ASMFC Atlantic Croaker 2010 Benchmark Stock Assessment

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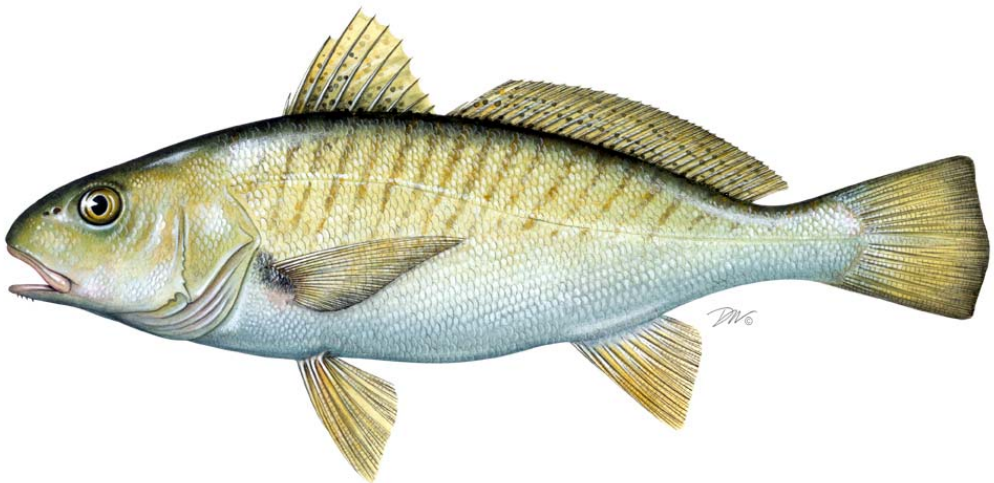
Atlantic States Marine Fisheries Commission

Atlantic Croaker 2010 Benchmark Stock Assessment



August 2010

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

PREFACE

The 2010 Benchmark Stock Assessment of Atlantic Croaker occurred through a joint Atlantic States Marine Fisheries Commission (ASMFC) and Southeast Data, Assessment, and Review (SEDAR) process. ASMFC organized and held a Data Workshop from July 20-24, 2009, and an Assessment Workshop from November 16-20, 2009. Participants of the Data Workshop included the ASMFC Atlantic Croaker Technical Committee, and other invited individuals from state and federal partners. Participants of the Assessment Workshop included the ASMFC Atlantic Croaker Stock Assessment Subcommittee. SEDAR coordinated a Review Workshop from March 8-12, 2010. Participants included members of the Atlantic Croaker Stock Assessment Subcommittee, and a Review Panel consisting of a chair, a reviewer appointed by ASMFC, and three reviewers appointed by the Center for Independent Experts.

This document contains the following reports:

Section A – 2010 Advisory Report

This report provides an executive summary of the stock assessment results supported by the Review Panel.

Section B – 2010 Stock Assessment Report for Peer Review

This report outlines the background information, data used, and model calibration for the assessment submitted by the Technical Committee to the Review Panel. The results of this document are not final because significant changes were made to the assessment data and model during the Review Workshop, as described in Section C.

Section C – Addendum to the 2010 Stock Assessment Report for Peer Review

This report provides the input data, model configuration, and results of the final model run to assess Atlantic croaker. The addendum was necessary because the Review Panel requested multiple changes to the stock assessment during the Review Workshop, as described in Section D. Not all the results were endorsed by the Review Panel, which is also described in Section D.

Section D – Review Panel Report for the 2010 Stock Assessment

This report, provided by the Review Panel Chair, provides the consensus opinions of the Review Panel on the final stock assessment for peer review. The report includes the Review Panel's summary findings, detailed discussion of each Term of Reference, and a summary of the results of analytical requests made at the Review Workshop. Individual reviewer reports are also available upon request from the ASMFC. Following the Review Workshop, the Stock Assessment Subcommittee completed the last analysis requested by the Review Panel, which affects some conclusions in the Review Panel Report, as described in Section E.

Section E – Response to Final Review Panel Request and Management Advice

This section includes several related documents: 1) A report from the Technical Committee that completes the last analysis requested by the Review Panel at the Review Workshop; 2) A memo from the Review Panel Chair confirming that the analysis was completed appropriately and that it confirms the not overfishing stock status determination; 3) A report from the Technical Committee to the Management Board with management advice based on the final assessment results; and 4) A memo from the Stock Assessment Subcommittee to the Technical Committee that makes several factual corrections to the Review Panel Report.

Atlantic Croaker Advisory Report - 2010

Status of Stock

Atlantic croaker is not experiencing overfishing. Biomass has been increasing and fishing mortality decreasing since the late 1980s. Biomass conclusions are based on information from the data compiled for the assessment, namely increasing indices of relative abundance and expanding age structure in the catch and indices. Model estimated values of fishing mortality (F), spawning stock biomass (SSB), and biological reference points are too uncertain to be used to determine stock status. However, the ratio of F to F_{MSY} (the F needed to produce maximum sustainable yield) is reliable and can be used to determine that overfishing is not occurring. It is not possible to be confident with regard to stock status, particularly a biomass determination, until the discards of Atlantic croaker from the South Atlantic shrimp trawl fishery can be adequately estimated and incorporated into the stock assessment.

Stock Identification and Distribution

Atlantic croaker (*Micropogonias undulatus*) is a demersal sciaenid present in estuarine and nearshore waters from the Gulf of Maine to Argentina. Along the U.S. Atlantic coast, the species is common from New Jersey through Florida, and most abundant between the Chesapeake Bay and Indian River Lagoon, Florida. Atlantic croaker exhibit migratory behavior. Genetic studies indicate a single stock of Atlantic croaker on the Atlantic coast.

Management Area

The management area for Atlantic croaker is the entire Atlantic coast from New Jersey to Florida, and from the estuaries eastward to the inshore boundary of the Exclusive Economic Zone. Amendment 1 defines northern (New Jersey to North Carolina) and southern (South Carolina to Florida) regions within the management areas based on the previous stock assessment that assessed the resource as two populations. The current assessment evaluates the status of the resource as one population within the management area due to inadequate evidence to support the existence of two separate stocks.

Catches

Atlantic croaker are part of a mixed-stock commercial fishery. They are caught commercially with a wide variety of gears; the dominant gears include gill nets, pound nets, haul seines, and otter trawls. Commercial landings of Atlantic croaker show a cyclical pattern, with periods of high landings in the late 1950s, late 1970s, and late 1990s to early 2000s, followed by periods of decreasing landings (Table 1, Figure 1). Since 2005, commercial landings have decreased from a high in the early 2000s, but remain above the historical average (1950-2008) of 6,012 metric tons (mt). Virginia and North Carolina report the most commercial landings, although Maryland and New Jersey have contributed a slightly higher percentage in recent years (Table 2).

Atlantic croaker are also an important component of the “scrap” or “bait” fisheries, particularly in North Carolina. Atlantic croaker landed in these fisheries are not reported to the species level and tend to be smaller than market-grade croaker. Estimates of scrap/bait landings in North Carolina have declined in recent years, from a high of 1,569 mt in 1989 to a low of 84 mt in

2008, primarily due to restrictions placed on the fisheries that produced the highest scrap/bait landings (Table 1).

Atlantic croaker are also discarded from some gears such as gill nets and otter trawls. This is primarily due to market pressures, as there are few restrictions on croaker harvest at the state level. Since 1988, estimated discards have fluctuated between 94 and 15,176 mt, averaging 2,503 mt (Table 1, Figure 2). Atlantic croaker, especially age-0 fish, are also caught as bycatch in shrimp trawls. There are no monitoring programs in place to document the annual magnitude of these discards; however, rough estimates of Atlantic croaker shrimp trawl discards suggest a general decline since 1995 (Table 1).

Recreational landings of Atlantic croaker since 1981 have increased and show an overall pattern similar to the commercial landings (Figure 1). Recreational landings peaked in 2001 at 5,026 mt (Table 1). The majority of Atlantic croaker are landed in Virginia (Table 3). The number of Atlantic croaker released alive by recreational anglers has also increased over this time period, and anglers have released a higher percentage of their croaker catch in more recent years (Table 4). Discard losses have generally increased, but are a small part of the recreational removals, averaging 111 mt since 1988 (Figure 2).

Data and Assessment

The Atlantic Croaker Technical Committee obtained commercial landings data from the Atlantic Coastal Cooperative Statistics Program (ACCSP) Data Warehouse and, in three cases, from individual state reports. Commercial biological sampling data collected by three states were used to characterize the catch. North Carolina provided estimates of scrap/bait landings of Atlantic croaker from its sampling of the fishery. Commercial discards from gill nets and otter trawls were estimated with data from the NMFS Pelagic Observer Program, assuming 100% mortality of Atlantic croaker bycatch. Rough estimates of shrimp-trawl discards of Atlantic croaker were calculated based on a review of available literature and shrimp landings data. These estimates were not used in the base run of the model, but were applied in sensitivity analyses. Recreational catch, harvest, and release estimates, as well as biological sampling data, were obtained from the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS). The release mortality rate was assumed to be 10% in the recreational fishery.

The assessment used four fishery-independent indices (Figure 3). These included two young-of-year (YOY) indices in the core area of Atlantic croaker distribution (the Virginia Institute of Marine Science (VIMS) Juvenile Trawl Survey in Chesapeake Bay and the North Carolina Program 195 Survey in the Pamlico Sound) and two indices that catch multiple ages classes and provide a large coverage area (the NMFS Fall Trawl Survey and the fall component of the Southeast Area Monitoring and Assessment Program (SEAMAP) South Atlantic Survey). A fishery-dependent index from MRFSS data was developed but not used in the final assessment model. Biological data from all the above fishery-dependent and fishery-independent sources were used to estimate life history parameters.

The model began in 1988, the year that consistent sampling of ages in the commercial catch began. A statistical catch-at-age model was used. The model was an update of the 2003 Atlantic croaker assessment model, modified to allow the use of catch-at-age data for the fleets and the non-YOY indices, the estimation of selectivity patterns for the fleets and non-YOY indices, and the estimation of the initial population numbers-at-age. A Beverton-Holt stock-recruit relationship was used to estimate recruitment in subsequent years. The model covered the entire stock on the Atlantic coast.

The Review Panel requested a number of changes to the data and model, many of which were incorporated into the assessment during the Review Workshop. The Panel also recommended changes to the calculation of the F_{MSY} reference points, which were completed after the Review Workshop. The final products resulted in a model deemed adequate for estimating the overfishing ratio. However, without a defensible discard history for the shrimp trawl fishery, or major restructuring of the model, the base model was deemed inadequate for estimating absolute values or an overfished ratio.

Biological Reference Points

Amendment 1 established the following biological reference point definitions for fishing mortality (F) and spawning stock biomass (SSB) based on maximum sustainable yield (MSY): F threshold = F_{MSY}; F target = 0.75 x F_{MSY}; SSB target = SSB_{MSY}; and SSB threshold = 0.7 x SSB_{MSY}. They apply only to the Mid-Atlantic region defined in Amendment 1. Because of the uncertainty surrounding the magnitude of Atlantic croaker bycatch in the South Atlantic shrimp trawl fishery and the application of the discard estimates in modeling, the Technical Committee recommended using relative rather than absolute values of F and SSB as reference points.

Overfishing threshold is $F/F_{MSY} = 1$
Overfishing target is $F/(F_{MSY}*0.75) = 1$

Overfished threshold is $SSB/(SSB_{MSY}(1-M)) = 1$
Overfished target is $SSB/SSB_{MSY} = 1$

Overfishing would be occurring if F/F_{MSY} were greater than 1 and the stock would be considered overfished if $SSB/(SSB_{MSY}(1-M))$ were less than 1.

The TC also recommended discontinuing the use of the Mid-Atlantic and South-Atlantic management regions, and that the reference points be applied to the entire management unit.

Fishing Mortality

Absolute estimates of total F are unavailable because of model uncertainty; however, the general trend in total F from the model is considered reliable due to support from the data. The trend in total F decreases substantially during the first five years of the time series (1988-1992) and shows an overall decline over the remainder of the time series, except for occasional, brief spikes (Figure 4). Retrospective analysis of the model showed that estimates of F decreased as more years of data were used.

A series of sensitivity runs conducted over a range of plausible values of shrimp-trawl fishing mortality found that the ratio of directed fishing mortality to F_{MSY} was less than one in all cases, indicating overfishing was not occurring.

Recruitment

Recruitment, estimated in the model as age-1 abundance, has been variable but generally increasing over the time series. Figure 5 shows the trend in recruitment; absolute values are omitted because of uncertainty in abundance estimates. The model estimated the production of strong year classes in 1997, 2001, and 2007.

Spawning Stock Biomass

Absolute estimates of SSB are unavailable because of model uncertainty; however, the general trend in SSB from the model is considered reliable due to support from the data. Spawning stock biomass shows a nearly consistent increasing trend since 1998 (Figure 5). Sensitivity runs of the model including rough estimates of shrimp trawl discards do not change the overall trend in SSB. Retrospective analysis of the model showed that estimates of SSB increased as more years of data were used.

Discards and Bycatch

Information on landings and discards of Atlantic croaker from gill net and ocean trawl fisheries was available from the NMFS Pelagic Observer Program, although the time series is limited. The data were used to estimate discards of croaker from these fisheries; however, the method of estimation was deemed unreliable due to the low number of observed trips which landed croaker. Ratios of croaker bycatch to shrimp landings were taken from several studies and used to generate rough estimates of croaker discards from shrimp trawls. These studies do not cover the full spatial or temporal range of the shrimp trawl fisheries. The estimates were not included in the base run, but were included in sensitivity runs. Adequate estimates cannot be developed from currently available data, and assessments of Atlantic croaker will be unreliable until adequate estimates are properly incorporated into modeling.

Uncertainty

The uncertainty of model estimates and biological reference points is dominated by the catch data set to which the model is fitted rather than the estimation procedure or model structure. Confidence intervals for the estimated quantities indicate that the base model estimated trends in spawning stock biomass and fishing mortality that were well determined (given the model assumptions). Sensitivity runs gave similar trends in stock metrics as those from the base run apart from when shrimp trawl discard estimates were included in the catch data. Retrospective analyses of the model illustrated a tendency to underestimate spawning stock biomass and overestimate fishing mortality across the time series of estimates. The retrospective bias does not affect the perception of the trends in the estimates; SSB has an upwards trend and F has a downwards trend. The sensitivity of stock status relative to reference levels is marginal compared to the sensitivity to the inclusion or exclusion of the shrimp trawl discard estimates.

Other Comments

Despite the uncertainty in assessment results caused by shrimp trawl bycatch, the Review Panel concluded that it is unlikely that the stock is in trouble. Biomass has been trending up, commercial catches are stable, and discards from the shrimp trawl fishery have been much reduced (as supported by point estimates from actual data: 11,600 tons in 1970; 13,000-15,000 tons annually in 1992-1994; and 5,500 tons annually in 2007-2008).

The Review Panel stressed the importance of developing valid estimates of shrimp trawl discards to improve the certainty of future stock assessment results. Rough estimates indicate that discards could be as large, or larger, than the directed harvest in some years. The Review Panel recommends development of a time series of effort for the shrimp fishery for use in estimating bycatch of Atlantic croaker. This information could be used to estimate discard mortality in the shrimp fishery for a number of species in the South Atlantic. Additionally, the Review Panel recommends the development and implementation of sampling programs for shrimp fisheries in order to monitor the relative importance of Atlantic croaker (and other fish supporting commercial and recreational fisheries) in these fisheries.

Sources of Information

Atlantic States Marine Fisheries Commission. 2010. Atlantic Croaker 2010 Stock Assessment Report for Peer Review. Washington (DC): ASMFC. A Report of the Atlantic Croaker Technical Committee and Stock Assessment Subcommittee. 236 p.

Atlantic States Marine Fisheries Commission. 2010. Addendum to the Atlantic Croaker 2010 Stock Assessment Report for Peer Review. Washington (DC): ASMFC. A Report of the Atlantic Croaker Stock Assessment Subcommittee. 81 p.

McKown K. 2010. SEDAR 20 Review Panel Consensus Report, Atlantic Croaker. Report prepared for the SEDAR 20 Review Workshop. 22 p.

Table 1. Coastwide Atlantic croaker landings and discard losses (metric tons), 1988-2008.

Year	Commercial Landings	Scrap/Bait Landings	Commercial Discard Losses	Recreational Landings	Recreational Discard Losses	Shrimp Trawl Discard Losses†	Total Removals (without shrimp trawl discard losses)
1988	4,742.6	1,465	416.0	2,106.5	19.2	7,123.7	8,749.3
1989	3,672.9	1,569	341.7	1,078.4	17.9	8,852.8	6,679.9
1990	2,756.4	1,249	98.5	778.8	34.1	7,027.3	4,916.9
1991	1,676.7	992	94.1	1,156.0	79.3	14,485.0	3,998.1
1992	1,944.1	689	426.2	1,191.9	40.7	13,626.2	4,292.0
1993	4,069.1	527	1,080.1	1,368.8	69.8	15,034.5	7,114.8
1994	4,910.8	899	3,744.2	2,208.6	88.5	13,529.5	11,851.1
1995	6,319.0	1,157	2,327.7	1,818.2	59.3	20,780.6	11,681.2
1996	9,636.7	478	665.4	1,857.7	68.0	9,476.4	12,705.8
1997	12,371.0	346	164.8	3,520.1	123.4	10,061.5	16,525.3
1998	12,541.0	175	15,176.8	3,588.5	135.3	7,280.3	31,616.6
1999	12,130.0	395	1,155.3	3,320.3	143.5	6,951.0	17,144.1
2000	12,118.0	301	1,802.4	4,395.3	232.3	5,630.4	18,849.0
2001	13,006.0	218	1,740.7	5,026.7	156.7	790.2	20,148.1
2002	11,865.0	163	7,163.7	4,152.7	156.7	4,321.6	23,501.1
2003	12,923.0	399	10,033.3	4,179.8	167.0	2,046.7	27,702.1
2004	12,982.0	225	675.0	4,000.6	132.0	2,161.3	18,014.6
2005	11,167.0	110	2,940.0	4,792.1	180.7	216.3	19,189.8
2006	9,514.1	139	130.4	4,184.1	157.1	1,498.4	14,124.6
2007	9,199.2	148	1,134.9	3,746.1	147.8	5,412.8	14,376.4
2008	8,777.0	84	1,258.7	2,406.6	120.4	5,839.7	12,646.8

†: Shrimp trawl discard estimates were used in sensitivity runs, but not in the base model.

Table 2. Atlantic croaker commercial landings (metric tons) by state, 1988-2008. An "*" indicates confidential data.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL
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		1.63	89.90	2,617.01	0.54		47.36
1991		0.00			14.19	0.32	2.80	74.45	1,558.98	*		25.74
1992					23.41	0.36	4.85	607.54	1,268.52			35.85
1993					83.20	1.13	71.70	2,388.15	1,482.18	*		23.60
1994					53.19	1.36	99.22	2,618.78	2,093.67	*		43.55
1995					151.80	5.90	249.35	3,171.08	2,731.21	*		10.38
1996				0.00	282.08	4.39	367.61	4,288.98	4,518.61			11.81
1997				0.59	904.67	4.77	660.30	5,839.52	4,858.73	*		16.59
1998				0.01	466.90	4.70	623.98	6,552.67	4,928.69			11.98
1999		0.00		0.00	939.41	6.68	718.68	5,845.28	4,620.07			12.17
2000		0.02		0.13	966.36	5.04	681.14	5,869.49	4,591.55			17.22
2001				0.14	630.42	10.31	1,012.94	5,911.87	5,451.01		*	6.73
2002		0.03		0.10	829.39	4.87	686.30	5,734.72	4,621.72	*	*	7.80
2003				0.83	714.74	7.51	694.92	4,960.85	6,544.97	0.06	*	7.44
2004	0.43	0.51		16.33	950.87	15.02	816.89	5,375.88	5,439.93	*	*	5.18
2005		*		0.08	838.13	18.14	630.18	4,287.07	5,399.24	0.02	*	7.49
2006				0.65	733.52	8.74	397.82	3,595.70	4,715.80	0.07	*	13.73
2007				0.28	615.98	6.19	262.62	4,987.78	3,311.81	*		12.26
2008				1.24	445.37	4.02	341.48	5,321.54	2,627.15	0.05	*	14.26

Table 3. Atlantic croaker recreational landings (metric tons) by state, 1988-2008.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL
1988						0.38	420.14	1,084.16	424.24	24.63	9.21	143.72
1989						0.13	8.70	603.03	298.67	36.54	9.59	121.69
1990						0.05	17.18	397.02	157.45	56.14	93.13	57.83
1991					1.93	4.98	53.16	783.68	71.50	7.33	24.54	208.82
1992						1.49	24.29	802.25	105.91	12.93	60.13	184.89
1993					0.38	4.37	216.27	904.27	128.30	8.17	25.22	81.87
1994					0.37	1.31	449.51	1,371.48	159.29	58.19	15.44	153.05
1995					4.32	37.58	257.21	1,213.32	147.91	11.51	9.46	136.92
1996					17.73	93.21	318.38	1,232.09	157.14	6.57	9.89	22.69
1997					126.42	154.28	507.03	2,504.40	140.34	24.43	11.91	51.29
1998	0.81				61.56	133.13	521.75	2,685.00	73.07	34.84	14.04	64.29
1999					136.94	236.83	464.58	2,253.64	96.59	11.95	14.68	105.08
2000					510.54	219.48	1,212.24	2,217.19	91.30	6.10	28.29	110.16
2001					513.48	137.93	579.91	3,480.62	161.00	4.88	3.56	145.35
2002					121.73	113.79	527.11	3,208.68	109.83	13.31	4.82	53.46
2003					309.61	118.87	938.40	2,573.29	144.04	26.94	32.60	36.01
2004					522.42	155.25	461.13	2,626.98	121.29	24.29	8.07	81.19
2005					539.61	383.71	427.53	3,283.89	65.29	19.09	6.31	66.72
2006					347.33	343.35	400.94	2,929.86	68.66	8.62	5.16	80.22
2007					185.67	151.86	479.13	2,771.71	39.46	17.85	6.18	94.25
2008					191.76	120.99	208.01	1,638.12	70.27	16.02	7.12	154.33

Table 4. Coastwide Atlantic croaker recreational catch, releases, and discard losses (alive releases x 10% release mortality) in numbers of fish, and the percent of fish caught that were released, 1988-2008.

Year	Catch	Harvest	Released Alive	Discard Losses	% of Catch Released
1988	10,628,620	8,205,384	2,423,236	242,324	22.8%
1989	7,433,973	5,007,653	2,426,320	242,632	32.6%
1990	10,735,559	4,775,162	5,960,397	596,040	55.5%
1991	18,810,146	6,390,181	12,419,965	1,241,997	66.0%
1992	13,125,922	6,643,974	6,481,948	648,195	49.4%
1993	17,057,138	7,000,061	10,057,077	1,005,708	59.0%
1994	23,225,549	10,205,819	13,019,730	1,301,973	56.1%
1995	15,049,200	7,473,870	7,575,330	757,533	50.3%
1996	14,040,092	6,920,798	7,119,294	711,929	50.7%
1997	21,918,968	10,926,856	10,992,112	1,099,211	50.1%
1998	19,973,286	9,249,619	10,723,667	1,072,367	53.7%
1999	21,657,907	9,116,593	12,541,314	1,254,131	57.9%
2000	27,136,831	10,710,547	16,426,284	1,642,628	60.5%
2001	24,906,349	13,248,180	11,658,169	1,165,817	46.8%
2002	23,348,275	11,557,153	11,791,122	1,179,112	50.5%
2003	23,027,139	10,451,573	12,575,566	1,257,557	54.6%
2004	21,108,281	10,982,805	10,125,476	1,012,548	48.0%
2005	24,884,881	11,595,508	13,289,373	1,328,937	53.4%
2006	21,723,863	10,225,534	11,498,329	1,149,833	52.9%
2007	25,519,137	10,647,377	14,871,760	1,487,176	58.3%
2008	23,171,921	9,193,527	13,978,394	1,397,839	60.3%

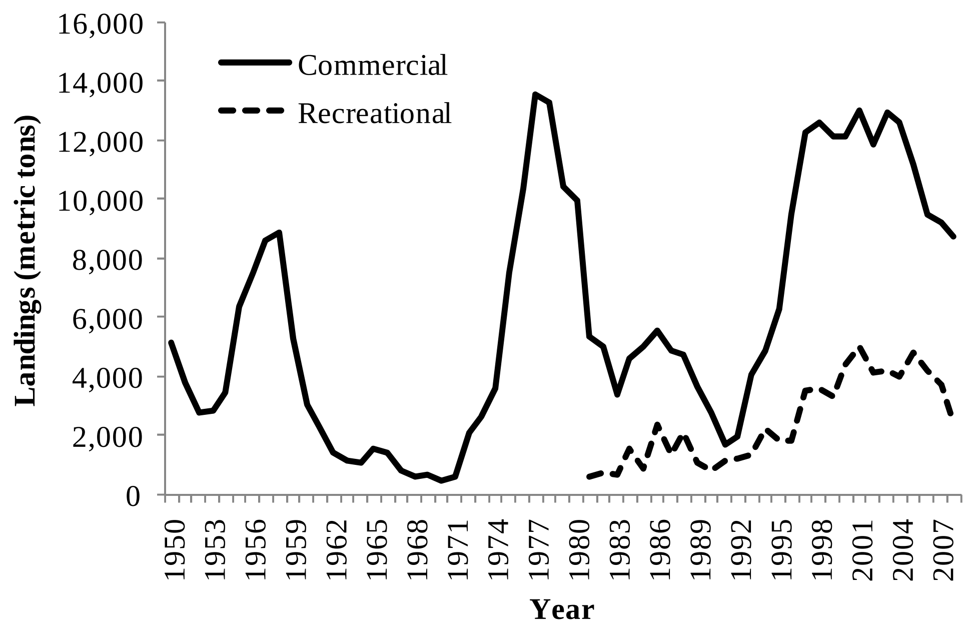


Figure 1. Coastwide commercial landings, 1950-2008, and coastwide recreational landings, 1981-2008.

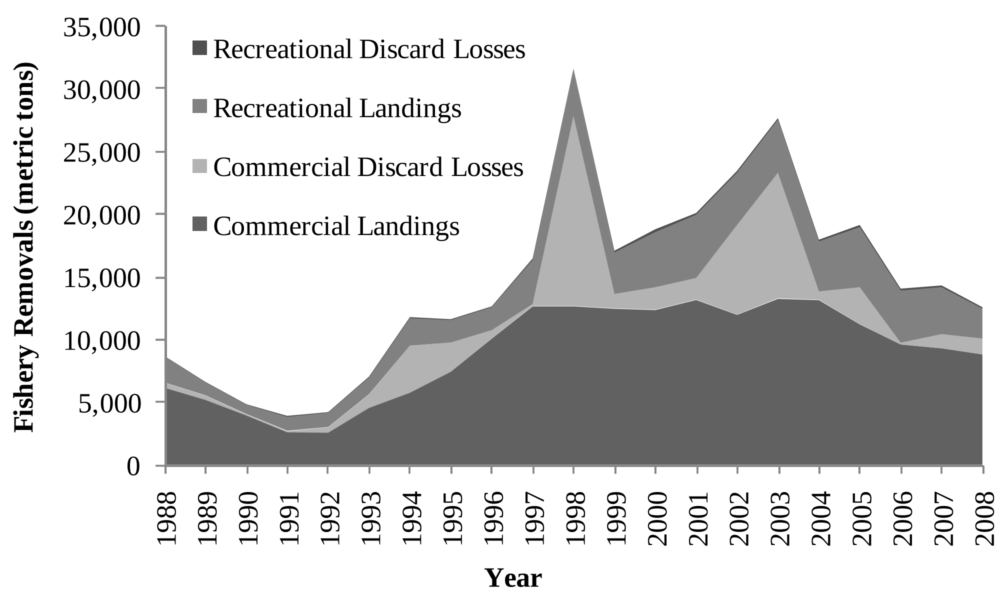


Figure 2. Coastwide fishery removals, by fishery and type of removal, of Atlantic croaker (metric tons). Commercial landings include the scrap/bait landings in North Carolina; commercial discards exclude shrimp trawl discard estimates.

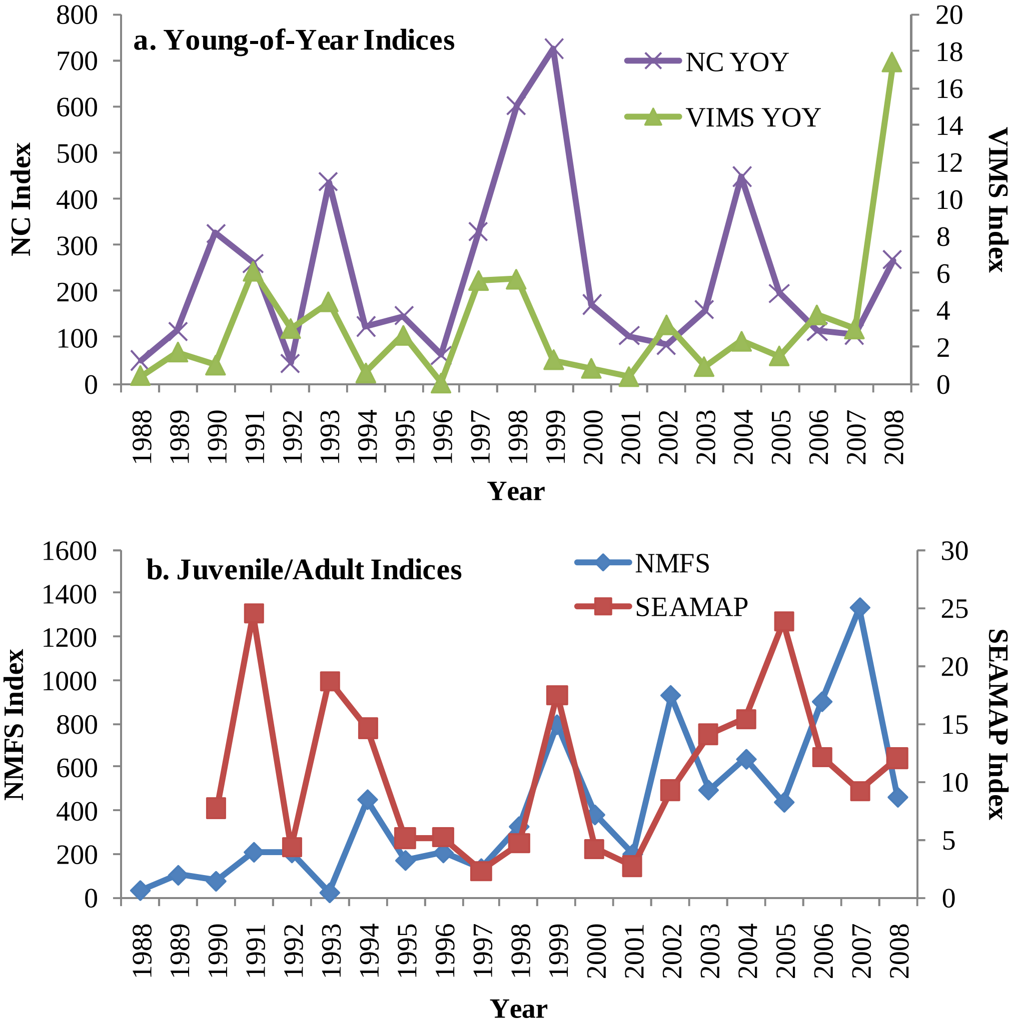


Figure 3. Fishery-independent indices of Atlantic croaker relative abundance used to assess the stock: a) young-of-year indices, b) juvenile/adult indices.

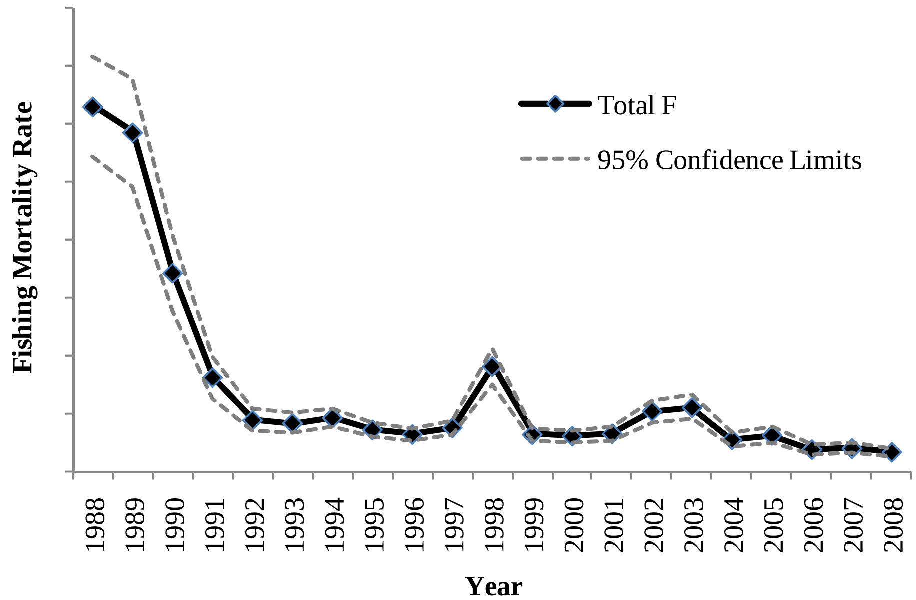


Figure 4. Trend in estimated total fishing mortality rate (F) of Atlantic croaker from the base model run. Absolute estimates of F are unreliable because of uncertainty regarding the estimation of Atlantic croaker discards in the shrimp trawl fishery, and the application of estimates in modeling.

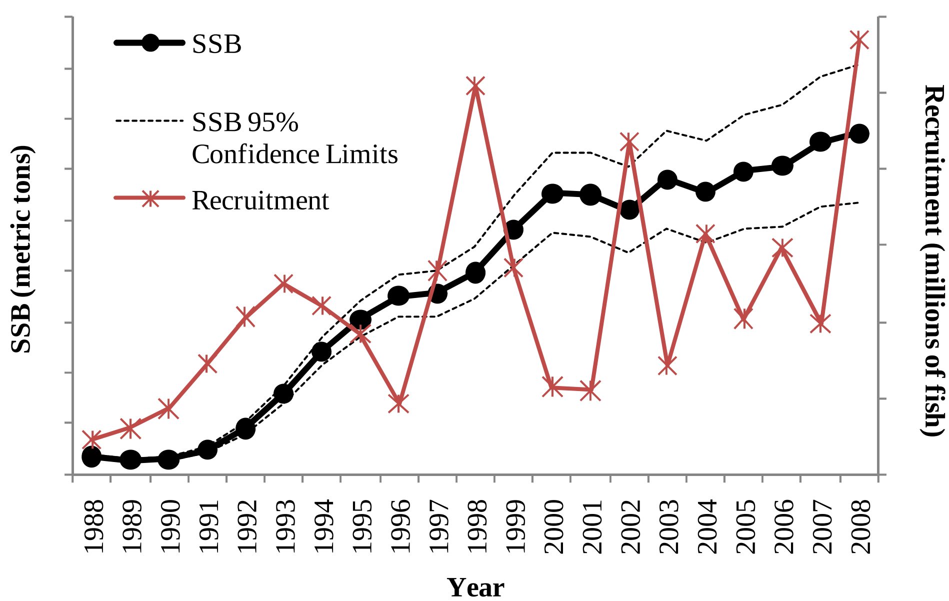
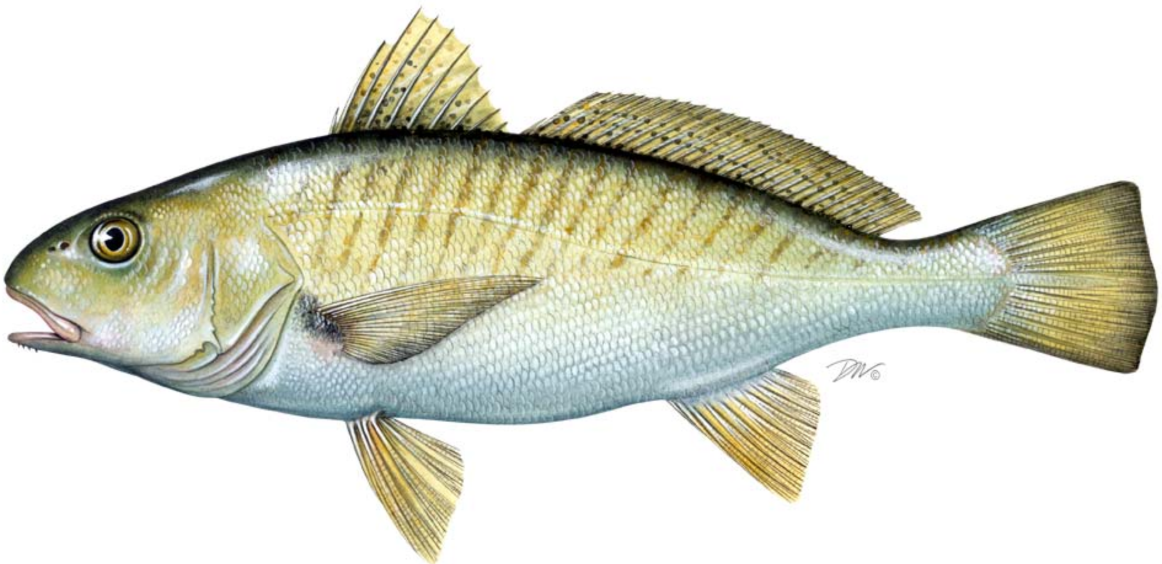


Figure 5. Trends in estimated spawning stock biomass (SSB, metric tons) and age-1 recruitment (numbers of fish) of Atlantic croaker from the base model run. Absolute estimates of stock size are unreliable because of uncertainty regarding the estimation of Atlantic croaker discards in the shrimp trawl fishery, and the application of estimates in modeling.

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 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_{MSY}). Overfishing for the mid-Atlantic is defined by a threshold fishing mortality rate (F) of 0.39 (F_{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 Previous ASMFC Assessment

In 2003, the ASMFC performed an assessment of Atlantic croaker, which underwent SEDAR review (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 members of the 2003 SEDAR review panel (with the exception of Dr. Steve Bobko, Old Dominion University, who did not participate in the second review; ASMFC 2005e).

The 2003/4 ASMFC assessment is the only stock assessment for Atlantic croaker that has been peer-reviewed for management. 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 Atlantic croaker in the Atlantic or sub-regions of the Atlantic (Barbieri et al. 1997; Lee 2005).

1.3.2 2003/2004 ASMFC Assessment Data

The following data were used in the 2003/4 ASMFC stock assessment of Atlantic croaker. Catch data included:

- 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 were provided by the NCDMF, VMRC, Maryland Department of Natural Resources (MDDNR), and MRFSS:

- Length composition 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 composition 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.
- Length composition of recreational landings: 1981–2002 MRFSS sampling.

Life history parameters consisted of growth, maturity, and natural mortality. Growth curve parameters were estimated using NCDMF data collected between 1996 and 2002, pooled by sex and un-weighted. Age data were derived from sectioned otoliths. The best-fit von Bertalanffy age-length model fit to these data was:

$$L_a = 434.6\left[1 - e^{-0.2415(a-1.9572)}\right]$$

where L_a is length in millimeters at age a.

The relationship of length and weight was described using an allometric model:

$$W_a = 5.49\times10^{-9} L_a^{3.13}$$

where L_a is length in millimeters at age a and W_a is weight in kilograms at age a.

The maturity schedule was taken from Barbieri et al. (1994b), with 0% mature at age 0, 90% mature at age 1, and 100% mature at age 2 and older. 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 results of the 2003/2004 assessment were used to develop the first recommendations for BRPs for Atlantic croaker. Reference points based on maximum sustainable yield (MSY) were recommended for the mid-Atlantic region (Table 1.3.3.1). The status of the Atlantic croaker occurring in the south Atlantic region could not be determined during the 2003/2004 stock assessment. As such, reference points were not developed for the south Atlantic region.

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 North Carolina data was used for both regions and all years.

Selectivities of the fleets and surveys were fixed inputs in 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 Atlantic croaker bycatch from the shrimp trawl fishery, which is believed to be an important source of mortality.

Unculled bait/scrap fishery landings of Atlantic croaker can account for a significant proportion of the Atlantic croaker catch, but as with bycatch, these data are not directly observed and reported, and levels of Atlantic 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 Atlantic 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 Atlantic croaker (i.e., part of mixed or unclassified bait) was not estimated. Rather, this method partitioned known Atlantic 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 10th 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_{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 2003/4 stock assessment concluded that the mid-Atlantic portion of the stock was not overfished and overfishing was not occurring. 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, 1.3.5.2).

No conclusions were made about the status of Atlantic 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 Atlantic 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 $SSB_{1973}/SSB_{\text{virgin}}$ 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 Previous ASMFC Assessment

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 North Carolina allowed the estimation of Atlantic 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 Atlantic 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 during the 2003/4 ASMFC assessment review.

Recommendations from the SASC included:

- Describe the distribution and movement of Atlantic 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_∞ 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_∞ 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_∞, because K and L_∞ 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_∞ 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_∞ 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 2.4.1.1). 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 2.4.1.2). 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 2.4.2.1.

Estimated natural mortality rates decreased with increasing age (Table 2.4.2.2). 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 2.4.2.2; Figure 2.4.2.1). The trends in age-specific *M* estimates for the fisheries-independent datasets were generally similar. All showed decreasing natural mortality rate with age (Table 2.4.2.2; Figures 2.4.2.1, 2.4.2.2, and 2.4.2.3). 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 NCDMF 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

New Jersey

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

Delaware

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.

Maryland

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.

Potomac River Fisheries Commission

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 5.1.1.2.1). 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, this report). 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 North Carolina's 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 croakers 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, this report). 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 during 1950–2008 averaged 21.7 million pounds, ranging from a low of 0.47 million pounds in 2005 to a high of 45.8 million pounds 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 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 Gill-net Observer Program dataset (Program 466, 2001–2008). Sample size was limited in the NMFS Observer Program (Table 5.1.3.3.1) and the programs do not cover the same areas (the North Carolina program is inshore and limited to one state, the NMFS program is offshore and covers a wider range of states) or target species (the North Carolina program only monitors summer flounder gill nets, 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 North Carolina 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 2003/4 assessment, discard ratios for gill nets and otter trawls were estimated with the PROC SURVEYMEANS algorithm in SAS, as was done in the previous assessment. The year- and gear-specific ratios for 2003–2008 were used to estimate the discards from gill-net 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 unrealistically large discard ratios (e.g., 95:1 for gill nets 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 assumed 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 Catch-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 gill net) 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 North Carolina'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, North Carolina 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 angler-trips were defined in two ways: (1) trips where Atlantic croakers were reported as targeted (variables “PRIM1” or “PRIM2”) or caught (Type A1+B1+B2); or (2) trips where Atlantic croakers were targeted or harvested (Type A+B1 only). Group catches of Type A fish were distributed by trip among all contributing anglers on each trip. 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 and were 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.

The estimated recreational catch and harvest CPUE indices were variable among years and followed similar patterns over the 1981 through 2008 (Table 5.2.4.1; Figure 5.2.4.1). A peak was observed in 1986 in both index series. No obvious increasing or deceasing trends are apparent in either index.

The previous ASMFC assessment developed two regional CPUE indices—one for the mid-Atlantic (New Jersey through North Carolina) and one for the south Atlantic (South Carolina through Florida)—due to perceived regional differences among trends in fisheries-independent indices (ASMFC 2005a). As a continuity case, regional recreational fishery CPUE indices were developed for the same time period covered in the previous ASMFC assessment (1982–2002) using the directed trips method. Recreational catch and harvest CPUE indices in the mid-Atlantic region showed a slightly increasing trend in the early part of the time series and were variable with little trend in the remaining years (Table 5.2.4.2; Figure 5.2.4.2). The indices of recreational catch and harvest CPUE in the south Atlantic exhibited little trend over the time series with the exception of a relatively high peak that occurred in 1986 (Table 5.2.4.2; Figure 5.2.4.2). Annual recreational catch and harvest CPUE values were higher in the mid-Atlantic than the south Atlantic for most of the time series (Tables 5.2.4.2, 5.2.4.3; Figure 5.2.4.2).

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 Summary of 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_∞ 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 α and β 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_{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:

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

where h is the steepness parameter, $SSB_{y\text{-}1}$ 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:

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

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

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

where q_i is the catchability coefficient for index i, $s_{i,a}$ is the selectivity for index i at age a, and Δ_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_{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 6.1.3.1).

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:

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

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, σ_f is a measure of dispersion for C_f, and λ_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):

$$\sigma^2_{f,y} = \log_e\left(\text{CV}^2_{f,y} + 1\right)$$

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

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

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 λ_{CAA} is the weighting factor for L_{CAA}.

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

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

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, $\sigma^2_{i,y}$ is the variance for index i in year y, and λ_I is the weighting factor for L_I.

The variance, $\sigma^2_{i,y}$, is computed from the coefficient of variation, CV, associated with the observed index values (Age-Structured Assessment Program, NFT 2009):

$$\sigma^2_{i,y} = \log_e\left(\mathrm{CV}^2_{i,y} + 1\right)$$

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

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

where V_y is the deviation in recruitment in year y and λ_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. In a perfectly fit model, the standardized residuals are normally distributed with mean 0 and standard deviation 1. Normal quantile plots (Q-Q plots) and distribution tests were applied to determine whether the standardized residuals were normally distributed.

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 6.1.4.1). 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 6.1.4.2). Values for age-specific maturity were estimated from NMFS Bottom Trawl Survey data using a logistic maturity function (Table 6.1.4.3).

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).

Selectivity

An initial run of the model was used to estimate selectivity patterns for the fleets and three of the indices (the recreational CPUE, the NEFSC Trawl Survey, and the SEAMAP Fall Survey). The young-of-year surveys (VIMS, NC P195) were assumed to select age-0 fish only. The model had difficulty fitting the selectivity for 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 selectivity estimates were then fixed and used as the assumed selectivity patterns for other model runs (Table 6.1.4.4).

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 Atlantic 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 ASMFC assessment of Atlantic croaker used an age-structured production model (ASPM), versions of which were implemented in both Excel and AD Model Builder (ASMFC 2005b, 2005d). 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 of this report.

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 (see Appendix 6 for details). The estimates of Z were produced to provide a comparison to the results of the preferred model base run (see Section 7.2, this report.).

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

Predicted annual catches were similar to observed values for all fleets (Figure 7.1.1). Standardized residuals from the fit of the base model to annual catch demonstrate a trend over time for all fleets (Figure 7.1.2). The trend suggests the model overestimated annual catch during the early 1980s through the mid- to late 1990s and underestimated 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 indicated both commercial landings and commercial scrap/bait/discards do not follow a normal distribution ($P \leq 0.01$; Figure 7.1.3).

The model predictions of annual indices are compared to observed values in Figures 7.1.4–7.1.8). Standardized residuals for the recreational CPUE show a trend over the model time period (Figure 7.1.9). 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 7.1.9). No obvious trends are apparent in the standardized residuals for the SEAMAP, VIMS, and NC195 indices (Figure 7.1.9). The standardized residuals for the recreational CPUE, NMFS, SEAMAP, and NC195 indices were found to be normally distributed ($P > 0.01$; Figure 7.1.10). 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 Atlantic 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.

Strong trends were observed in the Pearson's standardized residuals for the catch-at-age data. The residuals for the commercial landings (Figure 7.1.11), commercial scrap/bait/discards (Figure 7.1.12), and recreational harvest (Figure 7.1.13) catch-at-age data indicate the model estimated higher proportions of older fish than were observed during the mid- to late 1990s. The commercial landings (Figure 7.1.11) and recreational harvest (Figure 7.1.13) catch-at-age residuals also suggest overestimation of the proportion of younger fish throughout most of the 2000s. Recreational discard catch-at-age data were only available for four years, but the associated Pearson's standardized residuals suggest the model had difficulty in fitting these catch-at-age data as well (Figure 7.1.14).

7.1.2 Parameter Estimates

The model estimated a total of 174 parameters, which included 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 (Table 7.1.2.1); annual recruitment deviations from the stock-recruitment relationship (Table 7.1.2.2), and annual fully-selected fishing mortality rates for each fishery (Table 7.1.2.3).

7.1.2.1 Population Size

The model predicted that abundance and biomass of Atlantic croaker has been variable and generally increasing over the model time period (Figure 7.1.15). Predicted SSB also demonstrated an overall increase over time (Figure 7.1.16). Recruitment estimates were variable over the time series. The model predicted relatively strong year-classes occurred in 1983, 1998, 2002, and 2008—the final year in the model.

7.1.2.2 Exploitation Rates

Model estimates of abundance-weighted average F were strongly correlated to total catch for most of the time series (Figure 7.1.17). Abundance-weighted average F estimates exhibited a decreasing trend during the 1980s, bottoming out and then increasing throughout the 1990s to a peak in 1998 before declining again. The estimates for the most recent years are similar to the values estimated for the beginning of the time series.

7.1.2.3 Precision of Parameter Estimates

Although ADMB reports standard deviations for estimated parameters, these estimates are considered 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. When the catch-at-age was down-weighted, the estimated population biomass was much higher (Figure A8.6) and the estimated fishing mortality was much lower (Figure A8.7), 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.

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 (Figure A8.4), but it did affect the model's estimates of the biological reference points SSB_{MSY} and F_{MSY} (Figure A8.5), with lower values of steepness resulting in higher values of SSB_{MSY} and lower values of F_{MSY}.

Including the shrimp bycatch increased estimates of population biomass and fishing mortality, but decreased estimates of SSB relative to SSB_{MSY} (Figure 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_{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_{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 data 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_{MSY} over the entire time series (Figure A8.11.). The stock dipped below SSB_{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_{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

The selectivity patterns estimated for the base run of the hybrid model were compared to the selectivity patterns used in the 2003 assessment (estimated from an untuned VPA) and to selectivity patterns estimated using an alternative catch curve based approach (see Appendix 8 for more details).

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).

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 (Figure 7.2.1) and decreasing trends in F (Figure 7.2.2). 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_{MSY} and the fishing mortality target is defined as $0.75F_{\mathrm{MSY}}$. The biomass target is defined as SSB_{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 re-parameterized 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 Overfished Definition

The biomass target, SSB_{MSY} was estimated to be 26,268 mt in the base model. The biomass threshold is estimated as $(1 - M)*SSB_{MSY}$. Using the average M over ages 1–15+ (0.25), the biomass threshold has a value of 19,700 mt. Estimated SSB in 2008 was 39,728 mt, above both the threshold and the target, indicating the stock is not overfished (Figure 8.3.1.1).

8.3.2 Overfishing Definition

The fishing mortality threshold for Atlantic croaker is defined as F_{MSY}, which was estimated to equal 0.455 in the current assessment. The fishing mortality target ($0.75F_{MSY}$) was estimated at 0.341. The current population-weighted F averaged over ages 1–15+ ($F_{2008} = 0.22$) is below the estimated fishing mortality threshold and the target, indicating overfishing is not occurring (Figure 8.3.2.1).

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

<u>Short-Term Research Priorities</u> (for next benchmark assessment, in order of importance)

1. Continue fisheries-independent surveys throughout the species range and subsample for individual weights and ages, particularly in the southern range.
2. 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.
3. Maintain SEAMAP funding.
4. Increased observer coverage for commercial discards.
5. 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.
6. Conduct studies of discard mortality for recreational and commercial fisheries.
7. Conduct study on fecundity in the south Atlantic and continue to develop estimates of length-at-maturity and year-round reproductive dynamics.

8. Investigate environmental covariates in stock assessment models.
9. 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.
10. Re-examine historical ichthyoplankton studies of the Chesapeake Bay for an indication of the magnitude of estuarine spawning.

Long-Term Research Priorities (in order of importance)

1. Collect data on fishing attributes necessary to develop gear-type-specific fishing effort estimates.
2. 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.
3. 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.
4. Examine socioeconomic aspects of the fishery.

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 for Atlantic croaker occurring in the mid-Atlantic region estimated during 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_∞ represent total length in centimeters.

Location	Age Structure	Collection Period	L_∞	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_∞ represent total length in centimeters.

Type	**Area**	**Gear**	**Source**	**n**	**Max Age**	L_∞	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_∞ represent total length in centimeters.

Type	**Area**	**Gear**	**Source**	**Sex**	**n**	L_∞	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 2.4.1.1 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 2.4.1.2 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 2.4.2.1 Estimates of the von Bertalanffy age-length parameters used in Lorenzen's (2005) method to compute age-specific estimates of *M*. Values of L_∞ represent total length in centimeters.

Type	Area	Gear	Source	Sex	Max Age	L_∞	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 2.4.2.2 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			0.4082	5.443		3.221	322.7	9,592	2.467	2.141	23.09
1981			0.09072	10.66		0.9525	195.0	5,083	1.107	0.4708	32.71
1982				0.04536		3.175	54.16	4,910	0.1751	0.9875	43.25
1983	0.09072			0.09072		0.2268	68.29	3,288	1.451	0.4976	37.08
1984		0.04536	1.361	26.17		12.29	370.9	4,160	1.720	0.1969	59.59
1985	0.1814			22.14	0.04536	4.309	985.3	3,953	0.5697		52.45
1986				48.08	0.2268	62.37	1,066	4,275	0.4191		78.71
1987				162.2	0.3629	54.11	1,234	3,306	0.3166	0.2508	98.88
1988				13.65	0.09072	44.77	793.4	3,826	1.186	0.1379	63.53
1989				62.19		40.60	430.8	3,095	0.8845		43.11
1990		0.009072		0.2921		1.301	89.90	2,617	0.5398		47.36
1991		<0.01		14.19	0.3175	2.830	74.45	1,559	*		25.74
1992				23.41	0.3629	8.420	607.5	1,269			35.85
1993				83.20	1.134	90.70	2,388	1,482	*		23.60
1994				53.19	1.361	100.3	2,619	2,094	*		43.55
1995				151.8	5.897	248.7	3,171	2,731	*		10.38
1996			<0.01	282.1	4.391	531.1	4,289	4,519			11.81
1997			0.5938	904.7	4.767	746.0	5,840	4,859	*		16.59
1998			0.01406	466.9	4.703	576.4	6,553	4,929			11.98
1999		<0.01	<0.01	939.4	6.681	706.4	5,845	4,620			12.17
2000		0.01814	0.1293	966.4	5.044	668.8	5,869	4,592			17.22
2001			0.1429	630.4	10.31	995.5	5,912	5,451		*	6.727
2002		0.03039	0.1016	829.4	4.868	666.6	5,735	4,622	*	*	7.789
2003			0.8332	714.7	7.512	686.3	4,961	6,545	0.06350	*	7.438
2004	0.4332	0.5139	16.33	950.9	15.02	1,178	5,376	5,440	*	*	5.176
2005		*	0.08165	838.1	18.14	617.4	4,287	5,399	0.01860	*	7.489
2006			0.6518	733.5	8.744	446.1	3,596	4,716	0.07257	*	13.73
2007			0.2803	616.0	6.189	265.0	4,988	3,312	*		12.26
2008			1.239	445.4	4.018	363.4	5,322	2,627	0.05262	*	12.96

Table 5.1.3.1.1 Estimates of scrap/bait landings (mt) provided by NCDMF. Years prior to the start of the bait sampling program in 1986 were estimated from the proportion of Atlantic 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 Number of gill-net and otter trawl trips observed in the NMFS Observer Program where Atlantic croakers were discarded.

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 Number of trips, discards to landings ratios, standard errors, and estimates of Atlantic croaker discarded from commercial gill-net and otter trawl fisheries based on NMFS observer data.

	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	0.111	832.68
2004	5	0.176	0.20	938.291	8	0.10583	0.0776	7.57
2005	1	0.008	NA	34.7062	7	0.201441	0.0746	20.59
2006	1	0.010	NA	32.93294	4	0.001132	0.00141	0.05
2007	2	0.004	0.00	16.60957	25	0.978156	0.723	288.82
2008	2	0.043	0.00	182.5769	18	0.848476	0.529	233.03

Table 5.1.3.3.3 Estimated discards of Atlantic croaker from commercial gill-net and otter trawl fisheries using the geometric mean of the observed discard to landings ratios.

Year	Period	Gill Net (mt)	Otter Trawl (mt)
1950	Decr	4.82	0
1951	Decr	3.62	0
1952	Decr	2.65	0
1953	Incr	1.26	0
1954	Incr	3.59	0
1955	Incr	13.2	0
1956	Incr	7.66	0
1957	Incr	11.5	0
1958	Incr	7.89	0
1959	Decr	9.29	495
1960	Decr	11.6	313
1961	Decr	3.92	231
1962	Decr	3.87	210
1963	Decr	2.31	282
1964	Decr	2.28	235
1965	Decr	4.02	237
1966	Decr	6.75	208
1967	Decr	2.84	168
1968	Decr	1.56	160
1969	Decr	0.890	205
1970	Decr	1.30	109
1971	Decr	1.78	122
1972	Incr	4.27	1,521
1973	Incr	9.95	847
1974	Incr	7.92	1,285
1975	Incr	12.3	2,906
1976	Incr	25.4	5,078
1977	Incr	43.8	5,899
1978	Decr	43.4	2,242
1979	Decr	41.1	1,541
1980	Decr	67.7	1,133
1981	Decr	23.8	426
1982	Decr	22.1	466
1983	Decr	16.1	222
1984	Incr	38.5	1,188
1985	Incr	41.5	1,230

Table 5.1.3.3.3 *Continued*.

Year	Period	Gill Net (mt)	Otter Trawl (mt)
1986	Incr	56.3	1,256
1987	Decr	52.9	371
1988	Decr	56.4	360
1989	Decr	31.1	311
1990	Decr	17.0	81.5
1991	Decr	17.2	77.0
1992	Incr	26.6	400
1993	Incr	56.6	1,047
1994	Incr	69.3	1,506
1995	Incr	72.5	1,986
1996	Incr	120	2,661
1997	Incr	120	4,709
1998	Incr	171	3,132
1999	Steady	83.9	1,861
2000	Steady	113	1,734
2001	Steady	120	1,676
2002	Steady	103	1,656
2003	Decr	155	2,010
2004	Decr	203	1,607
2005	Decr	172	1,566
2006	Decr	130	1,442
2007	Decr	147	1,163
2008	Decr	162	944

Table 5.1.3.3.4 Discard to landings (D:L) ratios used to estimate discards in years without observer coverage.

	Gill Net		Otter Trawl	
Period	**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.

Year	Intercept (Type A only)		Headboat (Type B only)
	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.

Year	Harvest (Type A+B1)				Released Alive (Type B2)	
	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 Annual estimates of recreational fishery CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) for Atlantic croaker along the Atlantic coast based on the directed trips method, 1981–2008.

	Total Catch (A+B1+B2)			Harvest (A+B1)		
Year	**CPUE**	**PSE[CPUE]**	**# Directed Interviews**	**CPUE**	**PSE[CPUE]**	**# Directed Interviews**
1981	4.17	11.4	484	3.21	13.0	427
1982	4.16	16.5	683	3.41	20.0	581
1983	4.82	11.1	1,238	3.41	17.6	809
1984	5.78	8.52	1,035	4.76	10.4	882
1985	6.31	14.9	2,544	3.95	9.49	2,101
1986	10.5	11.7	2,849	9.64	14.4	2,510
1987	7.68	8.85	2,000	5.68	11.2	1,624
1988	7.98	7.29	1,770	7.00	8.84	1,549
1989	7.15	4.45	3,326	5.73	5.74	2,852
1990	9.40	6.23	2,169	5.54	7.74	1,644
1991	9.33	5.85	2,820	5.09	8.26	1,802
1992	8.14	5.73	3,236	5.67	8.14	2,351
1993	8.92	5.38	2,636	5.52	7.86	1,740
1994	8.94	3.70	5,646	5.67	5.29	3,883
1995	7.23	5.14	3,639	5.11	7.40	2,516
1996	7.43	5.66	3,615	5.09	8.84	2,502
1997	9.28	5.91	4,199	6.84	9.45	2,812
1998	7.65	4.61	4,990	5.63	7.60	3,161
1999	8.76	4.27	5,206	5.84	7.33	3,279
2000	8.00	3.95	4,525	4.87	6.48	2,909
2001	7.32	3.48	4,999	5.56	5.23	3,495
2002	8.29	3.34	5,218	6.00	4.92	3,427
2003	7.04	3.28	5,408	4.93	4.73	3,632
2004	6.64	4.04	4,802	5.13	6.07	3,454
2005	7.41	4.48	5,261	5.33	6.56	3,877
2006	6.63	5.10	4,034	5.29	8.89	2,528
2007	7.30	3.64	5,258	4.99	5.41	3,652
2008	7.53	3.84	5,109	5.51	6.14	3,293

Table 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 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 5.3.5.1 Atlantic croaker indices of abundance used in modeling.

	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

Table 6.1.3.1 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_{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 6.1.4.1 Values assumed for growth functions in the hybrid model.

Function	Parameter	Value
Age-Length (cm)	L_∞	43.1
	K	0.214
	a_0	-2.35
Length (cm)-Weight (kg)	α	7.30E-06
	β	3.14

Table 6.1.4.2 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 6.1.4.3 Age-specific selectivity values used in base run of the hybrid model.

	Commercial		Recreational			Fisheries-Independent			
Age	**Landings**	**Scrap/ Discard**	**Harvest**	**Discards**	**CPUE**	**NEFSC**	**SEAMAP**	**VIMS**	**NC P195**
0	0.03	0.16	0.11	0.15	0.15	0.28	1.00	1.00	1.00
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	0	0
4	1.00	0.20	0.98	1.00	1.00	0.77	0	0	0
5	1.00	0.10	1.00	0.73	1.00	0.61	0	0	0
6	1.00	0.05	1.00	0.32	1.00	0.45	0	0	0
7	1.00	0.03	1.00	0.10	1.00	0.25	0	0	0
8	1.00	0.01	1.00	0.03	1.00	0.09	0	0	0
9	1.00	0.01	1.00	0.01	1.00	0.02	0	0	0
10	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0
11	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0
12	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0
13	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0
14	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0
15	1.00	0.00	1.00	0.00	1.00	0.00	0	0	0

Table 7.1.2.1 Values of virgin recruitment (R_0), the ratio of *SSB* in the initial model year to the virgin level of spawning stock biomass (SSB_{Ratio}), and catchability coefficients (q_i) estimated by the base run of the hybrid model.

Parameter	Value
$\log_e(R_0)$	19.1
SSB_{Ratio}	0.572
$\log_e(q)$	
Rec. CPUE	-17.1
NMFS	-13.3
SEAMAP	-6.63
VIMS	-18.2
NC195	-13.6

Table 7.1.2.2 Annual recruitment deviations (V_y) estimated by the base run of the hybrid model.

Year	**$\log_e(V_y)$**
1982	-1.41
1983	1.38
1984	-0.510
1985	-0.359
1986	0.734
1987	-0.346
1988	-1.29
1989	-0.480
1990	-0.848
1991	-0.0477
1992	0.188
1993	0.493
1994	0.283
1995	-0.0384
1996	-1.02
1997	0.676
1998	1.52
1999	0.467
2000	-0.851
2001	-1.08
2002	1.29
2003	-0.920
2004	0.488
2005	0.0304
2006	0.405
2007	-0.00273
2008	1.25

Table 7.1.2.3 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	0.229	0.144	0.0308	0.000643
1982	0.258	0.194	0.0415	0.000636
1983	0.176	0.162	0.0341	0.00131
1984	0.169	0.0884	0.0601	0.000894
1985	0.118	0.0871	0.0246	0.000850
1986	0.127	0.0788	0.0584	0.000487
1987	0.102	0.0524	0.0294	0.000750
1988	0.0859	0.0670	0.0419	0.000458
1989	0.0692	0.110	0.0209	0.000472
1990	0.0573	0.103	0.0158	0.00100
1991	0.0362	0.101	0.0248	0.00278
1992	0.0447	0.0903	0.0259	0.00165
1993	0.112	0.0810	0.0295	0.00264
1994	0.0992	0.177	0.0458	0.00282
1995	0.124	0.117	0.0376	0.00166
1996	0.192	0.0430	0.0386	0.00183
1997	0.283	0.0263	0.0847	0.00367
1998	0.349	0.637	0.0971	0.00457
1999	0.281	0.0298	0.0832	0.00430
2000	0.187	0.0410	0.0823	0.00512
2001	0.195	0.0626	0.0884	0.00317
2002	0.225	0.345	0.0847	0.00357
2003	0.274	0.229	0.0972	0.00471
2004	0.262	0.0319	0.0949	0.00418
2005	0.253	0.104	0.117	0.00573
2006	0.222	0.0102	0.103	0.00482
2007	0.220	0.0458	0.0969	0.00448
2008	0.203	0.0464	0.0585	0.00335

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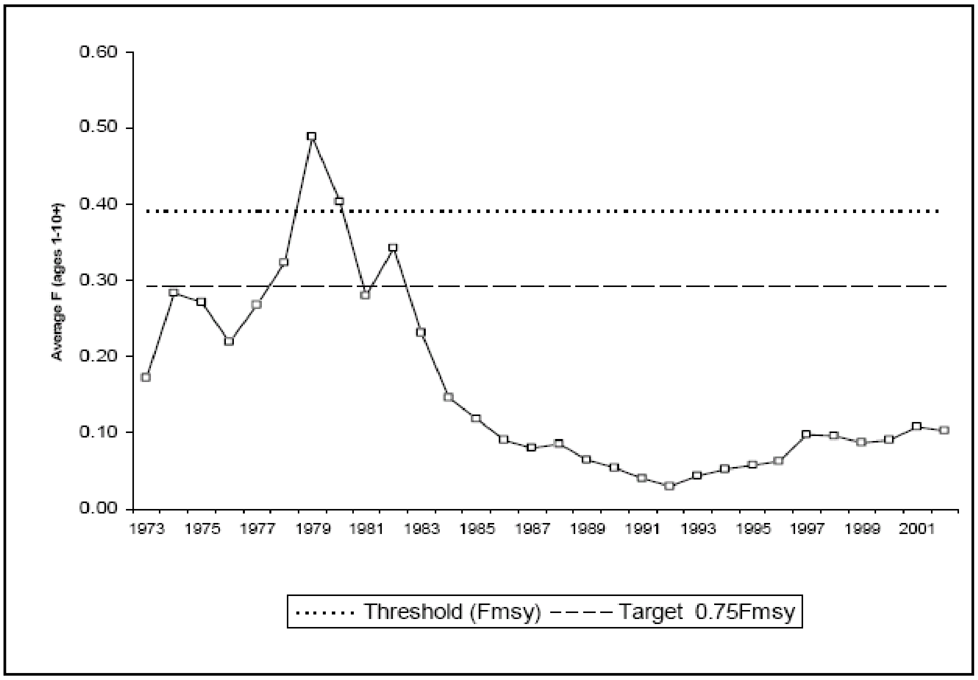


Figure 1.3.5.1 Fishing mortality rates and reference points estimated from the base run of the 2003/2004 ASMFC assessment (mid-Atlantic region only).

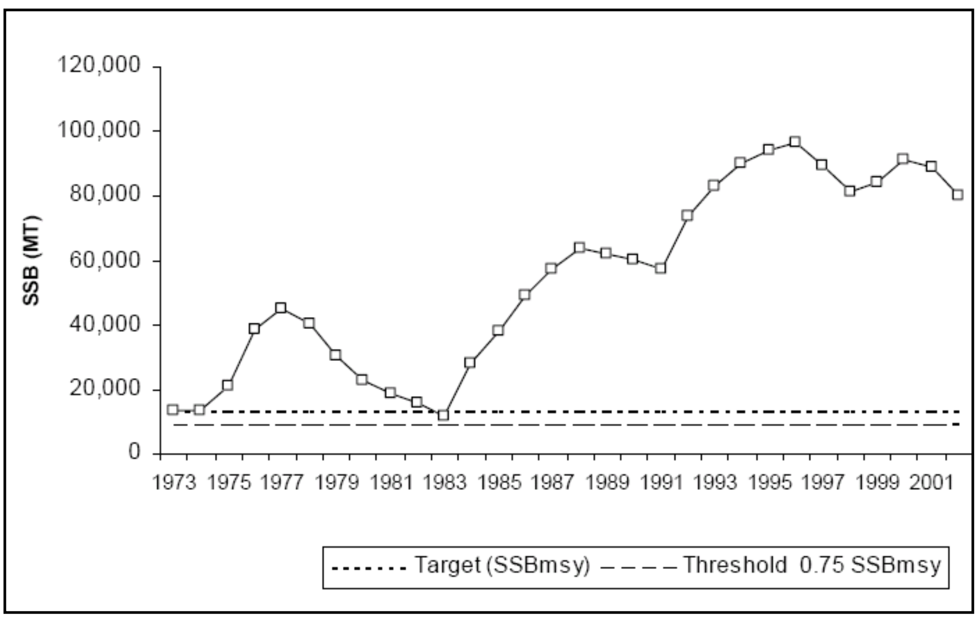


Figure 1.3.5.2 Abundance and reference points estimated from the base run of the 2003/2004 ASMFC assessment (mid-Atlantic region only).

