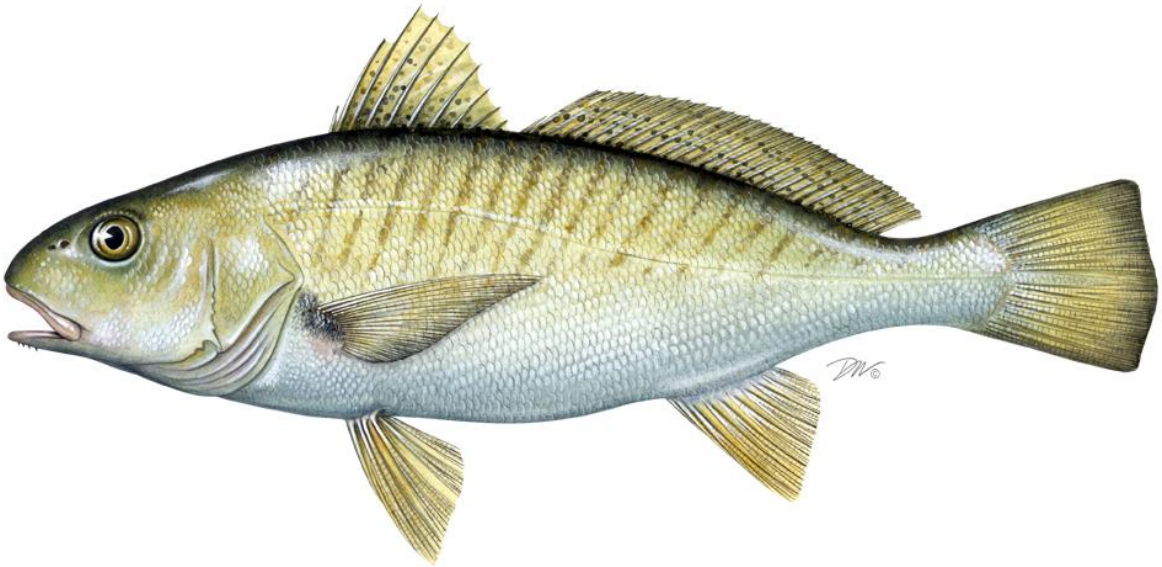
**Atlantic States Marine Fisheries Commission**

# *Atlantic Croaker 2010 Stock Assessment Report*



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## TERMS OF REFERENCE

The Atlantic Croaker Technical Committee adopted the following terms of reference for peer review:

1. Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
   a. Discuss the effects of data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, ageing accuracy, sample size, standardization of indices) on model inputs and outputs.
   b. Report standard errors of inputs and use them to inform the model if possible.
   c. Justify weighting or elimination of available data sources.

2. Evaluate models used to estimate population parameters (e.g., *F*, biomass, abundance) and biological reference points.
   a. Did the model have difficulty finding a stable solution? Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?
   b. Have the model strengths and limitations been clearly and thoroughly explained?
   c. If using a new model, has it been tested using simulated data?
   d. Has the model theory and framework been demonstrated and documented in the stock assessment literature?

3. State and evaluate assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs. Examples of assumptions may include (but are not limited to):
   a. Calculation of *M*.
   b. Choice to use (or estimate) constant, time-varying, or age-varying *M* and catchability.
   c. No error in the catch-at-age or catch-at-length matrix.
   d. Choice of a plus group.
   e. Population is at equilibrium.
   f. Constant ecosystem (abiotic and trophic) conditions.
   g. Choice of stock-recruitment function.
   h. Choice of proxies for MSY-based reference points.
   i. Determination of stock structure.

4. Evaluate uncertainty of model estimates and biological or empirical reference points.

5. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., *F*, SSB), reference points, and/or management measures.

6. Recommend stock status as related to reference points:
   a. Biomass threshold and target.
   b. *F* threshold and target.

7. Compare trends in population parameters and reference points with current and proposed modeling approaches. If outcomes differ, discuss potential causes of observed discrepancies.

8. If a minority [stock assessment] report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.

9. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

# 1 INTRODUCTION

## 1.1 Management Unit Definition

The existing management unit, area, and regions are defined in the Atlantic States Marine Fisheries Commission (ASMFC) Amendment 1 to the Interstate Fishery Management Plan for Atlantic Croaker (ASMFC 2005a).

Management unit refers to the resource under management. The Atlantic croaker management unit is the entire coast-wide distribution of the resource from the estuaries eastward to the inshore boundary of the EEZ. Management area refers to the geographic area under management. The Atlantic croaker management area covers the entire Atlantic coast distribution of the management unit from New Jersey through Florida. The management area is further divided into northern and southern regions, separated by the North Carolina/South Carolina border. Jurisdictions in the northern region include New Jersey, Delaware, Maryland, the Potomac River Fisheries Commission, Virginia, and North Carolina; jurisdictions in the southern region include South Carolina, Georgia, and Florida. The division into two management regions is based on the last ASMFC stock assessment, which assessed Atlantic croaker stock status separately for the two regions.

## 1.2 Regulatory History

### 1.2.1 Interstate Management

The Atlantic croaker interstate management program functions under the ASMFC's Interstate Fishery Management Program (ISFMP), with immediate oversight by the South Atlantic State-Federal Fisheries Management Board (Management Board).

The Fishery Management Plan (FMP) for Atlantic Croaker was adopted in 1987 and included the states from Maryland through Florida (ASMFC 1987). The major problem addressed in the plan was the lack of stock assessment data needed for effective management of the resource. Research and data collection programs were recommended, as were two management measures: the use of bycatch reduction devices in shrimp and finfish trawls, and increasing fishery selectivity to Atlantic croakers age one and older.

In 1993, the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) was established, allowing for enforcement of ASMFC management plans. Subsequently, the Management Board reviewed the FMP and found its recommendations to be vague and invalid, and the ISFMP Policy Board agreed that it contained no requirements. The Management Board recommended that an amendment be prepared to define management measures necessary to achieve the goals of the FMP. A workshop was held the same year to gather and review available data from which specific and rationale management measures could be drawn, and later in 1997, an Atlantic Croaker Technical Committee (TC) was appointed to continue the data collection and analysis initiated at the 1993 workshop.

In 2002, the Management Board directed the Atlantic Croaker TC to conduct the first ASMFC-sponsored coast-wide stock assessment of the species in preparation of developing an amendment. The stock assessment was approved by a Southeast Data, Assessment, and Review (SEDAR) review panel for use in management in June 2004, after which the Management Board initiated the development of an amendment to update the FMP. In November 2005, the

Management Board approved Amendment 1 to the Atlantic Croaker FMP, which was fully implemented by January 1, 2006 (ASMFC 2005a).

The goal of Amendment 1 is to utilize interstate management to perpetuate the self-sustainable Atlantic croaker resource throughout its range and generate the greatest economic and social benefits from its commercial and recreational harvest and utilization over time. Amendment 1 contains four objectives:

1) Manage the fishing mortality rate for Atlantic croaker to provide adequate spawning potential to sustain long-term abundance of the Atlantic croaker population.
2) Manage the Atlantic croaker stock to maintain the spawning stock biomass above the target biomass levels and restrict fishing mortality to rates below the threshold.
3) Develop a management program for restoring and maintaining essential Atlantic croaker habitat.
4) Develop research priorities that will further refine the Atlantic croaker management program to maximize the biological, social, and economic benefits derived from the Atlantic croaker population.

Amendment 1 expanded the management area to include the states from New Jersey through Florida. Consistent with the ASMFC stock assessment, it defines two Atlantic coast management regions: the south Atlantic region, including the states of Florida through South Carolina; and the mid-Atlantic region, including the states of North Carolina through New Jersey.

Biological reference points (BRPs) were established to define overfished and overfishing stock status for the mid-Atlantic region only. Stock estimates and BRPs for the south Atlantic region were not available due to a lack of data. Mid-Atlantic overfished status is defined by a threshold female spawning stock biomass (*SSB*) of 44.65 million pounds ($0.7 \times SSB_{\mathrm{MSY}}$), with a target *SSB* of 63.78 million pounds ($SSB_{\mathrm{MSY}}$). Overfishing for the mid-Atlantic is defined by a threshold fishing mortality rate ($F$) of 0.39 ($F_{\mathrm{MSY}}$), with a target $F$ of 0.29 ($0.75 \times F_{\mathrm{MSY}}$). Should it be determined that the stock is overfished or that overfishing is occurring, the Management Board must take action to recover the stock to the desired target level or to reduce the fishing mortality on the stock to the desired target level. In such a case, the Management Board will determine a stock rebuilding schedule.

Amendment 1 does not require any specific measures restricting recreational or commercial harvest of Atlantic croakers. Those states with more conservative measures are encouraged to maintain their regulations. Through adaptive management, the Management Board may revise Amendment 1, and regulatory and/or monitoring requirements (enforceable through the ACFCMA) could be included in the resulting addendum. The only existing requirement is for states to submit an annual compliance report by July 1 of each year that contains commercial and recreational landings as well as results from any monitoring programs that intercept Atlantic croakers.

### 1.2.2 State Management

Despite there being no required regulations, several states in the management unit have implemented regulations including creel/trip limits, size limits, and seasonal closures specific to Atlantic croaker (Table 1.2.2.1). In addition, gear restrictions such as minimum mesh sizes, bycatch reduction devices, and area closures implemented for other or multiple species limit the harvest and bycatch of Atlantic croakers (Table 1.2.2.2).

## 1.3 Assessment History

### 1.3.1 Types of Peer Reviews

In 2003, Atlantic croaker was assessed through the SEDAR process (ASMFC 2005b, 2005c). In 2004, the ASMFC's Atlantic Croaker Stock Assessment Subcommittee (SASC) reproduced the assessment for the mid-Atlantic region to address the SEDAR review panel's comments and concerns (ASMFC 2005d). The revised assessment was reviewed by the same 2003 SEDAR panel (with the exception of Dr. Steve Bobko, Old Dominion University, who did not participate in the second review; ASMFC 2005e).

The 2003/4 SEDAR assessment is the only official peer-reviewed stock assessment for Atlantic croaker. Florida looked at trends in catch and fishery-independent indices in 1997 to make a qualitative judgment of stock status. Other studies in academic settings have looked at the status of croaker in the Atlantic, or sub-regions of the Atlantic (Barbieri *et al.* 1997, Lee 2005).

### 1.3.2 Data Sets Used in the 2003/2004 Assessment

Catch data covered both commercial and recreational harvest:

- Commercial landings: 1950-2002 NOAA general canvas reports by state.
- Scrap landings: 1986-2002 North Carolina Division of Marine Fisheries (NCDMF) scrap estimates and 1989-2003 Virginia Marine Resources Commission (VMRC) size sample, market grade records.
- Recreational catch: 1981-2002 National Marine Fisheries Service (NMFS) estimates from the Marine Recreational Fisheries Statistics Survey (MRFSS).
- Bycatch: 1993-2002 Northeast Fisheries Science Center (NEFSC) observer data; discard to landings ratio for ocean gill-nets and trawls. Observer data from shrimp trawls was considered for use in estimating bycatch, but ultimately discarded as inadequate.

Both fishery-dependent and fishery-independent indices were used:

- Fishery-dependent: 1981-2002 MRFSS catch per unit effort (CPUE).
- Fishery-independent: 1973-2002 NMFS northeast bottom trawl survey, 1989-2002 Southeast Area Monitoring and Assessment Program (SEAMAP) survey, and 1973-2002 Virginia Institute of Marine Sciences (VIMS) spring trawl survey.

Biological data was provided by NCDMF, VMRC, Maryland Department of Natural Resources (MDDNR), and MRFSS:

- Size of commercial catch: 1982-2002 NCDMF fish house sampling of lengths and weights; 1986-2002 NCDMF scrap fishery sampling of lengths and weights; 1989-2002 VMRC fish house sampling of lengths and weights; 1993-2002 MDDNR pound net sampling of lengths and weight (1999+).
- Age of commercial catch: 1982-2002 NCDMF fish house sampling; 1986-2002 NCDMF scrap fishery sampling; 1999-2002 VMRC fish house sampling; 1999-2002 MDDNR pound net sampling.
- Size of recreational landings: 1981-2002 MRFSS sampling.

Life history parameters consisted of growth, maturity, and natural mortality. Length- and weight-at-age were calculated by the following equations, based on NCDMF data collected between 1996 and 2002, pooled by sex and unweighted.

$$L(a) = 434.6 * (1 - e^{-1.2415 * (a + 1.9572)}) \quad \text{Eqn. 1}$$

$$W(a) = 5.49 \times 10^{-19} * (L(a)^{3.13}) \quad \text{Eqn. 2}$$

where

(a) ages were based on sectioned otoliths,
(L) lengths were in mm, and
(W) weights were in kg.

The maturity schedule was taken from Barbieri *et al.* (1994b), with 0% mature at age-0, 90% mature at age-1, and 100% mature by age 2. Natural mortality (*M*) was assumed constant at 0.3 for all ages. Values from 0.2-0.4 were considered in sensitivity analyses.

### 1.3.3 Biological Reference Points

The 2003/2004 assessment put forth the first recommendations for BRPs. A determination of reference points and status could not be made for the south Atlantic region. Maximum sustainable yield (MSY) based reference points (Restrepo *et al.* 1998) were recommended for the mid-Atlantic region (Table 1.3.3.1).

### 1.3.4 Summary of Models

#### 1.3.4.1 Model Description

The reference points were developed from an age-structured production model (Punt *et al.* 1995). The model linked the population in successive years using a Beverton and Holt stock recruitment relationship re-parameterized in terms of steepness. The major deterministic components in the model were parameters that characterized the growth, fecundity, and morphometrics of the species; and selectivity patterns for all of the fisheries and indices included in the model. To obtain a solution, the model minimized the objective function by estimating a fully recruited fishing mortality rate of each year and fishery, catchability coefficients for the indices, virgin recruitment $R_0$ and a set of annual recruitment deviations from the stock-recruit relationship. Versions of the model were implemented in AD Model Builder and Excel and produced similar results.

#### 1.3.4.2 Model Assumptions and Limitations

The model generated an internal age-structure based on growth, natural mortality, and the stock-recruitment relationship, but could not fit this age-structure against observed values because the catch-at-age data were inadequate or non-existent for much of the time series.

The model was run separately for the mid-Atlantic and south Atlantic regions, as the SASC felt population trends in the two regions were different. The model assumed the regions were independent, with no migration between them. This assumption has not been validated.

The model calculates abundance of age-0 fish using a form of the Beverton and Holt stock-recruitment relationship that is a function of SSB, virgin recruitment ($R_0$) and steepness (h, defined as the proportion of virgin-stock recruitment production that occurs at 20% of the virgin spawning stock size). $R_0$ was estimated by the model, but h was provided as an input, as the data were not informative enough to adequately estimate it.

Natural mortality (*M*) was also provided as an input and fixed for all ages. Estimates from standard life-history based approaches ranged from 0.15 to 0.6; 0.3 was chosen for the base run.

A single growth curve developed from NC data was used for both regions and all years.

Selectivities of the fleets and surveys were fixed inputs to the model. They were estimated from catch-at-age data and an assumed selectivity curve shape (flat vs. domed).

#### 1.3.4.3 Data Time Series and Limitations

Data were not sufficient to produce annual estimates of croaker bycatch from the shrimp trawl fishery, which is believed to be an important source of mortality.

Unculled bait/scrap fishery landings of croaker can account for a significant proportion of the croaker catch, but as with bycatch, these data are not directly observed and reported, and levels of croaker scrap landings were estimated for North Carolina and Virginia. North Carolina estimates were developed from species ratios in scrap and market fish from fish house samples and total scrap:marketable landings ratio in North Carolina from 1986–2002, and on the ratio of 1986–1990 scrap:marketable landings alone for 1973–1985. Virginia estimates of reported croaker landings in the scrap/bait market grade for 1989–2002 were developed from scrap:marketable ratios and market grade landings data and biological field survey data; however, croaker that was landed as scrap but not reported as croaker (i.e., part of mixed or unclassified bait) was not estimated. Rather, this method partitioned known croaker landings into market grade and bait grade landings.

Recreational landings and releases were based solely on MRFSS data. There were no observed data on the sizes of released fish (the B2 component of the recreational catch), so the biomass of B2 catch was estimated by assuming released fish were likely to be equal to or lower than the $10^{th}$ percentile of measured (type A) fish, and that release mortality was 10%.

Recreational landings prior to 1981 were estimated by using state-specific correction factors based on the average ratio of annual commercial catch to total annual catch.

NMFS bottom trawl survey weight data were incomplete for fish weighing less than 100 g, therefore estimates of abundance from this index were for numbers of fish.

#### 1.3.4.4 Review of Other Models Available

In addition to the age-structured model, the SASC considered a non-equilibrium surplus production model (ASPIC; Prager 1994) for the 2003 assessment. However, this model was highly sensitive to the input parameters, and estimates of MSY and $B_{\text{initial}}/K$ tended towards the bounds. Additionally, the available indices predominately represented juveniles and age 1 fish, rather than reflecting the population as a whole, and the SASC was concerned with their suitability for a non-age-structured model.

The review panel recommended the consideration of non-age-structured models such as the Collie-Sissenwine/Catch Survey Analysis and a delay difference model, given the lack of catch-at-age data.

### 1.3.5 Results of the Assessment

The mid-Atlantic portion of the stock, which makes up the majority of the coast-wide stock, was determined to be not overfished and not experiencing overfishing. Fishing mortality and spawning stock biomass exhibited cyclical patterns over time, showing some stability over the last 3-5 years of the time series (Figures 1.3.5.1 and 1.3.5.2).

No conclusions were made about the status of croaker in the southern region.

### 1.3.6 Peer Review Comments

Most of the review panel's comments were addressed in the revised assessment in 2004. These included requests to:

- Include estimates of scrap fishery landings of croaker
- Consider at-sea observer data for discards and bycatch
- Extend the NMFS bottom trawl survey index to 1973
- Evaluate the difference between the delta lognormal and stratified mean standardized CPUE estimates from the NMFS bottom trawl survey index
- Include the VIMS trawl survey as a young-of-year (YOY) index
- Evaluate the model's ability to estimate $SSB_{1973}/SSB_{virgin}$ with the inclusion of the extended indices
- Evaluate the consequences of alternative weighting schemes and justify the final choice of weighting for the base run
- Determine the error distribution for current estimates of F and reference points and assess whether reference points could be statistically distinguished from model estimates

High priority issues from the 2003 review that were not addressed in 2004 included:

- Justification for the two-region model
- Consideration of non-age-structured models (e.g., CSA, delay-difference)

After reviewing the 2004 assessment, the panel agreed the SASC had done the best job possible with the available landings data, and approved the use of the original weighting scheme. The panel agreed the SASC had evaluated the major sources of uncertainty and accepted the stock status determination and the reference points for the mid-Atlantic region.

### 1.3.7 Strengths and Weaknesses of Past Assessment Efforts

The use of an age-structured production model allows the inclusion of juvenile and young-of-year indices of abundance and information on growth and maturity schedules despite the absence of catch-at-age observations. Fishery-independent indices cover a relatively large percent of the period of exploitation. Data sets from NC allowed the estimation of croaker landings from the bait/scrap fisheries.

The model did not perform satisfactorily in the south Atlantic region, and that portion of the stock could not be assessed. There was no biological justification for the regional split; this approach could reflect legitimate differences in population dynamics or simply a culling of unsatisfactory data. If fish are emigrating from the south Atlantic region into the mid-Atlantic region, estimates of the mid-Atlantic population size and exploitation rate could be overly optimistic.

Significant catch of croaker occurs in fisheries for which landings data are inadequate (the scrap fisheries, bycatch in gill nets and shrimp trawls, etc.). Some of these histories can be reconstructed, but there is a large degree of uncertainty in the estimated landings.

### 1.3.8 Past Research Recommendations

Research recommendations were developed by both the SASC and the review panel.

Recommendations from the SASC included:

- Describe the distribution and movement of croaker by age and season, especially for southern region (also recommended by the review panel);

- Conduct tagging and otolith microchemistry tagging studies to address the validity of a two-region model (also recommended by the review panel);
- Develop bycatch and discard estimates (also recommended by the review panel);
- Standardize ageing protocols for Atlantic croaker (also recommended by the review panel);
- Develop a fishery-independent index using state survey data;
- Develop a region- or coast-wide CPUE index;
- Investigate including climate factors in the model;
- Update maturity schedule;
- Examine socio-economic aspects of the fishery.

Recommendation from the review panel included:

- Evaluate possible temporal and spatial variability in growth not captured in the single growth curve used;
- Develop age-specific natural mortality estimates;
- Assess whether temporal and/or density-dependent shifts in reproductive dynamics (fecundity, maturity ogives, etc.) have occurred;
- Evaluate model effects of differing selectivity curves.

# 2 LIFE HISTORY

The Atlantic croaker, *Micropogonias undulatus*, is a demersal sciaenid common in estuarine and nearshore waters from the Gulf of Maine to Argentina (Joseph 1972; Chao and Musick 1977; Nelson et al. 1991; Stone et al. 1994). Along the U.S. Atlantic coast, the species is abundant between Indian River Lagoon, Florida, and Chesapeake Bay and supports important commercial and recreational fisheries in both the South Atlantic Bight and Mid-Atlantic Bight (Lankford and Targett 2001; Lee et al. 2001; ASMFC 2007). Jung and Houde (2003) observed that Atlantic croakers were the dominant species (by biomass) in their mid-water trawl in the lower Chesapeake Bay.

The Chesapeake Bay is important as both a spawning and nursery ground (Murdy et al. 1997). For Atlantic croaker, the upper bay region is important as a nursery ground for larval and juveniles, whereas older and mature fish exploit the lower bay as a spawning and feeding area.

Differences in spatial and temporal distribution, as well as differences in feeding behavior, reduce competition between juvenile sciaenids, such as Atlantic croaker and spot, and allow them to coexist. Predators of Atlantic croaker are larger piscivorous species such as striped bass, southern flounder, bluefish, weakfish, and spotted seatrout (ASMFC 1987).

## 2.1 Age

Initial studies of the age of Atlantic croakers in the Gulf of Mexico were based on the analysis of marks on scales (White and Chittenden 1977). These researchers found few age groups and concluded that this species has a short life span, early age at maturity, and could withstand considerable exploitation. Barger (1985) found that transverse sections of sagittal otoliths gave the most repeatable age estimates of Atlantic croakers from the Gulf of Mexico. Marginal increment analysis indicated that a single mark was deposited annually on the sagittae. Also, eight age groups were found suggesting that scales underestimate the true age of the fish in that area.

Ross (1988) also aged Atlantic croakers from North Carolina waters using scale analysis. Subsequently, Barbieri et al. (1994b) used sections of sagittae to age fish from the Chesapeake Bay during 1988-1991. A single annulus formed each year during April and May for all age classes. Their maximum age was 8 years. Since the publication of this study, the population has expanded and maximum observed age has increased. Age-12 fish were landed in Virginia and North Carolina in 2001 (Bobko et al. 2003; NCDMF 1999). More recently, a 17-year-old fish was landed by the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP). Sections of Atlantic croaker otoliths removed from archeological excavations near St. Augustine, Florida indicated that coastal Indians from the First Spanish period captured fish with a maximum age of 15 years (Hales and Reitz 1992).

Since Atlantic croakers have an extended spawning season and recruit to the estuarine nursery areas over an extended period, there are some problems associated with the assignment of the first annuli to fish taken along the Atlantic coast of the U.S. Atlantic. Croakers move into the estuaries north of North Carolina as early as July. This results in some Atlantic croakers being approximately seven to ten months of age during their first spring. Along the southeast coast (North Carolina and south), most Atlantic croakers recruit to the estuaries during January through March. These fish would be from two to five months of age during their initial spring. The YOY north of Cape Hatteras form a rather indistinct mark near the core of the otolith that has been designated as the first annulus by some researchers (e.g., Barbieri et al. 1994b). The problem lies in the fact that this mark is not seen in the transverse sections of the sagittae of all fish. In those fish with the ring proximate to the core, the indistinct mark is designated as the first annulus. If the mark is absent and the distance to the first well-defined increment is relatively large, one is added to the number of annuli. South of Chesapeake Bay, some fish do have the hazy area near the core, but many fish lack it. Ages of the fish from North Carolina and south have been determined by designating the first well-defined, distinct ring as the first annulus.

In October 2008, the ASMFC sponsored an Atlantic croaker ageing workshop in order to compare methods in sectioning and reading otoliths and establish coast-wide age interpretation methods (ASMFC, in press). For the purposes of stock assessments and other coast-wide analyses, the decision was made to count the first distinct ring as the first annulus and not count any ‘check marks’ that occurred in close proximity to the core of the otolith as annuli. Given the potential birth-date for an Atlantic croaker born between October and March, the check mark can be deposited between 3 and 8 months of age. The first true annulus is put down at the end of the second over-wintering period. The primary reason for not counting this check mark is to prevent an inaccurate year-class assignment resulting in a shift of the age distribution. It was noted that historical age data from Virginia (VMRC/ODU and VIMS) should be reviewed and possibly adjusted to account for this difference in ageing methodology.

Age data (sectioned otoliths) for the current assessment were available from the following sources:

1) Virginia commercial landings (1998-2008) aged by Old Dominion University;
2) Maryland commercial landings (2002-2008) aged by South Carolina DNR;
3) North Carolina fishery-independent and -dependent survey samples (1979-2008) aged by NCDMF;
4) Virginia and Maryland ChesMMAP (2002-2008) samples aged by VIMS;

5) North Carolina-Florida SEAMAP and Massachusetts-North Carolina NMFS survey samples (1997-2007) aged by South Carolina DNR; and
6) New Jersey commercial landings (2006-2008) aged by New Jersey Division of Fish and Wildlife.

## 2.2 Growth

Atlantic croakers may grow to over 50 centimeters in total length (Ross 1988) and have a maximum reported age of 17 years (ChesMMAP survey data, this report). Atlantic croakers exhibit rapid growth during their first year, but annual growth rate declines sharply in the second year and decreases progressively as they grow older (Ross 1988; Barbieri et al. 1994a). Barbieri et al. (1994a) looked at Atlantic croakers collected from the Chesapeake Bay and Virginia and North Carolina coastal waters and found that 64% of the cumulative total observed growth in length occurred in the first year and 84% was completed after two years. Jung and Houde (2003) reported similar growth patterns for the Chesapeake Bay.

Previous studies suggest that length at age may vary among geographic regions (Table 2.2.1), but direct comparison of these estimates is complicated by differences in collection gear, age structure, ageing method and criteria, and time period. For this report, average total lengths at age were calculated using available data from fisheries-independent (Table 2.2.2) and fisheries-dependent (Table 2.2.3) surveys. Only otolith-based age data were used. The resulting estimates are within the range of the published estimates, but comparisons may be misleading due to the differences previously listed.

Published estimates of the von Bertalanffy age-length function for Atlantic croaker show large variation (Table 2.2.4). Estimates of $L_\infty$ have ranged from 31.2 to 64.5 cm total length, and estimates of $K$ have ranged from 0.093 to 0.36 year$^{-1}$. For this report, von Bertalanffy age-length parameters were estimated using current available otolith-based age data (Table 2.2.5). The current estimates of $L_\infty$ are generally higher than earlier estimates (Barger 1985; Barbieri et al. 1994a). This is largely attributable to the increased number of older fish observed in recent samples. Current estimates of the growth coefficient, $K$, are generally lower than earlier estimates (Barger 1985; Barbieri et al. 1994a) that used otoliths for ageing; this is directly due to the higher estimates of $L_\infty$, because $K$ and $L_\infty$ are inversely related.

For Atlantic croaker, length may be a poor predictor of age. Previous studies have reported that observed length distributions showed large overlap among ages (White and Chittenden 1977; Barger 1985; Ross 1988; Barbieri et al. 1994a; Chittenden et al. 1994). Examination of the age-length data available for the current assessment also found that lengths varied greatly within ages.

Parameters of the length-weight relationship have been estimated for Atlantic croaker in a number of studies (Table 2.2.6). The relationship of total length in centimeters to weight in grams was modeled for this report using available data. The estimated parameters of the allometric length-weight function for each data source are presented in Table 2.2.7.

Sex-specific differences in growth are a characteristic of many fish populations. Previous studies found no difference in growth between sexes for Atlantic croaker—either in the length-weight relationship (Barger 1985; Barbieri et al. 1994a; Chittenden et al. 1994) or in length-at-age (Barger 1985; Barbieri et al. 1994a). For this report, the analysis of the residual sum of squares (ARSS) method was performed to compare growth between males and females within each

available dataset (Chen et al. 1992; Haddon 2001). The ARSS method provides a procedure for testing whether two or more nonlinear curves are statistically different. The approach requires that the same model be fit to each dataset being compared. The ARSS analysis was applied to compare estimated von Bertalanffy age-length curves and estimated length-weight curves between sexes within each dataset. Sex-specific parameter estimates of the von Bertalanffy age-length function are shown in Table 2.2.8, and sex-specific parameter estimates of the allometric length-weight function are shown in Table 2.2.9. Estimated values of $L_\infty$ and $K$ were generally higher for females than males (Table 2.2.8). Parameter estimates for both males and females collected from New Jersey commercial gill nets were associated with relatively large standard errors and may not be reliable. The value of $L_\infty$ estimated for females collected from North Carolina commercial pound nets was exceptionally high and associated with a large standard error; this estimate is not considered reliable. The ARSS detected significant differences ($P<0.001$; $\alpha=0.01$) between male and female age-length curves in most of the datasets (Table 2.2.10). Comparison of the length-weight curves between sexes yielded similar results; significant differences ($P<0.001$; $\alpha=0.01$) between sexes were found in seven of the thirteen datasets (Table 2.2.11). Four of the remaining datasets had calculated $P$-values less than 0.05. The results of the current analysis suggest that Atlantic croaker do exhibit differential sex-specific growth.

### 2.2.1 Length Data Conversions

The currently available length data represent lengths based on different measurement techniques (Table 2.2.1.1), as defined in Table 2.2.1.2. All lengths were converted to maximum total lengths for consistency. Length-length conversions were determined using the simple linear regression model: $Y = aX + b$ (Table 2.2.1.3). The model was fit to length measured in millimeters. Coefficients of determination ($r^2$) ranged from 0.96 to 0.99.

## 2.3 Reproduction

### 2.3.1 Spawning

Atlantic croakers have a unique reproductive seasonality, spawning in warm pelagic waters between early September and late December, depending on latitude (White and Chittenden 1977; Music and Pafford 1984; Able and Fahay 1997). Spawning peaks in the fall north of Cape Hatteras, NC and in the winter and early spring further south (Welsh and Breder 1924; Hildebrand and Schroeder 1928; Wallace 1940; Haven 1957, 1959; Ingle et al. 1962; Beaumariage and Wittich 1966; Morse 1980; Music and Pafford 1984; Norcross 1991; Norcross and Austin 1988; Hare and Able 2007).

### 2.3.2 Maturity

Published estimates of maturity for Atlantic croaker in the Atlantic Ocean are somewhat variable (Table 2.3.2.1). Welsh and Breder (1924) reported that Atlantic croakers reach maturity at age 3 or 4. Wallace (1940) reported that males first reach maturity at age 2 and females reach maturity at age 3. Wallace (1940) also reported a minimum length at maturity of 24.0 cm total length for males and 27.5 cm total length for females. More recent studies on Atlantic croaker maturity suggest this species matures at a smaller size and earlier age than reported previously. Morse (1980) and Barbieri et al. (1994b) reported minimum lengths at maturity for males and females that were smaller than those reported by Wallace (1940), but similar to each other. Barbieri et al. (1994b) found that over 85% of Atlantic croakers were mature by age 2 and all were mature by

age 3. One reason for the difference in estimates between the earlier and more recent studies may be due to how ages were determined. The earlier estimates were based on ages derived from length frequencies (Welsh and Breder 1924) and scales (Welsh and Breder 1924; Wallace 1940), which are considered less reliable than otolith ages for Atlantic croaker (Barbieri et al. 1994a). Barbieri et al. (1994b) used ages derived from otoliths to determine age at maturity.

Length and age at maturity were determined using available otolith-derived age data. A two-parameter logistic model was applied to estimate length at 50% maturity. The calculated maturity estimates are similar to the findings of Morse (1980) and Barbieri et al. (1994b), suggesting Atlantic croakers mature at a small size and early age (Table 2.3.2.1; Figure 2.3.2.1). The work of Barbieri et al. (1994b) and the current results suggest almost all Atlantic croakers are mature at age 2. Variability among the estimates may be partly attributable to differences in the time of year when samples are collected, given the protracted, bimodal spawning season.

### 2.3.3 Sex Ratio

Barbieri et al. (1994b) computed monthly sex ratios of Atlantic croakers collected mostly from commercial fisheries operating in the Chesapeake Bay. They found monthly fluctuations in sex ratio and that females dominated during the main spawning period (June/July-September/October) and were highest during August–October in both years of their study. Chittenden et al. (1994) reported similar results for the Chesapeake Bay. Barbieri et al. (1994b) suggested that the higher proportions of females observed during the first months of spawning could indicate that males migrate out of the bay earlier than females or that spawning-phase females are more susceptible to the commercial fishing gears from which samples were collected.

Annual and monthly sex ratios were calculated for the current assessment using available data. The monthly sex ratios show higher proportions of females were observed in the fall (August–October) for most of the datasets (Table 2.3.3.1). These results are consistent with those reported by Chittenden et al. (1994) and Barbieri et al. (1994b). Sex ratios were similar among the fisheries-independent trawl surveys with overall estimates ranging from 54% to 59%. Overall sex ratios were higher for the commercial fisheries data, ranging from 67% to 72%. Annual sex ratios were variable among years within each dataset (Figure 2.3.3.1). No substantial increasing or declining trends are obvious in recent years for any of the datasets. Similar to the monthly sex ratios, annual estimates derived from commercial fisheries samples (MDDNR, VMRC, and NCDMF) were generally higher than sex ratios derived from fisheries-independent samples (NMFS, ChesMMAP, and SEAMAP).

### 2.3.4 Fecundity

The two estimates of fecundity for Atlantic croaker found in the literature suggest fecundity may be high for this species. Hildebrand and Schroeder (1928) reported that a 39.5-cm female contained approximately 180,000 eggs. That estimate was based on a single fish caught in the mouth of the York River in October 1921. Morse (1980) estimated fecundity based on ovaries collected during the fall component of the NMFS Bottom Trawl Survey in 1973 and 1974. He estimated that fecundity ranged from 100,800 to 1,742,000 eggs for females ranging from 19.6 cm to 39.0 cm in total length. Morse's (1980) estimates were based on the assumption of determinate fecundity; however, Barbieri et al. (1994b) concluded that Atlantic croakers have indeterminate fecundity and suggested that estimates based on the assumption of determinate fecundity should not be used for management.

### 2.3.5 Stock Definition

The current ASMFC management plan for Atlantic croaker assumes a single stock for the Atlantic coast, but defines two management areas based on the NC/SC split used in the 2003/4 stock assessment (ASMFC 2005a). The question of whether one or two stocks of Atlantic croaker occur along the U.S. Atlantic coast has been investigated by a number of studies. White and Chittenden (1977) reported differences between the life histories of Atlantic croaker occurring in the warm-temperate waters of the Carolina Province than those found in the cold-temperate waters north of Cape Hatteras. These differences included spawning season, size- and age-at-maturity, and maximum size. White and Chittenden (1977) did note that growth rates appeared similar between the regions. Results reported by Ross (1988) were consistent with the proposed northern group life history (larger sizes and older ages), though he considered Cape Lookout as the zoogeographic boundary. He suggested that the possible mixing of Atlantic croaker may confound fishery management until adequate separation techniques are produced. Barbieri et al. (1994a) disputed the existence of a group of larger, older Atlantic croaker in the Chesapeake Bay as compared to fish occurring in more southern waters and suggested that the hypothesis of different groups occurring above and below Cape Hatteras should be reevaluated. They recommended that surveys of the age and size composition of Atlantic croaker over time were needed to fully assess this inquiry. An analysis of otolith microchemistry found no significant differences between juveniles from North Carolina and Virginia, suggesting larvae from north and south of Cape Hatteras may come from a single spawning site (Thorrold et al. 1997). A study of Atlantic croaker genetic population structure using mitochondrial DNA analysis found no evidence that Cape Hatteras represents a genetic stock boundary (Lankford 1997; Lankford et al. 1999). Lankford and Targett (2001) investigated adaptive variation in growth capacity and cold tolerance of young-of-year Atlantic croaker and found no geographic variation in these physiological traits, lending further support to hypothesis of a single stock along the Atlantic coast. More recently, a study by Baker et al. (2007) using macroparasites as biological tags provided weak support for the idea of two stocks roughly separated at Cape Hatteras.

An assessment of Atlantic croaker performed by Lee (2005) assumed a single stock occurring along the Atlantic coast due to lack of genetic evidence for separate stock groups. That assessment also reported strong correlations in year-class strength for Virginia and North Carolina, adding support to the coast-wide approach. The previous (2003) ASMFC Atlantic croaker assessment used a regional approach (ASMFC 2005b). The SASC reported differences in population trends between the northern (North Carolina and north) and southern (South Carolina to Florida) regions. The peer review panel debated whether the available information supported separating the stock into northern and southern components and concluded that further investigation into the question of stock structure was needed (ASMFC 2005c). An update of the ASMFC assessment reviewed and discussed the available research in detail (ASMFC 2005d). The SASC noted that genetic analyses have not supported the existence of separate stocks and suggested that further studies are needed.

## 2.4 Natural Mortality

One of the most important, and often most uncertain, parameters used in stock assessment modeling is natural mortality (*M*). Natural mortality rates assumed for Atlantic croaker in past studies have largely been based on catch curves or life history analogies, such as maximum age. For example, Ross (1988) estimated a total mortality rate (*Z*) value of 1.3 for ages 1 through 5

(based on scale ages) using on a catch curve analysis of North Carolina haul-seine catches. Barbieri et al. (1994a) estimated *Z* values for Atlantic croaker in the Chesapeake Bay using several approaches. Based on a maximum age of 8 years (derived from otolith ages), they estimated *Z*=0.55 using Hoenig's (1983) method and *Z*=0.58 using Royce's (1972) approach. They also applied a catch curve analysis to pooled age composition data from pound-net, haul-seine, and gill-net samples, which produced an estimate of 0.63 for *Z*. Barbieri et al. (1997) used *M* values ranging from 0.20 to 0.35 in a yield-per-recruit analysis of Atlantic croaker in the Middle Atlantic Bight. Those values were based on maximum ages and *Z* values reported in previous age and growth studies. Lee (2005) performed a stock assessment and yield-per-recruit analysis of Atlantic croaker occurring along the U.S. Atlantic coast assuming a value of 0.35 for natural mortality in the base model and evaluated model sensitivity using values of *M*=0.20 and *M*=0.50. The 2003 ASMFC assessment of Atlantic croaker in the mid-Atlantic region estimated *M* using several methods and used the mid-point of those estimates (*M*=0.30) in the model (ASMFC 2005b). The peer review panel of that assessment concluded that the method for estimating *M* was the best approach based on available information, though recommended that age-specific mortality rates be considered (ASMFC 2005c).

For the current assessment, a variety of indirect methods were applied to available data to derive estimates of *M* for Atlantic croaker. Approaches for computing both an age-constant *M* and age-varying *M* values were considered; the methods and resulting estimates are described below.

### 2.4.1 Estimates of Age-Constant *M*

There are several methods to estimate an age-constant *M* based on the relationship of natural mortality to various life history characteristics. The equations derived by Hoenig (1983) correspond to Alagaraja's (1984) method and the commonly used rule-of-thumb approach ($M = 3 / t_{max}$). These approaches predict *M* based solely on the maximum observed age in the population, $t_{max}$. Alverson and Carney's (1975) approach is based on von Bertalanffy growth and requires estimates of the growth coefficient, *K*, and $t_{max}$ to determine *M*. Jensen (1996) derived a simple theoretical relationship between *M* and the von Bertalanffy *K* ($M = 1.50 \times K$). Using Pauly's (1980) data for 175 species, Jensen (1996) showed the simple relationship: $M = 1.60 \times K$.

The approaches described above were used to calculate age-constant estimates of *M*. Values for the life history parameters required by the equations were derived from the data compiled for this assessment. The oldest age observed in the available data was 17 years (ChesMMAP survey data, 2008, this report); this was a single observation and no 16-year-old fish were observed in any of the datasets. The SASC agreed to assume a maximum age equal to 17 years for the natural mortality estimation methods that include $t_{max}$ in the equation. Estimates of the von Bertalanffy growth coefficient, *K*, are discussed in Section 2.2 of this report. Natural mortality estimates were calculated using both the minimum and maximum estimates of *K* for pooled sexes, females only, and males only. When data were pooled over sexes, the estimates of *K* ranged from 0.150 to 0.322 (Table 2.2.5). Estimates of *K* for female Atlantic croaker ranged from 0.064 to 0.379 and ranged from 0.050 to 0.256 for males (Table 2.2.8.).

The estimates of age-constant *M* based strictly on maximum age ranged from 0.18 to 0.27 (Table 2.5.1.1). Estimates of age-constant *M* that were based on methods that incorporated the von Bertalanffy *K* showed a larger range. Natural mortality estimates for sexes combined ranged from 0.138 to 0.516 (Table 2.5.1.2). The *M* estimates for males ranged from 0.075 to 0.410 and ranged from 0.096 to 0.606 for females.

### 2.4.2 Estimates of Age-Varying *M*

A number of methods have been developed to provide indirect estimates of *M* at age (Peterson and Wroblewski 1984; Boudreau and Dickie 1989; Lorenzen 1996, 2005). For this report, Lorenzen's (2005) approach was used to calculate age-specific *M* values for Atlantic croaker. This approach requires estimates of the von Bertalanffy age-length growth function (to translate length to age) and the range of ages over which *M* will be estimated. The age-specific estimates of *M* are scaled such that the cumulative natural mortality across the selected age range is equal to a "target" *M*.

Lorenzen's method was applied to estimate age-specific natural mortality rates based on available data from each of the fisheries-independent surveys (NMFS, ChesMMAP, and SEAMAP) and from all datasets combined (pooled over all available fisheries-dependent and fisheries-independent data). The fisheries-independent surveys were chosen because of their spatial coverage, time-series, and ages encountered. Age-specific *M* values were determined for combined sexes (pooled over males, females, unknown, and unsexed samples) and for males and females separately. The value for target *M* was determined for each data source and sex using Hoenig's (1983) regression method, where $t_{max}$ was set equal to the observed maximum age for the respective dataset. The von Bertalanffy parameter values and maximum ages used in estimating *M* for each dataset are given in Table 2.5.2.1.

Estimated natural mortality rates decreased with increasing age (Table 2.5.2.2). Based on the combined dataset, age-specific estimates of *M* ranged from 0.21 to 0.46 for pooled sexes over the observed age range, and from 0.21 to 0.45 for males and from 0.23 to 0.51 for females (Table 2.5.2.2; Figure 2.5.2.1). The trends in age-specific *M* estimates for the fisheries-independent datasets were generally similar. All showed decreasing natural mortality rate with age (Table 2.5.2.2; Figures 2.5.2.1, 2.5.2.2, and 2.5.2.3). The natural mortality estimates derived from the SEAMAP survey data were generally higher than those based on other data sources, due to the younger observed maximum age. The younger ages encountered by the SEAMAP are due to a combination of gear selectivity and survey area and not a true biological effect; therefore, the resulting estimates of *M*-at-age are higher than would be expected if the entire age range was represented

## 2.5 Diet

Atlantic croakers are opportunistic bottom-feeders on benthic epifauna and infauna and consume a variety of invertebrates, including polychaetes, mollusks, ostracods, copepods, amphipods, mysids, decapods, and occasionally fish (see ASMFC 1987 for a review). In Delaware Bay marsh creeks, Nemerson and Able (2004) found that juvenile diet transitioned along a salinity gradient but with high consumption of annelids occurring at all sites. In lower salinity, crustaceans figured prominently in the diet (15–34%), whereas mysids dominated at higher salinity sites (46%). The adult Atlantic croaker is an opportunistic bottom feeder of benthic epifauna and infauna. Three studies published since 2000 have reported information on adult Atlantic croaker diet. Results from the Chesapeake Bay Fishery-Independent Multi-Species Fisheries Survey (CHESFIMS) stated that most Atlantic croaker stomachs contained polychaetes and mysids (Miller et al. 2003b). Results of work conducted by the Chesapeake Bay Trophic Interactions Laboratory verified these results and documented similarities and differences in diet between seagrass habitat and river habitats as well as a shift in diet across seasons (Parthee et al. 2006). Diet was similar among seagrass and river habitats, with polychaetes and bivalves as primary prey types. Of bivalves, the softshell clam was the most heavily exploited species in

seagrass beds but found only rarely in the diet of Atlantic croaker in rivers. In rivers, amphipods, isopods, mysids, and crabs were important. Miscellaneous material in the diet included unidentified vegetation, detritus, sand, mud, and woody debris. Seasonal diet analysis showed that mysids and polychaetes were year-round prey items, supplemented by clams in the summer and crustaceans in the fall. A specialized study of adult diet conducted in the Neuse River Estuary, North Carolina during the summers of 1997 and 1998 documented a shift in diet due to hypoxic events (Powers et al. 2005). Whereas clams were normally an abundant item in the diet, less nutritional items such as plant and detrital material were seen after hypoxia.

## 2.6 Migration Patterns

The distribution and migration of larval and juvenile Atlantic croaker have been observed to follow the general trend of ontogenetic migration by estuarine fish described by Dando (1984) in which the post-larvae are normally found in the highly productive zone just down-estuary from the freshwater interface, and juveniles descend to the middle and lower reaches of an estuary as they grow. A three-year (1996–1999) ichthyoplankton survey conducted by Miller et al. (2003a) found little movement of larval Atlantic croaker out of the creeks where they were tagged. A 1998 tag-recapture study by Miller and Able (2002) on juvenile (age 0) Atlantic croaker in restored and reference marsh creeks of Delaware Bay found that 95% of the recaptures occurred in the subtidal and intertidal portions of the same tagging creek. A subsequent study of the restored Delaware Bay marshes by Nemerson and Able (2004) found juvenile Atlantic croaker abundance was one to three orders of magnitude higher in the lower bay, high-salinity marshes than in the upper bay, low-salinity marshes. A study conducted by Jung and Houde (2003) in Chesapeake Bay found most young-of-year concentrated near the estuarine turbidity maximum (a zone in the upper bay of increased suspended particle concentration) in the upper bay between summer and fall and moved down-estuary afterward. Miller et al. (2003a) found that each year-class migrated out of Delaware Bay and tidal creeks between late summer and October–November. This result was consistent with that of Haven (1957) in Chesapeake Bay.

Studies investigating the vertical distribution of larval Atlantic croaker have drawn conflicting conclusions. Govoni et al. (1994) found slight evidence of diel (day-night) vertical migration. Comyns and Lyczkowski-Shultz (2004) found slight evidence for “reverse diel vertical migration”, in which Atlantic croaker larvae were more common in deeper water during daylight. Atlantic croaker larvae were reported to migrate inshore from shelf waters in the lower layers of the Atlantic Ocean off of North Carolina in a study by Hare and Govoni (2005), while larval Atlantic croaker in the Gulf of Mexico displayed no consistent vertical distribution pattern in a study by Sogard et al. (1987).

The distribution of adult Atlantic croaker is associated with both seasonal coast-wide migrations and inshore/offshore migrations associated with spawning and maturity. Evidence based on field collections suggests that oceanic settlements of adult Atlantic croaker coincide with spawning in warm pelagic waters with area-specific recruitment peaks—in the fall north of Cape Hatteras, NC, and in the winter and early spring further south (Haven 1957, 1959; Ingle et al. 1962; Beaumariage and Wittich 1966; Music and Pafford 1984; Norcross and Austin 1988; Hare and Able 2007).

In the Middle Atlantic Bight, including the ocean south of Cape Hatteras, Atlantic croaker move northward and inshore during the warmer months, and southward and into the ocean during late fall or winter (Haven 1959; Norcross and Austin 1988; see also ASMFC 1987 for a review). This

information is supported by reports from trawlers targeting Atlantic croaker and tagging programs conducted in Chesapeake Bay and along the North Carolina coast (Haven 1957, 1959; Pacheco 1958, cited by Norcross and Austin 1988).

The Maryland Department of Natural Resources (MDDNR) conducted a tagging study on Atlantic croakers in the Chesapeake Bay during 2005 and 2006 as part of a statewide MDDNR-sponsored fishing tournament. Nine hundred fifty-six Atlantic croaker were tagged in 2005 and 448 were tagged in 2006 (MDDNR Fisheries Service, unpublished data). Twenty-six Atlantic croaker tag returns were made in 2005 and 2006 combined, and all fish were recaptured in the same year they were released. Fifteen fish were recaptured in Maryland, all of which were released in June and recaptured during June through August of the same year. Three fish released in June 2005 were recaptured in Virginia—from Hampton to Virginia Beach—during October and November in 2005. Three Atlantic croakers released from the same net near the mouth of the Potomac River on June 2, 2005 were recaptured in New Jersey during September through October in 2005. Another fish released from the net in the Potomac River in June 2005 was recaptured in North Carolina on December 28, 2005. Two Atlantic croakers released in the mouth of the Choptank River in June 2005 were recaptured in North Carolina in October 2005. One fish released in Tangier Sound in July 2006 was recaptured in October 2006 in North Carolina. The results of the MDDNR tagging study provide supporting evidence of a fall-winter migration from estuary to ocean for Atlantic croakers.

In the South Atlantic Bight, the migratory patterns of Atlantic croaker have been investigated through tagging programs in Florida and Georgia. Although there were no recaptures from Florida's program (Ingle et al. 1962; Beaumariage and Wittich 1966), enough recoveries were obtained from Georgia's program to determine seasonal movement (Music and Pafford 1984). The period of greatest movement was during spring-fall, and few Atlantic croakers remained in estuaries during winter. Although most recoveries were from the general area of release, there were three recoveries (3.5%) that moved far away—two fish traveled southward (138 km) and were recaptured during May and August in the St. Johns River, Florida, and the third fish moved northward (179 km) and was recaptured in May near Cane Island, South Carolina.

# 3 FISHERY DESCRIPTION

## 3.1 Commercial

Atlantic croakers have been part of a mixed-stock commercial fishery on the Atlantic coast since the 1800s. Atlantic croakers are caught commercially with a wide variety of gear. The dominant gears include gill nets, pound nets, haul seines, and trawls. Atlantic croaker is also a major component of the "scrap fishery". A scrap fishery is one in which fish species that are unmarketable as food, due to size or palatability, are sold unsorted, usually as bait. Atlantic croaker is the major component of the North Carolina scrap fishery, which is sampled by the NC DMF to provide quantitative estimates of Atlantic croaker landed as scrap. Atlantic croaker is also believed to be a component of the Virginia scrap or bait fishery, but the Virginia scrap fishery is not monitored so the magnitude of those catches is unknown. A number of regulations instituted by North Carolina—the elimination of fly-net fishing south of Cape Hatteras (1994); the introduction of BRDs in shrimp trawls (1992, by proclamation authority); limits on the incidental catch of finfish by shrimp and crab trawls in inside waters (since 1970s); and culling panels in long haul seines (1999)—may have indirectly reduced landings of juvenile Atlantic croaker and changed the length and age distributions of the harvest. In Georgia, trawl-caught

Atlantic croakers are sold as unsorted mixed fish along with spot, whiting, and small flounder; therefore, their estimates of commercial landings are tenuous. Small Atlantic croakers have been a major part of the bycatch in the southeastern Atlantic shrimp trawl fishery (Hoar et al. 1992; Nance 1998), but the use of TEDs and BRDs has reduced this bycatch, although the magnitude of the reduction is difficult to quantify.

### 3.2 Recreational

Recreational anglers target Atlantic croaker by bottom fishing and chumming with shrimp, clams, worms, cut fish, and soft or peeler crabs. Recreational harvests typically peak in the warmer months (May through October) when effort tends to be greatest. The majority of recreational fishing occurs in state waters. Anglers pursue Atlantic croakers from shore, private boats, and for-hire fisheries (Personal communication with NMFS Fisheries Statistics Division 2009).

## 4 HABITAT

### 4.1 Brief Overview of Habitat Requirements

Juvenile Atlantic croakers are found in estuaries along the Atlantic coast and are most commonly found from New Jersey southward (Diaz and Onuf 1985; Robbins and Ray 1986; Able and Fahey 1997). Nursery areas differ considerably among locations, possibly in response to tidal range. Atlantic croakers are able to tolerate a wide range of salinity, water temperature, and water depth; however, significant hypoxia-induced habitat shifts have been noted by Eby et al. (2005) and Craig and Crowder (2005). Juveniles are associated with areas of stable salinity, but adults prefer areas of high salinity and become less tolerant of cold temperatures.

Hare and Able (2007) studied winter temperature variability and its effect on Atlantic croaker population dynamics. They showed a correlation between Atlantic croaker adult abundance and winter temperatures with high abundance corresponding with warm winter water temperatures (Hare and Able, 2007). A coupled climate-population model based on temperature-driven, overwinter mortality of juveniles in estuarine habitats was developed (Hare et al., in press). The model indicated that both exploitation and climate change significantly affected Atlantic croaker abundance and distribution. They recommended that climate effects be incorporated into the stock assessment models and used for scientific advice to achieve sustainable exploitation.

Substrate plays a large role in determining juvenile Atlantic croaker distribution. Atlantic croakers were described by Petrik et al. (1999) as habitat generalists. Field surveys of post-settlement Atlantic croaker in estuarine nursery areas found no significant differences in abundances among submerged aquatic vegetation, marsh edge, and sandy bottom (Petrik et al. 1999). Refer to the ASMFC Fishery Management Plan for Atlantic Croaker (ASMFC 1987) and ASMFC Amendment 1 to the Interstate Fishery Management Plan for Atlantic Croaker (ASMFC 2005a) for more detailed information regarding Atlantic croaker habitat.

# 5 DATA SOURCES

## 5.1 Commercial Fisheries

### 5.1.1 Data Collection Methods

Commercial landings data are collected by the NMFS and individual state agencies. Federally-permitted dealers and fishermen must report to the NMFS using the appropriate reporting process. Individual states may also have reporting requirements for dealers and commercial fishermen harvesting and/or landing in their state. The NMFS has collected commercial fisheries landings statistics since 1880 and has performed in-depth surveys of commercial fisheries landings of all coastal states since 1951. State fishery agencies obtain commercial landings data through voluntary and/or mandatory reporting and surveys (Table 5.1.1.1). Commercial data are also collected by the Atlantic Coastal Cooperative Statistics Program (ACCSP) through the Standard Atlantic Fisheries Information System (SAFIS). In addition to SAFIS, commercial fisheries data collected through the other state and federal programs are submitted to the ACCSP. The ACCSP requires trip level reporting of specific data elements and provides quality assurance and quality control measures to ensure data are comparable and accurate (ACCSP 2004). For the current assessment, commercial landings data were obtained from the ACCSP Data Warehouse and, in three cases, from individual state reports. The types of information and level of detail collected varies among and within the NMFS and various state programs. Commercial landings by gear are available for all states for 1950 through 2008. The availability of commercial fisheries landings data by area (e.g., inshore vs. offshore, state vs. federal waters, NOAA statistical areas, etc.) and month is summarized in Table 5.1.1.2.

#### 5.1.1.1 Survey Methods

<u>New Jersey</u>

New Jersey relies on the NMFS for collecting commercial landings data.

<u>Delaware</u>

Delaware requires commercial fishermen to complete monthly logbook reports that detail daily effort and harvest. Federally-licensed fish dealers in Delaware report their Atlantic croaker purchases, but there is no reporting requirement for state-licensed fish dealers.

<u>Maryland</u>

Prior to 1980, the NMFS collected commercial landings data for Maryland. Beginning in 1980, Maryland instituted a mandatory monthly reporting system for commercial fishermen. Catch and effort data were summarized on standard forms by month and submitted to the Maryland Department of Natural Resources (MDDNR) Fisheries Service. Beginning in 2000, a daily reporting log was tested and phased in to replace the existing monthly forms, and all commercial fishermen were reporting on the new forms by July 1, 2005. The mandatory daily log forms are completed by the commercial fishermen and submitted to the MDDNR Fisheries Service on a monthly basis. Gear type, amount of gear, hours fished, statistical areas fished, and catch by species is recorded on the forms.

<u>Potomac River Fisheries Commission</u>

In 1964, the Potomac River Fisheries Commission (PRFC) required commercial fishermen to report daily fishing activity on a monthly basis. Since 1991, the PRFC has mandated that

fishermen submit the daily activity reports every week. From 1964 through 1979, the PRFC sent the commercial harvest reports to the NMFS in Easton, Maryland to be summarized. Those reports were published in a NMFS monthly landing bulletin along with Maryland and Virginia data. After the office in Easton closed, the NMFS office in Hampton, Virginia collected the PRFC commercial harvest data. The PRFC now sends their data to the Virginia Marine Resources Commission (VMRC), which then forwards the data to the NMFS.

Virginia

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) in Virginia. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS and it's predecessors since 1929 (NMFS, pers. comm.). The VMRC began collecting voluntary reports of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program. The PRFC has provided information on fish caught in their jurisdiction and landed in Virginia since 1973.

North Carolina

Prior to 1978, the NMFS collected commercial landings data for North Carolina. In 1978, the North Carolina Division of Marine Fisheries (NCDMF) entered into a cooperative program with the NMFS to maintain the monthly surveys of North Carolina's major commercial seafood dealers and to obtain data from more dealers. North Carolina initiated a Trip Ticket Program in January 1994 in response to a decrease in the NCDMF/NMFS cooperative reporting and due to an increase in demand for complete and accurate trip-level commercial landings statistics by fisheries managers. A trip ticket is a form used by state-licensed fish dealers to document all transfers of fish from the fishermen to the dealer. These forms collect information such as transaction date, area fished, gear used, and the quantity of each species landed. The data obtained through the North Carolina Trip Ticket Program allow for the calculation of fishery-specific effort (i.e., trips, licenses, participants, vessels) and provide a more detailed record of North Carolina's seafood landings. Beginning in 1994, the NCDMF instituted a trip-ticket system to track commercial landings. Total catch by gear, area, and market category are used to expand these data.

South Carolina

Landings of Atlantic croaker in South Carolina were collected by the NMFS through the early 1980s. In 2003, South Carolina instituted a wholesale dealer reporting system that provides monthly summaries from wholesale dealers with weight (and value) of fish purchased per species per month. Historically, lengths and otoliths were not collected from commercial fisheries; however, this program is part of the NMFS Trip Interview Program (TIP), and Atlantic croaker was recently added to the NMFS TIP target species list, so SC port samplers started collecting biological samples in 2009. Atlantic croakers landed as bycatch from the shrimp trawl fishery are also reported through the wholesale dealer reporting system.

Georgia

In 1989, Georgia instituted mandatory trip-level reporting for commercial fisheries dealers and fishermen. Georgia's estimates of Atlantic croaker landings are questionable. In Georgia,

Atlantic croakers landed by trawls are sold as unsorted mixed fish along with spot, whiting, and small flounder.

Florida

During 1950 through 1984, Florida's commercial landings data were collected from seafood dealers on a monthly basis by the NMFS. In late 1984, Florida agencies involved in the management of natural resources, including fisheries, established a trip-ticket (TTK) reporting system, known as the Marine Fisheries Information System, designed to monitor the fisheries productions. When the program first started, data were collected by both the NMFS and through the TTK system to enable a comparison of the new data collection system. In 1986, the TTK system became the official commercial fisheries landings data collection system in Florida after it was determined that the monthly dealer summaries and the detailed TTK information were comparable. The TTK program requires all wholesale and retail seafood dealers to report their purchase of saltwater products from commercial fishermen on a trip-level basis. Dealers report the SLP number, the wholesale dealer license number, the date of the sale, the gear used (since 1991), trip duration (time away from the dock), area fished (since 1986, but was mandatory from 1994), depth fished, number of traps or number of sets (where applicable), species landed, quantity landed, and price paid per pound for each trip.

#### 5.1.1.2 Sampling Intensity

Daily or trip-level commercial landings data are currently collected in most of the states within the ASMFC management region (Table 5.1.1.1). Commercial fishermen are required to report daily or trip-level activity in Delaware, Maryland, the PRFC jurisdiction, Virginia, and Georgia. In North Carolina, South Carolina, Georgia, and Florida, dealers must report trip-level data. There are no reporting requirements for commercial fisheries in New Jersey.

#### 5.1.1.3 Biases

For a number of states, the method of collecting commercial fisheries data has changed over time (see Section 5.1.1.1, this report). Within these states, data may not be comparable before and after the methodology changed. Other data limitations vary by state.

#### 5.1.1.4 Biological Sampling

Several states have sampling programs that collect biological samples from their commercial fisheries (Table 5.1.1.4.1). An overview of these sampling programs is provided below.

There are distinct seasonal and gear differences (selectivity) among the Atlantic croaker commercial fisheries. Because of these differences and the rapid growth of Atlantic croaker, commercial samples should be collected from each of the major gears throughout the year.

Market-grade landings of Atlantic croaker comprise only a portion of the total Atlantic croaker catch. The sampling programs described below do not collect biological samples from commercial catch that is discarded at sea (e.g., bycatch in shrimp trawls). Biological samples from bait/scrap fisheries are only available from North Carolina.

New Jersey

New Jersey initiated biological monitoring of commercially landed Atlantic croaker in 2006, partly supported with funding from the ACCSP. Annual sampling of the trawl and gill-net fisheries is conducted primarily from August through October along the New Jersey coast in

Belford, Point Pleasant, Barnegat Light, and Cape May. Length (fork and total length in millimeters), weight (kilograms), gear type, and location are recorded. Otoliths are collected for age determination and processed using the protocol from the ASMFC's Atlantic croaker age workshop (ASMFC, in press).

Maryland

Since 1993, the Maryland Department of Natural Resources (MDDNR) has sampled commercial pound nets during June through September. Atlantic croakers are measured for total length. Beginning in 1999, limited age, sex, and weight data have been collected. All otoliths are processed and read by the South Carolina Department of Natural Resources (SCDNR).

Virginia

In Virginia, staff from the Virginia Marine Resources Commission (VMRC) sample Atlantic croaker commercial landings from 50-pound boxes of the graded catch obtained at seafood dealers and buyers. Atlantic croaker are measured for total length in millimeters and weighed to the nearest 0.1 pound. Market category, harvest area, gear type, and total catch are noted. Beginning in 1998, samples have been purchased to excise otoliths for age determination. All ageing work (processing and reading) is performed at Old Dominion University's (ODU) Center for Quantitative Fisheries Ecology (CQFE).

North Carolina

The North Carolina Division of Marine Fisheries (NCDMF) has sampled major commercial fisheries since 1982. Atlantic croaker are sampled by gear, market category (in culled catches only), and area fished at local fish houses. Fish are measured for total length to the nearest millimeter and sample weights, as well as total weights, are taken to expand the sample data to the entire landings. Subsamples of Atlantic croaker are purchased from the major commercial fisheries to excise otoliths for age determination.

The NCDMF initiated sampling of scrap fish in 1986. The NCDMF defines scrap fish as those fish not marketed for human consumption and instead sold for bait, industrial use, or discarded. Staff samples at least one-half basket (~12 kg) of the scrap fish from each catch. The sample is sorted by species and weighed (kg). All individuals in the sample are measured for fork or total length to the nearest millimeter. If the catch of a particular species is exceptionally large, a random subsample of at least 30 individuals is taken for measurement, and the remaining fish are counted.

South Carolina

South Carolina port agents collect lengths and otoliths from a number of species as part of their commercial fisheries monitoring program. Otoliths are sent to Beaufort, NC to be read. Recently, Atlantic croaker was added to the program's list of target species. The target sample size for Atlantic croaker in 2009 is 120 lengths and 100 otoliths.

Florida

Florida collects sample lengths from the commercial fisheries and, when opportunity allows, collects weights of Atlantic croaker intercepted through a Trip Interview Program (TIP) at fish houses. While Atlantic croaker is included on the list of species to be sampled, they are only sampled "as available" due to its low priority and the small amounts that are generally landed. These data are available from 1991 through 2008.

#### 5.1.1.5 Ageing Methods

One of the research recommendations of the last ASMFC stock assessment was to standardize ageing procedures across states (ASMFC 2005b). The ASMFC held a workshop in 2008 to standardize methods for both red drum and Atlantic croaker (ASMFC, in press; see also Section 2.1, this report). At the workshop, it was agreed that readers would not count the smudge or check mark that occurred near the core in many Atlantic croakers and, instead, would count from the first distinct annulus. The birth-date for modeling purposes was considered to be January 1.

Virginia

The otoliths collected through the VMRC's Biological Sampling Program are processed and read by the Old Dominion University's Center for Quantitative Fisheries Ecology. Otoliths are processed following the methods described in Barbieri et al. (1994a) with a few modifications. Briefly, the left or right sagittal otolith is randomly selected and attached to a glass slide with Aremco's clear Crystalbond™ 509 adhesive. At least two serial transverse sections are cut through the core of each otolith with a Buehler Isomet low-speed saw equipped with a three-inch, fine-grit Norton diamond-wafering blade. Otolith sections are placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium.

All fish are aged in chronological order based on collection date, without knowledge of the specimen lengths. Two readers must age each otolith independently. When the readers' ages agree, that age is to be assigned to the fish. When the two readers disagree, both readers must re-age the fish together, again without any knowledge of previously estimated ages or specimen lengths and assign a final age to the fish. When the readers are unable to agree on a final age, the fish is excluded from further analysis.

The process for ageing Atlantic croaker otoliths in Virginia involves two steps: (1) read the otolith—count the number of annuli in the otolith transverse cross-section; and (2) determine the age of the fish in terms of sacrifice date and annulus formation period.

Historically, Virginia has counted the wide band/smudge closest to the otolith core as the first annulus, whereas most other states do not; however, since all Atlantic croaker in Virginia form that band and because Virginia uses the January 1 model birth-date, the sampled fish should be scored as the same age-class assignment as those scored in other states.

North Carolina

Atlantic croaker sagittal otolith samples are collected monthly from the winter trawl, long haul-seine, pound-net, sink-net, recreational hook-and-line fisheries, and NCDMF fisheries-independent programs. Sagittal otoliths have been collected since 1996. Each month, samples (n=15) are distributed across the length range in 15-mm length classes starting at 100 mm total length. Sagittal otoliths are removed, cleaned, and stored dry. Samples are weighed to the nearest 0.01 kg and measured for total length to the nearest millimeter. Date, gear, and water location are also recorded for each sample.

A transverse section through the focus on a plane perpendicular to the horizontal axis of the left otolith is prepared using a Hillquist thin-sectioning machine as described by Cowan et al. (1995). The system is calibrated with an ocular micrometer before each reading session. Sections are viewed under reflected light at 21X magnification. Annuli, marginal increment, and otolith size are measured (mm) on an image projected on a high resolution monitor from a video camera mounted on a microscope. Ages are assigned based on the number of otolith annuli viewed. The

ageing lab biologist reads the otolith section and measures the annuli. The samples are then independently read by the species lead biologist. If any differences are not resolved, the data are omitted.

The NCDMF publishes three-year reports that include species-specific age-length keys, which have been applied to expanded length-frequency data to estimate length-at-age for total commercial landings on an annual basis (for example, see NCDMF 2001, 2002). The age-length keys and expansions are applied on a seasonal basis: winter (January-March and October–December); and summer (April–September).

South Carolina

In the laboratory, the left sagittae are viewed under low magnification with a binocular microscope (10X) and marked with a soft lead pencil on the core. These are then embedded in epoxide resin in silicon molds. After the resin has polymerized, the embedded otoliths are glued to a card held in a jig attached to the arm of a low speed saw. The otolith is positioned so that a transverse section ~0.5-mm thick can be taken through the core. The Isomet Saw is equipped with a pair of diamond-wafering blades, separated by a plastic washer so that the section can be taken with a single cut. The resulting section is mounted on a labeled microscope slide with Cytoseal-XLY. After polymerization of the mounting medium, slides are stored in boxes until viewing. These are examined with a Nikon SMZU microscope equipped with a Supercircuits model PC - 23C high resolution camera with transmitted light. The video image is captured by a frame grabber board in a personal computer and is subsequently analyzed with the Image-Pro image analysis software. The following measurements are taken on each otolith section:

1) radius—distance in millimeters from the center of the core to the edge of the section as measured along the sulcus acousticus
2) $a_1$—distance in millimeters from the center of the core to the distal edge of the first annulus
3) $a_2$—distance in millimeters from the center of the core to the distal edge of the second annulus
4) $a_3$ to $a_n$—distance from the center of the core to the distal edge of the third annulus and from the core to the distal edge of the nth annulus
5) marginal increment—distance from the distal edge of the last annulus to the edge of the otolith section

Some Atlantic croaker otoliths vary with respect to diffuse, undefined marking near the core of the otolith. These diffuse areas are not interpreted as being a ring. The first annulus is considered the first well-defined, opaque band that can be traced around the entire section.

### 5.1.2 Commercial Landings

Coast-wide commercial landings of Atlantic croaker have fluctuated widely, ranging from a low of 460 mt in 1970 to over 13,000 mt in 1977 and 1978 (Figure 5.1.2.1). In the late 1950s, annual landings exceeded 8,000 mt and then declined to the time-series low in 1970. Commercial landings increased to a peak of 13,532 mt in 1977 followed by an overall general decline to 1,676 mt in 1991. Annual commercial landings increased again in the mid-1990s and averaged just over 12,000 mt a year from 1997 through 2005. In recent years, landings have steadily declined; the most recent estimate of Atlantic croaker commercial landings for the Atlantic coast is 8,473 mt, observed in 2008.

Within the ASMFC management region for Atlantic croaker (New Jersey to Florida), the majority of commercial landings have been attributable to North Carolina (52%) and Virginia (39%), with Maryland (4.7%) and New Jersey (3.5%) contributing smaller percentages (Table 5.1.2.1). The remaining states (in the management area) combined make up less than 1% of total coast-wide landings during the 1950 through 2008 time period; however, percentages vary from year to year, with states outside the mid-Atlantic region contributing higher percentages during years of higher total landings. Delaware landings averaged 15.1 mt a year during the 59-year time series; no commercial landings were reported for Delaware in 21 of those years. South Carolina and Georgia had relatively small commercial landings early in the time series that have tapered off to little to no landings in recent years. Annual landings from the east coast of Florida averaged 40.2 mt during 1950 to 2008 and were higher earlier in the time series than in recent years.

Commercial landings of Atlantic croaker north of New Jersey (outside the management area) have been small and sporadic with no reported landings for most years. In New Hampshire, commercial landings were only reported for a single year, 1972. In that year, a total of 8.02 mt of Atlantic croaker landings were reported, and 7.2 mt of that total were landed by surface longline gear. Data workshop participants agreed that these landings most likely represented a reporting error and did not include the New Hampshire landings in the coast-wide estimate.

### 5.1.3 Commercial Scrap Landings and Bycatch

The available research suggests that the magnitude of Atlantic croaker commercial scrap landings and bycatch may be high; however, it is also highly variable and driven not only by relative abundance of Atlantic croakers and target species, but also fishery regulations.

#### 5.1.3.1 Scrap Landings

Atlantic croakers are a major component of Atlantic coast scrap landings (NCDMF 2001). A scrap fishery is one in which fish species that are unmarketable as food, due to size or palatability, are sold unsorted, usually as bait. Because they are unsorted, scrap fishery landings are not included in state and federal Atlantic croaker landings estimates and represent an additional source of removals.

Quantifying the amount of Atlantic croaker landed as scrap fish along the Atlantic coast is difficult due to the limited availability of sampling. Currently, North Carolina is the only state along the east coast that routinely samples its commercial scrap landings (see Section 5.1.1.4). The total weight of each species in the scrap fish samples is calculated by determining the proportion of that species in the subsample and expanding to the respective species' proportional weight of the total scrap fish for the trip. The number of individuals per species in the scrap fish component is calculated by expanding the number of individuals in the sample to represent the total weight of the species for the scrap fish in the samples. Estimates of total scrap fish landings for individual species are determined by applying the tri-annual ratio of marketable fish to scrap fish in the fish house samples to the reported tri-annual marketable landings. For the 2004 Atlantic croaker stock assessment, the SASC used the NCDMF's estimates of scrap landings from 1986–2002 and estimated NC scrap landings from 1973–1985 based on a ratio of scrap to total unclassified finfish landings (1986–1990). The NCDMF provided estimates of Atlantic croaker scrap landings for 2003–2008 to extend the time series for the current assessment (Table 5.1.3.1.1).

The panel that reviewed the 2003 Atlantic croaker stock assessment expressed concern regarding the magnitude of Atlantic croaker scrap landings in states other than North Carolina which lacked any sampling (ASMFC 2005b), and thus requested the SASC to evaluate the potential of applying the North Carolina scrap fishery data to other states. The SASC for the 2004 assessment did undertake this task, but the current SASC understands the work to have estimated the proportion of landings that could be classified as scrap due to length, and thus the estimates do not represent an additional source of removals. The current SASC again reviewed its options for estimating additional scrap fishery removals from Virginia using North Carolina sampling data, but due to differences in the fisheries responsible for Atlantic croaker scrap landings in Virginia and North Carolina, can not provide a reliable estimate of Atlantic croaker scrap estimates for Virginia.

#### 5.1.3.2 Shrimp Trawl Bycatch

Atlantic croaker are also a component of the incidental catch in the southeastern Atlantic shrimp trawl fishery (Hoar et al. 1992; Nance 1998; NCDMF 1999, 2006). Several studies have evaluated this bycatch. Diamond et al. (1999) estimated that the bycatch of Atlantic croakers caught in shrimp trawls ranged between 5.80 and 12.7 mt from 1973 to 1975 (North Carolina to Florida) and was 611 mt in 1992 and 2,283 mt in 1993 (South Carolina to Florida). Georgia, South Carolina, and North Carolina began requiring Bycatch Reduction Devices (BRD) in trawls in 1992. In South Carolina, average catch rates per twenty-minute trawls, for two types of shrimp trawls-port two-seam and starboard tongue trawl-were 268 fish/tow and 54.1 fish/tow, or 2.86 kg and 1.30 kg per tow, respectively (Stender and Barans 1994). The average length of Atlantic croakers caught in the port two-seam trawl was 15.8 cm total length and the average length of Atlantic croakers caught in the starboard tongue trawl was 14.2 cm total length. North Carolina conducted an observer study of the near-shore ocean shrimp trawl fishery from 2007 to 2008 and estimated 1.19 kg of Atlantic croakers were caught for every 1.0 kg of shrimp (Brown 2009). In 2008, a total of 3,820 metric tons of shrimp were landed in North Carolina from trawls, suggesting a potential bycatch of 4,545 metric tons of Atlantic croaker, or nearly twice the reported landings. North Carolina inland shrimp fisheries are expected to have higher rates of Atlantic croaker bycatch, as they exert more effort in Atlantic croaker habitat (Street et al. 2005). The length distribution of the Atlantic croaker bycatch was similar to that of Atlantic croaker caught in the bait fishery.

Annual estimates of Atlantic croaker bycatch in the Atlantic shrimp trawl fishery were produced for 1950 through 2008. Given the lack of detailed effort data and limited bycatch characterization data, estimates were produced using a fish catch to shrimp catch ratio method (see Appendix 1). All catch ratios were derived from studies conducted in North Carolina and South Carolina and expanded to the entire coast and are listed in Appendix 1. Previous shrimp trawl bycatch analyses for Atlantic croaker showed over 99% of bycatch was Age 0 (Foster 2004). These estimates must be considered extremely crude; catch ratios are different between locations and between gears, but assumed homogeneous in this exercise. These data should not be used for stock assessment other than for sensitivity analyses.

Estimated annual Atlantic croaker bycatch from 1950–2008 averaged 21.7 million pounds with a range of 0.47 million in 2005 to 45.8 million in 1995. While there was no clear trend over the entire time series, there appeared to be a decline in bycatch estimates from the early 1950s through 1978, a steady increase from 1979 through 1995, and then a declining trend since then (see Figure A1.2, Appendix 1). The decline in estimated bycatch since 1995 is a reflection of

declining shrimp landings in the south Atlantic region since 1995. When compared to the reported commercial landings for the Atlantic coast, the estimated bycatch of Atlantic croaker was greater by several orders of magnitude for most years (see Figure A1.3, Appendix 1). This produced an estimated total landings for Atlantic croaker that was significantly higher than the actual reported commercial landings. Estimated bycatch made up 50% or greater of the revised total landings in most years. The exception was two time periods (1976–1981 and 1997–2008) where shrimp landings were low and the resulting estimated bycatch was also low. While the estimated levels of bycatch for Atlantic croaker in the shrimp fishery were admittedly rough approximations, the relative magnitude of the bycatch estimates in relation to the actual reported commercial landings indicate that the shrimp fishery could represent a significant portion of the fishing mortality beyond the already reported commercial landings on Atlantic croaker.

