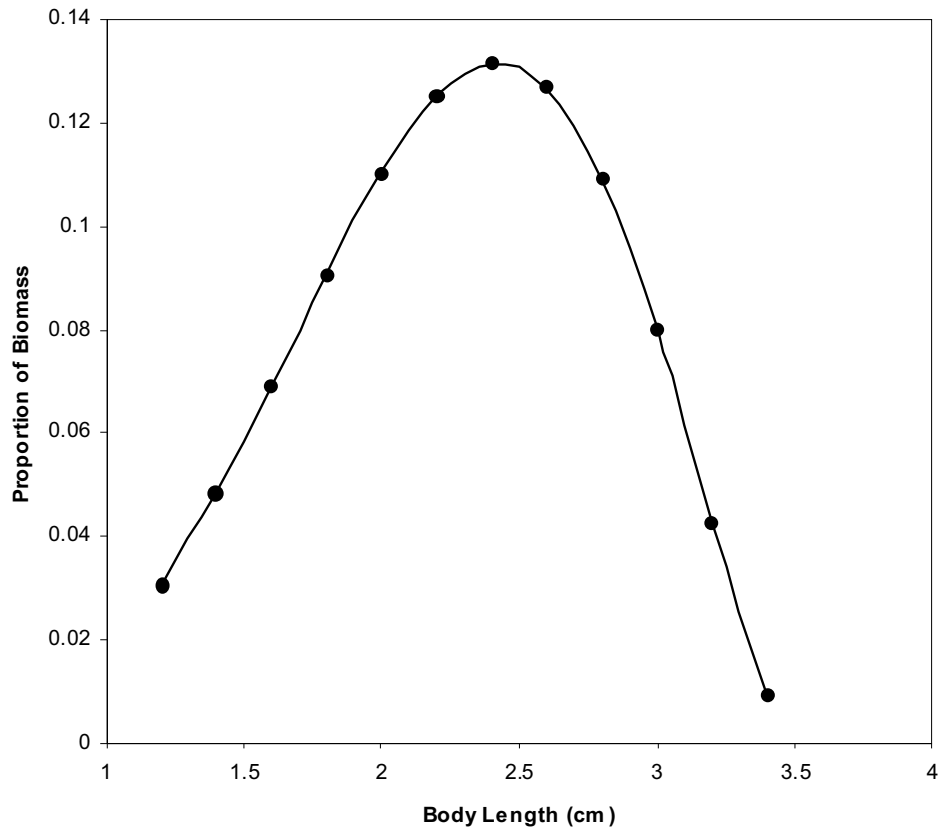


Figure D.18. Biomass size distribution of the benthic crustacean prey category.

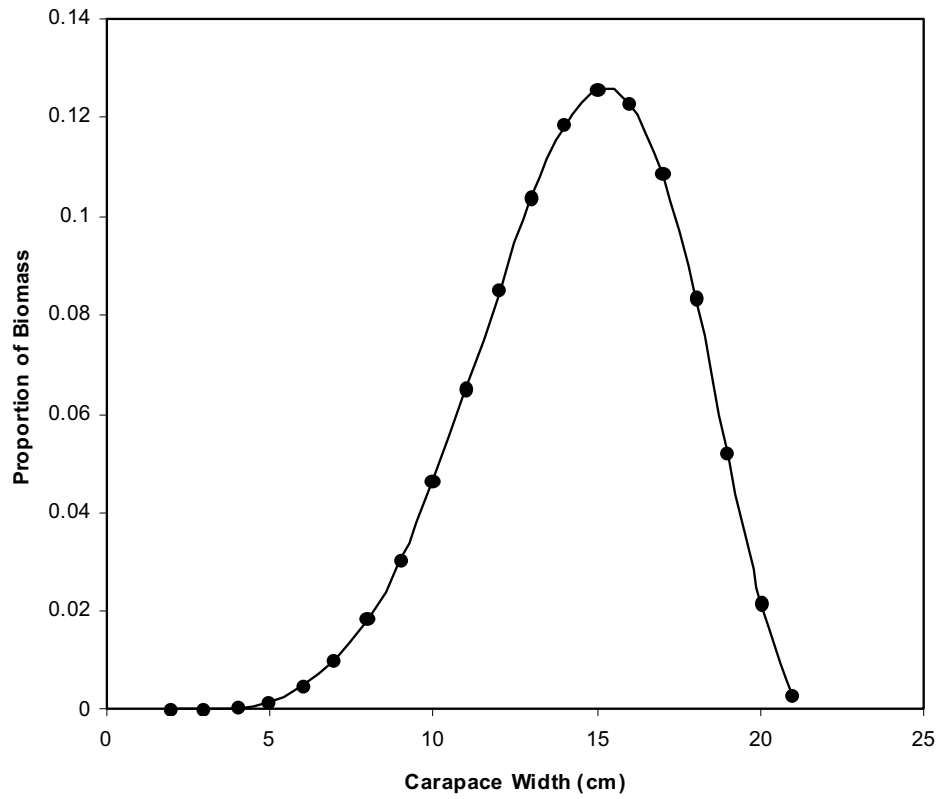


Figure D.19. Seasonal bay anchovy biomass (mt) estimates for the Chesapeake Bay (Rilling and Houde, 1999) and the New Jersey coast.

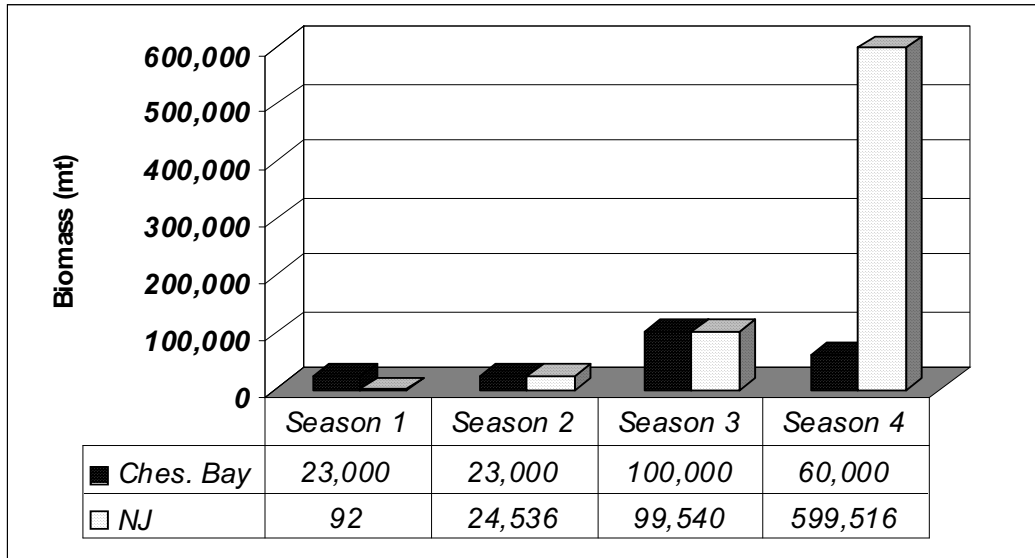




Figure D.20. Annual z-transformed (+2) CPUE indices for the Chesapeake Bay region.

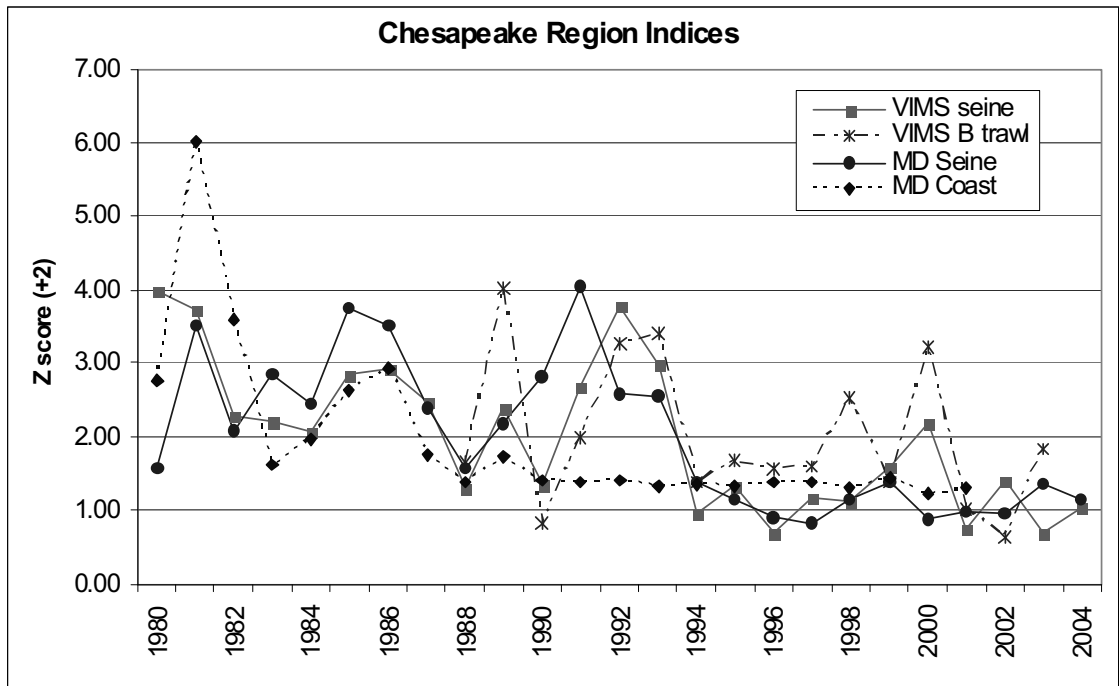


Figure D.21. Annual z-transformed (+2) CPUE indices for the Delaware Bay region.

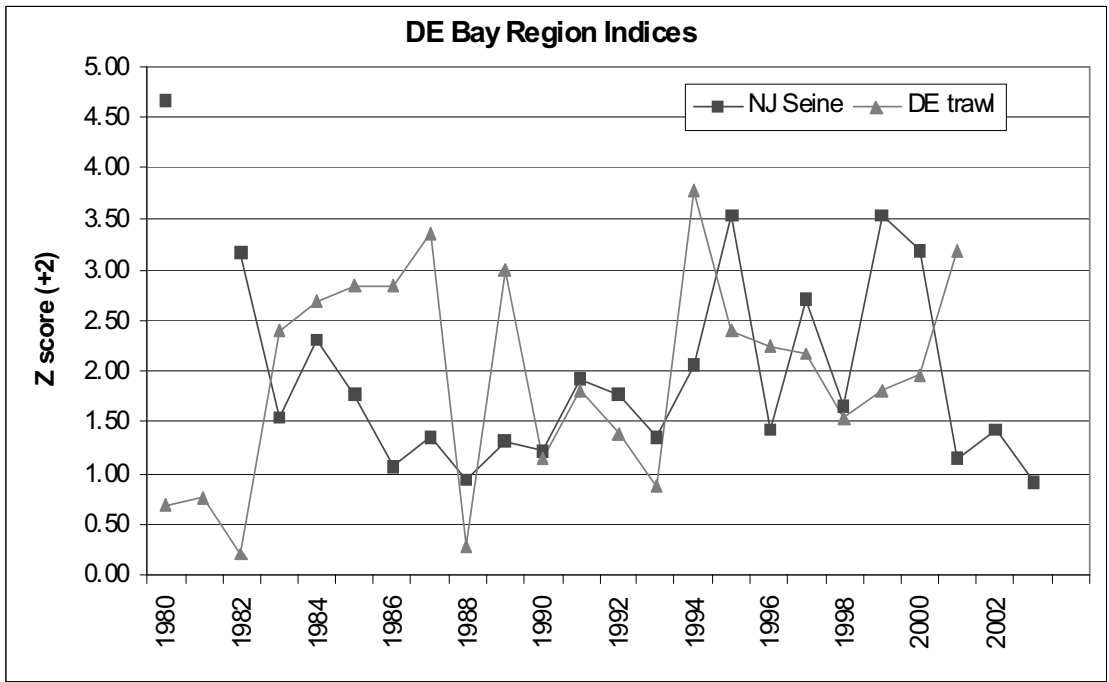


Figure D.22. Combined weighted Chesapeake Bay index, Delaware Bay index and a combined (Chesapeake and Delaware) *Estuary* index.

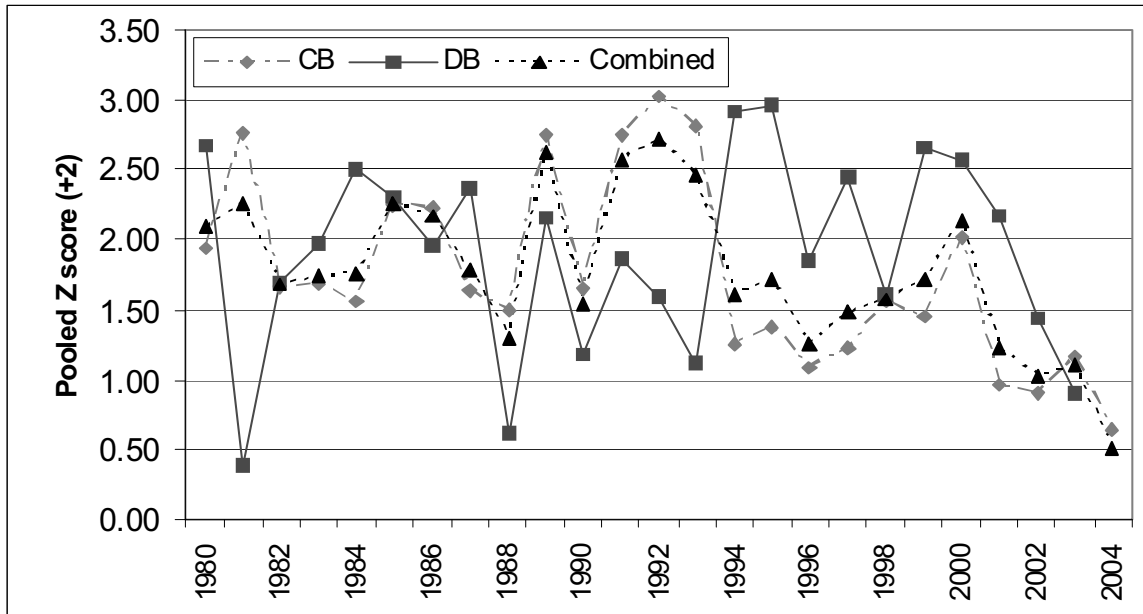


Figure D.23. Annual z-transformed (+3) CPUE indices for the NJ Ocean Trawl, SEAMAP survey, and a combined *Coastal* index.

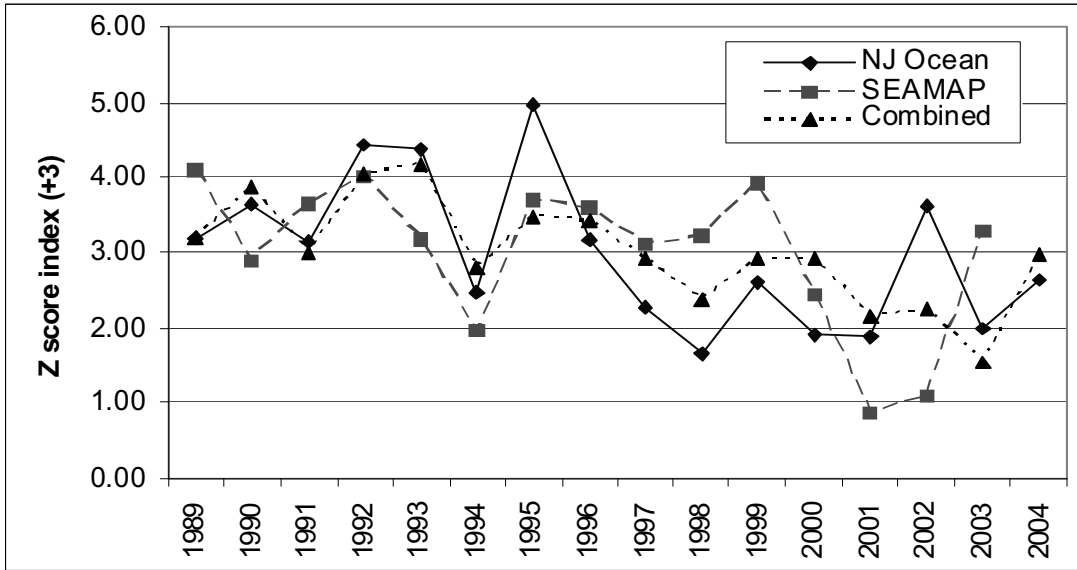


Figure D.24. Diet composition of (A) age-0, (B) age 1-2, and (C) age 3-5 striped bass in the Chesapeake Bay from Hartman & Brandt, 1995a.

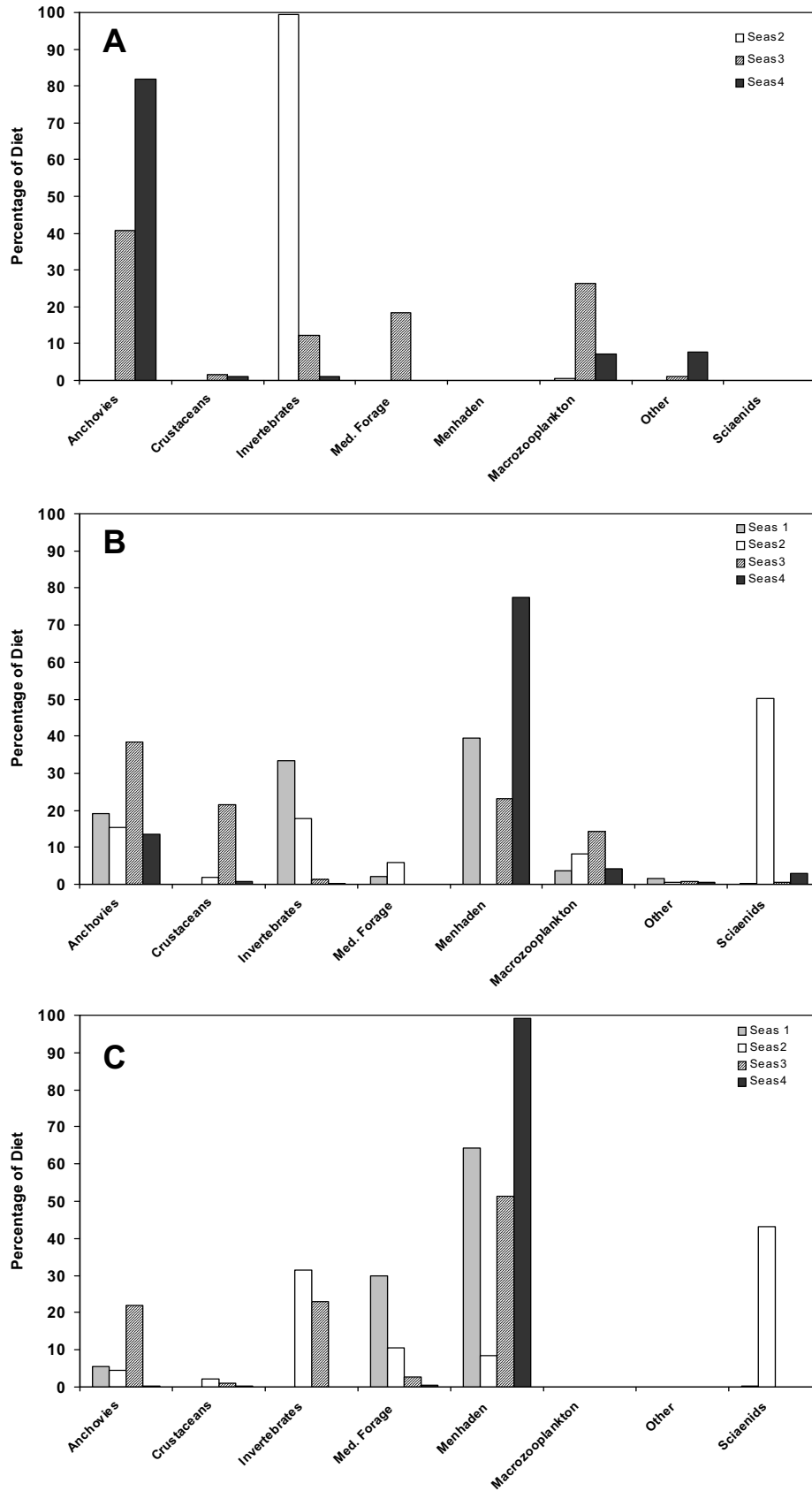


Figure D.25. Diet composition of (A) ages 5-6 and (B) ages 8+ striped bass in the Chesapeake Bay (Walter and Austin 2003).

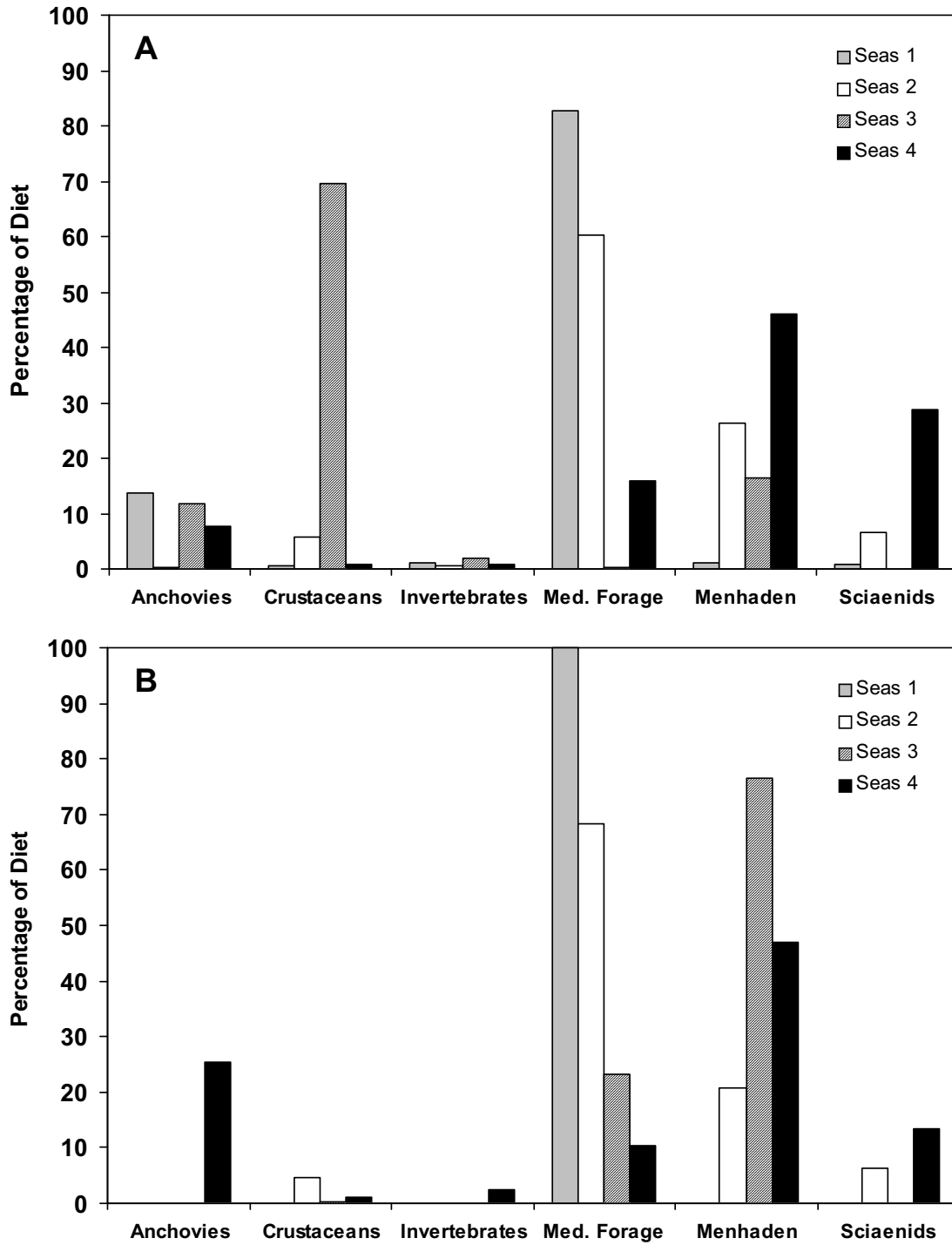


Figure D.26. Seasonal proportion of biomass in each prey category in the Chesapeake Bay region.

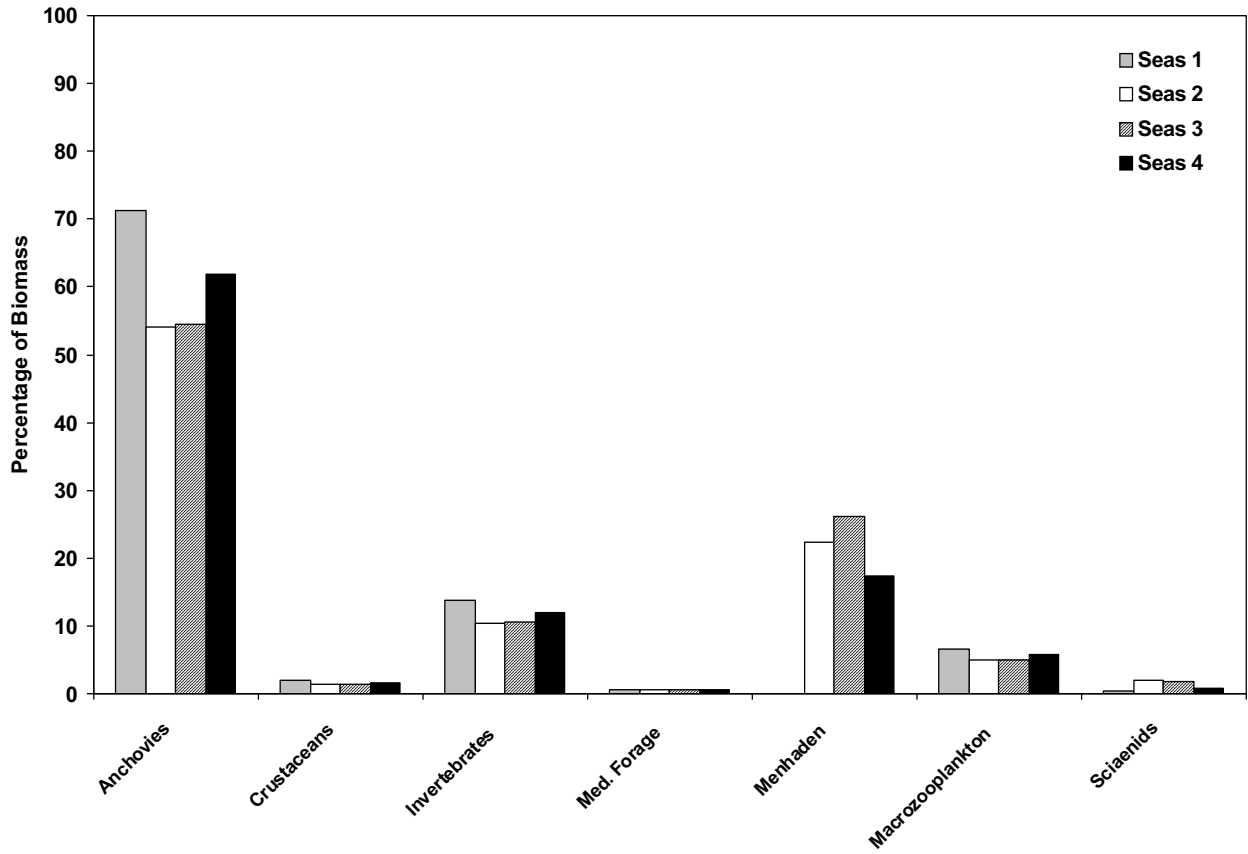


Figure D.27. Five regional strata were defined from North Carolina to the Gulf of Maine.

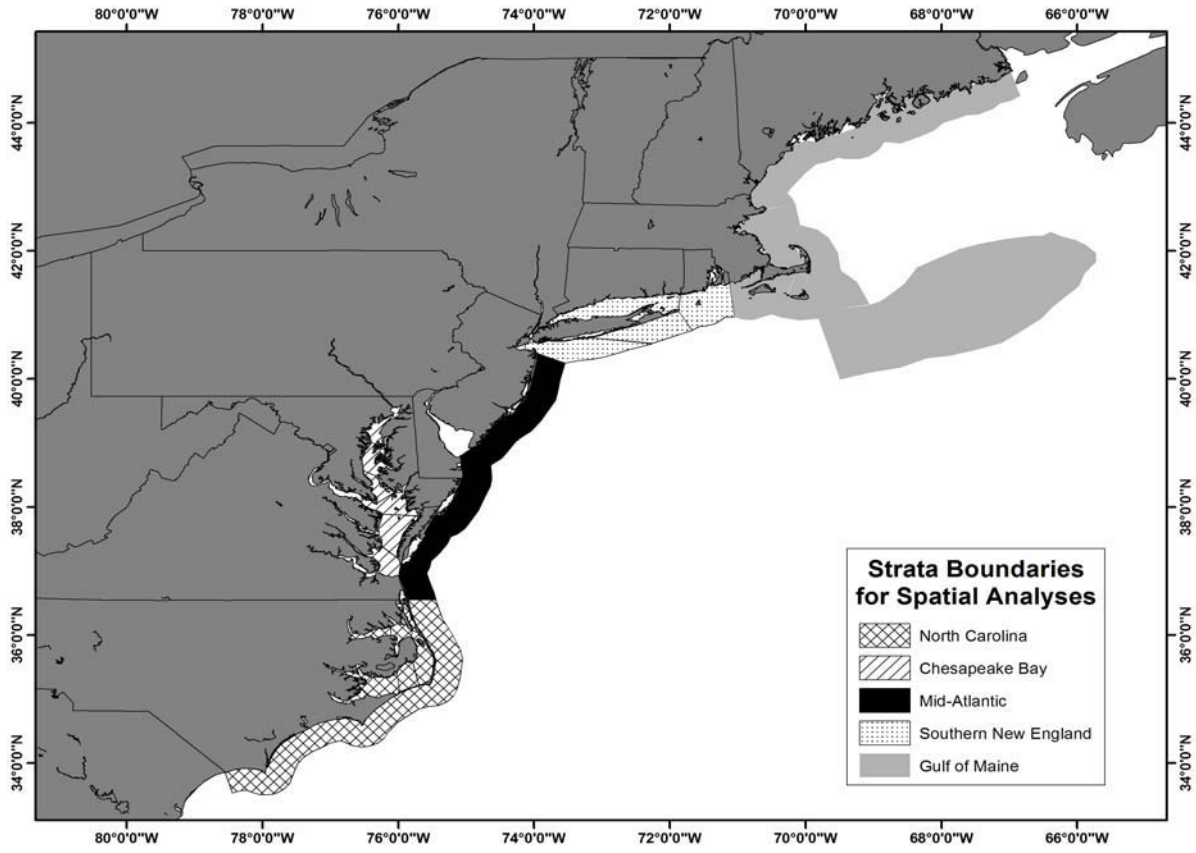
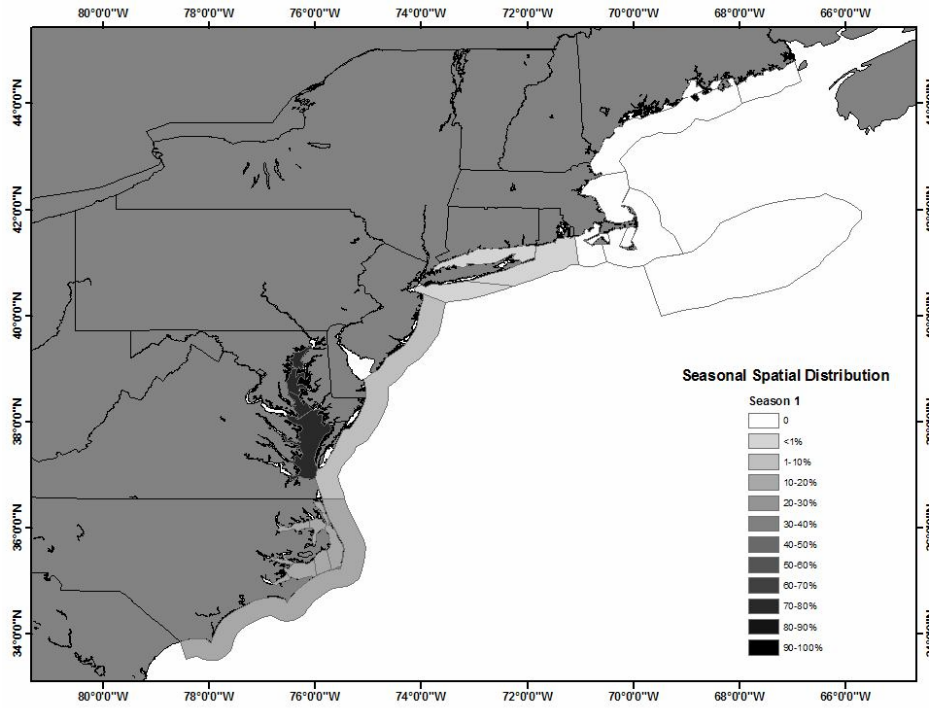




Figure D.28. Seasonal spatial distribution of striped bass based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

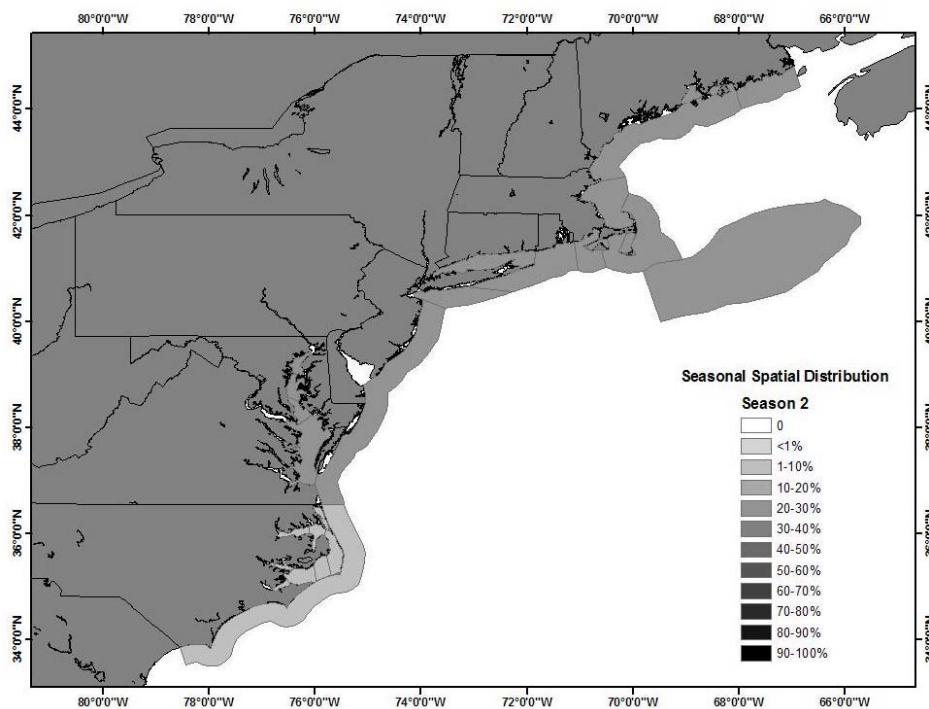
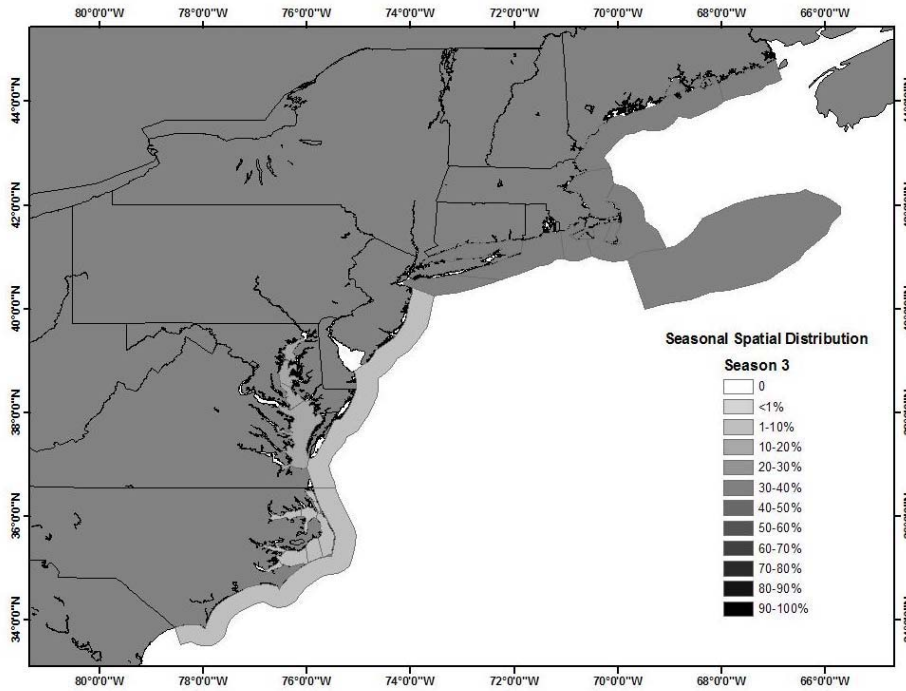


Figure D.28 (cont'd). Seasonal spatial distribution of striped bass based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

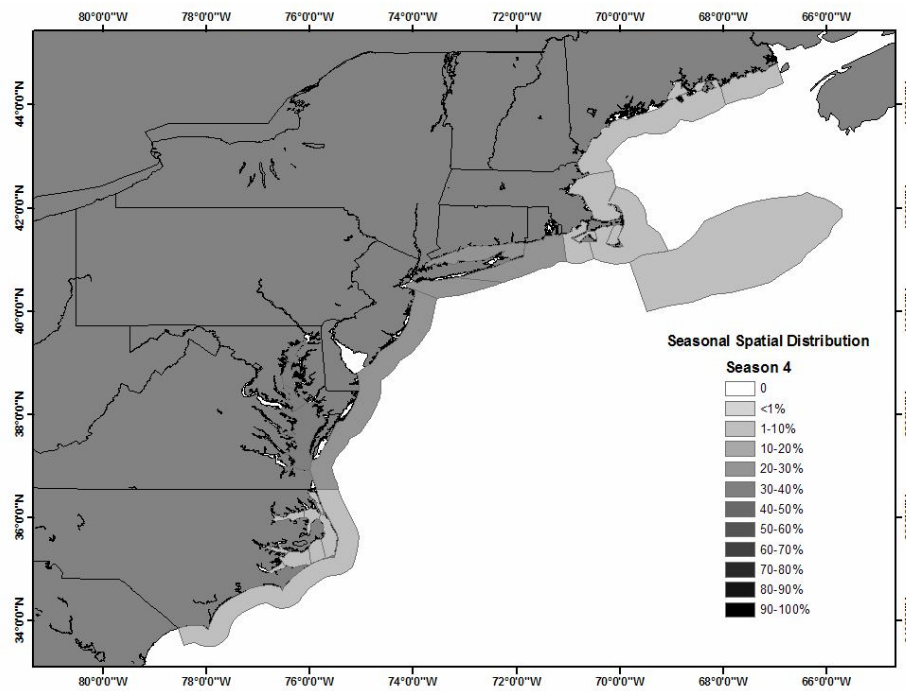


Figure D.29. Observed age-structure of striped bass catch within each region.

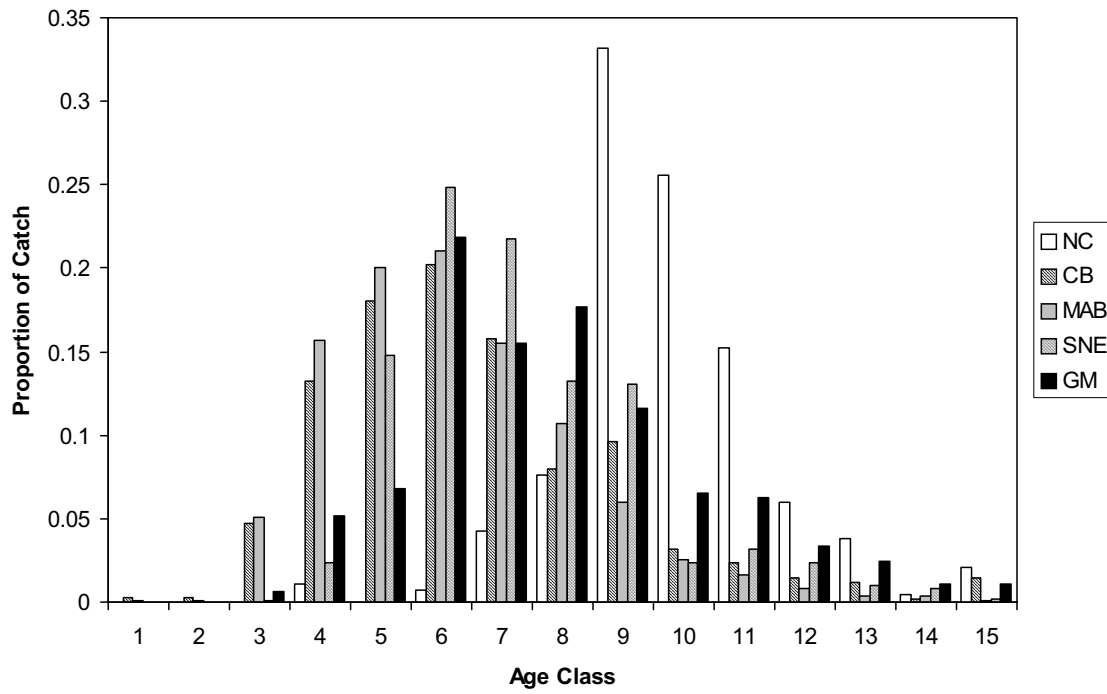
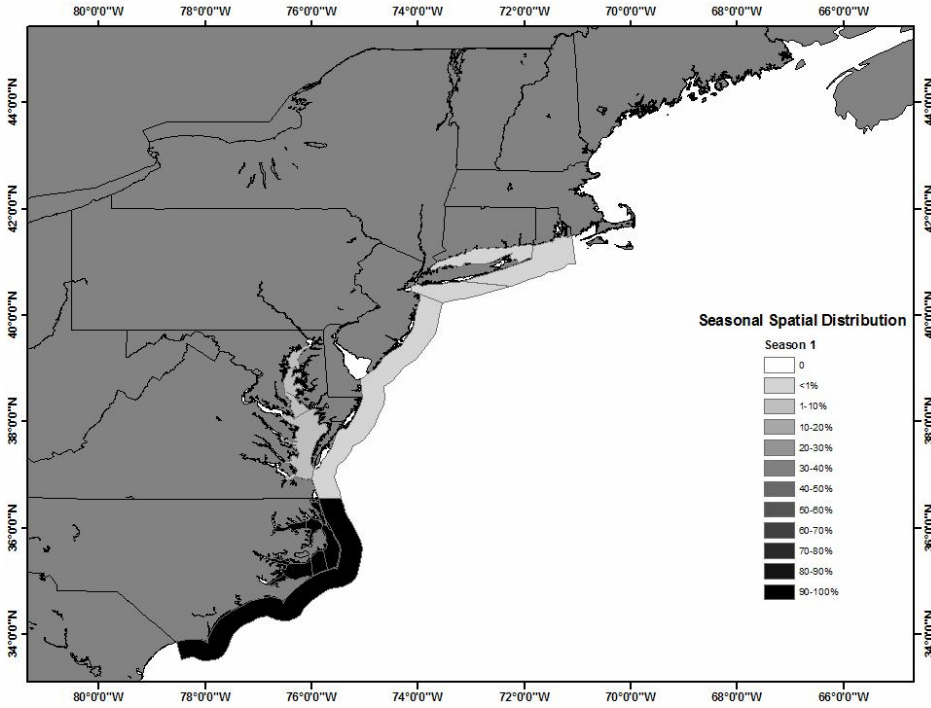


Figure D.30. Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

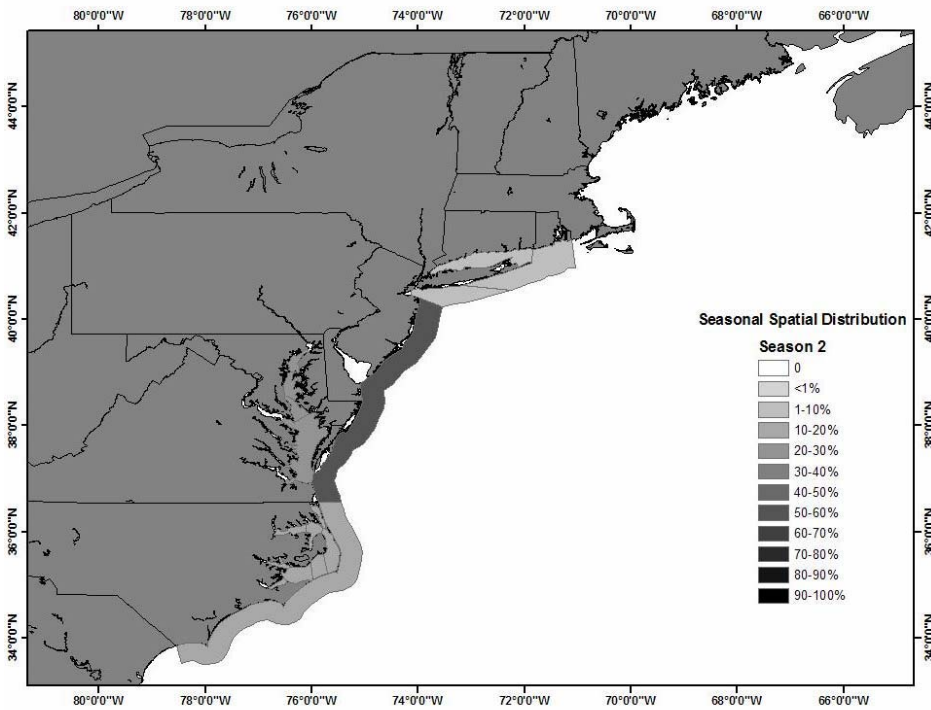
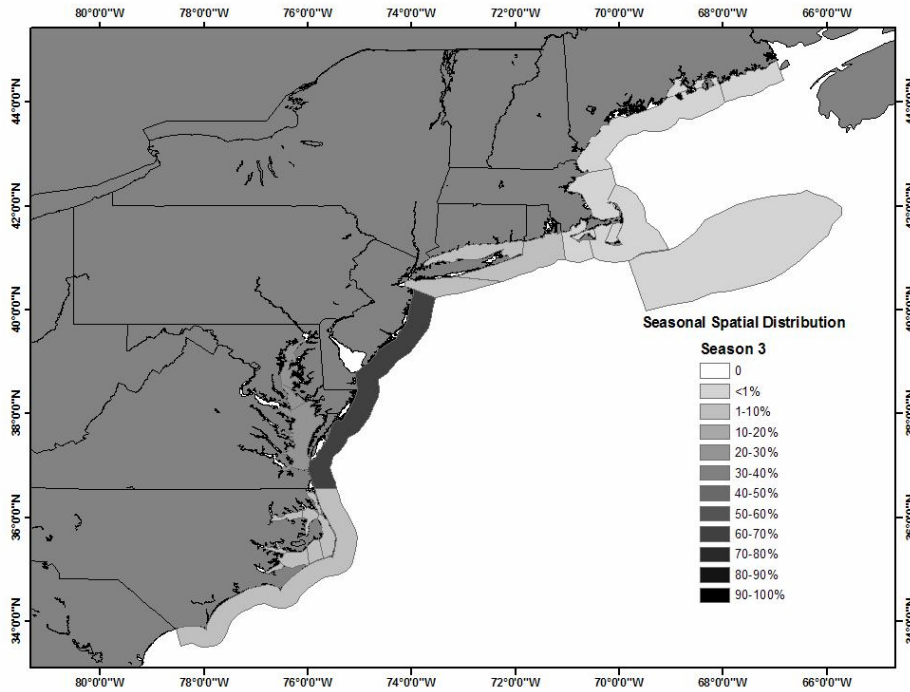


Figure D.30 (cont'd). Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

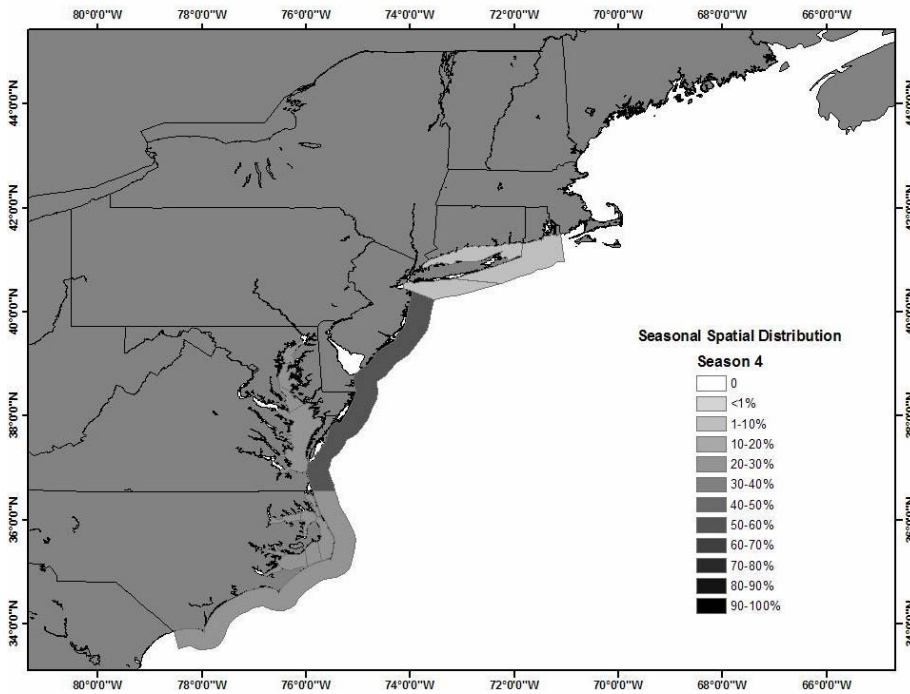


Figure D.31. Observed age-structure of weakfish catch within each region.

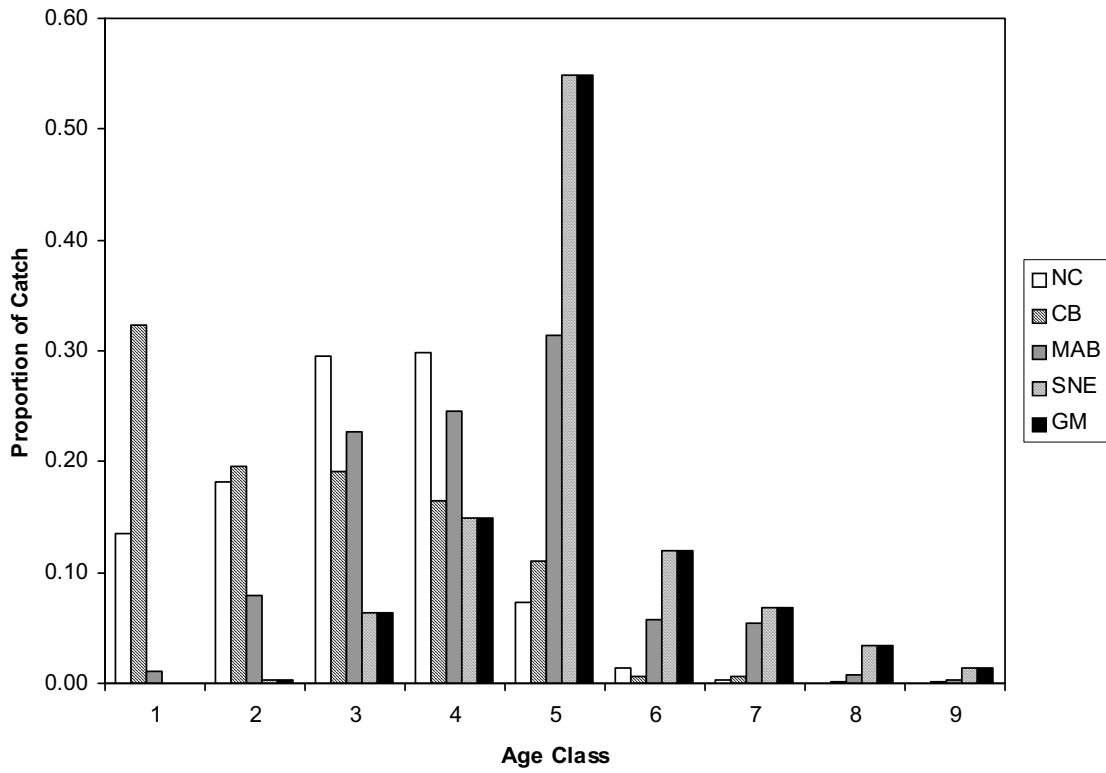
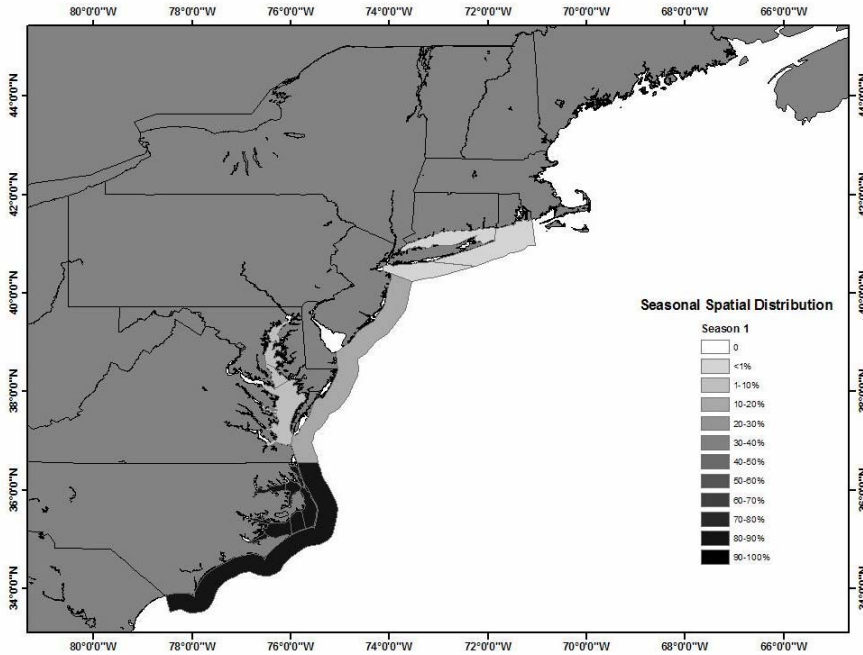


Figure D.32. Seasonal spatial distribution of bluefish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

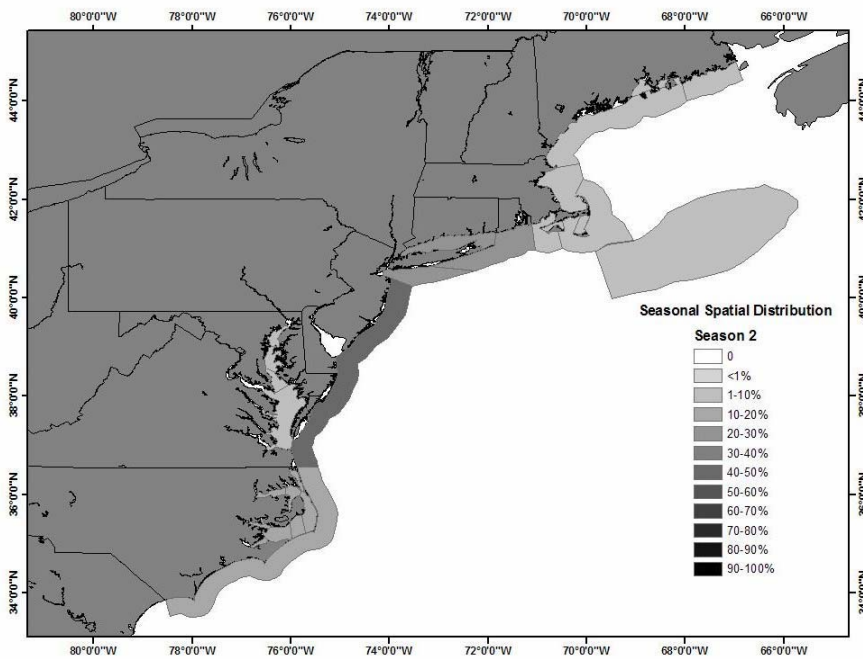
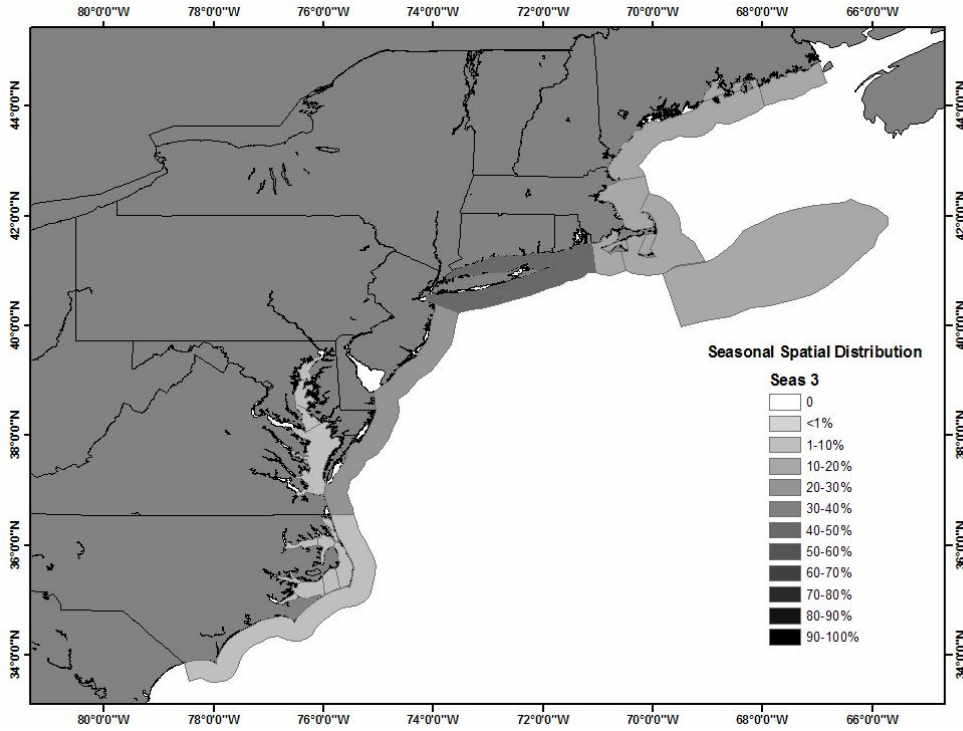


Figure D.32 (cont'd). Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

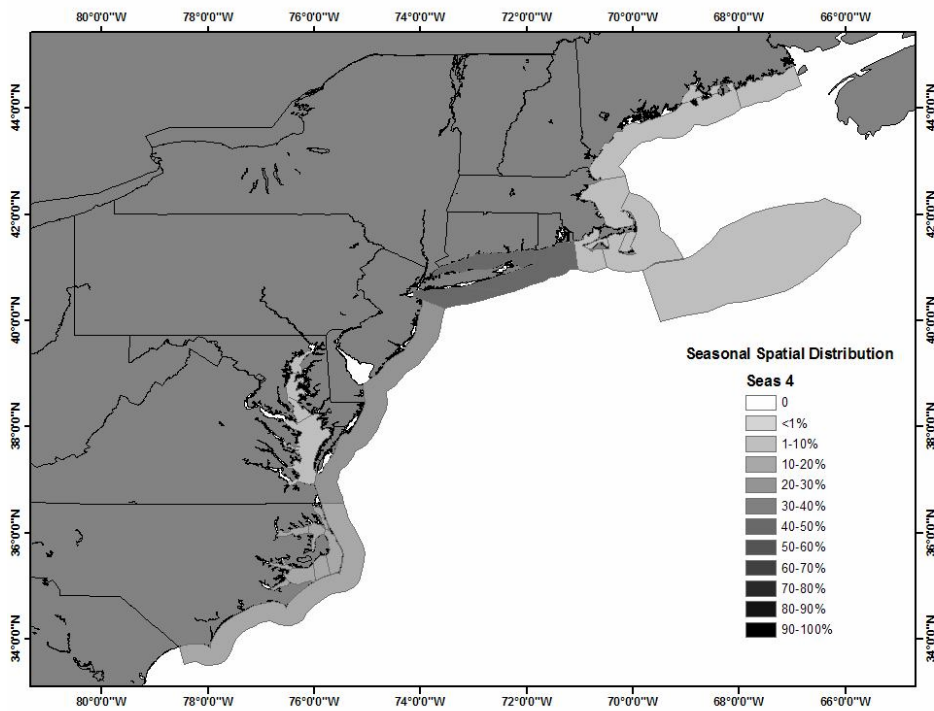




Figure D.33. Relative mean catch per tow of bluefish in each region for each season by the NMFS bottom trawl survey.

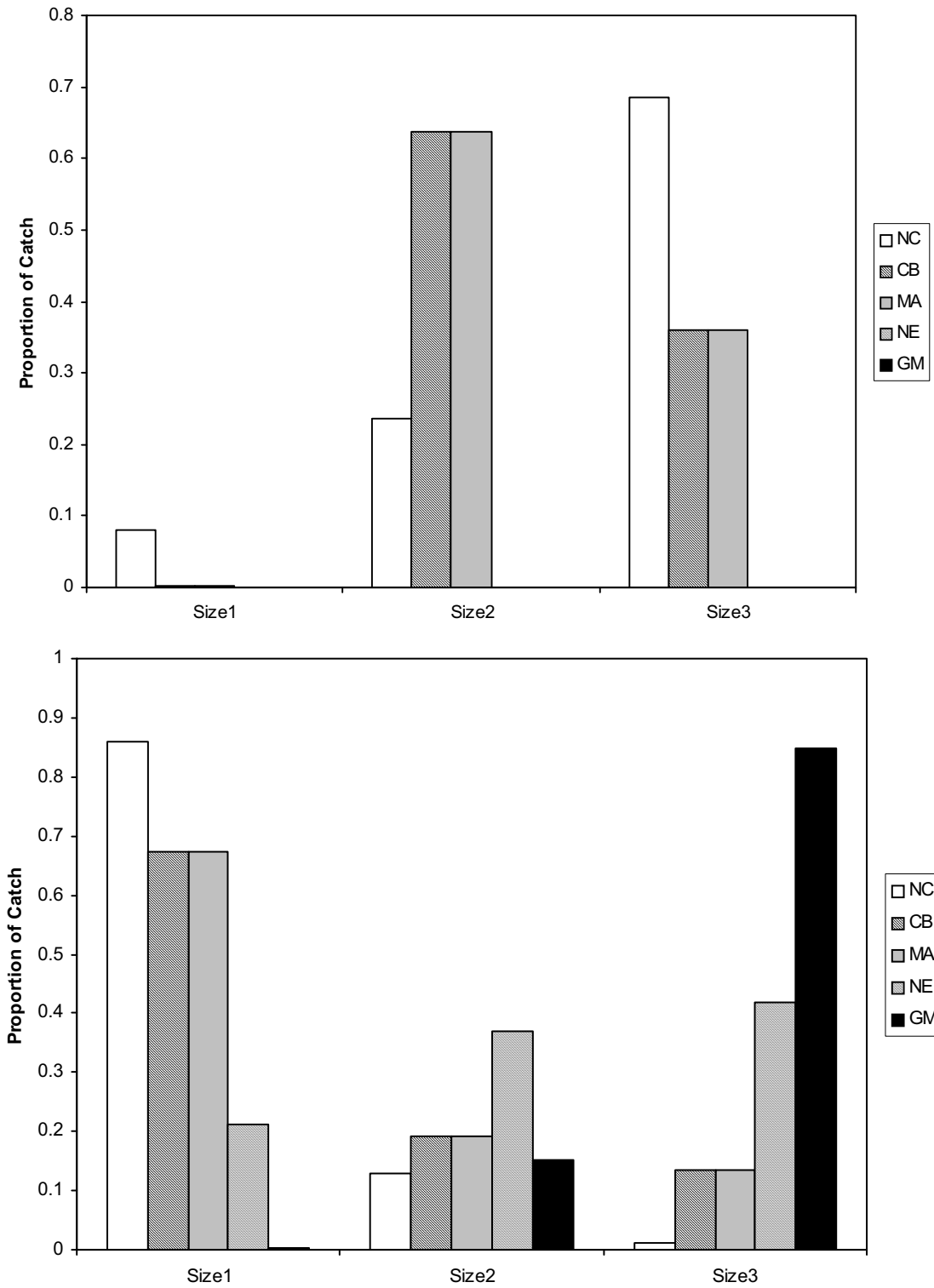
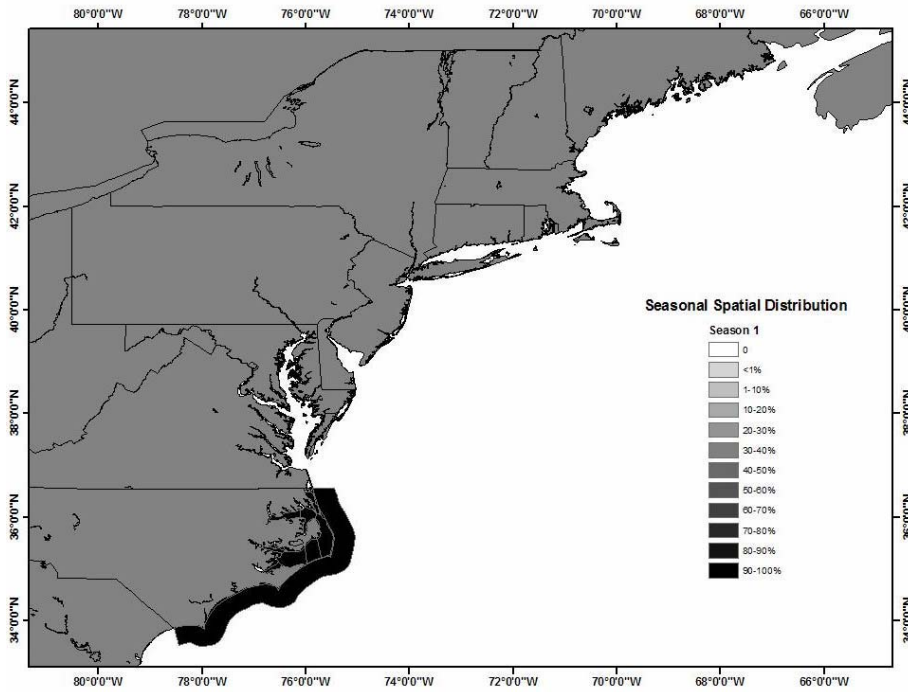


Figure D.34. Seasonal spatial distribution of menhaden based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

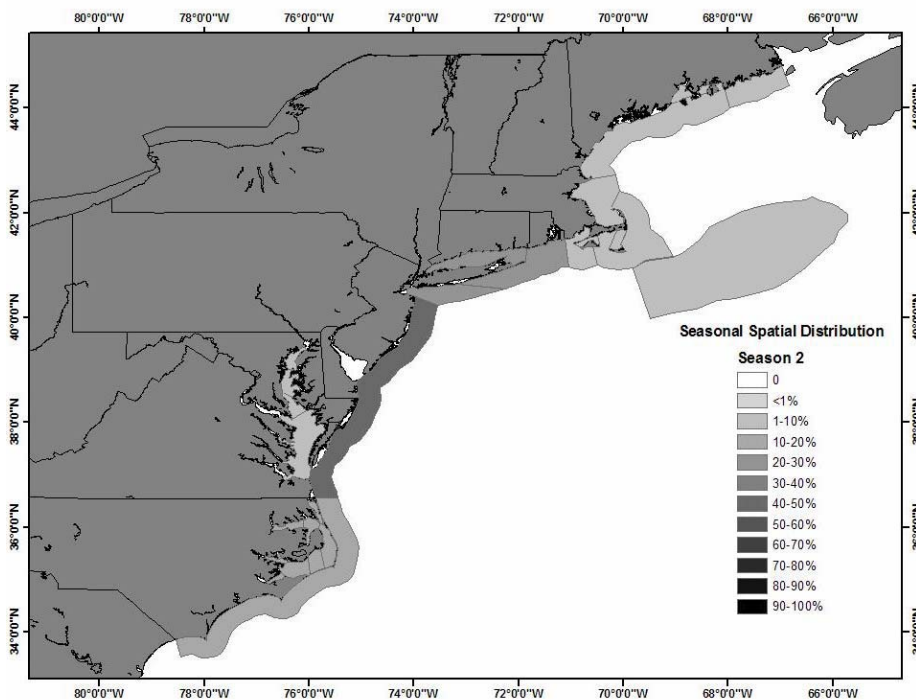
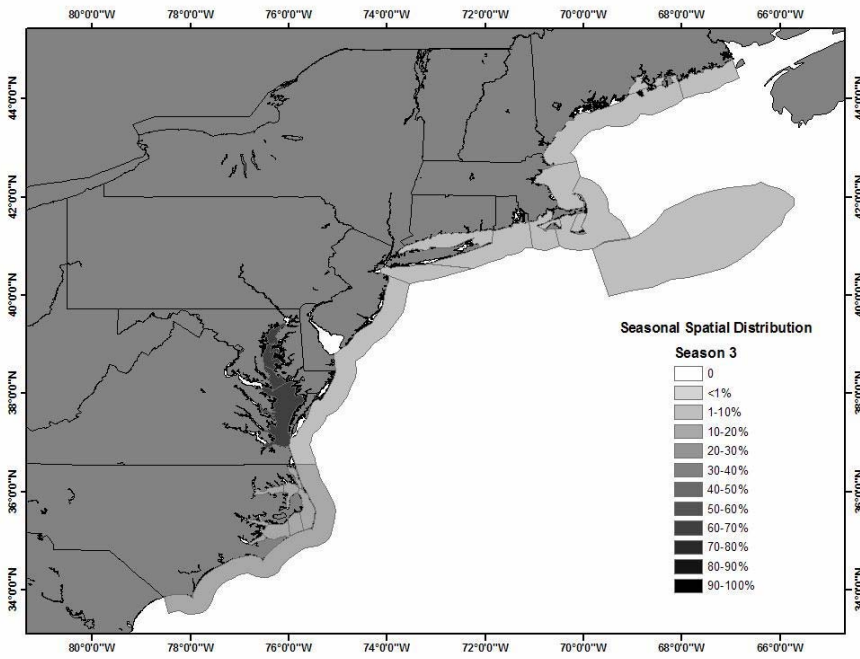


Figure D.34 (cont'd). Seasonal spatial distribution of menhaden based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

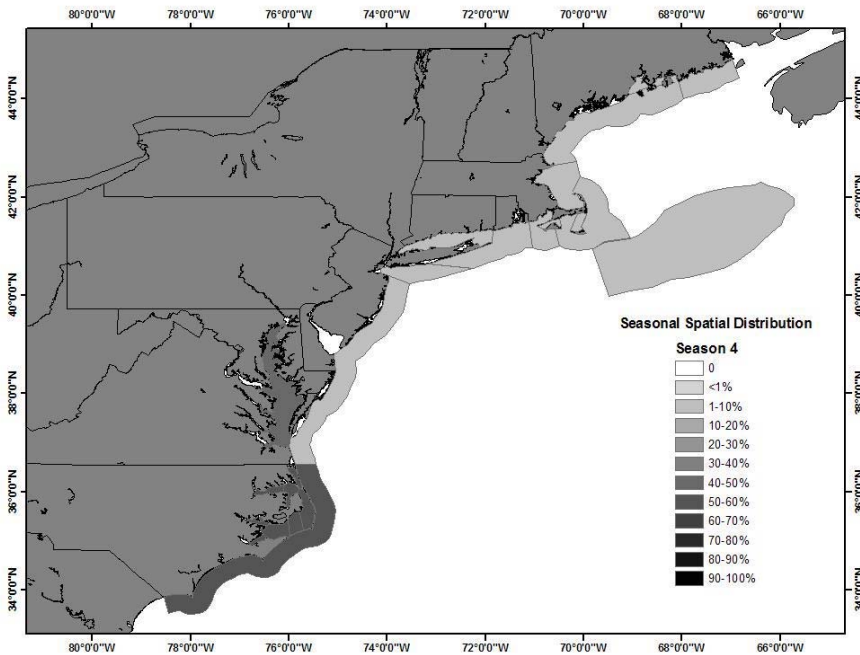


Figure D.35 (A.-C.). Seasonal spatial distribution of A) medium forage fish (primarily squid and butterfish), B) herrings (clupeids), and C) sciaenids (spot and croaker) from the mean catch per tow in each region from NMFS bottom trawl survey data.