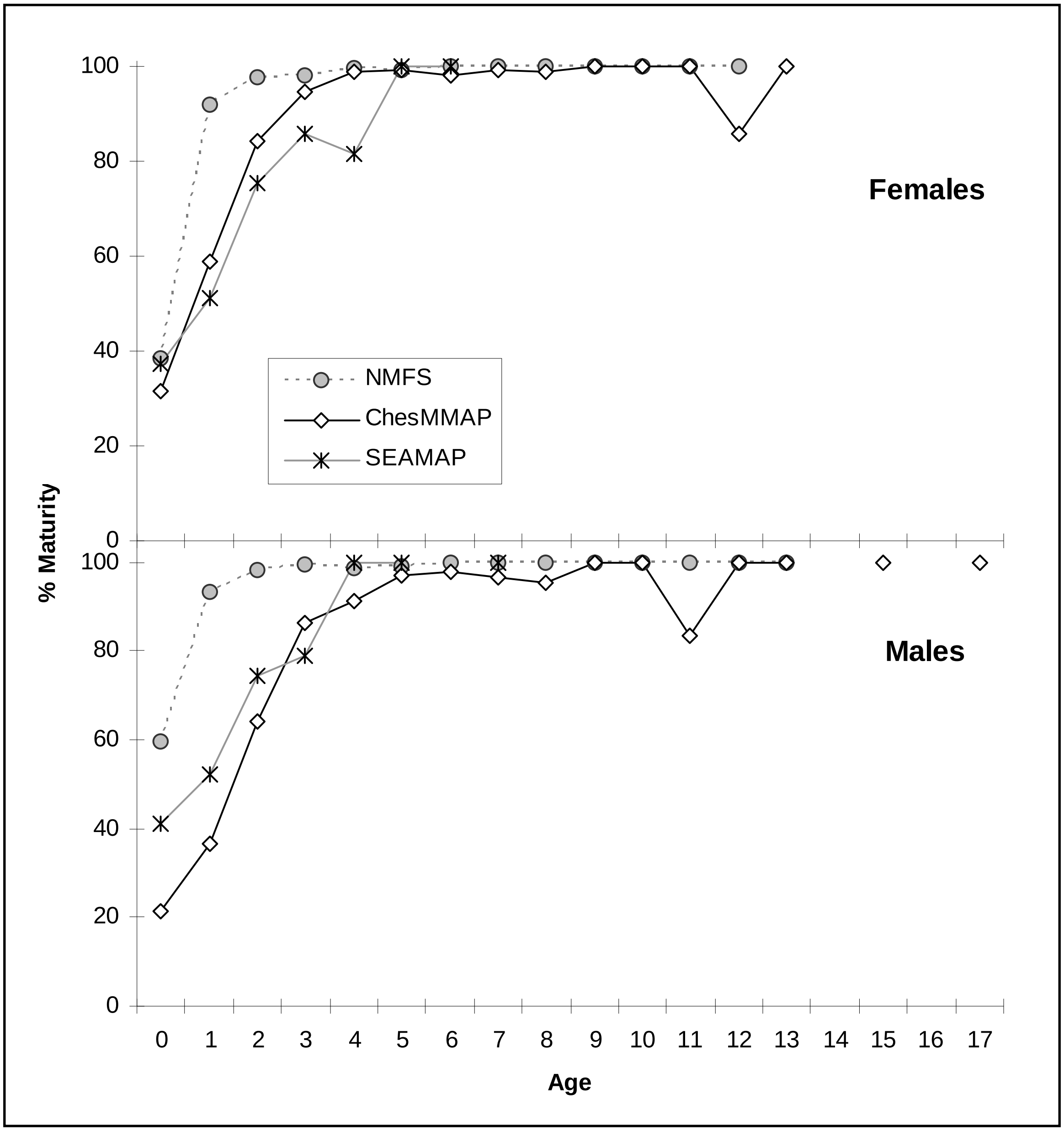


Figure 2.3.2.1 Estimated maturity schedule for Atlantic croaker females and males based on available datasets, pooled over years.

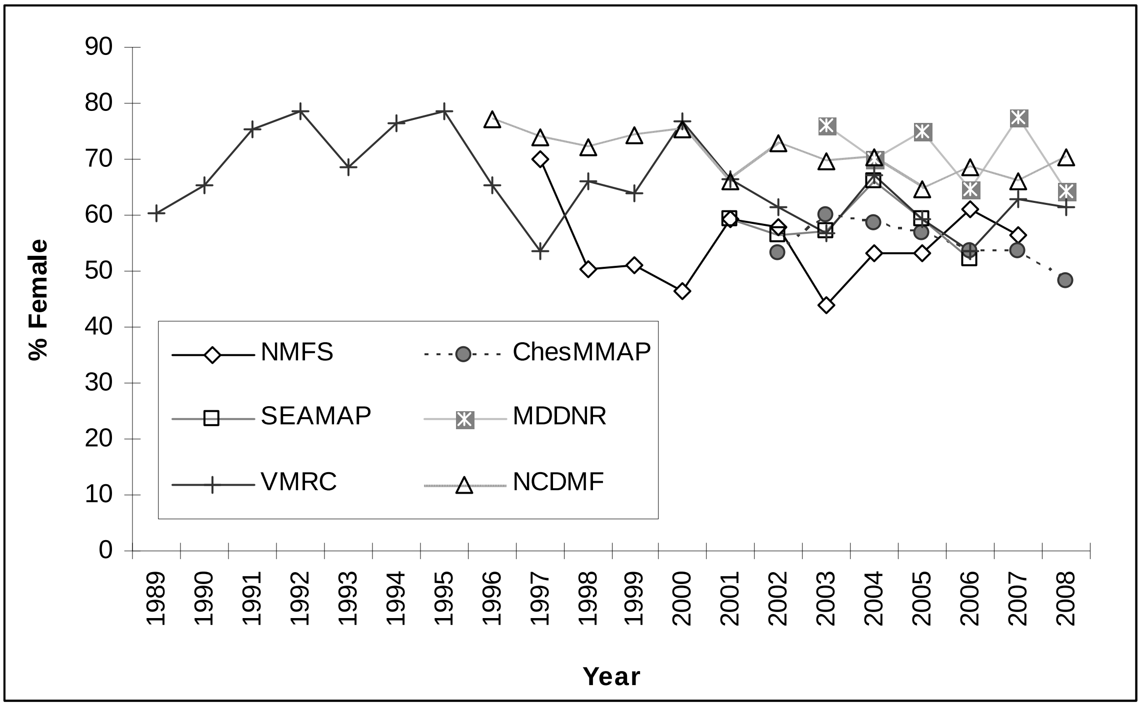


Figure 2.3.3.1 Estimated percent female Atlantic croaker for available datasets, by year.

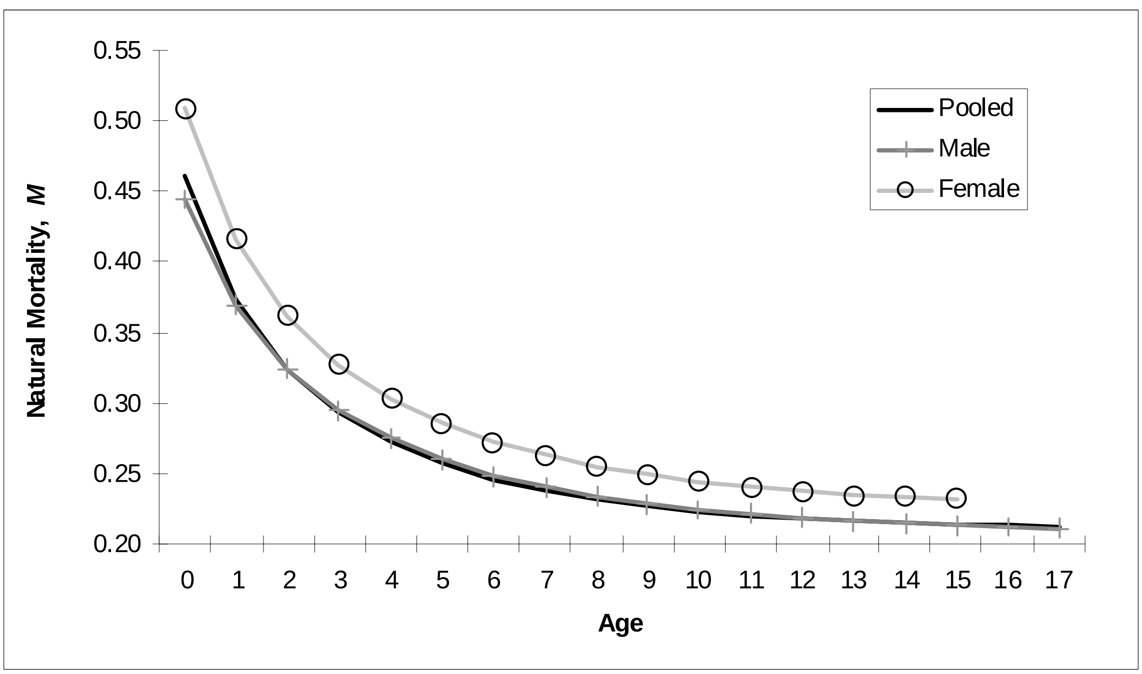


Figure 2.4.2.1 Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using all available data (fisheries-dependent and fisheries-independent data combined).

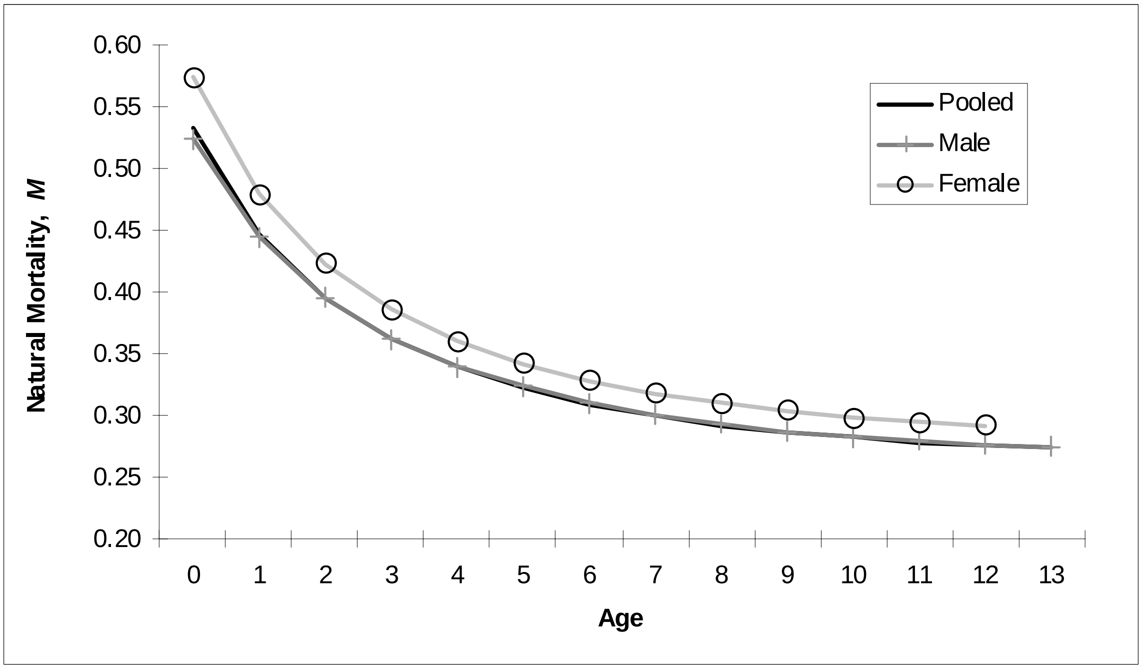


Figure 2.4.2.2 Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the NMFS Trawl Survey.

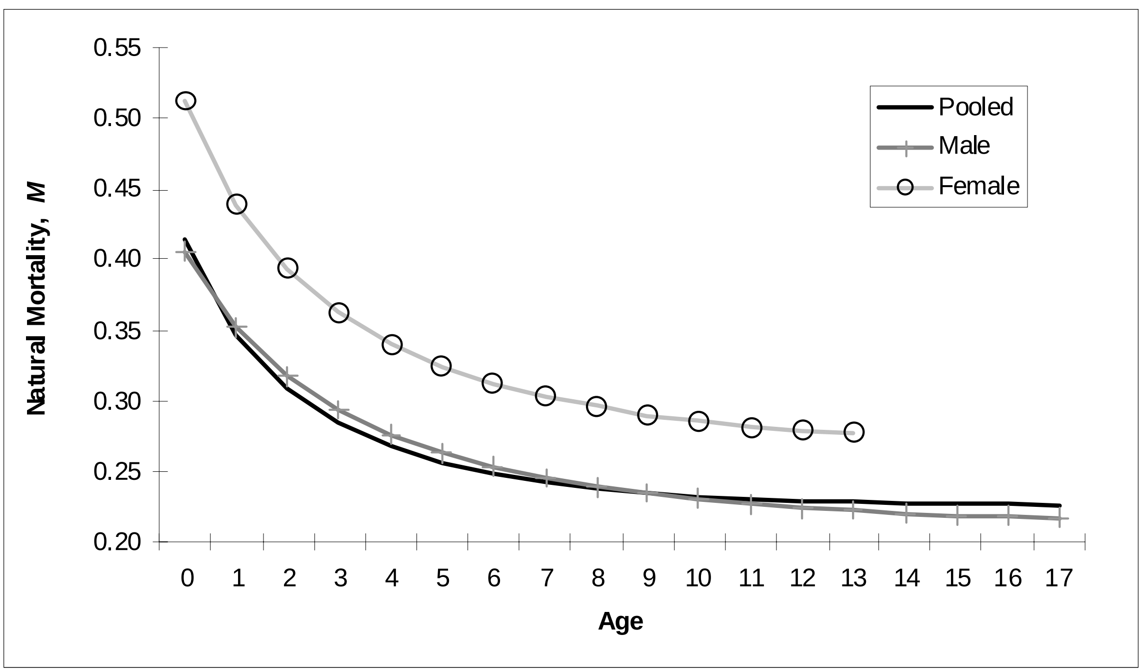


Figure 2.4.2.3 Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the ChesMMAP Trawl Survey.

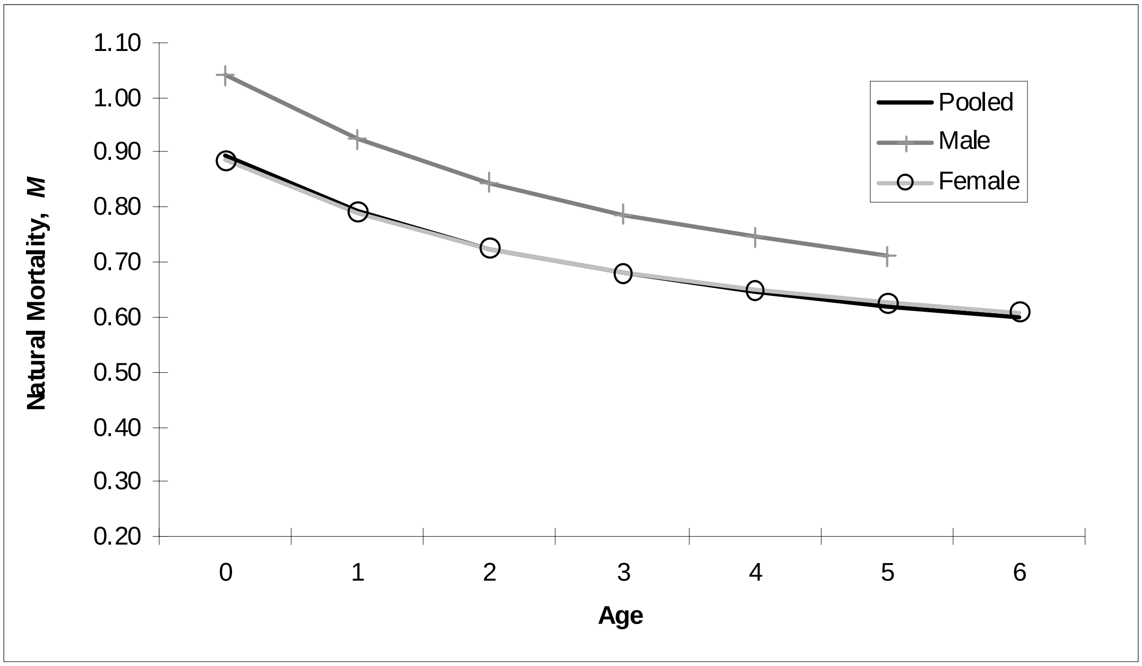


Figure 2.4.2.4 Estimates of age-specific natural mortality (*M*) for Atlantic croaker based on Lorenzen's method using available data from the SEAMAP Trawl Survey.

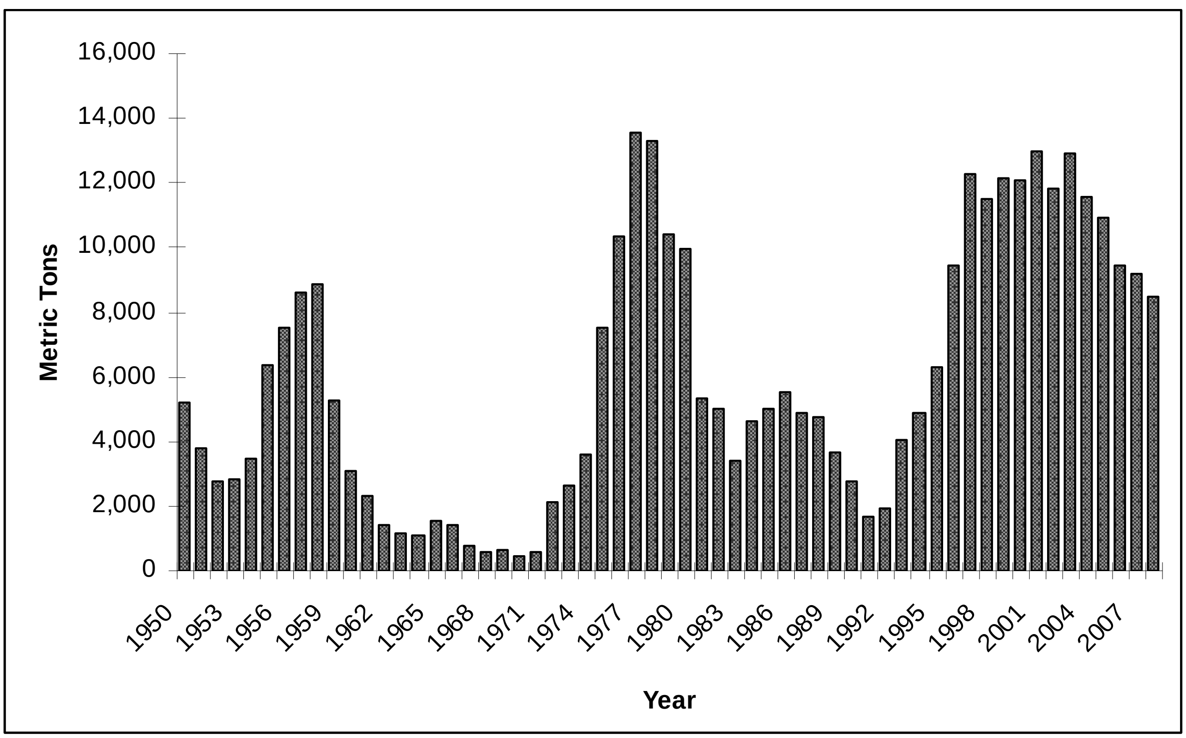
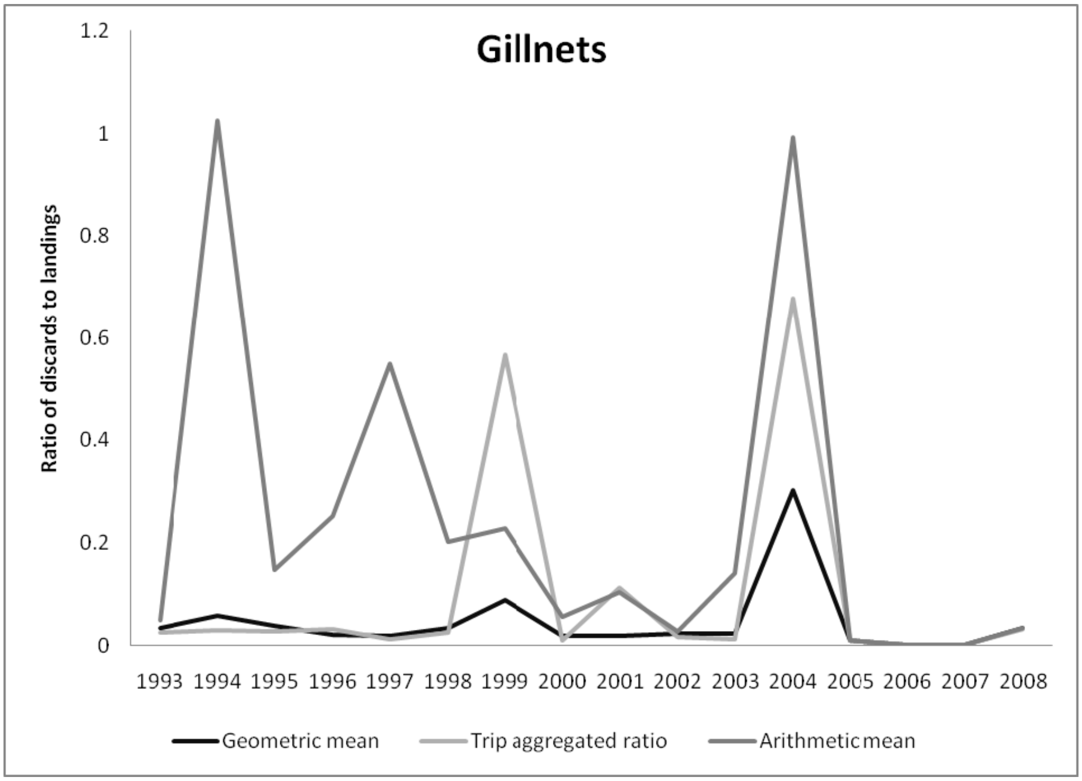
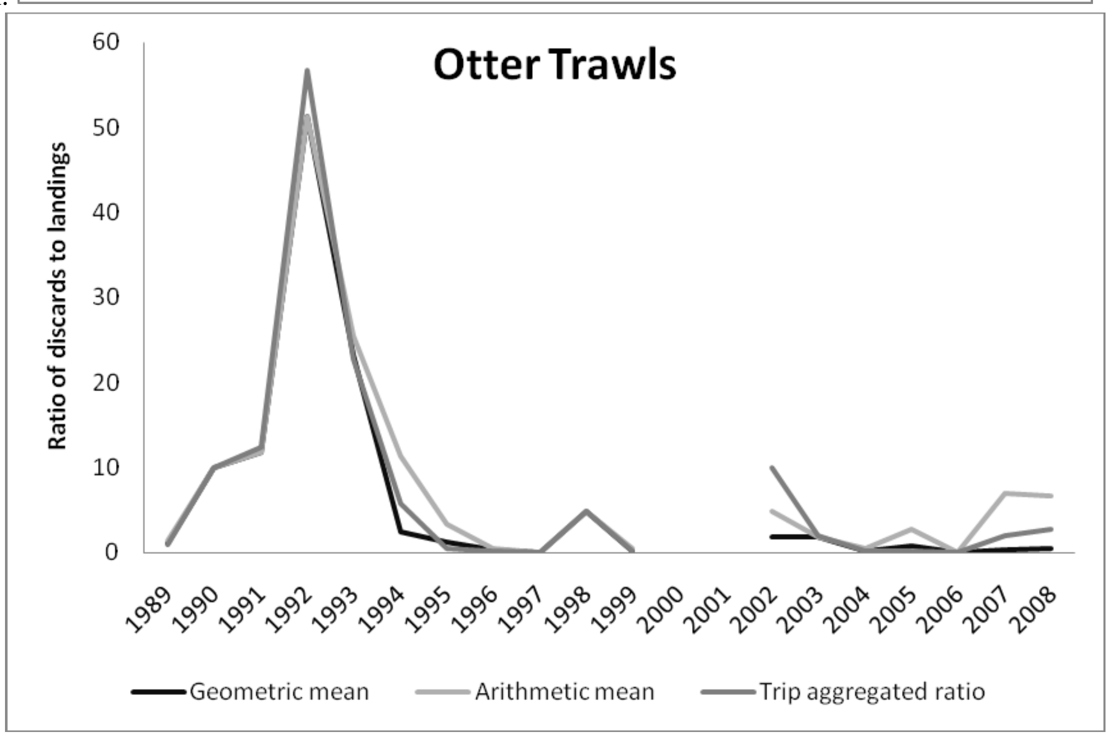


Figure 5.1.2.1 Annual commercial landings (metric tons) of Atlantic croaker along the Atlantic coast, 1950–2008.



A.



B.

Figure 5.1.3.3.1 Ratios of discards to landings of Atlantic croaker for gill nets (A) and otter trawls (B) calculated from trip level data using three different methods.

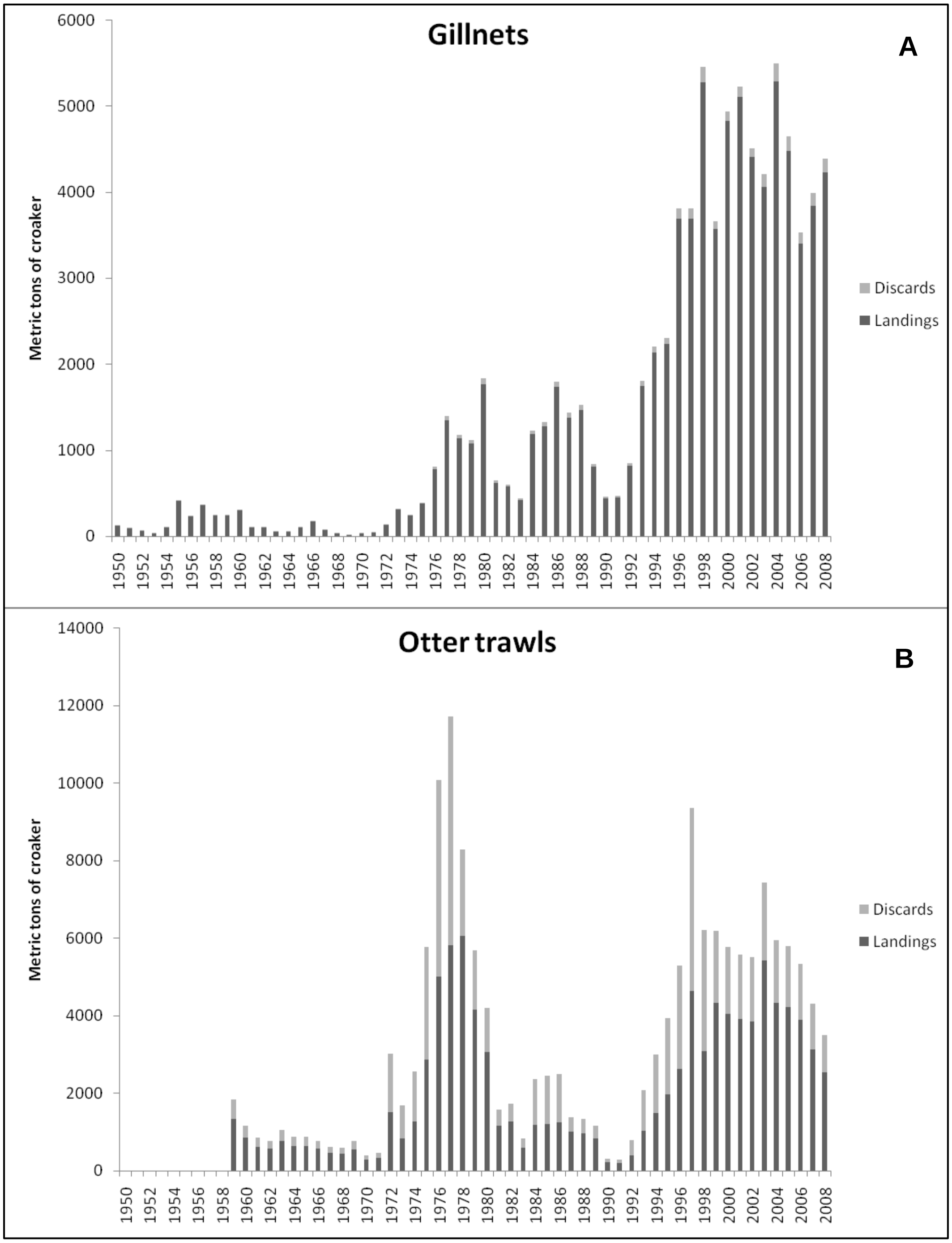


Figure 5.1.3.3.2 Landings and discards of Atlantic croaker for gill nets (A) and otter trawls (B) estimated using the geometric mean of the observed discard to landings ratios.

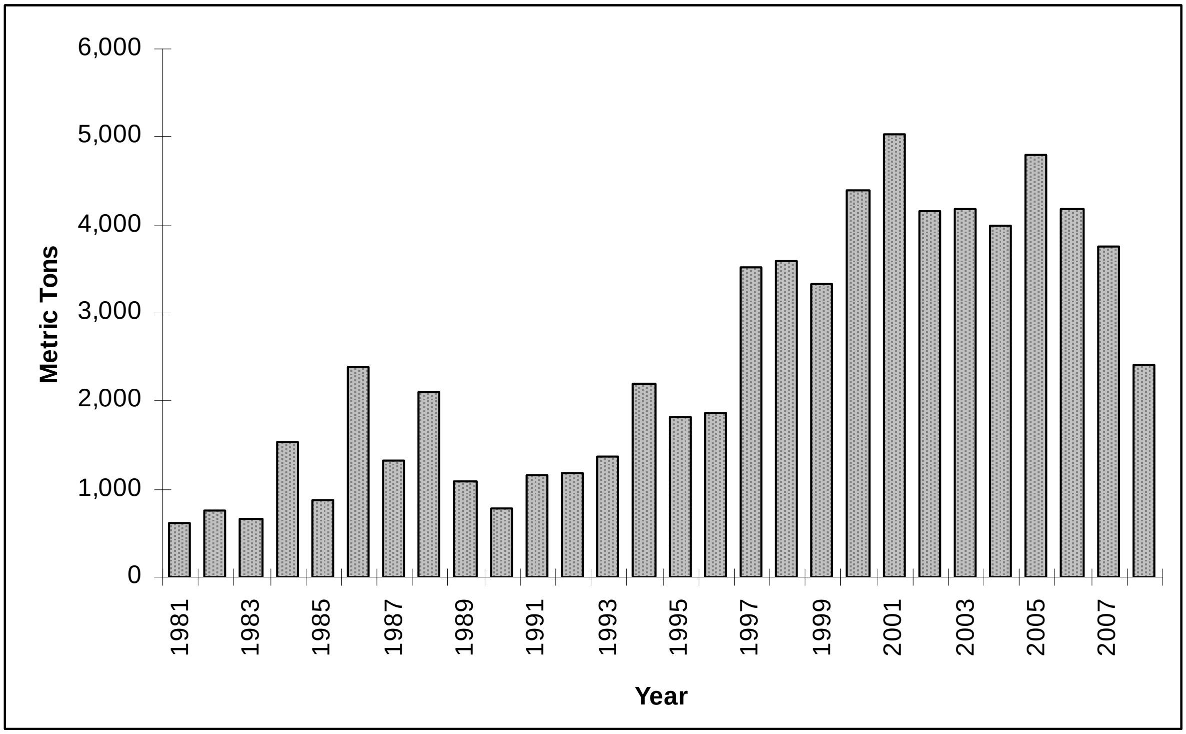


Figure 5.2.2.1 Annual recreational harvest (metric tons) of Atlantic croaker along the Atlantic coast, 1981–2008.

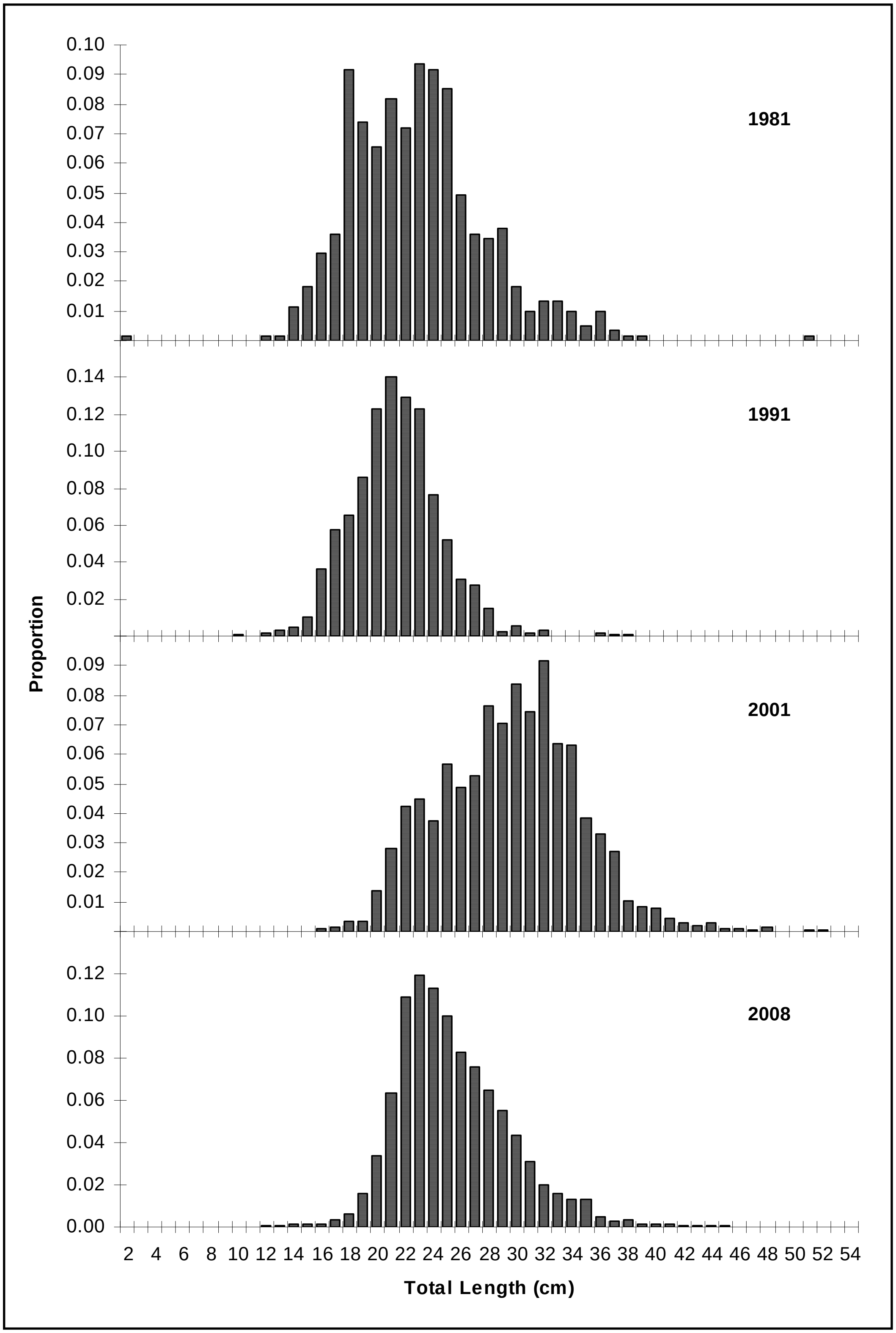


Figure 5.2.2.2 Length-frequency distribution of Atlantic croaker harvested (Type A+B1) by recreational fisheries along the Atlantic coast, for selected years.

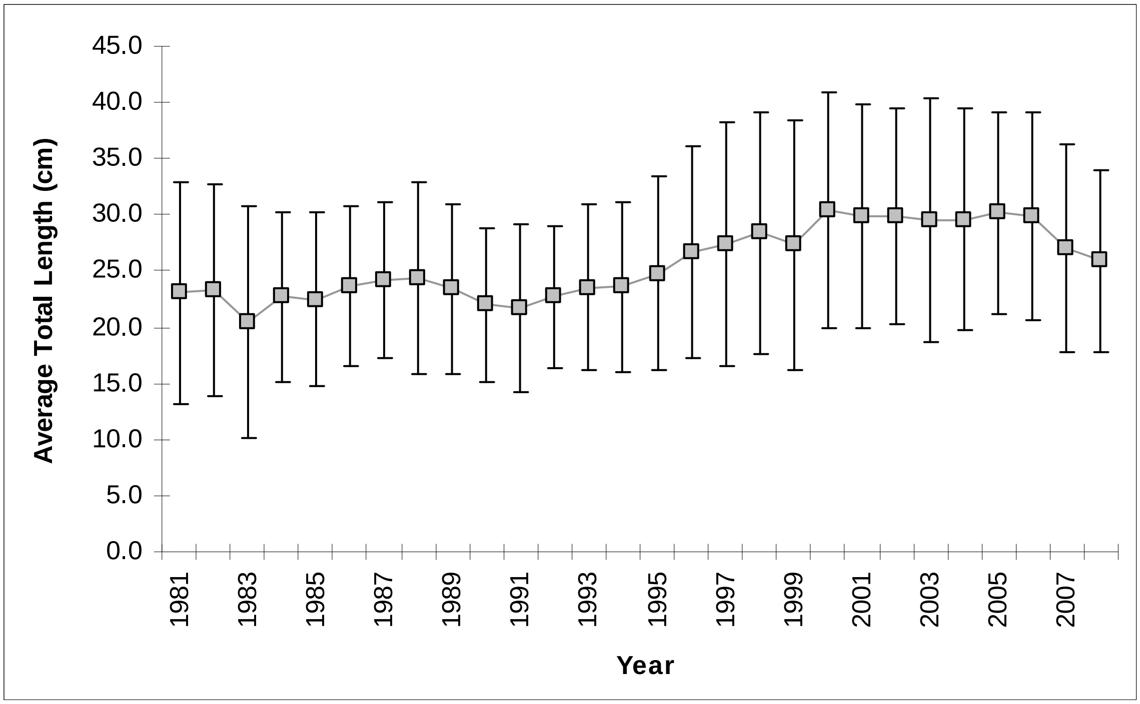


Figure 5.2.2.3 Annual average total length (cm) of Atlantic croaker harvested (Type A+B1) by recreational fisheries along the Atlantic coast, 1981–2008. The vertical bars represent plus and minus two standard deviations of the average lengths.

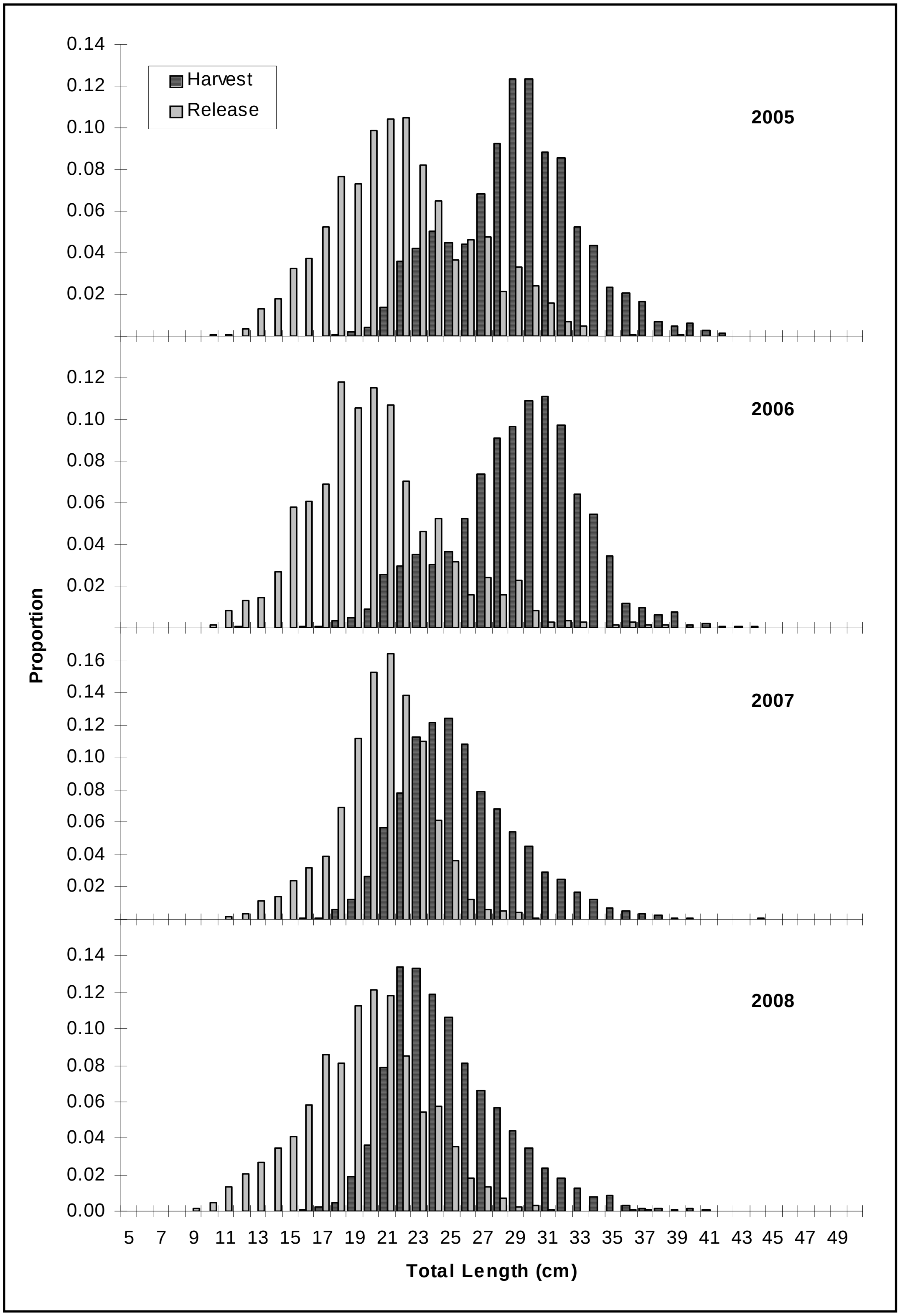


Figure 5.2.2.4 Length-frequency distributions of Atlantic croaker sampled by the MRFSS from recreational headboat harvest (Type A+B1) and live releases (Type B2) along the Atlantic coast, 2005–2008.

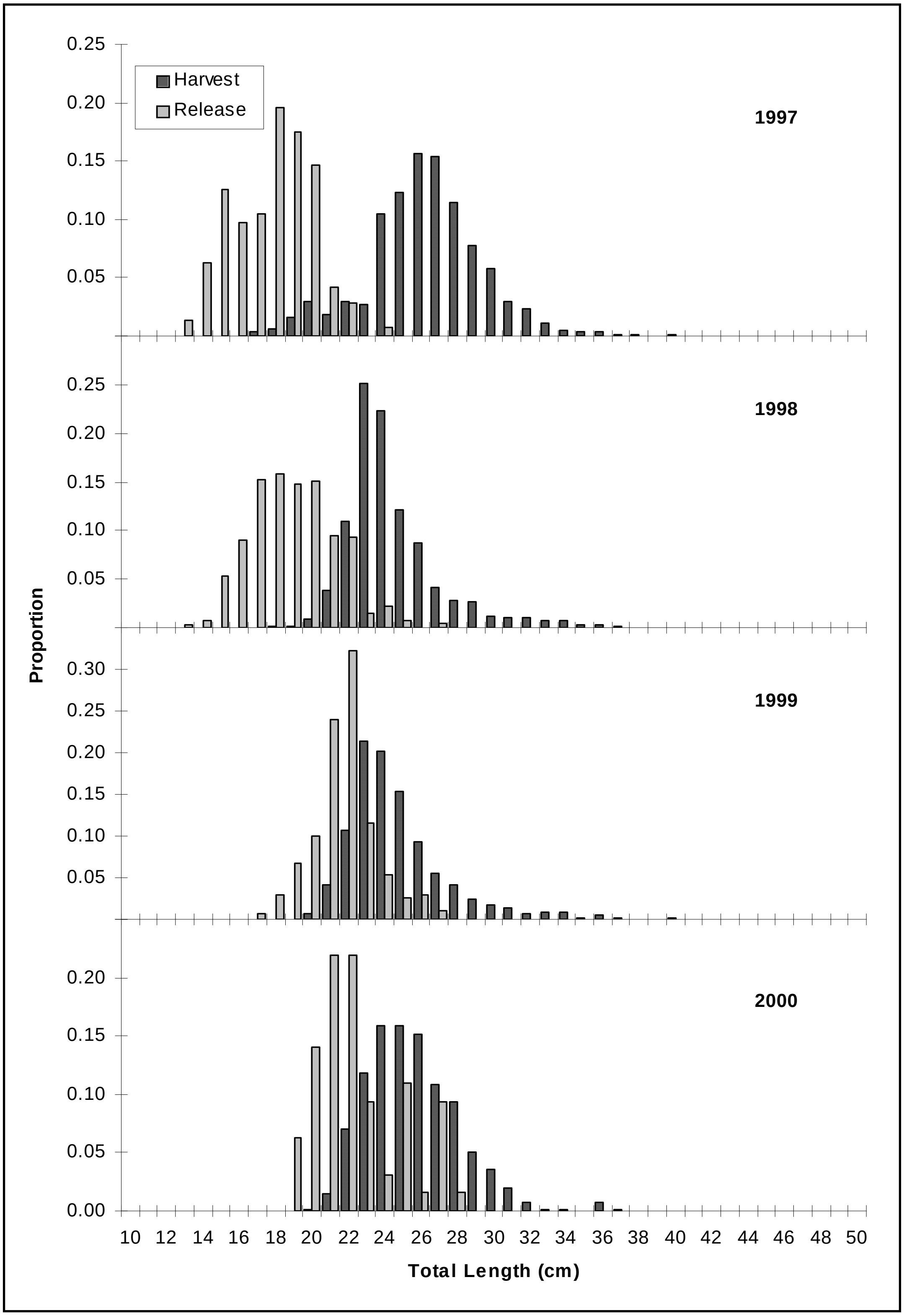


Figure 5.2.3.1 Length-frequency distribution of Atlantic croaker sampled during Maryland's headboat survey of recreational headboat harvest and releases in Maryland, 1997–2000.

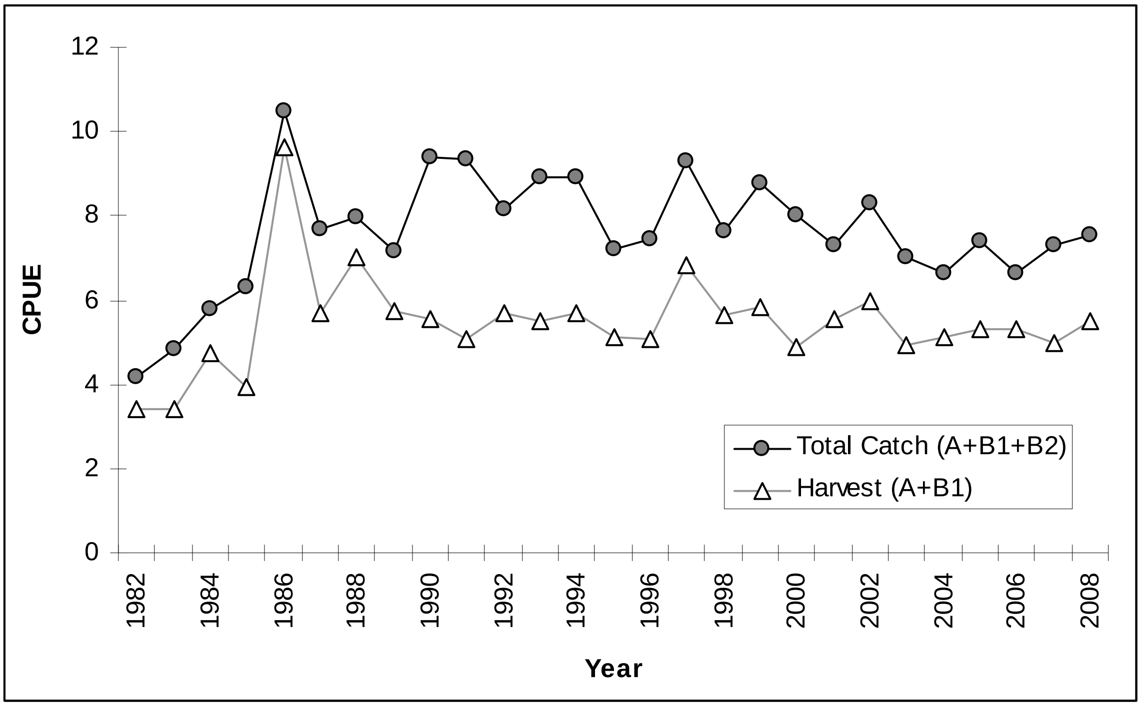


Figure 5.2.4.1 Annual estimates of recreational CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) based on the directed trips method, 1982–2008.

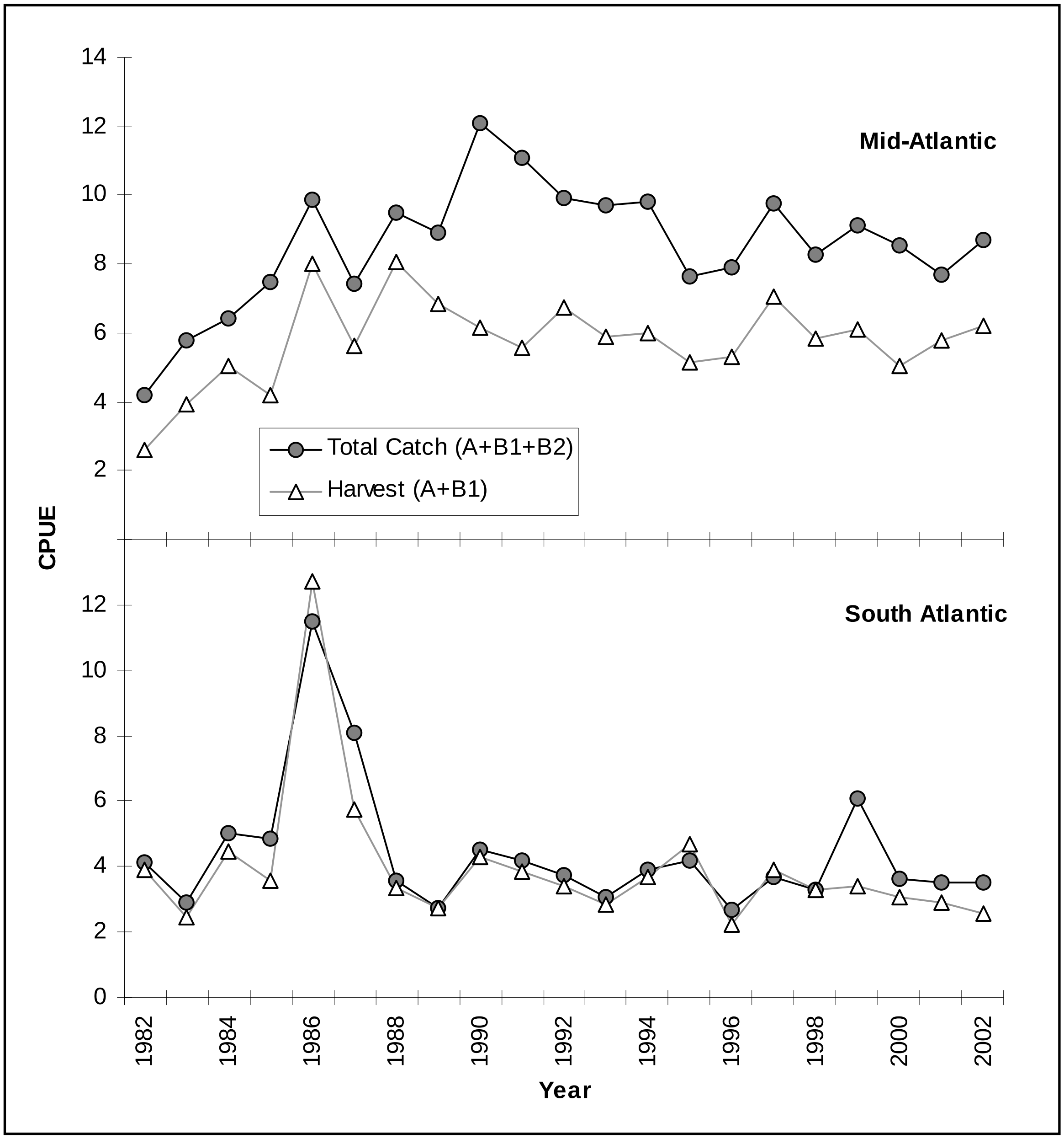


Figure 5.2.4.2 Annual estimates of recreational fishery CPUE (Type A+B1+B2) and harvest-per-unit-effort (Type A+B1) for Atlantic croaker in the mid-Atlantic (New Jersey to North Carolina) and south Atlantic (South Carolina to Florida) regions based on the directed trips method, 1982–2002.

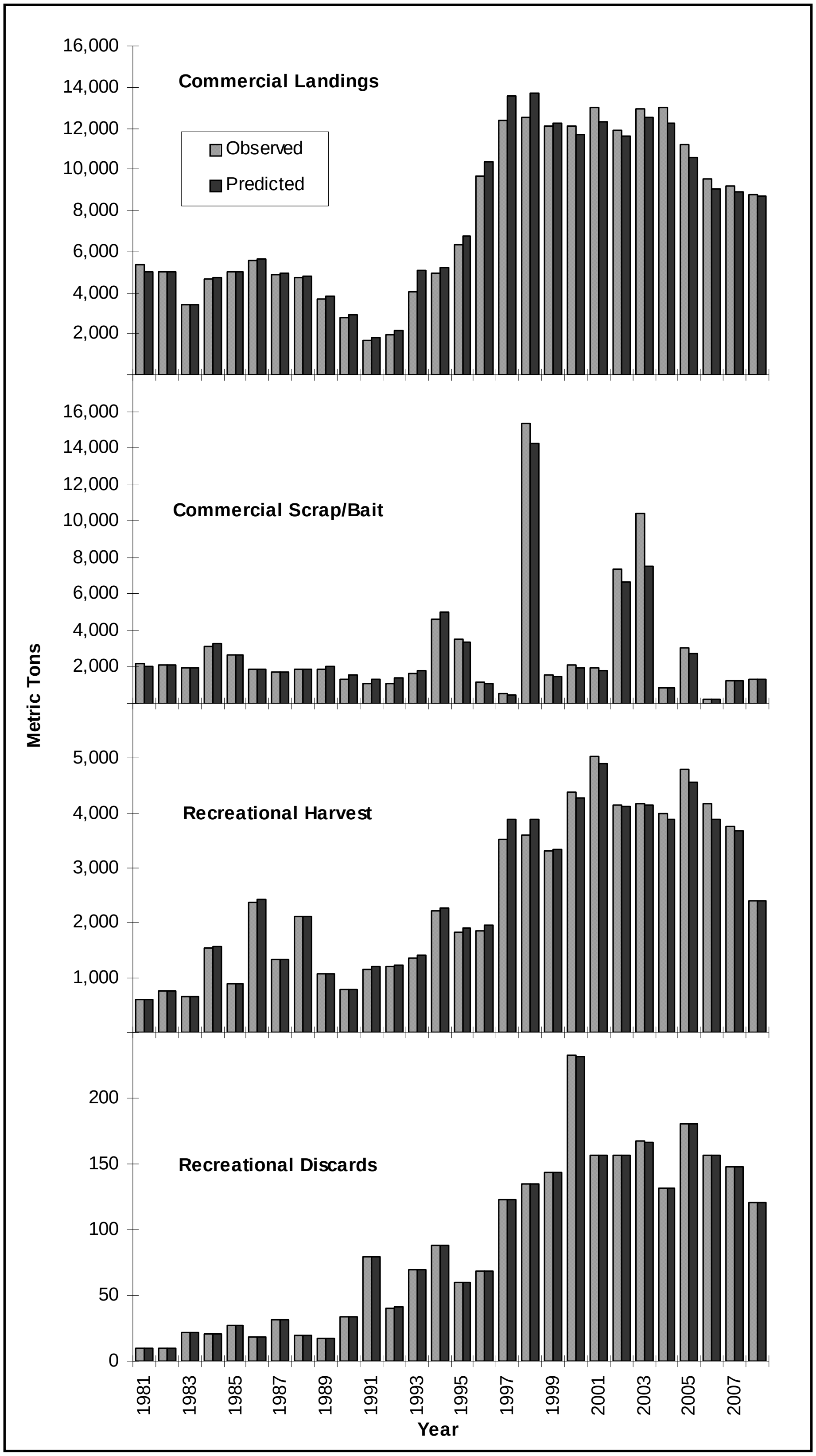


Figure 7.1.1.1 Observed and predicted catches from the base run of the hybrid model.

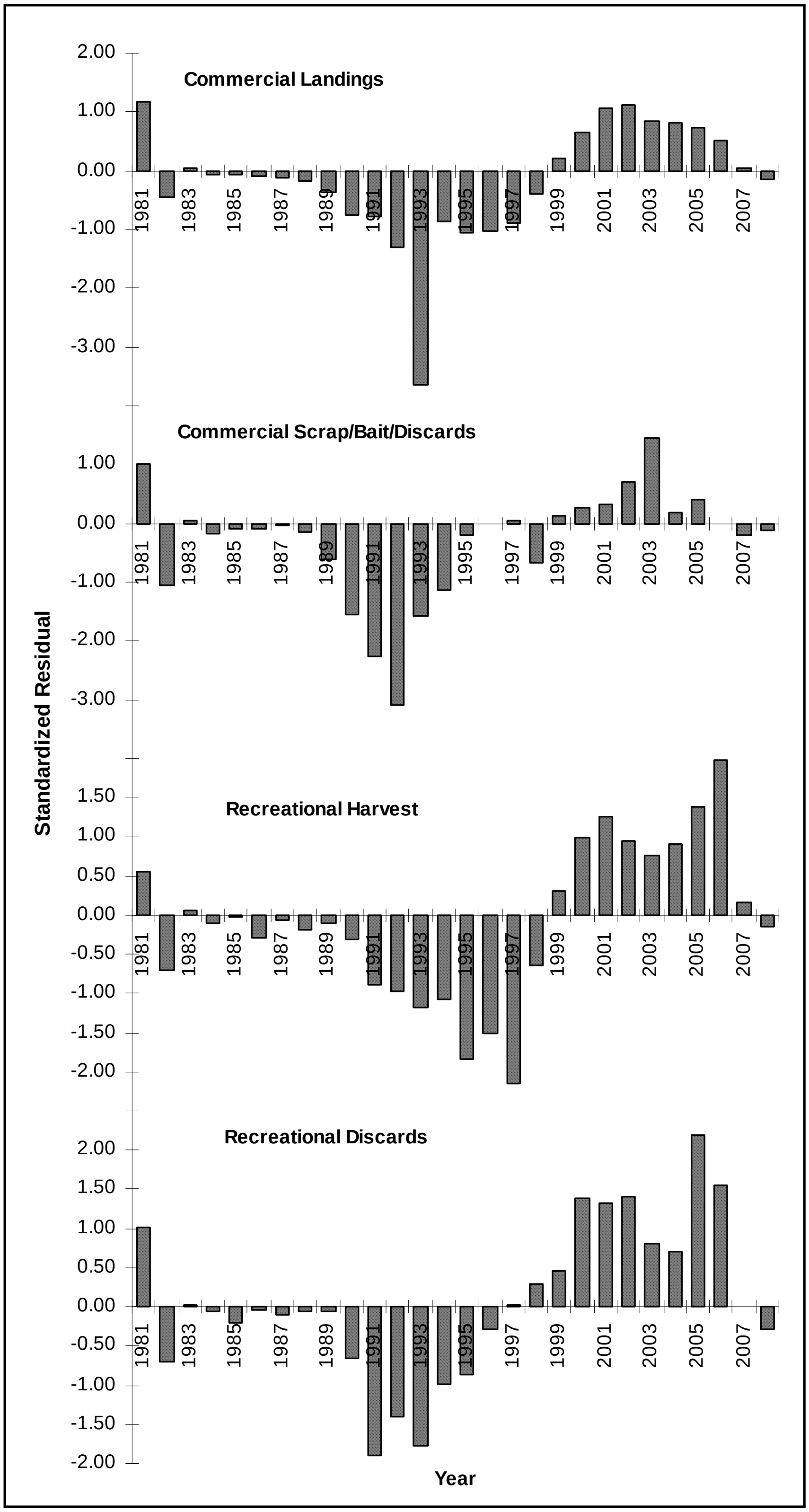


Figure 7.1.1.2 Standardized residuals for catch of each fleet from the base run of the hybrid model.

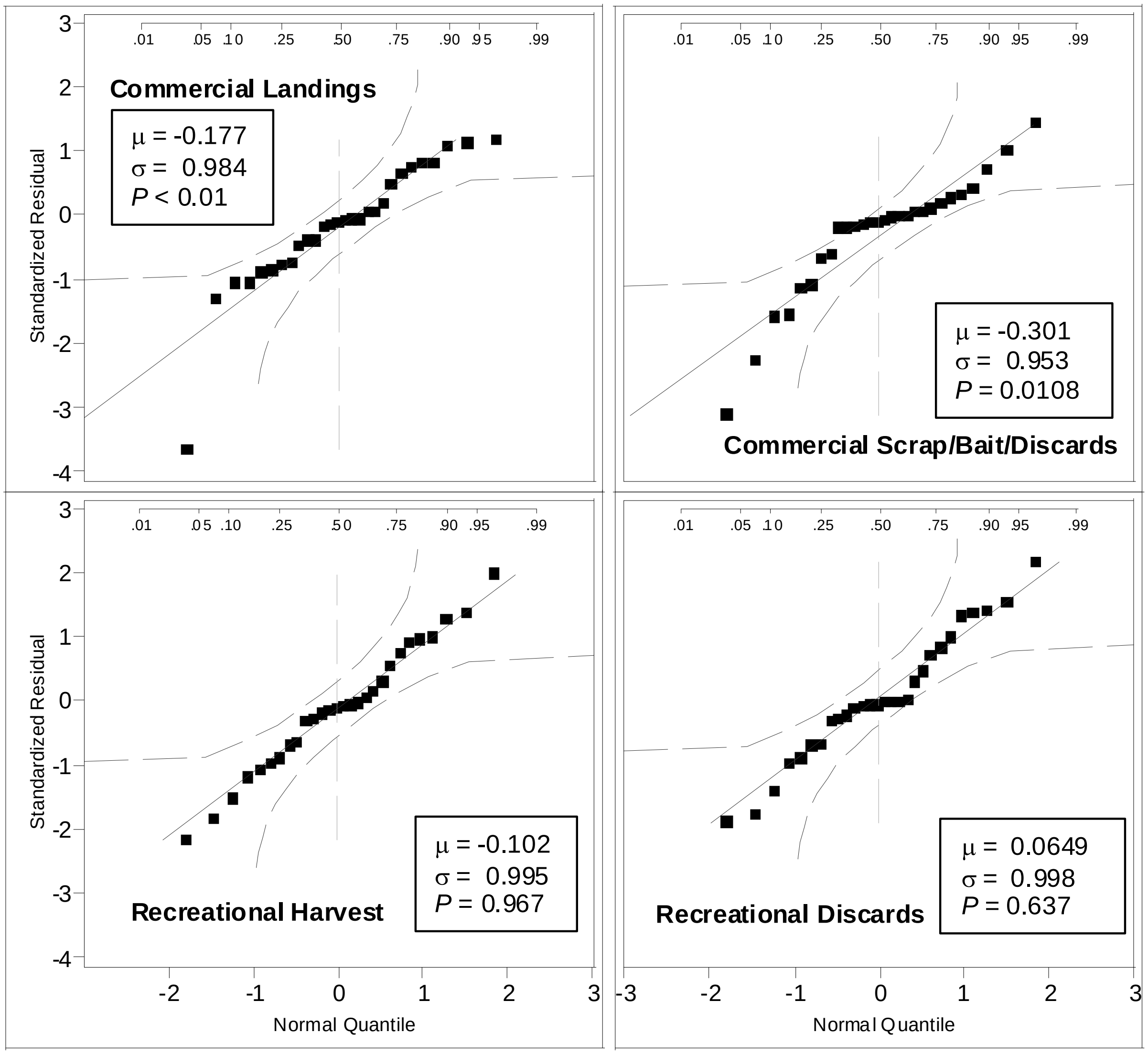


Figure 7.1.1.3 Normal quantile plots (Q-Q plots) of the standardized residuals for catch of each fleet from the base run of the hybrid model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

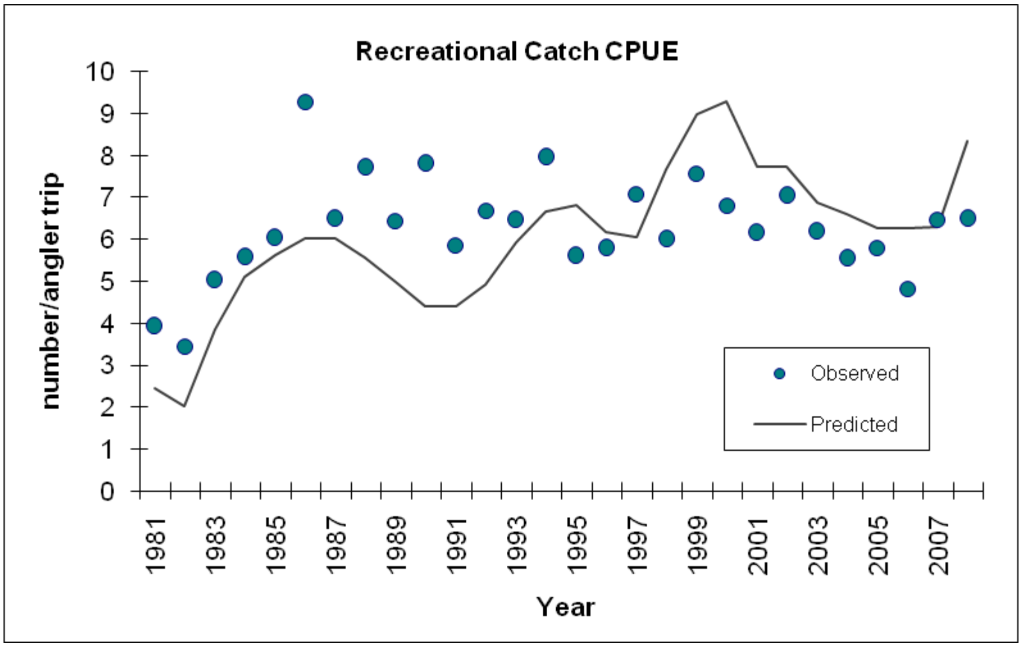


Figure 7.1.1.4 Observed and predicted recreational CPUE from the base run of the hybrid model.

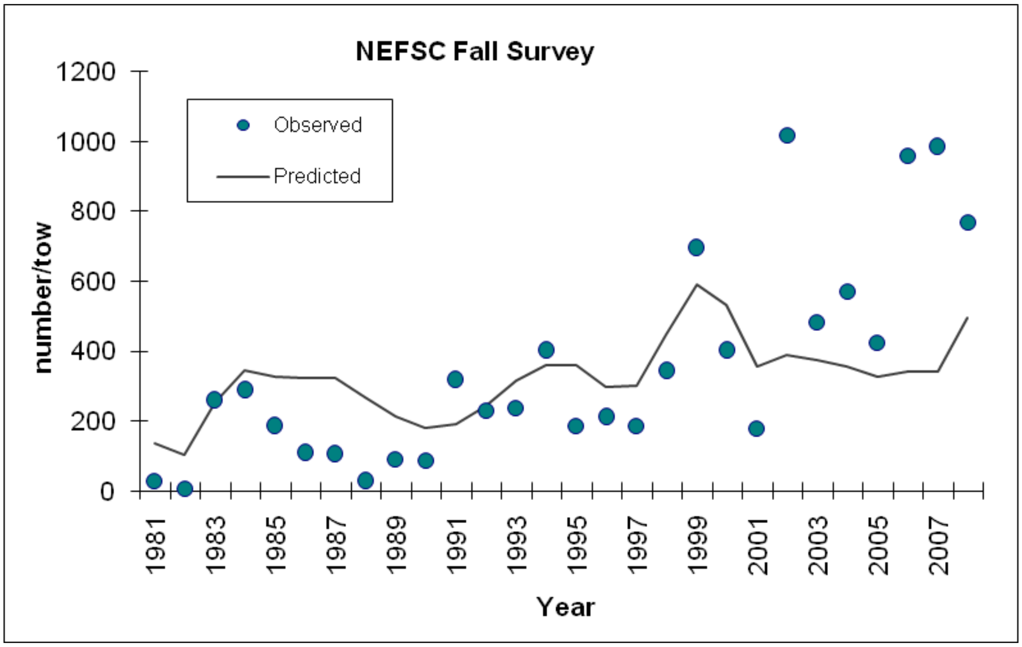


Figure 7.1.1.5 Observed and predicted NMFS Bottom Trawl Survey index from the base run of the hybrid model.