#### 5.1.3.3 Finfish Fishery Bycatch

Two datasets were available on commercial finfish fishery bycatch and discard rates: the NMFS Observer Program dataset (1989–2008) and the North Carolina Summer Flounder Gillnet Observer Program dataset (Program 466, 2001–2008). Although sample size was limited in the NMFS Observer Program (Table 5.1.3.3.1), the programs do not cover the same areas (the NC program is inshore and limited to one state, the NMFS program is offshore and covers a wider range of states) or target species (the NC program only monitors summer flounder gillnets, the NMFS program monitors several different fisheries). Because of these differences, the SASC felt the two programs were not directly comparable and chose not to use the NC program dataset to estimate discards, preferring the longer time-series of the NMFS program dataset.

For the continuity run of the age-structured production model used in the 2003/04 assessment, discard ratios for gillnets and otter trawls were estimated with the PROC SURVEYMEANS algorithm in SASC, as was done in the previous assessment. The year and gear specific ratios for 2003–2008 were used to estimate the discards from gillnet and otter trawl landings to extend that time-series (Table 5.1.3.3.2).

For use in all non-continuity runs of the current assessment, the SASC examined trends in three different ways of estimating discards: the PROC SURVEYMEANS method, the aggregate trips method (which calculates the ratio of total annual observed discards to total annual observed landings) and the geometric mean of the annual discard ratios. The geometric mean smoothed out high inter-annual variability seen in the other two methods (Table 5.1.3.3.3; Figure 5.1.3.3.1). The SASC chose to use the gear and year-specific geometric means of the ratios of discarded Atlantic croaker to landed Atlantic croaker, as was done in the scup assessment and recommended by the MAFMC (Northeast Data Poor Stocks Working Group 2009).

For years with no observer coverage, gear-specific ratios were estimated from two periods of observer coverage: years with increasing landings and years with decreasing landings (Table 5.1.3.3.4). These ratios were then applied to years without observer coverage based on trends in landings to estimate historical discards (Figure 5.1.3.3.2). Years prior to 1994 were not well covered and produced unrealistic large discard ratios (e.g., 95:1 for gillnets in 1993); therefore, the ratios for the unobserved time periods were used for these years as well.

There are no estimates of the discard mortality of Atlantic croakers caught as bycatch. Johnson (2003) determined the immediate (15–30 minutes) survival of discards onboard estuarine commercial shrimp trawlers. His results showed that the survival of Atlantic croakers decreased as time on deck increased—from 40% survival for Atlantic croakers that were on deck less than

20 minutes to 8% survival for Atlantic croakers that were on deck longer than 20 minutes. No other estimates of Atlantic croaker discard mortality were found. Therefore, 100% mortality was used in modeling.

### 5.1.4 Commercial Catch Rates

Available effort data are insufficient (spatially and temporally) to calculate CPUE from the commercial fishery. The finest measure of effort available is a fishing trip. Although some states ask harvesters to report additional information important for standardization such as the number of nets fished, length of nets, etc., that information has not been consistently provided and is considered unreliable.

### 5.1.5 Commercial Landings-at-Age

The states of North Carolina, Maryland, Virginia, and New Jersey collect both age and length samples of Atlantic croaker from their commercial fisheries. Together, North Carolina, Virginia, and Maryland account for the vast majority of the total commercial landings of Atlantic croaker along the Atlantic coast, ranging from 88.3 to 99.6% annually. The available biological samples do represent the core of the fishery; however, landings-at-age information have to be extrapolated for other states using the available data.

There were not enough samples to develop age-length keys by gear, so annual ALKs were developed for all gears combined. A comparison of state-specific ALKs over the period 1998–2008 using Fisher's exact test (Hayes, 1993) showed that there were no significant differences between the state keys at the overall significance level of $\alpha = 0.01$ (the significance level of individual test is adjusted to account for the multiple comparisons). Therefore a single ALK, combined over states, was developed for each year.

Length frequency samples by major gear (trawl, seine, pound net, and gillnet) were converted from numbers at length to proportion at weight using annual length-weight equations. For landings reported from all other gears, a single combined length frequency was used. The proportion at weight was multiplied by the total annual landings by gear to get total catch-in-weight-at-length. Catch-in-weight-at-length was converted to catch-in-weight-at-age using the annual ALKs. This catch-at-age was summed across gears to develop a single commercial catch-at-age.

The same approach was used to develop the catch-at-age for the discard/scrap fishery, using a combination of length frequencies from the NMFS Observer Database and NC's bait sampling program. Estimates of catch-at-age were developed for otter trawls separately and for all other gears combined, as sampling was not adequate to describe other gears individually.

Otolith sampling of ages was begun in 1996. Prior to that, NC collected scales to assign ages, beginning in the early 1980s; however, sampling was not annual until 1988. From 1996 to 1999, paired samples of otoliths and scales were collected from the same fish for comparisons. As with other species, scale ages in Atlantic croaker tended to overestimate age in the youngest year-classes and underestimate age in the older classes, compared to otolith ages.

A scale-otolith transition matrix was developed from the years where paired samples were available. This matrix is similar to an age-length key in that it calculates the proportion of each scale age that corresponds to each otolith age. When it is applied to a year-specific ALK developed from scale ages, it converts the proportion of each length bin at scale age into proportions at otolith age. This converted age-length key was applied to the observed length

frequencies from 1988–1995 to develop a catch-at-age. The transition matrix did not cover the full range of observed ages and sample sizes above age 6 were small. These converted ages were not used in the base model, but were included in a sensitivity run.

## 5.2 Recreational Fisheries

### 5.2.1 Data Collection

The Marine Recreational Fishery Statistics Survey (MRFSS) program collects data on marine recreational fishing to estimate statistics characterizing the catch and effort in marine recreational fisheries. Recreational fisheries statistics for Atlantic croaker were obtained from the MRFSS online data query (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.). Information on sample sizes was retrieved from the MRFSS raw intercept files.

#### 5.2.1.1 Sampling Methods

Data collection consists primarily of two complementary surveys: a telephone household survey and an angler-intercept survey. In 2005, the MRFFS began at-sea sampling of headboat (party boat) fishing trips. Data derived from the telephone survey are used to estimate the number of recreational fishing trips (effort) for each stratum (see following section). The intercept and at-sea headboat data are used to estimate catch-per-trip for each species encountered. The estimated number of angler trips is multiplied by the estimated average catch-per-trip to calculate an estimate of total catch for each survey stratum. A detailed description of the MRFSS sampling methods is provided in the MRFSS User's Manual (ASMFC 1994).

The MRFSS estimates are divided into three catch types depending on availability for sampling. The MRFSS classifies those fish brought to the dock in whole form, which are identified and measured by trained interviewers, as landings (Type A). Fish that are not in whole form (bait, filleted, released dead) when brought to the dock are classified as discards (Type B1), which are reported to the interviewer, but identified by the angler. Fish that are released dead during at-sea headboat sampling, which began in 2005, are also classified as Type B1 discards. The sum of Types A and B1 provides an estimate of total harvest for the recreational fishery. Anglers also report fish that are released live (Type B2) to the interviewer. Those fish that are released alive during the at-sea headboat survey are also considered Type B2 catch. Total recreational catch is considered the sum of the three catch types (A+B1+B2). The numbers of Atlantic croaker of each catch type that were sampled by the MRFSS are presented in Table 5.2.1.1.1.

#### 5.2.1.2 Sampling Intensity

The number of telephone interviews conducted during each wave varies based on the amount of fishing activity expected for the season (NMFS, pers. comm.). Telephone sampling effort is allocated among coastal counties in proportion to household populations. Specifically, the allocation is based on the ratio of the square root of the population within each county to the sum of the square roots of all county populations within the state.

Intercept sampling is random and stratified by year, state, wave (two-month sampling period), and mode (type of fishing). A minimum of 30 intercepts are performed per stratum, though samples are allocated beyond the minimum in proportion to the average fishing pressure of the previous three years.

#### 5.2.1.3 Biases

The MRFSS estimates are based on a stratified random sampling design and so are designed to be unbiased. There have been a few instances when the random telephone survey was found to be unrepresentative and an average estimate of trips was substituted. Most recently, the 2002 telephone survey data were discarded for waves 2 and 3 and effort estimates were instead based on a three-year average (1999–2001) for those waves. The MRFSS advises that the weight estimates are minimum values and so may not accurately reflect the actual total weight of fish harvested. Other caveats associated with these data are discussed at the following web site: http://www.st.nmfs.gov/st1/recreational/queries/caveat.html.

Recent concerns regarding the timeliness and accuracy of the MRFSS program prompted the NMFS to request a thorough review of the methods used to collect and analyze marine recreational fisheries data. The National Research Council (NRC) convened a committee to perform the review, which was completed in 2006 (NRC 2006). The review resulted in a number of recommendations for improving the effectiveness and utility of sampling and estimation methods. In response to the recommendations, the NMFS initiated the Marine Recreational Information Program (MRIP)—a program designed to improve the quality and accuracy of marine recreational fisheries data. The MRIP program is being phased in gradually and will eventually replace the MRFSS. The objective of the MRIP program is to provide timely and accurate estimates of marine recreational fisheries catch and effort and provide reliable data to support stock assessment and fisheries management decisions. The program will be reviewed periodically and undergo modifications as needed to address changing management needs.

#### 5.2.1.4 Biological Sampling

The MRFSS interviewers routinely sample fish of Type A catch that are encountered during the angler-intercept survey. Fish discarded during the at-sea headboat survey are also sampled—the headboat survey is the only source of biological data characterizing discarded catch that are collected by the MRFSS. The sampled fish are weighed to the nearest five one-hundredth (0.05) of a kilogram or the nearest tenth (0.10) of a kilogram (depending on scale used) and measured to the nearest millimeter for the length type appropriate to the morphology of the fish. The numbers of Atlantic croaker biological samples taken by the MRFSS are summarized in Table 5.2.1.4.1.

#### 5.2.1.5 Ageing Methods

Atlantic croakers sampled from recreational fisheries are not routinely aged.

#### 5.2.1.6 Development of Estimates

Estimates of harvest in terms of numbers are available for all three catch types (Type A, B1, and B2). Weight estimates are only available for recreational harvest (Type A+B1). Details describing how the MRFSS uses data collected from the telephone interviews and angler-intercept survey to develop catch and effort estimates can be found in the MRFSS User's Manual (ASMFC 1994).

The length distribution of recreational harvest was determined by expanding the length measurements from the angler-intercept survey to the harvest estimates in numbers (Type A+B1). Examination of the data indicated that length samples were adequate to expand at the state/year/wave stratum level. Length distributions were based on 10-mm increments. There were many cells (state/year/wave strata) that had fewer than 50 length measurements per cell.

For those cells that had less than 50 measurements, a length distribution based on a collapsed group of cells was used in a hierarchical manner:

1) If the number of length measurements were 50 or greater, those lengths were used to represent the state/year/wave strata.
2) If the number of length measurements were less than 50, the length distribution applied to the cell were based on state/year/wave strata. The two wave groups used were waves 1 to 3 collapsed and waves 4 to 6 collapsed.
3) If, after using the collapsed length distribution the number of measurements for the cell was less than 50, the length distribution used to fill the cell was based on the length distribution at the state/year stratum level.
4) If, after using the previous collapsed length distribution, the sample size was less than 50, a length distribution based on measurements at a sub-region/year level were applied. The fishery was divided into three regions: Northeast (Virginia and north); North Carolina; and Southeast (South Carolina and south).

If, after using this final criterion there were a small number of cells (4) with less than 50 measurements, the cells were not collapsed further.

Once the landings were assigned a length distribution, the harvest (Type A+B1) was appropriately apportioned among the length ranges representing the cell.

### 5.2.2 Recreational Harvest

Along the Atlantic coast, annual recreational harvest (Type A+B1) of Atlantic croaker has ranged from a low of 2.81 million fish in 1981 to a high of 13.2 million fish in 2001 during 1981 through 2008 (Table 5.2.2.1). In terms of weight, recreational harvest ranged from a low of 611 mt in 1981 to a high of 5,027 mt in 2001 for the same time period (Figure 5.2.2.1).

The majority of Atlantic croaker recreational harvest was taken in Virginia, which accounted for 62% of the total number of Atlantic croakers harvested by recreational anglers along the Atlantic coast during 1981 through 2008 (Table 5.2.2.2). A large part of the remaining recreational harvest numbers were attributed to Florida (10%), North Carolina (9.8%), and Maryland (8.9%) for the same time period. There were no estimates of recreational harvest for Rhode Island and New York and recreational harvest was estimated to occur in only one year for Massachusetts. New Jersey and Delaware had little to no Atlantic croaker harvest prior to 1993 but have had harvested more than 250,000 fish annually since 1999.

The lengths of Atlantic croaker harvested (Type A+B1) by recreational anglers along the Atlantic coast have varied between 2.2 and 55 cm total length (Figure 5.2.2.2). The average total length of Atlantic croaker harvested recreationally has ranged from a low of 20.4 cm observed in 1983 to 30.4 cm observed in 2000 (Figure 5.2.2.3). The length-frequency distributions and annual average lengths demonstrate an increase in the length of recreationally harvested Atlantic croakers during the early to mid-2000s (see also Lee 2005). The recreational length samples collected in 2007 and 2008 suggest the length of Atlantic croakers harvested by recreational anglers may be decreasing (Figure 5.2.2.4).

### 5.2.3 Recreational Live Releases

The estimated number of Atlantic croaker released alive by recreational anglers along the Atlantic coast has been variable, ranging from a low of 1.1 million fish in 1982 to a high of 16.4 million fish in 2000 (Table 5.2.2.1). The MRFSS estimates suggest a general increase in the number of live releases from 1981 through 2008.

No estimates of discard mortality for Atlantic croaker released alive from the recreational fishery were identified. Participants in the ASMFC Atlantic Croaker Data Workshop agreed to assume a discard mortality of 10% for Atlantic croaker released live (Type B2) from the recreational fishery. The participants noted that this estimate may not represent the true discard rate. Recreational discards are those fish caught and released alive, but assumed to die as result of such factors such as hooking mortality and improper handling.

The only sources of biological data characterizing fish released by recreational anglers are the MRFSS at-sea headboat survey (2005–present) and Maryland's headboat sampling program (1997–2000). Maryland's headboat survey samples both harvested and released fish. The MRFSS headboat live releases of Atlantic croakers ranged in length from 9.80 to 44.7 cm total length during 2005 to 2008 (Figure 5.2.2.4). Atlantic croakers sampled from headboat harvest by the MRFSS ranged from 11.9 to 47.0 cm total length during the same years. The lengths of Atlantic croaker releases sampled in the Maryland headboat survey ranged from 13.0 to 28.1 cm total length during 1997 to 2000 (Figure 5.2.3.1). Samples of fish harvested by Maryland headboats ranged from 15.8 to 46.7 cm total length. Visual comparisons of the length-frequency distributions of harvested and released Atlantic croakers collected from headboats by the MRFSS and Maryland surveys suggest the released fish are smaller than harvested fish (Figures 5.2.2.4, 5.2.3.1). The Kolmogorov-Smirnov two-sample test was used to test the null hypothesis that fish harvested and released from recreational headboats have identical length-frequency distributions against the one-sided alternative that the length-frequency distribution of fish released from headboats is less than the length-frequency distribution of fish harvested by headboats (Steel et al. 1997). Comparisons were made by year within each dataset (MRFSS headboat samples: 2005–2008; Maryland headboat survey: 1997–2000). For each year tested within each dataset, the null hypothesis was rejected ($P<0.001$) in favor of the alternative; that is, Atlantic croakers released from recreational headboats are smaller than Atlantic croakers harvested by recreational headboats. These results suggest that recreational anglers are discarding smaller fish.

Recreational releases are only reported by MRFSS as numbers. To estimate the weight of recreational releases, we used the ratio of the average weight of released fish (as calculated from the length frequencies observed from 2005–2008) to the average weight of retained fish over that same period to estimate the average weight of released fish in years prior to 2005, when only sizes of the retained fish were observed. This average weight was multiplied by the number of released fish to obtain a total weight of recreational releases. A 10% release mortality rate was assumed, so 10% of the total released biomass was included in the model as catch to represent the recreational release mortality.

### 5.2.4 Recreational Catch Rates

Recreational catch per unit effort (CPUE) was computed in units of number fish per angler-trip for the total catch and the harvest. Two different methods were used to calculate the CPUE: the directed trips method and the Stephens and MacCall (2004) method. The directed trips method produced unbiased estimates of "directed" angler trips by applying the proportion of intercepted trips that were "directed" toward Atlantic croaker to estimates of total marine recreational angler

trips. Directed trips were defined in two ways: either those trips where Atlantic croakers were reported as targeted (under the variables “prim1” or “prim2”) or caught (A1+B1+B2), or as trips where Atlantic croakers were targeted or harvested (A+B1 only). Type B2 group catches (fish released alive) were assigned angler-trip values based on the leader with additional anglers acting as followers. The proportion of directed trips was calculated based on the count of directed trips relative to all samples taken in a year/state/wave/mode/area strata. That proportion was then applied to the effort estimate for the same strata and summed up to the year/region level. The MRFSS data used included those areas ranging from Massachusetts to the east coast of Florida excluding Monroe County, accessed through the ACCSP Data Warehouse.

The Stephens and MacCall (2004) method used a binomial regression of the presence/absence of co-occurring species to subset trips that were likely to have occurred in Atlantic croaker habitat and thus were likely to have caught Atlantic croaker, whether or not they qualified as a "directed" trip. Catch data from this subset of trips were then standardized using the delta-lognormal method to produce a CPUE index (see Appendix 2). The TC was concerned that the species associations calculated by this method were not biologically realistic and decided that this method was not appropriate for the extensive geographic range and multiple fishing modes of the Atlantic croaker recreational data. This index was not used in this assessment.

Total catch per unit effort and harvest per unit effort track each other over the time-series (Figure 5.2.4.1, Table 5.2.4.1). Although the CPUE for the southern region is lower than the CPUE for the mid-Atlantic region, both indices show nearly identical trends in the directed trips method (Figure 5.2.4.2, Table 5.2.4.2 and 5.2.4.3). The recreational CPUE for the coast increased during the early 1980s, reaching its peak in 1986. Since 1987, CPUE has shown inter-annual variation without trend.

### 5.2.5 Recreational Catch-at-Age

Atlantic croaker samples from the recreational fishery are not routinely aged, thus age-length keys derived from commercial fishery samples were applied to the observed recreational length frequencies to develop recreational catch-at-age matrices.

Mortality due to recreational releases was assumed to be 10%. Length frequencies of released fish were only available from 2005–2008.

## 5.3 Fisheries-Independent Surveys

Thirty-one fisheries-independent surveys were examined and four were selected for use in the model (NMFS bottom trawl, VIMS, SEAMAP-South Atlantic, and the North Carolina 195 survey). These surveys generally provided a larger coverage area or sampled the core area of Atlantic croaker distribution, demonstrated regular encounters with Atlantic croaker, and positive encounters provided sample sizes sufficient to develop frequency distributions. The four selected surveys and resulting indices are described in this section and the remaining surveys are described in Appendix 3.

### 5.3.1 NMFS Bottom Trawl Survey

#### 5.3.1.1 Survey Design & Methods

In 1963, the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) implemented a multispecies bottom trawl program, which surveys over a large portion

of the Atlantic shelf (Avarovitz 1981; Grosslein 1969). The objective of the program is to monitor trends in abundance and distribution, characterize age/length structure, and better understand the biology and ecology of a wide array of finfish and invertebrate species.

The survey uses a stratified random design, with strata based on depth (0.0–9.0 m; 9.0–18 m; 18–27 m; 27–55 m; 55–110 m; 110–188 m; 188–366 m). Both inshore and offshore strata are sampled. The autumn survey is an inshore survey that samples sites from Cape Hatteras to Cape Cod. The area within each stratum is subdivided into one-nautical mile blocks that are selected randomly prior to the sampling trip.

The sampling gear is a #36 Yankee otter trawl rigged with rollers, 5-fathom legs, and 1,000-pound polyvalent door. A small-mesh cod-end liner (0.5-inch mesh) is used to retain young-of-year fish. Tow duration is 30 minutes.

#### 5.3.1.2 Sampling Intensity

The autumn component of the survey was initiated in 1963, and the spring survey began in 1968. Summer and winter surveys have been performed intermittently. The autumn component has been conducted consistently since 1972.

#### 5.3.1.3 Biological and Environmental Sampling

The catch of each tow is identified, counted, weighed, and measured. When the catch of a particular species is large, a subsample of individuals is measured. Data on sex, maturity, stomach contents, and disease are recorded.

Latitude, longitude, gear information, salinity, temperature, weather, and hydrographic parameters are recorded.

#### 5.3.1.4 Ageing Methods

Otoliths are removed from a subsample of Atlantic croaker caught and later aged at the laboratory.

#### 5.3.1.5 Evaluation of Survey Data

Data collected from the autumn component of the survey from 1972 onward were evaluated. An evaluation of the proportion of zero catches indicated that the occurrence of Atlantic croakers has been consistent throughout the duration of the survey. The length-frequency distributions of Atlantic croakers suggest the survey has primarily encountered age-1 fish. Early (≤ 8 cm total length) and late (mode at about 12-16 cm total length) age-0 Atlantic croakers were observed in some years (e.g., 1972, 1975, 1998, 1999, and 2001). These results are consistent with those documented by Lee (2005).

#### 5.3.1.6 Development of Estimates

Data from the fall months (September–November) were used to develop an index relative abundance (number per tow).

### 5.3.2 VIMS Juvenile Fish and Blue Crab Trawl Survey

#### 5.3.2.1 Survey Design & Methods

The Virginia Institute of Marine Science (VIMS) Juvenile Trawl Survey was implemented in 1955 to monitor the seasonal distribution and abundance of important finfish and invertebrate

species occurring in the Chesapeake Bay and its tributaries. The main objective of this survey is to develop indices of relative abundance to track year-class strength of target species.

The survey sites and sampling frequency has not been consistent throughout the history of the survey (Machut and Fabrizio 2009). The survey currently employs a mixed design, incorporating both stratified random sites and fixed (historical mid-channel) sites. The stratification system is based on depth and latitudinal regions in the bay (random stations), or depth and longitudinal regions in the tributaries (random and fixed stations). Each bay region spans 15 latitudinal minutes and consists of six strata: western and eastern shore shallow (4–12 ft), western and eastern shoal (12–30 ft), central plain (30–42 ft), and deep channel (>42 ft). Each tributary is partitioned into four regions of approximately ten longitudinal minutes, with four depth strata in each (4–12 ft, 12–30 ft, 30–42 ft, and >42 ft). Strata are collapsed in areas where certain depths are limited. In each tributary, fixed stations are spaced at approximately 5-mile intervals from the river mouths up to the freshwater interface. Fixed sites are assigned to strata based on location and depth. The stratified random sites are selected randomly from the National Ocean Service's Chesapeake Bay bathymetric grid, a database of depth records measured or calculated at 15-cartographic-second intervals.

The trawl gear configuration has been modified a number of times, but was standardized in 1979. The various gear configurations have been compared through extensive sampling in order to standardize the catch rates associated with each gear combination. Currently, a 30-ft semi-balloon otter trawl is towed by the R/V *Fish Hawk* using a 60-ft bridle. The trawl is composed of 1.5-in stretch mesh body, a 0.25-in mesh cod end liner, two 28 in × 19 in steel china-v doors, and an attached tickler chain. Tows are made along the bottom during daylight hours for five minutes. The trawl doors were changed in 1991, but the change did not significantly alter the catch.

#### 5.3.2.2 Sampling Intensity

Two to four sites are randomly selected for each bay stratum each month, and the number of sites varies seasonally. In shallow water strata, only one station is sampled per month. Bay sampling is not conducted during January and March, when few target species are available. One to two stations are randomly selected for most river strata each month. Fixed stations are sampled monthly.

#### 5.3.2.3 Biological and Environmental Sampling

The catch from each tow is sorted by species, and fish are enumerated and measured for length and all are released. Lengths are measured to the nearest millimeter using the length type appropriate for the morphology of each species. Random subsamples are taken when catches of a particular species are too large to process efficiently in the field. Invertebrates are identified and some are measured.

The volume of gelatinous zooplankton caught in the net is also measured for each tow because large catches of these organisms may affect the catch (e.g., changes in gear saturation or efficiency).

Hydrographic and station data such as latitude and longitude, depth, tidal current stage, secchi depth, air temperature, wind direction, wind speed, weather conditions, sea state, water temperature, salinity, and dissolved oxygen are also collected. Data characterizing the habitat or substrate type sampled by the trawl have been recorded since May 1998.

#### 5.3.2.4 Ageing Methods

No ageing is done in this survey.

#### 5.3.2.5 Evaluation of Survey Data

Staff at the VIMS has been revisiting the methods used to analyze the data collected by their various surveys and so the evaluation of the VIMS Juvenile Trawl Survey data was performed by VIMS personnel.

#### 5.3.2.6 Development of Estimates

A delta lognormal model was used to calculate an index of Atlantic croaker relative abundance (number per tow) based on data collected in April, May, and June during 1988 to 2008 (M. Fabrizio, VIMS, pers. comm.). The model was applied at the stratum level in order to maintain the integrity of the trawl stratified random sampling design. The proportion of positive tows within a stratum was calculated and the average of the log-transformed positive catches from that stratum was taken. A stratum average was then calculated by multiplying the proportion of positive tows and the back-transformed average of positive catches within each stratum. Stratum averages were then combined and weighted by area covered to produce the annual index.

The index represents fish that hatched the previous calendar year and belong to the cohort that survived one winter. The following length cut-offs were used in developing the index: April—110 mm total length; May—135 mm total length; and June—160 mm total length. The cut-offs were determined in the early 1990s based on the length-frequency distributions of the trawl survey catch. Woodward (2009) examined these length cut-offs and found that they were suitable for identifying fish from the recruiting year-class.

The trawl survey includes both random and fixed stations but the design is a random stratified survey design. The fixed stations were treated as random stations for the purposes of estimation. The fixed stations are found only in the rivers and the random stations far outnumber the fixed stations.

### 5.3.3 SEAMAP-SA Coastal Survey

#### 5.3.3.1 Survey Design & Methods

The Southeast Area Monitoring and Assessment Program - South Atlantic (SEAMAP-SA) Coastal Survey (previously known as the Shallow Water Trawl Survey) began in 1986 and is conducted by the South Carolina Department of Natural Resources (SCDNR) Marine Resources Division (MRD). This survey has provided long-term, fisheries-independent data characterizing the seasonal abundance and biomass of all finfish, elasmobranchs, decapod and stomatopod crustaceans, sea turtles, horseshoe crabs, and cephalopods that are accessible by high-rise trawls. The sampling area extends from the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, North Carolina, and Cape Canaveral, Florida (SEAMAP-South Atlantic Committee 2005).

The survey uses a stratified random design, where strata are delineated by the 4-m depth contour inshore and the 10-m depth contour off shore. A total of 102 stations are sampled each season within 24 shallow water strata. In previous years (1989–2000), stations in deeper strata—at depths ranging from 10 to 19 m—were also sampled in order to gather data on the reproductive condition of commercially important penaeid shrimp. Those strata were abandoned in 2001 in order to intensify sampling in the shallower depth zone.

The R/V *Lady Lisa*, a 23-m wooden-hulled, double-rigged, St. Augustine shrimp trawler owned and operated by the SCDNR, is used to tow paired 22.9-m mongoose-type Falcon trawl nets, without turtle excluder devices (TEDs). The body of the trawl is constructed of #15 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 41.3-mm stretch mesh and is protected by chafing gear of #84 twine with 10-cm stretch "scallop" mesh. A 91.4-m three-lead bridle is attached to each of a pair of wooden chain doors, which measure 3.0 m × 1.0 m and to a tongue centered on the headrope. The 26.3-m headrope, excluding the tongue, has one large (60 cm) Norwegian "polyball" float attached top center of the net between the end of the tongue and the tongue bridle cable and two 22.3-cm PVC foam floats located one-quarter of the distance from each end of the net webbing. A 1-ft chain drop-back is used to attach the 89-ft footrope to the trawl door. A 0.6-cm tickler chain, which is 0.9 m shorter than the combined length of the footrope and drop-back, is connected to the door alongside the footrope. Trawls are towed for twenty minutes, excluding wire-out and haul-back time, exclusively during daylight hours (1 hour after sunrise to 1 hour before sunset). Each net is processed separately and assigned a unique collection number.

#### 5.3.3.2 Sampling Intensity

Multi-legged cruises are conducted in the spring (April–May), summer (July), and fall (October).

#### 5.3.3.3 Biological and Environmental Sampling

After each tow, the contents of each net are sorted to species or genus, and the total biomass and number of individuals are recorded for all species of finfish, elasmobranchs, decapod and stomatopod crustaceans, cephalopods, sea turtles, xiphosurans, and cannonball jellies. Only total biomass is recorded for all other miscellaneous invertebrates and algae, which are treated as two separate taxonomic groups. Where a large number of individuals of a species occur in a tow, the entire catch is sorted and all individuals of that species are weighed; a random subsample is processed and the total number is estimated. For large trawl catches, the contents of each net are weighed prior to sorting and a randomly chosen subsample of the total catch is then sorted and processed. In every collection, each of the majority of priority species is weighed collectively and individuals are measured to the nearest centimeter. When a large number of individuals of any of the priority species are collected in a tow, a random subsample consisting of 30 to 50 individuals is weighed and measured. Sex and individual weights are collected for blue crabs, sharks, sea turtles, and horseshoe crabs. Reproductive information is collected for commercially important penaeid shrimp and blue crabs.

#### 5.3.3.4 Ageing Methods

Gonad and otolith specimens were collected from Atlantic croaker during 2001 through 2006, but these collections have been discontinued due to insufficiency of allocated funds.

#### 5.3.3.5 Evaluation of Survey Data

The autumn component of the SEAMAP-SA Coastal Survey has been conducted consistently since 1990, so data collected from 1990 onward were evaluated. An evaluation of the proportion of zero tows indicates that the SEAMAP-SA Coastal Survey has regularly encountered Atlantic croakers in the spring, summer, and fall components of the survey. Zero tows have been most prevalent during the spring component of the survey. The length-frequency distributions suggest that the majority of Atlantic croakers captured in the spring, summer, and fall components of the survey are one-year-olds.

#### 5.3.3.6 Development of Estimates

An index of relative biomass (kilograms per tow) was calculated using data from the fall component of the SEAMAP-SA Coastal Survey.

### 5.3.4 North Carolina Pamlico Sound Survey (Program 195)

#### 5.3.4.1 Survey Design and Methods

The Pamlico Sound Survey, also known as Program 195 (P195), was initiated by the NCDMF in 1987 to provide a long-term, fisheries-independent database for the waters of the Pamlico Sound, eastern Albemarle Sound, and the lower Neuse and Pamlico rivers (NCDMF 2009).

The survey samples fifty-two randomly selected stations based on a grid system (one-minute by one-minute grid system equivalent to one square nautical mile). Sampling is stratified by depth and geographic area. Shallow water is considered water between 6 to 12 feet in depth and deep water is considered water greater than 12 feet in depth. The seven designated strata are: Neuse River; Pamlico River; Pungo River; Pamlico Sound east of Bluff Shoal, shallow and deep; and Pamlico Sound west of Bluff Shoal, shallow and deep. As of March 1989, the randomly selected stations have been optimally allocated among the strata based upon all the previous sampling in order to provide the most accurate abundance estimates (PSE < 20) for selected species. A minimum of three stations (replicates) are maintained in each strata. A minimum of 104 stations are sampled each year to ensure maximum areal coverage.

Tow duration is 20 minutes at 2.5 knots using the R/V *Carolina Coast*, which is equipped with double-rigged demersal mongoose trawls. The R/V *Carolina Coast* is a 44-ft fiberglass hulled double-rigged trawler owned and operated by the NCDMF. The body of the trawl is constructed of #9 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 38.1-mm stretch mesh. The tailbag is 80 meshes around and 80 meshes long (approximately 3.1 m). A 36.6-m three-lead bridle is attached to each of a pair of wooden chain doors that measure 1.22 m × 0.0610 m and to a tongue centered on the headrope. A 60-cm “polyball” is attached between the end of the tongue and the tongue bridle cable. A 4.76-mm tickler chain that is 0.90 m shorter than the 10.4-m footrope is connected to the door next to the footrope. Trawl door coverage area is 9.51 sq m. The sampling coverage area is 8,152 sq m and the sampling coverage volume is 13,042 cu m.

Environmental data are recorded, including temperature, salinity, dissolved oxygen, wind speed, and direction.

#### 5.3.4.2 Sampling Intensity

The sampling season has undergone some changes since the survey’s inception. Beginning in 1991, sampling has been performed over a two-week period, usually the second and third weeks of both June and September. Sampling now occurs only in the Pamlico Sound and associated rivers and bays.

#### 5.3.4.3 Biological and Environmental Sampling

All species are sorted, and a total number and aggregate weight is recorded for each species. For target species, thirty to sixty individuals are measured, and total aggregate weights are taken. The catches from each of the two towed nets are combined to form a single sample in an effort to reduce variability.

#### 5.3.4.4 Ageing Methods

No ageing is done in this survey.

#### 5.3.4.5 Evaluation of Survey Data

An evaluation of the proportion of zero catches indicated that Atlantic croakers have been regularly encountered during both the June and September components of the survey. The length-frequency distributions indicate that age-0 and age-1 Atlantic croakers were captured during the June component of the Pamlico Sound Survey and that only age-0 Atlantic croakers were encountered during the September component of the survey. These results were also reported by Lee (2005).

#### 5.3.4.6 Development of Estimates

An index of relative young-of-year abundance (number per tow) was developed using the June observations of Atlantic croakers less than 14 cm total length (Lee 2005; Woodward 2009).

### 5.3.5 Indices

Five surveys were used to develop tuning indices used in the model. Four indices were based on fisheries-independent surveys (NMFS bottom trawl survey, VIMS survey, NC P195 survey, and a relative biomass index from the SEAMAP survey). A recreational catch CPUE based on MRFSS data (fisheries-dependent survey) was also used. The indices are summarized in Table 5.3.5.1.

## 6 METHODS

### 6.1 Age-Structured Production Model-Statistical Catch at Age Model Hybrid (Hybrid Model)—preferred model

#### 6.1.1 Overview

The age-structured production model applied in the previous ASMFC assessment of Atlantic croaker (ASMFC 2005b, 2005d) was modified to incorporate catch-at-age data for all or part of the time series being modeled. This hybrid model was developed using AD Model Builder (ADMB) software—a tool for developing and implementing nonlinear statistical models (ADMB Project 2009). Copies of the template file and data file used in the base run can be found in Appendix 8.

#### 6.1.2 Equations

Growth in length was described as a function of age based on the von Bertalanffy function:

$$L_a = L_\infty \left[ 1 - e^{-K\ a - a_0} \right]$$

where $L_a$ is length at age $a$, $L_\infty$ is the theoretical asymptotic average length, $K$ is growth rate at which the asymptote is approached, and $a_0$ is the hypothetical age at which length is zero.

Weight at age, $W_a$, is expressed as an allometric function of length:

$$W_a = \alpha L_a^{\ \beta}$$

where $L_a$ is length at age $a$, and $\alpha$ and $\beta$ are parameters describing the relationship.

Fishing mortality, $F$, was assumed to be separable into age and year effects:

$$F_{f,y,a} = s_{f,a}\hat{F}_{f,y}$$

where $s_{f,a}$ is selectivity for fleet $f$ at age $a$ and $\hat{F}_{f,y}$ is the fishing mortality rate of fully-selected fish for fleet $f$ in year $y$.

Total mortality in year $y$ at age $a$, $Z_{y,a}$, was calculated as:

$$Z_{y,a} = M_a + \sum_f F_{f,y,a}$$

where $M_a$ is the natural mortality rate at age $a$.

Unexploited spawning stock biomass-per-recruit, $SPR_0$, was computed as:

$$SPR_0 = 0.5 SPR_a W_a m_a$$

where $W_a$ is the individual weight at age $a$, $m_a$ is maturity at age $a$, and $SPR_a$ is the spawning stock biomass-per-recruit at age, which was calculated as:

$$SPR_a = \begin{cases} 1.0 & \text{for } a = 0, \\ SPR_{a-1} e^{-M_{a-1}} & \text{for } 1 \le a < A, \\ SPR_{a-1}\left(\dfrac{e^{-M_{a-1}}}{1-e^{-M_a}}\right) & \text{for } a = A \end{cases}$$

Population numbers-at-age in the initial year, $N_{1,a}$, were calculated as:

$$N_{1,a} = \begin{cases} R_0 SSB_{\text{Ratio}} & \text{for } a = 0, \\ N_{1,a-1} e^{-Z_{1,a-1}} & \text{for } 1 \le a < A, \\ N_{1,A-1} e^{-Z_{1,A-1}}\left(\dfrac{e^{-Z_{1,A-1}}}{1-e^{-Z_{1,A}}}\right) & \text{for } a = A \end{cases}$$

where $R_0$ is the virgin recruitment level and $SSB_{\text{Ratio}}$ is the ratio of spawning stock biomass (SSB) in the initial model year to the virgin level of spawning stock biomass.

For all other years, population abundance was computed as:

$$N_{y,a} = \begin{cases} \dfrac{0.8hR_0 SSB_{y-1}}{0.2R_0 SSB_{y-1} SPR_0 \;\; 1-h \;\; + SSB_{y-1}(h-0.2)} e^{V_y} & \text{for } a = 0, \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}} & \text{for } 1 \le a < A, \\ N_{y-1,A-1} e^{-Z_{y-1,A-1}} + N_{y-1,A} e^{-Z_{y-1,A}} & \text{for } a = A \end{cases}$$

where $h$ is the steepness parameter, $SSB_{y-1}$ is the spawning stock biomass in the previous year, and $V_y$ is the deviation in recruitment from the Beverton-Holt stock-recruitment relationship in year $y$.

Predicted catch in weight in year $y$ at age $a, \hat{C}_{y,a}$, was calculated using the Baranov catch equation:

$$\hat{C}_{f,y,a} = \frac{F_{f,y,a}}{M_a + F_{f,y,a}} N_{y,a} \left[ 1 - e^{-M_a + F_{f,y,a}} \right] W_a$$

The predicted indices, $\hat{I}$, were calculated as:

$$\hat{I}_{i,y} = \begin{cases} q_i \sum_a N_{y,a} s_{i,a} e^{-\Delta_i Z_{y,a}} & \text{for index in numbers} \\ q_i \sum_a N_{y,a} W_a s_{i,a} e^{-\Delta_i Z_{y,a}} & \text{for index in weight} \end{cases}$$

where $q_i$ is the catchability coefficient for index $i$, $s_{i,a}$ is the selectivity for index $i$ at age $a$, and $\Delta_i$ is the fraction of the year that has elapsed when the mid-point of the survey occurs.

### 6.1.3 Optimization

Estimated Parameters

The parameters estimated by the hybrid model are the fishing mortality rate for fully-selected fish for each fleet and year, $\hat{F}_{f,y}$ **;** the ratio of SSB in the initial model year to the virgin level of spawning stock biomass, $SSB_{\text{Ratio}}$; virgin recruitment, $R_0$; annual recruitment deviations, $V_y$; and catchability coefficients for each index, $q_i$. Bounds were imposed on all estimated parameters for numerical stability and to avoid unrealistic parameter values (Table 6.1.1).

Objective Function

Estimation of model parameters was achieved through minimization of a negative log-likelihood function. The total likelihood for the model is the weighted sum of individual likelihood components for catch, catch-at-age, indices, and recruitment deviations.

The likelihood component for the catch, $L_C$, was defined by:

$$L_C = \lambda_C \sum_f \left\{ \frac{\sum_y \left[ \log_e C_{f,y} - \log_e \hat{C}_{f,y} \right]}{2\sigma^2_{f,y}} + \log_e \sigma_{f,y} \right\}$$

where $C_{f,y}$ is the observed catch for fleet $f$ in year $y$, $\hat{C}_{f,y}$ is the predicted catch for fleet $f$ in year $y$, $\sigma_f$ is a measure of dispersion for $C_f$, and $\lambda_C$ is the weighting factor for $L_C$. The variance, $\sigma_{f,y}$, is

computed from the coefficient of variation, CV, associated with the observed catch values (Age-Structured Assessment Program, NFT 2009):

$$\sigma_{f,y}^2 = \log_e \ \mathrm{CV}_{f,y}^2 + 1$$

The likelihood component for the catch-at-age, $L_{CAA}$, was defined by:

$$L_{CAA} = -\lambda_{CAA} \sum_{f,y,a} n_{f,y,a} \, p_{f,y,a} \log_e \ \hat{p}_{f,y,a}$$

where $n_{f,y,a}$ is the sample size for fleet $f$ in year $y$ at age $a$, $p_{f,y,a}$ is the observed proportion of catch-at-age for fleet $f$ in year $y$ at age $a$, $\hat{p}_{f,y,a}$ is the predicted proportion of catch-at-age for fleet $f$ in year $y$ at age $a$, and $\lambda_{CAA}$ is the weighting factor for $L_{CAA}$.

The likelihood component for the indices, $L_I$, was defined by:

$$L_I = \lambda_I \sum_i \sum_y \left\{ \frac{\left[ \log_e \ I_{i,y} - \log_e \ \hat{I}_{i,y} \right]}{2\sigma_{i,y}^2} + \log_e \ \sigma_{i,y} \right\}$$

where $I_{i,y}$ is the observed index value for index $i$ in year $y$, $\hat{I}_{i,y}$ is the predicted index value for index $i$ in year $y$, $\sigma_{i,y}^2$ is the variance for index $i$ in year $y$, and $\lambda_I$ is the weighting factor for $L_I$. The variance, $\sigma_{i,y}^2$, is computed from the coefficient of variation, CV, associated with the observed index values (Age-Structured Assessment Program, NFT 2009):

$$\sigma_{i,y}^2 = \log_e \ \mathrm{CV}_{i,y}^2 + 1$$

The likelihood component for the recruitment deviations, $L_V$, was defined by:

$$L_V = \lambda_V \sum_y \left[ \log_e \ V_y \right]^2$$

where $V_y$ is the deviation in recruitment in year $y$ and $\lambda_V$ is the weighting factor for $L_V$.

Standardized residuals provide an indication of how well the data fit the model. Standardized residuals were calculated for catch, indices, and catch-at-age data.

Standardized residuals for catch, $u_{i,y}$, were calculated as:

$$u_{f,y} = \frac{\log_e \ C_{f,y} - \log_e \ \hat{C}_{f,y}}{\sqrt{\dfrac{\sum_y \left[ \log_e \ C_{f,y} - \log_e \ \hat{C}_{f,y} \right]^2}{N_f - 1}}}$$

where $N_f$ is the number of years catch data for fleet $f$ were observed.

Standardized residuals for the indices, $u_{i,y}$, were calculated as:

$$u_{i,y} = \frac{\log_e \; I_{i,y} \; - \log_e \; \hat{I}_{i,y}}{\sqrt{\frac{\left[\log_e \; I_{i,y} \; - \log_e \; \hat{I}_{i,y} \; \right]^2}{N_i - 1}}}$$

where $N_i$ is the number of years catch data for index $i$ were observed.

Standardized residuals for the catch-at-age data, $u_{\mathrm{CAA},y}$, were calculated as:

$$u_{CAA,y} = \frac{p_{f,y,a} - \hat{p}_{f,y,a}}{\sqrt{\frac{\hat{p}_{f,y,a} \; 1 - \hat{p}_{f,y,a}}{v_{f,y}}}}$$

where $v_{f,y}$ is the effective sample size for fleet f in year y and was calculated as (Methot 2000):

$$v_{f,y} = \frac{\sum_a p_{f,y,a} \; 1 - p_{f,y,a}}{\sum_a \; p_{f,y,a} - \hat{p}_{f,y,a}{}^2}$$

In a perfectly fit model, the standardized residuals are normally distributed with mean 0 and standard deviation 1.

### 6.1.4 Model Set-Up

Scope

The current assessment applies to the entire coast-wide stock, from New Jersey to Florida. The working group felt there was no strong evidence to support multiple stocks occurring along the U.S. Atlantic Coast (see Section 2.4, this report). As such, data characterizing Atlantic croaker throughout this range were considered in the assessment.

Biological Parameters

The values used for the age-length and length-weight parameters were set equal to the values estimated using all available datasets (Table 6.1.2). Age-specific natural mortality rates were assumed time-invariant and equal to the values estimated based on Lorenzen's method (see Section 2.5.2, this report; Table 6.1.3). Values for age-specific maturity were estimated from NMFS Bottom Trawl Survey data using a logistic maturity function (Table 6.1.3).

The steepness parameter of the Beverton-Holt stock-recruitment relationship, $h$, was set equal to 0.76—the value used in the base run of the previous ASMFC Atlantic croaker assessment (ASMFC 2005b, 2005d). This value was the modal value of estimates of the prior distribution reported by Myers et al. (2002).

Observed Data

The hybrid model was applied to data collected from 1981 through 2008. The start year was so chosen largely because recreational fisheries statistics are not available prior to 1981. The previous ASMFC assessment used 1973 as the initial model year, which required hind-casting recreational estimates based on the ratio of commercial landings to total landings (ASMFC 2005b, 2005d). While the review panel of that assessment approved the approach, the current working group was uncomfortable with the uncertainty associated with utilizing hind-cast estimates.

The base run of the assessment model for Atlantic croaker consisted of four fishing fleets and five indices. The observed catch data used in the base run were commercial landings, commercial scrap/bait, recreational harvest, and recreational discards (dead B2 fish). Recreational fishery catch-per-unit-effort (CPUE) based on total catch was the only fisheries-dependent index used in the model (see Section 4.2.4, this report). The fisheries-independent indices included the fall component of the NMFS Bottom Trawl Survey (NMFS) and the fall component of the SEAMAP-SA Coastal Survey (SEAMAP). Additionally, the spring component of the VIMS Juvenile Fish and Blue Crab Trawl Survey (VIMS) and the June component of the North Carolina Pamlico Sound Survey, also known as Program 195 (NC195), were used as young-of-year indices. Refer to Section 4.3 for a discussion of how the fisheries-independent indices were selected and calculated.

Year-specific CV estimates derived from empirical data were available for recreational harvest, recreational discards, and most of the fisheries-independent survey indices. CV estimates were not available for the VIMS index, so a value of 0.20 was assumed for all years.

In the case of the commercial landings, the CVs were assumed to be equal to 0.1 from 1981-1993 and equal to 0.05 from 1994 onwards. The higher CVs in the early years represent the time period of dealer reporting, which the SAS considered less reliable than the mandatory trip-ticket systems of fishermen reporting implemented in the major croaker landing states by 1994. The scrap and discard time series was considered less precisely estimated than the commercial landings, and so had a CV of twice the commercial landings.

The CVs used for the recreational data series were the percent standard errors (PSE) calculated by MRFSS for their estimates of recreational harvest in weight and numbers, and recreational releases in numbers. The PSE of the recreational harvest was used as a proxy for the CV of the recreational CPUE, as MRFSS does not calculate a PSE for estimates of effort.

Catch-at-age data based on otolith ages were available for 1996 through 2008 (see Section 4.1.5, this report) for the commercial (landed and scrap/bait) and recreational harvest fisheries, but were not available for the recreational release mortality component of the catch.

## 6.2 Other Models

### 6.2.1 Age-Structured Production Model (ASPM)

The 2003/2004 assessment of Atlantic croaker used an age-structured production model (ASPM), versions of which were implemented in both Excel and AD Model Builder. For this assessment, the SASC employed the ASPM implemented in AD Model Builder for two reasons: to produce a continuity run to examine the effect of adding additional years of data to the 2003/2004 assessment; and to produce a coast-wide run for comparison to the preferred model base run using a different model but the same data. Methods and results are described in detail in

Appendix 4; results are compared to the preferred model base run in Section 7.2 Model Comparison.

### 6.2.2 Non-Equilibrium Production Model (ASPIC)

The SASC used a non-equilibrium age-aggregated production model (using ASPIC software) and an EXCEL spreadsheet implementation of a logistic dynamic production model to produce model runs meant to support the results of the preferred model base run. Methods and results are described in detail in Appendix 5; results are compared to the preferred model base run in Section 7.2 Model Comparison.

### 6.2.3 Catch Curve Analysis

The SASC used linearized catch curves to estimate total annual mortality rates (Z) using otolith-based age data available from state commercial fisheries sampling programs. The estimates of Z were produced to support the results of the preferred model base run. Methods and results are described in detail in Appendix 6; results are compared to the preferred model base run in Section 7.2 Model Comparison.

### 6.2.4 Stock Synthesis

After running the ASPM but before developing the preferred model, the SASC attempted to assess Atlantic croaker using the Stock Synthesis (SS) model (Appendix 7). The SS model was considered because it could make full use of all available data with little preprocessing of the data required. Also, the SS model was used in the coast-wide assessment of Atlantic croaker performed by Lee (2005); however, the runs of the model failed to converge or produced unrealistic parameter estimates, and the SASC was forced to develop an alternative assessment approach. Results are thus not available for comparison to the preferred model base run.

# 7 RESULTS

## 7.1 Age-Structured Production Model-Statistical Catch at Age Model Hybrid (Hybrid Model)—preferred model

### 7.1.1 Goodness-of-Fit

Standardized residuals from the fit of the base model to annual catch demonstrate a trend over time that was observed for each fleet (Figure 7.1.2). The trend suggests the model is overestimating annual catch during the early 1980s through the mid- to late 1990s and underestimating catch during the mid- to late 1990s through the mid-2000s. A similar trend was observed in the residuals in the previous ASMFC assessment (ASMFC 2005a). Tests for normality of the standardized residuals indicate both commercial landings and commercial scrap/bait/discards do not follow a normal distribution ($P \leq 0.01$; Figure 7.1.4).

Standardized residuals for the recreational CPUE show a trend over the model time period (Figure 7.1.3). The trend suggests underestimation of recreational CPUE from the model start year through the mid-1990s and overestimation of this index through most of the remainder of the time series. The NMFS Bottom Trawl Survey index standardized residuals demonstrate an increasing trend over the model time period (Figure 7.1.3). No obvious trends are apparent in the standardized residuals for the SEAMAP, VIMS, and NC195 indices (Figures 7.1.3).The standardized residuals for the recreational CPUE, NMFS, SEAMAP, and NC195 indices were

found to be normally distributed ($P$>0.01; Figure 7.1.5). The VIMS standardized residuals were not normally distributed ($P$<0.01).

One of the factors that can cause trends in index residuals is incorrect assumptions about catchability in the applied model. The base run of the hybrid model assumed the indices were directly proportional to stock size and catchability was constant over time. These assumptions were considered reasonable as there were no significant changes to the design of the MRFSS or NMFS surveys over the model time period. Also, there were no large-scale changes to recreational fisheries regulations over this time. However, if the spatial distribution of a population expands or contracts into areas of varying catchability, temporal changes in catchability may result even if the survey design remains constant (Armstrong 2008). The geographical range of croaker catches increases in years of higher landings, suggesting the stock may expand its range in years of higher abundance. This issue should be explored in more depth.

### 7.1.2 Parameter Estimates

The model estimates a total of 174 parameters:, an annual recruitment deviation from the stock-recruitment relationship, the number of virgin recruits ($R_0$), the ratio of *SSB* in year 1 to virgin *SSB*, and a catchability coefficient ($q$) for each of the indices (presented in Tables 7.3.1 & 7.3.2), along with an annual fully selected fishing mortality rate for each fishery (Table 7.3.3).

#### 7.1.2.1 Exploitation Rate

Total fully selected $F$ across all fisheries and the abundance-weighted average $F$ have fluctuated over time, decreasing through the 1980s, bottoming out and then increasing throughout the 1990s, reaching an extreme peak in 1998 before declining again to current levels that approximately the same as those at the beginning of the time series (Figure 7.1.19). $F$ follows the trends in landings over time.

#### 7.1.2.2 Abundance Estimates

Biomass increased in the early years of the time series and has remained above $SSB_{MSY}$, with fluctuations (Figure 7.1.18). Abundance has been more variable, driven by variable recruitment (7.1.20).

#### 7.1.2.3 Precision of Parameter Estimates

Although ADMB reports standard deviations for estimated parameters, these estimates are biased low when constraints are placed on the parameters.

### 7.1.3 Sensitivity Analysis

The inputs and results of the sensitivity runs are described in more detail in Appendix 8; all figures and tables referred to with the prefix A8 are located in that section.

#### 7.1.3.1 Sensitivity to Model Configuration

The previous assessment down-weighted fishery-dependent information (all catch time series and the recreational CPUE) relative to the fishery-independent indices. The base model of this assessment weighted all input data equally, although inputs have different CVs. A number of sensitivity runs were carried out that examined the effects of different weighting schemes and assumptions about CVs.

The inputs that most affected the results of the model were the catch-at-age information and the recreational CPUE (Figure A8.6. A8.7). When the catch-at-age was down-weighted, the estimated population biomass was much higher and the estimated fishing mortality was much lower, both in absolute numbers and relative to MSY, than in the base case. When the recreational CPUE was down-weighted, the population trend changed from fairly steady levels in recent years to a strongly increasing trend from an overfished state in the 1980s and early 1990s to a stock well above $SSB_{\mathrm{MSY}}$ in the last decade. Meanwhile, fishing mortality showed a complementary trend of decreasing from overfishing in the 1980s to an $F$ below $F_{\mathrm{MSY}}$ in more recent years. The MRFSS index itself does not show a strong trend over most of the time series, and when included balances out the increasing trends in landings and fishery-independent indices.

#### 7.1.3.2 Sensitivity to Input Data

Steepness did not have a large effect on the estimates of spawning stock biomass over time or annual average fishing mortality rates (Fig. A8.4), but it did affect the model's estimates of the biological reference points $SSB_{\mathrm{MSY}}$ and $F_{\mathrm{MSY}}$ (Fig. A8.5), with lower values of steepness resulting in higher values of $SSB_{\mathrm{MSY}}$ and lower values of $F_{\mathrm{MSY}}$.

Including the shrimp bycatch increased estimates of population biomass and fishing mortality, but decreased estimates of $SSB$ relative to $SSB_{\mathrm{MSY}}$ (Fig. A8.12). Although estimates of $F$ with and without the bycatch were similar in recent years, the early years of the time series with shrimp bycatch showed much higher fishing mortality, even above $F_{\mathrm{MSY}}$. $F$ decreased in the mid- to late 1990s, possibly correlating with the introduction of mandatory turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) on shrimp trawls. The estimates of $SSB$ relative to $SSB_{\mathrm{MSY}}$ are lower than those of the base run, and the spawning stock biomass was below $SSB_{\mathrm{MSY}}$, although increasing.

When the catch-at-age from 1988 to 1995 (i.e., the years in which ages were converted from scale ages to otolith ages) were included, estimates of biomass were lower, both in absolute numbers and relative to $SSB_{\mathrm{MSY}}$ over the entire time series (Fig. A8.11.). The stock dipped below $\mathrm{SSB}_{\mathrm{MSY}}$ at the end of the time series. Fishing mortality estimates in recent years were very similar between the two runs, both in absolute numbers and relative to $F_{\mathrm{MSY}}$; however, fishing mortality estimates were much higher in the early years of the time series when the converted scale ages were included.

### 7.1.4 Retrospective Analysis

Retrospect bias was examined by successively removing years of catch from the time series used to fit the model, from 2008 back to 2003. There did appear to be a retrospective pattern, with increasing years of data increasing the estimates of biomass and decreasing the estimates of $F$ (Figure A8.14). Note that this is the opposite of the retrospective pattern that has plagued other assessments such as Atlantic herring, where biomass estimates decrease and $F$ estimates increase.

### 7.1.5 Selectivity

A run of the model was allowed to estimate the selectivity patterns for the fleets and the three surveys that targeted age-0+ fish (the recreational CPUE, the NEFSC Trawl Survey, and the SEAMAP Fall Survey). The young-of-year surveys (VIMS, NC P195) were assumed to only select age-0 fish. The model had difficulty fitting the recreational CPUE index independently,

most likely due to the short time series of catch-at-age data, so the selectivity of the recreational index at age was fixed to either the selectivity of the recreational harvest or recreational release fleets at that age, whichever was greater. The model estimates were then fixed and used as input data for other model runs.

The model-estimated selectivity patterns were compared to the selectivity patterns used in the 2003 assessment (estimated from an untuned VPA) and alternative method of estimating selectivity from catch-curves (see Appendix 8 for more details on the method).

Estimates of annual average fishing mortality in absolute numbers were similar across all selectivity patterns, but differences in selectivity patterns affected both the reference point estimates and population estimates (Fig. A8.13).

### 7.2 Model Comparison

The results of the continuity model and ASPIC showed similar trends to the results of the preferred hybrid model, both showing increasing trends in biomass (Fig. 7.1.21). and decreasing trends in F (Fig. 7.1.22). The hybrid model was slightly more pessimistic than the continuity run and ASPIC, estimating lower biomass in recent years and slightly higher F. The continuity run and the base model agreed that the stock was not overfished, and that overfishing was not occurring, with $SSB_{2008}$ above $SSB_{MSY}$ and $F_{2008}$ below $F_{MSY}$. The ASPIC model tuned using both the recreational CPUE index and the NEFSC Fall Survey index indicated that while $F_{2008}$ was below $F_{MSY}$, total biomass remained below $B_{MSY}$, although only by a small amount. When only the NEFSC Fall Survey index was used to tune ASPIC, the biomass was above $B_{MSY}$ (Figure A5.3).

## 8 BIOLOGICAL REFERENCE POINTS

### 8.1 Overfished and Overfishing Definitions

Amendment 1 to the Interstate Fishery Management Plan for Atlantic Croaker established biological reference points for the Atlantic croaker resource based on the results of previous ASMFC stock assessment (ASMFC 2005a; 2005d). The fishing mortality threshold is defined as $F_{\mathrm{MSY}}$ and the fishing mortality target is defined as $0.75F_{\mathrm{MSY}}$. The biomass target is defined as $SSB_{\mathrm{MSY}}$ and the biomass threshold is $(1 - M)\ SSB_{\mathrm{MSY}}$.

The reference point values were estimated for the mid-Atlantic region only in the last assessment, as follows: $F_{\mathrm{Threshold}} = 0.39$; $F_{\mathrm{Target}} = 0.29$; $SSB_{\mathrm{Target}} = 28{,}932$ mt; and $SSB_{\mathrm{Threshold}} = 20{,}252$ mt (where $M$ was assumed to be 0.30)

### 8.2 Stock Recruitment Analysis

The hybrid model incorporated a Beverton-Holt stock-recruitment relationship reparameterized in terms of steepness (see Section 6.1., this report). The results of the base run suggest a weak stock-recruitment relationship for Atlantic croaker. The base run of the hybrid model yielded an estimate of 220 million fish for the virgin recruitment level and 49,524 mt for the virgin spawning stock biomass.

## 8.3 Results

### 8.3.1 Overfishing Definition

Fishing mortality reference points calculated by this model are the $F$ threshold $F_{\mathrm{MSY}}$ 0.455 and a target $F$ of $0.75F_{\mathrm{MSY}}$ = 0.341. Based on these reference points, the population-weighted $F$ averaged over ages 1–15+ (0.22 in 2008) is below the threshold and the target, indicating overfishing is not occurring (Figure 7.1.18).

### 8.3.2 Overfished Definition

The biomass target, $SSB_{\mathrm{MSY}}$ was estimated to be 26,268 mt in the base model. Average $M$ over ages 1–15+ was 0.25, so biomass threshold $(1 - M)\ SSB_{\mathrm{MSY}}$ is $(1 - 0.25)\ SSB_{\mathrm{MSY}}$ or 19,700 mt. $SSB$ in 2008 was 39,728 mt, above both the threshold and the target, indicating the stock is not overfished (Figure 7.1.18.).

# 9 RECOMMENDATIONS AND FINDINGS

## 9.1 Evaluation of current status based on biological reference points

The abundance-weighted $F$ was below both the target and the threshold estimated by the base model in 2008 and had been for several years.

Annual spawning stock biomass estimates were above the threshold and target estimated by the base model in 2008 and had been for most of the time series.

These results indicate the stock is not overfished and overfishing is not occurring.

## 9.2 Research Recommendations

- Continue fisheries-independent surveys throughout the species range and subsample for individual weights and ages, particularly in the southern range.
- Historical summaries of landings data from NOAA indicate landings are available at a finer scale (e.g., landings by water body, month) for the earliest years than are currently reported. We encourage efforts to recover these data and make them available for stock assessments.
- Collect data on fishing attributes necessary to develop gear-type-specific fishing effort estimates.
- Encourage fishery-dependent biological sampling of Atlantic croaker from the southern region. Collect age samples from the recreational fishery when the length distribution of the recreational fishery samples is not adequately represented by the fisheries from which the age-length keys are developed.
- Increased observer coverage for commercial discards.
- Conduct studies of discard mortality for recreational and commercial fisheries.
- Hybrid random sampling of commercial catch: sample catch for ageing at random, and mark those samples as selected randomly, then supplement underrepresented length bins with additional samples—this will avoid the necessity of weighting length-at-age estimates by the fisheries length frequencies.

- Develop a coast-wide tagging program for Atlantic croaker to evaluate migration and movement and continue any coast-wide studies (e.g., genetics, otolith microchemistry) designed to improve understanding of stock definition.
- Maintain SEAMAP funding.
- Re-examine historical ichthyoplankton studies of the Chesapeake Bay for an indication of the magnitude of estuarine spawning.
- Conduct study on fecundity in the south Atlantic and continue to develop estimates of length-at-maturity and year-round reproductive dynamics.
- Investigate environmental covariates in stock assessment models.
- Examine socioeconomic aspects of the fishery.
- Develop and implement sampling programs for state-specific commercial scrap fisheries in order to monitor the relative importance of Atlantic croaker in the scrap landings.

## 10 MINORITY OPINIONS

There were no dissenting opinions among the Stock Assessment Subcommittee.

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## 12 TABLES

**Table 1.2.2.1** History of state regulations specific to Atlantic croaker.

| State | Regulation | Date |
|---|---|---|
| NJ | Minimum 3.75” stretched diamond mesh or 3.375” stretched square mesh in beam or otter trawl cod end for directed harvest (>100 pounds) | 2001 |
| DE | 8” total length minimum size limit | 1984 |
| MD | 10” total length minimum size limit | 1960s |
| | 9” total length minimum size limit; 20 fish recreational creel limit | 1993 |
| | 9” total length minimum size limit; 20 fish recreational creel limit; commercial closure January 1-March 15 | 1995 |
| | 9” total length minimum size limit; 25 fish recreational creel limit; commercial closure January 1-March 15 | 1997 |
| PRFC | 10” total length commercial minimum size limit | 1963 |
| | 10” total length commercial and recreational minimum size limit | 1982 |
| | 10” total length minimum size limit; 20 fish recreational creel limit | 1996 |
| | 25 fish recreational creel limit; no size limits | 1999 |
| GA | 8” total length minimum size limit; 25 fish/day recreational and commercial, except shrimp trawlers (no limit) | 1989 |

**Table 1.2.2.2** Additional regulations affecting the harvest and bycatch of Atlantic croaker.

| State | Regulation | Date |
|---|---|---|
| NJ | Weakfish gill-net and pound-net seasonal closures established and trawl minimum mesh reduced (3” diamond) | 1992 |
| | Weakfish trawl seasonal closure established, gill-net seasonal closure lengthened, and trawl minimum mesh increased (3.25”) | 1995 |
| DE | Weakfish gill-net minimum mesh size (3.125”) and seasonal closures affect the harvest of Atlantic croaker | 1995 |
| MD | Weakfish trawl minimum mesh increased to 3.375” square or 3.75” diamond and gill-net and trawl seasonal closure lengthened | 1995 |
| | Trawling prohibited in Chesapeake Bay and coastal bays, and within 1 mile of coastal shore | 1933 |
| VA | Trawling prohibited in all state waters | 1989 |
| | Weakfish commercial gear minimum mesh sizes increased and seasonal closures established or increased | 1995 |

**Table 1.2.2.2** *Continued.*

| State | Regulation | Date |
|---|---|---|
| NC | Minimum mesh size restrictions in shrimp trawl (1.5” tailbag) and crab trawls (3.0”) established | Pre-1975 |
| | Finfish trawling prohibited in internal waters; shrimp and crab trawls limited to 1,000 lb of incidental finfish bycatch per trip | 1983 |
| | Shrimp and crab trawls in inside waters limited to 500 lb of incidental finfish from December 1-February 28 and 1,000 lb from March 1-November 30 | 1991 |
| | Catch of unclassified bait limited to 5,000 lb/vessel/day | 1991 |
| | Minimum mesh size restriction in shrimp trawls (1.5” tailbag) and crab trawls (3.0”); shrimp trawls prohibited areas established and headrope length limited to 90 ft | 1991 |
| | Fly net minimum stretched mesh size of 3.0” square or 3.5” diamond; fly nets defined as nets having the first body (belly) section consisting of 35 or more continuous meshes of 8.0” or greater (stretched mesh) webbing behind the bottom and top line, with tailbags less than 15 feet in length; tailbags constructed of square mesh may have the terminal 3 feet of mesh hung on a diamond with a minimum stretched mesh length of 2.0” | 1992 |
| | Bycatch reduction devices required in all shrimp trawls. | 1994 |
| | Fly nets prohibited in ocean waters from Cape Hatteras to NC/SC state line | 1994 |
| | Fly net vessels limited to 150 lb weakfish unless all fly nets onboard meet definition; gill nets limited to 150 lb weakfish unless mesh length > 2.875” stretched | 1996 |
| | Shrimp and crab trawls in Atlantic Ocean prohibited from possessing incidental finfish December 1-March 31 unless weight of the combined shrimp and crab catch exceeds weight of finfish | 1997 |
| | Small mesh (<5.0”) estuarine gill-net attendance requirement, May 1-November 30 in select areas in inside waters | 1998 |
| | Mandatory use of long haul cull panels and swipe nets south/west of a line from Bluff Point in Pamlico Sound to Ocracoke Island | 1999 |
| | Authorized gear allowed and restrictions applied to the Recreational Commercial Gear License; modified in 2008 to allow mechanical retrieval of shrimp trawl | 1999 |
| | Crab trawl minimum mesh size increased to 4” in western Pamlico Sound | 2005 |
| | Headrope length internally limited to 90 feet and shrimp trawl prohibited areas established | 2006 |

**Table 1.2.2.2** *Continued.*

| State | Regulation | Date |
|---|---|---|
| SC | Net ban | 1987 |
| | Turtle excluder devices required in shrimp trawls in summer | 1988 |
| | Turtle excluder devices required in shrimp trawls year-round | 1991 |
| | Bycatch reduction devices required in shrimp trawls | 1996 |
| GA | Gill nets prohibited (except for shad and diamondback terrapin) | 1957 |
| | All sounds closed to large trawl shrimp fishery; TEDs mandated | 1990 |
| | Bycatch reduction devices mandatory in large trawl shrimp fishery. | 1996 |
| FL | Entangling nets (e.g., trammel and gill nets) prohibited in all state waters | 1995 |
| | Directed finfish trawl prohibited; bycatch reduction devices mandatory | 1996 |

**Table 1.3.3.1** Biological reference points from the 2003 ASMFC assessment.

| Reference Point | Estimate† |
|---|---|
| Fishing mortality threshold: $F_{MSY}$ | 0.39 |
| Fishing mortality target: $0.75 \times F_{MSY}$ | 0.29 |
| Biomass threshold: $0.5 \times SSB_{MSY}$ | 14,466 mt |
| Biomass target: $(1\text{-}M) \times SSB_{MSY} = 0.7 \times SSB_{MSY}$ | 20,252 mt |

†: From base run of revised 2004 model.