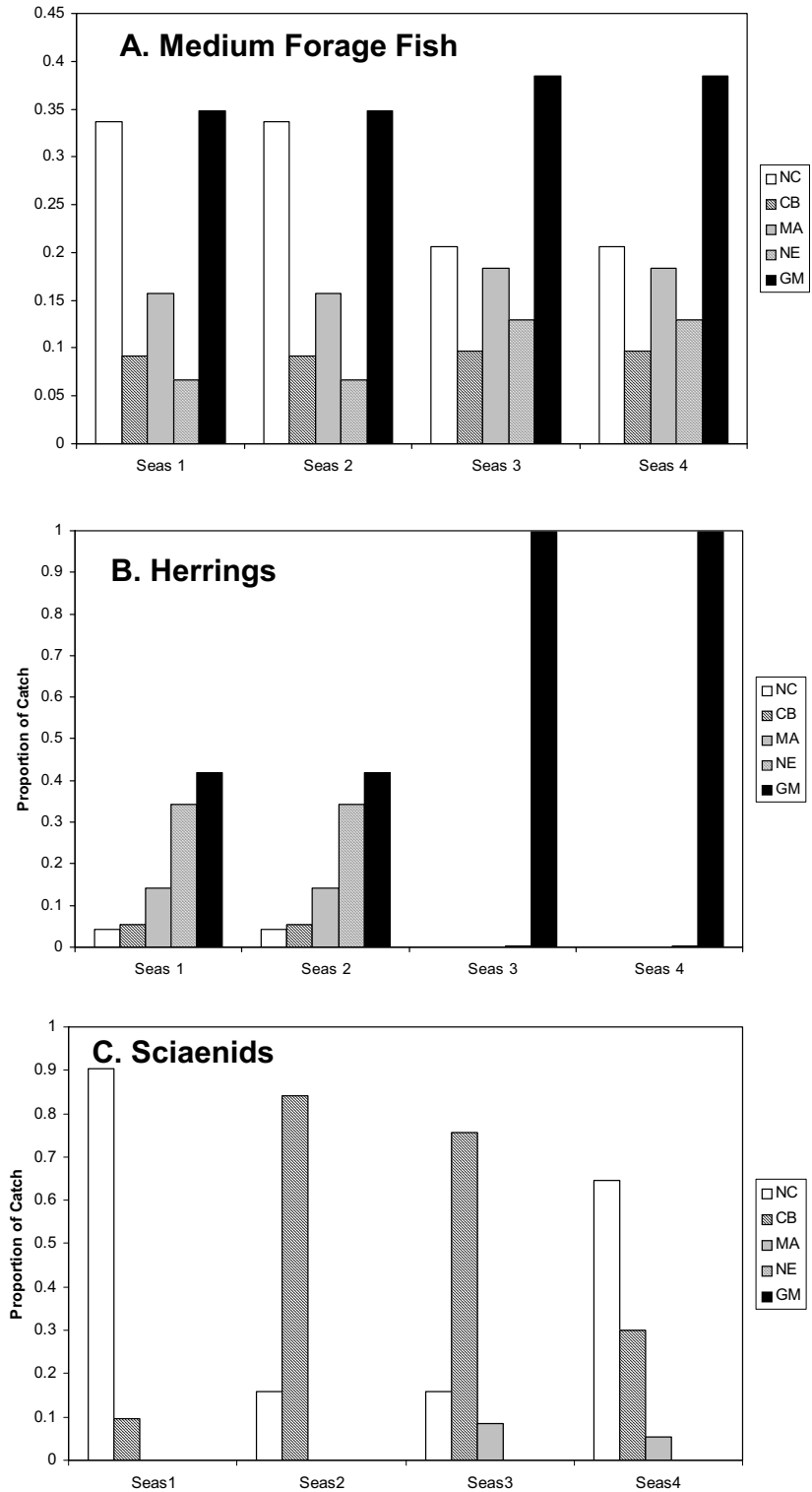


Figure D.36. Spatial distribution of anchovies, benthic invertebrates, benthic crustaceans and macrozooplankton.

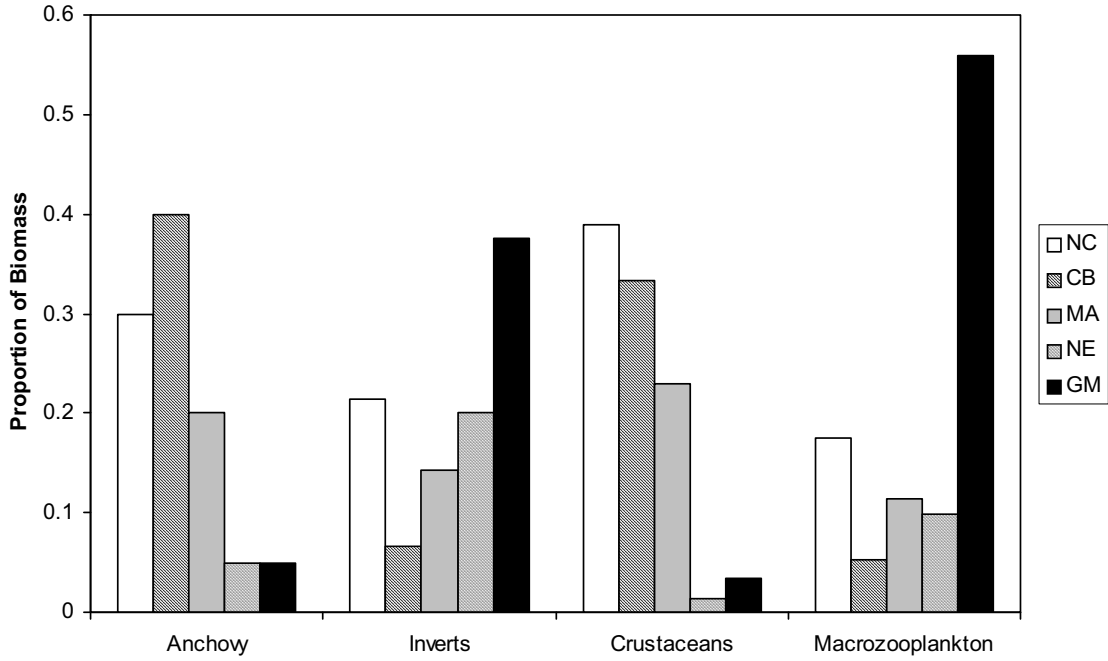


Figure D.37. Total population biomass (000 mt) for weakfish and striped bass.

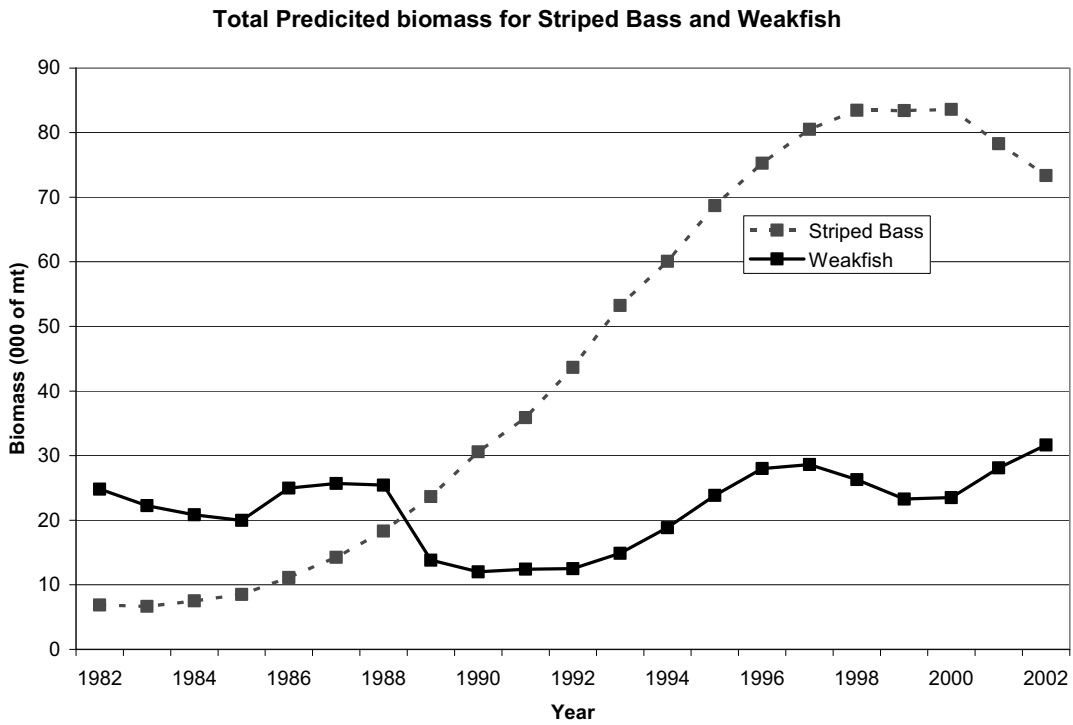


Figure D.38. Annual SSB (000 mt) for weakfish and striped bass.

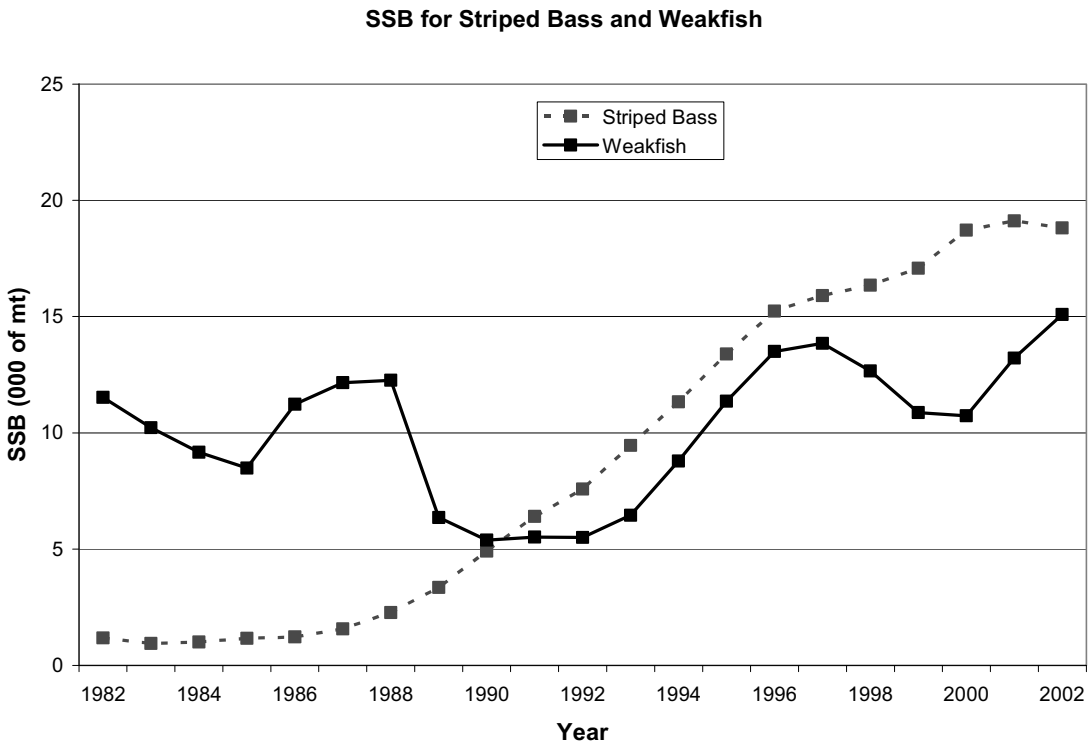


Figure D.39. Annual bluefish population biomass (000mt) by size class.

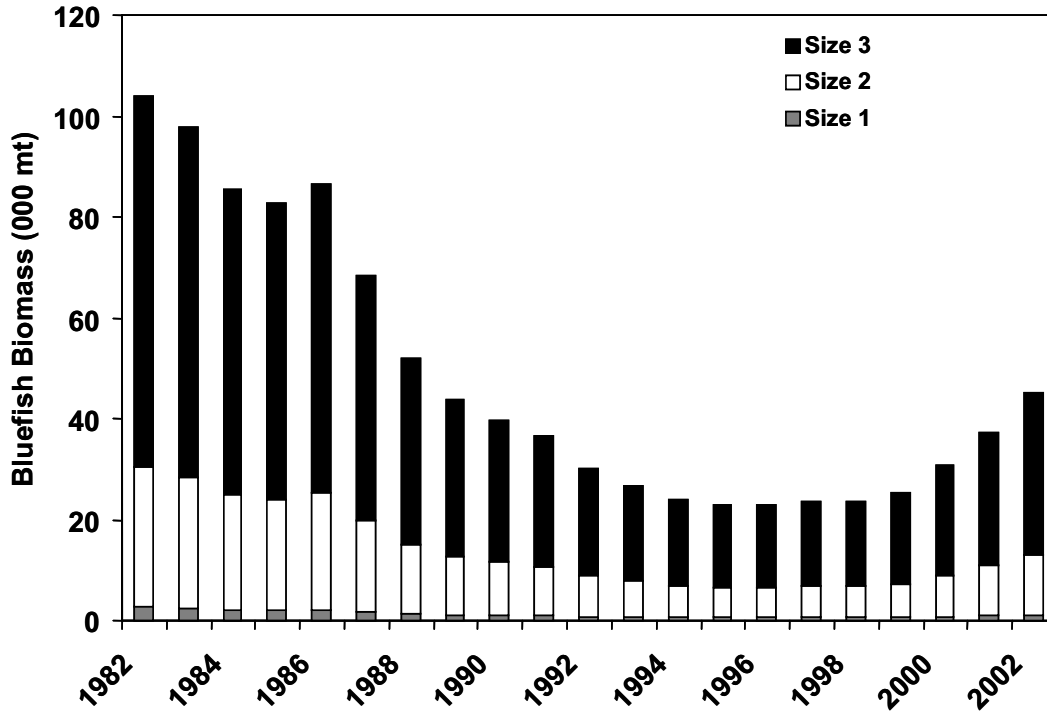


Figure D.40. Menhaden abundance at maturity (Age 2+, primary y-axis) and total menhaden abundance (secondary y-axis). Note the scale change on the secondary y-axis.

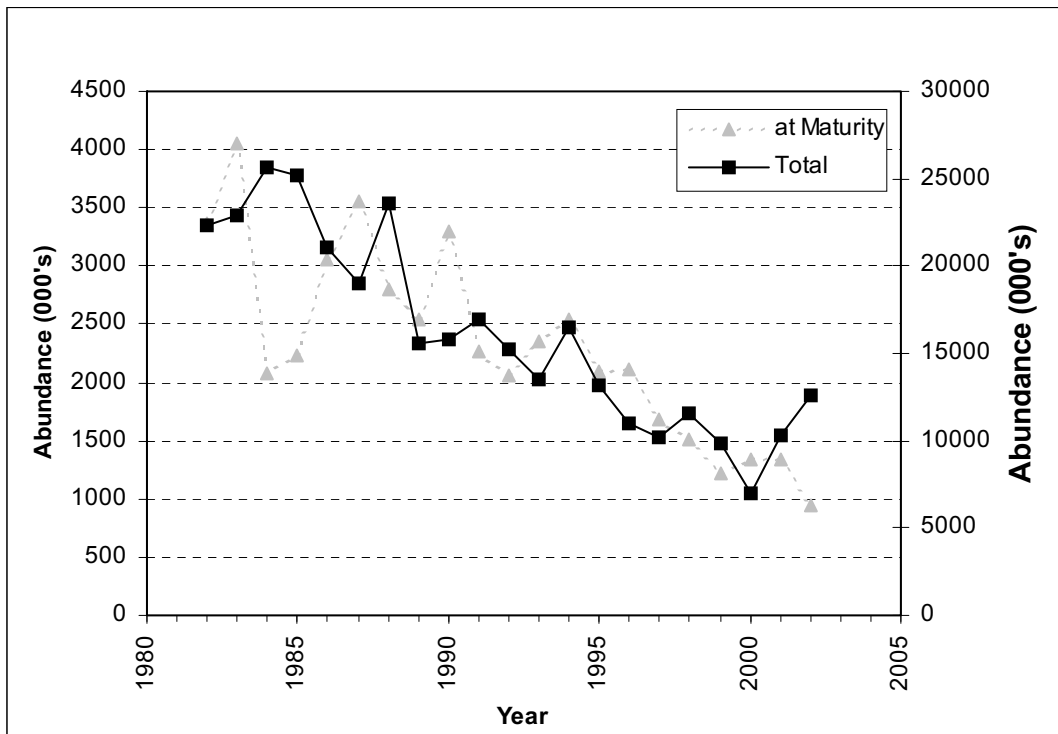


Figure D.41. Total menhaden SSB (primary y-axis) and population biomass (secondary y-axis) (000 mt). Note the scale change on the secondary y-axis.

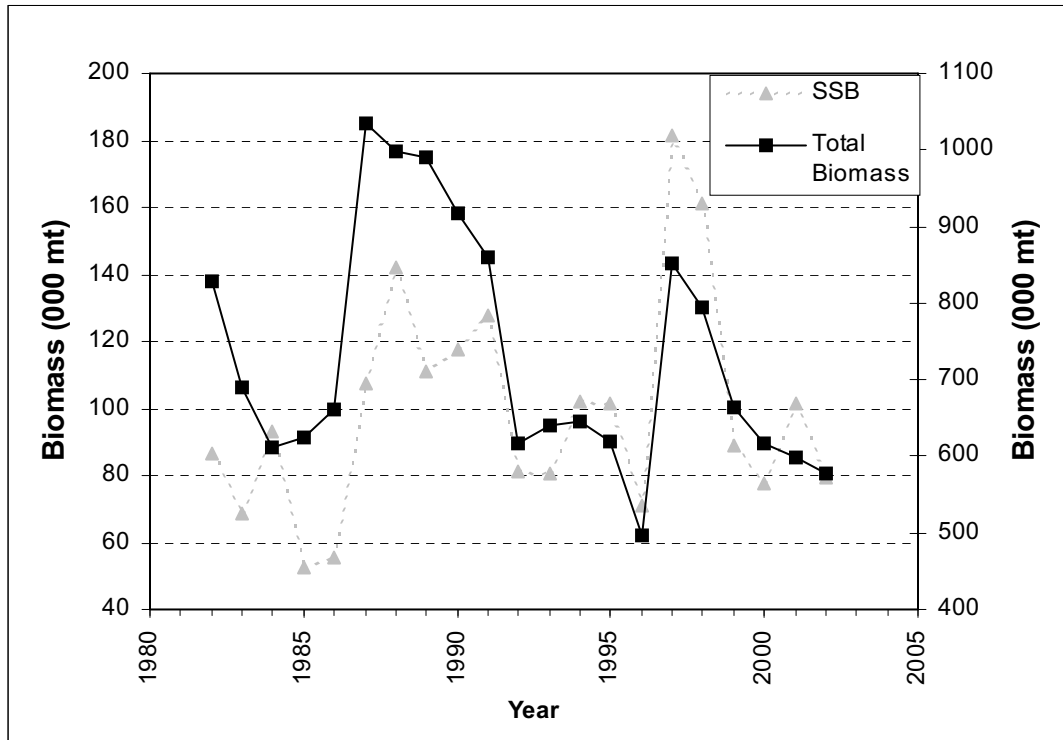


Figure D.42. Annual population biomass (000 mt) trends in MSVPA-X forage species.

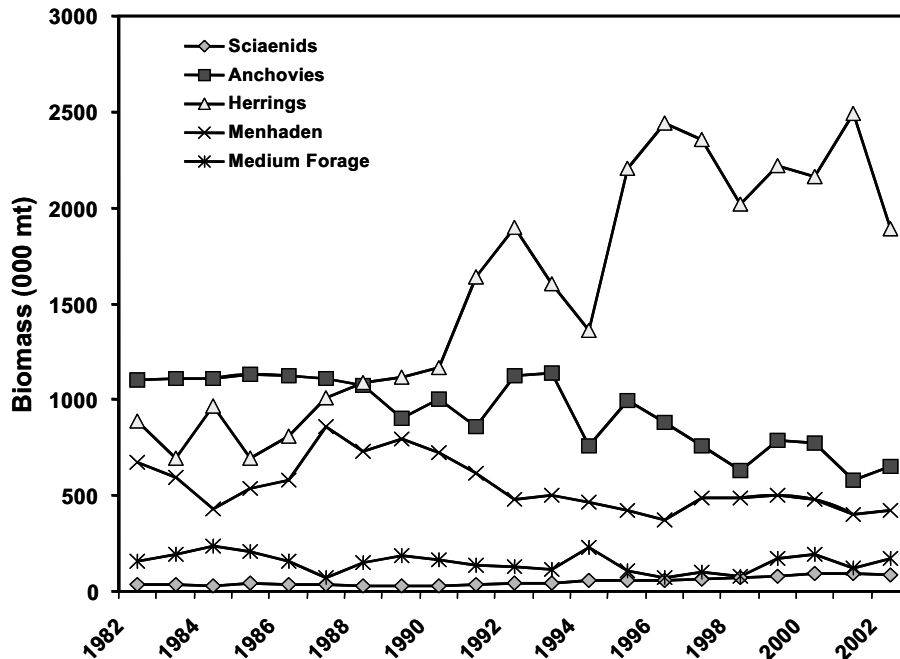




Figure D.43. Predicted average proportion of prey in striped bass diets.

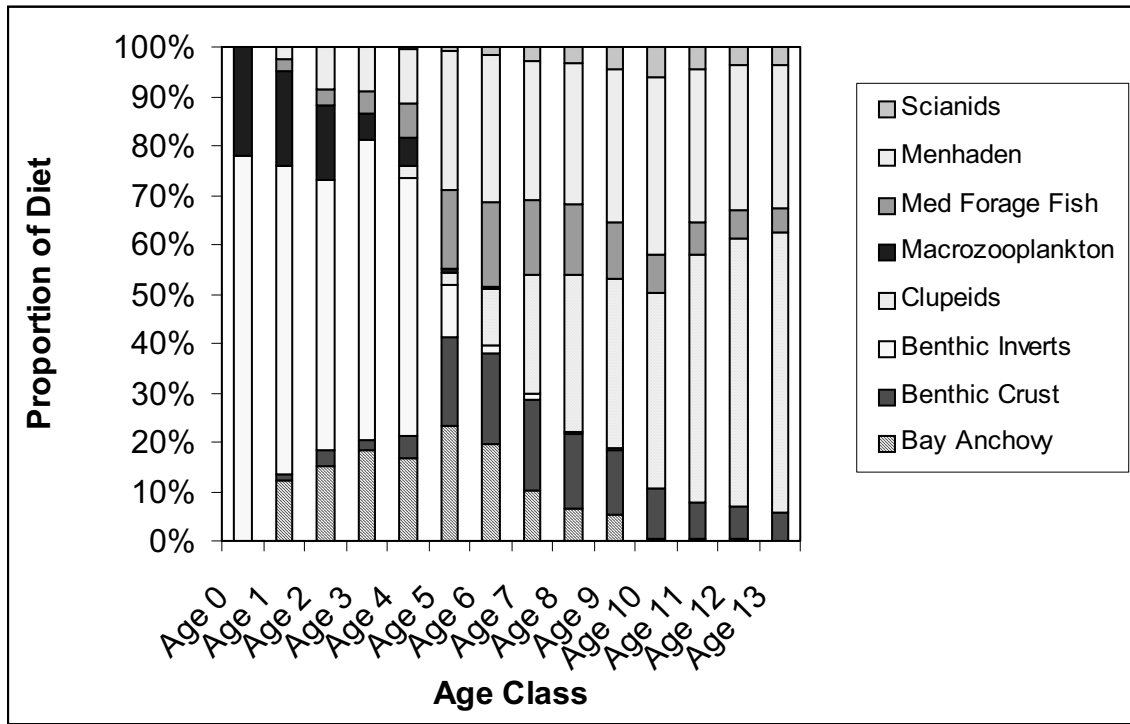


Figure D.44. Predicted average proportion of prey in weakfish diets.

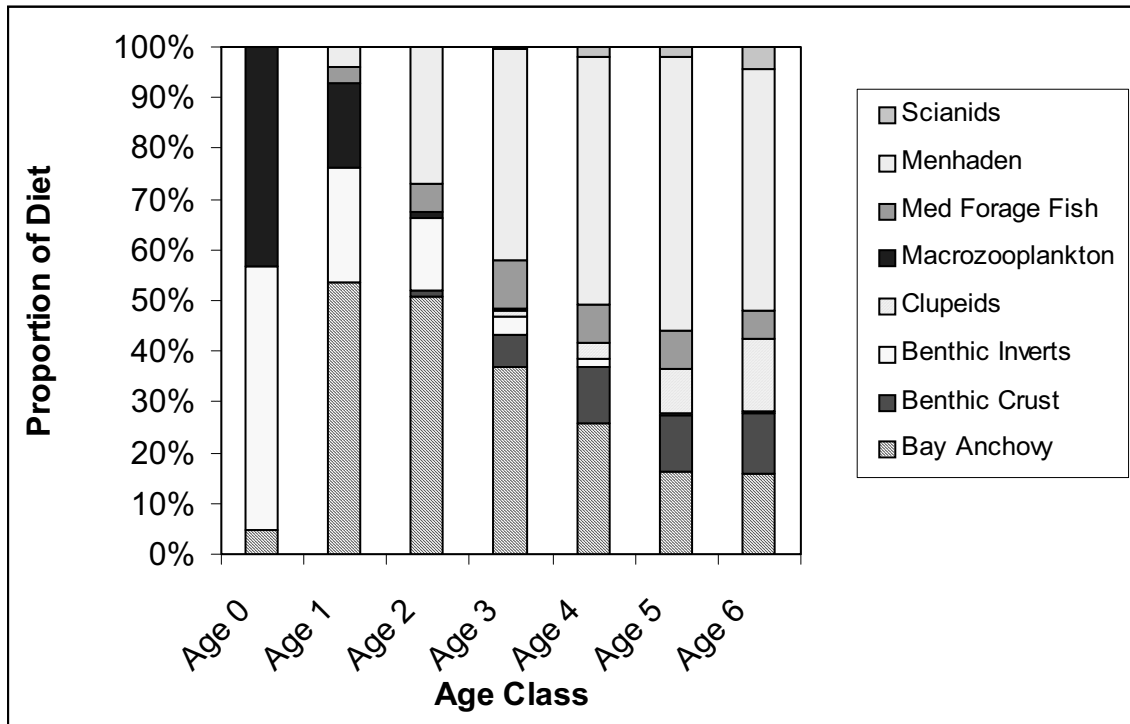


Figure D.45. Predicted average proportion of prey in bluefish diets.

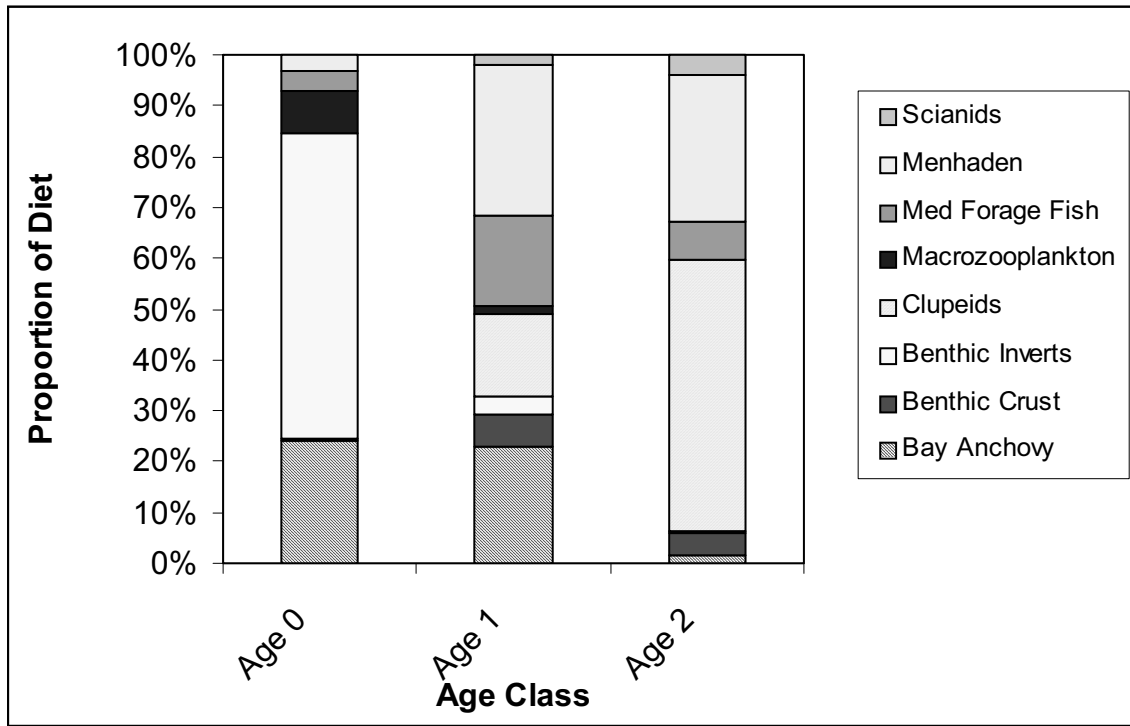


Figure D.46. Predicted total prey biomass consumed annually by all ages of striped bass.

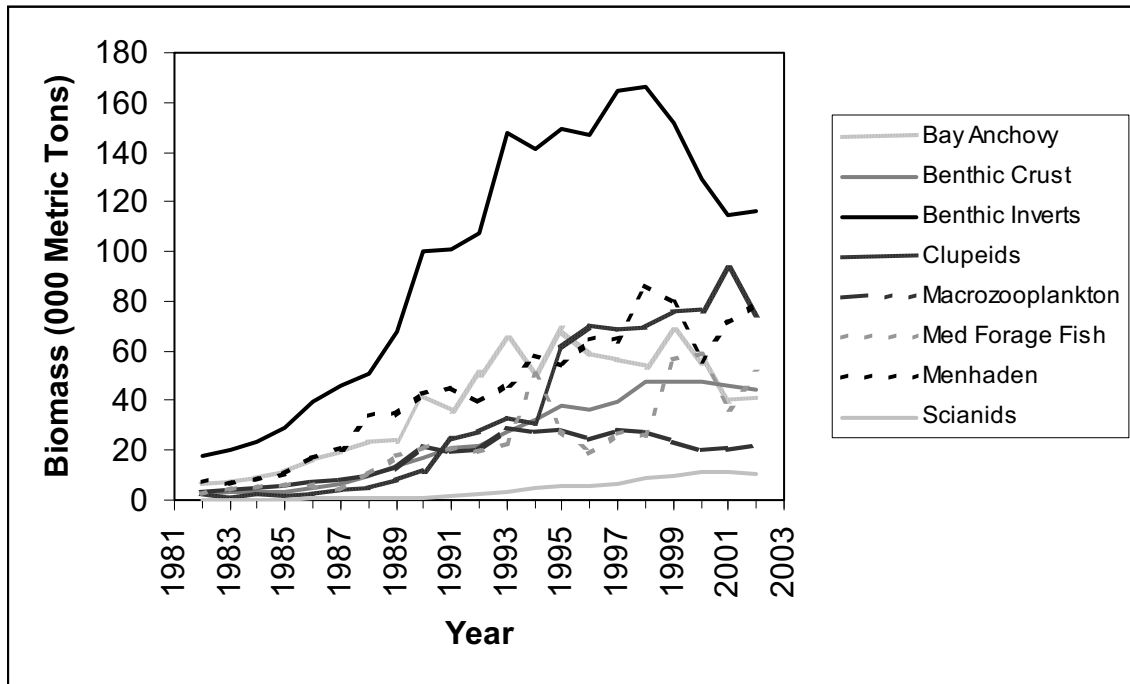


Figure D.47. Predicted total prey biomass consumed annually by all ages of weakfish.

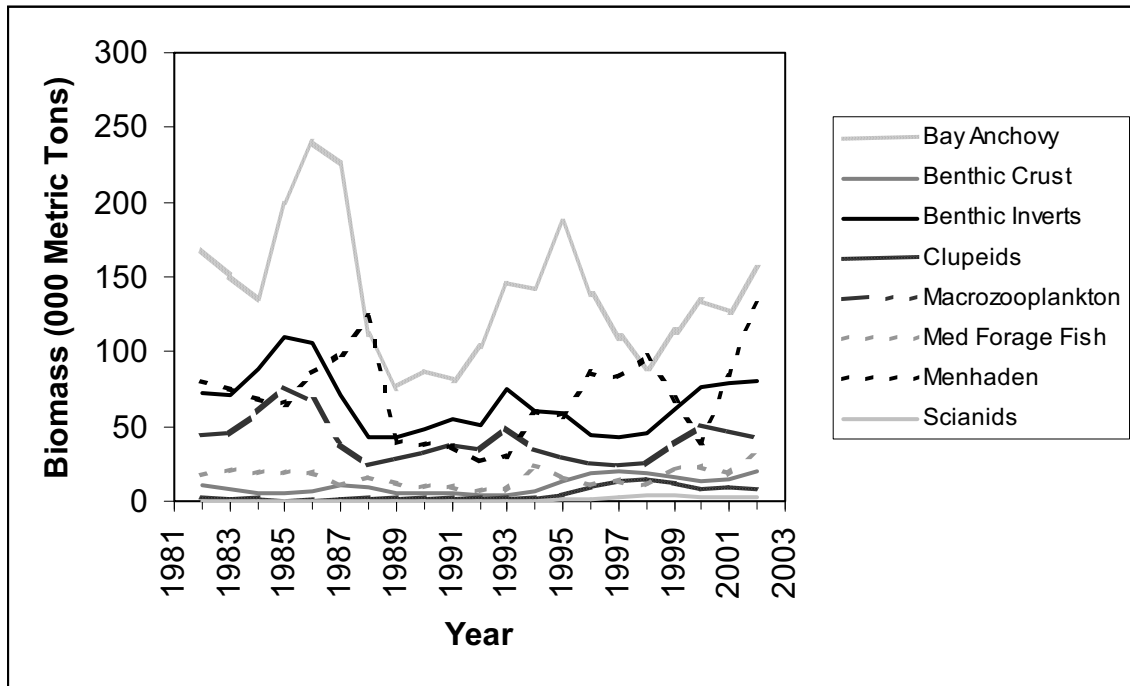


Figure D.48. Predicted total prey biomass consumed annually by all size classes of bluefish.

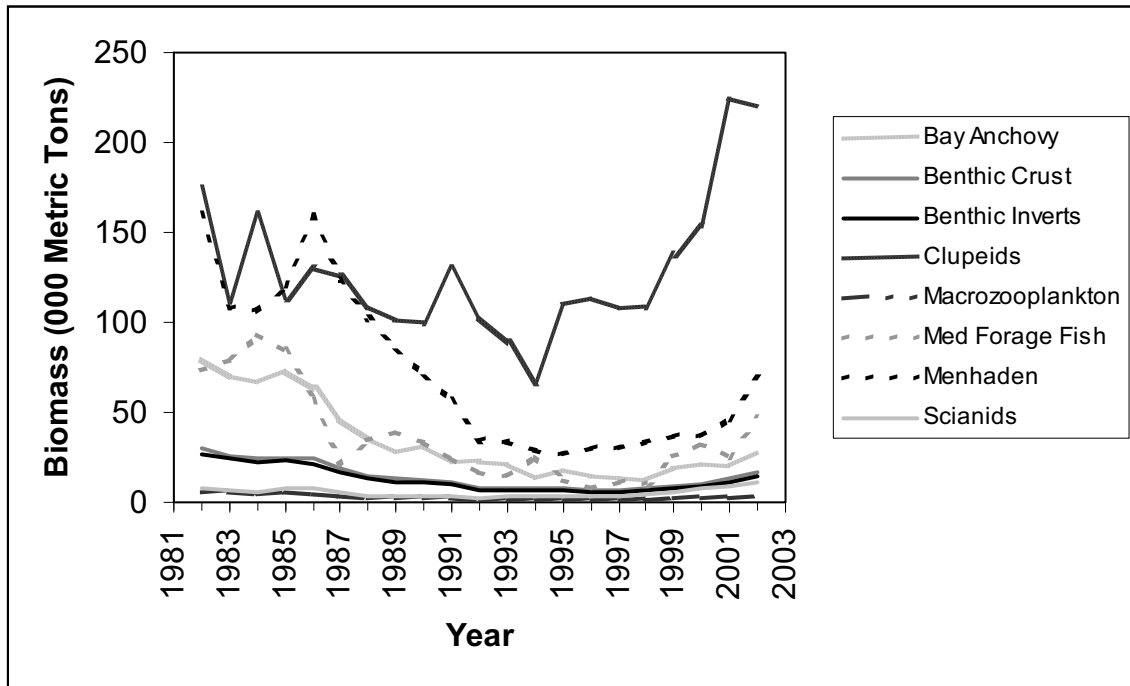


Figure D.49. Prey availability by species for Age 7 striped bass. Relative availability based on time series average.

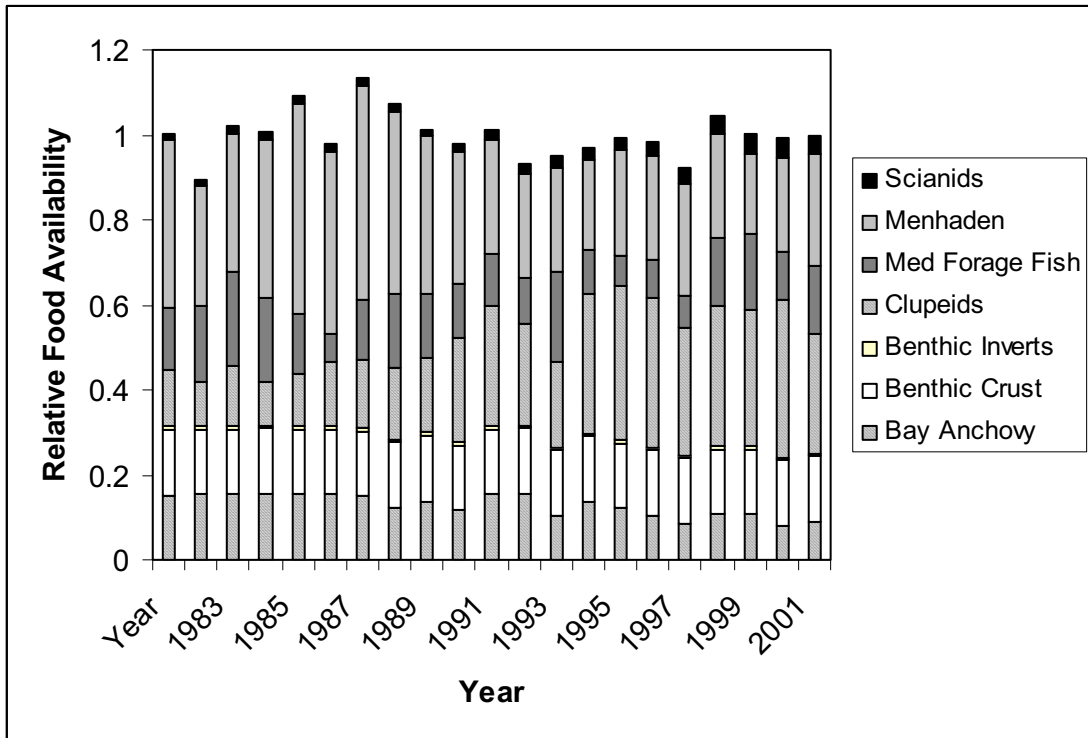


Figure D.50. Prey availability by species for age 4 weakfish. Relative availability is based on time series average.

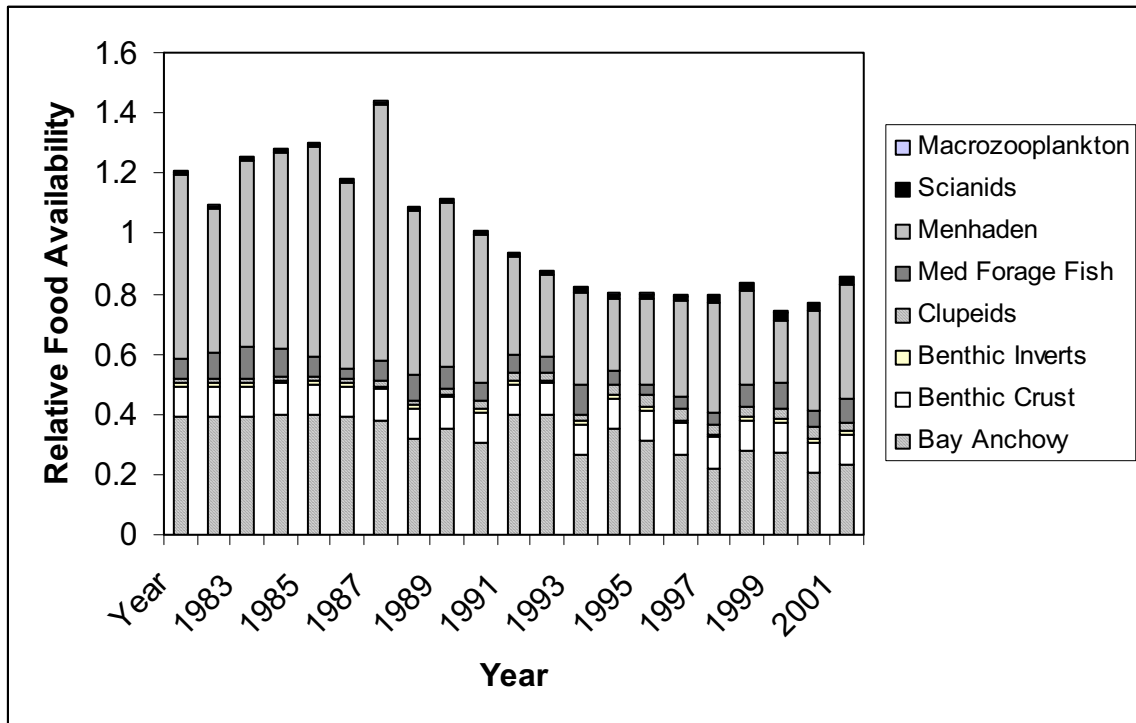




Figure D.51. Annual age-0 menhaden predation mortality (M2) by predator.

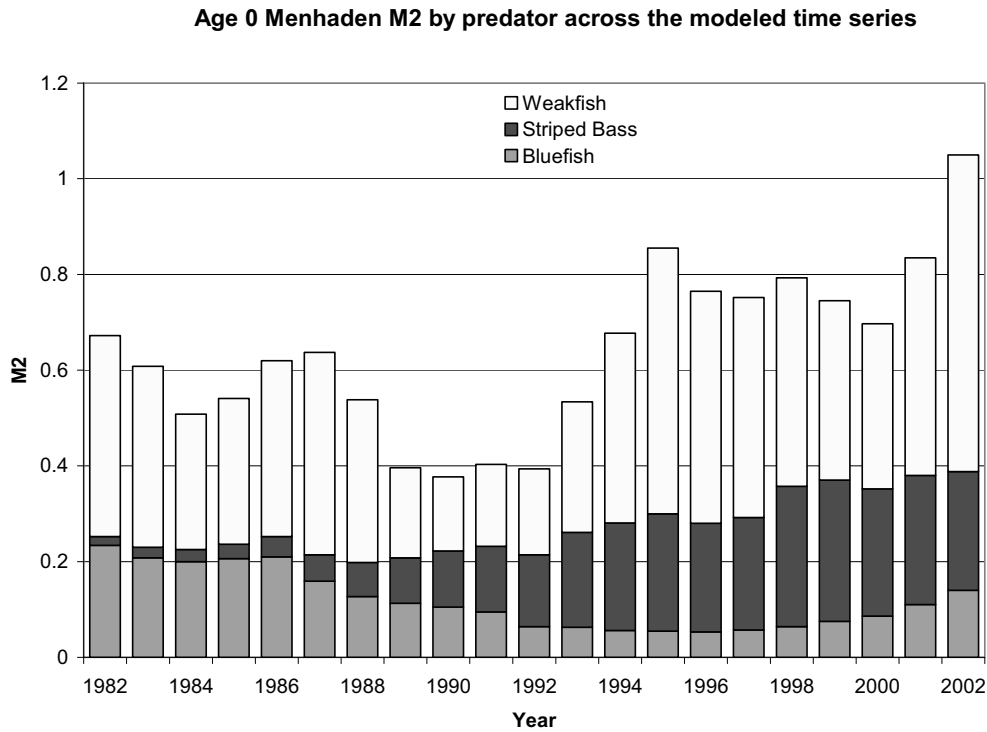


Figure D.52. Annual age-1 menhaden predation mortality (M2) by predator.

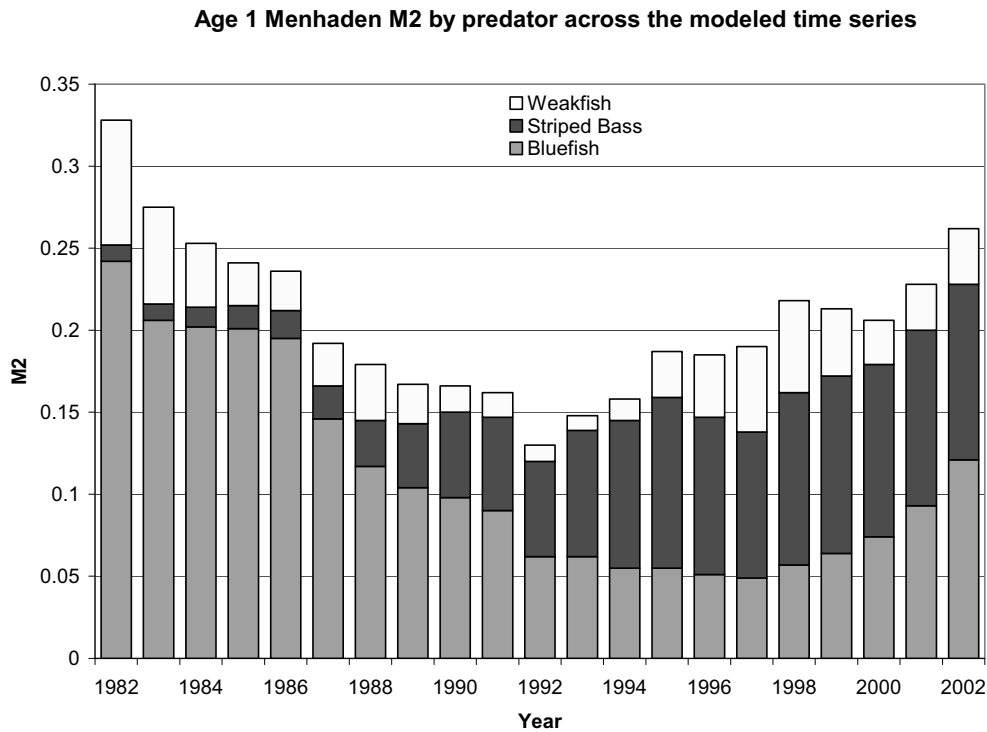


Figure D.53. Annual age-2 menhaden predation mortality (M2) by predator.

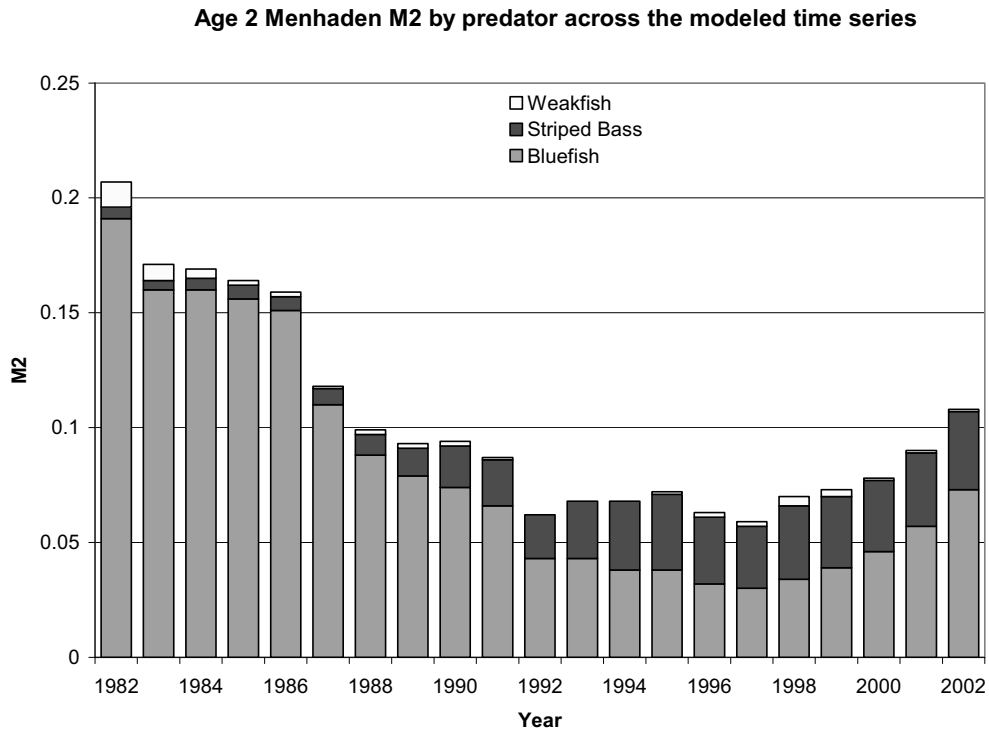
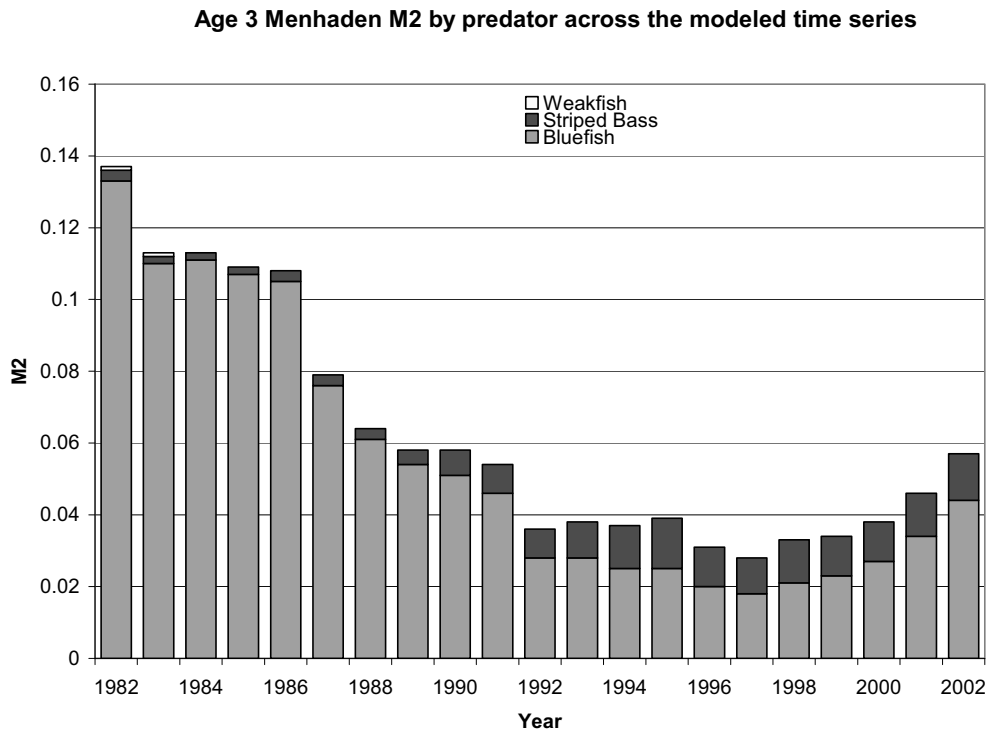


Figure D.54. Annual age-3 menhaden predation mortality (M2) by predator.



## **APPENDIX D1: SENSITIVITY ANALYSES**

### **D1 1.0 SENSITIVITY ANALYSIS SUMMARY**

The sensitivity of the MSVPA-X to changes in input is presented in this Appendix (D1). Several analyses were conducted to evaluate the sensitivity of the MSVPA-X to changes in input parameters. Specifically, sensitivity analyses of model to changes in “other natural mortality” (M1), prey type selectivity, prey size selectivity, predator weight-at-age, gastric evacuation rate parameters, predator and prey spatial overlap, and the addition and deletion of ‘other prey’ items are presented. An examination into the retrospective bias of the model in terminal year estimates is presented. In addition, a test of the forecast model is also presented that investigates the ability of MSVPA-X to reproduce past observations.

#### **D1 1.1 RETROSPECTIVE BIAS**

A series of retrospective runs were conducted to investigate bias in terminal year estimates for explicitly modeled species. Retrospective analyses were run by adjusting the terminal year in the configuration screen and comparing results for several years. Presented are the retrospective results of these runs for weakfish, striped bass, and menhaden fishing mortality (F) and spawning stock biomass (SSB). An examination of potential bias in predation mortality (M2) for menhaden is also presented.

Results suggest little retrospective bias in menhaden fishing mortality and spawning stock biomass (Figures D1.1 and D1.2 respectively). While a persistent bias is not evident in striped bass fishing mortality or spawning stock biomass (SSB) (Figures D1.3 and D1.4), large changes in terminal year estimates are observed. Similarly, weakfish fishing mortality (F) and SSB do not show a consistent bias in the terminal year (Figures D1.5 and D1.6), but large differences in both SSB and F are noted in the terminal years. M2 for menhaden is also variable in the terminal year; however, a persistent bias in the estimation of predation mortality is not apparent (Figure D1.7). Overall the results for both striped bass and weakfish are not surprising given the retrospective output in the single-species models for each (ASMFC, 2003; ASMFC, 2004; and Kahn, 2002).

#### **D1 1.2 DROPPING “OTHER PREY” ITEMS**

A sensitivity analysis to examine the effects of removing important “other prey” items from the model was conducted. To remove the selected prey item, the type preference for a given item was set to zero. Relative ranks of the remaining items were kept constant by adjustment within the type preference input. Items removed included bay anchovy, clupeids (herrings and others), and medium forage fish. Shown are the effects of these removals on menhaden M2, SSB and the average diet composition for striped bass across the time series.

Removal of prey items causes some departure from the base run with respect to menhaden predation mortality (Figure D1.8). The exclusion of anchovy produces the most substantial relative effect. In general, removal of prey items increases predation mortality on menhaden,

particularly early in the time series. However, no effect is noted on modeled SSB for menhaden (Figure D1.9) despite an increase in predation mortality.

Diet composition is also affected by removal of prey items for striped bass. As expected, striped bass diet composition changes as prey items are removed (Figures D1.10-D1.13). Removing clupeids appears to create the greatest effect on diet composition for striped bass, especially within the older age classes.

Predation mortality by predator across the time series was also examined (Figures D1.14-D1.17). The results suggest that the importance of striped bass consumption on M2 for menhaden diminishes when other prey items are removed. Weakfish consumption increases with removal of some items. Bluefish consumption of menhaden changes little until clupeids are removed.

### D1 1.3 CHANGE IN M1

“Other natural mortality” or M1 is a component of natural mortality related to all natural mortality causes other than predation. M1 usually constitutes a smaller component of total M for prey species and is a larger fraction or a full value of total natural mortality for a predator. Misspecification of M1 will generate some bias in total natural mortality estimates and consequently, bias in population abundance estimates. The sensitivity of a number of MSVPA outputs was investigated by varying M1 systematically on the range of 0.1-0.5 year<sup>-1</sup> with a step of 0.1 and M1=0.3 as a base or reference value. Corresponding changes in total menhaden abundance, biomass, spawning biomass, abundance of ages-0 and -1, predation M and average F for fully recruited ages are reported below.

#### D1 1.3.1 Age-0, age-1 and total menhaden abundance

Menhaden total abundance is lowest when M1=0.1. Increasing M1 leads to increased absolute abundance of menhaden (Figure D1.18) as expected. Changing M1 from 0.1 to 0.5 increased abundance approximately twofold. The relationship between changes in M1 and total abundance is slightly nonlinear, exhibiting larger relative changes in abundance as M1 increases (Figure D1.19). Consequently, population size estimates will be biased more by a positive bias in M1 than by a negative bias in M1 (e.g., the absolute change in population estimate will be larger when M1 increases by 50% than when it declines by 50%). Changes in absolute abundance of age-0 and age-1 groups are similar in direction and scale, with age-0 abundance responding at a slightly higher rate to the change in M1 (Figures D1.20 and D1.21).

#### D1 1.3.2 Menhaden total biomass and spawning stock biomass

Since total biomass is a product of abundance and weight-at-age, biomass responses to changes in M1 are similar to total abundance responses. Minimum values of biomass are estimated at M1=0.1 and biomass increases as M1 increases (Figure D1.22). Spawning stock biomass responses are similar to those for total biomass (Figure D1.23). Both total biomass and spawning stock biomass exhibit a slightly lower response rate to changes in M1 than does total abundance.

### D1 1.3.3 Average fishing mortality for fully recruited age groups

Changing M1 values lead to changes in fishing mortality that are opposite the changes in biomass and abundance. The lowest levels of M1 produce the highest estimates of fishing mortality and vice versa (Figure D1.24). Changes in fishing mortality are strictly proportional to changes in M1, which was predicted. The relative magnitude of change in F is substantially lower than that of the biomass and abundance (i.e., the F estimate is less sensitive to changes in M1 compared to biomass and abundance).

### D1 1.3.4 Predation mortality (M2) of ages 0 and 1 menhaden

Predation mortality has responded to changes in M1 similarly to the average fishing mortality – an increase in M1 causes a decline in estimated predation mortality and vice versa (Figures D1.25 and D1.26). Predation mortality changes proportionally to changes in M1. The relative magnitude of change in M2 is similar to changes in fishing mortality and is substantially lower than that of biomass and abundance. Consequently, M2 estimates are less sensitive to changes in M1 compared to biomass and abundance.

### D1 1.3.5 Conclusions

In general, the effect of ‘other mortality’ on estimated parameters of the menhaden population, such as abundance, biomass and spawning biomass, and fishing and predation mortality, is predictable and modest to low in magnitude. An increase in M1 leads to higher values of population size (numbers at age, biomass, spawning biomass) and lower values of predation and fishing mortalities. While changes in fishing and predation mortalities are symmetrical and proportional to changes in M1, population size parameters respond to changes in M1 nonlinearly, with greater changes following larger values of “other mortality”. Consequently, population size parameters seem to be more sensitive to changes or misspecifications of M1 than predation and fishing mortality estimates. A larger bias would be expected in population size estimates when M1 is overestimated.

## D1 1.4 EVACUATION RATES

Consumption rates of fishes can be estimated given information on gastric evacuation rates and stomach contents (Elliott and Persson, 1978). Gastric evacuation rates are influenced by a variety of factors including temperature, size of predator, prey type, size of prey, time since previous meal, size of meal, and number of meals. For striped bass, weakfish, and bluefish, very limited, experimentally derived data on gastric evacuation rates exist (see Hartman, 2000b and Buckel *et al.*, 1999 data on age-0 striped bass and bluefish, respectively). Because basic data to parameterize the simple evacuation rate model across all predator species, size, prey, and temperature combinations are not available, base values for the parameters associated with the exponential decay evacuation rate model (i.e.,  $\alpha = 0.004$  and  $\beta = 0.115$ ) are obtained from the literature (Durbin *et al.*, 1983). These standard parameters are applied to all species and age classes in the current application

To conduct this sensitivity analysis, changes in the evacuation rate parameter values ( $\alpha$  and  $\beta$ ) were chosen that allowed for a coarse examination of the effect those changes had on the MSVPA-X. Changes in each of the gut evacuation rate parameters for each predator were conducted to evaluate the importance of impacts on menhaden abundance, biomass, predation mortality, fishing mortality, and consumption outputs in the MSVPA-X. For each predator, four alternate model simulations were performed. Relative to the base value of  $\alpha = 0.004$ , this parameter was set equal to 0.002 and 0.006, while the parameter  $\beta$  was changed from a base value of  $\beta = 0.115$  to 0.05 and 0.20.

#### D1 1.4.1 Abundance

Changes in the gastric evacuation rate parameter  $\alpha$  for each predator has a slight impact on the abundance of age-0 menhaden (Figure D1.27 a.-c.). Decreases in  $\beta$  for each predator causes moderate decreases in age-0 menhaden abundance, while increasing  $\beta$  has little effect on age-0 menhaden abundance (Figure D1.28 a. – c.). The impact of changes to  $\alpha$  and  $\beta$  on age-1 menhaden is negligible.

#### D1 1.4.2 Spawning Stock Biomass

Spawning stock biomass of menhaden is insensitive to selected changes to both  $\alpha$  and  $\beta$ .

#### D1 1.4.3 Predation Mortality (M2)

Changes in predator gut evacuation rate parameters results in changes in both the magnitude and pattern of the M2 estimates from the MSVPA-X. Changes in  $\alpha$  for weakfish systematically impact the M2 rates on age-0 and, to a lesser extent, age-1 menhaden, while the M2 rates on older fish are not affected (Figure D1.29a. – b.). Predation mortality of all ages of menhaden is affected by altering the values for  $\alpha$  of bluefish, but interestingly the magnitude of the change to M2 on age-0 menhaden is less than on each older age-class (Figure D1.30a. – b.). Changing the  $\alpha$  value for striped bass impacts all age-classes, with age-1 menhaden experiencing the greatest divergence in M2 values from the base run (Figure D1.31a. – b.).

Decreasing  $\beta$  for weakfish causes a decrease in M2 for age-0 menhaden, while increasing  $\beta$  results in M2 values similar to the base run for age-0 menhaden (Figure D1.32a.). For age-1 and greater menhaden, M2 is consistently lower than the base run when  $\beta$  is both increased and decreased for weakfish (Figure D1.32b.). Changing  $\beta$  values, either up or down, for bluefish causes M2 of age-0 menhaden to decrease from base run levels (Figure D1.33a.). Decreasing  $\beta$  for bluefish results in lower M2 values on older menhaden, while increasing  $\beta$  generally leads to higher M2 values through the early 1990s and then to M2 rates similar to the base run (Figure D1.33b.). Decreasing  $\beta$  values for striped bass yields lower M2 rates on all ages of menhaden, while increasing  $\beta$  leads to lower M2 rates than the base run until the late 1980s when M2 rates increase to higher levels for all age classes (Figure D1.34a. – b.).

#### D1 1.4.4 Fishing Mortality

Average recruited fishing mortality on age-2+ menhaden is largely insensitive to changes in the values of  $\alpha$  and  $\beta$ .

#### D1 1.4.5 Consumption

Changing the  $\alpha$  parameter for striped bass causes systematic changes in consumption, as both increasing and decreasing  $\alpha$  led to an increase and decrease in consumption of the same magnitude (Figure D1.35a. – c.). Consumption of weakfish and bluefish is not affected by changes in  $\alpha$  for striped bass (Figures D1.36a. – c and D1.37a. – c.). Changing  $\alpha$  for bluefish and weakfish also cause systematic changes in consumption. Notably, striped bass consumption is slightly affected late in the time series (2000-2002), by changes in the  $\alpha$  values for weakfish.

Changing  $\beta$  for a single predator species impacts consumption rates for the other two predator species. Reducing  $\beta$  for striped bass results in decreased consumption by both striped bass and bluefish, but weakfish consumption is similar to that of the base run. For weakfish, increasing  $\beta$  does not result in large departures in consumption from the base run, but both striped bass and bluefish consumption are reduced (Figure D1.38 a. – c.) Decreasing  $\beta$  for weakfish leads to lower consumption for all predators. Increasing  $\beta$  for bluefish increases bluefish consumption, but lowers striped bass and weakfish consumption; decreasing  $\beta$  for bluefish reduces consumption for all predators (Figure D1.39a. – c). Increasing  $\beta$  for striped bass leads to increased striped bass consumption, reduced bluefish consumption, and increased consumption by weakfish late in the time series (Figure D1.40a. – c).

### D1 1.5 PREY TYPE PREFERENCES

#### D1 1.5.1 Introduction and Outline of Sensitivity Runs

This section describes a sensitivity analysis examining the ranks for prey preferences used in the base MSVPA-X run. To represent inherent uncertainties in developing ranks for prey preferences, two approaches were developed to explore the sensitivity of MSVPA-X to the base input ranks for prey preferences of the three predator species explicitly modeled (Tables D1.1A-D1.3A). This sensitivity is explored through two alternate simplifications of the base model rank preferences.

The first approach assumes that the ranks for all prey groupings not equal to zero were equally preferred for each predator and age modeled (Tables D1.1B-D1.3B). Four sensitivity MSVPA-X runs were made for this approach: three runs, each modifying just one predator species at a time (e.g., bluefish, weakfish, and striped bass); and one run modifying all three predator species at once. This approach is referred to as all ranks equal, and the short hand reference in the figures in the results section is ‘Equal’.