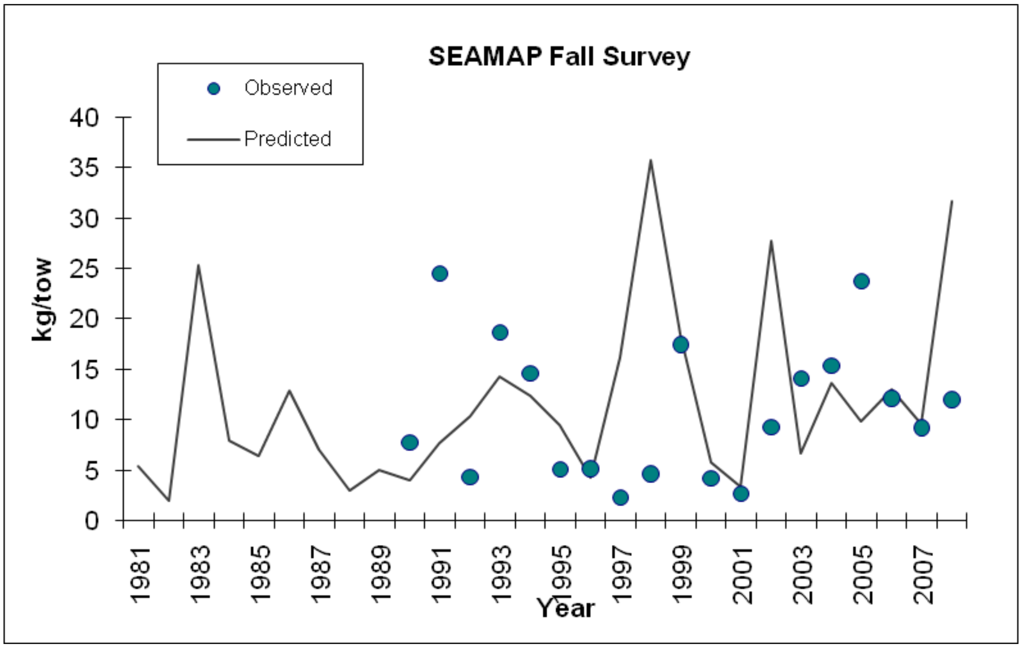


Figure 7.1.1.6 Observed and predicted SEAMAP-SA Coastal Survey index from the base run of the hybrid model.

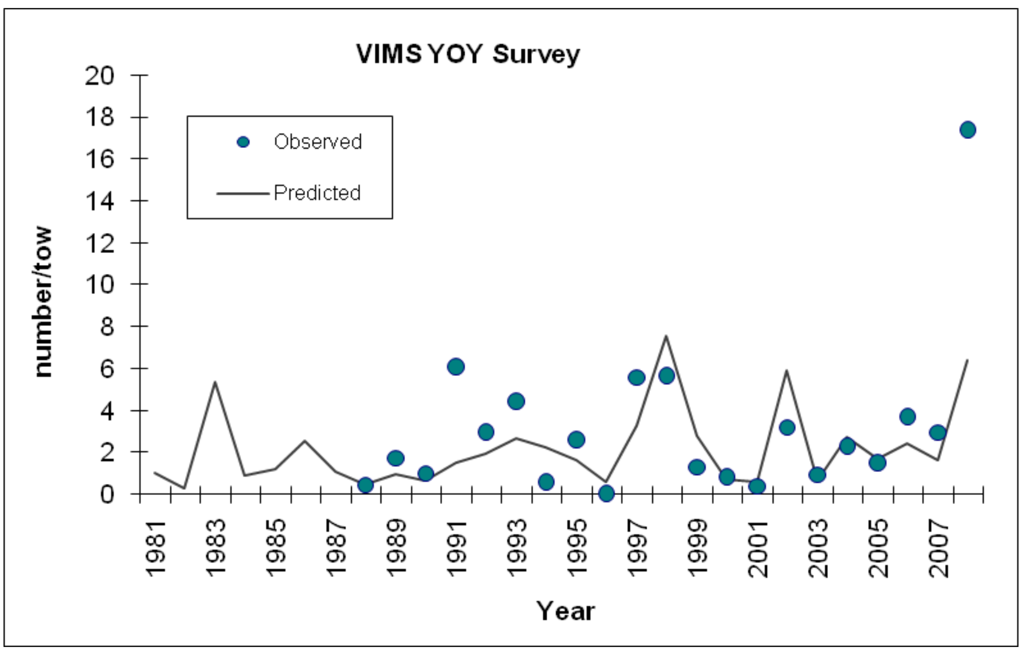


Figure 7.1.1.7 Observed and predicted VIMS young-of-year index from the base run of the hybrid model.

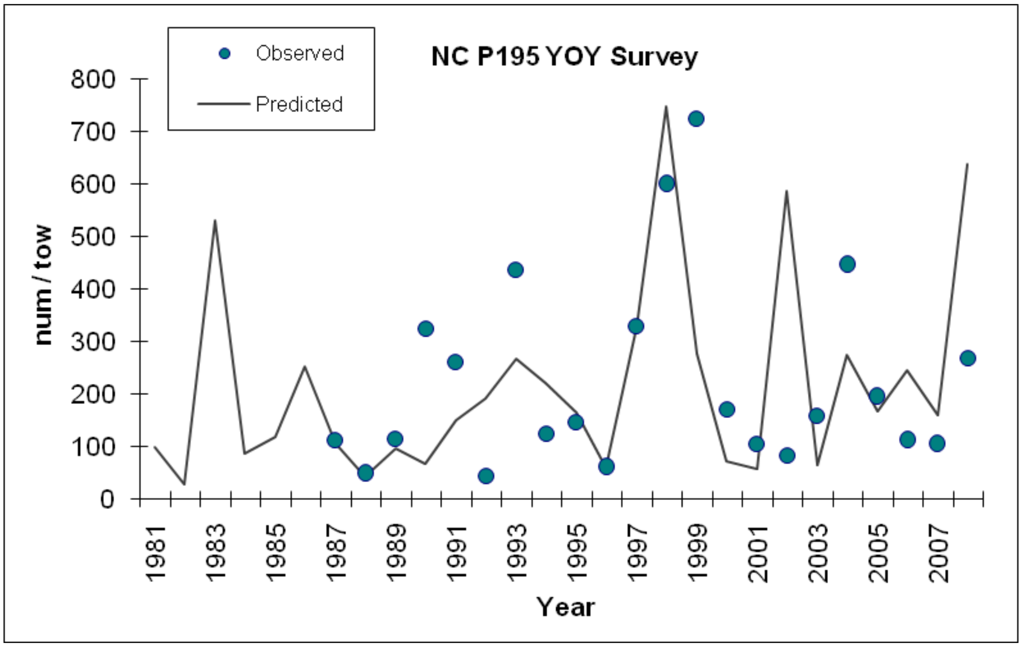


Figure 7.1.1.8 Observed and predicted NC Program 195 young-of-year index from the base run of the hybrid model.

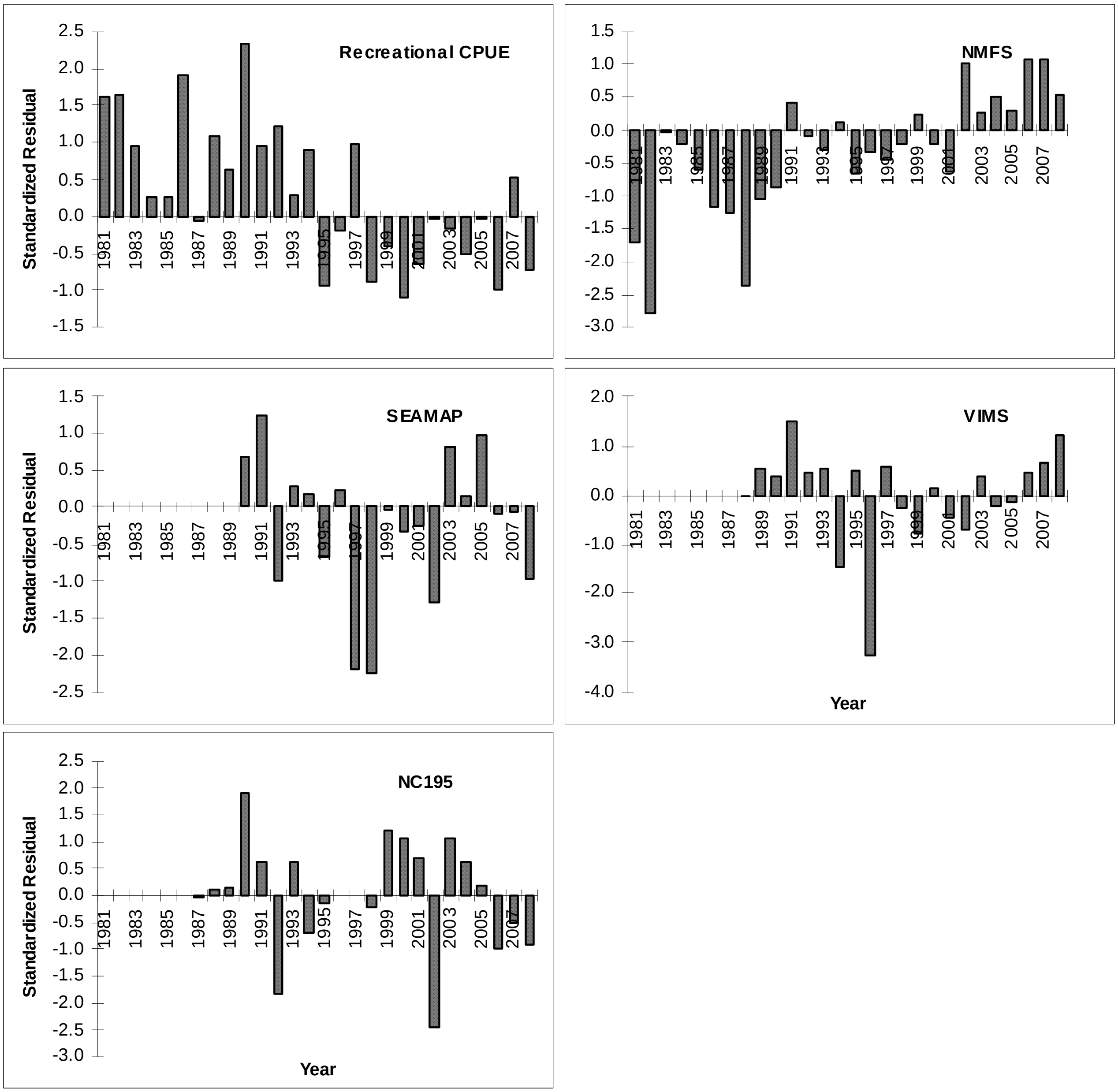


Figure 7.1.1.9 Standardized residuals for the indices from the base run of the hybrid model.

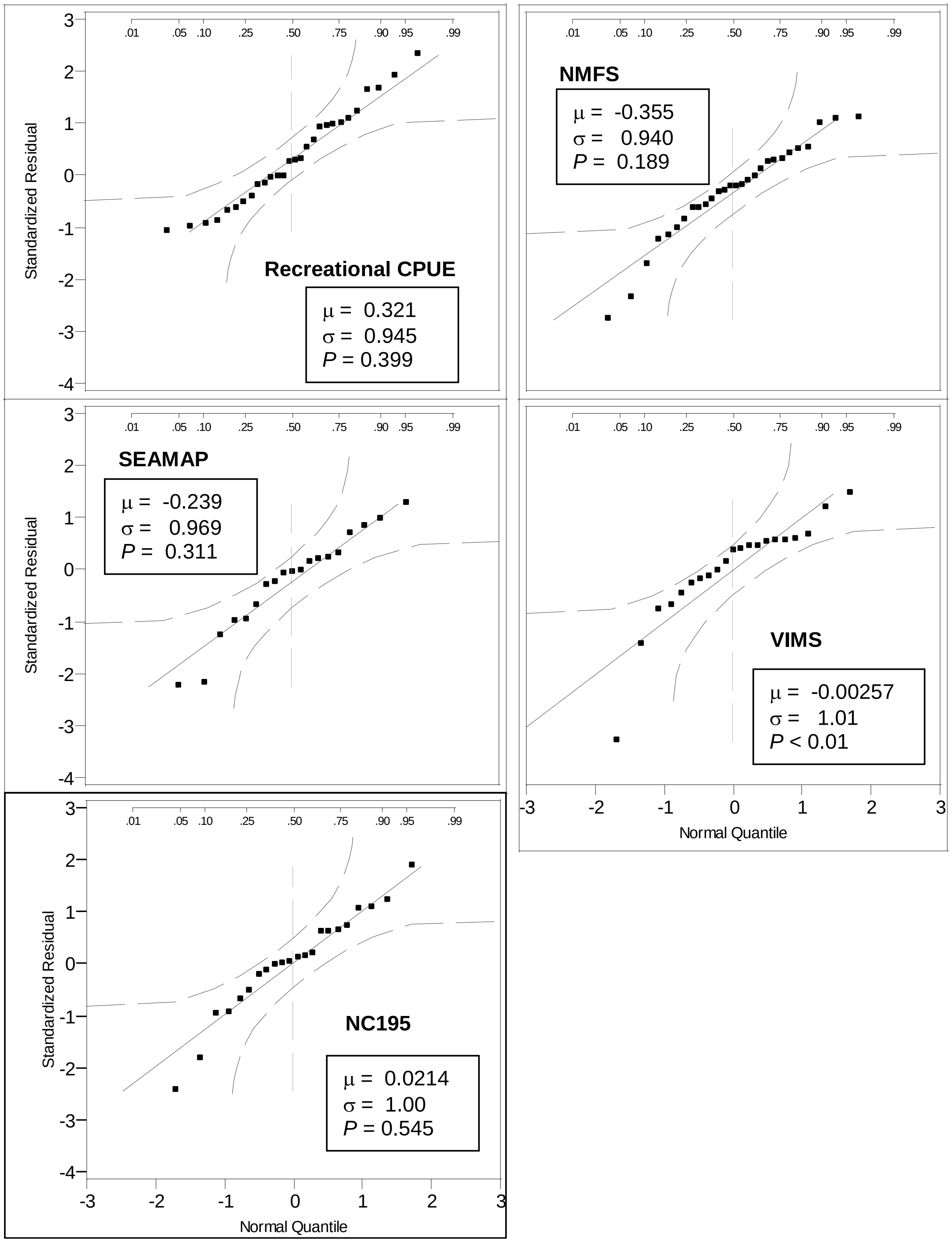


Figure 7.1.1.10 Normal quantile plots (Q-Q plots) of the standardized residuals for each index from the base run of the hybrid model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

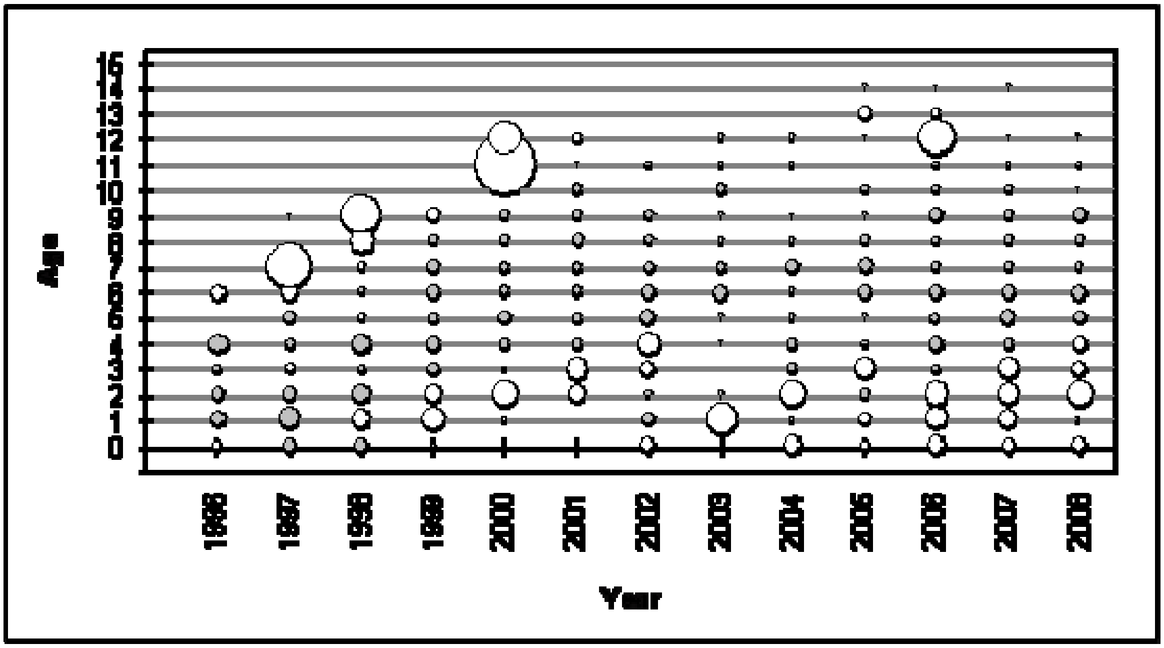


Figure 7.1.1.11 Pearson's standardized residuals for the commercial landings catch-at-age data from the base run of the hybrid model. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

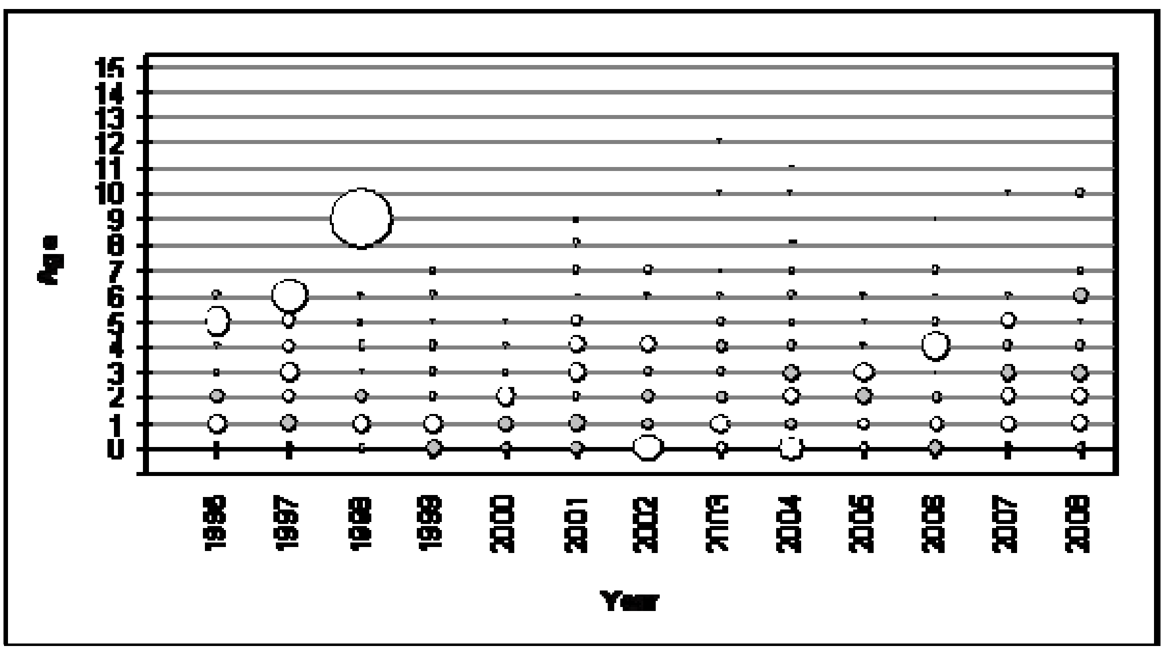


Figure 7.1.1.12 Pearson's standardized residuals for the commercial scrap/bait/discards catch-at-age data from the base run of the hybrid model. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

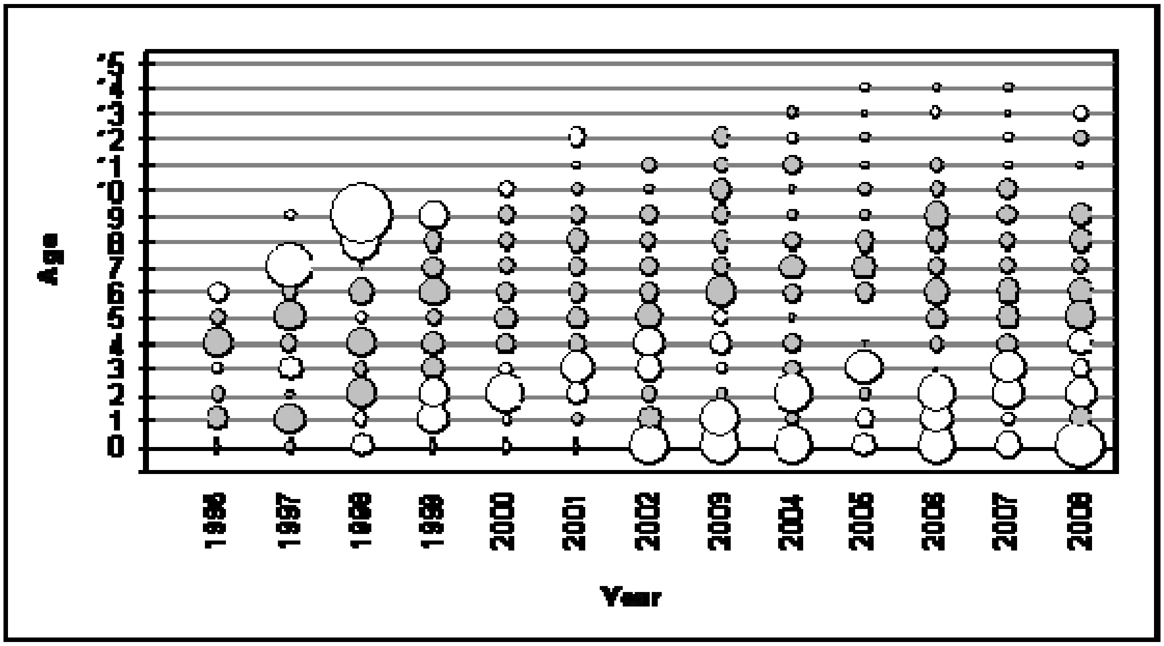


Figure 7.1.1.13 Pearson's standardized residuals for the recreational harvest catch-at-age data from the base run of the hybrid model. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

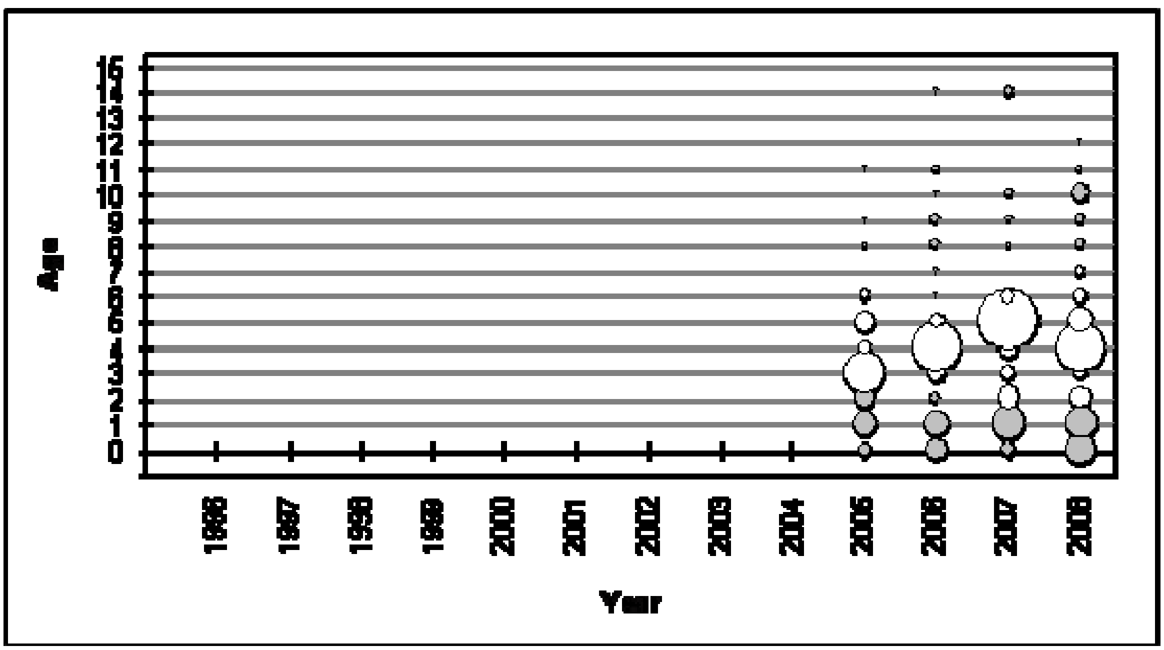


Figure 7.1.1.14 Pearson's standardized residuals for the recreational discards (dead B2 fish) catch-at-age data from the base run of the hybrid model. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

Figure 7.1.2.1.1 Predicted trends in population size of Atlantic croaker from the base run of the hybrid model.

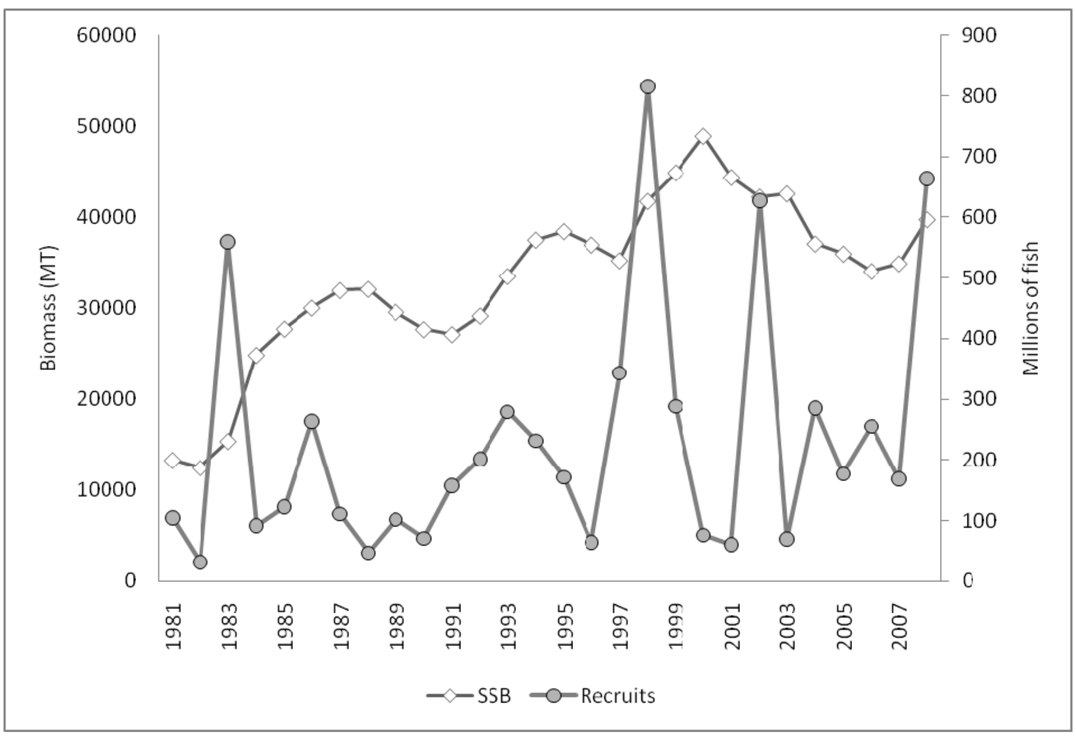


Figure 7.1.2.1.2 Predicted trends in recruitment (age-0) and spawning stock biomass of Atlantic croaker from the base run of the hybrid model.

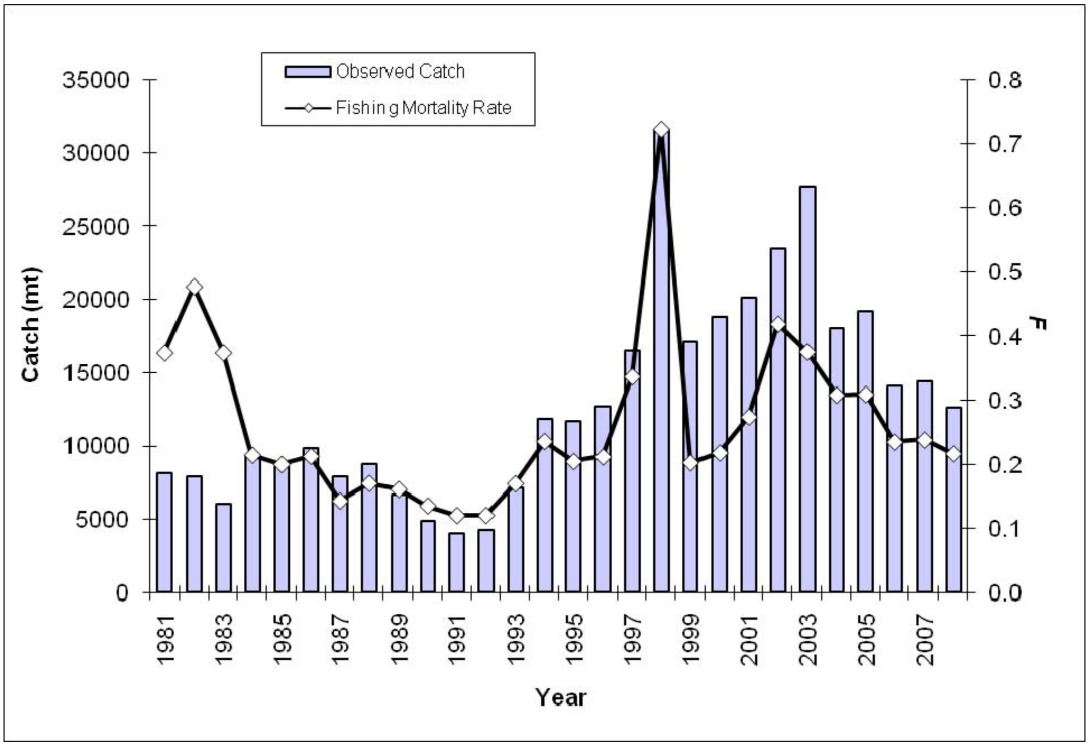


Figure 7.1.2.2.1 Observed total catch and predicted fishing mortality rates (average *F* over ages 1–15+, weighted by population abundance) from the base run of the hybrid model.

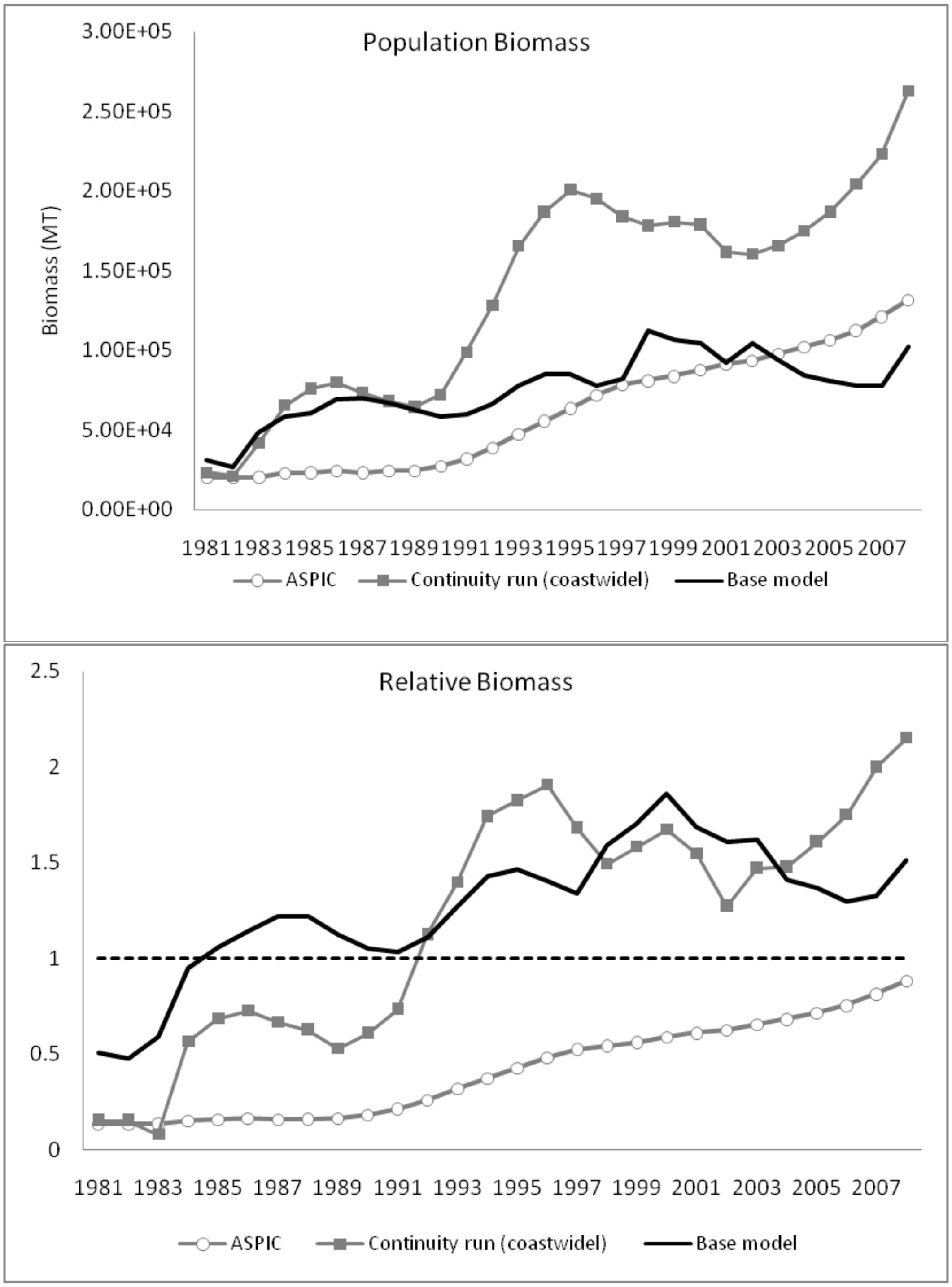


Figure 7.2.1 Estimates of population biomass estimates from the ASPIC, continuity run, and hybrid models.

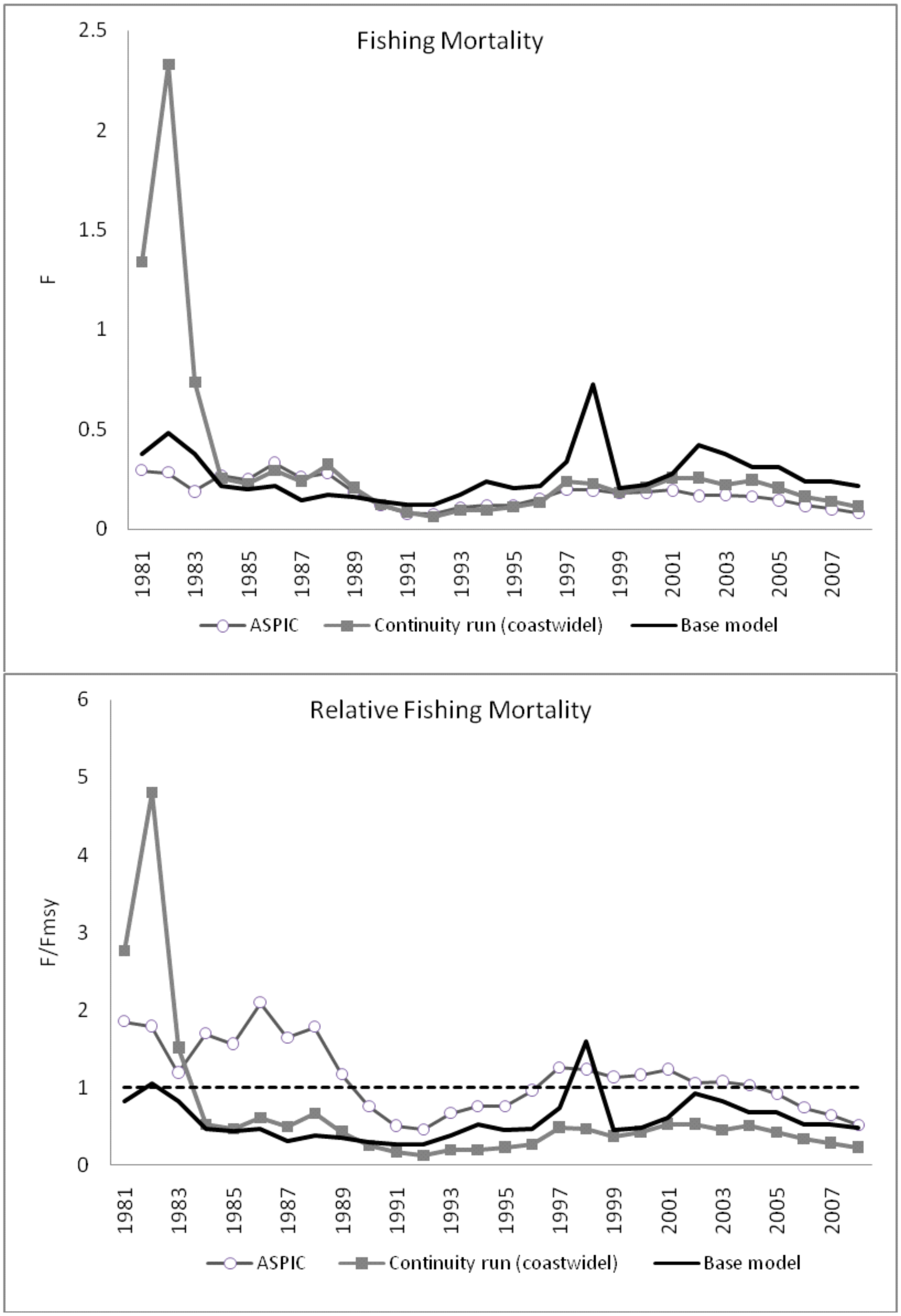


Figure 7.2.2 Estimates of fishing mortality from the ASPIC, continuity run, and hybrid models.

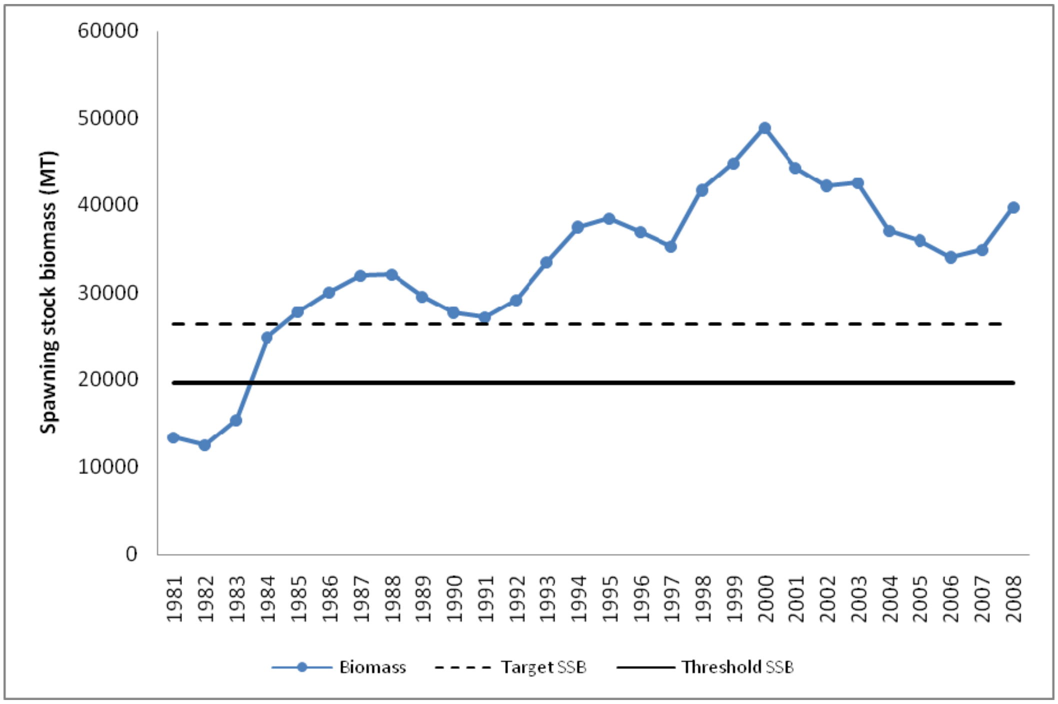


Figure 8.3.1.1 Predicted trends in spawning stock biomass relative to spawning stock biomass target and threshold estimated from the base run of the hybrid model.

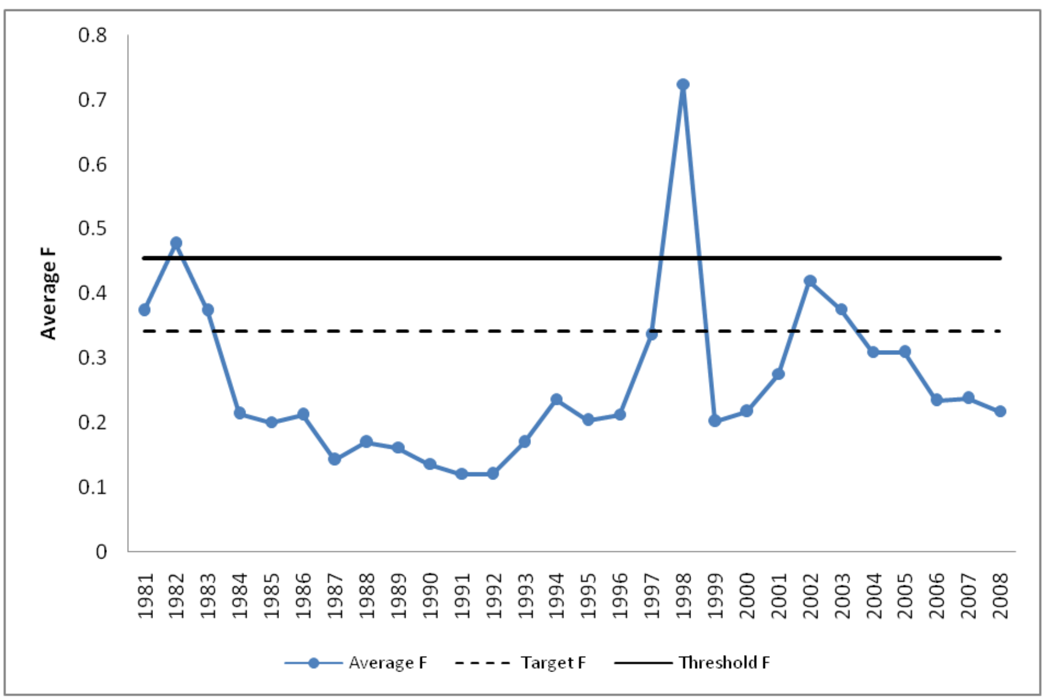


Figure 8.3.2.1 Predicted trends in fishing mortality rates (average *F* over ages 1–15+, weighted by population abundance) relative to fishing mortality target and threshold estimated from the base run of the hybrid model.

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.

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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 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

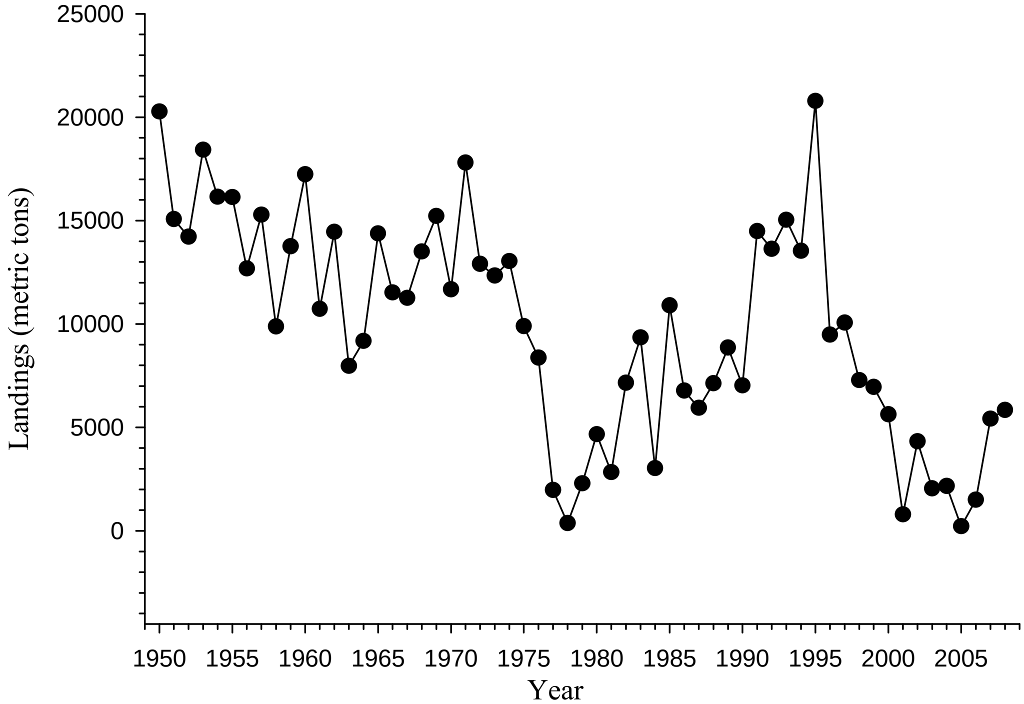


Figure A1.1 Penaeid shrimp landings for the Atlantic coast of the United States, 1950-2008.

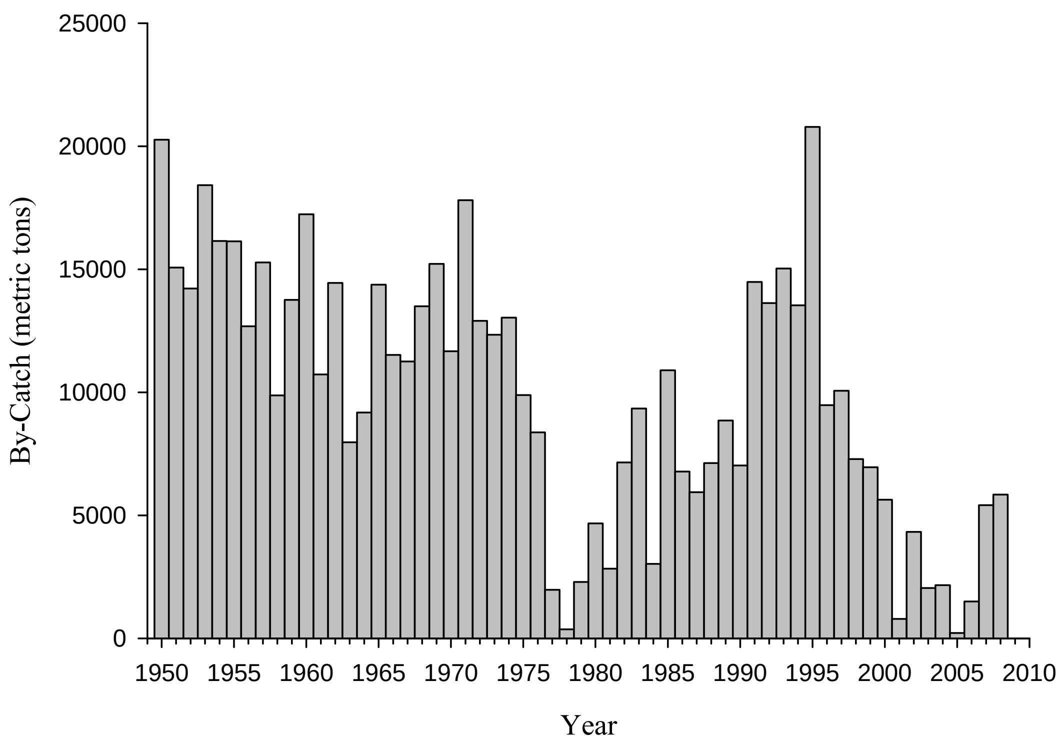


Figure A1. 2 Estimated bycatch (metric tons) of Atlantic croaker from the south Atlantic coast (NC-FL) of the United States, 1950-2008.

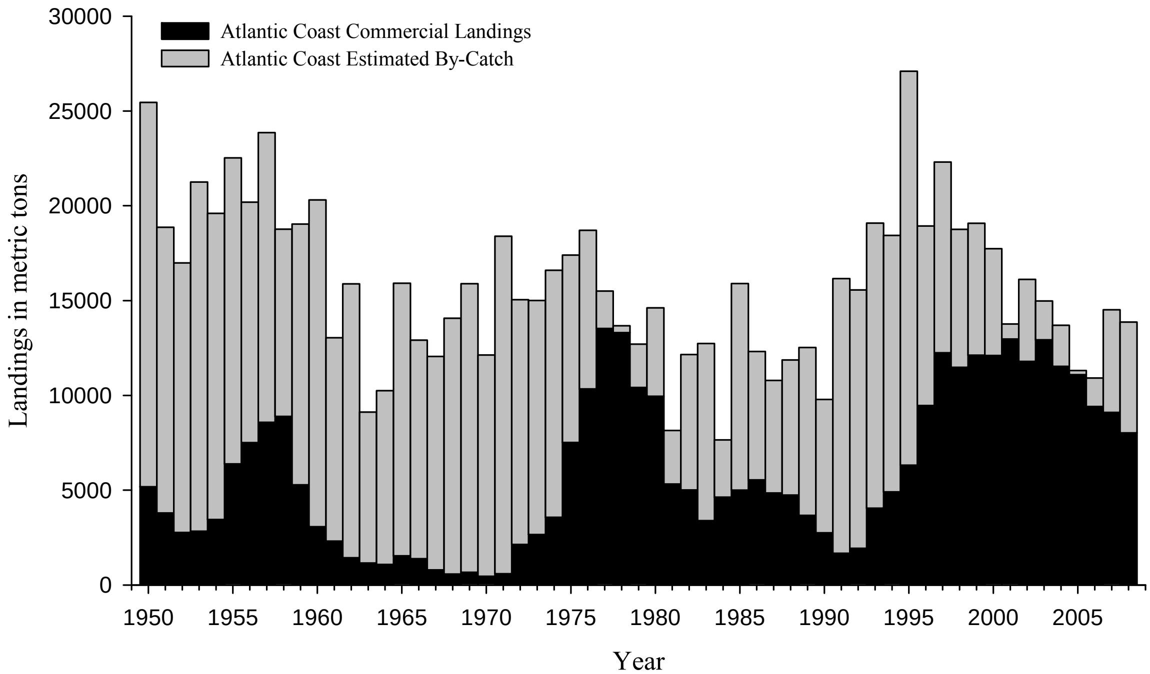


Figure A1.3 Total estimated landings (metric tons) of Atlantic croaker from both commercial landings and estimated shrimp bycatch, 1950-2008.

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 α = 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, π_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 π_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 α = 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													

Variables		df	Deviance	Mean dev	Δ mean dev	% expl	Cum %	log like	Δ log like	Chi sq	df	Prob Ho	AIC
Wave	Deviance	2003	3207.458	1.6013	0.3887	19.5%		-6852.61	-292.224	584.4482	38	4.9E-99	13783.21
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

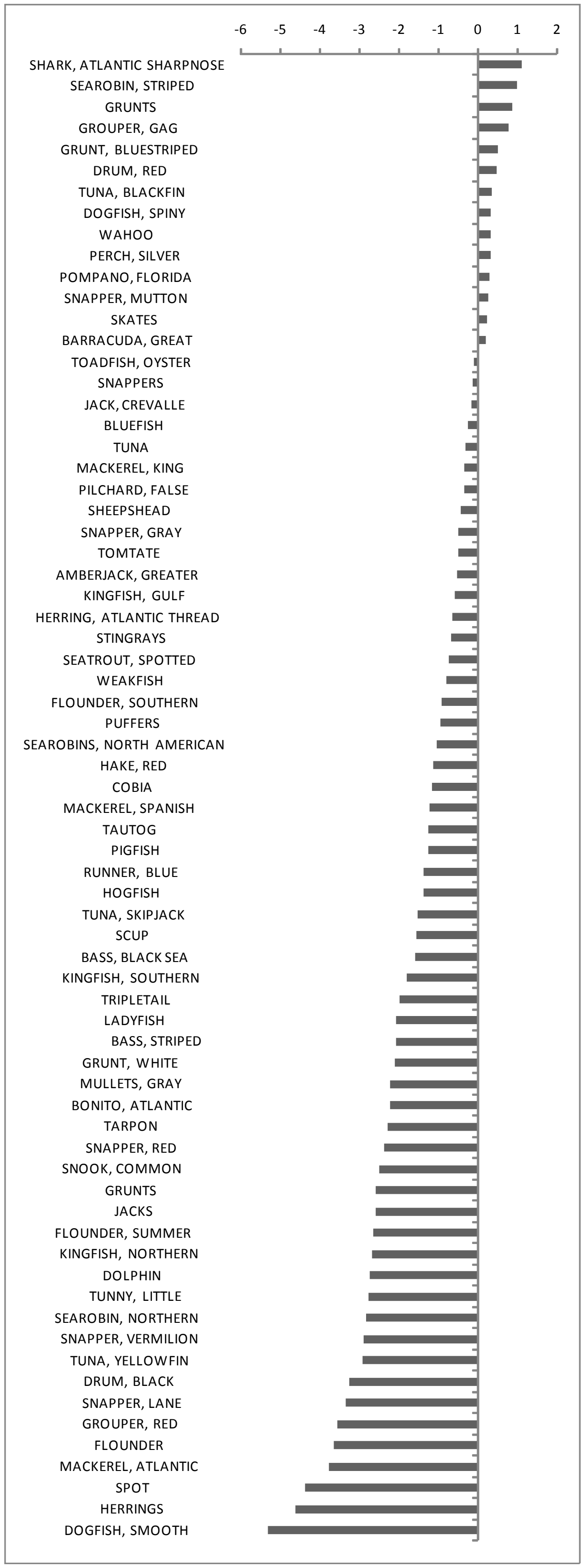


Figure A2.1 Species with significant ($p < 0.05$) logistic regression coefficients predicting presence of croaker

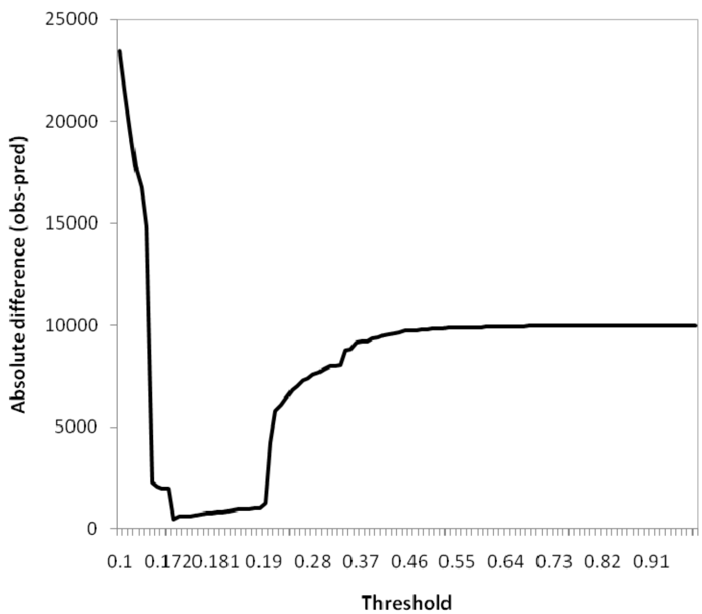


Figure A2.2 Threshold probability of a trip having occurred in croaker habitat plotted against the absolute difference between trips observed to have caught croaker and predicted trips in croaker habitat.

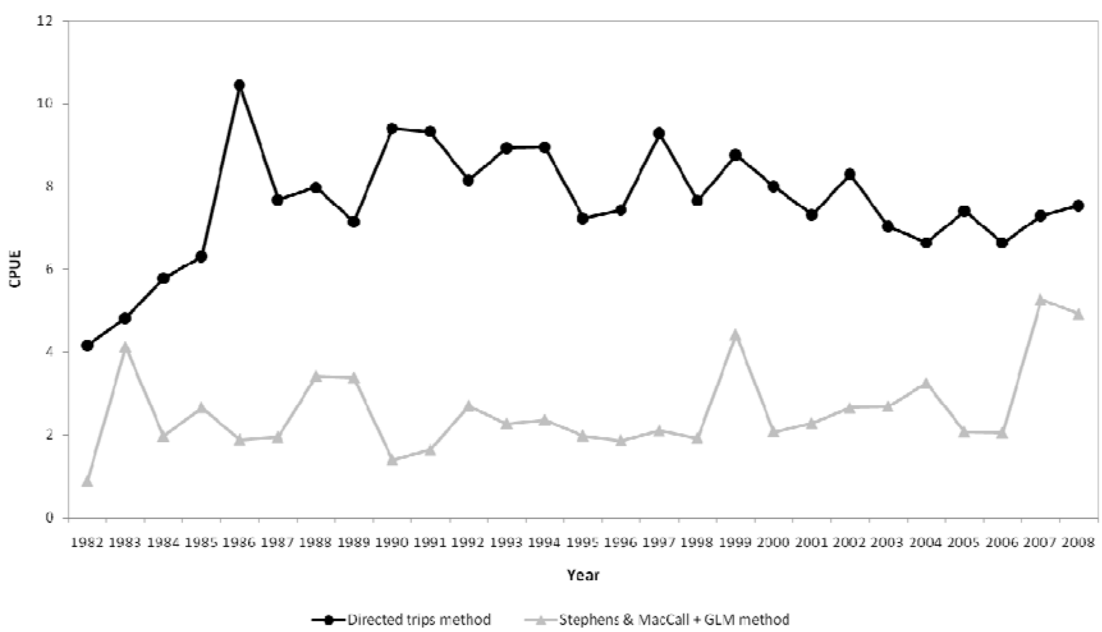


Figure A2.3 Coast-wide CPUE calculated using the directed trips methodology and the Stephens and MacCall (2004) sub-setting method standardized with a GLM.

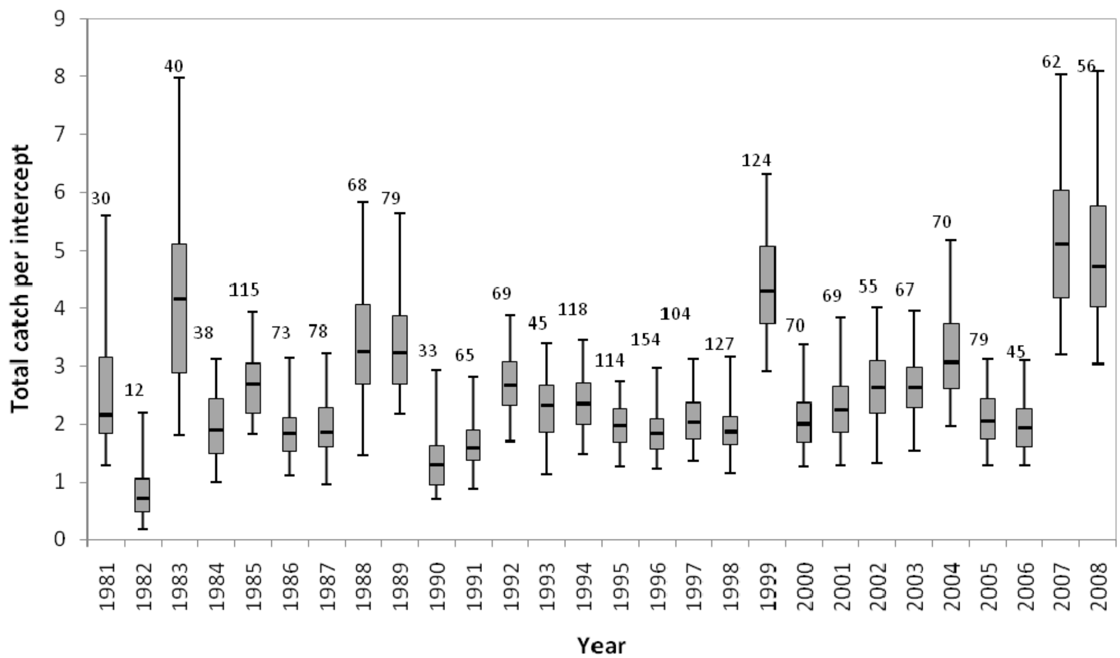
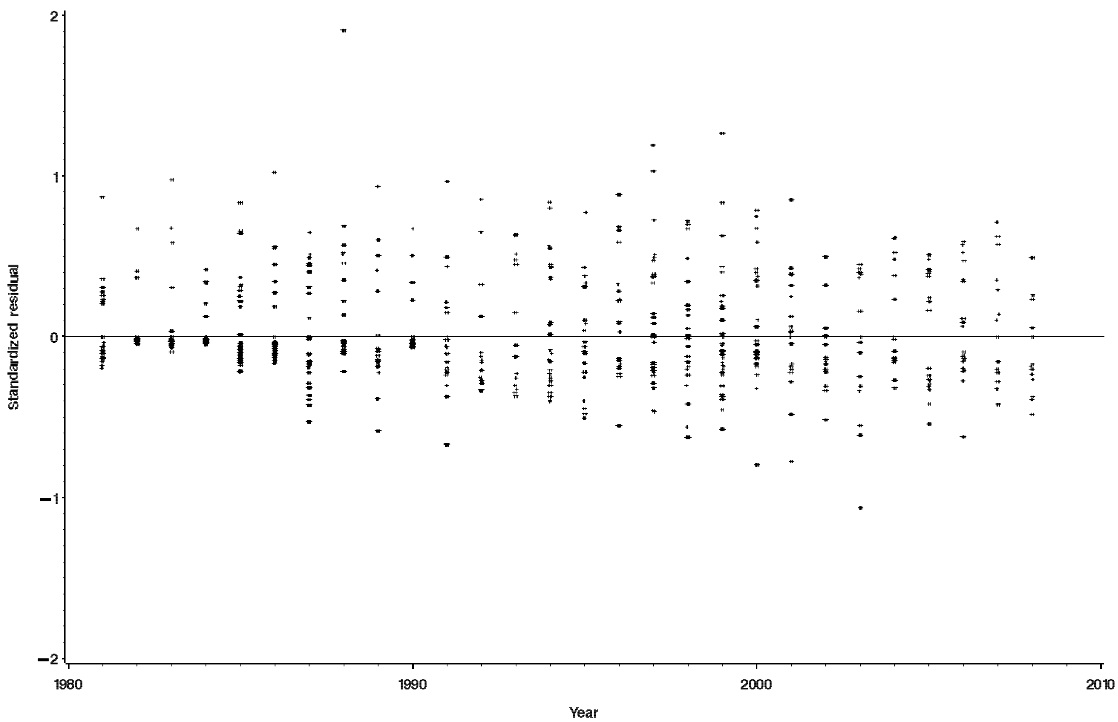
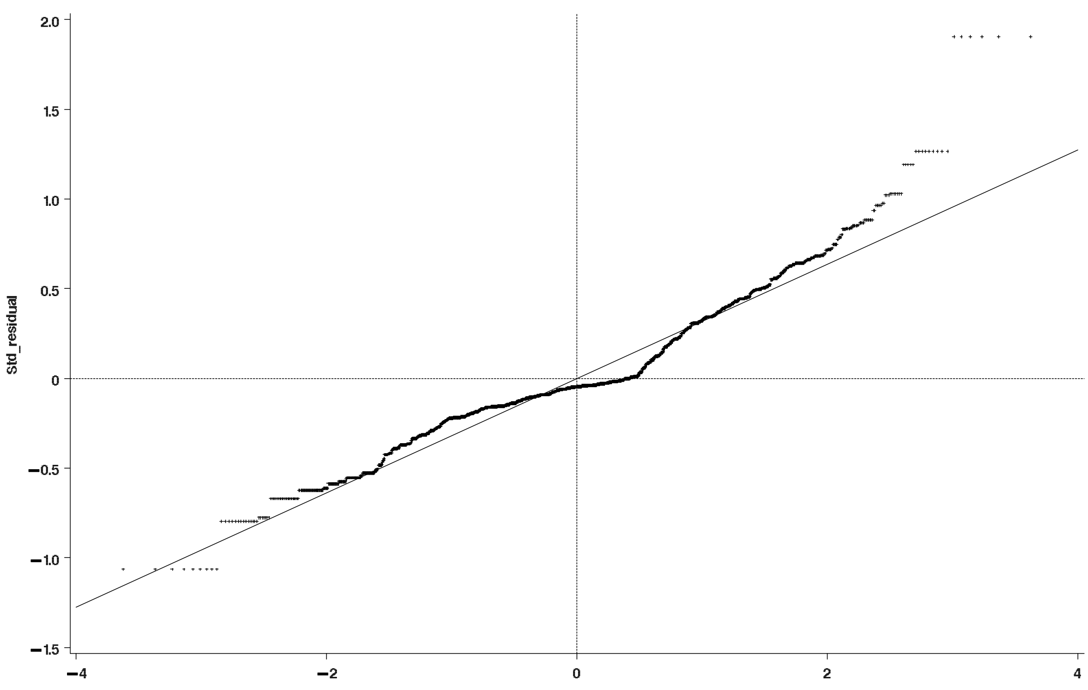


Figure A2.4 Standardized annual total catch of Atlantic croaker per intercept with intercepts selected by Stephens and MacCall's logistic regression. Vertical lines are 95% confidence intervals, boxes are the inter-quartile ranges, horizontal lines are medians of the outcomes, and numbers above the lines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

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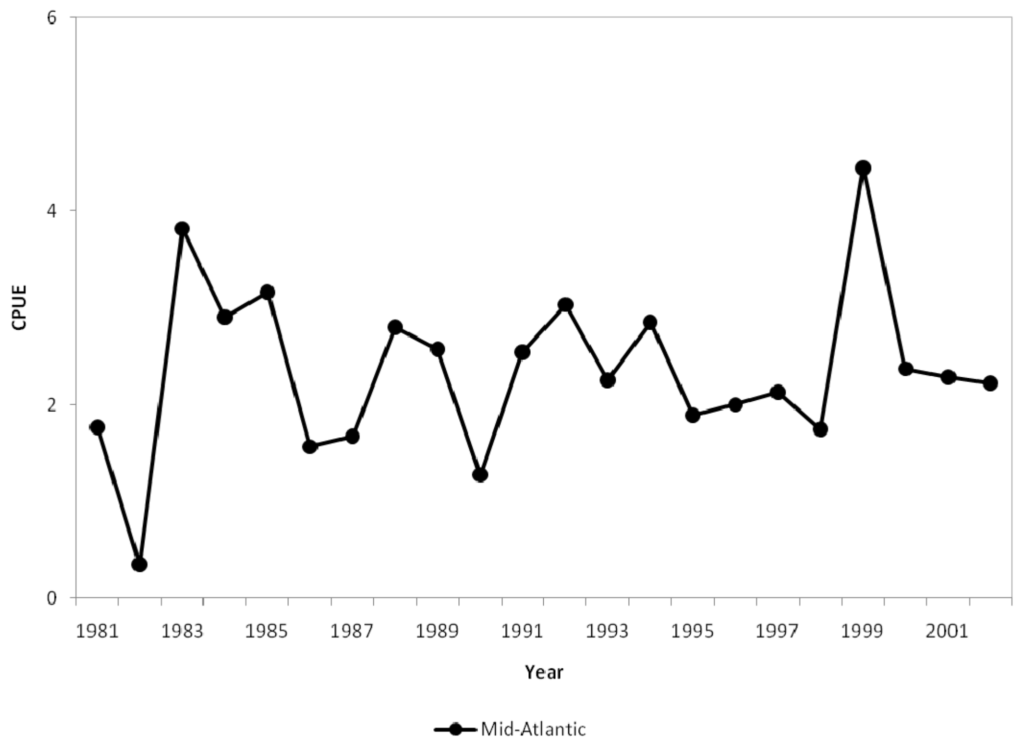

Figure A2.6 CPUE by region using the Stephens and MacCall (2004) sub-setting method and GLM standardization. The GLM failed to converge for the south Atlantic region, only the CPUE for the mid-Atlantic region is shown.

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 A3.1. 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).

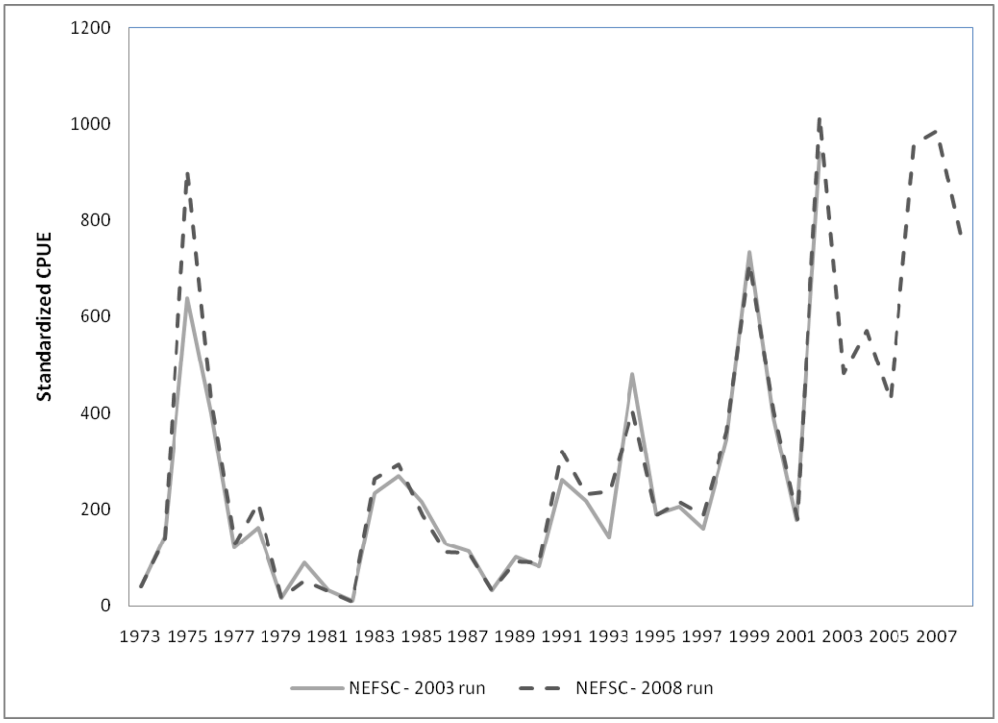
Landings (metric tons)				Indices				
Year	Commercial	Recreational	Scrap/ Discards	Year	NEFSC (fall)	MRFSS (year-round)	SEAMAP (fall)	VIMS (spring)
1973	2610.968	1,027	1,316	1973	40.4	-1	-1	-1
1974	3514.92	1,284	1,727	1974	142	-1	-1	-1
1975	7483.662	2,325	1,631	1975	906	-1	-1	-1
1976	10299.89	3,292	1,761	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.