**Table 2.2.1** Published values of observed average total length (centimeters) at age for Atlantic croaker.

| Location | Age Structure | Collection Period | Age | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| Georgia | scale | | 14.8 | 24.8 | 26.8 | 29.7 | | 38.9 | | | | Music and Pafford 1984 |
| Northern Gulf of Mexico | otolith | 1980-1981 | | 21.9 | 26.9 | 30.4 | 34.4 | 35.8 | 38.5 | 41.6 | 37.4 | Barger 1985 |
| North Carolina | scale | 1979-1981 | 14.4 | 19.2 | 27.1 | 32.0 | 37.1 | 43.0 | 47.3 | 51.4 | | Ross 1988 |
| Chesapeake Bay | otolith | 1988-1991 | | 20.1 | 26.3 | 27.4 | 28.5 | 29.0 | 30.7 | 30.9 | 31.3 | Barbieri et al. 1994a |

**Table 2.2.2** Calculated average total length (centimeters) at age for Atlantic croaker based on observations from available fisheries-independent survey datasets. [Note: ChesMMAP data included one fish with an age of –1 year, most likely a data entry error.]

| Area | Gear | Source | n | Age | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| NE Atlantic | Trawl | NMFS | 4,920 | | 18.7 | 22.5 | 26.6 | 29.3 | 32.2 | 32.8 | 35.3 | 36.2 | 37.9 | 38.2 | 37.6 | 40.3 | 37.3 | 38.5 | | | | |
| Ches. Bay | Trawl | ChesMMAP | 4,776 | 6.92 | 18.9 | 22.6 | 25.2 | 27.9 | 30.4 | 31.8 | 33.5 | 33.9 | 34.8 | 36.5 | 37.0 | 36.8 | 37.5 | 39.8 | | 33.6 | | 37.6 |
| SE Atlantic | Trawl | SEAMAP | 3,893 | | 16.7 | 19.1 | 21.6 | 23.0 | 23.5 | 25.2 | 23.3 | | | | | | | | | | | |

**Table 2.2.3** Calculated average total length (centimeters) at age for Atlantic croaker based on observations from available fisheries-dependent survey datasets.

| | | | | Age | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Area** | **Gear** | **Source** | **n** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
| NJ | Gill Net | NJBMF | 815 | | 30.3 | 31.1 | 32.4 | 34.2 | 35.0 | 34.8 | 37.4 | 36.6 | 36.1 | 37.4 | | | | | |
| NJ | Trawl | NJBMF | 382 | 17.7 | 23.2 | 27.3 | 29.0 | 31.2 | 31.3 | 35.3 | 34.3 | 34.6 | 37.5 | 35.9 | | | | | |
| MD | Pound Net | MDDNR | 569 | 19.6 | 22.3 | 25.7 | 29.4 | 33.7 | 37.2 | 38.2 | 39.9 | 40.5 | 40.9 | 40.3 | 39.1 | 37.1 | | | |
| VA | Gill Net | VMRC | 2,018 | 25.6 | 25.8 | 28.9 | 31.8 | 34.0 | 35.2 | 36.1 | 37.4 | 40.2 | 40.2 | 40.3 | 41.3 | 36.5 | 41.2 | 41.0 | |
| VA | Seine | VMRC | 426 | | 23.8 | 27.6 | 28.3 | 31.3 | 32.6 | 32.5 | 35.8 | 39.0 | 37.6 | 33.4 | 31.4 | | | | |
| VA | Pound Net | VMRC | 1,275 | 20.7 | 25.9 | 29.5 | 32.1 | 33.8 | 36.3 | 37.3 | 39.5 | 41.6 | 41.6 | 41.8 | 44.2 | 43.6 | 43.9 | | 49.2 |
| NC | Gill Net | NCDMF | 4,612 | 18.9 | 24.6 | 27.3 | 29.7 | 33.1 | 35.2 | 37.2 | 37.8 | 38.4 | 37.7 | 38.1 | 42.2 | 39.8 | 47.0 | 49.8 | |
| NC | Hook & Line | NCDMF | 83 | 16.6 | 20.7 | 22.5 | 24.2 | 23.7 | 37.6 | 39.8 | | | 45.1 | 46.0 | | | | | |
| NC | Pound Net | NCDMF | 277 | 16.1 | 19.0 | 22.1 | 29.1 | 31.6 | 31.8 | 35.8 | 37.5 | 37.1 | 36.8 | 32.3 | | | | | |
| NC | Seine | NCDMF | 811 | 16.1 | 20.6 | 24.4 | 25.3 | 26.5 | 28.6 | 30.9 | 33.1 | 33.5 | 40.7 | | | | | | |
| NC | Trawl | NCDMF | 2,946 | 15.2 | 20.9 | 25.0 | 29.0 | 32.8 | 35.6 | 37.3 | 38.3 | 37.4 | 38.2 | 39.4 | 41.4 | 43.6 | 40.8 | 39.4 | 41.8 |

**Table 2.2.4** Parameter estimates of the von Bertalanffy age-length growth function for Atlantic croaker from previous studies. Values of $L_\infty$ represent total length in centimeters.

| Location | Age Structure | Collection Period | $L_\infty$ | $K$ | $t_0$ | Reference |
|---|---|---|---|---|---|---|
| North Carolina | scale | | 59.0 | 0.31 | -0.0162 | Chittenden 1977 |
| Northern Gulf of Mexico | otolith | 1980-1981 | 41.9 | 0.27 | -1.41 | Barger 1985 |
| North Carolina | scale | 1979-1981 | 64.5 | 0.20 | -0.60 | Ross 1988 |
| Chesapeake Bay | otolith | 1988-1991 | 31.2 | 0.36 | -3.26 | Barbieri et al. 1994a |
| Florida | otolith | ~1450-1765 | 42.2 | 0.18 | -2.36 | Hales and Rietz 1992 |
| North Carolina | otolith | 1996-2002 | 43.4 | 0.24 | -1.96 | ASMFC 2005a |
| Virginia | otolith | 1998-2002 | 55.8 | 0.093 | -4.14 | ASMFC 2005a [1] |
| Virginia | otolith | 1998-2002 | 50.5 | 0.14 | -2.71 | ASMFC 2005a [2] |
| Virginia | otolith | 1998-2002 | 47.9 | 0.16 | -3.26 | ASMFC 2005a [3] |
| U.S. Atlantic coast | otolith | 1998-2002 | 44.8 | 0.25 | | Lee 2005 |

[1] Adjusted for month age, weight sample size (1/count age group)
[2] Adjusted for month age, not sample size weighted
[3] Based on biological age in months

**Table 2.2.5** Parameter estimates (standard error in parentheses) of the von Bertalanffy age-length growth function using available otolith-based age data, pooled over sexes (including unknown) and years. Values of $L_\infty$ represent total length in centimeters.

| Type | Area | Gear | Source | n | Max Age | $L_\infty$ | $K$ | $t_0$ |
|---|---|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | 4,920 | 13 | 41.8 (0.612) | 0.208 (0.00914) | -2.82 (0.0866) |
| Survey | Ches. Bay | Trawl | ChesMMAP | 4,772 | 17 | 37.2 (0.264) | 0.262 (0.00718) | -2.50 (0.0560) |
| Survey | SE Atlantic | Trawl | SEAMAP | 3,893 | 6 | 30.7 (1.98) | 0.195 (0.0346) | -4.02 (0.335) |
| Commercial | NJ | Gill Net | NJBMF | 815 | 10 | 37.0 (0.748) | 0.322 (0.0708) | -3.79 (0.989) |
| Commercial | NJ | Trawl | NJBMF | 382 | 10 | 38.8 (1.93) | 0.234 (0.0555) | -3.08 (0.751) |
| Commercial | MD | Pound Net | MDDNR | 569 | 12 | 46.0 (1.29) | 0.213 (0.0206) | -2.08 (0.226) |
| Commercial | VA | Gill Net | VMRC | 2,018 | 14 | 44.6 (1.03) | 0.166 (0.0170) | -4.42 (0.428) |
| Commercial | VA | Pound Net | VMRC | 1,275 | 15 | 48.1 (1.47) | 0.157 (0.0188) | -3.88 (0.458) |
| Commercial | VA | Seine | VMRC | 426 | 11 | 40.2 (2.26) | 0.186 (0.0447) | -3.91 (0.865) |
| Commercial | NC | Gill Net | NCDMF | 4,612 | 14 | 42.8 (0.482) | 0.214 (0.00920) | -2.85 (0.110) |
| Commercial | NC | Hook & Line | NCDMF | 83 | 10 | *Failed to converge* | | |
| Commercial | NC | Pound Net | NCDMF | 277 | 10 | 47.8 (3.48) | 0.150 (0.0251) | -2.46 (0.266) |
| Commercial | NC | Seine | NCDMF | 811 | 9 | 33.1 (1.25) | 0.301 (0.0352) | -2.24 (0.174) |
| Commercial | NC | Trawl | NCDMF | 2,946 | 15 | 43.5 (0.540) | 0.235 (0.00876) | -1.80 (0.0564) |

**Table 2.2.6** Parameter estimates of the allometric length-weight function for Atlantic croaker from previous studies, where length is measured as total length in centimeters and weight is measured in grams.

| Location | Collection Period | *a* | *b* | Reference |
|---|---|---|---|---|
| NW Gulf of Mexico | | 0.00741 | 3.15 | Dawson 1965 |
| Galveston Bay, TX | 1963-1964 | 0.00773 | 3.10 | Parker 1971 |
| Albemarle Sound, NC | 1972-1973 | 0.00721 | 3.15 | Hester and Copeland 1975 |
| Neuse River Estuary, NC | 1972-1973 | 0.00444 | 3.34 | Hester and Copeland 1975 |
| NW Gulf of Mexico | 1974 | 0.00776 | 3.15 | White and Chittenden 1976, 1977 |
| Georgia | | 0.0120 | 2.99 | Shipman 1983 |
| Georgia | | 0.00676 | 3.20 | Music and Pafford 1984 |
| Northern Gulf of Mexico | 1980-1981 | 0.00722 | 3.13 | Barger 1985 |
| North Carolina | 1979-1981 | 0.00545 | 3.23 | Ross 1988 |
| Chesapeake Bay | 1988-1991 | 0.00481 | 3.30 | Barbieri et al. 1994a |
| Northeast Atlantic | 1992-1999 | 0.00918 | 3.09 | Wigley et al. 2003 |

**Table 2.2.7** Parameter estimates (standard error in parentheses) of the allometric length-weight function for available datasets, pooled over sexes (including unknown) and years. The function was fit to total length in centimeters and weight in grams.

| Type | Area | Gear | Source | n | *a* | *b* |
|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | 4,919 | 0.00718 (0.000170) | 3.13 (0.00677) |
| Survey | Ches. Bay | Trawl | ChesMMAP | 4,960 | 0.00761 (0.000241) | 3.14 (0.00901) |
| Survey | SE Atlantic | Trawl | SEAMAP | 3,882 | 0.00670 (0.000235) | 3.12 (0.0116) |
| Commercial | NJ | Gill Net | NJBMF | 867 | 0.0297 (0.00377) | 2.78 (0.0358) |
| Commercial | NJ | Trawl | NJBMF | 442 | 0.0111 (0.000984) | 3.03 (0.0253) |
| Commercial | MD | Pound Net | MDDNR | 1,519 | 0.00950 (0.000758) | 3.08 (0.0218) |
| Commercial | VA | Gill Net | VMRC | 84,990 | 0.0245 (0.000252) | 2.80 (0.00293) |
| Commercial | VA | Pound Net | VMRC | 35,027 | 0.0101 (0.000155) | 3.05 (0.00428) |
| Commercial | VA | Seine | VMRC | 29,270 | 0.0106 (0.000192) | 3.04 (0.00536) |
| Commercial | NC | Gill Net | NCDMF | 6,088 | 0.0163 (0.000455) | 2.92 (0.00779) |
| Commercial | NC | Hook & Line | NCDMF | 254 | 0.0238 (0.00425) | 2.82 (0.0515) |
| Commercial | NC | Pound Net | NCDMF | 1,082 | 0.00801 (0.000454) | 3.14 (0.0162) |
| Commercial | NC | Seine | NCDMF | 2,479 | 0.00864 (0.000328) | 3.11 (0.0112) |
| Commercial | NC | Trawl | NCDMF | 5,645 | 0.00975 (0.00242) | 3.04 (0.00689) |
| Recreational | Atl. Coast | All | MRFSS | 93,781 | 0.0195 (0.000243) | 2.88 (0.00357) |

**Table 2.2.8** Parameter estimates (standard error in parentheses) of the von Bertalanffy age-length growth function using available otolith-based age data, by sex, pooled over years. Values of $L_\infty$ represent total length in centimeters.

| Type | Area | Gear | Source | Sex | n | $L_\infty$ | $K$ | $t_0$ |
|---|---|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | Male | 2,237 | 40.6 (0.846) | 0.200 (0.0128) | -3.04 (0.134) |
| | | | | Female | 2,631 | 43.3 (0.888) | 0.205 (0.0123) | -2.78 (0.116) |
| Survey | Ches. Bay | Trawl | ChesMMAP | Male | 2,089 | 39.2 (0.641) | 0.181 (0.0101) | -3.61 (0.146) |
| | | | | Female | 2,525 | 40.3 (0.577) | 0.198 (0.0101) | -3.24 (0.127) |
| Survey | SE Atlantic | Trawl | SEAMAP | Male | 1,606 | 32.4 (5.25) | 0.159 (0.0618) | -4.44 (0.702) |
| | | | | Female | 2,269 | 29.6 (1.93) | 0.220 (0.0433) | -3.85 (0.387) |
| Commercial | NJ | Gill Net | NJBMF | Male | 88 | 49.4 (50.6) | 0.0501 (0.162) | -18.6 (30.2) |
| | | | | Female | 157 | 41.1 (8.99) | 0.161 (0.214) | -7.33 (8.00) |
| Commercial | MD | Pound Net | MDDNR | Male | 165 | 43.7 (2.09) | 0.206 (0.0339) | -2.28 (0.389) |
| | | | | Female | 402 | 47.3 (1.57) | 0.211 (0.0240) | -2.08 (0.269) |
| Commercial | VA | Gill Net | VMRC | Male | 646 | 41.5 (1.39) | 0.183 (0.0308) | -4.28 (0.718) |
| | | | | Female | 1,352 | 46.0 (1.33) | 0.160 (0.0198) | -4.44 (0.508) |
| Commercial | VA | Pound Net | VMRC | Male | 341 | 46.5 (3.13) | 0.129 (0.0303) | -4.76 (0.942) |
| | | | | Female | 923 | 49.6 (1.76) | 0.156 (0.0218) | -3.88 (0.536) |
| Commercial | VA | Seine | VMRC | Male | 132 | 37.7 (2.47) | 0.249 (0.0853) | -2.96 (1.12) |
| | | | | Female | 220 | 39.3 (2.09) | 0.233 (0.0612) | -3.12 (0.871) |
| Commercial | NC | Gill Net | NCDMF | Male | 1,143 | 39.3 (0.557) | 0.256 (0.0174) | -2.45 (0.183) |
| | | | | Female | 3,344 | 46.8 (0.871) | 0.170 (0.0102) | -3.36 (0.156) |
| Commercial | NC | Hook & Line | NCDMF | Male | 21 | *Failed to converge* | | |
| | | | | Female | 52 | *Failed to converge* | | |
| Commercial | NC | Pound Net | NCDMF | Male | 120 | 45.7 (3.31) | 0.156 (0.0289) | -2.47 (0.330) |
| | | | | Female | 133 | 85.4 (51.0) | 0.0638 (0.0550) | -3.06 (0.775) |
| Commercial | NC | Seine | NCDMF | Male | 198 | 40.3 (4.80) | 0.151 (0.0440) | -3.58 (0.565) |
| | | | | Female | 465 | 31.1 (1.28) | 0.379 (0.0593) | -2.09 (0.244) |
| Commercial | NC | Trawl | NCDMF | Male | 794 | 44.3 (1.57) | 0.151 (0.0156) | -3.42 (0.257) |
| | | | | Female | 1,593 | 46.3 (0.944) | 0.202 (0.0124) | -2.24 (0.118) |

**Table 2.2.9** Parameter estimates (standard error in parentheses) of the allometric length-weight function for available datasets, by sex, pooled over years. The function was fit to total length in centimeters and weight in grams.

| Type | Area | Gear | Source | Sex | n | *a* | *b* |
|---|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | Male | 2,236 | 0.00746 (0.000257) | 3.12 (0.00993) |
| | | | | Female | 2,630 | 0.00693 (0.000234) | 3.14 (0.00956) |
| Survey | Ches. Bay | Trawl | ChesMMAP | Male | 2,149 | 0.00785 (0.000344) | 3.13 (0.0126) |
| | | | | Female | 2,607 | 0.00797 (0.000371) | 3.13 (0.0132) |
| Survey | SE Atlantic | Trawl | SEAMAP | Male | 1,604 | 0.00822 (0.000427) | 3.04 (0.0173) |
| | | | | Female | 2,260 | 0.00627 (0.000300) | 3.14 (0.0156) |
| Commercial | NJ | Gill Net | NJBMF | Male | 88 | 0.0363 (0.0180) | 2.71 (0.140) |
| | | | | Female | 157 | 0.0337 (0.00980) | 2.74 (0.0814) |
| Commercial | MD | Pound Net | MDDNR | Male | 455 | 0.0119 (0.00137) | 3.02 (0.0319) |
| | | | | Female | 1,054 | 0.00962 (0.00100) | 3.08 (0.0283) |
| Commercial | VA | Gill Net | VMRC | Male | 5,243 | 0.0220 (0.000711) | 2.84 (0.00919) |
| | | | | Female | 10,778 | 0.0228 (0.000499) | 2.84 (0.00614) |
| Commercial | VA | Pound Net | VMRC | Male | 2,839 | 0.0151 (0.000642) | 2.94 (0.0120) |
| | | | | Female | 5,465 | 0.0161 (0.000609) | 2.94 (0.0104) |
| Commercial | VA | Seine | VMRC | Male | 1,028 | 0.0160 (0.00120) | 2.93 (0.0221) |
| | | | | Female | 1,786 | 0.0155 (0.000953) | 2.95 (0.0176) |
| Commercial | NC | Gill Net | NCDMF | Male | 1,222 | 0.0170 (0.00119) | 2.90 (0.0196) |
| | | | | Female | 3,688 | 0.0185 (0.000665) | 2.89 (0.00996) |
| Commercial | NC | Hook & Line | NCDMF | Male | 19 | 0.00932 (0.00271) | 3.08 (0.0788) |
| | | | | Female | 76 | 0.0301 (0.00718) | 2.74 (0.0673) |
| Commercial | NC | Pound Net | NCDMF | Male | 137 | 0.00909 (0.000968) | 3.08 (0.0303) |
| | | | | Female | 183 | 0.00853 (0.00106) | 3.11 (0.0359) |
| Commercial | NC | Seine | NCDMF | Male | 262 | 0.0121 (0.00101) | 2.99 (0.0252) |
| | | | | Female | 643 | 0.00602 (0.000493) | 3.22 (0.0249) |
| Commercial | NC | Trawl | NCDMF | Male | 960 | 0.0104 (0.000630) | 3.02 (0.0172) |
| | | | | Female | 2,072 | 0.0130 (0.000610) | 2.96 (0.0129) |

**Table 2.2.10** Results of the ARSS analyses testing for differences in estimated von Bertalanffy age-length curves between sexes using available Atlantic croaker data.

| Type | Area | Gear | Source | degrees of freedom numerator | degrees of freedom denominator | *F*-statistic | *P*-value |
|---|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | 3 | 4,862 | 55.6 | < 0.001 |
| Survey | Ches. Bay | Trawl | ChesMMAP | 3 | 4,608 | 53.9 | < 0.001 |
| Survey | SE Atlantic | Trawl | SEAMAP | 3 | 3,869 | 19.6 | < 0.001 |
| Commercial | NJ | Gill Net | NJBMF | 3 | 239 | 6.03 | < 0.001 |
| Commercial | MD | Pound Net | MDDNR | 3 | 561 | 16.6 | < 0.001 |
| Commercial | VA | Gill Net | VMRC | 3 | 1,992 | 41.1 | < 0.001 |
| Commercial | VA | Pound Net | VMRC | 3 | 1,258 | 59.7 | < 0.001 |
| Commercial | VA | Seine | VMRC | 3 | 346 | 1.61 | 0.188 |
| Commercial | NC | Gill Net | NCDMF | 3 | 4,481 | 90.6 | < 0.001 |
| Commercial | NC | Hook & Line | NCDMF | *Failed to converge* | | | |
| Commercial | NC | Pound Net | NCDMF | 3 | 247 | 4.86 | 0.00266 |
| Commercial | NC | Seine | NCDMF | 3 | 657 | 7.76 | < 0.001 |
| Commercial | NC | Trawl | NCDMF | 3 | 2,381 | 83.7 | < 0.001 |

**Table 2.2.11** Results of the ARSS analyses testing for differences in estimated length-weight curves between sexes using available Atlantic croaker data.

| Type | Area | Gear | Source | degrees of freedom numerator | degrees of freedom denominator | *F*-statistic | *P*-value |
|---|---|---|---|---|---|---|---|
| Survey | NE Atlantic | Trawl | NMFS | 2 | 4,862 | 2.02 | 0.133 |
| Survey | Ches. Bay | Trawl | ChesMMAP | 2 | 4,752 | 29.1 | < 0.001 |
| Survey | SE Atlantic | Trawl | SEAMAP | 2 | 3,860 | 24.3 | < 0.001 |
| Commercial | NJ | Gill Net | NJBMF | 2 | 241 | 0.253 | 0.777 |
| Commercial | MD | Pound Net | MDDNR | 2 | 1,505 | 5.80 | 0.00311 |
| Commercial | VA | Gill Net | VMRC | 2 | 16,017 | 183 | < 0.001 |
| Commercial | VA | Pound Net | VMRC | 2 | 8,300 | 198 | < 0.001 |
| Commercial | VA | Seine | VMRC | 2 | 2,810 | 49.9 | < 0.001 |
| Commercial | NC | Gill Net | NCDMF | 2 | 4,906 | 42.1 | < 0.001 |
| Commercial | NC | Hook & Line | NCDMF | 2 | 91 | 4.85 | 0.00999 |
| Commercial | NC | Pound Net | NCDMF | 2 | 316 | 4.27 | 0.0149 |
| Commercial | NC | Seine | NCDMF | 2 | 901 | 53.2 | < 0.001 |
| Commercial | NC | Trawl | NCDMF | 2 | 3,028 | 3.40 | 0.0335 |

**Table 2.2.1.1** Sources of Atlantic croaker data and associated length measurements.

| Source | Total (max) | Total (relaxed) | Fork (midline) | Standard |
|---|---|---|---|---|
| NMFS | | | X | |
| ChesMMAP | | | | |
| SEAMAP | X | | | X |
| NJBMF | X | | X | |
| DEDFW | | | X | |
| MDDNR | X | | | |
| VMRC | X | | | |
| NCDMF | X | | | |
| SCDNR | X | | | |
| GADNR | | | X | |
| FLFWC | X | | | X |
| MRFSS | X | | | |

**Table 2.2.1.2** Description of length measurements used for Atlantic croaker.

| Measurement | Description |
|---|---|
| Total Length (max) | Measured from the most anterior point of the fish to the farthest tip of the tail with the tail compressed or squeezed together |
| Total Length (relaxed) | Measured from the most anterior point of the head to the tip of the tail when the tail is left in the "natural position" (not squeezed) |
| Fork Length (midline) | Measured from the most anterior point of the fish to the rear center edge of the tail |
| Standard Length | Measured from the most anterior point of the fish to the end of the vertebral column |

**Table 2.2.1.3** Parameter estimates (standard error in parentheses) of the length-length regression model for available datasets, pooled over sexes and years. The function was fit to total length in millimeters.

| Type | Area | Gear | Source | Length (X) | Length (Y) | n | Length Range | *a* | *b* | $r^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Survey | SE Atlantic | Trawl | SEAMAP | SL | TL | 3,897 | 62.0-374 | 1.16 (0.00379) | 13.1 (0.493) | 0.96 |
| Survey | SE Atlantic | Trawl | SEAMAP | TL | SL | 3,897 | 62.0-374 | 0.829 (0.00272) | -5.16 (0.551) | 0.96 |
| Commercial | New Jersey | All | NJBMF | FL | TL | 940 | 168-437 | 1.02 (0.002) | 0.178 (0.765) | 0.99 |
| Commercial | New Jersey | All | NJBMF | TL | FL | 940 | 168-437 | 0.975 (0.002) | 1.47 (0.747) | 0.99 |

**Table 2.3.2.1** Maturity schedule for Atlantic croaker from previous studies and estimated here based on available datasets, pooled over years. Length is represented as total length in centimeters.

| Type | Area | Gear | Source | Collection Period | n | Min. Length at Maturity | | Length at 50% Maturity [4] | | Min. Length at 100% Mature | | % Mature at Age 2 | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Males | Females | Males | Females | Males | Females | Males | Females | |
| Survey | Ches. Bay | | Literature | | | 24.0 | 27.5 | | | | | 45.0 | 0 | Wallace 1940 |
| Survey | NE Atlantic | Trawl | Literature | 1973-1976 | 1,708 | 17.0 | 18.0 | 18.7-22.4 | 18.5-23.3 | 23.0 | 25.0 | | | Morse 1980 |
| Commercial | Ches. Bay, VA, & NC | Various | Literature | 1990-1991 | 3,091 | 17.0 | 15.0 | 18.2 | 17.3 | 25.0 | 26.0 | >85.0 | | Barbieri et al. 1994b |
| Survey | NE Atlantic | Trawl | NMFS | 1997-2007 | 4,856 | 14.0 | 13.0 | 16.9 | 18.4 | 27.0 | 30.0 | 98.1 | 97.5 | This report |
| Survey | Ches. Bay | Trawl | ChesMMAP | 2002-2008 | 4,454 | 14.1 | 13.6 | 22.3 | 20.7 | 34.0 | 32.0 | 63.9 | 83.9 | This report |
| Survey | SE Atlantic | Trawl | SEAMAP | 2001-2006 | 3,771 | 13.0 | 13.0 | 18.4 | 19.0 | 25.0 | 25.0 | 69.0 | 72.9 | This report |
| Commercial | North Carolina | All | NCDMF [5] | 1996-2008 | 4,352 | 18.0 | 11.0 | 22.4 | 19.3 | 25.0 | 29.0 | 66.7 | 90.4 | This report |

[4] Length at 50% maturity values were model-estimated based on observed data

[5] Maturity data were collected from the NCDMF's Program 930 are not considered overly reliable and should be interpreted with caution; estimates for males are based on very low sample sizes (n=92 for entire time period)

**Table 2.3.3.1** Estimated percent female Atlantic croaker for available datasets, by month and annual, pooled over years.

| Type | Area | Gear | Source | Collection Period | n | % Female | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
| Survey | NE Atlantic | Trawl | NMFS | 1997-2007 | 4,868 | | | | | | | | | | | | | 54.0 |
| Survey | Ches. Bay | Trawl | ChesMMAP | 2002-2008 | 4,760 | | | 47.4 | 55.9 | 49.5 | 50.0 | 54.2 | 70.8 | 62.2 | 64.7 | 54.5 | | 54.8 |
| Survey | SE Atlantic | Trawl | SEAMAP | 2001-2006 | 3,880 | | | | 56.7 | 61.6 | | 56.4 | 53.5 | | 62.8 | 55.8 | | 58.5 |
| Commercial | Maryland | Pound Net | MDDNR | 2000, 2002-2008 | 1,522 | | | | | 62.5 | 69.6 | 61.1 | 78.8 | 93.1 | | | | 69.8 |
| Commercial | Virginia | All | VMRC | 1989-2008 | 31,716 | 50.0 | 41.9 | 67.3 | 71.3 | 68.0 | 66.6 | 54.4 | 62.2 | 79.0 | 72.7 | 69.7 | 64.0 | 66.5 |
| Commercial | North Carolina | All | NCDMF | 1996-2008 | 9,397 | 71.7 | 65.2 | 67.4 | 69.3 | 66.9 | 73.4 | 74.7 | 75.3 | 83.4 | 85.5 | 71.8 | 65.0 | 71.8 |

**Table 2.5.1.1** Estimates of age-constant natural mortality ($M$) for Atlantic croaker using Hoenig's methods based on maximum age, $t_{max}$. The maximum age was assumed equal to 17 years.

| Source | Equation | *M* Estimate |
|---|---|---|
| Hoenig 1983 | $M = \exp[1.44 - 0.982 \times \log_e(t_{max})]$ | 0.261 |
| Hoenig 1983; Rule-of-thumb | $M = -\log_e(0.05) / t_{max} \approx 3 / t_{max}$ | 0.176 |
| Hoenig 1983 | $M = -\log_e(0.01) / t_{max}$ | 0.271 |

**Table 2.5.1.2** Estimates of age-constant natural mortality ($M$) for Atlantic croaker using methods based on the von Bertalanffy growth coefficient, $K$. The maximum age, $t_{max}$, was assumed equal to 17 years.

| Source | Equation | Sex | *K* | | *M* Estimate |
|---|---|---|---|---|---|
| Alverson and Carney 1975 | $M = 3K / \{\exp[K(0.38 \times t_{max})] - 1\}$ | Pooled | min | 0.150 | 0.138 |
| | | | max | 0.322 | 0.275 |
| | | Male | min | 0.0501 | 0.182 |
| | | | max | 0.256 | 0.393 |
| | | Female | min | 0.0638 | 0.108 |
| | | | max | 0.379 | 0.375 |
| Jensen 1996 *theoretical* | $M = 1.50 \times K$ | Pooled | min | 0.150 | 0.225 |
| | | | max | 0.322 | 0.483 |
| | | Male | min | 0.0501 | 0.0752 |
| | | | max | 0.256 | 0.384 |
| | | Female | min | 0.0638 | 0.0957 |
| | | | max | 0.379 | 0.568 |
| Jensen 1996 *derived from Pauly (1980)* | $M = 1.60 \times K$ | Pooled | min | 0.150 | 0.240 |
| | | | max | 0.322 | 0.516 |
| | | Male | min | 0.0501 | 0.0802 |
| | | | max | 0.256 | 0.410 |
| | | Female | min | 0.0638 | 0.102 |
| | | | min | 0.379 | 0.606 |

**Table 2.5.2.1** Estimates of the von Bertalanffy age-length parameters used in Lorenzen's (2005) method to compute age-specific estimates of *M*. Values of $L_\infty$ represent total length in centimeters.

| Type | Area | Gear | Source | Sex | Max Age | $L_\infty$ | $K$ | $t_0$ |
|---|---|---|---|---|---|---|---|---|
| All | U.S. East Atlantic | All | All | Pooled | 17 | 43.1 | 0.214 | -2.35 |
| | | | | Male | 17 | 41.7 | 0.193 | -2.77 |
| | | | | Female | 15 | 45.7 | 0.191 | -2.58 |
| Survey | NE Atlantic | Trawl | NMFS | Pooled | 13 | 41.8 | 0.208 | -2.82 |
| | | | | Male | 13 | 40.6 | 0.200 | -3.04 |
| | | | | Female | 12 | 43.3 | 0.205 | -2.78 |
| Survey | Ches. Bay | Trawl | ChesMMAP | Pooled | 17 | 37.2 | 0.262 | -2.50 |
| | | | | Male | 17 | 39.2 | 0.181 | -3.61 |
| | | | | Female | 13 | 40.3 | 0.198 | -3.24 |
| Survey | SE Atlantic | Trawl | SEAMAP | Pooled | 6 | 30.7 | 0.195 | -4.02 |
| | | | | Male | 5 | 32.4 | 0.159 | -4.44 |
| | | | | Female | 6 | 29.6 | 0.220 | -3.85 |

**Table 2.5.2.2** Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method.

| | All | | | NMFS | | | ChesMMAP | | | SEAMAP | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Pooled** | **Male** | **Female** | **Pooled** | **Male** | **Female** | **Pooled** | **Male** | **Female** | **Pooled** | **Male** | **Female** |
| **0** | 0.461 | 0.445 | 0.508 | 0.533 | 0.524 | 0.574 | 0.415 | 0.406 | 0.512 | 0.894 | 1.04 | 0.888 |
| **1** | 0.374 | 0.370 | 0.416 | 0.447 | 0.444 | 0.479 | 0.347 | 0.352 | 0.439 | 0.794 | 0.925 | 0.790 |
| **2** | 0.324 | 0.325 | 0.362 | 0.396 | 0.395 | 0.423 | 0.308 | 0.318 | 0.393 | 0.727 | 0.846 | 0.725 |
| **3** | 0.293 | 0.295 | 0.327 | 0.362 | 0.363 | 0.386 | 0.284 | 0.293 | 0.362 | 0.680 | 0.788 | 0.681 |
| **4** | 0.272 | 0.275 | 0.303 | 0.338 | 0.340 | 0.360 | 0.268 | 0.276 | 0.340 | 0.645 | 0.745 | 0.649 |
| **5** | 0.257 | 0.260 | 0.285 | 0.321 | 0.323 | 0.342 | 0.256 | 0.263 | 0.324 | 0.619 | 0.712 | 0.626 |
| **6** | 0.246 | 0.249 | 0.272 | 0.309 | 0.310 | 0.328 | 0.248 | 0.253 | 0.312 | 0.600 | | 0.608 |
| **7** | 0.238 | 0.240 | 0.263 | 0.299 | 0.301 | 0.317 | 0.242 | 0.245 | 0.303 | | | |
| **8** | 0.232 | 0.234 | 0.255 | 0.292 | 0.294 | 0.309 | 0.238 | 0.239 | 0.296 | | | |
| **9** | 0.227 | 0.229 | 0.249 | 0.286 | 0.288 | 0.303 | 0.235 | 0.234 | 0.290 | | | |
| **10** | 0.223 | 0.224 | 0.244 | 0.282 | 0.283 | 0.298 | 0.232 | 0.230 | 0.286 | | | |
| **11** | 0.220 | 0.221 | 0.241 | 0.278 | 0.280 | 0.294 | 0.231 | 0.227 | 0.282 | | | |
| **12** | 0.218 | 0.219 | 0.238 | 0.276 | 0.277 | 0.291 | 0.229 | 0.225 | 0.279 | | | |
| **13** | 0.216 | 0.216 | 0.235 | 0.273 | 0.274 | | 0.228 | 0.222 | 0.277 | | | |
| **14** | 0.215 | 0.215 | 0.233 | | | | 0.227 | 0.221 | | | | |
| **15** | 0.214 | 0.213 | 0.232 | | | | 0.227 | 0.219 | | | | |
| **16** | 0.213 | 0.212 | | | | | 0.226 | 0.218 | | | | |
| **17** | 0.212 | 0.211 | | | | | 0.226 | 0.217 | | | | |

**Table 5.1.1.1** Summary of state-instituted programs for collecting commercial fisheries landings data.

| State / Jurisdiction | Source | Method of Reporting |
|---|---|---|
| New Jersey | Dealer | none |
| | Fisherman | none |
| Delaware | Dealer | none |
| | Fisherman | Mandatory monthly logbooks of daily activity (1985-present) |
| Maryland | Dealer | Mandatory monthly reporting of buying activity (2000-present) |
| | Fisherman | Mandatory monthly reporting (1980-2005); Mandatory daily logs (2000-present) [6] |
| PRFC | Dealer | none |
| | Fisherman | Mandatory reporting of daily activity (1964-present) |
| Virginia | Dealer | Voluntary monthly reporting (1973-1992) |
| | Fisherman | Mandatory trip-level reporting (1993-present) |
| North Carolina | Dealer | Monthly surveys (1978-1993); Mandatory trip-ticket reporting (1994-present) |
| | Fisherman | none |
| South Carolina | Dealer | Mandatory trip-ticket reporting |
| | Fisherman | none |
| Georgia | Dealer | Mandatory trip-level reporting (1989-present) |
| | Fisherman | Mandatory trip-level reporting (1989-present) |
| Florida | Dealer | Mandatory trip-ticket reporting (1984-present) [7] |
| | Fisherman | none |

[6] Maryland began phasing in the daily reporting logs in 2000; all commercial fishermen were reporting on the new forms by July 1, 2005

[7] The trip-ticket system became the official collection system in Florida in 1986

**Table 5.1.1.2** First year information on area and month are available for commercial landings data, by state.

| State | Commercial Landings by | |
|---|---|---|
| | Area | Month |
| New Jersey | 1962 | 1990 |
| Delaware | 1975 | 1995 |
| Maryland | 1964 | 1990 |
| Virginia | 1929 | 1973 |
| North Carolina | 1962 | 1972 |
| South Carolina | 1971 | 1978 |
| Georgia | 1962 | 1978 |
| Florida | 1961 | 1978 |

**Table 5.1.1.4.1** Availability of biological samples collected from commercial fisheries by state sampling programs.

| State | Lengths | | Weights | | Scales | | Otoliths | |
|---|---|---|---|---|---|---|---|---|
| | From | To | From | To | From | To | From | To |
| New Jersey | 2006 | 2008 | 2006 | 2008 | | | 2006 | 2008 |
| Maryland | 1993 | 2008 | 2000 | 2008 | | | 2000 | 2008 |
| Virginia | 1989 | 2008 | 1989 | 2008 | | | 1998 | 2008 |
| North Carolina | 1979 | 2008 | 1979 | 2008 | 1979 | 1999 | 1996 | 2008 |
| Florida | 1992 | 2008 | | | | | | |

**Table 5.1.2.1** Annual commercial landings (metric tons) of Atlantic croaker along the Atlantic coast, by state, 1950-2008. A "*" indicates confidential landings data.

| Year | MA | RI | NY | NJ | DE | MD | VA | NC | SC | GA | FL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1950** | | | | 17.19 | 2.767 | 1,142 | 3,027 | 950.6 | 13.20 | 0.4536 | 27.40 |
| **1951** | | | | 22.68 | 2.223 | 839.4 | 1,916 | 953.5 | 9.979 | | 55.02 |
| **1952** | | | | 37.51 | 3.765 | 385.7 | 1,652 | 610.7 | 10.43 | | 68.58 |
| **1953** | | | | 71.08 | 19.64 | 209.7 | 1,842 | 650.4 | 3.130 | | 42.64 |
| **1954** | | | | 167.5 | 27.26 | 414.1 | 2,324 | 460.6 | 2.313 | | 56.56 |
| **1955** | | | | 336.2 | 302.6 | 773.2 | 4,423 | 450.2 | 14.61 | | 91.44 |
| **1956** | | | | 34.84 | 12.34 | 793.2 | 4,385 | 2,190 | 33.34 | | 62.78 |
| **1957** | | | | 46.95 | 75.70 | 635.0 | 6,440 | 1,323 | 0.7711 | | 59.51 |
| **1958** | | | | 0.1814 | 1.451 | 298.7 | 5,378 | 3,139 | 4.400 | 0.04536 | 71.49 |
| **1959** | | | | 0.8165 | 3.946 | 380.3 | 3,472 | 1,386 | 4.082 | | 38.78 |
| **1960** | | | | 3.674 | 0.09072 | 265.8 | 1,784 | 949.3 | 9.299 | 0.1361 | 63.82 |
| **1961** | | | | 25.81 | | 22.18 | 1,398 | 795.4 | 6.033 | | 64.73 |
| **1962** | | | | 1.950 | | 5.035 | 586.8 | 754.2 | 15.10 | 0.2722 | 73.16 |
| **1963** | | | | | | 0.6804 | 55.52 | 1,032 | 16.42 | 0.3175 | 51.57 |
| **1964** | | | | | | 1.089 | 178.8 | 846.8 | 4.717 | 0.1814 | 45.90 |
| **1965** | | | | | | 0.1814 | 694.8 | 795.3 | 1.542 | 0.9525 | 48.44 |
| **1966** | | | | | | 0.3629 | 663.7 | 574.7 | 0.5897 | 2.313 | 150.0 |
| **1967** | | | | | | 0.5443 | 146.7 | 581.9 | | 2.722 | 65.23 |
| **1968** | | | | | | 0.04536 | 2.812 | 544.7 | | | 31.75 |
| **1969** | | | | | | 0.1814 | 28.67 | 620.8 | 0.09072 | 0.8165 | 22.63 |
| **1970** | | | | 0.09072 | | 0.04536 | 58.01 | 366.0 | 1.225 | 4.264 | 30.35 |
| **1971** | | | | 0.04536 | | 0.09072 | 120.2 | 430.1 | 0.6804 | 0.2268 | 40.73 |
| **1972** | | | | 0.1814 | | 0.2268 | 219.6 | 1,864 | 0.1814 | 1.089 | 45.86 |
| **1973** | | | 0.04536 | 16.83 | | 16.92 | 615.8 | 1,961 | 1.406 | 6.759 | 46.67 |
| **1974** | | | | 20.46 | | 54.57 | 681.3 | 2,759 | 18.10 | 3.856 | 29.53 |
| **1975** | | | | 401.5 | 0.5897 | 290.2 | 2,141 | 4,650 | 1.588 | 1.814 | 27.90 |
| **1976** | 0.04536 | | | 317.8 | 1.179 | 484.9 | 2,675 | 6,821 | 0.5897 | 6.169 | 35.56 |
| **1977** | | 0.1814 | | 670.7 | 4.037 | 314.0 | 3,901 | 8,616 | 0.2722 | 3.175 | 22.45 |
| **1978** | | 0.04536 | | 297.1 | 3.311 | 270.8 | 3,673 | 9,047 | 0.3311 | 0.2554 | 17.90 |
| **1979** | | 1.179 | 2.812 | 41.28 | 1.678 | 44.18 | 969.1 | 9,325 | 3.212 | 8.680 | 17.53 |

**Table 5.1.2.1** *Continued.*

| Year | MA | RI | NY | NJ | DE | MD | VA | NC | SC | GA | FL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1980** | | | 0.41 | 5.44 | | 3.22 | 322.74 | 9,592.03 | 2.47 | 2.14 | 23.09 |
| **1981** | | | 0.09 | 10.66 | | 0.95 | 194.96 | 5,082.66 | 1.11 | 0.47 | 32.71 |
| **1982** | | | | 0.05 | | 3.18 | 54.16 | 4,910.12 | 0.18 | 0.99 | 43.25 |
| **1983** | 0.09 | | | 0.09 | | 0.23 | 68.29 | 3,288.40 | 1.45 | 0.50 | 37.08 |
| **1984** | | 0.05 | 1.36 | 26.17 | | 12.29 | 370.93 | 4,159.79 | 1.72 | 0.20 | 59.59 |
| **1985** | 0.18 | | | 22.14 | 0.05 | 4.31 | 985.33 | 3,952.80 | 0.57 | | 52.45 |
| **1986** | | | | 48.08 | 0.23 | 62.37 | 1,065.82 | 4,275.03 | 0.42 | | 78.71 |
| **1987** | | | | 162.20 | 0.36 | 54.11 | 1,233.65 | 3,306.32 | 0.32 | 0.25 | 98.88 |
| **1988** | | | | 13.65 | 0.09 | 44.77 | 793.44 | 3,825.79 | 1.19 | 0.14 | 63.53 |
| **1989** | | | | 62.19 | | 40.60 | 430.75 | 3,095.35 | 0.88 | | 43.11 |
| **1990** | | 0.01 | | 0.29 | | 1.30 | 89.90 | 2,617.01 | 0.54 | | 47.36 |
| **1991** | | <0.01 | | 14.19 | 0.32 | 2.80 | 74.45 | 1,558.98 | * | | 25.74 |
| **1992** | | | | 23.41 | 0.36 | 8.42 | 607.54 | 1,268.52 | | | 35.85 |
| **1993** | | | | 83.20 | 1.13 | 90.70 | 2,388.15 | 1,482.18 | * | | 23.60 |
| **1994** | | | | 53.19 | 1.36 | 100.32 | 2,618.78 | 2,093.67 | * | | 43.55 |
| **1995** | | | | 151.80 | 5.90 | 248.67 | 3,171.08 | 2,731.21 | * | | 10.38 |
| **1996** | | | <0.01 | 282.08 | 4.39 | 531.07 | 4,288.98 | 4,518.61 | | | 11.81 |
| **1997** | | | 0.59 | 904.67 | 4.77 | 745.96 | 5,839.52 | 4,858.73 | * | | 16.59 |
| **1998** | | | 0.01 | 466.90 | 4.70 | 576.42 | 6,552.67 | 4,928.69 | | | 11.98 |
| **1999** | | <0.01 | <0.01 | 939.41 | 6.68 | 706.44 | 5,845.28 | 4,620.07 | | | 12.17 |
| **2000** | | 0.02 | 0.13 | 966.36 | 5.04 | 668.80 | 5,869.49 | 4,591.55 | | | 17.22 |
| **2001** | | | 0.14 | 630.42 | 10.31 | 995.48 | 5,911.87 | 5,451.01 | | * | 6.73 |
| **2002** | | 0.03 | 0.10 | 829.39 | 4.87 | 666.61 | 5,734.72 | 4,621.72 | * | * | 7.80 |
| **2003** | | | 0.83 | 714.74 | 7.51 | 686.33 | 4,960.85 | 6,544.97 | 0.06 | * | 7.44 |
| **2004** | 0.43 | 0.51 | 16.33 | 950.87 | 15.02 | 1,177.82 | 5,375.88 | 5,439.93 | * | * | 5.18 |
| **2005** | | * | 0.08 | 838.13 | 18.14 | 617.42 | 4,287.07 | 5,399.24 | 0.02 | * | 7.49 |
| **2006** | | | 0.65 | 733.52 | 8.74 | 446.14 | 3,595.70 | 4,715.80 | 0.07 | * | 13.73 |
| **2007** | | | 0.28 | 615.98 | 6.19 | 265.03 | 4,987.78 | 3,311.81 | * | | 12.26 |
| **2008** | | | 1.24 | 445.37 | 4.02 | 363.44 | 5,321.54 | 2,627.15 | 0.05 | * | 14.26 |

**Table 5.1.3.1.1.** Estimates of scrap/bait landings (MT) provided by NC DMF. Years prior to the start of the bait sampling program in 1986 were estimated from the proportion of croaker in the unclassified finfish bait landings from 1986–1990.

| Year | Scrap/Bait |
|---|---|
| 1981 | 1,714 |
| 1982 | 1,599 |
| 1983 | 1,701 |
| 1984 | 1,880 |
| 1985 | 1,393 |
| 1986 | 565 |
| 1987 | 1,286 |
| 1988 | 1,465 |
| 1989 | 1,569 |
| 1990 | 1,249 |
| 1991 | 992 |
| 1992 | 689 |
| 1993 | 527 |
| 1994 | 899 |
| 1995 | 1,157 |
| 1996 | 478 |
| 1997 | 346 |
| 1998 | 175 |
| 1999 | 395 |
| 2000 | 301 |
| 2001 | 218 |
| 2002 | 163 |
| 2003 | 399 |
| 2004 | 225 |
| 2005 | 110 |
| 2006 | 139 |
| 2007 | 148 |
| 2008 | 84 |

**Table 5.1.3.3.1** Observed trips where Atlantic croakers were discarded, by gear (NMFS Program).

| Year | GILL NET | TRAWL | OTHER | Total |
|---|---|---|---|---|
| **1989** | | 4 | | 4 |
| **1990** | | 1 | | 1 |
| **1991** | | 2 | | 2 |
| **1992** | | 2 | | 2 |
| **1993** | 6 | 5 | | 11 |
| **1994** | 39 | 9 | | 48 |
| **1995** | 50 | 25 | 1 | 76 |
| **1996** | 29 | 8 | | 37 |
| **1997** | 26 | 1 | | 27 |
| **1998** | 19 | 1 | 1 | 21 |
| **1999** | 10 | 9 | 1 | 20 |
| **2000** | 16 | 3 | | 19 |
| **2001** | 9 | 15 | | 24 |
| **2002** | 5 | 20 | 1 | 26 |
| **2003** | 10 | 5 | | 15 |
| **2004** | 5 | 8 | | 13 |
| **2005** | 1 | 7 | 3 | 11 |
| **2006** | 1 | 4 | | 5 |
| **2007** | 2 | 25 | | 27 |
| **2008** | 2 | 18 | | 20 |
| **Total** | **230** | **172** | **7** | **409** |

**Table 5.1.3.3.2** Estimates of discards based on discards: landings ratios from NMFS observer data using SAS PROC SURVEYMEANS for continuity run.

| | **Gill Net** | | | | **Otter Trawl** | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **N** | **Ratio** | **Std.Err.** | **Discards (MT)** | **N** | **Ratio** | **Std.Err.** | **Discards (MT)** |
| **2003** | 10 | 0.009 | 0.00 | 36.58548 | 5 | 1.781534 | 0.11108 | 832.68 |
| **2004** | 5 | 0.176 | 0.20 | 938.291 | 8 | 0.10583 | 0.077603 | 7.57 |
| **2005** | 1 | 0.008 | NA | 34.7062 | 7 | 0.201441 | 0.074577 | 20.59 |
| **2006** | 1 | 0.010 | NA | 32.93294 | 4 | 0.001132 | 0.001408 | 0.05 |
| **2007** | 2 | 0.004 | 0.00 | 16.60957 | 25 | 0.978156 | 0.7225 | 288.82 |
| **2008** | 2 | 0.043 | 0.00 | 182.5769 | 18 | 0.848476 | 0.529248 | 233.03 |

**Table 5.1.3.3.3** Estimated discards by gear and year using the geometric mean of the observed discard to landings ratios.

| YEAR | Period | Gillnet Discards (MT) | Otter Trawl Discards (MT) |
|---|---|---|---|
| **1950** | Decr | 4.82 | 0.00 |
| **1951** | Decr | 3.62 | 0.00 |
| **1952** | Decr | 2.65 | 0.00 |
| **1953** | Incr | 1.26 | 0.00 |
| **1954** | Incr | 3.59 | 0.00 |
| **1955** | Incr | 13.20 | 0.00 |
| **1956** | Incr | 7.66 | 0.00 |
| **1957** | Incr | 11.51 | 0.00 |
| **1958** | Incr | 7.89 | 0.00 |
| **1959** | Decr | 9.29 | 495.10 |
| **1960** | Decr | 11.56 | 313.38 |
| **1961** | Decr | 3.92 | 230.93 |
| **1962** | Decr | 3.87 | 209.96 |
| **1963** | Decr | 2.31 | 282.39 |
| **1964** | Decr | 2.28 | 234.90 |
| **1965** | Decr | 4.02 | 237.47 |
| **1966** | Decr | 6.75 | 207.60 |
| **1967** | Decr | 2.84 | 167.88 |
| **1968** | Decr | 1.56 | 160.10 |
| **1969** | Decr | 0.89 | 204.75 |
| **1970** | Decr | 1.30 | 108.63 |
| **1971** | Decr | 1.78 | 121.63 |
| **1972** | Incr | 4.27 | 1521.13 |
| **1973** | Incr | 9.95 | 847.41 |
| **1974** | Incr | 7.92 | 1285.36 |
| **1975** | Incr | 12.25 | 2905.68 |
| **1976** | Incr | 25.36 | 5077.64 |
| **1977** | Incr | 43.77 | 5898.78 |
| **1978** | Decr | 43.42 | 2242.31 |
| **1979** | Decr | 41.11 | 1540.56 |
| **1980** | Decr | 67.71 | 1133.35 |
| **1981** | Decr | 23.83 | 425.76 |
| **1982** | Decr | 22.06 | 466.43 |
| **1983** | Decr | 16.09 | 222.00 |
| **1984** | Incr | 38.48 | 1187.91 |
| **1985** | Incr | 41.53 | 1230.32 |

**Table 5.1.3.3.3** *Continued.*

| | | | |
|---|---|---|---|
| **1986** | Incr | 56.26 | 1255.72 |
| **1987** | Decr | 52.85 | 370.95 |
| **1988** | Decr | 56.35 | 359.66 |
| **1989** | Decr | 31.08 | 310.58 |
| **1990** | Decr | 17.00 | 81.54 |
| **1991** | Decr | 17.15 | 76.95 |
| **1992** | Incr | 26.58 | 399.65 |
| **1993** | Incr | 56.61 | 1047.35 |
| **1994** | Incr | 69.30 | 1506.23 |
| **1995** | Incr | 72.48 | 1985.84 |
| **1996** | Incr | 119.83 | 2660.74 |
| **1997** | Incr | 119.84 | 4708.73 |
| **1998** | Incr | 171.25 | 3131.67 |
| **1999** | Steady | 83.93 | 1860.53 |
| **2000** | Steady | 113.35 | 1734.37 |
| **2001** | Steady | 119.79 | 1676.35 |
| **2002** | Steady | 103.44 | 1655.68 |
| **2003** | Decr | 155.48 | 2009.53 |
| **2004** | Decr | 202.64 | 1607.35 |
| **2005** | Decr | 171.67 | 1565.74 |
| **2006** | Decr | 130.20 | 1441.65 |
| **2007** | Decr | 147.32 | 1162.87 |
| **2008** | Decr | 161.97 | 943.96 |

**Table 5.1.3.3.4** Ratios used to estimate discards in years without observer coverage.

| **Landings** | **Gillnet** | | **Otter Trawls** | |
|---|---|---|---|---|
| | D:L ratio | N trips | D:L ratio | N trips |
| **Decreasing** | 0.038344 | 14 | 0.370568 | 46 |
| **Increasing** | 0.032455 | 135 | 1.013822 | 27 |

**Table 5.2.1.1.1** Numbers of Atlantic croaker samples reported by the MRFSS angler-intercept survey and at-sea headboat survey, by catch type, 1981–2008.

| | Landings (Type A) | Dead Discards (Type B1) | | Released Alive (Type B2) | |
|---|---|---|---|---|---|
| **Year** | **Intercept** | **Intercept** | **Headboat** | **Intercept** | **Headboat** |
| **1981** | 642 | 331 | | 601 | |
| **1982** | 1,004 | 356 | | 727 | |
| **1983** | 1,226 | 301 | | 4,088 | |
| **1984** | 1,414 | 670 | | 1,680 | |
| **1985** | 3,269 | 1,252 | | 6,665 | |
| **1986** | 5,048 | 540 | | 6,277 | |
| **1987** | 2,964 | 858 | | 4,736 | |
| **1988** | 2,768 | 863 | | 3,519 | |
| **1989** | 3,592 | 1,863 | | 6,243 | |
| **1990** | 2,084 | 1,275 | | 8,923 | |
| **1991** | 2,076 | 1,466 | | 12,891 | |
| **1992** | 2,730 | 2,426 | | 11,524 | |
| **1993** | 2,292 | 865 | | 11,081 | |
| **1994** | 5,925 | 1,322 | | 26,631 | |
| **1995** | 3,074 | 1,555 | | 10,753 | |
| **1996** | 3,132 | 1,408 | | 10,689 | |
| **1997** | 3,588 | 2,073 | | 15,834 | |
| **1998** | 3,792 | 4,220 | | 18,214 | |
| **1999** | 3,906 | 3,331 | | 23,663 | |
| **2000** | 3,917 | 1,722 | | 19,101 | |
| **2001** | 5,787 | 5,624 | | 15,186 | |
| **2002** | 6,882 | 5,460 | | 20,378 | |
| **2003** | 6,216 | 5,243 | | 19,094 | |
| **2004** | 6,118 | 5,208 | | 12,266 | |
| **2005** | 8,171 | 6,213 | 4 | 14,574 | 1,533 |
| **2006** | 4,538 | 3,011 | 0 | 11,336 | 931 |
| **2007** | 5,974 | 4,743 | 5 | 19,450 | 2,664 |
| **2008** | 6,297 | 5,065 | 0 | 18,679 | 1,513 |

**Table 5.2.1.4.1** Numbers of Atlantic croakers that were available for biological sampling in the MRFSS angler-intercept survey and at-sea headboat survey, by survey component, 1981–2008.

| | Intercept (Type A only) | | Headboat (Type B only) |
|---|---|---|---|
| **Year** | **Weighed** | **Measured** | **Measured** |
| **1981** | 554 | 610 | |
| **1982** | 902 | 910 | |
| **1983** | 1,121 | 1,177 | |
| **1984** | 1,290 | 1,320 | |
| **1985** | 2,989 | 2,987 | |
| **1986** | 4,727 | 4,726 | |
| **1987** | 2,825 | 2,830 | |
| **1988** | 2,476 | 2,532 | |
| **1989** | 3,067 | 2,782 | |
| **1990** | 1,722 | 1,720 | |
| **1991** | 1,903 | 1,615 | |
| **1992** | 2,369 | 2,254 | |
| **1993** | 2,042 | 2,025 | |
| **1994** | 5,367 | 5,360 | |
| **1995** | 2,646 | 2,657 | |
| **1996** | 2,636 | 2,670 | |
| **1997** | 3,132 | 3,050 | |
| **1998** | 3,312 | 3,337 | |
| **1999** | 3,136 | 3,049 | |
| **2000** | 3,300 | 3,177 | |
| **2001** | 5,237 | 5,213 | |
| **2002** | 6,443 | 6,323 | |
| **2003** | 5,646 | 5,558 | |
| **2004** | 5,524 | 5,703 | |
| **2005** | 7,751 | 7,707 | 1,324 |
| **2006** | 4,284 | 4,116 | 824 |
| **2007** | 5,194 | 5,039 | 2,473 |
| **2008** | 5,812 | 5,717 | 1,450 |

**Table 5.2.2.1** Estimated amount of Atlantic croaker harvested (Type A+B1) and released alive (Type B2) by recreational anglers along the Atlantic coast, 1981–2008.

| | Harvest (Type A+B1) | | | | Released Alive (Type B2) | |
|---|---|---|---|---|---|---|
| **Year** | **Number** | **PSE[Number]** | **Weight (mt)** | **PSE[Weight]** | **Number** | **PSE[Number]** |
| **1981** | 2,811,540 | 13.0 | 610.9 | 13.0 | 1,276,758 | 22.6 |
| **1982** | 2,925,906 | 19.9 | 751.6 | 22.0 | 1,126,329 | 28.8 |
| **1983** | 5,167,608 | 17.6 | 663.8 | 16.1 | 3,910,452 | 10.9 |
| **1984** | 7,978,846 | 10.4 | 1,544 | 15.4 | 3,465,600 | 14.7 |
| **1985** | 4,741,104 | 9.50 | 878.2 | 9.90 | 4,677,994 | 28.3 |
| **1986** | 12,657,861 | 14.4 | 2,385 | 17.7 | 3,204,735 | 11.3 |
| **1987** | 7,139,230 | 11.2 | 1,331 | 10.0 | 4,607,712 | 14.4 |
| **1988** | 8,205,384 | 8.80 | 2,106 | 10.3 | 2,423,236 | 11.2 |
| **1989** | 5,007,653 | 5.70 | 1,078 | 6.20 | 2,426,320 | 6.80 |
| **1990** | 4,775,162 | 7.70 | 778.8 | 8.10 | 5,960,397 | 9.30 |
| **1991** | 6,390,181 | 8.30 | 1,156 | 8.60 | 12,419,965 | 7.80 |
| **1992** | 6,643,974 | 8.10 | 1,192 | 7.60 | 6,481,948 | 8.10 |
| **1993** | 7,000,061 | 7.90 | 1,369 | 7.50 | 10,057,077 | 7.30 |
| **1994** | 10,205,819 | 5.30 | 2,209 | 5.50 | 13,019,730 | 5.10 |
| **1995** | 7,473,870 | 7.40 | 1,818 | 8.00 | 7,575,330 | 7.10 |
| **1996** | 6,920,798 | 8.80 | 1,858 | 8.90 | 7,119,294 | 7.10 |
| **1997** | 10,926,856 | 9.50 | 3,520 | 9.40 | 10,992,112 | 7.10 |
| **1998** | 9,249,619 | 7.60 | 3,588 | 8.10 | 10,723,667 | 5.60 |
| **1999** | 9,116,593 | 7.30 | 3,320 | 7.90 | 12,541,314 | 5.10 |
| **2000** | 10,710,547 | 6.50 | 4,395 | 6.90 | 16,426,284 | 5.00 |
| **2001** | 13,248,180 | 5.20 | 5,027 | 5.50 | 11,658,169 | 4.50 |
| **2002** | 11,557,153 | 4.90 | 4,153 | 4.90 | 11,791,122 | 4.50 |
| **2003** | 10,451,573 | 4.70 | 4,180 | 5.20 | 12,575,566 | 4.50 |
| **2004** | 10,982,805 | 6.10 | 4,001 | 6.40 | 10,125,476 | 5.30 |
| **2005** | 11,595,508 | 6.60 | 4,792 | 6.90 | 13,289,373 | 6.10 |
| **2006** | 10,225,534 | 8.90 | 4,184 | 9.30 | 11,498,329 | 5.50 |
| **2007** | 10,647,377 | 5.40 | 3,746 | 5.90 | 14,871,760 | 4.90 |
| **2008** | 9,193,527 | 6.10 | 2,407 | 6.70 | 13,978,394 | 4.90 |

**Table 5.2.2.2** Annual recreational harvest (numbers; Type A+B1) of Atlantic croaker along the Atlantic coast, by state, 1981–2008.

| Year | MA | RI | NY | NJ | DE | MD | VA | NC | SC | GA | FL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | | | | 1,054 | 3,003 | | 964,013 | 1,043,240 | 165,742 | 35,591 | 598,896 |
| **1982** | | | | | | 10,452 | 273,039 | 596,493 | 193,554 | 169,749 | 1,682,619 |
| **1983** | | | | | | 108,355 | 2,154,133 | 1,620,909 | 60,811 | 75,173 | 1,148,227 |
| **1984** | | | | | | 211,035 | 2,047,720 | 2,147,871 | 588,114 | 202,364 | 2,781,742 |
| **1985** | | | | | | 21,276 | 2,284,334 | 723,933 | 260,265 | 144,341 | 1,306,955 |
| **1986** | | | | | 4,694 | 123,578 | 6,384,966 | 356,742 | 599,442 | 69,887 | 5,118,552 |
| **1987** | | | | | | 208,488 | 3,234,224 | 904,030 | 166,978 | 44,783 | 2,580,727 |
| **1988** | | | | | 1,186 | 1,005,452 | 4,048,690 | 2,256,128 | 144,057 | 64,093 | 685,778 |
| **1989** | | | | | 478 | 22,871 | 2,203,504 | 2,131,763 | 217,023 | 72,598 | 359,417 |
| **1990** | | | | | 281 | 100,673 | 2,374,679 | 1,063,452 | 346,631 | 585,380 | 304,064 |
| **1991** | | | | 16,235 | 37,500 | 288,471 | 4,298,542 | 434,067 | 100,816 | 184,435 | 1,030,115 |
| **1992** | | | | | 9,854 | 117,427 | 4,524,040 | 723,823 | 74,051 | 440,185 | 754,595 |
| **1993** | | | | 2,552 | 19,352 | 805,560 | 4,990,098 | 755,998 | 32,700 | 89,734 | 304,067 |
| **1994** | | | | 1,567 | 5,718 | 1,633,581 | 6,494,691 | 1,179,735 | 188,520 | 102,974 | 599,032 |
| **1995** | | | | 15,184 | 136,865 | 827,183 | 5,029,708 | 850,606 | 75,422 | 100,826 | 438,076 |
| **1996** | | | | 35,037 | 235,389 | 775,115 | 4,997,021 | 662,240 | 37,464 | 61,957 | 116,575 |
| **1997** | | | | 342,089 | 385,586 | 1,053,232 | 8,066,926 | 661,116 | 118,428 | 64,050 | 235,430 |
| **1998** | 1,477 | | | 143,404 | 391,231 | 1,126,058 | 6,730,181 | 387,427 | 170,528 | 64,953 | 234,360 |
| **1999** | | | | 357,261 | 662,724 | 1,209,572 | 5,881,671 | 442,185 | 54,761 | 104,438 | 403,982 |
| **2000** | | | | 1,023,442 | 517,886 | 2,674,880 | 5,486,159 | 391,056 | 32,332 | 128,922 | 455,870 |
| **2001** | | | | 1,177,813 | 312,005 | 1,319,928 | 9,335,313 | 635,552 | 19,802 | 21,503 | 426,264 |
| **2002** | | | | 253,472 | 261,634 | 1,223,385 | 9,129,060 | 408,944 | 66,409 | 36,497 | 177,751 |
| **2003** | | | | 692,391 | 341,174 | 1,619,766 | 6,695,192 | 490,399 | 198,339 | 248,853 | 165,459 |
| **2004** | | | | 1,172,210 | 494,104 | 870,844 | 7,292,880 | 474,180 | 135,842 | 44,825 | 497,921 |
| **2005** | | | | 1,254,957 | 934,207 | 809,894 | 7,791,125 | 292,629 | 128,956 | 40,094 | 343,647 |
| **2006** | | | | 698,428 | 863,288 | 833,190 | 7,069,449 | 434,735 | 38,682 | 40,378 | 247,383 |
| **2007** | | | | 355,067 | 400,518 | 1,092,784 | 7,753,422 | 397,702 | 131,686 | 46,966 | 469,232 |
| **2008** | | | | 475,373 | 349,229 | 689,154 | 6,524,884 | 372,778 | 100,460 | 45,598 | 636,050 |

**Table 5.2.4.1** Recreational total catch and harvest per angler trip (CPUE).

| Year | Total Catch (A+B1+B2) CPUE | Total Catch PSE | Directed TotCatch Interviews | Harvest (A+B1) CPUE | Harvest PSE | Directed Harvest Interviews |
|---|---|---|---|---|---|---|
| 1981 | 4.17 | 11.40 | 484.00 | 3.21 | 13.01 | 427.00 |
| 1982 | 4.16 | 16.48 | 683.00 | 3.41 | 19.95 | 581.00 |
| 1983 | 4.82 | 11.07 | 1238.00 | 3.41 | 17.62 | 809.00 |
| 1984 | 5.78 | 8.52 | 1035.00 | 4.76 | 10.43 | 882.00 |
| 1985 | 6.31 | 14.86 | 2544.00 | 3.95 | 9.49 | 2101.00 |
| 1986 | 10.45 | 11.72 | 2849.00 | 9.64 | 14.41 | 2510.00 |
| 1987 | 7.68 | 8.85 | 2000.00 | 5.68 | 11.22 | 1624.00 |
| 1988 | 7.98 | 7.29 | 1770.00 | 7.00 | 8.84 | 1549.00 |
| 1989 | 7.15 | 4.45 | 3326.00 | 5.73 | 5.74 | 2852.00 |
| 1990 | 9.40 | 6.23 | 2169.00 | 5.54 | 7.74 | 1644.00 |
| 1991 | 9.33 | 5.85 | 2820.00 | 5.09 | 8.26 | 1802.00 |
| 1992 | 8.14 | 5.73 | 3236.00 | 5.67 | 8.14 | 2351.00 |
| 1993 | 8.92 | 5.38 | 2636.00 | 5.52 | 7.86 | 1740.00 |
| 1994 | 8.94 | 3.70 | 5646.00 | 5.67 | 5.29 | 3883.00 |
| 1995 | 7.23 | 5.14 | 3639.00 | 5.11 | 7.40 | 2516.00 |
| 1996 | 7.43 | 5.66 | 3615.00 | 5.09 | 8.84 | 2502.00 |
| 1997 | 9.28 | 5.91 | 4199.00 | 6.84 | 9.45 | 2812.00 |
| 1998 | 7.65 | 4.61 | 4990.00 | 5.63 | 7.60 | 3161.00 |
| 1999 | 8.76 | 4.27 | 5206.00 | 5.84 | 7.33 | 3279.00 |
| 2000 | 8.00 | 3.95 | 4525.00 | 4.87 | 6.48 | 2909.00 |
| 2001 | 7.32 | 3.48 | 4999.00 | 5.56 | 5.23 | 3495.00 |
| 2002 | 8.29 | 3.34 | 5218.00 | 6.00 | 4.92 | 3427.00 |
| 2003 | 7.04 | 3.28 | 5408.00 | 4.93 | 4.73 | 3632.00 |
| 2004 | 6.64 | 4.04 | 4802.00 | 5.13 | 6.07 | 3454.00 |
| 2005 | 7.41 | 4.48 | 5261.00 | 5.33 | 6.56 | 3877.00 |
| 2006 | 6.63 | 5.10 | 4034.00 | 5.29 | 8.89 | 2528.00 |
| 2007 | 7.30 | 3.64 | 5258.00 | 4.99 | 5.41 | 3652.00 |
| 2008 | 7.53 | 3.84 | 5109.00 | 5.51 | 6.14 | 3293.00 |

**Table 5.2.4.1** Annual estimates of recreational fishery CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) for Atlantic croaker in the mid-Atlantic region (New Jersey to North Carolina) based on the directed trips method, 1982–2002.

| | Total Catch (A+B1+B2) | | | Harvest (A+B1) | | |
|---|---|---|---|---|---|---|
| **Year** | **CPUE** | **PSE[CPUE]** | **# Directed Interviews** | **CPUE** | **PSE[CPUE]** | **# Directed Interviews** |
| **1982** | 4.17 | 21.9 | 190 | 2.61 | 18.1 | 167 |
| **1983** | 5.80 | 13.6 | 776 | 3.92 | 22.9 | 461 |
| **1984** | 6.44 | 9.38 | 518 | 5.03 | 11.4 | 450 |
| **1985** | 7.47 | 20.3 | 1,764 | 4.19 | 11.3 | 1,495 |
| **1986** | 9.87 | 8.44 | 2,475 | 8.01 | 10.9 | 2,235 |
| **1987** | 7.42 | 5.47 | 1,492 | 5.63 | 7.17 | 1,250 |
| **1988** | 9.50 | 7.63 | 1,490 | 8.07 | 9.14 | 1,337 |
| **1989** | 8.91 | 4.67 | 2,895 | 6.84 | 6.06 | 2,494 |
| **1990** | 12.1 | 7.16 | 1,709 | 6.16 | 9.29 | 1,328 |
| **1991** | 11.1 | 6.48 | 2,435 | 5.57 | 9.87 | 1,549 |
| **1992** | 9.90 | 6.53 | 2,449 | 6.74 | 9.93 | 1,737 |
| **1993** | 9.69 | 5.59 | 2,311 | 5.88 | 8.33 | 1,516 |
| **1994** | 9.79 | 3.91 | 5,230 | 5.98 | 5.68 | 3,622 |
| **1995** | 7.61 | 5.29 | 3,337 | 5.15 | 7.53 | 2,341 |
| **1996** | 7.92 | 5.84 | 3,339 | 5.31 | 9.09 | 2,352 |
| **1997** | 9.77 | 6.09 | 3,877 | 7.05 | 9.80 | 2,612 |
| **1998** | 8.26 | 4.83 | 4,414 | 5.85 | 7.95 | 2,897 |
| **1999** | 9.10 | 4.47 | 4,594 | 6.12 | 7.74 | 2,907 |
| **2000** | 8.53 | 4.13 | 3,960 | 5.05 | 6.83 | 2,601 |
| **2001** | 7.68 | 3.61 | 4,492 | 5.76 | 5.40 | 3,215 |
| **2002** | 8.70 | 3.44 | 4,747 | 6.21 | 5.03 | 3,208 |

**Table 5.2.4.3** Annual estimates of recreational fishery CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) for Atlantic croaker in the south Atlantic (South Carolina to Florida) based on the directed trips method, 1982–2002.

| | Total Catch (A+B1+B2) | | | Harvest (A+B1) | | |
|---|---|---|---|---|---|---|
| **Year** | **CPUE** | **PSE[CPUE]** | **# Directed Interviews** | **CPUE** | **PSE[CPUE]** | **# Directed Interviews** |
| **1982** | 4.15 | 23.2 | 493 | 3.93 | 27.5 | 414 |
| **1983** | 2.90 | 12.3 | 462 | 2.45 | 15.1 | 348 |
| **1984** | 5.02 | 16.0 | 517 | 4.47 | 18.6 | 432 |
| **1985** | 4.83 | 18.8 | 780 | 3.59 | 17.2 | 606 |
| **1986** | 11.5 | 26.8 | 374 | 12.7 | 28.8 | 275 |
| **1987** | 8.09 | 20.4 | 508 | 5.77 | 26.4 | 374 |
| **1988** | 3.58 | 23.7 | 280 | 3.37 | 31.4 | 212 |
| **1989** | 2.71 | 14.6 | 431 | 2.75 | 17.5 | 358 |
| **1990** | 4.51 | 11.0 | 460 | 4.30 | 13.7 | 316 |
| **1991** | 4.18 | 9.52 | 385 | 3.83 | 12.6 | 253 |
| **1992** | 3.75 | 6.34 | 787 | 3.38 | 6.79 | 614 |
| **1993** | 3.04 | 9.68 | 325 | 2.82 | 12.1 | 224 |
| **1994** | 3.90 | 8.51 | 416 | 3.69 | 11.8 | 261 |
| **1995** | 4.17 | 21.2 | 302 | 4.71 | 32.2 | 175 |
| **1996** | 2.66 | 13.3 | 68 | 2.25 | 21.3 | 150 |
| **1997** | 3.68 | 12.7 | 322 | 3.90 | 19.0 | 200 |
| **1998** | 3.31 | 10.8 | 572 | 3.27 | 16.8 | 263 |
| **1999** | 6.08 | 14.2 | 612 | 3.42 | 15.4 | 372 |
| **2000** | 3.61 | 8.08 | 565 | 3.05 | 13.4 | 308 |
| **2001** | 3.54 | 9.60 | 507 | 2.89 | 14.9 | 280 |
| **2002** | 3.54 | 9.11 | 471 | 2.56 | 15.8 | 219 |

**Table**

| | Rec. CPUE (num/trip) | | NMFS (num/tow) | | SEAMAP Fall (kg/tow) | | VIMS (num/tow) | | NC195 June (num/tow) | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Index** | **CV[Index]** | **Index** | **CV[Index]** | **Index** | **CV[Index]** | **Index** | **CV[Index]** | **Index** | **CV[Index]** |
| **1981** | 3.94 | 0.11 | 29.4 | 0.47 | | | | | | |
| **1982** | 3.45 | 0.066 | 8.26 | 0.25 | | | | | | |
| **1983** | 5.04 | 0.058 | 262 | 0.33 | | | | | | |
| **1984** | 5.60 | 0.077 | 292 | 0.21 | | | | | | |
| **1985** | 6.05 | 0.072 | 189 | 0.26 | | | | | | |
| **1986** | 9.27 | 0.040 | 111 | 0.35 | | | | | | |
| **1987** | 6.52 | 0.049 | 109 | 0.57 | | | | | 112 | 0.84 |
| **1988** | 7.73 | 0.051 | 31.0 | 0.42 | | | 0.440 | 0.2 | 50.0 | 0.52 |
| **1989** | 6.44 | 0.037 | 91.0 | 0.41 | | | 1.71 | 0.2 | 114 | 0.70 |
| **1990** | 7.83 | 0.049 | 88.8 | 0.28 | 7.72 | 0.29 | 1.00 | 0.2 | 325 | 0.71 |
| **1991** | 5.85 | 0.047 | 321 | 0.31 | 24.5 | 0.27 | 6.08 | 0.2 | 261 | 1.5 |
| **1992** | 6.68 | 0.040 | 231 | 0.27 | 4.32 | 0.18 | 2.98 | 0.2 | 44.1 | 0.81 |
| **1993** | 6.48 | 0.045 | 238 | 0.43 | 18.7 | 0.10 | 4.43 | 0.2 | 437 | 0.83 |
| **1994** | 7.98 | 0.029 | 405 | 0.29 | 14.6 | 0.33 | 0.580 | 0.2 | 124 | 1.2 |
| **1995** | 5.63 | 0.039 | 187 | 0.26 | 5.08 | 0.36 | 2.61 | 0.2 | 146 | 0.95 |
| **1996** | 5.81 | 0.041 | 215 | 0.20 | 5.14 | 0.23 | 0.0300 | 0.2 | 61.9 | 0.78 |
| **1997** | 7.08 | 0.045 | 187 | 0.28 | 2.30 | 0.44 | 5.58 | 0.2 | 330 | 0.64 |
| **1998** | 6.02 | 0.036 | 347 | 0.20 | 4.65 | 0.33 | 5.65 | 0.2 | 602 | 0.53 |
| **1999** | 7.56 | 0.037 | 698 | 0.20 | 17.5 | 0.25 | 1.30 | 0.2 | 725 | 1.5 |
| **2000** | 6.80 | 0.036 | 405 | 0.28 | 4.19 | 0.33 | 0.830 | 0.2 | 171 | 0.81 |
| **2001** | 6.17 | 0.033 | 180 | 0.33 | 2.66 | 0.27 | 0.380 | 0.2 | 104 | 0.54 |
| **2002** | 7.07 | 0.030 | 1018 | 0.32 | 9.24 | 0.44 | 3.18 | 0.2 | 83.2 | 0.74 |
| **2003** | 6.20 | 0.035 | 483 | 0.18 | 14.1 | 0.35 | 0.920 | 0.2 | 159 | 0.80 |
| **2004** | 5.57 | 0.040 | 572 | 0.19 | 15.4 | 0.21 | 2.29 | 0.2 | 448 | 0.62 |
| **2005** | 5.79 | 0.044 | 426 | 0.26 | 23.8 | 0.17 | 1.50 | 0.2 | 196 | 0.59 |
| **2006** | 4.81 | 0.040 | 960 | 0.12 | 12.1 | 0.14 | 3.72 | 0.2 | 113 | 0.82 |
| **2007** | 6.47 | 0.036 | 987 | 0.30 | 9.20 | 0.31 | 2.96 | 0.2 | 106 | 0.72 |
| **2008** | 6.52 | 0.041 | 770 | 0.16 | 12.0 | 0.25 | 17.4 | 0.2 | 268 | 0.56 |

**5.3.5.1** Atlantic croaker indices of abundance used in modeling.

**Table 6.1.1** Upper and lower bounds specified for parameters estimated by hybrid model.

| Parameter | Lower Bound | Upper Bound | note |
|---|---|---|---|
| Fully-selected fishing mortality, $F_{f,y}$ | 0.0 | 3.0 | |
| $SSB_{\text{Ratio}}$ | 0.00001 | 1.0 | |
| Virgin recruitment, $R_0$ | 10 | 25 | $\log_e$-space |
| Recruitment deviations, $V_y$ | -7.5 | 7.5 | $\log_e$-space |
| Catchability coefficients, $q_i$ | -25 | 5 | $\log_e$-space |

**Table 6.1.2** Values assumed for growth functions in the hybrid model.

| Function | Parameter | Value |
|---|---|---|
| Age-Length (cm) | $L_\infty$ | 43.1 |
| | $K$ | 0.214 |
| | $a_0$ | -2.35 |
| | | |
| Length (cm)-Weight (kg) | $\alpha$ | 7.30E-06 |
| | $\beta$ | 3.14 |

**Table 6.1.3** Age-specific natural mortality and maturity values used in base run of the hybrid model.

| **Age** | ***M*** **(year$^{-1}$)** | **Maturity (prop. mature)** |
|---|---|---|
| **0** | 0.461 | 0.43 |
| **1** | 0.374 | 0.86 |
| **2** | 0.324 | 0.98 |
| **3** | 0.293 | 1.00 |
| **4** | 0.272 | 1.00 |
| **5** | 0.257 | 1.00 |
| **6** | 0.246 | 1.00 |
| **7** | 0.238 | 1.00 |
| **8** | 0.232 | 1.00 |
| **9** | 0.227 | 1.00 |
| **10** | 0.223 | 1.00 |
| **11** | 0.220 | 1.00 |
| **12** | 0.218 | 1.00 |
| **13** | 0.216 | 1.00 |
| **14** | 0.215 | 1.00 |
| **15+** | 0.214 | 1.00 |

**Table 6.1.14** Age-specific selectivity values used in base run of the hybrid model.

| Age | Commercial | Scrap/ Discard | Rec Harvest | Rec Release | Rec CPUE | NEFSC | SEAMAP | VIMS | NC P195 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.03 | 0.16 | 0.11 | 0.15 | 0.15 | 0.28 | 1.00 | 1 | 1 |
| 1 | 0.39 | 1.00 | 0.35 | 0.40 | 0.40 | 0.73 | 0.12 | 0 | 0 |
| 2 | 0.92 | 0.75 | 0.70 | 0.71 | 0.71 | 1.00 | 0.004 | 0 | 0 |
| 3 | 1.00 | 0.39 | 0.91 | 0.94 | 0.94 | 0.93 | 0.00 | 0 | 0 |
| 4 | 1.00 | 0.20 | 0.98 | 1.00 | 1.00 | 0.77 | 0.00 | 0 | 0 |
| 5 | 1.00 | 0.10 | 1.00 | 0.73 | 1.00 | 0.61 | 0.00 | 0 | 0 |
| 6 | 1.00 | 0.05 | 1.00 | 0.32 | 1.00 | 0.45 | 0.00 | 0 | 0 |
| 7 | 1.00 | 0.03 | 1.00 | 0.10 | 1.00 | 0.25 | 0.00 | 0 | 0 |
| 8 | 1.00 | 0.01 | 1.00 | 0.03 | 1.00 | 0.09 | 0.00 | 0 | 0 |
| 9 | 1.00 | 0.01 | 1.00 | 0.01 | 1.00 | 0.02 | 0.00 | 0 | 0 |
| 10 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 11 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 12 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 13 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 14 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 15 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |

**Table 6.3.1** Values of virgin recruitment ($R_0$), the ratio of SSB in the initial model year to the virgin level of spawning stock biomass ($SSB_{\text{Ratio}}$), and catchability coefficients ($q_i$) estimated by the base run of the hybrid model.

| **Parameter** | **Value** |
|---|---|
| **$\log_e(R_0)$** | 19.1 |
| **$SSB_{\text{Ratio}}$** | 0.57 |
| | |
| **$\log_e(q)$** | |
| Rec. CPUE | -17.1 |
| NMFS | -13.3 |
| SEAMAP | -6.6 |
| VIMS | -18.2 |
| NC195 | -13.6 |

**Table 6.3.2** Annual recruitment deviations ($V_y$) estimated by the base run of the hybrid model.

| Year | $\log_e(V_y)$ |
|---|---|
| **1982** | -1.4 |
| **1983** | 1.38 |
| **1984** | -0.5 |
| **1985** | -0.3 |
| **1986** | 0.73 |
| **1987** | -0.3 |
| **1988** | -1.2 |
| **1989** | -0.4 |
| **1990** | -0.8 |
| **1991** | -0.0 |
| **1992** | 0.18 |
| **1993** | 0.49 |
| **1994** | 0.28 |
| **1995** | -0.0 |
| **1996** | -1.0 |
| **1997** | 0.67 |
| **1998** | 1.51 |
| **1999** | 0.46 |
| **2000** | -0.8 |
| **2001** | -1.0 |
| **2002** | 1.29 |
| **2003** | -0.9 |
| **2004** | 0.48 |
| **2005** | 0.03 |
| **2006** | 0.40 |
| **2007** | -0.0 |
| **2008** | 1.25 |

**Table 7.3.3** Fully-selected fishing mortality rates ($\hat{F}_{f,y}$) estimated by the base run of the hybrid model.

| Year | Commercial Landings | Commercial Scrap/Bait | Recreational Harvest | Recreational Discards |
|---|---|---|---|---|
| **1981** | 0.2288 | 0.1438 | 0.0308 | 0.0006 |
| **1982** | 0.2579 | 0.1940 | 0.0415 | 0.0006 |
| **1983** | 0.1764 | 0.1622 | 0.0341 | 0.0013 |
| **1984** | 0.1691 | 0.0884 | 0.0601 | 0.0009 |
| **1985** | 0.1181 | 0.0871 | 0.0246 | 0.0009 |
| **1986** | 0.1268 | 0.0788 | 0.0584 | 0.0005 |
| **1987** | 0.1020 | 0.0524 | 0.0294 | 0.0007 |
| **1988** | 0.0859 | 0.0670 | 0.0419 | 0.0005 |
| **1989** | 0.0692 | 0.1098 | 0.0209 | 0.0005 |
| **1990** | 0.0573 | 0.1033 | 0.0158 | 0.0010 |
| **1991** | 0.0362 | 0.1014 | 0.0248 | 0.0028 |
| **1992** | 0.0447 | 0.0903 | 0.0259 | 0.0016 |
| **1993** | 0.1122 | 0.0810 | 0.0295 | 0.0026 |
| **1994** | 0.0992 | 0.1773 | 0.0458 | 0.0028 |
| **1995** | 0.1240 | 0.1166 | 0.0376 | 0.0017 |
| **1996** | 0.1918 | 0.0430 | 0.0386 | 0.0018 |
| **1997** | 0.2833 | 0.0263 | 0.0847 | 0.0037 |
| **1998** | 0.3494 | 0.6372 | 0.0971 | 0.0046 |
| **1999** | 0.2809 | 0.0298 | 0.0832 | 0.0043 |
| **2000** | 0.1869 | 0.0410 | 0.0823 | 0.0051 |
| **2001** | 0.1952 | 0.0626 | 0.0884 | 0.0032 |
| **2002** | 0.2251 | 0.3446 | 0.0847 | 0.0036 |
| **2003** | 0.2743 | 0.2292 | 0.0972 | 0.0047 |
| **2004** | 0.2623 | 0.0319 | 0.0949 | 0.0042 |
| **2005** | 0.2528 | 0.1044 | 0.1173 | 0.0057 |
| **2006** | 0.2224 | 0.0102 | 0.1027 | 0.0048 |
| **2007** | 0.2199 | 0.0458 | 0.0969 | 0.0045 |
| **2008** | 0.2035 | 0.0464 | 0.0585 | 0.0033 |

## 13 FIGURES

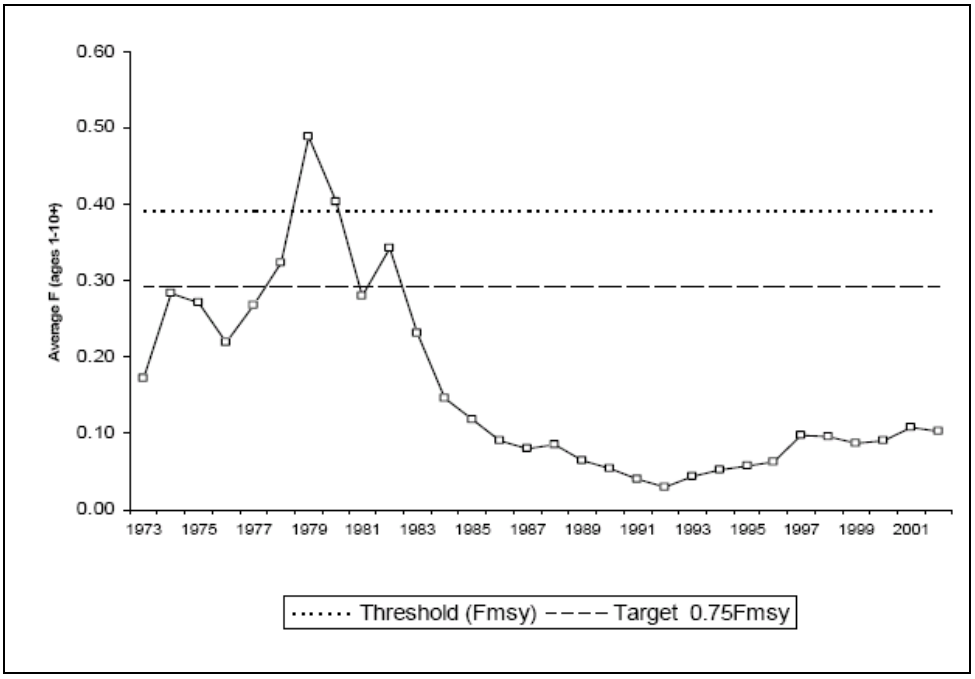



**Figure 1.3.5.1** Fishing mortality rates vs. reference points for 2003/4 base model assessment (mid-Atlantic region only).