The second approach distinguishes two major prey groupings: fish and invertebrates. All prey categories within each of these two groups were given equal rank for prey preference (Tables D1.1C-D1.3C). In many instances, rankings of fish and invertebrate prey categories were inter-

mixed. To address that situation for the sensitivity runs, all prey categories of the group (fish or invertebrate) with the top ranking received the highest ranking regardless of initial position. For example, if, for a given predator species and age, benthic crustaceans were initially ranked as 1, clupeids ranked 2, and macroinvertebrates ranked 3, then the final sensitivity rankings would be benthic crustaceans 1.5, macroinvertebrates 1.5 (i.e., all 'invertebrates', reflecting the ranking for two groups tied), and clupeids 3. As with the first approach, four sensitivity MSVPA-X runs were made, first modifying one predator at a time (3 runs) and then modifying all three predators (1 run). This approach is referred to as equal ranks of fish and invertebrates, and the short hand reference in the figures in the results is 'Fish/Invert'.

The remainder of this section describes the results of these sensitivity MSVPA-X runs relative to the results from the base run (described elsewhere, but here implying the initial base rank prey preference matrices for the three predator species). In particular, aspects of menhaden population dynamics (natural and fishing mortality, abundance for ages 0-1, and spawning stock biomass) and predator diet of menhaden (percent diet composition and consumption of menhaden) are explored.

#### D1 1.5.2 Results of Sensitivity Runs

##### *Annual menhaden M2 at age-0,-1, and -2*

M2 is that portion of menhaden natural mortality associated with predation by three predators (bluefish, weakfish and striped bass) explicitly modeled in MSVPA-X. Table D1.4 summarizes annual estimates of M2 on ages 0-2 menhaden for the first approach with all ranks equal, while Table D1.5 summarizes annual estimates of M2 on ages 0-2 menhaden for the second approach with equal ranks for fish and invertebrate.

Although the general pattern of predator mortality on age-0 menhaden (M2 on age-0 menhaden) are similar, estimates of M2 from the base run are highest compared to all ranks equal for one or all of the three predator species (Figure D41). Lowest estimates of M2 on age-0 menhaden are obtained when all ranks equal for all three predators. For a single predator, the lowest estimates are associated with all equal ranks for weakfish. Little difference is noted with all ranks equal for bluefish. Similar patterns are found when equal ranks of fish and invertebrates are assumed (Figure D1.42). The primary difference is a narrowing in differences with the various sensitivity runs for this alternate assumption in rank preferences.

The general pattern and magnitude of predator mortality on age-1 menhaden (M2 on age-1 menhaden) are similar, with estimates of the base run generally intermediate to most of the sensitivity runs for all equal ranks assumed in one or all of the three predator species (Figure D1.43). Highest estimates of M2 on age-1 menhaden are associated with bluefish, and lowest estimates with weakfish when assuming equal rank preference. Similar patterns are also found when equal ranks of fish and invertebrates are assumed (Figure D1.44). Highest estimates of M2 on age-1 menhaden are associated with simplifying rank assumption for bluefish and weakfish, and the lowest values for base, striped bass and all three predators.



Although the general pattern and magnitude of predator mortality on age-2 menhaden (M2 on age-2 menhaden) are similar, the lowest estimates of M2 on age-2 menhaden are associated with the base run, striped bass and weakfish compared to the assumption of all equal ranks for bluefish and all predators (Figure D1.45). Similar results are found when equal ranks of fish and invertebrates are assumed (Figure D1.46).

#### *Annual menhaden average recruited F*

Annual estimates of average F (for age-2+ menhaden) are summarized for both alternate approaches to sensitivity in ranking (Table D1.6). Only very minor differences are noted among various runs with the base run for average recruited F (Figures D1.47 and D1.48). Hence, annual estimates of average recruited F appear to be insensitive to errors in rank preferences.

#### *Annual menhaden abundance at age-0 and 1*

Annual estimates of abundance of age-0 and age-1 menhaden (in millions of fish) are summarized for all ranks equal (Table D1.7) and for equal ranks of fish and invertebrates (Table D1.8).

Although the general temporal pattern and magnitude of age-0 abundance of menhaden is maintained, there are moderate deviations from the base run when all equal ranks are assumed in one or all of the three predator species (Figure D1.49). Generally the highest estimates are associated with the base run, and lowest estimates associated with equal rank preferences for weakfish all three predators. Similar patterns are also found when equal ranks of fish and invertebrates are assumed, but with intermediate levels for the base run (Figure D1.50).

Only very minor differences are noted among various sensitivity runs for abundance of age-1 menhaden compared to the base run (Figures D1.51 and D1.52). Hence, annual estimates of age-1 menhaden appear to be fairly insensitive to alternative simplification in rank preferences.

#### *Annual menhaden SSB*

Annual estimates of menhaden spawning stock biomass (in 1000 mt) are summarized for all ranks equal (Table D1.9) and for equal ranks of fish and invertebrates (Table D1.10). Only very minor differences are noted among the various sensitivity runs compared to the base run for spawning stock biomass (SSB; Figures D1.53 and D1.54). Hence, annual estimates of menhaden SSB appear to be insensitive to alternative simplification of rank preferences.

#### *Percent menhaden in diet composition*

Age-specific diet composition of menhaden (percent composition) for the three predator species are summarized by predator age for sensitivity to both alternate ranking approaches (Table D1.11).

Age-specific patterns in diet composition of menhaden in striped bass are presented in Figures D1.55 and D1.56. For the assumption of all equal ranks, all sensitivity runs show a pattern of low

percent of menhaden in diet of young striped bass, and higher percent of menhaden in diet of older striped bass. Diet compositions, when all equal ranks are assumed for striped bass and all three predators, are lower for younger ages of striped bass (age 1-6) and higher for older ages of striped bass (age 9-13), as compared to the base run and assumption of all equal ranks for bluefish and weakfish. This same pattern with age is found also for the assumption of equal ranks for fish and invertebrates.

Regardless of sensitivity run, the pattern is somewhat different for diet composition of menhaden with the shorter-lived (as modeled) weakfish (Figures D1.57 and D1.58). For these sensitivity runs, the base run and both alternate rank preferences for striped bass and bluefish give the highest percent of menhaden in the diet of weakfish. Low percentages are associated with both alternate rank preferences for weakfish and all three predators.

Discerning changes in bluefish diet composition by size class is difficult because only three size classes of bluefish are modeled. Nonetheless, menhaden increase in abundance in bluefish diets as bluefish size increases (Figures D1.59 and D1.60). Similar to the diet compositions of menhaden for striped bass and weakfish, two groupings of similar estimates are found. One group consists of the base run and diet composition estimates with both alternate rank preferences for striped bass and weakfish, and the other group consists of both alternate rank preferences for bluefish and all three predators.

#### *Consumption of menhaden by predators*

Consumption of menhaden by predators (biomass, 1000 mt) is summarized for all ranks equal (Table D1.12) and for equal ranks of fish and invertebrates (Table D1.13).

The general pattern and magnitude of menhaden consumption by striped bass are similar among sensitivity runs, with generally increasing consumption of menhaden over time for the base run and sensitivity runs for the assumption of all ranks equal in one or all predator species (Figure D1.61). Low values of menhaden consumption are found with striped bass and all three predators, while higher values are associated with the base run and all ranks equal for weakfish and bluefish. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.62).

High menhaden consumption by weakfish is found for the base run and for all equal ranks for striped bass and bluefish (Figure D1.63). Lower values of menhaden consumption are found for all ranks equal for weakfish and for all three predators. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.64).

Low values of menhaden consumption by bluefish are found for the base run and for assumed equal rank preferences for striped bass and weakfish (Figure D1.65). Higher values of menhaden consumption are found for all ranks equal for bluefish and for all three predators. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.66).

### D1 1.5.3 Discussion

The first alternate approach, assuming equal ranks for all positive species groupings, assumes that little is known about prey preference beyond which species groups are preyed upon by a particular age or size group of predator (Table D1.1B-D1.3B). The second alternate approach, separating prey preference into equal ranks for fish and invertebrates, allows for some separation of ranks between these larger groupings (Table D1.1C-D1.1C).

When considering the results of these sensitivity runs, first we investigated different aspects of menhaden population dynamics: annual estimates of natural mortality by predation (ages 0-2), fully recruited fishing mortality (age-2+), and abundance (age-0 and 1, and spawning stock biomass). Natural mortality is split into fixed base natural mortality due to a variety of sources (M1), and that portion of natural mortality that is explicitly considered in this model due to predation by striped bass, weakfish, and bluefish (M2). Specifically, we consider the sensitivity of M2 for ages 0-2 menhaden (Table D1.4-D1.5 and Figures D1.41-D1.46). When comparing M2 among the base run and each of the two alternate simplifying assumptions for rank preference for all three predators, M2 from the base run was highest for age-0, generally intermediate for age-1, and lowest for age-2. On the other hand, average recruited F (ages 2+) for menhaden show very little, if any, sensitivity to the ranks for prey preference (Table D1.6 and Figures D1.47-D1.48).

Menhaden abundance is considered in two ways. First, we estimate abundance in numbers of age-0 and age-1 menhaden, and next we estimate spawning stock biomass (weight of mature female menhaden, SSB). We note some sensitivity in estimating abundance of age-0 menhaden, with the base run providing generally higher estimates than from the two alternate simplifying assumptions for rank preferences for all three predators. However, little sensitivity in abundance is observed for age-1 menhaden (Table D1.7-D1.8 and Figures D1.49-D1.52). Furthermore, there is negligible sensitivity observed in SSB (Table D1.9-D1.10 and Figures D1.53-D1.54). This suggests that we should not expect sensitivity in abundance of menhaden age-3 or older.

Next, we considered the sensitivity in measures of menhaden in the diet of the modeled predators. This aspect was considered in two ways: percent menhaden in the diet composition of the three predators by predator age, and annual estimates of consumption of menhaden biomass in the predator diets (Tables D1.11-D1.13 and Figures D1.55-D1.66). For diet composition and consumption of menhaden, most deviation from the base run is associated with the simplifying rank preference assumption applied to the species considered and all three predators.

### D1 1.6 WEIGHT-AT-AGE

This sensitivity analysis examined the effects of changes of constant weight-at-age (based on time series average) and variable weight-at-age (observed data from stock assessment reports) for striped bass and weakfish.

## D1 1.6.1 Methods

The weight-at-age matrix for striped bass and weakfish in the base run is based on average values calculated from observed data (1982-2002 for striped bass and 1991-2002 for weakfish) from research studies. In the alternative run, constant weight-at-age tables for striped bass and weakfish were replaced with observed (variable) weight-at-age values (obtained from assessment documents) and its impact on predator total consumption rate, predator consumption of menhaden, and menhaden predation mortality (M2) was evaluated.

## D1 1.6.2 Results

### Total Consumption Rate:

Total consumption rate for striped bass change little under variable (observed) weight-at-age scenario (Figure D1.67). For weakfish, the variable weight-at-age generates higher total consumption rates during early 1980s, but differences in recent years are not significant (Figure D1.68).

### Predator Consumption of Menhaden

Predator consumption of menhaden by striped bass changes little under variable weight-at-age scenario (Figure D1.69). For weakfish, the variable weight-at-age generates higher consumption of menhaden during early 1980s, but differences in recent years are not significant (Figure D1.70).

### Predation mortality (M2)

Predation mortality (M2) of menhaden by striped bass calculated based on variable (observed) weight-at-age are similar to those calculated based on constant weight-at-age (Figure D1.71). For weakfish, predation mortality (M2) calculated based on variable weight-at-age is significantly higher during early to mid 1980s and differences are less significant in recent years (Figure D1.72).

## D1 1.7 SPATIAL OVERLAP

### D1 1.7.1 Introduction and Outline of Spatial Overlap Sensitivity

This series of model runs examined the sensitivity of the MSVPA-X model to changes in the 'Base' spatial overlap values of each predator by age, and their associated prey for all seasons. Spatial overlap values range from 0 (no overlap) to 1 (complete overlap) and therefore, there are thousands of possible spatial overlap combinations for a given predator, prey and seasonal combination. To help simplify the analysis, runs were conducted using spatial overlap values equal to 1 for all species combinations (i.e., all prey for all seasons set equal to 1 for a given predator) and the results were evaluated relative to the 'Base' run (See Table D1.14, S.B. – All, termed Predator Runs). A feature of the MSVPA-X allows the modeler to remove the seasonal aspect of the spatial overlap index if seasonal data is not available or, potentially, if seasonal

aspects or movements are not important. Therefore, sensitivity runs comparing spatial overlap values with seasonality and without seasonality were also investigated (Table D1.14, N.S. 1 and N.S. Ave, termed Seasonal Runs).

#### D1 1.7.2 Annual Menhaden M2 Results

Menhaden M2 is slightly sensitive to changes in spatial overlap values for the Predator runs and sensitivity tend to decrease with age: age-0 being most sensitive and age-2 being least sensitive (Figures D1.73a – c). Setting the weakfish spatial overlap equal to 1, Weak run, lowers age-0 M2 compared to the Base in almost all years but has little effect on age-1 and age-2 M2. When the bluefish spatial overlap is set equal to 1, Blue run, menhaden M2 increases for all ages in the early part of the time series (1982 – 1987) when bluefish abundance was at its peak; while menhaden M2 increases for all ages in the later part of the time series (1997 – 2002) for the striped bass run, S.B., as the striped bass population recovered.

The Seasonal runs show similar sensitivity trends in that M2 was slightly sensitive to the seasonal aspect of the spatial overlap values, however sensitivity tend to increase with age (Figures D1.74a – c). Seasonal runs tend to be more variable than Predator runs for all age groups and menhaden M2 increased for all age groups compared to the Base. As expected, the All and N.S. 1 runs – all predators' spatial overlap values equal to 1 – produce similar results. The N.S. Ave run, averaging the seasonal spatial overlap values, tend to produce the highest M2 estimates for all ages and is the greatest departure from the Base run estimates. These results emphasize the overall importance and sensitivity of the seasonality aspect incorporated in the model, and the need to accurately describe the movements of the predators in relationship to their prey.

#### D1 1.7.3 Annual Menhaden Abundance for Ages 0 and 1 Results

Age-0 menhaden total abundance is less sensitive to spatial overlap changes than the age-0 M2 estimates (Figure D1.75a). Also, age-0 abundance trends for a particular model run are what one would expect based on the M2 results – i.e., higher M2 estimates for a particular model run, compared to the Base, produces higher abundance estimates. Age-1 menhaden abundance is not sensitive to changes in spatial overlap values with all Predator runs producing similar results (Figure D1.75b).

Seasonal runs produce similar results as the Predator runs – a slight sensitivity for age-0 abundance, no real sensitivity for age-1 and logical abundance estimates are produced based on the M2 results (Figures D1.76a - b).

#### D1 1.7.4 Annual Menhaden SSB Results

Menhaden spawning stock biomass estimates are not sensitive to changes in spatial overlap values for either the Predator runs or the Seasonal runs with all runs producing nearly identical results (Figures D1.77a - b). These results are expected since most of the menhaden spawning stock is comprised of 3+ individuals and menhaden predation mortality is predominantly on age

0 – 2. Also, as discussed above, model sensitivity to menhaden predation mortality decreases with age and therefore, has a decreased effect on spawning tock biomass.

#### D1 1.7.5 Annual Menhaden Average Recruited (2+) F Results

Similar to menhaden spawning stock biomass, annual fully recruited F estimates are not very sensitive to changes in the spatial overlap values for both the Predator and Seasonal runs (Figures D1.78a - b).

#### D1 1.7.6 Predator Diet Composition Results

Increasing a particular predator's spatial overlap to 1 for all prey and all seasons has a mixed effect on menhaden in the diet when compared to the Base run. For example, menhaden predation (i.e., more menhaden in diet) increases for ages 4 – 8 striped bass and decreases for the other ages, weakfish predation on menhaden is significantly lower for all ages, while bluefish predation increases for middle aged bluefish and decreases for young and old bluefish (Figures D1.80a – c). When all three predators's spatial overlap values are set equal to 1 (All), menhaden predation remains relatively the same in striped bass and bluefish when compared to their specific predator run; while weakfish predation increases slightly compared to the weakfish specific run for all ages but remains below Base run levels (Figure D1.80b).

Changes in diet composition for the other prey types are also highly variable as well as species and age dependent. Clupeids are more abundant in the diet for all ages of striped bass, while medium forage fish and anchovies are much less common (Figures D1.79d and D1.80a). The same pattern is true for bluefish as well (Figures D1.79f and D1.80c). Due to the increase in spatial overlap, clupeids are significantly more common in the diets of weakfish. This result is logical because the clupeid group, largely consisting of Atlantic herring, is found predominantly in New England and the Gulf of Maine where weakfish are not commonly found. Medium forage fish and bay anchovy are more common in the diet of older weakfish and macrozooplankton and benthic invertebrates are much more abundant among all ages (Figures D1.79b and D1.80b). As with menhaden, the diet composition of the other prey types for all three predators remains relatively similar between their predator specific model run and the All predator run, with weakfish the most variable between the runs (Figures D1.79d – f and D1.80a – c).

In predator specific runs (striped bass, weakfish, or bluefish), diet composition only changes in the predator whose spatial overlap is set to 1, the other predators' diets are relatively unaffected (Figures D1.79a – c).

#### D1 1.7.7 Total Predator Consumption by Prey Type Results

Due to the high sensitivity in the predator diet composition, predator consumption as also highly sensitive to changes in spatial overlap values. Menhaden consumption by striped bass increases from the Base run, as does the associated variability in all years when the striped bass spatial overlap was equal to 1, particularly in the later part of the time series with the increasing and expanding striped bass population (Figure D1.81a). Weakfish consumption of menhaden is the lowest for the weakfish specific run which corresponds to the decrease of menhaden in the diet

for that particular run (Figure D1.81b). Bluefish consumption of menhaden is the greatest for the Blue and All predator runs and the most variable early in the time series when bluefish abundance is high (Figure D1.81c).

Other prey consumption was also highly variable depending upon the prey type and model run but reflected the results observed in the diet composition. For example, there is a substantial increase in clupeid consumption by weakfish in the Weakfish and All predator model runs due to the large increase of clupeids in their diet (Figure D1.81b).

## D1 1.8 PREY SIZE PREFERENCE

### *D1 1.8.1 Background*

Prey size-selectivity comprises one component of feeding selectivity in the MSVPA-X and a critical consideration in determining the suitability of prey item are predator-prey length ratios. For a predator of a given length, prey size-selectivity will be dome shaped. For example, prey selected by a predator must fall within a suitable size range that the predator can catch and consume. If a predator can consume a wide variety of prey sizes relative to its own size, the selectivity curve will be ‘flattened’ or ‘squashed’. Predators that have a limited range of suitable prey sizes have a more ‘peaked’ or ‘narrow’ selectivity curve. There is limited data on prey size-selectivity available for the predator species, in particular for weakfish and bluefish. To account for the uncertainty inherent in these data sensitivity analyses were performed to determine the impact of slight changes in the prey size-selectivity curve parameters, directional shifts in median size of prey, and changes in the prey size range consumed by predators.

### D1 1.8.2 Methods

The following scenarios were tested to test the sensitivity of the MSVPA-X to various size selectivities. Each scenario was compared to the output from the base run output, and the outputs evaluated were predation mortality (M2) on age-0, 1, and 2 menhaden, the total abundance of age-0 and 1 menhaden, spawning stock biomass of menhaden, and average recruited F on age-2+ menhaden, and predator diet composition and consumption rates. In general, results are reported as percent change from the base run result relative to the change in the input value. Prey size-selectivity parameters can be changed in the MSVPA-X configuration for striped bass and weakfish, but bluefish must be changed in the single-species configuration for each sensitivity run. The values of the size selectivity parameters,  $\alpha$  and  $\beta$ , used in the analyses are provided in Tables D1.15 and D1.16.

- 1) Size selectivity parameters ( $\alpha$  and  $\beta$ ) were adjusted by  $\pm 1\%$  for all predators in the model (striped bass, bluefish, and weakfish). The goal of this scenario was to determine if the model is highly sensitive to small changes in  $\alpha$  and  $\beta$  values.
- 2) Scenarios were conducted to investigate how shifts in the median prey size-selectivity impact each of the specified outputs above. For all predators combined, shifts in median prey size-selectivity of  $\pm 10\%$  and  $\pm 20\%$  were investigated. The  $\alpha$  and  $\beta$  values were

adjusted using the 'sisesel' macro in Excel that calculates the size selectivity parameters the same way as in the MSVPA-X model.

3) To evaluate the impacts of changes in the range of prey sizes selected by predators, the size ranges or predator-prey size ratios were expanded or contracted by  $\pm 10\%$  employing a similar method as in 2. Values for  $\alpha$  and  $\beta$  were selected that achieved a 10% expansion and a 10% contraction in the size range of prey selected, while keeping the median size consistent with the base run median size. Striped bass data were available in prey size ranges, but bluefish and weakfish data were presented in terms of predator to prey length ratios; however, the adjustments to the size selectivity curves were performed the same.

### D1 1.8.3 Results

1) The MSVPA is robust to 1% changes in the prey size-selectivity curve parameters  $\alpha$  and  $\beta$  as these changes slightly altered the output parameters investigated: total, age-0 and age-1 abundance (Table D1.17); spawning stock biomass (Table D1.18), predation mortality (M2) on age-0 and age-1 menhaden (Table D1.19), fishing mortality (Tables D1.20 and D1.21), predator diet composition (Figure D1.82a.- c.), predator consumption rates (Figure D1.83a.-c.).

2) Changes in the median size prey selected by the predators results in expected changes in the output variables observed.

#### **Total, age-0 and age-1 abundance** (Figure D1.84 a.-c., Table D1.22)

Decreases in median size of 10% and 20% changes the abundance of age-0, age-1 and total abundance from less than 1% to approximately 10%. Increases in median sizes to 10% and 20% greater than the base run, results in changes in abundance of the same order and in a few cases exceed the change in the input values for  $\alpha$  and  $\beta$ . Age-0 abundance is more sensitive than both age-1 and total abundance for each scenario, except the decrease in median prey size by 20%.

#### **Spawning stock biomass** (Table D1.23)

Spawning stock abundance is insensitive to changes in median prey size of  $\pm 10\%$  and  $\pm 20\%$ .

#### **Predation mortality (M2) on age-0 and age-1 menhaden** (Figure D1.85a.-b., Table D1.24)

Predation mortality estimates behaves expectedly for the given changes in  $\alpha$  and  $\beta$ . Note that in the scenarios for age-1 menhaden in which median prey size-selectivity is increased, M2 is substantially higher than the base run and the scenarios where median prey size is decreased.

#### **Fishing mortality** (Figure D1.86a.-c., Table D1.25)

Fishing mortality by age and average recruited F are not sensitive to shifts in median prey size.

#### **Predator diet composition & predator consumption rates** (Figures D1.82a.-c. and D1.83a.-c.; Table D1.26)



The proportion of menhaden in the diet of the predator species and the consumption of menhaden are the MSVPA-X outputs most affected by changing the median size range of prey selectivity. The changes in proportion of menhaden in each predator diet and the amount of menhaden consumed typically changes relative to the change in median prey size and trends are generally consistent across the scenarios investigated; however, two scenarios affect the proportion of menhaden in the diet of striped bass (Figure D1.826a, the 10% decrease in median prey size and the 20% increase in median prey size).

3) Changes in the range of prey sizes selected by predators, the size ranges

#### **Total, age-0 and age-1 abundance (Figure D1.87)**

Abundance of menhaden (age-0, age-1, and total) is insensitive to contractions and expansions in the range of prey size-selectivity for all predators.

#### **Spawning stock biomass (Figure D1.88)**

Spawning stock biomass of menhaden was insensitive to contractions and expansions in the range of prey size-selectivity for all predators.

#### **Predation mortality (M2) on age-0 and age-1 menhaden (Table D1.26)**

Decreasing the size range of prey selected increases M2 on the smaller and younger menhaden and reduces M2 on older and larger menhaden compared to the base run. Increasing the size range of prey selectivity has the inverse effect.

#### **Fishing mortality (Figure D1.89; Table D1.25)**

Neither fishing mortality by age nor average recruited F is sensitive to increases or decreases in prey size-selectivity.

#### **Predator diet composition and predator consumption rates (Figures D1.90a.-c. and D1.91a.-c.)**

Estimates and trends in the proportion of menhaden in the diet of the predator species and the consumption of menhaden are predictable and consistent for most of the scenarios tested. For the scenario in which the prey size-selectivity decreased, the largest impact on a predator is for bluefish. In that scenario, consumption of menhaden by bluefish declines substantially; however, total consumption for bluefish of all prey types increases early in the time series, 1982-1990 (Table D1.27). Beginning in 1991, total consumption of bluefish with a decreased size selectivity range is lower than the base run and remains so for the duration of the time series. The total consumption of bluefish in the base run and in the scenario with an increased size range is similar throughout the time series. In addition, the proportion of menhaden consumed declines in the largest size group of bluefish.

## D1 2.0 FORECAST PROJECTION RESULTS AND ACCURACY

The MSVPA-X application includes a forecast module that allows exploration of the potential effects of various exploitation patterns, recruitment successes and other “Full MSVPA prey” biomass dynamics. When simulating fishing pressure, the user can enter expected levels of removals in total weight for both prey (menhaden) and predators (striped bass, blue fish, weakfish) or fishing mortality rates for the designated forecast period. Forecasting options for recruitment include several stock-recruitment functions, probability matrices, as well as, the ability to prescribe specific values for each year of the forecast. While these options provide flexibility for future exploration of stock dynamics, it is desirable to test the reliability of model predictions prior to the practical use of the forecasting module.

### D1 2.1 FORECAST MODULE ACCURACY

One possible approach to testing the model is to investigate if the forecasting module can reproduce historical observations. To test the ability of the model to reproduce past observations, we used the results of the base run for the 1982 –2002 period. MSVPA-X estimates of population sizes for 1996 were used as a starting point and projections were made for the 1997-2002 period. Estimates of striped bass, weakfish and menhaden recruitment for 1997-2002 from the base run were used as recruitment input for the projection module. Base run estimates of predators fishing mortality rates for the same period served as an input for the forecast module. Fishing pressure on menhaden was simulated in two ways: by entering observed catches for each year of the forecast and by entering “observed” values of fishing mortality (from the “base” run). Projected dynamics of predators and prey were compared with “observed” values from the base run.

Forecasted trends in menhaden total abundance, biomass, spawning stock biomass, predation mortality are similar to those in the base run (Figure 1.92). The forecasted results are not sensitive to the method of fishing removal. Whether the removals are imitated via the total number of fish removed or the fishing mortality applied to the stock, the outputs are very similar, except for the estimate of average recruited F for menhaden. Due to the calculation method used in the forecast module, it is advised to use fishing mortality for the projection rather than absolute catch values. Forecasted and base run values of total absolute abundance and biomass are very close as well. However, there are some differences in the forecasted and “observed” values of menhaden spawning stock biomass (lower values are predicted), predation and fishing mortality (higher predicted values compared to observed for both predation and fishing mortality of menhaden). While the predicted predation mortality on age-0 menhaden does not differ much from the observed, the differences in predicted and observed values of predation on age-1 are more substantial. We were not able to pinpoint the exact reason of such divergence, and further careful analysis is warranted.

### D1 2.2 FORECAST MODEL RESULTS

The forecast model is implemented using the base run configuration for the MSVPA-X model with a 5-year projection from 2003-2007. This time frame is chosen based to the potential

limitations of the stock-recruitment relationship for menhaden (Section 2.1). The input for the von Bertalanffy and length-weight relationships for each explicitly modeled species are:

	$L_{inf}$	K	$T_{zero}$	L-W $\alpha$	L-W $\beta$
Menhaden	33	0.3737	-0.5642	-10.787	2.9565
Striped Bass	158	0.075	-0.9855	-8.753	2.41222
Weakfish	73.44	0.1745	-0.4719	-6.822	1.7642

The stock-recruitment relationships used in this example projection for each species are: menhaden – random from quartiles, striped bass – Ricker, and weakfish – random from quartiles. Bluefish, and other prey biomasses were assumed to be stable across the projected time frame. Likewise, fishing removals (as F) for all explicitly modeled predators and prey were also assumed constant.

Figure 1.93 (a-c) display the results of the forecast projection for: spawning stock biomass of menhaden, striped bass and weakfish; predation mortality on age-0 through age-4 menhaden; and the amount of menhaden consumed by striped bass, weakfish and bluefish. Overall weakfish and striped bass SSB are expected to decrease over the projected time frame, while menhaden SSB is expected to increase. Predation mortality on ages 1-3 menhaden is simulated to remain fairly constant while predation mortality for age-0 menhaden is projected to decrease slightly. However, the weakfish consumption on menhaden is projected to grow, peaking around 2004.

## APPENDIX D1 REFERENCES

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## APPENDIX D1 TABLES

Table D1.1. Base and alternate prey-preference rankings for striped bass in sensitivity MSVPA-X runs.

A. Base	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper_2002_13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden_2002	0	3	3	2	2	2	2	4	4	5	5	5	5	5
Bay Anchovy	0	7	7	6	7	6	5	6	6	6	6	6	6	6
Benthic Crustaceans	0	1	1	4	3	3	3	2	2	2	2	2	2	2
Benthic														
Invertebrates	1	5	5	3	5	5	8	7	7	7	7	7	7	7
Clupeids	0	0	0	0	6	8	7	5	5	4	4	3	3	3
Macrozooplankton	2	6	6	7	8	7	6	0	0	0	0	0	0	0
Medium Forage														
Fish	0	4	4	1	1	1	1	1	1	1	1	1	1	1
Sciaenids	0	2	2	5	4	4	4	3	3	3	3	4	4	4

B. Equal	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper_2002_13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden_2002	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Bay Anchovy	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Benthic Crustaceans	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Benthic														
Invertebrates	1.5	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Clupeids	0	0	0	0	4.5	4.5	4.5	4	4	4	4	4	4	4
Macrozooplankton	1.5	4	4	4	4.5	4.5	4.5	0	0	0	0	0	0	0
Medium Forage														
Fish	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Sciaenids	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4

Table D1.1 (Cont'd). Base and alternate prey-preference rankings for striped bass in sensitivity MSVPA-X runs.

C. Fish/Invert	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper_2002_13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden_2002	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Bay Anchovy	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Benthic														
Crustaceans	0	2	2	6	7	7	7	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Benthic														
Invertebrates	1.5	2	2	6	7	7	7	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Clupeids	0	0	0	0	3	3	3	3	3	3	3	3	3	3
Macrozooplankton	1.5	2	2	6	7	7	7	0	0	0	0	0	0	0
Medium Forage														
Fish	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Sciaenids	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3

Table D1.2. Base and alternate prey-preference rankings for weakfish in sensitivity MSVPA-X runs.

<b>A. Base</b>	<b>Age 0</b>	<b>Age 1</b>	<b>Age 2</b>	<b>Age 3</b>	<b>Age 4</b>	<b>Age 5</b>	<b>Age 6</b>
<b>Striper_2002_13+</b>	0	0	0	0	0	0	0
<b>Weakfish_2002</b>	0	0	0	0	0	0	0
<b>Menhaden_2002</b>	4	1	1	3	3	1	3
<b>Bay Anchovy</b>	3	2	4	6	6	6	5
<b>Benthic Crustaceans</b>	0	6	5	5	4	4	4
<b>Benthic Invertebrates</b>	2	7	6	8	8	8	8
<b>Clupeids</b>	0	0	0	2	2	2	2
<b>Macrozooplankton</b>	1	5	7	7	7	7	7
<b>Medium Forage Fish</b>	0	4	3	4	5	5	6
<b>Sciaenids</b>	0	3	2	1	1	3	1

<b>B. Equal</b>	<b>Age 0</b>	<b>Age 1</b>	<b>Age 2</b>	<b>Age 3</b>	<b>Age 4</b>	<b>Age 5</b>	<b>Age 6</b>
<b>Striper_2002_13+</b>	0	0	0	0	0	0	0
<b>Weakfish_2002</b>	0	0	0	0	0	0	0
<b>Menhaden_2002</b>	2.5	4	4	4.5	4.5	4.5	4.5
<b>Bay Anchovy</b>	2.5	4	4	4.5	4.5	4.5	4.5
<b>Benthic Crustaceans</b>	0	4	4	4.5	4.5	4.5	4.5
<b>Benthic Invertebrates</b>	2.5	4	4	4.5	4.5	4.5	4.5
<b>Clupeids</b>	0	0	0	4.5	4.5	4.5	4.5
<b>Macrozooplankton</b>	2.5	4	4	4.5	4.5	4.5	4.5
<b>Medium Forage Fish</b>	0	4	4	4.5	4.5	4.5	4.5
<b>Sciaenids</b>	0	4	4	4.5	4.5	4.5	4.5

<b>C. Fish/Invert</b>	<b>Age 0</b>	<b>Age 1</b>	<b>Age 2</b>	<b>Age 3</b>	<b>Age 4</b>	<b>Age 5</b>	<b>Age 6</b>
<b>Striper_2002_13+</b>	0	0	0	0	0	0	0
<b>Weakfish_2002</b>	0	0	0	0	0	0	0
<b>Menhaden_2002</b>	3.5	2.5	2.5	3	3	3	3
<b>Bay Anchovy</b>	3.5	2.5	2.5	3	3	3	3
<b>Benthic Crustaceans</b>	0	6	6	7	7	7	7
<b>Benthic Invertebrates</b>	1.5	6	6	7	7	7	7
<b>Clupeids</b>	0	0	0	3	3	3	3
<b>Macrozooplankton</b>	1.5	6	6	7	7	7	7
<b>Medium Forage Fish</b>	0	2.5	2.5	3	3	3	3
<b>Sciaenids</b>	0	2.5	2.5	3	3	3	3

Table D1.3. Base and alternate prey-preference rankings for bluefish in sensitivity MSVPA-X runs.

<b>A. Base</b>	<b>Size 1</b>	<b>Size 2</b>	<b>Size 3</b>
<b>Striper_2002_13+</b>	0	0	0
<b>Weakfish_2002</b>	0	0	0
<b>Menhaden_2002</b>	4	4	5
<b>Bay Anchovy</b>	2	7	6
<b>Benthic Crustaceans</b>	5	6	4
<b>Benthic Invertebrates</b>	6	8	7
<b>Clupeids</b>	7	2	3
<b>Macrozooplankton</b>	8	5	8
<b>Medium Forage Fish</b>	1	1	1
<b>Sciaenids</b>	3	3	2

<b>B. Equal</b>	<b>Size 1</b>	<b>Size 2</b>	<b>Size 3</b>
<b>Striper_2002_13+</b>	0	0	0
<b>Weakfish_2002</b>	0	0	0
<b>Menhaden_2002</b>	4.5	4.5	4.5
<b>Bay Anchovy</b>	4.5	4.5	4.5
<b>Benthic Crustaceans</b>	4.5	4.5	4.5
<b>Benthic Invertebrates</b>	4.5	4.5	4.5
<b>Clupeids</b>	4.5	4.5	4.5
<b>Macrozooplankton</b>	4.5	4.5	4.5
<b>Medium Forage Fish</b>	4.5	4.5	4.5
<b>Sciaenids</b>	4.5	4.5	4.5

<b>C. Fish/Invert</b>	<b>Size 1</b>	<b>Size 2</b>	<b>Size 3</b>
<b>Striper_2002_13+</b>	0	0	0
<b>Weakfish_2002</b>	0	0	0
<b>Menhaden_2002</b>	3	3	3
<b>Bay Anchovy</b>	3	3	3
<b>Benthic Crustaceans</b>	7	7	7
<b>Benthic Invertebrates</b>	7	7	7
<b>Clupeids</b>	3	3	3
<b>Macrozooplankton</b>	7	7	7
<b>Medium Forage Fish</b>	3	3	3
<b>Sciaenids</b>	3	3	3



Table D1.4. Estimates of M2 (age 0-2) for menhaden with equal prey-preference ranking.

Year	Base			Bluefish			Weakfish			Striped Bass			All Predators		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1982	0.672	0.328	0.207	0.637	0.355	0.256	0.508	0.314	0.206	0.672	0.327	0.207	0.471	0.340	0.256
1983	0.607	0.276	0.171	0.576	0.296	0.211	0.459	0.265	0.170	0.605	0.274	0.171	0.424	0.284	0.211
1984	0.508	0.252	0.168	0.479	0.272	0.206	0.392	0.246	0.168	0.503	0.250	0.168	0.357	0.264	0.206
1985	0.542	0.241	0.164	0.511	0.262	0.203	0.406	0.237	0.164	0.536	0.239	0.163	0.367	0.255	0.204
1986	0.620	0.235	0.158	0.598	0.264	0.200	0.461	0.230	0.158	0.612	0.231	0.158	0.429	0.255	0.199
1987	0.637	0.193	0.119	0.621	0.217	0.149	0.488	0.188	0.119	0.626	0.188	0.118	0.459	0.207	0.148
1988	0.538	0.180	0.099	0.525	0.198	0.123	0.436	0.175	0.099	0.521	0.173	0.098	0.405	0.186	0.121
1989	0.396	0.167	0.093	0.384	0.183	0.114	0.335	0.164	0.093	0.370	0.158	0.091	0.297	0.171	0.112
1990	0.377	0.166	0.093	0.367	0.182	0.113	0.322	0.164	0.094	0.344	0.155	0.091	0.277	0.168	0.111
1991	0.404	0.162	0.087	0.394	0.178	0.105	0.346	0.160	0.087	0.365	0.152	0.086	0.297	0.166	0.104
1992	0.394	0.130	0.062	0.384	0.140	0.073	0.292	0.129	0.062	0.353	0.121	0.061	0.240	0.130	0.073
1993	0.534	0.148	0.068	0.524	0.159	0.080	0.391	0.148	0.068	0.478	0.136	0.068	0.323	0.147	0.080
1994	0.678	0.158	0.068	0.667	0.167	0.078	0.477	0.157	0.068	0.616	0.144	0.068	0.403	0.152	0.078
1995	0.854	0.188	0.072	0.840	0.196	0.083	0.635	0.185	0.072	0.784	0.172	0.072	0.551	0.179	0.083
1996	0.765	0.185	0.063	0.753	0.193	0.072	0.592	0.180	0.063	0.703	0.174	0.064	0.519	0.178	0.073
1997	0.752	0.191	0.060	0.741	0.200	0.068	0.608	0.183	0.059	0.691	0.182	0.061	0.534	0.183	0.069
1998	0.794	0.217	0.070	0.783	0.228	0.080	0.647	0.209	0.070	0.714	0.207	0.072	0.555	0.209	0.082
1999	0.745	0.214	0.073	0.733	0.226	0.085	0.621	0.209	0.073	0.665	0.200	0.074	0.528	0.208	0.086
2000	0.697	0.206	0.077	0.685	0.221	0.091	0.583	0.204	0.078	0.630	0.195	0.079	0.503	0.207	0.092
2001	0.835	0.228	0.090	0.821	0.247	0.107	0.664	0.224	0.090	0.771	0.218	0.092	0.583	0.233	0.109
2002	1.050	0.261	0.109	1.032	0.286	0.130	0.812	0.256	0.109	0.996	0.254	0.112	0.736	0.273	0.133

Table D1.5. Estimates of M2 (age 0-2) for menhaden with fish/invert prey-preference ranking.

Year	Base			Bluefish			Weakfish			Striped Bass			All Predators		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1982	0.672	0.328	0.207	0.664	0.375	0.267	0.590	0.322	0.207	0.671	0.327	0.208	0.581	0.369	0.268
1983	0.607	0.276	0.171	0.599	0.313	0.218	0.534	0.272	0.171	0.603	0.275	0.171	0.522	0.308	0.218
1984	0.508	0.252	0.168	0.501	0.289	0.214	0.452	0.250	0.168	0.501	0.250	0.168	0.439	0.285	0.215
1985	0.542	0.241	0.164	0.534	0.279	0.211	0.474	0.239	0.164	0.533	0.239	0.164	0.457	0.275	0.211
1986	0.620	0.235	0.158	0.619	0.280	0.208	0.545	0.233	0.158	0.610	0.232	0.158	0.535	0.276	0.208
1987	0.637	0.193	0.119	0.636	0.228	0.154	0.566	0.191	0.119	0.625	0.189	0.118	0.554	0.223	0.155
1988	0.538	0.180	0.099	0.536	0.207	0.128	0.492	0.178	0.099	0.522	0.175	0.099	0.475	0.201	0.127
1989	0.396	0.167	0.093	0.396	0.191	0.118	0.368	0.166	0.093	0.372	0.161	0.092	0.345	0.184	0.118
1990	0.377	0.166	0.093	0.378	0.189	0.117	0.351	0.165	0.093	0.345	0.159	0.093	0.320	0.181	0.116
1991	0.404	0.162	0.087	0.404	0.184	0.108	0.377	0.161	0.087	0.367	0.157	0.088	0.341	0.179	0.109
1992	0.394	0.130	0.062	0.390	0.144	0.075	0.343	0.130	0.062	0.352	0.125	0.063	0.296	0.140	0.077
1993	0.534	0.148	0.068	0.529	0.163	0.082	0.461	0.148	0.068	0.478	0.144	0.070	0.399	0.159	0.084
1994	0.678	0.158	0.068	0.670	0.170	0.080	0.573	0.158	0.068	0.617	0.153	0.070	0.505	0.165	0.082
1995	0.854	0.188	0.072	0.840	0.200	0.084	0.733	0.186	0.072	0.781	0.181	0.076	0.650	0.192	0.088
1996	0.765	0.185	0.063	0.754	0.196	0.073	0.661	0.181	0.063	0.702	0.182	0.066	0.589	0.189	0.077
1997	0.752	0.191	0.060	0.742	0.202	0.070	0.678	0.187	0.060	0.699	0.191	0.063	0.616	0.199	0.073
1998	0.794	0.217	0.070	0.785	0.231	0.081	0.717	0.213	0.070	0.725	0.217	0.075	0.641	0.226	0.086
1999	0.745	0.214	0.073	0.738	0.230	0.086	0.684	0.213	0.073	0.677	0.210	0.077	0.611	0.225	0.090
2000	0.697	0.206	0.077	0.691	0.225	0.093	0.642	0.205	0.078	0.646	0.206	0.082	0.586	0.225	0.097
2001	0.835	0.228	0.090	0.828	0.253	0.110	0.750	0.226	0.090	0.784	0.228	0.095	0.693	0.251	0.114
2002	1.050	0.261	0.109	1.041	0.293	0.134	0.935	0.259	0.109	1.004	0.264	0.115	0.881	0.294	0.140

Table D1.6. Menhaden annual average F (age 2+) with both prey-preference ranking.

Year	Base	Bluefish		Weakfish		Striped Bass		All Predators	
	-	Equal	F&I	Equal	F&I	Equal	F&I	Equal	F&I
<b>1982</b>	1.594	1.546	1.539	1.596	1.594	1.593	1.593	1.547	1.538
<b>1983</b>	1.442	1.407	1.401	1.443	1.442	1.442	1.442	1.407	1.4
<b>1984</b>	1.486	1.448	1.442	1.484	1.486	1.486	1.486	1.448	1.442
<b>1985</b>	1.534	1.492	1.485	1.529	1.534	1.534	1.534	1.491	1.485
<b>1986</b>	1.180	1.148	1.142	1.171	1.180	1.180	1.180	1.147	1.142
<b>1987</b>	1.053	1.032	1.030	1.042	1.053	1.053	1.053	1.032	1.03
<b>1988</b>	1.268	1.249	1.245	1.248	1.268	1.269	1.268	1.245	1.245
<b>1989</b>	1.219	1.201	1.198	1.192	1.219	1.220	1.218	1.195	1.197
<b>1990</b>	1.156	1.141	1.139	1.130	1.156	1.157	1.156	1.135	1.139
<b>1991</b>	1.363	1.351	1.348	1.334	1.363	1.364	1.362	1.337	1.347
<b>1992</b>	1.014	1.006	1.004	0.988	1.014	1.014	1.013	0.992	1.003
<b>1993</b>	1.036	1.027	1.026	1.002	1.036	1.035	1.033	1.011	1.024
<b>1994</b>	0.969	0.963	0.962	0.938	0.969	0.968	0.966	0.948	0.96
<b>1995</b>	1.237	1.231	1.229	1.199	1.237	1.237	1.235	1.207	1.227
<b>1996</b>	0.750	0.746	0.745	0.726	0.750	0.749	0.749	0.730	0.744
<b>1997</b>	0.915	0.911	0.910	0.891	0.915	0.914	0.913	0.892	0.908
<b>1998</b>	1.339	1.332	1.331	1.303	1.339	1.338	1.336	1.308	1.328
<b>1999</b>	1.182	1.174	1.173	1.145	1.182	1.181	1.179	1.153	1.175
<b>2000</b>	0.883	0.876	0.876	0.857	0.883	0.883	0.882	0.860	0.874
<b>2001</b>	1.243	1.235	1.233	1.212	1.243	1.242	1.241	1.212	1.231
<b>2002</b>	1.175	1.168	1.167	1.145	1.175	1.174	1.173	1.148	1.166

Table D1.7. Menhaden abundance at age 0-1 (millions) with equal prey-preference ranking.

Year	Base		Bluefish		Weakfish		Striped Bass		All Predators	
	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1
1982	10187.5	8817.3	10190.0	9234.6	8565.8	8696.5	10187.5	8808.0	8309.5	9143.5
1983	15412.0	3413.4	15423.0	3546.7	13331.2	3380.2	15377.7	3411.2	13301.2	3509.8
1984	18489.6	5068.0	18623.2	5253.0	16493.2	5038.0	18352.7	5058.9	16504.3	5217.8
1985	16256.0	6647.8	16484.1	6931.6	14166.3	6621.7	16112.4	6629.3	14243.7	6887.1
1986	12039.3	5937.9	12156.2	6235.7	10188.9	5913.9	11889.3	5924.5	10172.6	6192.0
1987	11209.1	4263.8	11346.1	4420.3	9577.9	4244.0	10956.9	4242.4	9539.6	4379.1
1988	16877.3	3938.7	16985.8	4063.8	15167.0	3920.2	16447.0	3908.1	14941.0	4015.2
1989	6690.1	6374.5	6763.3	6532.8	6267.3	6358.1	6439.5	6317.7	6110.3	6459.2
1990	9613.7	2917.2	9679.1	2988.6	9087.7	2906.5	9228.7	2879.2	8790.2	2946.1
1991	10432.6	4208.9	10478.5	4292.2	9871.6	4202.0	9997.4	4173.1	9505.8	4251.2
1992	9118.2	4094.4	9173.9	4163.9	8266.5	4089.0	8683.5	4065.9	7903.7	4128.6
1993	7338.8	3857.4	7395.8	3925.9	6362.5	3857.4	6894.7	3818.8	5970.5	3884.8
1994	11130.9	2843.4	11163.8	2889.7	9113.9	2841.5	10355.6	2810.1	8453.5	2850.3
1995	7299.2	3728.8	7261.8	3781.1	5793.6	3718.2	6745.1	3682.4	5491.5	3727.6
1996	6800.5	2045.6	6801.4	2073.5	5655.5	2035.1	6358.7	2026.1	5303.4	2046.7
1997	6357.5	2096.7	6375.8	2126.8	5435.6	2081.6	6051.0	2082.0	5100.8	2096.8
1998	8061.8	1990.2	8103.7	2025.0	6921.7	1971.7	7375.7	1971.8	6385.2	1991.1
1999	6265.4	2395.8	6343.4	2447.2	5531.2	2383.2	5750.0	2369.9	5135.1	2410.6
2000	3806.0	1884.5	3865.4	1938.7	3387.3	1880.1	3535.8	1868.2	3198.8	1915.9
2001	7725.9	1224.4	7805.6	1263.6	6552.3	1220.7	7230.7	1214.0	6127.2	1247.7
2002	9427.0	2228.8	9657.2	2289.2	8045.1	2242.1	8939.1	2222.0	7566.3	2277.3

Table D1.8. Menhaden abundance at age 0-1 (millions) with fish/invert prey-preference ranking.

Year	Base		Bluefish		Weakfish		Striped Bass		All Predators	
	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1
1982	10187.5	8817.3	10672.2	9452.3	9354.3	8768.9	10173.9	8808.0	9793.4	9402.4
1983	15412.0	3413.4	16066.5	3614.7	14359.3	3400.7	15368.1	3411.2	14874.9	3600.2
1984	18489.6	5068.0	19386.0	5348.6	17483.4	5054.7	18309.0	5059.7	18235.4	5330.4
1985	16256.0	6647.8	17194.8	7068.8	15182.9	6630.7	16075.5	6630.7	15921.0	7047.7
1986	12039.3	5937.9	12587.3	6359.8	11061.9	5932.8	11862.5	5926.7	11531.2	6348.7
1987	11209.1	4263.8	11607.4	4481.7	10418.7	4255.3	11043.6	4251.7	10719.7	4457.9
1988	16877.3	3938.7	17360.2	4108.1	16232.9	3929.9	16526.7	3919.2	16249.7	4084.0
1989	6690.1	6374.5	6905.5	6591.9	6498.5	6369.0	6488.1	6339.9	6518.7	6550.3
1990	9613.7	2917.2	9848.0	3013.3	9366.6	2912.2	9290.0	2894.4	9277.7	2991.4
1991	10432.6	4208.9	10638.7	4318.8	10171.7	4208.9	10077.9	4195.8	10005.8	4305.7
1992	9118.2	4094.4	9317.8	4186.8	8671.7	4094.4	8745.4	4090.0	8465.0	4174.8
1993	7338.8	3857.4	7467.5	3963.6	6837.6	3857.4	6945.2	3852.1	6298.5	3939.7
1994	11130.9	2843.4	11244.2	2901.7	10007.8	2843.4	10457.2	2837.5	9508.7	2894.8
1995	7299.2	3728.8	7302.8	3797.7	6433.9	3725.3	6786.3	3719.3	6032.6	3783.8
1996	6800.5	2045.6	6875.1	2084.0	6113.2	2037.0	6390.6	2043.9	5795.2	2073.5
1997	6357.5	2096.7	6420.3	2133.5	5880.3	2090.5	6056.6	2104.5	5643.7	2132.5
1998	8061.8	1990.2	8165.2	2032.5	7455.1	1980.9	7535.2	1993.3	7121.6	2023.8
1999	6265.4	2395.8	6410.4	2460.2	5898.4	2393.6	5891.4	2396.1	5694.8	2458.8
2000	3806.0	1884.5	3920.4	1949.9	3591.8	1884.5	3637.2	1891.3	3546.5	1956.2
2001	7725.9	1224.4	7870.2	1274.0	7073.8	1221.6	7381.4	1228.2	6971.4	1274.6
2002	9427.0	2228.8	9708.9	2297.1	8720.7	2226.8	9115.8	2230.7	8538.6	2316.2

Table D1.9. Menhaden spawning stock biomass (1000 mt) with equal prey-preference ranking.

<b>Year</b>	<b>Base</b>	<b>Bluefish</b>	<b>Weakfish</b>	<b>Striped Bass</b>	<b>All Predators</b>
<b>1982</b>	86.3	88.6	86.3	86.4	88.6
<b>1983</b>	68.7	70.5	68.7	68.7	70.5
<b>1984</b>	92.9	94.3	92.9	93.0	94.3
<b>1985</b>	52.3	53.3	52.3	52.3	53.4
<b>1986</b>	55.6	57.0	55.6	55.6	57.0
<b>1987</b>	107.6	109.8	107.6	107.6	109.8
<b>1988</b>	142.1	143.8	142.1	142.1	143.8
<b>1989</b>	111.2	112.6	111.2	111.2	112.6
<b>1990</b>	117.5	118.9	117.5	117.5	118.9
<b>1991</b>	127.7	128.8	127.7	127.7	128.8
<b>1992</b>	81.0	81.5	81.0	81.0	81.5
<b>1993</b>	80.8	81.3	80.8	80.8	81.4
<b>1994</b>	102.2	102.9	102.2	102.4	102.9
<b>1995</b>	101.4	101.8	101.4	101.4	101.9
<b>1996</b>	70.8	71.2	70.8	70.8	71.2
<b>1997</b>	181.7	182.4	181.8	181.8	182.5
<b>1998</b>	161.1	161.6	161.1	161.2	161.7
<b>1999</b>	89.0	89.4	89.0	89.0	89.4
<b>2000</b>	77.8	78.2	77.8	77.8	78.3
<b>2001</b>	101.4	102.0	101.4	101.5	102.1
<b>2002</b>	79.6	80.1	79.6	79.7	80.2

Table D1.10. Menhaden spawning stock biomass (1000 mt) with fish/invert prey-preference ranking.

<i>Year</i>	<b>Base</b>	<b>Bluefish</b>	<b>Weakfish</b>	<b>Striped Bass</b>	<b>All Predators</b>
<b>1982</b>	86.3	88.9	86.3	86.4	89.0
<b>1983</b>	68.7	70.7	68.7	68.7	70.8
<b>1984</b>	92.9	94.5	92.9	93.0	94.5
<b>1985</b>	52.3	53.5	52.3	52.3	53.5
<b>1986</b>	55.6	57.2	55.6	55.6	57.3
<b>1987</b>	107.6	110.2	107.6	107.6	110.2
<b>1988</b>	142.1	144.1	142.1	142.1	144.1
<b>1989</b>	111.2	112.8	111.2	111.3	112.8
<b>1990</b>	117.5	119.1	117.5	117.6	119.2
<b>1991</b>	127.7	128.9	127.7	127.8	129.0
<b>1992</b>	81.0	81.6	81.0	81.1	81.6
<b>1993</b>	80.8	81.4	80.8	80.9	81.5
<b>1994</b>	102.2	103.0	102.2	102.5	103.1
<b>1995</b>	101.4	101.9	101.4	101.5	102.1
<b>1996</b>	70.8	71.3	70.8	70.9	71.4
<b>1997</b>	181.7	182.6	181.8	181.9	182.7
<b>1998</b>	161.1	161.6	161.1	161.3	161.8
<b>1999</b>	89.0	89.4	89.0	89.1	89.5
<b>2000</b>	77.8	78.3	77.8	77.9	78.4
<b>2001</b>	101.4	102.1	101.4	101.5	102.3
<b>2002</b>	79.6	80.2	79.6	79.7	80.4

Table D1.11. Diet composition of menhaden (%) for each predator age.

Striped Bass									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Age 0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Age 1	2.4%	2.4%	2.5%	2.2%	2.3%	1.1%	0.6%	1.1%	0.6%
Age 2	8.4%	8.5%	8.6%	8.0%	8.2%	4.1%	2.2%	4.0%	2.2%
Age 3	8.7%	8.8%	8.9%	8.4%	8.5%	5.1%	2.7%	5.0%	2.8%
Age 4	11.2%	11.4%	11.5%	10.9%	11.1%	5.2%	9.4%	5.1%	9.5%
Age 5	28.1%	28.5%	28.6%	27.5%	27.8%	18.4%	21.4%	18.2%	21.6%
Age 6	29.7%	30.1%	30.3%	29.3%	29.5%	19.8%	22.1%	19.7%	22.4%
Age 7	28.2%	28.6%	28.8%	27.9%	28.1%	25.7%	28.6%	25.8%	29.0%
Age 8	28.9%	29.3%	29.5%	28.7%	28.8%	27.0%	29.7%	27.2%	30.1%
Age 9	31.1%	31.5%	31.6%	30.9%	31.0%	38.2%	41.3%	38.4%	41.8%
Age 10	35.8%	36.2%	36.3%	35.8%	35.8%	44.7%	47.2%	45.0%	47.7%
Age 11	31.3%	31.6%	31.7%	31.2%	31.2%	41.0%	43.0%	41.3%	43.4%
Age 12	29.3%	29.6%	29.7%	29.2%	29.3%	38.8%	40.5%	39.1%	40.9%
Age 13	29.1%	29.4%	29.5%	29.1%	29.1%	38.4%	39.9%	38.7%	40.2%

Weakfish									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Age 0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Age 1	4.0%	4.0%	4.1%	1.0%	2.4%	3.9%	3.9%	1.0%	2.3%
Age 2	26.9%	27.1%	27.4%	13.8%	20.7%	26.5%	26.6%	13.5%	20.7%
Age 3	41.5%	41.8%	42.1%	27.2%	33.8%	41.0%	41.2%	27.0%	33.9%
Age 4	48.9%	49.4%	49.6%	37.5%	43.3%	48.5%	48.7%	37.5%	43.7%
Age 5	53.9%	54.3%	54.5%	38.8%	43.9%	53.5%	53.7%	38.9%	44.3%
Age 6	47.7%	48.2%	48.3%	42.1%	46.6%	47.5%	47.6%	42.2%	47.1%

Bluefish									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Size 1	3.1%	1.7%	4.4%	2.8%	2.9%	3.0%	3.0%	1.5%	4.1%
Size 2	29.7%	24.7%	29.8%	29.1%	29.4%	29.4%	29.5%	23.9%	29.3%
Size 3	29.0%	36.7%	38.0%	29.0%	29.0%	29.0%	29.0%	36.5%	37.9%



Table D1.12. Consumption of menhaden (1000 mt) by predators for equal prey-preference ranking.

Year	<i>When modifying:</i>														
	Base			Bluefish			Weakfish			Striped Bass			All Predators		
	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF
1982	6.9	80.0	160.7	7.1	81.2	183.3	6.8	52.4	158.8	5.3	80.8	161.1	5.3	53.1	181.6
1983	6.2	74.6	107.5	6.3	75.3	118.2	6.0	44.7	105.6	4.3	75.3	107.7	4.3	45.5	116.7
1984	8.4	68.7	107.0	8.6	69.6	112.9	8.2	41.2	105.4	5.6	69.1	107.1	5.6	41.9	111.5
1985	10.6	65.8	120.2	10.9	67.2	129.9	10.4	36.9	118.5	7.2	66.1	120.3	7.3	37.8	128.3
1986	16.7	85.3	160.1	17.1	86.4	183.6	16.2	48.2	157.5	11.2	85.4	160.0	11.2	49.0	181.1
1987	20.6	98.9	123.8	21.0	100.1	143.4	20.0	60.0	121.7	14.3	98.4	123.3	14.2	60.7	141.2
1988	34.2	122.9	102.5	34.6	123.5	113.7	33.4	82.2	100.9	22.6	122.2	101.9	22.4	82.3	111.6
1989	34.6	38.5	85.4	35.0	38.8	98.9	34.5	27.2	85.2	24.7	38.1	84.9	24.9	27.2	98.2
1990	42.4	37.3	70.6	42.8	37.4	80.0	42.1	24.7	70.3	29.9	36.7	70.0	30.0	24.4	79.2
1991	45.0	35.9	56.9	45.2	36.0	64.6	44.7	24.2	56.7	33.3	35.4	56.5	33.3	23.8	64.0
1992	39.7	26.9	34.8	40.0	27.0	39.5	39.3	14.8	34.6	29.6	26.4	34.6	29.4	14.6	39.2
1993	47.2	30.8	33.8	47.5	31.0	39.3	46.4	16.5	33.6	36.1	30.0	33.6	35.7	16.0	38.9
1994	58.0	60.1	29.4	58.3	60.2	33.3	56.1	30.4	28.9	43.0	57.9	29.1	41.8	29.3	32.6
1995	54.1	57.3	26.5	54.2	57.0	30.8	52.4	33.3	26.2	41.9	55.4	26.3	41.3	32.9	30.4
1996	65.0	85.6	29.7	65.1	85.3	34.4	62.6	52.5	29.2	50.1	83.2	29.5	48.7	51.1	33.7
1997	64.8	83.5	29.9	65.0	83.3	34.6	62.7	55.6	29.4	50.7	82.7	29.8	49.0	54.1	33.9
1998	86.7	97.0	33.4	87.3	97.1	37.9	83.7	62.7	32.7	64.9	93.1	32.9	63.4	60.6	36.8
1999	80.2	68.5	36.8	81.2	69.1	42.6	78.6	46.4	36.3	61.1	66.0	36.4	60.6	45.2	41.7
2000	56.6	38.7	37.1	57.4	39.2	44.4	55.8	26.2	36.8	46.0	37.6	36.8	46.1	25.8	43.9
2001	70.7	84.8	46.7	71.6	85.6	52.9	68.4	51.0	45.7	54.3	82.4	46.2	53.1	49.4	51.3
2002	79.2	134.2	69.2	81.0	137.6	78.5	79.3	83.6	69.3	63.1	131.7	68.8	63.2	81.4	77.0

Table D1.13. Consumption of menhaden (1000 mt) by predators for fish/invert prey-preference ranking.

Year	<i>When modifying:</i>														
	Base			Bluefish			Weakfish			Striped Bass			All Predators		
	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF
1982	6.9	80.0	160.7	7.2	82.8	200.7	6.8	65.5	159.9	5.7	80.6	160.9	5.9	68.3	200.0
1983	6.2	74.6	107.5	6.4	76.9	129.4	6.1	58.6	106.6	4.4	75.1	107.6	4.5	60.7	128.5
1984	8.4	68.7	107.0	8.8	71.1	125.7	8.3	54.3	106.2	5.4	68.8	106.9	5.6	56.5	124.9
1985	10.6	65.8	120.2	11.1	68.8	143.8	10.5	50.1	119.4	7.0	65.9	120.1	7.2	52.4	142.9
1986	16.7	85.3	160.1	17.3	87.9	200.8	16.4	65.3	158.6	11.7	85.1	159.7	12.1	67.9	199.6
1987	20.6	98.9	123.8	21.2	100.9	155.2	20.4	78.4	122.9	15.4	98.8	123.6	15.6	80.5	154.1
1988	34.2	122.9	102.5	34.9	124.4	124.1	34.1	103.4	102.2	24.8	122.3	102.1	25.1	103.7	123.0
1989	34.6	38.5	85.4	35.2	39.0	106.6	34.6	33.0	85.3	27.1	38.2	85.0	27.6	33.2	106.2
1990	42.4	37.3	70.6	43.0	37.6	86.3	42.3	30.7	70.5	31.9	36.9	70.2	32.3	30.6	85.9
1991	45.0	35.9	56.9	45.4	36.0	69.9	44.9	30.1	56.9	35.9	35.6	56.7	36.2	29.9	69.5
1992	39.7	26.9	34.8	40.2	27.2	42.5	39.5	20.1	34.7	31.3	26.5	34.7	31.4	20.0	42.3
1993	47.2	30.8	33.8	47.7	31.0	42.2	46.8	22.7	33.7	39.0	30.1	33.7	38.5	21.4	41.6
1994	58.0	60.1	29.4	58.3	60.1	35.8	56.9	42.6	29.1	46.0	58.3	29.2	45.5	41.5	35.3
1995	54.1	57.3	26.5	54.2	56.7	33.0	53.2	42.7	26.3	44.9	55.6	26.4	44.5	41.3	32.7
1996	65.0	85.6	29.7	65.3	85.2	36.8	63.6	64.3	29.4	52.8	83.5	29.6	52.1	62.4	36.3
1997	64.8	83.5	29.9	65.1	83.0	37.0	63.7	67.7	29.6	55.3	82.3	29.8	54.7	66.1	36.6
1998	86.7	97.0	33.4	87.4	96.9	40.8	85.2	77.2	33.0	70.9	94.4	33.1	70.5	75.6	40.2
1999	80.2	68.5	36.8	81.4	69.1	45.7	79.5	56.8	36.6	67.3	67.1	36.6	67.7	56.2	45.3
2000	56.6	38.7	37.1	57.6	39.3	47.3	56.2	32.0	36.9	51.5	38.3	37.0	52.0	32.1	47.2
2001	70.7	84.8	46.7	71.6	85.3	57.0	69.2	65.5	46.0	59.7	83.4	46.5	59.8	65.6	56.3
2002	79.2	134.2	69.2	80.6	136.5	84.4	79.1	106.8	69.1	68.7	133.3	69.1	69.4	106.2	84.0

Table D1.14. Summary of the Spatial Overlap sensitivity runs – model run name and a brief description. Refer to table when looking at figures below. Areas highlighted in grey are referred to as ‘Predator Runs’ and those in yellow are ‘Seasonal Runs’. \* Description of how original ‘Base’ run spatial overlap values were developed is described in document.

<b>Model Run Name</b>	<b>Spatial Overlap Description/Combination</b>
Base	Original spatial overlap values *
Ex 1	<b>Striped Bass</b> values = 1 for all prey and seasons Other predators same as Base
Ex 2	<b>Weakfish</b> values = 1 for all prey and seasons Other predators same as Base
Ex 3	<b>Bluefish</b> values = 1 for all prey and seasons Other predators same as Base
Ex 4	<b>All Predators</b> = 1 for all prey and seasons
Ex 5	<b>All Predators</b> = 1 for all prey and <b>NO seasons</b> Compared to Ex 4
Ex 6	Average seasonal values for <b>All predators</b> and <b>NO seasons</b> . Compared to Base

Table D1.15. Values of the prey size selectivity curve parameters,  $\alpha$  and  $\beta$ , for the base run and sensitivity analyses scenarios 1) Is the MSVPA highly sensitive to the values selected for  $\alpha$  and  $\beta$  ( $\pm 1\%$  change in the parameters), and 2) How sensitive is the MSVPA to shifts in median size of animals consumed.

Size Selectivity Parameters	Base Run		-1% Change in $\alpha$ and $\beta$		+1% Change in $\alpha$ and $\beta$		-10% Shift in median size		+10% Shift in median size		-20% Shift in median size		+20% Shift in median size	
	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$
<b>Age 0-4 Striped Bass</b>	2.98	11.244	2.9502	11.13156	3.0098	11.35644	2.7	10.8	3.3	11.6	2.37	11.6	3.7	12.15
<b>Age 5-9 Striped Bass</b>	9.1	35.2	9.009	34.848	9.191	35.552	8.05	30	10.72	32	6.75	28.4	12.3	33
<b>Age 10+ Striped Bass</b>	13.9	51.2	13.761	50.688	14.039	51.712	8.65	50	16	53	10.6	48	19.5	25
<b>Weakfish</b>	10.1	25.5	9.999	25.245	9.191	35.552	8.65	25	11.1	25	7.5	24.5	12.5	25
<b>Bluefish</b>	10.1	25.5	9.999	25.245	9.191	35.552	8.65	25	11.1	25	7.5	24.5	12.5	25

Table D1.16. Values of the prey size selectivity curve parameters,  $\alpha$  and  $\beta$ , for the scenarios with a change in prey size range compared to the base run to test the sensitivity of the model to dramatically different prey size selectivity curves.

Size Selectivity Parameters	Base Run		Decrease in prey size range (10%)		Increase in prey size range (10%)	
	$\alpha$	$\beta$	$\alpha$	$\beta$	$\alpha$	$\beta$
<b>Age 0-4 Striped Bass</b>	2.98	11.244	6.85	31	2.55	9
<b>Age 5-9 Striped Bass</b>	9.1	35.2	20.2	82	6.7	25
<b>Age 10+ Striped Bass</b>	13.9	51.2	33	130	12.1	44
<b>Weakfish</b>	10.1	25.5	27.2	72	8	20
<b>Bluefish</b>	10.1	25.5	27.2	72	8	20

Table D1.17. Percent change in abundance (numbers) of age-0, age-1 and total abundance of menhaden given a  $\pm 1\%$  change in the prey size selectivity curve parameters  $\alpha$  &  $\beta$  from the base run condition for all predators combined (striped bass, weakfish and bluefish) in the MSVPA-X.

Year	-1% change in $\alpha$ & $\beta$			+1% change in $\alpha$ & $\beta$		
	Age 0	Age 1	Total	Age 0	Age 1	Total
1982	0.287	0.105	0.172	0.287	0.105	0.173
1983	0.041	0.000	0.028	0.041	0.000	0.029
1984	0.270	0.079	0.209	0.262	0.079	0.205
1985	0.292	0.086	0.211	0.233	0.056	0.165
1986	0.365	0.093	0.235	0.365	0.025	0.210
1987	-0.224	0.000	-0.123	0.160	0.000	0.096
1988	0.248	0.000	0.177	0.350	0.109	0.269
1989	0.312	0.041	0.151	0.043	0.044	0.036
1990	0.062	0.171	0.080	0.000	0.000	0.010
1991	0.101	-0.005	0.061	-0.090	0.000	-0.056
1992	-0.027	0.000	-0.017	-0.013	-0.110	-0.038
1993	-0.354	0.000	-0.192	-0.132	-0.029	-0.097
1994	0.119	-0.127	0.058	0.113	0.035	0.072
1995	0.256	0.000	0.136	0.864	0.094	0.509
1996	0.290	-0.044	0.171	0.209	0.112	0.151
1997	-4.400	-0.105	-2.783	0.171	0.000	0.116
1998	0.394	-0.075	0.261	0.175	0.085	0.137
1999	0.313	0.008	0.193	0.000	0.054	0.013
2000	0.247	-0.005	0.129	0.097	0.000	0.063
2001	0.841	-0.016	0.629	-0.326	0.000	-0.244
2002	0.152	0.000	0.111	0.075	0.045	0.065

Table D1.18. Spawning stock biomass (SSB) in thousands of metric tons of menhaden from the base run MSVPA configuration and the SSB of menhaden a  $\pm$  1 percent change in the prey size selectivity curves  $\alpha$  &  $\beta$ .