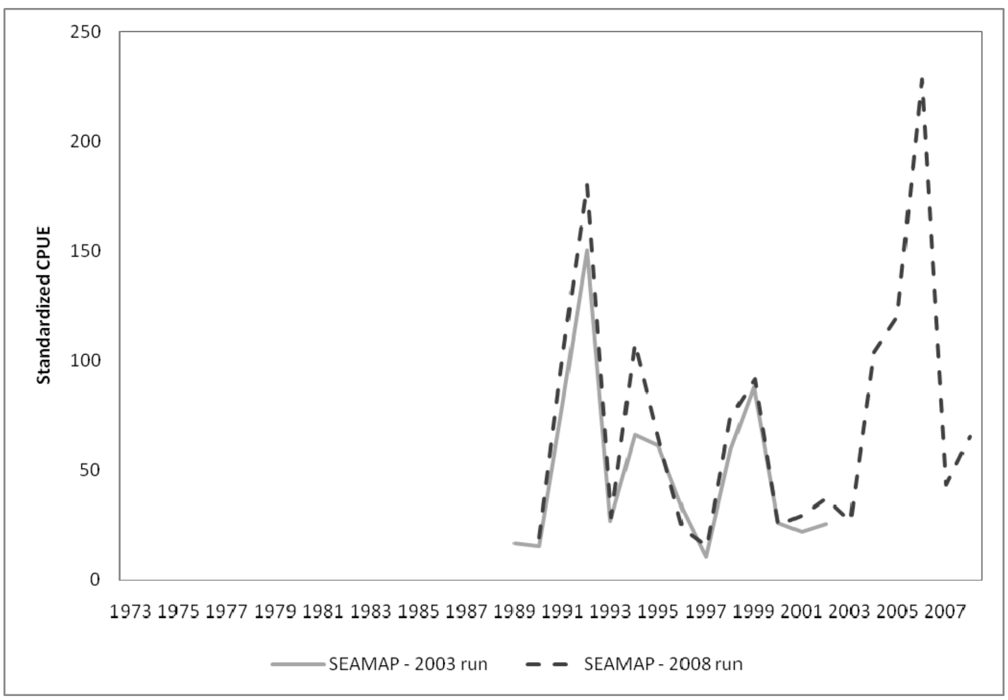
Age	Commercial	Scrap/ Discard	Rec Harvest	Shrimp Bycatch	NEFSC Trawl	MRFSS	SEAMAP	VIMS
0	0.036	0.083	0.286	1	0.79	0.08	1	1
1	0.383	0.737	1	0	1	0.74	0.4	0
2	0.606	0.863	0.508	0	0.4	0.86	0	0
3	0.809	0.972	0.209	0	0.34	0.97	0	0
4	1	1	0.082	0	0.11	1	0	0
5	1	1	0.01	0	0.12	1	0	0
6	1	1	0.015	0	0	1	0	0
7	1	1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

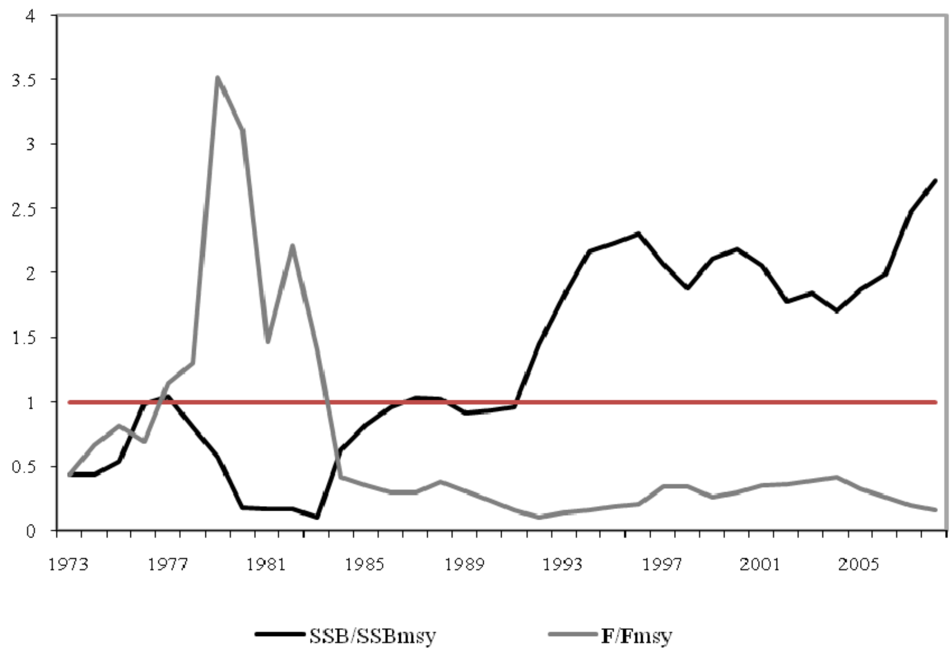
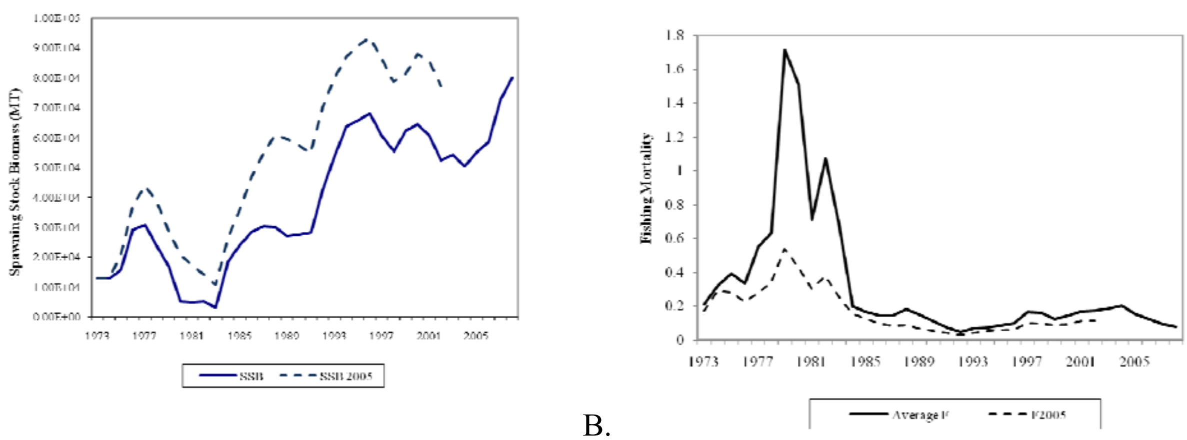


Figure A4.2 Continuity run spawning stock biomass and fishing mortality relative to the values needed to produce MSY.

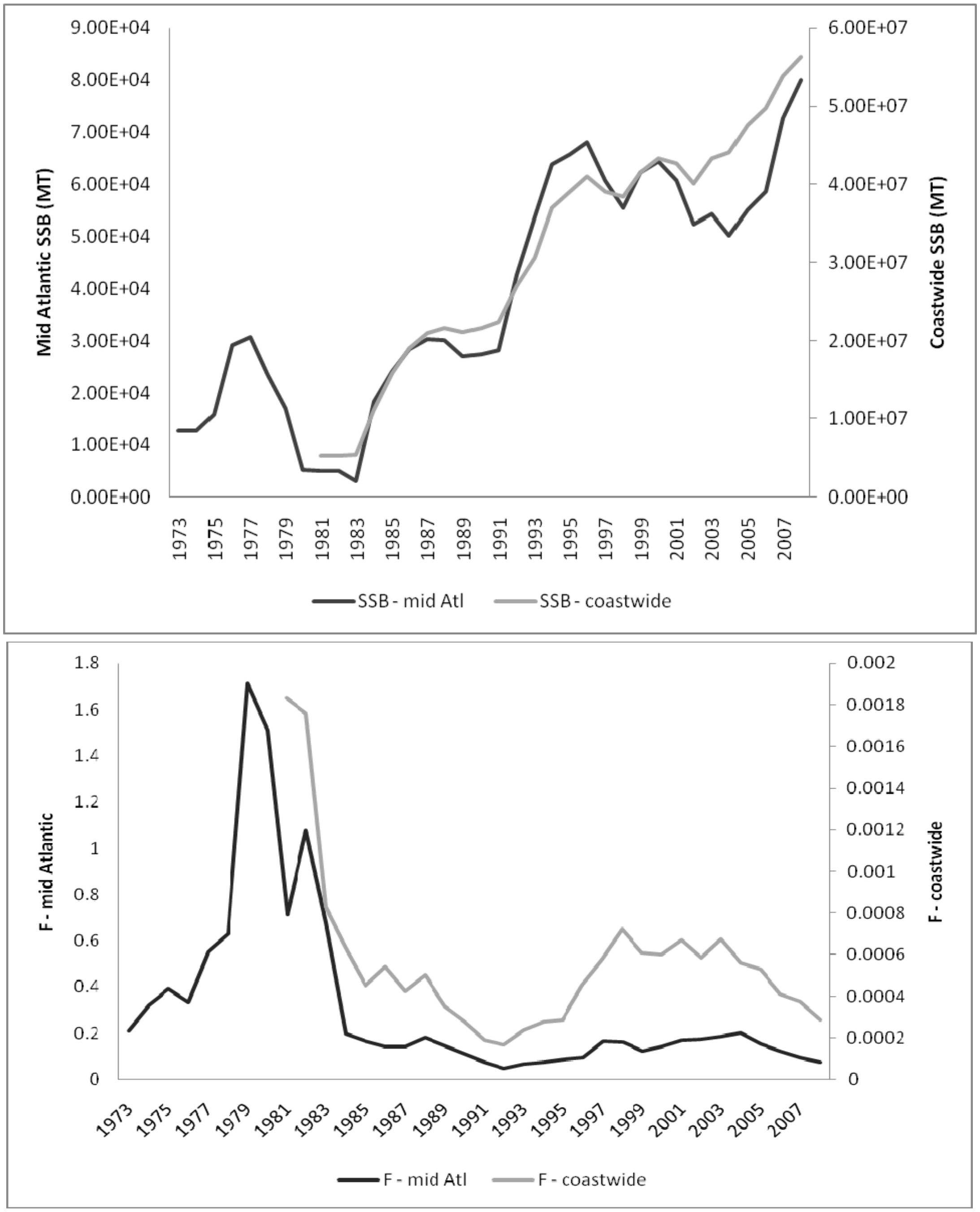


A.

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.

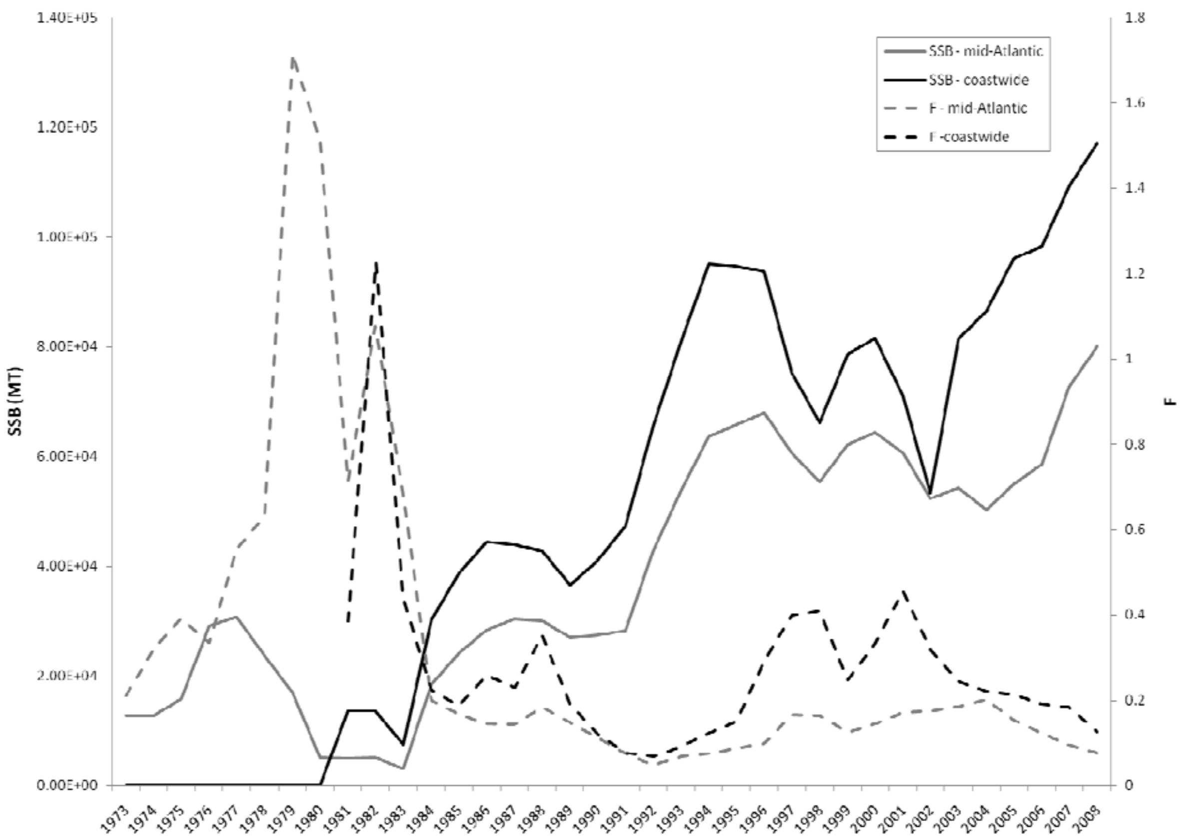
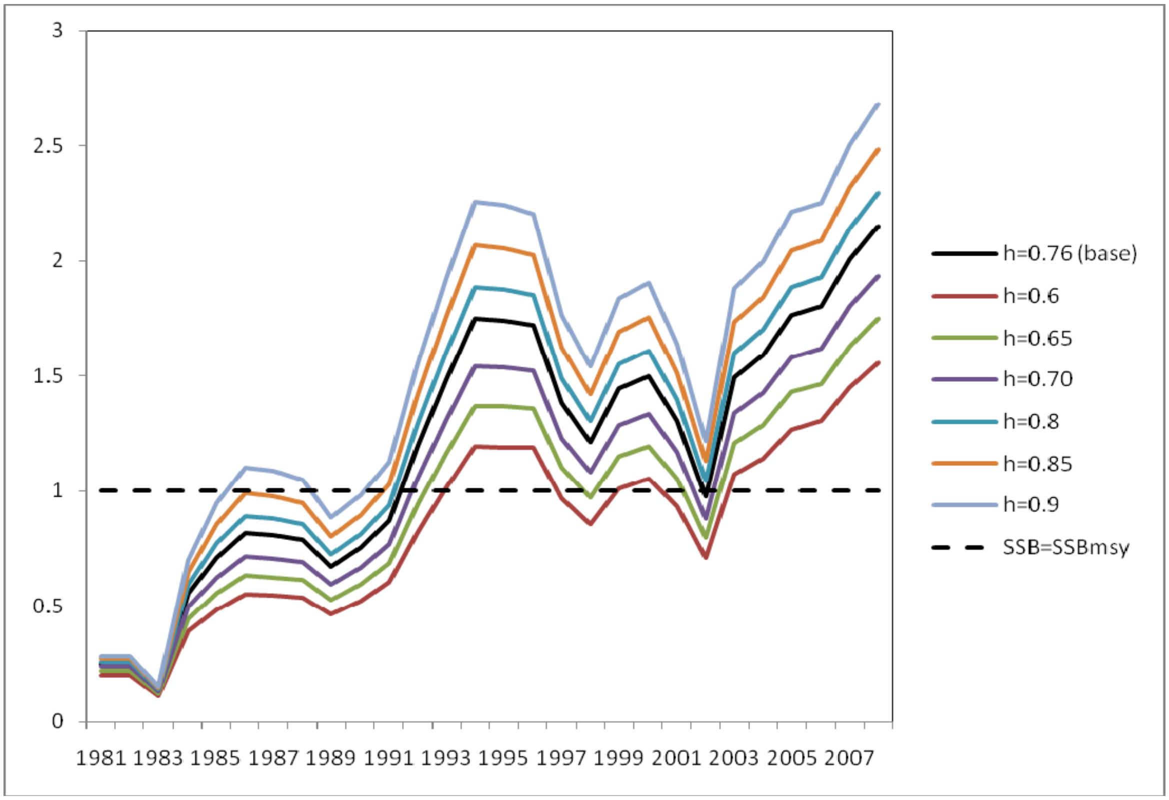
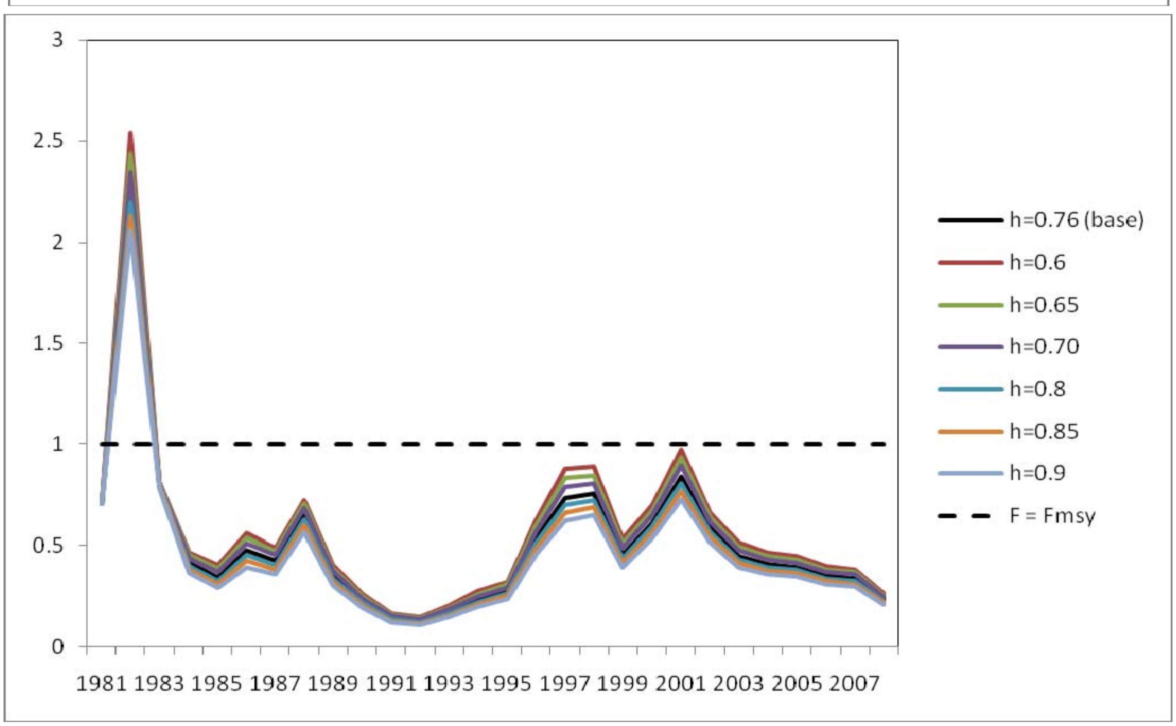


Figure A4.5 Estimates of SSB and F from the ASPM coast-wide data run with the new estimates of SEAMAP selectivity, plotted on the same scale as the mid-Atlantic only data runs.



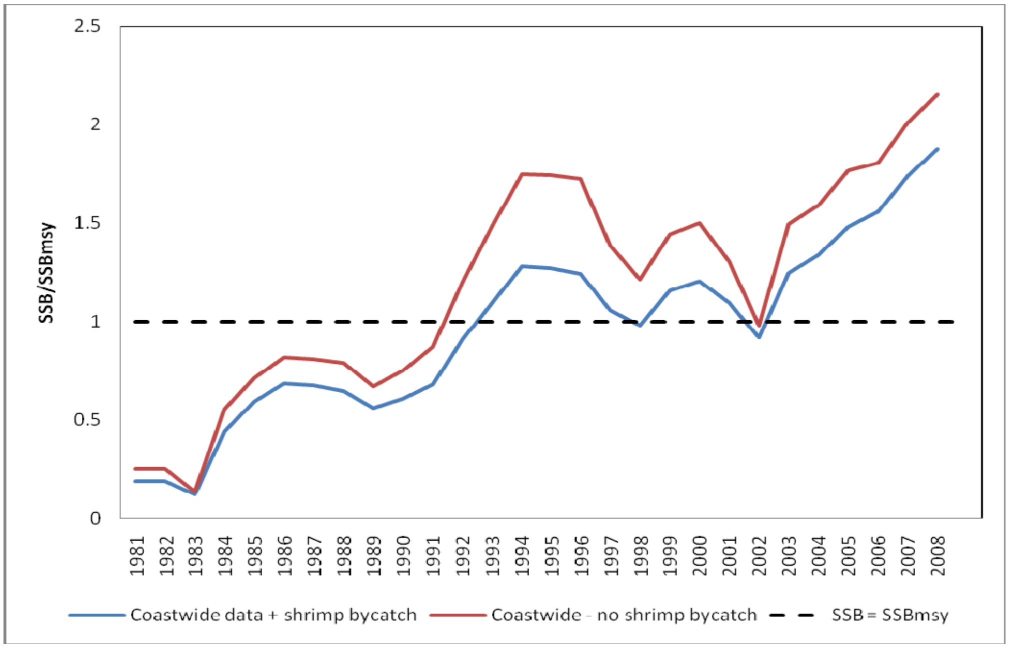
A.



B.

Figure A4.6 SSB/SSBMSY (A) and F/FMSY (B) for varying values of steepness (h) from the ASPM coast-wide data run.

A.



B.

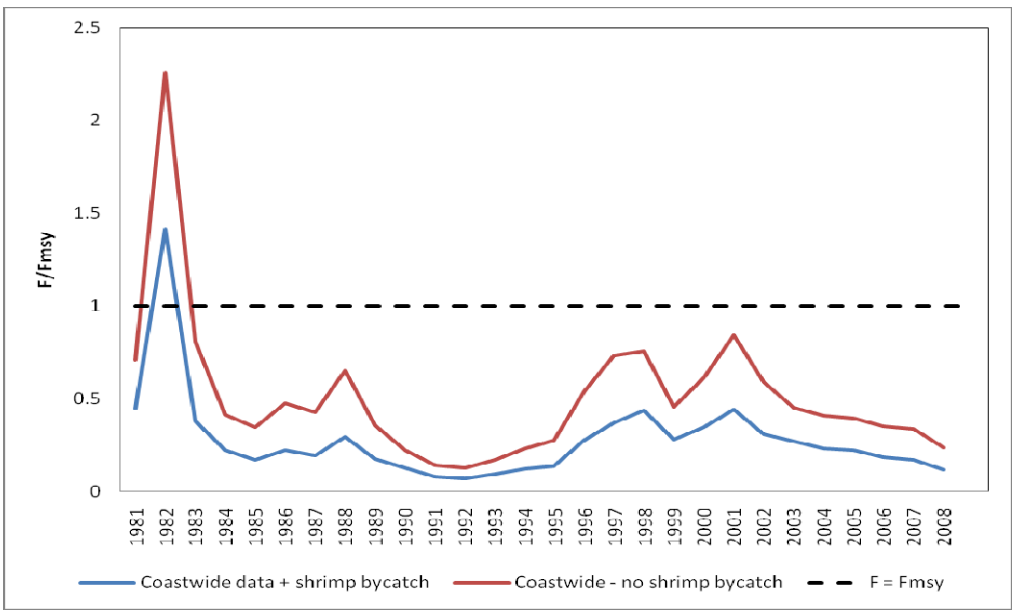


Figure A4.7 Relative trends in SSB (A) and F (B) from the ASPM coast-wide data runs with and without croaker discards from shrimp trawls.

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., $H_{max} \sim$ 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.

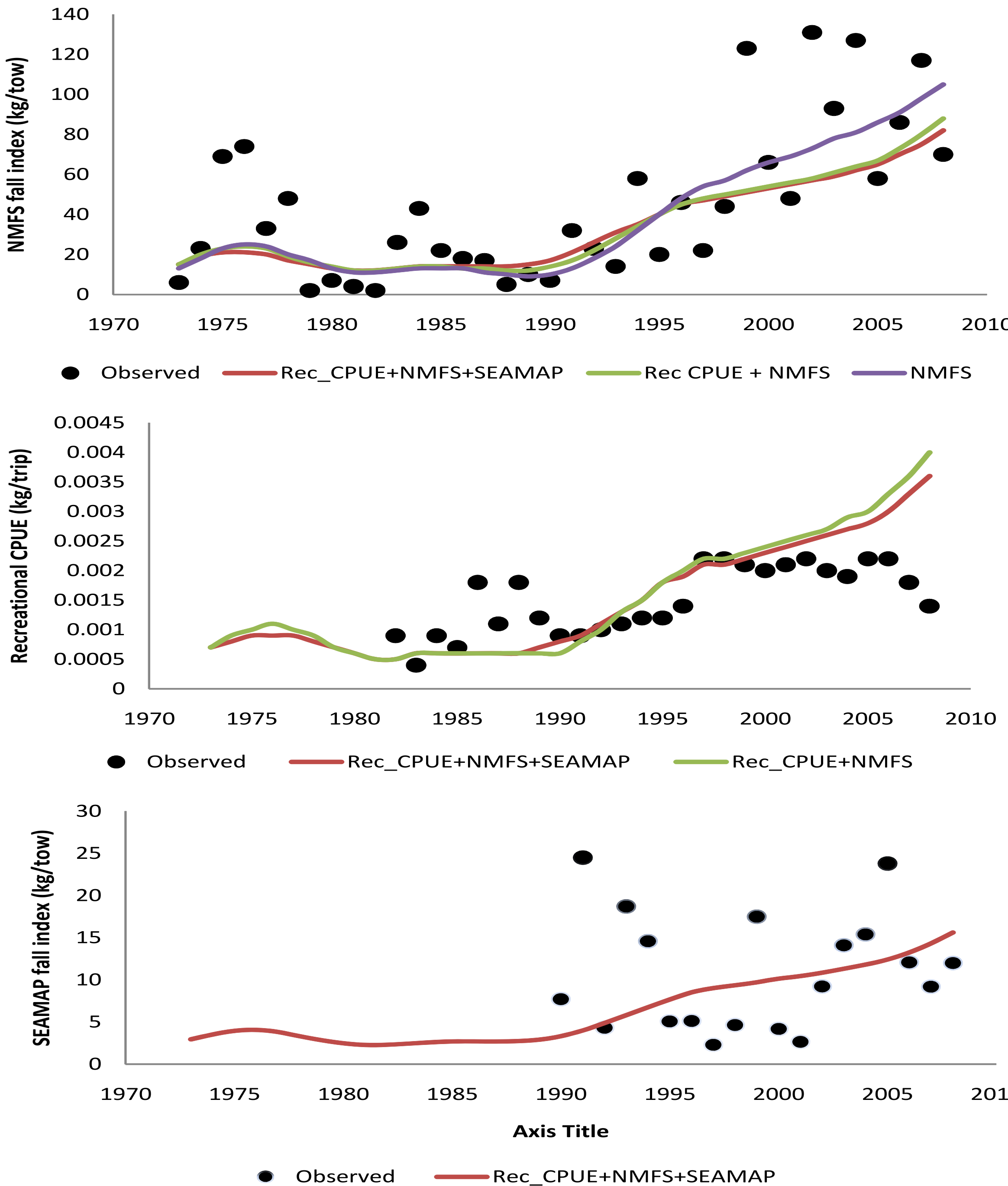

Figure A5.1 Goodness-of-fit of ASPIC program (version 5.34) applied to Atlantic croaker total harvests from the U.S. Atlantic coast, 1973-2008. ASPIC was tuned with observed (filled circle) NMFS fall index (top), recreational CPUE (middle), and SEAMAP fall index (bottom) under different model configurations. 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.

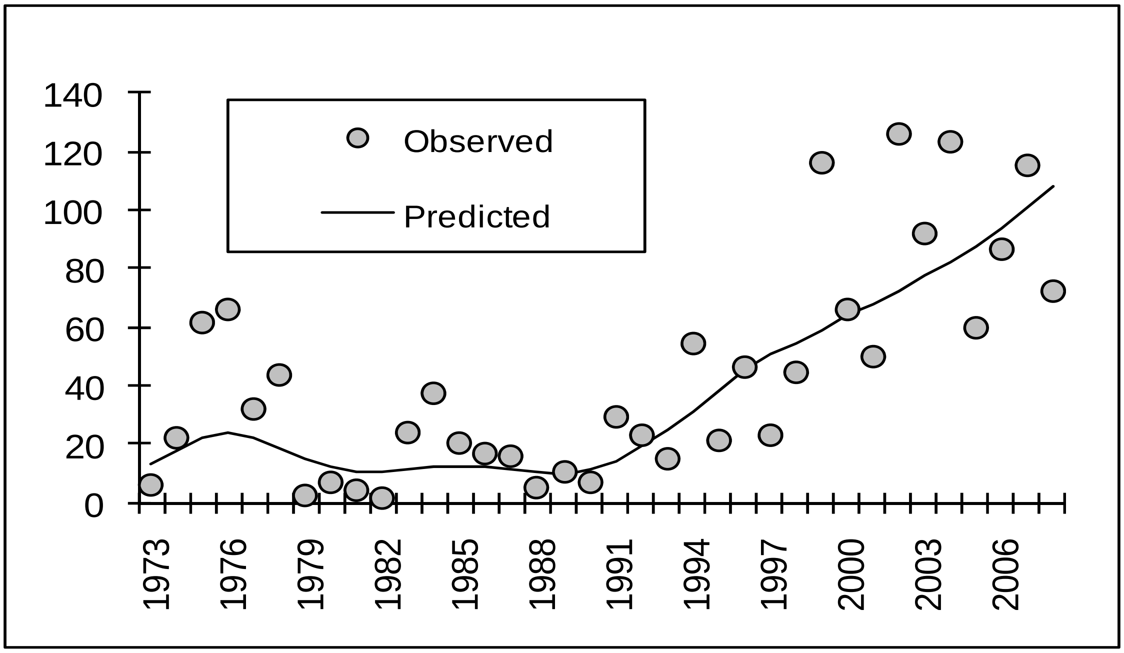

Figure A5.2 Excel fit of the logistic production model applied to Atlantic croaker fishery data on the U.S. Atlantic coast, 1973-2008. The tuning index was NMFS fall index.

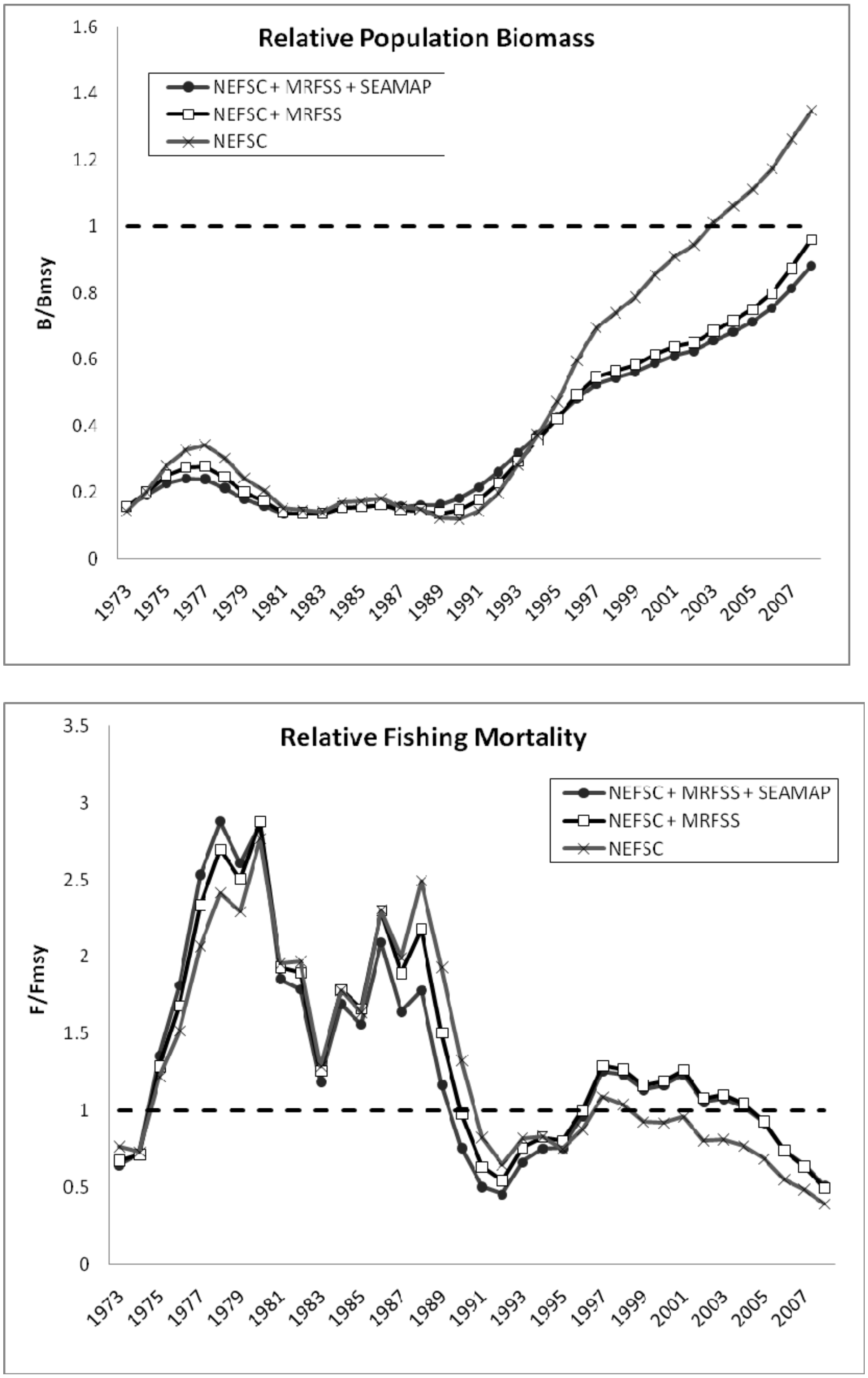

Figure A5.3 Trajectories of biomass (top) and fishing mortality (bottom) relative to the values needed to produce MSY for Atlantic croaker stock on the U.S. Atlantic coast, estimated using ASPIC program (version 5.34) with different combinations of tuning indices.

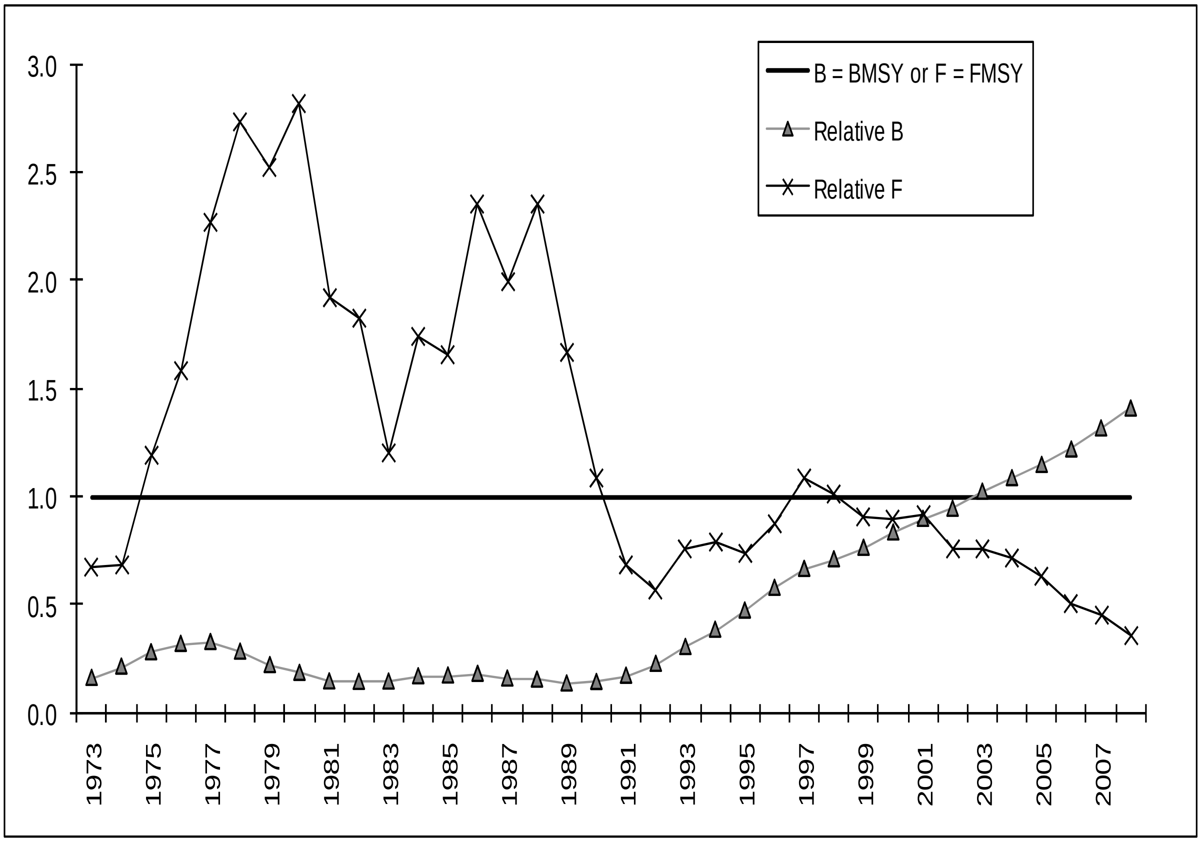

Figure A5.4 Annual variations of the relative biomass and fishing mortality of Atlantic croaker on the U.S Atlantic coast obtained from EXCEL run of a logistic production model tuned with NMFS fall index, 1972 - 2008. The horizontal line shows the level of $B/_{BMSY} = 1$ and $F/F_{MSY} = 1$

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).

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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 (σ^2) and coefficient of variation (CV) about each Z estimate are also given.

Year-Class	*Z*	σ^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 (σ^2) and coefficient of variation (CV) about each Z estimate are also given.

Year-Class	*Z*	σ^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

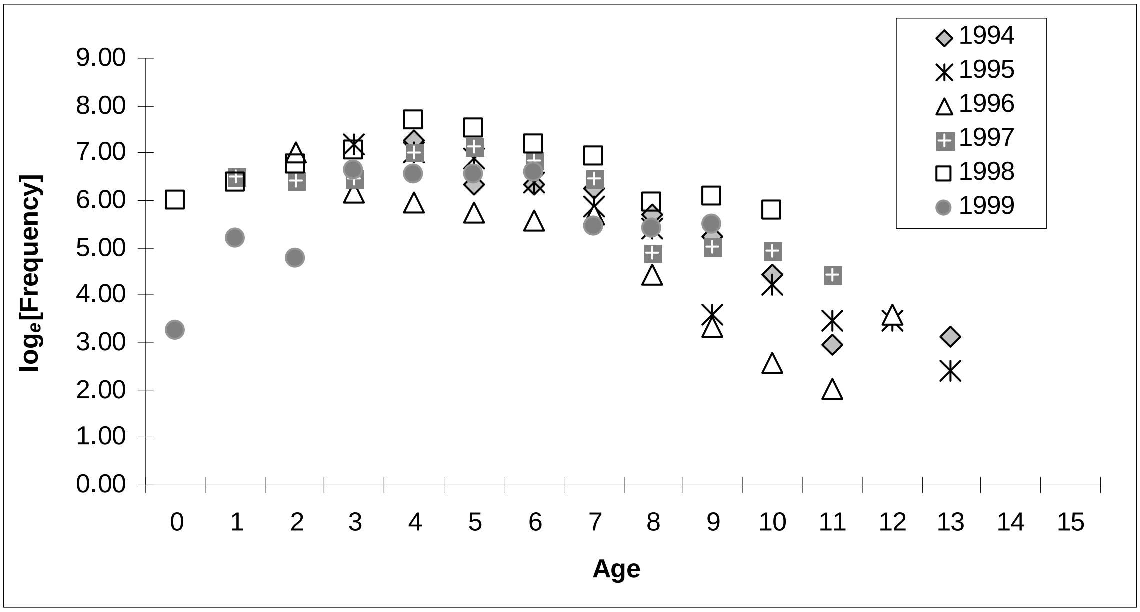


Figure A6. 1 Catch curves used to estimate instantaneous total mortality for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program, 1994 -1999.

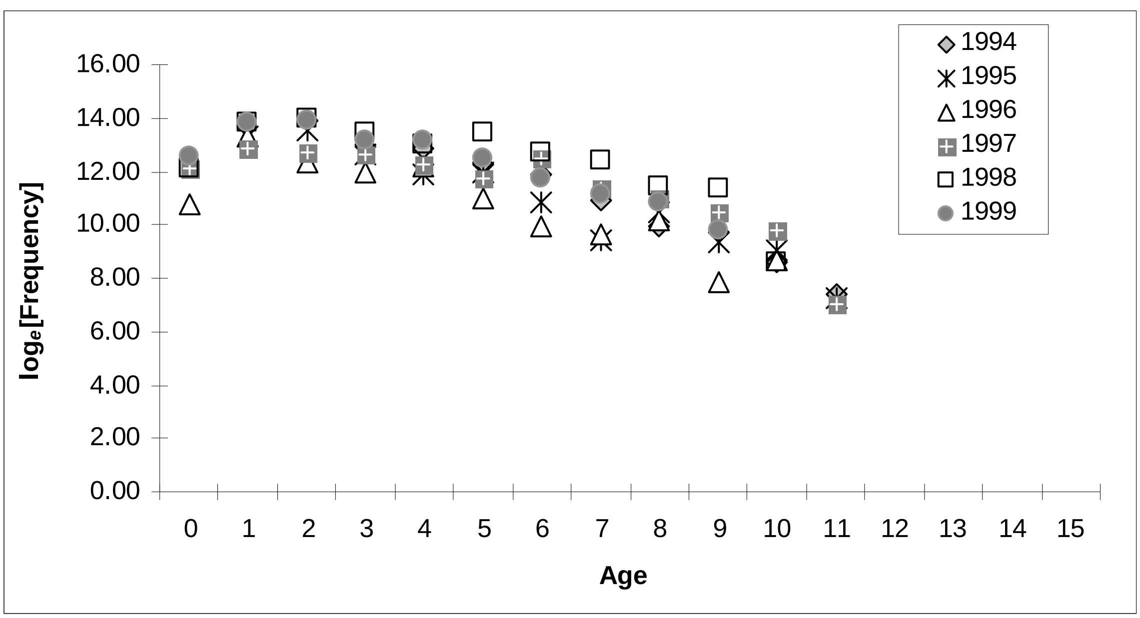


Figure A6. 2 Catch curves used to estimate instantaneous total mortality for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program, 1994 - 1999.

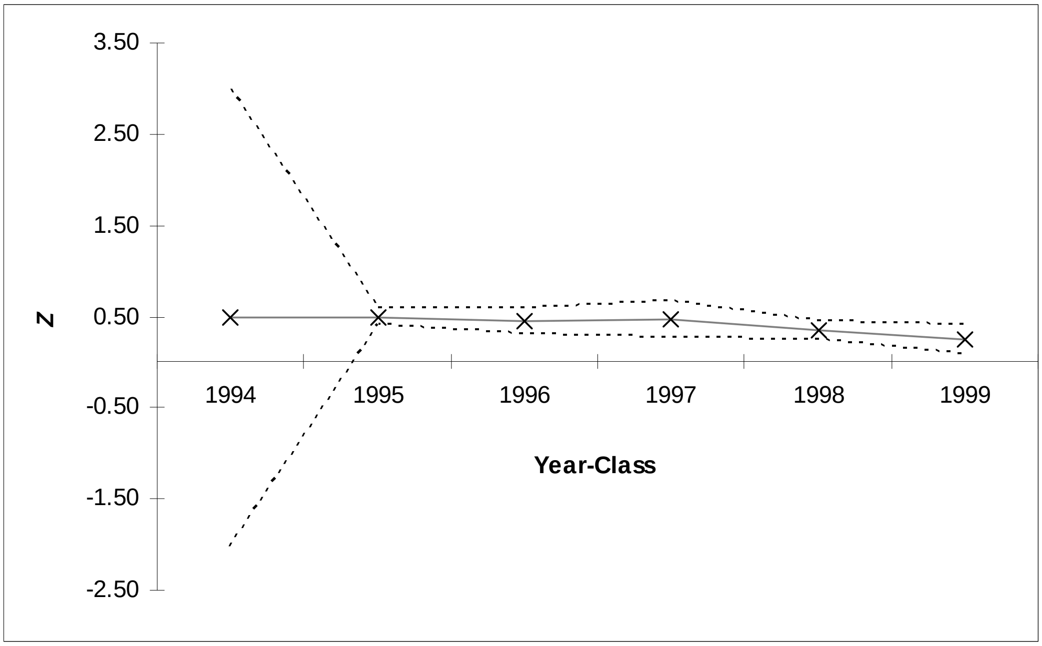


Figure A6. 3 Catch curve estimates of instantaneous total mortality (Z) for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program. Dashed lines represent the lower and upper 95% confidence limits about the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

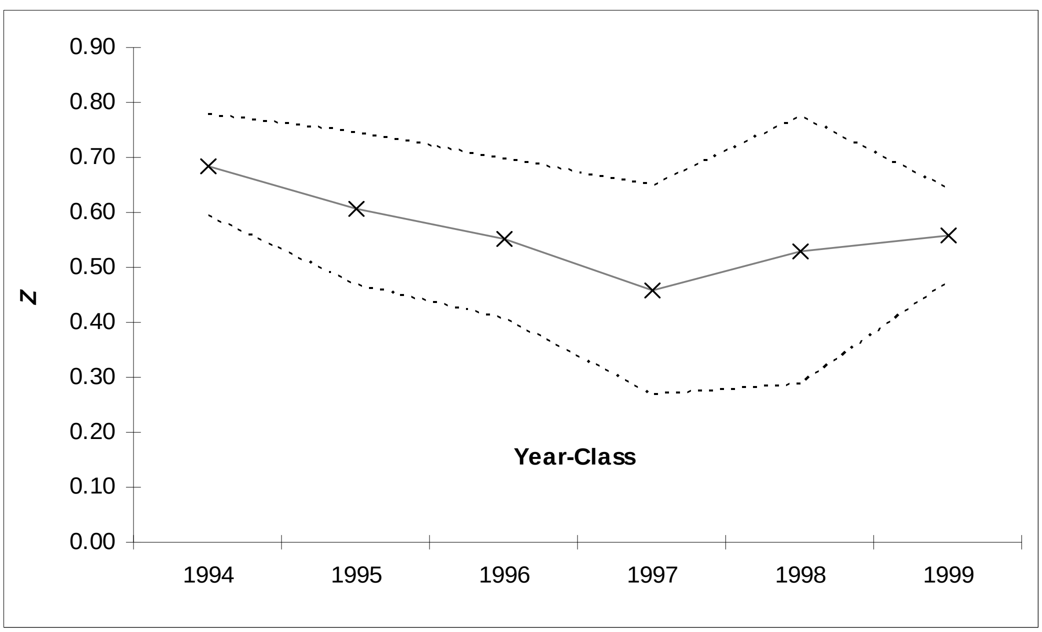


Figure A6. 4 Catch curve estimates of instantaneous total mortality (Z) for true cohorts (multiple years, single cohort) for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program. Dashed lines represent the lower and upper 95% confidence limits about the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

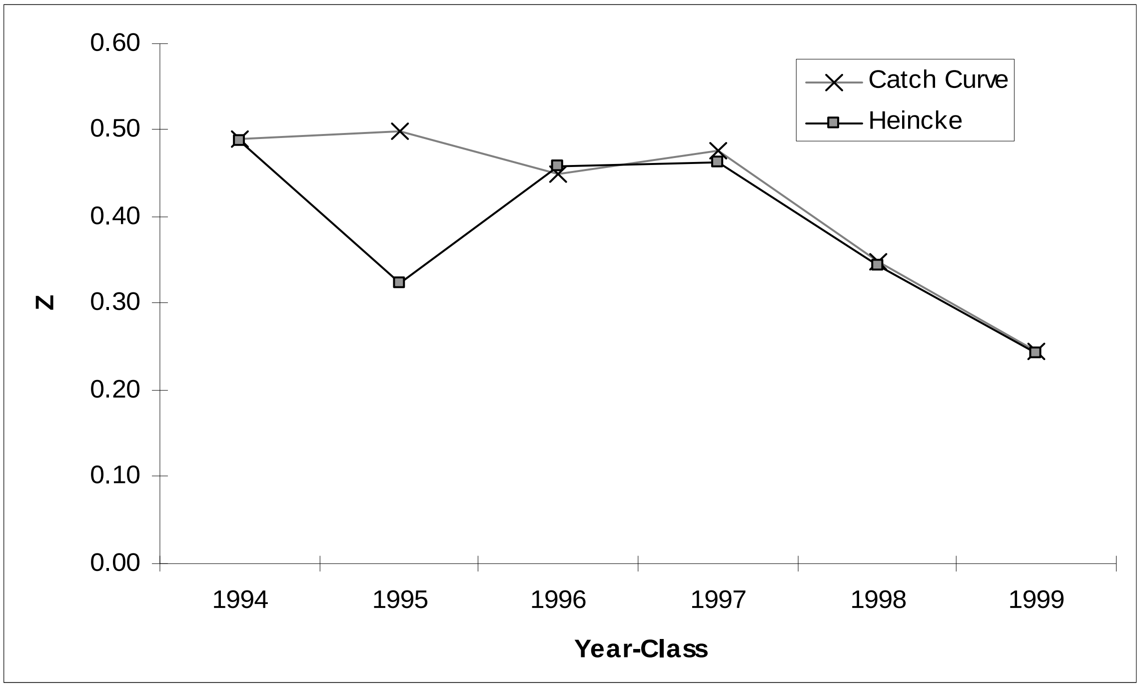


Figure A6. 5 Comparison of instantaneous total mortality rates (Z) estimated by catch curves and Heincke's method for Atlantic croaker using available data from the VMRC commercial fisheries biological sampling program.

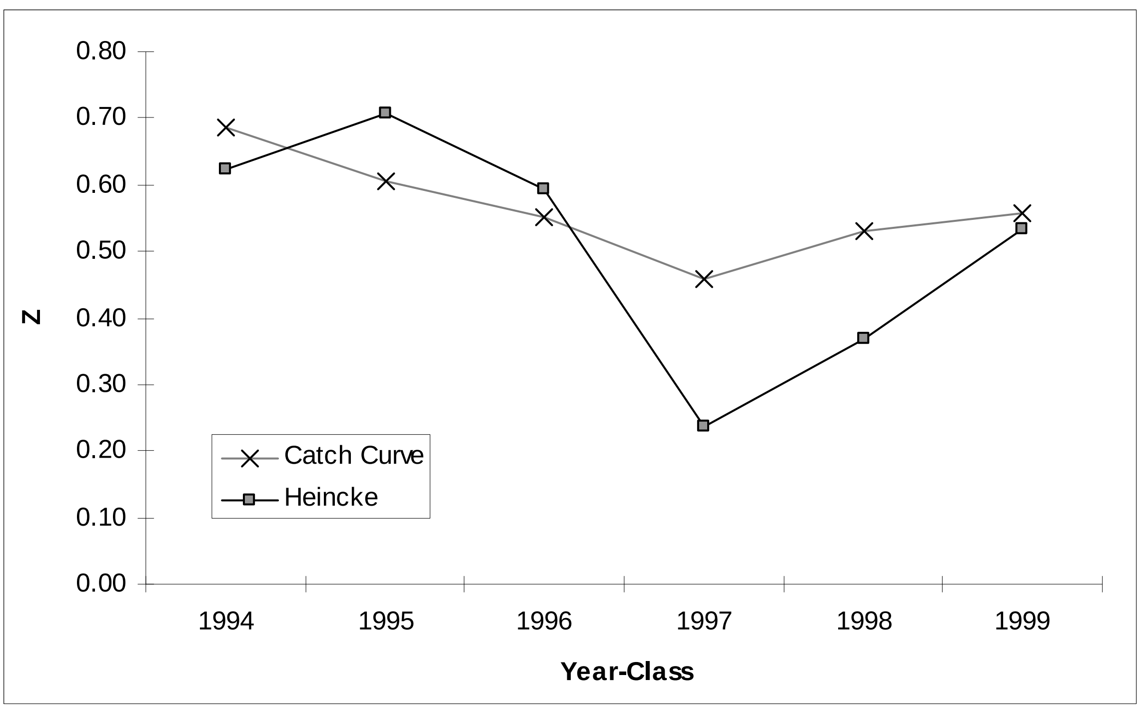


Figure A6. 6 Comparison of instantaneous total mortality rates (Z) estimated by catch curves and Heincke's method for Atlantic croaker using available data from the NCDMF commercial fisheries biological sampling program.

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

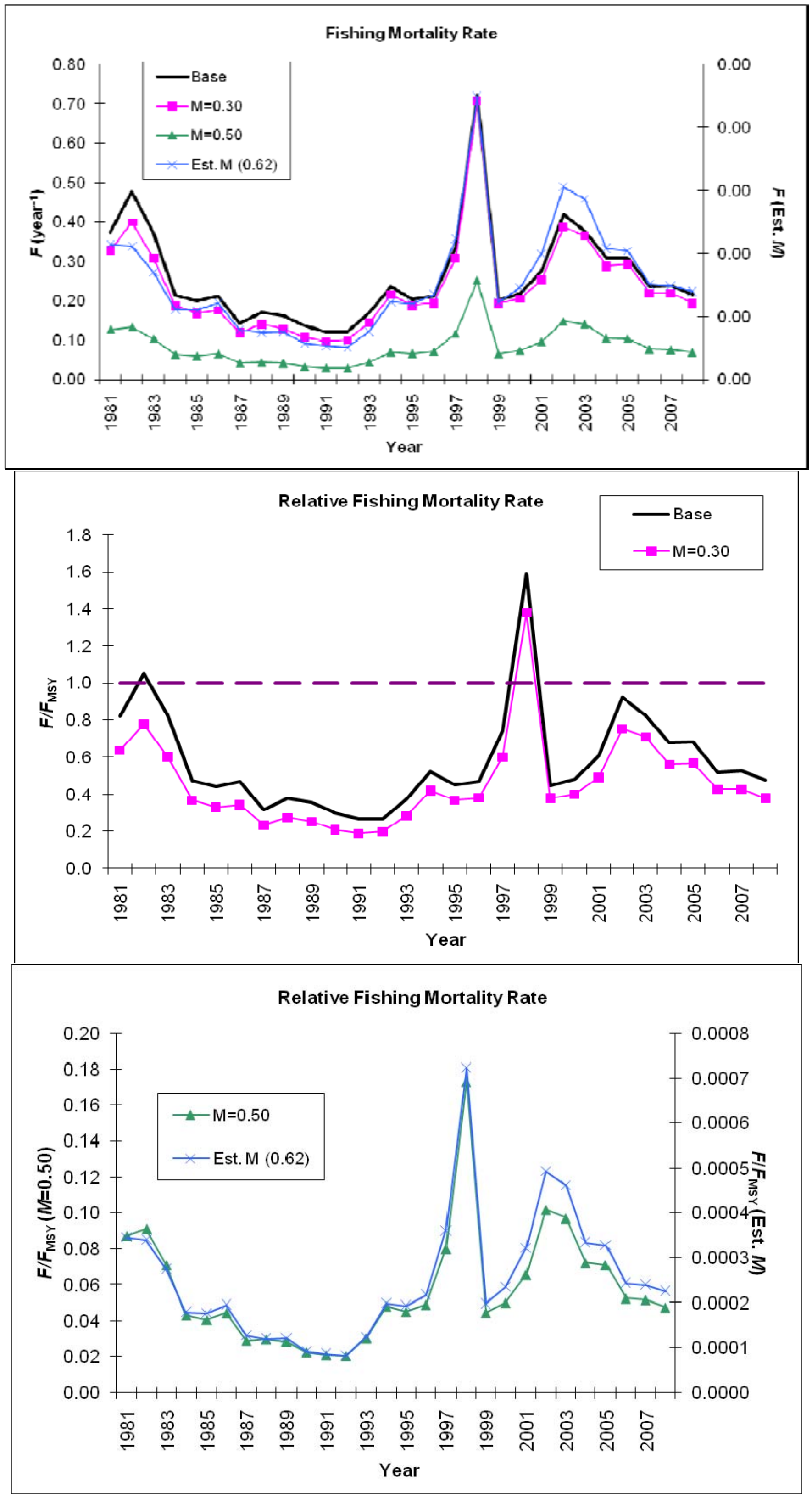


Figure A8. 1 Average fishing mortality under different natural mortality assumptions.

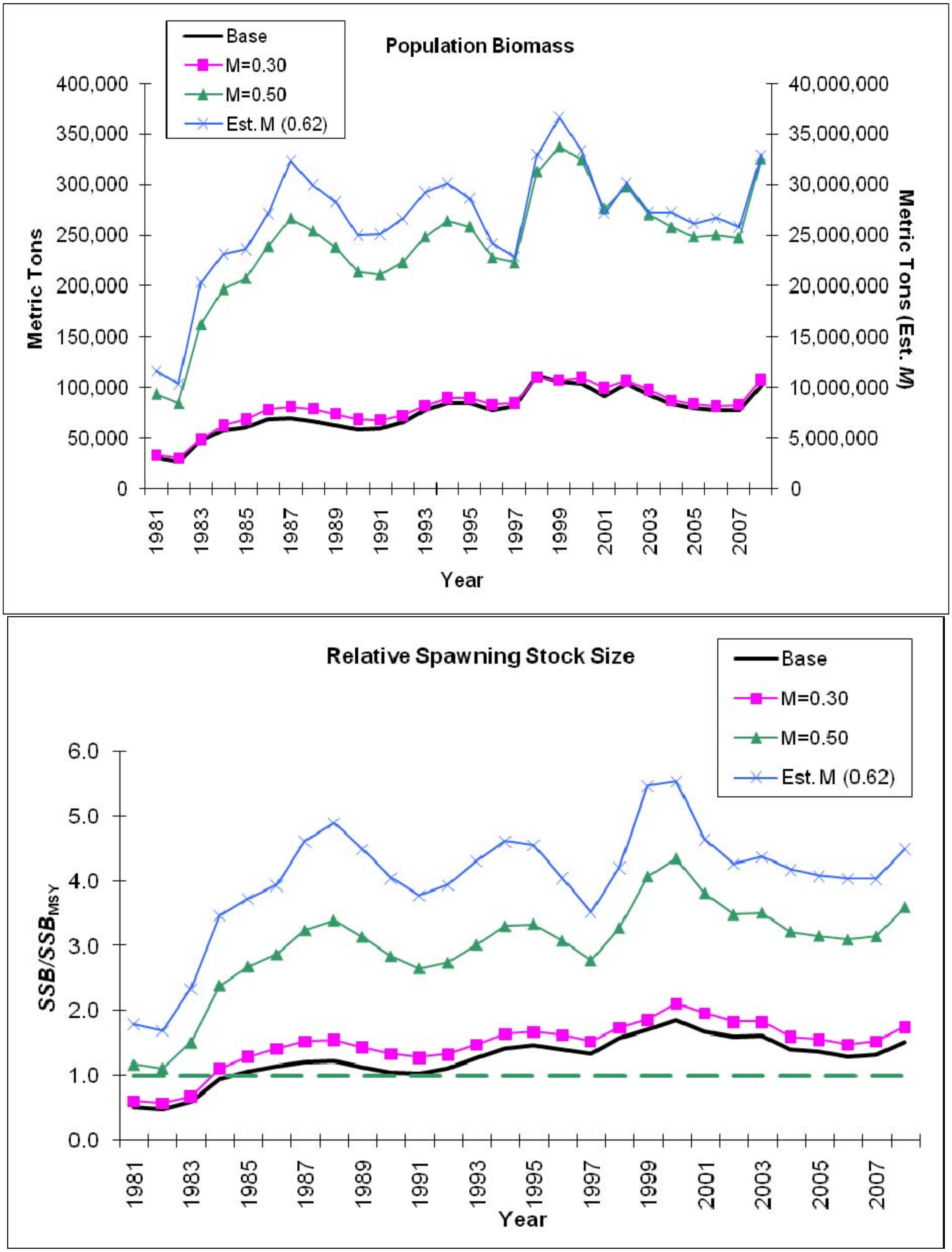


Figure A8. 2 Population biomass under different natural mortality assumptions.

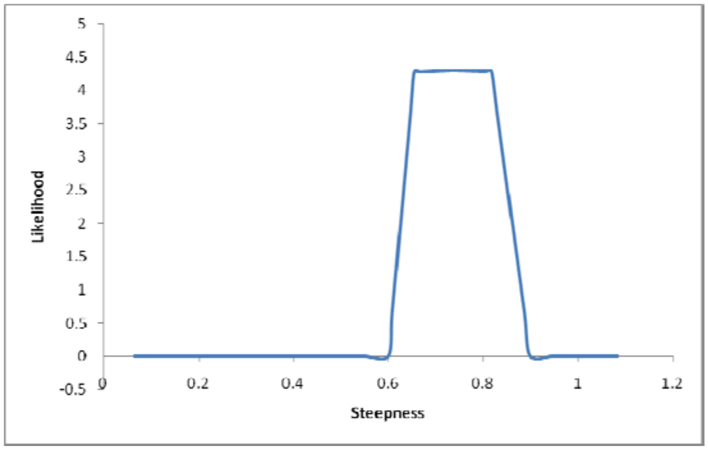


Figure A8. 3 Likelihood profile of steepness parameter estimated by model.

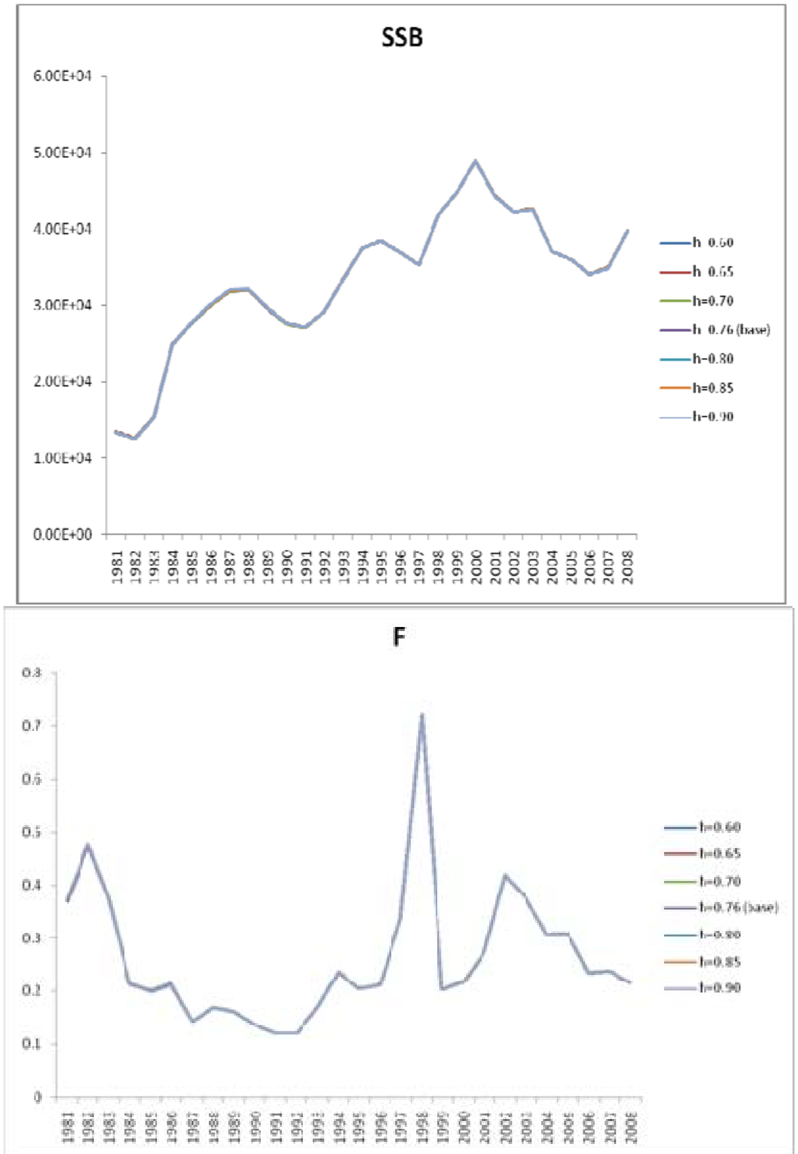
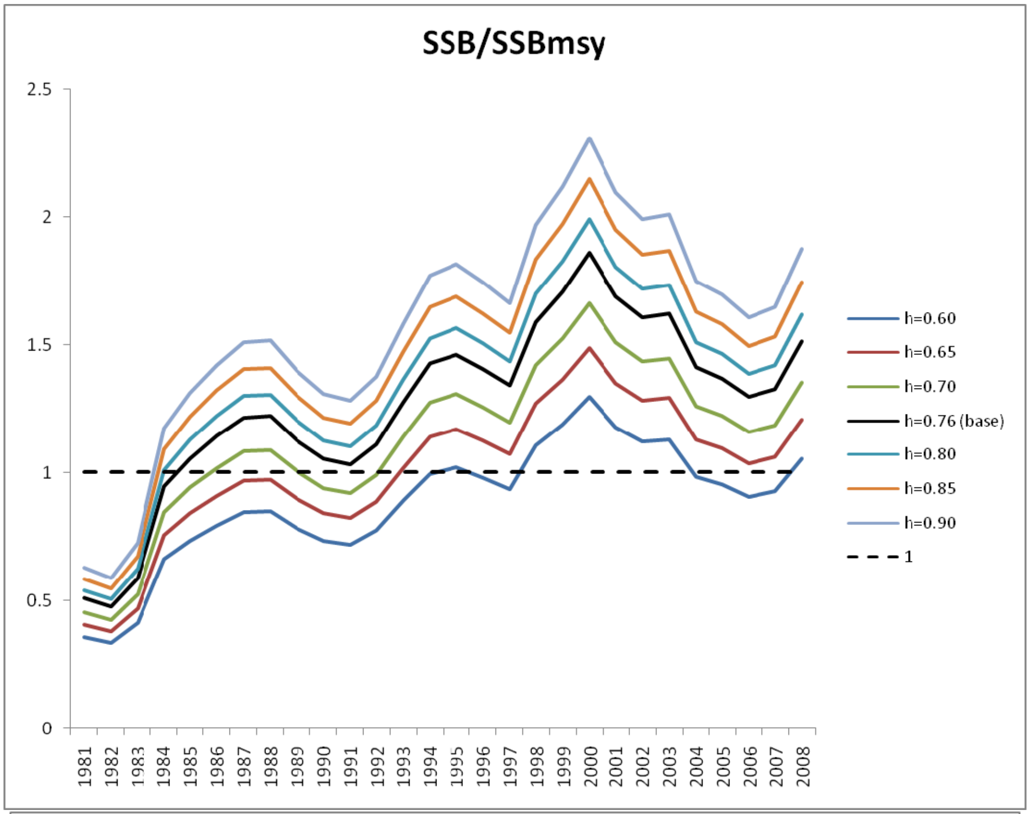


Figure A8. 4 Spawning stock biomass and average fishing mortality for different values of steepness (h).



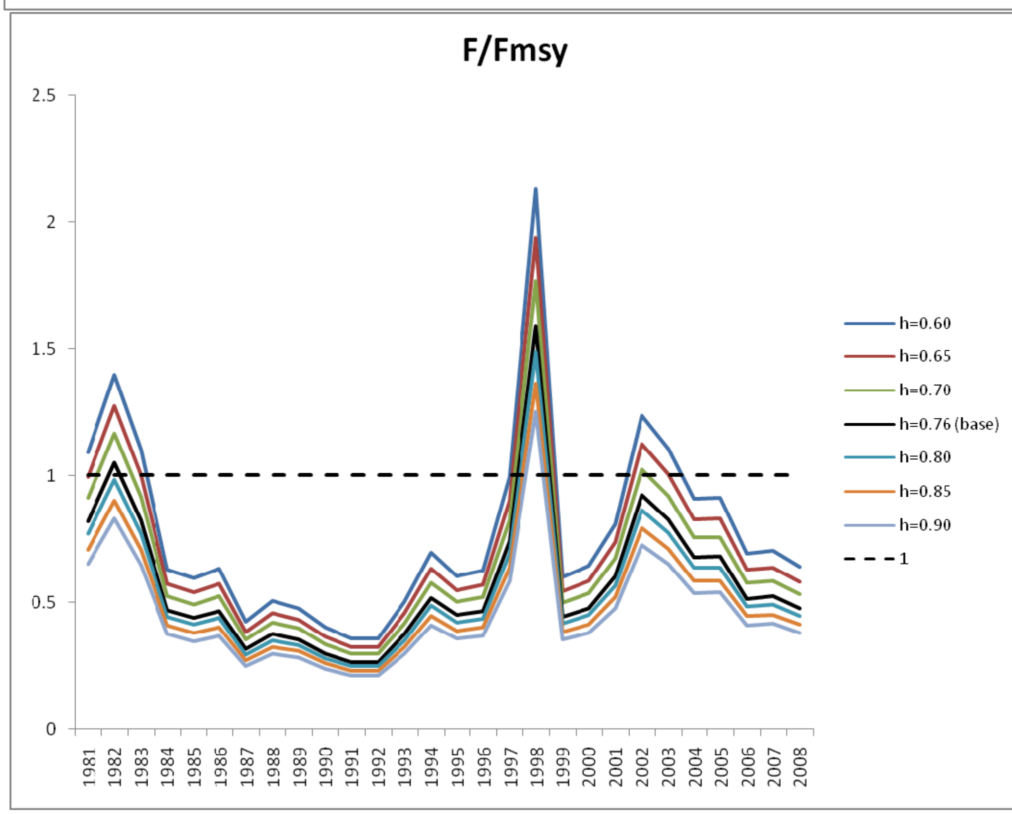


Figure A8. 5 Relative stock status for different values of steepness.