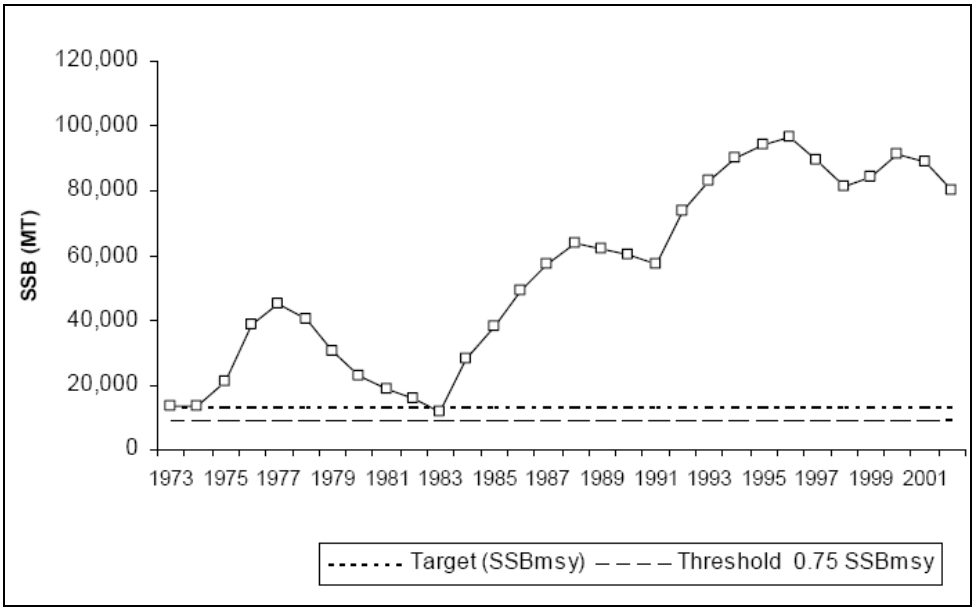



**Figure 1.3.5.2** Abundance vs. reference points for 2003/2004 base model assessment (mid-Atlantic region only).

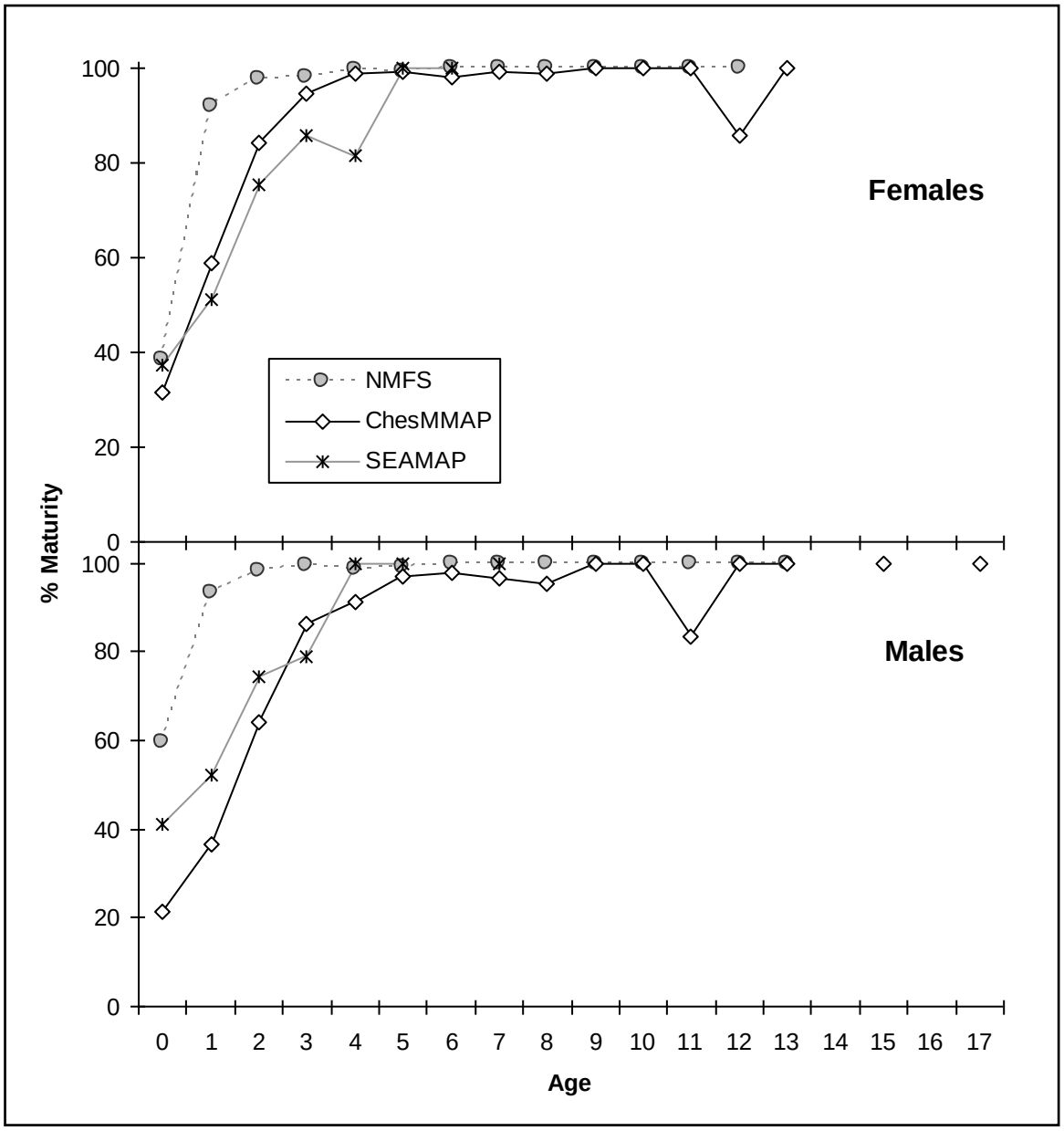



**Figure 2.3.2.1** Estimated maturity schedule for Atlantic croaker females and males based on available datasets, pooled over years.

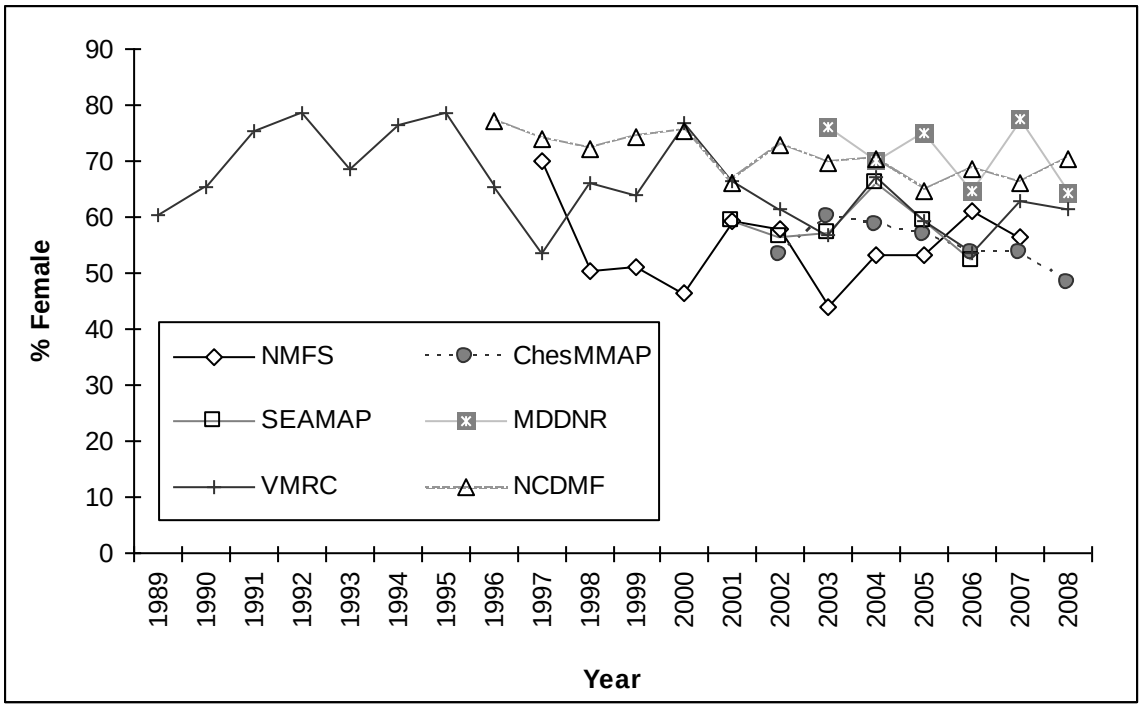



**Figure 2.3.3.1** Estimated percent female Atlantic croaker for available datasets, by year.

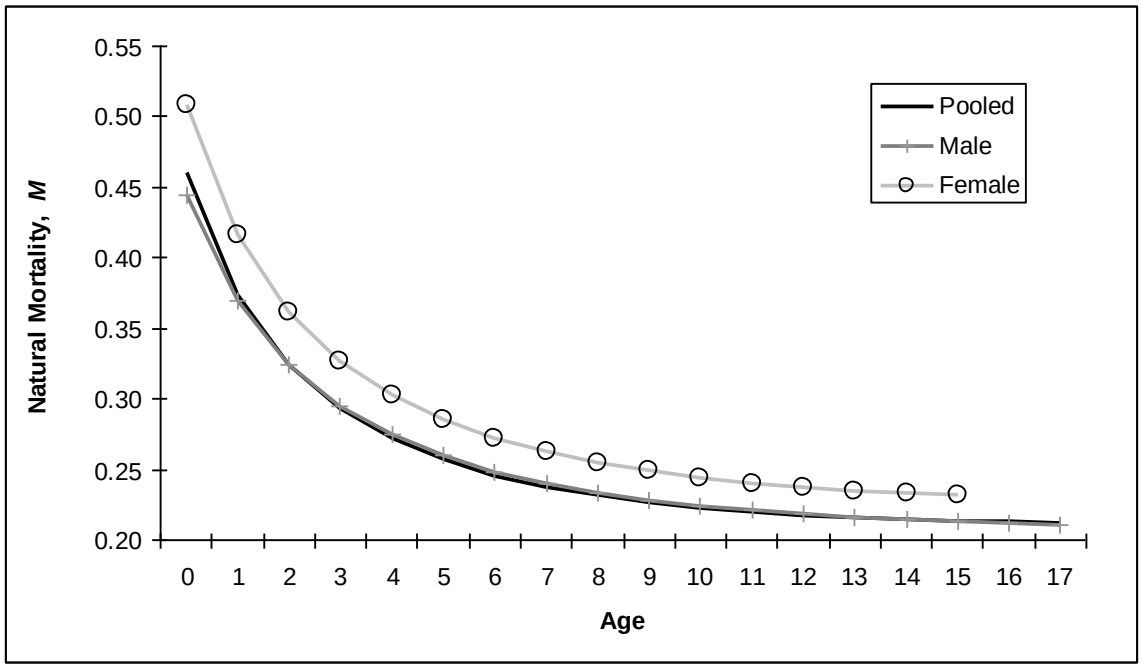



**Figure 2.5.2.1** Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using all available data (fisheries-dependent and fisheries-independent data combined).

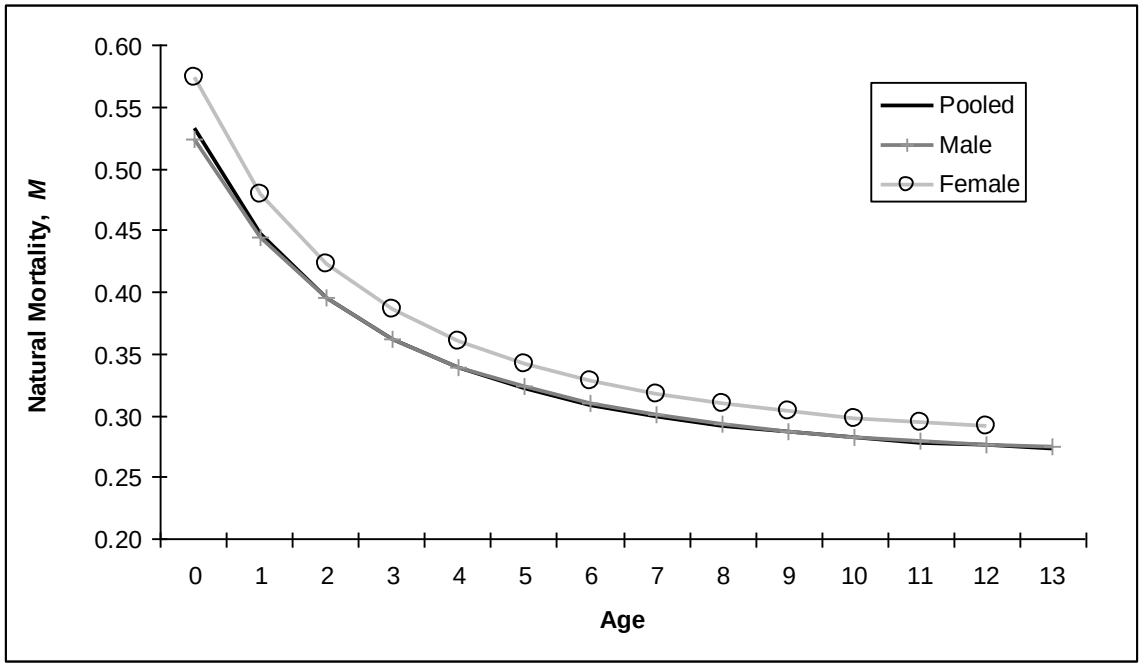



**Figure 2.5.2.2** Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the NMFS Trawl Survey.

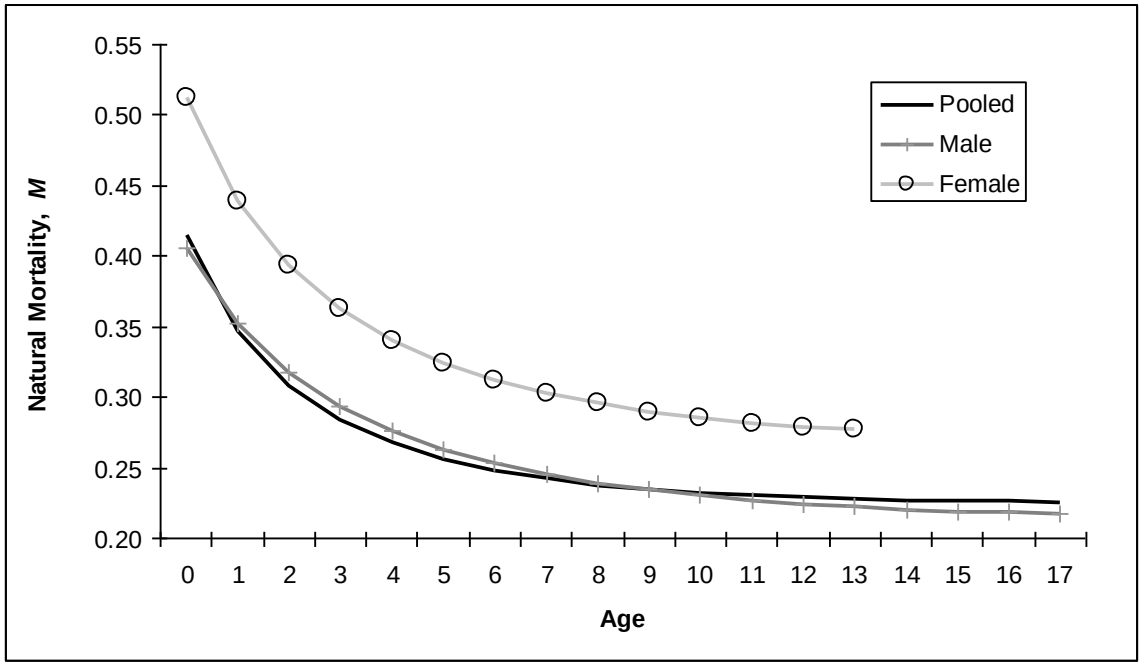



**Figure 2.5.2.3** Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the ChesMMAP Trawl Survey.

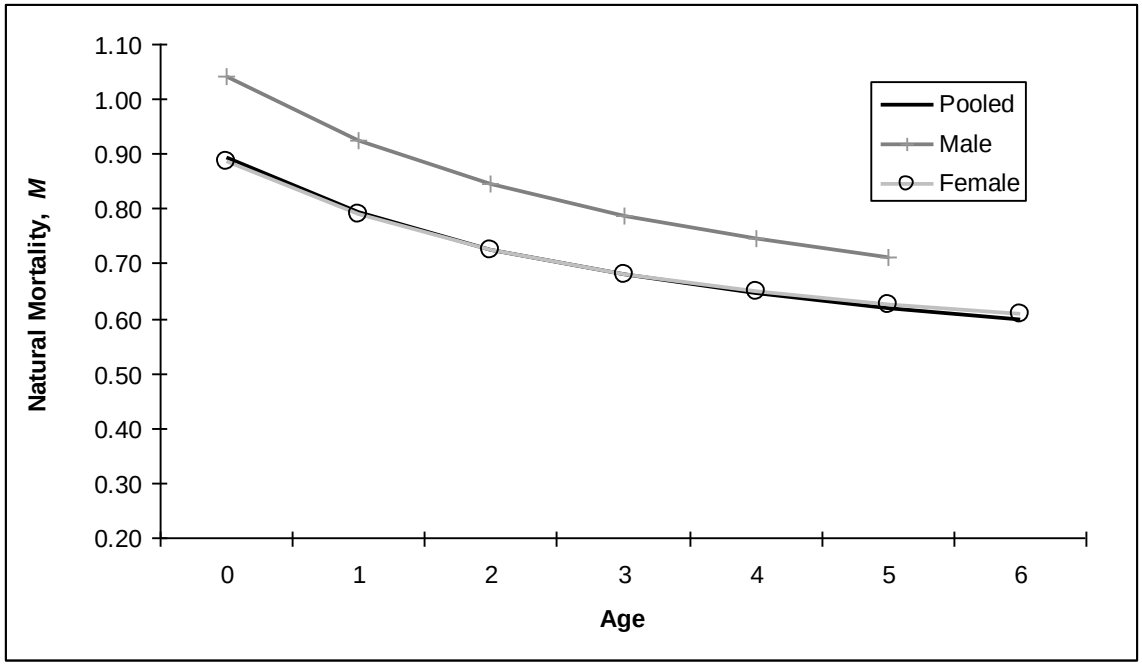



**Figure 2.5.2.4** Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the SEAMAP Trawl Survey.

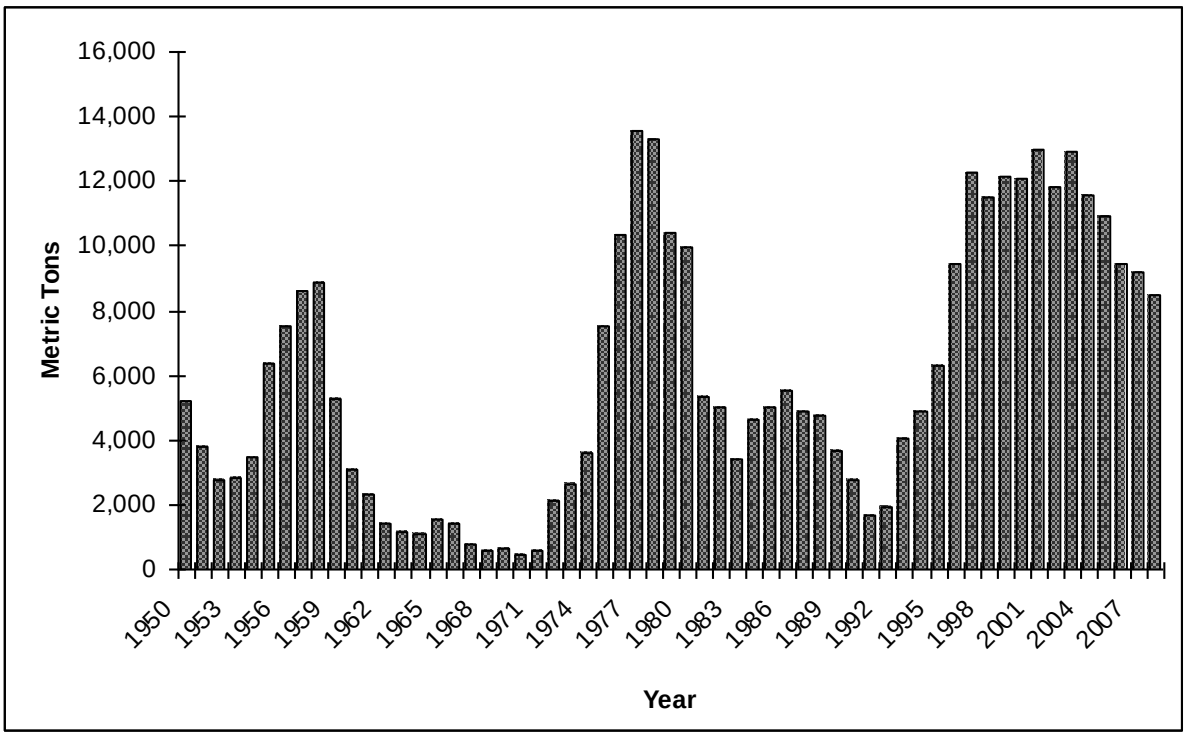
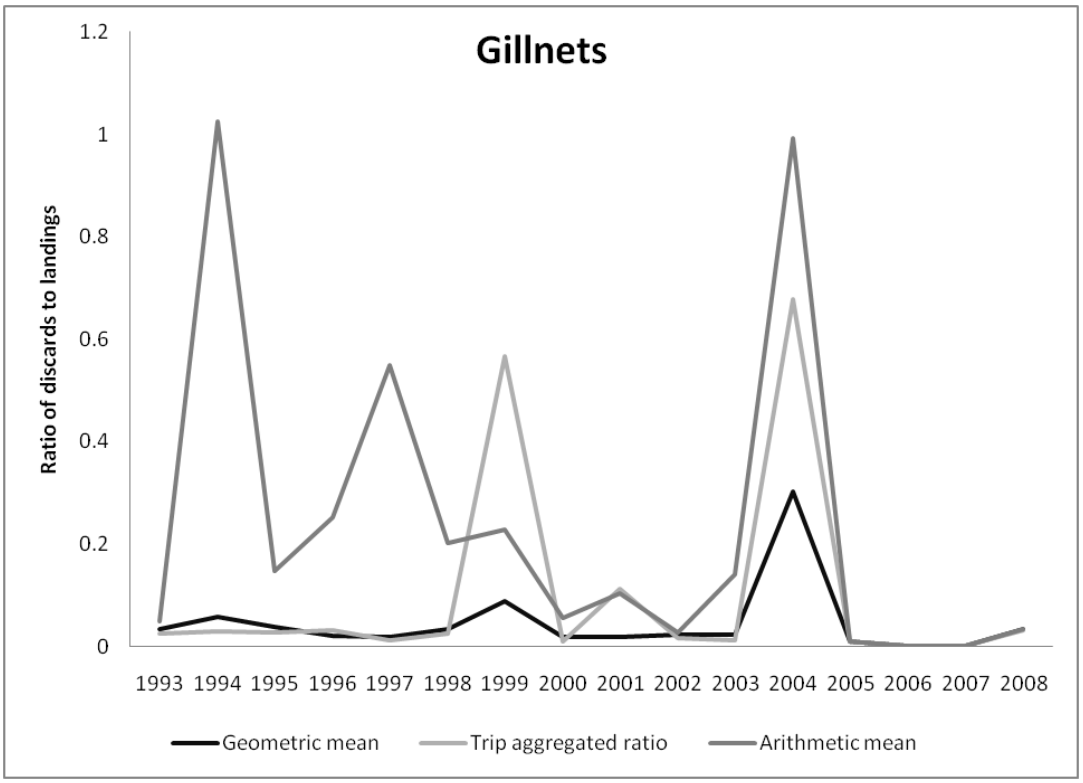



**Figure 5.1.2.1** Annual commercial landings (metric tons) of Atlantic croaker along the Atlantic coast, 1950–2008.

A.




B.

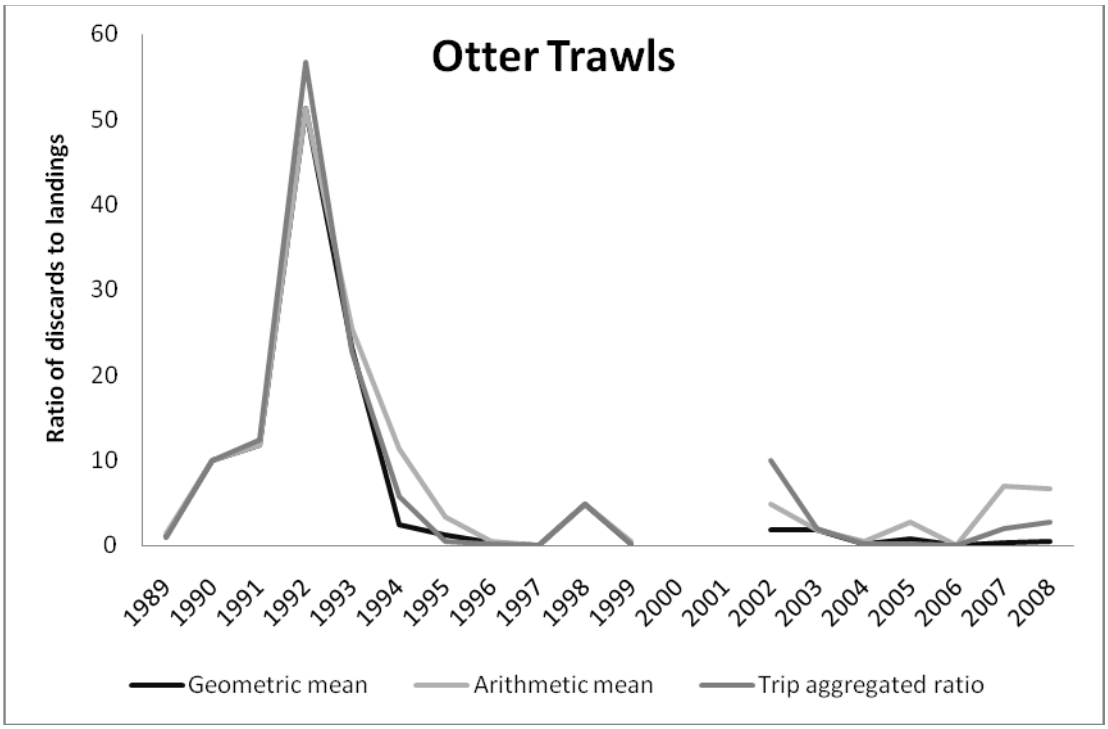
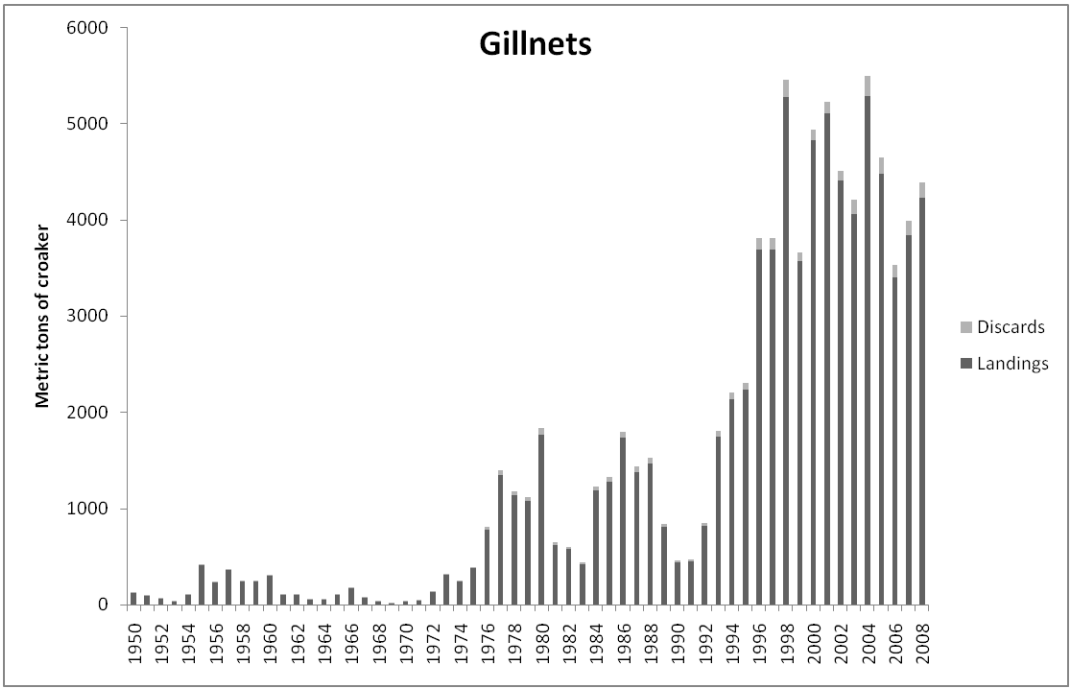



**Figure 5.1.3.3.1** Ratios of discards to landings from trip level data using three different methods.

A.




B.

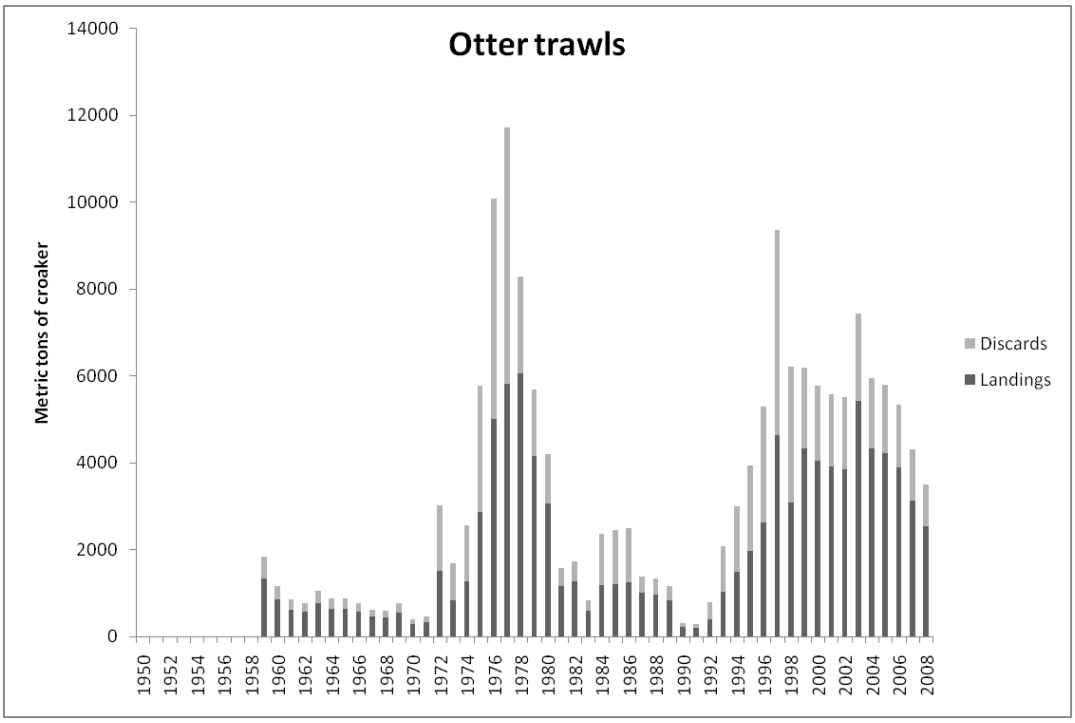



**Figure 5.1.3.3.2** Landings and discards of croaker from gillnet (A) and otter trawl (B) fisheries, estimated using the geometric mean of the observed discard to landings ratios.

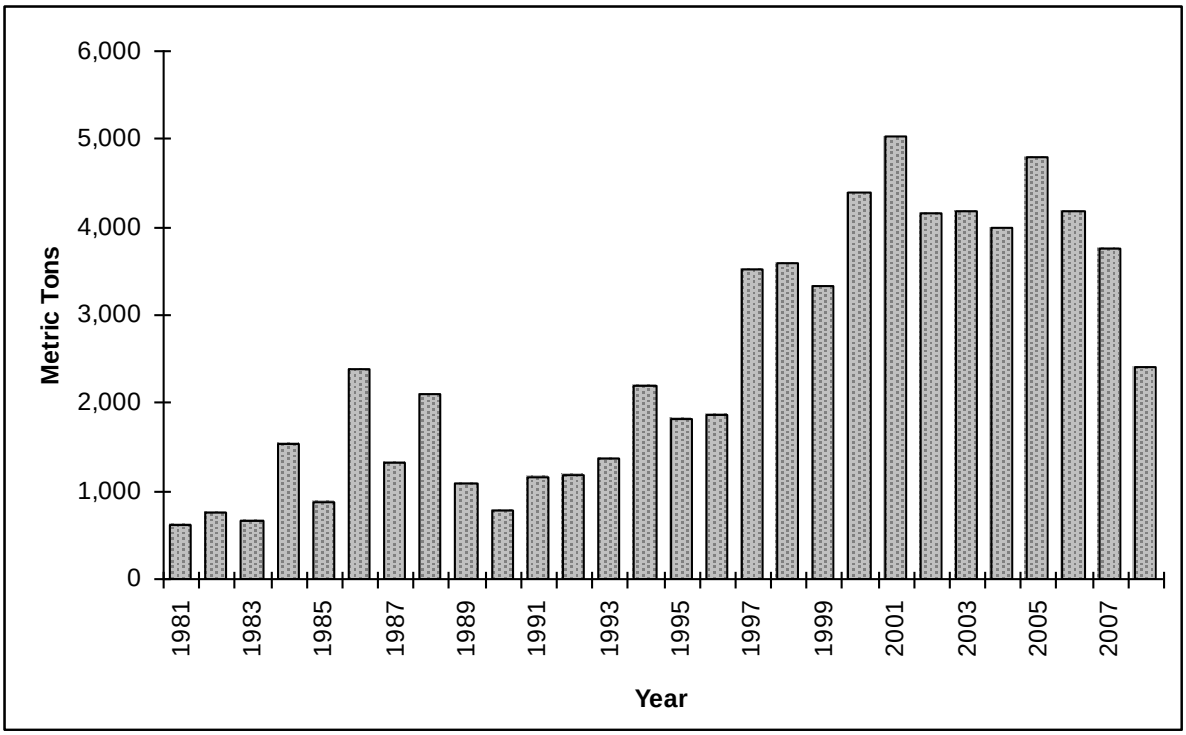



**Figure 5.2.2.1** Annual recreational harvest (metric tons) of Atlantic croaker along the Atlantic coast, 1981–2008.

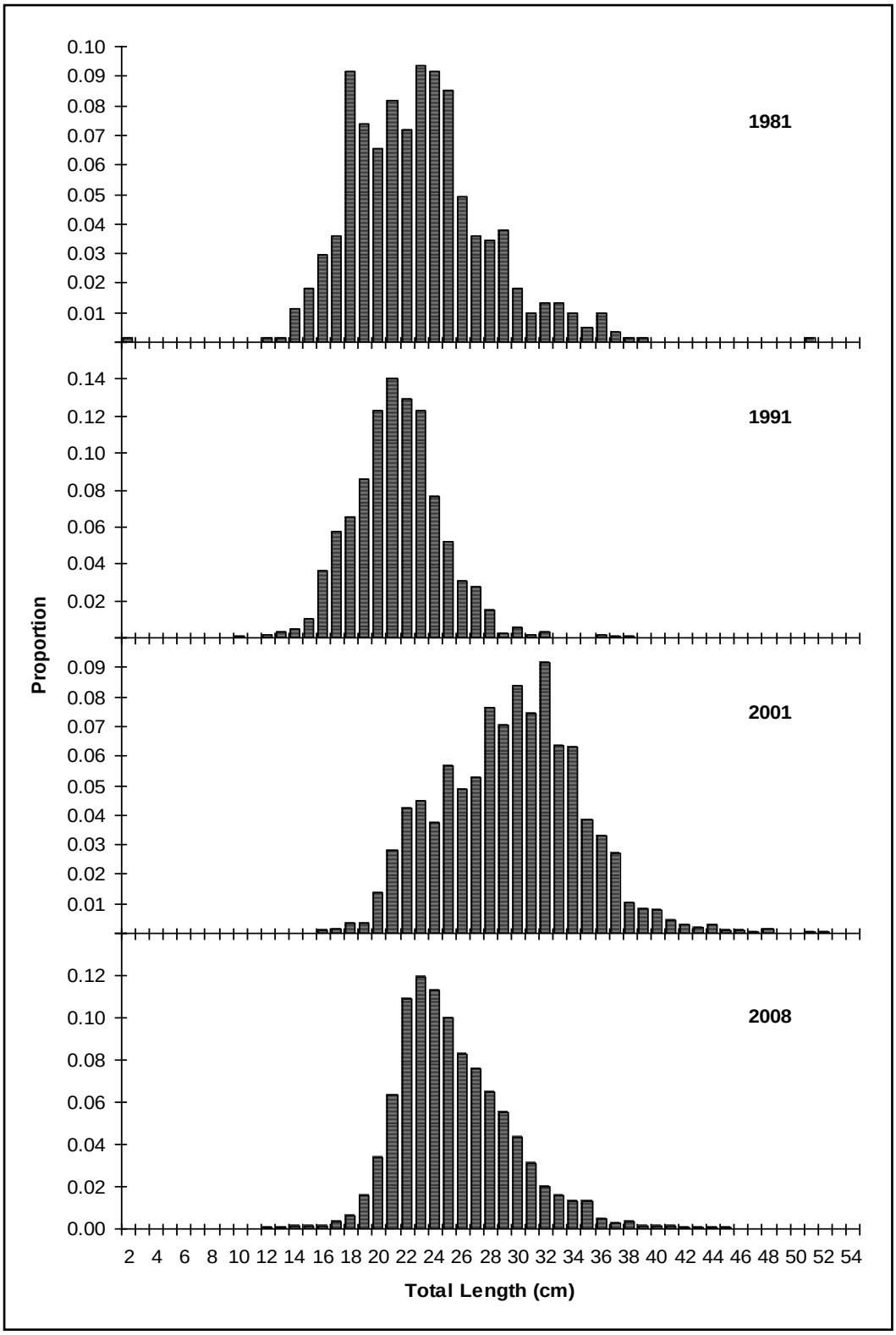



**Figure 5.2.2.2** Length-frequency distribution of Atlantic croaker harvested (Type A+B1) by recreational fisheries along the Atlantic coast, for selected years.

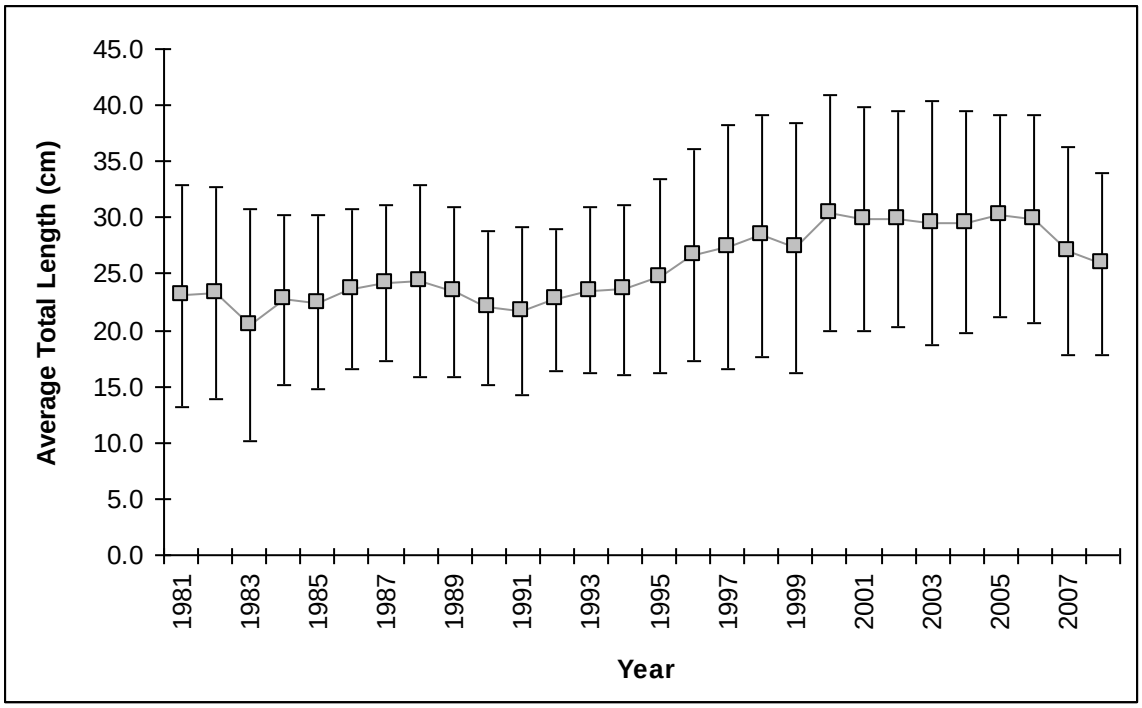



**Figure 5.2.2.3** Annual average total length (cm) of Atlantic croaker harvested (Type A+B1) by recreational fisheries along the Atlantic coast, 1981–2008. The vertical bars represent plus and minus two standard deviations of the average lengths.

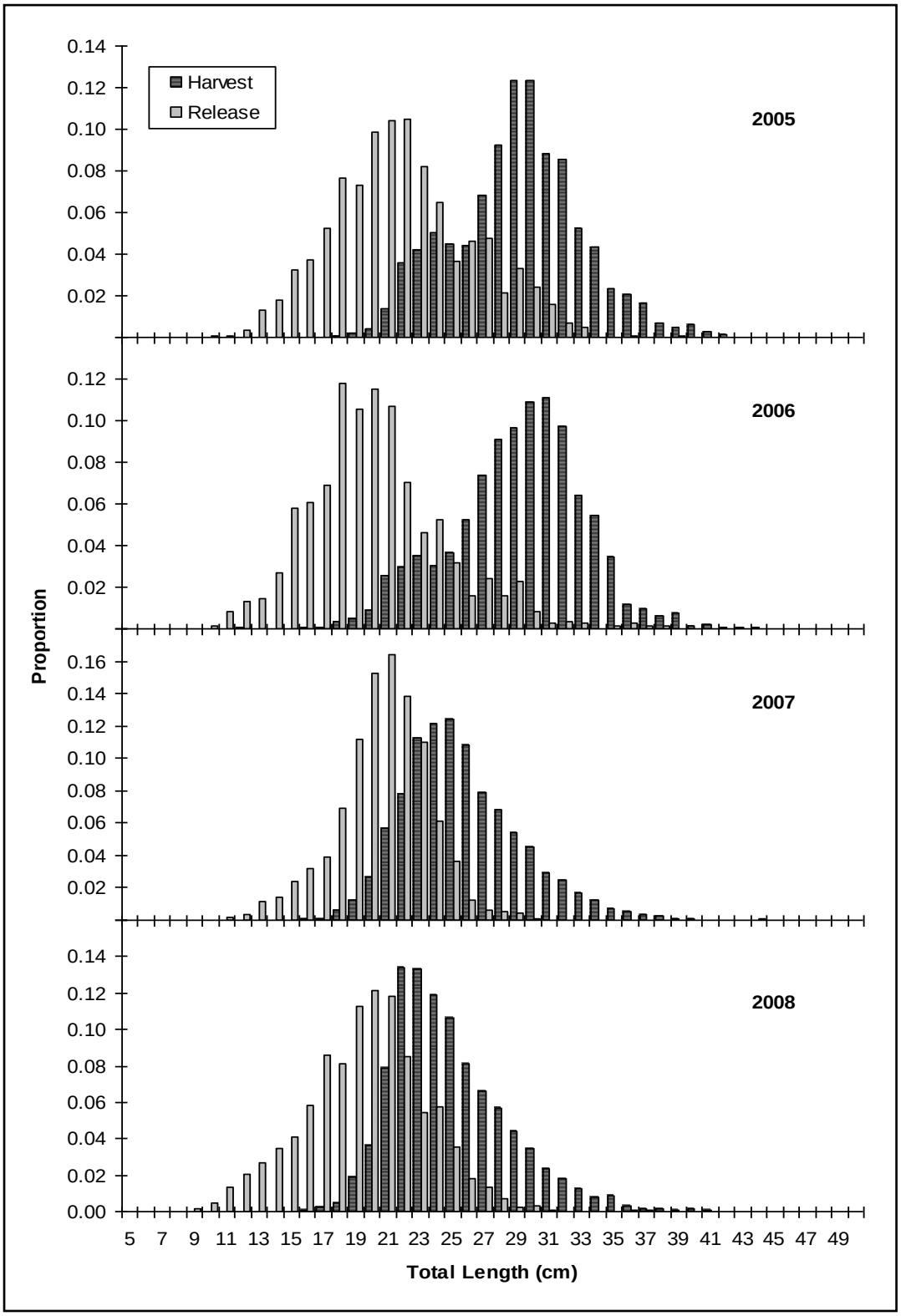



**Figure 5.2.2.4** Length-frequency distribution of Atlantic croaker sampled by the MRFSS from recreational headboat harvest (Type A+B1) and live releases (Type B2) along the Atlantic coast, 2005–2008.

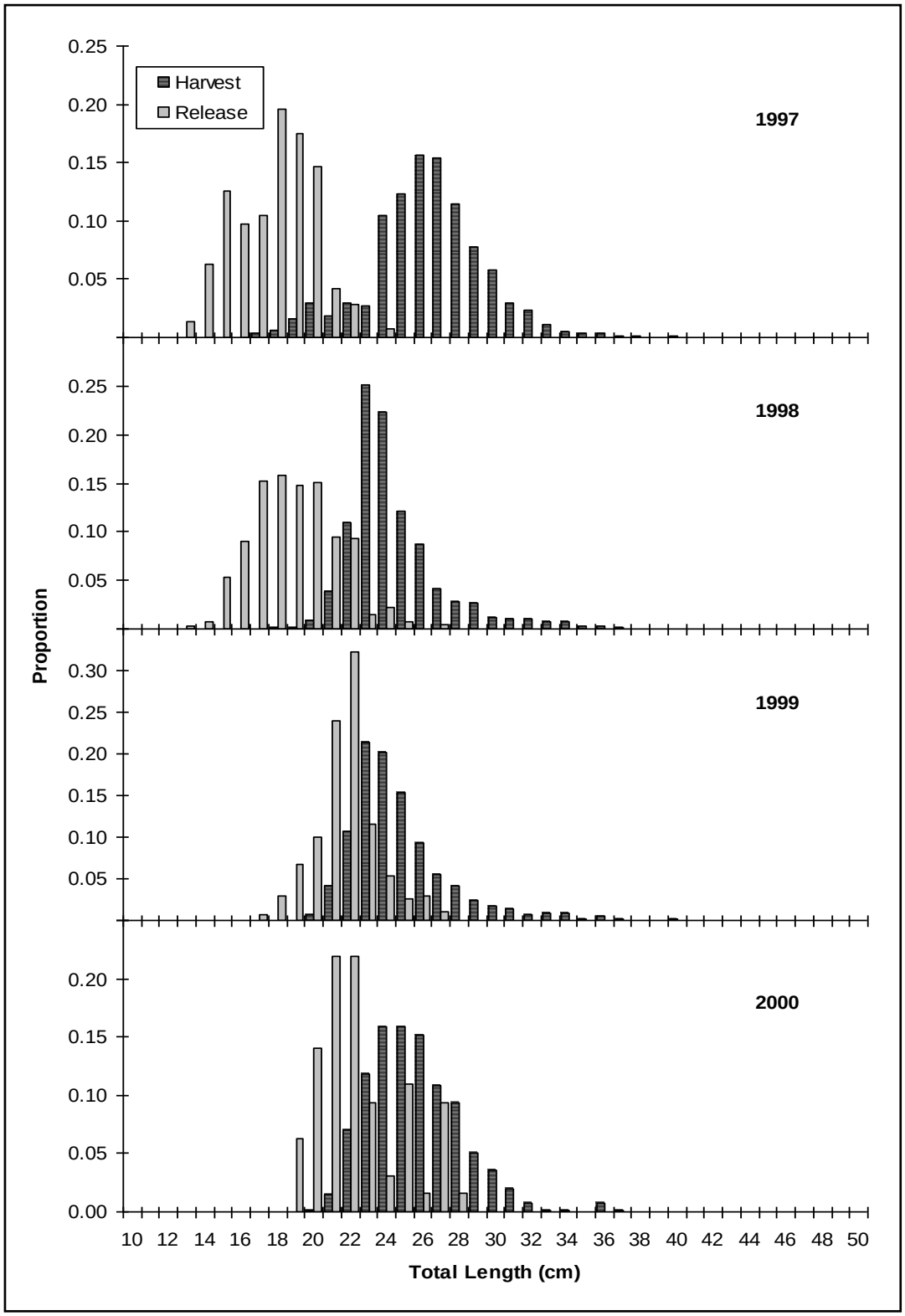



**Figure 5.2.3.1** Length-frequency distribution of Atlantic croaker sampled during Maryland's headboat survey of recreational headboat harvest and releases in Maryland, 1997–2000.

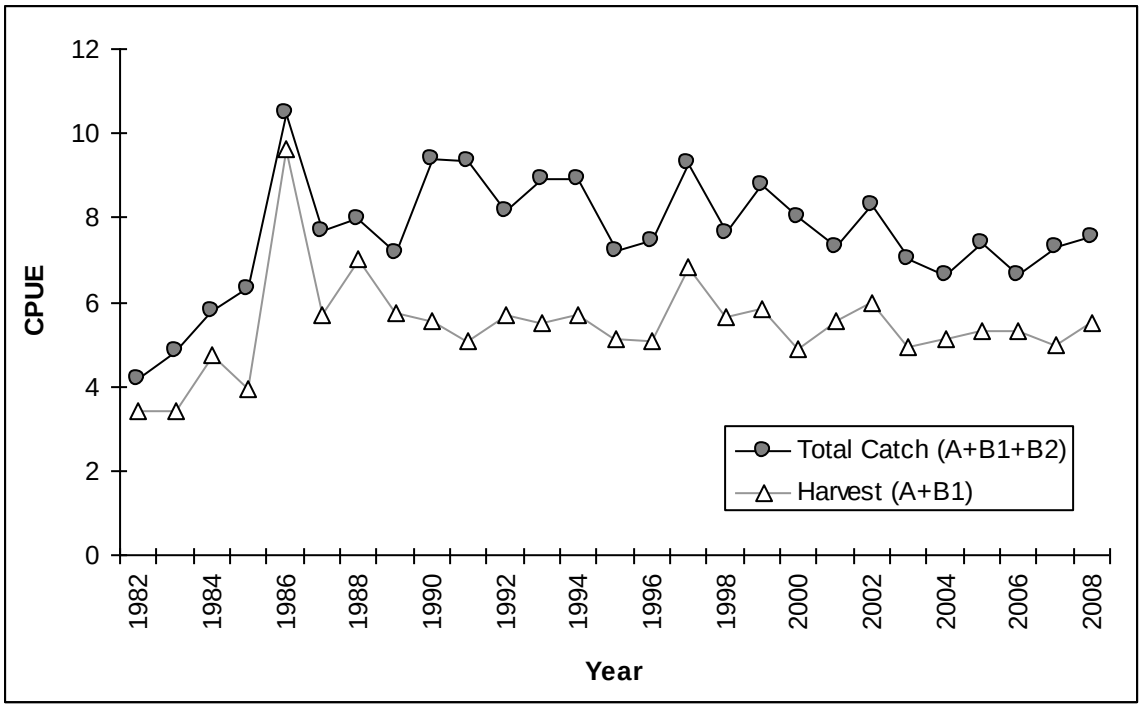



**Figure 5.2.4.1** Annual estimates of recreational CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) based on the directed trips method, 1982–2008.

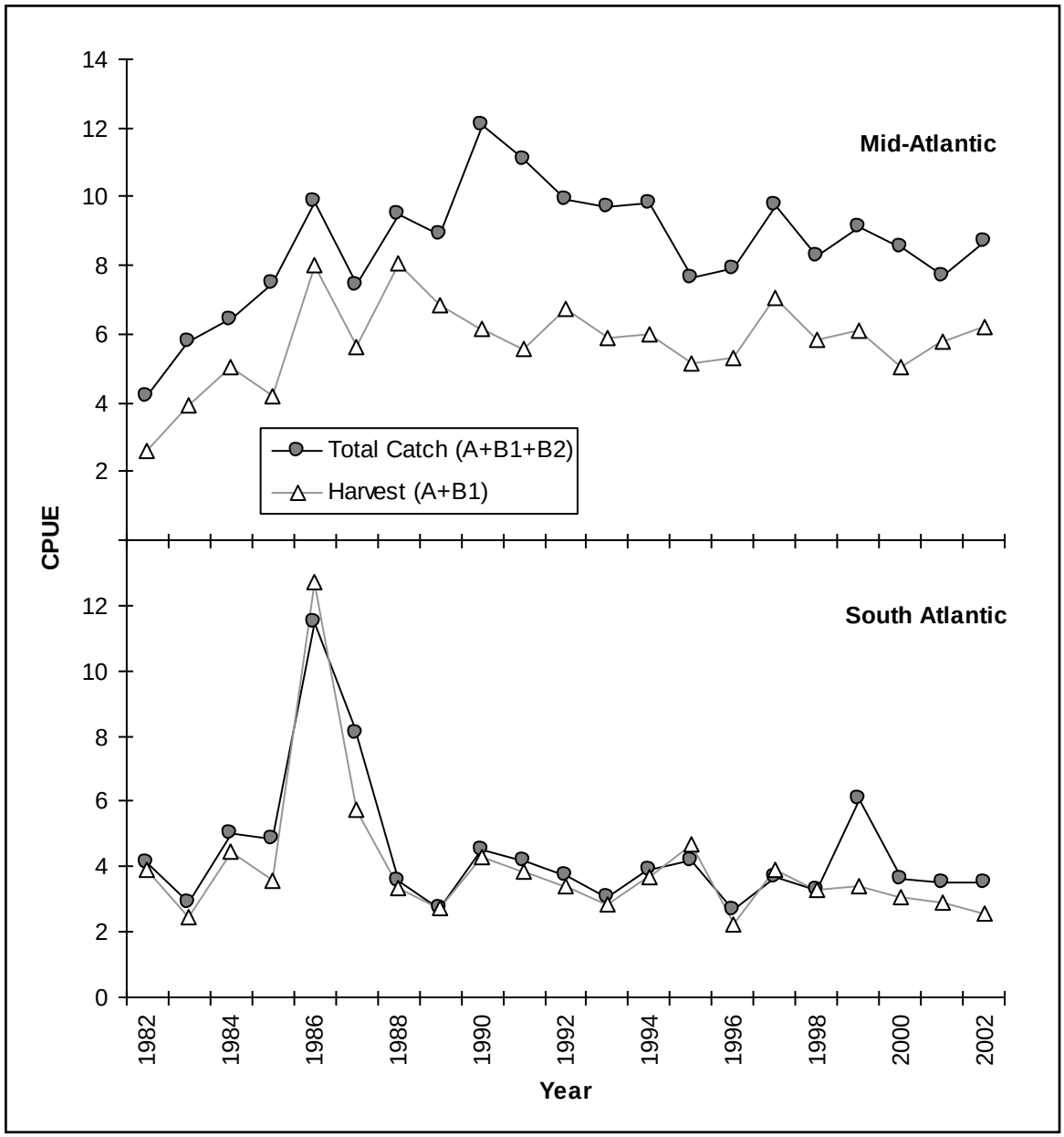



**Figure 5.2.4.2** Annual estimates of recreational fishery CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) for Atlantic croaker in the mid-Atlantic (New Jersey to North Carolina) and south Atlantic (South Carolina to Florida) regions based on the directed trips method, 1982–2002.

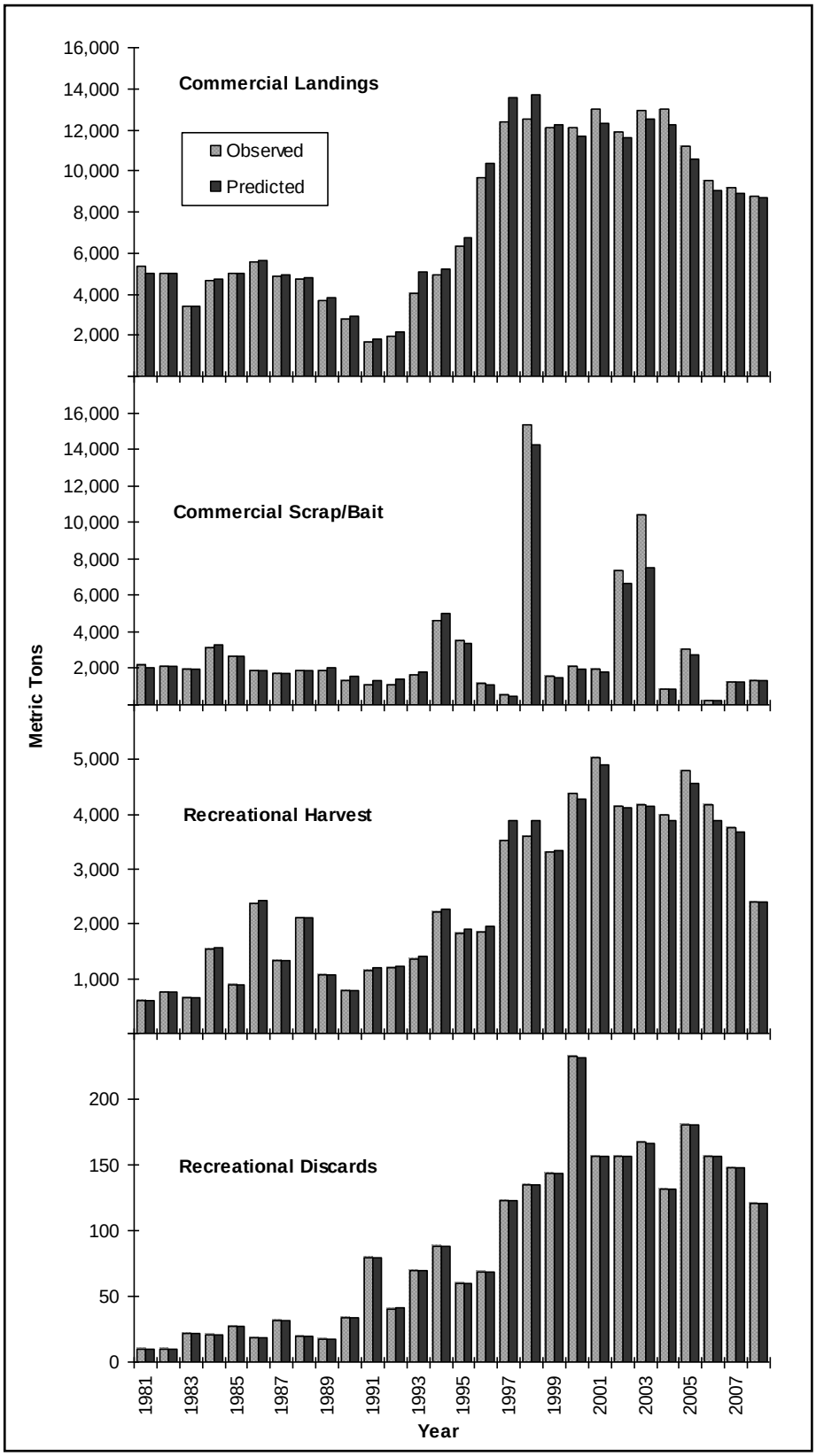



**Figure 7.1.1** Observed and predicted catches from the base run of the hybrid model.

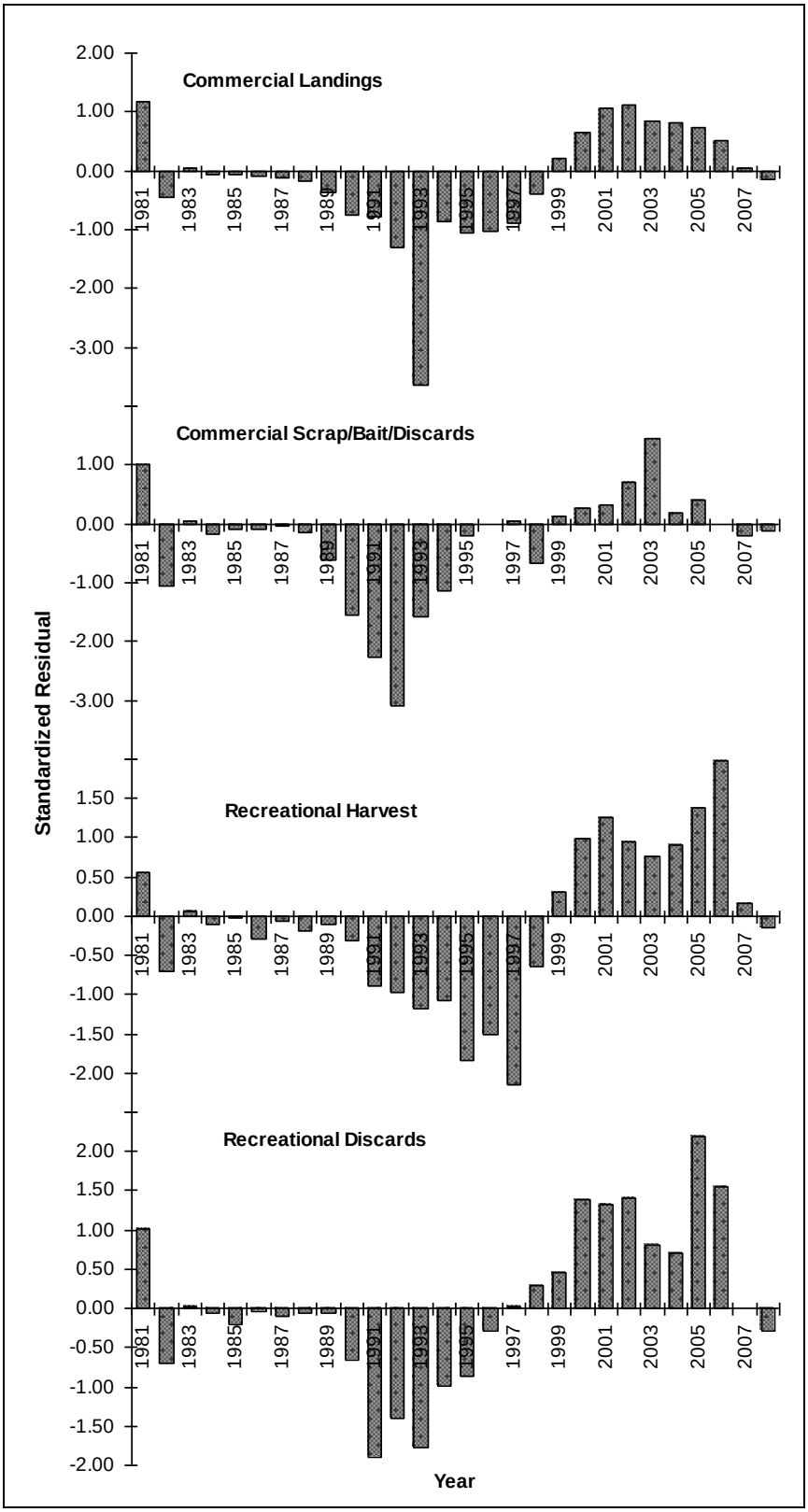
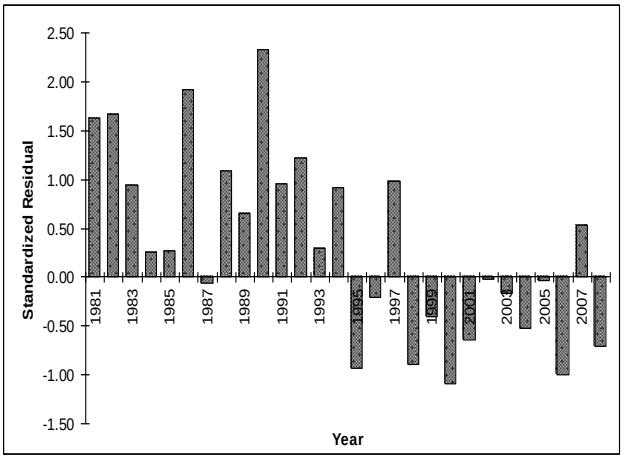
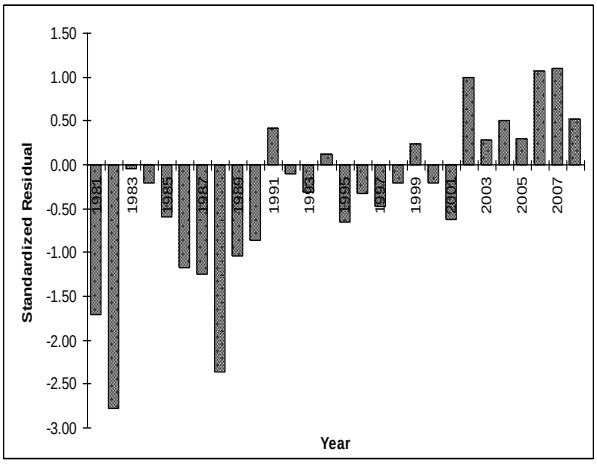



**Figure 7.1.2** Standardized residuals for catch of each fleet from the base run of the hybrid model.

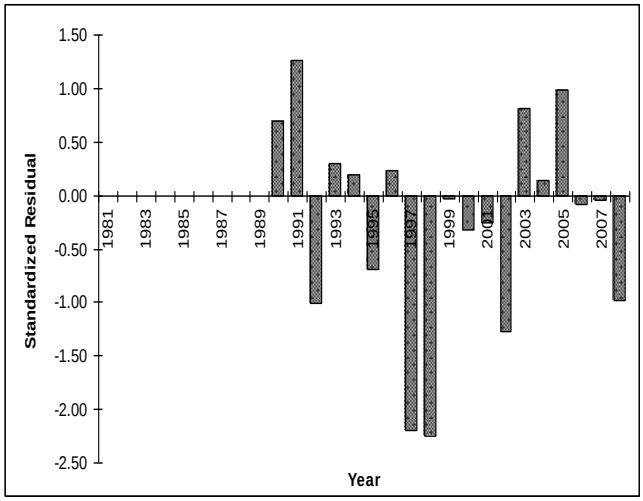
A. Recreational CPUE



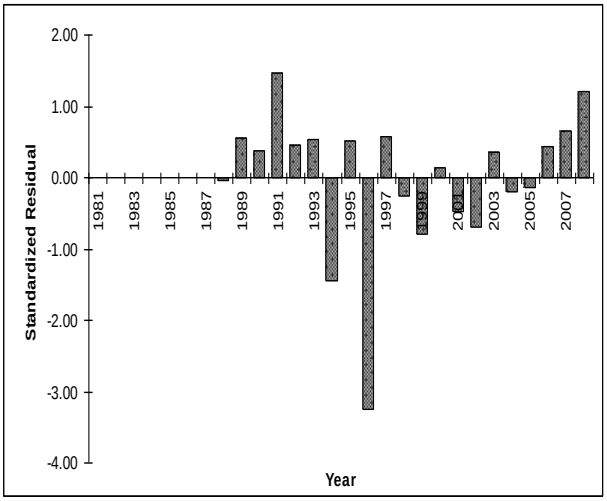

B. NMFS Trawl Survey




C. SEAMAP Fall Survey




D. VIMS YOY Survey




E. NC P195 YOY Survey

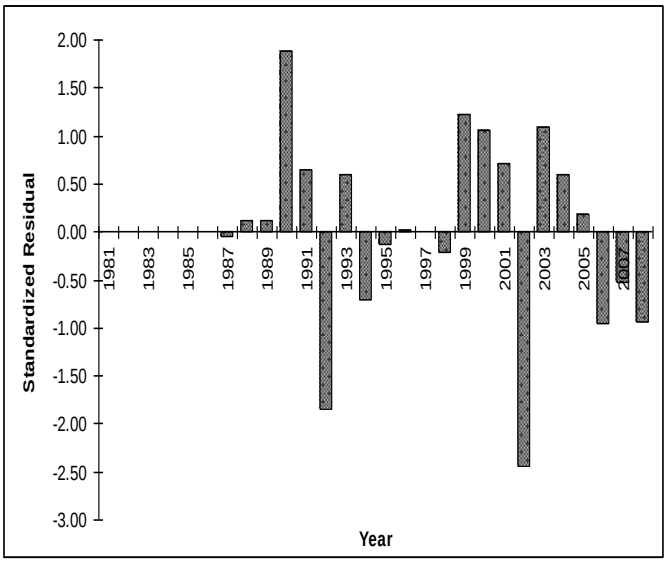



**Figure 7.2.3.** Standardized residuals for the indices from the base run of the hybrid model.

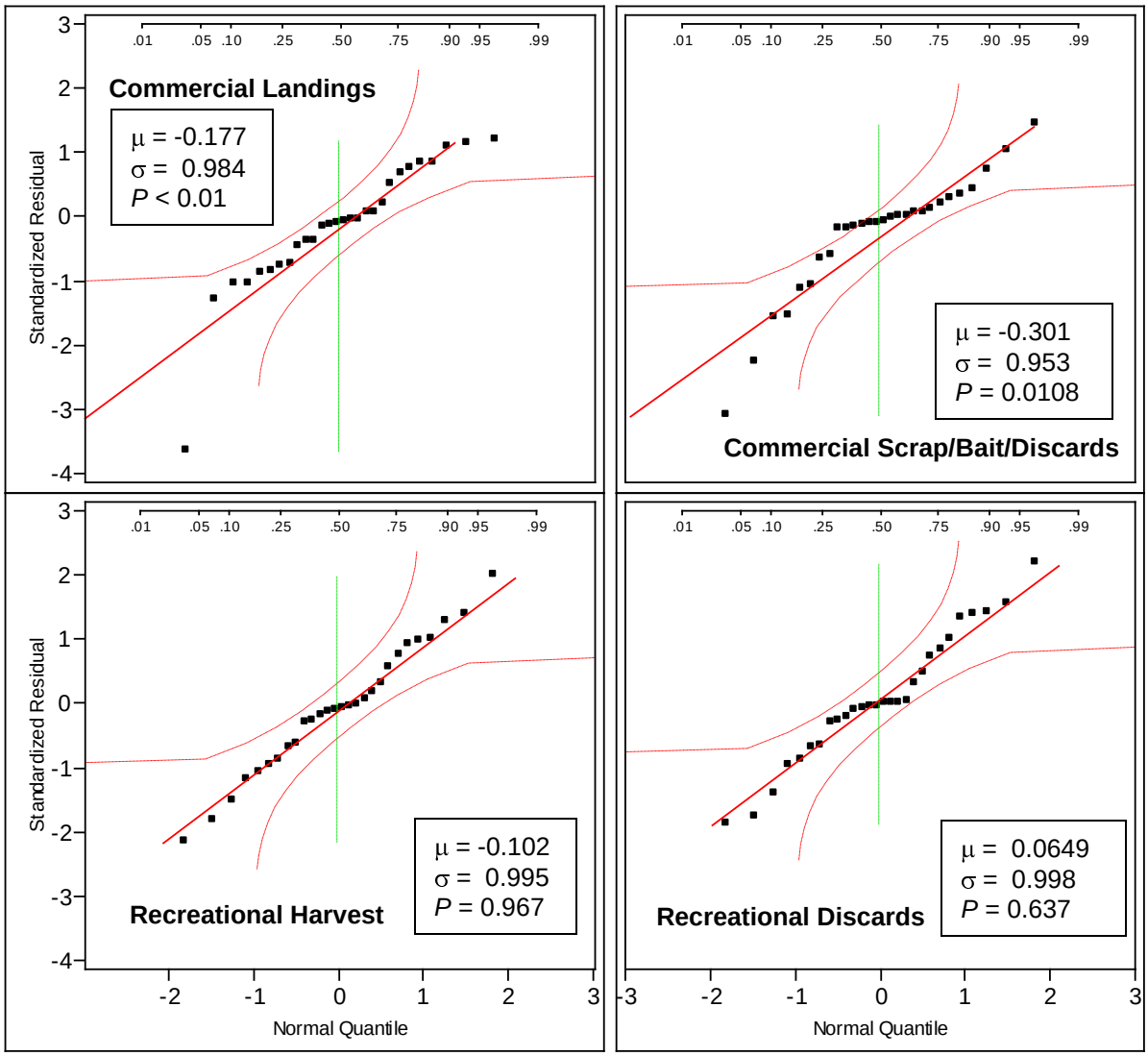



**Figure 7.1.4.** Normal quantile plots (Q-Q plots) of the standardized residuals for catch of each fleet from the base run of the hybrid model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