<b>Base Run SSB</b>	<b>SSB with a -1% change in <math>\alpha</math> &amp; <math>\beta</math></b>	<b>SSB with a +1% change in <math>\alpha</math> &amp; <math>\beta</math></b>
86.31	86.31	86.3
68.73	68.73	68.72
92.93	92.98	92.93
52.3	52.3	52.27
55.58	55.58	55.58
107.6	107.58	107.58
142.1	142.09	142.07
111.24	111.24	111.23
117.54	117.53	117.53
127.72	127.72	127.72
81.02	81.02	81.02
80.75	80.76	80.77
102.24	102.25	102.38
101.38	101.39	101.38
70.78	70.78	70.77
181.74	181.75	181.67
161.14	161.15	161.14
89	89.01	89
77.76	77.79	77.74
101.38	101.38	101.38
79.57	79.59	79.57

Table D1.19. Change in predation mortality (M2) for age-0 and age-1 menhaden from the base run when the size selectivity curve parameters ( $\alpha$  &  $\beta$ ) in the MSVPA-X are changed by  $\pm 1$  percent.

Year	Age 0			Age 1		
	Base Run M2 Rates by Year	Change in M2 from Base Run		Base Run M2 Rates by Year	Change in M2 from Base Run	
		-1% Change in $\alpha$ & $\beta$	+1% Change in $\alpha$ & $\beta$		-1% Change in $\alpha$ & $\beta$	+1% Change in $\alpha$ & $\beta$
1982	0.672	-0.002	0.003	0.328	-0.001	0
1983	0.607	-0.002	0.002	0.276	0	0
1984	0.508	-0.001	0.002	0.252	0	0
1985	0.542	-0.001	0.002	0.241	0	0
1986	0.62	-0.002	0.002	0.235	0	0
1987	0.637	-0.002	0.002	0.193	0	0
1988	0.538	-0.002	0.002	0.18	0	0
1989	0.396	-0.002	0.001	0.167	0	0
1990	0.377	-0.001	0.002	0.166	0	-0.001
1991	0.404	-0.002	0.001	0.162	0	0
1992	0.394	-0.001	0.002	0.13	-0.001	0
1993	0.534	-0.002	0.002	0.148	0	0
1994	0.678	-0.003	0.003	0.158	0	0
1995	0.854	-0.003	0.003	0.188	0	0.001
1996	0.765	-0.003	0.002	0.185	0	0
1997	0.752	-0.001	0.003	0.191	0.001	0
1998	0.794	-0.004	0.004	0.217	0	0
1999	0.745	-0.004	0.004	0.214	0	0
2000	0.697	-0.003	0.003	0.206	0	0
2001	0.835	-0.004	0.004	0.228	0	0
2002	1.05	-0.004	0.005	0.261	0	-0.001



Table D1.20. Change in fishing mortality (F) for age-0 and age-1 menhaden from the base run when the size selectivity curve parameters ( $\alpha$  &  $\beta$ ) in the MSVPA-X are changed by  $\pm 1$  percent.

Year	Age 0			Age 1		
	Base Run F Rates by Year	Change in F from Base Run		Base Run F Rates by Year	Change in F from Base Run	
		-1% Change in $\alpha$ & $\beta$	+1% Change in $\alpha$ & $\beta$		-1% Change in $\alpha$ & $\beta$	+1% Change in $\alpha$ & $\beta$
1982	0.018	0	0	0.157	0	0
1983	0.104	0	0	0.23	0	0
1984	0.112	0	0	0.316	0	0
1985	0.062	0	0	0.247	0	0
1986	0.013	0	0	0.055	0	0
1987	0.006	0	0	0.174	0	0
1988	0.031	0	0.001	0.104	0	0
1989	0.033	0	0	0.272	0	0
1990	0.047	0	0	0.071	0	0
1991	0.13	0	0	0.387	0	0
1992	0.065	0	0	0.263	0	0
1993	0.014	0	0	0.14	0	0
1994	0.013	0	0	0.141	0	0
1995	0.014	0	0	0.218	0	0.001
1996	0.008	0	0	0.146	0	0
1997	0.007	-0.001	0	0.172	-0.001	0
1998	0.016	0	0	0.135	0	0
1999	0.053	0	0	0.185	0	0
2000	0.034	0	0	0.094	0	0
2001	0.005	0	0	0.052	0	0
2002	0.036	0	0	0.141	0	0

Table D1.21. Average recruited fishing mortality on age-2 and older menhaden for the base run and for  $\pm 1\%$  changes in the size selectivity curve parameters  $\alpha$  and  $\beta$ .

Year	Average Recruited F		
	Base Run	-1% change in $\alpha$ and $\beta$	+1% change in $\alpha$ and $\beta$
1982	1.594	1.594	1.594
1983	1.442	1.442	1.442
1984	1.486	1.486	1.486
1985	1.534	1.534	1.534
1986	1.18	1.18	1.18
1987	1.053	1.053	1.053
1988	1.268	1.268	1.269
1989	1.219	1.219	1.219
1990	1.156	1.156	1.156
1991	1.363	1.363	1.363
1992	1.014	1.014	1.014
1993	1.036	1.036	1.035
1994	0.969	0.969	0.968
1995	1.237	1.237	1.237
1996	0.75	0.75	0.75
1997	0.915	0.915	0.915
1998	1.339	1.338	1.339
1999	1.182	1.181	1.182
2000	0.883	0.883	0.883
2001	1.243	1.243	1.243
2002	1.175	1.174	1.175

Table D1.22. Percent change from base run MSVPA-X abundance results for age-0, age-1 and total abundance of menhaden for sensitivity analysis scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

Year	Percent Change from Base Run Results for age-0, age-1, and Total Menhaden Abundance															
	10% Decrease in Median Prey Size				10% Increase in Median Prey Size				20% Decrease in Median Prey Size				20% Increase in Median Prey Size			
	Age 0	Age 1	Total	Total	Age 0	Age 1	Total	Total	Age 0	Age 1	Total	Total	Age 0	Age 1	Total	Total
1982	3.989	1.955	2.934	-13.352	-7.949	-9.226	-4.663	0.915	-1.539	-21.181	-13.486	-15.136				
1983	3.504	1.178	2.831	-10.646	-7.093	-8.320	-3.576	0.756	-2.082	-16.957	-11.880	-13.469				
1984	2.895	0.985	2.436	-10.696	-5.649	-8.825	-1.997	1.569	-1.024	-17.756	-9.382	-14.717				
1985	6.188	0.719	4.340	-14.567	-5.939	-11.012	-4.879	2.162	-2.464	-27.462	-9.814	-20.458				
1986	9.196	2.046	6.179	-15.529	-5.824	-10.520	-6.550	2.253	-2.854	-30.617	-10.253	-20.543				
1987	11.338	2.451	7.622	-16.989	-5.134	-11.149	-6.693	1.485	-3.320	-31.819	-10.033	-21.149				
1988	6.758	2.628	5.457	-9.507	-5.728	-7.771	-0.410	1.262	0.053	-15.002	-10.816	-12.655				
1989	4.517	1.773	2.902	-7.991	-5.244	-5.664	2.984	1.997	2.286	-12.740	-8.889	-9.375				
1990	4.551	2.002	3.414	-7.171	-5.570	-5.577	2.326	3.003	2.225	-13.382	-9.454	-10.325				
1991	4.496	1.587	3.318	-6.943	-4.778	-5.581	2.567	2.336	2.295	-11.743	-7.921	-9.482				
1992	5.349	1.497	3.753	-9.036	-5.065	-6.903	2.365	2.489	2.223	-15.165	-8.028	-11.554				
1993	6.174	1.807	4.040	-11.610	-6.828	-8.520	1.649	3.417	2.048	-20.563	-10.357	-14.657				
1994	10.796	2.149	7.825	-13.192	-8.279	-10.630	-0.985	3.285	0.086	-26.139	-13.368	-20.552				
1995	9.855	2.481	6.362	-6.628	-8.949	-6.561	3.296	2.419	2.697	-13.027	-15.477	-12.369				
1996	7.394	3.143	5.421	-7.689	-8.951	-6.855	3.845	1.755	2.938	-14.039	-16.108	-12.709				
1997	8.186	3.730	6.089	-10.284	-9.205	-8.621	5.850	1.111	4.058	-17.499	-16.125	-15.101				
1998	8.627	3.889	6.821	-10.230	-11.366	-9.291	7.327	2.040	5.568	-16.334	-19.099	-15.264				
1999	8.426	3.740	6.394	-9.471	-11.178	-8.952	7.138	3.114	5.404	-15.646	-18.804	-15.067				
2000	8.290	3.757	5.814	-10.533	-10.597	-8.960	5.483	3.805	4.275	-18.290	-17.808	-15.681				
2001	10.419	3.953	8.511	-13.154	-11.173	-11.446	4.204	3.839	3.801	-23.222	-18.564	-20.254				
2002	8.806	2.786	7.204	-12.641	-9.947	-11.339	1.650	3.343	1.926	-20.814	-16.013	-18.731				

Table D1.23. Percent change in menhaden spawning stock biomass from MSVPA-X base run configuration and for four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

Year	Percent Change in Spawning Stock Biomass from MSVPA-X Base Run Configuration			
	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size
1982	2.61	0.94	1.56	0.32
1983	2.27	0.58	1.43	-0.06
1984	1.83	0.96	1.07	0.62
1985	1.89	0.75	1.20	0.31
1986	2.54	0.95	1.66	0.31
1987	2.27	0.70	1.55	0.05
1988	1.44	0.40	0.96	-0.18
1989	1.50	0.22	1.02	-0.58
1990	1.39	-0.13	1.00	-1.24
1991	1.06	-0.13	0.77	-1.14
1992	0.90	-0.41	0.68	-2.00
1993	0.97	-0.92	0.83	-2.72
1994	0.70	-1.03	0.63	-3.31
1995	0.71	-0.94	0.64	-3.00
1996	1.03	-1.23	0.88	-4.99
1997	0.73	-0.69	0.57	-4.74
1998	0.56	-0.41	0.43	-5.00
1999	0.66	-0.66	0.53	-4.60
2000	0.94	-0.86	0.77	-4.50
2001	0.96	-0.70	0.75	-3.45
2002	1.12	-0.60	0.84	-3.63

Table D1.24. Predation mortality (M2) values for age-0 and age-1 menhaden for the base run MSVPA-X configuration and for four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

Year	Age-0					Age-1				
	Base Run	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size	Base Run	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size
1982	0.672	0.644	0.735	0.731	0.764	0.328	0.322	0.406	0.33	0.451
1983	0.607	0.578	0.664	0.662	0.691	0.276	0.279	0.35	0.28	0.392
1984	0.508	0.486	0.564	0.554	0.598	0.252	0.254	0.314	0.246	0.347
1985	0.542	0.498	0.632	0.618	0.705	0.241	0.253	0.307	0.233	0.34
1986	0.62	0.55	0.723	0.706	0.806	0.235	0.234	0.292	0.227	0.326
1987	0.637	0.541	0.742	0.725	0.819	0.193	0.181	0.245	0.188	0.285
1988	0.538	0.487	0.584	0.567	0.603	0.18	0.165	0.231	0.178	0.27
1989	0.396	0.369	0.423	0.397	0.433	0.167	0.158	0.216	0.155	0.244
1990	0.377	0.346	0.411	0.378	0.434	0.166	0.158	0.214	0.148	0.239
1991	0.404	0.369	0.432	0.401	0.453	0.162	0.153	0.208	0.143	0.232
1992	0.394	0.355	0.419	0.404	0.447	0.13	0.122	0.17	0.111	0.188
1993	0.534	0.47	0.564	0.55	0.601	0.148	0.141	0.197	0.124	0.218
1994	0.678	0.591	0.721	0.714	0.775	0.158	0.147	0.219	0.135	0.245
1995	0.854	0.783	0.839	0.843	0.837	0.188	0.172	0.262	0.172	0.304
1996	0.765	0.73	0.754	0.743	0.756	0.185	0.163	0.257	0.178	0.302
1997	0.752	0.709	0.746	0.721	0.742	0.191	0.161	0.267	0.189	0.314
1998	0.794	0.744	0.79	0.752	0.783	0.217	0.188	0.311	0.207	0.36
1999	0.745	0.692	0.743	0.71	0.741	0.214	0.19	0.307	0.195	0.354
2000	0.697	0.649	0.698	0.682	0.707	0.206	0.185	0.288	0.183	0.326
2001	0.835	0.754	0.87	0.856	0.907	0.228	0.205	0.316	0.204	0.356
2002	1.05	0.939	1.096	1.101	1.135	0.261	0.233	0.346	0.239	0.39

Table D1.25. Average recruited fishing mortality estimates for age-2+ menhaden from the base run configuration of the MSVPA-X and four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

Year	Average Recruited F for Age 2+ Menhaden				
	BASE	(-)10% Median	(+)10% Median	(-)20% Median	(+)20% Median
1982	1.594	1.634	1.597	1.619	1.582
1983	1.442	1.47	1.441	1.461	1.429
1984	1.486	1.519	1.49	1.508	1.479
1985	1.534	1.568	1.538	1.559	1.524
1986	1.18	1.209	1.184	1.201	1.173
1987	1.053	1.073	1.055	1.068	1.046
1988	1.268	1.29	1.268	1.284	1.256
1989	1.219	1.238	1.213	1.234	1.198
1990	1.156	1.17	1.147	1.168	1.133
1991	1.363	1.379	1.353	1.377	1.335
1992	1.014	1.024	1.004	1.023	0.988
1993	1.036	1.046	1.021	1.046	1.004
1994	0.969	0.978	0.955	0.978	0.937
1995	1.237	1.249	1.221	1.248	1.187
1996	0.75	0.758	0.739	0.758	0.717
1997	0.915	0.923	0.905	0.922	0.878
1998	1.339	1.351	1.323	1.348	1.288
1999	1.182	1.193	1.166	1.191	1.135
2000	0.883	0.893	0.874	0.891	0.85
2001	1.243	1.257	1.233	1.254	1.202
2002	1.175	1.186	1.164	1.184	1.134

Table D1.26. Predation mortality (M2) estimates for age-0 through age-6 menhaden for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

M2	Age-0			Age-1			Age-2			Age-3			Age-4		
	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%
<b>1982</b>	0.672	0.994	0.628	0.328	0.204	0.319	0.207	0.018	0.202	0.137	0.002	0.137	0.091	0	0.095
<b>1983</b>	0.607	0.895	0.567	0.276	0.175	0.271	0.171	0.016	0.168	0.113	0.002	0.114	0.075	0	0.079
<b>1984</b>	0.508	0.734	0.481	0.252	0.148	0.246	0.168	0.015	0.164	0.113	0.002	0.114	0.075	0	0.079
<b>1985</b>	0.542	0.763	0.518	0.241	0.143	0.236	0.164	0.015	0.16	0.11	0.002	0.111	0.073	0	0.077
<b>1986</b>	0.62	0.803	0.589	0.235	0.113	0.232	0.158	0.012	0.154	0.108	0.001	0.108	0.073	0	0.077
<b>1987</b>	0.637	0.748	0.598	0.193	0.069	0.195	0.119	0.007	0.117	0.079	0.001	0.08	0.054	0	0.057
<b>1988</b>	0.538	0.68	0.499	0.18	0.068	0.183	0.099	0.006	0.1	0.064	0.001	0.066	0.043	0	0.047
<b>1989</b>	0.396	0.543	0.362	0.167	0.073	0.166	0.093	0.007	0.095	0.059	0.001	0.062	0.04	0	0.043
<b>1990</b>	0.377	0.488	0.351	0.166	0.082	0.164	0.093	0.01	0.096	0.058	0.002	0.062	0.038	0	0.043
<b>1991</b>	0.404	0.527	0.373	0.162	0.076	0.161	0.087	0.01	0.091	0.054	0.002	0.059	0.037	0.001	0.042
<b>1992</b>	0.394	0.517	0.369	0.13	0.067	0.13	0.062	0.008	0.066	0.036	0.001	0.041	0.025	0	0.029
<b>1993</b>	0.534	0.681	0.503	0.148	0.081	0.149	0.068	0.011	0.074	0.039	0.002	0.045	0.027	0.001	0.032
<b>1994</b>	0.678	0.852	0.631	0.158	0.091	0.162	0.068	0.013	0.075	0.038	0.002	0.044	0.025	0.001	0.031
<b>1995</b>	0.854	1.098	0.799	0.188	0.104	0.198	0.072	0.014	0.082	0.039	0.002	0.047	0.026	0.001	0.033
<b>1996</b>	0.765	0.99	0.711	0.185	0.094	0.2	0.063	0.012	0.073	0.032	0.002	0.039	0.02	0	0.026
<b>1997</b>	0.752	1.016	0.684	0.191	0.087	0.205	0.06	0.009	0.071	0.028	0.001	0.035	0.017	0	0.022
<b>1998</b>	0.794	1.07	0.715	0.217	0.103	0.229	0.07	0.012	0.083	0.033	0.002	0.041	0.02	0	0.026
<b>1999</b>	0.745	1.015	0.67	0.214	0.103	0.224	0.073	0.011	0.086	0.035	0.001	0.044	0.021	0	0.027
<b>2000</b>	0.697	0.924	0.636	0.206	0.098	0.214	0.077	0.01	0.089	0.038	0.001	0.047	0.023	0	0.03
<b>2001</b>	0.835	1.098	0.761	0.228	0.105	0.234	0.09	0.011	0.101	0.046	0.001	0.055	0.028	0	0.035
<b>2002</b>	1.05	1.334	0.961	0.261	0.115	0.267	0.109	0.013	0.119	0.057	0.002	0.067	0.035	0	0.044

Table D1.26 (Cont'd). Predation mortality (M2) estimates for age-0 through age-6 menhaden for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

M2 Year	Age-5			Age-6		
	Base	-10%	+10%	Base	-10%	+10%
1982	0.062	0	0.068	0.043	0	0.05
1983	0.051	0	0.057	0.035	0	0.041
1984	0.051	0	0.057	0.035	0	0.041
1985	0.05	0	0.055	0.034	0	0.04
1986	0.051	0	0.057	0.035	0	0.041
1987	0.039	0	0.043	0.029	0	0.033
1988	0.031	0	0.035	0.023	0	0.027
1989	0.028	0	0.032	0.021	0	0.025
1990	0.027	0	0.031	0.02	0	0.024
1991	0.028	0	0.033	0.02	0	0.025
1992	0.02	0	0.024	0.016	0	0.02
1993	0.021	0	0.026	0.017	0	0.022
1994	0.02	0	0.025	0.016	0	0.021
1995	0.02	0	0.026	0.016	0	0.021
1996	0.015	0	0.019	0.012	0	0.016
1997	0.012	0	0.016	0.009	0	0.012
1998	0.014	0	0.019	0.01	0	0.014
1999	0.015	0	0.02	0.011	0	0.015
2000	0.016	0	0.022	0.012	0	0.017
2001	0.02	0	0.026	0.015	0	0.02
2002	0.025	0	0.033	0.019	0	0.026



Table D1.27. Total biomass (000 MT) consumed by bluefish for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

<b>Year</b>	<b>Base Run</b>	<b>Decreased Range</b>	<b>Increased Range</b>
1982	558.72	724.41	560.67
1983	428.04	673.61	434.35
1984	487.23	671.36	491.3
1985	452.55	691.32	457.97
1986	469.84	603.41	469.9
1987	359.98	407.24	360.39
1988	315.98	367.03	315.59
1989	283.69	305.33	282.91
1990	263.72	295.18	264.08
1991	261.59	253.08	261.45
1992	197.03	187.96	197.13
1993	177.53	177.99	178.47
1994	154.36	162.96	154.6
1995	184.95	157.04	185.39
1996	182.73	141.69	182.92
1997	178.99	138.39	179.08
1998	186.09	148.96	185.78
1999	244.06	203.46	243.54
2000	272.14	227.37	272.01
2001	353.88	262.26	352.76
2002	409.46	359.72	409.18

## APPENDIX D1 FIGURES

Figure D1.1. Plot of menhaden fishing mortality over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

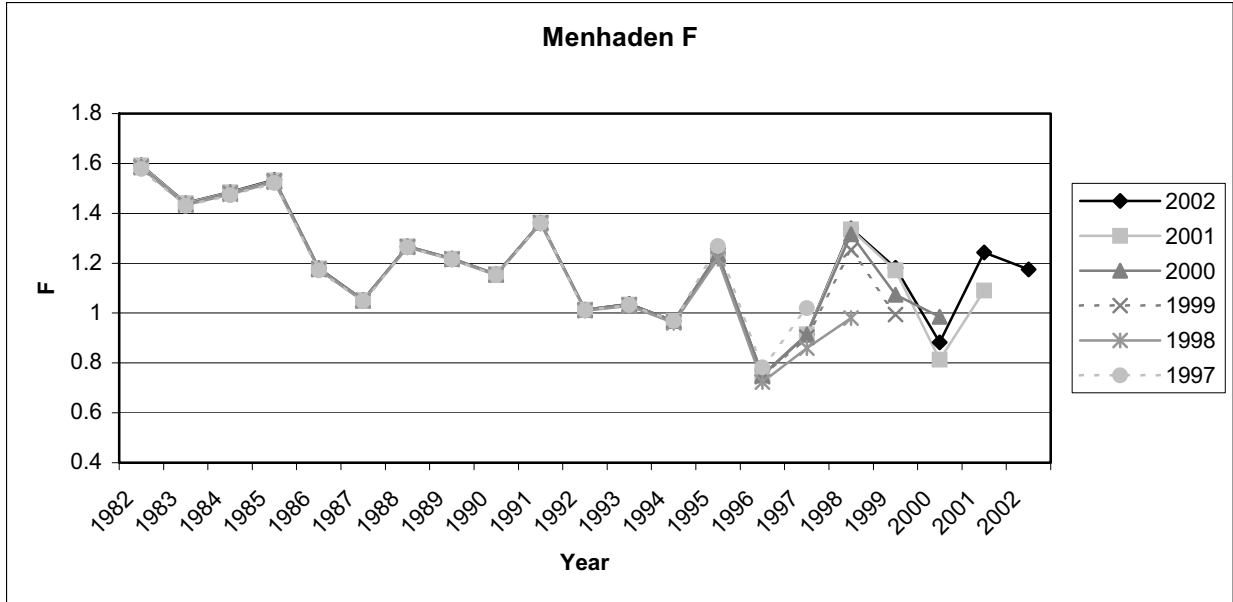


Figure D1.2. Plot of menhaden spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

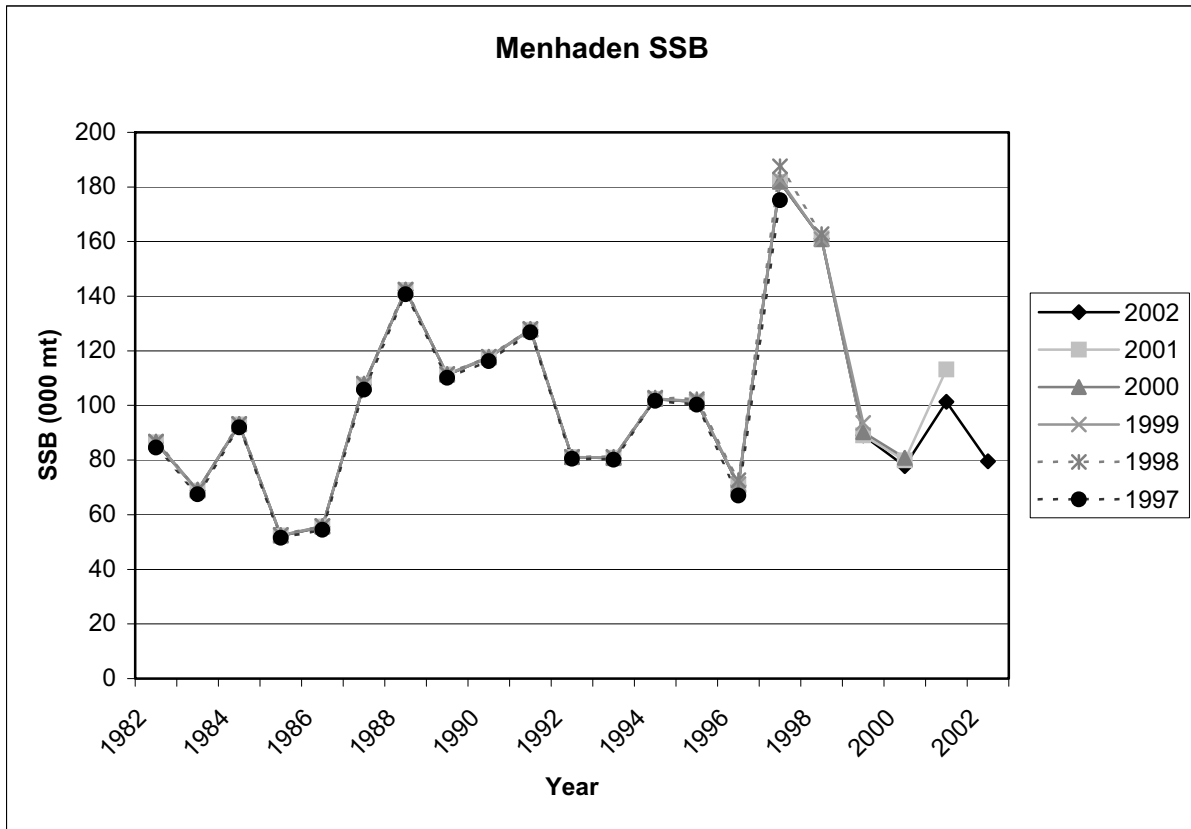


Figure D1.3. Plot of striped bass fishing mortality (F) over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

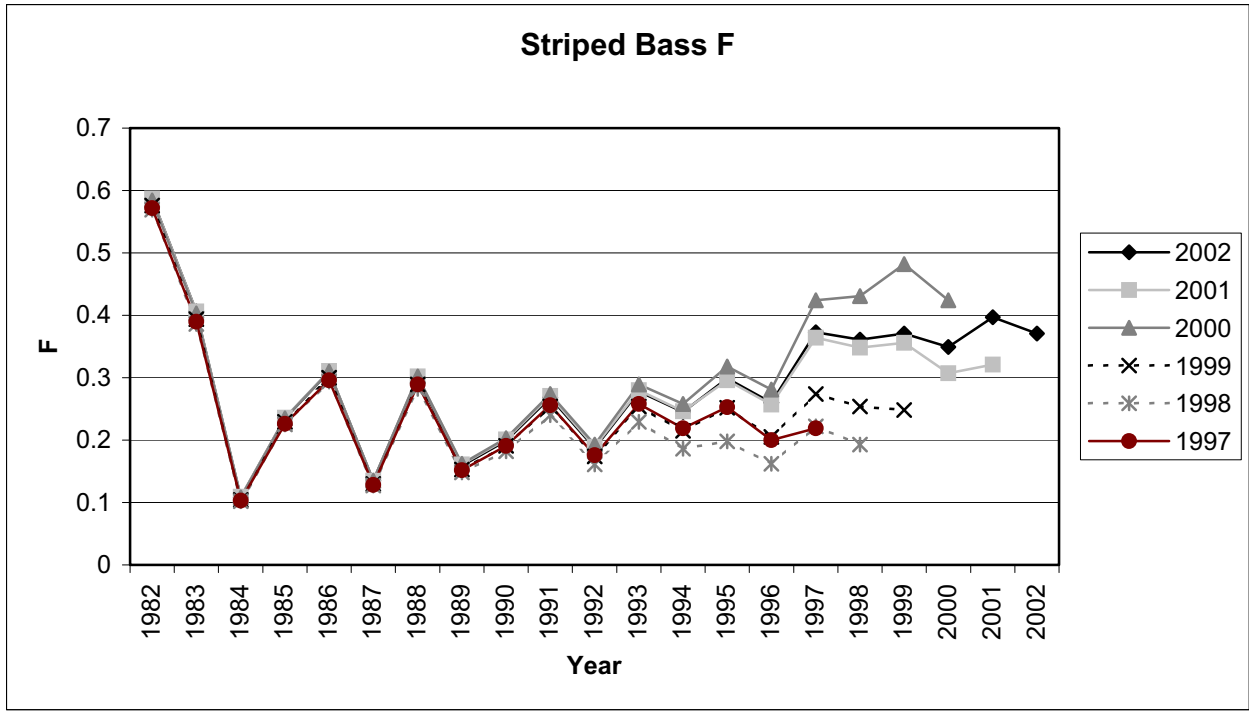


Figure D1.4. Plot of striped bass spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

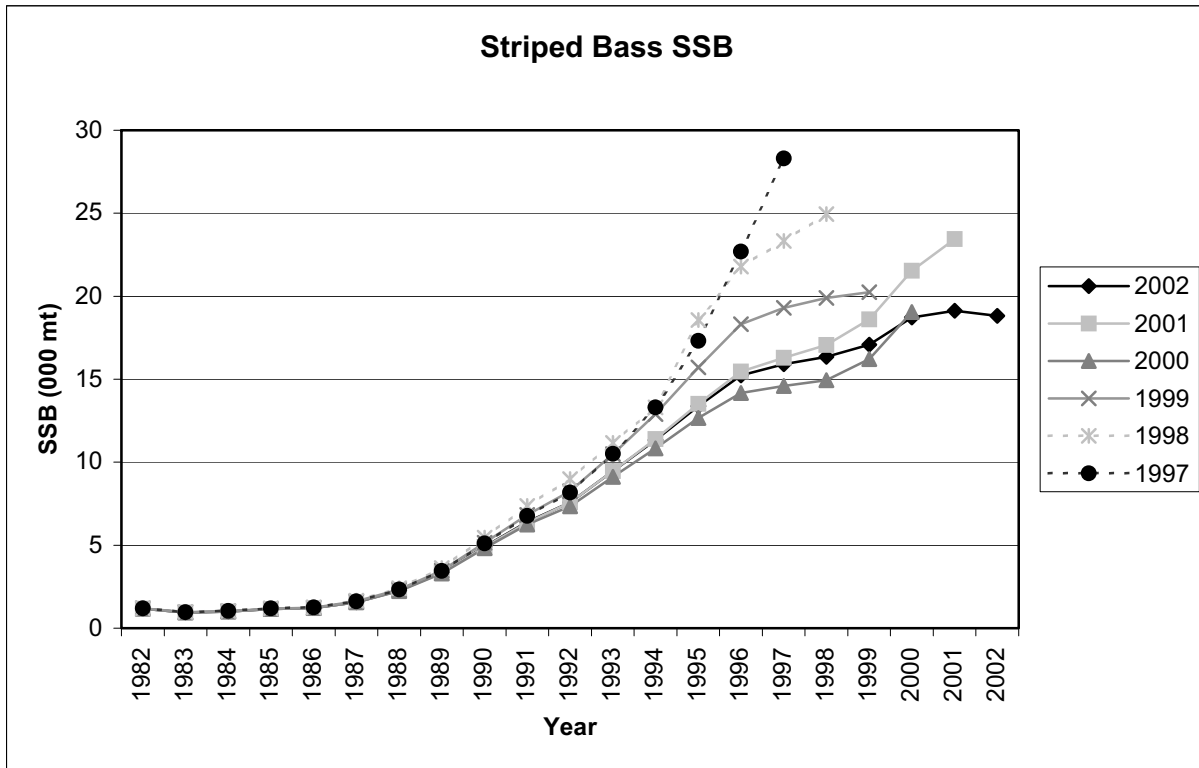


Figure D1.5. Plot of weakfish fishing mortality (F) over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

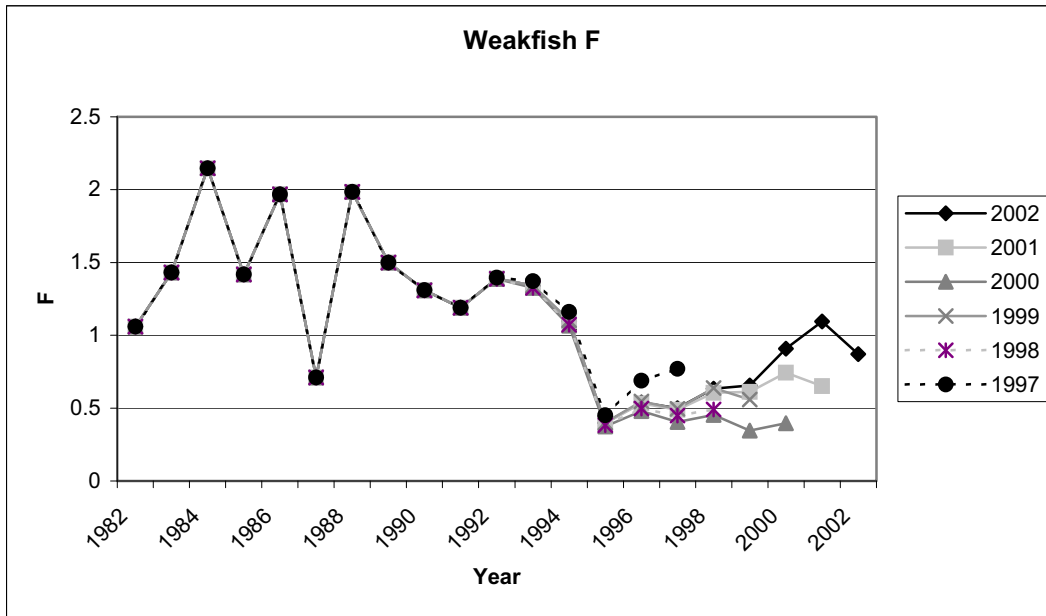


Figure 1.6. Plot of weakfish spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

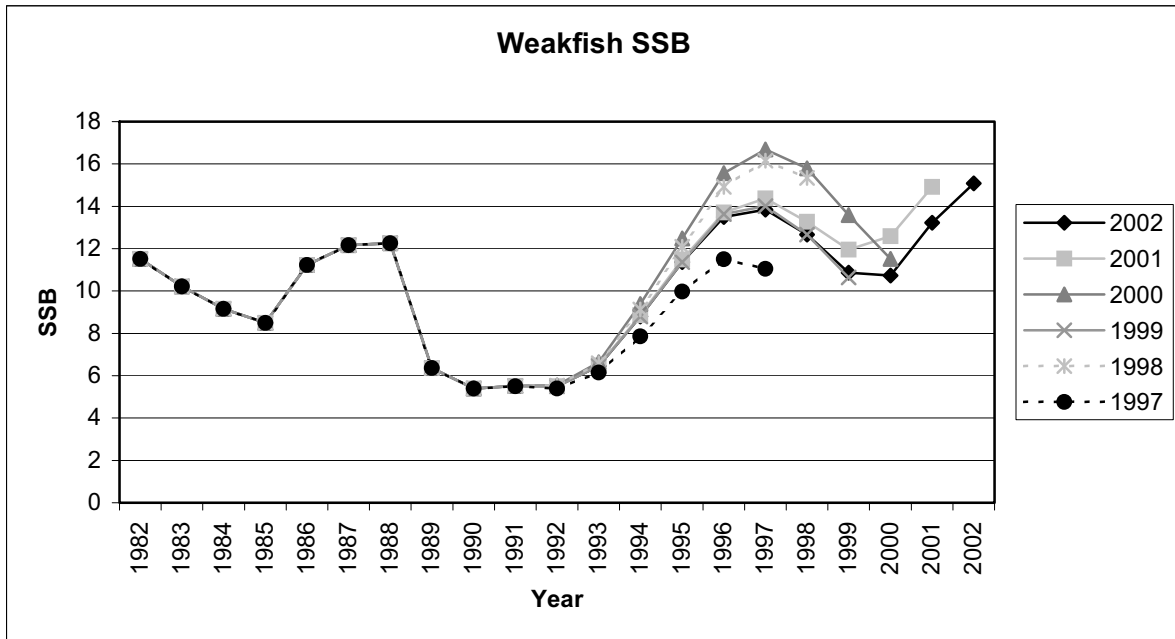


Figure D1.7. Terminal year predation mortality (M2) estimates for age-0 menhaden over time to investigate terminal year bias in M2 estimation in the MSVPA-X model.

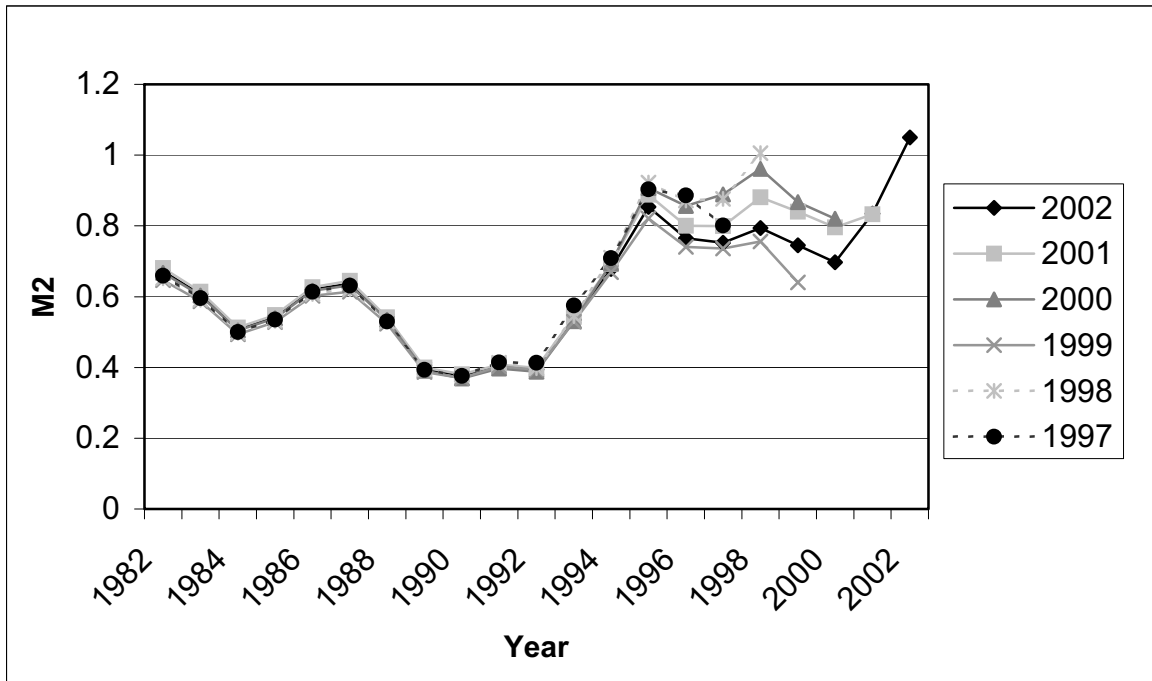




Figure D1.8. Predation mortality estimates for age-0 menhaden for the base run and 3 scenarios where one “other prey” group was removed. Runs were made with the removal of each of the following groups: bay anchovy, clupeids, and medium forage fish.

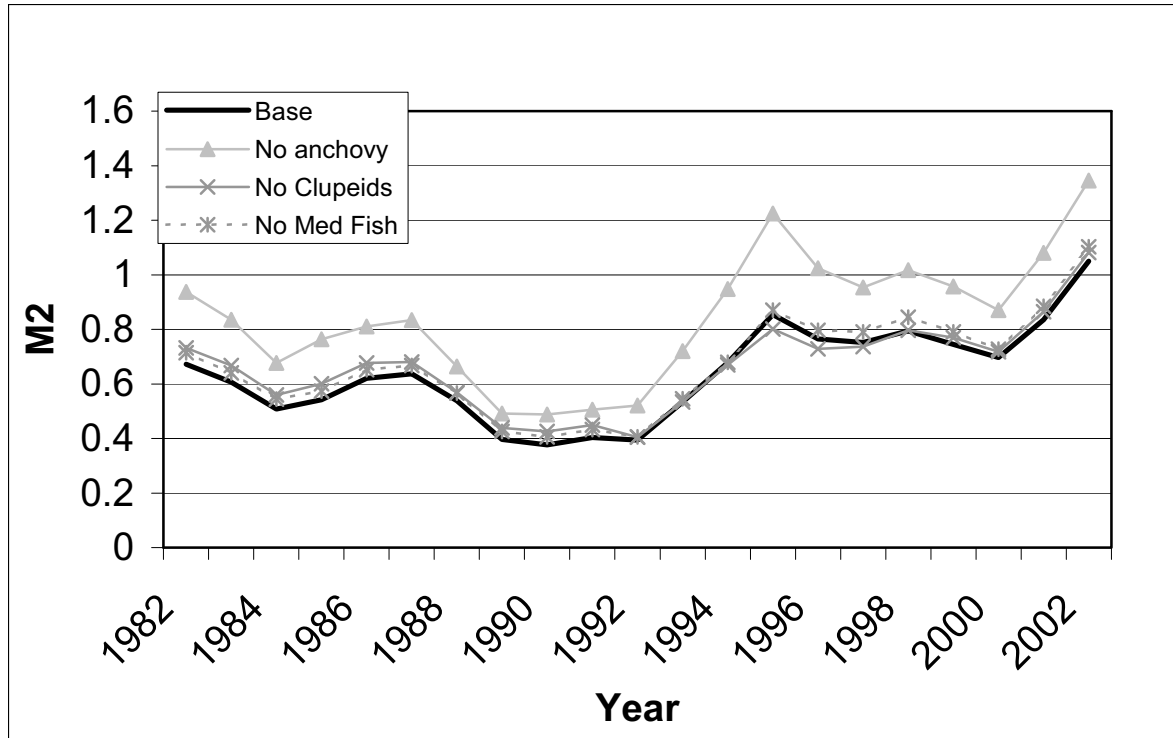


Figure D1.9. Spawning stock biomass (SSB in 000 mt) estimates for menhaden for the base run and 3 scenarios where one “other prey” group was removed. Runs were made with the removal of each of the following groups: bay anchovy, clupeids, and medium forage fish.

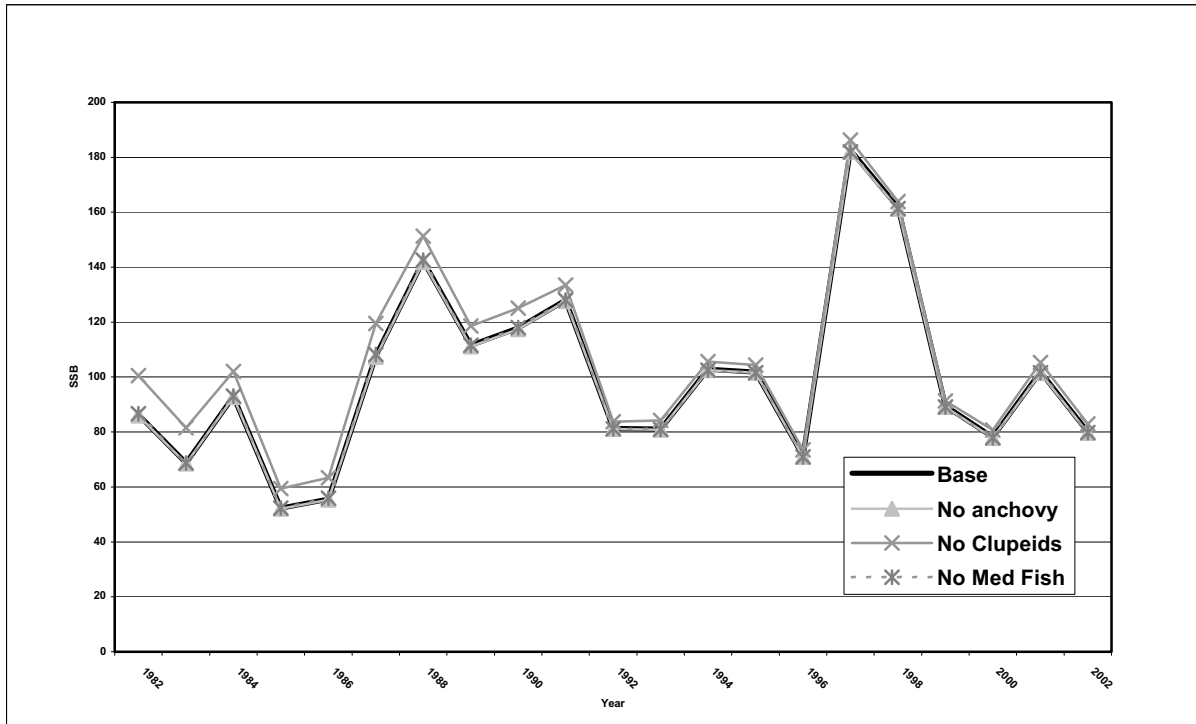


Figure D1.10. The average diet composition across years modeled (1982-2002) for striped bass by age in the base run MSVPA-X model.

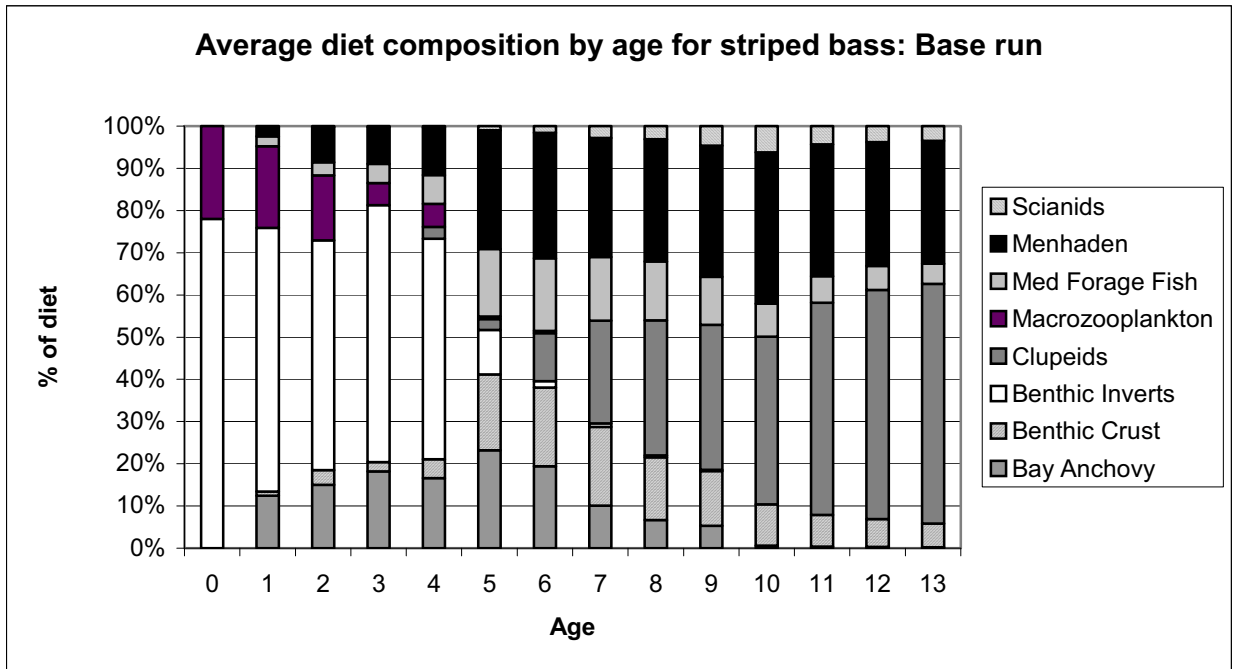


Figure 1.11. The average diet composition across years modeled (1982-2002) for striped bass by age in the 'no anchovy run' in the MSVPA-X model.

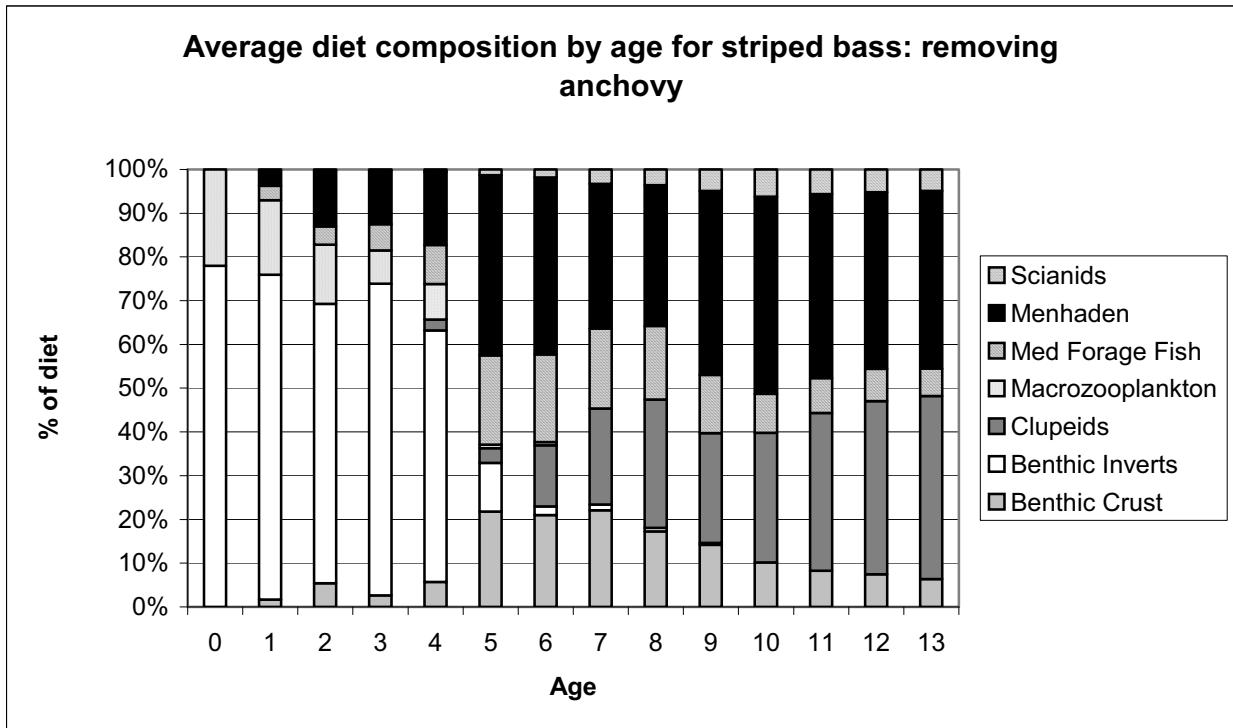


Figure D1.12. The average diet composition across years modeled (1982-2002) for striped bass by age in the ‘no clupeids run’ in the MSVPA-X model.

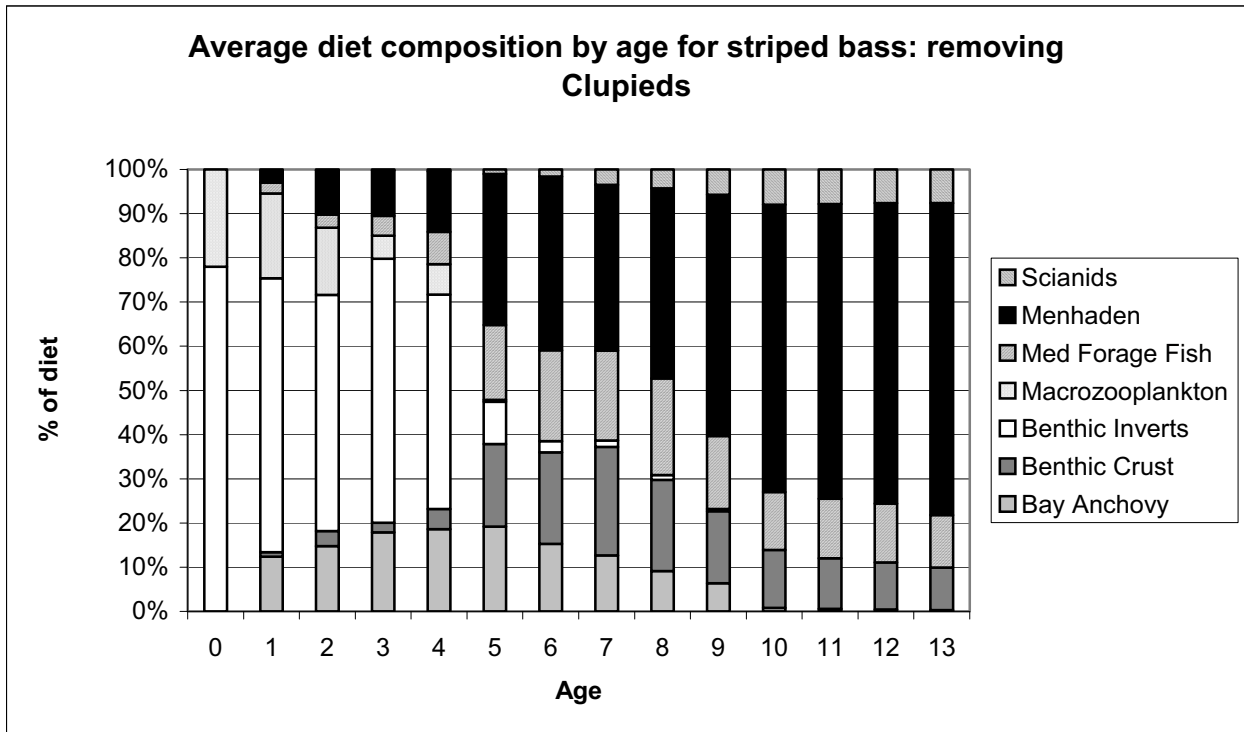


Figure D1.13. The average diet composition across years modeled (1982-2002) for striped bass by age in the ‘no medium forage fish run’ in the MSVPA-X model.

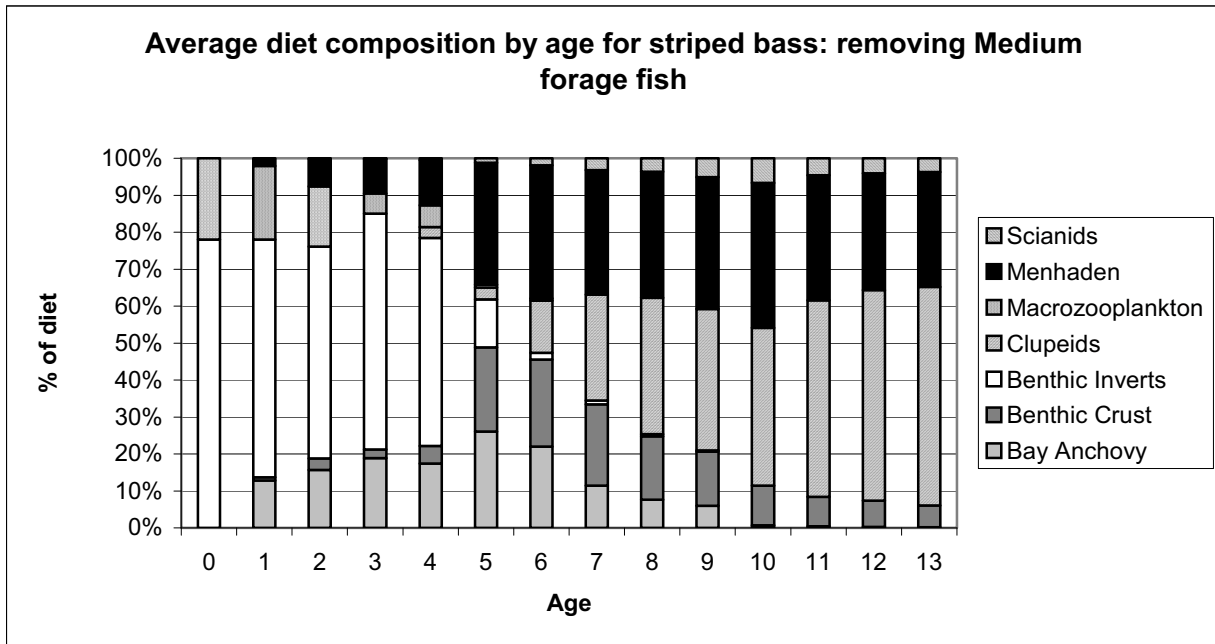


Figure D1.14. Predation mortality (M2) by predator and year for age-0 menhaden in the base run of the MSVPA-X model.

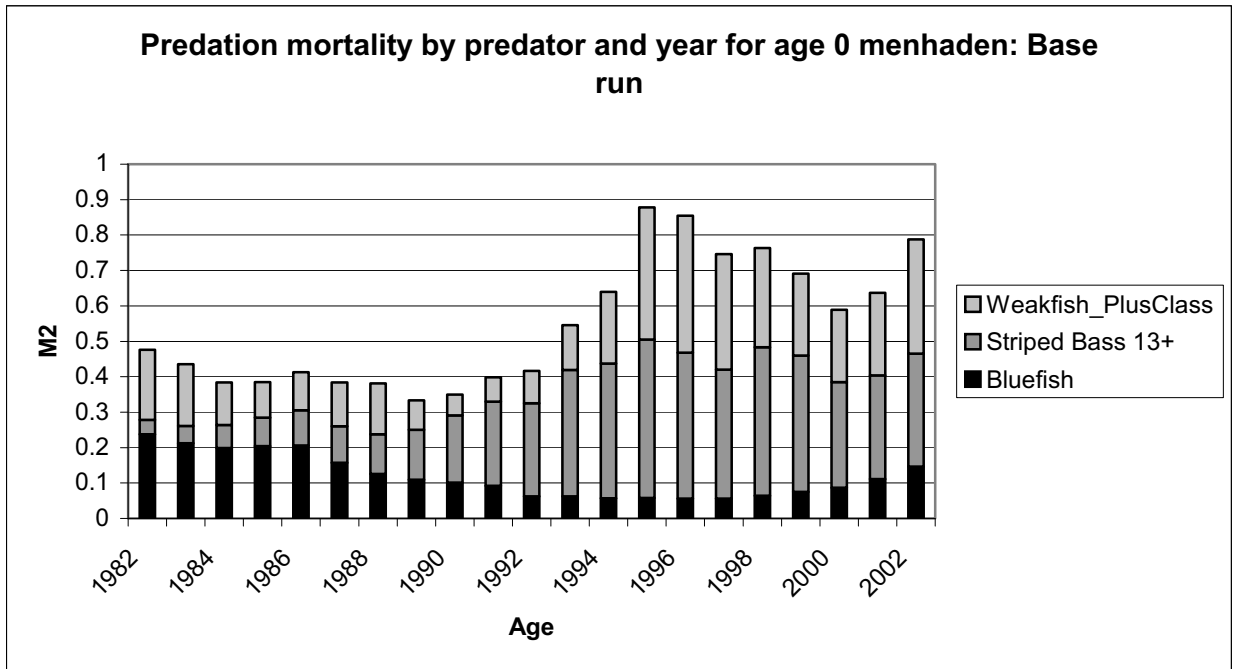


Figure D1.15. Predation mortality (M2) by predator and year for age-0 menhaden in the 'no clupeid run' of the MSVPA-X model.

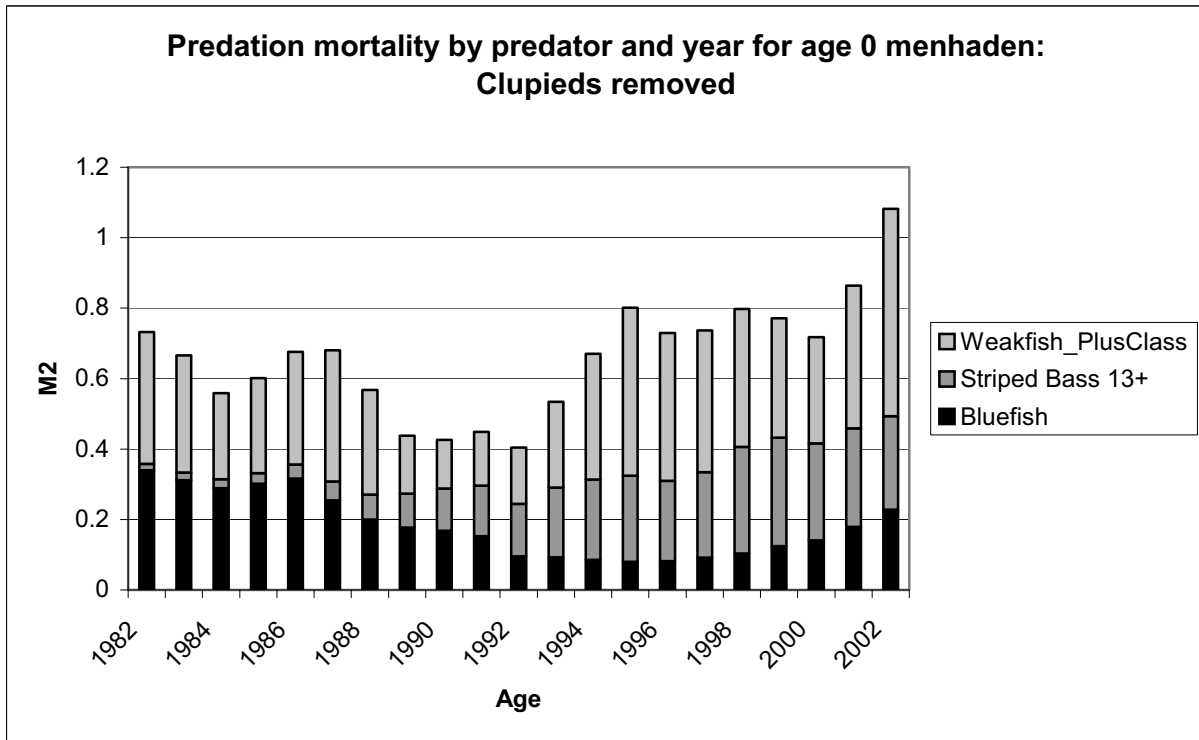




Figure D1.16. Predation mortality (M2) by predator and year for age-0 menhaden in the ‘no anchovy run’ of the MSVPA-X model.

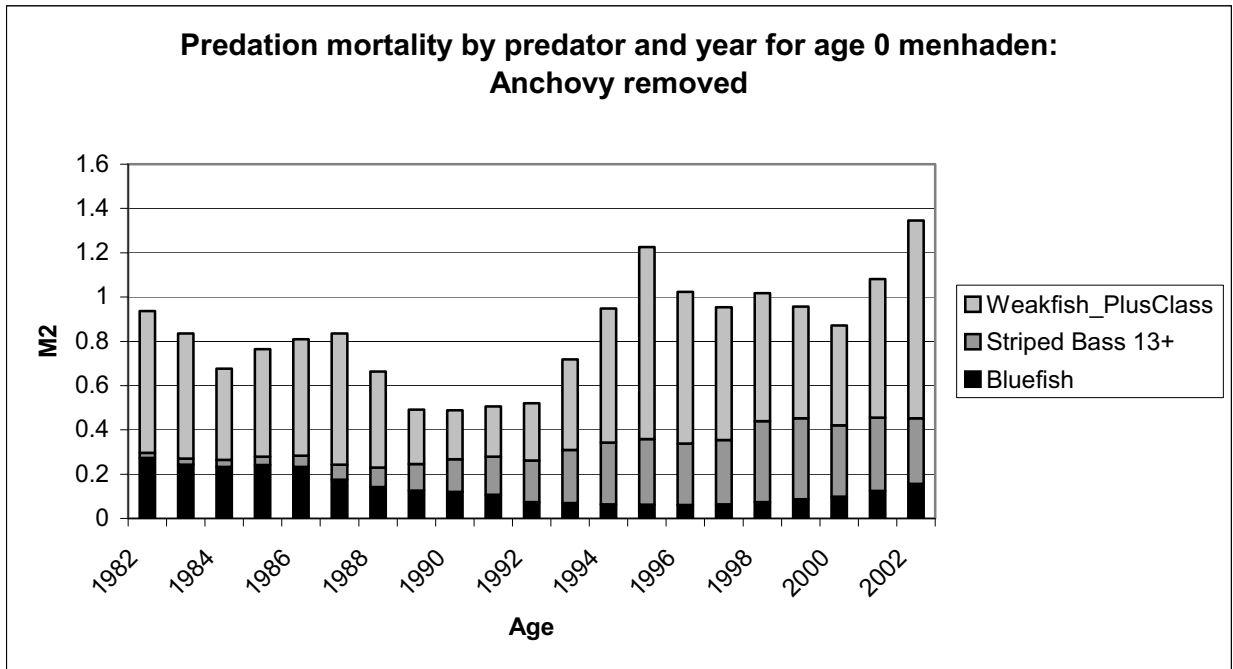


Figure D1.17. Predation mortality (M2) by predator and year for age-0 menhaden in the 'no medium forage fish run' of the MSVPA-X model.

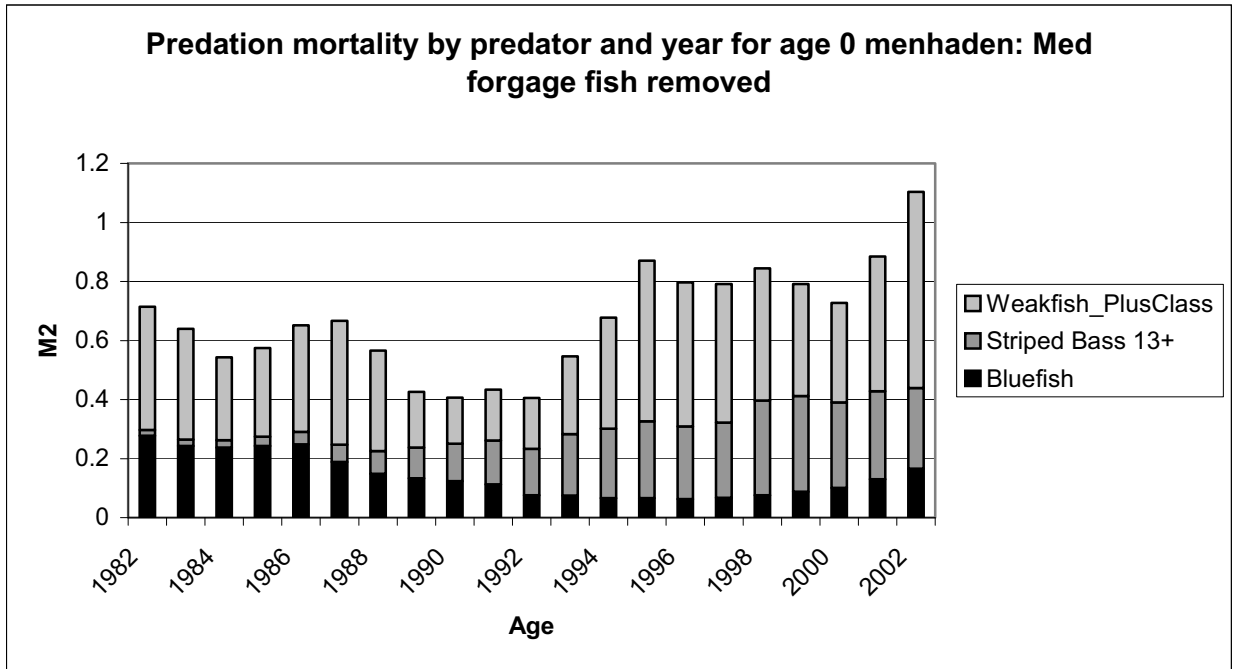


Figure D1.18. Total abundance of menhaden population at different values of M1.

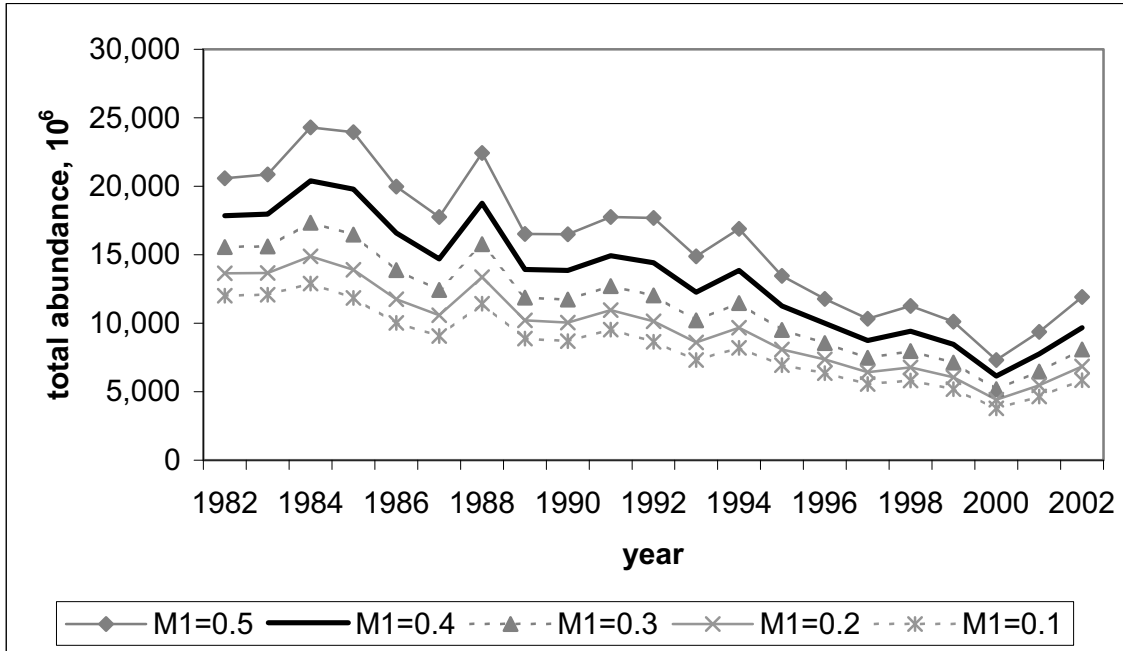


Figure D1.19. Relative changes in menhaden abundance in response to changes in M1.