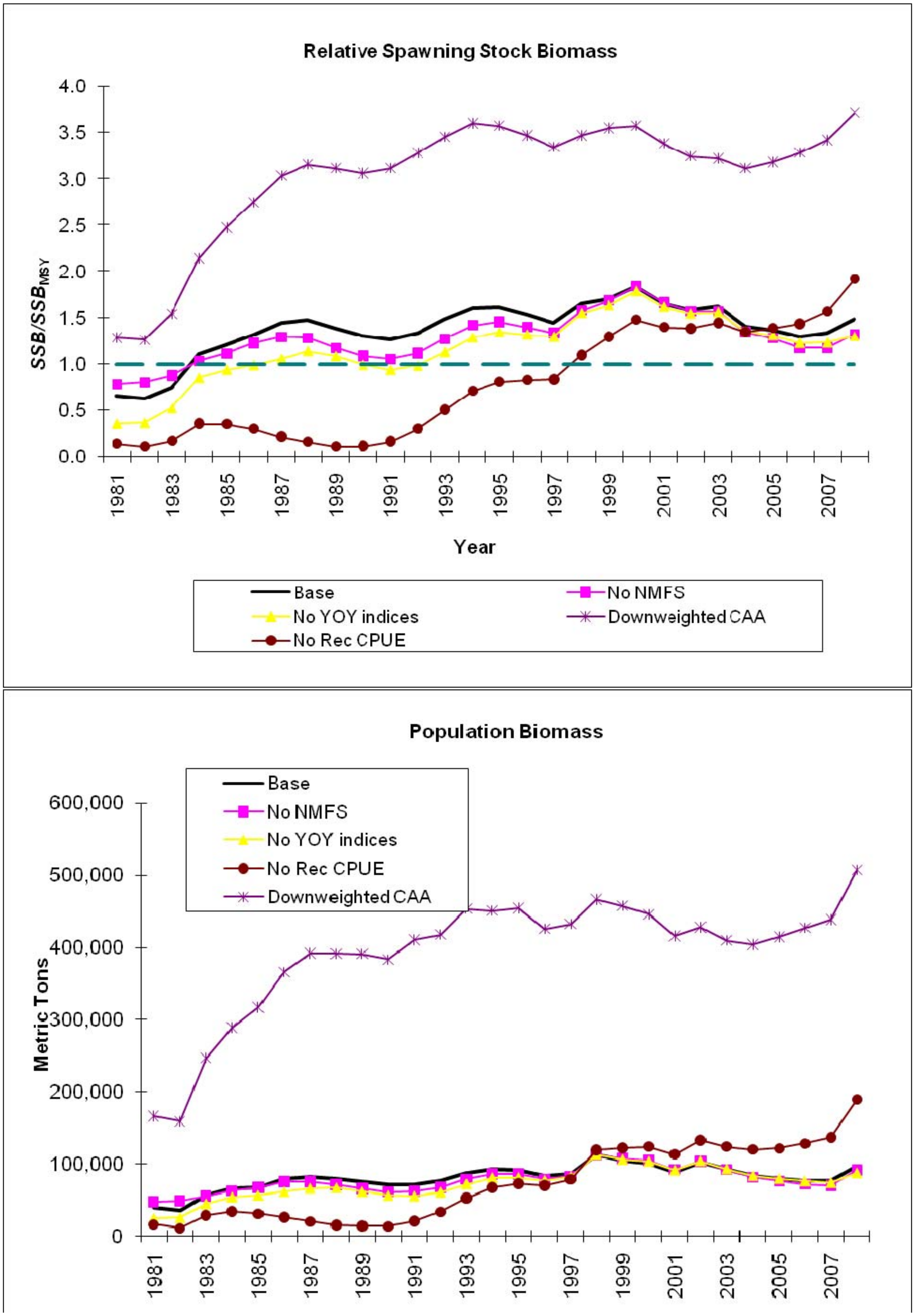


Figure A8. 6 Population biomass and relative SSB as a function of omitted or reweighted model inputs.

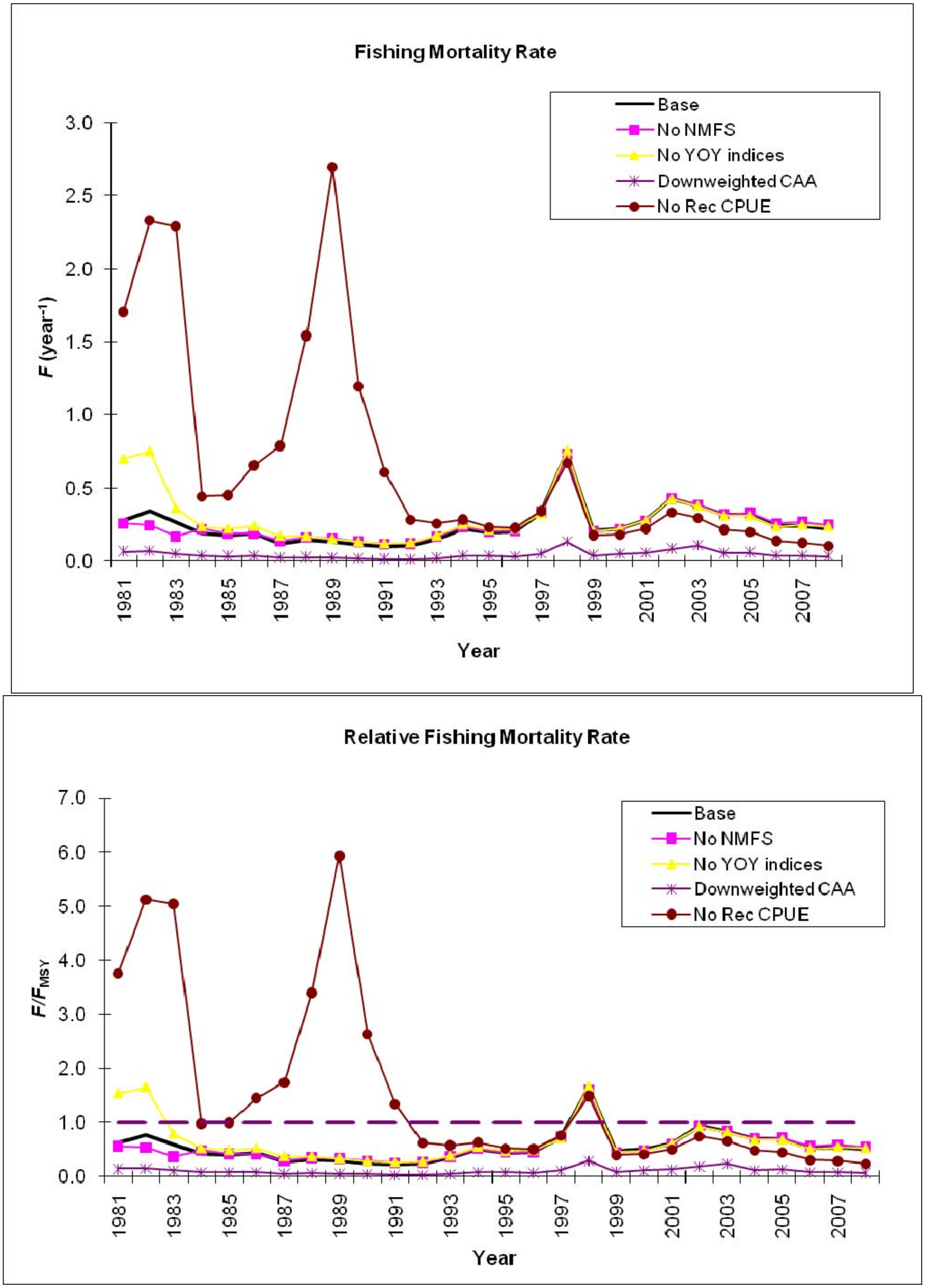


Figure A8. 7 Fishing mortality as a function of omitted or reweighted model inputs.

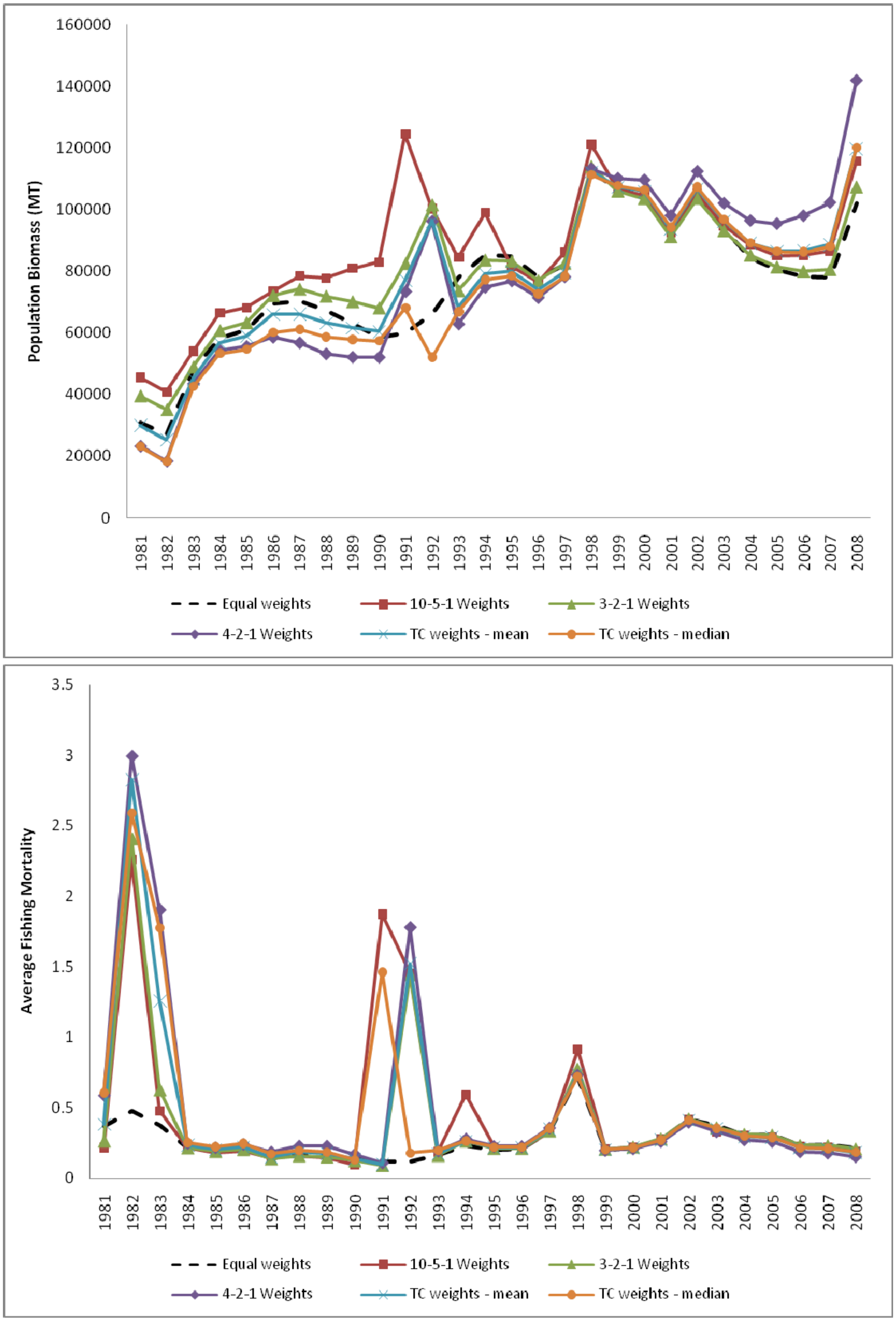
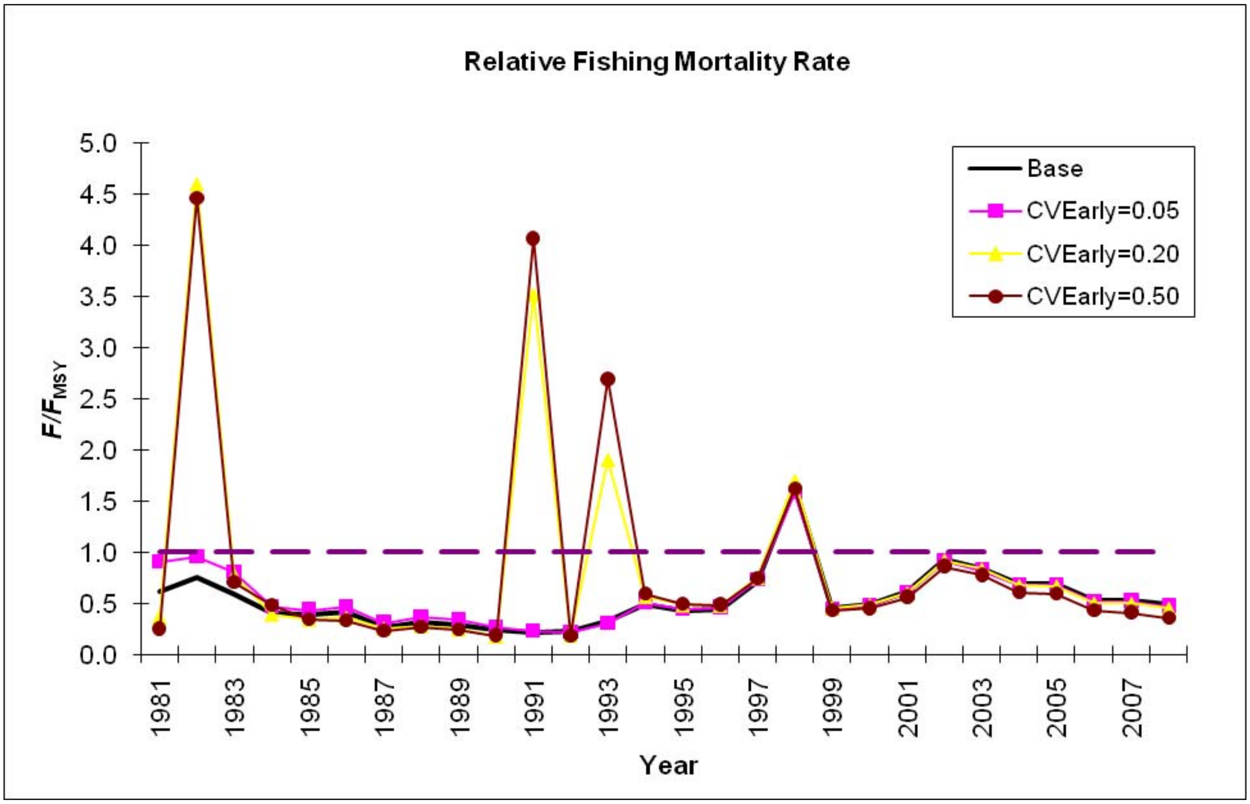


Figure A8. 8 Population biomass (top) and fishing mortality (bottom) estimates under different input data weighting schemes (see Table A8.1 for weights).



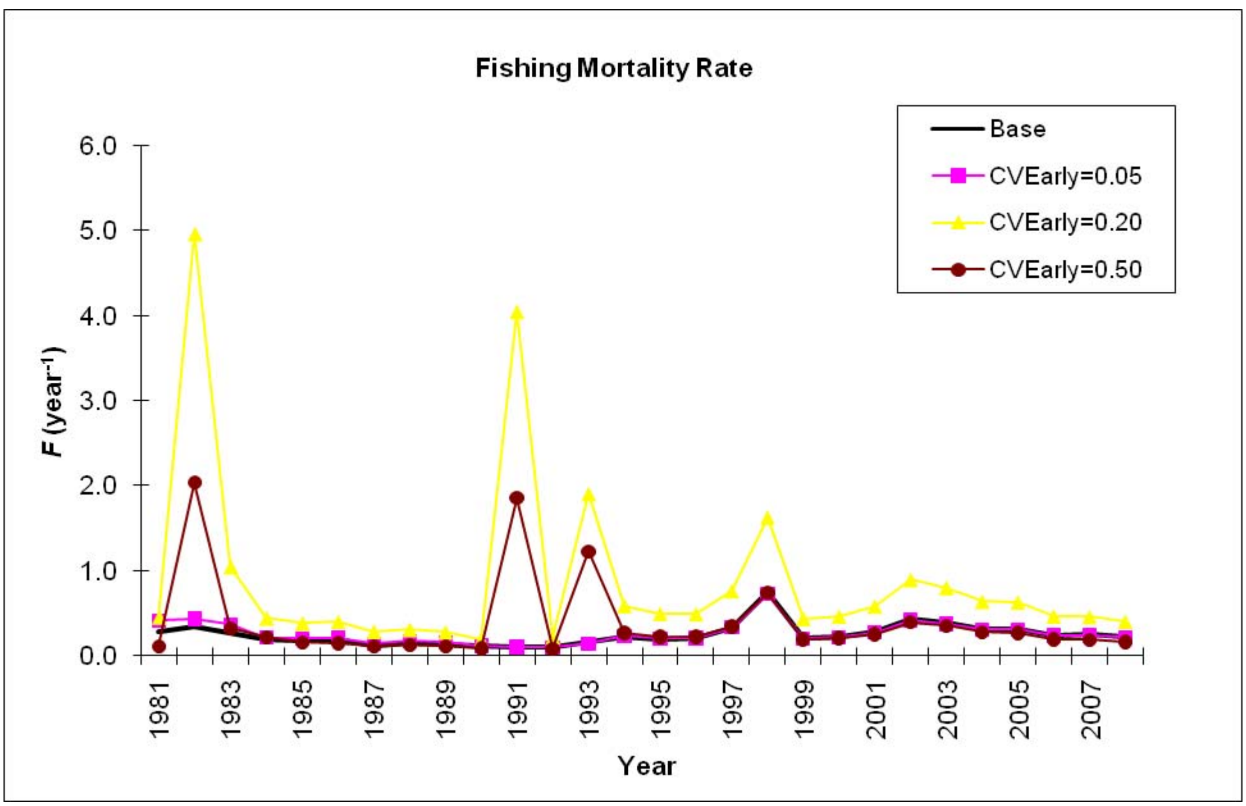


Figure A8. 9 Fishing mortality rates as a function of the assumed CV in the early (1981-1993) part of the time series.

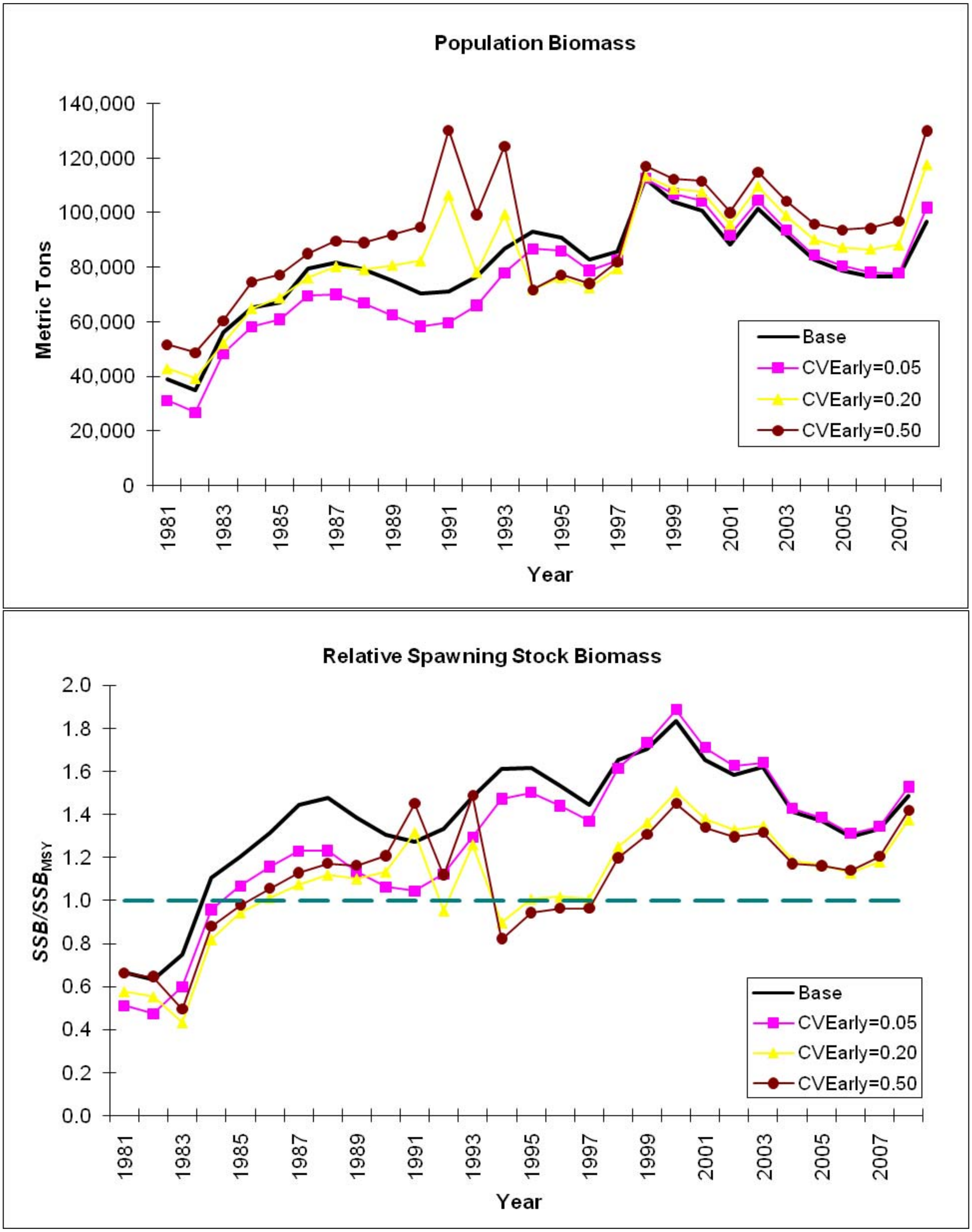


Figure A8. 10 Biomass as a function of the assumed CV in the early (1981-1993) part of the time series.

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.

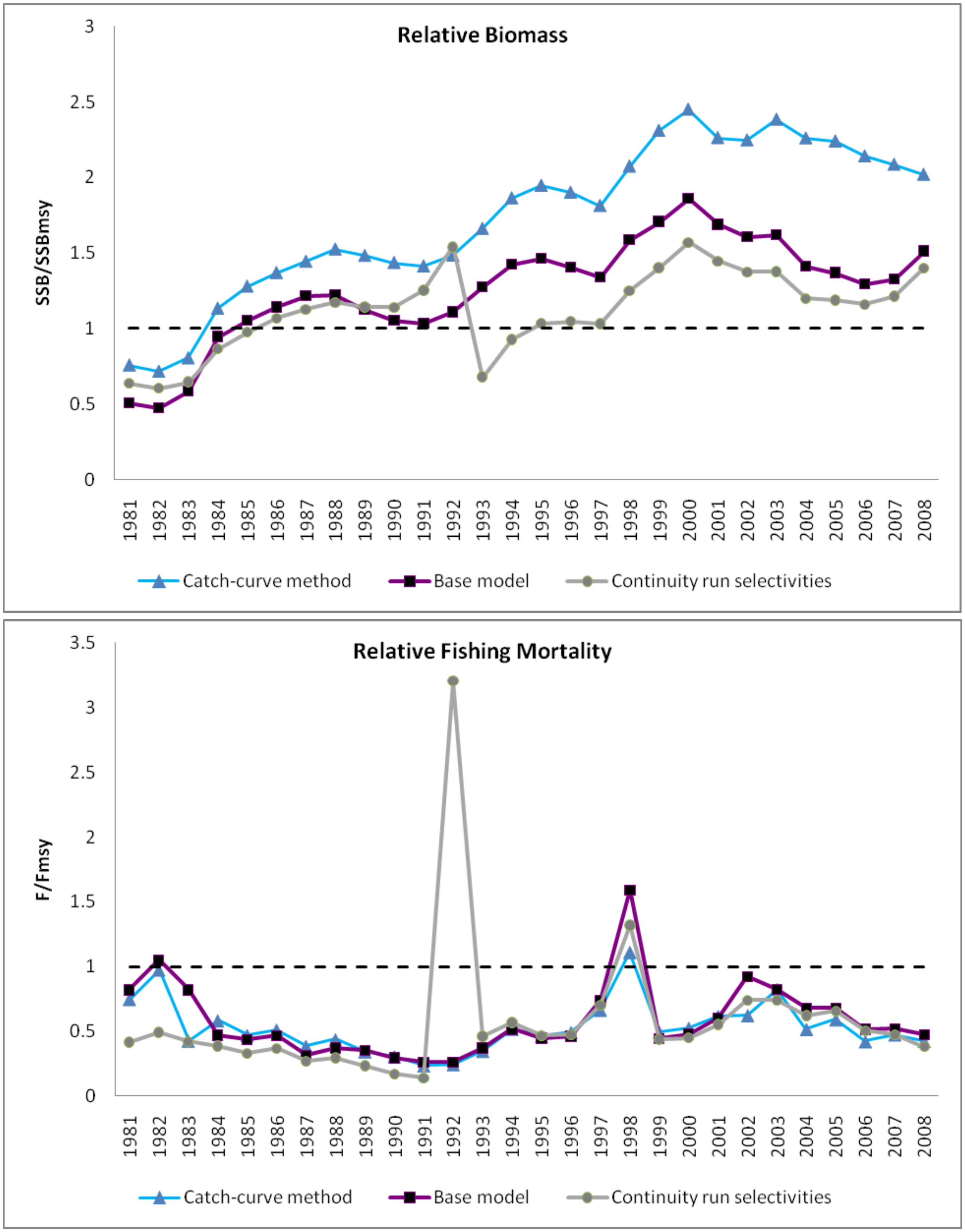


Figure A8.13 Relative spawning stock biomass (top) and fishing mortality (bottom) estimated under different fixed selectivity patterns.

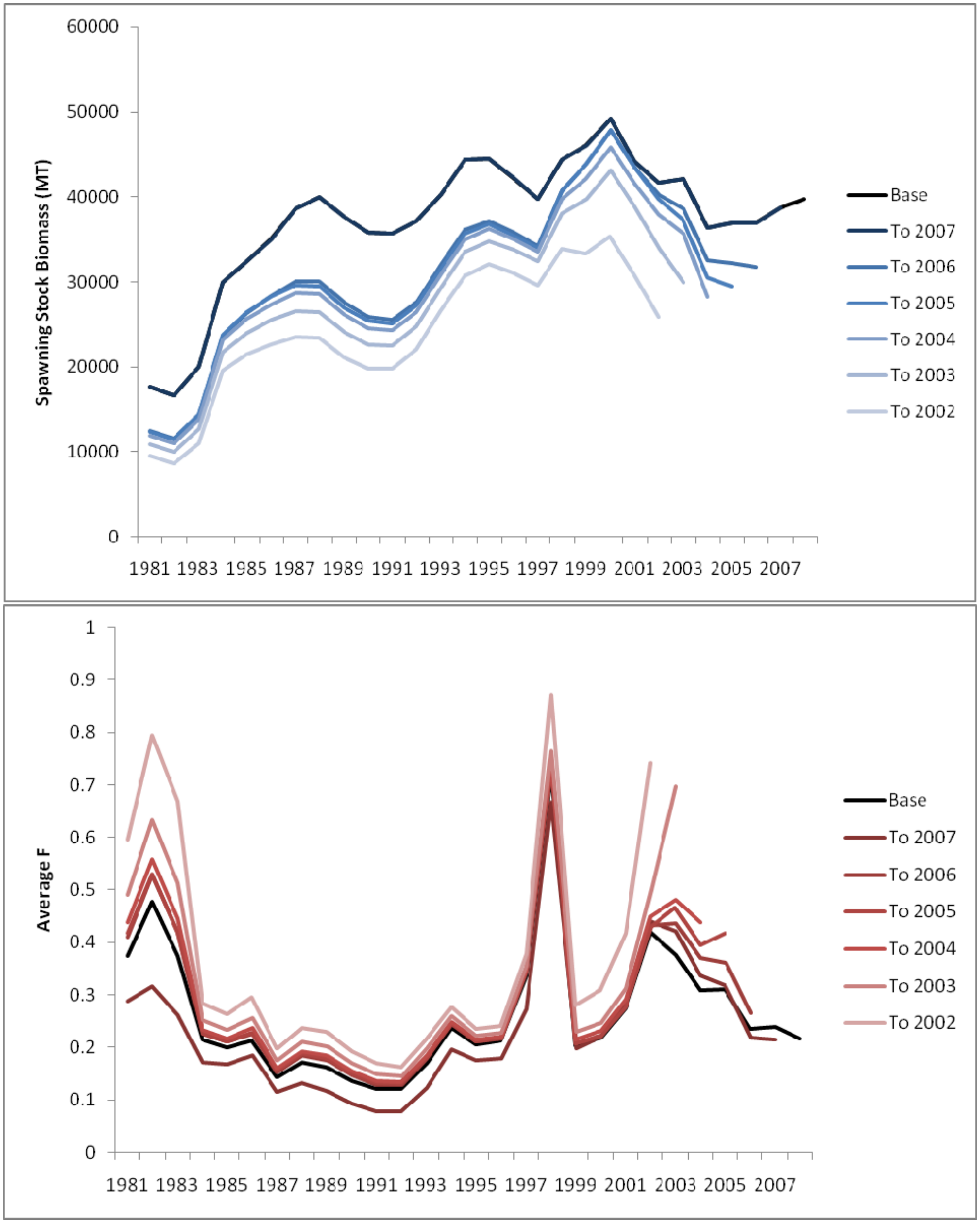


Figure A8.14 Retrospective pattern in estimates of spawning stock biomass (top) and average fishing mortality (bottom). As years of data are added (darker lines), estimates of population size increase and estimates of F decrease.

ADDENDUM TO THE ATLANTIC CROAKER 2010 STOCK ASSESSMENT REPORT FOR PEER REVIEW

A.1 Purpose

The SEDAR 20 Review Workshop met in Charleston, South Carolina from March 8 to March 12, 2010 to review the stock assessment of Atlantic croaker prepared by the ASMFC Atlantic Croaker Technical Committee and Stock Assessment Subcommittee. This appendix describes the revisions to the assessment that were made in response to recommendations of the SEDAR 20 review panel. To gain a full understanding of the assessment and its review through time, the reader should also review the original Stock Assessment Report for Peer Review and the Review Panel Report.

A.2 Revised Hybrid Statistical Catch-at-Age Model

A.2.1 Overview of Recommendations

The Review Panel requested the following changes to the input data:

- Assume the model start year is 1988 and include available scale-derived catch-at-age data for 1988–1995
- Omit the recreational CPUE index
- Recalculate the NMFS Bottom Trawl Survey index
- Use the age data from the NMFS Bottom Trawl Survey index
- Use the maturity schedule from the previous assessment

The Review Panel also requested the following changes to the model configuration:

- Allow the model to estimate the selectivity patterns of the fisheries and the indices for which age data were available
- Allow the model to estimate the initial abundance of all age classes
- Standardize the composite selectivity pattern used to estimate MSY to a maximum of 1

This revised model was run with and without the estimates of shrimp bycatch.

A.2.2 Input Data Modifications

The original base model started in 1981 and included only otolith-derived catch-at-age data, which were available for 1996–2008. In order for the model to better estimate the initial abundance-at-age, the Review Panel recommended that only years with catch-at-age data be included in the model. Using only otolith-derived age data would limit the time-series to 1996–2008. In order to extend the time-series, the Panel recommended that the scale-derived catch-at-age be included. Scale-ages have been collected consistently since 1988, and were collected concurrently with otoliths from 1996-1999. This period of overlap was used to develop a scale-otolith transition matrix to convert scale ages into otolith ages (see Section 5.15 in the main report).

The Panel recommended that the recreational CPUE index be dropped from the model, as they were concerned that it was not truly indexing the abundance of croaker.

The Panel was concerned that the post-stratification of the NMFS Bottom Trawl Survey data resulted in strata that were not sampled in all years. The NMFS index was calculated by post-stratifying the data into three depths: shallow (0–9 m), mid (9–18 m), and deep (18–27 m). The shallow depth stratum was not sampled in all years, and the Panel agreed that it should not be included in the calculation of the index. The Panel recommended recalculating the index using the mid and deep depth strata and including a north-south stratification (Figure A.1). The Panel also recommended interpreting the estimated catchability coefficient (q) for the NMFS survey in terms of area-swept as an additional model diagnostic.

The NMFS Bottom Trawl Survey and the SEAMAP Trawl Survey age a subset of the fish that are caught, providing index-at-age data. In the original model, the index-at-age data were used only to estimate selectivity. The Panel recommended that these data be incorporated into the full model, and the revised model now uses estimates of index proportion-at-age in the likelihood calculations, similar to the way the fleet catch-at-age data is used.

The maturity schedule used in the original base run assumed 43% of age-0 fish were mature. This was based on the data collected during the fall component of the NMFS Bottom Trawl Survey. The mature age-0 fish were biologically closer to age-1, given the fall spawning season of Atlantic croaker. However, they were still in the age-0 class, according to accepted ageing protocols, as they had not experienced their second winter which forms the first true annulus. The Review Panel was concerned that this maturity schedule was not consistent with the time-step of the spawner-recruit relationship in the model and recommended the use of the maturity schedule used in the last assessment, which had 0% of age-0 mature, 90% of age-1, and 100% of age-2+ mature, based on Barbieri *et al.* (1994), who found that over 85% of fish were mature by the end of their first year.

A.2.3 Modifications to Model Configuration

The original base model calculated population numbers at age in the first model year based on estimated virgin recruitment (R_0) and the SSB_{Ratio} (the ratio of SSB in the initial model year to the virgin level of SSB). Recruitment was assumed constant prior to the first model year. The Review Panel recommended that the model be reconfigured to directly estimate the abundance-at-age in the first year.

The Panel recommended that the model estimate the selectivity patterns of the fisheries and indices for which age data were available. In the original base model, an initial run was made to estimate selectivity patterns that were used in all subsequent runs. The revised model estimated selectivity using a four-parameter double-logistic function. The selectivity pattern for the recreational harvest was assumed asymptotic (only two selectivity parameters estimated). The selectivity of the YOY indices and the shrimp fishery, when included, was assumed to be 100% at age 0 and 0% for all other ages.

The final change was to standardize the composite selectivity pattern used to estimate MSY to 1 by dividing by the maximum selectivity-at-age calculated from the fishery selectivities and the last three years of landings.

A.2.4 Results

A.2.4.1 Parameter Estimates

Parameter estimates and their standard deviations are reported in Tables A.1–A.3. Standard deviations were estimated by AD Model Builder using the delta-method, which tends to underestimate error when informative priors or parameter bounds are used.

The model estimated a q of 8.36 x 10^{-7} for the NMFS trawl survey. The NMFS trawl sweeps an area of 0.0112 nm^2 per tow and a total area of 3,391 nm^2. This translates into an area-swept q of 0.253, which is reasonable for a survey of this magnitude.

A.2.4.2 Stock Abundance and Biomass

The revised model predicted a steadily increasing trend in abundance and total biomass over the model time series (Figure A.2). Likewise, the revised model predicted that SSB increased steadily over time (Figure A.3). The results of the revised model show that SSB was below estimated SSB_{MSY} during the beginning of the time series and exceeded SSB_{MSY} in 1998 and later (Figure A.4). When shrimp-trawl bycatch was included in the model, estimates of abundance and biomass demonstrated a gradual increase over time, similar to the model run without shrimp-trawl bycatch (Figure A.5). Estimates of SSB also showed an increasing trend over time when shrimp-trawl bycatch was included (Figure A.6). Annual estimates of abundance, biomass, and SSB were higher in the shrimp-trawl bycatch run. The results of the model run that included shrimp-trawl bycatch suggest that SSB has exceeded SSB_{MSY} since 2003 (Figure A.7).

A.2.4.3 Fishery Selectivity

The revised model estimated a dome-shaped pattern for commercial landings (Figure A.8). In the original model, commercial landings were assumed to have an asymptotic pattern. An asymptotic pattern was assumed for the recreational harvest in the revised model, which estimated that age 4 was the first age fully-selected in the recreational harvest (Figure A.8). The predicted selectivity patterns for the commercial scrap/discards and recreational discards suggest that one-year-olds are the dominant age of Atlantic croaker caught in these fisheries. The selectivity pattern predicted for the SEAMAP index suggests a predominance of age-0 Atlantic croaker in the survey, which is consistent with the observed data (Figure A.9). Inclusion of shrimp-trawl bycatch in the model yielded similar estimates of selectivity for all fleets except commercial landings (Figure A.10). The shrimp-trawl bycatch run predicted that commercial landings selectivity was higher at older ages than the run that did not include shrimp-trawl bycatch. The predicted selectivity patterns for the NMFS and SEAMAP indices were similar between runs with and without shrimp-trawl bycatch (Figure A.11).

A.2.4.4 Fishing Mortality

The revised model predicted a substantial decrease in total fishing mortality during the first five years of the time series (1988–1992; Figure A.12) Total F estimates showed an overall decline over the remainder of the time series, with brief spikes in 1998 and 2002–2003. The estimates of total F from the model run that included shrimp-trawl bycatch showed a similar trend to estimates of the run that did not include shrimp-trawl bycatch, but absolute values of total F were higher overall when shrimp-trawl bycatch was included (Figure A.13).

A.2.4.5 Benchmarks / Reference Points

Estimates of biomass and fishing mortality reference points for Atlantic croaker based on the revised model are presented in Table A.4. The biomass-based reference points are higher than the values estimated by the original model. Estimates of SSB have exceeded the biomass threshold since 1995 and have exceeded the biomass target since 1998 (Figure A.14). The 2008 estimate of SSB is higher than the biomass target and threshold, suggesting the stock is currently not overfished. Including shrimp-trawl bycatch in the model resulted in higher estimates of the biomass target and threshold (Table A.5). Similar to the run without shrimp-trawl bycatch, the 2008 estimate of SSB from the shrimp-trawl bycatch run is higher than both of the biomass reference points (Figure A.15). Although SSB_{2008} remains above SSB_{MSY} when shrimp-trawl bycatch is included, the estimate of SSB_{MSY} is much higher than the estimate of SSB_{MSY} from the base model without shrimp-trawl bycatch.

The fishing mortality reference points estimated by the revised model are lower than the values estimated by the original model (Table A.4). Total F estimates exceeded the fishing mortality threshold prior to 1991 (Figure A.16). Estimates of total F exceeded the fishing mortality target during 1988–1991 and again in 1998. Total F in 2008 was below the fishing mortality target and threshold, which suggests the Atlantic croaker stock is currently not experiencing overfishing. The inclusion of shrimp-trawl bycatch in the model yielded lower estimates of the fishing mortality reference points (Table A.5). The shrimp-trawl bycatch run estimated that total F in 2008 was below the fishing mortality target and threshold (Figure A.17); however, the results of this run suggest that the Atlantic croaker stock has been overfished for most of the model time series. Estimates of F_{MSY} were similar for the revised model without shrimp-trawl bycatch and runs of the revised model that assumed different levels of shrimp-trawl bycatch, suggesting the estimated fishing mortality reference points are robust (see also Section A.2.4.7).

A.2.4.6 Measures of Overall Model Fit

The predicted values of annual catch were similar to observed values for all fisheries (Figures A.18–A.21); however, the trend in the annual catch standardized residuals remained (Figure A.22). Normal quantile plots suggest the annual catch standardized residuals of each fishing fleet are not normally distributed (Figure A.23). The revised model provided reasonable fits to the indices (Figures A.24–A.27). No apparent trends were observed in the standardized residuals of the indices (Figure A.28). In the original base run, the NMFS index standardized residuals showed an increasing trend over time. The standardized residuals of the indices were found to be normally distributed ($P > 0.01$; Figure A.29). The VIMS standardized residuals were nearly non-normal ($P = 0.0104$), likely due to the model's poor fit to the VIMS 2008 observed index value (Figure A.26). The standardized residuals of the fishery and index catch-at-age data suggested the revised model provided a better fit to the age data than the original base model, which demonstrated strong patterns in the catch-at-age residuals (Figures A.30–A.35). Most of the larger ($\geq \pm 2$) catch-at-age residuals are positive, suggesting the model predicted a lower proportion of fish at age than was observed.

A.2.4.7 Evaluation of Uncertainty

The original estimates of shrimp-trawl bycatch were based on ratios of Atlantic croaker landings to shrimp landings from several studies over different time periods, which ranged from 1.15 to 1.66. The SASC considered these estimates quite unreliable. The Panel agreed and asked the working group to run the revised model using different assumed levels of shrimp-trawl bycatch. The different levels of shrimp-trawl bycatch in the sensitivity runs ranged from 10% to 1,000% (i.e., 10 times) of the original estimate.

Estimates of F_{MSY} were fairly similar across the different levels of shrimp-trawl bycatch (Table A.6; Figure A.36). The ratio of $F_{2008}/F_{\mathrm{MSY}}$ increased with increasing levels of shrimp-trawl bycatch, but even at 10 times the original estimates, the ratio remained below 1, indicating overfishing was not occurring.

Estimates of SSB_{MSY} increased as shrimp-trawl bycatch increased, and the ratio of $SSB_{2008}/SSB_{\mathrm{MSY}}$ decreased (Table A.6; Figure A.37). At four times the original estimates, the ratio dropped below 1 indicating the stock was overfished.

A.3 Discussion

Model predictions tracked trends in the observed data. Trends in the annual catch residuals, which were observed in the original base run of this assessment and in the previous ASMFC assessment (ASMFC 2005a), persisted. There were no obvious trends observed in the standardized residuals of the annual indices or the standardized residuals of the fleet and index catch-at-age data. The revised base run and sensitivity runs of the revised model were consistent in predicting that the Atlantic croaker stock was not experiencing overfishing as of 2008. Most runs agreed that the stock was not overfished as well. The model predicted the stock status was overfished in 2008 when estimates of shrimp-trawl bycatch were assumed to be four times the original estimates (which would represent a bycatch ratio of more than 4 kg of Atlantic croaker to 1 kg of shrimp).

Table A.1. Population-related parameters and standard deviations estimated from the base run of the revised model.

Description	Parameter	Estimate	Standard Deviation
Virgin Recruitment ($\log_e$-space)	R_0	20.2	0.230
Recruitment Deviations ($\log_e$-space)	V_{1989}	-0.206	0.0789
	V_{1990}	0.329	0.0726
	V_{1991}	0.805	0.0673
	V_{1992}	0.817	0.0782
	V_{1993}	0.601	0.106
	V_{1994}	0.197	0.137
	V_{1995}	-0.130	0.159
	V_{1996}	-0.892	0.173
	V_{1997}	0.133	0.174
	V_{1998}	0.776	0.173
	V_{1999}	0.120	0.178
	V_{2000}	-0.779	0.188
	V_{2001}	-0.849	0.193
	V_{2002}	0.533	0.188
	V_{2003}	-0.580	0.190
	V_{2004}	0.201	0.191
	V_{2005}	-0.229	0.191
	V_{2006}	0.135	0.194
	V_{2007}	-0.274	0.202
	V_{2008}	0.773	0.211
Index Catchability (log-space)	q_{NMFS}	-13.99	0.124
	q_{SEAMAP}	-7.59	0.0801
	q_{VIMS}	-18.98	0.0679
	q_{NC195}	-14.33	0.150
Initial Abundance-at-Age ($\log_e$-space)	$N_{1988,1}$	18.3	0.0593
	$N_{1988,2}$	17.9	0.0617
	$N_{1988,3}$	16.8	0.0732
	$N_{1988,4}$	15.7	0.100
	$N_{1988,5}$	14.6	0.145
	$N_{1988,6}$	13.4	0.241
	$N_{1988,7}$	12.3	0.392
	$N_{1988,8}$	10.6	0.877
	$N_{1988,9}$	10.2	1.05
	$N_{1988,10}$	9.88	1.15
	$N_{1988,11}$	-4.87	653
	$N_{1988,12}$	-4.87	625
	$N_{1988,13}$	-4.87	615
	$N_{1988,14}$	-4.86	644
	$N_{1988,15}$	-4.85	642
	$N_{1988,16}$	-4.86	631

Table A.2. Estimates of fishing mortality rates for fully-selected fish and associated standard deviations from the base run of the revised model, by fleet and year.

Fleet	Year	Estimate	Standard Deviation
Commercial Landings	1988	0.699	0.0676
	1989	0.674	0.0716
	1990	0.410	0.0491
	1991	0.143	0.0186
	1992	0.0864	0.0115
	1993	0.101	0.0130
	1994	0.0753	0.00688
	1995	0.0725	0.00645
	1996	0.0931	0.00810
	1997	0.110	0.00951
	1998	0.105	0.00951
	1999	0.0880	0.00851
	2000	0.0739	0.00711
	2001	0.0755	0.00720
	2002	0.0707	0.00691
	2003	0.0773	0.00807
	2004	0.0758	0.00820
	2005	0.0633	0.00706
	2006	0.0516	0.00587
	2007	0.0474	0.00544
	2008	0.0425	0.00487
Commercial Scrap/Discards	1988	0.251	0.0473
	1989	0.310	0.0578
	1990	0.164	0.0334
	1991	0.0860	0.0200
	1992	0.0426	0.00934
	1993	0.0350	0.00724
	1994	0.0768	0.00866
	1995	0.0519	0.00584
	1996	0.0181	0.00207
	1997	0.00928	0.00107
	1998	0.227	0.0244
	1999	0.0161	0.00188
	2000	0.0211	0.00250
	2001	0.0258	0.00311
	2002	0.112	0.0133
	2003	0.119	0.0136
	2004	0.0117	0.00150
	2005	0.0360	0.00463
	2006	0.00321	0.000427
	2007	0.0145	0.00194
	2008	0.0142	0.00194

Table A.2. *Continued.*

Fleet	Year	Estimate	Standard Deviation
Recreational Harvest	1988	0.306	0.0348
	1989	0.182	0.0177
	1990	0.107	0.0128
	1991	0.0917	0.0117
	1992	0.0486	0.00590
	1993	0.0311	0.00364
	1994	0.0329	0.00335
	1995	0.0205	0.00234
	1996	0.0177	0.00209
	1997	0.0310	0.00371
	1998	0.0296	0.00338
	1999	0.0236	0.00284
	2000	0.0264	0.00300
	2001	0.0288	0.00299
	2002	0.0242	0.00249
	2003	0.0241	0.00270
	2004	0.0223	0.00272
	2005	0.0256	0.00326
	2006	0.0212	0.00303
	2007	0.0180	0.00225
	2008	0.0108	0.00138
Recreational Discards	1988	0.00252	0.000307
	1989	0.00260	0.000232
	1990	0.00360	0.000405
	1991	0.00472	0.000481
	1992	0.00134	0.000136
	1993	0.00147	0.000137
	1994	0.00147	0.000111
	1995	0.000927	0.0000847
	1996	0.00114	0.000106
	1997	0.00232	0.000227
	1998	0.00196	0.000174
	1999	0.00151	0.000124
	2000	0.00255	0.000212
	2001	0.00225	0.000194
	2002	0.00246	0.000232
	2003	0.00211	0.000188
	2004	0.00183	0.000185
	2005	0.00224	0.000239
	2006	0.00195	0.000211
	2007	0.00172	0.000182
	2008	0.00129	0.000143

Table A.3. Estimated selectivity parameters and associated standard deviations from the base run of the revised model, by fleet/index.

Fleet/Index	Parameter	Estimate	Standard Deviation
Commercial Landings	α_1	0.931	0.0687
	β_1	0.537	0.0406
	α_2	11.3	0.378
	β_2	0.961	0.168
Commercial Scrap/Discards	α_1	0.667	0.0615
	β_1	0.376	0.0211
	α_2	4.59E-08	0.000178
	β_2	1.33	0.0450
Recreational Harvest	α_1	0.857	0.0888
	β_1	0.566	0.0554
Recreational Discards	α_1	0.0392	38.3
	β_1	0.0425	41.5
	α_2	4.29E-08	0.000166
	β_2	1.59	0.0770
NMFS	α_1	0.689	0.235
	β_1	0.554	0.132
	α_2	8.93	1.52
	β_2	1.82	1.44
SEAMAP	α_1	0.000543	2.10
	β_1	15.0	0.124
	α_2	3.06E-08	0.000119
	β_2	0.537	0.0251

Table A.4. Estimated biomass and fishing mortality reference points from the base run of the revised model.

Reference Point	**Definition**	**Estimate**
Biomass Target (mt)	SSB_{MSY}	72,362
Biomass Threshold (mt)	$(1\text{-}M)SSB_{\mathrm{MSY}}$	54,180
Fishing Mortality Target (year^{-1})	$0.75F_{\mathrm{MSY}}$	0.274
Fishing Mortality Threshold (year^{-1})	F_{MSY}	0.365

Table A.5. Estimated biomass and fishing mortality reference points from the base run of the revised model that included shrimp bycatch.

Reference Point	**Definition**	**Estimate**
Biomass Target (mt)	SSB_{MSY}	125,635
Biomass Threshold (mt)	$(1\text{-}M)SSB_{\mathrm{MSY}}$	94,067
Fishing Mortality Target (year^{-1})	$0.75F_{\mathrm{MSY}}$	0.236
Fishing Mortality Threshold (year^{-1})	F_{MSY}	0.314

Table A.6. Estimated reference points and relative status for differing levels of shrimp-trawl bycatch.

Percent of original shrimp-trawl bycatch estimates	**Fmsy**	**Fcurrent/ Fmsy**	**SSBmsy**	**SSBcurrent/ SSBmsy**
0%	0.364	0.179	74517.6	1.91
10%	0.359	0.215	78354.9	1.79
50%	0.338	0.318	100502	1.50
100%	0.317	0.407	125635	1.34
200%	0.283	0.632	167282	1.21
400%	0.333	0.763	238435	0.99
1000%	0.575	0.734	425051	0.69

Table A.7. Fishing mortality and spawning stock biomass estimates from the revised model run without shrimp-trawl bycatch

Year	Total F	SSB (MT)
1988	1.26	6,989
1989	1.17	5,626
1990	0.68	5,917
1991	0.33	9,368
1992	0.18	17,896
1993	0.17	31,860
1994	0.19	48,448
1995	0.15	60,885
1996	0.13	70,198
1997	0.15	71,173
1998	0.36	79,245
1999	0.13	96,283
2000	0.12	110,607
2001	0.13	110,040
2002	0.21	103,911
2003	0.22	116,053
2004	0.11	111,161
2005	0.13	119,304
2006	0.08	121,395
2007	0.08	130,786
2008	0.07	134,143

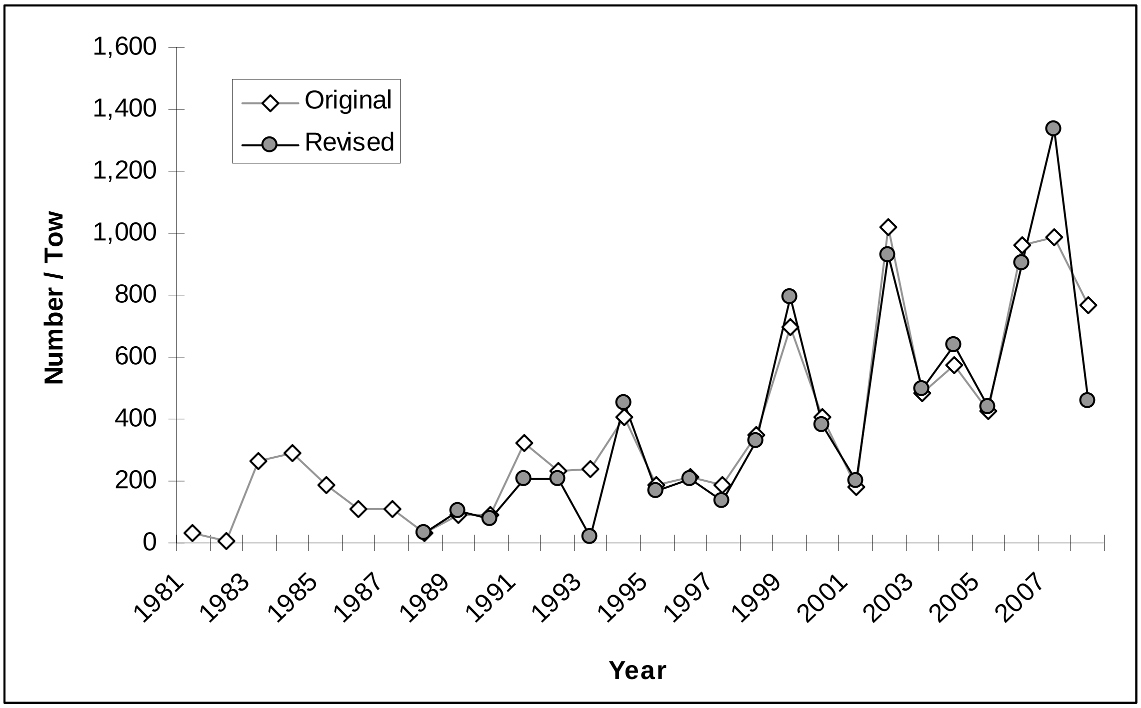


Figure A.1. Comparison of revised NMFS Bottom Trawl Survey index to the index used in the original model. The revised index was post-stratified by depth—mid and deep only—and latitude (north-south) whereas the original index was post-stratified by depth only (shallow, mid, and deep).

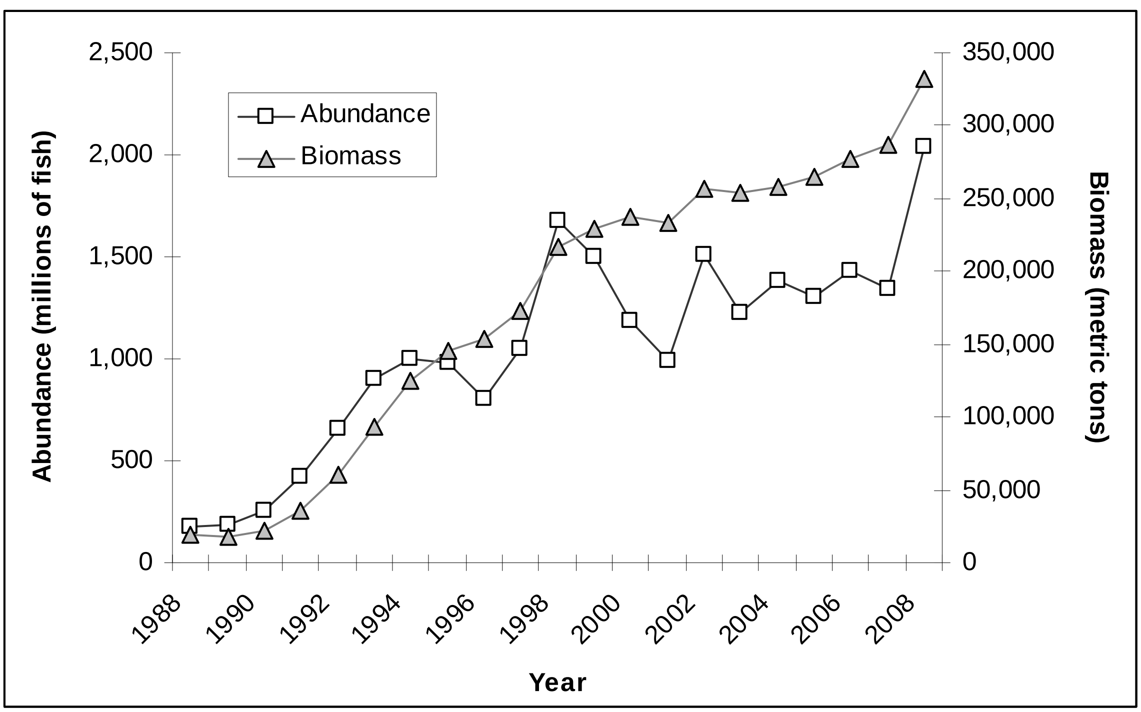


Figure A.2. Predicted trends in population size of Atlantic croaker from the base run of the revised model.

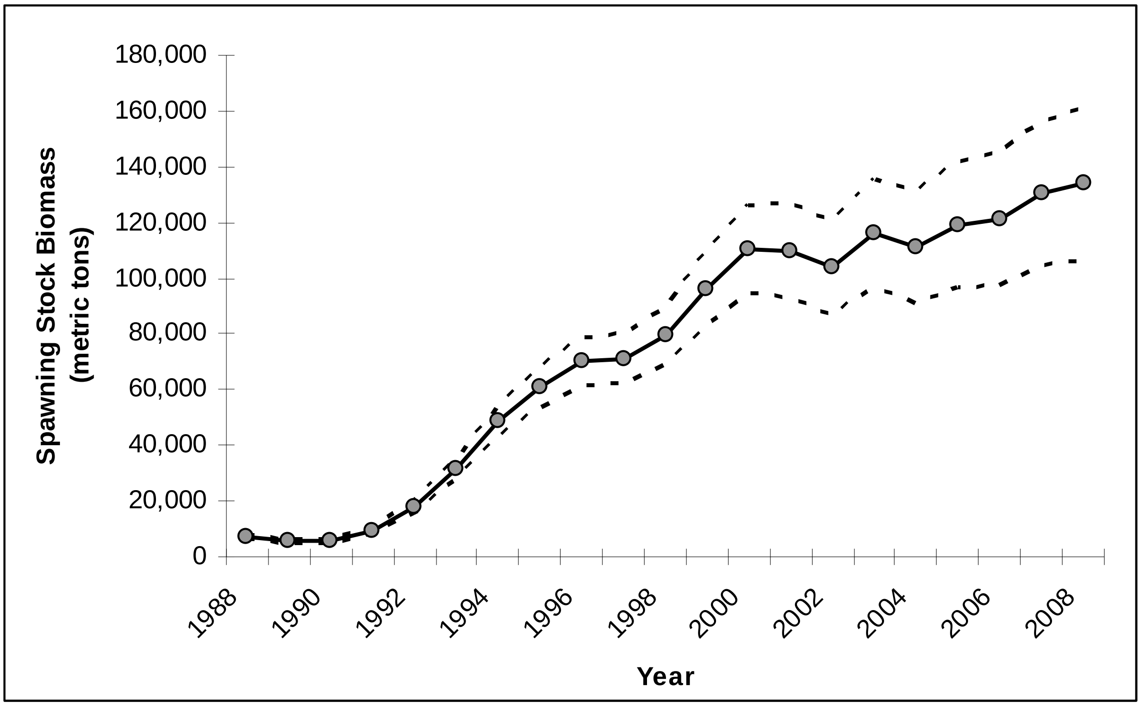


Figure A.3. Predicted trends in spawning stock biomass of Atlantic croaker from the base run of the revised model. The dashed lines represent ± 2 standard deviations of the estimates.

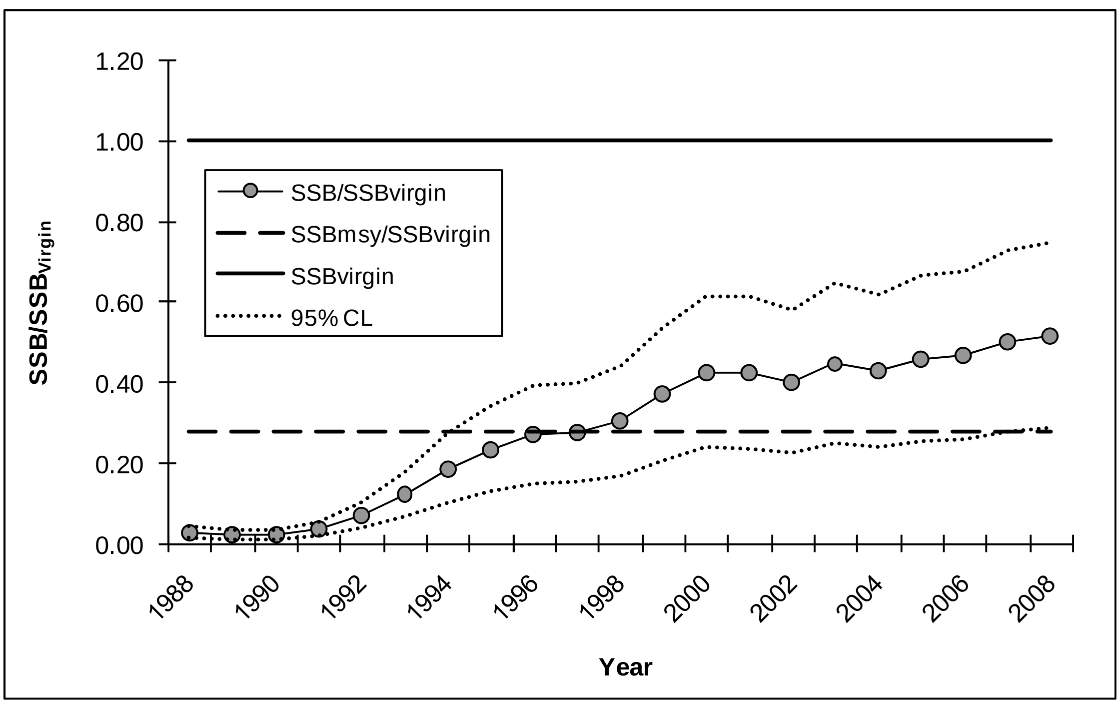


Figure A.4. Predicted spawning stock biomass and SSB_{MSY} relative to the virgin level of SSB from the base run of the revised model.

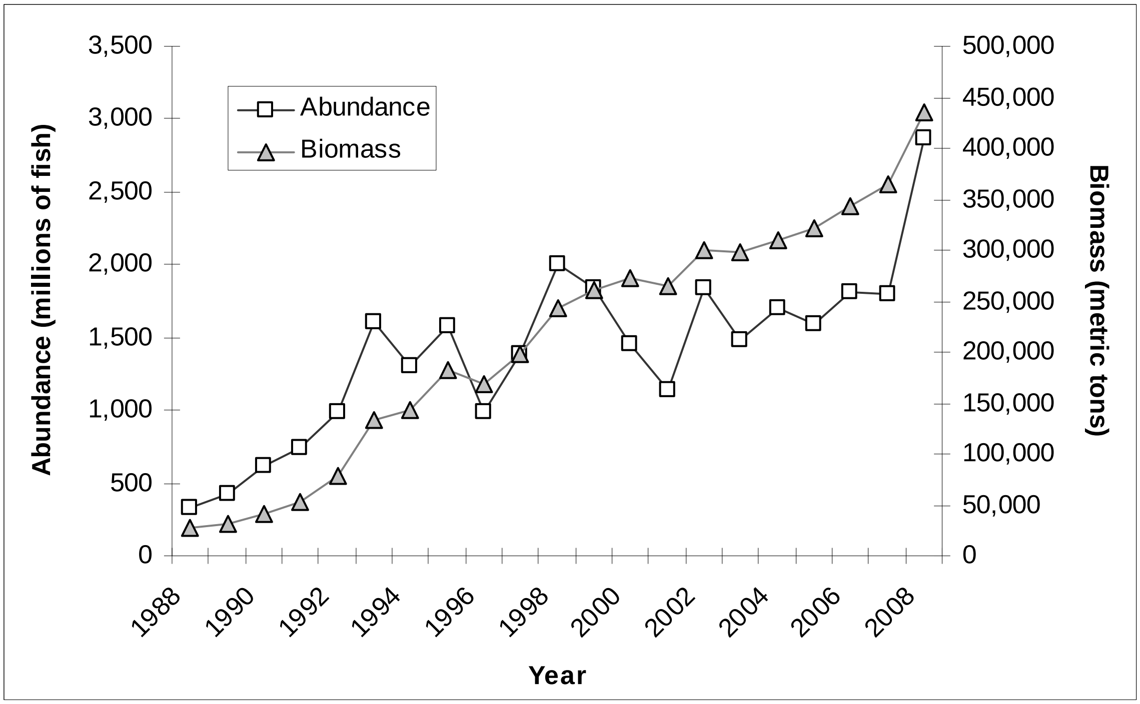


Figure A.5. Predicted trends in population size of Atlantic croaker from the base run of the revised model that included shrimp bycatch.

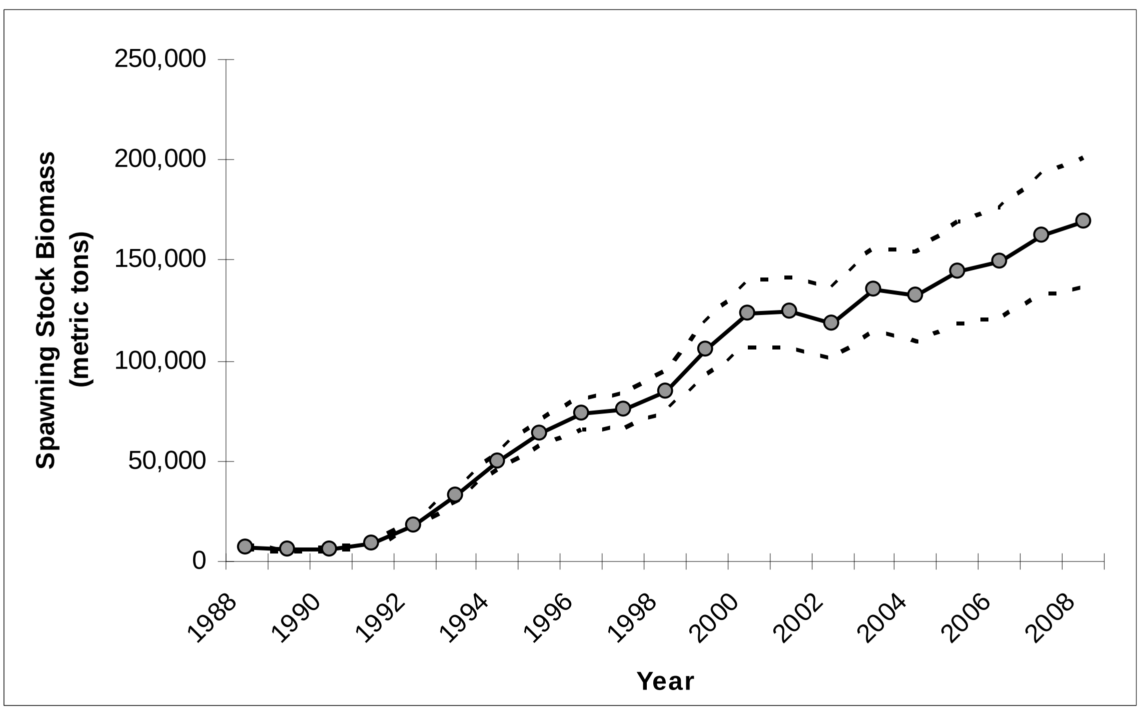


Figure A.6. Predicted trends in spawning stock biomass of Atlantic croaker from the revised model that included shrimp bycatch. The dashed lines represent ± 2 standard deviations of the estimates.

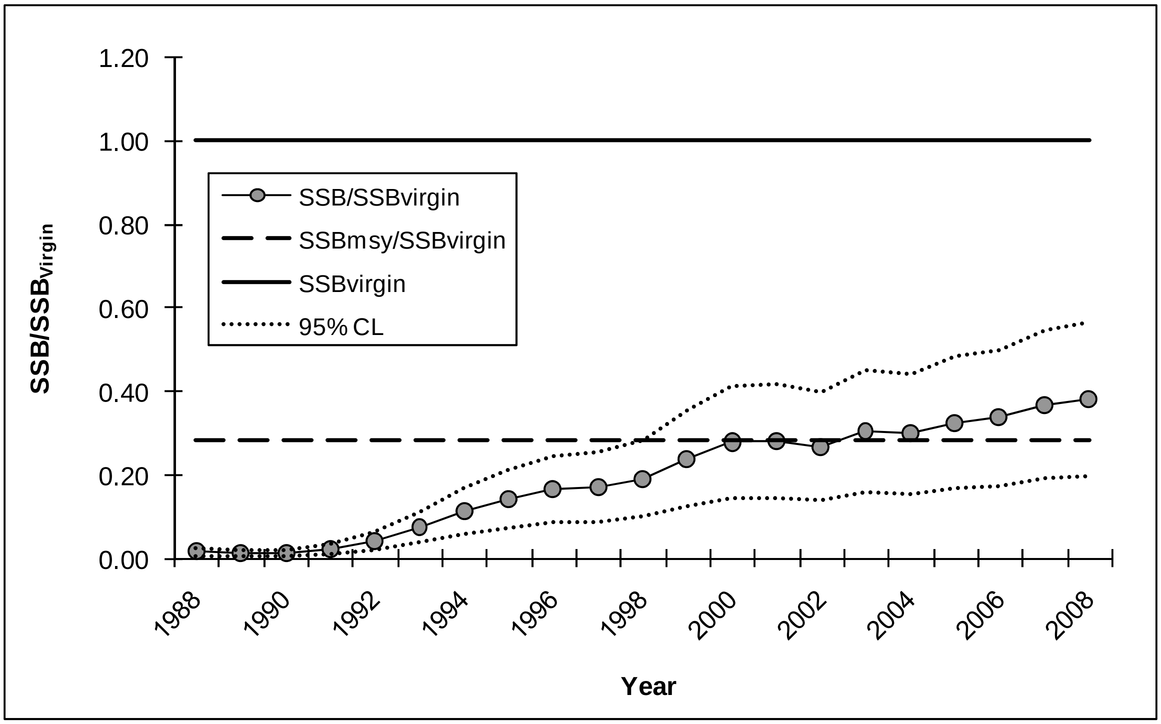


Figure A.7. Predicted spawning stock biomass and SSB_{MSY} relative to the virgin level of SSB from the revised model that included shrimp bycatch.