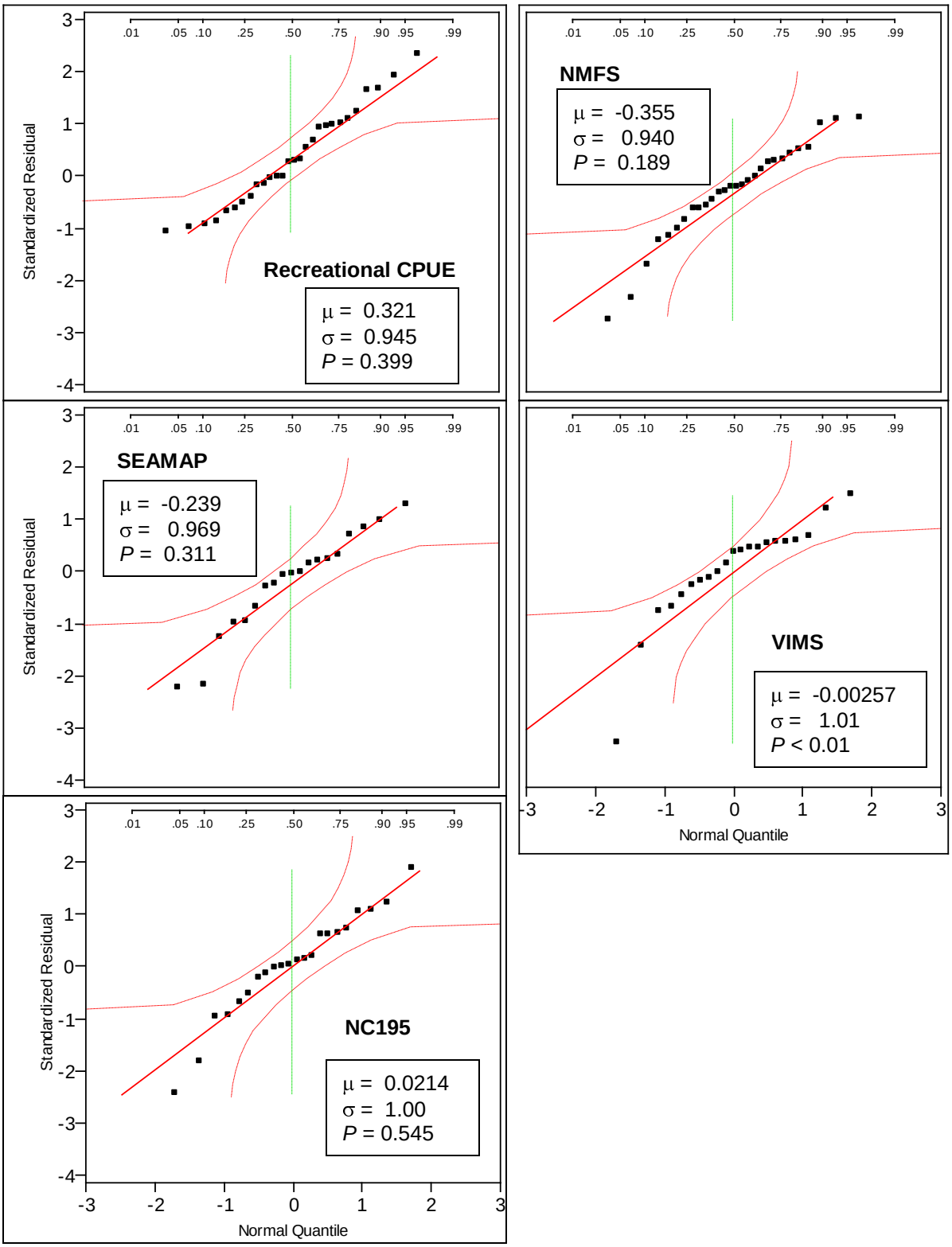



**Figure 7.1.5.** Normal quantile plots (Q-Q plots) of the standardized residuals for each index from the base run of the hybrid model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

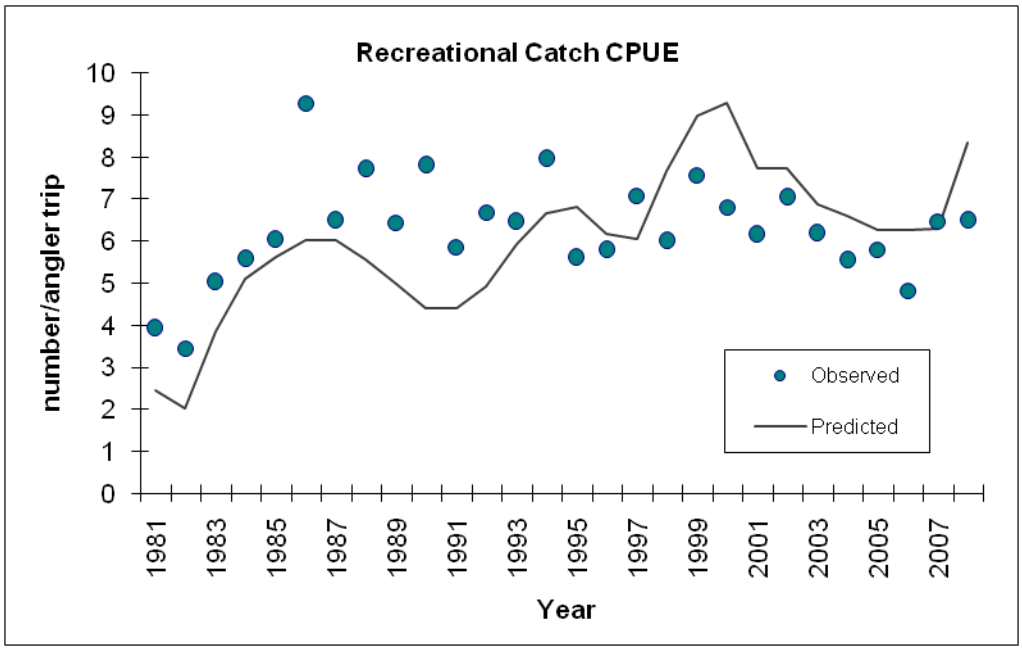



**Figure 7.1.6** Observed and predicted recreational CPUE from the base run of the hybrid model.

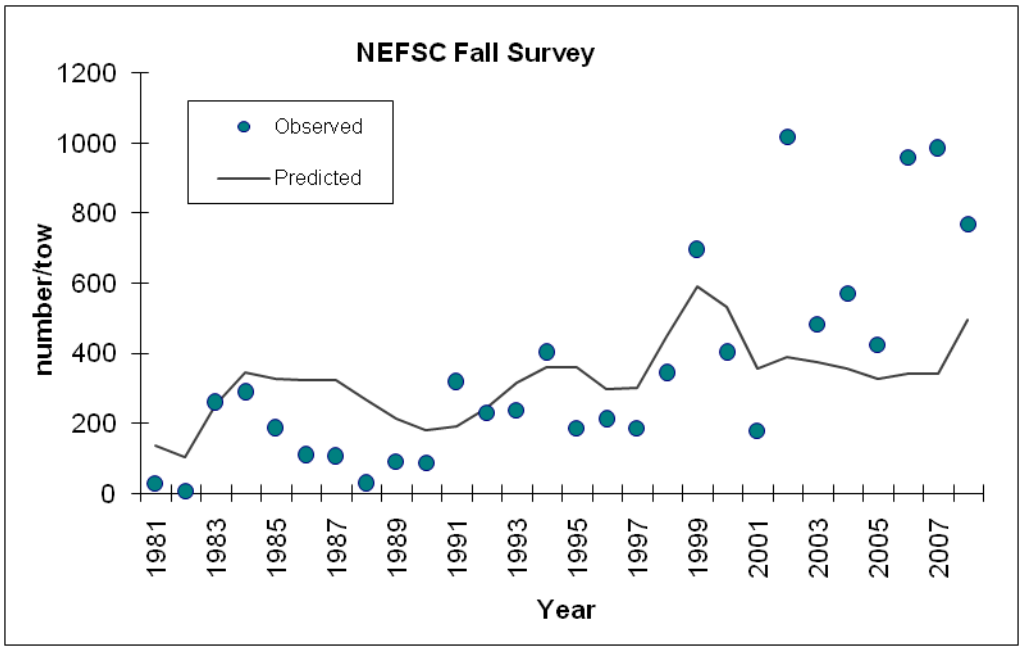



**Figure 7.1.7** Observed and predicted NMFS Bottom Trawl Survey index from the base run of the hybrid model.

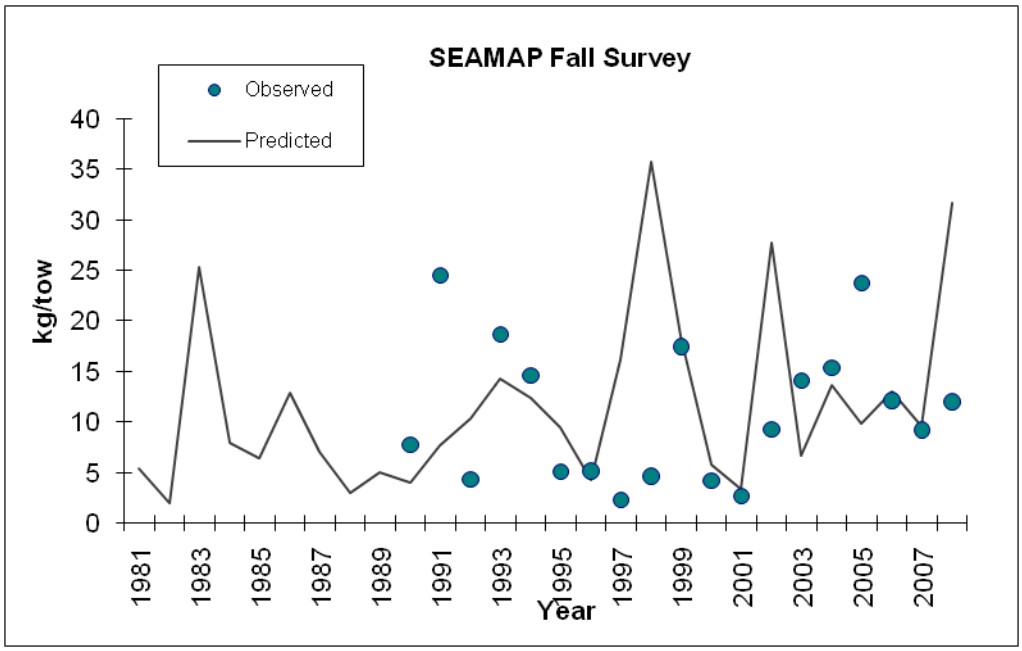



**Figure 7.1.8** Observed and predicted SEAMAP-SA Coastal Survey index from the base run of the hybrid model.

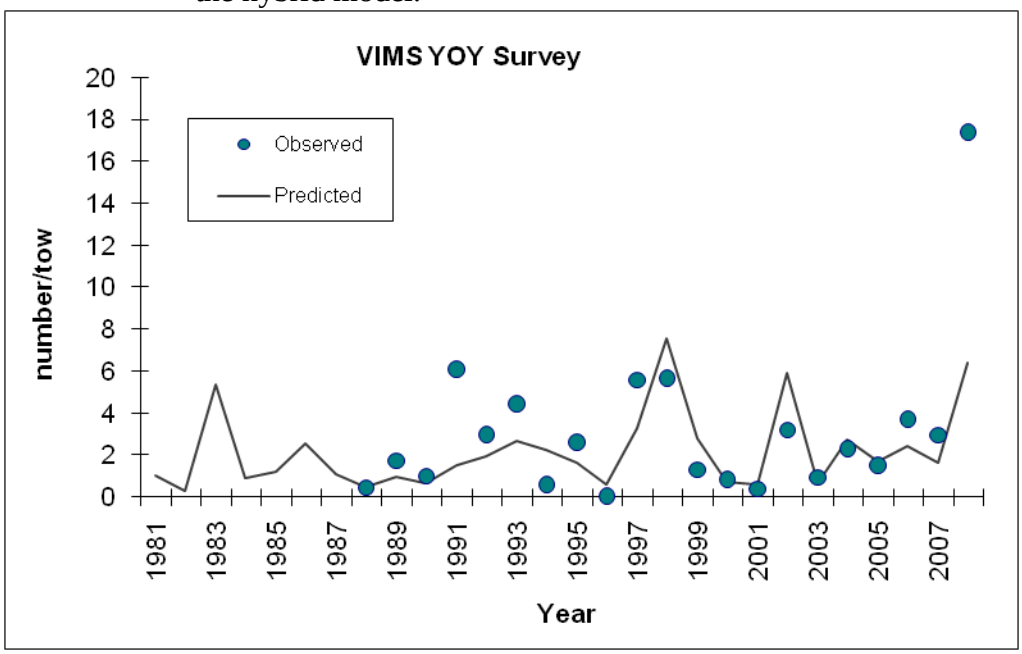



**Figure 7.1.9** Observed and predicted VIMS young-of-year index from the base run of the hybrid model.

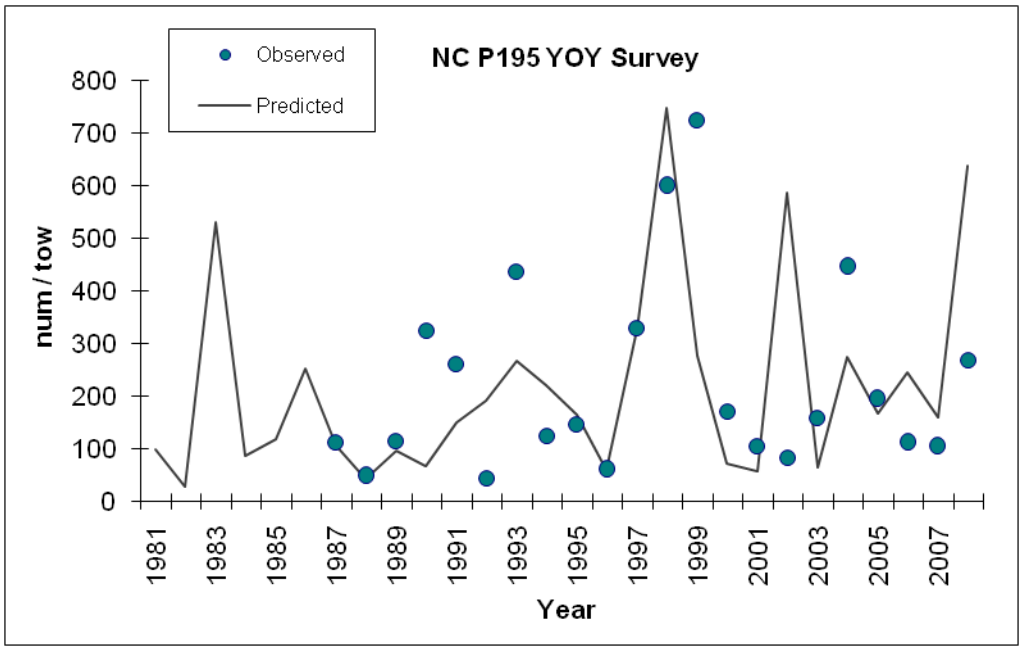



**Figure 7.1.10** Observed and predicted NC Program 195 young-of-year index from the base run of the hybrid model.

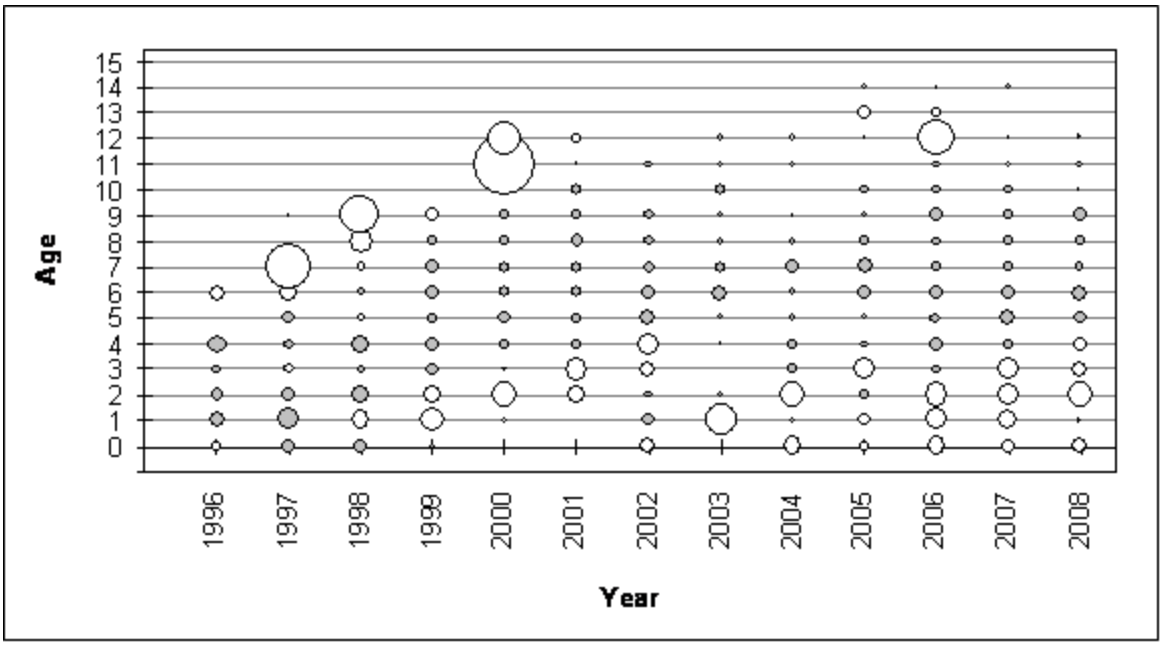



**Figure 7.1.11** Standardized residuals for the commercial landings catch-at-age from the base run of the hybrid model.

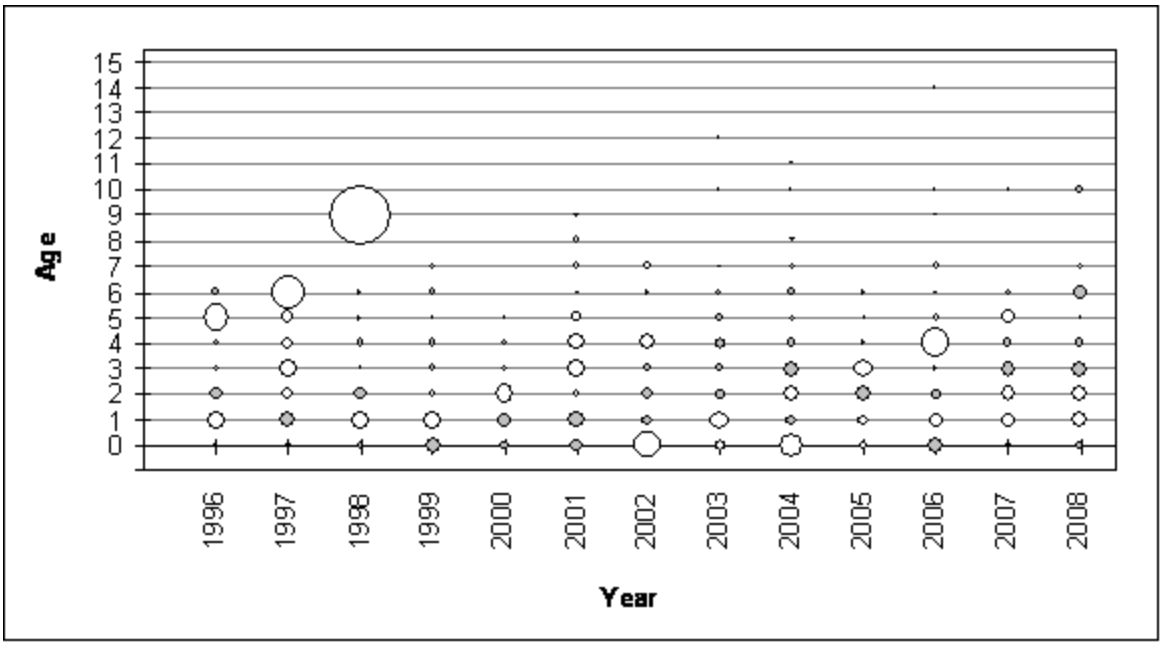



**Figure 7.1.12** Standardized residuals for the commercial scrap/bait/discards catch-at-age from the base run of the hybrid model.

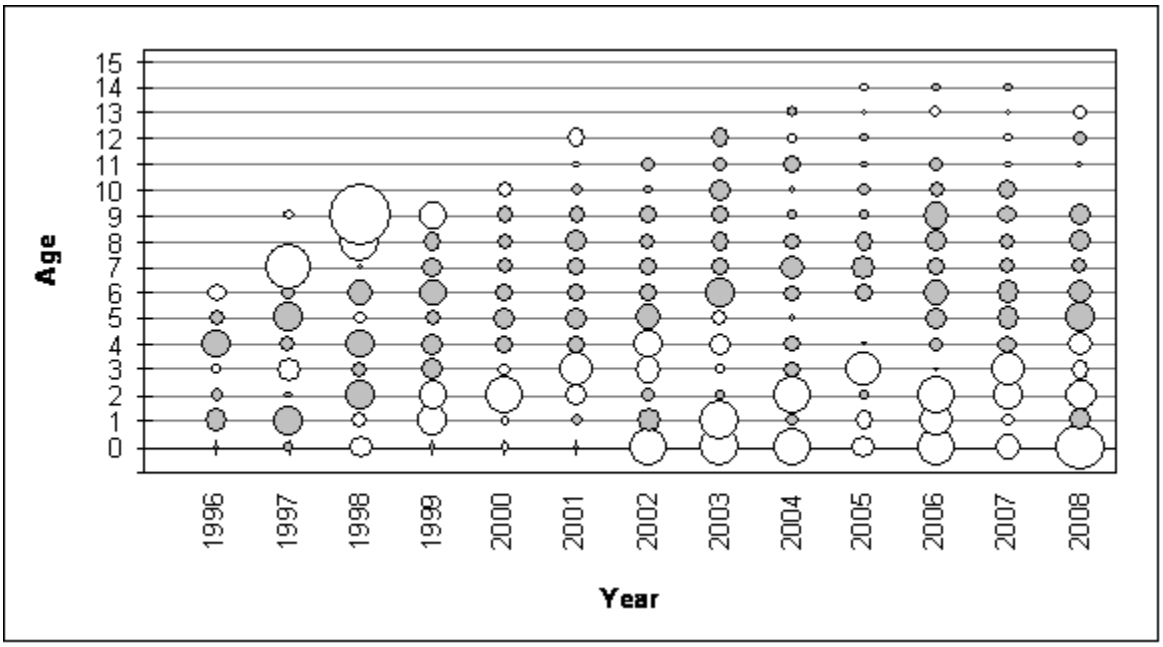



**Figure 7.1.13.** Standardized residuals for the recreational harvest catch-at-age from the base run of the hybrid model.

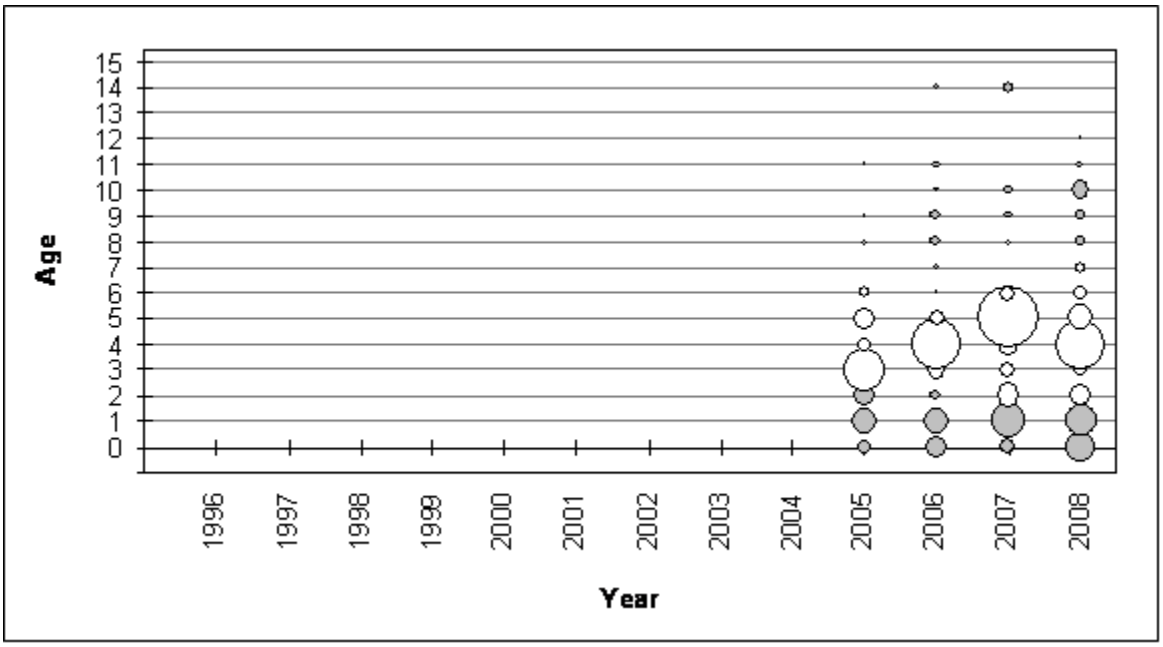



**Figure 7.1.14** Standardized residuals for the recreational discards catch-at-age from the base run of the hybrid model.

**Figure 7.1.15** Predicted trends in population size of Atlantic croaker from the base run of the hybrid model.

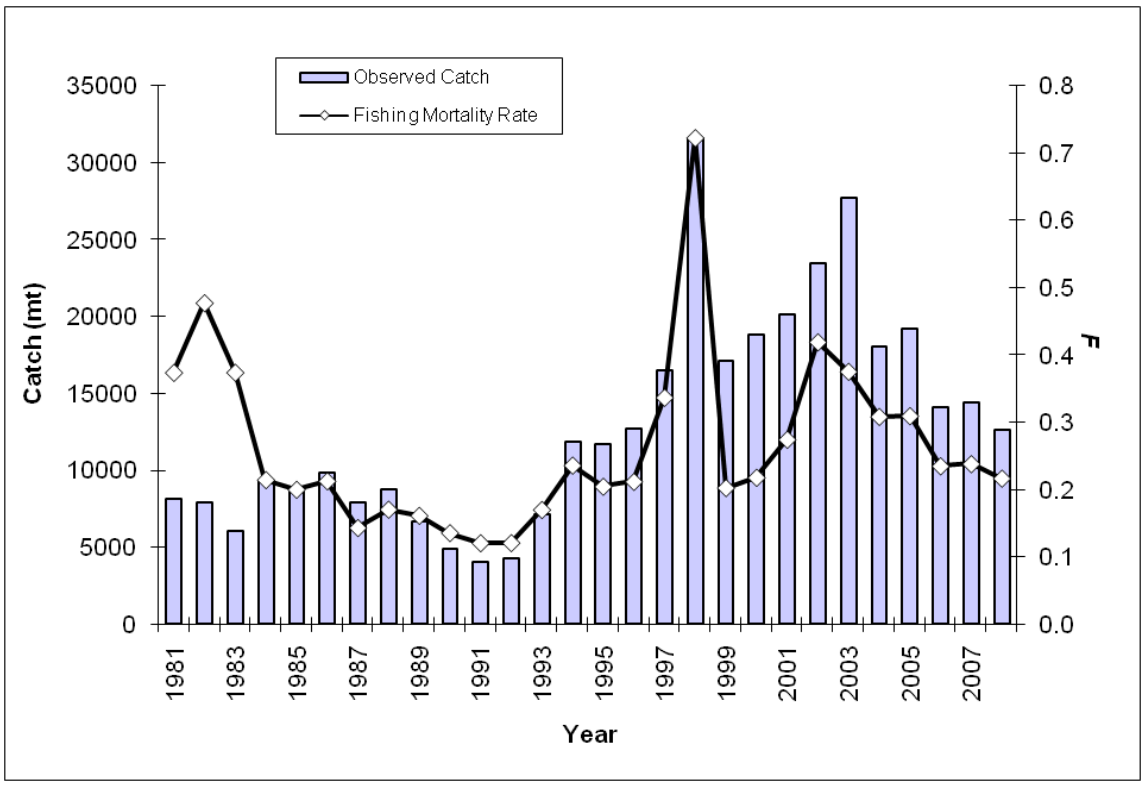



**Figure 7.1.16** Observed total catch and predicted fishing mortality rates (average *F* over ages 1–15+, weighted by population abundance) from the base run of the hybrid model.

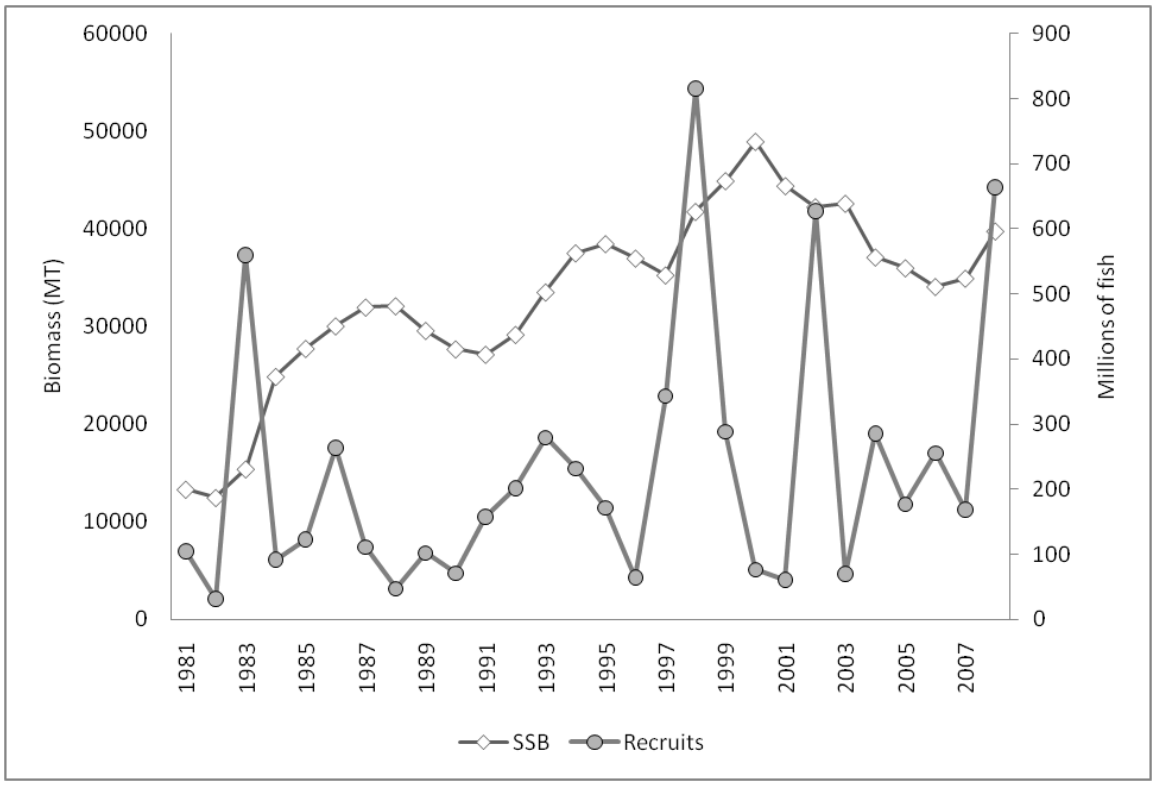



**Figure 7.1.17** Predicted trends in recruitment (age-0) and spawning stock biomass of Atlantic croaker from the base run of the hybrid model.

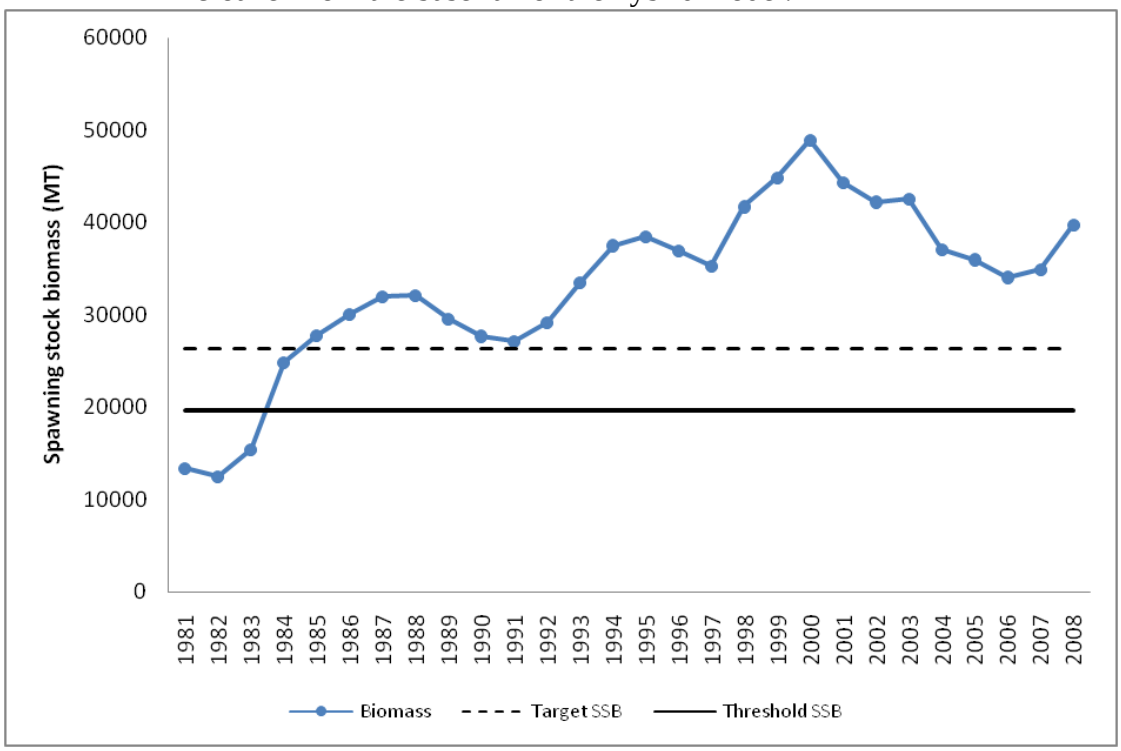



**Figure 7.1.18** Predicted trends in spawning stock biomass relative to spawning stock biomass target and threshold estimated from the base run of the hybrid model.

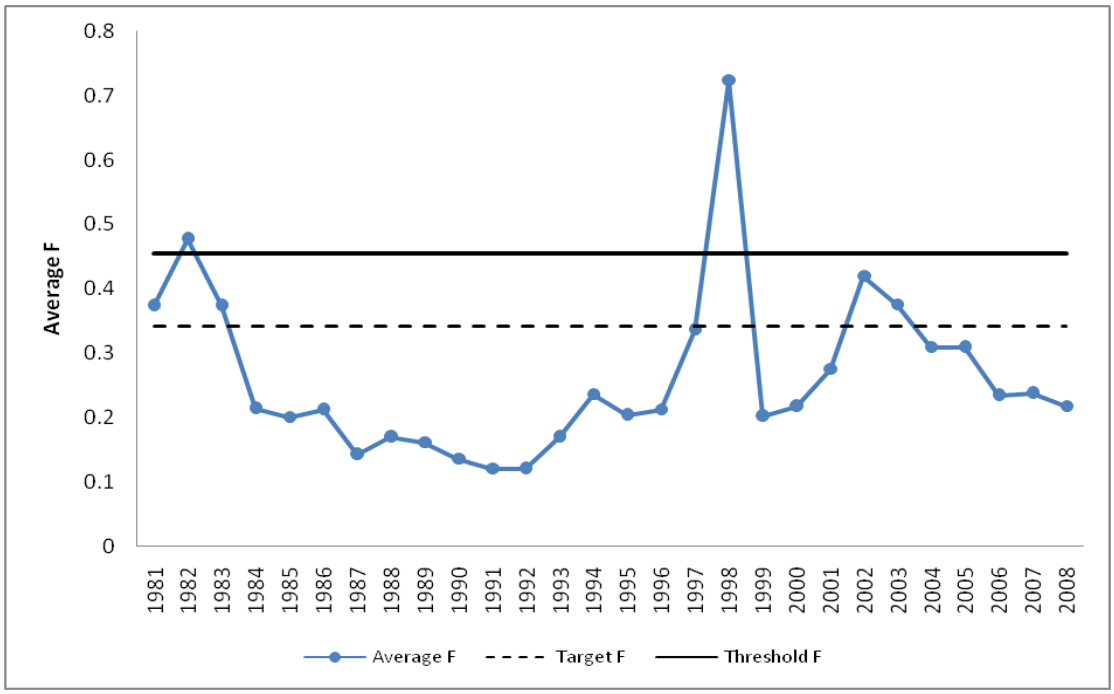



**Figure 7.1.19** Predicted trends in fishing mortality rates (average *F* over ages 1–15+, weighted by population abundance) relative to fishing mortality target and threshold estimated from the base run of the hybrid model.

**Figure 7.1.20** Trends in fishing mortality rates and spawning stock biomass relative to values needed to produce MSY estimated from the base run of the hybrid model.

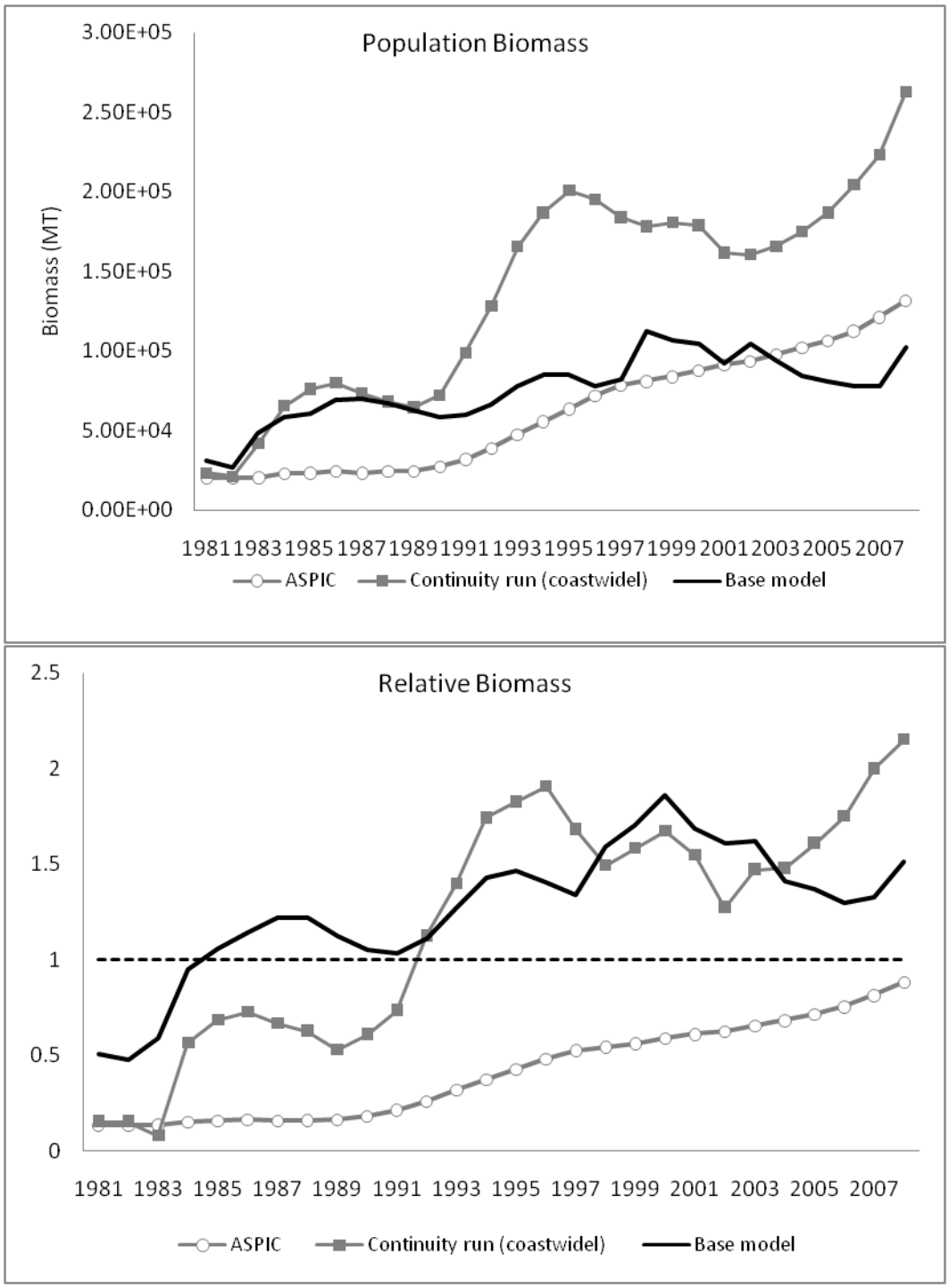



**Figure 7.1.21** Population biomass estimates from three different models.

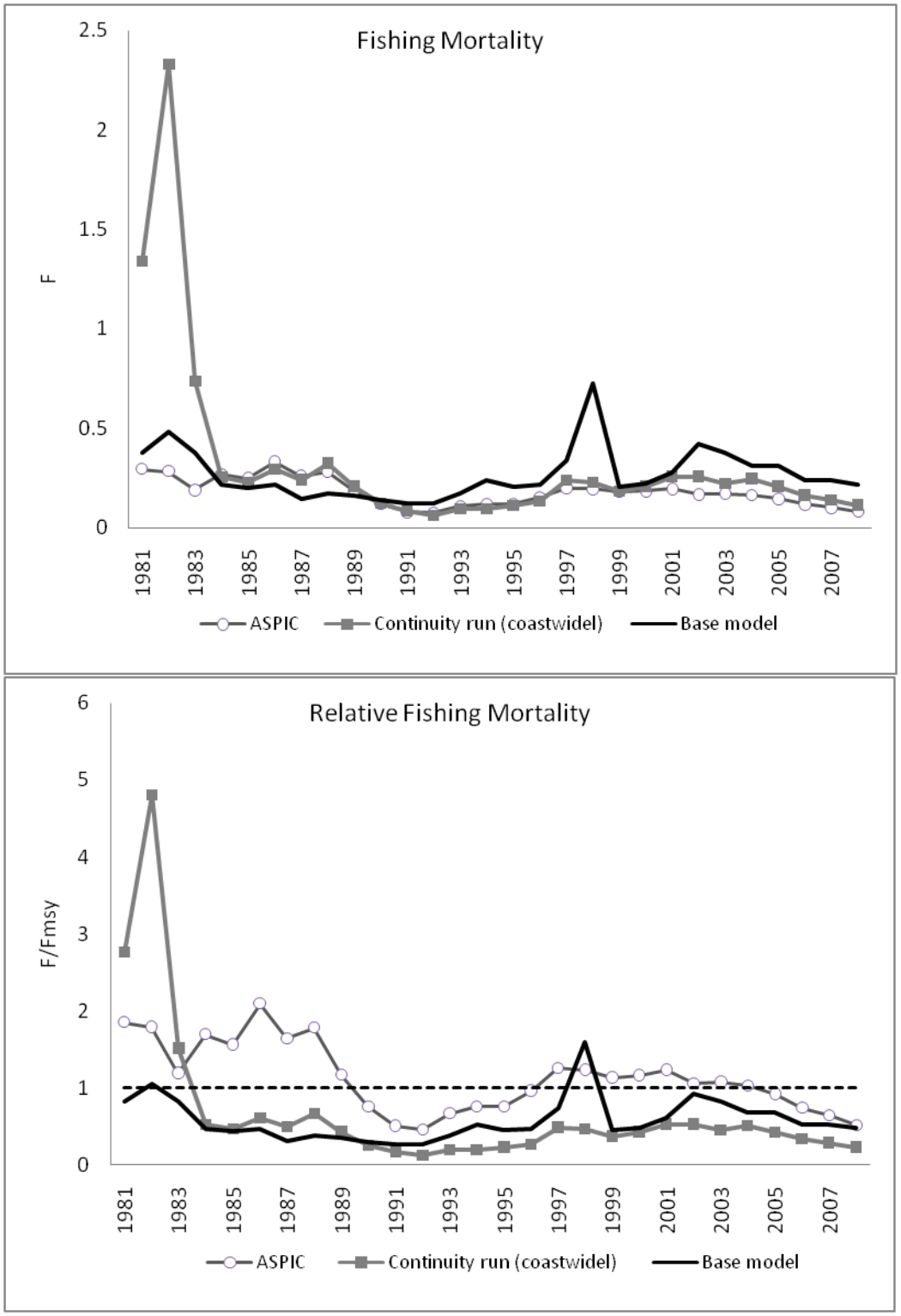



**Figure 7.1.22** Fishing mortality estimates from three different models.

# 14 APPENDICES

## Appendix 1: Estimates of Annual Atlantic Croaker Bycatch in the Shrimp Trawl Fishery, 1973-2008, Based on a Simple Fish:Shrimp Ratio Approach

Contributed by Eric Robillard (Georgia Department of Natural Resources)
and Chris McDonough (South Carolina Department of Natural Resources)

### Overview

Annual estimates of Atlantic croaker bycatch in the Atlantic shrimp trawl fishery were produced for 1950 through 2008. Given the lack of detailed effort data and limited bycatch characterization data, estimates were produced using a fish catch to shrimp catch ratio method. All catch ratios were derived from studies conducted by North Carolina Division of Marine Fisheries (NCDMF) and expanded to the entire coast. Previous shrimp trawl bycatch analyses for croaker showed over 99% of bycatch was Age 0 (Foster 2004). These estimates must be considered extremely crude, catch ratios are different between locations and between gears, but assumed homogeneous in this exercise. These data should not be used for stock assessment other than for sensitivity analyses.

### Data Sources

*Atlantic Coast Commercial Shrimp Trawl Landings, 1950-2008*
Annual landings, in pounds, from the shrimp trawl fishery for the Atlantic coast of the United States were provided by NMFS for Atlantic croaker and penaeid shrimp from 1950-2008. Over the time series, shrimp landings have averaged 21.5 million pounds ranging from 10.7 million (2005) to 36.1 million (1950) with an overall declining trend (Figure A1.1).

Landings have stayed at or below the long term mean since 1976 except during four years (1980, 1985, 1991, and 1995). Landings in recent years have steadily declined and remained below the long term mean since 1999.

*Wolff, 1972 (Wolff)*
From June through August 1970, 39 trawl tows were sampled to determine discard ratios of finfish to commercially valuable shrimp by weight. Of the 39 tows, 4 were classified as “Ocean”, 18 as “Core Sound”, and 17 as “Pamlico Sound”. In addition to general location, day vs. night, total finfish catch weight, total shrimp catch weight, and the resulting fish:shrimp ratio were reported for each sampled trawl tow. Finfish species composition and percent by weight were reported for all tows combined. No length data were available from the 39 tows.

*NMFS Bycatch Characterization, 1992-1994 (NMFS)*
From 1992-1994, approximately 685 trawl tows were sampled during a NMFS bycatch characterization study. Data available from each sample included location, tow duration, gear information, total weight of penaeid shrimp by species, total weight and total number of Atlantic croaker. Lengths (TL mm) were recorded for croaker from approximately 288 tows. Of the 685

tows, 17 were made in 1992, 146 in 1993, and 522 in 1994. By area, 36 were in Ocean waters, 629 were in Inside waters, and 20 had missing or erroneous location information. These data are summarized in Nance et al. (1997).

*Brown, 2009 (Brown)*
From July 2007 through June 2008, 314 trawl tows were sampled to determine discard ratios of finfish to commercially valuable shrimp by weight. In addition to general location, day vs. night, total finfish catch weight, total shrimp catch weight, and the resulting fish:shrimp ratio were reported for each sampled trawl tow. Finfish species composition and percent by weight were reported for all tows combined. Length frequency distributions were available for key finfish species, which included Atlantic croaker.

**Methods & Estimates**

*Croaker:Shrimp Ratios*
For each of the three bycatch and discard datasets described above, croaker:shrimp ratios were calculated by dividing croaker catch weight summed across all tows by shrimp catch weight summed across all tows (Table A1.1). Since tow duration was not available from Wolff, differences in duration among tows were not taken into account. While not desirable, this decision was made to keep ratio estimation consistent among the three datasets. For Wolff, NMFS, and Brown, tow catches were summed across years.

For Wolff (1972), the fish:shrimp ratio for all 39 tows was 5.38:1. Atlantic croaker made up 24.2% by weight of the total finfish catch from all tows. 24.2% of 5.38 is approximately 1.30, so the overall croaker:shrimp ratio was 1.30:1.

For NMFS, the croaker:shrimp ratio for all years, areas combined was 1.66:1. While not used in subsequent calculations, ratios by year (pooled over area) were 1.83:1 in 1992, 1.07:1 in 1993, and 1.77:1 in 1994.

For Brown (2009), Atlantic croaker represented 24.7% of the total biomass, which resulted in a croaker:shrimp ratio of 1.4:1 for the tongue net and 0.90:1 for the double seamed trawl. The two ratios were combined, which resulted and an overall ratio of 1.15:1 for croaker to shrimp.
The three ratios (one from each bycatch dataset) based on croaker and shrimp catches pooled over years and areas were considered to be the base case for subsequent calculations.

*Annual Atlantic Croaker Bycatch By Weight*
The first step in estimating total annual bycatch of croaker was deciding how to apply the ratios from the three datasets to the time series, 1950-2008. Wolff ratio was used for years 1950 through 1991. NMFS ratio was used for 1992-1998, and Brown ratio was used for 1999-2008. In this method, a ratio was used from the first year in which the underlying data were collected until the year preceding the next available ratio. There are serious shortcomings to this method, and numerous alternatives could be employed. This issue is revisited in the Discussion section.

After allocating the years in the time series among the three ratios, annual croaker bycatch was calculated by multiplying annual shrimp landings by the appropriate croaker:shrimp ratio and then subtracting the reported croaker landings:

| | | | | | | |
|---|---|---|---|---|---|---|
| Annual Croaker Bycatch | = | Annual Shrimp Landings | x | Croaker: Shrimp Ratio | – | Reported Croaker Landings, |

with all landings from the commercial shrimp trawl fishery (Table A1.2). Annual croaker bycatch from 1950-2008 averaged 21.7 million pounds with a range of 0.47 million in 2005 to 45.8 million in 1995. While there was no clear trend over the entire time series, there appeared to be a decline in bycatch estimates from the early 1950's through 1978, a steady increase from 1979 through 1995, and then a declining trend since then (Figure A1.2). The decline in estimated bycatch since 1995 is a reflection of declining shrimp landings in the south Atlantic region since 1995.

When compared to the reported commercial landings for the Atlantic coast, the estimated bycatch of croaker was greater by several orders of magnitude for most years (Figure A1.3). This produced estimated total landings for Atlantic croaker that were significantly higher than the actual reported commercial landings. Estimated bycatch made up 50% or greater of the revised total landings in most years. The exception was two time periods (1976-1981 and 1997-2008) where shrimp landings were low and the resulting estimated bycatch was also low.

## Discussion

Due to the scarcity of information concerning Atlantic croaker bycatch in the commercial shrimp trawl fishery relative to the time series of the current assessment, numerous subjective decisions were made to produce this initial set of estimates. The rationale for, along with possible alternatives too, these decisions are provided below. Undoubtedly, significant changes will need to be made to the methodology and resulting estimates presented in this report, if more accurate or representative bycatch data becomes available.

*Fish:Shrimp Ratio Bycatch Estimation Approach*

At the heart of this approach are at least two key assumptions. First, croaker abundance and shrimp abundance are related, or more correctly, the catchability of croaker and the catchability of shrimp are directly, linearly related. The second assumption is that available bycatch information is sufficient to produce ratio estimates representative of the fishery over the time series considered. It is beyond the capabilities of the author to address these assumptions other than to provide several references on the subject (Peuser 1996; Nance et al. 1997; Diamond 2003) and to state that 7 years of bycatch characterization data are being applied to a 58 year time series.

*Ratio Calculations*

One of the goals in producing these initial estimates was to incorporate all bycatch information that was readily available. Because the three bycatch datasets had different levels of detail, all methods and estimates were standardized to the lowest level. The Wolff dataset had the lowest level of detail providing most information at the tow level (general area, total weight of shrimp and total weight of fish per trawl tow) and one critical piece of information at the study level

(proportional fish species composition of total fish landings summed over all tows). Shrimp and croaker catches from NMFS and Brown datasets were expanded, as needed, to the tow level and then summed across all tows to produce a base case croaker:shrimp ratio for each of the two datasets consistent with the Wolff base case ratio. This method ignores all ancillary information from NMFS and Brown that could have been used to calculate ratios by strata such as year or season, based on catches standardized to a consistent unit of effort (e.g., tow hour).

*Discards vs. Landings*

Reported landings of croaker must be considered when producing bycatch estimates. Sampling in the three bycatch studies was conducted at sea, meaning that any ratios calculated from these data would reflect croaker to be discarded as well as croaker to be landed. For this reason, annual reported landings from the shrimp trawl fishery were subtracted from the total bycatch estimate to produce a discard bycatch estimate. This method assumes that reported landings come from the total bycatch indiscriminately. It is more likely that reported landings are comprised of the largest fish in the bycatch, disproportionate to their numbers.

*Possible Alternatives*

The following paragraphs provide alternative ratio approaches using the current datasets, with advantages, disadvantages and potential changes in the estimates relative to the base case, area pooled.

**Consider only NMFS dataset:** This is the most extensive bycatch characterization dataset currently available. It includes hundreds of observed tows providing the largest spatial and temporal coverage. The NMFS mean size and age composition are already being applied to most of the time series, 1973-1998. Disadvantages include applying three consecutive years of data to the remaining 27 and applying a ratio based on BRD impacted catches two years prior to BRD implementation. Likely changes to the estimates may result in a slight increase in annual bycatch overall.

**Pool all datasets:** Given the limited information available and realizing that over a 59 year time series many aspects of the croaker population(s), shrimp population(s), and the shrimp fishery are subject to change, pooling all available information might produce an average set of estimates for the time series. This approach would require some weighting scheme among the datasets or the resulting estimates would still be dominated by the NMFS. Effects on bycatch estimates would depend heavily on the weighting scheme.

**Smooth transitions between datasets:** The current stepwise approach produces dramatic changes across the time series. A smoothing function would allow for less abrupt changes that might be more realistic, however this would require some means of evaluating the smoothing function.

**Calculate ratios using different methodologies appropriate to the level of coverage in each dataset:** This approach might improve estimates for the latter part of the time series, 1992-2002, as separate ratios could be calculated for more spatial, temporal strata. Likely impacts on the estimates would be minimal prior to 1992.

**References**

Brown K. 2009. Characterization of the near-shore commercial shrimp trawl fishery from Carteret County to Brunswick County, North Carolina. In: Documentation and reduction of bycatch in North Carolina fisheries. Completion Report for Interstate Fisheries Management Program Implementation for North Carolina. 34 pp.

Diamond SL. 2003. Estimation of bycatch in shrimp trawl fisheries: a comparison of estimation methods using field data and simulated data. Fish. Bull. 101:484-500.

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Johnson G. 2003. The role of trawl discards in sustaining blue crab production. Fishery Resource Grant 99-EP-07. 127 pp.

Nance J, Scott-Denton E, Martinez E, Watson J, Shah A, Foster D. 1997. Bycatch in the southeast shrimp trawl fishery. A data summary report, SFA Task N-10.03.

Peuser R. (ed.) 1996. Estimates of finfish bycatch in the South Atlantic shrimp fishery. Prepared by the SEAMAP South Atlantic Committee, Shrimp Bycatch Work Group, Final Report. Atlantic States Marine Fisheries Commission, April 1996, 64 pp.

Wolff M. 1972. A study of North Carolina scrap fishery. NC Department of Natural and Economic Resources, Special Scientific Report 20, 29 pp.

**Table A1.1** Summary of croaker:shrimp ratios by weight. Croaker and shrimp total weights are in pounds for Wolff, and kilograms for NMFS and Brown.

| Study | Total Weight of Shrimp | Total Weight of Croaker | Ratio |
|---|---|---|---|
| **Wolff** | 408.66 | 531.94 | 1.30 |
| **NMFS** | 28,272.0 | 46,931.5 | 1.66 |
| **Brown** | 15,277.3 | 17,034.2 | 1.15 |

**Table A1.2** Reported annual shrimp and croaker landings from the south Atlantic shrimp trawl fishery, with estimated croaker bycatch by weight. Croaker:Shrimp ratios and croaker weights were obtained from the National Marine Fisheries Service, Commercial Catch Statistics.

| Year | Shrimp (MT) | Ratio | Croaker Landings (MT) | Estimated By-Catch (MT) |
|---|---|---|---|---|
| 1950 | 16352.06 | 1.30 | 991.52 | 20266.16 |
| 1951 | 12373.51 | 1.30 | 1018.32 | 15067.25 |
| 1952 | 11466.58 | 1.30 | 689.57 | 14216.98 |
| 1953 | 14705.35 | 1.30 | 696.05 | 18420.90 |
| 1954 | 12818.00 | 1.30 | 519.41 | 16144.00 |
| 1955 | 12835.83 | 1.30 | 556.19 | 16130.39 |
| 1956 | 11513.15 | 1.30 | 2286.03 | 12681.07 |
| 1957 | 12813.83 | 1.30 | 1382.68 | 15275.31 |
| 1958 | 10067.17 | 1.30 | 3214.51 | 9872.80 |
| 1959 | 11678.55 | 1.30 | 1429.07 | 13753.04 |
| 1960 | 14043.22 | 1.30 | 1022.36 | 17233.83 |
| 1961 | 8918.05 | 1.30 | 865.99 | 10727.48 |
| 1962 | 11762.22 | 1.30 | 842.63 | 14448.26 |
| 1963 | 6974.74 | 1.30 | 1100.36 | 7966.80 |
| 1964 | 7746.21 | 1.30 | 897.46 | 9172.62 |
| 1965 | 11706.08 | 1.30 | 846.12 | 14371.78 |
| 1966 | 9418.05 | 1.30 | 727.48 | 11515.98 |
| 1967 | 9157.51 | 1.30 | 649.71 | 11255.05 |
| 1968 | 10824.99 | 1.30 | 576.33 | 13496.16 |
| 1969 | 12200.23 | 1.30 | 644.26 | 15216.03 |
| 1970 | 9285.08 | 1.30 | 401.72 | 11668.88 |
| 1971 | 14056.24 | 1.30 | 471.66 | 17801.45 |
| 1972 | 11396.33 | 1.30 | 1910.43 | 12904.79 |
| 1973 | 11040.05 | 1.30 | 2015.87 | 12336.19 |
| 1974 | 12187.66 | 1.30 | 2809.61 | 13034.35 |
| 1975 | 11206.80 | 1.30 | 4680.59 | 9888.25 |
| 1976 | 11713.29 | 1.30 | 6862.27 | 8365.01 |
| 1977 | 8162.95 | 1.30 | 8640.32 | 1971.51 |
| 1978 | 7254.36 | 1.30 | 9064.05 | 366.62 |
| 1979 | 8954.69 | 1.30 | 9352.86 | 2288.24 |
| 1980 | 10988.22 | 1.30 | 9618.08 | 4666.60 |
| 1981 | 6112.07 | 1.30 | 5116.07 | 2829.62 |
| 1982 | 9310.07 | 1.30 | 4953.68 | 7149.41 |
| 1983 | 9745.57 | 1.30 | 3326.85 | 9342.39 |
| 1984 | 5573.60 | 1.30 | 4220.10 | 3025.57 |
| 1985 | 11455.78 | 1.30 | 3996.57 | 10895.94 |
| 1986 | 8562.14 | 1.30 | 4355.18 | 6775.60 |
| 1987 | 7187.11 | 1.30 | 3405.16 | 5938.09 |
| 1988 | 8472.09 | 1.30 | 3890.06 | 7123.66 |
| 1989 | 9224.80 | 1.30 | 3139.49 | 8852.75 |
| 1990 | 7455.24 | 1.30 | 2664.46 | 7027.34 |
| 1991 | 12361.13 | 1.30 | 1584.45 | 14485.01 |
| 1992 | 8992.69 | 1.66 | 1301.67 | 13626.18 |
| 1993 | 9963.82 | 1.66 | 1505.42 | 15034.52 |
| 1994 | 9437.57 | 1.66 | 2136.88 | 13529.49 |
| 1995 | 14169.74 | 1.66 | 2741.14 | 20780.63 |
| 1996 | 8437.39 | 1.66 | 4529.67 | 9476.40 |
| 1997 | 8997.59 | 1.66 | 4874.50 | 10061.49 |
| 1998 | 7361.51 | 1.66 | 4939.84 | 7280.27 |
| 1999 | 10071.53 | 1.15 | 4631.29 | 6950.96 |
| 2000 | 8901.59 | 1.15 | 4606.39 | 5630.44 |
| 2001 | 5432.24 | 1.15 | 5456.83 | 790.24 |
| 2002 | 7782.90 | 1.15 | 4628.76 | 4321.57 |
| 2003 | 7476.59 | 1.15 | 6551.38 | 2046.70 |
| 2004 | 6613.36 | 1.15 | 5444.10 | 2161.27 |
| 2005 | 4888.82 | 1.15 | 5405.85 | 216.29 |
| 2006 | 5414.99 | 1.15 | 4728.81 | 1498.42 |
| 2007 | 7596.81 | 1.15 | 3323.52 | 5412.81 |
| 2008 | 7374.63 | 1.15 | 2641.08 | 5839.74 |

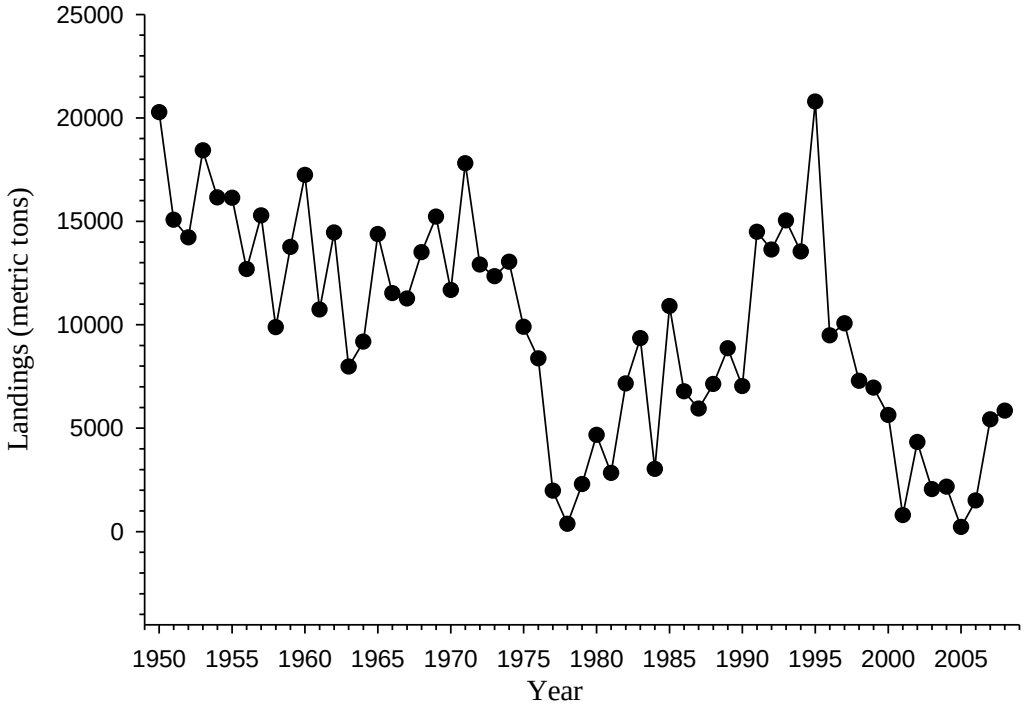



**Figure A1.1** Penaeid shrimp landings for the Atlantic coast of the United States, 1950-2008.

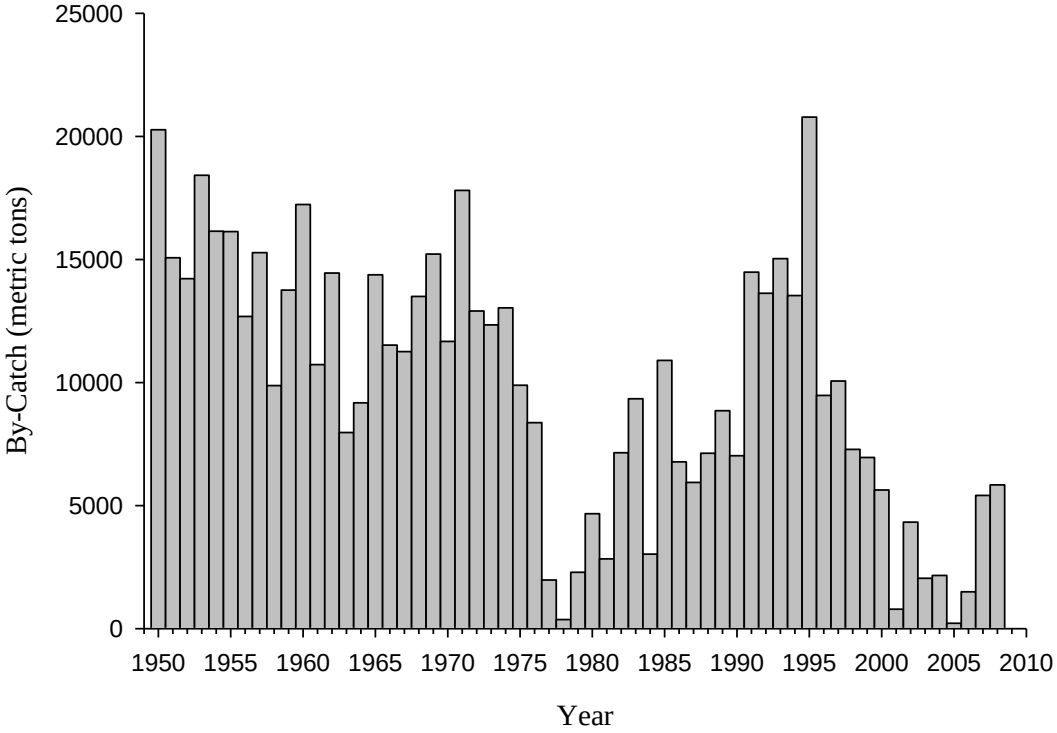



**Figure A1. 2** Estimated bycatch (metric tons) of Atlantic croaker from the south Atlantic coast (NC-FL) of the United States, 1950-2008.

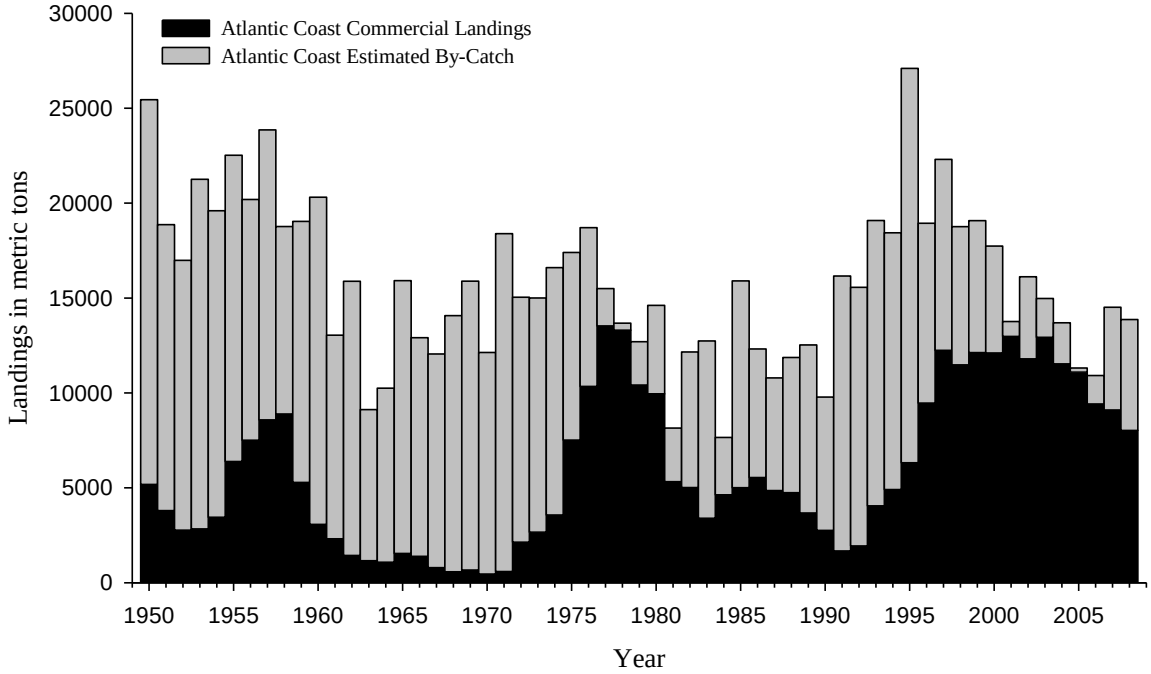



**Figure A1.3** Total estimated landings (metric tons) of Atlantic croaker from both commercial landings and estimated shrimp bycatch, 1950-2008.

## Appendix 2: Exploring the Use of the Stephens and MacCall (2004) Method to Develop a Standardized CPUE from MRFSS Data

Contributed by Katie Drew (Atlantic States Marine Fisheries Commission)
and Julie Defilippi (Atlantic Coastal Cooperative Statistics Program)

The directed trip method of estimating effort (counting trips that targeted or caught croaker as croaker-directed trips) may underestimate nominal effort by underestimating the number of zero-catch trips. Zero-catch trips are only included when the angler *reported* targeting croaker; trips where the angler did not catch croaker and also did not report a target species or reported targeting multiple species will not be included, but it is reasonable to assume that some of those trips had the potential to catch croaker, and thus represent effort with zero catch. In order to account for these zero-catch trips, a second CPUE index was produced using the Stephens and MacCall (2004) method to calculate effort. This method uses a logistic regression of presence or absence by species on each angler-intercept to predict whether the target species (Atlantic croaker) could have been caught on the trip. This index was then standardized using a GLM.

The angler-intercept data were rearranged to one record per intercept with binomial (presence or absence) information for each of 94 species (species that occurred on less than 1% of the total number of intercepts were omitted). The response variable in the logistic regression was the presence (1) or absence (0) of Atlantic croaker on each angler-intercept and the predictor variables in the full model were the presence or absence of the other 93 species. There were 70 species (Figure A2.1) whose regression coefficients were significant at the $\alpha = 0.05$ level and those species were used in the final, reduced model.

Based on the species composition of the reported catch, trip $i$ can be assigned a probability, $\pi_i$, of having fished in croaker habit, thus having the potential to catch croaker. That trip would be included in the catch rate analysis if $\pi_i$ exceeds some critical value. The critical value was chosen to minimize the absolute difference between observed number of trips that caught Atlantic croaker and the predicted number of trips fishing in croaker habitat (Figure A2.2).

Once the MRFSS intercepts for calculating the catch rates were selected, the total number of Atlantic croaker caught was calculated for each selected intercept and annual catch rates were estimated with generalized linear models (GLM). An approach based on Lo et al. (1992) was applied by dividing the data into two datasets: 1) Atlantic croaker presence or absence data and fit to a GLM with a binomial distribution with a logit link and 2) the total catch of Atlantic croaker on positive intercepts were fit to a GLM with a gamma distribution with a log link. Potential explanatory variables were year (1981-2008), wave (two-month time period), mode (man-made shore, beach/bank, shore, party boat, charter boat, party/charter boat, private/rental boat), area (nearshore or offshore), hours fished (0, 2, 4, 6, 8+ hr), and the number of anglers on the trip (1, 2, 3, 4, 5+). Potential variables were evaluated for inclusion in the GLM through a step-wise process. For each step-wise level, provided that the variable with the lowest Akaike Information Criterion (AIC) value was also significant at the $\alpha = 0.05$ level (from twice the change in log-likelihood), that variable was added to the model for use in the calculations in the next step (Table A2.1 and A2.2). Plots of the standardized residuals were centered around zero

except for the earliest years of the time series, where there were more positive deviations (Figure A2.5).

The annual mean catch per intercept values were calculated with a Monte Carlo method based on the number of intercepts by two-month wave, hours fished, mode, area, and number of anglers per year to determine the probability of a non-zero intercept multiplied by the mean number of Atlantic croaker caught per angler. Random variation was added to each outcome by multiplying the standard error of the proportion positive by a random, normal deviate and by multiplying the standard error of the number per intercept by a different random, normal deviate. After the random deviates were added to the terms, the terms were back-transformed to their original scales and multiplied together. This process was repeated for each of the angler-intercepts and the index was the mean of the outcomes by year (Table A2.3, Figure A2.3).

The previous assessment developed two regional CPUE indices, one for the mid-Atlantic (NJ-NC) and one for the south Atlantic (SC-FL), due to perceived regional differences between trends in fishery-independent indices. As a continuity case, regional recreational CPUEs were developed for the time period covered in the previous assessment (1982-2002). The GLM failed to converge for the south Atlantic region, so only the results from the mid-Atlantic region are shown here.

The directed trips method produced a higher CPUE than the Stephens and MacCall (2004) sub-setting and GLM standardization method—not surprising, as the latter method theoretically includes more zero-catch effort—but the overall trends were broadly similar, showing increases in the early 1980s and fluctuations after that, with a slight downward trend in the most recent years (Figure A2.3).

The TC was concerned with the results of the Stephens and MacCall (2004) method. The TC believed that species associations that were determined to be statistically significant were not biologically realistic. In some cases the habitats of associated species did not overlap with croaker habitat (e.g., spiny dogfish and blackfin tuna). In other cases, the range of the associated species did not cover the full range of croaker; for example, many of the associated species were almost exclusively in Florida (e.g., Florida pompano, wahoo, several species of snappers and groupers).

Additionally, the Stephens and MacCall (2004) method of trip sub-setting produced a smaller number of trips than were observed with croaker catch, apparently omitting true positive trips on the basis of their species composition.

The Stephens and MacCall (2004) method was originally developed to subset trips in a California headboat fishery. Because of the aforementioned concerns about the results, the TC felt this method was not appropriate to apply to the croaker recreational data, which cover a much wider geographical range than the original method dealt with and come from several different modes of fishing. The index developed from this method was not used in the assessment.

## References

Lo, N.C.H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences 49(12):2515-2526.

Stephens, A., and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research (Amsterdam) 70(2-3):299-310.