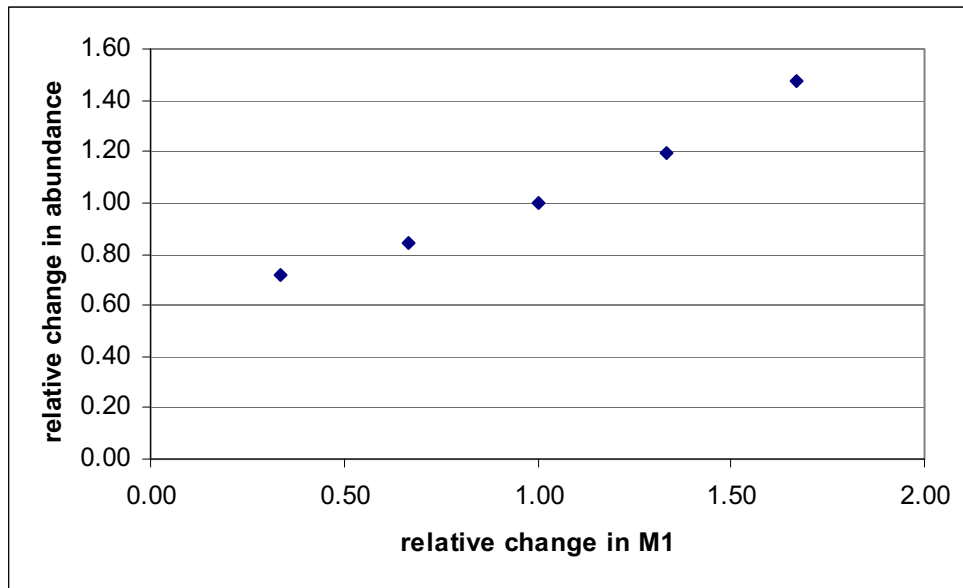


Figure D1.20. Total abundance of age-0 menhaden at different values of M1.

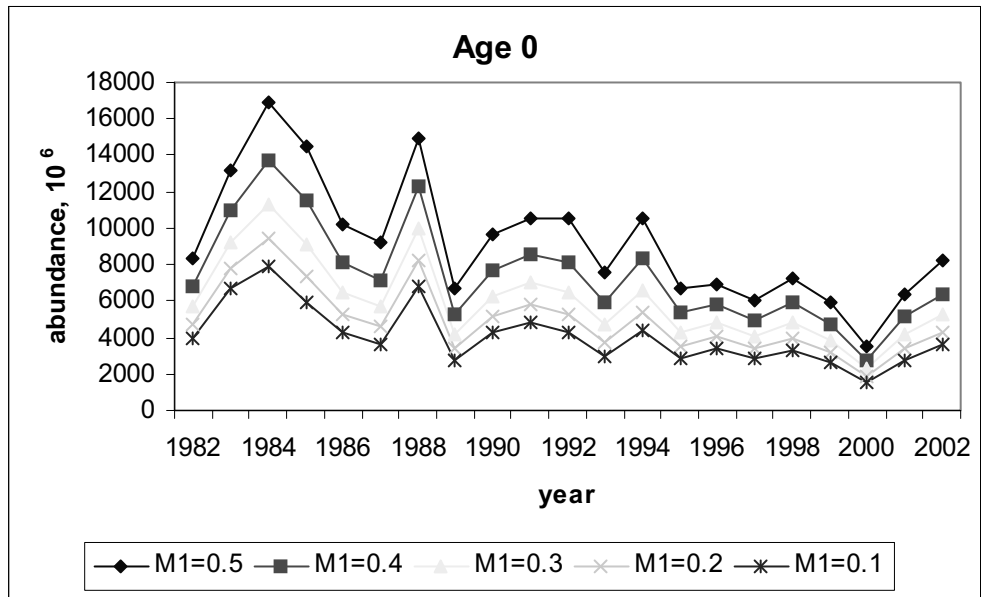


Figure D1.21. Total abundance of age-1 menhaden at different values of M1.

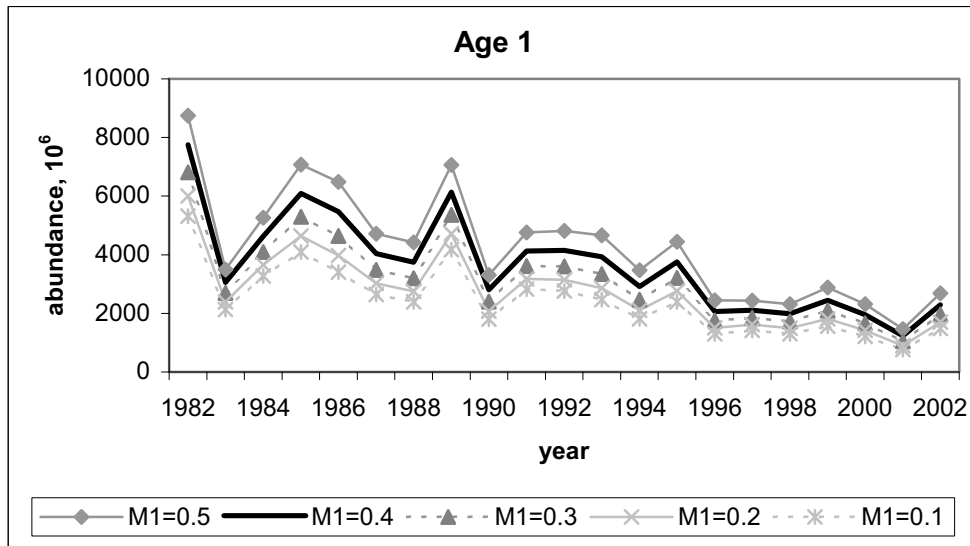


Figure D1.22. Total biomass of menhaden population at different values of M1.

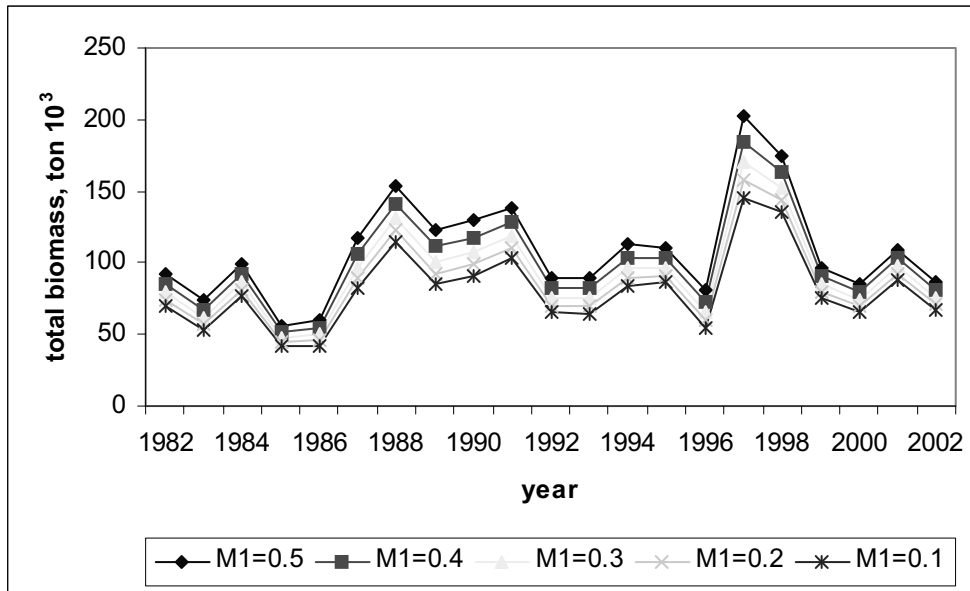


Figure D1.23. Spawning stock biomass of menhaden population at different values of M1.

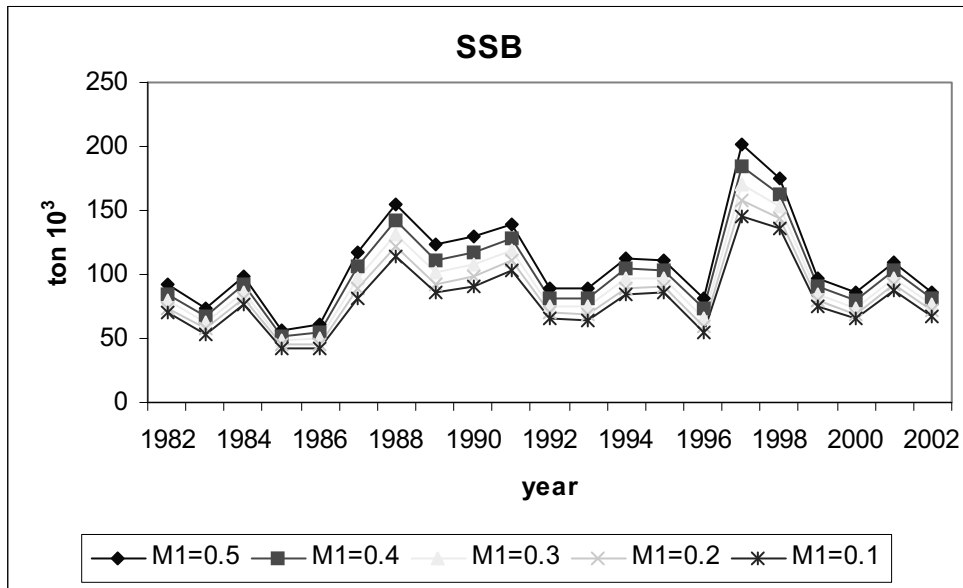




Figure D1.24. Average fishing mortality for fully recruited age groups and different M1 values.

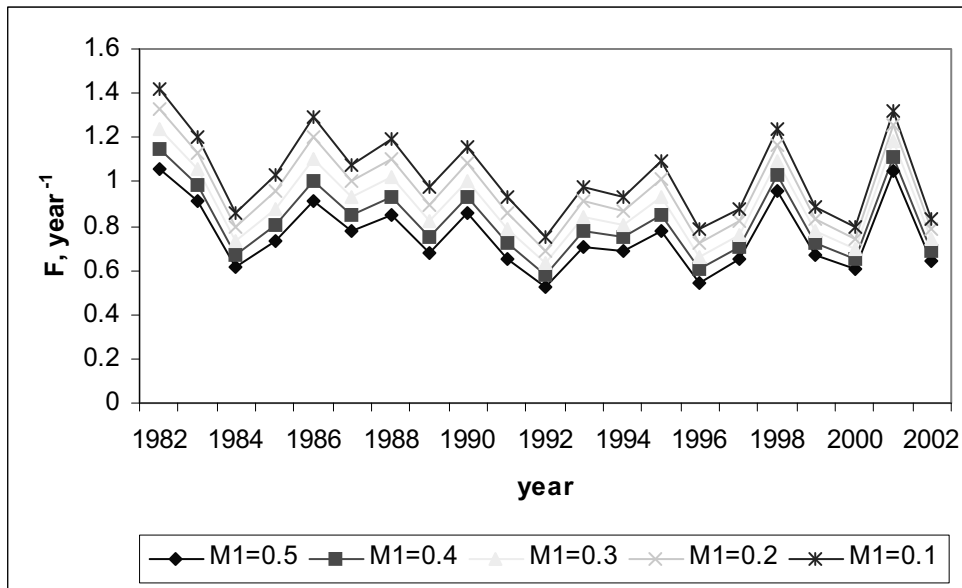


Figure D1.25. Predation mortality (M2) for fully age-0 menhaden and different M1 values.

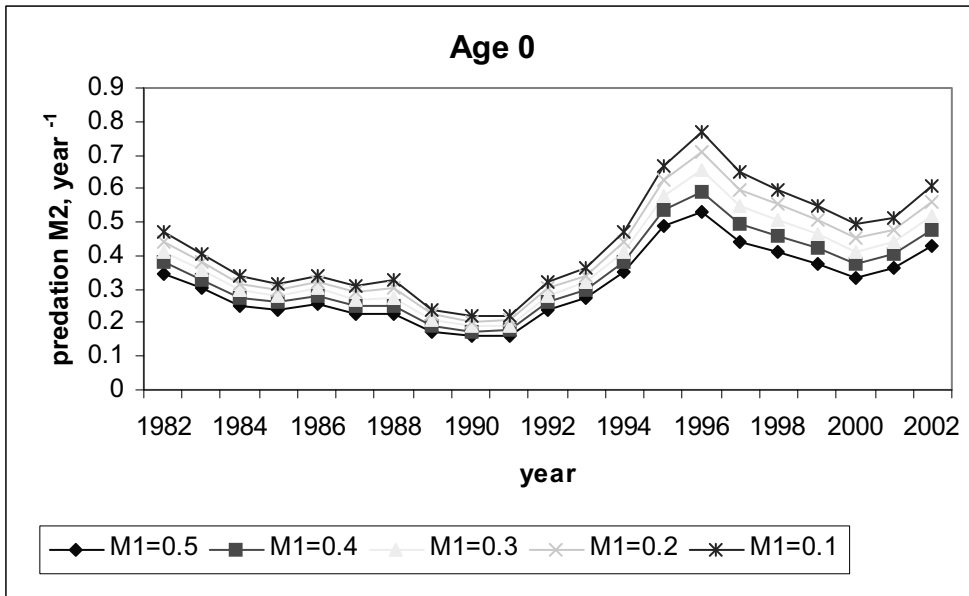


Figure D1.26. Predation mortality (M2) for fully age-1 menhaden and different M1 values.

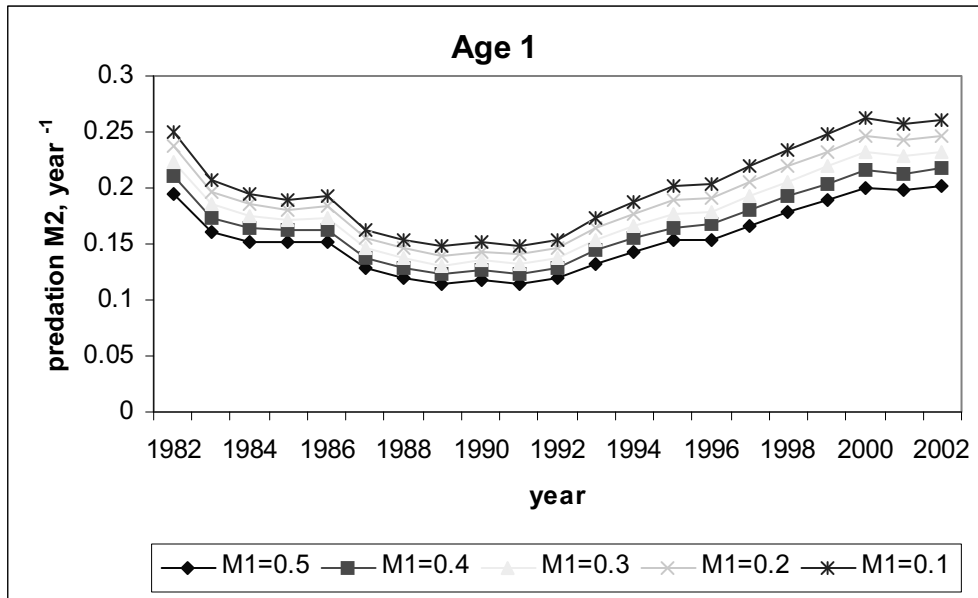


Figure D1.27. Impact of alternative values for the gastric evacuation rate parameter  $\alpha$  on the abundance (millions of fish) of age-0 abundance of menhaden in the MSVPA-X model.

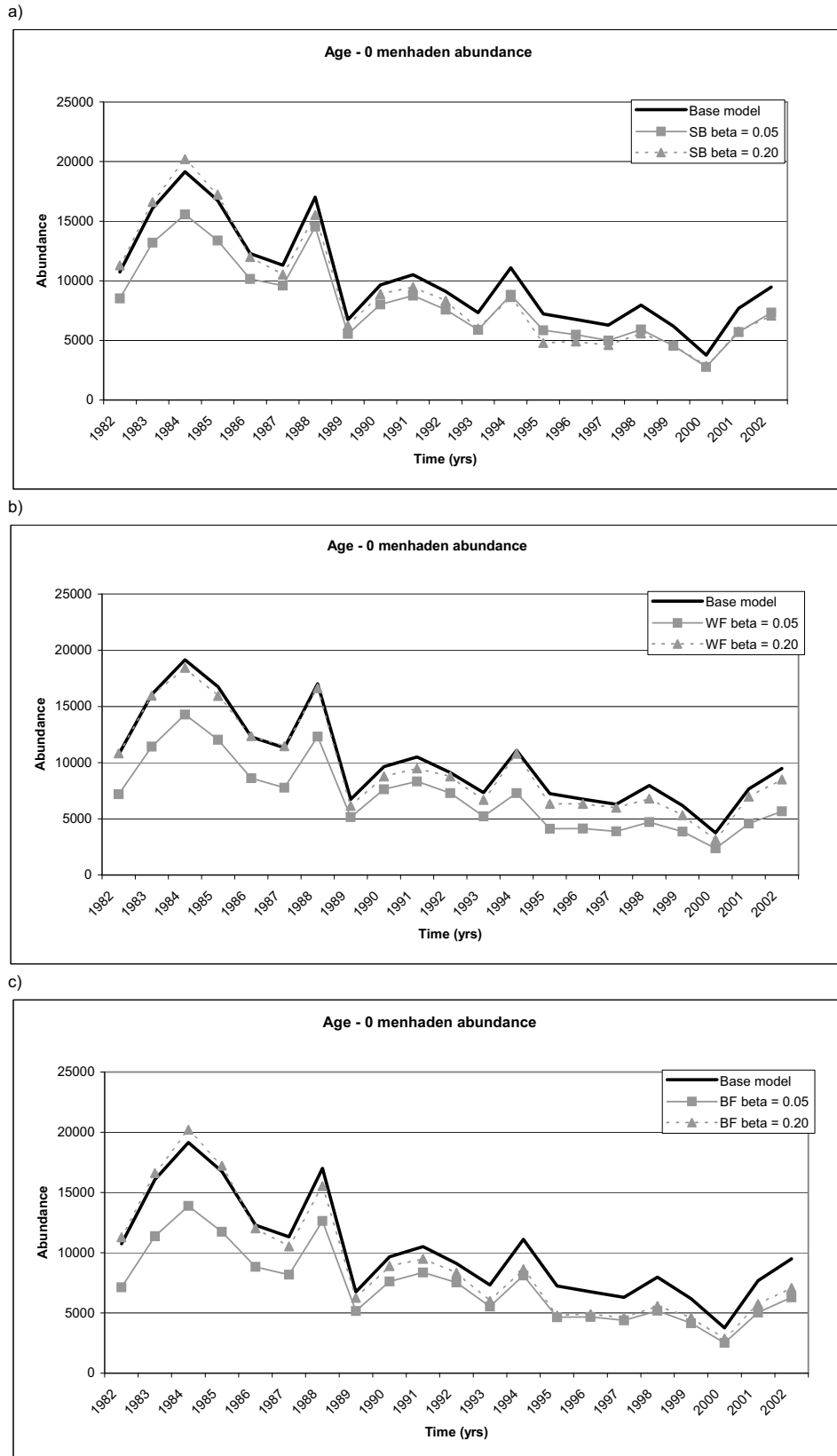


Figure D1.28. Impact of alternative values for the gastric evacuation rate parameter  $\beta$  on the abundance (millions of fish) of age-0 abundance of menhaden in the MSVPA-X model.

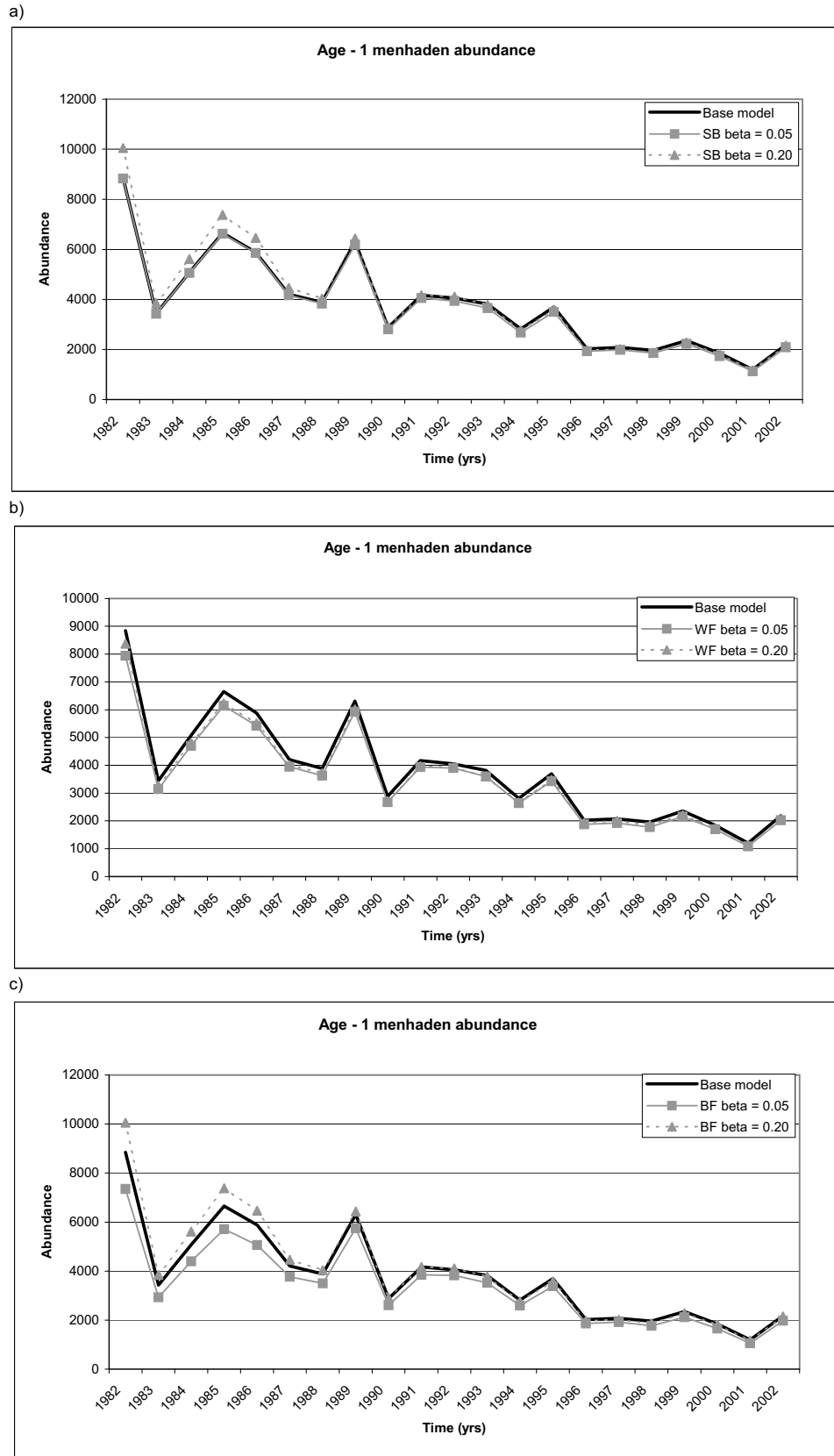


Figure D1.29. The affect of changing the gastric evacuation parameter  $\alpha$  for weakfish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

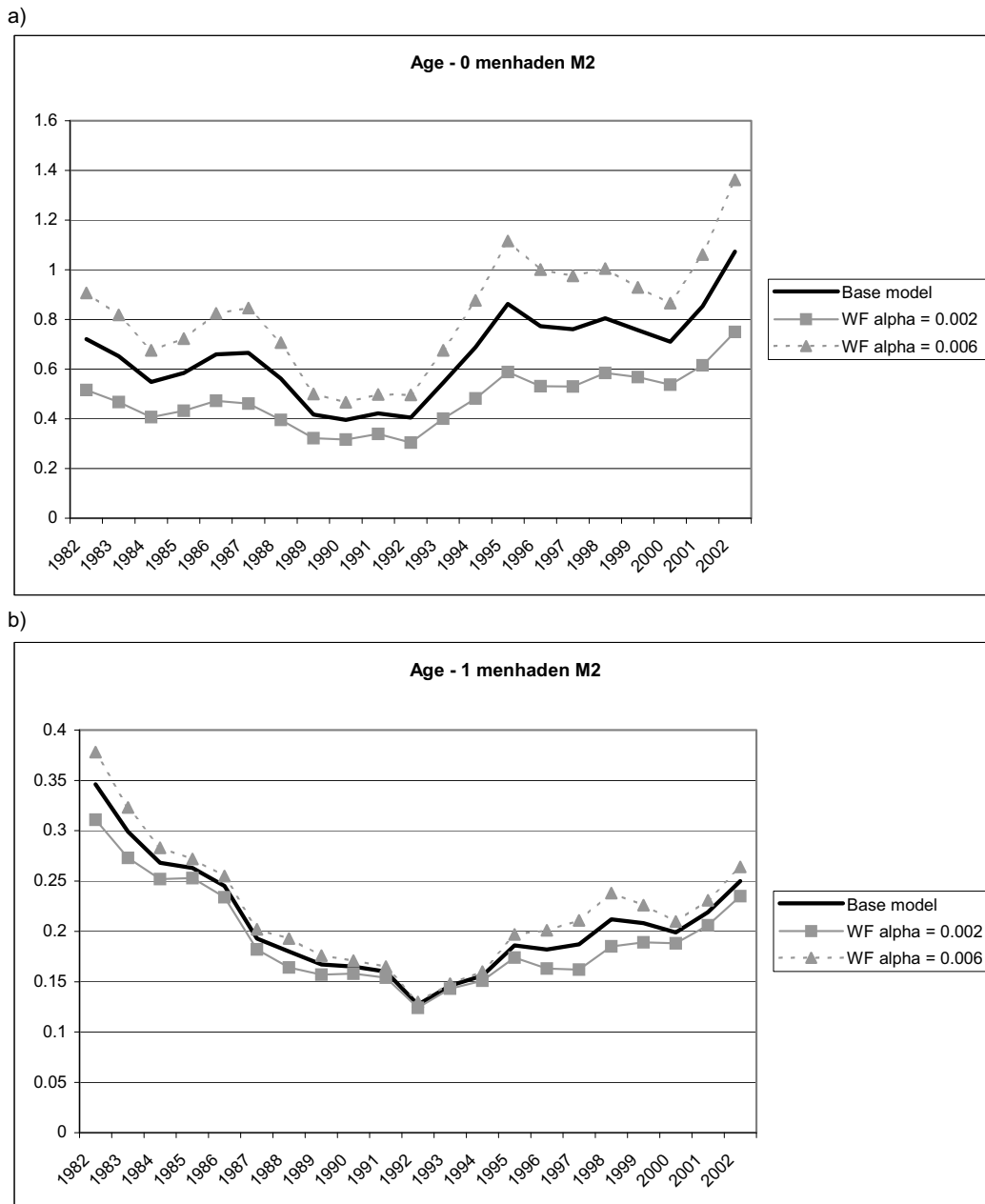
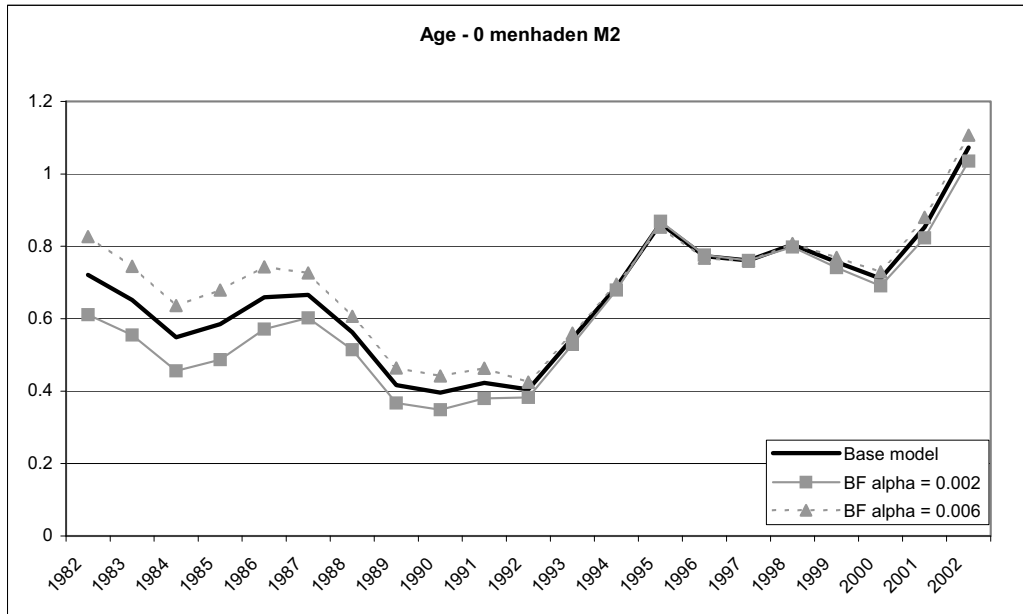


Figure D1.30. The affect of changing the gastric evacuation parameter  $\alpha$  for bluefish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

a)



b)

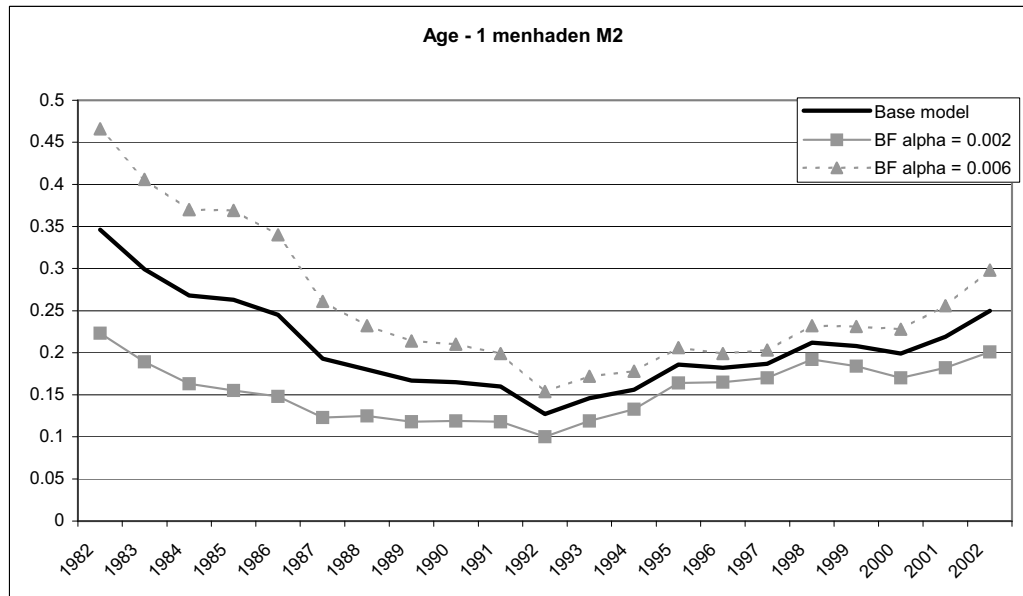
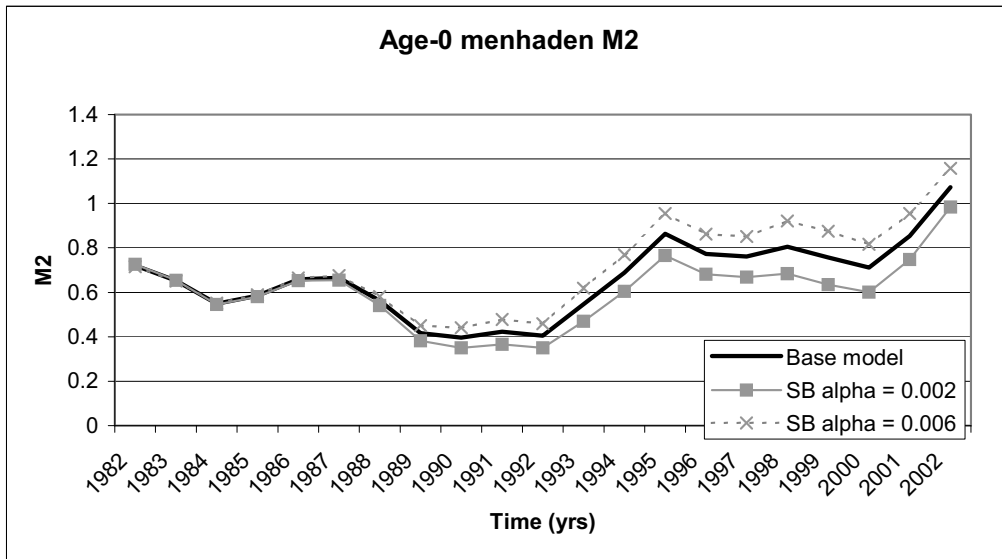


Figure D1.31. The affect of changing the gastric evacuation parameter  $\alpha$  for striped bass on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

a)



b)

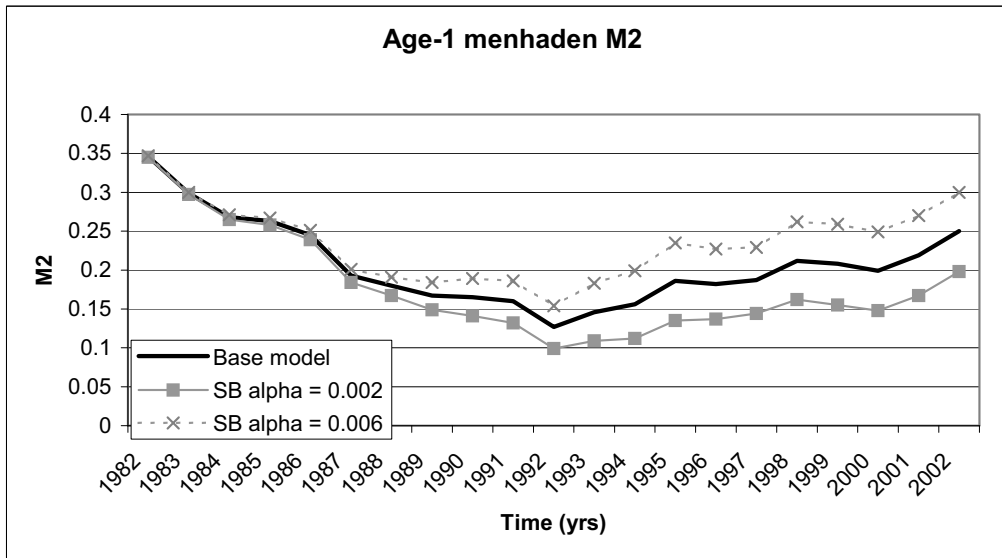




Figure D1.32. The affect of changing the gastric evacuation parameter  $\beta$  for weakfish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden

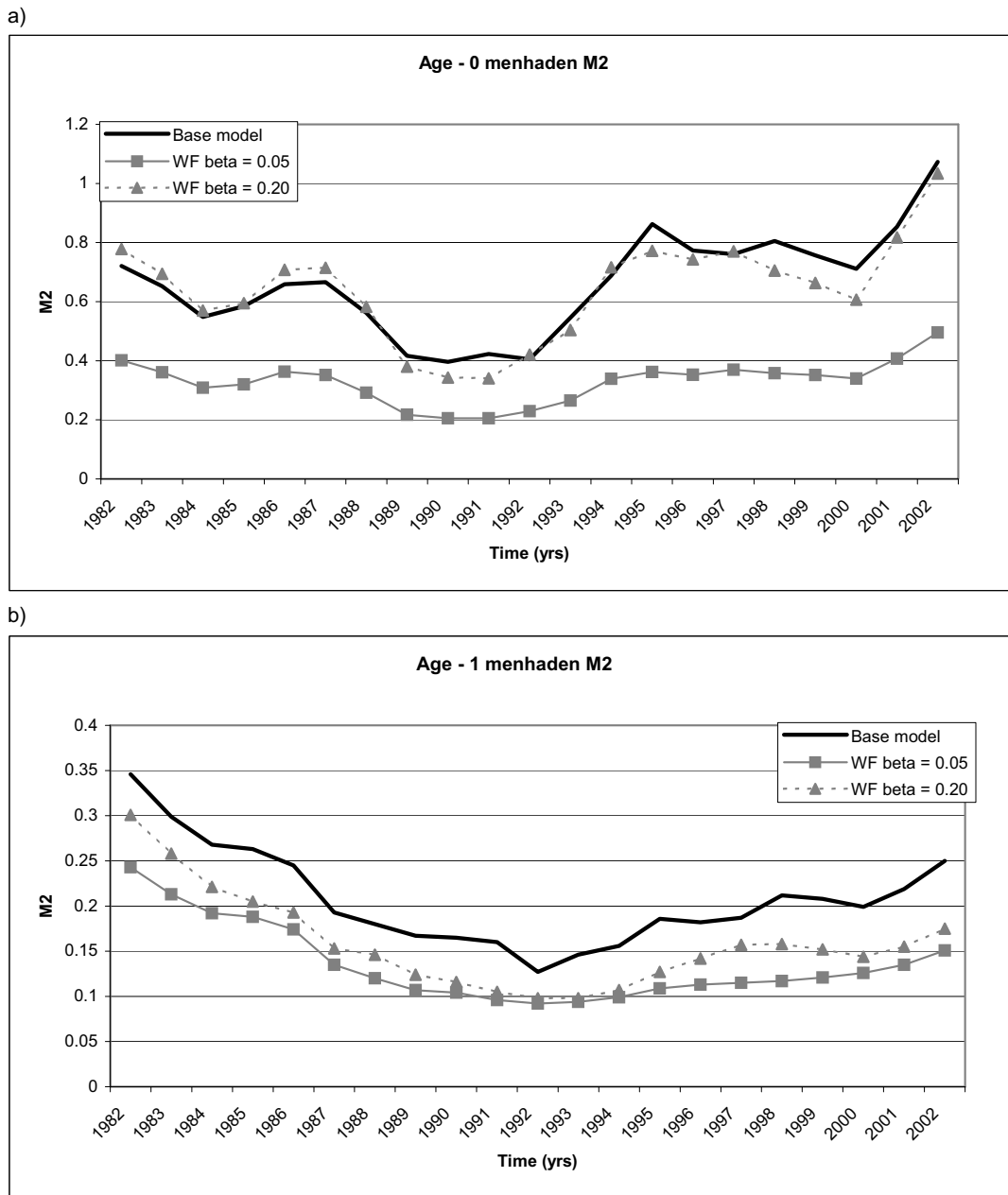


Figure D1.33. The affect of changing the gastric evacuation parameter  $\beta$  for bluefish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden

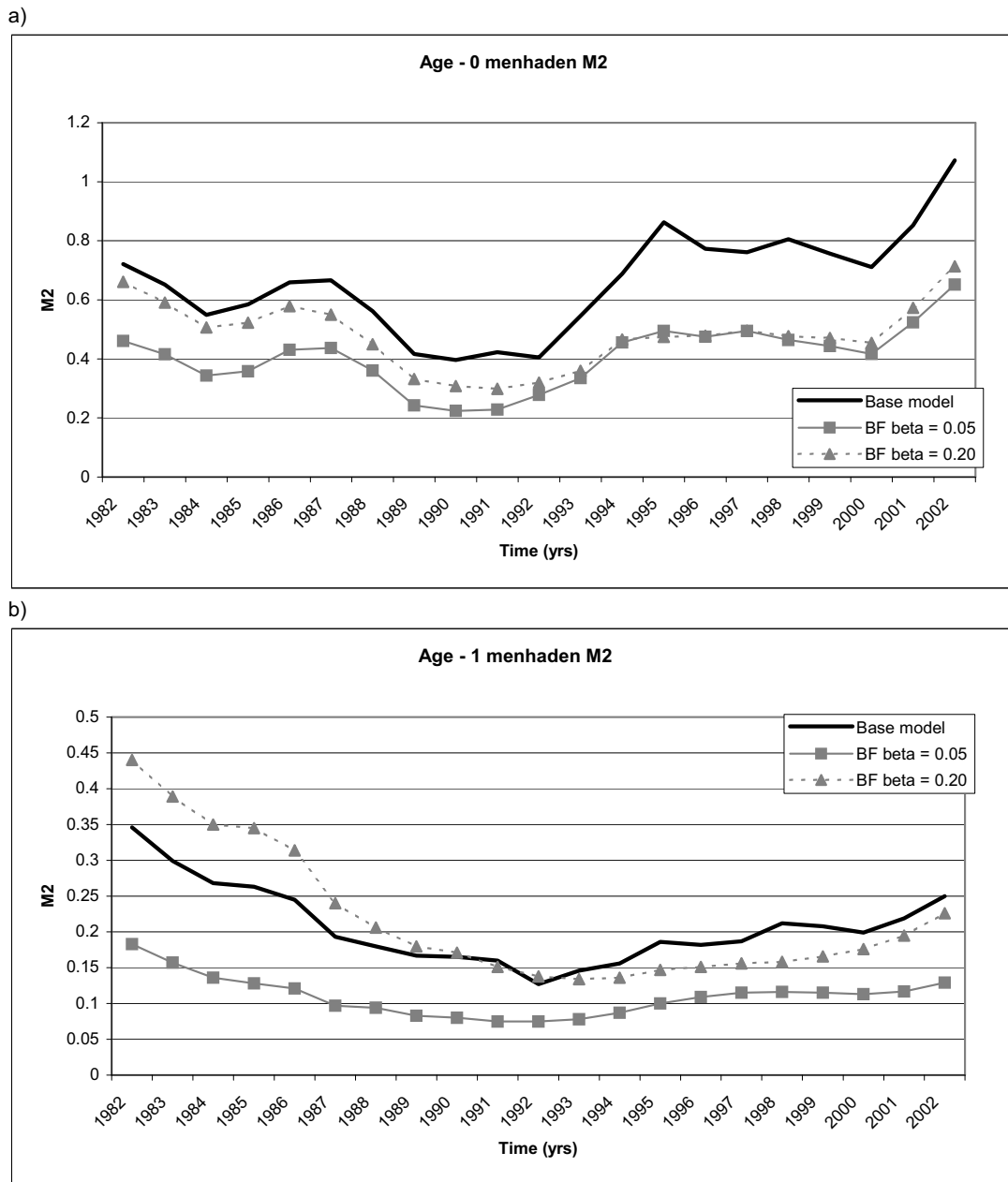


Figure D1.34. The affect of changing the gastric evacuation parameter  $\beta$  for striped bass on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

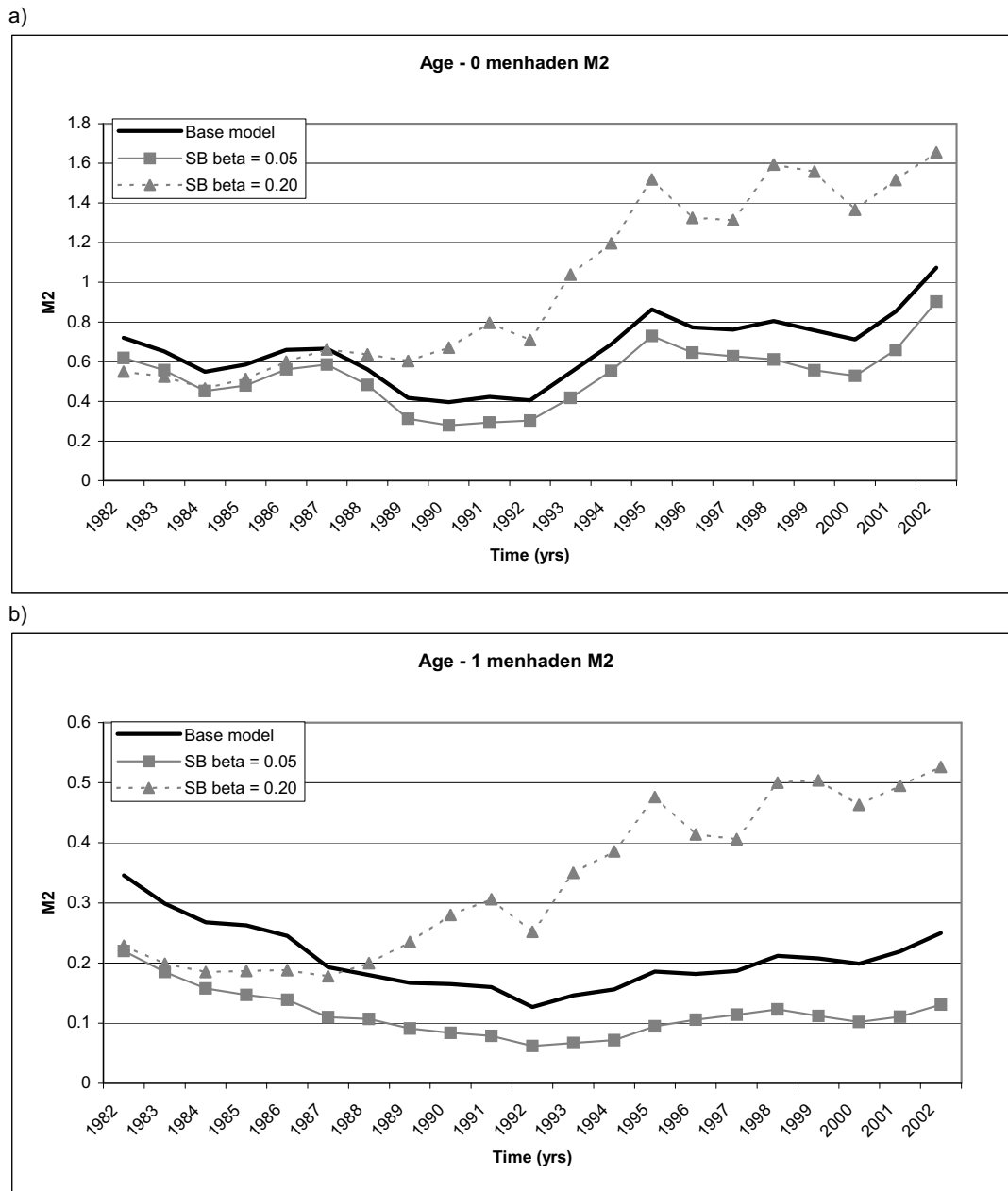


Figure D1.35. The affect of changing the gastric evacuation parameter  $\alpha$  for striped bass on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

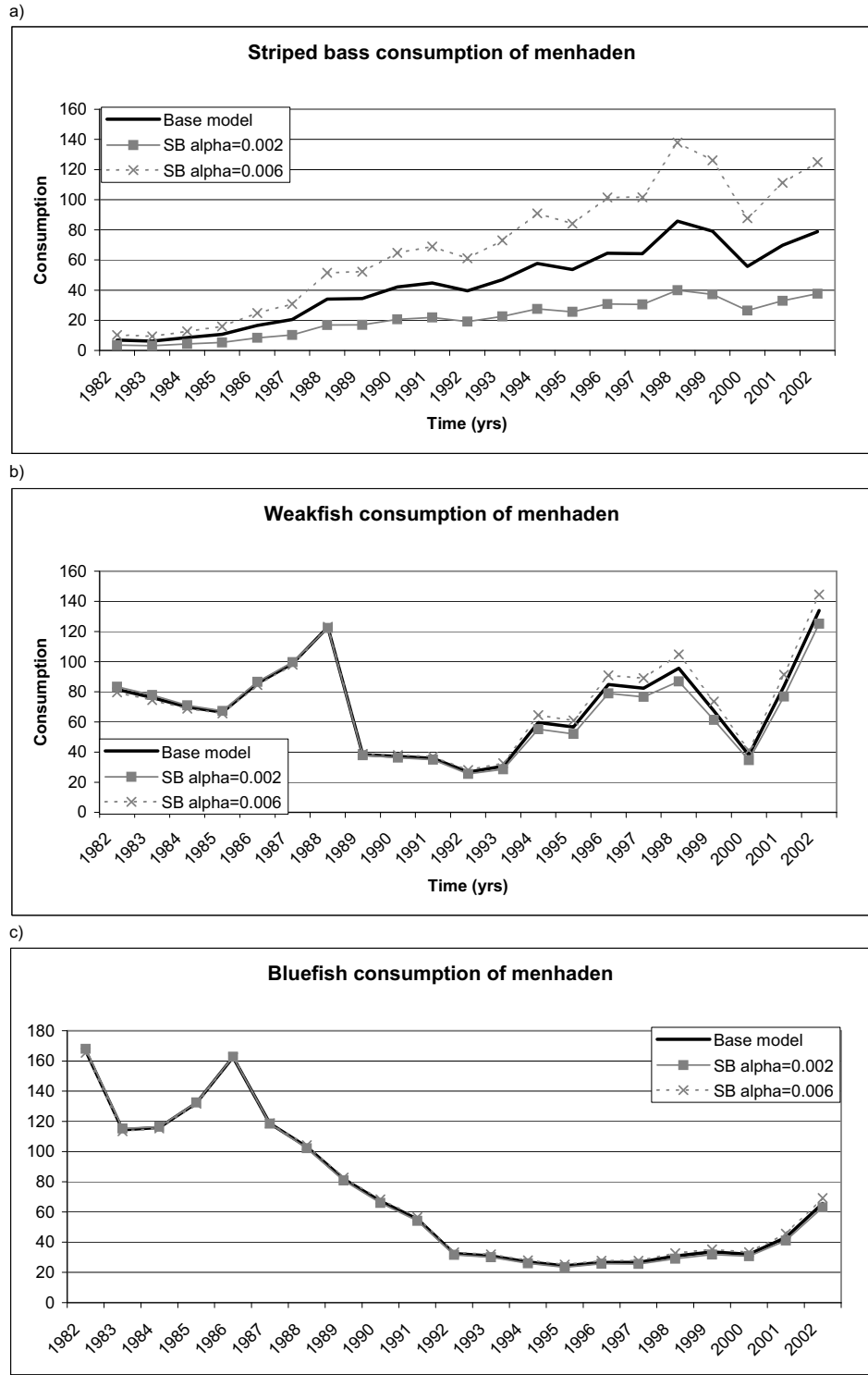


Figure D1.36. The affect of changing the gastric evacuation parameter  $\alpha$  for weakfish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

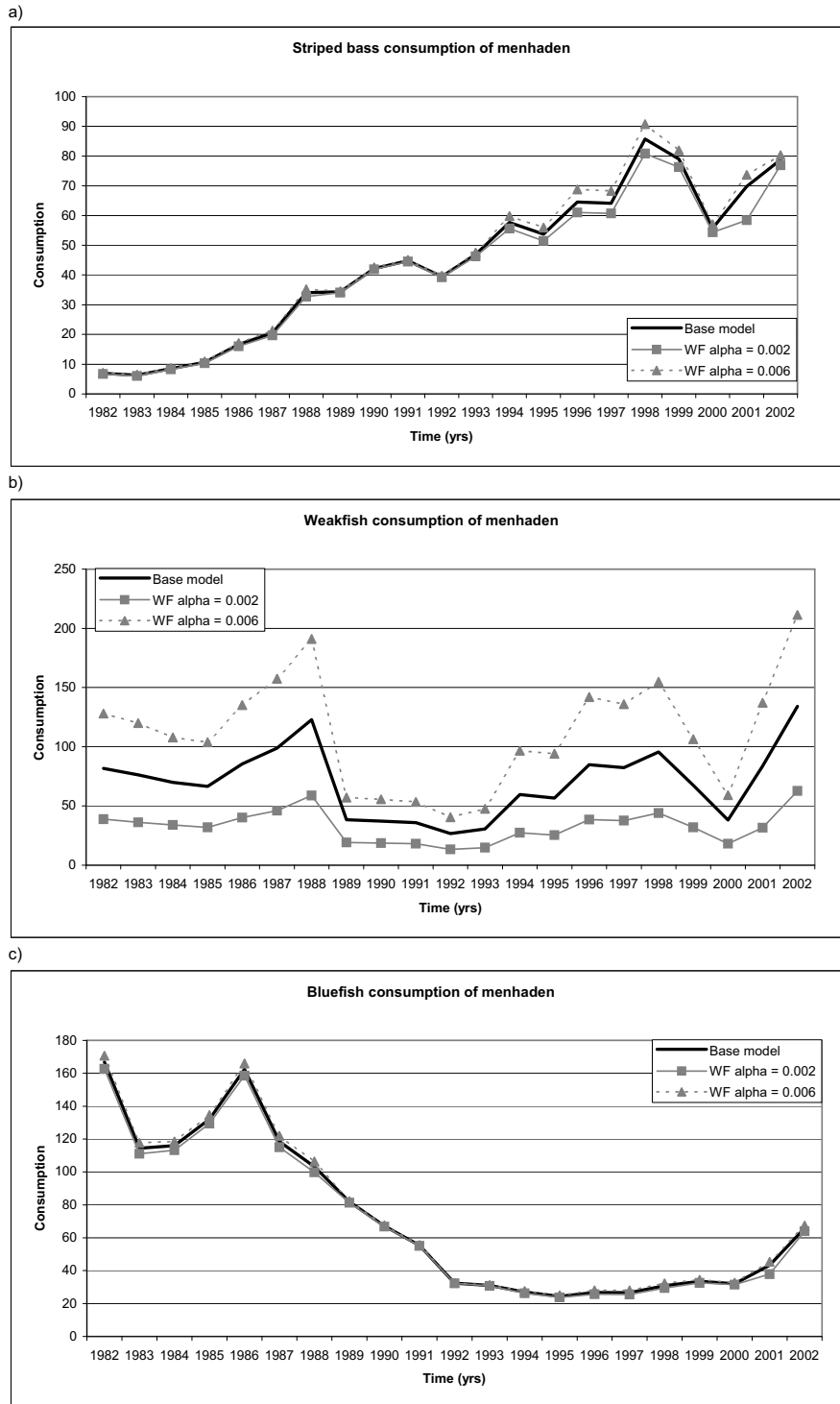


Figure D1.37. The affect of changing the gastric evacuation parameter  $\alpha$  for bluefish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

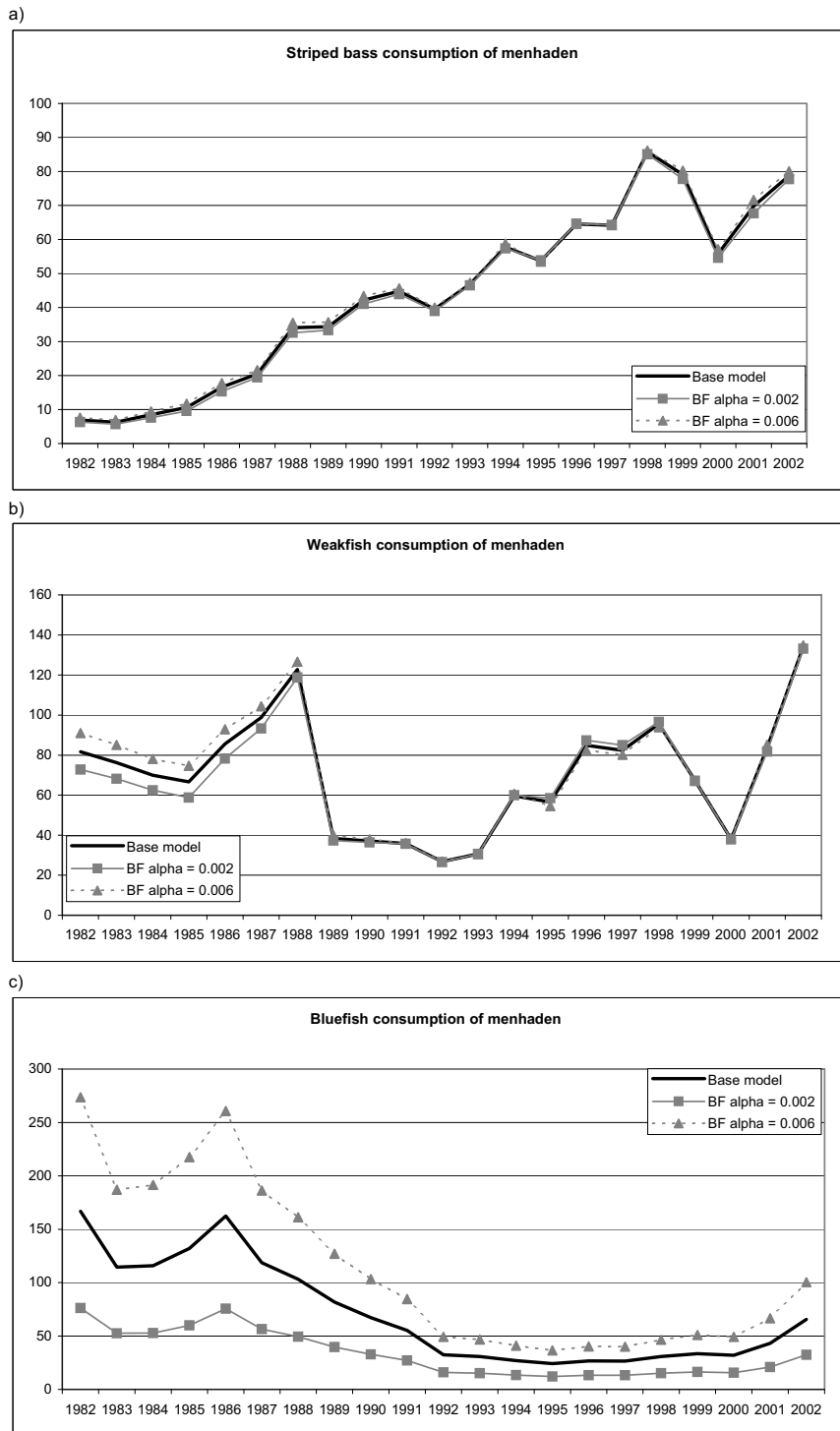


Figure D1.38. The affect of changing the gastric evacuation parameter  $\beta$  for weakfish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

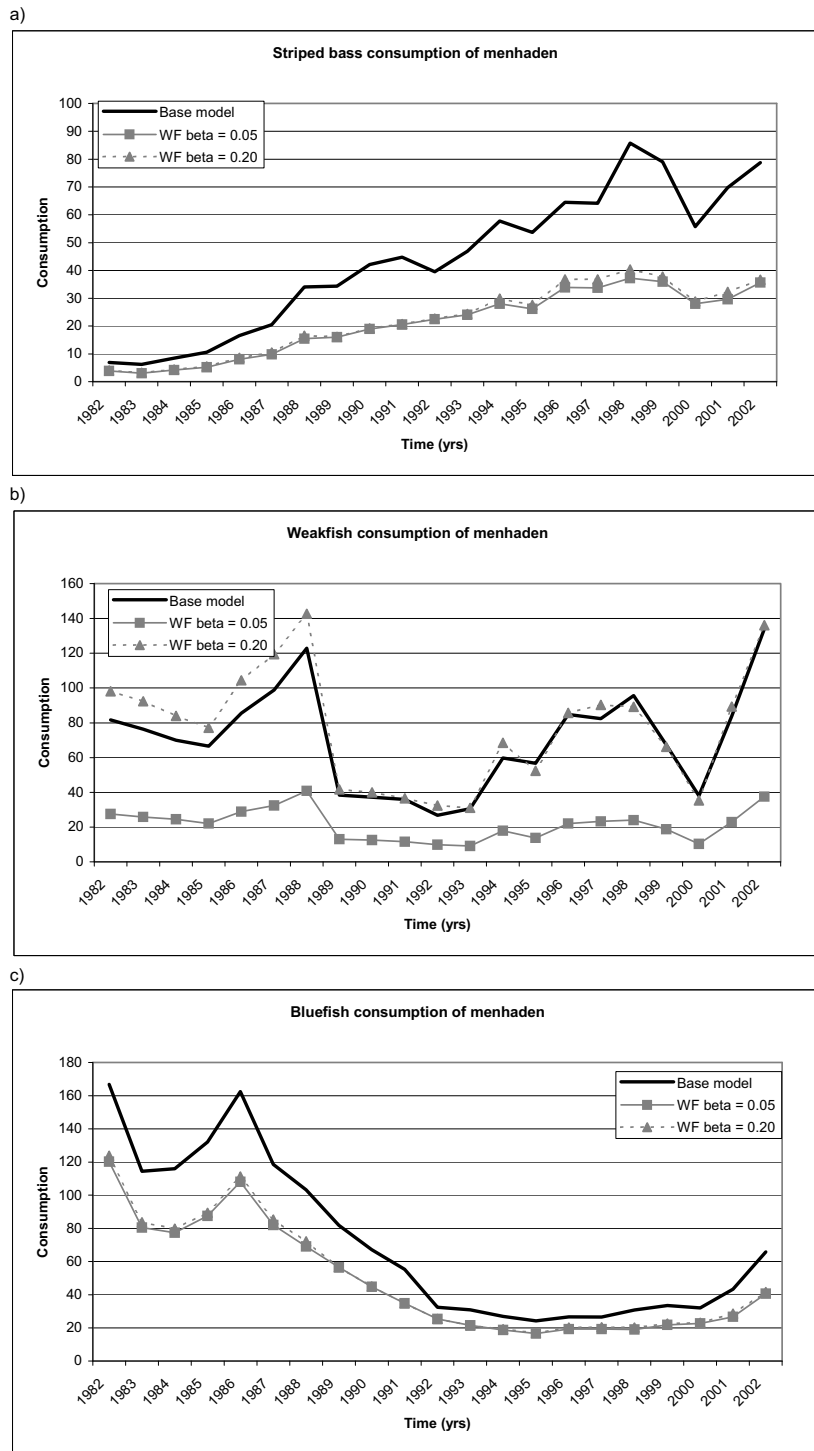


Figure D1.39. The affect of changing the gastric evacuation parameter  $\beta$  for bluefish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

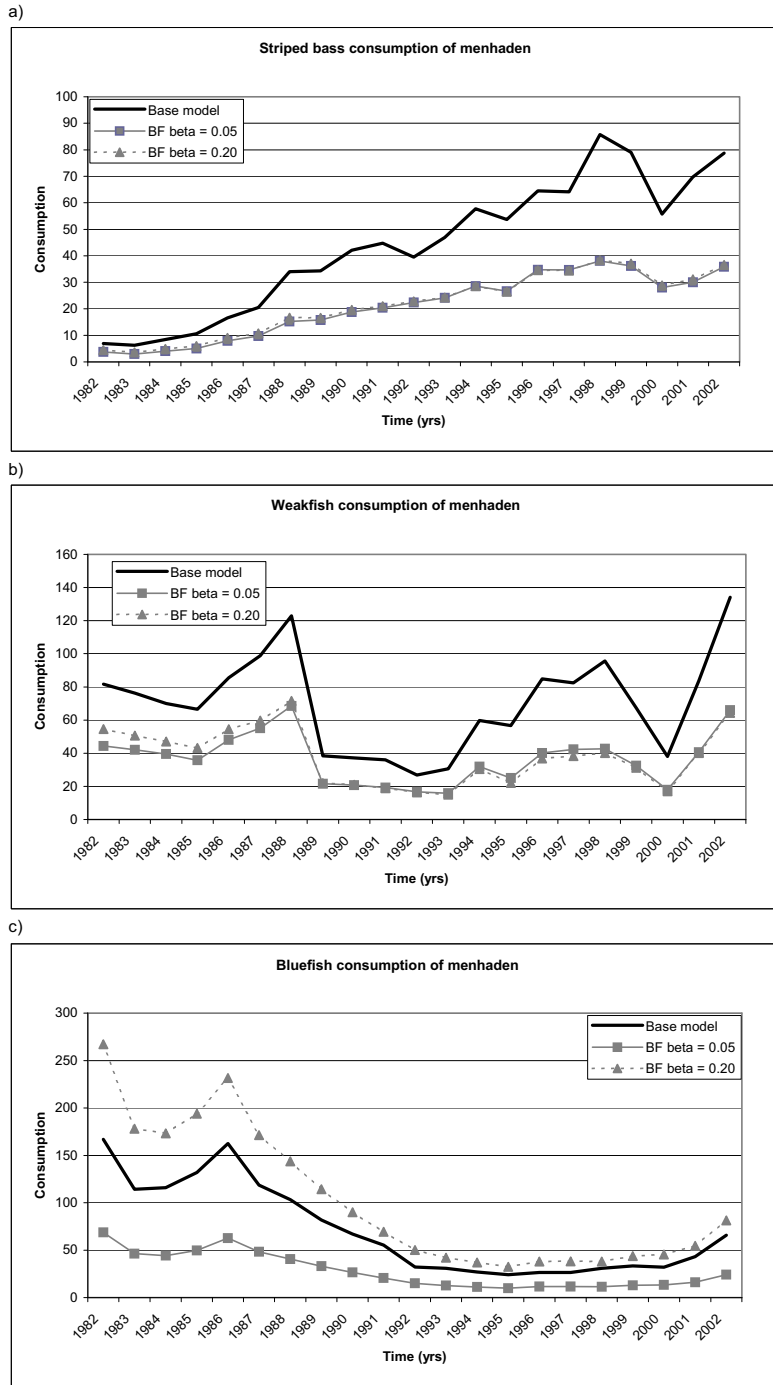




Figure D1.40. The affect of changing the gastric evacuation parameter  $\beta$  for striped bass on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

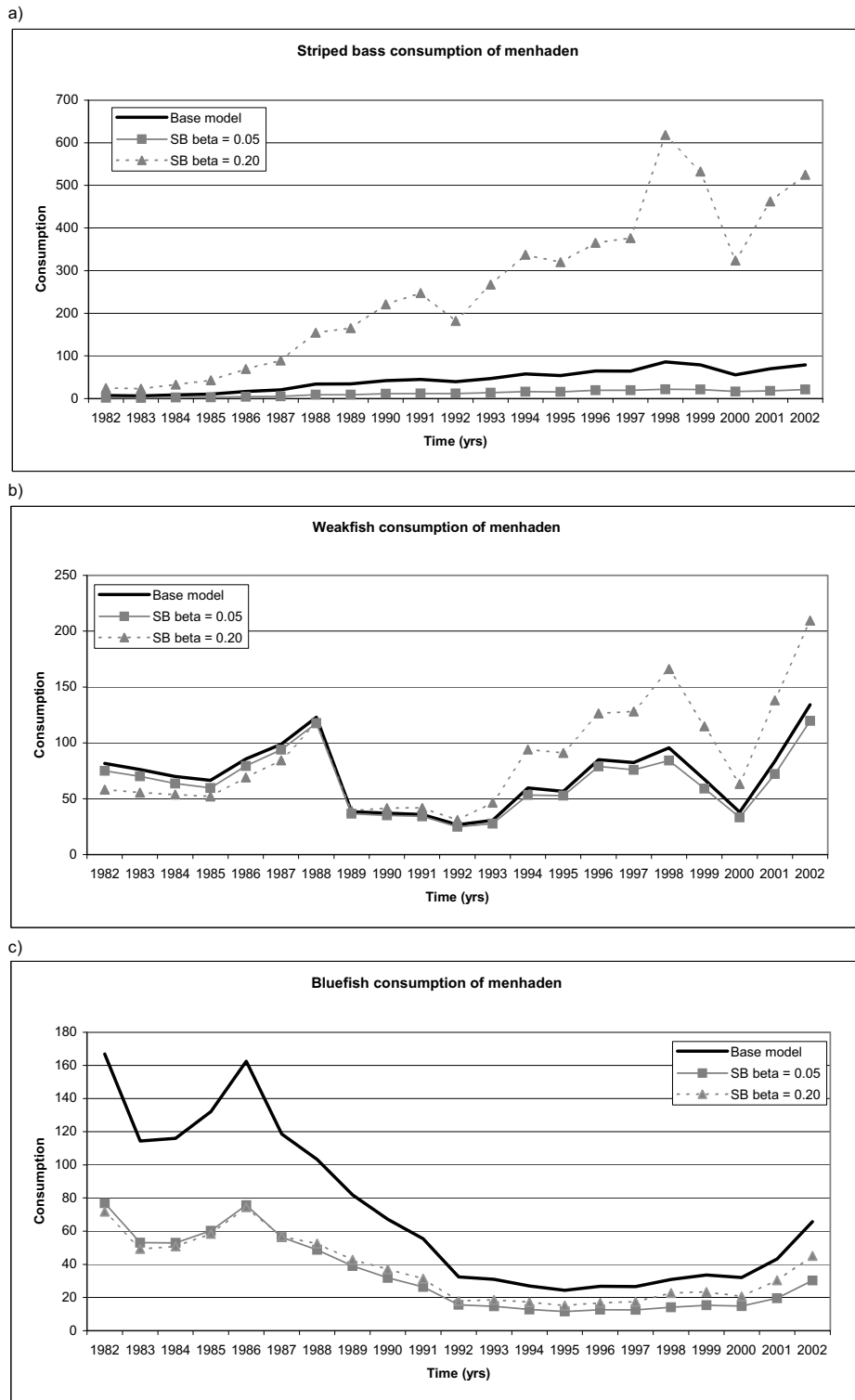


Figure D1.41. Comparison of predation mortality (M2) for age-0 menhaden with preference typed ranking all equal.