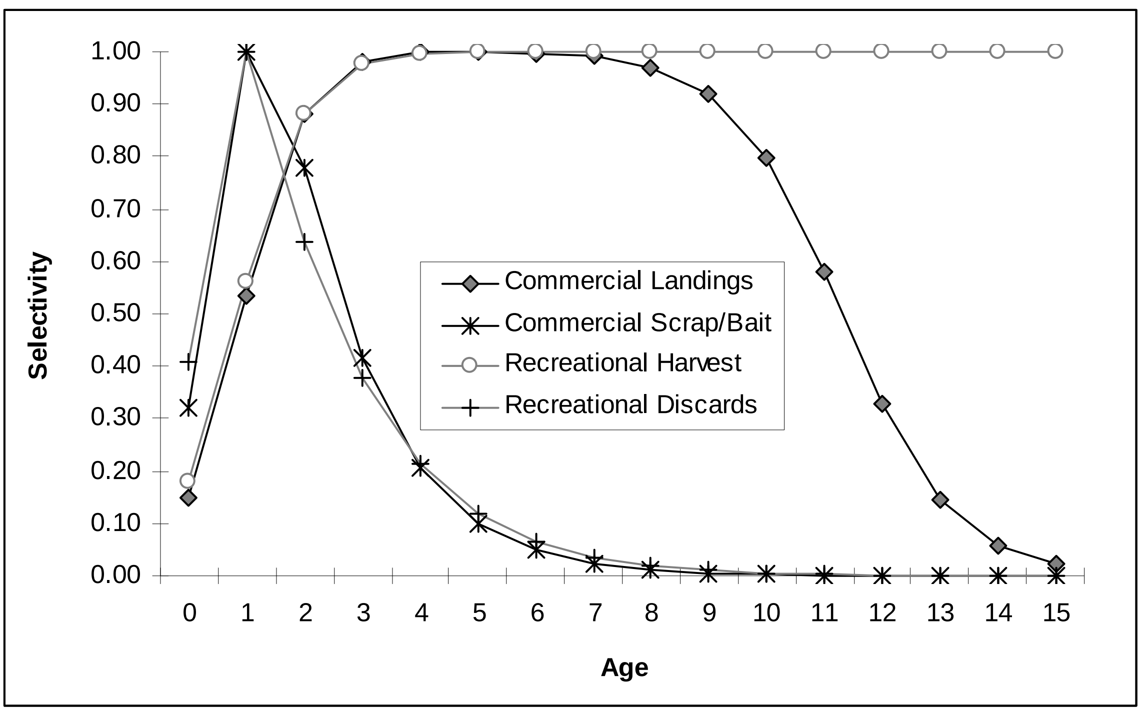


Figure A.8. Estimated selectivity patterns of the fisheries from the base run of the revised model.

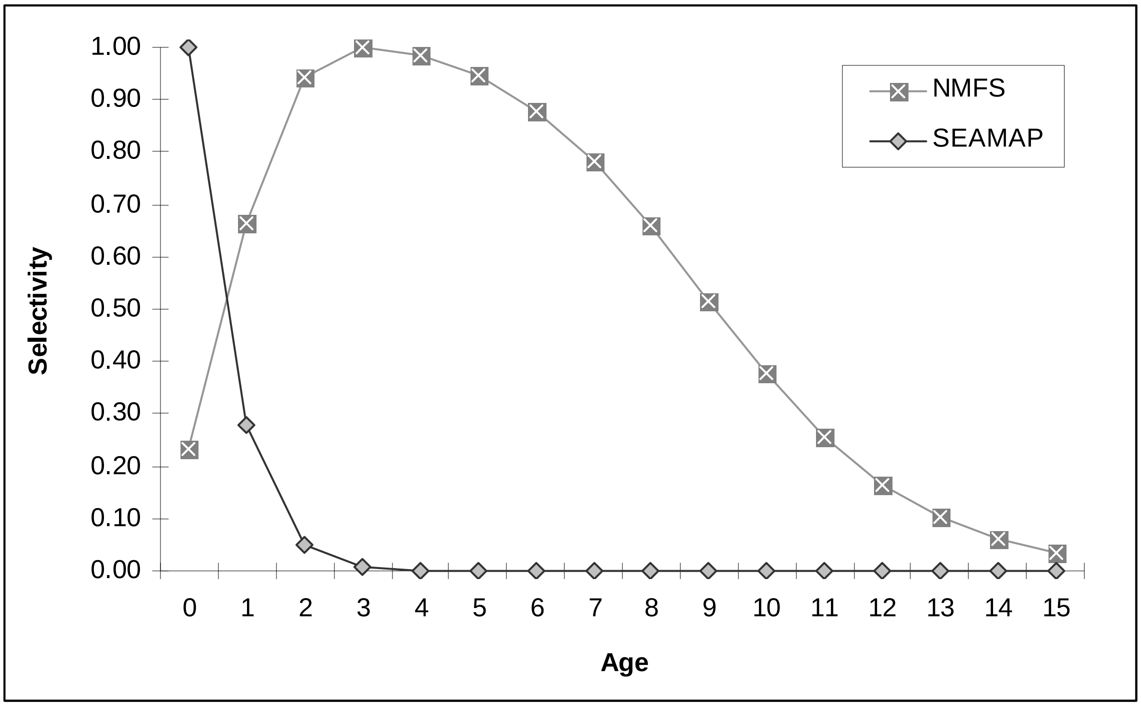


Figure A.9. Estimated selectivity patterns of the indices from the base run of the revised model.

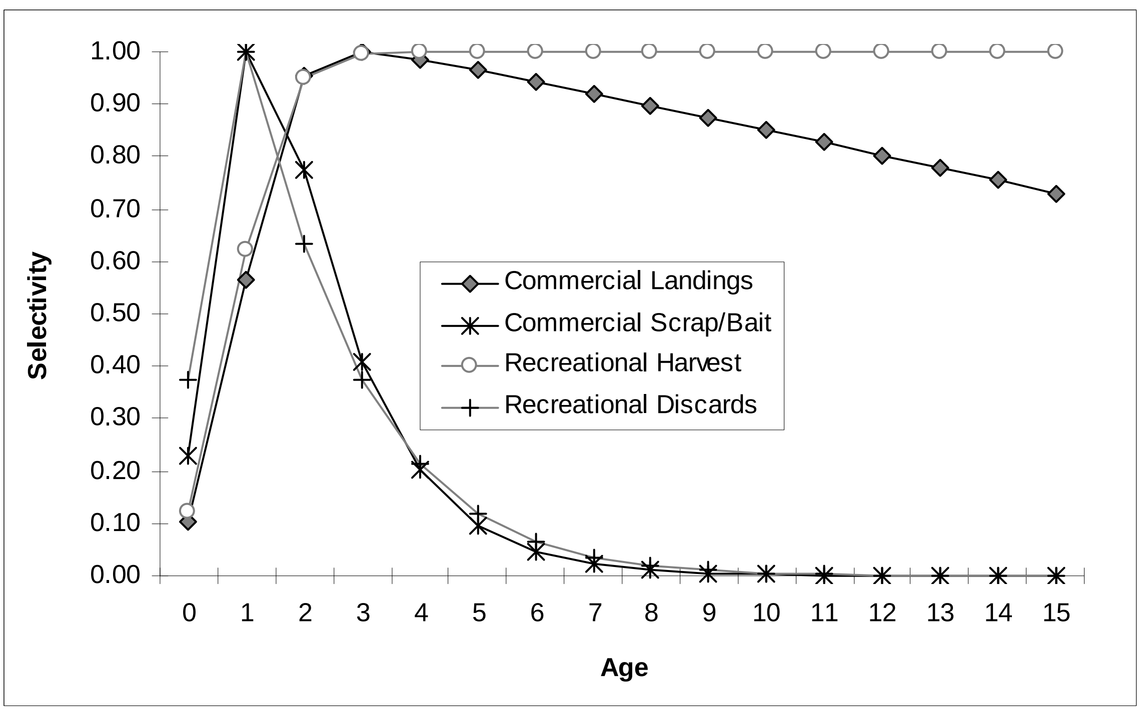


Figure A.10. Estimated selectivity patterns of the fisheries from the revised model that included shrimp bycatch.

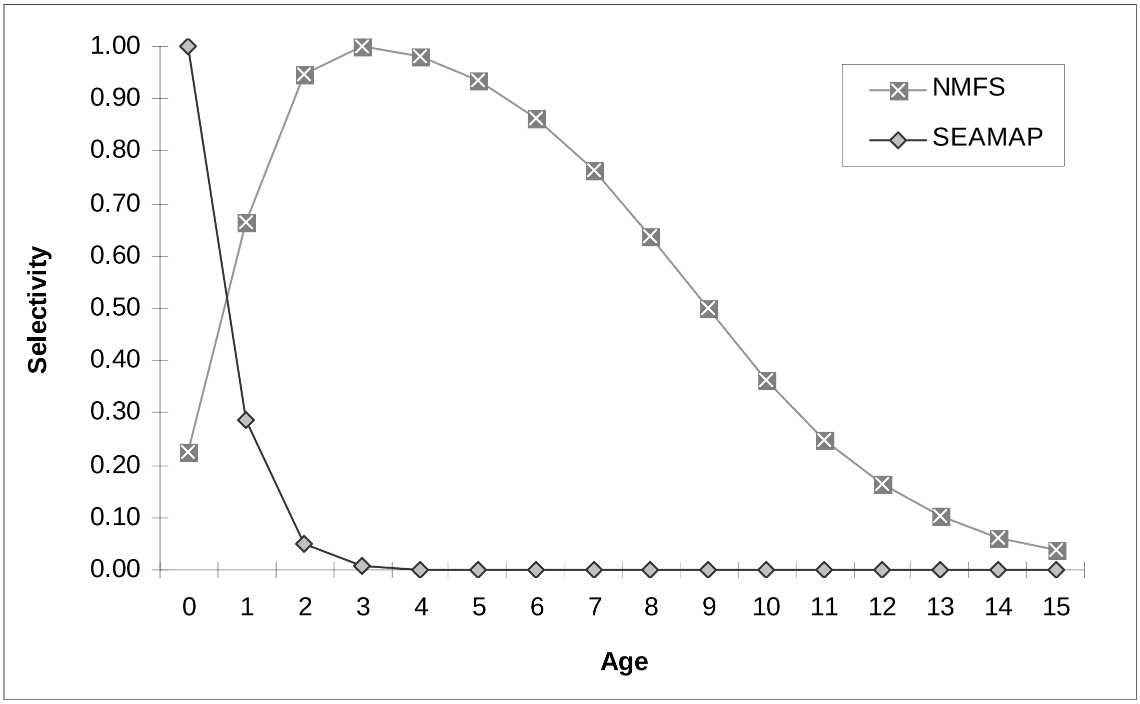


Figure A.11. Estimated selectivity patterns of the indices from the revised model that included shrimp bycatch.

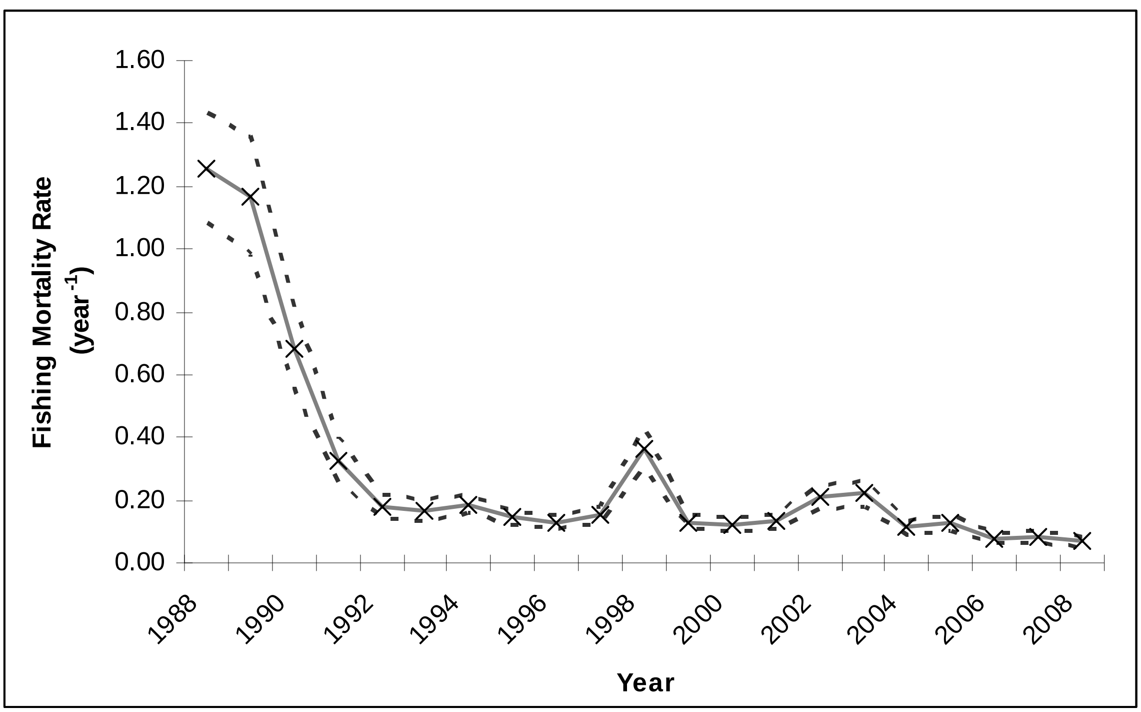


Figure A.12. Predicted total fishing mortality rate from the base run of the revised model. The dashed lines represent ± 2 standard deviations of the estimates.

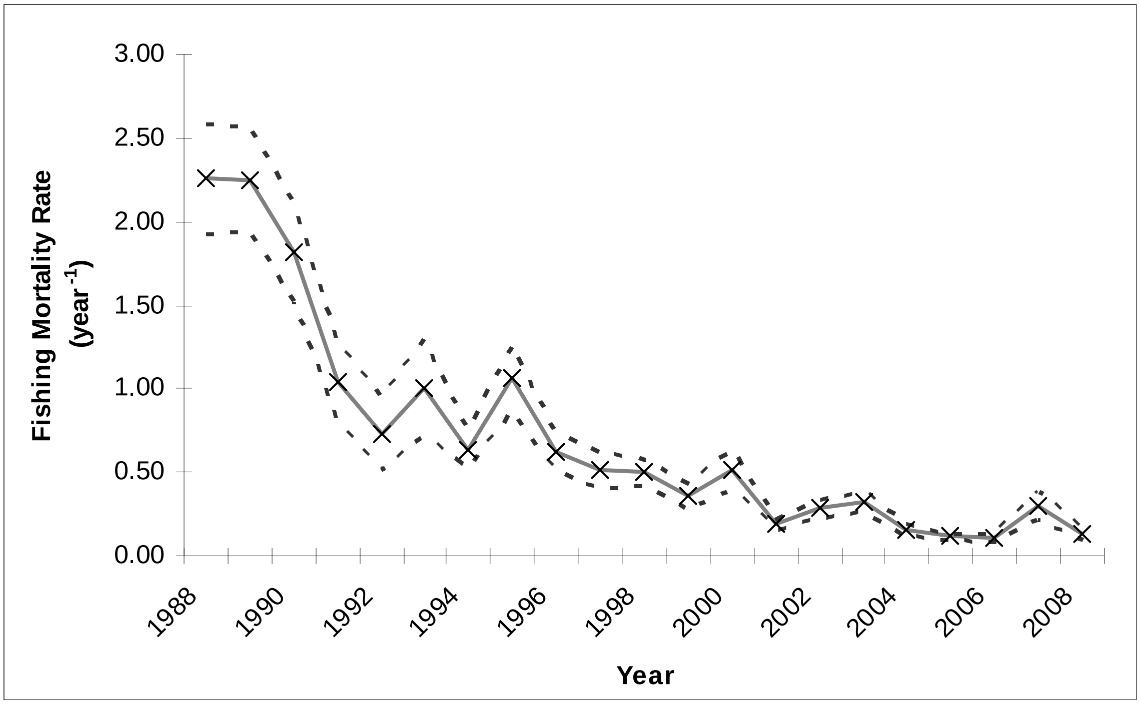


Figure A.13. Predicted total fishing mortality rate from the revised model that included shrimp bycatch. The dashed lines represent ± 2 standard deviations of the estimates.

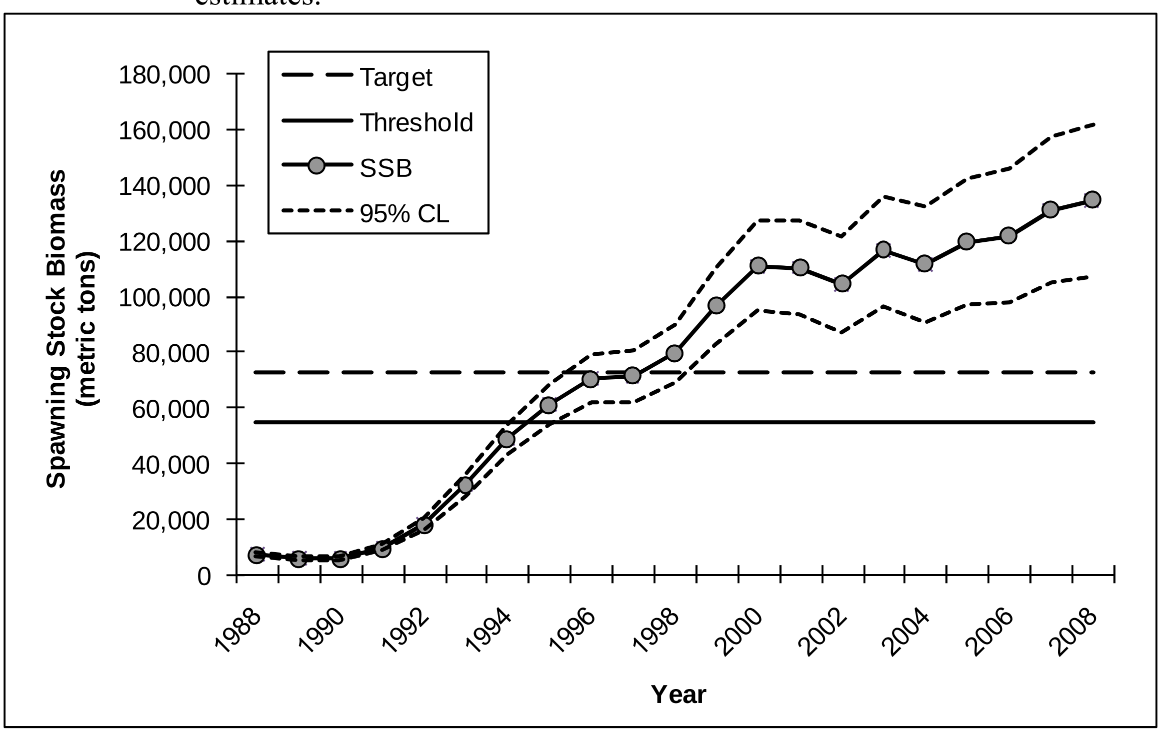


Figure A.14. Predicted trends in spawning stock biomass plotted with the estimated biomass target (SSB_{MSY}) and threshold (1-M · SSB_{MSY}) from the base run of the revised model.

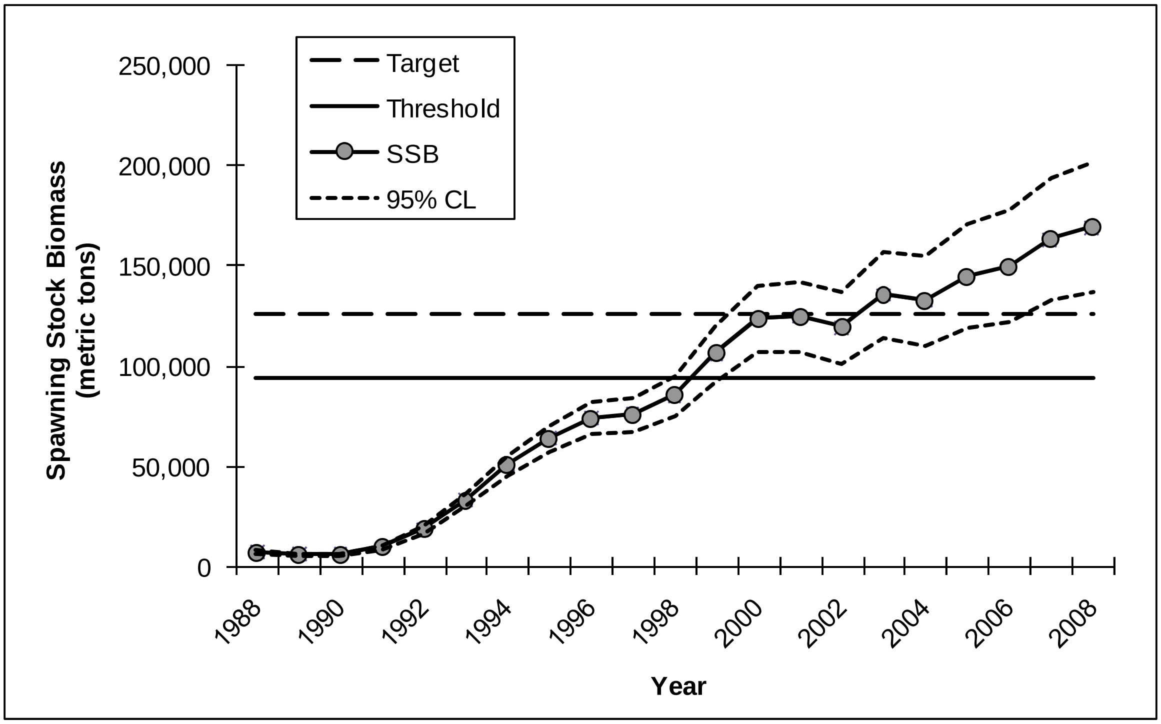


Figure A.15. Predicted trends in spawning stock biomass plotted with the estimated biomass target (SSB_{MSY}) and threshold (1-M · SSB_{MSY}) from the revised model that included shrimp bycatch.

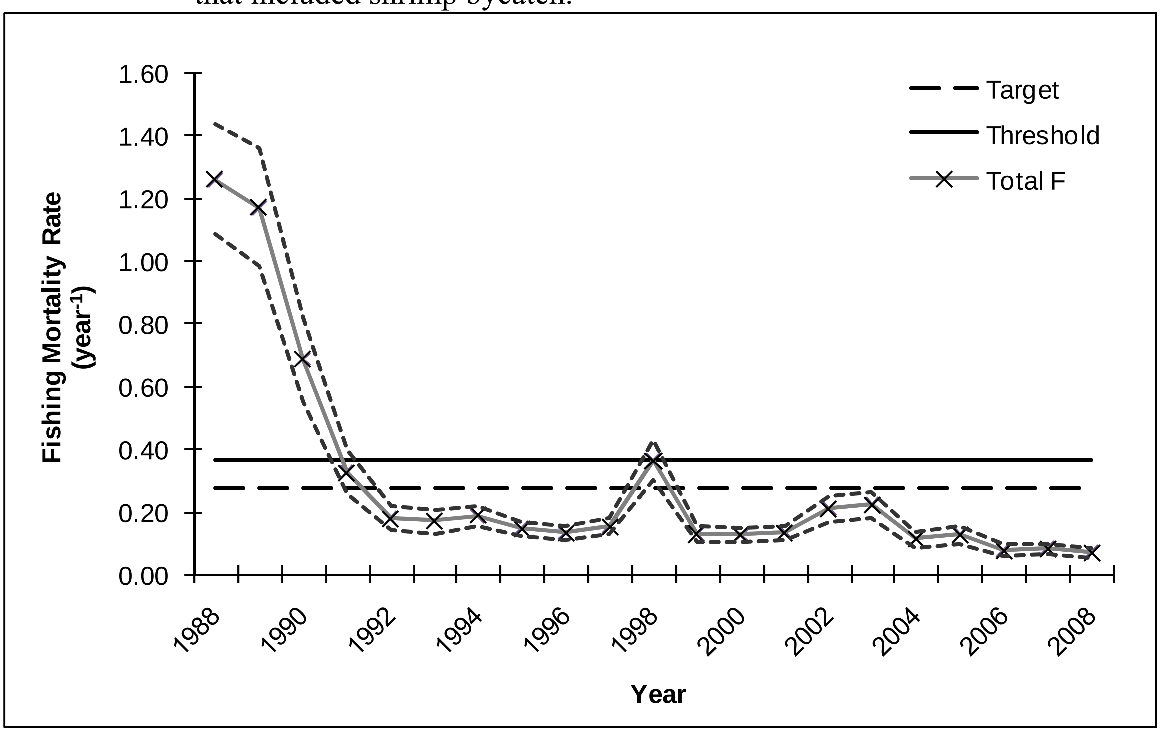


Figure A.16. Predicted trends in total fishing mortality rate plotted with the estimated fishing mortality target (0.75 · F_{MSY}) and threshold (F_{MSY}) from the base run of the revised model.

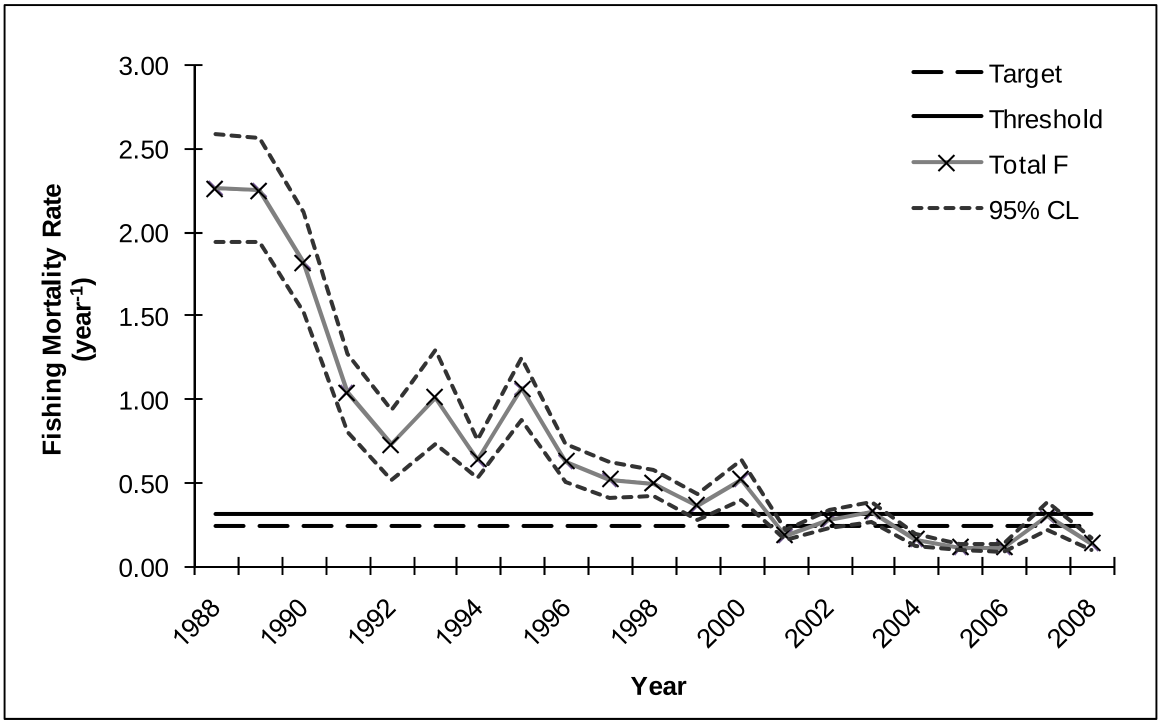


Figure A.17. Predicted trends in total fishing mortality rate plotted with the estimated fishing mortality ($0.75 \cdot F_{MSY}$) and threshold (F_{MSY}) from the revised model that included shrimp bycatch.

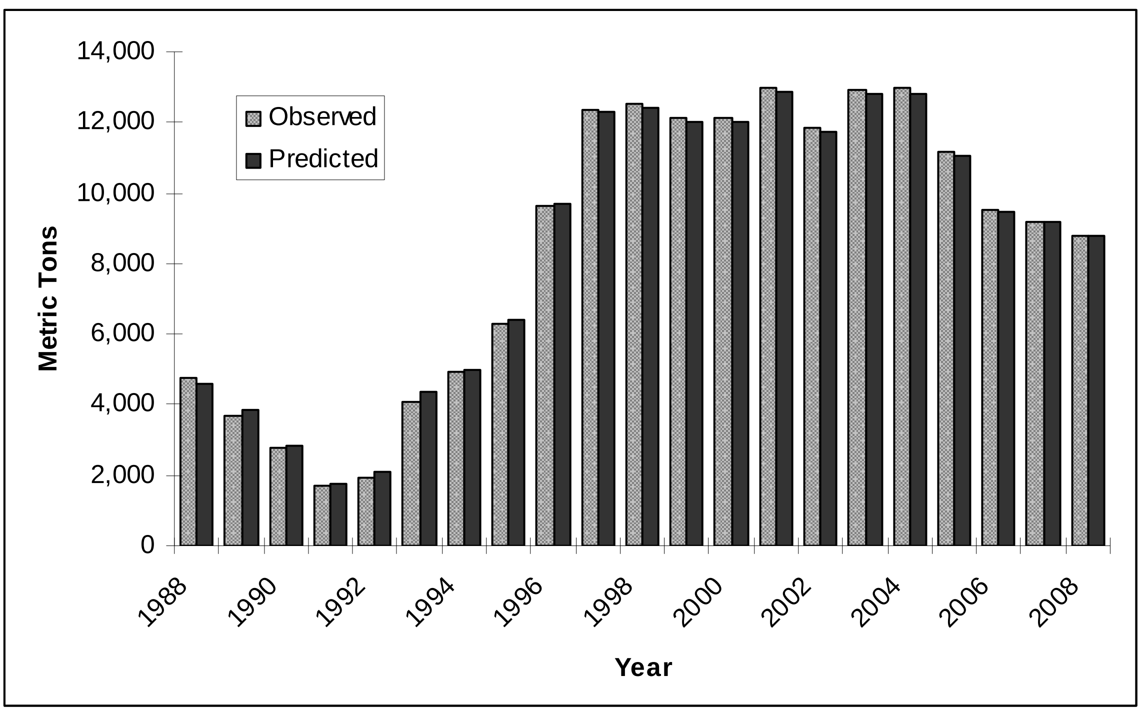


Figure A.18. Observed and predicted commercial landings from the base run of the revised model.

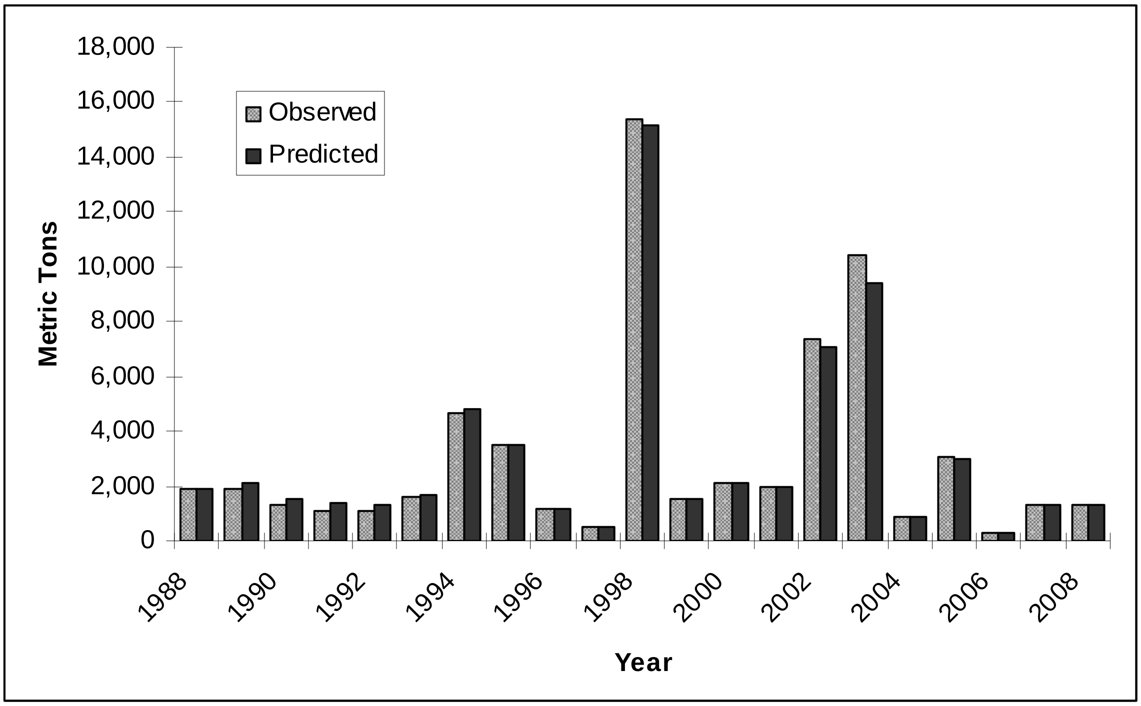


Figure A.19. Observed and predicted commercial scrap/discards/bait from the base run of the revised model.

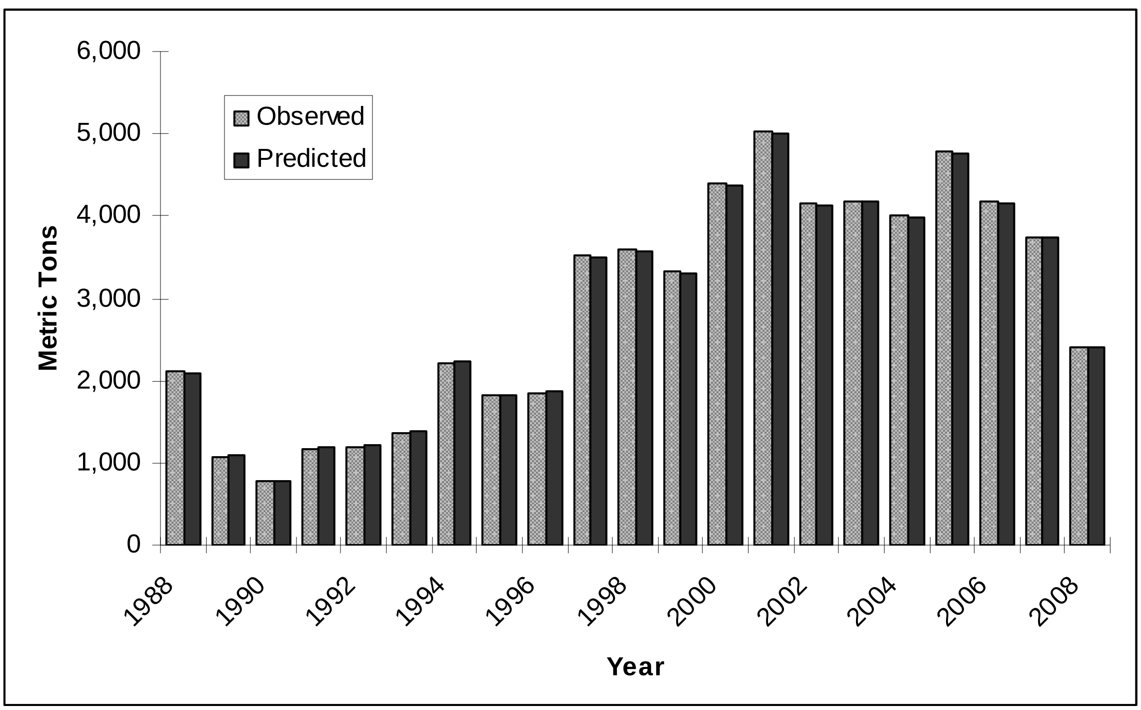


Figure A.20. Observed and predicted recreational harvest from the base run of the revised model.

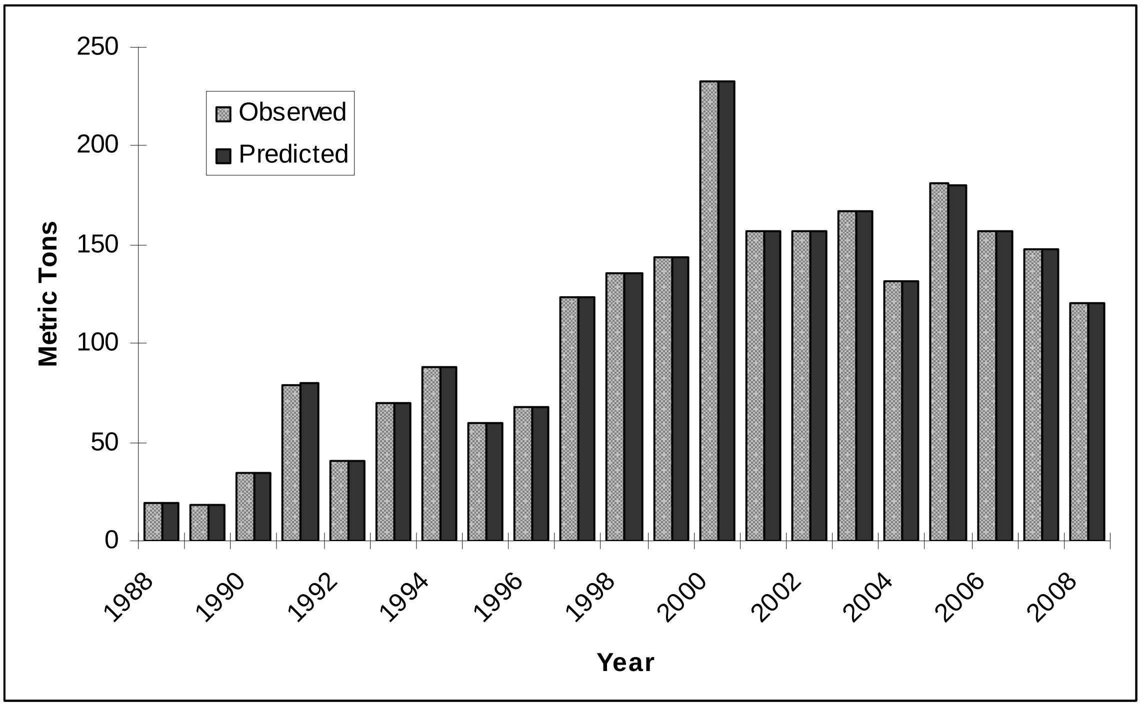


Figure A.21. Observed and predicted recreational discards (dead B2 fish) from the base run of the revised model.

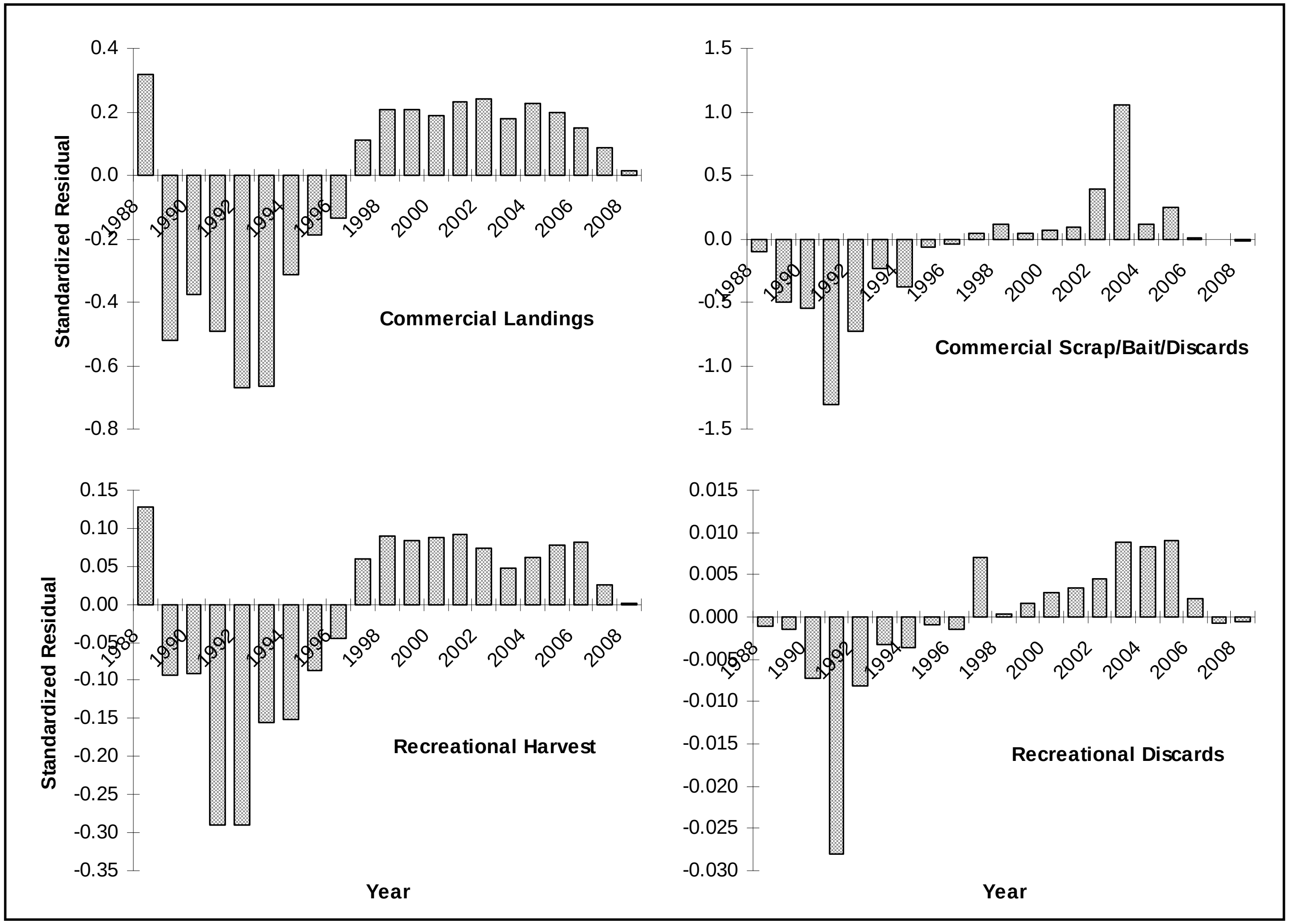


Figure A.22. Standardized residuals for catch of each fleet from the base run of the revised model.

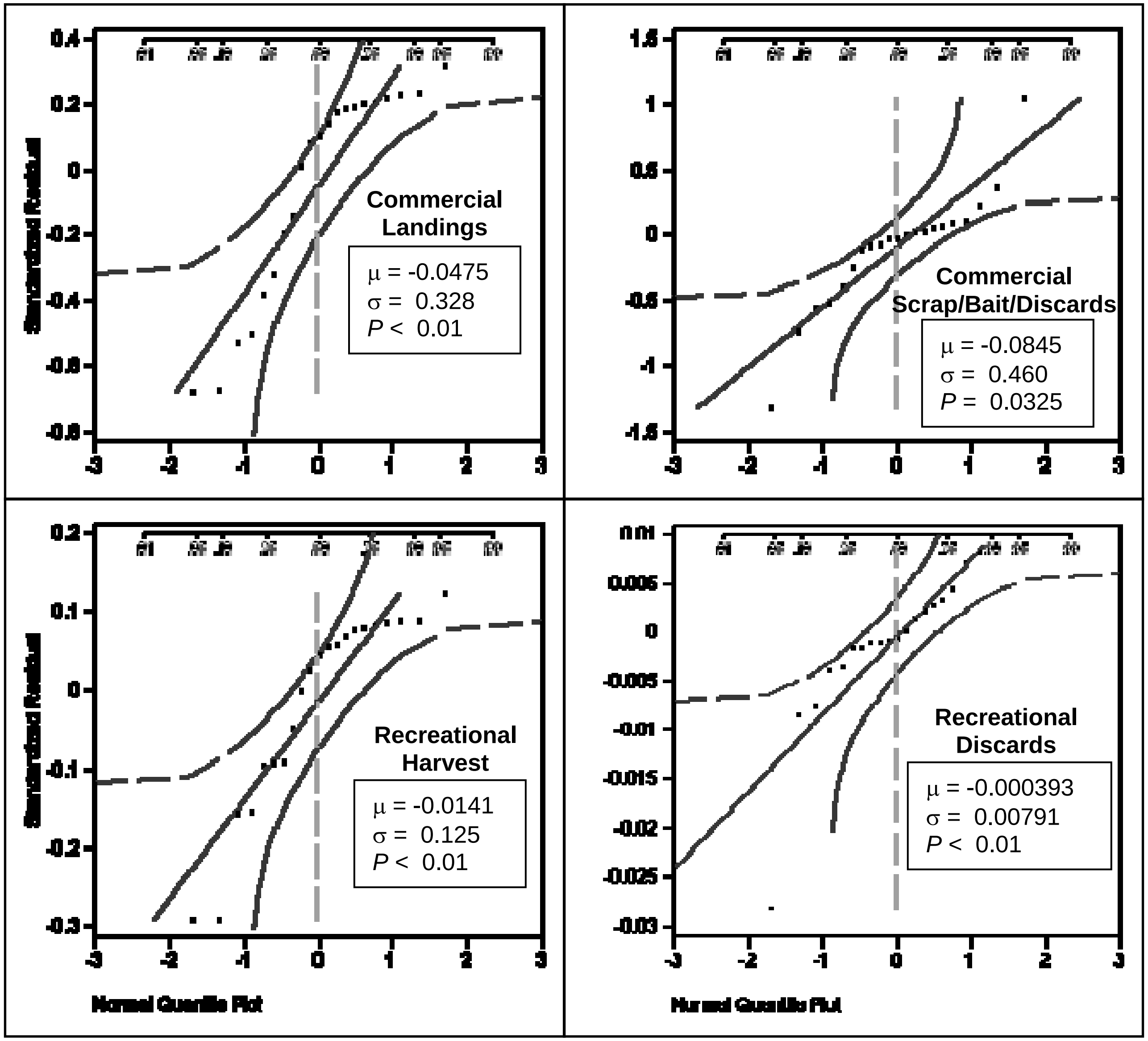


Figure A.23. Normal quantile plots (Q-Q plots) of the standardized residuals for catch of each fleet from the base run of the revised model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

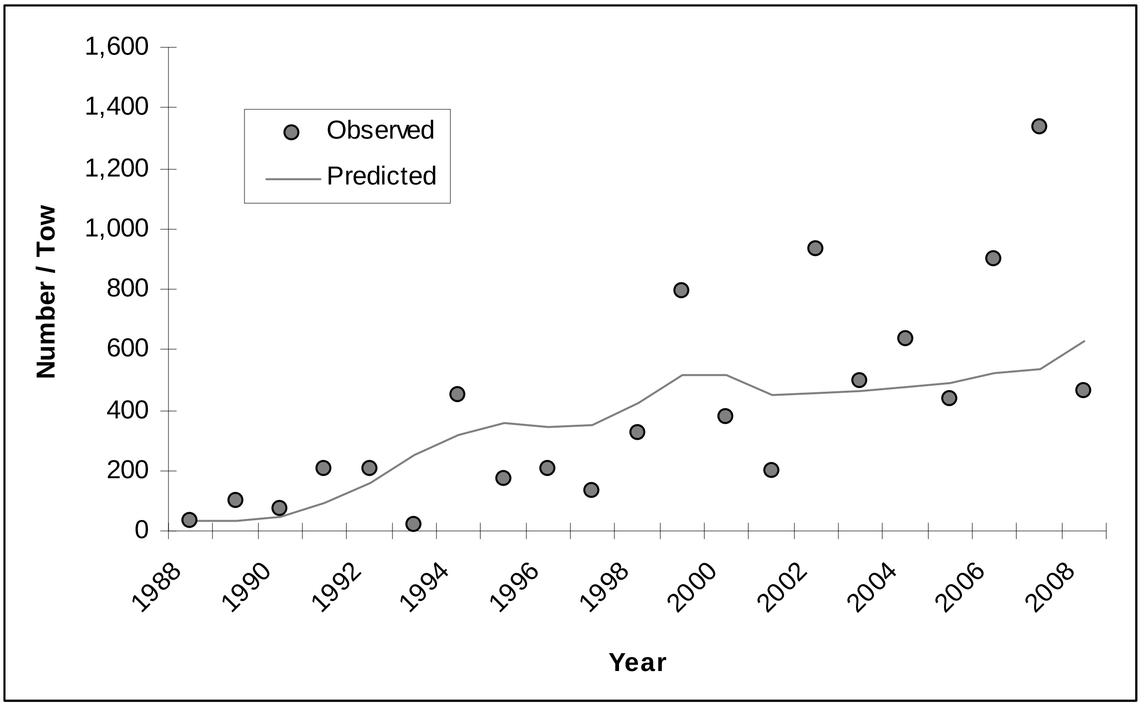


Figure A.24. Observed and predicted NMFS Bottom Trawl Survey index from the base run of the revised model.

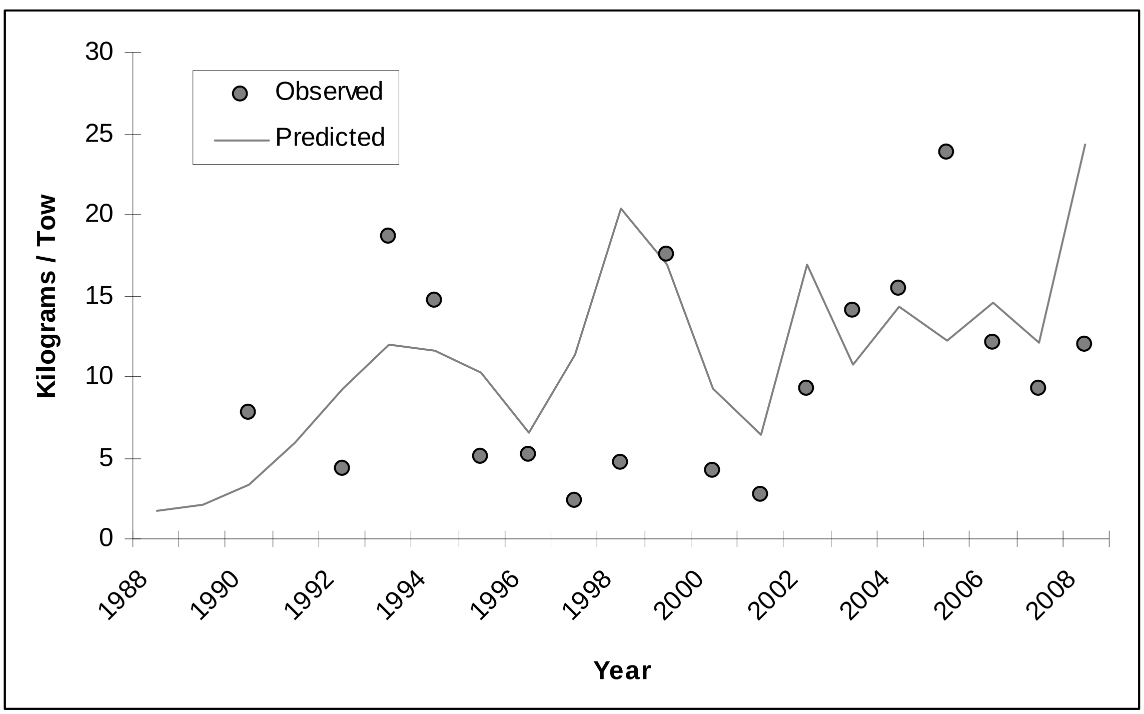


Figure A.25. Observed and predicted SEAMAP-SA Coastal Survey index from the base run of the revised model.

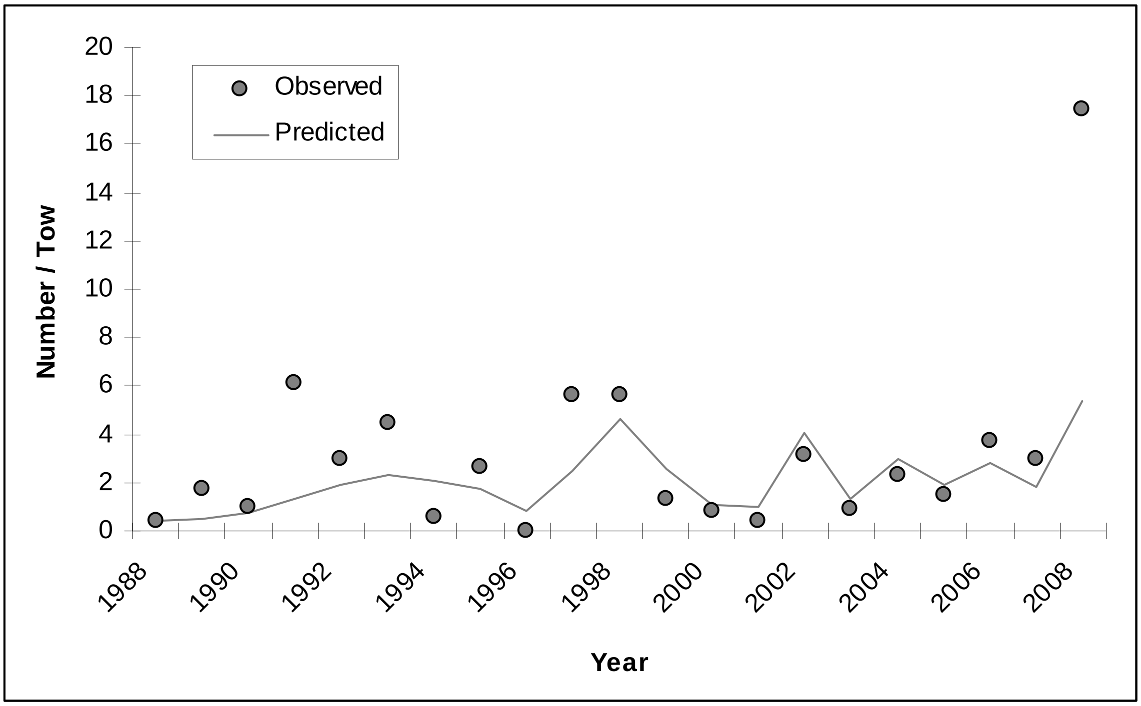


Figure A.26. Observed and predicted VIMS young-of-year index from the base run of the revised model.

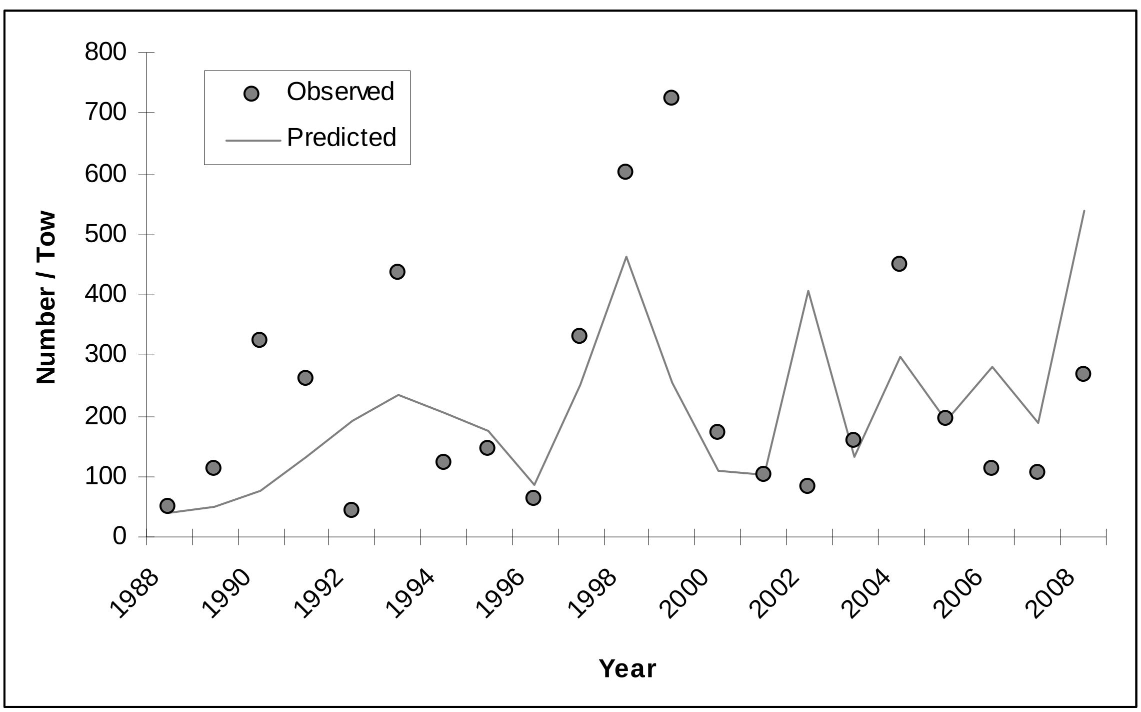


Figure A.27. Observed and predicted NC Program 195 young-of-year index from the base run of the revised model.

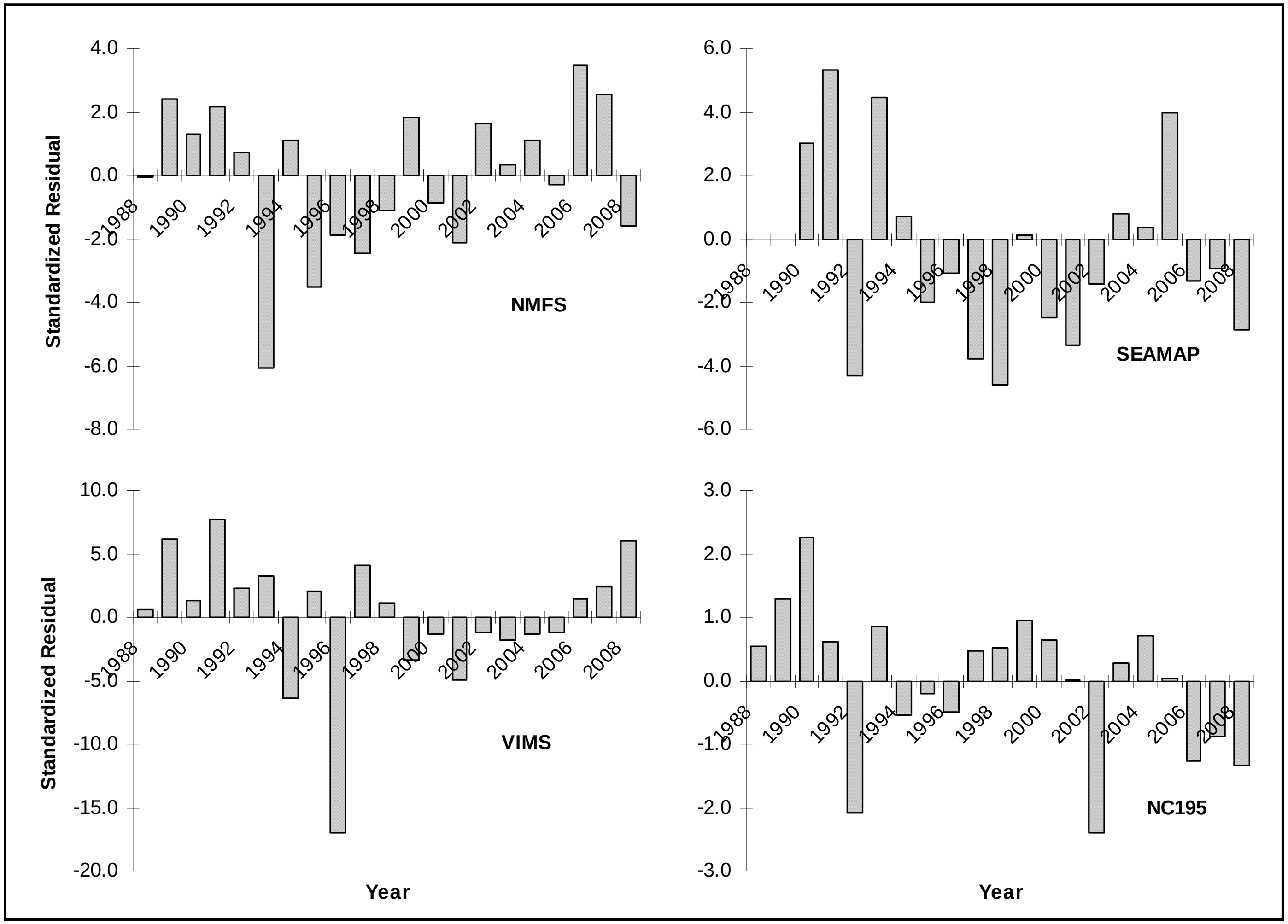


Figure A.28. Standardized residuals for each index from the base run of the revised model.

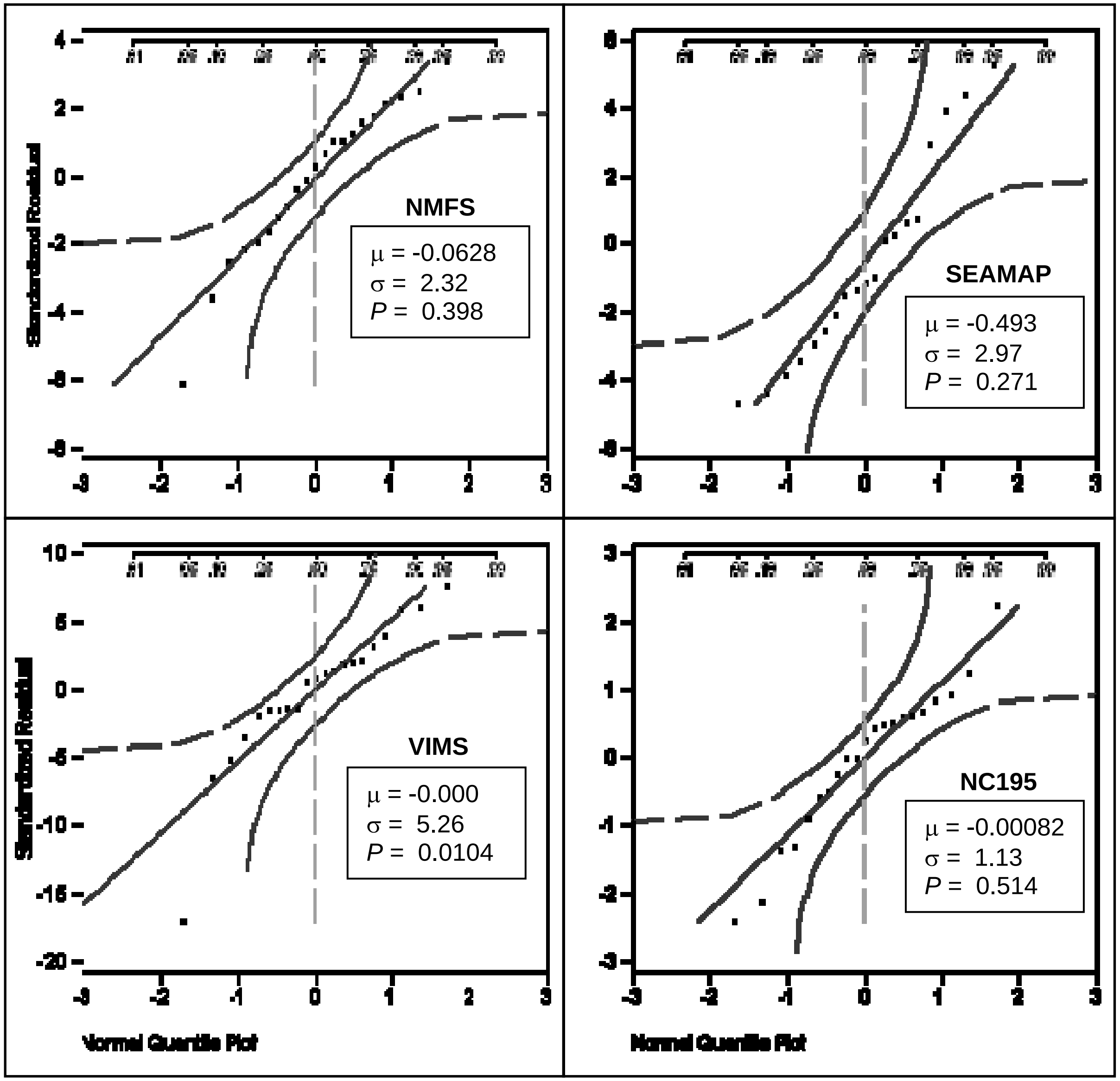


Figure A.29. Normal quantile plots (Q-Q plots) of the standardized residuals for each index from the base run of the revised model. The mean (μ), standard deviation (σ), and test for normality (*P*-value) of the standardized residuals is also given.