**Table A2.1** Stepwise selection of variables to include in estimating the proportion of positive MRFSS intercepts for Atlantic croaker (shaded lines) with a GLM (binomial distribution and logit link) selected with Stephens and MacCall logistic regression based on lowest AIC values. The fields include the variables, the degrees of freedom for that variable (df), the deviance of the model with those variables, the mean deviance (deviance/df), the change in mean deviance ( Δ mean dev), percent reduction in mean deviance (% mean dev), cumulative reduction in mean deviance, log likelihood, the change in log likelihood from previous run, minus two times the change in log-likelihood, chi-square value, the Chi-square degrees of freedom, the probability of the null hypothesis (Prob Ho), and the Akaike Information Criterion (AIC).

| Variables | | df | Deviance | Mean dev | Δ mean dev | % expl | Cum % | log like | Δ log like | Chi sq | df | Prob Ho | AIC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Null | Deviance | 9503 | 9934.142 | 1.0454 | | | | -4967.07 | | | 1 | | 9936.142 |
| | | | | | | | | | | | | | |
| Year | Deviance | 9476 | 9719.268 | 1.0257 | 0.0197 | 1.9% | | -4859.64 | -107.431 | 214.8624 | 27 | 3.57E-31 | 9775.28 |
| Wave | Deviance | 9498 | 9761.947 | 1.0278 | 0.0176 | 1.7% | | -4880.97 | -86.0976 | 172.1952 | 5 | 2.48E-35 | 9773.947 |
| Area | Deviance | 9502 | 9922.002 | 1.0442 | 0.0012 | 0.1% | | -4961 | -6.07 | 12.14 | 1 | 0.000494 | 9926.002 |
| Mode_fx | Deviance | 9497 | 9758.832 | 1.0276 | 0.0178 | 1.7% | | -4879.42 | -87.6553 | 175.3106 | 6 | 3.36E-35 | 9772.832 |
| Region | Deviance | 9502 | 9912.634 | 1.0432 | 0.0022 | 0.2% | | -4956.32 | -10.754 | 21.508 | 1 | 3.52E-06 | 9916.634 |
| Hr fished | Deviance | 9499 | 9912.528 | 1.0435 | 0.0019 | 0.2% | | -4956.26 | -10.8072 | 21.6144 | 4 | 0.000239 | 9922.528 |
| Num anglers | Deviance | 9499 | 9582.214 | 1.0088 | 0.0366 | 3.5% | 3.5% | -4791.11 | -175.964 | 351.9284 | 4 | 6.72E-75 | 9592.214 |
| | | | | | | | | | | | | | |
| WITH Num_anglers | | | | | | | | | | | | | |
| Year | Deviance | 9472 | 9470.188 | 0.9998 | 0.0456 | 4.4% | | -4735.09 | -231.977 | 463.9542 | 31 | 1.14E-78 | 9534.188 |
| Wave | Deviance | 9494 | 9400.876 | 0.9902 | 0.0552 | 5.3% | 8.8% | -4700.44 | -266.633 | 533.2662 | 9 | 4.3E-109 | 9420.876 |
| Area | Deviance | 9498 | 9563.73 | 1.0069 | 0.0385 | 3.7% | | -4781.86 | -185.206 | 370.4124 | 5 | 7.04E-78 | 9575.73 |
| Mode_fx | Deviance | 9493 | 9467.471 | 0.9973 | 0.0481 | 4.6% | | -4733.74 | -233.336 | 466.671 | 10 | 5.79E-94 | 9489.471 |
| Region | Deviance | 9498 | 9569.178 | 1.0075 | 0.0379 | 3.6% | | -4784.59 | -182.482 | 364.9642 | 5 | 1.05E-76 | 9581.178 |
| Hr fished | Deviance | 9495 | 9558.781 | 1.0067 | 0.0387 | 3.7% | | -4779.39 | -187.681 | 375.361 | 8 | 3.47E-76 | 9576.781 |
| | | | | | | | | | | | | | |
| With Num_anglers and Wave | | | | | | | | | | | | | |
| Year | Deviance | 9467 | 9296.378 | 0.982 | 0.0634 | 6.1% | | -4648.19 | -318.882 | 637.7638 | 36 | 3.5E-111 | 9370.378 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Deviance | 9493 | 9393.066 | 0.9895 | 0.0559 | 5.3% | | -4696.53 | -270.538 | 541.0762 | 10 | 7.3E-110 | 9415.066 |
| Mode_fx | Deviance | 9488 | 9335.361 | 0.9839 | 0.0615 | 5.9% | 14.7% | -4667.68 | -299.391 | 598.781 | 15 | 6.4E-118 | 9367.361 |
| Region | Deviance | 9493 | 9398.17 | 0.99 | 0.0554 | 5.3% | | -4699.09 | -267.986 | 535.9722 | 10 | 9E-109 | 9420.17 |
| Hr fished | Deviance | 9490 | 9375.175 | 0.9879 | 0.0575 | 5.5% | | -4687.59 | -279.484 | 558.967 | 13 | 4.2E-111 | 9403.175 |
| | | | | | | | | | | | | | |
| With Num_anglers, Wave and Mode | | | | | | | | | | | | | |
| Year | Deviance | 9461 | 9239.167 | 0.9766 | 0.0688 | 6.6% | 21.2% | -4619.58 | -347.488 | 694.9752 | 42 | 3.5E-119 | 9325.167 |
| Area | Deviance | 9487 | 9337.508 | 0.9836 | 0.0618 | 5.9% | | -4665.75 | -301.317 | 602.634 | 16 | 6.3E-118 | 9365.508 |
| Region | Deviance | 9487 | 9331.946 | 0.9837 | 0.0617 | 5.9% | | -4665.97 | -301.098 | 602.196 | 16 | 7.8E-118 | 9365.946 |
| Hr fished | Deviance | 9484 | 9305.023 | 0.9811 | 0.0643 | 6.2% | | -4652.51 | -314.56 | 629.119 | 19 | 3.6E-121 | 9345.023 |
| | | | | | | | | | | | | | |
| With Num_anglers, Wave, Mode and Year | | | | | | | | | | | | | |
| Area | Deviance | 9460 | 9236.265 | 0.9763 | 0.0691 | 6.6% | | -4618.13 | -348.939 | 697.8776 | 43 | 3.7E-119 | 9324.265 |
| Region | Deviance | 9460 | 9235.586 | 0.9763 | 0.0691 | 6.6% | | -4617.79 | -349.278 | 698.5562 | 43 | 2.7E-119 | 9323.586 |
| Hr fished | Deviance | 9457 | 9203.392 | 0.9732 | 0.0722 | 6.9% | 28.2% | -4601.7 | -365.375 | 730.7506 | 46 | 4.7E-124 | 9297.392 |
| | | | | | | | | | | | | | |
| With Num_anglers, Wave, Mode, Year and Hrs_fished | | | | | | | | | | | | | |
| Area | Deviance | 9456 | 9199.377 | 0.9729 | 0.0725 | 6.9% | | -4599.69 | -367.383 | 734.7652 | 47 | 2.9E-124 | 9295.377 |
| Region | Deviance | 9456 | 9198.986 | 0.9728 | 0.0726 | 6.9% | 35.1% | -4599.49 | -367.578 | 735.1566 | 47 | 2.4E-124 | 9294.986 |
| | | | | | | | | | | | | | |
| With Num_anglers, Wave, Mode, Year, Hrs_fished and Region | | | | | | | | | | | | | |
| Area | Deviance | 9455 | 9194.749 | 0.9725 | 0.0729 | 7.0% | 42.1% | -4597.37 | -369.697 | 739.3932 | 48 | 1.3E-124 | 9292.749 |

**Table A2.2** Stepwise selection of variables to include in estimating the total catch of Atlantic croaker on positive MRFSS intercepts for Atlantic croaker (shaded lines) with a GLM (gamma distribution and log link) selected with Stephens and MacCall logistic regression based on lowest AIC values. The fields include the variables, the degrees of freedom for that variable (df), the deviance of the model with those variables, the mean deviance (deviance/df), the change in mean deviance ( Δ mean dev), percent reduction in mean deviance (% mean dev), cumulative reduction in mean deviance, log likelihood, the change in log likelihood from previous run, minus two times the change in log-likelihood, chi-square value, the Chi-square degrees of freedom, the probability of the null hypothesis (Prob Ho), and the Akaike Information Criterion (AIC).

| Variables | | df | Deviance | Mean dev | Δ mean dev | % expl | Cum % | log like | Δ log like | Chi sq | df | Prob Ho | AIC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Null | Deviance | 2041 | 4061.562 | 1.99 | | | | -7144.83 | | | 1 | | 14291.66 |
| | | | | | | | | | | | | | |
| Year | Deviance | 2014 | 3756.441 | 1.8652 | 0.1248 | 6.3% | | -7047.22 | -97.6115 | 195.223 | 27 | 2.01E-27 | 14150.44 |
| Wave | Deviance | 2036 | 3935.723 | 1.9331 | 0.0569 | 2.9% | | -7105.38 | -39.454 | 78.908 | 5 | 1.42E-15 | 14222.75 |
| Area | Deviance | 2040 | 3826.557 | 1.8758 | 0.1142 | 5.7% | | -7070.25 | -74.5833 | 149.1666 | 1 | 2.64E-34 | 14144.5 |
| Mode_fx | Deviance | 2035 | 3330.565 | 1.6366 | 0.3534 | 17.8% | 17.8% | -6898.66 | -246.17 | 492.3392 | 6 | 3.8E-103 | 13811.32 |
| Region | Deviance | 2040 | 4015.314 | 1.9683 | 0.0217 | 1.1% | | -7130.46 | -14.3745 | 28.749 | 1 | 8.24E-08 | 14264.91 |
| Hr fished | Deviance | 2037 | 4019.452 | 1.9732 | 0.0168 | 0.8% | | -7131.75 | -13.0823 | 26.1646 | 4 | 2.93E-05 | 14273.5 |
| Num anglers | Deviance | 2037 | 3804.513 | 1.8677 | 0.1223 | 6.1% | | -7063.05 | -81.783 | 163.566 | 4 | 2.51E-34 | 14136.1 |
| | | | | | | | | | | | | | |
| WITH Mode | | | | | | | | | | | | | |
| Year | Deviance | 2008 | 3220.472 | 1.6038 | 0.3862 | 19.4% | 37.2% | -6857.55 | -287.283 | 574.5656 | 33 | 4.4E-100 | 13783.1 |
| Wave | Deviance | 2030 | 3314.132 | 1.6326 | 0.3574 | 18.0% | | -6892.6 | -252.23 | 504.4594 | 11 | 3.6E-101 | 13809.2 |
| Area | Deviance | 2034 | 3321.271 | 1.6329 | 0.3571 | 17.9% | | -6895.24 | -249.594 | 499.1878 | 7 | 1.2E-103 | 13806.47 |
| Region | Deviance | 2034 | 3327.267 | 1.6358 | 0.3542 | 17.8% | | -6897.45 | -247.384 | 494.7674 | 7 | 1.1E-102 | 13810.89 |
| Hr fished | Deviance | 2031 | 3303.112 | 1.6263 | 0.3637 | 18.3% | | -6888.52 | -256.309 | 512.617 | 10 | 8.9E-104 | 13799.04 |
| Num anglers | Deviance | 2031 | 3291.446 | 1.6206 | 0.3694 | 18.6% | | -6884.19 | -260.639 | 521.2788 | 10 | 1.2E-105 | 13790.38 |
| | | | | | | | | | | | | | |
| With Mode and Year | | | | | | | | | | | | | |
| Wave | Deviance | 2003 | 3207.458 | 1.6013 | 0.3887 | 19.5% | | -6852.61 | -292.224 | 584.4482 | 38 | 4.9E-99 | 13783.21 |

| Variables | | df | Deviance | Mean dev | Δ mean dev | % expl | Cum % | log like | Δ log like | Chi sq | df | Prob Ho | AIC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Deviance | 2007 | 3213.932 | 1.6014 | 0.3886 | 19.5% | | -6855.07 | -289.764 | 579.5278 | 34 | 1.8E-100 | 13780.13 |
| Region | Deviance | 2007 | 3214.85 | 1.6018 | 0.3882 | 19.5% | | -6855.42 | -289.415 | 578.8306 | 34 | 2.5E-100 | 13780.83 |
| Hr fished | Deviance | 2004 | 3196.994 | 1.5953 | 0.3947 | 19.8% | | -6848.62 | -296.21 | 592.4206 | 37 | 2.9E-101 | 13773.24 |
| Num anglers | Deviance | 2004 | 3181.037 | 1.5873 | 0.4027 | 20.2% | 57.4% | -6842.52 | -302.311 | 604.6222 | 37 | 9.2E-104 | 13761.04 |
| | | | | | | | | . | | | | | |
| With Mode, Year and Num_anglers | | | | | | | | | | | | | |
| Wave | Deviance | 1999 | 3166.792 | 1.5842 | 0.4058 | 20.4% | | -6837.05 | -307.78 | 615.5602 | 42 | 5.5E-103 | 13760.1 |
| Area | Deviance | 2003 | 3175.749 | 1.5855 | 0.4045 | 20.3% | | -6840.49 | -304.339 | 608.6776 | 38 | 5.6E-104 | 13758.98 |
| Region | Deviance | 2003 | 3177.582 | 1.5864 | 0.4036 | 20.3% | | -6841.2 | -303.636 | 607.2712 | 38 | 1.1E-103 | 13760.39 |
| Hr fished | Deviance | 2000 | 3157.563 | 1.5788 | 0.4112 | 20.7% | 78.1% | -6833.5 | -311.335 | 622.6696 | 41 | 5E-105 | 13750.99 |
| | | | | | | | | | | | | | |
| With Mode, Year, Num_anglers and Hr_fished | | | | | | | | | | | | | |
| Wave | Deviance | 1995 | 3144.325 | 1.5761 | 0.4139 | 20.8% | | -6828.38 | -316.45 | 632.8996 | 46 | 3.6E-104 | 13750.76 |
| Area | Deviance | 1999 | 3151.946 | 1.5768 | 0.4132 | 20.8% | 98.8% | -6831.33 | -313.503 | 627.006 | 42 | 2.6E-105 | 13748.66 |
| Region | Deviance | 1999 | 3153.304 | 1.5774 | 0.4126 | 20.7% | | -6831.85 | -312.979 | 625.9572 | 42 | 4.2E-105 | 13749.7 |
| | | | | | | | | | | | | | |
| With Mode, Year, Num_anglers, Hr_fished and Area | | | | | | | | | | | | | |
| Wave | Deviance | 1994 | 3136.285 | 1.5729 | 0.4171 | 21.0% | 119.8% | -6825.27 | -319.566 | 639.1316 | 47 | 7.4E-105 | 13746.53 |
| Region | Deviance | 1998 | 3148.273 | 1.5757 | 0.4143 | 20.8% | | -6829.91 | -314.922 | 629.8446 | 43 | 2.7E-105 | 13747.82 |
| | | | | | | | | | | | | | |
| With Mode, Year, Num_anglers, Hr_fished, Area and Wave | | | | | | | | | | | | | |
| Region | Deviance | 1993 | 3132.098 | 1.5715 | 0.4185 | 21.0% | 140.8% | -6823.64 | -321.191 | 642.3826 | 48 | 6.1E-105 | 13745.28 |

**Table A2.3** GLM-standardized total catch rates of Atlantic croaker from charterboat and private/rental boat MRFSS modes from nearshore and offshore waters from New Jersey through Florida using intercepts selected with the Stephens and MacCall logistic regressions. N is the number of intercepts included in the analysis where Atlantic croaker were caught.

| Year | N | Mean | CV | Scaled to Mean |
|---|---|---|---|---|
| 1981 | 41 | 1.77 | 0.23 | 0.71 |
| 1982 | 16 | 0.35 | 0.41 | 0.14 |
| 1983 | 57 | 3.82 | 0.26 | 1.54 |
| 1984 | 65 | 2.90 | 0.21 | 1.17 |
| 1985 | 156 | 3.16 | 0.20 | 1.28 |
| 1986 | 65 | 1.57 | 0.22 | 0.63 |
| 1987 | 95 | 1.67 | 0.20 | 0.68 |
| 1988 | 87 | 2.80 | 0.20 | 1.13 |
| 1989 | 182 | 2.57 | 0.16 | 1.04 |
| 1990 | 55 | 1.27 | 0.21 | 0.52 |
| 1991 | 92 | 2.54 | 0.20 | 1.03 |
| 1992 | 91 | 3.03 | 0.16 | 1.23 |
| 1993 | 62 | 2.25 | 0.22 | 0.91 |
| 1994 | 244 | 2.85 | 0.14 | 1.15 |
| 1995 | 194 | 1.89 | 0.15 | 0.76 |
| 1996 | 265 | 2.00 | 0.14 | 0.81 |
| 1997 | 144 | 2.13 | 0.17 | 0.86 |
| 1998 | 134 | 1.74 | 0.17 | 0.70 |
| 1999 | 154 | 4.45 | 0.14 | 1.80 |
| 2000 | 92 | 2.37 | 0.18 | 0.96 |
| 2001 | 119 | 2.28 | 0.15 | 0.92 |
| 2002 | 68 | 2.22 | 0.20 | 0.90 |

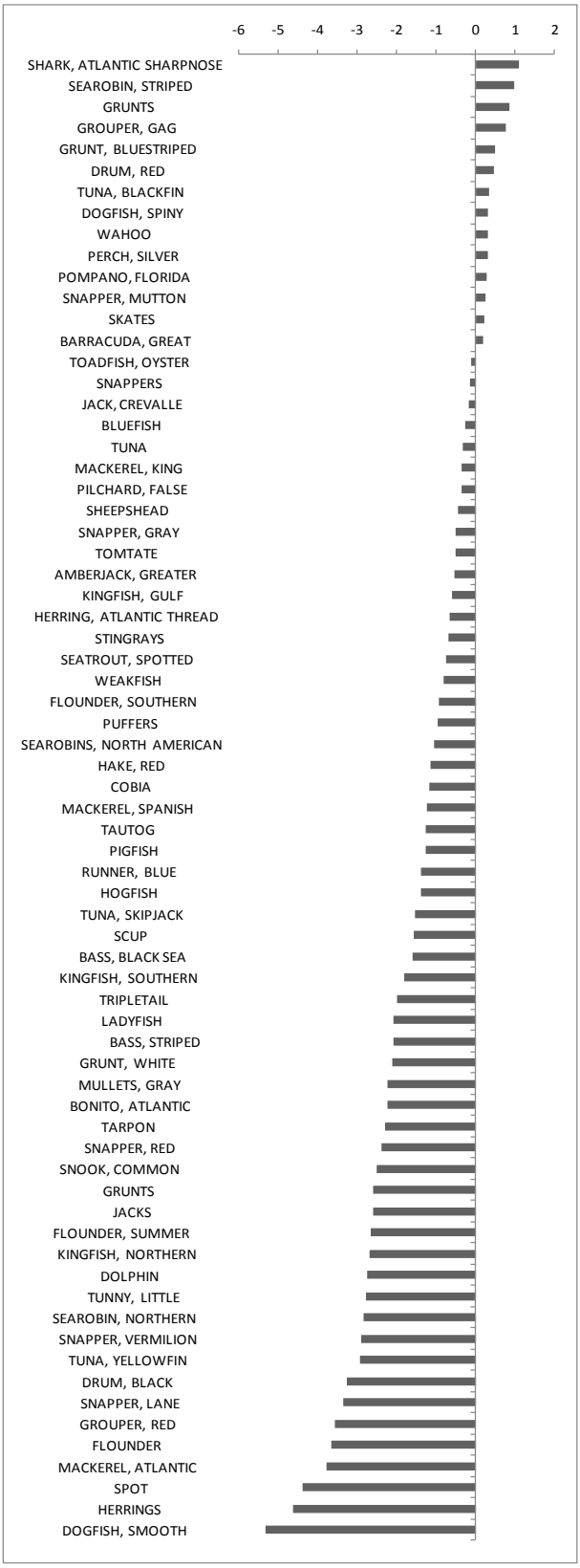



**Figure A2.1** Species with significant ($p < 0.05$) logistic regression coefficients predicting presence of croaker

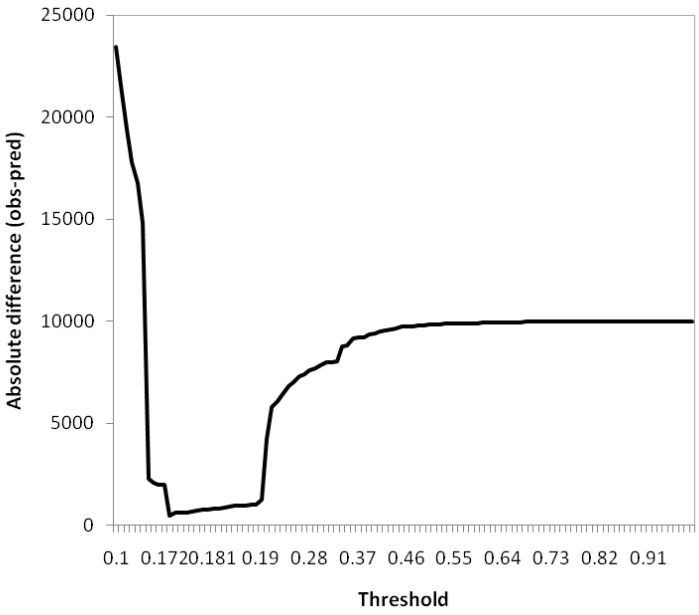



**Figure A2.2** Threshold probability of a trip having occurred in croaker habitat plotted against the absolute difference between trips observed to have caught croaker and predicted trips in croaker habitat.

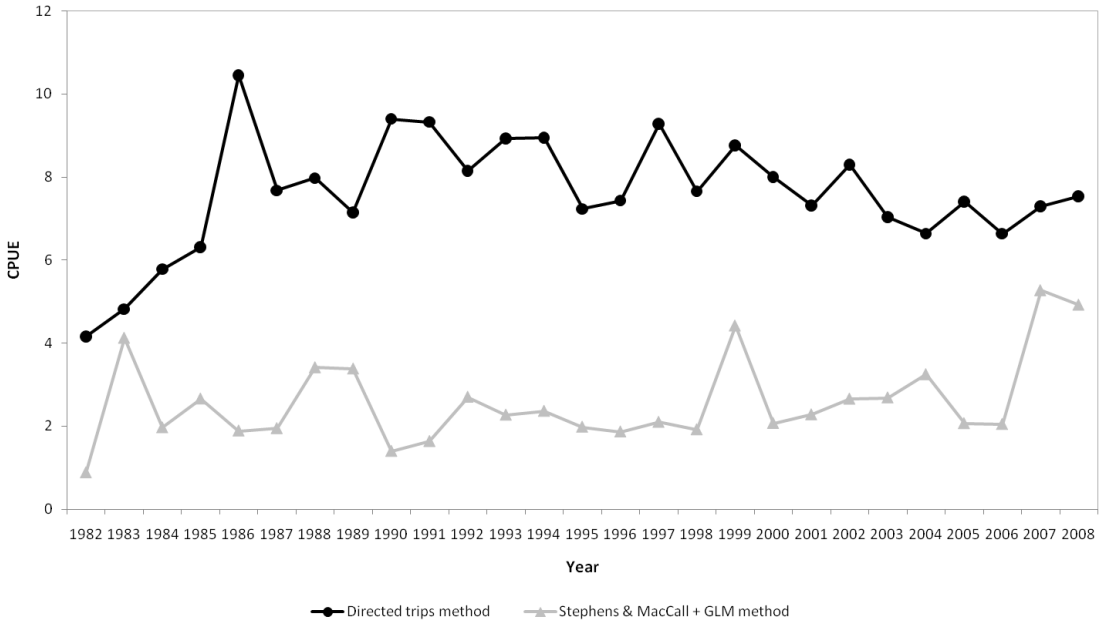



**Figure A2.3** Coast-wide CPUE calculated using the directed trips methodology and the Stephens and MacCall (2004) sub-setting method standardized with a GLM.

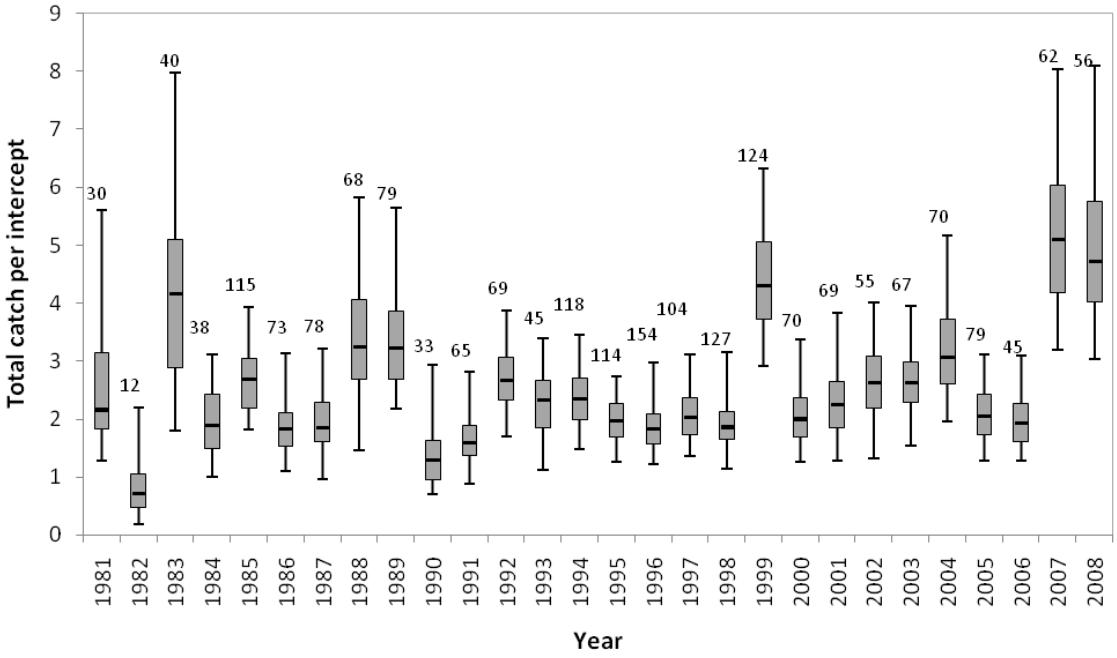
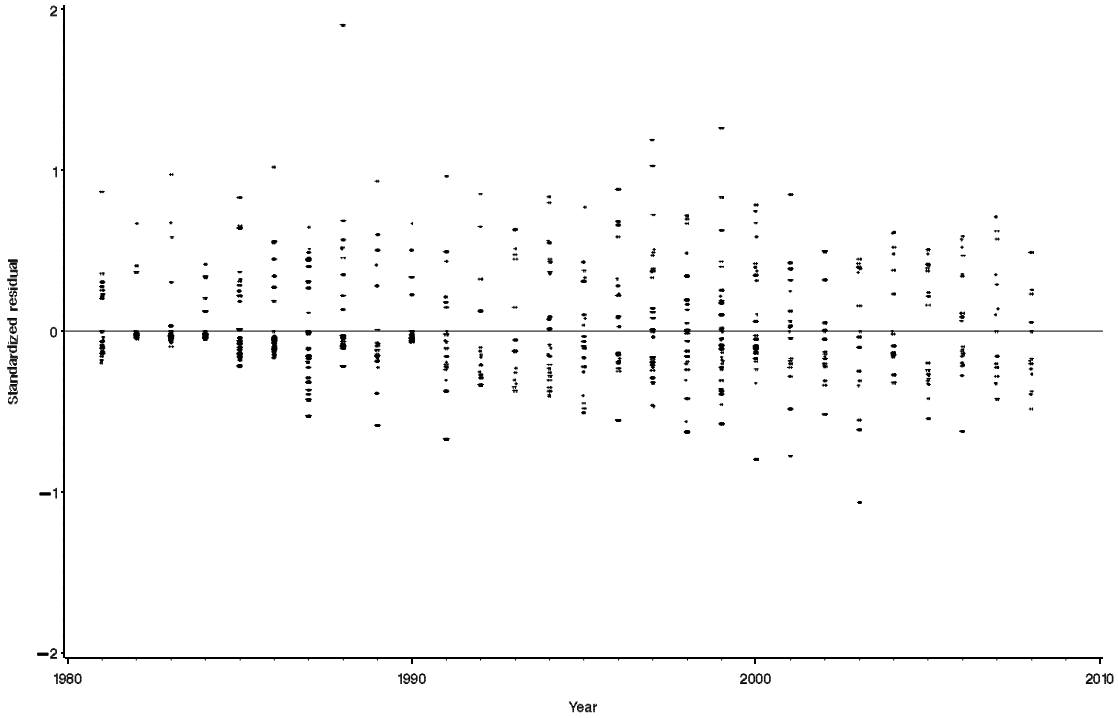
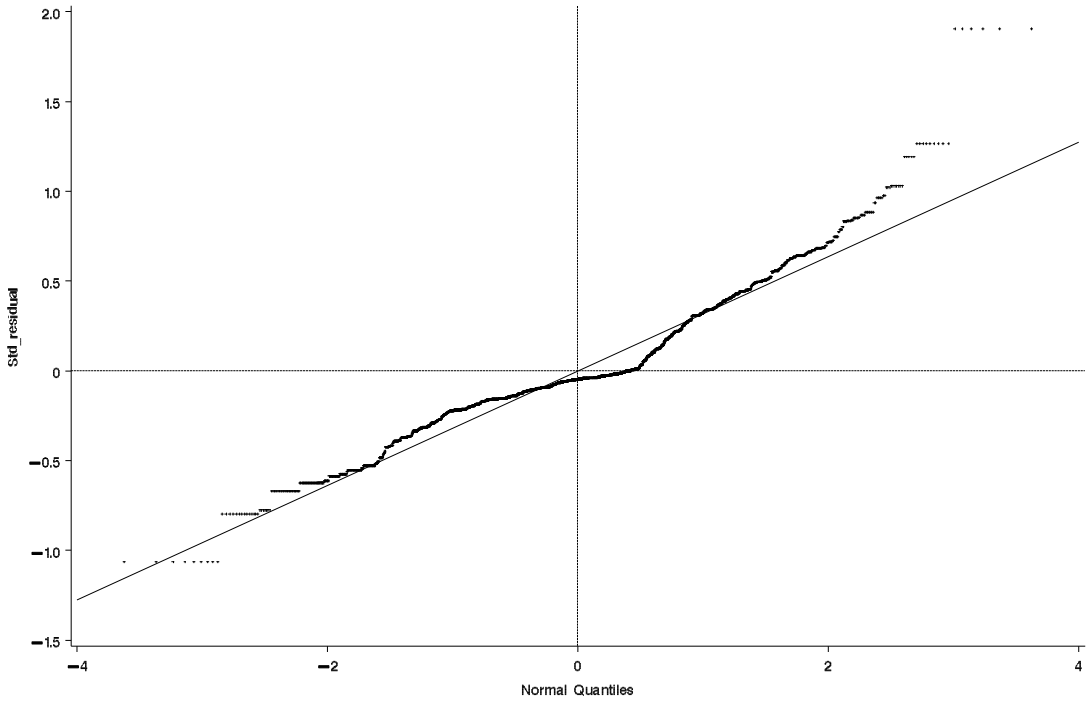



**Figure A2.4** Standardized annual total catch of Atlantic croaker per intercept with intercepts selected by Stephens and MacCall's logistic regression. Vertical lines are 95% confidence intervals, boxes are the inter-quartile ranges, horizontal lines are medians of the outcomes, and numbers above the lines are the number of intercepts that caught Atlantic croaker for each year.




A.




B.

**Figure A2.5** Standardized residuals by year (A) and q-q plot of residuals (B) of the CPUE index developed using the Stephens and MacCall (2004) method of trip selection with GLM standardization.

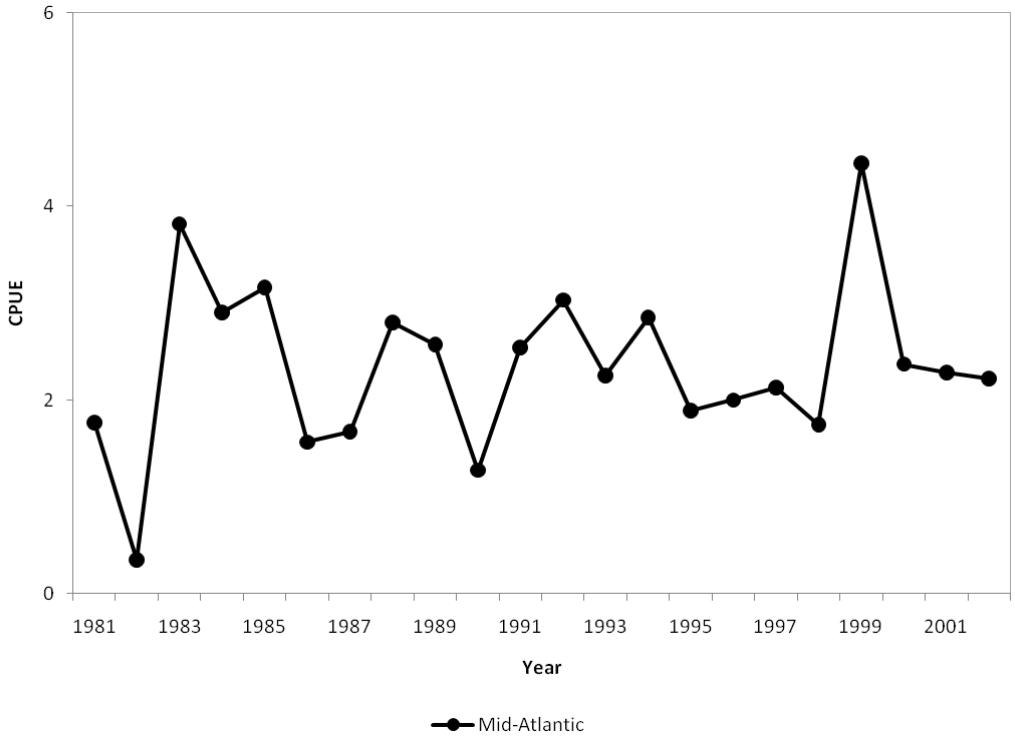



**Figure A2.6** CPUE by region using the Stephens and MacCall (2004) sub-setting method and GLM standardization. The GLM failed to converge for the south Atlantic region, only the CPUE for the mid-Atlantic region is shown.

## Appendix 3: Fishery-Independent Surveys Considered for Development of Tuning Indices

Contributed by Laura M. Lee (Virginia Marine Resources Commission)

### OVERVIEW

A number of fisheries-independent surveys along the U.S. Atlantic Coast encounter Atlantic croaker (Table 1). Rather than include all survey data simply because they are available, the working group felt it was important to evaluate and understand each dataset in terms of how it represents and characterizes the Atlantic croaker population. The report examines the available fisheries-independent survey datasets for their potential use in the current stock assessment. The objective is to ensure meaningful choices are made with respect to selection and use of survey data in the assessment. The issues considered included: length of time series, sample timing and spatial coverage, catchability/availability to the survey gear, changes in sampling methodology, and survey design.

- Length of time series—the available time series should be of sufficient length to detect meaningful trends
- Sample timing and spatial coverage—the survey should collect samples in a time and area when Atlantic croakers are expected to be available to the gear; indices developed from surveys should be representative of the entire stock if the assessment model does include a spatial component
- Catchability/Availability—the survey gear should be capable of catching Atlantic croakers if they are available; a high proportion of zero tows that is observed consistently over the survey time series may suggest Atlantic croakers are not available and/or have a low catchability to the gear
- Changes in sampling methodology—surveys should maintain a consistent sampling design and methodology over the time series; if such changes do occur, they need to be accounted for in the development of the index or it will not be possible to determine if observed variability is due to changes in the survey, changes in the stock, or both
- Survey design—surveys that employ standard statistically-based designed are preferred; standard sampling designs have associated design-based estimators of which the statistical properties are well known; applying these estimators to surveys that utilize non-standard designs (e.g., fixed-sampling) is not technically valid (Houghton 1987; Nicholson et al. 1991; Warren 1993, 1994, 1995), though they are often still used without the regard for the potential bias introduced; the reliability of an index calculated from a fixed-design survey using these estimators can be evaluated by examining the ‘persistence’ of observations; otherwise, geostatistical methods should be considered for computing indices from surveys with non-standard designs

## NEAMAP NEARSHORE TRAWL SURVEY

### Survey Design & Methods

The first full-scale cruise of the Northeast Area Monitoring and Assessment Program (NEAMAP) Nearshore Trawl Survey occurred in the fall of 2007. This fisheries-independent survey is a cooperative state-federal partnership that was initiated to collect data from areas where current sampling is absent or inadequate. The survey is conducted in the nearshore coastal waters of the mid-Atlantic and southern New England regions. The main objective of the survey is to estimate abundance, biomass, age/length structure, diet composition, and other parameters used in stock assessments for fish and invertebrates of management interest.

The survey uses a stratified random design, with strata based on region and depth. Sampling sites within each stratum are selected using a grid system (1.5 × 1.5 minute squares equivalent to 2.25 $nm^2$), where each cell in the grid represents a potential sampling location. The number of sites sampled in each stratum is determined by proportional allocation based on the surface area of each stratum. A minimum of 2 sites are sampled in each stratum. All sampling is performed during daylight hours using a 400 × 12 cm three-bridle four-seam bottom trawl, paired with a set of Thyboron Type IV 66-in trawl doors. Tow duration is 20 minutes with a target tow speed of 3.1 knots.

Data characterizing the station, tow parameters, and gear are also recorded for each tow along with atmospheric, weather, and hydrographic data.

### Sampling Intensity

A total of 150 sites are sampled during the spring and fall components of the survey. Sampling 150 sites per cruise yields a sampling intensity of approximately 1 station per 30 $nm^2$, the survey's target sampling intensity.

### Biological Sampling

The catch from each tow is sorted by species and modal size group (i.e., small, medium, and large size) within species. At a minimum, aggregate biomass (0.01 kg) and individual length measurements (measured in millimeters using the length type appropriate for the morphology of each species) are taken for each fish species. For some species, including Atlantic croaker, a subsample of three individuals per length group is sampled for full processing. Species that are selected for full processing are weighed (individual whole and eviscerated weights to the nearest 0.001 kg), and macroscopic sex and maturity stage are determined. Stomachs are removed from most species and those containing prey items are preserved for further evaluation.

### Ageing Methods

Ageing structures are removed from each individual in a subsample.

### Evaluation of Survey Data

A peer review of the NEAMAP Trawl Survey raised concerns about potential over-stratification of the survey. Additional sampling sites were added to the 2009 fall and spring cruises to address this issue. After completion of both cruises, an analysis will be performed to determine if there is a need to re-stratify the NEAMAP survey area.

An index derived from the NEAMAP Trawl Survey could only be calculated for two years and so would be of little value for the current stock assessment. The data collected from the

NEAMAP Trawl Survey should be considered for use in future assessments when a sufficient time series is available.

## NEW JERSEY DELAWARE BAY TRAWL SURVEY

### Survey Design & Methods

Since 1991, New Jersey's Delaware Bay Trawl Survey has targeted juvenile finfish species that inhabit the Delaware Bay. The sampling area extends from Villas in Cape May to the Cohansey River in Cumberland County.

The survey utilizes a 16-foot otter trawl. Single ten-minute tows are conducted against the tide at each station. Basic water quality parameters including water temperature, salinity, and dissolved oxygen are also recorded.

### Sampling Intensity

During the course of the survey, the sampling months, number of stations, and station locations have varied. Currently, sampling is conducted once monthly from April through October at 11 fixed stations.

### Biological Sampling

All Atlantic croaker collected are identified, counted, and measured in total length. If counts are high, fifty individuals are randomly selected for length measurements.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This is a fixed-design survey and was not selected given the availability of surveys that utilize standard statistically-based designs. Additionally, this is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## NEW JERSEY DELAWARE RIVER SEINE SURVEY

### Survey Design & Methods

Since 1980, the New Jersey Department of Environmental Protection (NJDEP) has conducted a striped bass survey in the Delaware River to provide an annual index of striped bass juvenile abundance. By 1987, the survey evolved into a sampling scheme that consisted of sixteen fixed stations that were sampled twice a month from mid-July through mid-November, with two seine hauls taken at each station. This methodology was used consistently from 1987 to 1990. After a thorough statistical analysis of the first ten years of data, the consulting firm, Versar Inc, provided a number of recommendations for the survey design. Those recommendations included: a) sampling season from August through October; b) utilizing both fixed and random stations; c) concentrating fifty percent of the sampling effort to Region II; and d) eliminating replicate samples. These recommendations were incorporated into the sampling protocol from 1991 to 1997.

The Delaware River recruitment survey area is divided into three distinct habitats:

- Region I—brackish, tidal water extending from the springtime saltwater/freshwater interface to the Delaware Memorial Bridges
- Region II—brackish to fresh tidal water extending from the Delaware Memorial Bridges to the Schuylkill River at the Philadelphia Naval Yard
- Region III—tidal freshwater from Philadelphia to the fall line at Trenton

Field sampling utilizes a bagged, 100-foot long by 6-foot deep by 0.25-inch mesh beach seine. Basic water quality parameters including water temperature, salinity, and dissolved oxygen are also recorded.

**Sampling Intensity**

A fixed station format has been used since 1998, in which 32 stations are sampled twice monthly from August through October. Alternate sites are sampled occasionally due to tidal extremes, sediment, or construction.

**Biological Sampling**

All striped bass that are caught are quantified and measured. Prior to 2002, all Atlantic croaker were counted, but only minimum and maximum lengths were recorded for each tow. Beginning in 2002, a subsample of 30 to 50 Atlantic croaker has been sampled for length measurements only.

**Ageing Methods**

This survey does not collect structures for ageing.

**Evaluation of Survey Data**

The autumn component of the Delaware River Seine Survey has been conducted consistently since 1998, so data collected from 1998 onward were evaluated. Due to the high proportion of "zero" catches, it was determined that these data were not useful for the assessment. Additionally, this is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## NEW JERSEY OCEAN TRAWL SURVEY

**Survey Design & Methods**

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988. Sampling is conducted in the nearshore waters from the entrance of New York Harbor south to the entrance of the Delaware Bay.

The survey utilizes a stratified random design. There are 15 strata with 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). Samples are collected using a two-seam trawl with forward netting of 4.7-inch stretch mesh and rear netting of 3.1-inch stretch mesh. The cod end is 3.0-inch stretch mesh and is lined with a 0.25-inch bar mesh liner. Tow duration is 20 minutes.

A series of water quality parameters, such as surface and bottom salinity, temperature, and dissolved oxygen, are recorded at the start of each tow.

**Sampling Intensity**

Samples are collected five times a year (January, April, June, August, and October).

### Biological Sampling

After each tow, the total weight of each species is measured in kilograms and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest centimeter.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

New Jersey Ocean Trawl Survey data were available from 1989 through 2008. An evaluation of the proportion of zero catches suggests that the occurrence of Atlantic croaker in the survey has been variable among years. Abundance of Atlantic croakers has been most consistent in August and October, when juveniles recruit to the gear. The August and October length-frequency distributions indicate that the survey has most often encountered age-1 and age-2 Atlantic croakers; age-0 fish have been occasionally encountered.

This survey covers only a part of the stock's range so an index developed from this survey would not be considered representative of the stock as a whole.

## PSEG IMPINGEMENT MONITORING

### Survey Design & Methods

The Public Service Enterprise Group (PSEG) Nuclear, LLC of New Jersey operates several ecological monitoring programs in the Delaware Estuary. The objective of the PSEG impingement monitoring program is to estimate the seasonal frequency, abundance, and the initial survival of fish species impinged at Units 1 and 2 at the Salem Generating Station.

In addition to the biological data, other data recorded for all samples includes the number of pumps and screens in operation, screen speed, tidal stage and elevation, air temperature, sky condition, wind direction, wave height, water temperature, and salinity. Any detritus collected with the sample is weighed to the nearest 0.1 kilogram.

### Sampling Intensity

Impingement sampling is performed three days per week during January through December. The sampling days are selected randomly within each seven-day weekly sampling time frame. During each 24-hr sampling period, ten samples are collected at approximately 2.5-hr intervals, which allows for monitoring over a complete diel period and two full tidal cycles.

### Biological Sampling

Impinged finfish and blue crab are removed from debris for processing. The condition (live, dead, or damaged) of collected individuals is determined, and organisms are then sorted by species. Aggregate counts and weights are recorded for each species observed in each condition category. All individuals of each species in each condition category are measured for length to the nearest millimeter. Subsamples of at least 100 individuals are taken when catches are too large to process in entirety. Individuals are also weighed to the nearest 0.1 gram.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The PSEG Impingement Monitoring Survey is a fixed-design survey, and sampling occurs at one site. The potential bias of the survey data could not be evaluated in terms of persistence since there is only one site. The use of a single site also complicated the possibility of applying geostatistical methods to derive model-based estimators using the survey data.

## PSEG ENTRAINMENT MONITORING

### Survey Design & Methods

The objective of the annual PSEG Entrainment Monitoring Survey is to produce accurate density estimates of fish entrained through the Circulating Water Intake System (CWIS) at Units 1 and 2 at the Salem Generating Station.

During each sampling event, samples are collected at the midpoint of the water column in the Salem Generating Station's circulating water intake structure by pumping river water out of the intake bay using a 6-inch (15.2-cm), single-port impeller, centrifugal fish pump and into a 1.0-m diameter, 0.5-mm mesh, conical plankton net within which the sample is concentrated. Ichthyoplankton samples are preserved immediately in a 10 percent formalin/rose-bengal solution. The sample rate is approximately 1.0 $m^3$/minute. Sample volume and flow rate are determined during each sampling event. Calibration of the flowmeter is checked and maintained within factory specifications on a monthly basis.

Water temperature, salinity, tidal elevation and stage, and the number of circulating water pumps and traveling screens in operation are recorded during each sampling event.

### Sampling Intensity

Entrainment sampling events are 24 hours in duration to allow for monitoring over a complete diel period and two tidal cycles. The frequency and intensity of sampling may vary throughout the year.

### Biological Sampling

In the laboratory, all fish specimens are cleaned, transferred to isopropanol, and identified to the lowest practicable taxonomic level. The life stage of each individual is determined, and the total number of individuals is enumerated. The lengths of up to 50 individuals of each species in each life stage, except eggs, are measured to the nearest 1.0 millimeter. All larvae all measured for total length, and juveniles and adults are measured using the length type appropriate for the morphology of the species.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

As with the PSEG Impingement Monitoring Survey, this is a fixed-design survey, and sampling occurs at one site. The potential bias of the survey data could not be evaluated in terms of persistence since there is only one site. The use of a single site also complicated the possibility of applying of geostatistical methods to derive model-based estimators using the survey data.

## PSEG BOTTOM TRAWL MONITORING PROGRAM

### Survey Design & Methods

The objective of the PSEG Bottom Trawl Monitoring Program is to develop indices of abundance for target species, which includes Atlantic croaker. Sampling is performed in the Delaware River Estuary from the mouth of the Delaware Bay to just north of the Delaware Memorial Bridge.

The survey uses a stratified random design. Sites are randomly selected from each of eight zones in the Delaware Bay: Zones 1, 2, and 3 (lower bay); Zones 4, 5, and 6 ("middle" bay); and Zones 7 and 8 (upper bay / lower Delaware River). The number of sampling sites within each zone was determined using a Neyman allocation procedure based on the proportional area of each zone and historical fisheries data.

All sampling is performed during the daytime using a 4.9-m semi-balloon otter trawl with 17-ft headrope and 21-ft footrope. The trawl body is nylon net made of #9 thread with 1.5-in stretch (0.75-in square) mesh. The cod end is constructed of #15 thread with 1.25-in stretch (0.625-in square) mesh and fully-rigged with four 2-in I.D. net rings at the top and bottom for lazy line and purse rope. An inner liner of 0.50-in stretch (0.25-in square) mesh #63 knotless nylon netting is inserted and hogtied in the cod end. The trawl doors are 24 inches in length and 12 inches wide and are made of 0.75-in marine ply board, 1.25-in × 1.25-in straps and braces, and a 0.50-in × 2-in bottom shoe runner. Tow duration is 10 minutes at 6 ft/sec against the direction of the tide. Information on water quality, water clarity, weather, and tidal stage are also recorded at each sampling site.

### Sampling Intensity

A total of 40 sites are sampled once a month from April through November.

### Biological Sampling

After each tow, all finfish and invertebrates are identified to the lowest practicable taxonomic level and counted. The lengths of target species, which includes Atlantic croaker, are measured to the nearest millimeter using the length type appropriate for the species' morphology. If more than 100 individuals of a target species are collected, a subsample of 100 individuals is taken for measurement.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The data from this survey were not readily available in a usable format for evaluation.

## DELAWARE JUVENILE FINFISH TRAWL SURVEY

### Survey Design & Methods

The Delaware Division of Fish and Wildlife's (DEDFW) Juvenile Finfish Trawl Survey has been monitoring juvenile fish and crab abundance in Delaware's inshore waters since 1980.

At each site, the 19-m R/V *First State* tows a 4.8-m semi-balloon trawl with a 1.3-cm cod end liner. Tows are made against the current for ten minutes.

### Sampling Intensity

Sampling is conducted monthly from April through October at 39 fixed sites throughout the Delaware Bay and river.

### Biological Sampling

The catch from each tow is sorted by species, and individuals are measured and weighed.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This is a fixed-design survey and was not selected given the availability of surveys that utilize standard statistically-based designs. Additionally, this is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## DELAWARE ADULT FINFISH TRAWL SURVEY

### Survey Design & Methods

The DEDFW's Adult Finfish Trawl Survey was implemented in 1966 as a long-term fisheries-independent monitoring program. The survey is primarily used to monitor the abundance of sub-adult and adult fish. There are several gaps in sampling in the survey's history, but sampling has been consistently performed every year since 1990.

There are nine fixed sampling sites, which are all located off shore in the Delaware Bay. Tows are made using the 19-m R/V *First State*, which tows 9.1-m otter trawl with 5.1-cm cod end liner. Tow duration is twenty minutes, and tows are made against the current.

### Sampling Intensity

Sampling is conducted monthly from March through December.

### Biological Sampling

The catch from each tow is sorted by species, and individuals are measured and weighed.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This is a fixed-design survey and was not selected given the availability of surveys that utilize standard statistically-based designs. Additionally, this is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## UNIVERSITY OF DELAWARE INLET SURVEY

### Survey Design & Methods

The University of Delaware's Inlet Survey was a short-term survey performed in 2006 and 2007 as part of a thesis project (Rhode 2008). The survey operated in the Roosevelt Inlet, which is just

inside Cape Henlopen, on the southern shore at the mouth of Delaware Bay. Samples were collected from a dock at the university, about 0.3 kilometers inside the inlet, at the mouth of the Broadkill River. The river is approximately 60-m wide and 3-m deep during mean low water at the sampling site.

A 1-m diameter ring plankton net made of 1-mm mesh was deployed approximately 1 meter below the surface for 30 minutes. A series of three replicate samples were collected during each sampling event. The volume of water filtered was estimated using a flowmeter attached to the net.

Surface water temperature and salinity were measured and recorded at the start and end of each sampling event.

**Sampling Intensity**

Sampling was conducted weekly during nighttime flood tides.

**Biological Sampling**

All ichthyoplankton caught were sorted in the laboratory and preserved in 95% ethanol. All larval fish were identified and counted. A random subsample of at least 20 individuals of each species was measured for standard lengths to the nearest 0.1 millimeter.

**Ageing Methods**

This survey does not collect structures for ageing.

**Evaluation of Survey Data**

The survey time series (2 years) was considered too limited to develop an index that would be considered useful for the current stock assessment.

## MARYLAND BLUE CRAB TRAWL SURVEY

### Survey Design & Methods

In 1977, the Maryland Department of Natural Resources (MDDNR) Fisheries Service established their Blue Crab Trawl Survey in order to monitor the blue crab population in the Chesapeake Bay and its tributaries. Finfish collected by the survey have been enumerated since 1980 (Davis et al.1995).

The survey collects data from six river systems in Maryland's Chesapeake Bay region: the Chester River, Eastern Bay, Choptank River, and Patuxent River (six fixed sampling locations each); Tangier Sound (five stations); and Pocomoke Sound (eight stations).

The survey utilizes a 4.9-m semi-balloon otter trawl with a body and cod end of 25-mm stretch mesh and a 13-mm stretch mesh cod end liner. The gear is towed for 6 minutes at 4.0-4.8 km/h.

### Sampling Intensity

Each station is sampled once a month from May through October.

### Biological Sampling

The first 20 individuals of each species are measured for total length to the nearest millimeter.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This is a fixed-design survey and was not selected given the availability of surveys that utilize standard statistically-based designs.

## MARYLAND JUVENILE STRIPED BASS SURVEY

### Survey Design & Methods

The Maryland DNR Juvenile Striped Bass Survey was first initiated in 1954 to monitor juvenile striped bass occurring in the Chesapeake Bay. The sampling sites are divided among the four major striped bass spawning and nursery areas—seven each in the Potomac River and head of the bay area and four each in the Nanticoke and Choptank rivers. At each site, replicate hauls are taken at a minimum of 30 minutes apart.

The survey utilizes a 30.5 × 1.24-m bag-less beach seine made of 6.4-mm untreated bar mesh. The net is set by hand perpendicular to shore and swept with the current. The area swept is equivalent to a 729 $m^2$ quadrant when the net is full deployed. When depths of 1.6 m or greater are encountered, the offshore end is deployed along this depth contour, and an estimate of the distance from the beach is recorded.

### Sampling Intensity

From 1954 to 1961, the survey stations and timing were inconsistent, and stations were generally sampled once a year. In 1962, stations were standardized and were sampled twice a year. The current methodology, established in 1996, calls for all sites to be sampled in July, August, and September of each year.

### Biological Sampling

All species of fish are identified and enumerated.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The MDDNR Juvenile Striped Bass Survey has been conducted consistently since 1996, so data collected from 1996 onward were evaluated. Due to the high proportion of zero catches of Atlantic croaker, this survey was not used to develop an index.

## MARYLAND COASTAL BAYS FISHERIES TRAWL SURVEY

### Survey Design & Methods

The MDDNR Fisheries Service has been conducting the Coastal Bays Fisheries Trawl Survey in Maryland's coastal bays since 1972. A standardized sampling protocol has been in use since 1989. The survey targets finfish and invertebrates.

Trawl sampling is conducted at 20 fixed sites throughout Maryland's coastal bays. The boat operator takes into account wind and tide (speed and direction) when determining trawl direction. A standard 4.9-m semi-balloon trawl net is used in areas with a depth greater than 1.1 m. Each trawl is a standard 6-minute (0.1 hr) tow at a speed of approximately 2.8 knots. Speed is monitored during the tow using GPS. Waypoints marking the sample start (gear fully deployed) and stop (point of gear retrieval) locations are taken using the GPS to determine the area swept (hectares). Time is tracked using a stop watch, which is started at full gear deployment.

### Sampling Intensity

Sampling is conducted monthly from April through October.

### Biological Sampling

Fishes and invertebrates are identified, counted, and measured for total length using a wooden millimeter measuring board with a 90-degree right angle. At each site, a subsample of the first 20 fish (when applicable) of each species are measured and the remainder are counted.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The MDDNR Coastal Bays Fisheries Trawl Survey has been conducted consistently since 1989, so only data collected from 1989 onward were evaluated. Most of the Atlantic croaker observed are caught in October and are age 0. The VIMS and NC Program 195 surveys were selected to develop young-of-year indices for use in the assessment model. Those surveys were selected because they were considered centrally located relative to the stock's range and because the states where those surveys are conducted are responsible for the majority of commercial and recreational catches of Atlantic croaker. The SASC decided it was not necessary to include an additional young-of-year index.

## MARYLAND COASTAL BAYS FISHERIES SEINE SURVEY

### Survey Design & Methods

The MDDNR Fisheries Service's Coastal Bays Fisheries Seine Survey has been sampling Maryland's coastal bays since 1972. The survey has employed a standardized protocol since 1989. The survey samples the shallow regions of the coastal bays frequented by juvenile finfish.

Shore beach seine sampling is conducted at 19 fixed sites once per month in June and September. A 30.5 m × 1.8 m × 6.4 mm mesh bag seine is deployed at 18 of the fixed sites in depths less than 1.1 m along the shoreline. A 15.24 m version of the previously described net is used at site S019 due to its restricted sampling area.

### Sampling Intensity

Sampling is conducted at 19 fixed sites once per month in June and September.

### Biological Sampling

Fishes and invertebrates are identified, counted, and measured for total length using a wooden millimeter measuring board with a 90 degree right angle. At each site, a subsample of the first 20 fish (when applicable) of each species are measured and the remainder are counted.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The MDDNR Coastal Bays Fisheries Seine Survey has been conducted consistently since 1989, so data collected from 1989 onward were evaluated. Due to the high proportion of zero catches of Atlantic croaker, this survey was not used to develop an index.

## ChesMMAP TRAWL SURVEY

### Survey Design & Methods

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey was implemented in 2002 to supplement data needs of single and multispecies stock assessment models. The survey provides data on relative abundance, length, weight, sex ratio, maturity, age, and trophic interactions for recreationally and commercially important species in the bay.

The ChesMMAP survey samples the main stem of the Chesapeake Bay. The timing of the cruises is based on the seasonal abundances of fishes in the bay. Sampling locations are selected using a stratified random design, with strata based on water depth (3.0-9.1 m, 9.1-15.2 m, and >15.2 m) within five 30-minute latitudinal regions of the bay. The number of sites sampled in each stratum of each region is proportional to the surface area of water in that stratum.

Tow duration is 20 minutes at approximately 3.5 knots, and tows are conducted in the same general direction as the tidal current. The survey is performed using the R/V *Bay Eagle*, a 65-ft aluminum hull, twin diesel engine vessel capable of multi-day deployments. The trawl net is a 13.7-m (headrope length) 4-seam balloon otter trawl. The wings and body of the net are constructed of #21 cotton twine with 15.2-cm mesh, and the cod end is constructed of #48 twine with 7.6-cm mesh, with no liner. The legs of the net are 6.1 m and connected directly to 1.3 m × 0.8 m steel V-trawl doors weighing 83.9 kg each, with a tickler chain attached between them.

The trawl net is deployed with a single-warp system using 9.5-mm steel cable with a 37.6-m bridle constructed of 7.9-mm cable.

Computer software records data from the net monitoring gear as well as a continuous GPS stream during each tow.

**Sampling Intensity**

The ChesMMAP survey conducts five cruises per year (March, May, July, September, and November) and samples approximately 80 to 90 sites a year in the main stem of the Chesapeake Bay.

**Biological Sampling**

The catch from each tow is sorted and individual lengths are recorded by species or length class (if distinct classes within a particular species are evident). Stomach contents, weight, girth, sex, and gonad stage are taken from a subsample of each species or length class.

**Ageing Methods**

Ageing structures are taken from a subsample of each species or length class.

**Evaluation of Survey Data**

An evaluation of the proportion of zero tows suggested that the ChesMMAP Trawl Survey has encountered Atlantic croakers on a regular basis. The survey has consistently encountered Atlantic croakers age-1 and older during May and July. This survey was not selected due to is short time series.

## NORTH CAROLINA JUVENILE ANADROMOUS TRAWL SURVEY (PROGRAM 100)

**Survey Design & Methods**

In 1982, the North Carolina Division of Marine Fisheries (NCDMF) initiated the Juvenile Anadromous Trawl Survey, also known as Program 100 (P100). The survey targets juvenile Alosids and striped bass. Since 1982, the survey has sampled seven stations, known as the Hassler stations, in Albemarle Sound. During July 1984, twelve sampling stations were added in the Central Albemarle Sound area (Central stations) to establish a juvenile index of striped bass abundance for this area. This sampling was also started to determine if a shift in the striped bass nursery area had occurred.

The survey utilizes an 18-foot semi-balloon trawl with a body mesh size of 0.75 inch and a 0.25-mesh tailbag. Tow duration at the Hassler stations is 15 minutes. At the Central stations, the trawl is towed for ten minutes. Temperature, salinity, and dissolved oxygen are recorded.

**Sampling Intensity**

All stations (Hassler and Central) are sampled every other week from July through October.

**Biological Sampling**

The catch of each tow is sorted by species, counted, and measured. Atlantic croakers are measured for total length to the nearest millimeter.

**Ageing Methods**

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This is a fixed-design survey and was not selected given the availability of surveys that utilize standard statistically-based designs.

## NORTH CAROLINA ESTUARINE TRAWL SURVEY (PROGRAM 120)

### Survey Design & Methods

In 1971, the NCDMF initiated the statewide Estuarine Trawl Survey, also known as Program 120 (P120). The initial objectives of the survey were to identify primary nursery areas and produce annual recruitment indices for economically important species such as spot, Atlantic croaker, weakfish, flounder, blue crab, and brown shrimp. Other objectives included monitoring species distribution by season and by area and providing data for evaluation of environmental impact projects. Various gears and methodology have been used in the survey since 1971.

Major gear changes and standardization in sampling occurred in 1978 and 1989. In 1978, tow times were set at one minute during the daylight hours. In 1989, an analysis was conducted to determine a more efficient sampling time frame for developing juvenile abundance indices with acceptable precision levels for the target species. A fixed set of 105 core stations was identified and sampling was to be conducted in May and June only, except for July sampling for weakfish (dropped in 1998, Program 195 deemed adequate), and only the 10.5-ft headrope trawl would be used. In 2004, July sampling of a subset of the core stations was reinstituted in order to produce a better index for spotted sea trout. Currently, the gear is towed for one minute during daylight hours and covers 75 yards.

Environmental data are recorded, including temperature, salinity, dissolved oxygen, wind speed, and direction. Additional habitat fields were added in 2008.

### Sampling Intensity

Prior to 1989, sampling was seasonal. From 1989 to 2003 a fixed set of 105 core stations was identified and sampling was conducted in May and June only. Since 2004, additional July sampling of a subset of the core stations has been conducted.

### Biological Sampling

All species caught are identified and sorted, and a total number is recorded for each species. For target species, thirty to sixty individuals are measured for length.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The evaluation of the proportion of zero catches for this survey suggests that Atlantic croakers have been commonly encountered. The length-frequency distributions of Atlantic croakers collected by the Estuarine Trawl Survey show that age-0 fish dominated the survey catch, consistent with the results reported by Lee (2005). The SASC had decided that young-of-year indices would be developed from surveys that are conducted in Virginia and North Carolina, as

these states are centrally located relative to the range of the stock and are responsible for the majority of commercial and recreational catches along the coast. Major changes were made to the design of the Program 120 survey in 1978 and 1989. As such, the NCDMF Program 195 survey could provide a longer young-of-year index (1987–2008) and was chosen over this survey for use in the assessment model.

## NORTH CAROLINA INDEPENDENT GILL NET SURVEY (PROGRAM 915)

### Survey Design & Methods

The NCDMF operates two fisheries-independent gill net surveys, known as Program 915 (P915). The River Independent Gill Net Survey (RIGNS) started in 1998 and samples the Neuse, Pamlico, and Pungo river systems. The Pamlico Sound Independent Gill Net Survey (PSIGNS) was initiated in May of 2001. Sampling in the RIGNS was dropped after 2000 and resumed in 2003 to present. The PSIGNS has sampled continuously since 2001. A primary objective of both the PSIGNS and the RIGNS is to provide independent relative abundance indices for key estuarine species, including Atlantic croaker.

The survey employs a stratified random design, where sampling is stratified by area and water depth. The Pamlico Sound is divided into eight areas (Hyde County 1-4 and Dare County 1-4). The Neuse River is divided into four areas (Upper, Upper-Middle, Middle-Lower, and Lower) and the Pamlico River is divided into four areas (Upper, Middle, Lower, and Pungo River). A one minute by one minute grid (i.e., one square nautical mile) was overlaid over all areas and each grid is classified as either shallow (<6 ft), deep (≥6 ft), or both, based on bathymetric maps.

For each random grid selected, both a shallow and deep sample is collected. Each sample (both shallow and deep) consists of eight 30-yard segments of 3.0-, 3.5-, 4.0-, 4.5-, 5.0-, 5.5-, 6.0-, and 6.5-inch stretched mesh gill net, for a total of 240 yards per sample. Nets are typically deployed within an hour of sunset and retrieved the next morning, so all soak times are approximately 12 hours. This sampling design results in a total of approximately 64 gill-net samples (32 deep and 32 shallow samples) being collected per month across both the rivers and sound.

Physical and environmental conditions, including surface and bottom water temperature ($^{o}$C), salinity (ppt), dissolved oxygen (mg/L), bottom composition, as well as a qualitative assessment of sediment size, are recorded upon retrieval of the nets on each sampling trip. All attached submerged aquatic vegetation (SAV) in the immediate sample area is identified to species and density of coverage is estimated visually when possible. Additional habitat data recorded included distance from shore, presence or absence of sea grass or shell, and substrate type.

### Sampling Intensity

Each area is sampled twice a month.

### Biological Sampling

Each collection of fish per mesh size (30-yard net) is sorted into individual species groups. All species groups are enumerated and an aggregate weight (nearest 0.01 kilogram) is obtained for most species, including damaged (partially eaten or decayed) fish. The condition of each individual is recorded as live, dead, spoiled, or parts. Individuals are measured to the nearest millimeter for either fork or total length according to the morphology of the species.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

This survey mainly encounters age-1+ Atlantic croaker. The SASC felt an index developed from this survey would not be representative of the entire stock.

## NOAA BEAUFORT INLET ICHTHYOPLANKTON SAMPLING PROGRAM

### Survey Design & Methods

NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) initiated the Beaufort Inlet Ichthyoplankton Sampling Program in November 1986. The survey is the longest consecutive ichthyoplankton sampling program along the U.S. east coast. Data collected from the survey have been for research on topics such as larval transport, biological characteristics of larvae, and timing of immigration.

Sampling is conducted from an observation platform on the Pivers Island Bridge. The bridge spans a 40-m wide channel and is located approximately 1.5 km upstream from Beaufort Inlet—one of five major inlets into North Carolina estuaries. The channel has a maximum depth (high tide) of about 3 meters. Four replicate sets are collected weekly during nighttime flood tides.

### Sampling Intensity

During 1984 through 2004, sampling was performed from November through April; sampling has been conducted year-round since 2005.

### Biological Sampling

Larvae are sampled from the upper surface layer (0.0-1.0 m) using a 2-$m^2$ rectangular plankton net with 1-mm mesh and fitted with a flowmeter. Prior to 1998, the volume of water sampled was variable. In 1998, a digital flowmeter was mounted in the net opening and the volume sampled was standardized to approximately 100 $m^3$. Larval samples are preserved in 95% solutions of ethanol and sorted and identified to species.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

These data were not available for the assessment.

## SOUTH CAROLINA ROTENONE SURVEY

### Survey Design & Methods

The South Carolina Rotenone Survey targeted newly settled and juvenile fish inhabiting salt marsh habitats. Each sampling site was located near low water at the mouth of a small estuarine creek, which drained an area of tidal salt marsh flat. Samples were collected by blocking the creek with a fine-mesh stop net during high tide and capturing fish as the tide ebbed through low

tide. Fish in the creek were killed using rotenone, allowing them to flow downstream into the net. The creek was also swept with hand nets in order to collect any stationary specimens.

**Sampling Intensity**

The survey was performed from June 1986 until July 1994. Sampling was generally conducted monthly at four fixed sites, but incomplete coverage across sites and months slightly complicates data interpretation.

**Biological Sampling**

All fish that were collected were identified and counted, and subsamples were taken to measure individuals for standard length to the nearest millimeter.

**Ageing Methods**

This survey does not collect structures for ageing.

**Evaluation of Survey Data**

This survey could not be evaluated because zero tows were not included in data file.

**SOUTH CAROLINA ELECTROFISHING SURVEY**

**Survey Design & Methods**

The South Carolina Electrofishing Survey began in May 2001 and samples six strata within estuarine systems along the South Carolina coast. These include the lower and upper Edisto rivers, the Combahee River, the upper Ashley River, the upper Cooper River, and the North Santee River. Winyah Bay replaced the North Santee stratum in November 2003. The upper Edisto and Combahee river strata are freshwater systems, whereas the others have salinities of up to ~10 ppt.

The shorelines of each stratum are partitioned into 926-m long intervals, with each one representing a potential sampling site. Prior to each month's sampling, sites are chosen from a table of random numbers without replacement. Since light rainfall reduced freshwater runoff and allowed the penetration of tidal salt water further upriver, additional upstream sites had to be added in some strata since the effectiveness of the shocking unit declines at salinities above ~12 ppt.

At each randomly chosen site, a fifteen-minute set is made along the shoreline in a Smith-Root electrofishing boat (Smith-Root, Inc., 14014 NE Salmon Creek Avenue, Vancouver, WA 98686). Sampling is performed with the boat moving in the direction of the current, which allows stunned fish to be easily netted as they float alongside the boat, rather than being swept behind the boat and missed. Straight shorelines are sampled by shocking at idle-speed, approximately 1.5 to 3.0 meters from the bank. More complex locations that contain submerged trees, remnants of old docks, mouths of tributaries, and sloughs require more maneuvering with the boat to ensure all areas are sampled.

Initial testing with the electrical settings on the generator indicated that an input of ~3,000 watts of pulsed direct current yielded good collections of fish without causing obvious significant damage to them. In the oligohaline and freshwater areas, low conductivity requires higher voltage and lower amperage settings to achieve the desired power level.

### Sampling Intensity

The number of potential sites in each stratum is: North Santee River = 82; Upper Cooper River = 63; Upper Ashley River = 80; Lower Edisto River = 88; Upper Edisto River = 86; Combahee River = 232; Winyah Bay = 65. Variability in the number of sites has been caused by drought conditions during some years.

### Biological Sampling

Captured fish are placed in a live well until the end of each fifteen-minute set, at which time they are counted and measured. A subsample of 25 randomly selected individuals of each species is collected, and the standard length of each individual is measured to the nearest millimeter. All fish are released alive.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

Due to the high proportion of zero catches of Atlantic croaker, this survey was not used to develop an index. In addition, this survey is conducted too far upriver to be expected to produce a reliable Atlantic croaker index. It is also questionable whether an index derived from this survey would be representative of stock-wide dynamics.

## SOUTH CAROLINA TRAMMEL NET SURVEY

### Survey Design & Methods

The South Carolina Trammel Net Survey was initiated in 1991 and is still ongoing. It uses a stratified random sampling protocol covering seven different strata within four major estuarine systems. The strata include the ACE Basin (AB), Ashley River (AR), Charleston Harbor (CH), Lower Wando River (LW), McBanks (MB), Cape Romain Harbor (RH), and Winyah Bay (WB), with approximately 30 sites in each stratum. Sites are selected at random without replacement and sampled monthly during early to late ebb tide using a trammel net that is 184 m long and 2.1 m deep with 177-mm outer mesh and 63-mm inner mesh. Each net is set close to shore (<2 m depth) by a fast moving boat and the enclosed section of water is then vigorously disturbed on the surface for 10 minutes before retrieving the net.

### Sampling Intensity

The survey samples approximately 30 sites in four major estuarine systems on a monthly basis.

### Biological Sampling

Fish are collected in a live well until the net has been completely hauled, after which they are counted, measured for standard length to the nearest millimeter, and released alive. Measurements are only taken from the first 25 randomly selected individuals of each species collected.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

this is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## GEORGIA ECOLOGICAL MONITORING SURVEY

### Survey Design & Methods

The Georgia Coastal Resources Division's (GACRD) Marine Fisheries Section has conducted monthly ecological monitoring of finfish, shrimp, and crabs through their Ecological Monitoring Survey (EMS). The information collected by the EMS survey is used to assess stock status and determine optimum opening and closing dates for harvest seasons.

The survey follows a fixed design, with sampling sites located in six of Georgia's commercially important estuarine systems: Wassaw, Ossabaw, Sapelo, St. Simons, St. Andrew, and Cumberland. Each system is divided into three sectors: 1) large creeks and rivers; 2) open sounds; and 3) nearshore ocean waters associated with the state's territorial waters from the beaches to three miles off shore.

Tows are made using the 60-ft R/V *Anna*. The gear consists of 12.2-m flat otter trawls with 4.8-cm stretch mesh webbing for the body and bag. Tow duration is 15 minutes. Environmental parameters are collected to determine their impacts on the resources.

### Sampling Intensity

Sampling is conducted monthly at two sites in each estuarine system, for a total of 36 sites sampled each month. Sampling occurs during the first half of the month on neap tides when possible.

### Biological Sampling

The catch from each tow is deposited in a large culling table where shrimp, blue crabs, and fish are sorted by species and quantitative measurements are taken.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

The Ecological Monitoring Survey mainly encounters young-of-year Atlantic croaker. The VIMS and NC Program 195 surveys were selected to develop young-of-year indices for use in the assessment model. Those surveys were selected because they were considered centrally located relative to the stock's range and because the states where those surveys are conducted are responsible for the majority of commercial and recreational catches of Atlantic croaker. The SASC decided it was not necessary to include an additional young-of-year index.

## GEORGIA SUMMER GILL-NET SURVEY

### Survey Design & Methods

The primary target of Georgia's Summer Gill Net Survey is young-of-year red drum. Monitoring recreationally important finfish species is a secondary objective of the program. The survey utilizes a mixed (stratified random and fixed) sampling design. Sites are selected based on water system, region within the system (QUAD grid), and nursery area type (primary or secondary). The number of sites sampled per stratum is proportionate to the size of the stratum. Selected sites are sampled once per survey month. All sampling occurs during the last three hours of ebb tide and only during daylight hours.

The survey gear is a 300 ft × 9 ft gill net constructed of a single panel with 2.5-in stretch mesh webbing. The net has a 0.5-in diameter float rope and a 75-lb lead line. A 25-lb anchor chain is attached to each end of the lead line, and a large orange bullet float is attached to each end of the float line.

A sampling event consists of a single net set. The net is deployed by boat starting at the bank, follows a semicircular path, and ends back at the same bank. The net is deployed against the tidal current. Immediately after deployment, the net is actively fished by making two to three passes with the boat in the area enclosed by the net. After the last pass is made, the net is retrieved starting with the end that was first set. The soak time is variable but generally less than 30 minutes. As the net is retrieved, the catch is removed and released back into the water, inside a holding pen tied to the boat. After the net is fully retrieved, all catch is processed for information and released. In addition to catch information, temporal, spatial, weather, hydrographic, and physio-chemical data are collected during each sampling event.

### Sampling Intensity

Sampling is conducted in the Wassaw Sound and the Altamaha Sound Region from June through August.

### Biological Sampling

All catch is identified to species and counted. All finfish specimens are measured for centerline in millimeters.

### Ageing Methods

This survey does not collect structures for ageing.

### Evaluation of Survey Data

Length-frequency distributions of Atlantic croakers caught by this survey indicate most are age 1+. This is a localized survey so an index developed from this survey would not be considered representative of the stock as a whole.

## FLORIDA FISHERIES-INDEPENDENT MONITORING PROGRAM

### Survey Design & Methods

The Florida Fish and Wildlife Conservation Commission (FLFWC) Fish and Wildlife Research Institute's (FWRI) Fisheries-Independent Monitoring (FIM) program samples estuarine, bay, and coastal systems around Florida to support the management of Florida's estuarine and marine fisheries resources. The survey methodology was standardized in the 1996/1997 sampling season and currently uses a stratified random design. The survey region is divided into zones based on

logistical and hydrological characteristics. The survey zones are stratified by habitat (e.g., depth, shore type, bottom vegetation). The main sampling areas for Atlantic croaker are the Indian River Lagoon and Jacksonville study areas.

The FIM uses a variety of gear types to ensure that a wide range of fish lengths and ages are collected. The sampling gears commonly used are a 21.3-m center bag seine, a 6.1-m otter trawl, and a 183-m haul seine. The 21.3-m seine is used to collect juvenile and sub-adult fishes (especially young-of-year) in shallow waters of 1.8 m or less. The 6.1-m trawl is designed to collect juvenile and sub-adult fishes in deeper waters (1.0-7.6 m). Larger sub-adult and adult fishes are collected in shallow waters (≤2.5 m) along shorelines using the 183-m haul seine. Data on water quality and habitat are recorded at each site.

**Sampling Intensity**

Sampling is conducted monthly at randomly-selected sites within the strata of each zone.

**Biological Sampling**

At each station, each fish is identified to species, measured for length, sexed, and counted.

**Ageing Methods**

For species important to Florida's fisheries, hard parts are collected for ageing. When there are too many individuals of a given species to easily measure in the field, the sample is split into smaller, more manageable subsamples. For example, up to 40 Atlantic croaker per 10-mm length class captured during sampling are measured for length and counted. When more than 40 fish are encountered, length frequencies of the 40 fish are expanded based on the ratio of a particular length class to the total number caught to estimate the sample length frequency.

**Evaluation of Survey Data**

The FIM surveys are conducted in a localized area near the southern boundary of the stock.

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**Table 1.** Summary of fisheries-independent surveys along the U.S. Atlantic Coast considered for use in the current stock assessment.

| Agency | Gear / Survey | Sampling Area | Survey Design | Start Year |
|---|---|---|---|---|
| NMFS | Autumn Bottom Trawl Survey | NE Atlantic | Stratified random | 1972 |
| NEAMAP | Nearshore Trawl Survey | NE Atlantic | Stratified random | 2007 |
| NJBMF | Delaware River Seine Survey | Delaware River | Fixed | 1980 |
| NJBMF | Delaware Bay Trawl Survey | Delaware Bay | Fixed | 1991 |
| NJBMF | Ocean Trawl Survey | New Jersey nearshore marine waters | Stratified random | 1988 |
| PSEG | Impingement Monitoring | Delaware Estuary | Fixed | ? |
| PSEG | Entrainment Monitoring | Delaware Estuary | Fixed | ? |
| PSEG | Bottom Trawl Survey | Delaware Estuary | Stratified random | ? |
| DEDWF | Juvenile Finfish Trawl Survey | Delaware Bay & Delaware River | Fixed | 1980 |
| DEDWF | Adult Finfish Trawl Survey | Delaware Bay off shore | Fixed | 1966 |
| UD | Inlet Survey (ichthyoplankton) | Roosevelt Inlet, Delaware Bay | Fixed | 2006 |
| MDDNR | Blue Crab Trawl Survey | Chesapeake Bay & tributaries | Fixed | 1977 |
| MDDNR | Juvenile Striped Bass Seine Survey | Chesapeake Bay | Fixed | 1954 |
| MDDNR | Coastal Bays Trawl Survey | Maryland's coastal bays | Fixed | 1972 |
| MDDNR | Coastal Bays Seine Survey | Maryland's coastal bays | Fixed | 1972 |
| VIMS | Juvenile Fish and Blue Crab Trawl Survey | Chesapeake Bay & tributaries | Mixed (stratified random and fixed) | 1955 |
| VIMS | Juvenile Striped Bass Seine Survey | lower Chesapeake Bay | Fixed | 1967 |
| VIMS | ChesMMAP Trawl Survey | main-stem Chesapeake Bay | Stratified random | 2002 |

## Appendix 4: Age-Structured Production Model

Contributed by Katie Drew (Atlantic States Marine Fisheries Commission)

### Introduction

The 2003/2004 assessment of croaker used an age-structured production model (ASPM), versions of which were implemented in both Excel and AD Model Builder. The ASPM is an age-structured, forward-projecting model that estimates abundance- and catch-at-age for each year, but sums the estimated catch-at-age to fit against the total observed catch. The ASPM implemented in AD Model Builder was run for this assessment for two reasons: to produce a continuity run to examine effect of adding additional years of data to the 2003/2004 assessment; and to produce a coast-wide run for comparison to the preferred model base run using a different model but the same data.