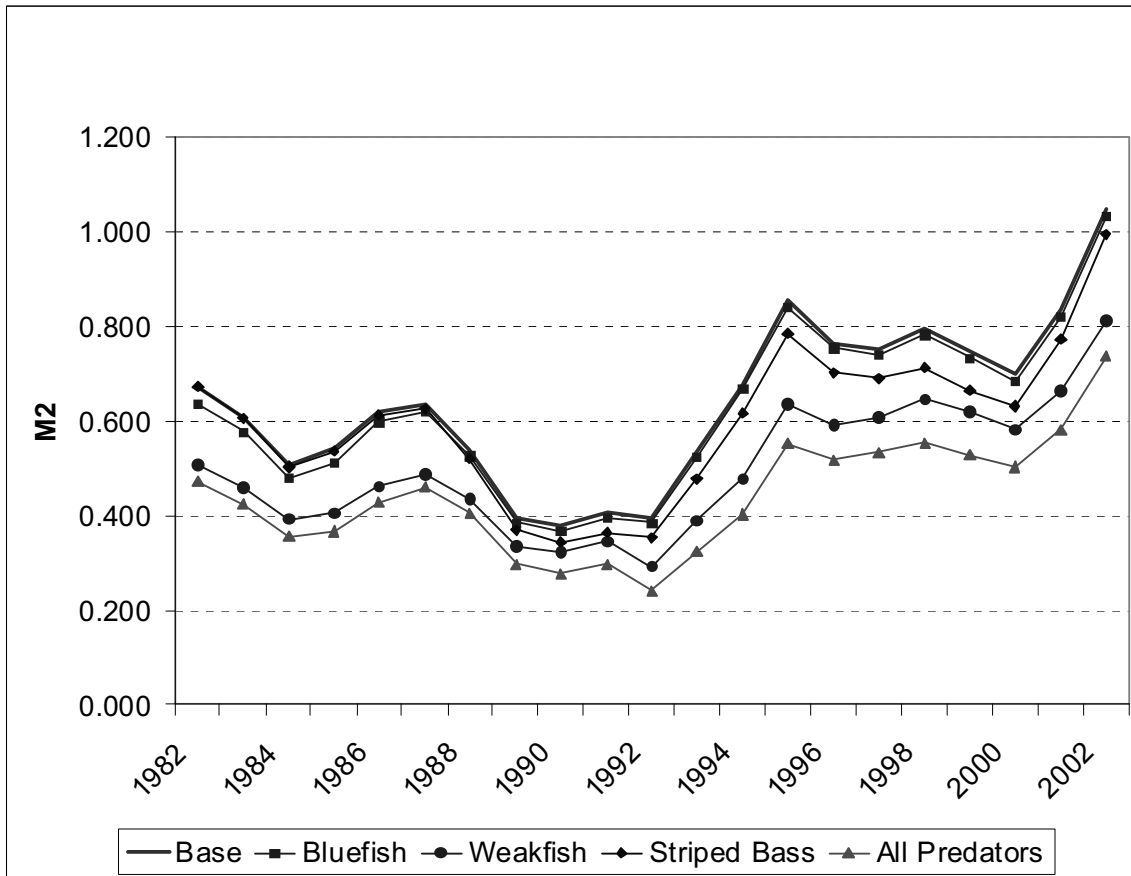


Figure D1.42. Comparison of predation mortality for age-0 menhaden with preference type ranking equal for fish and invertebrates.

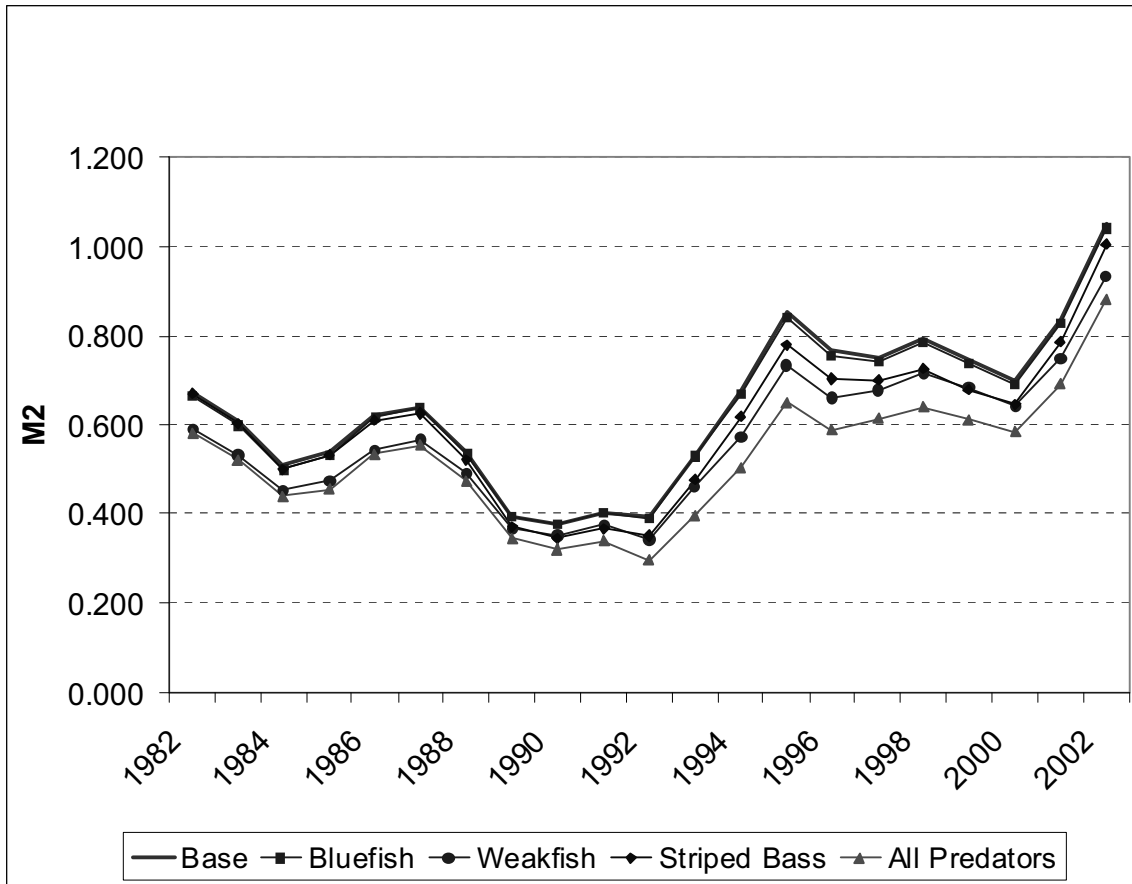


Figure D1.43. Comparison of predation mortality (M2) for age-1 menhaden with preference type ranking all equal.

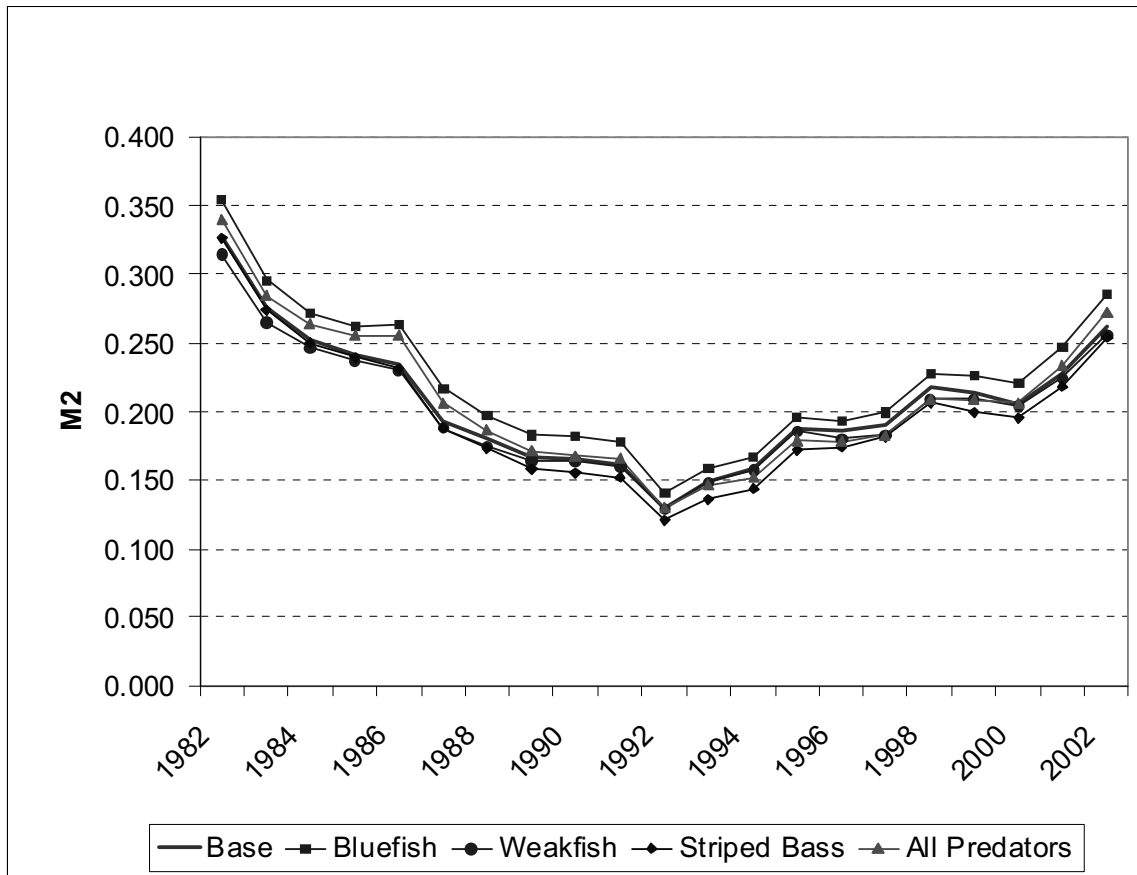


Figure D1.44. Comparison of predation mortality for age-1 menhaden with preference type ranking equal for fish and invertebrates.

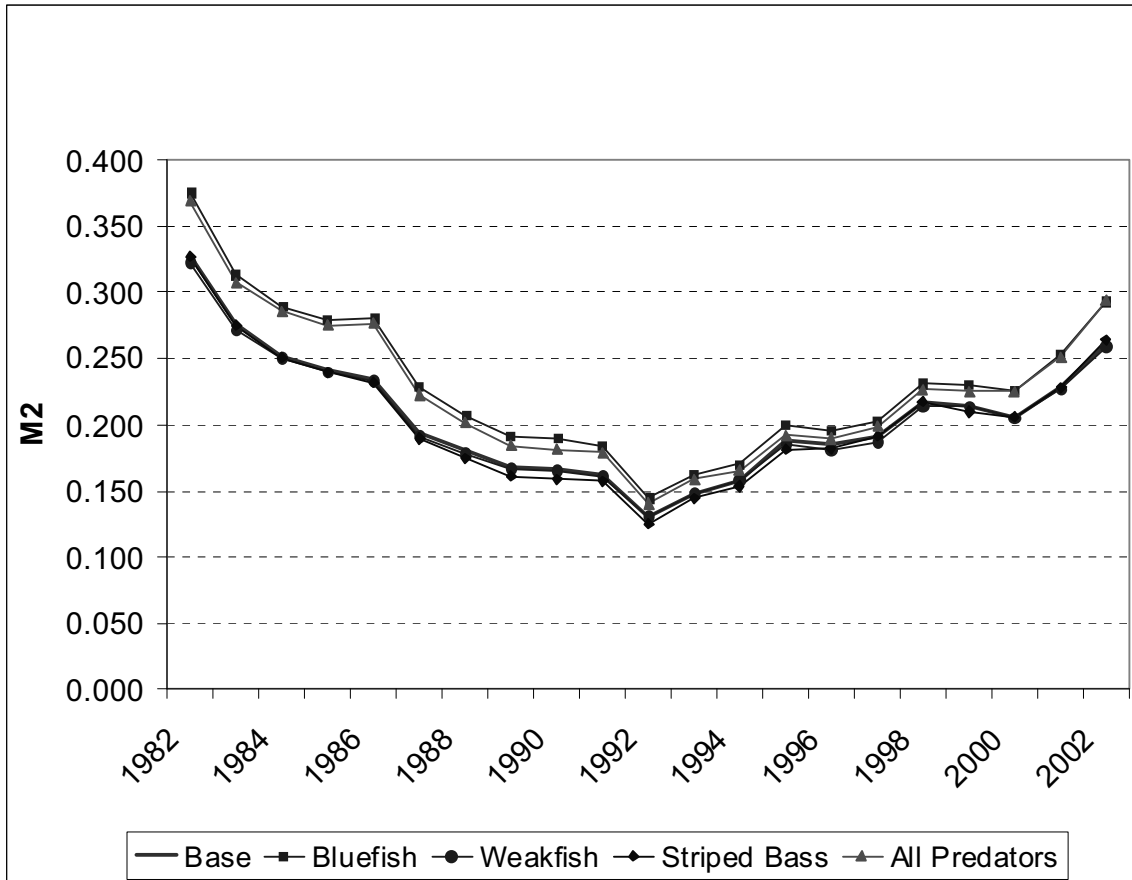


Figure D1.45. Comparison of predation mortality (M2) for age-2 menhaden with preference type ranking all equal.

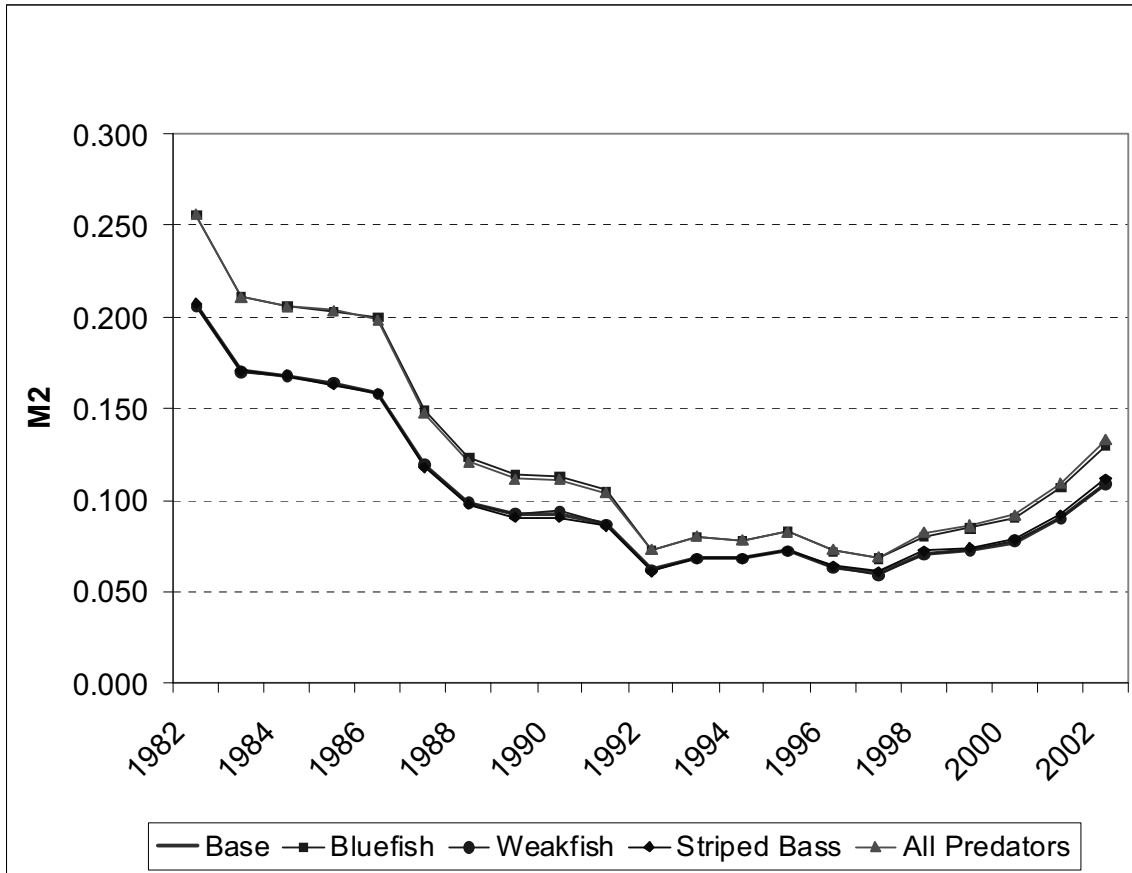


Figure D1.46. Comparison of predation mortality (M2) for age-2 menhaden with preference type ranking equal for fish and invertebrates.

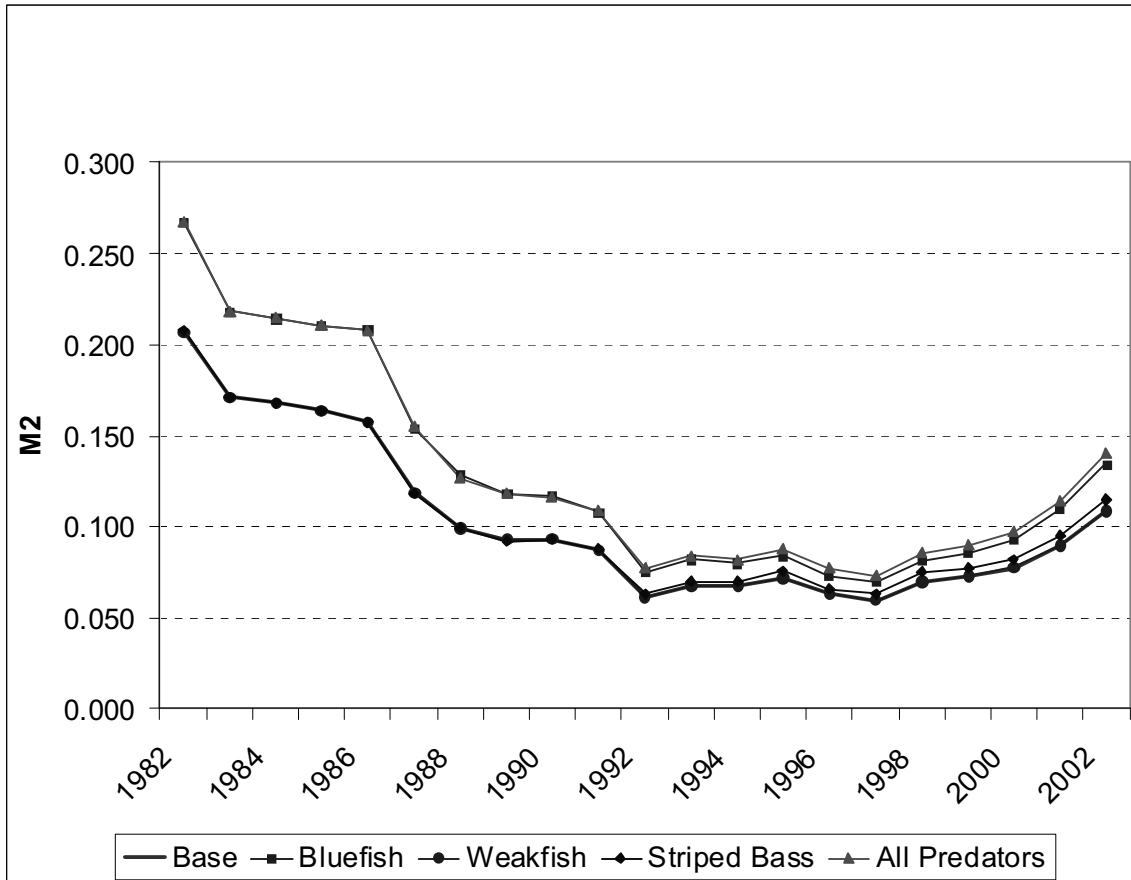


Figure D1.47. Comparison of average fishing mortality (F) for menhaden with preference type ranking all equal.

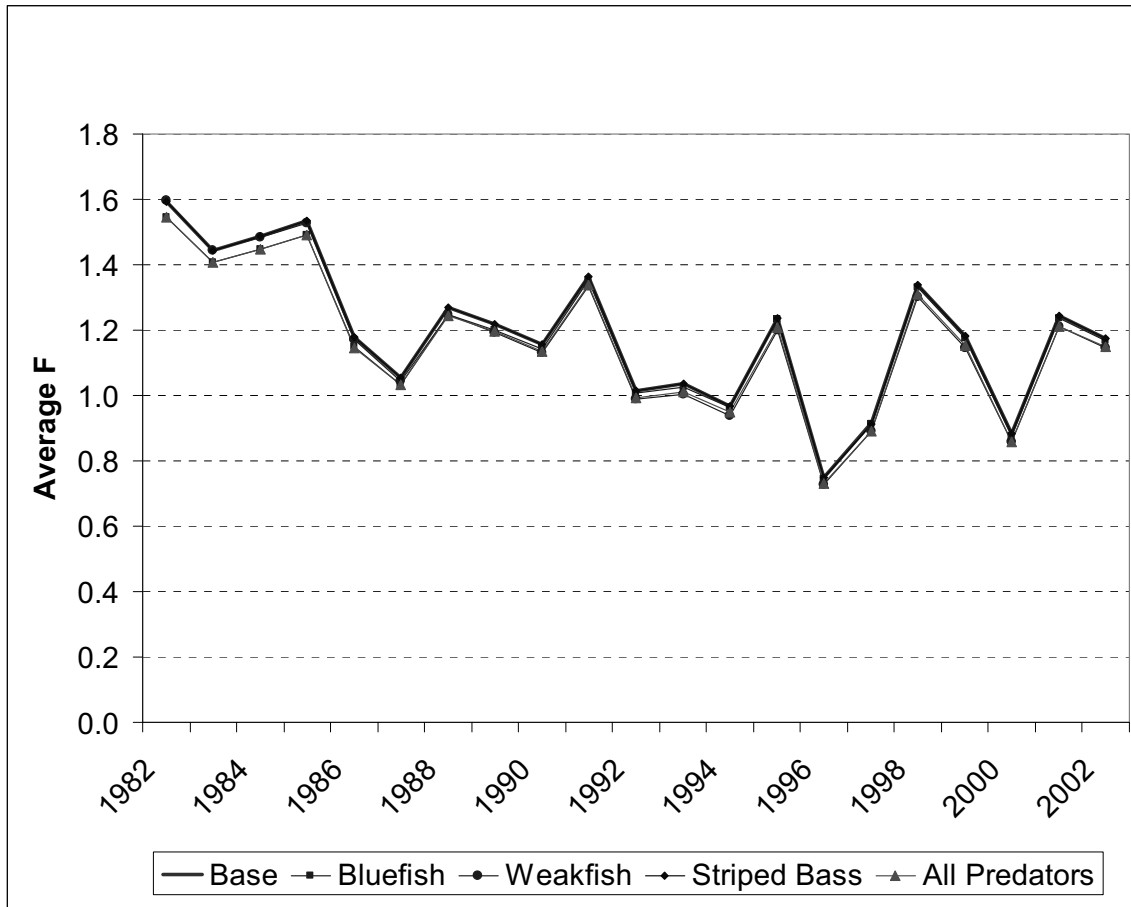




Figure D1.48. Comparison of average fishing mortality (F) for menhaden with preference type ranking equal for fish and invertebrates.

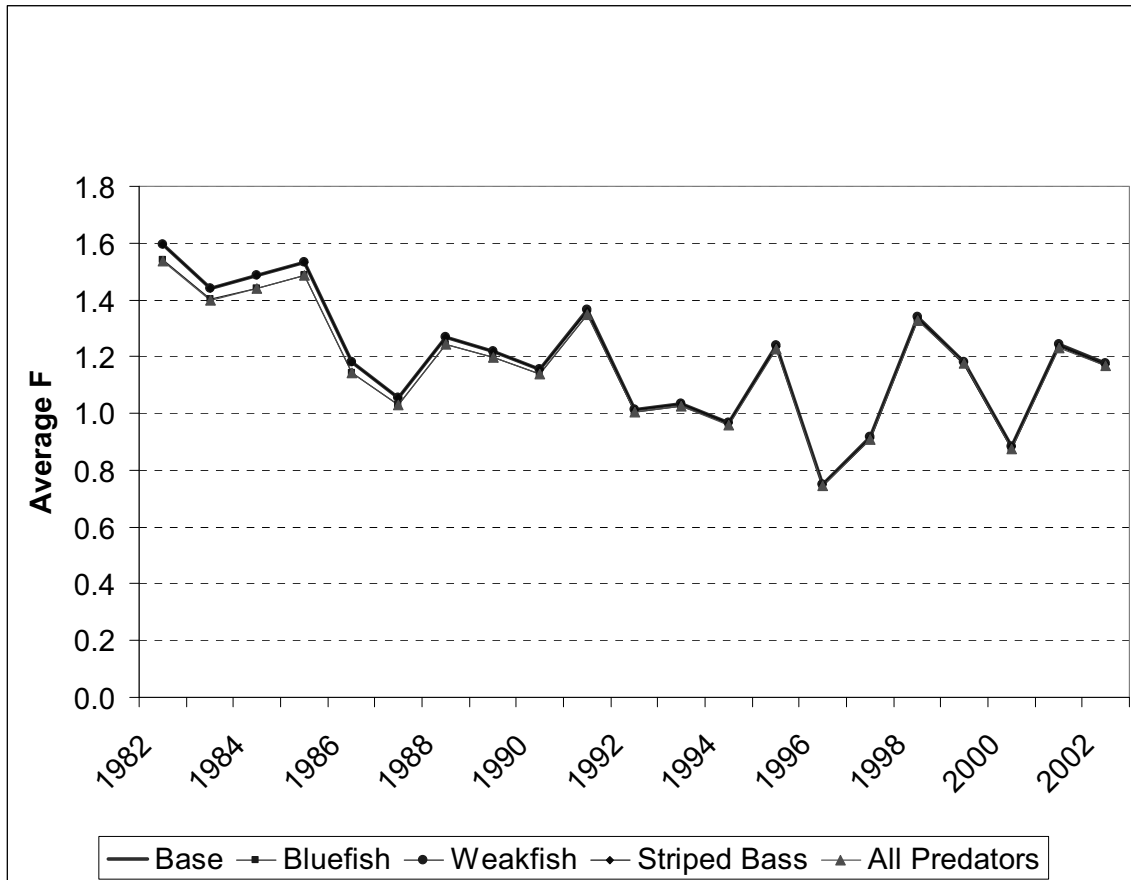


Figure D1.49. Comparison of abundance of age-0 menhaden with preference type ranking all equal.

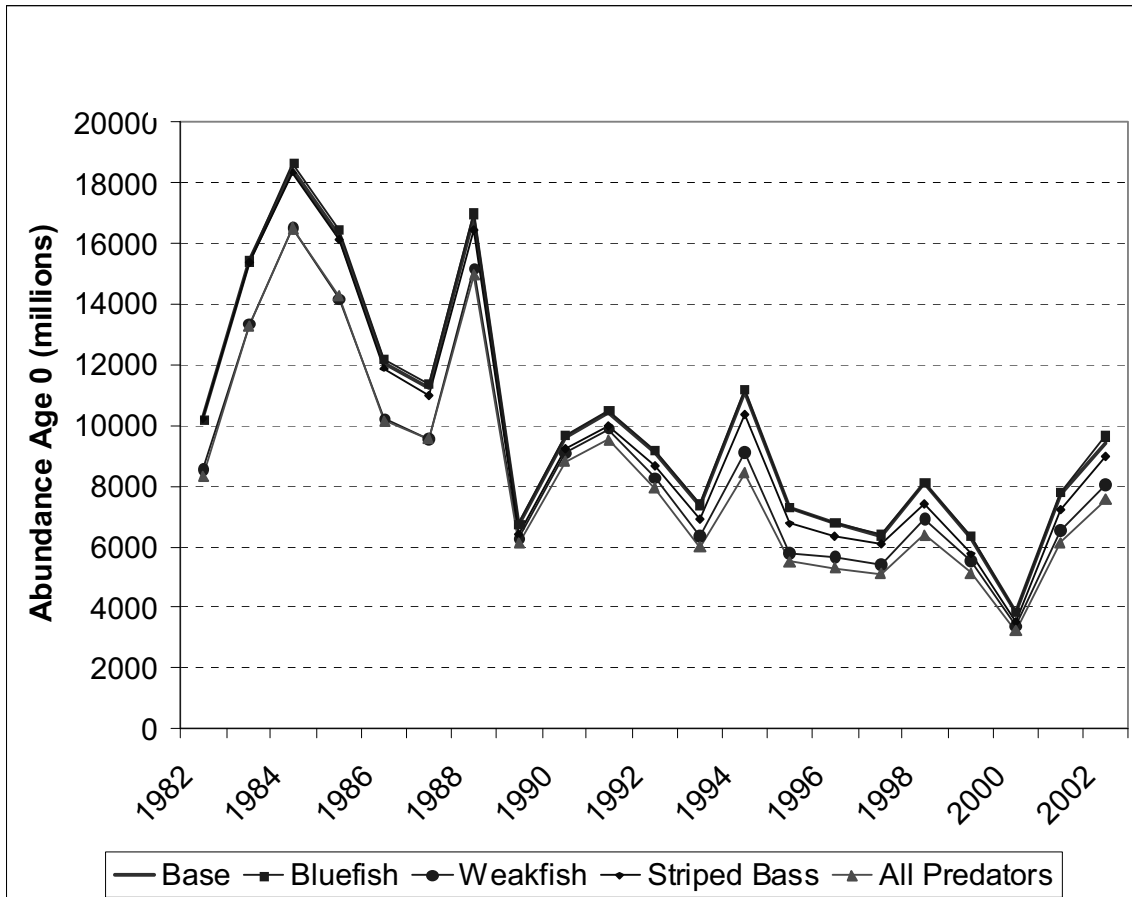


Figure D1.50. Comparison of abundance of age-0 menhaden with preference type ranking equal for fish and invertebrates.

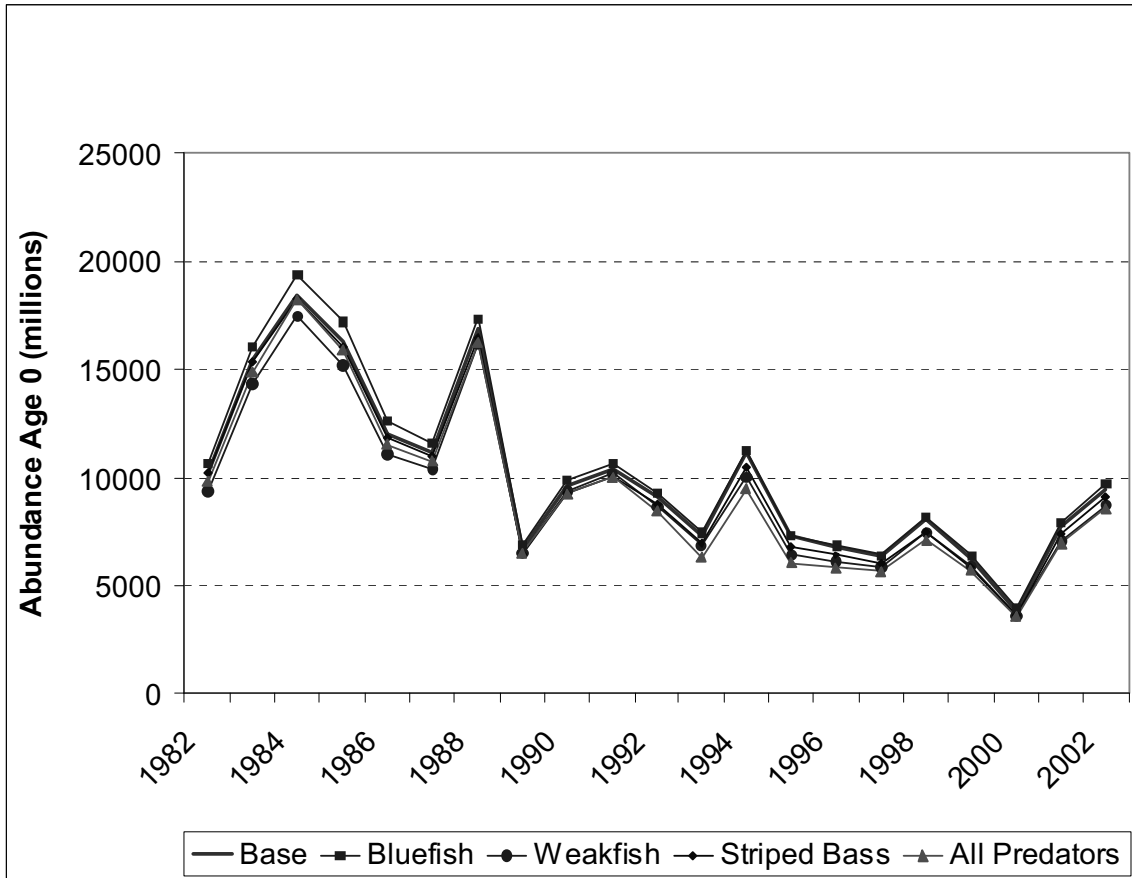


Figure D1.51. Comparison of abundance of age-1 menhaden with preference type ranking all equal.

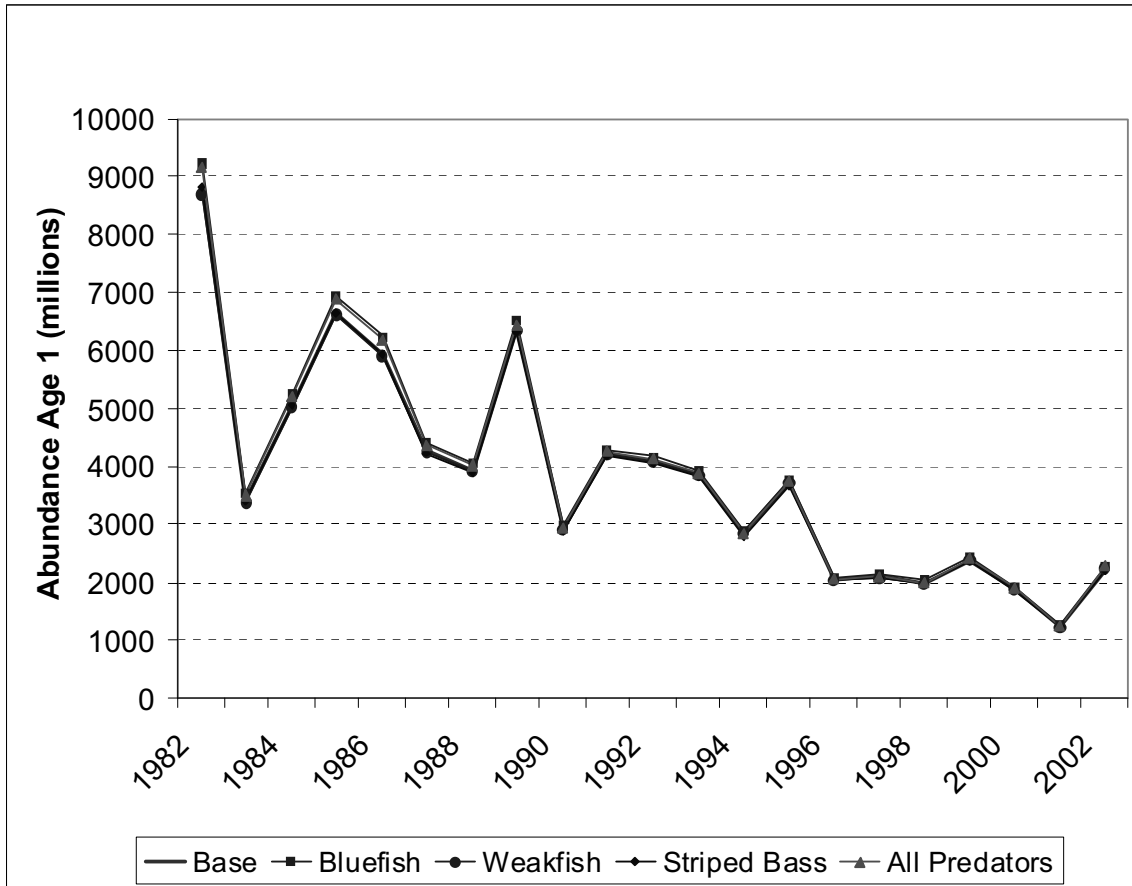


Figure D1.52. Comparison of abundance of age-1 menhaden with preference type ranking equal for fish and invertebrates.

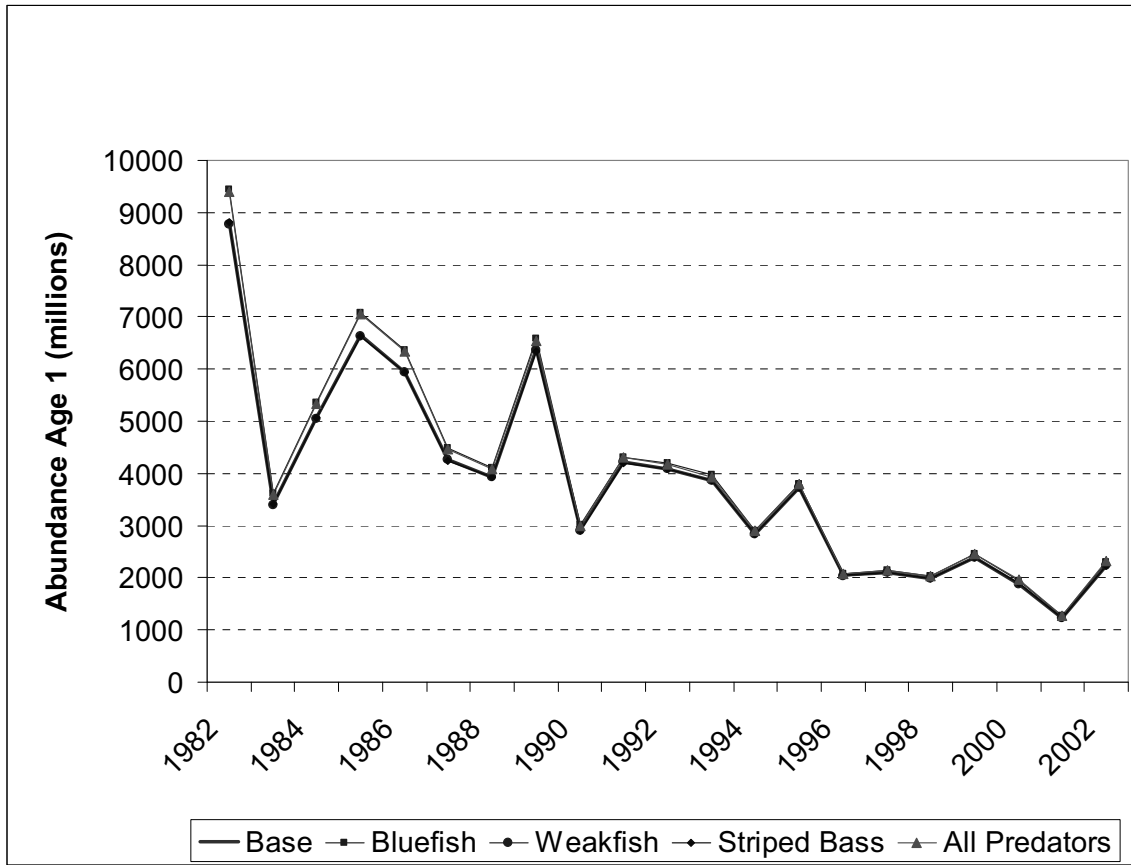


Figure D1.53. Comparison of menhaden spawning stock biomass (SSB) with preference type ranking all equal.

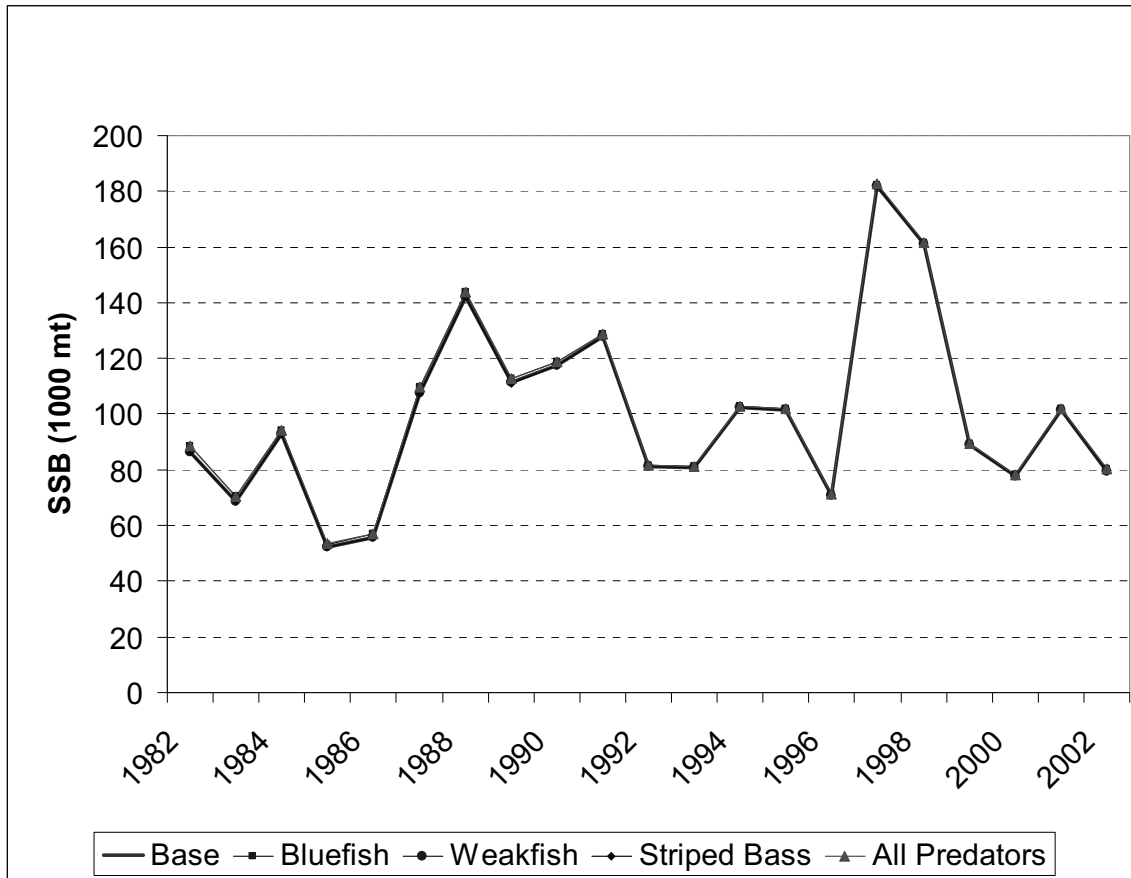


Figure D1.54. Comparison of menhaden spawning stock biomass (SSB) with preference type ranking equal for fish and invertebrates.

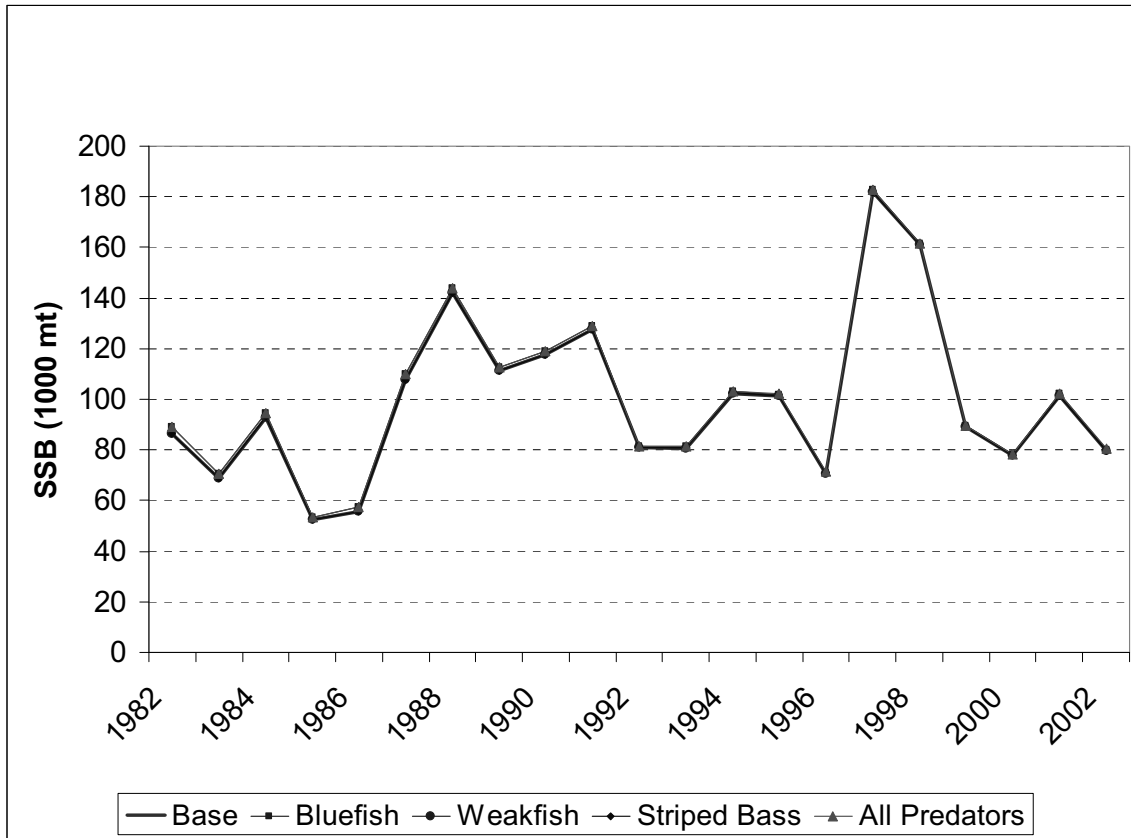


Figure D1.55. Menhaden in diet of striped bass (equal weighting).

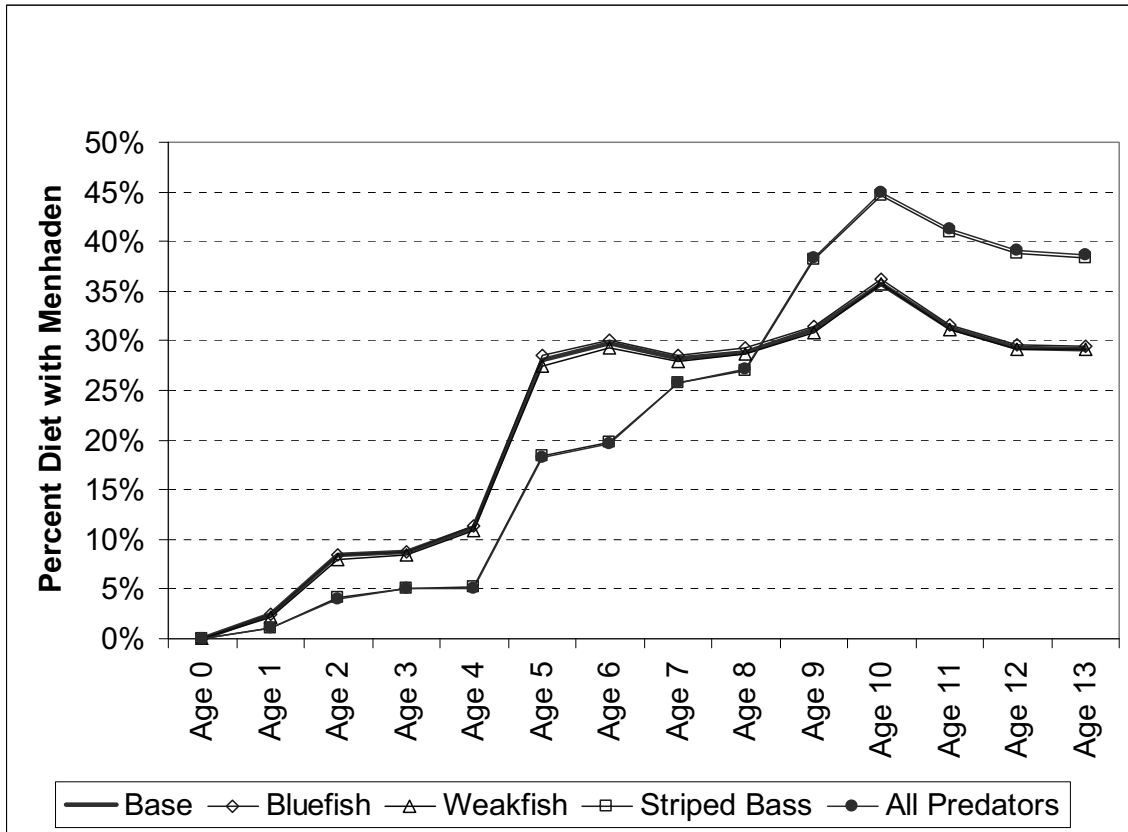




Figure D1.56. Menhaden in diet of striped bass (fish and invertebrate equal weighting).

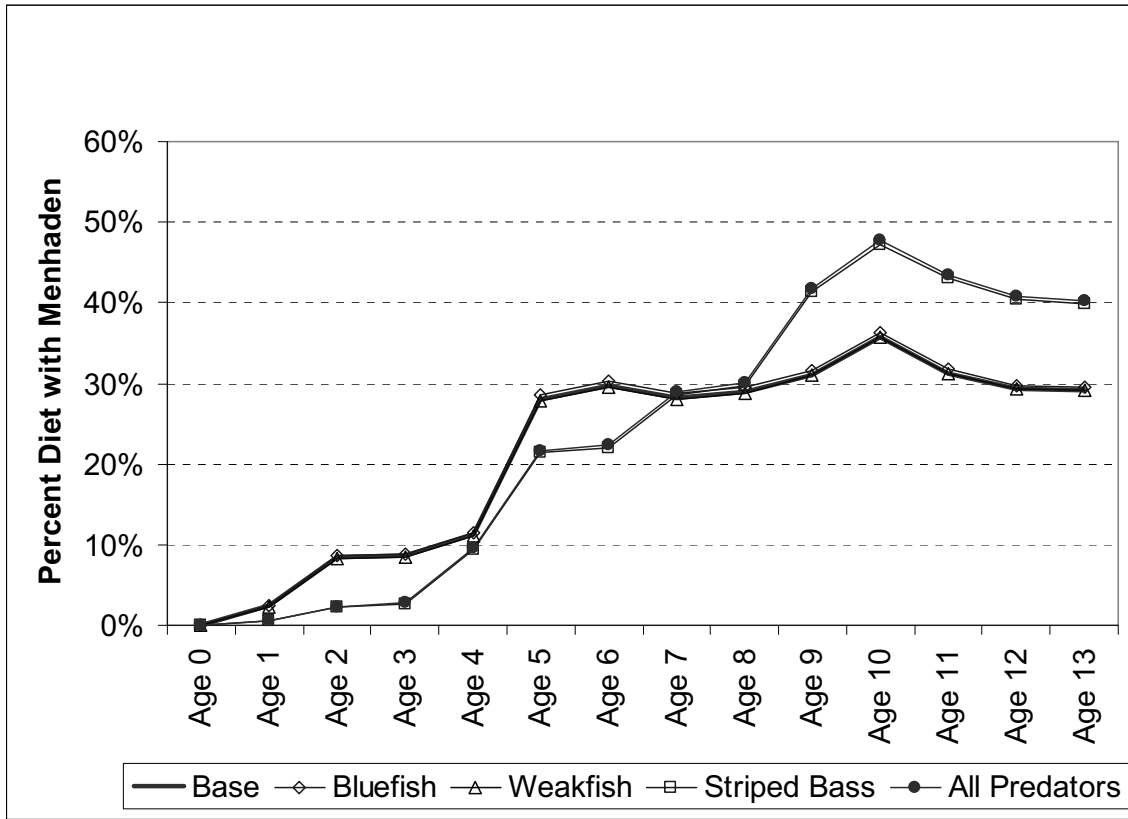


Figure D1.57. Menhaden in diet of weakfish (equal weighting).

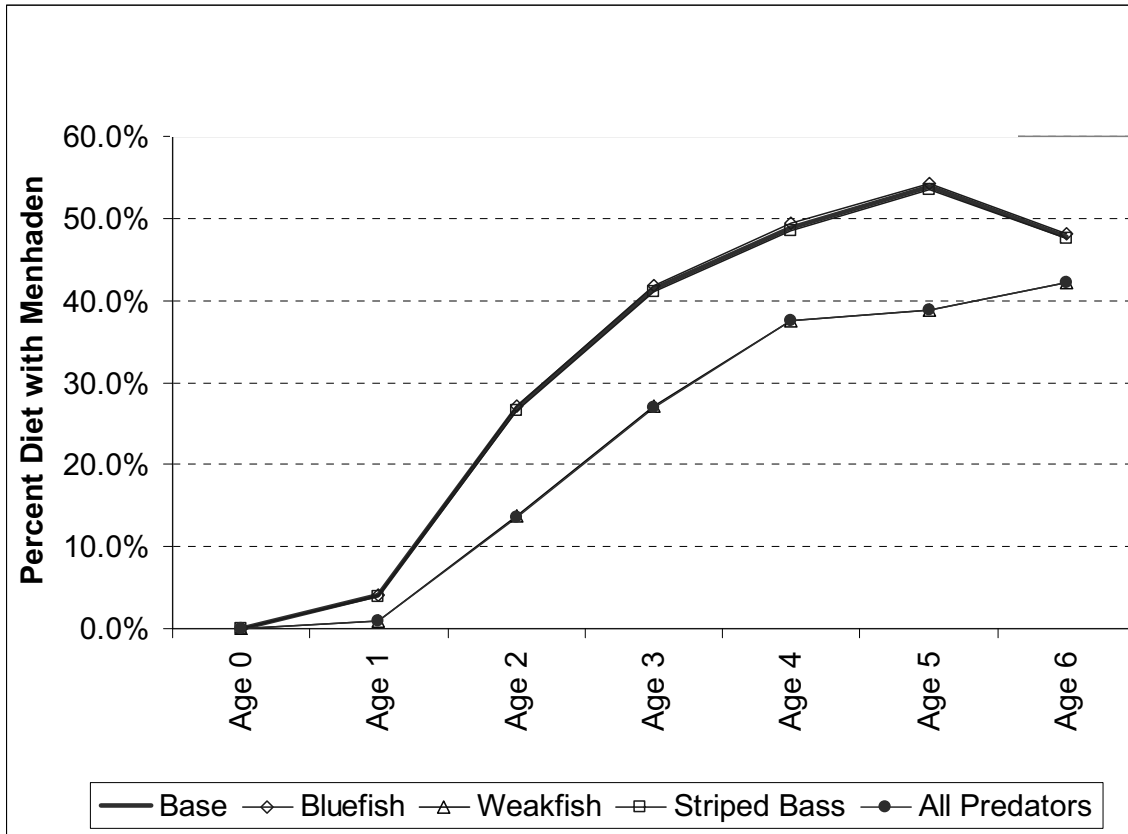


Figure D1.58. Menhaden in diet of weakfish (fish and invertebrate equal weighting).

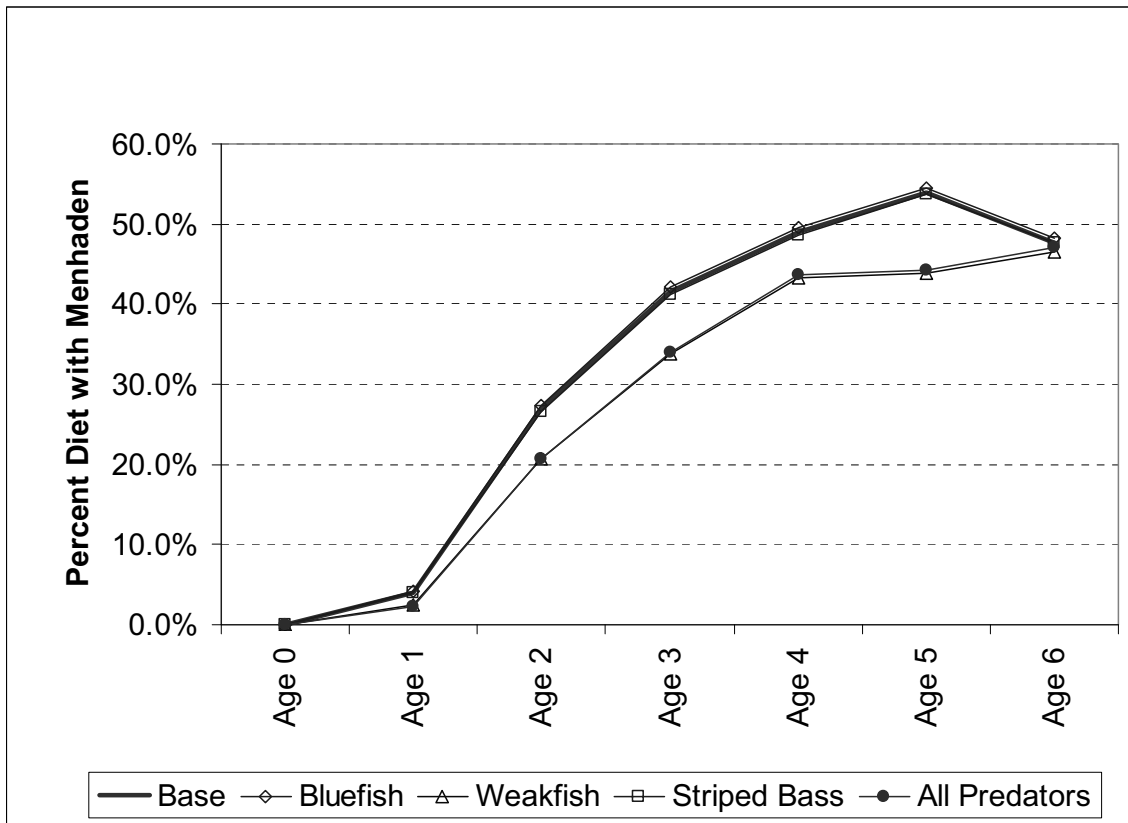


Figure D1.59. Menhaden in diet of bluefish (equal weighting).

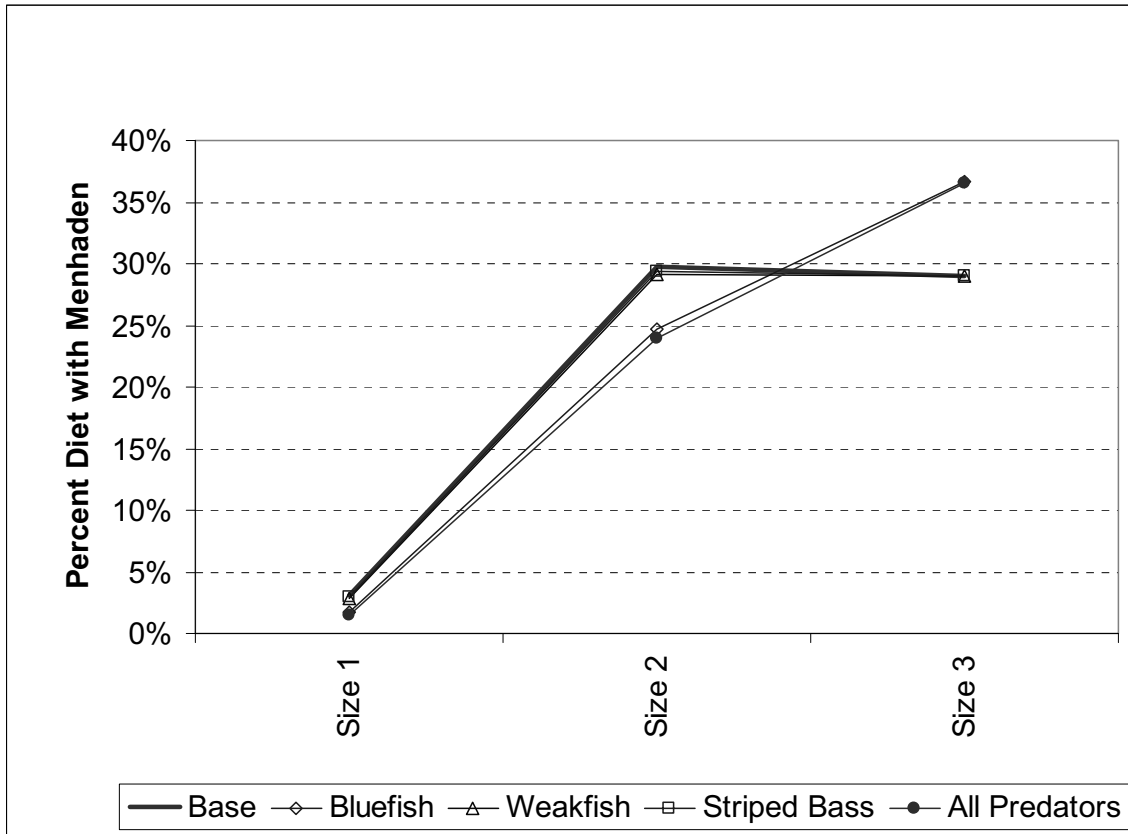


Figure D1.60. Menhaden in diet of bluefish (fish and invertebrate equal weighting).

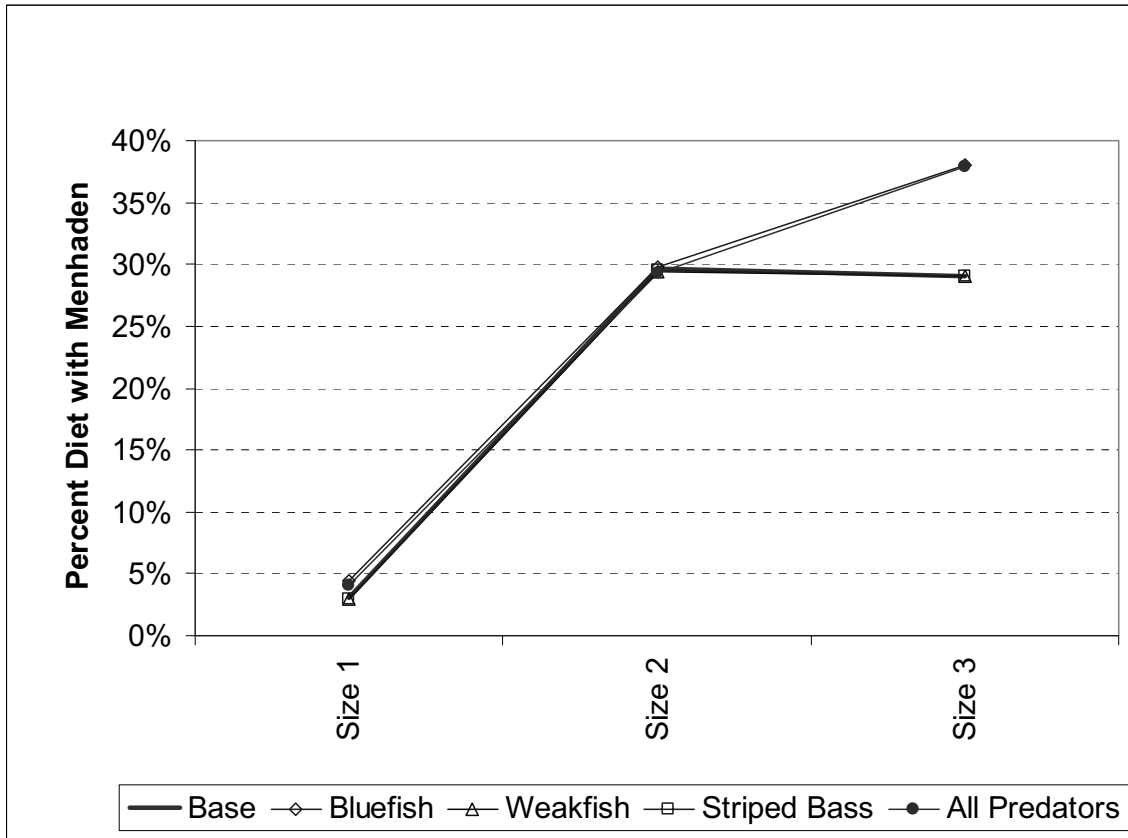


Figure D1.61. Consumption of menhaden by striped bass (equal preferences).

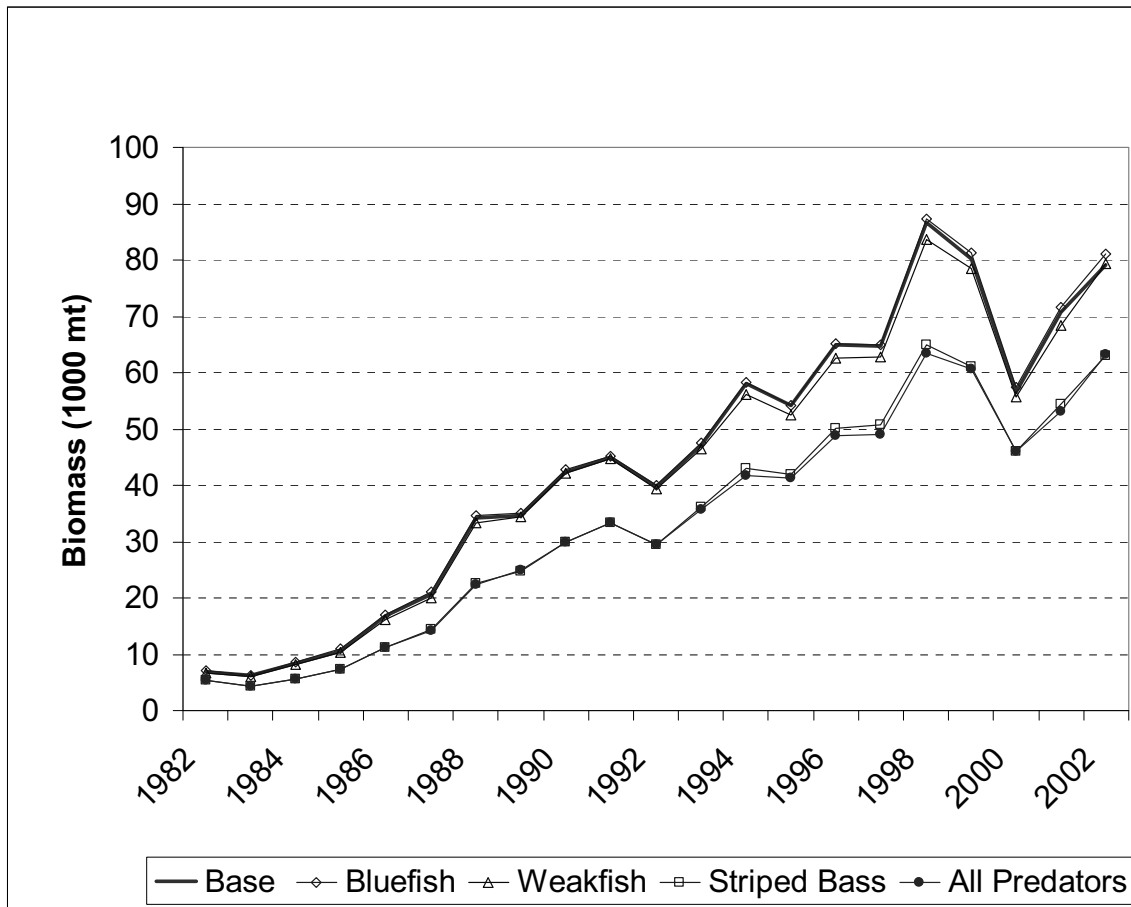


Figure D1.62. Consumption of menhaden by striped bass (fish and invertebrates equal preferences).