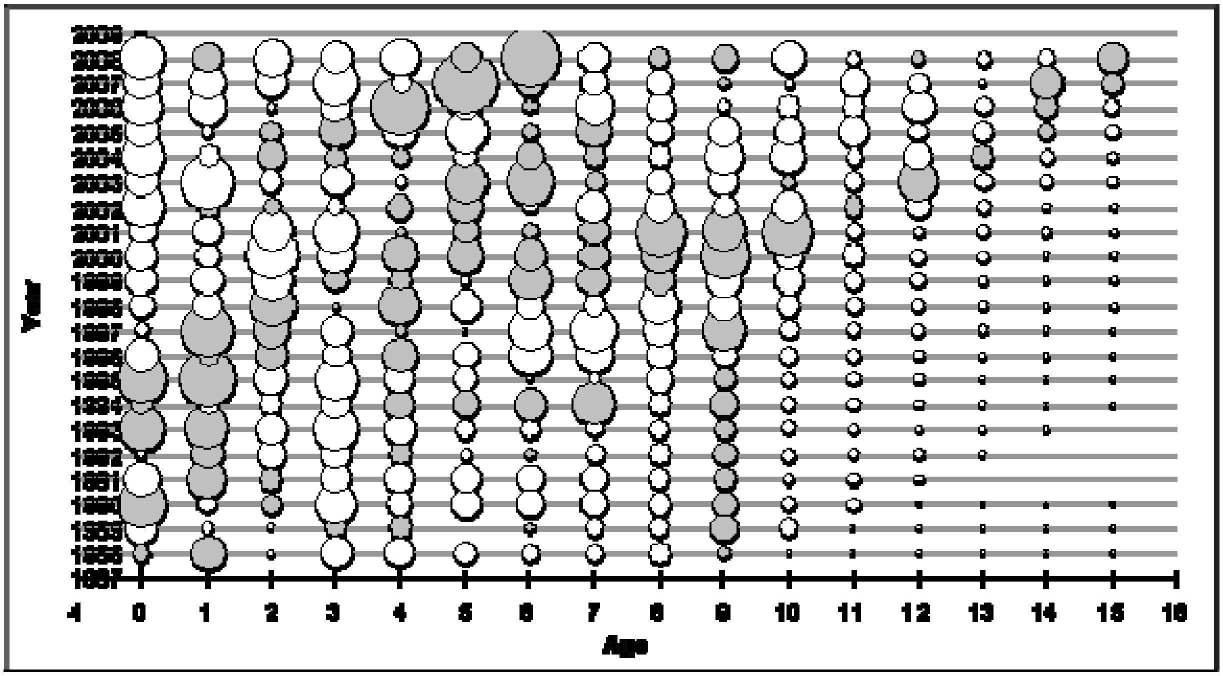


Figure A.30. Pearson's standardized residuals from the fit of the revised model to the commercial landings catch-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

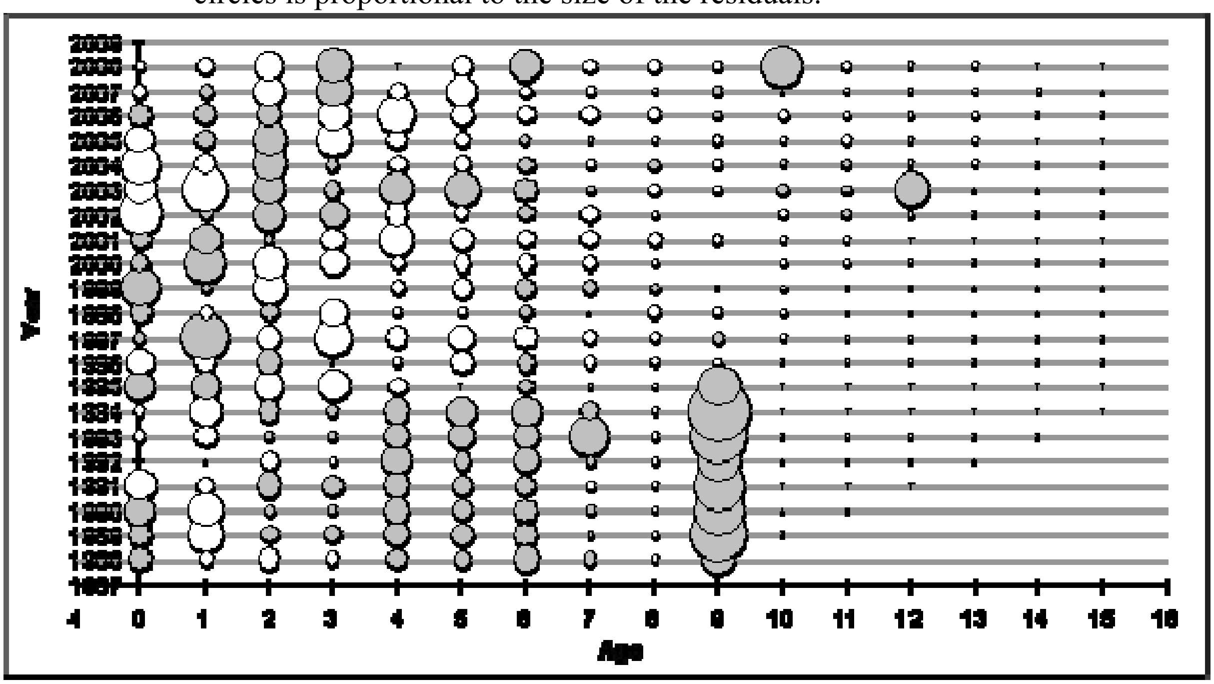


Figure A.31. Pearson's standardized residuals from the fit of the revised model to the commercial scrap/bait/discards catch-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

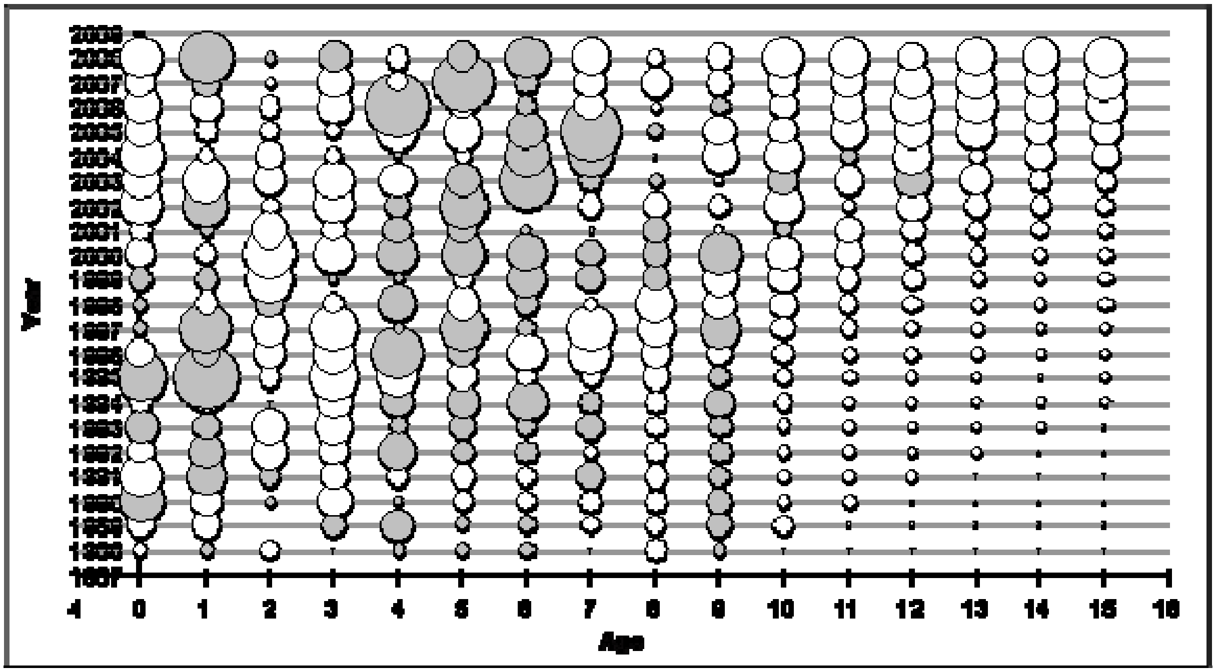


Figure A.32. Pearson's standardized residuals from the fit of the revised model to the recreational harvest catch-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

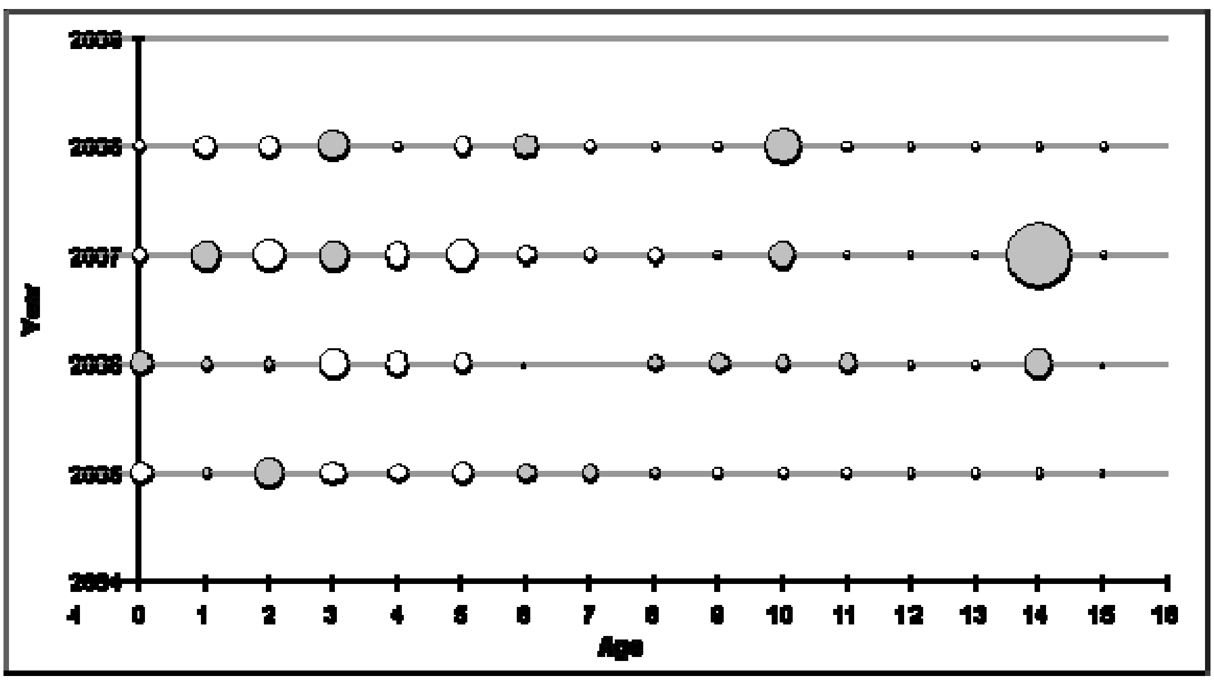


Figure A.33. Pearson's standardized residuals from the fit of the revised model to the recreational discards (dead B2 fish) catch-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

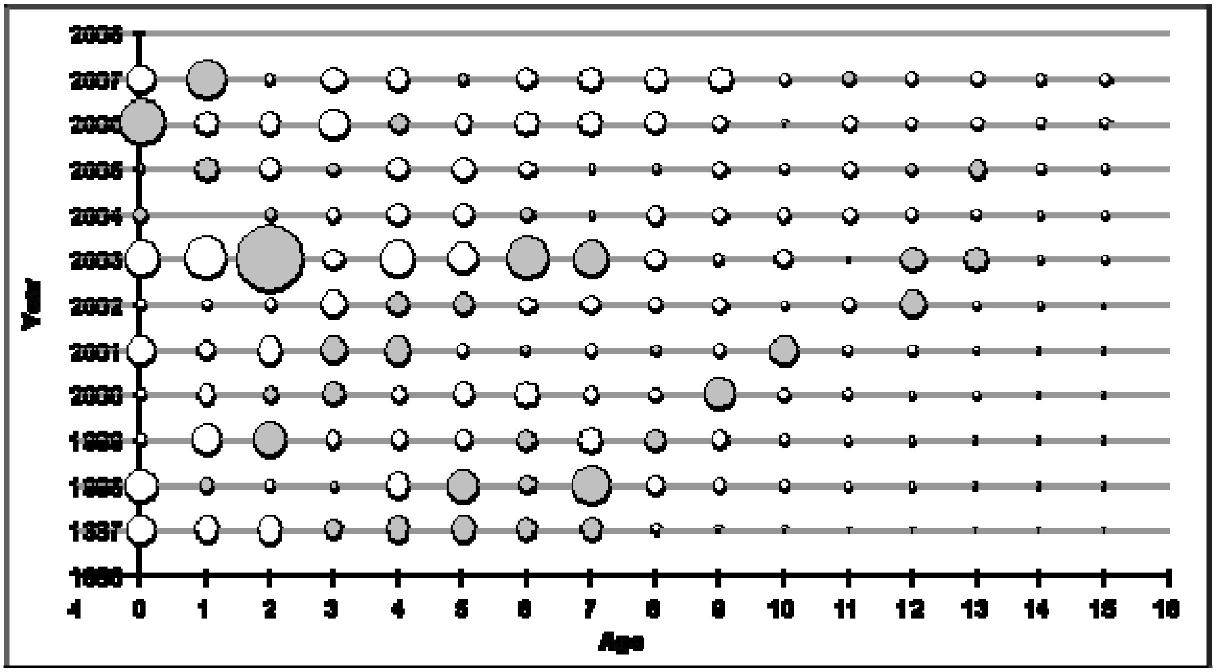


Figure A.34. Pearson's standardized residuals from the fit of the revised model to the NMFS Bottom Trawl Survey index-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

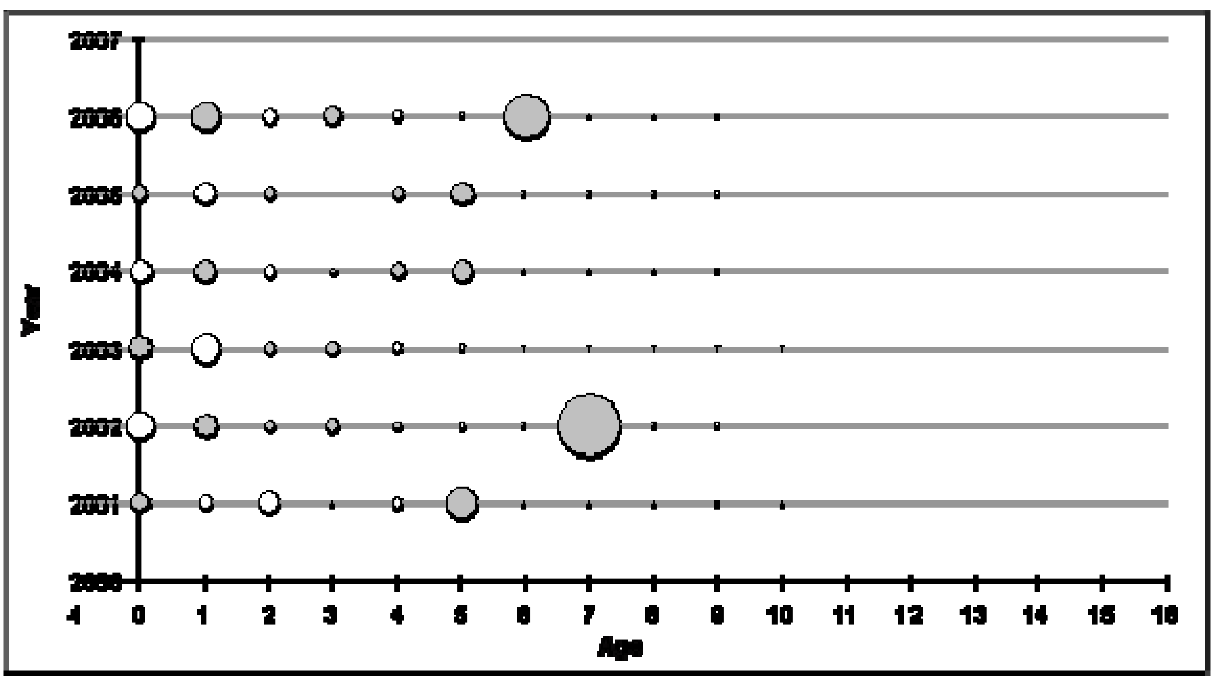


Figure A.35. Pearson's standardized residuals from the fit of the revised model to the SEAMAP-SA Coastal Survey index-at-age data. Gray circles represent positive residuals while white circles represent negative residuals. The area of the circles is proportional to the size of the residuals.

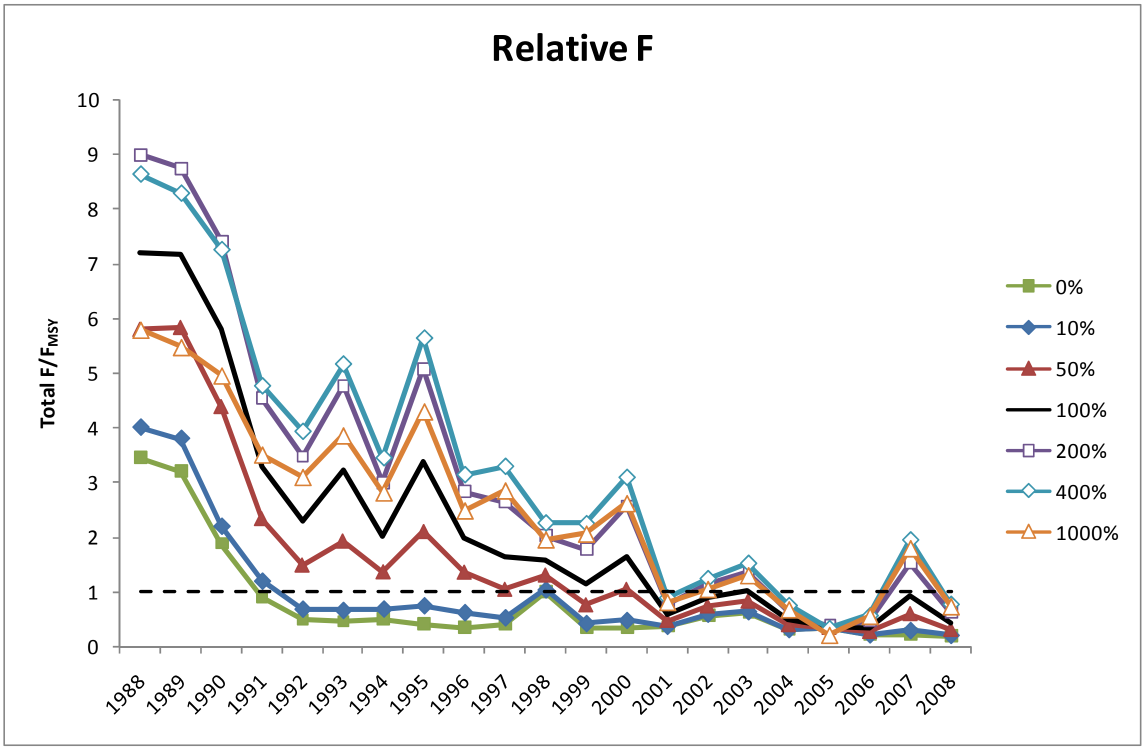


Figure A.36. Estimates of total F relative to F_{MSY} for different percentages of the original estimates of shrimp-trawl bycatch.

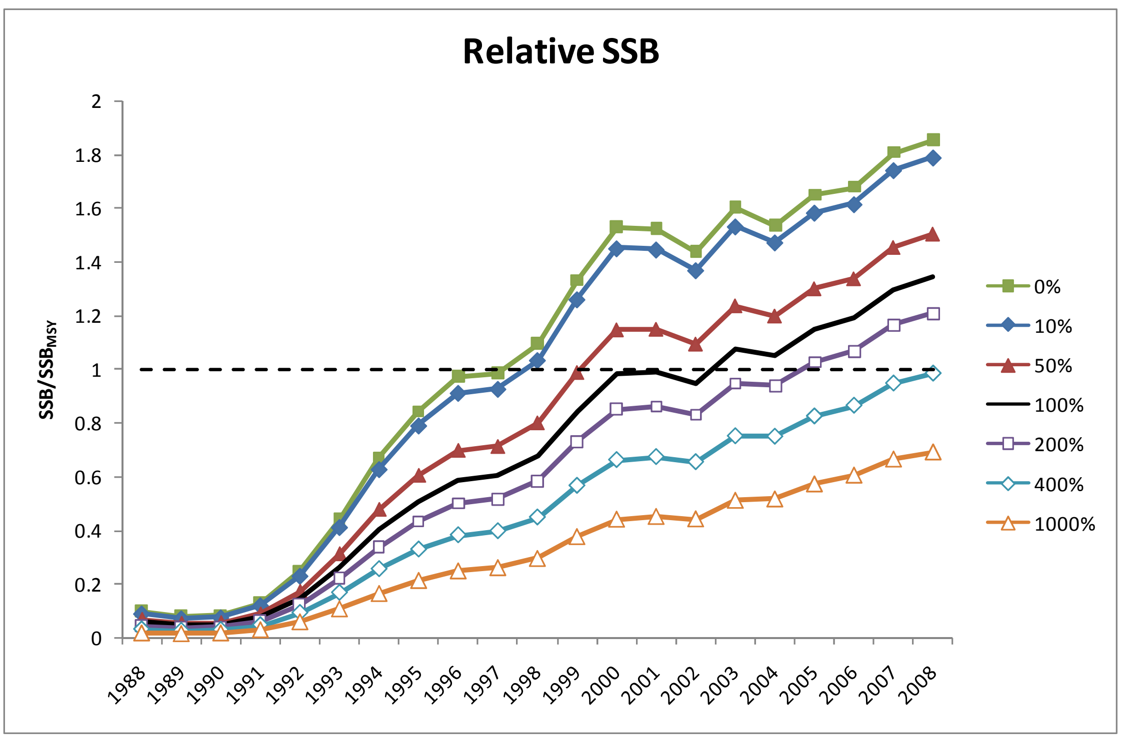


Figure A.37. Estimates of SSB relative to SSB_{MSY} for different percentages of the original estimates of shrimp-trawl bycatch.

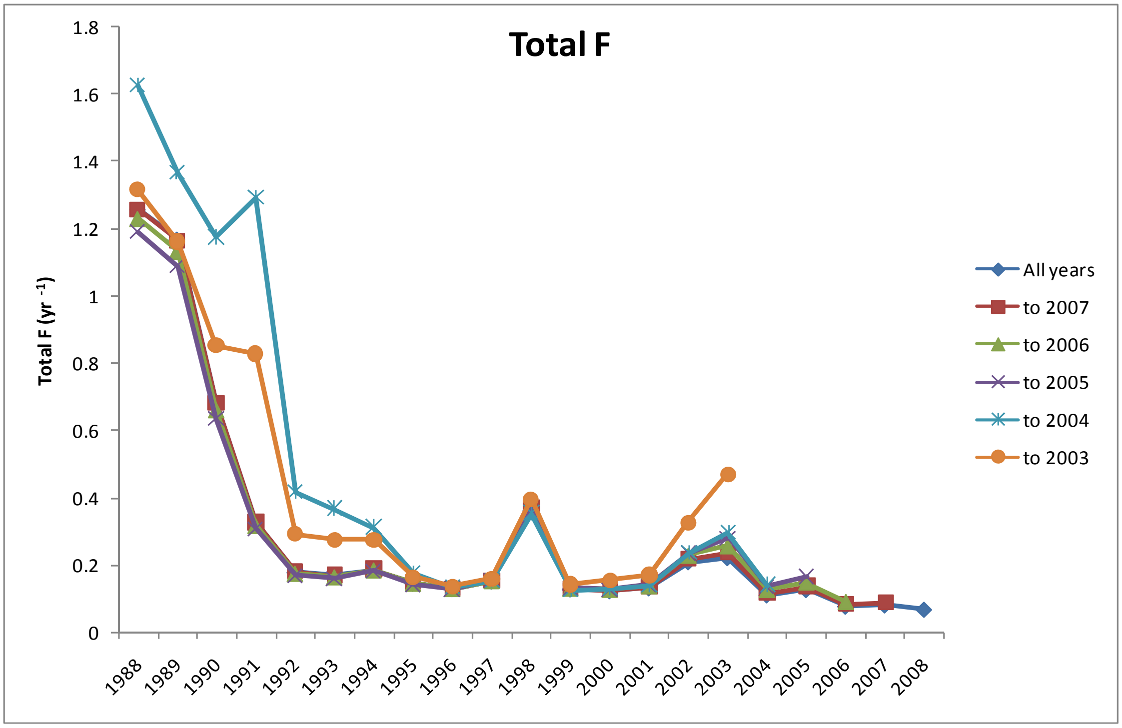


Figure A.38. Retrospective pattern in estimates of total F for the model run without shrimp-trawl bycatch.

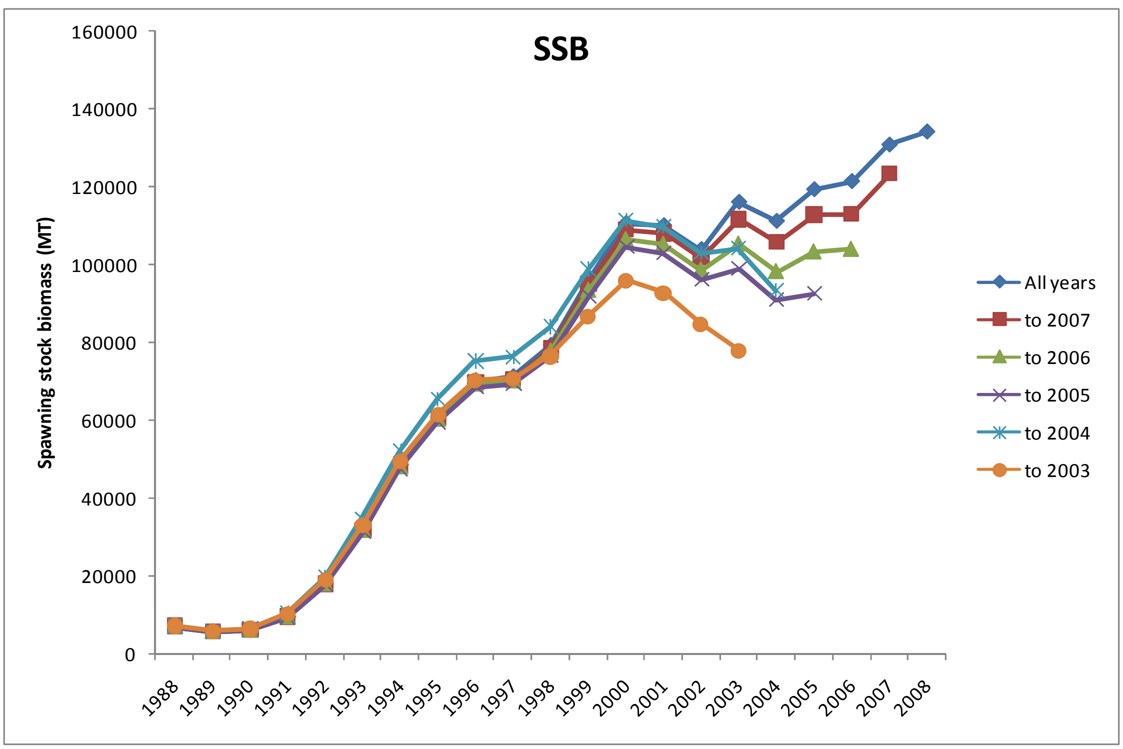


Figure A.39. Retrospective patterns in estimates of spawning stock biomass for the model run without shrimp-trawl bycatch.

APPENDIX A1: ADMB CODE AND INPUT DATA FOR REVISED MODEL

```
//HYBRID ASPM-SCAM Fisheries Stock Assessment Model v. 2
//Developed by kdrew & llee December 2009/January 2010 for spring 2010
Atlantic Croaker Stock Assessment
//Version 2 incorporates fit to index proportion-at-age

DATA_SECTION
//Looping Variables
  int i
  int j
  int k

//Model Dimensions
  init_adstring runname
  init_int n_year                   //Number of years
  init_int n_age                    //Number of ages
  init_vector age(1,n_age)
  init_number start_year
//  init_number sel2_year

//Growth & Maturity Parameters
  init_vector M(1,n_age)            //Age-specific mortality based on
Lorenzen
  init_number L_inf                 //von Bertalanffy L_inf in cm
  init_number K                     //von Bertalanffy K
  init_number t_0                   //von Bertalanffy t_0
  init_number lw_a                  //Parameter 'a' from length-weight
where length in cm and weight in kg
  init_number lw_b                  //Parameter 'b' from length-weight
where length in cm and weight in kg
  init_vector maturity(1,n_age)     //Age-specific maturity
  init_number h                     //Steepness parameter
  init_vector NAA_init(1,n_age)

//Catch Data
  init_int n_fleet                              //Number of fishing
fleets
  init_int n_sel_est                            //Number of fleets to
estimate selectivity for
  int n_sel_fixed                                       //Number of
fleets to fix selectivity for
  !!n_sel_fixed = n_fleet - n_sel_est;
  !!cout << "# Fixed Sels: " << n_sel_fixed << endl;
  init_matrix obs_catch(1,n_fleet,1,n_year)     //Fleet catches by year
  init_matrix obs_cv_catch(1,n_fleet,1,n_year)  //Catch CV by year


//Index Data
  init_int n_index                                  //Number of index
series
  init_ivector unit_index(1,n_index)                //Units for indices
(0=number; 1=weight)
```

```
  init_vector time_index(1,n_index)                  //Fraction of year
elapsed before index occurs
  init_vector flag_yoy(1,n_index)                    //Indicates if
index is YOY index (0=no; 1=yes)
  int n_yoy                                          //Number of YOY
indices==>NOT read in
 LOCAL_CALCS
    //Determine number of YOY indices
    n_yoy = 0.0;
    for (i=1;i<=n_index;i++)
    {
      n_yoy += flag_yoy(i);
    }
 END_CALCS
  init_matrix obs_index(1,n_index,1,n_year)          //Observed index
values by year
  init_matrix obs_cv_index(1,n_index,1,n_year)       //Observed index CV
by year
  int n_iaa                                          //Number of indices
with age data==>NOT read in
  !! n_iaa = n_index - n_yoy;                        //Calculate number
of index-at-age matrices to read in
  !!cout << "# IAA: " << n_iaa << endl;

//Selectivity Data
   init_vector full_age_fleet(1,n_fleet)   //Age of full selection
   init_vector full_age_ind(1,n_iaa)

  init_vector sel_shape(1,n_sel_est)
  init_matrix fixed_sel_fleet(1,n_sel_fixed,1,n_age)
  int nselparms

 LOCAL_CALCS
   nselparms = 0;
   for (i=1;i<=n_sel_est;i++) {
      if(sel_shape(i)==1) nselparms+=n_age;
      if(sel_shape(i)==2) nselparms+=2;
      if(sel_shape(i)==3) nselparms+=4;
    }
    cout << nselparms <<endl;
 END_CALCS

  init_vector sel_ini(1,nselparms)
  init_vector sel_lo(1,nselparms)
  init_vector sel_hi(1,nselparms)

  init_vector sel_shape_ind(1,n_iaa)
  int nselparms_ind

 LOCAL_CALCS
   nselparms_ind = 0;
   for (i=1;i<=n_iaa;i++) {
      if(sel_shape_ind(i)==1) nselparms_ind+=n_age;
      if(sel_shape_ind(i)==2) nselparms_ind+=2;
```

```
      if(sel_shape_ind(i)==3) nselparms_ind+=4;
   }
 END_CALCS


  init_vector sel_ini_ind(1,nselparms_ind)
  init_vector sel_lo_ind(1,nselparms_ind)
  init_vector sel_hi_ind(1,nselparms_ind)
  !!cout << "sel_ini_ind: " << sel_ini_ind << endl;


//Index- and Catch-at-Age Data
  init_3darray obs_iaa(1,n_iaa,1,n_year,1,n_age)    //Observed index-
at-age values
  matrix sum_obs_iaa(1,n_iaa,1,n_year)              //Index-at-age
summed over age by index and year==>NOT read in
  3darray obs_prop_iaa(1,n_iaa,1,n_year,1,n_age)    //Observed
proportion index-at-age==>NOT read in
 LOCAL_CALCS
    //Calculate proportion observed IAA
    sum_obs_iaa = 0.0;
    for (i=1;i<=n_iaa;i++)
    {
      for (j=1;j<=n_year;j++)
        {
         for (k=1;k<=n_age;k++)
            {
                sum_obs_iaa(i,j) += obs_iaa(i,j,k);
            }
         }
    }

    obs_prop_iaa = 0.0;
    for (i=1;i<=n_iaa;i++)
    {
       for (j=1;j<=n_year;j++)
       {
           for (k=1;k<=n_age;k++)
           {
               if (sum_obs_iaa(i,j) > 0.0)
               {
                   obs_prop_iaa(i,j,k) = obs_iaa(i,j,k) /
(sum_obs_iaa(i,j));
               }
               else
               {
                   obs_prop_iaa(i,j,k) = 0.0;
               }
            }
        }
    }
 END_CALCS
```

```
  init_3darray obs_caa(1,n_fleet,1,n_year,1,n_age)  //Observed catch-
at-age values
  init_vector nsamp_caa(1,n_year)                   //Catch-at-age
sample sizes
  init_matrix index_ess(1,n_iaa,1,n_year)
  matrix sum_obs_caa(1,n_fleet,1,n_year)            //Catch-at-age
summed over age by fleet and year==>NOT read in
  3darray obs_prop_caa(1,n_fleet,1,n_year,1,n_age)  //Observed
proportion catch-at-age==>NOT read in
 LOCAL_CALCS
    //Calculate proportion observed CAA
    sum_obs_caa = 0.0;
    for (i=1;i<=n_fleet;i++)
    {
      for (j=1;j<=n_year;j++)
        {
          for (k=1;k<=n_age;k++)
            {
                sum_obs_caa(i,j) += obs_caa(i,j,k);
            }
         }
    }

    obs_prop_caa = 0.0;
    for (i=1;i<=n_fleet;i++)
    {
        for (j=1;j<=n_year;j++)
        {
          for (k=1;k<=n_age;k++)
             {
                 if (sum_obs_caa(i,j) > 0.0)
                 {
                  obs_prop_caa(i,j,k) = obs_caa(i,j,k) /
(sum_obs_caa(i,j));
                 }
                 else
                 {
                  obs_prop_caa(i,j,k) = 0.0;
                 }
            }
        }
    }
 END_CALCS

//Model Weights
  init_vector lambda_catch(1,n_fleet)           //Lambda weights for
each fleet
  init_vector lambda_index(1,n_index)           //Lambda weights for
each index
  init_number lambda_caa                        //Lambda weight for
catch age composition data, all sources
  init_number lambda_iaa                        //Lambda weight for
index age composition data, all sources
```

```
  init_number lambda_recdev                     //Lambda weight for
recruitment deviations


INITIALIZATION_SECTION

//  h h_init
//   SSB_ratio SSB_ratio_init
  ln_N_ini NAA_init
  sel_pars sel_ini
  sel_pars_ind sel_ini_ind


PARAMETER_SECTION

//   init_bounded_number M(0.05,1.5,1)
//   init_bounded_number h(0.6,0.99,1)
//  init_bounded_number SSB_ratio(0.00001,1.0,1)
   init_bounded_number ln_R0(10,25,1)
   init_bounded_vector ln_recdev(1,n_year-1,-7.5,7.5,3)
   init_bounded_matrix F_full(1,n_fleet,1,n_year,0.0,3.0,1)
   init_bounded_number_vector sel_pars(1,nselparms,sel_lo,sel_hi,2)
   init_bounded_number_vector
sel_pars_ind(1,nselparms_ind,sel_lo_ind,sel_hi_ind,2)
   init_bounded_number_vector ln_N_ini(1,n_age,-5.0,30.0,1)
   init_bounded_vector ln_q_index(1,n_index,-25,5,1)

   vector len_at_age(1,n_age)
   vector wgt_at_age(1,n_age)

   matrix sel_fleet(1,n_fleet,1,n_age)
   matrix sel_index(1,n_iaa,1,n_age)

   3darray F_age(1,n_fleet,1,n_year,1,n_age)
   vector F_year(1,n_year)
   sdreport_vector F_year_sd(1,n_year)
   matrix F_total(1,n_year,1,n_age)
   matrix Z_total(1,n_year,1,n_age)


   matrix pop_num(1,n_year,1,n_age)
   vector pop_num_full(1,n_year)
   matrix pop_wgt(1,n_year,1,n_age)
   vector pop_wgt_tot(1,n_year)

   number SPR_F0
   matrix S0_per_R(1,n_year,1,n_age)
   number SSB0
   number SRR_R0
   number SRR_alpha
   number SRR_beta
   vector SSB(1,n_year)
   sdreport_vector SSB_sd(1,n_year)
```

```
matrix pred_catch(1,n_fleet,1,n_year)
matrix stdev_catch(1,n_fleet,1,n_year)
3darray pred_caa_wgt(1,n_fleet,1,n_year,1,n_age)
3darray pred_caa_num(1,n_fleet,1,n_year,1,n_age)
matrix sum_pred_caa(1,n_fleet,1,n_year)
3darray pred_prop_caa(1,n_fleet,1,n_year,1,n_age)

matrix pred_index(1,n_index,1,n_year)
matrix stdev_index(1,n_index,1,n_year)
3darray pred_iaa(1,n_iaa,1,n_year,1,n_age)
matrix sum_pred_iaa(1,n_iaa,1,n_year)
3darray pred_prop_iaa(1,n_iaa,1,n_year,1,n_age)

matrix stdres_catch(1,n_fleet,1,n_year)
matrix res_catch(1,n_fleet,1,n_year)
vector res2_catch(1,n_fleet)
matrix sqres_catch(1,n_fleet,1,n_year)
vector sum_sqres_catch(1,n_fleet)
vector wgtd_sum_sqres_catch(1,n_fleet)

3darray res_caa(1,n_fleet,1,n_year,1,n_age)
3darray sqres_caa(1,n_fleet,1,n_year,1,n_age)
3darray nsqres_caa(1,n_fleet,1,n_year,1,n_age)
matrix sum_nsqres_caa(1,n_fleet,1,n_year)
vector sum2_nsqres_caa(1,n_fleet)
vector wgtd_sum2_nsqres_caa(1,n_fleet)

matrix stdres_index(1,n_index,1,n_year)
matrix res_index(1,n_index,1,n_year)
vector res2_index(1,n_index)
matrix sqres_index(1,n_index,1,n_year)
vector sum_sqres_index(1,n_index)
vector wgtd_sum_sqres_index(1,n_index)

3darray res_iaa(1,n_iaa,1,n_year,1,n_age)
3darray sqres_iaa(1,n_iaa,1,n_year,1,n_age)
3darray nsqres_iaa(1,n_iaa,1,n_year,1,n_age)
matrix sum_nsqres_iaa(1,n_iaa,1,n_year)
vector sum2_nsqres_iaa(1,n_iaa)
vector wgtd_sum2_nsqres_iaa(1,n_iaa)

number LL_catch
number LL_caa
number LL_index
number LL_iaa
number LL_recdev

matrix F_wgtd(1,n_year,1,n_age)
vector F_tmp(1,n_year)
vector F_wgtd_avg(1,n_year)
sdreport_vector F_wgtd_avg_sd(1,n_year)
number avg_land
vector sel_msy(1,n_age)
matrix N_msy(1,3,1,n_age)
```

```
   vector SSB_msy(1,3)
   sdreport_number SSB_msy_out
   vector msy_outx(1,400)
   vector xx(1,400)
   sdreport_number msy_out
   sdreport_number F_msy_out
   vector F_msy(1,3)
   matrix Z_msy(1,3,1,n_age)
   vector L_msy(1,3)
   vector spr_msy(1,3)
   vector R_eq(1,3)
   number df
   number dmsy
   number ddmsy
   number R0

   vector SSB_relative(1,n_year)
   sdreport_vector SSB_relative_sd(1,n_year)
   vector SSB_rel_virgin(1,n_year)
   sdreport_vector SSB_rel_virgin_sd(1,n_year)
   vector F_relative(1,n_year)
   sdreport_vector F_relative_sd(1,n_year)
   vector F_yr_relative(1,n_year)
   sdreport_vector F_yr_relative_sd(1,n_year)

   objective_function_value f

PRELIMINARY_CALCS_SECTION

  //Calculate length (cm) and weight (mt) at age
  len_at_age = 0.0;
  wgt_at_age = 0.0;
  for (i=1;i<=n_age;i++)
  {
      len_at_age(i) = L_inf *(1 - mfexp(-K *( (i-1) - t_0 ) ) );
      wgt_at_age(i) = ( lw_a * pow( len_at_age(i),lw_b ) ) * 0.001;
  }

  //Calculate survival per recruit with no fishing mortality
  S0_per_R = 0.0;
  for (i=1;i<=n_year;i++)
  {
      for (j=1;j<=1;j++)
      {
          S0_per_R(i,j) = 1;
      }
      for (j=2;j<n_age;j++)
      {
          S0_per_R(i,j)= S0_per_R(i,j-1) * exp(-M(j-1));
      }
      for (j=n_age;j<=n_age;j++)
      {
          S0_per_R(i,j)= S0_per_R(i,j-1) *  ( (mfexp(-M(j-1)) / (1-
mfexp(-M(j)))) );
```

```
    }
  }

  //Calculate SSB per recruit under no exploitation in year 1
  SPR_F0 = 0.0;
    for (i=1;i<=n_age;i++)
    {
        SPR_F0 += 0.5 * S0_per_R(1,i) * wgt_at_age(i) * maturity(i);
    }


PROCEDURE_SECTION

  get_SRR();
  //cout << "made it through SRR" << endl;
  calc_selectivity();
  //  cout << "got sels" << endl;
  calc_mortality();
  //cout << " made it through mortality" << endl;
  calc_popn_size();
  //cout << " made it through popn size" << endl;
  calc_pred_cat();
  //cout << " made it through predicted catch" << endl;
  calc_pred_index();
  //cout << " made it through predicted index" << endl;
  calc_stdev_obs();
  //cout << " made it through stdev obs" << endl;
  calc_resids();
  //cout << " made it through resids" << endl;
  calc_ref_points();
  //cout << " made it through ref pts" << endl;
  evaluate_the_objective_function();
  //cout << " made it through the objective function" << endl;


FUNCTION get_SRR
  //converts unexploited SSB and steepness to alpha and beta for
Beverton-Holt SRR
  SRR_R0 = mfexp(ln_R0);
   SSB0 = SRR_R0*SPR_F0;

  SRR_alpha = 4.0*h*SRR_R0 /(5.0*h -1.0);
  SRR_beta = SSB0*(1.0-h)/(5.0 * h - 1.0);

FUNCTION calc_selectivity
  dvariable alpha1;
  dvariable beta1;
  dvariable alpha2;
  dvariable beta2;
  dvariable sel_max;
  dvariable sel_p1;
  dvariable sel_p2;

  k=0;
```

```
  for(i=1; i<=n_sel_est; i++){
    if(sel_shape(i) == 1){
      for(j=1; j<=n_age; j++){
       k+=1;
       if(age(k) == full_age_fleet(i)) {
             sel_pars(k) = 1.0;
       }
       else sel_fleet(i,j) = sel_pars(k);
      }
      sel_max=max(sel_fleet(i));
      sel_fleet(i) = sel_fleet(i) / sel_max;
    }

    if(sel_shape(i) == 2) {
     alpha1 = sel_pars(k+1);
     beta1 = sel_pars(k+2);
     k+=2;
     for(j=1;j<=n_age;j++){
        sel_fleet(i,j) = 1.0 / (1.0 + mfexp((alpha1 - age(j)) /
beta1));
     }
      sel_max = max(sel_fleet(i));
      sel_fleet(i) = sel_fleet(i)/sel_max;
    }

    if(sel_shape(i) == 3){
      alpha1 = sel_pars(k+1);
      beta1  = sel_pars(k+2);
      alpha2 = sel_pars(k+3);
      beta2  = sel_pars(k+4);
      k+=4;
      for(j=1; j<=n_age; j++){
         sel_p1 = 1.0 / (1.0 + mfexp((alpha1 - age(j)) / beta1));
         sel_p2 = 1.0-(1.0/(1.0+mfexp((alpha2 - age(j)) / beta2)));
         sel_fleet(i,j) = sel_p1 * sel_p2;
      }
      sel_max = max(sel_fleet(i));
      sel_fleet(i) = sel_fleet(i)/sel_max;
    }
  }
  for(i=1; i<=n_sel_fixed; i++){
        for(j=1;j<=n_age; j++){
            sel_fleet(i+n_sel_est,j) = fixed_sel_fleet(i,j);
        }
   }
  k=0;
  for(i=1; i<=n_iaa; i++){

  if(sel_shape_ind(i) == 1){
    for(j=1; j<=n_age; j++){
      k+=1;
      if(age(k) == full_age_ind(i)){
            sel_pars_ind(k) = 1.0;
```

```
      }
      else sel_index(i,j) = sel_pars_ind(k);
    }
    sel_max = max(sel_index(i));
    sel_index(i) = sel_index(i)/sel_max;

  }

  if(sel_shape_ind(i) == 2) {
     alpha1 = sel_pars_ind(k+1);
     beta1 = sel_pars_ind(k+2);
     k+=2;
     for(j=1;j<=n_age;j++){
        sel_index(i,j) = 1.0 / (1.0 + mfexp((alpha1 - age(j)) /
beta1));
     }
      sel_max = max(sel_index(i));
      sel_index(i) = sel_index(i)/sel_max;
     }

  if(sel_shape_ind(i) == 3){
     alpha1 = sel_pars_ind(k+1);
     beta1  = sel_pars_ind(k+2);
     alpha2 = sel_pars_ind(k+3);
     beta2  = sel_pars_ind(k+4);
     k+=4;
     for(j=1; j<=n_age; j++){
        sel_p1 = 1.0 / (1.0 + mfexp((alpha1 - age(j)) / beta1));
        sel_p2 = 1.0 - (1.0 / (1.0 + mfexp((alpha2 - age(j)) /
beta2)));
        sel_index(i,j) = sel_p1 * sel_p2;
     }
     sel_max = max(sel_index(i));
     sel_index(i) = sel_index(i)/sel_max;

    }
  }

//  for(i=1; i<=n_fleet; i++){
//   k = full_age_fleet(i)+1;
//      sel_fleet(i,k) = 1;
//  }
//  for(i=1; i<=n_iaa; i++){
//   k = full_age_ind(i)+1;
//      sel_index(i,k) = 1;
//  }



FUNCTION calc_mortality
  //Calculate fishing mortality for fleet i in year y at age k
  for (i=1;i<=n_fleet;i++)
  {
     F_age(i) = 0.0;
```

```
      for (j=1;j<=n_year;j++)
      {
        for (k=1;k<=n_age;k++)
          {
            F_age(i,j,k) = F_full(i,j) * sel_fleet(i,k);
          }
      }
  }

  //Calculate total fishing mortality in year i at age j
  F_total =0.0;
  for (i=1;i<=n_year;i++)
  {
    for (j=1;j<=n_age;j++)
      {
        for (k=1;k<=n_fleet;k++)
          {
            F_total(i,j) += F_age(k,i,j);
          }
       }
  }

  //Calculate total mortality in year i at age
  Z_total = 0.0;
  for (i=1;i<=n_year;i++)
  {
    for (j=1;j<=n_age;j++)
      {
        Z_total(i,j) = F_total(i,j) + M(j);
      }
  }

  //Calculate fishing mortality in year j
  F_year = 0.0;
  for (i=1;i<=n_fleet;i++)
  {
    for (j=1;j<=n_year;j++)
      {
        F_year(j) += F_full(i,j);
      }
 }


FUNCTION calc_popn_size
 //Calculate population numbers at age i in year 1
 pop_num=0.0;
 for(i=1;i<=n_age; i++){
     pop_num(1,i) = mfexp(ln_N_ini(i));
 }

//   pop_num(1,1) = ((SRR_alpha * (SSB_ratio * mfexp(ln_R0) * SPR_F0))
/ (SRR_beta + (SSB_ratio * mfexp(ln_R0) * SPR_F0))) *
mfexp(ln_recdev(1));
```

```
//   for (i=2;i<n_age;i++)
//   {
//    pop_num(1,i) = pop_num(1,i-1) * ( mfexp (-( M(i-1) + F_total(1,i-
1) ) ) );
//   }

//   pop_num(1,n_age) = pop_num(1,n_age-1) * (mfexp (-( M(n_age-1) +
F_total(1,n_age-1) ) ) /
//                   ( 1 - mfexp(-( M(n_age) + F_total(1,n_age) )) ) );
//

  //Calculate SSB in year 1
  SSB = 0.0;
  for (i=1;i<=n_age;i++)
  {
      SSB(1) += 0.5 * ( pop_num(1,i) * maturity(i) * wgt_at_age(i) );
  }

  //Calculate population numbers and SSB at age j in year 2 to end
  for (i=2;i<=n_year;i++)
  {
    for (j=1;j<=1;j++)
    {
     pop_num(i,1) = (SRR_alpha * (SSB(i-1)) / (SRR_beta + (SSB(i-1))))
*mfexp(ln_recdev(i-1));
     SSB(i) += 0.5 * ( pop_num(i,j) * maturity(j) * wgt_at_age(j) );
    }
    for (j=2;j<n_age;j++)
    {
      pop_num(i,j) = pop_num(i-1,j-1)* mfexp( -(M(j-1) + F_total(i-1,j-
1)));
      SSB(i) += 0.5 * ( pop_num(i,j) * maturity(j) * wgt_at_age(j) );
    }
    for (j=n_age;j<=n_age;j++)
    {
     pop_num(i,n_age) = ( pop_num(i-1,n_age-1)* mfexp( -(M(n_age-1) +
F_total(i-1,n_age-1))) ) +
                          ( pop_num(i-1,n_age)* mfexp( -(M(n_age) +
F_total(i-1,n_age))) );
          SSB(i) += 0.5 * ( pop_num(i,j) * maturity(j) * wgt_at_age(j)
);
      }
  }

  pop_num_full = 0.0;
  for (i=1;i<=n_year;i++)
  {
    for (j=1;j<=n_age;j++)
    {
     pop_num_full(i) += pop_num(i,j);
    }
  }

  //Calculate population weight in year i at age j
```

```
  pop_wgt = 0.0;

  for (i=1;i<=n_year;i++)
  {
     for (j=1;j<=n_age;j++)
     {
      pop_wgt(i,j) = pop_num(i,j) * wgt_at_age(j);
     }
  }

  pop_wgt_tot = 0.0;
  for (i=1;i<=n_year;i++)
  {
   for (j=1;j<=n_age;j++)
   {
    pop_wgt_tot(i) += pop_wgt(i,j);
   }
  }

  if(sd_phase)
  {
      F_year_sd = F_year;
      SSB_sd = SSB;
  }


FUNCTION calc_pred_cat
  //Calculate predicted CAA
  for (i=1;i<=n_fleet;i++)
  {
   pred_caa_num(i) = 0.0;
   pred_caa_wgt(i) = 0.0;
   for (j=1;j<=n_year;j++)
   {
       for (k=1;k<=n_age;k++)
       {
           pred_caa_num(i,j,k) = pop_num(j,k) * (F_age(i,j,k) /
Z_total(j,k)) * (1- mfexp(-(Z_total(j,k))));
           pred_caa_wgt(i,j,k) = pred_caa_num(i,j,k) * wgt_at_age(k);
          }
      }
  }

  //Calculate predicted catch
  pred_catch = 0.0;
  for (i=1;i<=n_fleet;i++)
  {
   for (j=1;j<=n_year;j++)
     {
       for (k=1;k<=n_age;k++)
         {
           pred_catch(i,j) += pred_caa_wgt(i,j,k);
         }
      }
```

```
  }

  //Calculate proportion predicted CAA
  sum_pred_caa = 0.0;
  for (i=1;i<=n_fleet;i++)
  {
    for (j=1;j<=n_year;j++)
     {
        for (k=1;k<=n_age;k++)
         {
              sum_pred_caa(i,j) += pred_caa_wgt(i,j,k);
         }
      }
  }

  for (i=1;i<=n_fleet;i++)
  {
    pred_prop_caa(i) = 0.0;
    for (j=1;j<=n_year;j++)
     {
        for (k=1;k<=n_age;k++)
         {
               pred_prop_caa(i,j,k) = pred_caa_wgt(i,j,k) /
(sum_pred_caa(i,j));
         }
      }
  }


FUNCTION calc_pred_index
  //Calculate predicted indices
//  pred_index_num = 0.0;
//  pred_index_wgt = 0.0;
  pred_index = 0.0;
  for (i=1;i<=n_index;i++)
  {
    for (j=1;j<=n_year;j++)
    {
      if (flag_yoy(i) == 0)
      {
        pred_iaa(i,j) = 0.0;
        for (k=1;k<=n_age;k++)
        {
           if (unit_index(i) == 0)
           {
            pred_iaa(i,j,k) = mfexp(ln_q_index(i)) * (pop_num(j,k) *
sel_index(i,k) * mfexp(-1. * time_index(i) * (F_total(j,k) + M(k))));
           }
           else
           {
            pred_iaa(i,j,k) = mfexp(ln_q_index(i)) * (pop_wgt(j,k) *
sel_index(i,k) * mfexp(-1. * time_index(i) * (F_total(j,k) + M(k))));
           }
           pred_index(i,j) += pred_iaa(i,j,k);
```

```
        }
        pred_iaa(i,j) = pred_iaa(i,j) / pred_index(i,j);
         }
         else
         {
             if (unit_index(i) == 0)
             {
                 pred_index(i,j) = mfexp(ln_q_index(i)) * (pop_num(j,1)
* mfexp(-1. * time_index(i) * (F_total(j,1) + M(1))));
             }
             else
             {
                 pred_index(i,j) = mfexp(ln_q_index(i)) * (pop_wgt(j,1)
* mfexp(-1. * time_index(i) * (F_total(j,1) + M(1))));
             }
         }
      }
   }


  //Calculate proportion predicted IAA
  sum_pred_iaa = 0.0;
  for (i=1;i<=n_iaa;i++)
  {
      for (j=1;j<=n_year;j++)
      {
          for (k=1;k<=n_age;k++)
          {
              sum_pred_iaa(i,j) += pred_iaa(i,j,k);
          }
       }
   }

   for (i=1;i<=n_iaa;i++)
   {
      pred_prop_iaa(i) = 0.0;
      for (j=1;j<=n_year;j++)
      {
          for (k=1;k<=n_age;k++)
          {
               pred_prop_iaa(i,j,k) = pred_iaa(i,j,k) /
(sum_pred_iaa(i,j));
          }
       }
   }


FUNCTION calc_stdev_obs
  //Calculate stdev of catch
  stdev_catch = 0.0;
  for (i=1;i<=n_fleet;i++)
  {
      for (j=1;j<=n_year;j++)
      {
```

```
          if (obs_cv_catch(i,j) > 0.0)
          {
              stdev_catch(i,j) = sqrt( log ( square ( obs_cv_catch(i,j)
) + 1 ) );
          }
          else
          {
              stdev_catch(i,j) = 0.0;
          }
      }
  }

  //Calculate stdev of indices
  stdev_index = 0.0;
  for (i=1;i<=n_index;i++)
  {
      for (j=1;j<=n_year;j++)
      {
          if (obs_cv_index(i,j) > 0.0)
          {
              stdev_index(i,j) = sqrt( log ( square ( obs_cv_index(i,j)
) + 1 ) );
          }
          else
          {
              stdev_index(i,j) = 0.0;
          }
      }
  }


FUNCTION calc_resids
  double small_c = 1.0e-06;

  //Calculate catch residuals and standardized residuals
  res_catch = 0.0;
  res2_catch = 0.0;
  sqres_catch = 0.0;
  stdres_catch = 0.0;
  for (i=1;i<=n_fleet;i++)
  {
      for (j=1;j<=n_year;j++)
      {
          if (obs_catch(i,j) > -1.0 )
          {
              res_catch(i,j) = log( obs_catch(i,j) + small_c ) - log(
pred_catch(i,j) + small_c ) ;
              res2_catch(i) += square ( res_catch(i,j) ) ;
              sqres_catch(i,j) = ( square( res_catch(i,j) ) / ( 2.0 *
square(stdev_catch(i,j)) ) ) + log(stdev_catch(i,j));
          }
          else
          {
              res_catch(i,j) = 0.0;
```

```
                sqres_catch(i,j) = 0.0;
            }
            if (stdev_catch(i,j) > 0.0)
            {
                stdres_catch(i,j) = res_catch(i,j) / stdev_catch(i,j) ;
            }
            else
            {
                stdres_catch(i,j) = 0.0;
            }
        }
     }

    sum_sqres_catch = 0.0;
    wgtd_sum_sqres_catch = 0.0;
    for (i=1;i<=n_fleet;i++)
    {
        for (j=1;j<=n_year;j++)
        {
            sum_sqres_catch(i) += sqres_catch(i,j);
        }
        wgtd_sum_sqres_catch(i) = sum_sqres_catch(i) * lambda_catch(i);
    }

    //Calculate CAA residuals; CAA standardized residuals calculated
  externally for now
    sum_nsqres_caa = 0.0;
    sum2_nsqres_caa = 0.0;
    wgtd_sum2_nsqres_caa = 0.0;
    for (i=1;i<=n_fleet;i++)
    {
        res_caa(i) = 0.0;
        sqres_caa(i) = 0.0;
        nsqres_caa(i) = 0.0;
        for (j=1;j<=n_year;j++)
        {
            for (k=1;k<=n_age;k++)
            {
                if (obs_caa(i,j,k) > -1.0)
                {
                    res_caa(i,j,k) = log( obs_prop_caa(i,j,k) + small_c )
  - log( pred_prop_caa(i,j,k) + small_c );
                    sqres_caa(i,j,k) = obs_prop_caa(i,j,k) * log
  (pred_prop_caa(i,j,k) + small_c );
                }
                else
                {
                    res_caa(i,j,k) = 0.0;
                    sqres_caa(i,j,k) = 0.0;
                }

                nsqres_caa(i,j,k) = sqres_caa(i,j,k) * nsamp_caa(j);
                sum_nsqres_caa(i,j) += nsqres_caa(i,j,k) ;
            }
```

```
            sum2_nsqres_caa(i) += sum_nsqres_caa(i,j) ;
        }
        wgtd_sum2_nsqres_caa(i) = -1.0 * sum2_nsqres_caa(i) * lambda_caa;
    }

    //Calculate index residuals and standardized residuals
    res_index = 0.0;
    res2_index = 0.0;
    sqres_index = 0.0;
    stdres_index = 0.0;
    for (i=1;i<=n_index;i++)
    {
        for(j=1;j<=n_year;j++)
        {
            if (obs_index(i,j) > -1.0)
            {
                res_index(i,j) = log( obs_index(i,j) ) - log(
  pred_index(i,j) );
                res2_index(i) += square ( res_index(i,j) );
                sqres_index(i,j) = ( square( res_index(i,j) ) /( 2.0 *
  square( stdev_index(i,j) ) ) )
                                       + log( stdev_index(i,j) );
            }
            else
            {
                res_index(i,j) = 0.0;
                sqres_index(i,j) = 0.0;
            }
            if (stdev_index(i,j) > 0.0)
            {
                stdres_index(i,j) = res_index(i,j) / stdev_index(i,j) ;
            }
            else
            {
                stdres_index(i,j) = 0.0;
            }
        }
    }

    sum_sqres_index = 0.0;
    wgtd_sum_sqres_index = 0.0;
    for (i=1;i<=n_index;i++)
    {
        for (j=1;j<=n_year;j++)
        {
            sum_sqres_index(i) += sqres_index(i,j) ;
        }
        wgtd_sum_sqres_index(i) = sum_sqres_index(i) * lambda_index(i);
    }

    //Calculate IAA residuals; IAA standardized residuals calculated
  externally for now
    sum_nsqres_iaa = 0.0;
    sum2_nsqres_iaa = 0.0;
```

```
  wgtd_sum2_nsqres_iaa = 0.0;
  for (i=1;i<=n_iaa;i++)
  {
      res_iaa(i) = 0.0;
      sqres_iaa(i) = 0.0;
      nsqres_iaa(i) = 0.0;
      for (j=1;j<=n_year;j++)
      {
          for (k=1;k<=n_age;k++)
          {
              if (obs_iaa(i,j,k) > -1.0)
              {
                  res_iaa(i,j,k) = log( obs_prop_iaa(i,j,k) + small_c )
- log( pred_prop_iaa(i,j,k) + small_c );
                  sqres_iaa(i,j,k) = obs_prop_iaa(i,j,k) * log
(pred_prop_iaa(i,j,k) + small_c );
              }
              else
              {
                  res_iaa(i,j,k) = 0.0;
                  sqres_iaa(i,j,k) = 0.0;
              }
//            if (sum_obs_iaa(i,j) <= 200)
//            {
//                nsqres_iaa(i,j,k) = sqres_iaa(i,j,k) *
sum_obs_iaa(i,j);
//            }
//            else
//            {
                  nsqres_iaa(i,j,k) = sqres_iaa(i,j,k) *
index_ess(i,j);
//            }
              sum_nsqres_iaa(i,j) += nsqres_iaa(i,j,k) ;
          }
          sum2_nsqres_iaa(i) += sum_nsqres_iaa(i,j) ;
      }
      wgtd_sum2_nsqres_iaa(i) = -1.0 * sum2_nsqres_iaa(i) * lambda_iaa;
  }


FUNCTION calc_ref_points
  //Calculated weighted-F
  F_tmp = 0.0;
  F_wgtd = 0.0;
  for (i=1;i<=n_year;i++)
  {
      for (j=2;j<=n_age;j++)
      {
         F_wgtd(i,j) = F_total(i,j) * pop_num(i,j);
         F_tmp(i) += F_wgtd(i,j);
      }
  }

  F_wgtd_avg = 0.0;
```

```
for (i=1;i<=n_year;i++)
{
    F_wgtd_avg(i) = F_tmp(i) / pop_num_full(i);
}

if(sd_phase)
{
    F_wgtd_avg_sd = F_wgtd_avg;
}

//Below borrowed from EWilliams
df=0.00001;

avg_land=0.0;
for (i=1;i<=n_fleet;i++)
{
    for (j=n_year-2;j<=n_year;j++)
    {
        avg_land +=obs_catch(i,j);
    }
}

sel_msy=0.0;
for (i=1;i<=n_fleet;i++)
{
    for (k=1; k<=n_age; k++)
    {
        for (j=n_year-2;j<=n_year;j++)
        {
            sel_msy(k) +=sel_fleet(i,k)*obs_catch(i,j)/avg_land;
        }
    }
}
sel_msy = sel_msy/(max(sel_msy));

//use Newton's method to get Fmsy, MSY, and Smsy
F_msy(1)=0.05;
for (i=1; i<=10; i++)
{
    F_msy(2)=F_msy(1)-df;
    F_msy(3)=F_msy(1)+df;
    L_msy=0.0;
    Z_msy(1)=sel_msy*F_msy(1)+M;
    Z_msy(2)=sel_msy*F_msy(2)+M;
    Z_msy(3)=sel_msy*F_msy(3)+M;
    //Initial age
    N_msy(1,1)=1.0;
    N_msy(2,1)=1.0;
    N_msy(3,1)=1.0;
    for (k=2; k<=n_age;k++)
    {
        N_msy(1,k)=N_msy(1,k-1)*mfexp(-1.*Z_msy(1,k-1));
        N_msy(2,k)=N_msy(2,k-1)*mfexp(-1.*Z_msy(2,k-1));
        N_msy(3,k)=N_msy(3,k-1)*mfexp(-1.*Z_msy(3,k-1));
```

```
      }
      //last age is pooled
      N_msy(1,n_age)=N_msy(1,n_age-1)*mfexp(-1.*Z_msy(1,n_age-1))/(1.-
mfexp(-1.*Z_msy(1,n_age)));
      N_msy(2,n_age)=N_msy(2,n_age-1)*mfexp(-1.*Z_msy(2,n_age-1))/(1.-
mfexp(-1.*Z_msy(2,n_age)));
      N_msy(3,n_age)=N_msy(3,n_age-1)*mfexp(-1.*Z_msy(3,n_age-1))/(1.-
mfexp(-1.*Z_msy(3,n_age)));

spr_msy(1)=sum(elem_prod(elem_prod(N_msy(1),wgt_at_age),maturity));

spr_msy(2)=sum(elem_prod(elem_prod(N_msy(2),wgt_at_age),maturity));

spr_msy(3)=sum(elem_prod(elem_prod(N_msy(3),wgt_at_age),maturity));
      R_eq(1)=(SRR_R0/((5*h-1)*spr_msy(1)))*(4*h*spr_msy(1)-SPR_F0*(1-
h));
      R_eq(2)=(SRR_R0/((5*h-1)*spr_msy(2)))*(4*h*spr_msy(2)-SPR_F0*(1-
h));
      R_eq(3)=(SRR_R0/((5*h-1)*spr_msy(3)))*(4*h*spr_msy(3)-SPR_F0*(1-
h));

      //Initial age
      N_msy(1)=R_eq(1);
      N_msy(2)=R_eq(2);
      N_msy(3)=R_eq(3);
      for (k=2; k<=n_age; k++)
      {
          N_msy(1,k)=N_msy(1,k-1)*mfexp(-1.*Z_msy(1,k-1));
          N_msy(2,k)=N_msy(2,k-1)*mfexp(-1.*Z_msy(2,k-1));
          N_msy(3,k)=N_msy(3,k-1)*mfexp(-1.*Z_msy(3,k-1));
      }
      //last age is pooled
      SSB_msy=0.0;
      N_msy(1,n_age)=N_msy(1,n_age-1)*mfexp(-1.*Z_msy(1,n_age-1))/(1.-
mfexp(-1.*Z_msy(1,n_age-1)));
      N_msy(2,n_age)=N_msy(2,n_age-1)*mfexp(-1.*Z_msy(2,n_age-1))/(1.-
mfexp(-1.*Z_msy(2,n_age-1)));
      N_msy(3,n_age)=N_msy(3,n_age-1)*mfexp(-1.*Z_msy(3,n_age-1))/(1.-
mfexp(-1.*Z_msy(3,n_age-1)));

SSB_msy(1)=0.5*sum(elem_prod(elem_prod(N_msy(1),wgt_at_age),maturity));

SSB_msy(2)=0.5*sum(elem_prod(elem_prod(N_msy(2),wgt_at_age),maturity));

SSB_msy(3)=0.5*sum(elem_prod(elem_prod(N_msy(3),wgt_at_age),maturity));

      L_msy=0.0;
      for(k=1; k<=n_age; k++)
      {
          L_msy(1)+=N_msy(1,k)*((Z_msy(1,k)-M(k))/Z_msy(1,k))*(1.-
mfexp(-1.*Z_msy(1,k)))*wgt_at_age(k);
          L_msy(2)+=N_msy(2,k)*((Z_msy(2,k)-M(k))/Z_msy(2,k))*(1.-
mfexp(-1.*Z_msy(2,k)))*wgt_at_age(k);
```

```
          L_msy(3)+=N_msy(3,k)*((Z_msy(3,k)-M(k))/Z_msy(3,k))*(1.-
mfexp(-1.*Z_msy(3,k)))*wgt_at_age(k);
      }
      dmsy=(L_msy(3)-L_msy(2))/(2.*df);
      ddmsy=(L_msy(3)-2.*L_msy(1)+L_msy(2))/square(df);
      if(square(ddmsy)<=1e-12)
      {
          F_msy(1)=F_msy(1);
      }
      if(square(ddmsy)>1e-12)
      {
          F_msy(1)-=(dmsy/ddmsy);
      }
      if(F_msy(1)<=df)
     {
         F_msy(1)=df;
     }
  }

  msy_out=L_msy(1);
  F_msy_out=F_msy(1);
  SSB_msy_out=SSB_msy(1);

  //f_c_ratio =f_by_yr(n_year);
  //ssb_c_ratio=SSB(n_year);
  //End of borrowed

  //Calculate relative stock status
  for (i=1;i<=n_year;i++)
  {
      SSB_relative(i) = SSB(i) / SSB_msy(1) ;
      F_relative(i) = F_wgtd_avg(i) / F_msy(1) ;
      F_yr_relative(i) = F_year(i) / F_msy(1) ;
      SSB_rel_virgin(i) = SSB(i) / SSB0;
  }

  if(sd_phase)
  {
      SSB_relative_sd = SSB_relative;
      SSB_rel_virgin_sd = SSB_rel_virgin;
      F_relative_sd = F_relative;
      F_yr_relative_sd = F_yr_relative;
  }


FUNCTION evaluate_the_objective_function

  LL_catch = 0.0;
  LL_caa = 0.0;
  LL_index = 0.0;
  LL_iaa = 0.0;

  //Calculate likelihood for catch, CAA, and indices
  LL_catch = sum(wgtd_sum_sqres_catch);
```

```
  LL_caa = sum(wgtd_sum2_nsqres_caa);
  LL_index = sum(wgtd_sum_sqres_index);
  LL_iaa = sum(wgtd_sum2_nsqres_iaa);

  //Calculate likelihood for recruitment deviations
  LL_recdev = 0.0;
  for (i=1;i<n_year;i++)
  {
      LL_recdev += pow(ln_recdev(i),2) * lambda_recdev;
  }

  //Calculate total likelihood
  f = LL_catch + LL_caa + LL_index + LL_iaa + LL_recdev;


TOP_OF_MAIN_SECTION
  arrmblsize=2000000;


REPORT_SECTION
  if (last_phase()){

     {


             ofstream ofs(runname);


     ofs << "Quick_Results " << endl;
     ofs << "   " << endl;

     ofs << "   " << endl;
     ofs << "Likelihood " << endl;
     ofs << "LL_catch   " << "   " << LL_catch << endl;
     ofs << "LL_CAA     " << "   " << LL_caa << endl;
     ofs << "LL_index   " << "   " << LL_index << endl;
     ofs << "LL_recdev  " << "   " << LL_recdev << endl;
     ofs << "Total_LL   " << "   "  << f << endl;
     ofs << "   " << endl;

     ofs << "REFERENCE_POINTS" << endl;
     ofs << "   " << endl;
     ofs << "Fmsy   " << F_msy(1) << endl;
     ofs << "Fcurrent  " << F_year(n_year) << endl;
     ofs << "Fcurrent/Fmsy " << F_year(n_year)/F_msy(1) << endl;
     ofs << "SSBmsy  " << SSB_msy(1)  << endl;
     //ofs << "SSB Threshold  " << 0.75 * SSB_msy(1)  << endl;
     ofs << "SSBcurrent  " << SSB(n_year)  << endl;
     ofs << "SSBcurrent/SSBmsy " << SSB(n_year)/SSB_msy(1) << endl;
     ofs << "   " << endl;
     //ofs << "Log_R0     " << "   " << ln_R0 << endl;
     ofs << "Virgin_SSB: " << SSB0 <<endl;
     ofs << "SPR_F0:  " << "   " << SPR_F0 << endl;
     ofs << "Steepness  " << "   " << h << endl;
```

```
     ofs << "   " << endl;
     ofs << "Log_q_indices " << endl;
     for (i=1;i<=n_index;i++)
     {
         ofs << "Index_#" << i << "   " << ln_q_index(i) << endl;
     }
     ofs << "   " << endl;
     ofs << "Recruits "  << "    " << "SSB "  << "    " <<  "Total_F "
<< endl;
     for (i=1;i<=n_year;i++)
     {
         ofs << pop_num(i,1)/1000000  << "     " << SSB(i) << "     "
<< F_year(i) << "     " << endl;
     }
     ofs << endl;
     ofs <<"SSB/SSBvirgin " << "    " << " SSB/SSBmsy " << "
F_total/Fmsy" << "     Avg_F/Fmsy"  << endl;
     for(i=1; i<=n_year; i++)
     {
       ofs <<  SSB(i)/SSB0  << "     " << SSB(i)/SSB_msy(1) << "    "
<<  F_year(i)/F_msy(1) << "     " << F_wgtd_avg(i)/F_msy(1) << endl;
     }
     ofs << "   " << endl;
     ofs << "Total Abundance       Total Biomass" << endl;
     for (i=1;i<=n_year;i++)
     {
         ofs << start_year + i - 1 << "    " << pop_num_full(i)/1000000
<< "     "  << pop_wgt_tot(i) << endl;
     }
     ofs << "   " << endl;
     }
    }

  //Create report for model results
  report << "HYBRID_ASPM-SCAM_MODEL " << endl;
  report << "    " << endl;
  report << "MODEL_STRUCTURE " << endl;
  report << "    " << endl;
  report << "N_years       " << n_year << endl;
  report << "N_ages        " << n_age << endl;
  report << "    " << endl;
  report << "N_fleets      " << n_fleet << endl;
  report << "N_index       " << n_index << endl;
  report << "    " << endl;
  report << "h_(steepness) " << h << endl;
  report << "    " << endl;
  report << "    " << endl;

  report << "MODEL_FIT  " << endl;
  report << "    " << endl;
  report << "Model_Weights " << endl;
  report << "Lambda_catch   " << lambda_catch << endl;
  report << "Lambda_index   " <<  lambda_index << endl;
  report << "Lambda_caa     " <<  lambda_caa << endl;
```

```
report << "Lambda_iaa     " <<  lambda_iaa << endl;
report << "Lambda_recdev  " <<  lambda_recdev << endl;
report << "    " << endl;
report << "Likelihood " << endl;
report << "LL_catch   " << LL_catch << endl;
report << "LL_CAA     " << LL_caa << endl;
report << "LL_index   " << LL_index << endl;
report << "LL_IAA     " << LL_iaa << endl;
report << "LL_recdev  " << LL_recdev << endl;
report << "Total_LL   " << f << endl;
report << "    " << endl;
report << "    " << endl;

report << "ESTIMATED_PARAMETERS " << endl;
report << "    " << endl;
//report << "ln_SSB0    " << ln_SSB0 << endl;
report << "    " << endl;
//report << "SSB_ratio  " << SSB_ratio << endl;
report << "    " << endl;
report << "Log_q_indices " << endl;
for (i=1;i<=n_index;i++)
{
    report << "Index_#" << i << "   " << ln_q_index(i) << endl;
}
report << "    " << endl;
report << "Full_fishing_mortality " << endl;
report << "Year " ;
for (i=1;i<=n_fleet;i++)
{
    report << "      " << "Fleet_#" << i ;
}
report << endl;
for (i=1;i<=n_year;i++)
{
    report << start_year - 1 + i << "    " ;
    for (j=1;j<=n_fleet;j++)
    {
        report << "      " << F_full(j,i);
    }
    report << endl;
}
report << "    " << endl;
report << "    " << endl;

report << "GROWTH_&_MATURITY " << endl;
report << "    " << endl;
report << "von_Bertalanffy_Age-Length(cm) " << endl;
report << "L_inf  " << L_inf << endl;
report << "K      " << K << endl;
report << "t_0    " << t_0 << endl;
report << "    " << endl;
report << "Allometric_Length(cm)-Weight(kg) " << endl;
report << "LW_a   " << lw_a << endl;
report << "LW_b   " << lw_b << endl;
```

```
  report << "    " << endl;
  report << "Age " << "  " << "Length_(cm) " << "  " << " Weight_(kg) "
         << "  " << " Natural_Mortality " << "  " << " Maturity " <<
endl;
  for (i=1;i<=n_age;i++)
  {
      report << i-1 << "       " << len_at_age(i) << "        " <<
wgt_at_age(i)/0.001
             << "          " << M(i)
             << "          " << maturity(i) << endl;
  }
  report << "    " << endl;
  report << "    " << endl;

  report << "REFERENCE_POINTS" << endl;
  report << "    " << endl;
  report << "Fmsy              " << F_msy(1) << endl;
  report << "Fcurrent          " << F_wgtd_avg(n_year) << endl;
  report << "Fcurrent/Fmsy     " << F_wgtd_avg(n_year)/F_msy(1) <<
endl;
  report << "SSBmsy            " << SSB_msy(1)  << endl;
  report << "SSBcurrent        " << SSB(n_year)  << endl;
  report << "SSBcurrent/SSBmsy " << SSB(n_year)/SSB_msy(1) << endl;
  report << "    " << endl;
  report << "    " << endl;
  report << "MSY_selectivity: " << sel_msy << endl;
  report << "CATCH " << endl;
  report << "    " << endl;
  report << "Fleet_selectivity " << endl;
  report << sel_fleet << endl;
  report << "    " << endl;
  report << "Predicted_catch " << endl;
  report << "            " ;
  for (i=1;i<=n_fleet;i++)
  {
      report << "Fleet_#" << i << "     ";
  }
  report << endl;
  report << "Year " ;
  for (i=1;i<=n_fleet;i++)
  {
      report << "       " << "Obs. " << "    " << "Pred. " ;
  }
  report << endl;
  for (i=1;i<=n_year;i++)
  {
      report << start_year - 1 + i << "    " ;
      for (j=1;j<=n_fleet;j++)
      {
          report << "      " << obs_catch(j,i) << "    " <<
pred_catch(j,i);
      }
      report << endl;
  }
```

```
 report << "    " << endl;
 report << "N-weighted_F " << endl;
 for (i=1;i<=n_year;i++)
 {
     report << start_year - 1 + i << "   " << F_wgtd_avg(i) << endl;
 }
 report << "    " << endl;
 report << "Predicted_CAA_wgt " << endl;
 report << pred_caa_wgt << endl;
 report << "   " << endl;
 report << "Total_fishing_mortality " << endl;
 report << F_total << endl;
 report << "    " << endl;
 report << "    " << endl;

 report << "INDICES " << endl;
 report << "    " << endl;
 report << "Index_units        " << endl;
 report << unit_index << endl;
 report << "Index_timing       " << endl;
 report << time_index << endl;
 report << "Flag_YOY           " << endl;
 report << flag_yoy << endl;
 report << "Index_selectivity  " << endl;
 report << sel_index << endl;
 report << "    " << endl;
 report << "Predicted_indices " << endl;
 report << "            " ;
for (j=1;j<=n_index;j++){
 report << "Index #" << i << endl;
 report << "Pred." << endl;
   for (i=1;i<=n_year;i++)
     {
         report  << pred_index(j,i) << endl;
     }
     report << endl;
 }
 report << "    " << endl;
 report << "Predicted_prop_IAA " << endl;
 report << pred_prop_iaa << endl;
 report << "    " << endl;
 report << "    " << endl;

 report << "POPULATION " << endl;
 report << "    " << endl;
 report << "SSB0     " << SSB0 << endl;
 report << "R0     " << SRR_R0 << endl;
 report << "SRR_alpha     " << SRR_alpha << endl;
 report << "SRR_beta     " << SRR_beta << endl;
 report << "    " << endl;
 report << "    " << endl;
 report << "Year " << "    " << "Female_SSB_(mt) " << endl;
 for (i=1;i<=n_year;i++)
 {
```

```
  report << start_year - 1 + i << "        " <<  SSB(i) << endl;
}
report << "Year " << "    " << "Log_recruit_devs "   << endl;
for(i=1; i<=n_year; i++){
      //report << start_year + i << "        "
      report <<   ln_recdev(i) << endl;
}

report << "    " << endl;
report << "Population_numbers_at_age_(000s) " << endl;
report << pop_num/1000 << endl;
report << "    " << endl;
report << "Population_weight_at_age_(mt) " << endl;
report << pop_wgt << endl;
report << "    " << endl;
report << "Survival_per_recruit " << endl;
report << S0_per_R << endl;
report << "    " << endl;
report << "    " << endl;

report << "RESIDUALS " << endl;
report << "    " << endl;
report << "Catch_residuals " << endl;
report << "Year " << "   ";
for (i=1;i<=n_fleet;i++)
{
    report << "Fleet_#" << i << "         "  ;
}
report << endl;
for (i=1;i<=n_year;i++)
{
    report << start_year + i - 1 << "  " ;
    for (j=1;j<=n_fleet;j++)
    {
        report << "      " << res_catch(j,i);
    }
    report << endl;
}
report << "    " << endl;
report << "Catch_standardized_residuals " << endl;
report << "Year " << "   ";
for (i=1;i<=n_fleet;i++)
{
    report << "Fleet_#" << i << "         "  ;
}
report << endl;
for (i=1;i<=n_year;i++)
{
    report << i << "  " ;
    for (j=1;j<=n_fleet;j++)
    {
        report << "      " << stdres_catch(j,i);
    }
    report << endl;
```

```
}
report << "    " << endl;
report << "    " << endl;
report << "Index_residuals " << endl;
report << "Year " << "   ";
for (i=1;i<=n_index;i++)
{
    report << "Index_#" << i << "      ";
}
report << endl;
for (i=1;i<=n_year;i++)
{
    report << start_year + i - 1 << "  " ;
    for (j=1;j<=n_index;j++)
    {
        report << "      " << res_index(j,i);
    }
    report << endl;
}
report << "    " << endl;
report << "Index_standardized_residuals " << endl;
report << "Year " << "   ";
for (i=1;i<=n_index;i++)
{
    report << "Index_#" << i << "      ";
}
report << endl;
for (i=1;i<=n_year;i++)
{
    report << start_year + i - 1 << "  " ;
    for (j=1;j<=n_index;j++)
    {
        report << "      " << stdres_index(j,i);
    }
    report << endl;
}
report << "    " << endl;
report << "    " << endl;
report << "IAA_residuals " << endl;
report << res_iaa << endl;
report << "    " << endl;
report << "CAA_residuals " << endl;
report << res_caa << endl;
report << "   " << endl;
```