### Methods

#### Continuity Run

For the continuity run, the ASPM was run for the mid-Atlantic region only. Data and indices used in the 2003 assessment were updated through 2008 with methods as close as possible to those used in the previous assessment.

Commercial and recreational data from 2003-2008 from North Carolina to New Jersey were added to the time series. Discard ratios for 2003-2008 were estimated from the NMFS Observer Data using SAS Proc Surveymeans, as in the 2003 assessment, and used to estimate croaker discards (see Discards, Section 5.1). The discard estimates were combined with North Carolina's estimates of scrap landings from 2003-2008 to extend the scrap/bait fishery time-series (Table A4.1).

The same four indices, updated with data from 2003-2008, were used to tune the model: the NEFSC fall trawl survey, the VIMS spring young-of-year survey, the SEAMAP survey, and the MRFSS recreational CPUE index (Table A4.1). Only data from North Carolina north was used for the MRFSS and SEAMAP indices.

There were some complications in updating the indices for the continuity run. The 2003 assessment used stratified mean estimates for the NEFSC trawl survey and standardized the SEAMAP index using the delta-lognormal method. The exact values reported in the assessment report could not be replicated using these methods, but the values generated differed only slightly (Figure A4.1). Additionally, VIMS has changed the method used to standardize its index since the last assessment, so the updated index was used for the entire index.

Abundance of age-0 fish was calculated with a Beverton and Holt stock-recruitment relationship re-parameterized in terms of steepness. The fixed parameters included a von Bertalanffy growth curve, fecundity, steepness, and selectivities of the fisheries and indices. Estimated parameters included annual fully-recruited fishing mortality by fishery, catchability coefficients for the indices, virgin recruitment, and annual recruitment deviations. Three fisheries were modeled: commercial, recreational, and a scrap/bait fishery (Table A4.1).

The 2003 estimates of selectivity for the fisheries and indices were used, which had been developed from the available catch-at-age data and the expert opinion of the TC (Table A4.2).

### Coast-wide Run

An additional run of the ASPM was also conducted for the entire coast with updated data and indices. Commercial and recreational data from South Carolina, Georgia, and Florida were added. The recreational CPUE and SEAMAP index were revised to include coast-wide data (Table A4.3). Additionally, the selectivity patterns of the fleets and surveys estimated by the hybrid model (see main report) were used in place of the values from the last assessment. Sensitivity runs were carried out with different estimates of steepness ($0.6 \leq h \leq 0.9$), and with the estimates of shrimp bycatch developed in this assessment.

## Results

### Continuity Run

The mid-Atlantic region was not overfished and overfishing was not occurring (Figure A4.2). Estimates of biomass were lower than the corresponding estimates from the 2003 assessment, and estimates of F were higher, suggesting a possible retrospective bias (Figure A4.3). Biomass in the mid-Atlantic showed an increasing trend since the last assessment, while fishing mortality has declined slightly.

### Coast-wide Run

When the landings were expanded to include the entire coast, the model resulted in unrealistic estimates of biomass and fishing mortality, several orders of magnitude different from the mid-Atlantic estimates (Figure A4.4).

When the selectivities estimated by the hybrid model were used, the estimates of biomass and fishing mortality were more realistic and on the same order of magnitude as the mid-Atlantic estimates. Coast-wide estimates of spawning stock biomass were lower than the mid-Atlantic estimates, and the coast-wide estimates of fishing mortality were higher (Figure A4.5). The trends were very similar, and the coast-wide model agreed with the mid-Atlantic model that the stock was not overfished and overfishing was not occurring, and also that biomass showed an increasing trend since the last assessment.

The assumed value of steepness (h) did not affect the trends in biomass or F, but did affect the magnitude of both the absolute values and values relative to $SSB_{MSY}$ and $F_{MSY}$ (Figure A4.6). Higher values of steepness resulted in higher values of $SSB/SSB_{MSY}$ and lower values of $F/F_{MSY}$; all runs agreed that the stock was not overfished and no overfishing was occurring.

Similarly, adding shrimp bycatch did not change the overall trends in biomass and F, but did change the absolute estimates. Including shrimp bycatch resulted in higher estimates of SSB but lower estimates of SSB relative to $SSB_{MSY}$, and the opposite pattern for F (Figure A4.7).

**Table A4.1** Inputs to ASPM mid-Atlantic continuity run (-1 indicates missing values in the model code).

| Landings (metric tons) | | | | Indices | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Commercial | Recreational | Scrap/ Discards | Year | NEFSC (fall) | MRFSS (year-round) | SEAMAP (fall) | VIMS (spring) |
| 1973 | 2610.968 | 1,027 | 1,316 | 1973 | 40.4 | -1 | -1 | -1 |
| 1974 | 3514.92 | 1,284 | 1,727 | 1974 | 142 | -1 | -1 | -1 |
| 1975 | 7483.662 | 2,325 | 1,631 | 1975 | 906 | -1 | -1 | -1 |
| 1976 | 10299.89 | 3,292 | 1,761 | 1976 | 426 | -1 | -1 | -1 |
| 1977 | 13505.62 | 3,547 | 2,236 | 1977 | 129 | -1 | -1 | -1 |
| 1978 | 13291.77 | 3,211 | 2,680 | 1978 | 213 | -1 | -1 | -1 |
| 1979 | 10381.31 | 2,036 | 3,193 | 1979 | 16.6 | -1 | -1 | -1 |
| 1980 | 9923.427 | 1,019 | 2,579 | 1980 | 52.3 | -1 | -1 | -1 |
| 1981 | 5289.229 | 449 | 1,790 | 1981 | 29.4 | 3.94 | -1 | -1 |
| 1982 | 4967.495 | 366 | 1,627 | 1982 | 8.26 | 3.45 | -1 | -1 |
| 1983 | 3357.002 | 432 | 1,693 | 1983 | 263 | 5.04 | -1 | -1 |
| 1984 | 4569.188 | 619 | 2,002 | 1984 | 292 | 5.6 | -1 | -1 |
| 1985 | 4964.621 | 546 | 1,702 | 1985 | 189 | 6.05 | -1 | -1 |
| 1986 | 5451.531 | 1,067 | 930 | 1986 | 111 | 9.27 | -1 | -1 |
| 1987 | 4756.649 | 880 | 1,705 | 1987 | 109 | 6.52 | -1 | -1 |
| 1988 | 4677.743 | 1,958 | 1,715 | 1988 | 31.0 | 7.73 | -1 | 0.44 |
| 1989 | 3628.892 | 938 | 1,664 | 1989 | 91.0 | 6.44 | -1 | 1.71 |
| 1990 | 2708.824 | 614 | 1,275 | 1990 | 88.8 | 7.83 | 19.09 | 1 |
| 1991 | 1650.741 | 1,004 | 1,019 | 1991 | 321 | 5.85 | 104.23 | 6.08 |
| 1992 | 1904.673 | 1,005 | 858 | 1992 | 231 | 6.68 | 180.25 | 2.98 |
| 1993 | 4026.359 | 1,375 | 952 | 1993 | 238 | 6.48 | 28.42 | 4.43 |
| 1994 | 4866.222 | 2,116 | 1,268 | 1994 | 405 | 7.98 | 107.92 | 0.58 |
| 1995 | 6309.333 | 1,713 | 1,484 | 1995 | 189 | 5.63 | 62.65 | 2.61 |
| 1996 | 9461.675 | 1,821 | 710 | 1996 | 216 | 5.81 | 23.2 | 0.03 |
| 1997 | 12267.98 | 3,460 | 753 | 1997 | 188 | 7.08 | 14.97 | 5.58 |
| 1998 | 12576.94 | 3,533 | 459 | 1998 | 361 | 6.02 | 73.79 | 5.65 |
| 1999 | 12130.12 | 3,134 | 715 | 1999 | 712 | 7.56 | 91.16 | 1.3 |
| 2000 | 12113.58 | 4,375 | 596 | 2000 | 405 | 6.8 | 24.67 | 0.83 |
| 2001 | 13016.56 | 4,955 | 511 | 2001 | 180 | 6.17 | 29.41 | 0.38 |
| 2002 | 11876.99 | 4,170 | 424 | 2002 | 1018 | 7.07 | 36.79 | 3.18 |
| 2003 | 12923 | 4,084.220 | 1,256 | 2003 | 483 | 6.2 | 26.36 | 0.92 |
| 2004 | 12598.6 | 3,887.077 | 1,217 | 2004 | 572 | 5.57 | 103.71 | 2.29 |
| 2005 | 11172.76 | 4,700.031 | 252 | 2005 | 426 | 5.79 | 119.88 | 1.5 |
| 2006 | 9451.583 | 4,090.145 | 173 | 2006 | 960 | 4.81 | 228.26 | 3.72 |
| 2007 | 9184.375 | 3,627.818 | 518 | 2007 | 987 | 6.47 | 43.07 | 2.96 |
| 2008 | 8739.557 | 2,229.158 | 521 | 2008 | 770 | 6.52 | 65.16 | 17.44 |

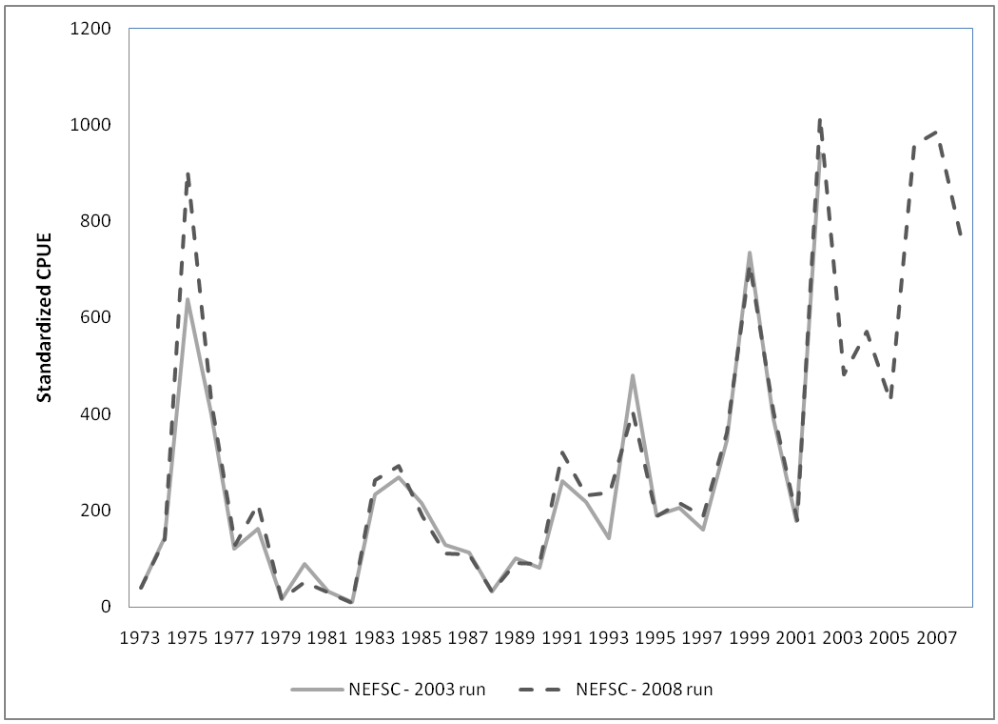
**Table A4.2** Selectivities for fisheries and indices input to the mid-Atlantic continuity run.

| Age | Commercial | Scrap/ Discard | Rec Harvest | Shrimp Bycatch | NEFSC Trawl | MRFSS | SEAMAP | VIMS |
|---|---|---|---|---|---|---|---|---|
| **0** | 0.036 | 0.083 | 0.286 | 1 | 0.79 | 0.08 | 1 | 1 |
| **1** | 0.383 | 0.737 | 1 | 0 | 1 | 0.74 | 0.4 | 0 |
| **2** | 0.606 | 0.863 | 0.508 | 0 | 0.4 | 0.86 | 0 | 0 |
| **3** | 0.809 | 0.972 | 0.209 | 0 | 0.34 | 0.97 | 0 | 0 |
| **4** | 1 | 1 | 0.082 | 0 | 0.11 | 1 | 0 | 0 |
| **5** | 1 | 1 | 0.01 | 0 | 0.12 | 1 | 0 | 0 |
| **6** | 1 | 1 | 0.015 | 0 | 0 | 1 | 0 | 0 |
| **7** | 1 | 1 | 0.01 | 0 | 0 | 1 | 0 | 0 |
| **8** | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| **9** | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| **10+** | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

**Table A4.3** Revised recreational CPUE and SEAMAP indices used in the coast-wide run of the ASPM**.**

| | Rec. CPUE (num/trip) | | SEAMAP Fall (kg/tow) | |
|---|---|---|---|---|
| **Year** | **Index** | **CV[Index]** | **Index** | **CV[Index]** |
| **1981** | 3.94 | 0.11 | | |
| **1982** | 3.45 | 0.066 | | |
| **1983** | 5.04 | 0.058 | | |
| **1984** | 5.6 | 0.077 | | |
| **1985** | 6.05 | 0.072 | | |
| **1986** | 9.27 | 0.040 | | |
| **1987** | 6.52 | 0.049 | | |
| **1988** | 7.73 | 0.051 | | |
| **1989** | 6.44 | 0.037 | | |
| **1990** | 7.83 | 0.049 | 7.72 | 0.29 |
| **1991** | 5.85 | 0.047 | 24.5 | 0.27 |
| **1992** | 6.68 | 0.040 | 4.32 | 0.18 |
| **1993** | 6.48 | 0.045 | 18.7 | 0.10 |
| **1994** | 7.98 | 0.029 | 14.6 | 0.33 |
| **1995** | 5.63 | 0.039 | 5.08 | 0.36 |
| **1996** | 5.81 | 0.041 | 5.14 | 0.23 |
| **1997** | 7.08 | 0.045 | 2.30 | 0.44 |
| **1998** | 6.02 | 0.036 | 4.65 | 0.33 |
| **1999** | 7.56 | 0.037 | 17.5 | 0.25 |
| **2000** | 6.8 | 0.036 | 4.19 | 0.33 |
| **2001** | 6.17 | 0.033 | 2.66 | 0.27 |
| **2002** | 7.07 | 0.030 | 9.24 | 0.44 |
| **2003** | 6.2 | 0.035 | 14.1 | 0.35 |
| **2004** | 5.57 | 0.040 | 15.4 | 0.21 |
| **2005** | 5.79 | 0.044 | 23.8 | 0.17 |
| **2006** | 4.81 | 0.040 | 12.1 | 0.14 |
| **2007** | 6.47 | 0.036 | 9.20 | 0.31 |
| **2008** | 6.52 | 0.041 | 12.0 | 0.25 |

A.




B.

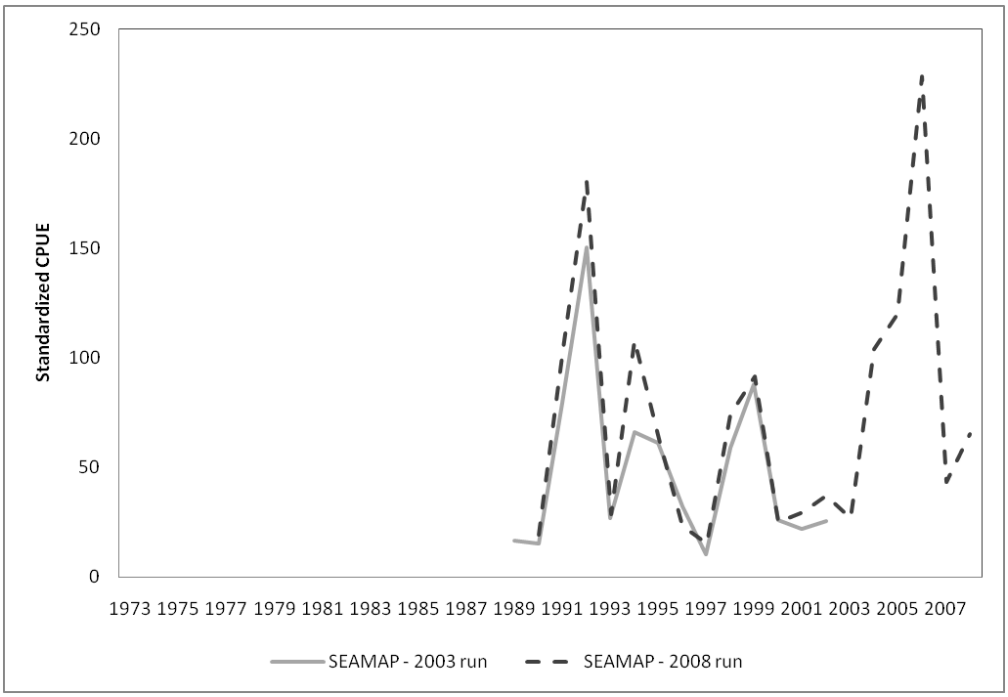



**Figure A4.1** Index values for the NEFSC trawl survey (A) and SEAMAP survey (B) as estimated by the 2003 assessment (solid lines) and this assessment (dashed lines).

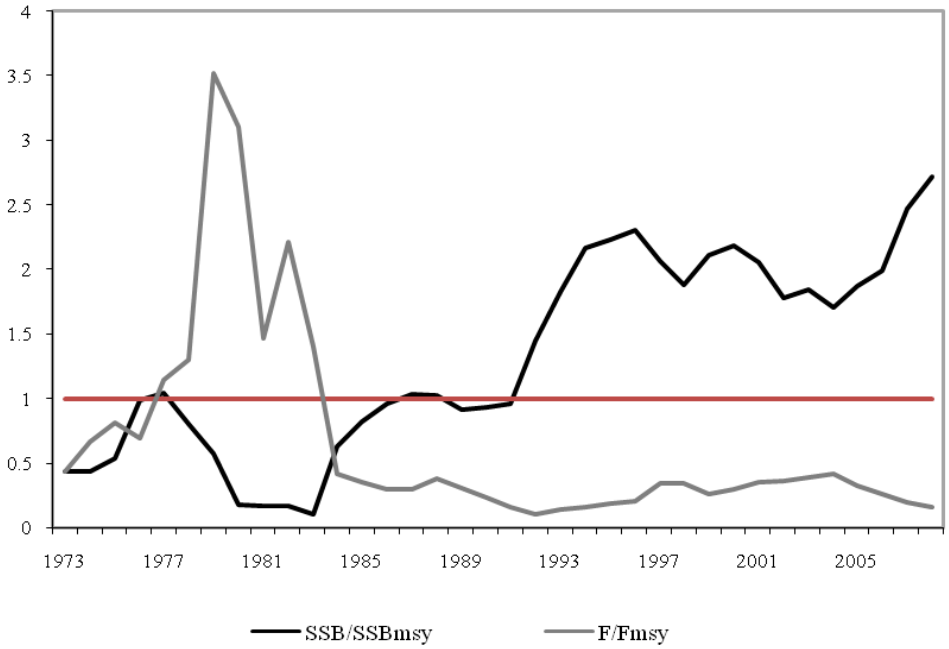
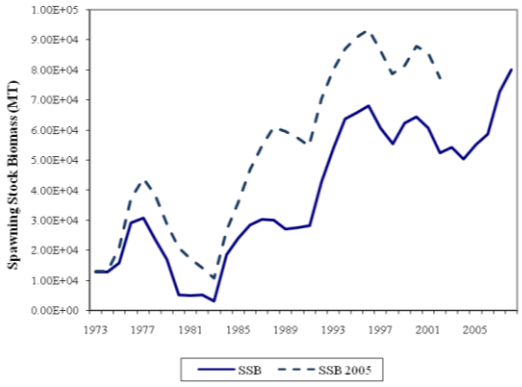
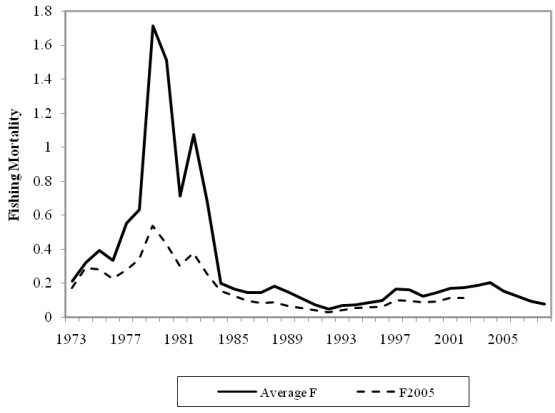



**Figure A4.2** Continuity run spawning stock biomass and fishing mortality relative to the values needed to produce MSY.



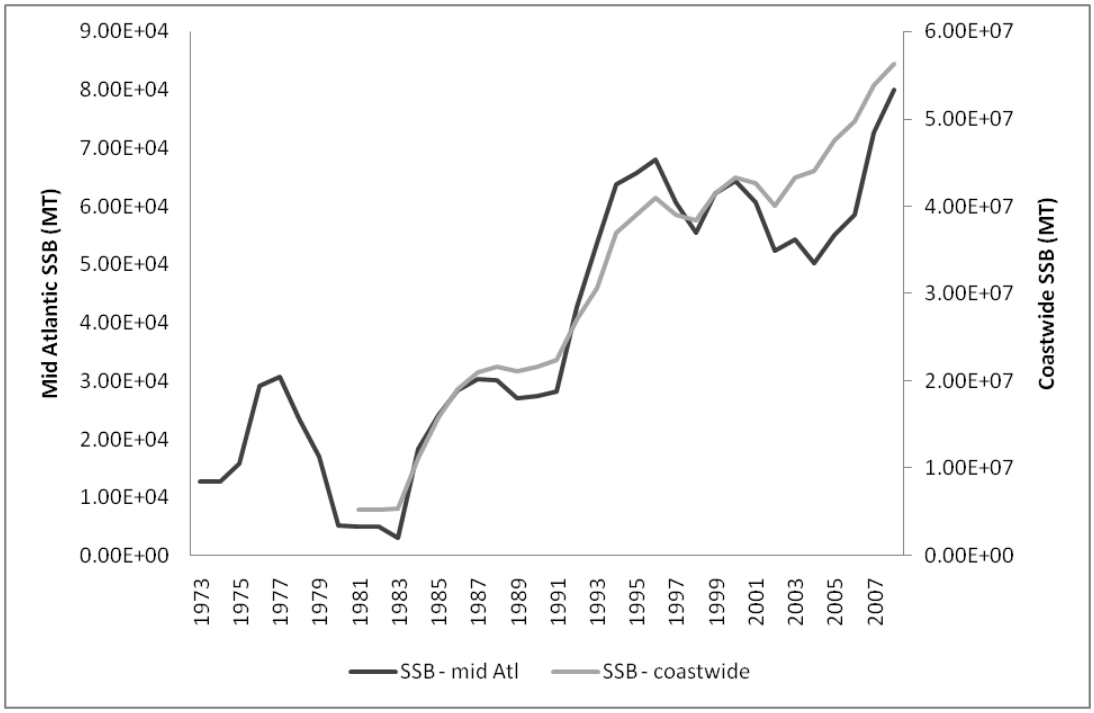

A.




B.

**Figure A4.3** Estimates of SSB (A) and F (B) from the 2003 assessment (dashed lines) and the continuity run of this assessment (solid lines).

A.




B.

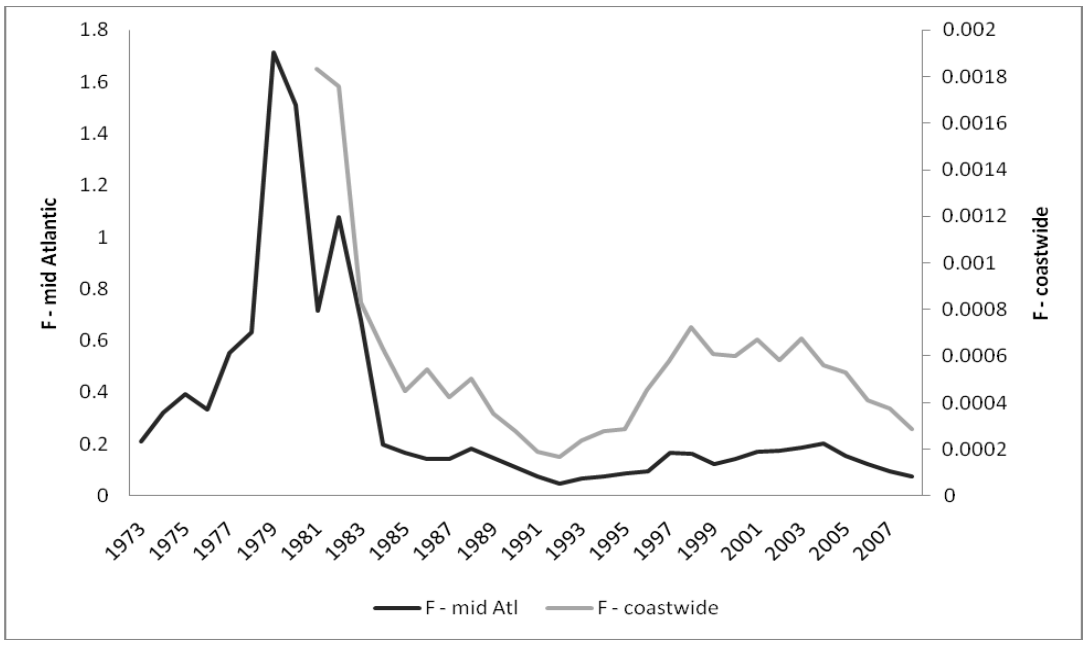



**Figure A4.4** Estimates of SSB (A) and F (B) from the continuity run with mid-Atlantic data only (black lines) and the ASPM with coast-wide data (grey lines). Note the difference in the scale of the axes.

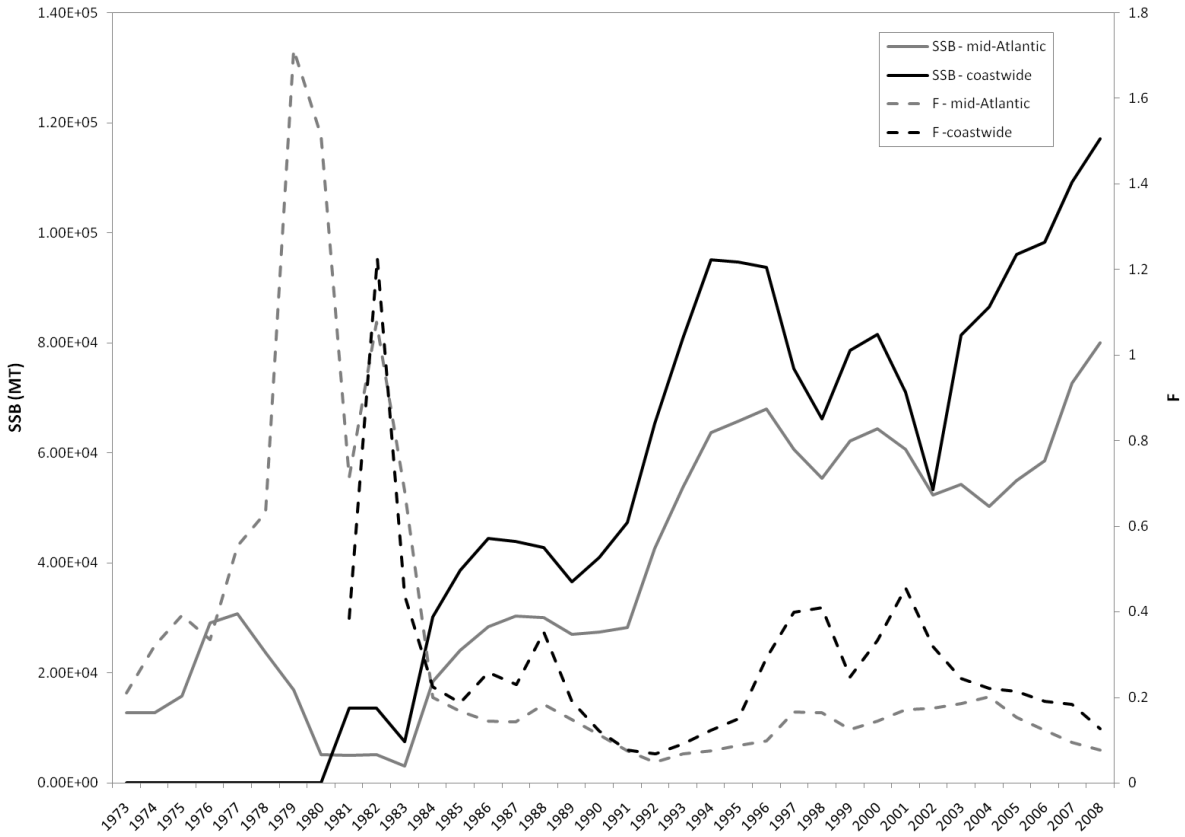
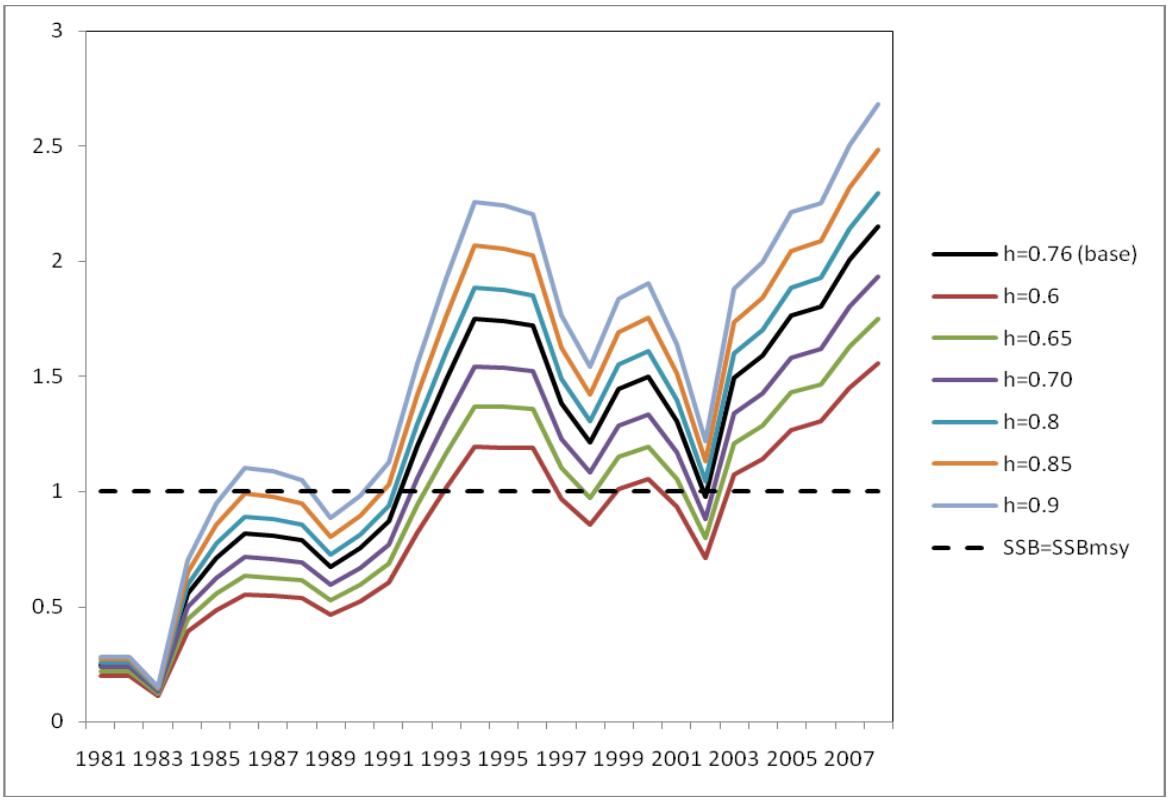



**Figure A4.5** Estimates of SSB and F from the ASPM coast-wide data run with the new estimates of SEAMAP selectivity, plotted on the same scale as the mid-Atlantic only data runs.

A.




B.

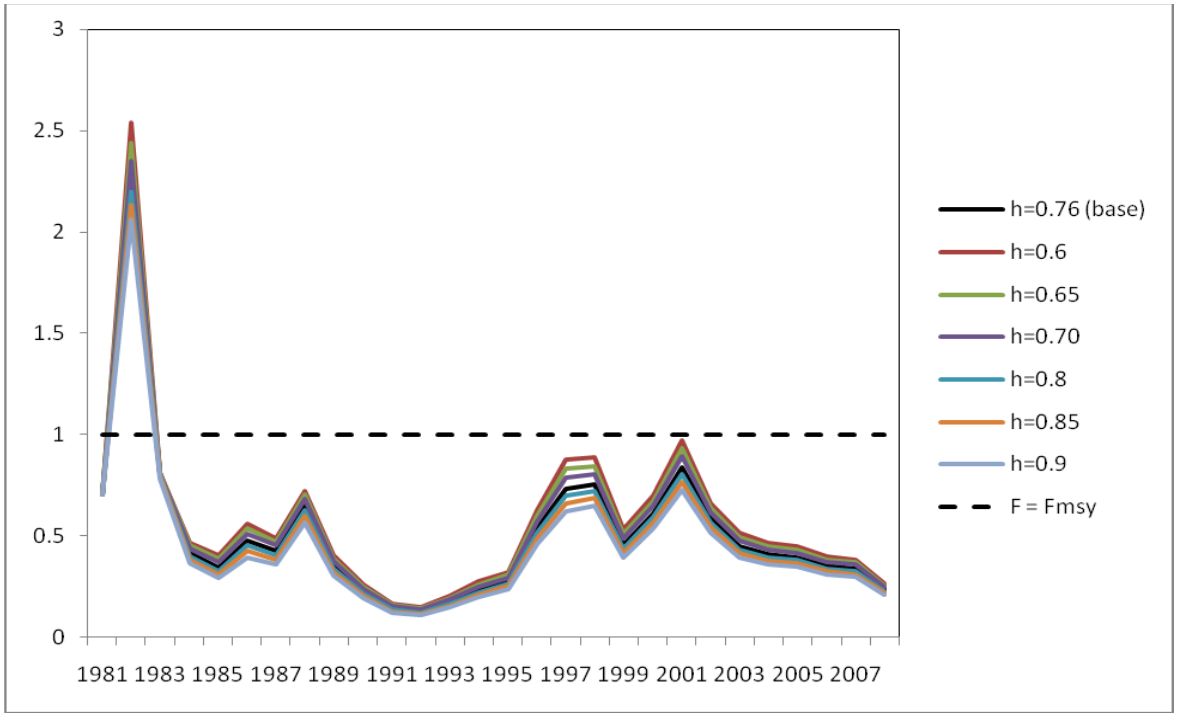
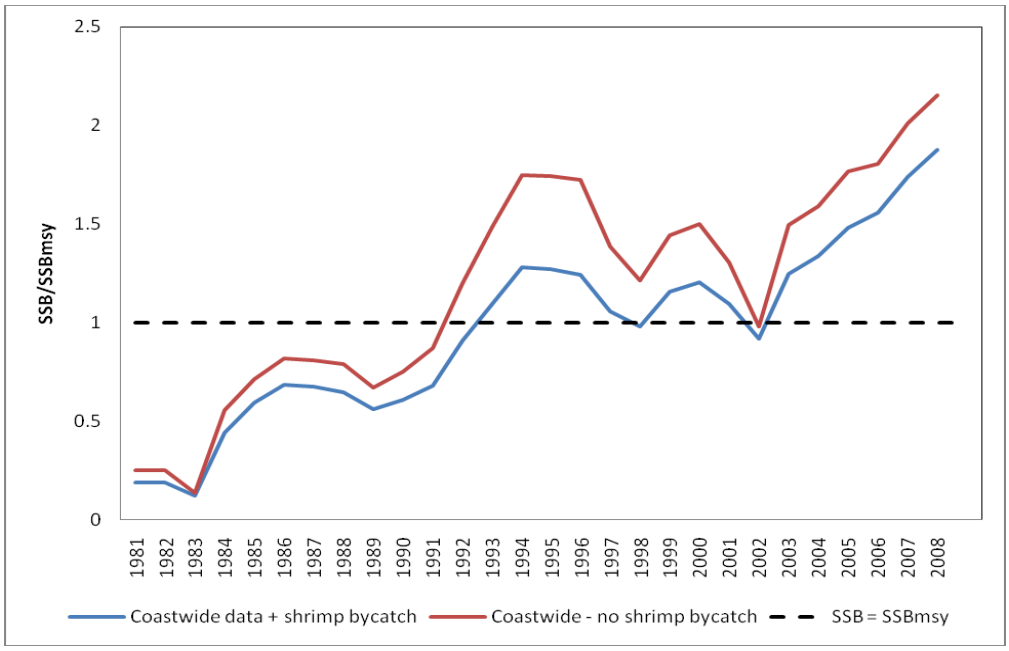



**Figure A4.6** $SSB/SSB_{MSY}$ (A) and $F/F_{MSY}$ (B) for varying values of steepness (h) from the ASPM coast-wide data run

A.




B.

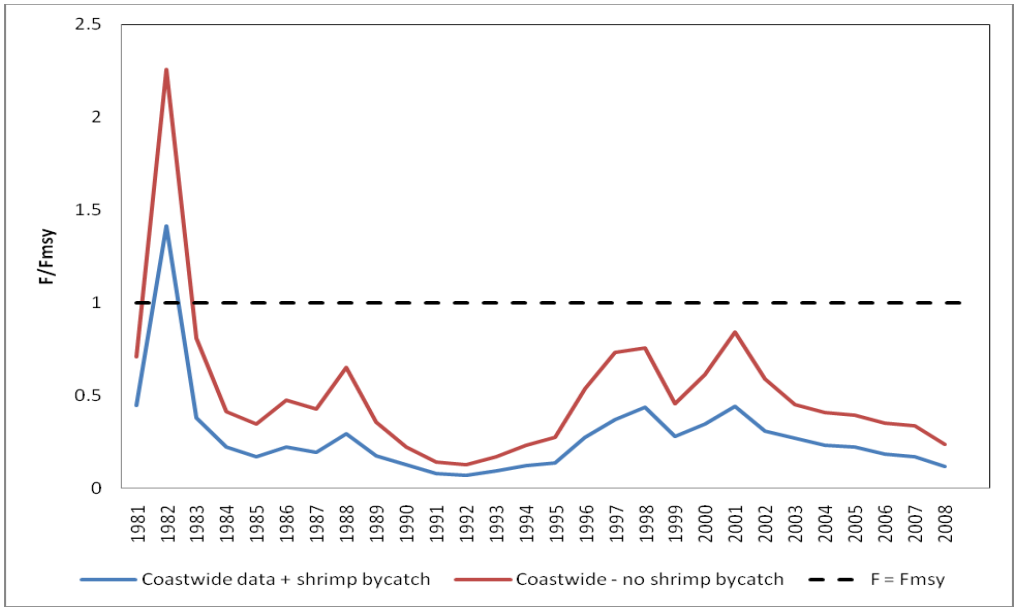



**Figure A4.7** Relative trends in SSB (A) and F (B) from the ASPM coast-wide data runs with and without croaker discards from shrimp trawls.

## Appendix 5: Fitting the non-equilibrium production model to Atlantic croaker fishery data

Contributed by Joseph Munyandorero (Florida Fish and Wildlife Conservation Commission) and Eric Robillard (Georgia Department of Natural Resources)

### Input Data and Model Assumptions, Specifications, and Configurations

Atlantic croaker (*Micropoginias undulates*) fishery data were fitted with non-equilibrium, age-aggregated production model using primarily ASPIC software (version 5.34; NOAA Fisheries 2005, Prager 2005) developed based on Prager's (1994) work. Analyses dealt with the logistic or Graham-Schaefer model shape. This form of model is often used as a default because of its theoretical simplicity and because it is considered a central case among possible shapes of production model. A number of assumptions underlie this model. General assumptions (common to all production models) are: (i) change in productivity (i.e., biomass over time) respond instantaneously to changes in population size; (ii) changes in the (biotic and abiotic) environments are ignored; (iii) the intrinsic rate of population growth (r) and the carrying capacity (i.e., virgin, maximum size) of the stock (K) are constant; and (iv) size or age structure of the population have no major effects on population dynamics. The specific property of the model is that $B_{MSY} = K/2$ where $B_{MSY}$ is the stock biomass (B) at which the (usually constant) maximum sustainable yield, MSY, could be annually taken. The input data were combined tonnage of commercial and recreational harvests (type A+B1) obtained from1973 through 2008, the recreational CPUE (1982-2008), the NMFS fall index (1973-2008), and the SEAMAP fall index (1990-2008). All tuning indices were expressed in biomass. They were selected on the basis of their wide geographical coverage and long-time series; all of them were assumed to represent the Atlantic croaker stock status.

ASPIC model specifications are summarized in Table A5.1. The ASPIC program fits the models under the assumption of no process error; specifically, runs were conditioned on observed harvests, meaning that harvests were assumed to be measured without error and that lognormal observation errors are in the annual abundance indices (Prager 1994; Prager et al. 1996). ASPIC runs were unconstrained (i.e., no penalty to discourage $B_{1973}$ to be greater than K) and performed with the Monte Carlo (MC) phase by direct optimization with bootstrap (500 trials). The MC method helps avoid local minima. In fact, it improves the initial fit by randomly searching for a better one in the neighborhood of the initial fit. Bootstrapping serves to construct the distributions and bias-corrected (BC), non-parametric 80% confidence intervals (CI) of parameter estimates and derived management quantities of interest (e.g., MSY; biomass trajectories). Confidence Intervals were generated by running the ASPIC projections option (i.e., ASPICP - ASPIC's auxiliary program for forward-projections) over 2009-2023 assuming a hypothetical annual total allowable catch (TAC) of 15,000 mt. This amount of TAC was broadly the average of harvests recorded from 1998 through 2008. A 15-year time period was selected for forward-projection of the population because this is the longest projection period allowed by ASPICP and confidence in projection model results decreases at longer timeframes (Davis et al., 2006). Furthermore, ASPIC generates a nonparametric statistic called relative interquartile range (RIQ), which is analog of the coefficient of variation (CV) and measures estimates precision. All starting parameter guesses of biomass (i.e., the ratio of initial biomass $B_{1973}$ to K: $B_{1973}/K$), MSY, and K were based on the maximum harvest ($H_{max}$) recorded from 1973 through 2008 (i.e., $H_{max}$ ~ 18,000 mt). Specifically, in the absence of other information, the starting guess of $B_{1973}/K$ is

initialized at 0.5 (i.e., $B_{1973} = B_{MSY}$); that of MSY can be set to $0.5H_{max}$ while a reasonable guess for K could be 2-10 times $H_{max}$ (Prager 2005). For this study, these guesses were 0.5, 9,000 mt (constraint: 1,000-50,000 mt), and 40,000 mt (constraint: 36,000-500,000 mt), respectively. The starting guesses for index catchability (q) were assigned arbitrarily in such a way that they fall within the range of values internally accepted by ASPIC. A two-step approach was used to weigh indices of abundance. First, an equal weight of 1was assigned to all indices. Second, the final weight was the reciprocal of or the integer close to the inverse-variance weighting (see Prager 1994) generated internally by ASPIC after runs using equal weights. All parameters were estimated, and the goodness-of-fit also included the reliability statistics. These are the coverage index, C* [$C^* = (B_{max}-B_{min})/K$; where $B_{max}$ and $B_{min}$ are maximum and minimum estimated biomass, respectively] and the nearness index, N* [$N^* = 1 - |\min(B-B_{MSY})|/K$ ].(NOAA Fisheries 2005; see Prager et al. 1996 for rationale). The former index measures how widely the stock has varied between B = 0 and B = K. The latter measures how closely the stock biomass approached $B_{MSY}$; it is defined to equal 1 if the biomass trajectory is estimated to have crossed 1 (Prager et al. 1996). Thus, both indices ranges from 0 (least reliable) to 1 (most reliable), 1 being the ideal estimate (NOAA Fisheries 2005).

Base ASPIC was configured to include all selected indices. Given that ASPIC assumes that each index of abundance is representative of the population being assessed, disagreement (e.g., negative correlations) between any pair of indices cannot be reconciled by the model, potentially resulting in run errors. ASPIC detected a negative correlate between SEAMAP fall index and the recreational CPUE. The base ASPIC configuration was retained because the negative correlation in question was relatively small (r = - 0.13), but the resulting effects on croaker stock's status indicators was subsequently checked by successively dropping the SEAMAP fall index and the recreational CPUE. In other words, alternate ASPIC configurations consisted of keeping the total harvest, recreational CPUE, and NMFS fall index on the one hand and, on the other, the total harvest and NMFS fall index.

ASPIC runs were supplemented with an EXCEL spreadsheet implementation of a logistic dynamic production model where inputs were total harvest and NMFS fall index.

Production models estimate status indicators useful in guiding management. These include annual fishing mortality (F), MSY, $B_{MSY}$, and F at MSY ($F_{MSY} = MSY/B_{MSY}$). However, absolute levels of stock biomass (and related quantities), which include uncertainty in the estimate of q, are estimated with less precision (Prager 1994, 2005). In contrast, estimates of annual relative F and relative B, which are the ratios of F and B to $F_{MSY}$ and $B_{MSY}$ (thereby estimated by canceling q out), respectively, are deemed to present a more precise picture of the exploitation conditions and of the stock status.

**Results and Discussion**

All ASPIC runs converged normally. This was indicative (at least in theory) that the data fitted the model fairly well or, equivalently, that they were sufficiently informative to estimate the desired benchmarks and derived parameters (Prager et al. 1996; Prager 2005). Overall and in comparison with the equal weighting approach, use of the two-step weighting scheme improved the initial parameter estimates and yielded "reasonable" good fits of observed indices (Figure A5.1). Various model configurations produced almost similar fits to the recreational CPUE, but

they underestimated and overestimated the observed CPUE in early years and in the most recent years, respectively. All model configurations also fitted similarly the NMFS fall index until 1996. Since then, estimated NMFS fall index became higher while those from other configurations remained lower and comparable. The SEAMAP fall index was rather noisy. The results from the EXCEL-based model tuned with NMFS fall index were similar to those produced using their ASPIC model counterpart (Figure A5.2).

Estimates of key management benchmarks and derived parameters for Atlantic croaker, as well as indicators of goodness-of-fit from fitting the logistic production model under different configurations and implementations are shown in Table A5.2. Uncorrected estimates of $B_{1973}/K$ and MSY are similar. Bias-corrected (BC) estimates of $B_{1973}/K$ and MSY from base ASPIC and ASPIC tuned with the recreational CPUE and NMFS fall index are also similar and are associated with small absolute relative biases (0.79% - 8.37%). BC estimates of $B_{1973}/K$ and MSY from ASPIC tuned with NMFS fall index moderately or highly overestimate the corresponding uncorrected estimates, with biases exceeding 100% and 15%, respectively. However, based on the spread of BC 80% CIs and the magnitude of RIQs, point and BC estimates of $B_{1973}/K$ and MSY from ASPIC tuned with NMFS fall index appear to be more precise. BC estimates of $B_{MSY}$ and $F_{MSY}$ are comparable for base ASPIC and ASPIC tuned with the recreational CPUE and NMFS fall index, and are larger and smaller, respectively, than those obtained from ASPIC tuned with NMFS fall index. BC estimates of $F_{MSY}$ are more precise than those of $B_{MSY}$ (smaller RIQs) and are generally accompanied with smaller relative biases. ASPIC literature does not indicate any thresholds for severe biases; however, a simulation study conducted by Prager et al. (1996) suggests that biases smaller than or equal to |15%| should not be detrimental to the validity of estimates. Based on this criterion, results from ASPIC tuned with the recreational CPUE and NMFS fall index should be preferable (note that uncorrected and BC estimates from this ASPIC configuration also are intermediate of those generated by base ASPIC and ASPIC tuned with NMFS fall index alone). Concerning the reliability of estimates, the coverage index suggests moderately reliable results (C* = 0.41-0.66). This index was developed by Prager et al. (1996) as a “fingerprint” checking lack of contrast in the data, which is considered the major cause of failure in production modeling (Hilborn and Walters 1992). The data analyzed exhibited enough contrasts. Rather, estimate of C* rightly measures here the range of estimated biomass relative to the corresponding estimated carrying capacity, which is lower for base ASPIC than for other ASPIC configurations. Whatever the reasons behind low or moderate estimates of the coverage index, Prager et al. (1996) showed that production models are still capable to generate relatively good estimates of key benchmarks (e.g., MSY) and capture the main features of the stock status (e.g., overexploitation vs. underexploitation; trend in recovery). Estimates of the nearness index were high (0.98-1.0), indicating reliable results in that, especially in the most recent years, the biomass increased, getting closer or passing through $B_{MSY}$.

Whatever the ASPIC model configuration including parameter starting guesses and weights assigned to abundance indices, MC searches yielded biomass whose trajectories were tracking the trends of NMFS fall index (Figure A5.3). EXCEL-based logistic model tuned with NMFS fall index also reveals this feature (Figure A5.4). That trend stabilized at lower levels between 1973 through 1990 and, since then, pictured a steady increase of Atlantic croaker’s stock biomass. Specifically, uncorrected and BC estimates of relative biomass ($B_t/B_{MSY}$) had similar

trends and were of the same magnitude throughout the study period. However, results from base ASPIC and ASPIC tuned with the recreational CPUE and NMFS fall index suggest that annual biomass never reached $B_{MSY}$ during the modeling timeframe; biomass only tended to $B_{MSY}$ in 2007-2008 ($B_t/B_{MSY} > 0.88$; Figure A5.3), this being the sole justification of the nearness index values of 0.98 and 1 (Table A5.2). Estimates of $B_t/B_{MSY}$ from ASPIC tuned with NMFS alone were expectedly more optimistic in that they already became closer to and exceeded 1 since 2002. Uncorrected and BC estimates of relative fishing mortality ($F_t/F_{MSY}$) obtained from various production model configurations and implementations also exhibited similar trends and closer values over 1973-2008 (Figure A5.4; Figure A5.5). Overall, they depict three phases. From 1973 through 1989/1990, values of $F_t/F_{MSY}$ varied considerably but were always far above 1. This situation, in conjunction with lower levels of estimated $B_t/B_{MSY}$ (Figure A5.3; Figure A5.4), may signal overexploitation of Atlantic croaker that was occurring during this period. During 1990/1991-1996, the levels of $F_t/F_{MSY}$ were smaller than 1 while Atlantic croaker stock biomass started rebounding. The period 1997-2008 was first marked by $F_t/F_{MSY}$ levels slightly greater than 1 (1997-2004), which varied smoothly and progressively declined at levels smaller than 1(here, production model tuned with NMFS fall index alone was again more optimistic because estimates of $F_t/F_{MSY} < 1$ were obtained since 1999). Whatever the level of $F_t/F_{MSY}$ estimated during the latter period, it is likely that Atlantic croaker stock was not impaired by exploitation, because, even though relative biomass was smaller than 1, it increased steadily over time (note that this period also coincide with larger harvests that have so far been recorded).

For base ASAP runs, the trajectories of bias-corrected 80% CIs of $B_t/B_{MSY}$ and $F_t/F_{MSY}$ suggest less uncertainty about the estimates of these parameters over 1973-early 1990s, and conversely thereafter (Figure A5.3; Figure A5.5). Furthermore, the trajectories of uncorrected and BC $B_t/B_{MSY}$ and $F_t/F_{MSY}$ along side of each other indicate that they were often associated with small biases. All these statistics were generated based on an arbitrary, hypothetical TAC of 15,000 mt projected forward annually during 2009-2023. It represents 68% of MSY (i.e., about 22,000 mt according to various model outputs). Such a harvest would not impair the Atlantic croaker stock during the projection timeframe because $F_t/F_{MSY}$ levels would remain smaller than 1, and conversely for $B_t/B_{MSY}$. It may, however, be useful to evaluate trends in biomass over time for a range of projected TAC levels. Effects of additional management options investigated in terms of TACs are 36%MSY (.i.e., 7,920 mt), 52% MSY (i.e., 11,440 mt, close to the 2008 total harvest of 11,184 mt), 84%MSY (i.e., ~ 18,480 mt), and MSY itself (Figure A5.6). For each ASPIC model configuration, estimates of $B_t/B_{MSY}$ and their 80% CIs remain unchanged across 1973-2008 whatever the TAC. Trajectories during the projection timeframe are also optimistic because $B_t/B_{MSY} > 1$, but these decrease with larger TACs. Moreover, the projected biomass is more likely certain when it is based on r smaller TACs (narrower BC 80% CIs) than when it is obtained by the larger ones (wider BC 80% CIs). Finally, projections from base ASPIC seem to be more conservative in that, especially for larger TACs, the resulting biomass would decline slowly.

## Conclusion

Production modeling of Atlantic croaker on the U.S. Atlantic coast showed that this stock's abundance was highly driven by the trends of NMFS fall index. Relative biomass and relative fishing mortality were estimated with relatively good precision that was greater in the first half of the time series than in the second half. In addition, these estimates can be reasonably considered reliable, at least on the basis of the estimated reliability statistics.

Overall, production modeling revealed that the stock of Atlantic croaker on the U.S. Atlantic coast was overexploited prior to the 1990s ($B_t/B_{MSY}$ < <1; $F_t/F_{MSY}$ >1) and started to rebuild thereafter (increasing $B_t/B_{MSY}$ or $B_t/B_{MSY}$ >= 1; $F_t/F_{MSY}$ near or smaller than 1).

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**Table A5.1** ASPIC model specifications applied to Atlantic croaker stock on the U.S. Atlantic coast following the logistic or Graham-Schaefer model shape. Fisheries data used were available from 1973 through 2008.

| Fitting options | Attributes, starting guesses, and other values |
|---|---|
| Program mode | Bootstrap |
| Optimization mode | Condition on yield |
| Objective function | Sum of Squared Errors |
| Monte Carlo (MC) | Enabled |
| Number of MC search | 20000 |
| **Parameter starting guesses and constraints**[1] | |
| * B1/K | 0.5 |
| * MSY | 9,000 mt (1,000 - 50,000 mt) |
| * K[1] | 40,000 (36,000 - 500,000 mt) |
| **Covergence criteria (CC) for** | |
| * Simplex optimization | 0.00000001 |
| * Restart | 0.00000003 |
| * Number of restart | 6 |
| * Estimating F | 0.0001 |
| **Additional parameters** | |
| * Number of time step per year | NA |
| * Maximum F allowed | 8 |
| * Penalty term | Off |
| * Random seed | 3941285 |
| **Starting guess for catchability (q)** | |
| * recreational CPUE | 0.000001 |
| * NMFS Fall index | 0.00001 |
| * SEAMAP Fall index | 0.0001 |
| **Final weights of abundance indices**[2] | |
| * recreational CPUE | 0.47; 1 |
| * NMFS Fall index | 2.25; 2; 1 |
| * SEAMAP Fall index | 2.1 |

[1] Figures in parentheses indicate the constrained range of parameter estimates

[2] In the raws of index weights, the first figure correspond to base ASPIC; the second to ASPIC tuned with the recreational CPUE and NMFS fall index; the third (where it appears) to ASPIC turned with NMFS fall index alone. NMFS

**Table A5.2** Estimates of basic management benchmarks and derived parameters and of goodness-of-fit statistics from fitting the logistic production models to Atlantic croaker fishery data on the U.S. Atlantic coast, 1973-2008.

| Type of estimate* | Model configurations and/or implementations | | | |
|---|---|---|---|---|
| | Base ASPIC** | ASPIC tuned with recreational CPUE & NMFS fall index | ASPIC tuned with NMFS fall index only | Excel spreadsheet*** |
| **$B_{1973}$/K (unitless)** | | | | |
| Point estimate | 0.08 | 0.08 | 0.07 | 0.09 |
| Bias-corrected estimate | 0.08 | 0.08 | 0.14 | |
| Relative bias | 2.87% | -2.73% | 100.04% | |
| 80% confidence interval | 0.044 - 0.100 | 0.060 - 0.111 | 0.059 - 0.104 | |
| Relative Interquartile | 0.40 | 0.34 | 0.26 | |
| **MSY (mt/year)** | | | | |
| Point estimate | 23660 | 22120 | 20300 | 21369 |
| Bias-corrected estimate | 23473 | 23971 | 23465 | |
| Relative bias | -0.79% | 8.37% | 15.59% | |
| 80% confidence interval | 18550- 40360 | 16250- 27720 | 15830- 25570 | |
| Relative Interquartile | 0.52 | 0.30 | 0.22 | |
| **$B_{MSY}$ (mt)** | | | | |
| Point estimate | 149100 | 103900 | 63060 | 67195 |
| Bias-corrected estimate | 128180 | 121160 | 76870 | |
| Relative bias | -14.03% | 16.61% | 21.90% | |
| 80% confidence interval | 89320 - 237100 | 61460 - 147400 | 38870 - 113000 | |
| Relative Interquartile | 0.59 | 0.39 | 0.48 | |
| **$F_{MSY}$ (per year)** | | | | |
| Point estimate | 0.16 | 0.21 | 0.32 | 0.32 |
| Bias-corrected estimate | 0.20 | 0.21 | 0.36 | |
| Relative bias | 25.68% | -1.66% | 11.97% | |
| 80% confidence interval | 0.106- 0.175 | 0.163- 0.267 | 0.198- 0.394 | |
| Relative Interquartile | 0.26 | 0.23 | 0.32 | |
| **Goodness-of-fit** | | | | |
| Weighted Sum of Squared Errors | 48.63 | 31.19 | 19.76 | 37.02 |
| Contrast index (Ideal = 1) | 0.41 | 0.46 | 0.66 | 0.64 |
| Nearness Index (Ideal = 1) | 0.98 | 1.00 | 1.00 | 1.00 |

* ASPIC estimates are from bootstraped analysis. ** Base ASPIC configuration involved the use of total harvests (1973 -2008) and recreational CPUE (1982-2008), SEAMAP fall index (1990-2008), and NMFS fall index (1973 - 2008). ***Analysis with Excel relied on total harvests and NMFS fall index and generated point estimates only, using solver.

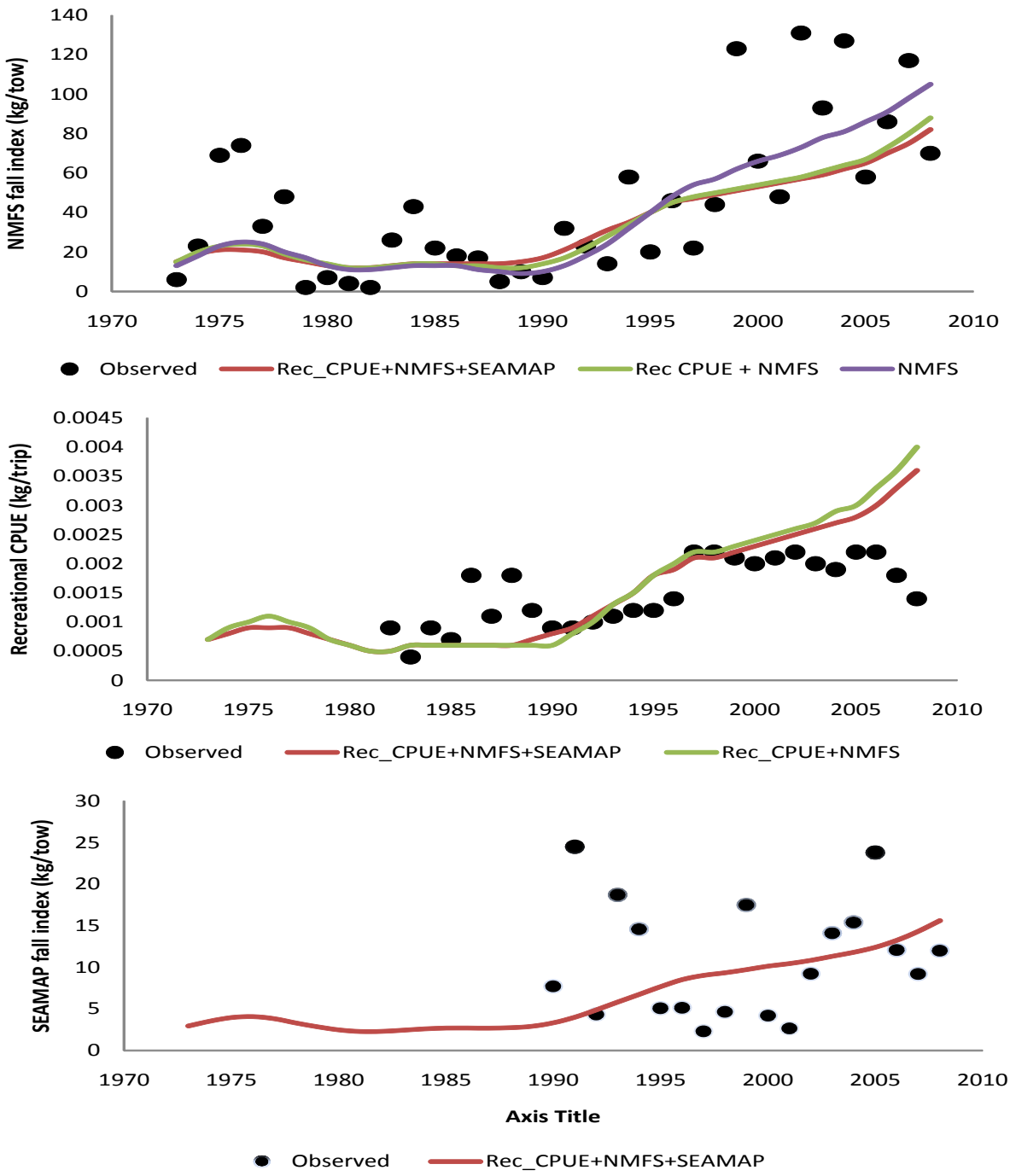


**Figure A5.1** Goodness-of-fit of ASPIC program (version 5.34) applied to Atlantic croaker total harvests from the U.S. Atlantic coast, 1973-2008. ASPIC was tuned with observed (filled circle) NMFS fall index (top), recreational CPUE (middle), and SEAMAP fall index (bottom) under different model configurations. Specifically, red, green, and blue lines represent the fitted indices when ASPIC was tuned with all the three indices, without SEAMAP fall index, and with NMFS fall index only, respectively.

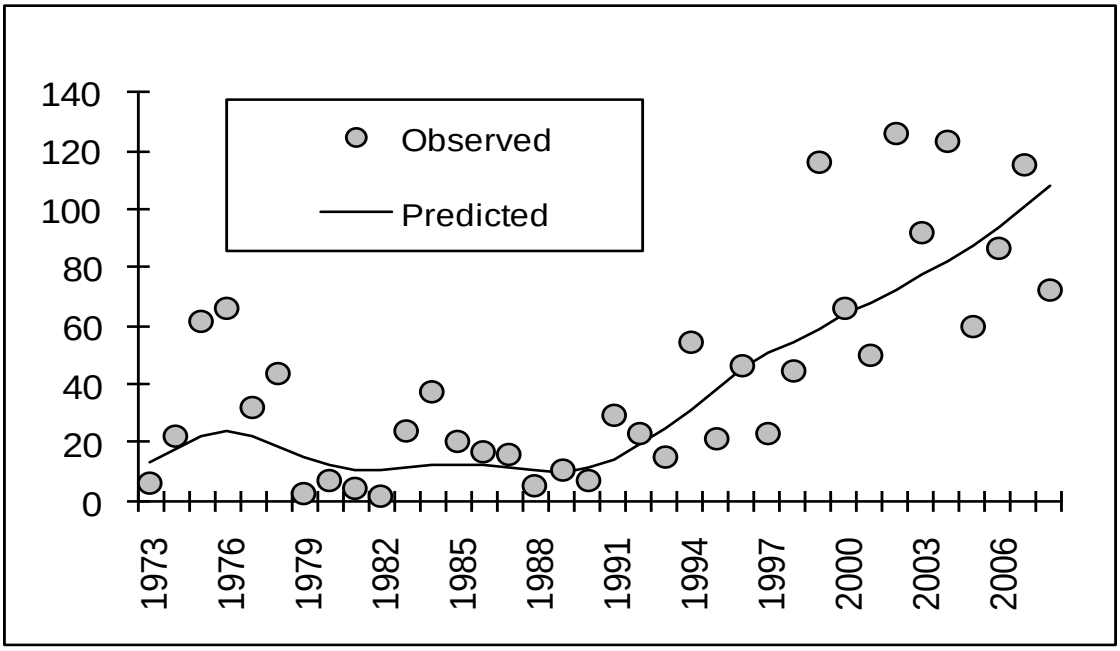


**Figure A5.2** Excel fit of the logistic production model applied to Atlantic croaker fishery data on the U.S. Atlantic coast, 1973-2008. The tuning index was NMFS fall index.

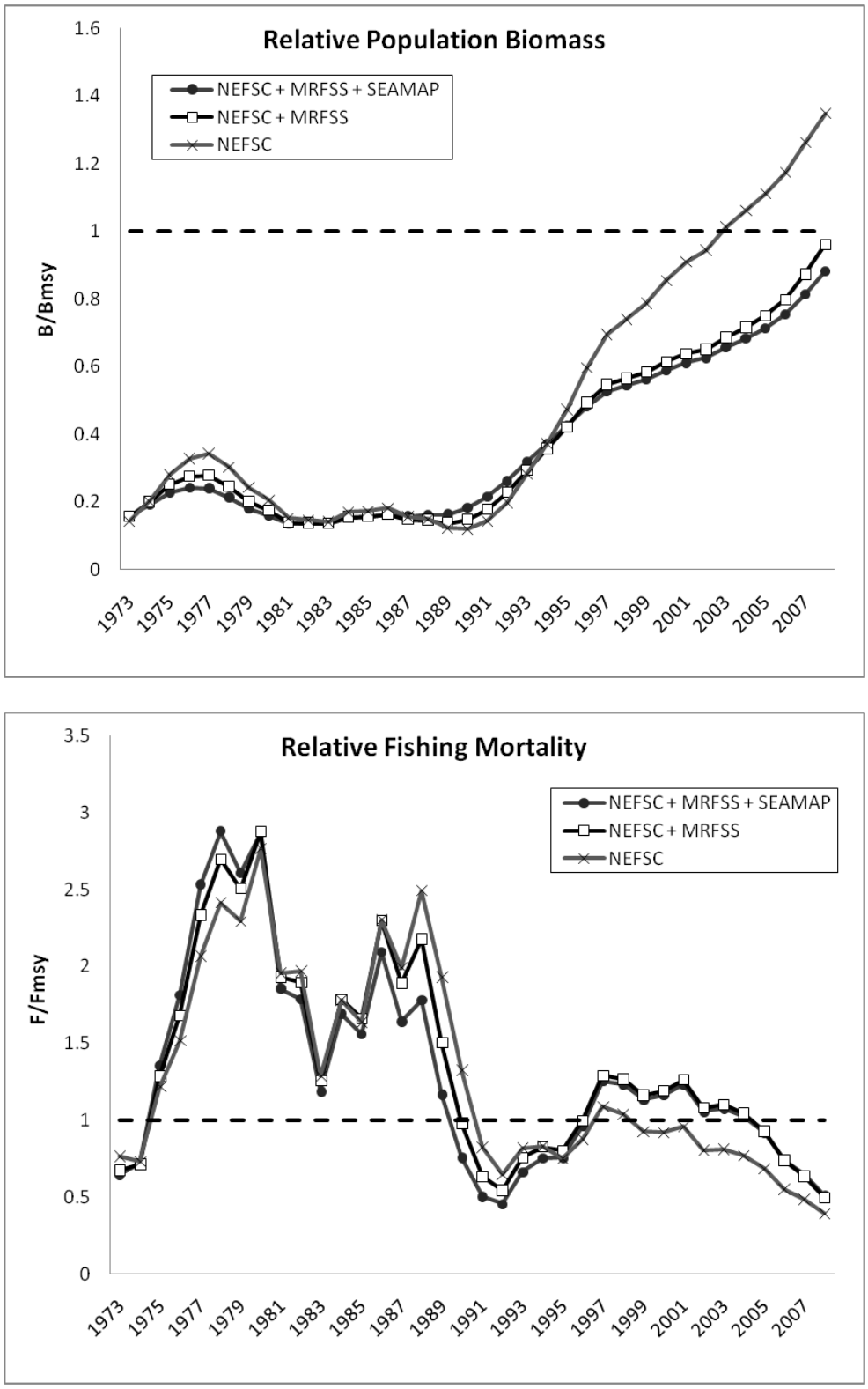


**Figure A5.3** Trajectories of biomass (top) and fishing mortality (bottom) relative to the values needed to produce MSY for Atlantic croaker stock on the U.S. Atlantic coast, estimated using ASPIC program (version 5.34) with different combinations of tuning indices.

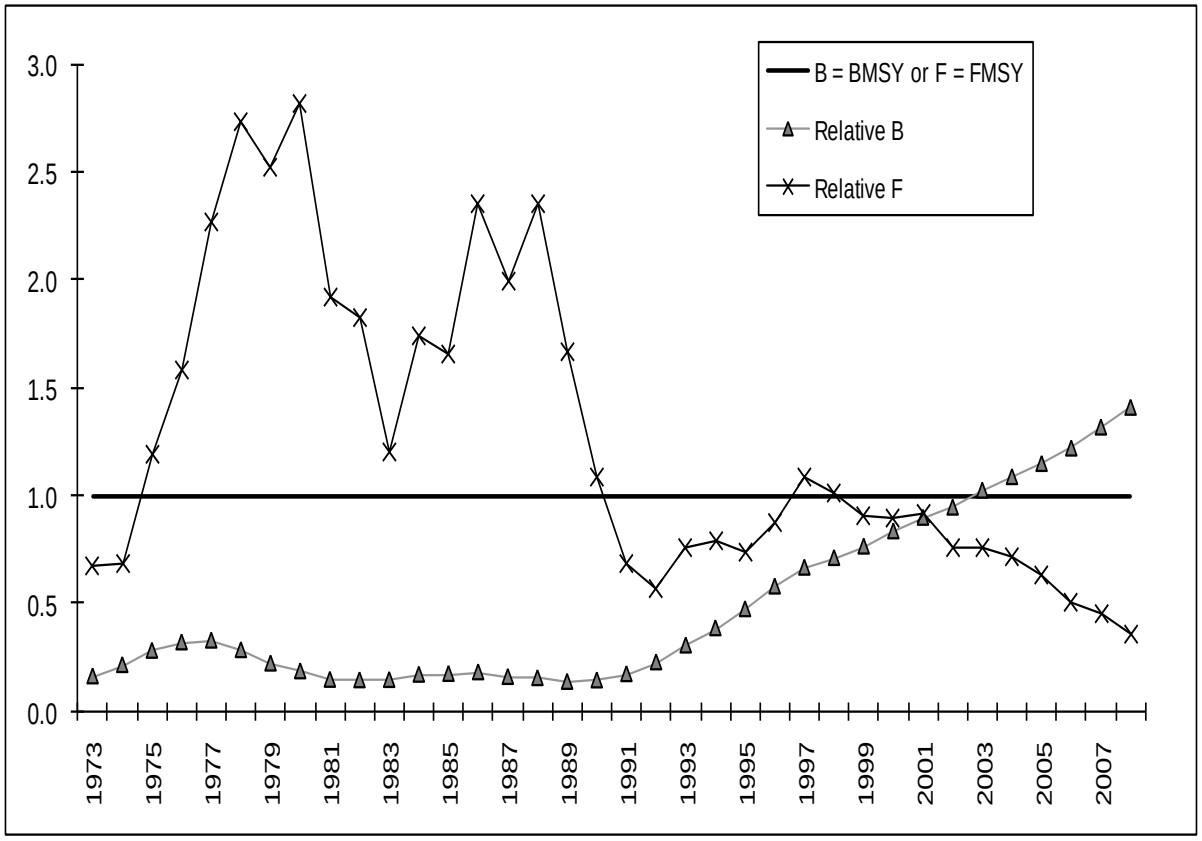


**Figure A5.4** Annual variations of the relative biomass and fishing mortality of Atlantic croaker on the U.S Atlantic coast obtained from EXCEL run of a logistic production model tuned with NMFS fall index, 1972 - 2008. The horizontal line shows the level of $B/_{BMSY} = 1$ and $F/F_{MSY} = 1$

## Appendix 6: Catch Curve Estimates of Total Mortality for Atlantic Croaker

Contributed by Harry Rickabaugh (Maryland Department of Natural Resources)
and Laura M. Lee (Virginia Marine Resources Commission)

### Methods

Linearized catch curves were used to estimate instantaneous total annual mortality rates (Z) for Atlantic croakers using otolith-based age data available from state commercial fisheries sampling programs. Observed numbers of catch-at-age were plotted on a logarithmic ($\log_e$) scale and a straight line was fit to points corresponding to the fully recruited age-classes. The instantaneous total mortality rate was estimated as the slope of the fitted line.

The catch curve analysis was applied to true cohorts. Catch curves of synthetic cohorts were considered, the synthetic cohort represents multiple year-classes observed in a single year. This approach assumes recruitment is constant across years, fishing and natural mortality rates are constant, and vulnerability to the gear is constant for fully recruited age-classes. The assumption of const recruitment is not appropriate for Atlantic croaker. Therefore, catch curves of synthetic cohorts were not produced. The assumption of constant recruitment can be avoided by applying the catch curves to individual year-classes over time (i.e., true cohorts). This approach still assumes constant mortality and equal vulnerability to the gear for fully-recruited age classes.

Catch curve estimates of total mortality were calculated for all year-classes based on true cohorts. Total mortality rates for true cohorts were estimated for cohorts that have passed completely through the survey. For cohorts in which maximum age was limited by the available years of sampling, only cohorts with data available through age nine or older (the 1999 and earlier cohorts) were used. The variances, coefficients of variation (CV), and lower and upper 95% confidence limits of the instantaneous mortality rate estimates were also computed.

Survival rates were also estimated for as $e^{-Z}$, where $Z$ is the total mortality rate estimated from the catch curve analyses. Annual survival was also estimated using Heincke's method (1913, cited in Ricker 1975) for comparison. In Heincke's method, successive ages are weighted by their abundance. This method can be useful if the ages of older fish are unreliable; as older fish tend to be less common in a sample, their numbers would be given less weight.

Random age and length data from Virginia commercial harvest sampling was used to construct an age length key for all gears combined, which was used to derive catch at age from Virginia commercial landings. North Carolina data consisted of non-random age sampling and random length sampling. A sub sample of observed fish are measured and weighed. This information is used to estimate the total number of fish in each length group by market category. The estimated length frequency distribution, for all gears combined, was applied to the non random ages to create the catch at age for this analysis. Maryland age data was also considered, but the 2002 sample was considered inadequate (66 samples and no fish less than age 3) to be used. With only 6 years of data available (2003-2008), meaningful catch curves could not be produced.

One centimeter length groups were used to construct all length and age keys. When a length group did not have an associated age frequency for a given year adjacent age frequencies were used. If two adjacent age frequencies were available they were averaged. For North Carolina data if no age frequency was available for fish in the 12 cm length group, or any smaller length groups, fish were assumed to be age 0.

**Results**

The first age at full recruitment and maximum age varied among year-classes (Figures A6.1 and A6.2). Age at full recruitment ranged from two to five years in Virginia and one to two years in North Carolina. Analysis in both states was limited by available data to the 1994-1999 cohorts. Estimates of Z from catch curve analysis ranged from 0.245 to 0.499 for Virginia (Table A6. 1) and 0.459 and 0.685 for North Carolina (Table A6. 2). The variance and coefficient of variation were high for the 1994 cohort estimate of Z in Virginia (Table A6.1). This may have been do to the age of first capture occurring at age four with no data available for age 3 or younger fish, since age samples were not available prior to the 1997 sampling year. The Z estimates by cohort for Virginia were similar for 1994-1997 cohorts and were lower for the 1998 and 1999 cohorts (Figure A6.3). North Carolina estimates of Z were similar for all cohorts, with 1994 experiencing the highest level of mortality and 1997 the lowest (Figure A6.4).