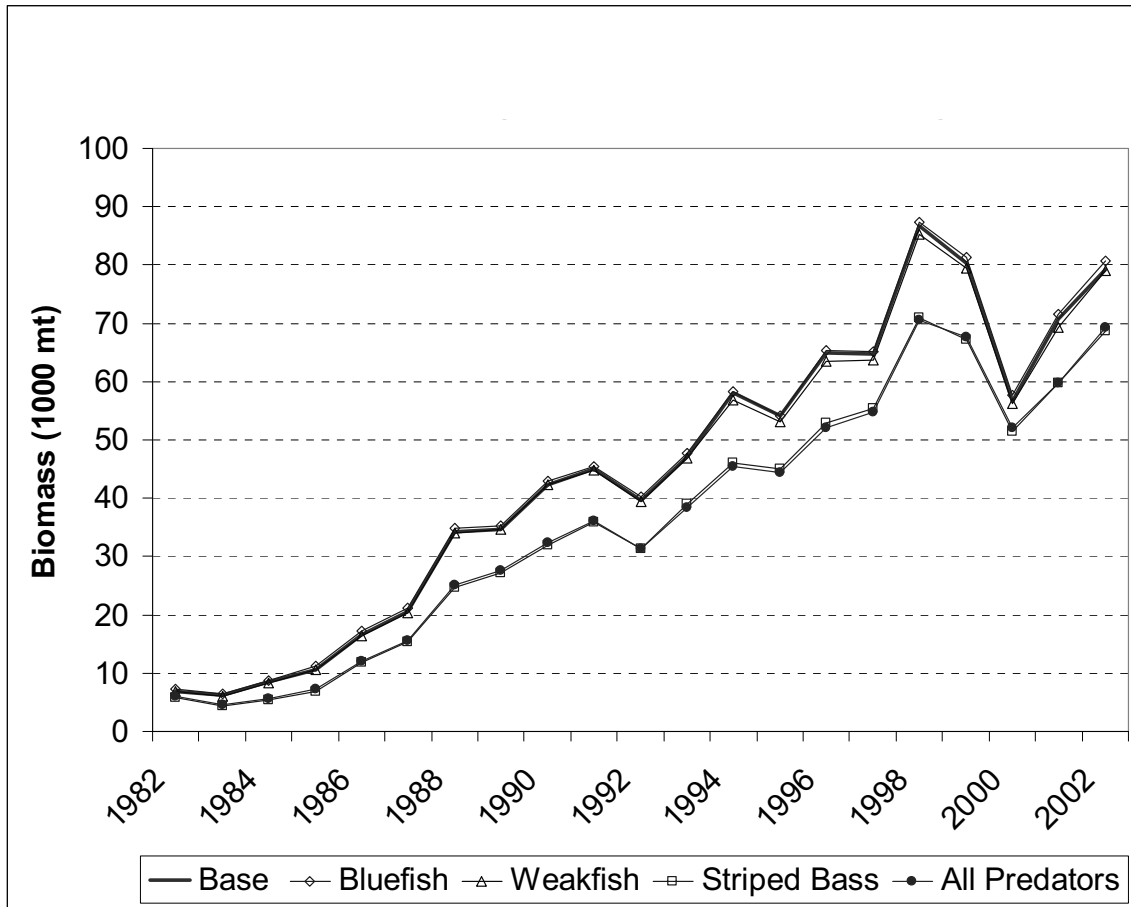


Figure D1.63. Consumption of menhaden by weakfish (equal preferences).

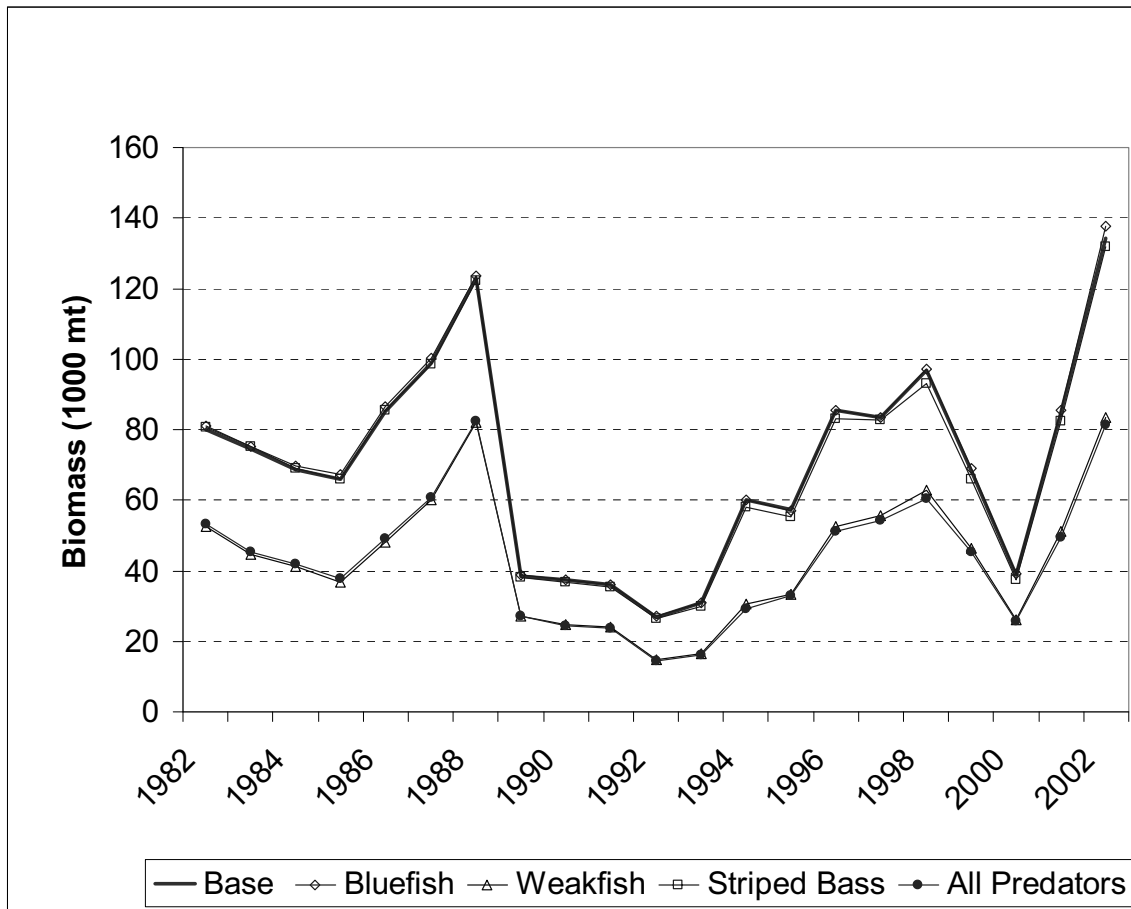




Figure D1.64. Consumption of menhaden by weakfish (fish and invertebrates equal preferences).

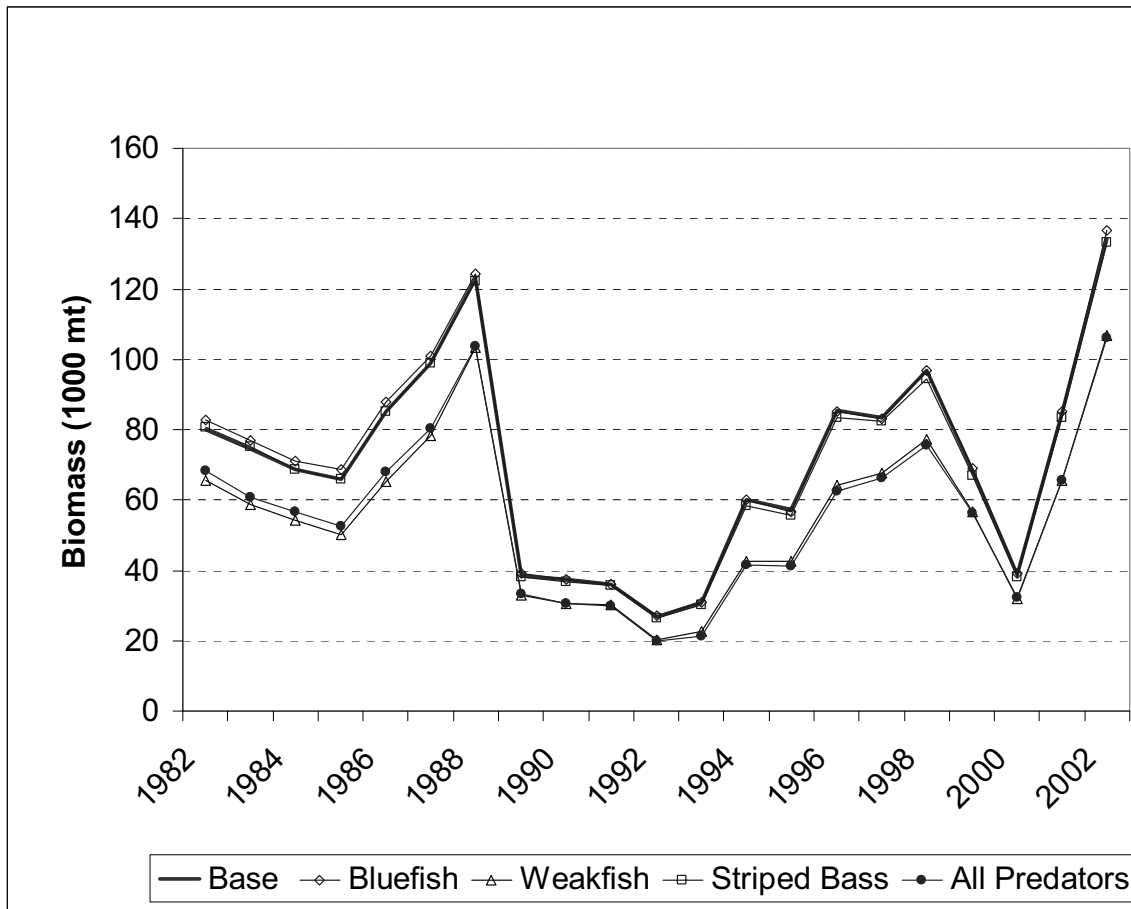


Figure D1.65. Consumption of menhaden by bluefish (equal preferences).

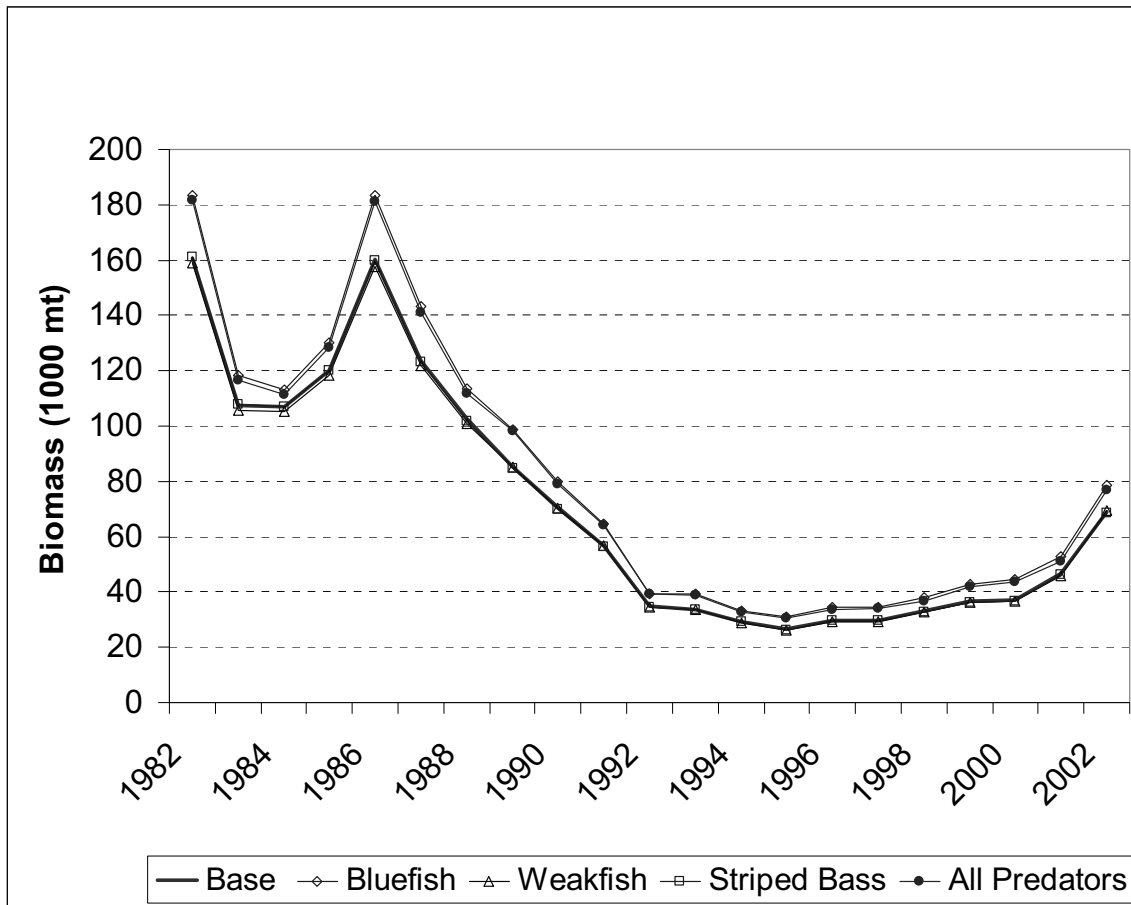


Figure D1.66. Consumption of menhaden by bluefish (fish and invertebrates equal preferences).

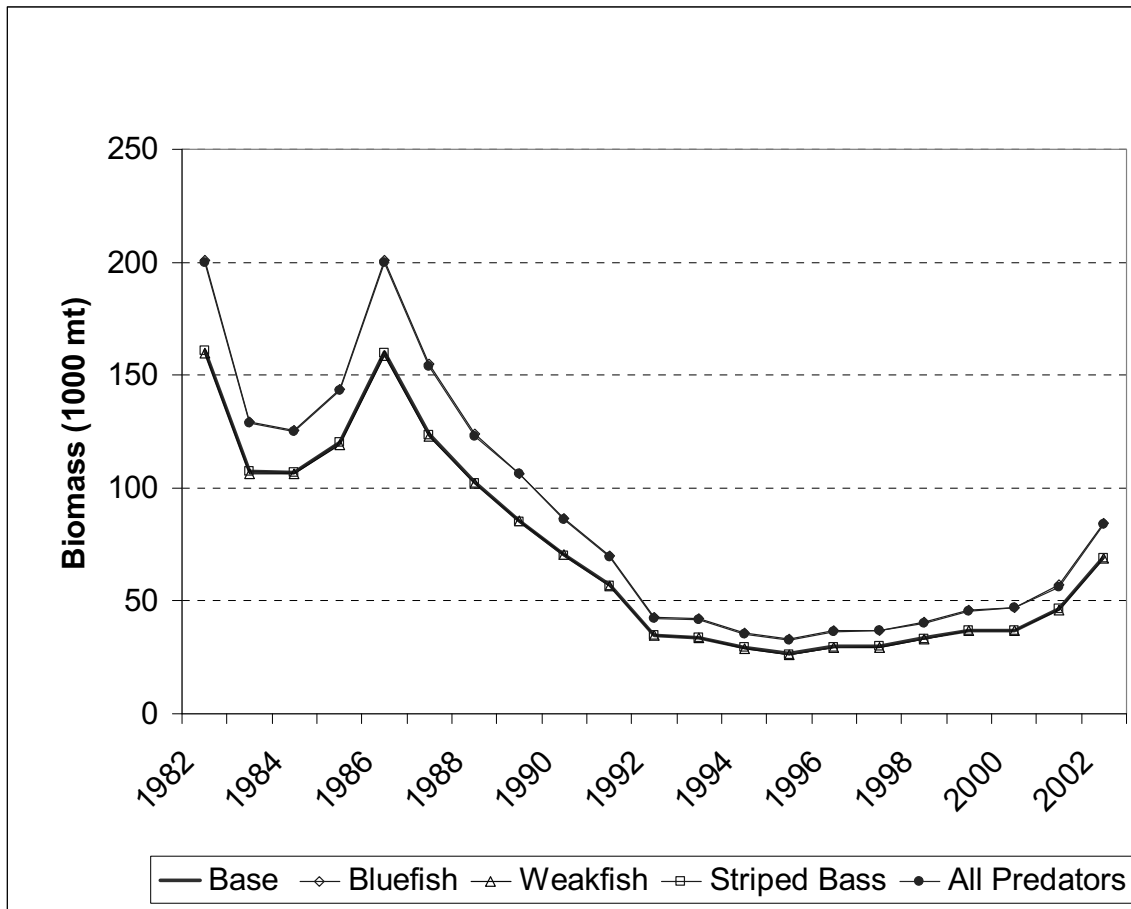


Figure D1.67. Total consumption (000 mt) of prey by striped bass for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

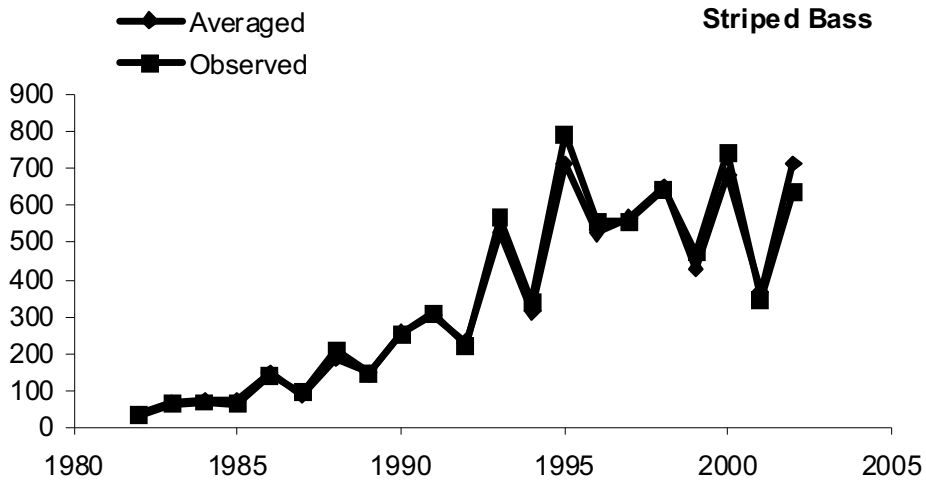


Figure D1.68. Total consumption (000 mt) of prey by weakfish for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

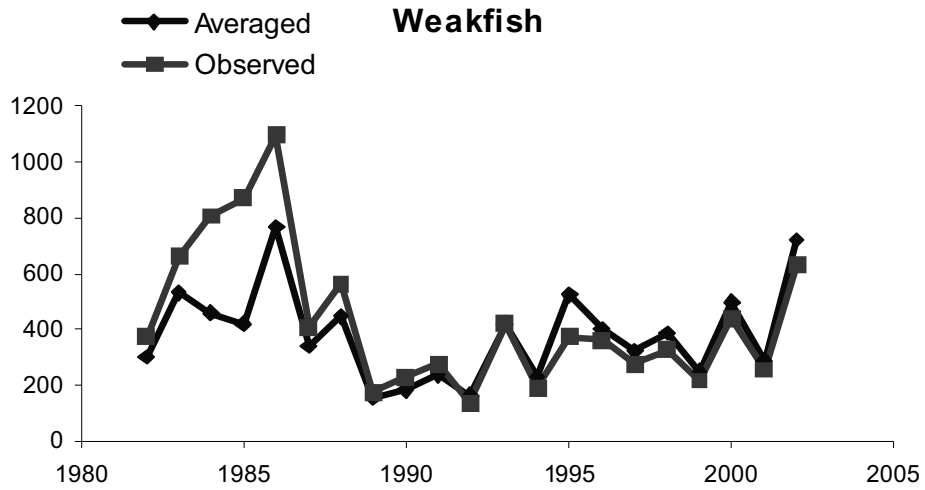


Figure D1.69. Total consumption (000 mt) of menhaden by striped bass for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

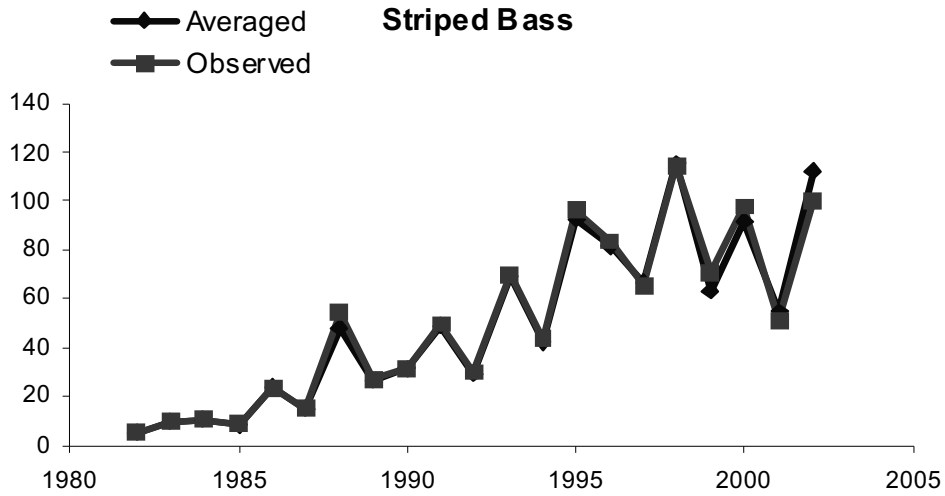


Figure D1.70. Total consumption (000 mt) of menhaden by weakfish for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

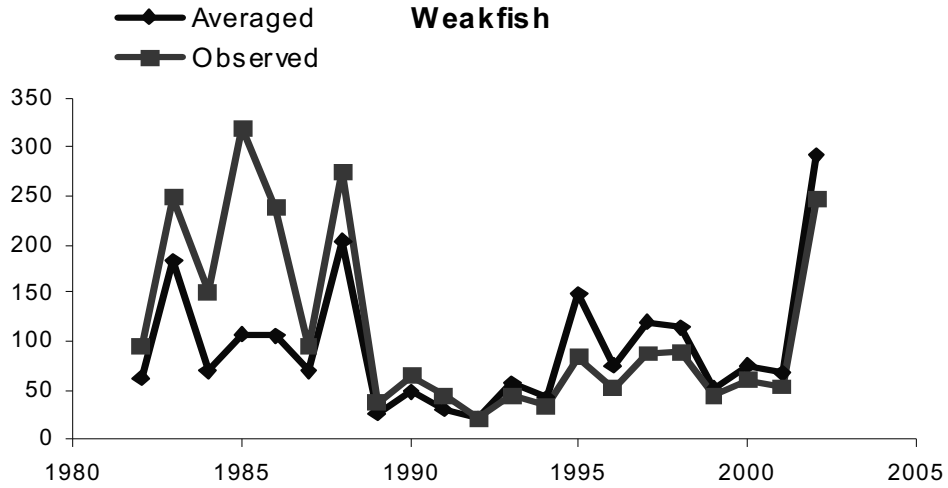


Figure D1.71. Predation mortality (M2) of menhaden by striped bass calculated based on variable (observed) weight-at-age and based on constant weight-at-age.

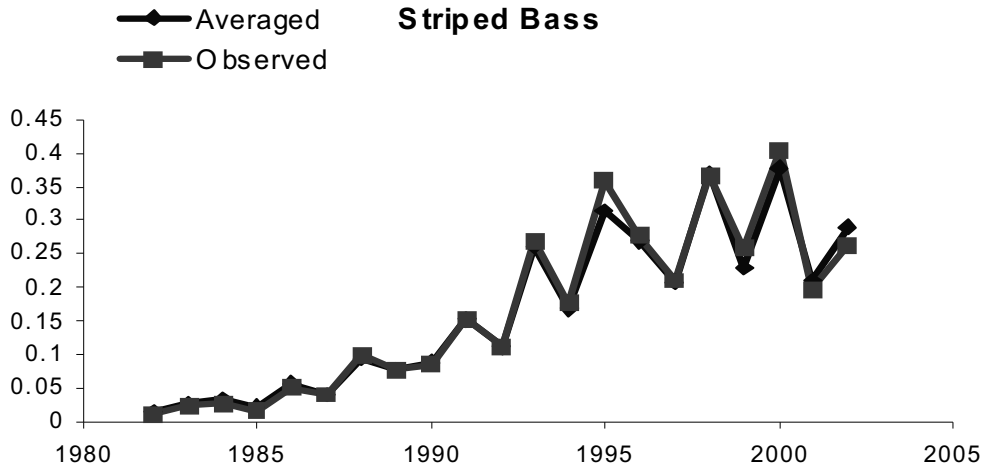




Figure D1.72. Predation mortality (M2) of menhaden by weakfish calculated based on variable (observed) weight-at-age and based on constant weight-at-age

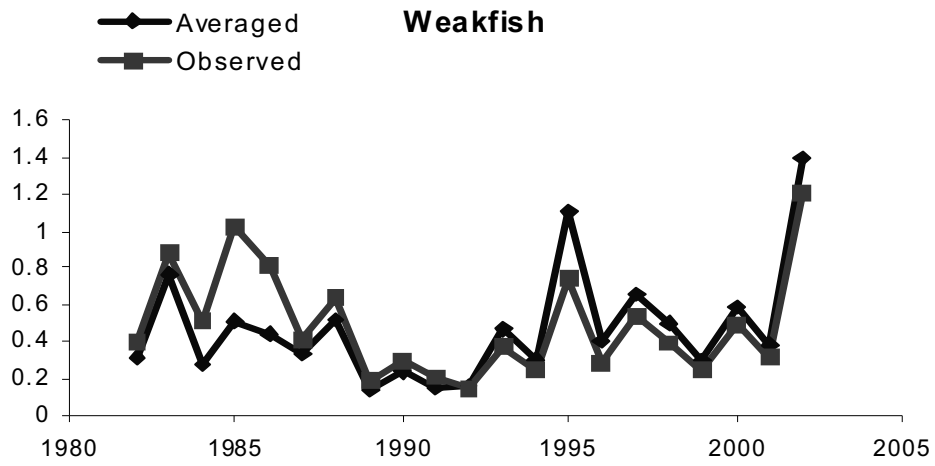
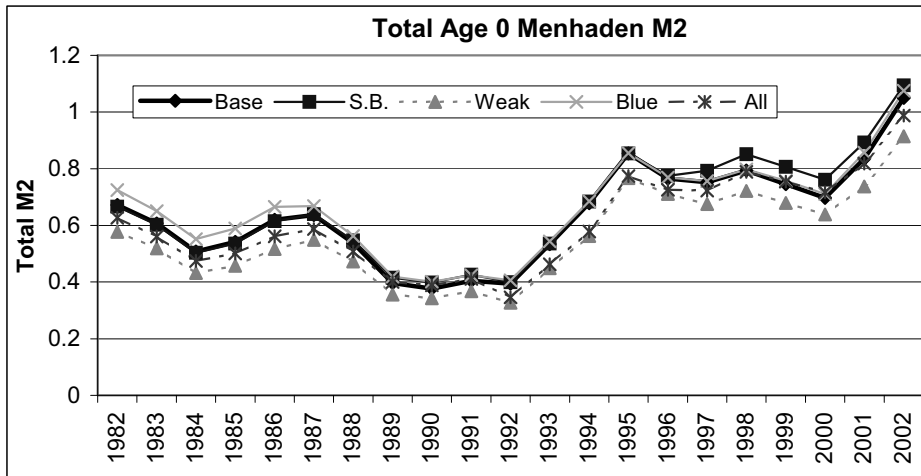
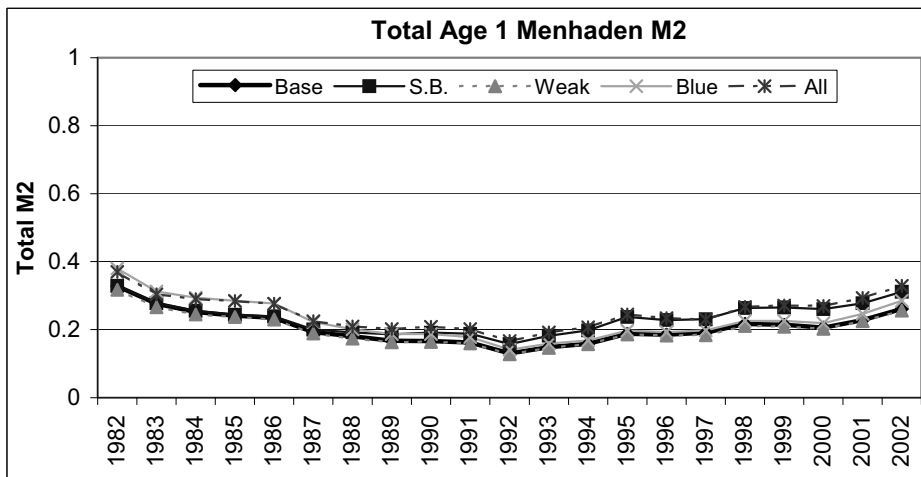


Figure D1.73a - c. Annual total menhaden predation mortality for the different predator runs. See Table D1.14 for explanation of model runs.

a.)



b.)



c.)

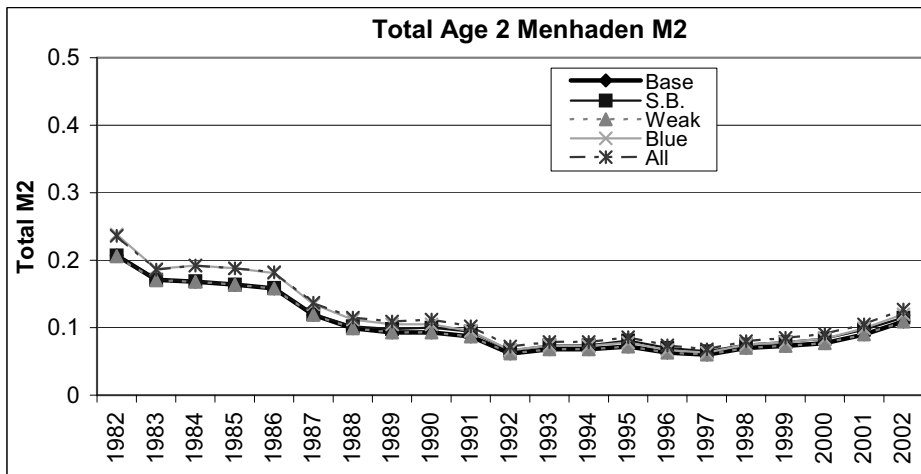
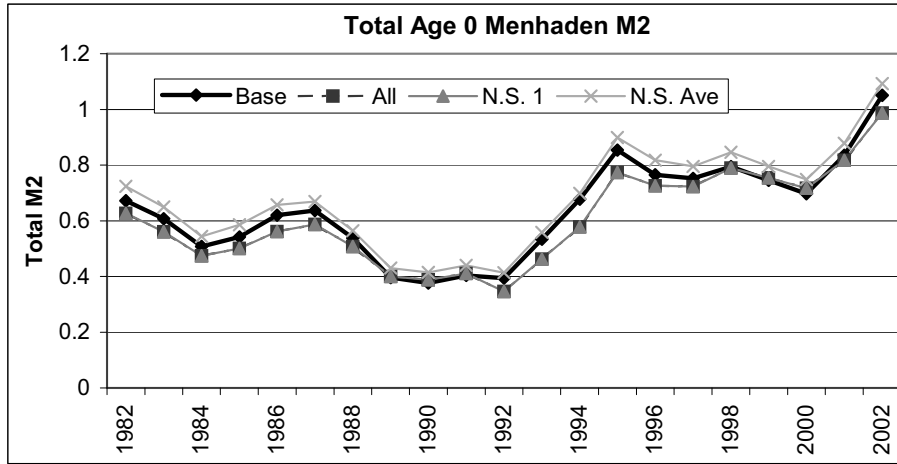
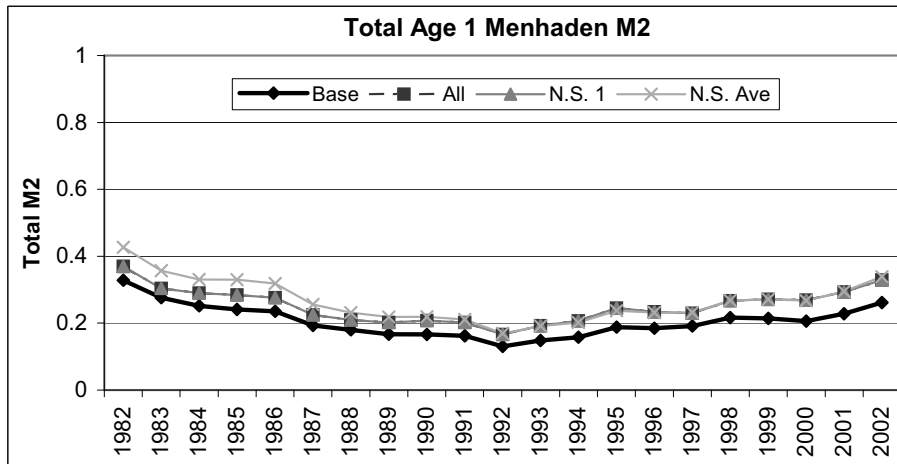


Figure D1.74a - c. Annual total Menhaden predation mortality for the different seasonal runs. See Table D1.14 for explanation of model runs.

a.)



b.)



c.)

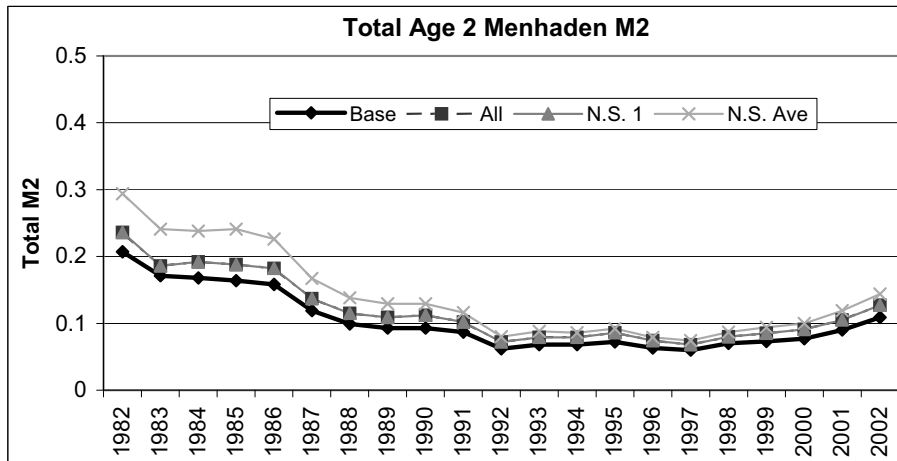
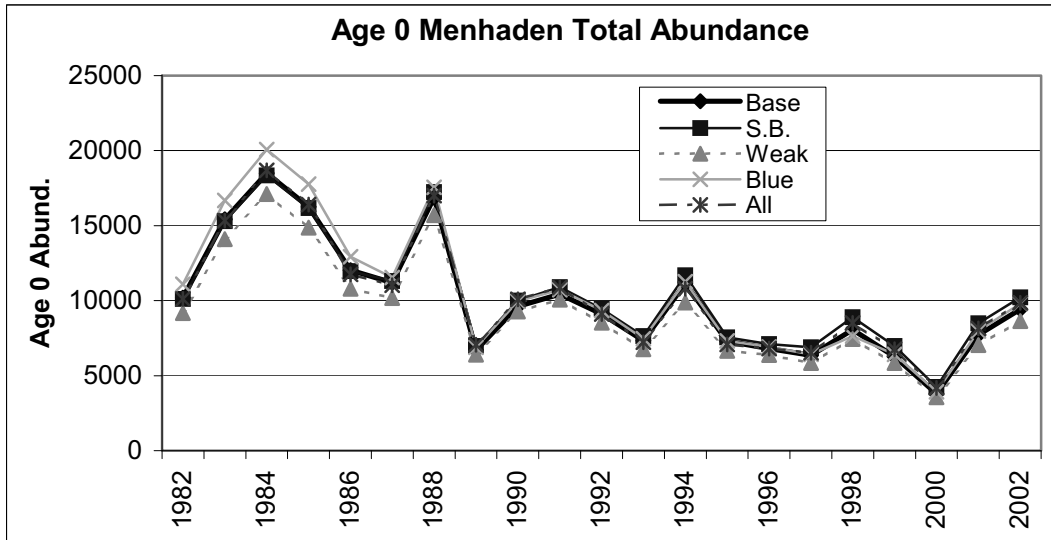


Figure D1.75a - b. Total menhaden abundance (millions of fish) by age for the different Predator runs.

a.)



b.)

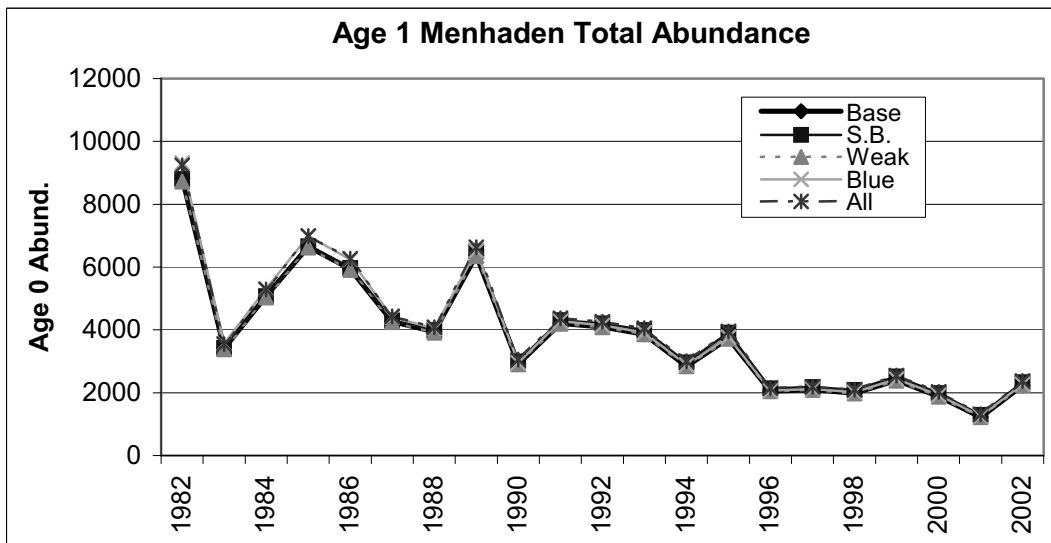
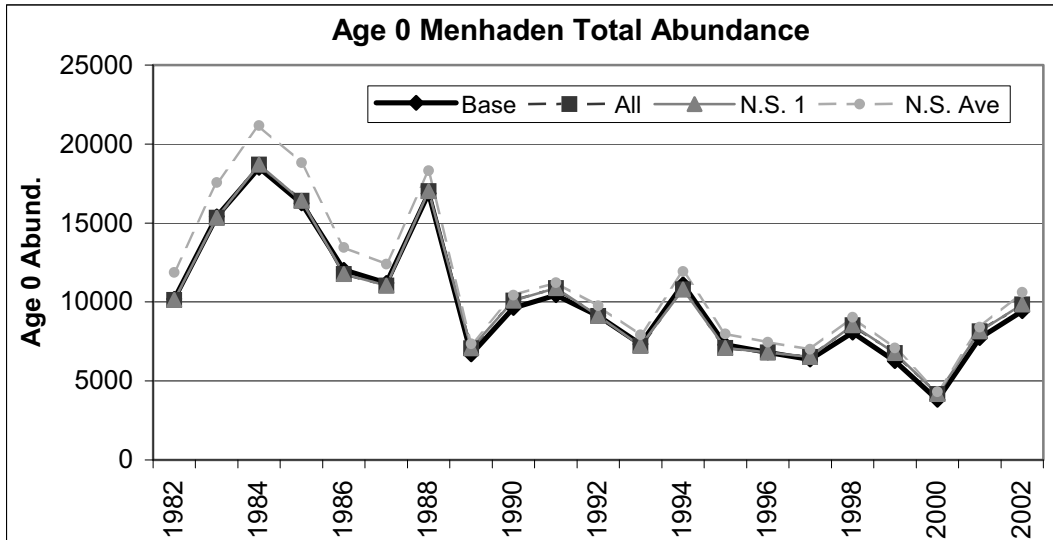


Figure D1.76. Total menhaden abundance (millions of fish) by age for the different Seasonal runs

a.)



b.)

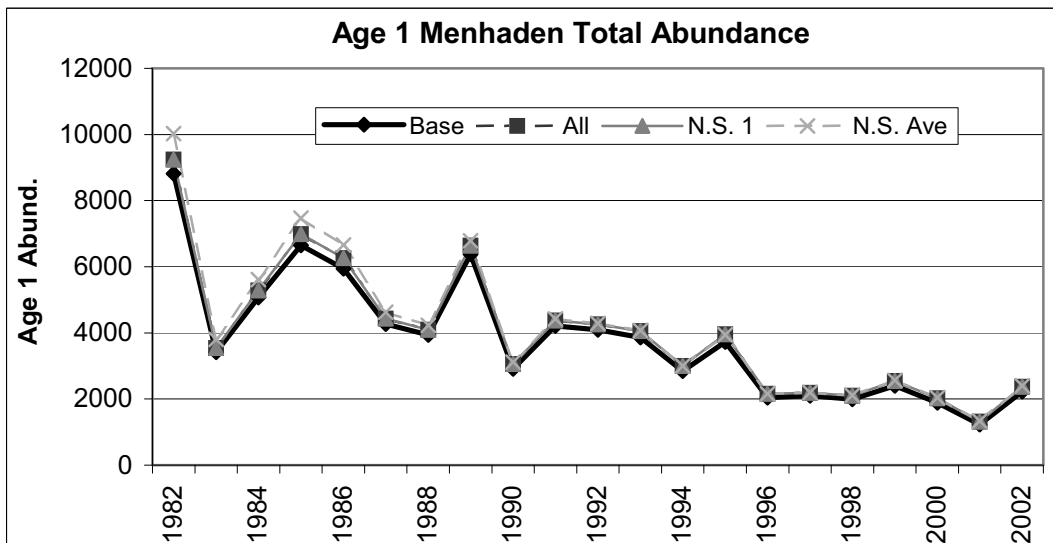
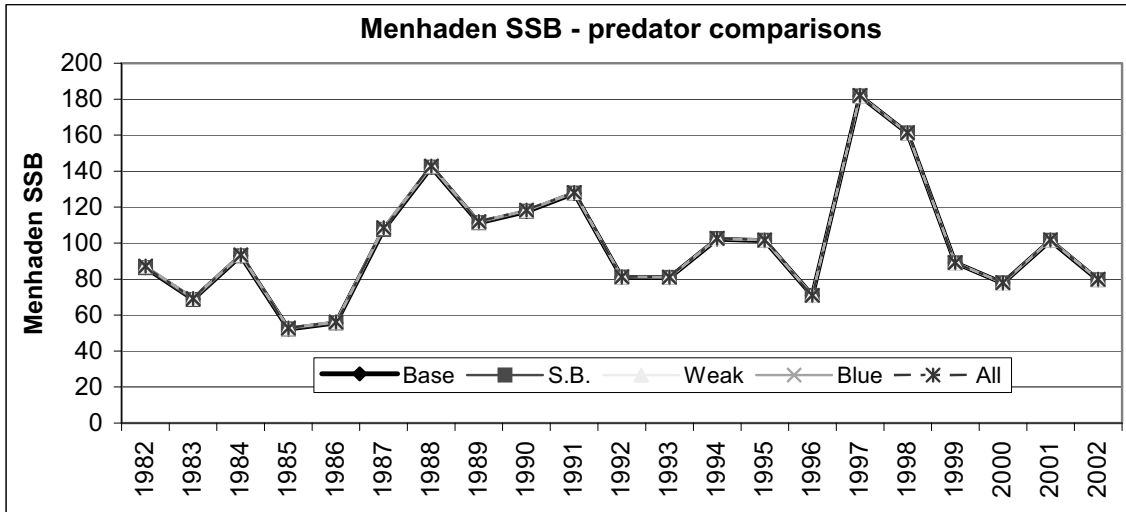


Figure D1.77. Annual menhaden spawning stock biomass (SSB in 000 mt) a.) Predator runs b.) Seasonal runs.

a.)



b.)

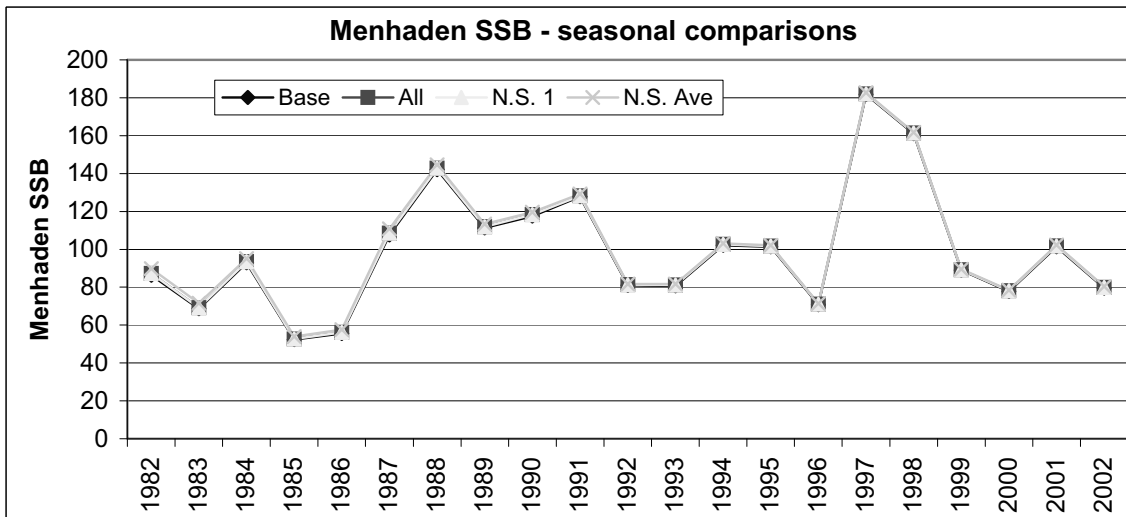
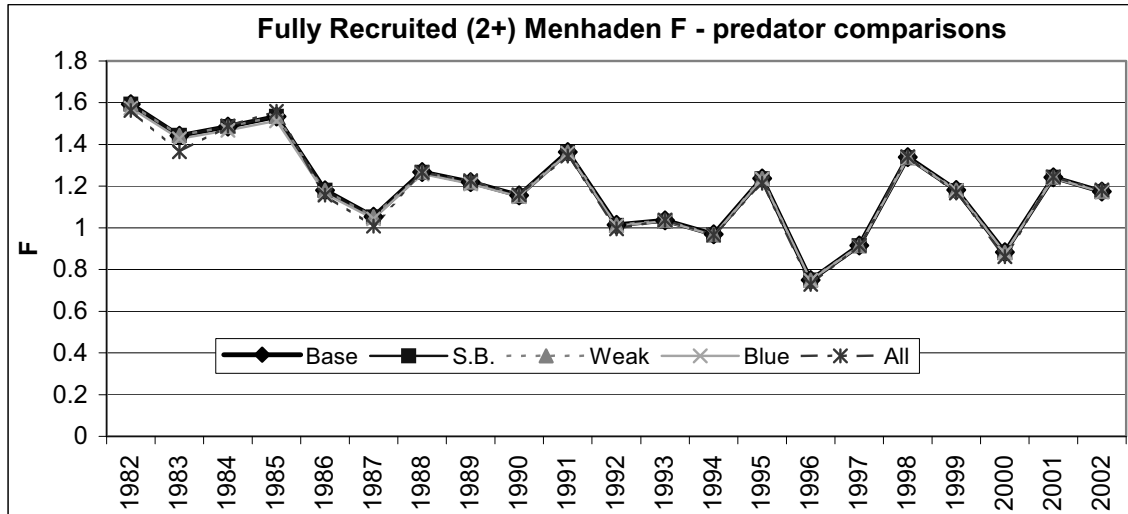


Figure D1.78a - b. Annual menhaden fully recruited (2+) fishing mortality (F) a.) Predator runs b.) Seasonal.

a.)



b.)

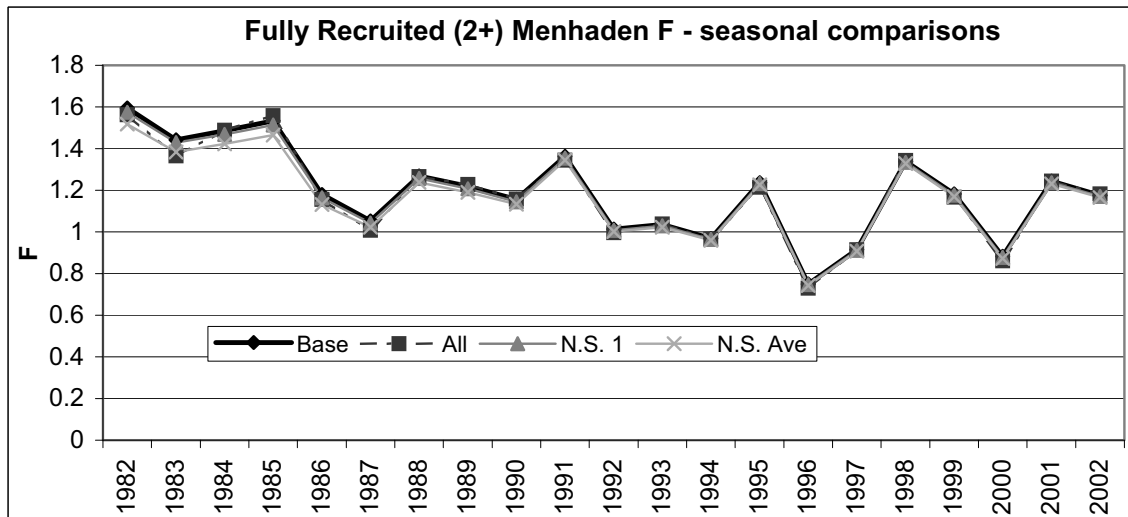


Figure D1.79a - f. The relative change in the proportion of a particular prey item in the diet of each predator by age ((sensitivity run prop./base run prop.) - 1)). Figures a – c compare the Weak run to the Base and figures d - f compare the All predator run to the Base.

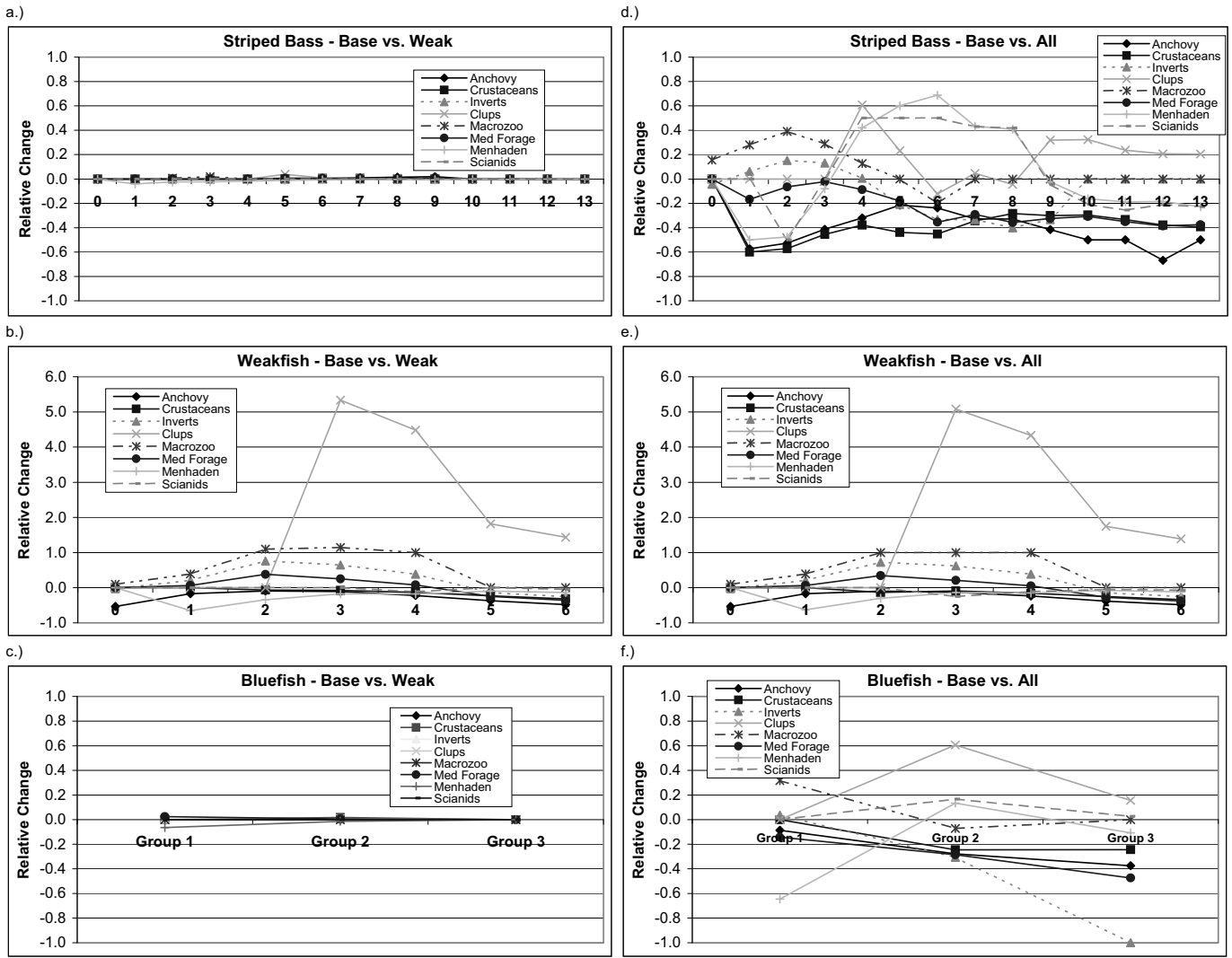




Figure D1.80a - c. Average proportion of prey, for a few key species, in diet by predator and age. Figures compare Predator runs for the Base, the model run where that specific predator spatial overlap was = to 1, and where all predators overlap was equal to 1 - a.) striped bass b.) weakfish c.) bluefish.

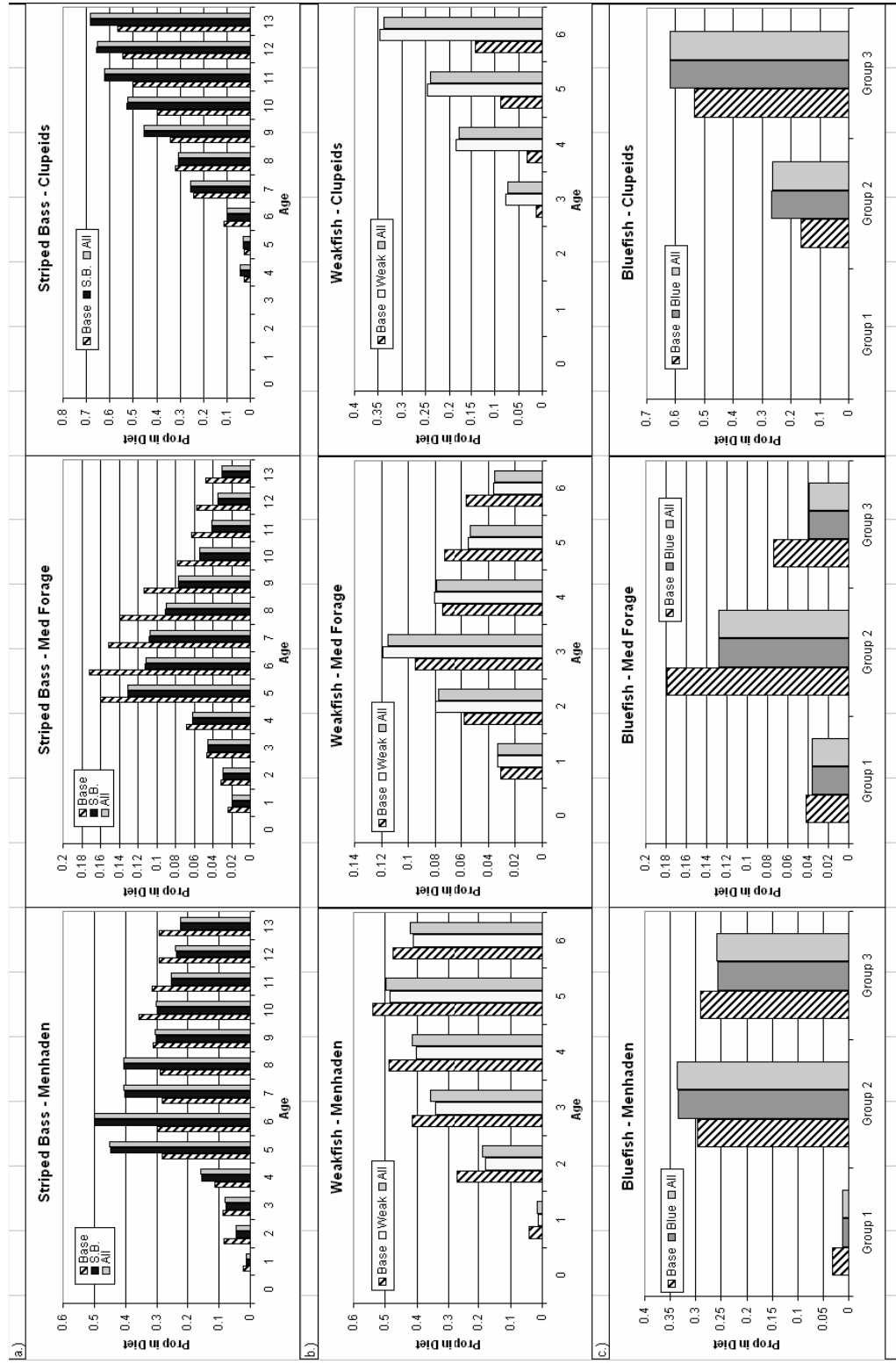


Figure D1.81a - c. Total consumption (biomass, 1000 mt) by year and by each predator for a few key prey species for each Predator run - a.) striped bass b.) weakfish c.) bluefish.

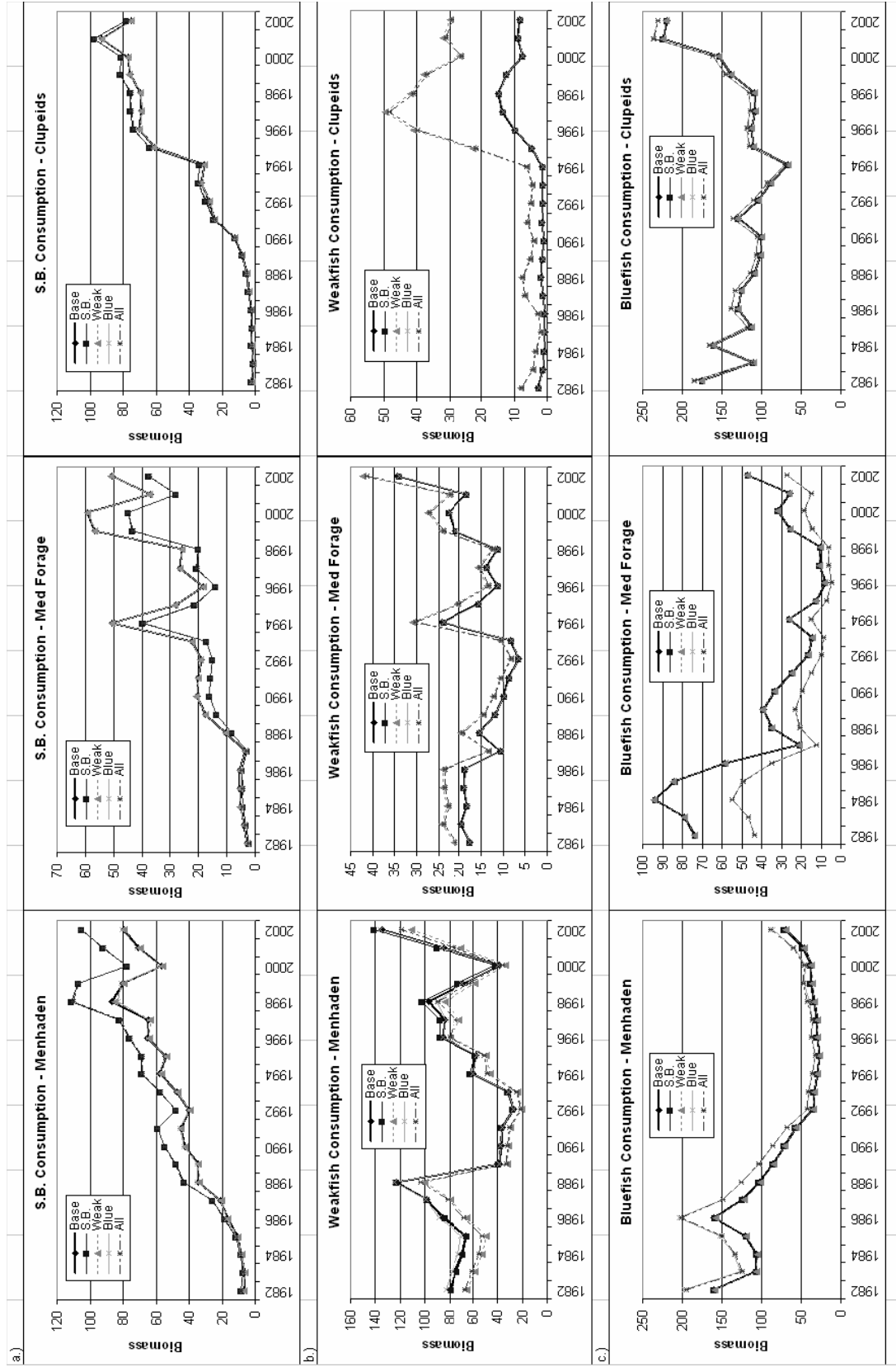
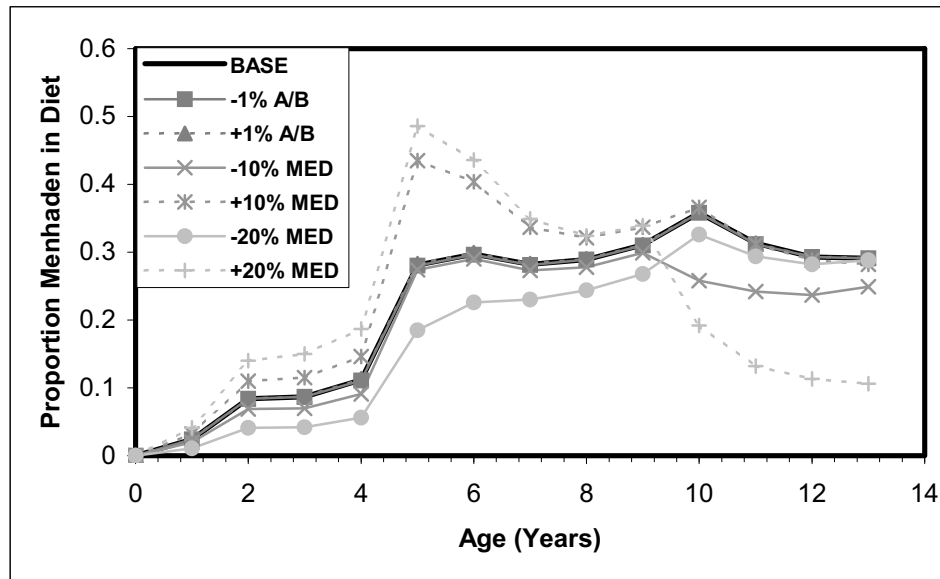


Figure D1.82. Average proportion of menhaden in striped bass (a), weakfish (b) and bluefish (c) diets by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters  $\alpha$  and  $\beta$  were changed by  $\pm 1\%$ , and four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

a)



b)

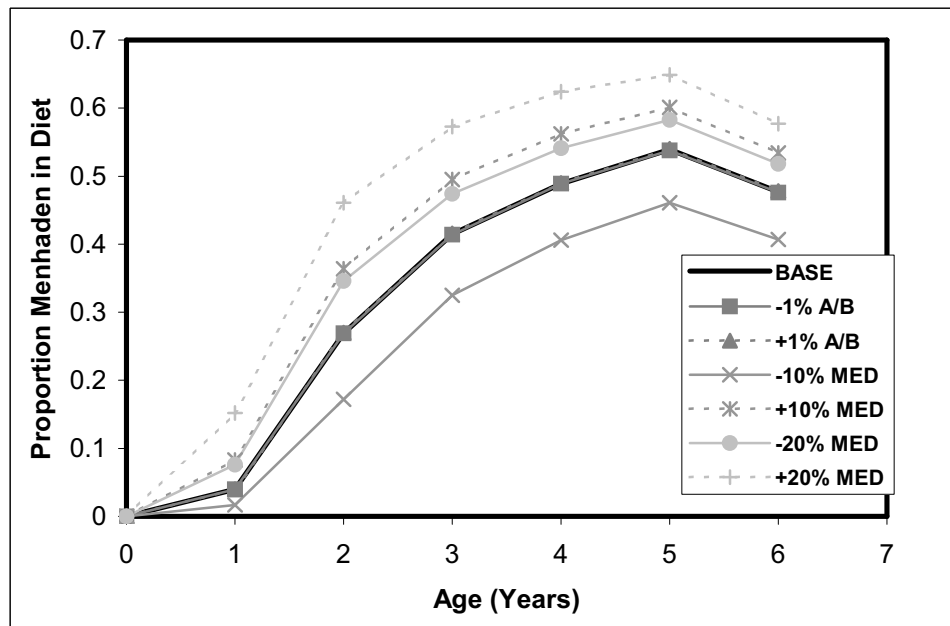


Figure D1.82 (Cont'd). Average proportion of menhaden in striped bass (a), weakfish (b) and bluefish (c) diets by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters  $\alpha$  and  $\beta$  were changed by  $\pm 1\%$ , and four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

c)

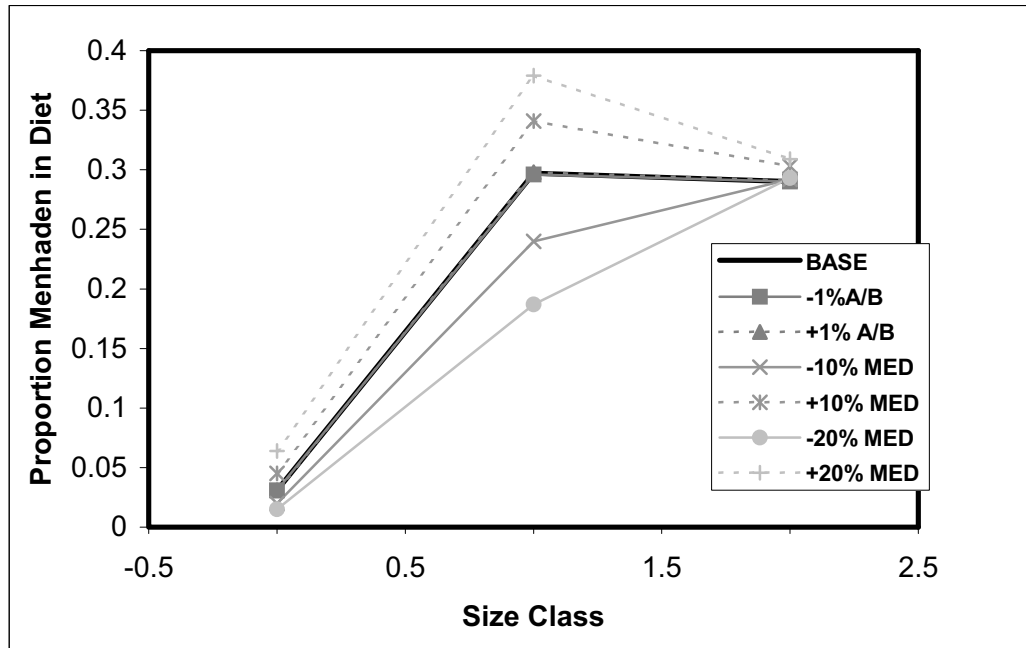
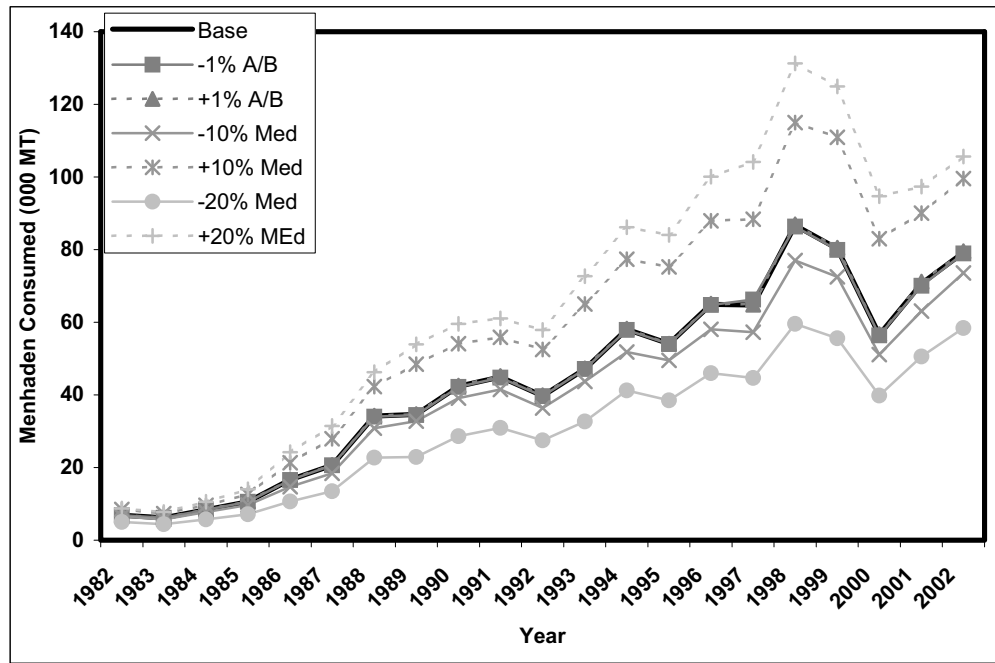