Both the Heincke's and catch curve methods of estimating Z gave similar results for Virginia with one exception: Heincke's method estimated Z at 0.32 for the 1995 cohort, while catch curve analysis estimated Z at 0.50 for the 1995 cohort (Figure A6. 5). There was more disparity in the North Carolina estimates of Z than those of Virginia, but the two methods did exhibit similar trends (Figure A6. 6).

**References**

Heincke F. 1913. Investigations on the plaice. General report I. Plaice fishery and protective measures. Preliminary brief summary of the most important points on the report. *Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer* 16. 67 p.

Ricker WE. 1975. Computations and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada No. 191. 382 p.

**Table A6. 1** Catch curve estimates of total instantaneous mortality (*Z*) based on true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program. The variance ($\sigma^2$) and coefficient of variation (CV) about each *Z* estimate are also given.

| Year-Class | *Z* | $\sigma^2$[Z] | CV[Z] |
|---|---|---|---|
| **1994** | 0.489 | 1.1248 | 2.169 |
| **1995** | 0.499 | 0.0017 | 0.083 |
| **1996** | 0.450 | 0.0042 | 0.145 |
| **1997** | 0.476 | 0.0062 | 0.165 |
| **1998** | 0.348 | 0.0018 | 0.121 |
| **1999** | 0.245 | 0.0038 | 0.252 |

**Table A6. 2** Catch curve estimates of total instantaneous mortality (*Z*) based on true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program. The variance ($\sigma^2$) and coefficient of variation (CV) about each *Z* estimate are also given.

| Year-Class | *Z* | $\sigma^2$[Z] | CV[Z] |
|---|---|---|---|
| **1994** | 0.685 | 0.0016 | 0.059 |
| **1995** | 0.606 | 0.0036 | 0.099 |
| **1996** | 0.552 | 0.0040 | 0.115 |
| **1997** | 0.459 | 0.0070 | 0.183 |
| **1998** | 0.530 | 0.0107 | 0.195 |
| **1999** | 0.559 | 0.0012 | 0.062 |

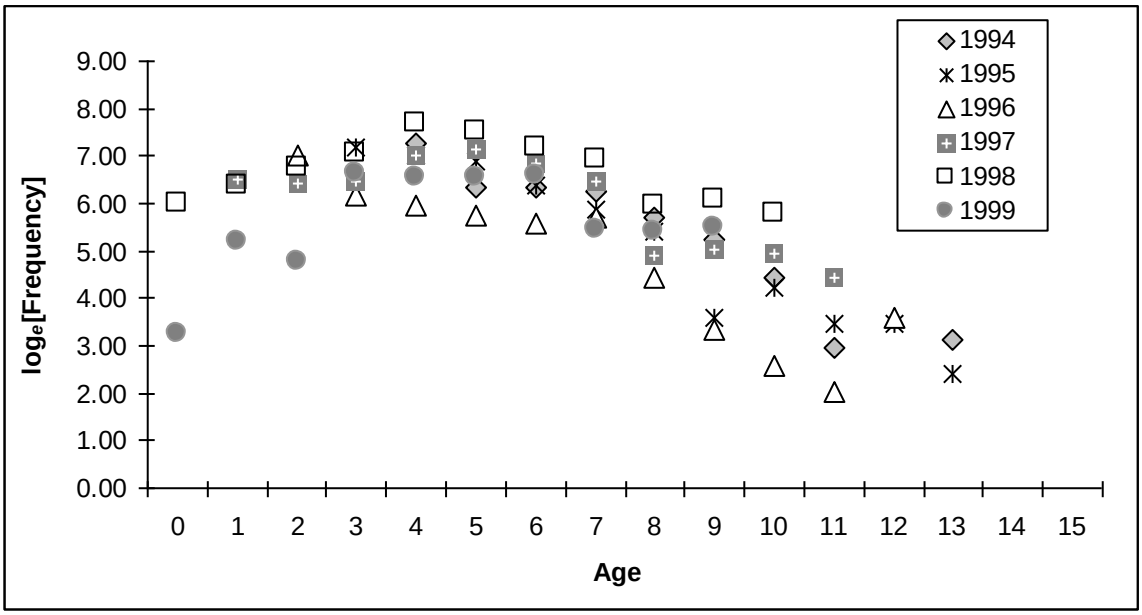


**Figure A6. 1** Catch curves used to estimate instantaneous total mortality for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program, 1994 -1999.

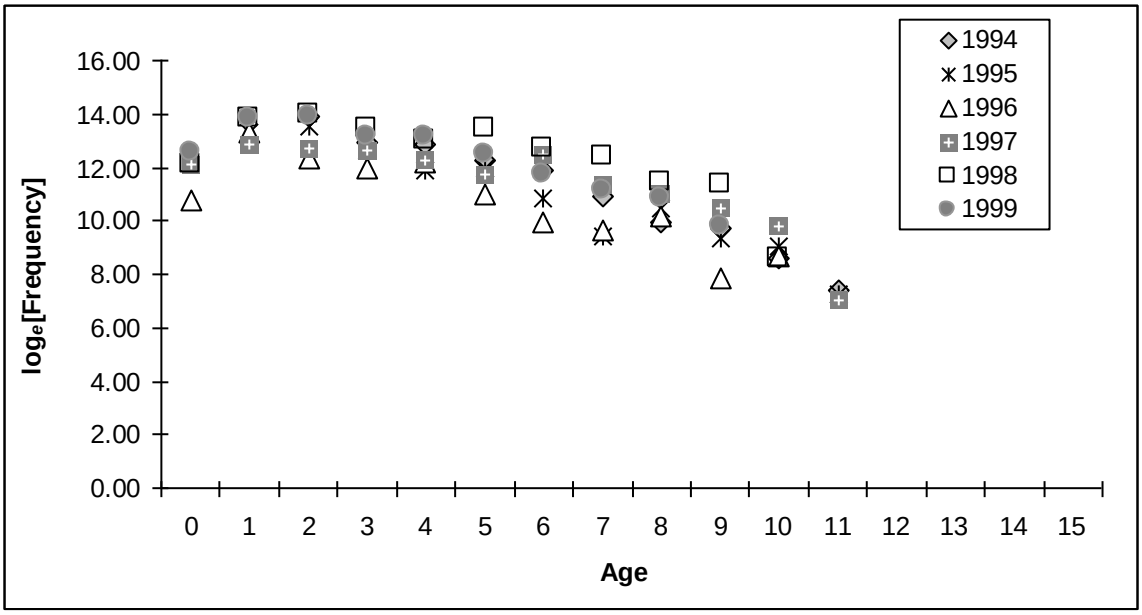


**Figure A6. 2** Catch curves used to estimate instantaneous total mortality for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program, 1994 - 1999.

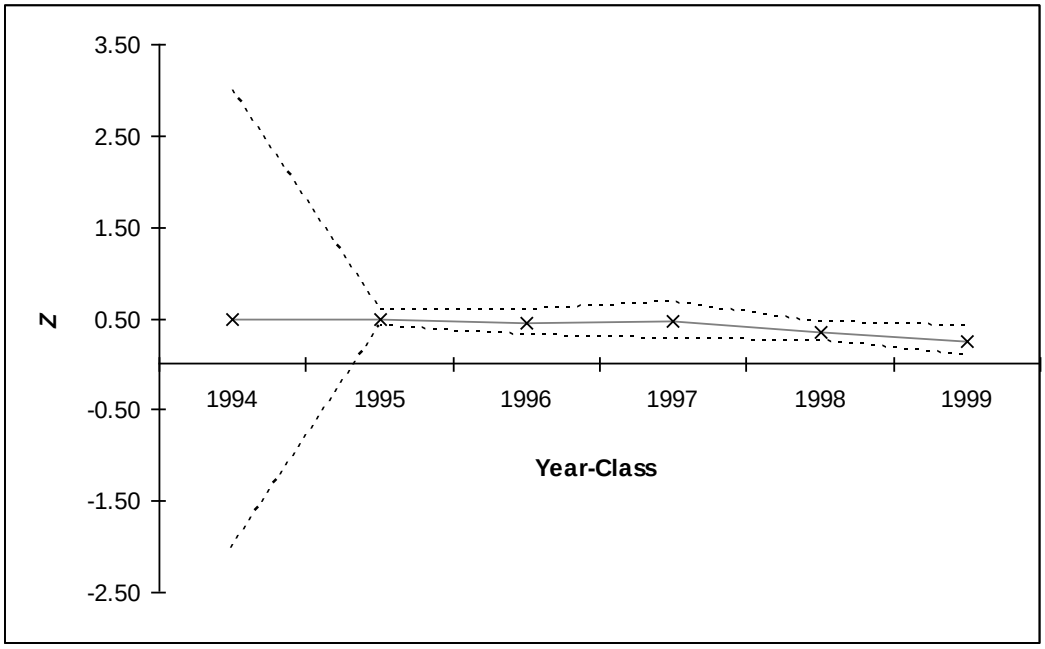


**Figure A6. 3** Catch curve estimates of instantaneous total mortality (Z) for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program. Dashed lines represent the lower and upper 95% confidence limits about the estimates.

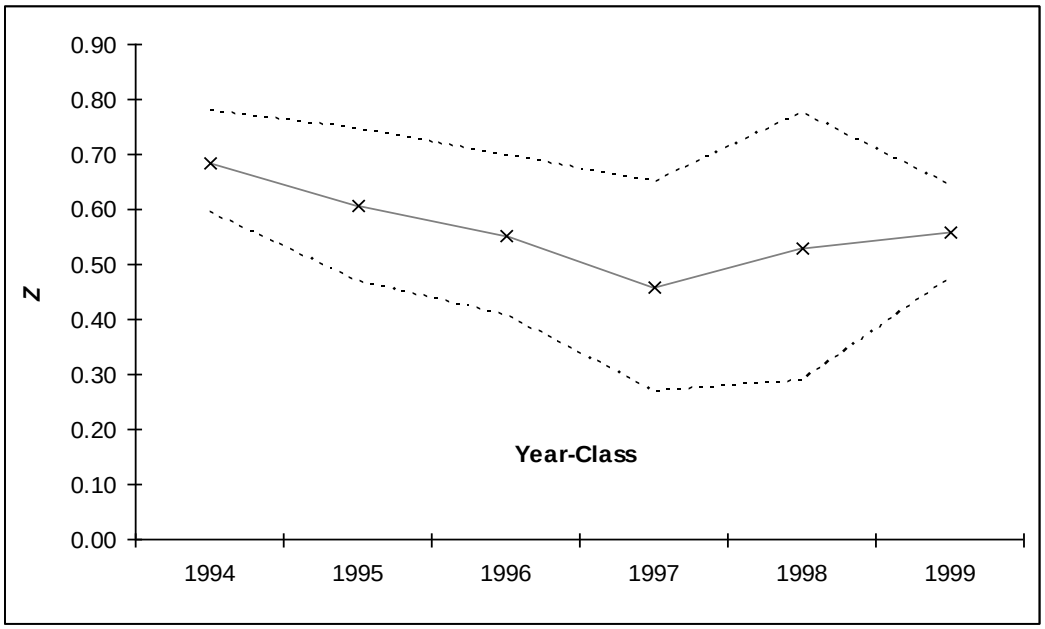


**Figure A6. 4** Catch curve estimates of instantaneous total mortality (Z) for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program. Dashed lines represent the lower and upper 95% confidence limits about the estimates.

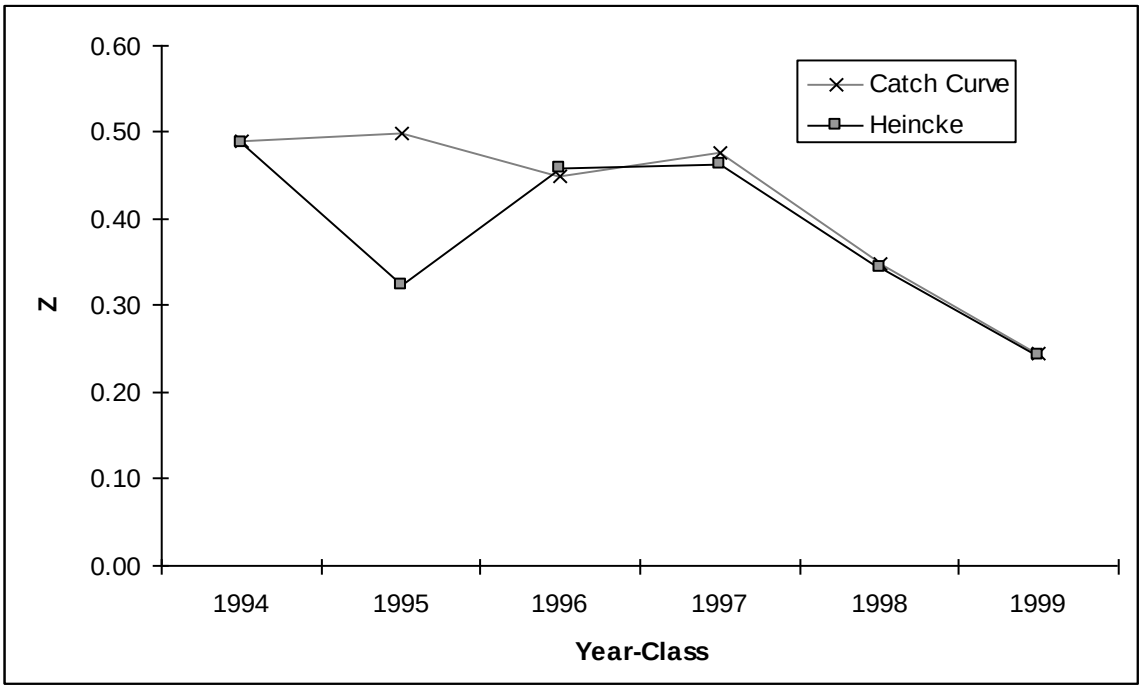


**Figure A6. 5** Comparison of instantaneous total mortality rates (Z) estimated by catch curves and Heincke's method for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program.

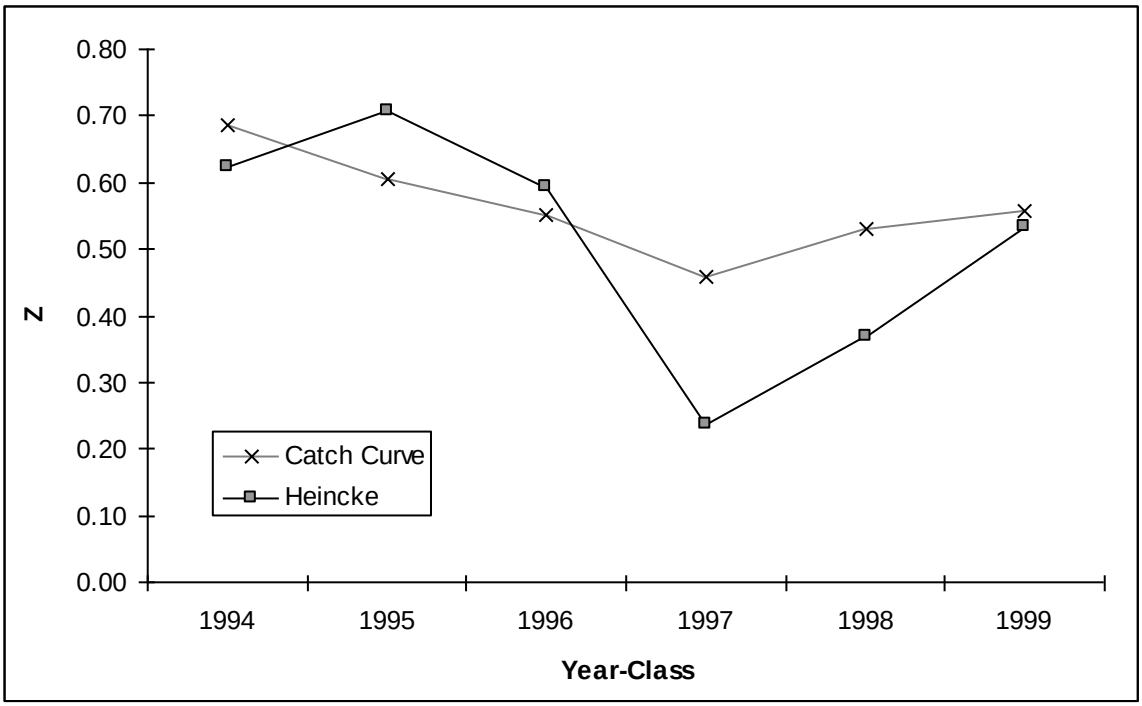


**Figure A6. 6** Comparison of instantaneous total mortality rates (Z) estimated by catch curves and Heincke's method for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program.

## Appendix 7: Stock Synthesis

Contributed by Laura M. Lee (Virginia Marine Resources Commission)

The data available for Atlantic croaker include catch, indices, age and length compositions, and information that can be used to characterize life history parameters. The Stock Synthesis (SS) model is a flexible model that was designed to incorporate a variety of data from fisheries-dependent and fisheries-independent sources. The SS model was considered because it could make full use of all available data with little preprocessing of the data required. Also, the SS model was used in the coast-wide assessment of Atlantic croaker performed by Lee (2005).

The assessment by Lee (2005) used version 1 of the SS modeling program. The model has since undergone a number of updates, most notably the conversion of the code from FORTRAN to C++ within the AD Model Builder (ADMB) environment. The current text version, version 3.04b, was applied in the current assessment (Methot 2009; NFT 2009).

The model utilized available data from 1981 through 2008. The stock was assumed to include Atlantic croaker occurring from New Jersey to Florida. The SS model was set up to accommodate four commercial gears—gill net, pound net, seine, and trawl—and a recreational fishery. A fisheries-dependent index of recreational harvest-per-unit-effort was developed from the MRFSS data. Data collected from the NMFS Bottom Trawl Survey and SEAMAP-SA Coastal Survey were used to compute fisheries-independent indices of relative abundance. Survey indices based on the spring component of the VIMS Juvenile Fish and Blue Crab Trawl Survey and the June component of the North Carolina Pamlico Sound Survey were used as indices of relative recruitment. Age and length composition data from the fisheries and surveys were also used. Natural mortality was assumed to be age-specific and time-invariant. The Lorenzen-based M estimates (pooled over sources and sexes; Table 2.5.2.2) were entered as the assumed values for age-specific natural mortality (see Section 2.5.2).

The SAS consulted with the developer of Stock Synthesis, Dr. Richard Methot, who kindly reviewed the input files and provided advice and guidance throughout the modeling process. Initial runs of the model failed to converge or produced unrealistic parameter estimates. A number of alternative model configurations were attempted with little improvement. As time became a limiting factor, the working group decided to abandon the SS model and pursue other approaches. The working group recommends that the SS model be considered in the future when more time can be devoted to development of the model.

### References

Lee, L.M. 2005. Population dynamics of Atlantic croaker occurring along the U.S. east coast, 1981-2002. M.S. Thesis. North Carolina State University, Raleigh, NC. 109 p.

Methot, R.D., Jr. 2009. User manual for Stock Synthesis: model version 3.04b. Updated Sept 29, 2009. NOAA Fisheries, Seattle, WA. 159 p.

NFT (NOAA Fisheries Toolbox). 2009. Stock Synthesis 3 Text Version, Version 3.04b. Available: http://nft.nefsc.noaa.gov (October 2009).

## Appendix 8: Sensitivity Runs of the Hybrid Model

Contributed by Laura M. Lee (Virginia Marine Resources Commission)
and Katie Drew (Atlantic States Marine Fisheries Commission)

The SAS identified several model inputs with assumptions or uncertainties that had the potential to affect the model results. The effects of these inputs were tested with a series of sensitivity runs. The inputs tested included:

- Natural mortality
- Steepness
- Weighting of inputs
- Inclusion of scale-derived catch-at-age
- Inclusion of shrimp trawl bycatch estimates
- Selectivity patterns
- Retrospective bias

### Natural Mortality

The base model used the Lorenzen method to calculate age-specific natural mortality (M). The model was also run with a constant, fixed M of 0.3 (the value used in the last assessment) and a fixed M of 0.5. A run was also done where an age-constant M was estimated by the model.

The model estimated an M of 0.62. This M and the M of 0.5 produced estimates of fully-recruited F that showed similar patterns to the base model and the M of 0.3, but were several orders of magnitude smaller (Figure A8. 1). Estimates of biomass were also higher under higher levels of natural mortality (M=0.62 estimated, M=0.5 fixed), both in absolute size and relative to MSY (Figure A8. 2).

### Steepness

Steepness (h) is a parameter in the stock-recruitment relationship that describes the proportion of unexploited recruitment the population produces at 20% of the unexploited spawning stock size. In the base model, h was fixed at 0.76, the same value used in the last assessment and based on Myers *et al.*'s (2002) review of observed stock-recruitment relationships.

To examine the effects of the steepness assumption on the model results, the model was rerun with different fixed values of h ranging from 0.6 to 0.9. In addition, the base model was also allowed to estimate h.

The model estimated a value of 0.736 for h, similar to the base value of 0.76. However, the likelihood profile was rather broad over the limits placed on h (0.6 to 0.9), indicating the parameter was not well fit (Figure A8. 3). When other sensitivity runs were allowed to fit h, the estimate often went to the bounds. Because of these results, steepness was fixed in all other runs at 0.76.

Steepness did not have a large effect on the estimates of spawning stock biomass over time or annual average fishing mortality rates (Figure A8. 4). It did affect the model's estimates of the

biological reference points $SSB_{MSY}$ and $F_{MSY}$, with lower values of steepness resulting in higher values of $SSB_{MSY}$ and lower values of $F_{MSY}$. This is not surprising, since steepness is a measure of the resiliency of the stock. In all cases, $SSB_{2008}$ was above $SSB_{MSY}$ and $F_{2008}$ was above $F_{MSY}$ (Figure A8.5).

**Weighting of inputs**

In the base model, the fishery-independent and fishery-dependent inputs were weighted equally ($\lambda = 1$) but had different annual CVs. In the case of the tuning indices and the recreational harvest, these CVs were estimated from the data. In the case of the commercial landings, the CVs were assumed to be equal to 0.1 from 1981-1993 and equal to 0.05 from 1994 onwards. The higher CVs in the early years represent the time period of dealer reporting, which the SAS considered less reliable than the trip-ticket systems of fishermen reporting implemented in the major croaker landing states by 1994. The scrap and discard time series was considered less precisely estimated than the commercial landings, and so had a CV of twice the commercial landings. The TC was concerned about differences in the magnitudes of the CVs between data series, particularly between the fishery dependent (which, with the exception of the recreational harvest and release CVs, were assumed) and the fishery independent (which, with the exception of the VIMS survey, were empirically estimated) data sets. A series of sensitivity runs were carried out with different sets of CVs and equal weights to look at the effects of the CVs on the results. These runs included using the commercial CVs for all data sets, using the recreational harvest CVs for all data sets, and using the commercial CVs for the catch data sets and the NEFSC trawl survey CVs

For the sensitivity runs, the effects of dropping individual indices from the fit were examined, as was the effect of increasing the weights of the different data sources, based on the TC members expert opinion, both as individuals and using the mean and median of suggested values as consensus opinions. Additionally, the effects of assumptions about the CV of the early time series were also considered, by running the model with a range of higher and lower values for those years.

The inputs that most affected the results of the model were the catch-at-age information and the recreational CPUE (Figure A8. 6, Figure A8. 7.). When the catch-at-age was down-weighted, the estimated population biomass was much higher and the estimated fishing mortality was much lower, both in absolute numbers and relative to MSY, than in the base case. When the recreational CPUE was down-weighted, the population trend changed from fairly steady levels in recent years to a strongly increasing trend from an overfished state in the 1980s and early 1990s to a stock well above $SSB_{MSY}$ in the last decade. Meanwhile, fishing mortality showed a complementary trend of decreasing from overfishing in the 1980s to an F below $F_{MSY}$ in more recent years. The MRFSS index itself does not show a strong trend over most of the time series, and when included balances out the increasing trends in landings and fishery-independent indices.

Increasing the CV in the early years of the fishery for the commercial and scrap/discard fleets did not have a large impact on the estimates of fishing mortality in more recent years, although some spikes were seen in early years (Figure A8. 9.8). Spawning stock biomass relative to $SSB_{MSY}$ was lower in runs with a higher CV in the early period (Figure A8. 10).

**Inclusion of scale-derived catch-at-age**

From 1988 to 1995, NC regularly collected scales to age croaker. A scale-otolith transition matrix was used to convert scale age-length keys to otolith age-length key. These catch-at-age data were not included in the base run, but were included as a sensitivity run.

When the catch-at-age from 1988 to were included, estimates of biomass were lower, both in absolute numbers and relative to $SSB_{MSY}$ over the entire time series, declining in recent years below $SSB_{MSY}$ (Figure A8.11). Fishing mortality estimates in recent years were very similar between the two runs, both in absolute numbers and relative to $F_{MSY}$ (Figure A8.11) . However, fishing mortality estimates were much higher in the early years of the time series when the converted scale ages were included.

**Inclusion of shrimp trawl bycatch data**

Age-0 croaker are often caught in shrimp trawls as bycatch; however, there are very few data series to with which to precisely and accurately quantify these catches. The working group did not feel the estimates developed at the Assessment Workshop (see Appendix) were appropriate to include in the base model due to their high degree of uncertainty. Instead, the estimated shrimp trawl landings were included as a sensitivity run.

Including the shrimp bycatch increased estimates of population biomass and fishing mortality, but decreased estimates of SSB relative to $SSB_{MSY}$ (Figure A8. 12). SSB shows an increasing trend, but remains below $SSB_{MSY}$. Although estimates of F with and without the bycatch were similar in recent years, the early years of the time series with shrimp bycatch showed much higher fishing mortality, well above $F_{MSY}$ in some years. F decreased in the mid- to late 1990s, possibly correlating with the introduction of mandatory turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) on shrimp trawls.

**Selectivity Patterns**

A run of the model was allowed to estimate the selectivity patterns for the fleets and the three surveys that targeted age-0+ fish (the recreational CPUE, the NEFSC Trawl Survey, and the SEAMAP Fall Survey). The young-of-year surveys (VIMS, NC P195) were assumed to only select age-0 fish. The model had difficulty fitting the recreational CPUE index independently, most likely due to the short time series of catch-at-age data, so the selectivity of the recreational index at age was fixed to either the selectivity of the recreational harvest or recreational release fleets at that age, whichever was greater. The model estimates were then fixed and used as input data for the base and other model runs.

The model-estimated selectivity patterns were compared to the selectivity patterns used in the 2003 assessment (estimated from an untuned VPA) and alternative method of estimating selectivity from catch-curves. The catch-curve method was based on Restrepo et al. (2007) and used a Z estimated from the descending limb of a catch curve of a fishery where the selectivity was assumed to be asymptotic to predict the catch at non-fully selected ages. The ratio of observed to predicted catches provided an estimate of selectivity that was smoothed with a logistic or double logistic curve.

Estimates of annual average fishing mortality in absolute numbers were similar across all selectivity patterns, but differences in selectivity patterns affected both the reference point estimates and population estimates (Figure A8.13).

**Retrospective analysis**

Age-structured models can sometimes show a retrospective bias, where adding years of data to the end of a time series changes estimates of stock status in earlier years. To check for this pattern, the model was rerun a total of 6 times, each time removing one more year of data from the time series.

There did appear to be a retrospective pattern, with increasing years of data increasing the estimates of biomass and decreasing the estimates of F (Figure A8.14).

**References**

Restrepo, V., J. Ortiz de Urbina, J.M. Fromentin, and H. Arrizabalaga. 2007. Estimates of selectivity for eastern Atlantic bluefin tuna from catch curves. Col. Vol. Sci. Pap. ICCAT, 60(3): 937-948.

**Table A8. 1** Lambda values of different data sources for input weighting sensitivity runs.

| Data Source | 10-5-1 Weights | 3-2-1 Weights | 4-2-1 Weights | TC Mean Weights | TC Median Weights |
|---|---|---|---|---|---|
| Commercial Landings | 10 | 3 | 2 | 2 | 2 |
| Scrap/Discard Landings | 1 | 1 | 1 | 0.875 | 1 |
| Recreational Harvest | 5 | 2 | 2 | 1.5 | 1.5 |
| Recreational Release Mortality | 1 | 1 | 1 | 0.875 | 1 |
| Recreational CPUE | 10 | 3 | 1 | 1.375 | 1 |
| NEFSC Trawl Survey | 10 | 3 | 4 | 2.75 | 2.5 |
| SEAMAP Fall Trawl Survey | 1 | 1 | 2 | 1.5 | 1.5 |
| VIMS YOY Survey | 5 | 2 | 3 | 2 | 2 |
| NC P195 YOY Survey | 1 | 1 | 3 | 1.75 | 1.5 |
| Total CAA | 5 | 2 | 2 | 1.5 | 1.5 |
| Recruitment Deviations | 5 | 2 | 1 | 1.125 | 1 |

**Table A8.2** Selectivity patterns used in sensitivity runs. See Table 6.2.1.1.2 for the continuity run selectivities also included here.

**Base Model (Estimated)**

| Age | Comm | Comm Scrap/Bait | Rec_Harv | Rec_Dead_B2 | MRFSS | NMFS | SEAMAP | VIMS/ NC195 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.045 | 0.28 | 0.048 | 0.52 | 0.048 | 0.81 | 1 | 1 |
| 1 | 0.12 | 1 | 0.12 | 1 | 0.12 | 1 | 0.33 | 0 |
| 2 | 0.24 | 0.61 | 0.24 | 0.45 | 0.24 | 0.89 | 0.07 | 0 |
| 3 | 0.4 | 0.35 | 0.4 | 0.2 | 0.4 | 0.61 | 0.01 | 0 |
| 4 | 0.58 | 0.2 | 0.56 | 0.09 | 0.56 | 0.36 | 0 | 0 |
| 5 | 0.73 | 0.11 | 0.71 | 0.04 | 0.71 | 0.2 | 0 | 0 |
| 6 | 0.85 | 0.06 | 0.83 | 0.02 | 0.83 | 0.11 | 0 | 0 |
| 7 | 0.92 | 0.03 | 0.9 | 0 | 0.9 | 0.06 | 0 | 0 |
| 8 | 0.96 | 0 | 0.95 | 0 | 0.95 | 0.03 | 0 | 0 |
| 9 | 0.98 | 0 | 0.97 | 0 | 0.97 | 0.02 | 0 | 0 |
| 10 | 0.99 | 0 | 0.98 | 0 | 0.98 | 0.01 | 0 | 0 |
| 11 | 0.99 | 0 | 0.99 | 0 | 0.99 | 0.01 | 0 | 0 |
| 12 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 13 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 14 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 15 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

**Catch-curve based method**

| Age | Comm | Comm Scrap/Bait | Rec_Harv | Rec_Dead_B2 | MRFSS | NMFS | SEAMAP | VIMS/ NC195 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.51 | 0.7 | 0.17 | 0.59 | 0.17 | 0.76 | 1 | 1 |
| 1 | 1 | 1 | 0.96 | 1 | 0.96 | 0.97 | 0.34 | 0 |
| 2 | 1 | 0.48 | 1 | 0.43 | 1 | 1 | 0.06 | 0 |
| 3 | 1 | 0.16 | 1 | 0.28 | 1 | 0.67 | 0.02 | 0 |
| 4 | 1 | 0.06 | 1 | 0.06 | 1 | 0.46 | 0.01 | 0 |
| 5 | 1 | 0.03 | 1 | 0.01 | 1 | 0.29 | 0 | 0 |
| 6 | 1 | 0.02 | 1 | 0 | 1 | 0.21 | 0 | 0 |
| 7 | 1 | 0.01 | 1 | 0 | 1 | 0.11 | 0 | 0 |
| 8 | 1 | 0 | 1 | 0 | 1 | 0.03 | 0 | 0 |
| 9 | 1 | 0 | 1 | 0 | 1 | 0.02 | 0 | 0 |
| 10 | 1 | 0 | 1 | 0 | 1 | 0.01 | 0 | 0 |
| 11 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 12 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 13 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 14 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 15 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

| Continuity Run | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Age** | **Commercial** | **Scrap/Discard** | **Rec Harvest** | **Rec CPUE** | **NEFSC** | **SEAMAP** | **VIMS** |
| **0** | 0.036 | 0.083 | 0.286 | 0.08 | 0.79 | 1 | 1 |
| **1** | 0.383 | 0.737 | 1 | 0.74 | 1 | 0.4 | 0 |
| **2** | 0.606 | 0.863 | 0.508 | 0.86 | 0.4 | 0 | 0 |
| **3** | 0.809 | 0.972 | 0.209 | 0.97 | 0.34 | 0 | 0 |
| **4** | 1 | 1 | 0.082 | 1 | 0.11 | 0 | 0 |
| **5** | 1 | 1 | 0.01 | 1 | 0.12 | 0 | 0 |
| **6** | 1 | 1 | 0.015 | 1 | 0 | 0 | 0 |
| **7** | 1 | 1 | 0.01 | 1 | 0 | 0 | 0 |
| **8** | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **9** | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **10+** | 1 | 1 | 0 | 1 | 0 | 0 | 0 |

**Table A8. 3** Biological reference points as a function of steepness (h).

| h | $SSB_{MSY}$ | $F_{MSY}$ |
|---|---|---|
| 0.6 | 37,673 | 0.339 |
| 0.65 | 32,903 | 0.373 |
| 0.7 | 29,424 | 0.409 |
| 0.76 (base) | 26,268 | 0.455 |
| 0.8 | 24,569 | 0.487 |
| 0.85 | 22,760 | 0.530 |
| 0.9 | 23,437 | 0.577 |

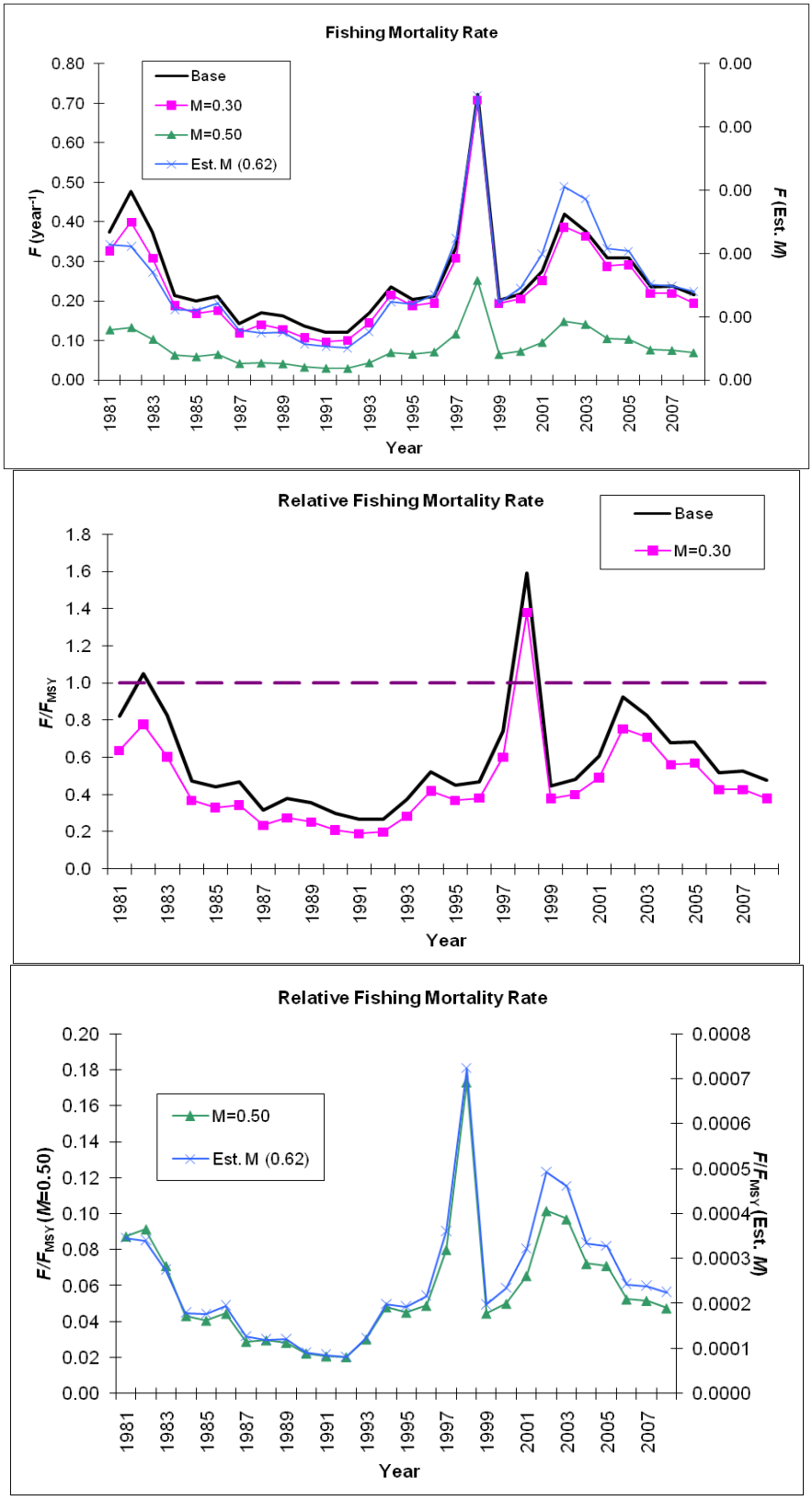


**Figure A8. 1** Average fishing mortality under different natural mortality assumptions.

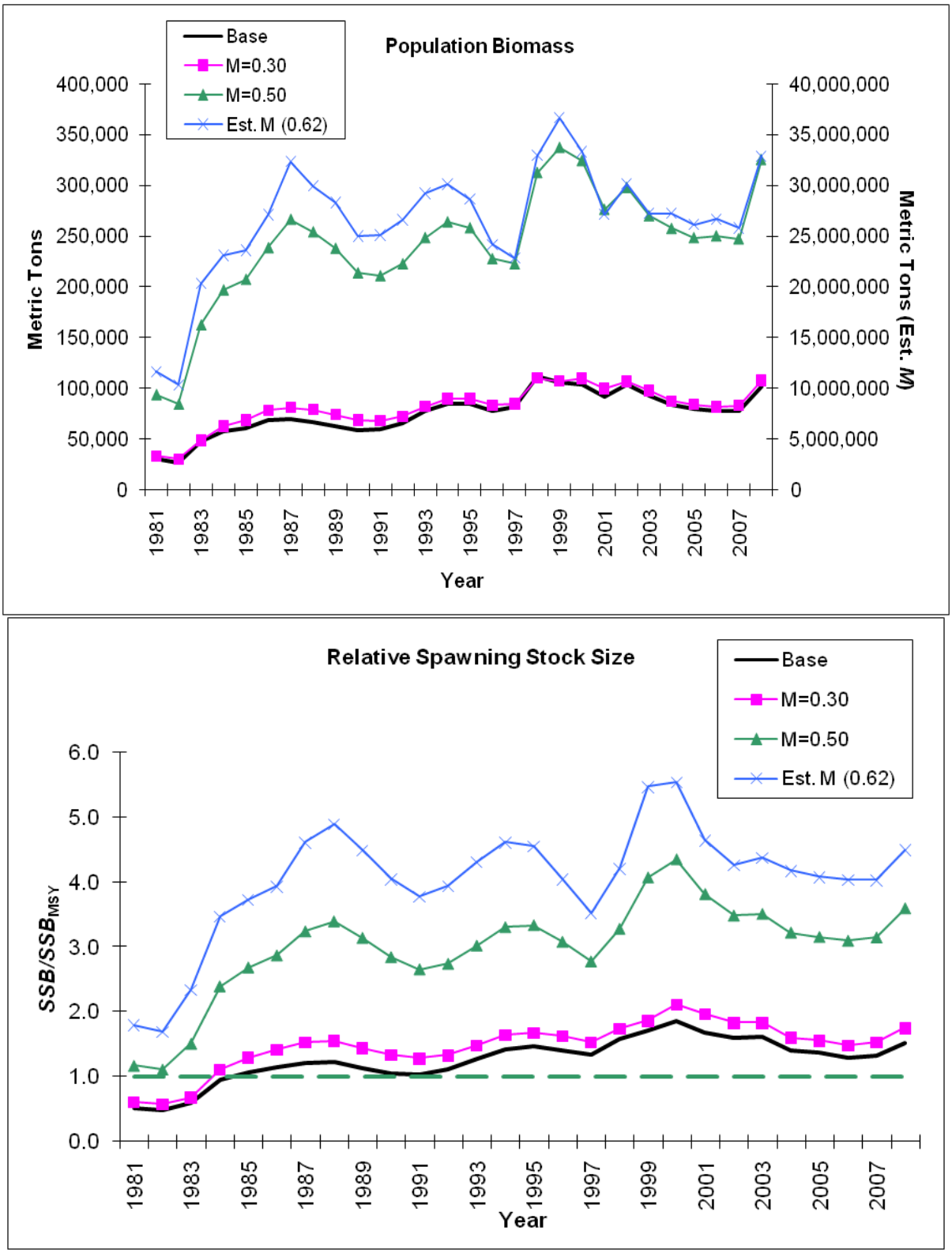


**Figure A8. 2** Population biomass under different natural mortality assumptions.

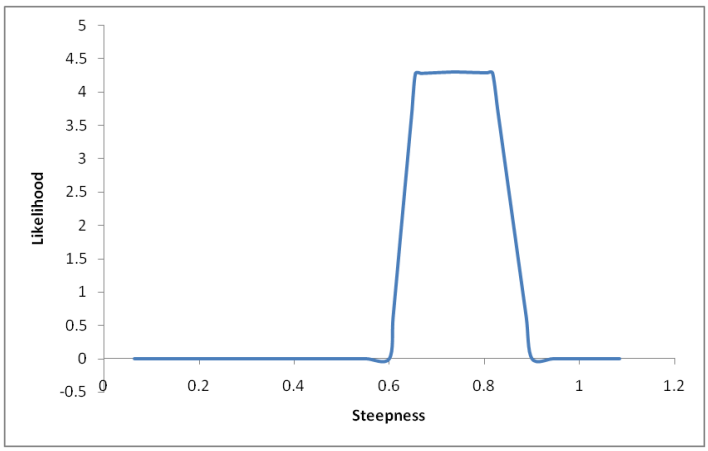


**Figure A8. 3** Likelihood profile of steepness parameter estimated by model.

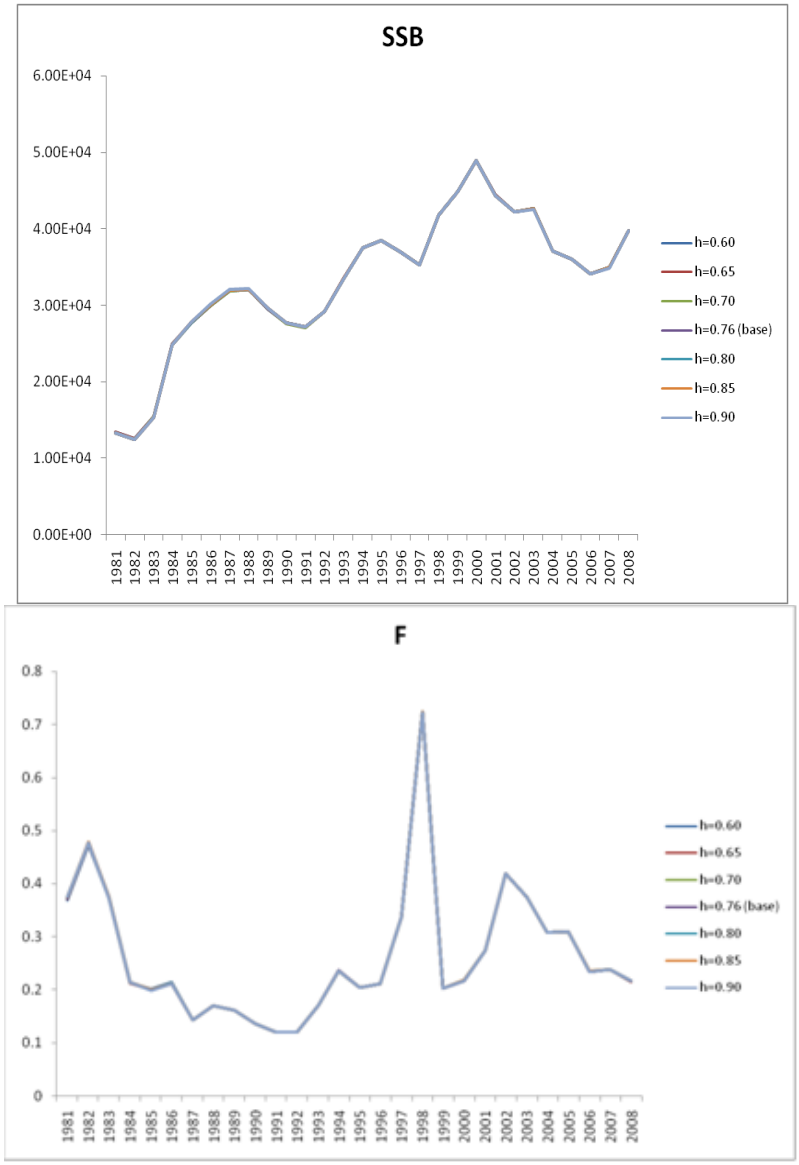


**Figure A8. 4** Spawning stock biomass and average fishing mortality for different values of steepness (h).

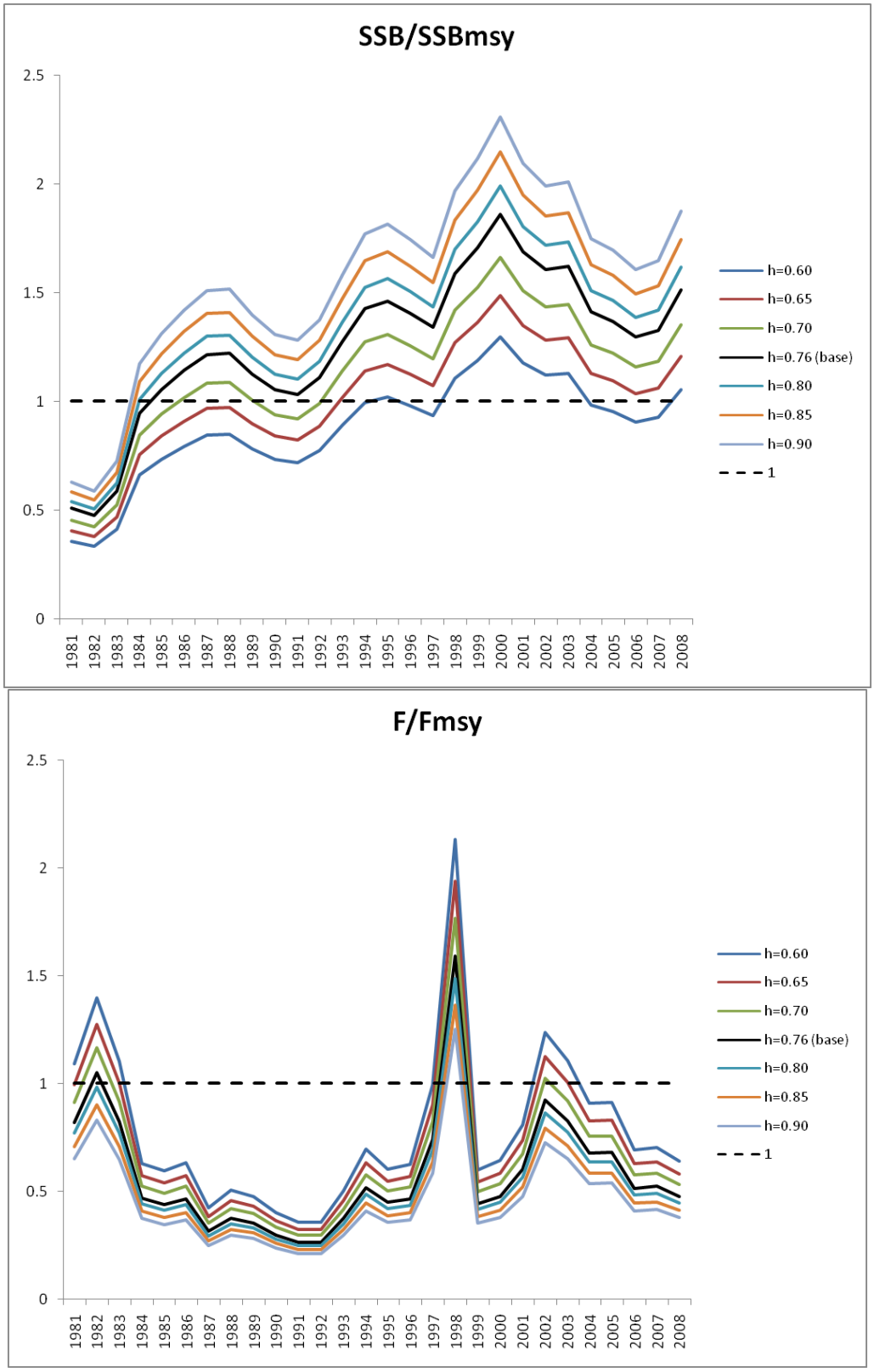


**Figure A8. 5** Relative stock status for different values of steepness.

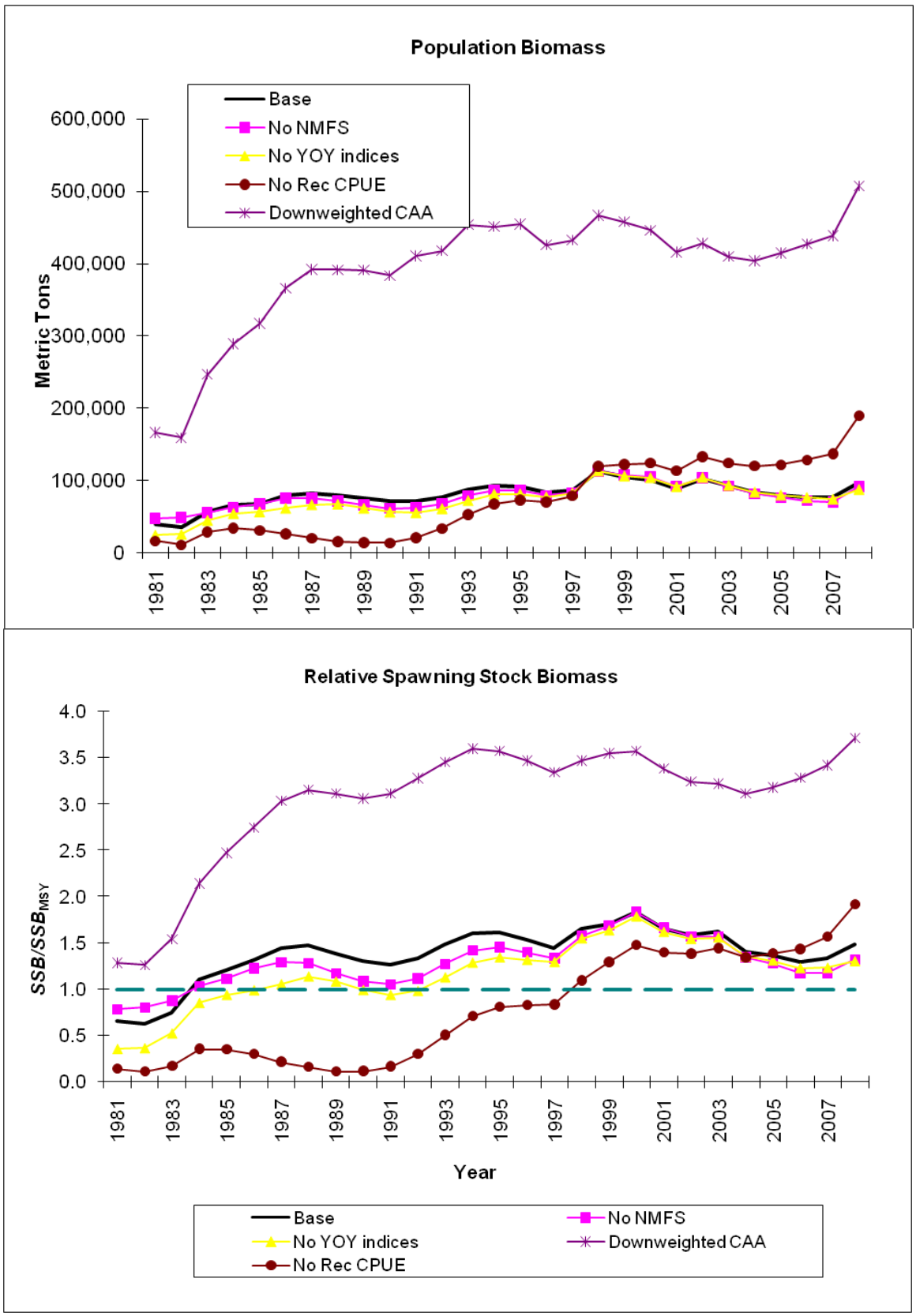


**Figure A8. 6** Population biomass and relative SSB as a function of omitted or reweighted model inputs.

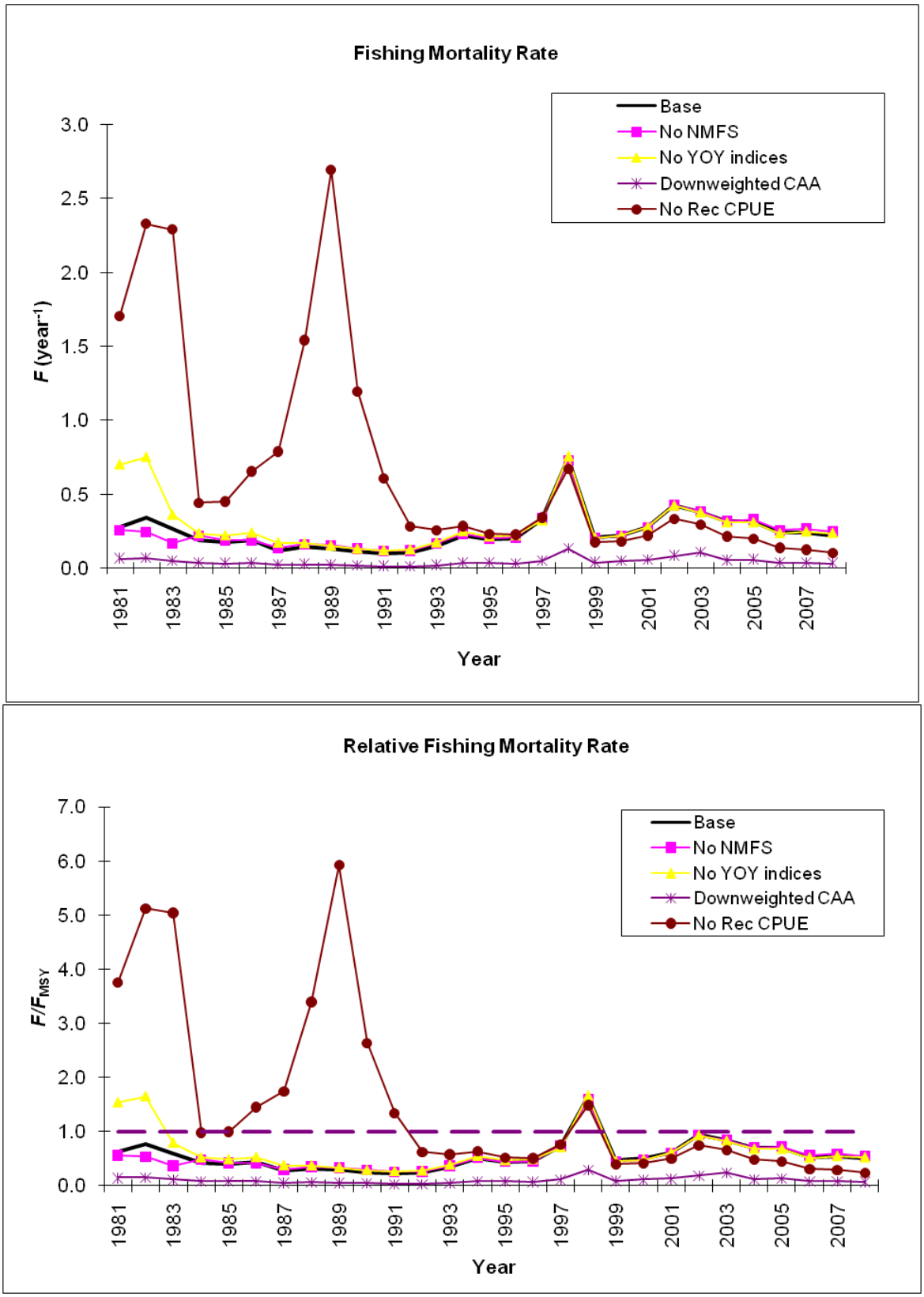


**Figure A8. 7** Fishing mortality as a function of omitted or reweighted model inputs.

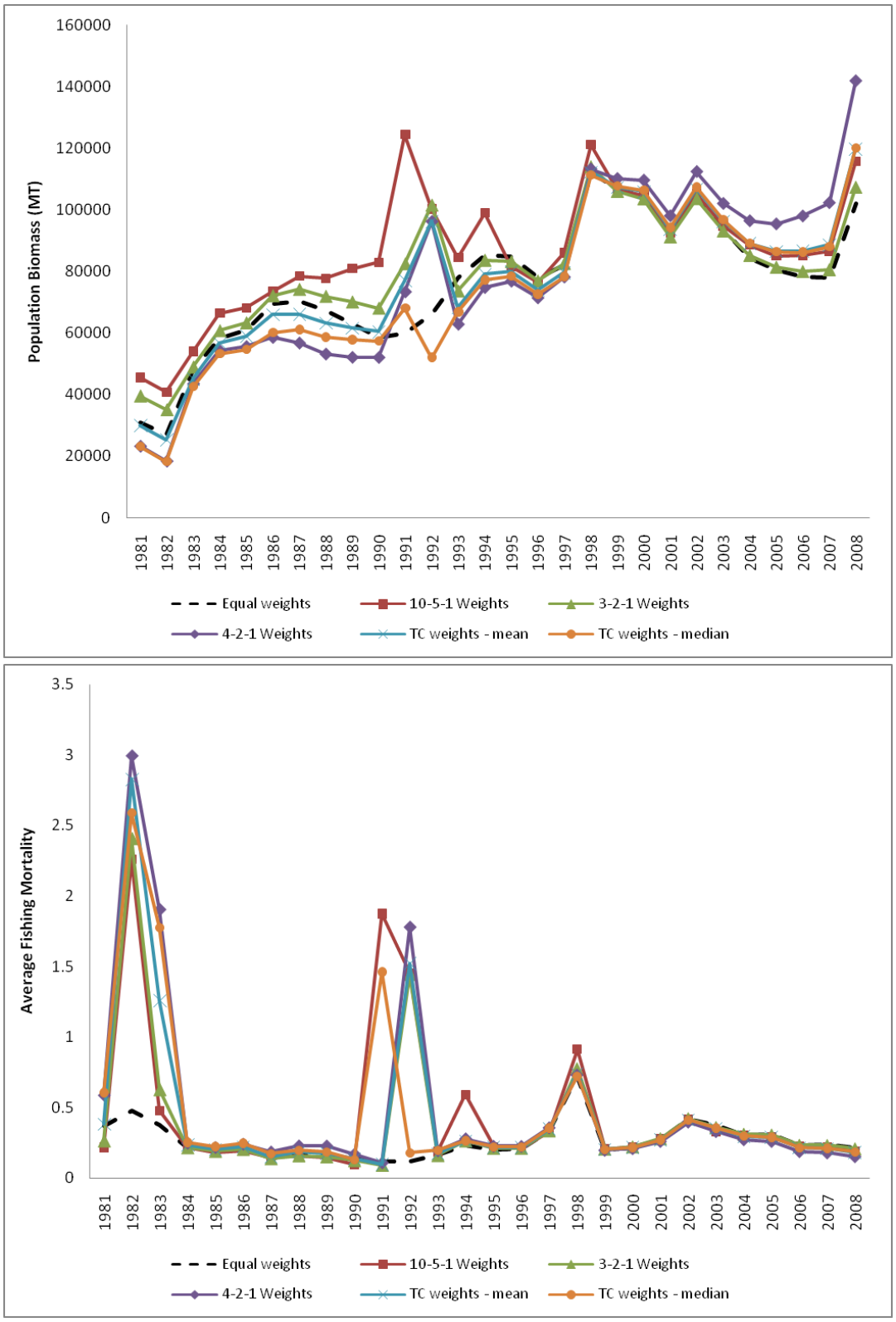


**Figure A8. 8** Population biomass (top) and fishing mortality (bottom) estimates under different input data weighting schemes (see Table A8.1 for weights).

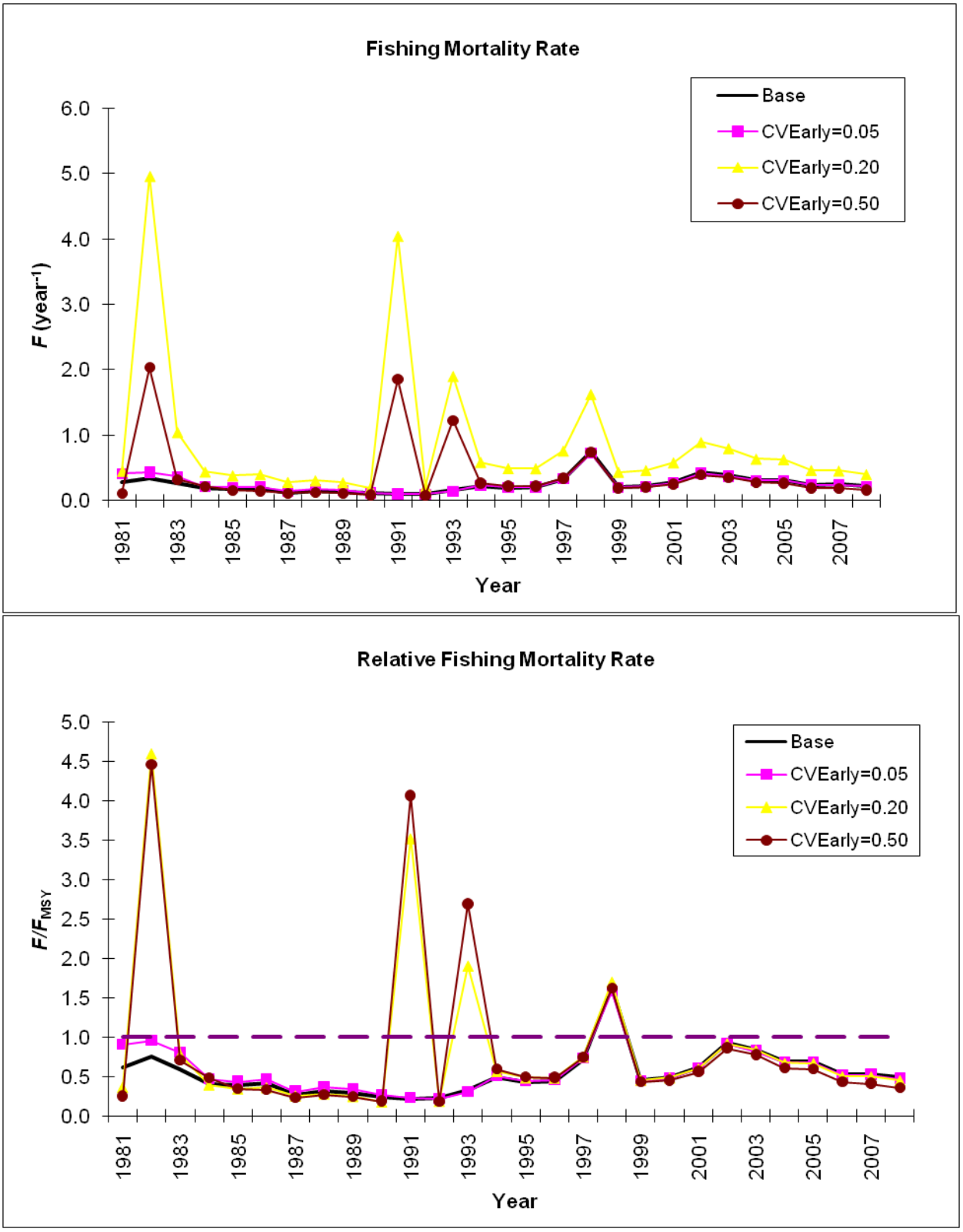


**Figure A8. 9** Fishing mortality rates as a function of the assumed CV in the early (1981-1993) part of the time series.

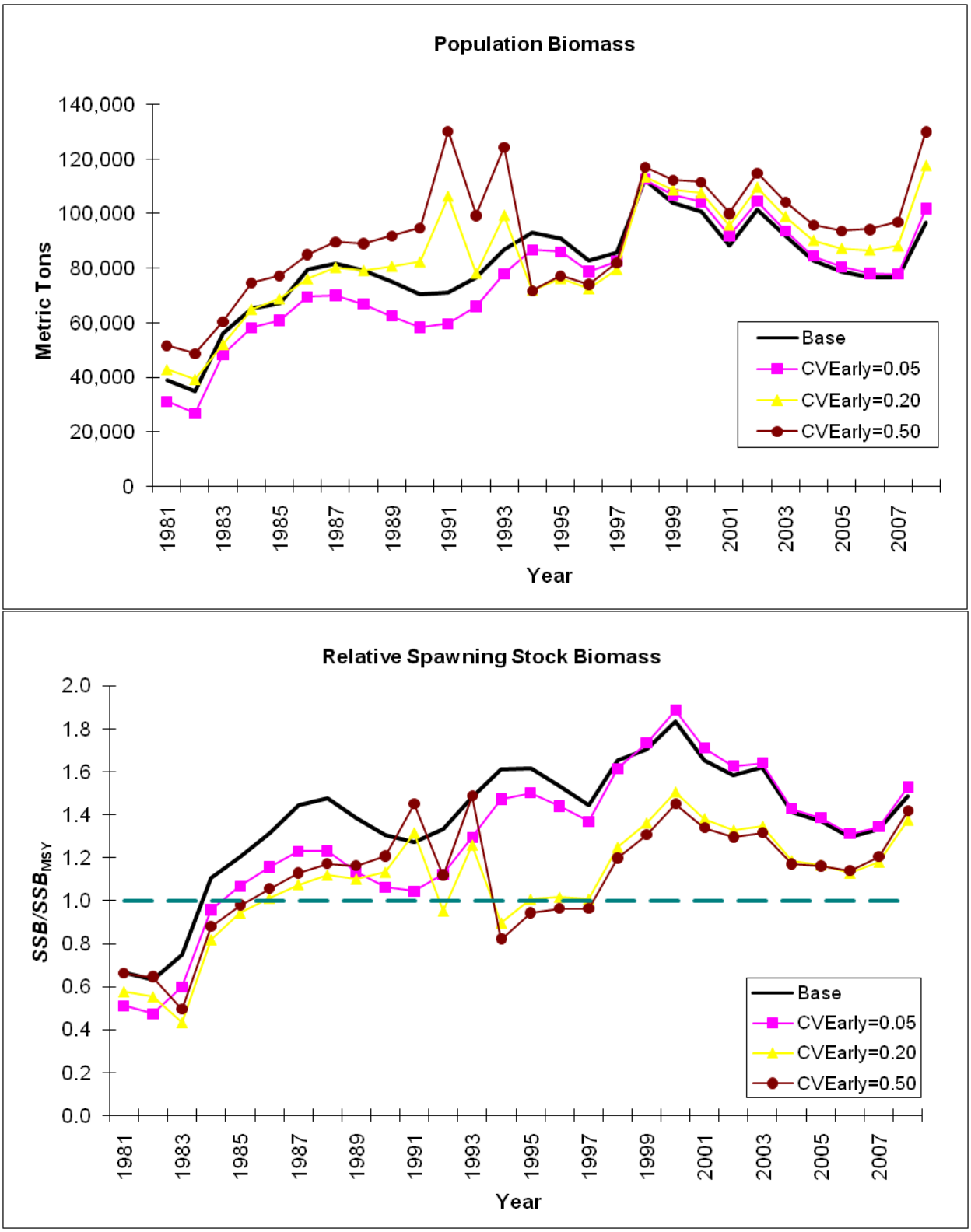


**Figure A8. 10** Biomass as a function of the assumed CV in the early (1981-1993) part of the time series.

**Figure A8.11** Effects of including catch-at-age derived from scale ages converted to otolith ages on estimates of population biomass (top) and average F (bottom).

**Figure A8. 12** Estimates of biomass (top) and fishing mortality (bottom) with and without shrimp trawl bycatch of croaker.

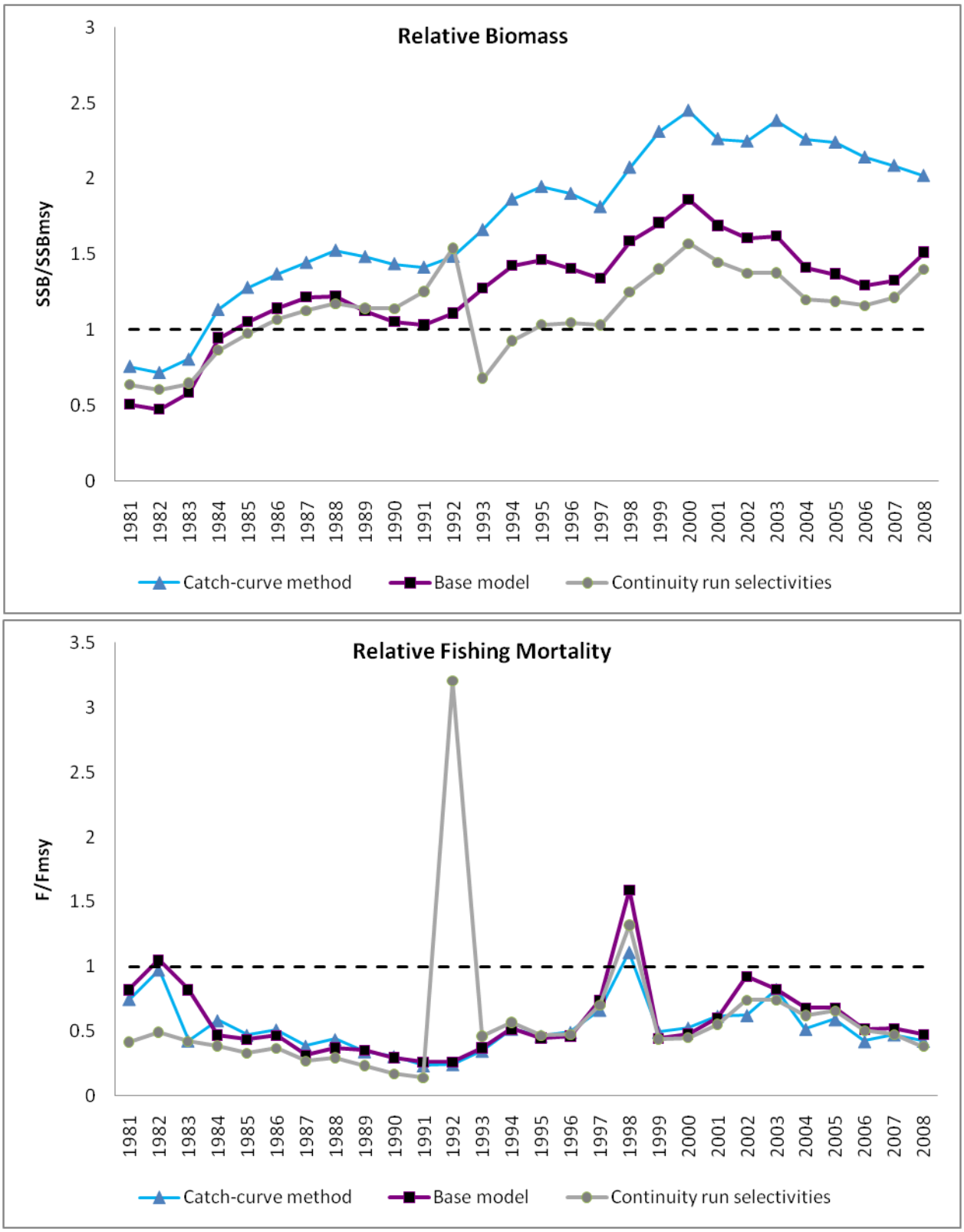


**Figure A8.13** Relative spawning stock biomass (top) and fishing mortality (bottom) estimated under different fixed selectivity patterns.

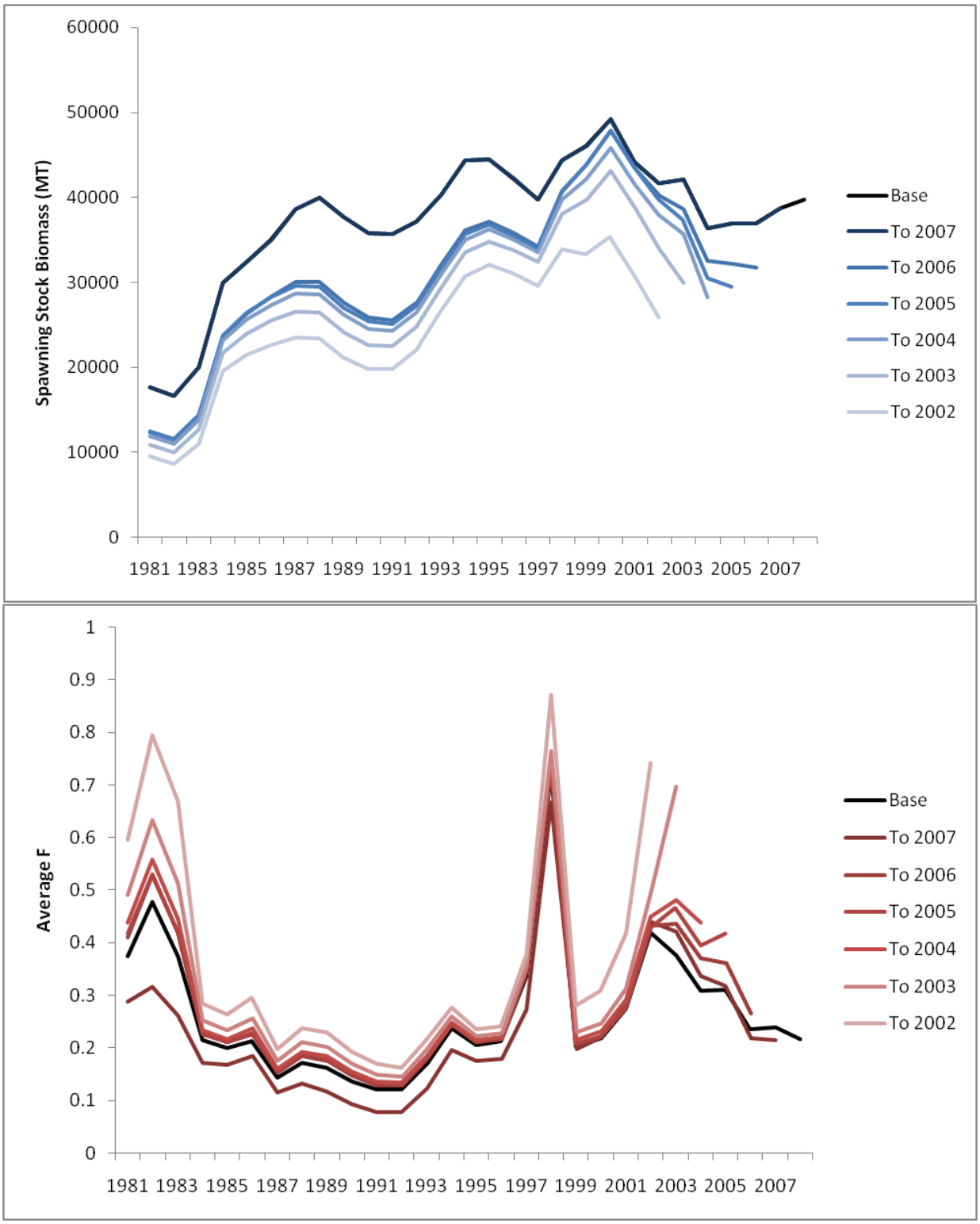


**Figure A8.14** Retrospective pattern in estimates of spawning stock biomass (top) and average fishing mortality (bottom). As years of data are added (darker lines), estimates of population size increase and estimates of F decrease.