Figure D1.83. Total menhaden consumed in thousands of metric tons by striped bass (a), weakfish (b), and bluefish (c) by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters  $\alpha$  and  $\beta$  were changed by  $\pm 1\%$ , and four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

a)



b)

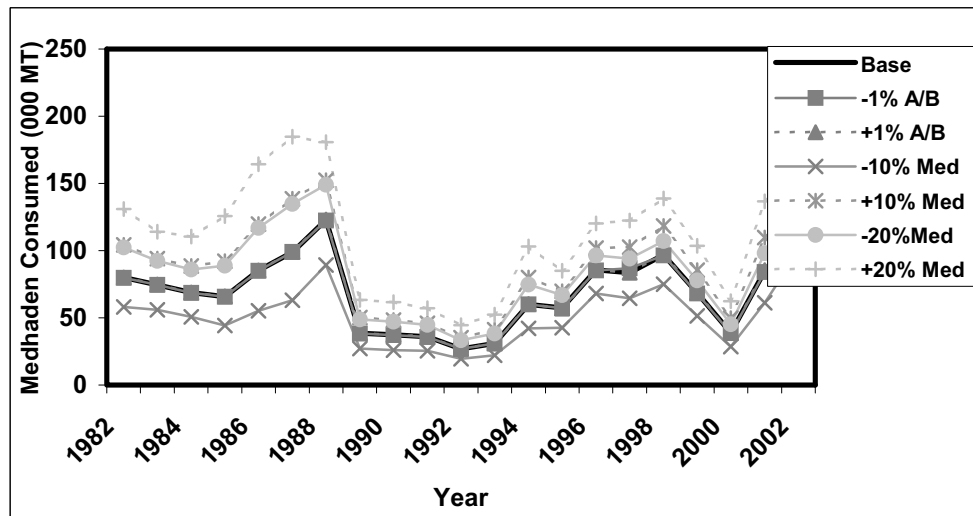


Figure D1.83 (Cont'd). Total menhaden consumed in thousands of metric tons by striped bass (a), weakfish (b), and bluefish (c) by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters  $\alpha$  and  $\beta$  were changed by  $\pm 1\%$ , and four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

c)

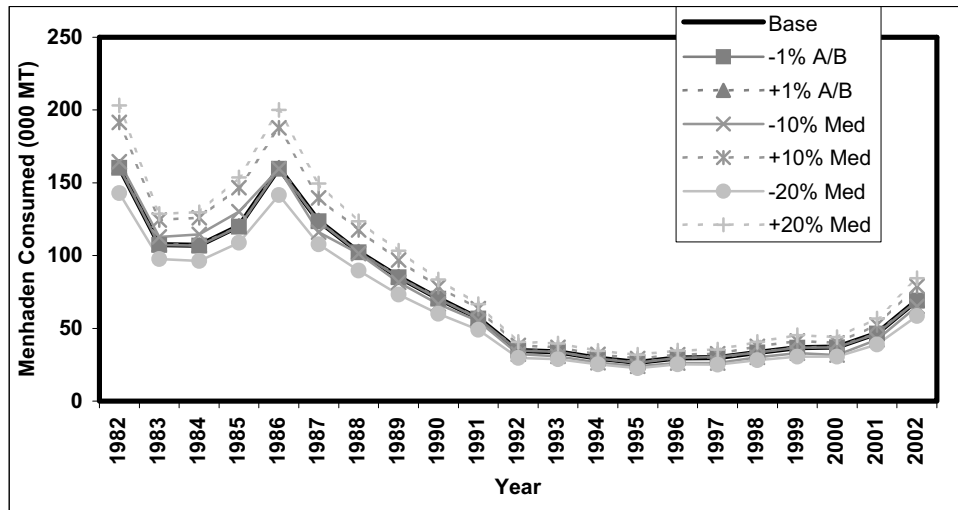
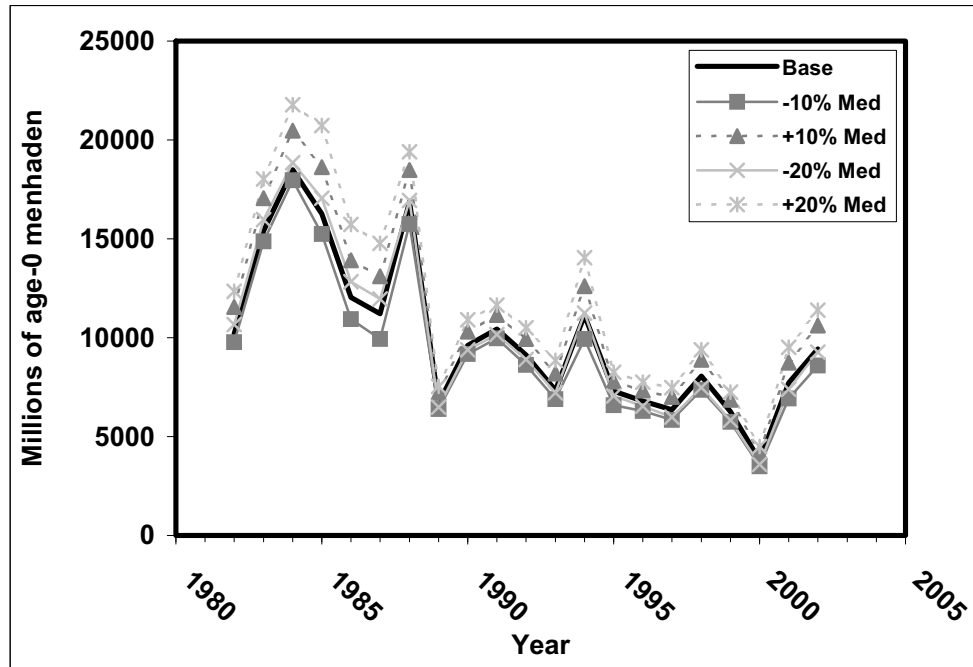


Figure D1.84 Age-0 (a), age-1 (b), and total abundance (c) of menhaden from the base run MSVPA and for four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

a)



b)

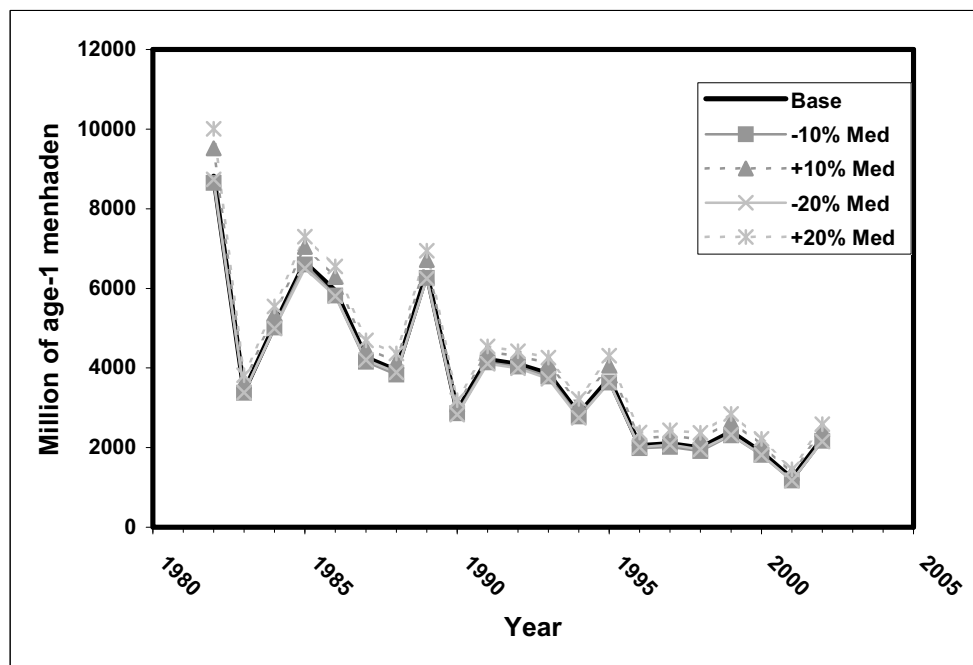


Figure D1.84 (Cont'd). Age-0 (a), age-1 (b), and total abundance (c) of menhaden from the base run MSVPA and for four scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

c)

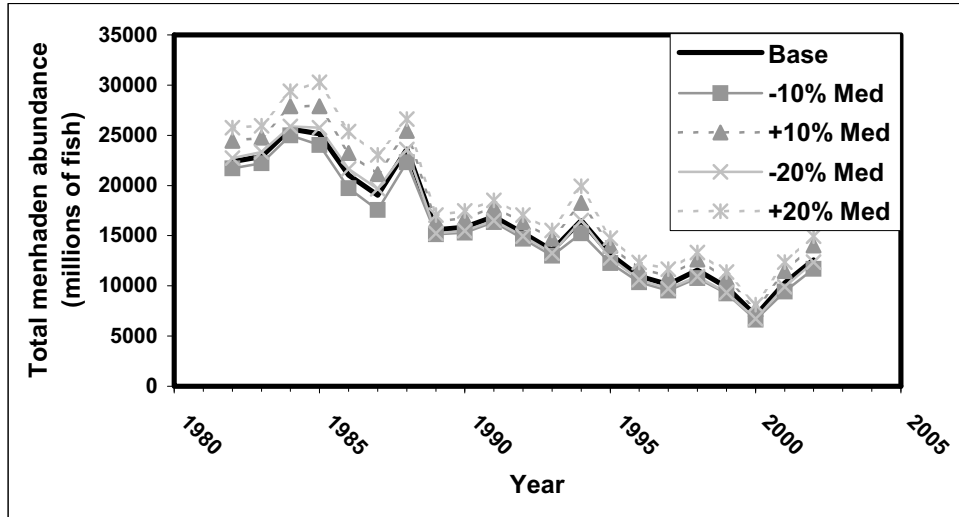
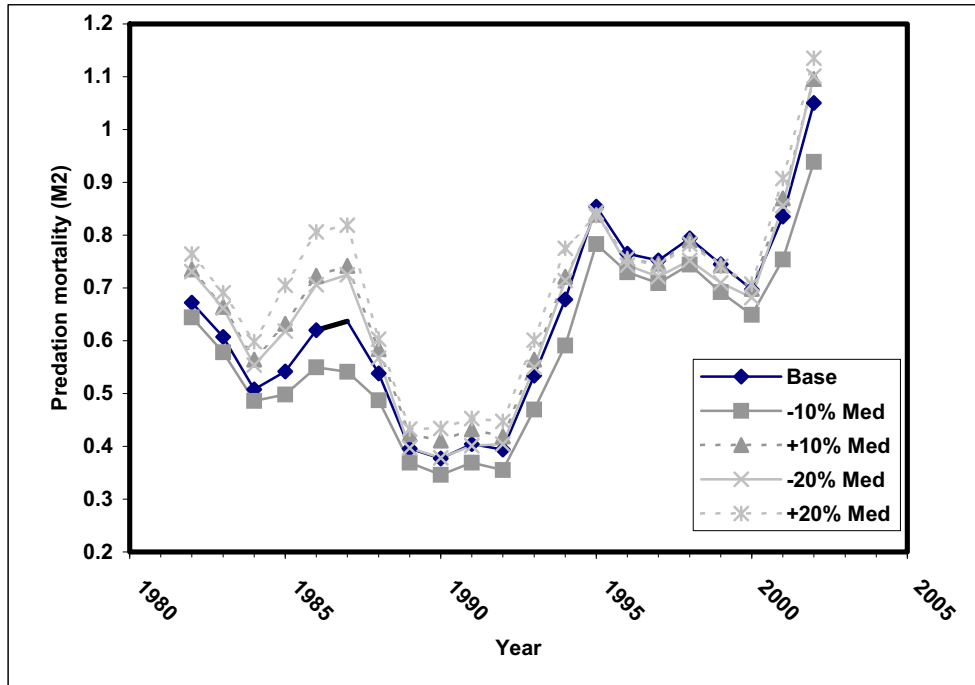




Figure D1.85. Predation mortality rates (M2) on age-0 (a) and age-1 (b) menhaden for each year. M2 values for the base run configuration are plotted against M2 values from scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

a)



b)

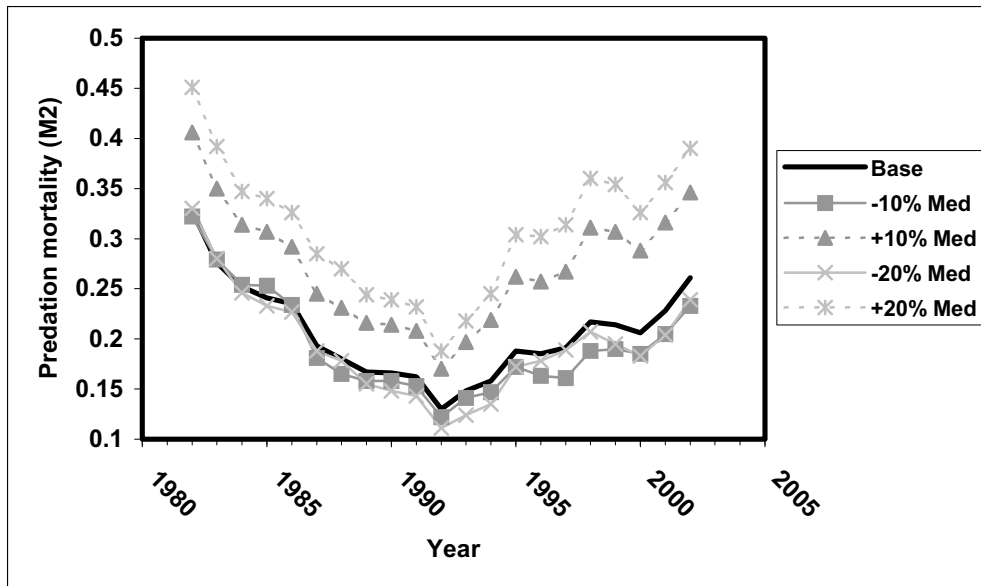
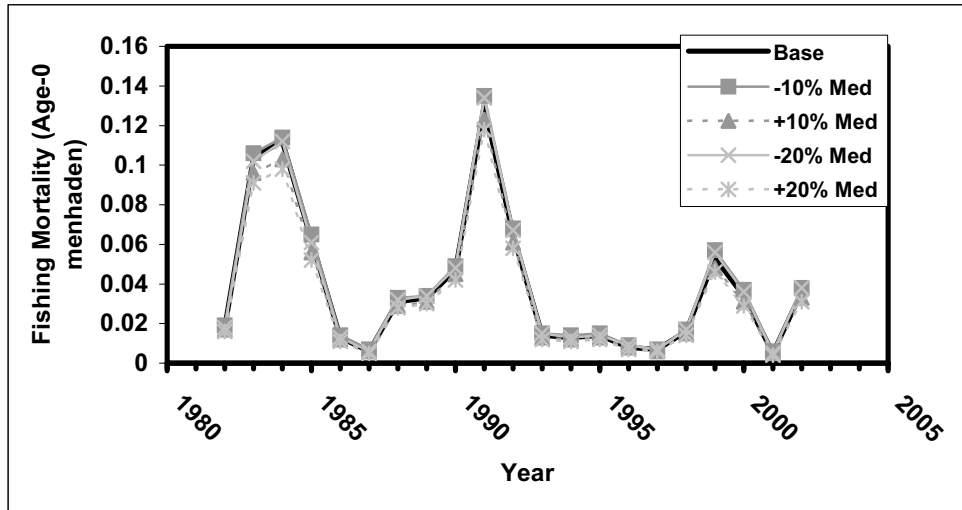


Figure D1.86. Fishing mortality estimates on age-0 (a), age-3 (b) and age-6+ (c) menhaden in the MSVPA-X. Results are shown for the base run configuration and for scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

a)



b)

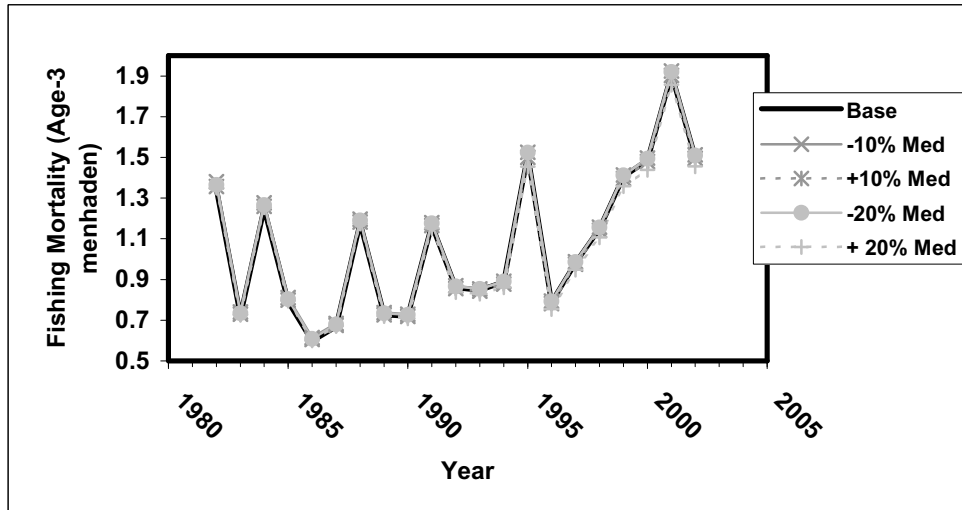


Figure D1.86 (Cont'd). Fishing mortality estimates on age-0 (a), age-3 (b) and age-6+ (c) menhaden in the MSVPA-X. Results are shown for the base run configuration and for scenarios in which the median size of prey selected for each predator was shifted by  $\pm 10\%$  and  $\pm 20\%$ .

c)

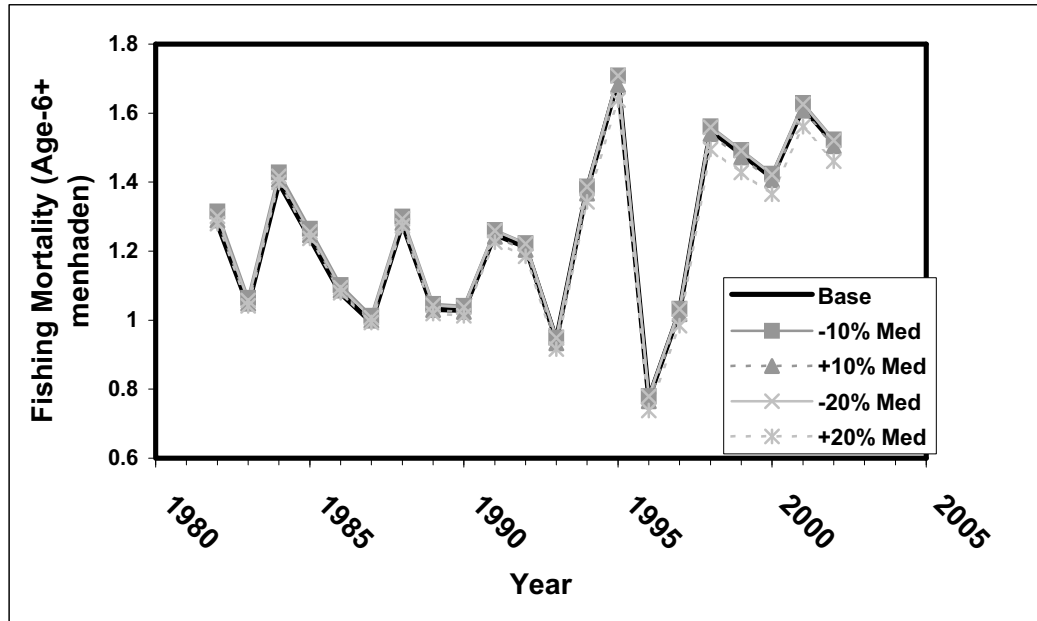
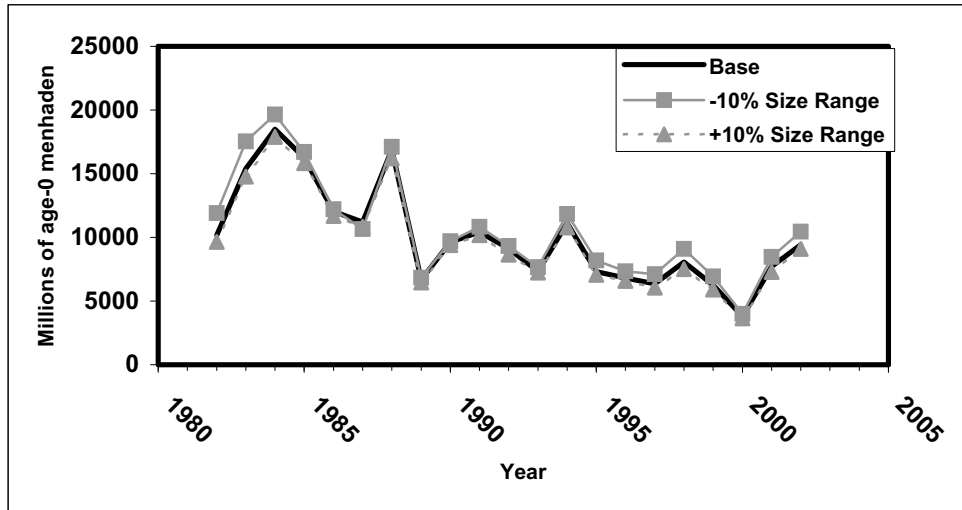


Figure D1.87. Age-0 (a), age-1 (b) and total abundance (c) of menhaden from the base run MSVPA for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

a)



b)

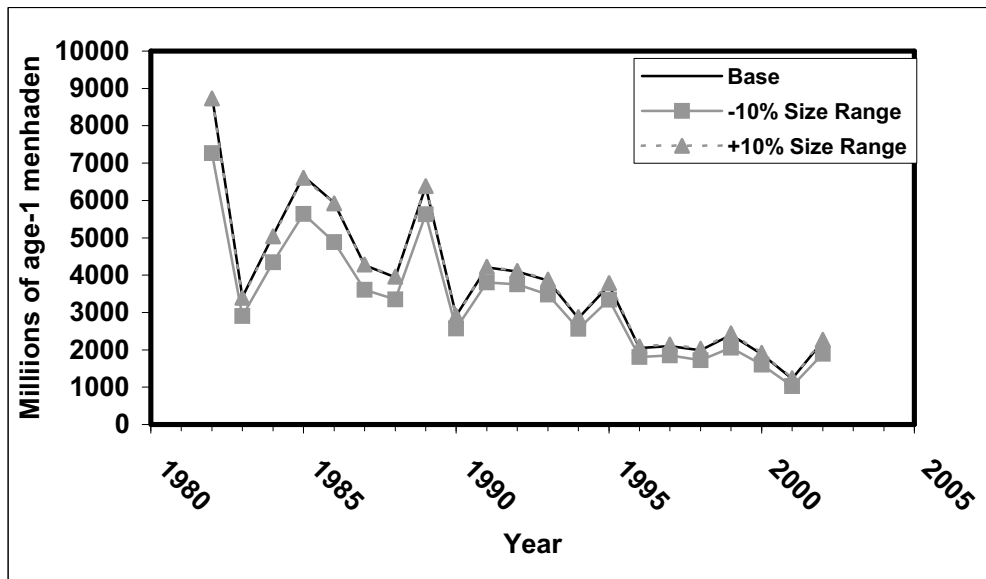


Figure D1.87 (cont'd). Age-0 (a), age-1 (b) and total abundance (c) of menhaden from the base run MSVPA for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

c)

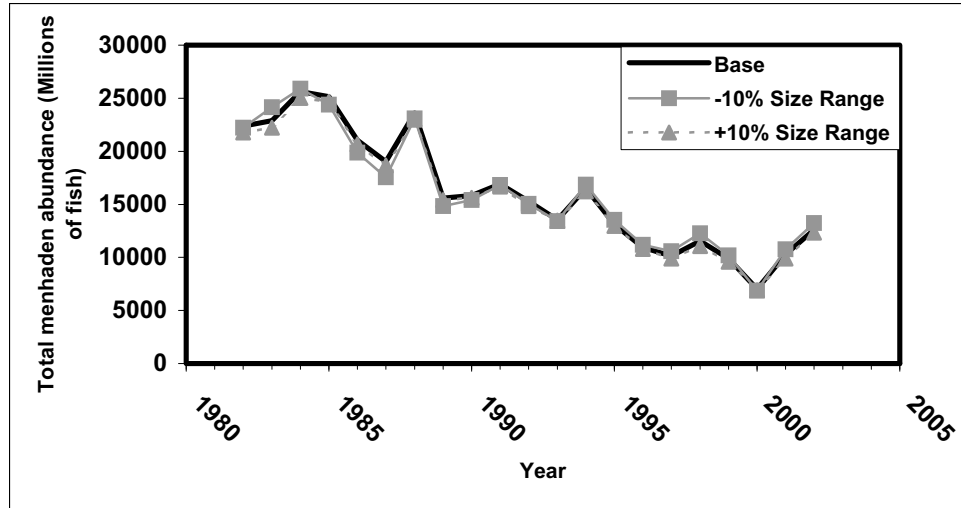


Figure D1.88. Spawning stock biomass (SSB in 000 mt) of menhaden from the base run MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

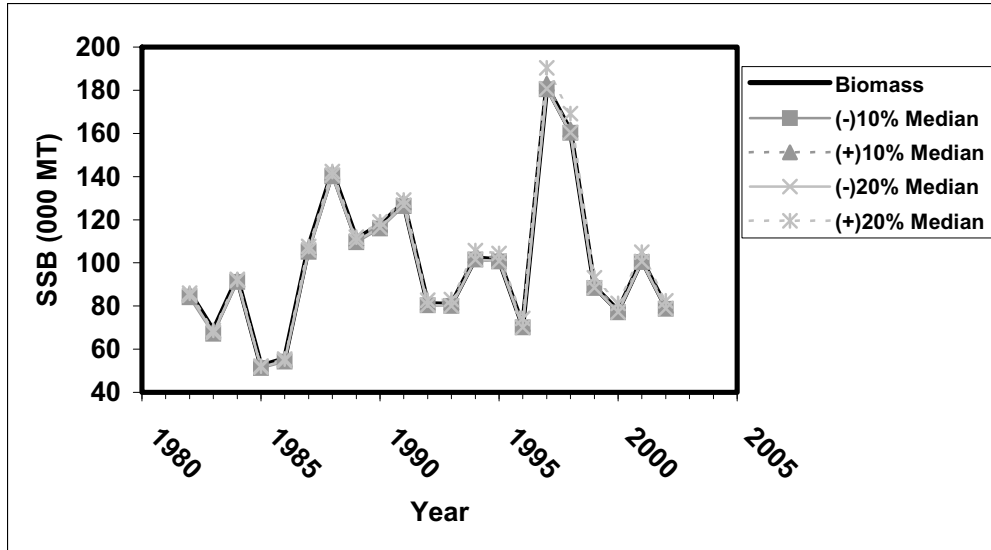
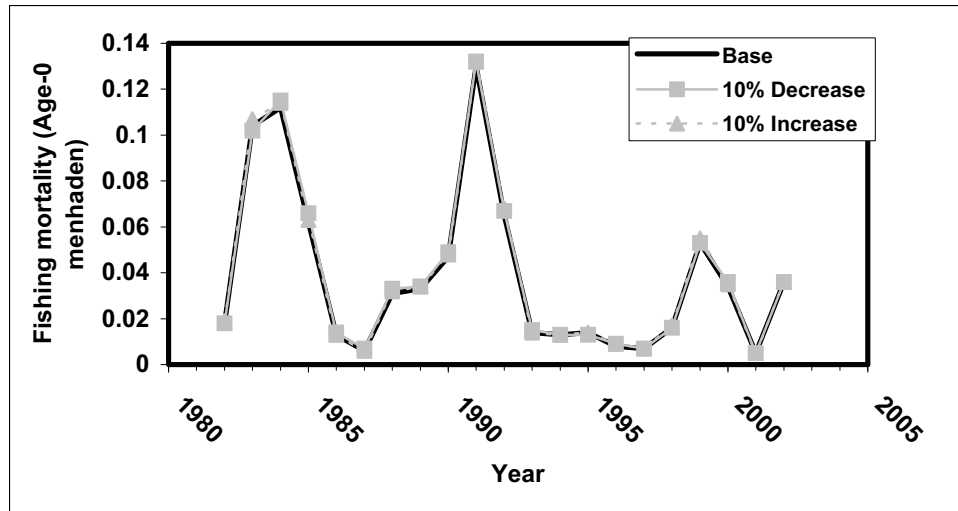


Figure D1.89. Fishing mortality (F) estimates for age-0 (a), age-3 (b), age-6+ (c) and average recruited F (age-2+) menhaden from the base run MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

a)



b)

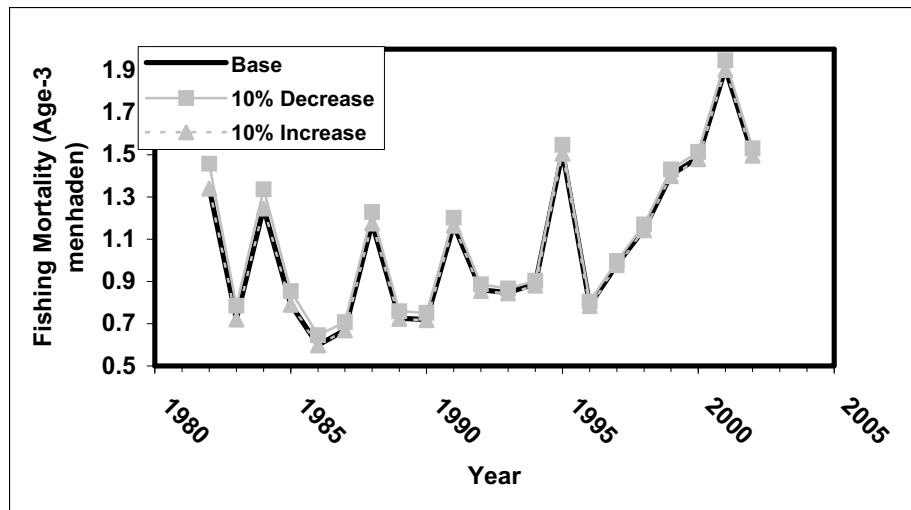
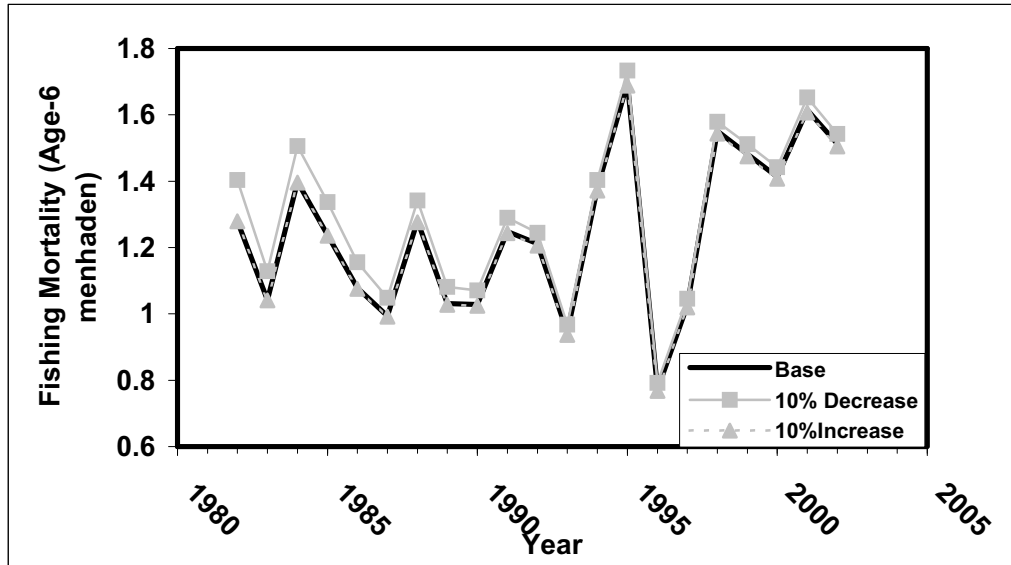


Figure D1.89 (cont'd). Fishing mortality (F) estimates for age-0 (a), age-3 (b), age-6+ (c) and average recruited F (age-2+) menhaden from the base MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

c)



d)

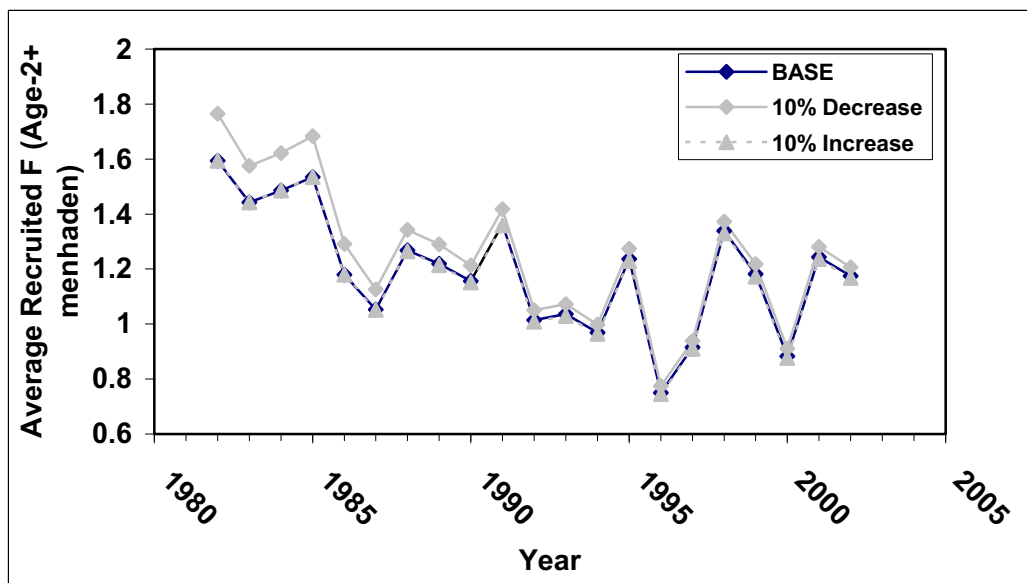
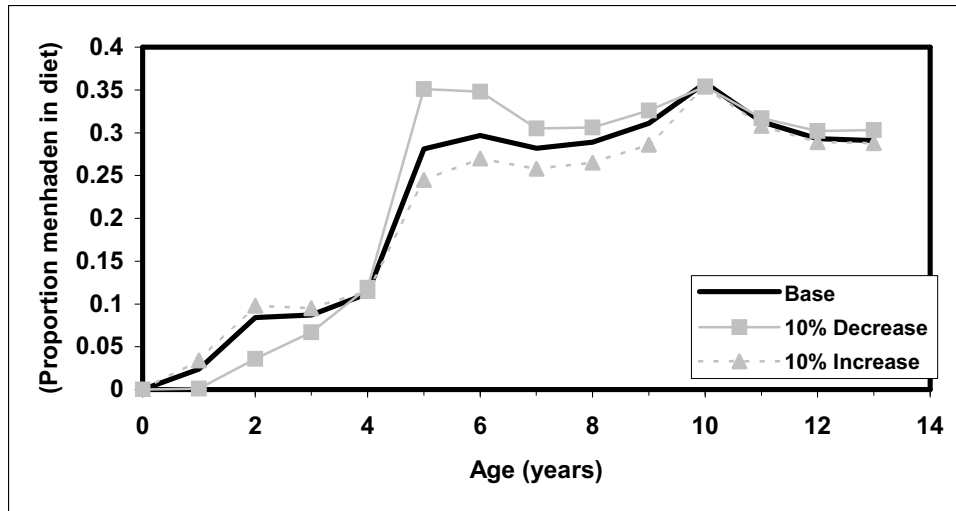




Figure D1.90. Proportion of menhaden in the diet of striped bass (a), weakfish (b), and bluefish (c) by age for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

a)



b)

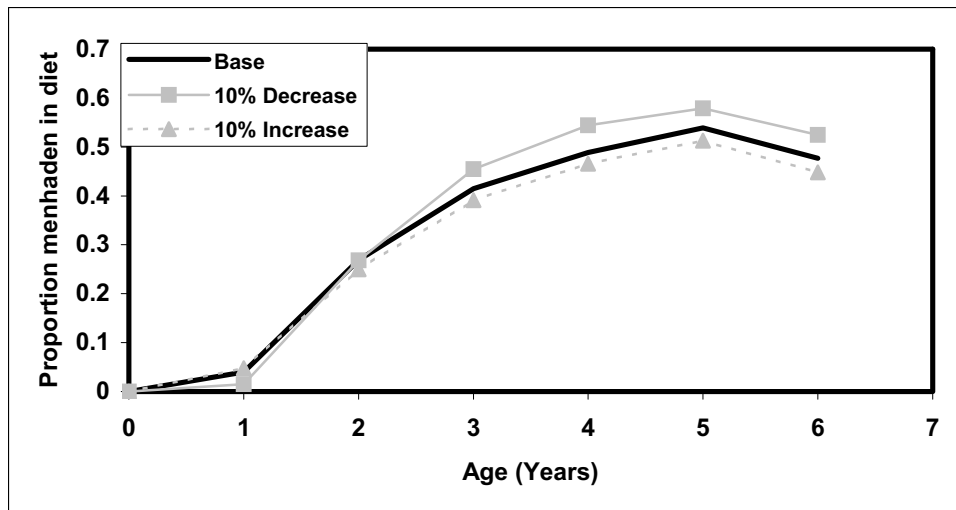


Figure D1.90 (cont'd). Proportion of menhaden in the diet of striped bass (a), weakfish (b), and bluefish (c) by age for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

c)

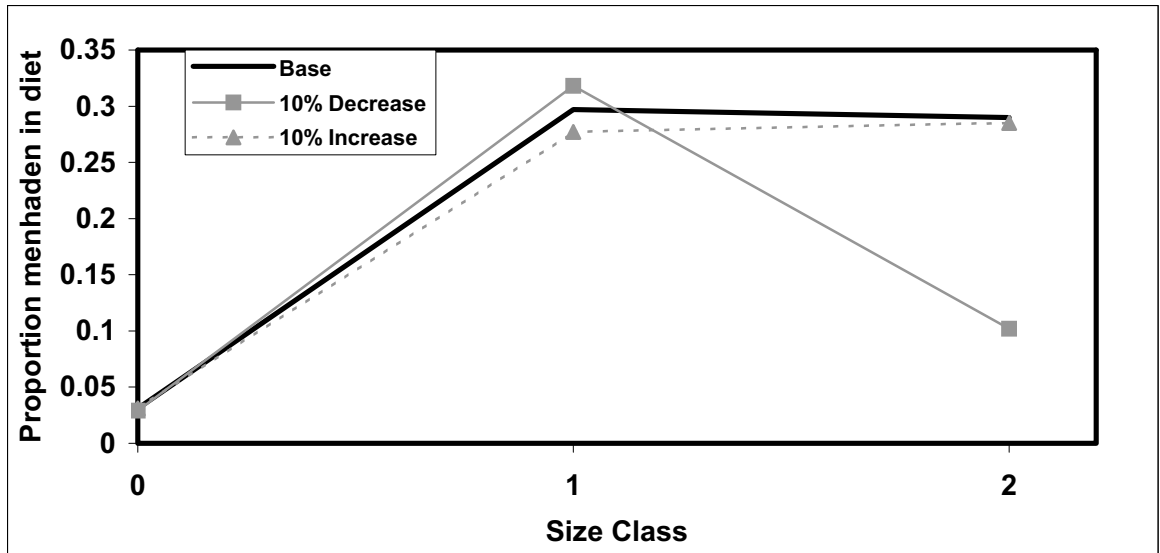
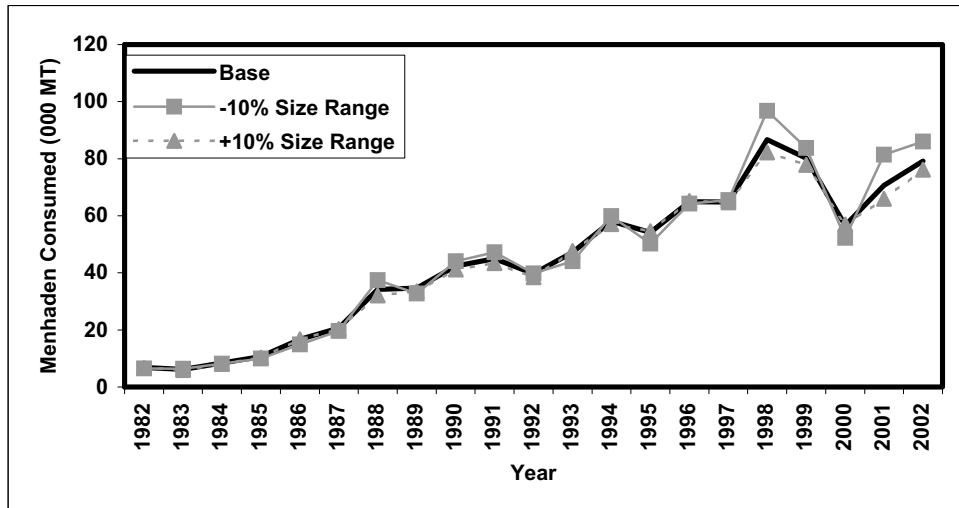


Figure D1.91. Total menhaden consumed by striped bass (a), weakfish (b), and bluefish (c) by year for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

a)



b)

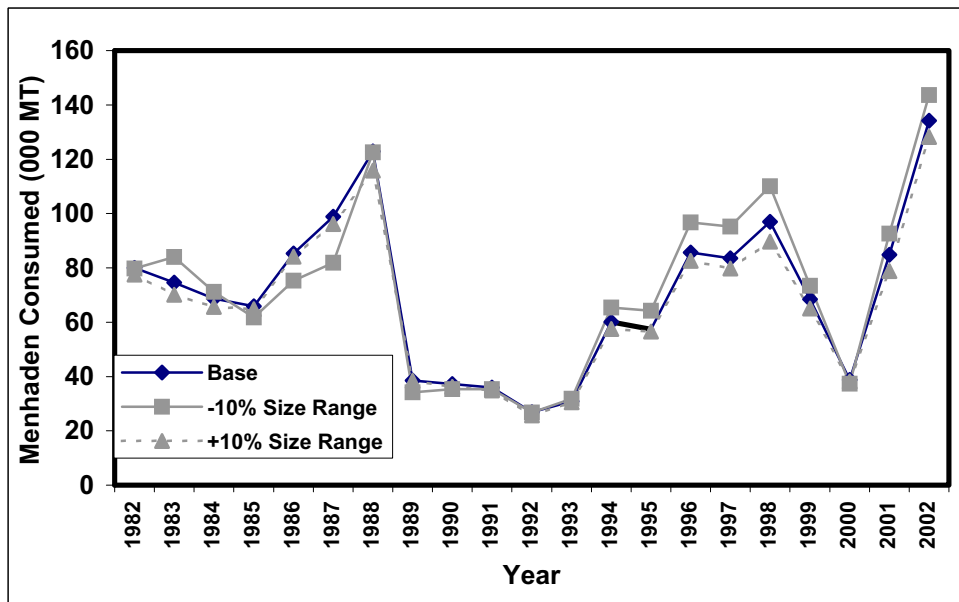


Figure D1.91 (cont'd). Total menhaden consumed by striped bass (a), weakfish (b), and bluefish (c) by year for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by  $\pm 10\%$ .

c)

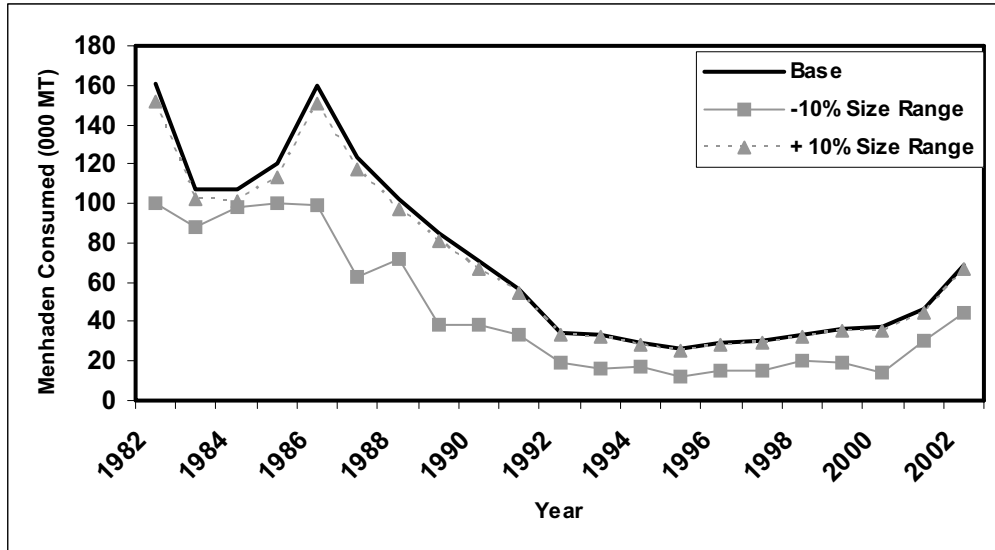


Figure D1.92. Comparison of observed (base run) and forecasted (using observed catch or observed F) menhaden population parameters dynamics for 1996-2002. The units for total biomass and spawning stock biomass are in 000 mt and total abundance is in millions of fish.

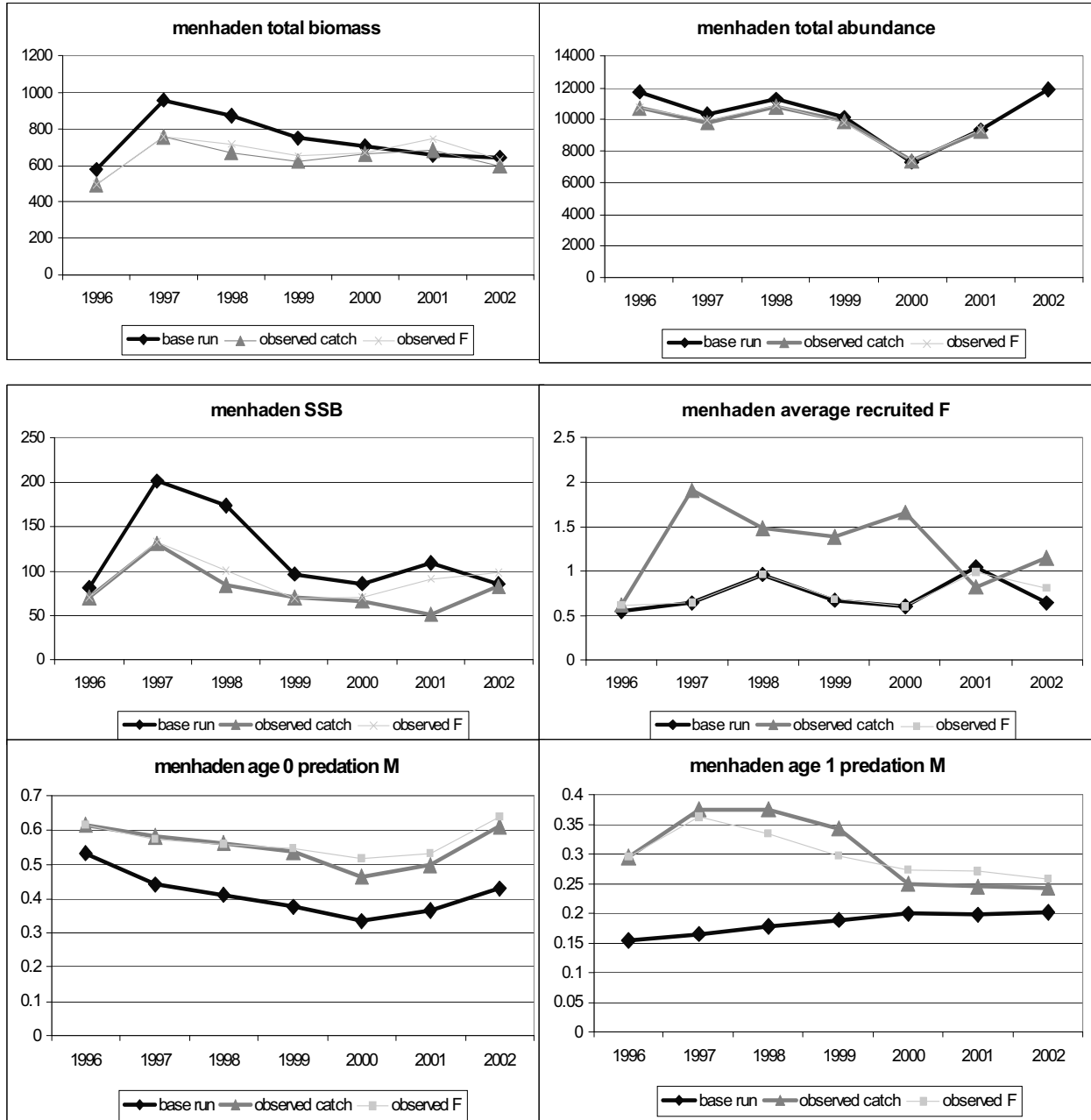
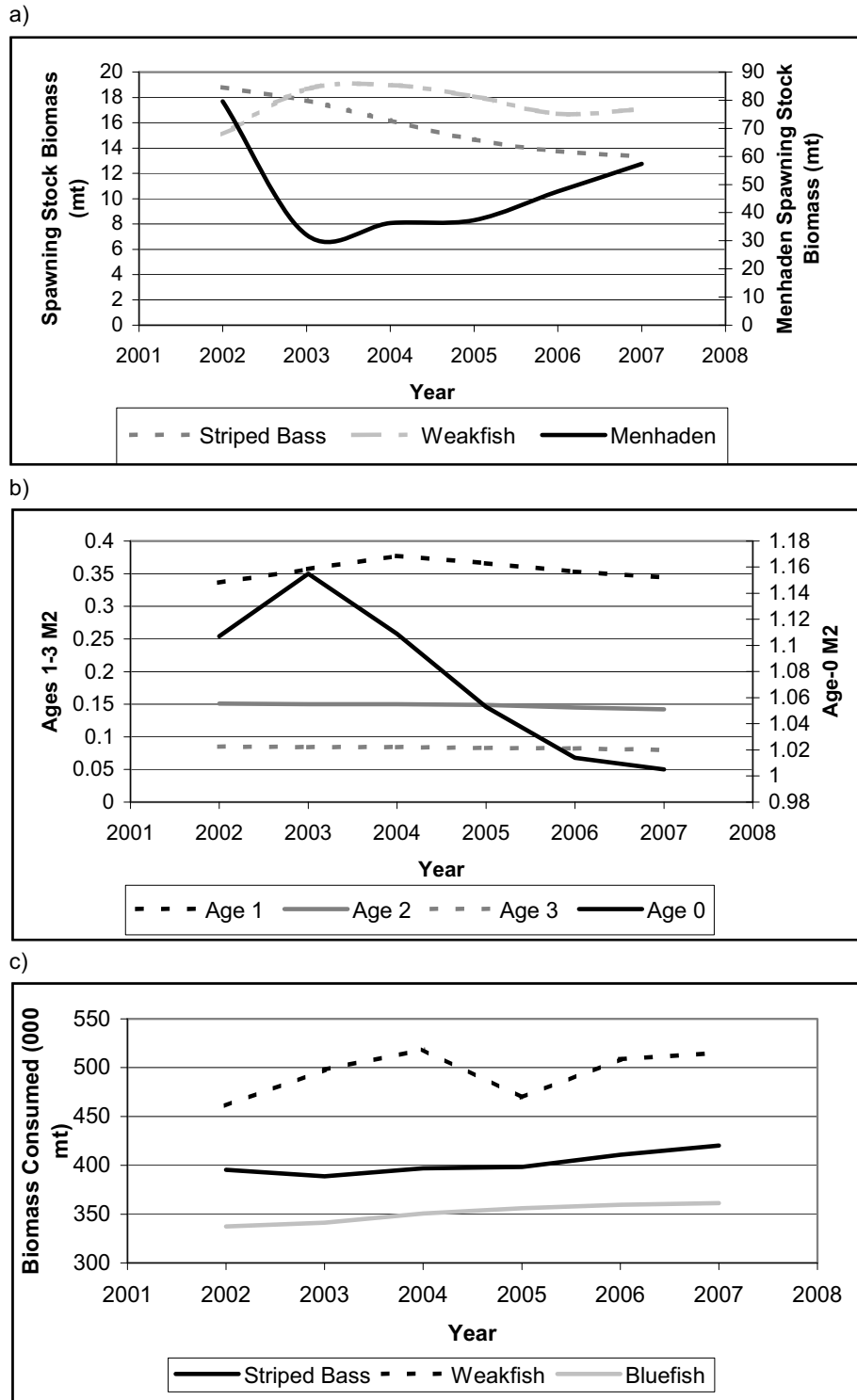


Figure D1.93(a-c). Results of the forward projection for: a) spawning stock biomass of menhaden, striped bass and weakfish; b) predation mortality on age-0 through age-3 menhaden; and c) the amount of menhaden consumed by striped bass, weakfish and bluefish.



## **APPENDIX D2: ASMFC SINGLE-SPECIES RESEARCH RECOMMENDATIONS**

### ATLANTIC MENHADEN

#### **ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)**

##### Prioritized Research Needs

1. Evaluate effects of selected environmental factors on growth, survival and abundance of juvenile and adult menhaden, particularly in Chesapeake Bay and other coastal nursery areas.
  - Develop and test methods for estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques.
  - Determine how loss/degradation of critical estuarine and nearshore habitat affects growth, survival and abundance of juvenile and adult menhaden abundance.
  - Monitor landings, size, age, gear, and harvest area in the reduction and bait fisheries, and determine age composition by area. Enhance biostatistical sampling of bait samples in purse seine fisheries for Virginia and New Jersey to improve stock assessment.
  - Study the ecological role of menhaden (predator-prey relationships, nutrient enrichment, oxygen depletion, etc.) in major Atlantic coast embayments and estuaries.
  - The feasibility of estimating year-class strength using biologically stratified sampling design should be evaluated. The efforts could be supported by process studies linking plankton production to abundance of young menhaden (need resources).
2. Evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year menhaden abundance.
  - Monte Carlo simulations should be conducted to evaluate precision of VPA.
  - 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 pilots.
  - Re-evaluate menhaden natural mortality, by age and response to changing predator population sizes.
3. Determine the effects of fish diseases (such as ulcerative mycosis and toxic dinoflagellates) on the menhaden stock.
  - Determine the effects of regulations on the fishery, the participants, and the stock.

- Growth back-calculation studies should be pursued to investigate historical trends in growth rate. The NMFS has an extensive database on scale growth increments that should be utilized for this purpose.
4. Monitor fish kills along the Atlantic coast and use the NMFS Beaufort Laboratory as a repository for these reports.
  5. Develop bycatch studies of menhaden by other fisheries. DISCARDS
  6. Periodically monitor the economic structure and sociological characteristics of the menhaden reduction industry.

**Atlantic Menhaden Stock Assessment Report for Peer Review: Stock Assessment Report No. 04-01 (Supplement), February 2004 (ASMFC, 2004a)**

Research and Monitoring Recommendations (number reflects relative ranking with 1 being the highest priority)

1. Conduct new size and age at maturity research by geographic regions along the Atlantic coast.
  - Develop coast wide tagging program to examine stock structure, spatial and temporal patterns in movement and migration, and to estimate exchange rate among geographic regions (i.e., inshore-offshore and latitudinal).
  - Develop a spatially explicit age-structured model to account for spatial and temporal differences in size/age distributions, size/age at maturity, and fishing effort and catchability rates.
  - Develop statistical sampling methods to improve catch and effort statistics in the recreational fishery. Evaluate extent of recreational netting of menhaden for bait purposes.
  - Monitor landings, size, age, gear, and harvest area in the reduction and bait fisheries, and determine age composition by area. Maintain biostatistical sampling of bait samples in purse seine fisheries for Virginia and New Jersey and enhance this sampling in Maryland, the Potomac, and North Carolina to improve stock assessment (ongoing).
  - Study the ecological role of menhaden (predator-prey relationships, nutrient enrichment, oxygen depletion, etc.) in major Atlantic coast embayments and estuaries (predator-prey interactions being evaluated through ASMFC multispecies efforts). Re-evaluate menhaden natural mortality by age and the response to changing predator population sizes (evaluated through MS model, incorporated variable  $M$  in assessment).



- Maintain and expand seine indices estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques, particularly needed in mid-Atlantic region (ongoing research).
- Periodically monitor the economic structure and sociological characteristics of the menhaden reduction industry (Committee on Economic and Social Sciences - CESS).
- Determine the effects of regulations on the fishery, the participants and the stock (CESS ongoing project).
- Define local depletion in qualitative and quantitative terms. Determine environmental influences. Studies should not be limited to Chesapeake Bay.

2. Evaluate effects of selected environmental factors on growth, survival and abundance of juvenile and adult menhaden, particularly in Chesapeake Bay and other coastal nursery areas (NMFS/CBO ongoing project).

- Determine how loss/degradation of critical estuarine and nearshore habitat affects growth, survival, and abundance of juvenile and adult menhaden abundance.
- Evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year menhaden abundance (ASMFC MSC project).

3. Determine the causes of fish diseases (such as ulcerative mycosis and toxic dinoflagellates) on the menhaden stock (ongoing research in MD/VA).

- Monitor fish kills along the Atlantic coast and use the NMFS Beaufort Laboratory as a repository for these reports (ongoing).
- Investigate the amount or extent of bycatch in the menhaden fishery. Evaluate whether a statistically valid observer program is needed to document possible sea turtle interactions with the various gear types. Develop bycatch studies of menhaden by other fisheries.
- 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 pilots.

**Terms of Reference & Advisory Report to Atlantic Menhaden Stock Assessment Peer Review: Stock Assessment Report No. 04-01, February 2004 (ASMFC, 2004b)**

1. Issue: There is no adult abundance index to tune the population model.

- Evaluate commercial purse seine fishery effort (vessel/weeks) series as a possible tuning index in the model. Evaluate any measure of effort contained in this or other data series.
- Evaluate the data collected in the Captain's Daily Fishing reports for an adult abundance index. If these data are not useful, explore the utility of a commercial fishery-based adult index, developed jointly with the fishermen, for future assessments.

2. Issue: Recent relative productivities of menhaden nursery areas coast wide are unknown.
  - Investigate if there are any existing studies that could assist in evaluating current productivity.
  - Develop protocols to quantify contribution of different nursery areas to the adult stock.
3. Issue: M-at-age is an improvement over constant M assumption. However, there is concern that not all key sources of mortality have been accounted for and little is known about the temporal patterns of mortality.
  - Identify key sources of non-fishing mortality for menhaden.
  - Enhance the coverage of the MSVPA to more predator and prey species.
  - Determine if there are temporal patterns in these sources.
  - Validate assumptions about applying results from MSVPA to the 1955-1980 period.
4. Issue: There have been large changes in size-at-age over the 1955-2002 period. These trends are not a problem for the model but could have an impact on forecasts.
  - Evaluate historical change in size (weight and length) at age using existing data (e.g., scale incremental widths).
5. Issue: There are patterns in residuals of numbers at age for commercial catch estimated by the model.
  - Investigate if the selectivity model is causing this pattern.
  - Look at spatial changes in fishing pattern as well as fish distribution.
6. Issue: Current fecundity estimates are from studies in the 1980s and earlier.
  - Update the fecundity-at-size estimates and maturity ogives.
7. Issue: Cannot address local depletion questions with the current model.
  - Investigate methods to determine the proportion of the stock that may reside in a particular area in any one season and whether regional reference points can be developed to address local depletion.
  - Extend these methods to track changes in distribution over time.
8. Issue: Control plot determination of overfishing/overfished is based on point estimates only.
  - Develop uncertainty measures or risk analysis for control plots.

9. Issue: It is difficult to distinguish between results of different models and model assumptions.

- Develop measures (goodness of fit and complexity) to screen multiple models.

10. Issue: The assessment model assumes a unit stock.

- Test this assumption using otolith microchemistry and/or genetic markers.

## STRIPED BASS

### **ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)**

#### Prioritized Research Needs

1. Develop refined and cost-efficient coastal monitoring regime for striped bass stocks, including spawning stock biomass modeling and virtual population analysis (VPA).
2. Conduct sensitivity analysis on current state and federal fishery-dependent and -independent monitoring programs to determine which, if any, may be eliminated.
3. An evaluation of the overfishing definition should be made relative to uncertainty in biological parameters.
4. Simulation models should be developed to look at the implications of overfishing definitions relative to development of a striped bass population which will provide “quality” fishing. Quality fishing must first be defined.
5. Quota calculation methods should be refined which allow better estimates among various components of the fishery.
6. Examine differential reporting rates between commercial and recreational fishermen using high reward tags.
7. Develop studies to provide information on the magnitude of hook and release and bycatch mortality, including factors that influence their magnitude and means of reducing or eliminating this source of mortality.
8. Further study should be conducted on the discrepancy in ages between scale-based and otolith-based ages. Particular emphasis should be placed on comparisons with known age fish determined from coded wire tags. Comparisons should be made among age readers and areas.
9. Increase sea sampling of commercial fisheries, such as the dogfish gillnet fishery which may have high levels of discards.
10. Continue in-depth analysis of migrations, stock composition, etc. using mark-recapture data.
11. Continue to conduct research to determine limiting factors affecting recruitment and possible density implications.
12. Determine inherent viability of eggs and larvae.

13. Additional research should be conducted to determine the pathogenicity of the IPN virus isolated from striped bass to other warm water and marine species, such as flounder, menhaden, shad, largemouth bass and catfish.

**Report of the 36th Northeast Regional Stock Assessment Workshop (36th SAW):  
Stock Assessment Review Committee (SARC) Consensus Summary of Assessments**

- Conduct a workshop to evaluate an appropriateness of scales in ageing old fish.
- Explore applicability of Bayesian framework to striped bass assessment.
- Develop the model that will combine VPA and tagging data.

## WEAKFISH

### **ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)**

#### Prioritized Research Needs

##### High Priority

- Collect catch and effort data including size and age composition of the catch, determine stock mortality throughout the range, and define gear characteristics. In particular, increase length–frequency sampling, particularly in fisheries from Maryland and farther north.
- Develop latitudinal, seasonal, and gear specific age-length keys for the Atlantic coast. Increase sample sizes to consider gear specific keys.
- Derive estimates of discard mortality rates and the magnitude of discards for all commercial gear types from both directed and non-directed fisheries. In particular, quantify trawl bycatch, refine estimates of mortality for below minimum size fish, and focus on factors such as distance from shore and geographical differences. Update the scale – otolith comparison for weakfish.

##### Medium Priority

- Define reproductive biology of weakfish, including size at sexual maturity, maturity schedules, fecundity, and spawning periodicity. Continue research on female spawning patterns: what is the seasonal and geographical extent of "batch" spawning; do females exhibit spawning site fidelity?
- Conduct hydrophonic studies to delineate weakfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Continue studies on mesh-size selectivity; up-to-date (1995) information is available only for North Carolina's gillnet fishery. Mesh-size selectivity studies for trawl fisheries are particularly sparse.
- Assemble socio-demographic-economic data as it becomes available from ACCSP.
- Additional investigation is needed in developing consistent otolith-based catch matrices including the EM algorithm.
- The impact of ageing errors and other statistical uncertainties in the catch-at-age matrix on virtual population analysis (VPA) should be included. Retrospective analyses are needed on all VPA approaches investigated.
- Develop a spawner recruit relationship

Summary Report by the Chair on the 40th North East Regional Stock Assessment  
Review Committee (SARC)

Recommendations for Future Assessments

- There exists a considerable amount of information that in principle should permit an assessment using catch-at-age analysis. The basic information should be thoroughly evaluated as to its suitability for this approach.
- The commercial and recreational data should be examined with regard to its precision and accuracy, both in terms of the absolute estimates of catches and its age composition.
- The survey catch rates at age should be evaluated with respect to the spatial and temporal distribution of age groups over time to try to gain an understanding of why there are no consistent year-class signals within surveys.
- The survey distributions should be compared to observed changes in the pattern of the fisheries for weakfish to try to explain the inconsistencies in the trends observed in the different series.
- Work should be undertaken to validate the ageing methods employed.
- It is of primary importance to carefully evaluate the input data in terms of the information content regarding relative year-class strength. This evaluation could take the form of more statistically based GLM approach along the lines of the graphical analysis (i.e., Pope-Shepherd-Nicholson analysis of year-class, age and year effects). Alternatively the survey analysis approach suggested by Cook (1997) and subsequent developments under SURBA could have merit in this regard.
- It seems unlikely that statistical modeling will be able to reconcile the very different perspective on year-class strength between the fishery-independent surveys and the index obtained from the NMFS Marine Recreational Fisheries Statistics Survey. This problem should be given urgent attention through a focused research project that considers alternative hypotheses for the divergence.

The SARC was informed about a possible ecological explanation for the possible decline of the weakfish stock that requires review. Other explanations related to the survey indices and the recreational fishery statistics under the amended FMP also need to be given careful consideration.

## BLUEFISH

### **ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)**

#### Prioritized Research Needs

1. Data needs:
  - a) Sampling of size and age composition of the fisheries by gear type and statistical area should be increased.
  - b) Commercial and recreational landings of bluefish should be targeted for biological data collection wherever possible.
  - c) Increase intensity of biological sampling of the NER commercial and coast wide recreational fisheries.
2. Continue research on species interactions and predator-prey relationships.  
A scale-otolith age comparison study needs to be completed for bluefish.
3. Explore alternative methods for assessing bluefish, such as length-based and modified DeLury models.
4. Measures of CPUE under different assumptions of effective effort should be evaluated to allow evaluation of sensitivity of results.
5. Initiate fisheries dependent and independent sampling of offshore populations of bluefish during winter months.
6. Conduct research to determine the timing of sexual maturity and fecundity of bluefish.
7. Work should continue on catch and release mortality.
8. Any archived age data for bluefish should be aged and used to supplement North Carolina DMF keys in future assessments.
9. Conduct research on oceanographic influences on bluefish recruitment, including information on migratory pathways of larval bluefish.
10. Study tag mortality and retention rates for the American Littoral Society dorsal loop and other tags used for bluefish.
11. A coastal surf-zone seine study needs to be initiated to provide more complete indices of juvenile abundance.



12. Test the sensitivity of the bluefish assessment to assumptions concerning age-varying  $M$ , levels of age-0 discard, and the selection pattern.
13. Increase sampling frequencies when bluefish are encountered, especially when medium size fish are encountered.
14. Scientific investigations should be conducted on bluefish to develop an understanding of the long-term, synergistic effects of combinations of environmental variables on various biological and sociological parameters such as reproductive capability, genetic changes, and suitability for human consumption.
15. Studies on the interactive effects of pH, contaminants, and other environmental variables on survival of bluefish.
16. Investigate the relationship of epidemic dermatological disease of bluefish exhibited in the Tar-Pamlico estuary to environmental toxics or other parameters.
17. Investigate the distribution of adult bluefish (particularly the spring-spawned cohort) in the South Atlantic Bight and juvenile bluefish (including the pelagic stage); and develop precise information on the distribution and relative abundance of bluefish in inshore areas, especially estuaries and embayments.

**41st Northeast Regional Stock Assessment Workshop (SAW-41) Stock Assessment Review Committee (SARC) Meeting, Chair's Report (NEFSC, 2005)**

Short-term

- Continue to develop statistically appropriate models for this stock, including valuation of uncertainty and sensitivity. This modeling should also test sensitivity to data quality. The BTC should avoid double use of the data as model input.
- Evaluate the fishery-independent surveys used to tune the model with special emphasis on determining if the state surveys can be combined to yield better temporal and spatial representation of stock abundance. The BTC should encourage the states to coordinate their survey efforts for bluefish to improve the quality of data that can be obtained. We suggest a workshop to address this and other data issues.
- Evaluate the use of otolith and scale ageing of bluefish. We suggest this be a separate workshop to evaluate the best ageing structure and its reliability for stock assessment input. After the evaluation, intensify collection of age data from commercial and recreational fisheries, and evaluate the validity of combining age classes across years in an ALK.

### Long-term

- Improve sampling coast wide by gear and fishery sector to obtain information with special emphasis on mid-size fish. This may require alternative fishery-independent assessment methodologies (such as lidar, archival tagging, sonar).
- Increase fishery-independent sampling to better represent the population's offshore and southern habitat.

Determine if discard mortality of 15% for the recreational fishery is accurate.