Input data for model run without shrimp-trawl bycatch

```
#MODEL_STRUCTURE
#Run name
   base.rep
#Number of years
    21
#N ages
    16
#Age
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
#START_YEAR
  1988
#START_SELEX_PERIOD_2
#  1996
#BIOLOGICAL_DATA
#M_at_Age
    0.461   0.374   0.324   0.293   0.272   0.257   0.246   0.238
0.232   0.227   0.223   0.220   0.218   0.216   0.215   0.214
#L_inf
    43.1
#K
    0.214
#t_0
    -2.35
#LW_a
    7.30E-06
#LW_b
    3.14
#Maturity_at_Age
    0   0.9 1   1   1   1   1   1   1   1   1   1   1   1   1   1
#Steepness
    0.76
#INI
# 12.5      12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5
      12.5  12.5  12.5  12.5  12.5
# 10  10    10    10    10    10    10    10    10    10    10    10    10
      10    10    10
#     18.47889305 17.18567125 17.62743474 18.21236546 16.61904668
      15.89777436 17.26701441 13.94070605 14.50690621 13.99238397
      13.50906827 13.03138341 12.55470987 12.07842108 11.60369809
      12.10481481
 18.5 17.2  17.6  18.2  16.6  15.9  17.3  13.9  14.5  14.0  13.5  13.0
      12.6  12.1  11.6  12.1


#NUMBER_FLEETS
4
#NUMBER_EST_SELECTIVITY_PATTERNS
4
#FLEET_NAMES
# Commercial Scrap-Discard Rec-Harvest Rec-Release
```

```
#OBSERVED_CATCH_BY_YEAR_(-999_for_missing_data)
#Commercial
4742.6  3672.9  2756.4  1676.7  1944.1  4069.1  4910.8  6319    9636.7
12371   12541   12130   12118   13006   11865   12923   12982   11167
9514.1  9199.2  8777
#Scrap/Discards
1881    1910.7  1347.5  1086.1  1115.2  1607.1  4643.2  3484.7  1143.4
510.8   15352   1550.3  2103.4  1958.7  7326.7  10432   899.95  3050
269.36  1283.2  1342.8
#Recreational harvest
2106.5  1078.4  778.81  1156    1191.9  1368.8  2208.6  1818.2  1857.7
3520.1  3588.5  3320.3  4395.3  5026.7  4152.7  4179.8  4000.6  4792.1
4184.1  3746.1  2406.6
#Recreational release mortality (10% B2)
19.184  17.933  34.1    79.294  40.725  69.766  88.534  59.276  68.035
123.37  135.32  143.54  232.33  156.69  156.69  167.03  132.04  180.74
157.06  147.84  120.36


#CATCH_CVs
#Commercial
0.1 0.1 0.1 0.1 0.1 0.1 0.05    0.05    0.05    0.05    0.05    0.05
0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
#Scrap/Discards (2x commercial CVs)
0.2 0.2 0.2 0.2 0.2 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1
#Rec Harvest
0.1 0.062   0.081   0.086   0.076   0.075   0.055   0.08    0.089
0.094   0.081   0.079   0.069   0.055   0.049   0.052   0.064   0.069
0.093   0.059   0.067
#Rec release mortality
0.11    0.068   0.093   0.078   0.081   0.073   0.051   0.071   0.071
0.071   0.056   0.051   0.05    0.045   0.045   0.045   0.053   0.061
0.055   0.049   0.049


#NUMBER_INDICES
4

#INDEX_UNITS_(0=number;1=weight)
#NMFS   SEAMAP  VIMS NC195
0 1 0 0

#INDEX_TIMING
#NMFS   SEAMAP  VIMS NC195
0.75 0.875  0.417 0.50

#INDEX_YOY_FLAG_(0=no;1=yes)
0 0 1 1

#INDEX_VALUES_BY_YEAR_(-999_for_missing_data)
#NMFS
31.8    102 74.6    208 205 21.6    450 170 205 133 326 795 380 199 930
494 636 438 901 1334    461
```

```
#SEAMAP
-999	-999	7.72	24.5	4.32	18.7	14.6	5.08	5.14
2.3 4.65	17.5	4.19	2.66	9.24	14.1	15.4	23.8
12.1	9.2 12
#VIMS
0.44	1.71	1	6.08	2.98	4.43	0.58	2.61	0.03
5.58	5.65	1.3 0.83	0.38	3.18	0.92	2.29	1.5 3.72
2.96	17.4
#NC P195
50  114 325 261 44.1	437 124 146 61.9	330 602 725 171 104 83.2
159 448 196 113 106 268

#INDEX_CVs
#NMFS
0.48	0.51	0.34	0.4 0.34	0.42	0.32	0.21	0.28
0.41	0.24	0.24	0.37	0.4 0.45	0.22	0.26	0.4 0.16
0.37	0.2
#SEAMAP
-999	-999	0.29	0.27	0.18	0.1 0.33	0.36	0.23
0.44	0.33	0.25	0.33	0.27	0.44	0.35	0.21	0.17
0.14	0.31	0.25
#VIMS
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2
#NC P195
0.52	0.7 0.71	1.5 0.81	0.83	1.2 0.95	0.78	0.64
0.53	1.5 0.81	0.54	0.74	0.8 0.62	0.59	0.82	0.72
0.56

#Fleet age of full selectivity
 3 1 5 4
#Age of full selectivity for non-YOY indices
 2 0

#SEL_SHAPE_FLEET (1=non-parametric, 2=single logistic, 3=double
logistic)
 3 3 2 3
#Fixed sel patterns: Shrimp trawl bycatch
# 1	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0

#INITIALIZE_FLEET_SEL_PARS
#INITIAL_GUESS
 2 0.2 7 0.2 1 0.7 2 0.3 3 0.2 2 0.3 7 0.3
#LOWER_&_UPPER_BOUNDS
 0  0	0	0	0	0	0	0	0	0	0	0	0	0
 15 15	15	15	15	15	15	15	15	15	15	15	15	15


#SEL_SHAPE_INDEX
 3 3
#SEL_PAR_BOUNDS_INDEX (Length: n_ages * sel_shape=1 + 2*sel_shape=2 +
4*sel_shape=3)
#INTIAL_GUESS
```

```
 1 0.4 7 0.2 0 0.7 3 0.5
#LOWER_&_UPPER_BOUNDS
0   0   0   0   0   0   0   0
15  15  15  15  15  15  15  15



#CAA_DATA
#IAA_BY_INDEX_AND_YEAR_AND_AGE_non-YOY_indices_(number)_(-
999_for_missing_data)

-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
0   0   1   6   6   4   2   1   0   0   0   0   0   0   0   0
46  71  20  32  12  40  13  20  0   0   0   0   0   0   0   0
13  31  32  3   5   3   6   0   2   0   0   0   0   0   0   0
20  78  163 65  8   6   2   6   3   9   0   0   0   0   0   0
2   21  40  101 42  4   9   4   5   1   4   0   0   0   0   0
66  27  26  33  76  27  2   2   3   1   1   0   1   0   0   0
0   72  206 20  7   30  63  20  1   3   0   1   2   1   0   0
88  58  160 20  8   19  43  12  0   1   0   0   0   0   0   0
46  151 35  105 8   2   15  21  7   0   1   0   1   1   0   0
259 93  149 14  140 9   1   3   8   3   1   0   0   0   0   0
35  258 102 91  19  67  4   0   1   2   2   1   0   0   0   0
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
```

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-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
159 48  8   7   0   2   0   0   0   0   0   0   0   0   0   0
170 47  8   5   1   0   0   1   0   0   0   0   0   0   0   0
169 59  10  3   0   0   0   0   0   0   0   0   0   0   0   0
149 58  11  1   1   1   0   0   0   0   0   0   0   0   0   0
188 72  15  4   1   1   0   0   0   0   0   0   0   0   0   0
94  92  4   5   0   0   1   0   0   0   0   0   0   0   0   0
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999


#CAA_BY_FLEET_AND_YEAR_AND_AGE_(metric_tons)_(-999_for_missing_data)
426.6   1857.8  1424.2  614.1   271.0   95.7    39.7    5.8 0.0 7.7 0.0
0.0 0.0 0.0 0.0 0.0
348.7   1093.5  1175.3  588.3   294.4   111.5   43.8    10.1    0.1 7.3
0.0 0.0 0.0 0.0 0.0 0.0
625.1   1003.7  714.7   245.4   111.1   36.7    14.4    2.0 0.0 3.4 0.0
0.0 0.0 0.0 0.0 0.0
183.2   746.0   522.3   141.2   57.7    17.1    6.5 0.5 0.0 2.2 0.0 0.0
0.0 0.0 0.0 0.0
210.4   797.6   544.7   230.3   104.6   36.1    15.3    2.3 0.0 2.8 0.0
0.0 0.0 0.0 0.0 0.0
507.3   1554.1  1261.7  452.3   190.6   64.3    25.0    7.5 0.0 6.3 0.0
0.0 0.0 0.0 0.0 0.0
253.3   1052.1  1543.4  1007.5  617.2   248.2   96.8    80.5    0.5
11.4    0.0 0.0 0.0 0.0 0.0 0.0
398.6   1704.1  1624.3  1226.2  841.3   337.3   139.9   33.9    0.9
12.5    0.0 0.0 0.0 0.0 0.0 0.0
6.4 1243.6  2631.7  2337.8  2338.2  907.9   171.1   0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0
344.9   1402.9  2920.2  2345.9  2808.8  1899.3  491.7   5.5 0.0 151.7
0.0 0.0 0.0 0.0 0.0 0.0
561.2   1365.2  1693.5  2220.3  3062.8  1732.3  1229.7  622.6   42.8
10.8    0.0 0.0 0.0 0.0 0.0 0.0
165.9   2288.8  1450.3  996.5   1747.1  1530.0  1989.0  1239.3  689.0
33.8    0.0 0.0 0.0 0.0 0.0 0.0
17.8    1107.9  2860.2  1394.9  941.1   1559.9  1365.0  1171.4  952.5
727.7   20.0    0.0 0.0 0.0 0.0 0.0
```

42.1 400.7 1573.8 3383.0 1825.6 692.4 1016.7 1106.0 1476.3
848.4 596.5 35.4 8.7 0.0 0.0 0.0
60.6 614.1 1010.7 2200.1 4090.7 1914.3 390.3 477.8 414.3
406.0 128.9 157.0 0.0 0.0 0.0 0.0
0.0 897.4 738.7 742.9 2186.9 4328.0 2092.4 436.2 443.0
345.9 410.0 121.2 180.3 0.0 0.0 0.0
6.2 569.9 3849.9 1021.9 958.4 1661.3 3065.3 1174.0 193.3
128.2 122.7 166.7 18.8 45.3 0.0 0.0
25.3 1255.6 1196.6 3627.3 386.4 251.9 1334.3 2298.6 484.7
52.8 121.1 57.6 57.9 4.5 12.7 0.0
11.6 418.4 1894.3 733.5 3666.4 348.5 444.8 530.9 949.3
361.8 55.1 68.7 0.1 12.1 18.5 0.0
9.4 597.7 918.1 1250.8 702.0 3332.2 489.6 233.8 493.3
844.2 235.3 6.5 24.6 17.9 33.7 10.0
42.4 714.6 1102.7 945.1 1266.4 784.6 2445.0 176.2 277.9
510.2 348.4 110.4 26.7 9.2 0.0 17.1
351.8 1005.5 354.4 101.0 47.7 11.8 7.2 0.6 0.0 1.1 0.0 0.0
0.0 0.0 0.0 0.0
515.1 674.1 512.3 132.1 52.9 16.3 5.3 0.4 0.0 2.2 0.0 0.0
0.0 0.0 0.0 0.0
439.1 558.0 242.2 66.2 29.1 8.0 3.9 0.3 0.0 0.9 0.0 0.0 0.0
0.0 0.0 0.0
172.1 543.8 280.1 57.1 24.3 5.4 2.4 0.0 0.0 0.9 0.0 0.0 0.0
0.0 0.0 0.0
205.3 602.8 220.4 51.8 25.2 5.5 3.4 0.2 0.0 0.6 0.0 0.0 0.0
0.0 0.0 0.0
216.8 733.3 464.1 118.0 48.8 13.7 5.4 5.1 0.0 1.8 0.0 0.0
0.0 0.0 0.0 0.0
411.7 1653.1 1735.2 530.1 207.7 70.1 23.2 3.7 0.0 8.4 0.0
0.0 0.0 0.0 0.0 0.0
447.4 1640.0 978.6 260.9 108.9 31.2 13.0 1.0 0.0 3.8 0.0
0.0 0.0 0.0 0.0 0.0
19.8 353.4 466.8 217.2 72.6 4.1 9.5 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
73.4 212.3 142.7 43.8 34.8 3.7 0.0 0.0 0.0 0.1 0.0 0.0 0.0
0.0 0.0 0.0
3638.4 6340.3 2351.8 1363.3 985.5 438.5 192.8 39.7 1.5 0.0
0.0 0.0 0.0 0.0 0.0 0.0
268.7 930.8 187.8 63.4 47.3 14.7 27.1 8.3 1.9 0.2 0.0
0.0 0.0 0.0 0.0 0.0
92.7 1030.7 766.5 159.5 25.6 17.2 6.3 2.9 1.6 0.5 0.0 0.0
0.0 0.0 0.0 0.0
110.6 536.2 738.0 542.3 22.2 0.8 6.9 1.2 0.2 0.2 0.1 0.0 0.0
0.0 0.0 0.0
363.9 1625.9 1938.0 2125.4 1017.3 176.4 60.5 2.8 10.4 4.7
0.0 1.4 0.0 0.0 0.0 0.0
32.4 4391.4 2033.6 931.0 1451.4 1309.8 234.4 20.8 4.1 3.4
7.5 2.2 10.2 0.0 0.0 0.0
16.4 166.8 578.1 69.2 20.2 18.5 26.1 2.7 1.3 0.2 0.3
0.2 0.0 0.0 0.0 0.0
89.8 1547.7 832.0 445.0 47.2 15.6 42.6 25.8 3.7 0.1
0.2 0.0 0.2 0.0 0.0 0.0
35.4 91.0 126.6 9.7 5.2 0.4 0.3 0.3 0.4 0.2 0.0 0.0 0.0 0.0 0.0
0.0

69.3 561.5 200.6 392.4 35.5 15.3 3.1 1.5 1.9 2.0 0.2 0.0
0.0 0.0 0.0 0.0
213.0 310.1 346.7 277.2 113.8 8.7 62.0 0.1 0.1 0.3 10.9
0.0 0.0 0.0 0.0 0.0
187.2 749.2 590.3 324.7 158.6 62.2 25.9 4.6 0.1 3.7 0.0
0.0 0.0 0.0 0.0 0.0
134.5 300.3 332.4 167.5 89.8 35.1 13.8 2.8 0.1 2.1 0.0
0.0 0.0 0.0 0.0 0.0
182.9 265.7 185.7 80.1 41.4 14.8 6.1 1.1 0.0 1.0 0.0 0.0
0.0 0.0 0.0 0.0
137.4 503.7 336.4 98.6 49.0 15.3 6.1 8.0 0.0 1.4 0.0 0.0
0.0 0.0 0.0 0.0
133.0 488.9 305.7 138.6 78.1 30.3 13.0 2.6 0.1 1.6 0.0
0.0 0.0 0.0 0.0 0.0
155.7 454.8 404.9 188.9 99.9 37.6 16.0 8.6 0.1 2.3 0.0
0.0 0.0 0.0 0.0 0.0
93.7 499.1 729.4 425.3 271.2 118.1 50.3 15.9 0.6 5.0
0.0 0.0 0.0 0.0 0.0 0.0
121.5 520.2 513.3 326.6 209.6 82.4 33.4 7.5 0.2 3.6 0.0
0.0 0.0 0.0 0.0 0.0
12.8 257.9 376.7 386.1 533.7 248.2 42.3 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0
139.3 369.8 524.9 544.5 792.6 782.0 324.0 8.0 0.0 35.2
0.0 0.0 0.0 0.0 0.0 0.0
241.3 443.7 352.3 581.6 810.0 487.2 454.2 199.9 13.5
4.7 0.0 0.0 0.0 0.0 0.0 0.0
127.3 817.4 365.6 226.8 427.1 387.5 498.2 295.8 167.5
7.0 0.0 0.0 0.0 0.0 0.0 0.0
22.6 454.0 1026.9 493.3 353.9 612.1 522.7 398.1 288.1
218.9 4.7 0.0 0.0 0.0 0.0 0.0
33.4 240.0 728.9 1597.3 797.2 268.2 356.2 333.1 365.5
180.1 111.2 11.9 3.8 0.0 0.0 0.0
54.3 306.0 291.9 608.8 1375.2 730.0 138.5 198.0 176.5
163.9 51.4 58.3 0.0 0.0 0.0 0.0
1.0 439.9 199.6 190.0 523.5 1251.4 718.6 139.6 200.0
165.9 194.2 58.5 97.7 0.0 0.0 0.0
11.8 194.6 901.9 235.0 256.0 505.6 1078.1 460.1 81.1
59.4 54.8 123.0 10.0 29.3 0.0 0.0
25.5 487.7 382.7 1178.0 145.4 122.7 682.4 1280.3 286.4
32.8 79.0 40.6 33.5 10.6 4.7 0.0
38.6 217.7 737.5 270.9 1543.8 152.3 198.9 276.8 484.1
191.9 25.6 29.8 0.0 7.7 8.6 0.0
27.9 453.7 433.5 615.8 261.4 1147.6 166.4 79.0 169.4
284.2 81.9 2.9 6.3 6.3 8.8 0.9
36.0 280.1 400.9 355.9 382.2 202.5 478.3 31.6 50.5
89.9 74.7 15.5 5.8 1.1 0.0 1.7
-999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
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-999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
11.6 85.5 39.6 31.4 3.4 0.9 4.2 3.5 0.6 0.0 0.0 0.0 0.0 0.0
0.0 0.0
27.2 50.0 54.2 6.8 13.0 1.1 1.0 1.1 1.6 0.6 0.1 0.2 0.0 0.0
0.1 0.0
10.5 75.4 17.0 38.7 2.6 1.6 0.2 0.2 0.1 0.4 0.5 0.0 0.0 0.0
0.6 0.0
24.4 26.1 28.4 22.6 10.3 1.3 5.6 0.1 0.1 0.1 1.2 0.0 0.0
0.0 0.0 0.0

##CAA_EFFECTIVE_SAMPLE_SIZES_BY_YEAR_(-999_for_missing_data;_max_200)
200
200
200
200
200
200
200
200
200
200
200
200
200
200
200
200
200
200

```
200
200
200
#Index ESS = # Tows
-999    -999    -999    -999    -999    -999    -999    -999    -999
4   24  22  25  21  23  30  24  30  31  43  -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    60  51  59  53  69  41  -999    -999

#MODEL_WEIGHTS
#Lambda_Catch
#Comm Comm_Scrap/Bait/Disc Rec_Harv Rec_Dead_B2
1 1 1 1

#Lambda_Index
#NMFS   SEAMAP  VIMS NC195
1 1 1 1

#Lambda_CAA
1

#Lambda_IAA
1

#Lambda_Rec_Devs
1
```

Input data for model run with shrimp-trawl bycatch

```
#MODEL_STRUCTURE
  hybrid2_shrimp.rep
#Number of years
    21
#N ages
    16
#Age
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
#START_YEAR
  1988
#START_SELEX_PERIOD_2
#  1996
#BIOLOGICAL_DATA
#M_at_Age
    0.461   0.374   0.324   0.293   0.272   0.257   0.246   0.238
0.232   0.227   0.223   0.220   0.218   0.216   0.215   0.214
#L_inf
    43.1
#K
    0.214
#t_0
    -2.35
#LW_a
    7.30E-06
#LW_b
    3.14
#Maturity_at_Age
    0   0.9 1   1   1   1   1   1   1   1   1   1   1   1   1   1
#Steepness
    0.76
#INI
 10   10    10    10    10    10    10    10    10    10    10    10    10
      10    10    10

#NUMBER_FLEETS
5
#NUMBER_EST_SELECTIVITY_PATTERNS
4
#FLEET_NAMES
# Commercial Scrap-Discard Rec-Harvest Rec-Release

#OBSERVED_CATCH_BY_YEAR_(-999_for_missing_data)
#Commercial
4742.6  3672.9  2756.4  1676.7  1944.1  4069.1  4910.8  6319    9636.7
12371   12541   12130   12118   13006   11865   12923   12982   11167
9514.1  9199.2  8777
#Scrap/Discards
1881    1910.7  1347.5  1086.1  1115.2  1607.1  4643.2  3484.7  1143.4
510.8   15352   1550.3  2103.4  1958.7  7326.7  10432   899.95  3050
269.36  1283.2  1342.8
```

```
#Recreational harvest
2106.5  1078.4  778.81  1156    1191.9  1368.8  2208.6  1818.2  1857.7
3520.1  3588.5  3320.3  4395.3  5026.7  4152.7  4179.8  4000.6  4792.1
4184.1  3746.1  2406.6
#Recreational release mortality (10% B2)
19.184  17.933  34.1    79.294  40.725  69.766  88.534  59.276  68.035
123.37  135.32  143.54  232.33  156.69  156.69  167.03  132.04  180.74
157.06  147.84  120.36
#Shrimp_bycatch
7123.7      8852.8      7027.3      14485.0     13626.2     15034.5
      13529.5     20780.6     9476.4      10061.5     7280.3      6951.0
      5630.4      790.2 4321.6      2046.7      2161.3      216.3 1498.4
      5412.8      5839.7


#CATCH_CVs
#Commercial
0.1 0.1 0.1 0.1 0.1 0.1 0.05    0.05    0.05    0.05    0.05    0.05
0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
#Scrap/Discards (2x commercial CVs)
0.2 0.2 0.2 0.2 0.2 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1
#Rec Harvest
0.1 0.062   0.081   0.086   0.076   0.075   0.055   0.08    0.089
0.094   0.081   0.079   0.069   0.055   0.049   0.052   0.064   0.069
0.093   0.059   0.067
#Rec release mortality
0.11    0.068   0.093   0.078   0.081   0.073   0.051   0.071   0.071
0.071   0.056   0.051   0.05    0.045   0.045   0.045   0.053   0.061
0.055   0.049   0.049
#Shrimp bycatch CVs (3x Comm CVs)
0.3   0.3   0.3   0.3   0.3   0.3   0.15  0.15  0.15  0.15  0.15  0.15
      0.15  0.15  0.15  0.15  0.15  0.15  0.15  0.15  0.15


#NUMBER_INDICES
4

#INDEX_UNITS_(0=number;1=weight)
#NMFS   SEAMAP  VIMS NC195
0 1 0 0

#INDEX_TIMING
#NMFS   SEAMAP  VIMS NC195
0.75 0.875  0.417 0.50

#INDEX_YOY_FLAG_(0=no;1=yes)
0 0 1 1

#INDEX_VALUES_BY_YEAR_(-999_for_missing_data)
#NMFS
31.8    102 74.6    208 205 21.6    450 170 205 133 326 795 380 199 930
494 636 438 901 1334    461
#SEAMAP
```

```
-999    -999    7.72    24.5    4.32    18.7    14.6    5.08    5.14
2.3 4.65    17.5    4.19    2.66    9.24    14.1    15.4    23.8
12.1    9.2 12
#VIMS
0.44    1.71    1   6.08    2.98    4.43    0.58    2.61    0.03
5.58    5.65    1.3 0.83    0.38    3.18    0.92    2.29    1.5 3.72
2.96    17.4
#NC P195
50  114 325 261 44.1    437 124 146 61.9    330 602 725 171 104 83.2
159 448 196 113 106 268

#INDEX_CVs
#NMFS
0.48    0.51    0.34    0.4 0.34    0.42    0.32    0.21    0.28
0.41    0.24    0.24    0.37    0.4 0.45    0.22    0.26    0.4 0.16
0.37    0.2
#SEAMAP
-999    -999    0.29    0.27    0.18    0.1 0.33    0.36    0.23
0.44    0.33    0.25    0.33    0.27    0.44    0.35    0.21    0.17
0.14    0.31    0.25
#VIMS
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2
#NC P195
0.52    0.7 0.71    1.5 0.81    0.83    1.2 0.95    0.78    0.64
0.53    1.5 0.81    0.54    0.74    0.8 0.62    0.59    0.82    0.72
0.56

#Fleet age of full selectivity
 3 1 5 4 0
#Age of full selectivity for non-YOY indices
 2 0

#SEL_SHAPE_FLEET (1=non-parametric, 2=single logistic, 3=double
logistic)
 3 3 2 3
#Fixed sel patterns: Shrimp trawl bycatch
 1     0     0     0     0     0     0     0     0     0     0     0     0
      0     0     0

#INITIALIZE_FLEET_SEL_PARS
#INITIAL_GUESS
 2 0.2 7 0.2 1 0.7 2 0.3 3 0.2 2 0.3 7 0.3
#LOWER_&_UPPER_BOUNDS
 0  0   0   0   0   0   0   0   0   0   0   0   0   0
 15 15  15  15  15  15  15  15  15  15  15  15  15  15


#SEL_SHAPE_INDEX
 3 3
#SEL_PAR_BOUNDS_INDEX (Length: n_ages * sel_shape=1 + 2*sel_shape=2 +
4*sel_shape=3)
#INTIAL_GUESS
 1 0.4 7 0.2 0 0.7 3 0.5
```

```
#LOWER_&_UPPER_BOUNDS
0   0   0   0   0   0   0   0
15  15  15  15  15  15  15  15



#CAA_DATA
#IAA_BY_INDEX_AND_YEAR_AND_AGE_non-YOY_indices_(number)_(-
999_for_missing_data)

-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
0   0   1   6   6   4   2   1   0   0   0   0   0   0   0   0
46  71  20  32  12  40  13  20  0   0   0   0   0   0   0   0
13  31  32  3   5   3   6   0   2   0   0   0   0   0   0   0
20  78  163 65  8   6   2   6   3   9   0   0   0   0   0   0
2   21  40  101 42  4   9   4   5   1   4   0   0   0   0   0
66  27  26  33  76  27  2   2   3   1   1   0   1   0   0   0
0   72  206 20  7   30  63  20  1   3   0   1   2   1   0   0
88  58  160 20  8   19  43  12  0   1   0   0   0   0   0   0
46  151 35  105 8   2   15  21  7   0   1   0   1   1   0   0
259 93  149 14  140 9   1   3   8   3   1   0   0   0   0   0
35  258 102 91  19  67  4   0   1   2   2   1   0   0   0   0
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
```

```
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
159 48  8   7   0   2   0   0   0   0   0   0   0   0   0   0
170 47  8   5   1   0   0   1   0   0   0   0   0   0   0   0
169 59  10  3   0   0   0   0   0   0   0   0   0   0   0   0
149 58  11  1   1   1   0   0   0   0   0   0   0   0   0   0
188 72  15  4   1   1   0   0   0   0   0   0   0   0   0   0
94  92  4   5   0   0   1   0   0   0   0   0   0   0   0   0
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
#-999   -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999    -999    -999
-999    -999    -999    -999    -999    -999    -999


#CAA_BY_FLEET_AND_YEAR_AND_AGE_(metric_tons)_(-999_for_missing_data)
426.6   1857.8  1424.2  614.1   271.0   95.7    39.7    5.8 0.0 7.7 0.0
0.0 0.0 0.0 0.0 0.0
348.7   1093.5  1175.3  588.3   294.4   111.5   43.8    10.1    0.1 7.3
0.0 0.0 0.0 0.0 0.0 0.0
625.1   1003.7  714.7   245.4   111.1   36.7    14.4    2.0 0.0 3.4 0.0
0.0 0.0 0.0 0.0 0.0
183.2   746.0   522.3   141.2   57.7    17.1    6.5 0.5 0.0 2.2 0.0 0.0
0.0 0.0 0.0 0.0
210.4   797.6   544.7   230.3   104.6   36.1    15.3    2.3 0.0 2.8 0.0
0.0 0.0 0.0 0.0 0.0
507.3   1554.1  1261.7  452.3   190.6   64.3    25.0    7.5 0.0 6.3 0.0
0.0 0.0 0.0 0.0 0.0
253.3   1052.1  1543.4  1007.5  617.2   248.2   96.8    80.5    0.5
11.4    0.0 0.0 0.0 0.0 0.0 0.0
```

398.6   1704.1 1624.3 1226.2 841.3   337.3   139.9   33.9   0.9
12.5   0.0 0.0 0.0 0.0 0.0 0.0
6.4 1243.6 2631.7 2337.8 2338.2 907.9   171.1   0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0
344.9   1402.9 2920.2 2345.9 2808.8 1899.3 491.7   5.5 0.0 151.7
0.0 0.0 0.0 0.0 0.0 0.0
561.2   1365.2 1693.5 2220.3 3062.8 1732.3 1229.7 622.6   42.8
10.8   0.0 0.0 0.0 0.0 0.0 0.0
165.9   2288.8 1450.3 996.5   1747.1 1530.0 1989.0 1239.3 689.0
33.8   0.0 0.0 0.0 0.0 0.0 0.0
17.8   1107.9 2860.2 1394.9 941.1   1559.9 1365.0 1171.4 952.5
727.7   20.0   0.0 0.0 0.0 0.0 0.0
42.1   400.7   1573.8 3383.0 1825.6 692.4   1016.7 1106.0 1476.3
848.4   596.5   35.4   8.7 0.0 0.0 0.0
60.6   614.1   1010.7 2200.1 4090.7 1914.3 390.3   477.8   414.3
406.0   128.9   157.0   0.0 0.0 0.0 0.0
0.0 897.4   738.7   742.9   2186.9 4328.0 2092.4 436.2   443.0
345.9   410.0   121.2   180.3   0.0 0.0 0.0
6.2 569.9   3849.9 1021.9 958.4   1661.3 3065.3 1174.0 193.3
128.2   122.7   166.7   18.8   45.3   0.0 0.0
25.3   1255.6 1196.6 3627.3 386.4   251.9   1334.3 2298.6 484.7
52.8   121.1   57.6   57.9   4.5 12.7   0.0
11.6   418.4   1894.3 733.5   3666.4 348.5   444.8   530.9   949.3
361.8   55.1   68.7   0.1 12.1   18.5   0.0
9.4 597.7   918.1   1250.8 702.0   3332.2 489.6   233.8   493.3
844.2   235.3   6.5 24.6   17.9   33.7   10.0
42.4   714.6   1102.7 945.1   1266.4 784.6   2445.0 176.2   277.9
510.2   348.4   110.4   26.7   9.2 0.0 17.1
351.8   1005.5 354.4   101.0   47.7   11.8   7.2 0.6 0.0 1.1 0.0 0.0
0.0 0.0 0.0 0.0
515.1   674.1   512.3   132.1   52.9   16.3   5.3 0.4 0.0 2.2 0.0 0.0
0.0 0.0 0.0 0.0
439.1   558.0   242.2   66.2   29.1   8.0 3.9 0.3 0.0 0.9 0.0 0.0 0.0
0.0 0.0 0.0
172.1   543.8   280.1   57.1   24.3   5.4 2.4 0.0 0.0 0.9 0.0 0.0 0.0
0.0 0.0 0.0
205.3   602.8   220.4   51.8   25.2   5.5 3.4 0.2 0.0 0.6 0.0 0.0 0.0
0.0 0.0 0.0
216.8   733.3   464.1   118.0   48.8   13.7   5.4 5.1 0.0 1.8 0.0 0.0
0.0 0.0 0.0 0.0
411.7   1653.1 1735.2 530.1   207.7   70.1   23.2   3.7 0.0 8.4 0.0
0.0 0.0 0.0 0.0 0.0
447.4   1640.0 978.6   260.9   108.9   31.2   13.0   1.0 0.0 3.8 0.0
0.0 0.0 0.0 0.0 0.0
19.8   353.4   466.8   217.2   72.6   4.1 9.5 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
73.4   212.3   142.7   43.8   34.8   3.7 0.0 0.0 0.0 0.1 0.0 0.0 0.0
0.0 0.0 0.0
3638.4 6340.3 2351.8 1363.3 985.5   438.5   192.8   39.7   1.5 0.0
0.0 0.0 0.0 0.0 0.0 0.0
268.7   930.8   187.8   63.4   47.3   14.7   27.1   8.3 1.9 0.2 0.0
0.0 0.0 0.0 0.0 0.0
92.7   1030.7 766.5   159.5   25.6   17.2   6.3 2.9 1.6 0.5 0.0 0.0
0.0 0.0 0.0 0.0

110.6 536.2 738.0 542.3 22.2 0.8 6.9 1.2 0.2 0.2 0.1 0.0 0.0
0.0 0.0 0.0
363.9 1625.9 1938.0 2125.4 1017.3 176.4 60.5 2.8 10.4 4.7
0.0 1.4 0.0 0.0 0.0 0.0
32.4 4391.4 2033.6 931.0 1451.4 1309.8 234.4 20.8 4.1 3.4
7.5 2.2 10.2 0.0 0.0 0.0
16.4 166.8 578.1 69.2 20.2 18.5 26.1 2.7 1.3 0.2 0.3
0.2 0.0 0.0 0.0 0.0
89.8 1547.7 832.0 445.0 47.2 15.6 42.6 25.8 3.7 0.1
0.2 0.0 0.2 0.0 0.0 0.0
35.4 91.0 126.6 9.7 5.2 0.4 0.3 0.3 0.4 0.2 0.0 0.0 0.0 0.0 0.0
0.0
69.3 561.5 200.6 392.4 35.5 15.3 3.1 1.5 1.9 2.0 0.2 0.0
0.0 0.0 0.0 0.0
213.0 310.1 346.7 277.2 113.8 8.7 62.0 0.1 0.1 0.3 10.9
0.0 0.0 0.0 0.0 0.0
187.2 749.2 590.3 324.7 158.6 62.2 25.9 4.6 0.1 3.7 0.0
0.0 0.0 0.0 0.0 0.0
134.5 300.3 332.4 167.5 89.8 35.1 13.8 2.8 0.1 2.1 0.0
0.0 0.0 0.0 0.0 0.0
182.9 265.7 185.7 80.1 41.4 14.8 6.1 1.1 0.0 1.0 0.0 0.0
0.0 0.0 0.0 0.0
137.4 503.7 336.4 98.6 49.0 15.3 6.1 8.0 0.0 1.4 0.0 0.0
0.0 0.0 0.0 0.0
133.0 488.9 305.7 138.6 78.1 30.3 13.0 2.6 0.1 1.6 0.0
0.0 0.0 0.0 0.0 0.0
155.7 454.8 404.9 188.9 99.9 37.6 16.0 8.6 0.1 2.3 0.0
0.0 0.0 0.0 0.0 0.0
93.7 499.1 729.4 425.3 271.2 118.1 50.3 15.9 0.6 5.0
0.0 0.0 0.0 0.0 0.0 0.0
121.5 520.2 513.3 326.6 209.6 82.4 33.4 7.5 0.2 3.6 0.0
0.0 0.0 0.0 0.0 0.0
12.8 257.9 376.7 386.1 533.7 248.2 42.3 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0
139.3 369.8 524.9 544.5 792.6 782.0 324.0 8.0 0.0 35.2
0.0 0.0 0.0 0.0 0.0 0.0
241.3 443.7 352.3 581.6 810.0 487.2 454.2 199.9 13.5
4.7 0.0 0.0 0.0 0.0 0.0 0.0
127.3 817.4 365.6 226.8 427.1 387.5 498.2 295.8 167.5
7.0 0.0 0.0 0.0 0.0 0.0 0.0
22.6 454.0 1026.9 493.3 353.9 612.1 522.7 398.1 288.1
218.9 4.7 0.0 0.0 0.0 0.0 0.0
33.4 240.0 728.9 1597.3 797.2 268.2 356.2 333.1 365.5
180.1 111.2 11.9 3.8 0.0 0.0 0.0
54.3 306.0 291.9 608.8 1375.2 730.0 138.5 198.0 176.5
163.9 51.4 58.3 0.0 0.0 0.0 0.0
1.0 439.9 199.6 190.0 523.5 1251.4 718.6 139.6 200.0
165.9 194.2 58.5 97.7 0.0 0.0 0.0
11.8 194.6 901.9 235.0 256.0 505.6 1078.1 460.1 81.1
59.4 54.8 123.0 10.0 29.3 0.0 0.0
25.5 487.7 382.7 1178.0 145.4 122.7 682.4 1280.3 286.4
32.8 79.0 40.6 33.5 10.6 4.7 0.0
38.6 217.7 737.5 270.9 1543.8 152.3 198.9 276.8 484.1
191.9 25.6 29.8 0.0 7.7 8.6 0.0

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27.9    453.7   433.5   615.8   261.4   1147.6  166.4   79.0    169.4
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#Lambda_Catch
#Comm Comm_Scrap/Bait/Disc Rec_Harv Rec_Dead_B2
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#Lambda_Index
#NMFS   SEAMAP  VIMS NC195
1 1 1 1

#Lambda_CAA
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#Lambda_IAA
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#Lambda_Rec_Devs
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Southeast Data, Assessment, and Review 20

Review Panel Report

Atlantic Croaker

Kim McKown, Panel Chair

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Kim McKown, New York State Department of Environmental Conservation
Dr. Tim Miller, NMFS Northeast Fisheries Science Center
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Prepared for the SEDAR 20 Review Workshop
Workshop dates: March 8-12, 2010
Report date: April 9, 2010

Section D

Acknowledgments
The Panel thanks all of the individuals who contributed to the review of the Atlantic croaker stock assessment report. The Panel thanks members of the Atlantic Croaker Technical Committee (TC) and Stock Assessment Subcommittee (SASC) for preparation of the report. In particular, the Panel thanks Linda Barker, Eric Robillard, Laura Lee, and Katie Drew from the Atlantic Croaker SASC for their informative presentations, for answering numerous questions and responding to additional analysis requests, and for participating in constructive discussions.

The Panel also thanks Dale Theiling from SEDAR and Patrick Campfield from ASMFC for coordinating the peer review and preparation of this report.

Introduction:
The Review Workshop of the 2010 Atlantic Croaker Assessment Report was held March 8 – 12, 2010 in Charleston, South Carolina. The Review Workshop provided a comprehensive and in-depth evaluation of this assessment. This report contains the Panel's summary findings, detailed discussion of each TOR, and a summary of the results of analytical requests.

1. Summary of findings

- The Panel concludes that in 2008 overfishing was probably not occurring. From examination of the data compiled for the stock assessment it appears that there has been an upward trend in biomass since the 1980s and a decreasing trend in F (since commercial catches have been fairly constant since the mid 1990s). There has also been an expansion in age classes in the catch and indices, which is consistent with increasing biomass and decreasing F.

- It is not possible to be confident with regard to the overfished status until the discards from the shrimp fisheries are properly incorporated into the stock assessment.

- The Panel is very concerned about the lack of adequate estimates of Atlantic croaker bycatch in the shrimp fishery. Rough estimates of bycatch indicate it could be as large as or larger than the directed harvest in some years. These estimates are based on the ratio of croaker catch to shrimp landings in some years, and therefore are more likely to track shrimp catch rather than croaker. Sensitivity analyses indicate the inclusion of shrimp bycatch affects the overfished status determination. The Panel recommends development of a time series of effort for the shrimp fishery for use in estimating bycatch of Atlantic croaker. This information could be used to estimate bycatch mortality in the shrimp fishery for a number of species in the south Atlantic. In addition, the Panel recommends the development and implementation of sampling programs for shrimp fisheries in order to monitor the relative importance of Atlantic croaker (and other fish supporting commercial and recreational fisheries) in these fisheries.

- The Panel requested a number of changes to the base model run, but without a defensible discard history for the shrimp fishery, or a major restructuring of the model, an adequate base model could not be developed. There are also problems with the definition of Fmsy and Bmsy which will need to be addressed for the next assessment (see short term research recommendation g).

- The Panel believes it is unlikely that the stock is in trouble. Biomass was trending up, commercial catches were stable, and discards from the shrimp fishery were much reduced (three points estimates from actual data: 1970: 11,600 t; 1992-1994: 13,000-15,000 t annually; 2007-08: 5,500 t annually).

2. Comments on specific Terms of Reference

1. *Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:*

   The Atlantic croaker fishery was modeled as one east coast stock. The Atlantic Croaker Stock Assessment Subcommittee (Assessment Team) used commercial and recreational landings and discards at age from the east coast of the United States, one fishery dependent index developed from the Marine Recreational Fishery Statistical Survey (MRFSS), and four fishery independent indices including; National Marine Fisheries Service (NMFS) bottom trawl survey, Virginia Institute of Marine Science (VIMS) survey, SEAMAP-South Atlantic survey, and North Carolina 195 survey. In addition growth, weight, maturity, and natural mortality at age were developed using both fishery dependent and independent information.

   The Assessment Team did a thorough job of presenting and discussing the fishery-dependent and fishery-independent data used in the assessment. Commercial landings data by gear was available from 1950 to 2008 from Florida (FL) to New Jersey (NJ) which spans the range of the stock. These data were collected by NMFS and State agencies at various reporting levels over the time series. The commercial landings data from 1981 through 2008 from FL to NJ were used in the assessment to conform to the years where recreational landings are available. Daily or trip-level data are currently collected in most states in the Atlantic States Marine Fisheries Commission (ASMFC) management region. A weakness in the data is that data collection methods have changed over time for a number of states. Data may not be comparable throughout the time series before and after the change in these states. The bulk of the landings come from Virginia (VA) and North Carolina (NC). The Panel was concerned about the CVs used for the commercial landings data. Some of the Panel suggests it's better to develop reasonable bounds on the catch history and to explore sensitivities to alternative catch histories. The Panel had questions about the use of gillnets, which was a significant part of the fishery in recent years. The main concern is about changes in fishery selectivity (see short term research recommendation h). The current effort data by gear are not adequate to examine changes.

   There are three major types of commercial discard; scrap, finfish, and shrimp. Information on the amount of discards by year and area is more uncertain than landings.

The scrap fishery is one in which the fish species that are unmarketable as food, are sold unsorted, usually as bait. NC initiated a scrap fishery sampling program in 1986, which was used to estimate the proportion of croaker in the unsorted landings. Atlantic croaker is a major component of the NC scrap fishery. There is concern that there is no data to estimate landings from scrap fisheries in other states. Different gears are used in other states with scrap landings, so the NC data would not be appropriate to use. Estimates of scrap landings have declined by an order of magnitude since the early part of the assessment time period. This decline may be due to the enactment of various gear related regulations along the coast.

A variety of gears used to catch finfish along the coast also have a bycatch of Atlantic croaker. NMFS observer data were used to estimate the bycatch in gillnets and otter trawls. The Assessment Team estimated croaker bycatch using the method recommended for scup during the 2009 data poor workshop. The Panel believes this method is unreliable for croaker, due to the low number of trips which landed croaker.

Atlantic croaker is also a bycatch in the southeastern Atlantic shrimp fishery. The Assessment Team developed rough bycatch estimates using the ratio of croaker catch to shrimp catch. These estimates indicated that in some years the bycatch was larger than the directed harvest. The Panel is concerned that this method is more a reflection of shrimp landings than croaker bycatch.

Recreational landings and discards were provided through MRFSS from 1981 through 2008. The majority of the harvest was in VA (62%), with FL, NC and Maryland (MD) next in importance. MRFSS harvest estimates for croaker were fairly reliable with low proportional standard errors. The Panel inquired about the use of 10% discard mortality for the recreational fishery. There are no discard mortality studies on Atlantic croaker; the 10% is based on rates used for red drum and weakfish (other sciaenids).

Information from biological sampling for length, weight and age for the commercial fishery was available from a number of states over differing time frames. NC (1979 to 2008) and VA (1989 to 2008) had the longest sampling programs, with NC being the only state that sampled over the assessment time series. NC initiated a biological sampling program for the scrap fishery in 1986, and is the only program along the coast. The information collected from the scrap fish sampling is used to estimate the proportion of croaker in the fishery and the size structure. There are no long term programs for collecting biological data on the bycatch of croaker in the shrimp fishery, but historical work indicates that nearly all the discarded bycatch were age 0. Recreational length information was collected in MRFSS intercept survey. Croaker ageing was originally determined using scales, but switched to otoliths in 1996. NC's biological sampling collected paired samples of scales and otoliths from 1996 – 1999 which were used to develop a scale-otolith transition matrix. The matrix was used to convert scale based age-length keys (ALK). The 2005 Peer Review Panel had concerns about ageing protocols, so an ASMFC ageing workshop was conducted in 2008. New ageing protocols were developed. The Panel had concerns that length, weight and maturity at age might be mismatched with cohort due to the new ageing protocol and the protracted spawning period. The Assessment Team reviewed the length and weight at age and found that they were cohort based. The Panel continues to have concerns about the maturity at age, since new maturity estimates have a much higher percentage of mature age 0's compared to the past. The Panel concurs with the development and use of age varying M.

A fishery-dependent and four fishery-independent indices were developed. Recreational catch per unit effort (CPUE) indices were developed using two methods; directed trips and that of Stephens and MacCall (2004). The Panel was concerned about using the directed trips method, and thought it may under represent trips with no croaker. The Assessment Team was concerned that the Stephens and MacCall (2004) method resulted in some unrealistic species associations. The Panel believes the unrealistic species associations were probably due to use of the full data set without stratification. The Panel recommends using the Stephens and MacCall (2004) approach with the coast divided into subareas based on expected species associations.

The NMFS Northeast Fisheries Science Center (NEFSC) multispecies trawl survey was used to develop an index. The survey uses a stratified random design based on 3 depth strata. On examination, the Panel found that the inshore strata were not consistently sampled, and there was also concern about using numbers per tow rather than area swept (area-swept estimates enable the estimated trawl-survey proportionality constant to be used as a model diagnostic). The Panel recommended dropping the inshore depth strata, development of a depth by latitude based stratification using the mid and offshore depth strata and estimating the index using area swept approach (see section 2.2 (5)). The Assessment Team also developed fishery-independent indices using data from the Virginia Institute of Marine Science (VIMS) Juvenile Trawl Survey, the Southeast Area Monitoring and Assessment Program (SEAMAP) South Atlantic Coastal Survey, and NC Survey 195 which catches young of the year (YOY) croaker.

Specific questions specified in TOR 1 are addressed below.

a. Discuss the effects of data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, aging accuracy, sample size, standardization of indices) on model inputs and outputs.

Strengths of the fishery-dependent and fishery-independent data:

- Landings data were available from all states in the range of Atlantic croaker distribution, and biological samples are available from states with the major fishery (88 to 99%).
- Paired scale/otolith collections were used to develop scale-otolith transition matrix and applied to the scale based age-length keys.
- The 2005 Peer Review Panel recommended the standardization of ageing procedures across states. The ASMFC held an ageing workshop in 2008 which developed standardized ageing protocols.

Data weaknesses:

- Collection of landings data have changed over time and may not be comparable before and after the change.
- No reliable estimates of bycatch in the shrimp fishery (see short term research recommendation a).
- The Panel believes the method used to estimate the finfish fishery bycatch using NMFS observer data is unreliable and recommends an alternative approach (see short term research recommendation e).
- There is no information available to estimate landings in VA scrap fishery.
- Otolith ages have not been validated with known age samples (see long term research recommendation a).
- The Panel is concerned about the effect of protracted spawning on age determination and the maturity at age proportions. We recommend that the maturity at age schedule be determined using a definition of cohorts based on the spawning season in the mid-Atlantic region (Chesapeake Bay) (see short term research recommendation b).
- The Panel was concerned that using only one ALK may not be adequate due to year round fisheries operations, fast growth and protracted spawning season (see long term research recommendation c).
- Use of the directed trips method to estimate a recreational CPUE index may not be appropriate. The Panel recommends using the Stephens and MacCall (2004) method based on subareas (see short term research recommendation d).
- The NMFS survey inshore depth stratum was sampled inconsistently. The Panel recommended an alternative stratification scheme (see above).

b. *Report standard errors of inputs and use them to inform the model if possible.*

The Panel was concerned about the CVs used for the commercial landings data. Some of the Panel suggests it's better to develop reasonable bounds (tighter for years more certain about and larger for less certain years) and then evaluate sensitivity within those bounds rather than assuming CVs (see above).

The Panel recommends investigating alternative methods of developing empirical uncertainty estimates of the scrap fishery discards (see short term research recommendation i).

The Panel was concerned that the effective sample size on the commercial landings at age was too high. They recommend that it be based on the number of biological samples.

c. *Justify weighting or elimination of available data sources.*

The Panel was concerned about the estimation method for the recreation index. The Panel recommended dropping the index in the short term and re-estimating the index using the Stephens and MacCall (2004) approach in the future (see short term research recommendation d).

2. *Evaluate models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points.*

   The structure used for the assessment model is based on a well established age structured production model (ASPM) - forward VPA combination that has been applied for many assessment analyses. The model structure was considered appropriate for fitting a population model to the available information; however, a number of concerns were raised about some of the assumptions made when constructing the input data sets, the fit function formulation and derivation of the diagnostic output.

   Strengths of the croaker assessment are:

   - The model structure can be customized to the data available for fitting the assessment and has therefore been defined for the known population and fishery characteristics thereby using the available information appropriately.
   - The model is predominantly based on well sampled time series of catch data from commercial and recreational fisheries (including discards) derived with reasonable certainty, catch at age information from the two main fisheries, and fishery independent survey data.
   - The model was compared against alternative models that apply differing structural assumptions (an alternative ASPM structure and a biomass dynamic model - ASPIC), which gave similar trends in the stock dynamics and exploitation rates and similar perceptions of stock and fishing mortality trends.

   Weaknesses were apparent in that:

   - Although based on known formulations, the code implementation was developed by the assessment experts prior to the meeting and no evaluations were presented from testing against simulated data which would allow validation of the model point and uncertainty estimates.
   - Comparisons were not presented against output from "off the shelf models" with equivalent model structures which are available within the published literature and which have been used to fit similar assessment data sets.

   Specific concerns, raised about model structure and coding issues, which were discussed and reviewed with the Assessment Team included:

   - The coding of several parts of the model which did not follow standard formulations e.g. the multinomial assumption on proportions at age and the scaling of the selection pattern used within the estimation of Fmsy.
   - The assumption of a population age structure at equilibrium in the first year when strong year class effects were apparent throughout the available catch at age data.
   - The use of aggregated indices from the NMFS and SEAMAP surveys when age structure information was available.
   - The inclusion of the recreational CPUE data set, which appears to indicate no change in stock status for the majority of the time series. Either the data set is uninformative or the modeling assumptions used to fit the data set were inappropriate.

- The use of the shrimp by-catch data which is based on a raising procedure which results in croaker by-catch being directly proportional to shrimp landings rather than the effort expended and incoming croaker year class strength.

Specific questions specified in TOR 2 are addressed below.

a. *Did the model have difficulty finding a stable solution? Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?*
   Sensitivity analyses were presented within the assessment report and during the review. The dominant sensitivities in model estimates are not dependent on the model structure or starting values but derive from the data sets to which the model is fitted and assumptions concerning the biological characteristics of the stock, specifically the shrimp by-catch and the maturity of the age 0 croaker.

b. *Have the model strengths and limitations been clearly and thoroughly explained?*
   Model strengths and weaknesses were reviewed with the Assessment Team and are discussed above in this section and below in TOR 3

c. *If using a new model, has it been tested using simulated data?*
   No, this is discussed above in this section.

d. *Has the model theory and framework been demonstrated and documented in the stock assessment literature?*
   Yes, discussed above in this section.

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):*

   Maturity: Maturity for age 0 was initially modeled at 43% mature. The Panel considered this unlikely for a species that spawns primarily in the autumn and winter. A review of the species spawning and growth patterns established that there is potential for uncertainty as to which year class (as required by the assessment model) a fish counted as 0 group is derived from. Fish from the previous year class could potentially be included within the new maturity ogive applied in the assessment. It was established that this was unlikely to be the case for the catch at age data, for which the adjustment was made when reading and compiling the otolith data. Following a review with the Assessment Team the maturity ogive from the previous assessment, which assumes that 0 group are not mature, was applied within the assessment formulation.

Specific questions specified in TOR 3 are addressed below.

a. *Calculation of M.*

Natural mortality: The assessment uses instantaneous natural mortality rates which decline with age and are constant over all years. The values are averaged across values derived from a series of methodologies applied to historical growth data and, although the analyses showed a range of values, the Panel agreed that the appropriate selections had been made and appropriate structure applied within the model.

b. *Choice to use (or estimate) constant, time-varying, or age-varying M and catchability.*
   See discussion above

c. *No error in the catch-at-age or catch-at-length matrix.*
   Multinomial error was modeled for the fit to the catch at age data from the commercial, recreational and survey time series. As noted within TOR 1 the original formulation of the error model was incorrect, following a review with the Assessment Team this was corrected and the appropriate formulation derived.

d. *Choice of a plus group.*
   This was modeled appropriately.

e. *Population is at equilibrium.*
   This is also addressed in TOR 2, model structure. The assumption of a population age structure at equilibrium in the first year was considered inappropriate, when strong year class effects were apparent throughout the available catch at age data. Following discussions with the Assessment Team the starting populations for each cohort present within the first year were estimated, improving the fit of the model.

f. *Constant ecosystem (abiotic and trophic) conditions.*
   There was no information on changes in ecosystem conditions, they are not considered within the assessment model. However, discussions did note anecdotal reports relating to environmental conditions in Chesapeake Bay that could impact on the population dynamics of this species.

g. *Choice of stock-recruitment function.*
   A Beverton and Holt stock-recruitment (S-R) relationship is estimated by fitting to derived estimates of spawning stock size (S) and recruitment at age 0 within the model. Due to a lack of information the relationship at low stock size, the curve is conditioned on a fixed slope at the origin (steepness). The Panel considered this approach appropriate.

h. *Choice of proxies for MSY-based reference points.*
   The method used to calculate the MSY-based biomass and fishing mortality thresholds and targets are considered appropriate. However, sensitivity resulting from the inclusion or omission of the shrimp by-catch ensured that stock status relative to reference levels could not be determined, as described above.

i. *Determination of stock structure.*
Stock definition: The assessment of croaker assumes a single population with mixing. Although alternative hypotheses of multiple stocks have been suggested, the information available for deriving separate assessments is too sparse and therefore the current level of aggregation is considered appropriate.

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

Confidence intervals for the estimated stock metrics were provided and sufficient to determine that the base model estimated trends in biomass and fishing mortality were well determined (given the model assumptions). Sensitivity runs gave similar trends in stock metrics as those from the base run apart from when shrimp by-catch estimates were included in the catch data. The uncertainty of model estimates and biological and empirical reference points is therefore dominated by the catch data set to which the model is fitted rather than the estimation procedure or model structure.

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.*

Retrospective analyses of the model were conducted and illustrated a tendency to under-estimate stock biomass and over-estimate fishing mortality across the time series of estimates. The retrospective bias does not affect the perception of the trends in the assessment estimates, biomass has an upwards trend and fishing mortality has recently been declining. The sensitivity of stock status relative to reference levels is marginal compared to the sensitivity to the inclusion or exclusion of the shrimp by-catch discussed earlier, and therefore the retrospective pattern was not considered further.

6. *Recommend stock status as related to reference points:*

In 2008 overfishing was probably not occurring. There has been an upward trend in biomass since the 1980s and a decreasing trend in F. There has also been an expansion in age classes in the catch and indices, which is consistent with increasing biomass and decreasing F.

However, the evaluation of stock status relative to reference points could not be made as a result of the uncertainty introduced by the lack of appropriate information on the shrimp by-catch.

Studies have established that the shrimp by-catch could constitute a substantial number of 0 group fish. When estimates of the by-catch are included in the assessment, there is a marked revision in the estimated 0 group recruitment level, time series structure and mortality rate, and the stock status relative to reference points is revised substantially.

Specific questions specified in TOR 6 are addressed below.

a. *Biomass threshold and target.*
b. *F threshold and target.*
   The method used to calculate the biomass and fishing mortality thresholds and targets is considered appropriate. However, sensitivity resulting from the inclusion or omission of the shrimp by-catch ensured that stock status relative to reference levels could not be determined, as described above.

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

Comparisons were made with an alternative age structured production model and with a biomass dynamic model. Both models gave similar perceptions of increasing biomass levels and decreasing mortality rates. As discussed under TOR 6, reference levels and the relative stock status could not be determined due to the uncertainty induced by the level of shrimp by-catch having a similar impact on the alternative model estimates.

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.*

There was no minority report submitted to the review.

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.*

The Panel endorses the Atlantic croaker assessment research recommendations and has additional short and long term research recommendations which are detailed below. The short and long term recommendations are in priority order.

Short Term (improvements for the next benchmark review)

a. Develop a time series of effort for the shrimp fishery for use in modeling the bycatch of Atlantic croaker within the stock assessment model. Rough estimates of croaker bycatch in the shrimp fishery indicate it could be as large as, or larger than, the directed harvest in some years. These estimates are based on the ratio of croaker catch to shrimp landings (in three short time periods), and therefore, within each time period, they tend to track shrimp catch rather than croaker bycatch. Instead of trying to estimate croaker bycatch outside the model it is better to do it internally to allow for changes in croaker recruitment. The suggested approach is to develop an effort time series and supply it as input data to the model together with the observations from the three studies (i.e., as catch per unit of shrimp effort). A similar approach could be used to model bycatch mortality in the shrimp fishery for a number of species in the south Atlantic.

b. The Panel is concerned about the effect of protracted spawning on age determination and the maturity at age proportions. We recommend that the maturity at age schedule be determined using a definition of cohorts based on the spawning season in the mid-Atlantic region (Chesapeake Bay).

c. Due to the apparent inability to distinguish some portions of age 0 and age 1 cohorts for croaker and onset of maturity during this period, it would be beneficial to explore a method of calculating spawning biomass in the assessment model that uses a length-based maturity ogive along with predicted yearly length composition.

d. Re-examine development of recreational CPUE index using the Stephens and MacCall (2004) method with the coast divided into subareas based on expected species association with Atlantic croaker by area.

e. The estimation method for croaker discards using observer data is unreliable. Although the method was applied for the scup assessment, the numbers of trips observed that landed croaker is very small in many years for both gillnet and otter trawl gears. The geometric mean is not recommended with low sample sizes nor would the ratio-type estimators in the Standardized Bycatch Reporting Methodology (Wigley *et al*. 2006) be recommended under these conditions. As such, a better approach would be to use a ratio-type estimator examined by Wigley *et al*. (2006) with observed landings of a larger aggregation of species in the denominator and corresponding total landings for expansion. There will be more variability of the discard of croaker from trip to trip (with a large number of zero observations), but the much larger sample size will help overcome this variability. Furthermore, this methodology provides estimates of uncertainty corresponding to annual discard estimates that can be used in the assessment model.

f. Due to the poor information on stock and recruitment, there is little ability to estimate steepness within the model. Examine alternative types of reference points that do not rely on a defined stock–recruitment relationship. SPR based reference points should be considered. An appropriate level of SPR can be determined for croaker by considering the trade-off between yield and SSB over a range of plausible levels of steepness. This evaluation can be done using models with deterministic recruitment or stochastic recruitment.

g. Carefully consider how to best determine F-based reference points (e.g., F_{MSY} or $F_{\%SPR}$) given the presence of the bycatch from the shrimp fisheries. The current approach uses a single average selectivity (from the recent time period combined across all fisheries) in conjunction with a single F. Manipulation of F to achieve a particular target (MSY or some %SPR) therefore involves scaling the effort in all fisheries up or down by the same proportion. This makes little sense given the independence of the shrimp fisheries and the directed croaker fisheries. A better approach would be to scale the effort in the directed fisheries while holding the shrimp effort constant.

h. The gillnet fishery has been a significant part of the fishery in recent years (⅓ - ½ of the landings). More information is needed on the fishery to estimate any changes in selectivity. Explore commercial fishery landings reports for gillnet information directed at Atlantic croaker and other species that may also catch croaker.

i. Investigate alternative methods of developing empirical uncertainty estimates of the scrap fishery discards. Perhaps a model for estimating the proportion of croaker in the scrap fishery could be derived to provide variance estimates for this proportion and estimated total croaker scrap landings.

Long Term

a. Atlantic croaker otolith ageing methods have not been validated with known ages. The Panel recommends development of an age validation program. The program could be based on marking (e.g. tetracycline), tagging, or tank studies.

b. Develop and implement compatible and co-ordinated sampling programs for state-specific commercial scrap and shrimp fisheries in order to monitor the relative importance of Atlantic croaker in these fisheries.

c. Estimates of catch-at-age for a year-round fishery may not be reliably estimated from a length frequency and a *single* age-length key if some of the vulnerable fish are growing significantly during the fishing season (because age proportions at given length keep changing). If this is a problem for some of the croaker catch-at-age data, there are two alternative methods for avoiding the problem, that should be investigated:
    a. Development of separate age-length keys for different times of year
    b. Directly sample for age (otoliths) year round

3. Summary results of analytical requests

1) *What proportion of commercial discard samples (number of trips, weight of discards) are omitted from the estimation of overall discards due to a lack of landings in some trips?*

   Rationale for request: There was a concern that if there were a significant number of fishing trips where no croaker was landed but discarding had occurred, the level of discarding could be seriously underestimated.

   Response (R01): Table of the data by year showing number of sample trips separately for gillnets and trawls and number of sample trips with no landings.

   Outcome: The data presented confirmed the concerns of the Panel.

2) *Describe details of changes in the gill net fishery (numbers, mesh size) over time.*

Rationale for request: There was a concern that given the relative growth in this sector of the fishery in recent years, changes in regulations could have driven a change in selectivity that would need to be modeled.

Response (R02): Table describing regulatory changes in gill nets by state. No information appears to be available on numbers (i.e. effort) for the gill net fishery.

Outcome: Changes in the gill net fishery had occurred but were probably not currently a critical issue in selectivity.

3) *Map showing distribution of fisheries, areas of origin of index data*

Rationale for request: The Panel wished to have an adequate understanding of the spatial scale and distribution of the fishery and understand the spatial scale of the various indices and how they related to the fishery.

Response (R03): PowerPoint presentation with text describing distribution of the commercial fishery; text describing the areas of origin of the index data; map (1) of distribution of stock and locations of origin of index data; map (2) showing distribution of the commercial fisheries along the coast; table showing the distribution of the different gear types by state.

Outcome: The maps and other data provided materially helped in the Panel's deliberations of the fishery and in enabling clear discussions with all participants.

4) *Check whether F_{MSY} is number weighted or not.*

Rationale for request: The over-fishing determination compared a number-weighted F with F_{MSY}. The Panel wanted confirmation that F_{MSY} was also number-weighted.

Response: The Assessment Team checked and told the Panel that F_{MSY} was not number-weighted.

Outcome: In the light of the response, the Panel noted that the comparisons were therefore inappropriate. It was also noted that the overfishing definition should be done using full F and full F_{MSY} (rather than number weighted versions).

5) *NMFS survey information especially with respect to the 0-9m strata. Define swept area of the 30 minute tow (e.g. speed and door spread), geographical coverage of survey (map).*

Rationale for request: Given the low number of tows in the shallowest depth strata (0-9m) there was a concern that this survey may not be representative of the croaker stock. Improved understanding of the survey together with the direct stock estimates from the swept area would assist in understanding the relevance of this index.

Responses (R05): Working paper by McDonough (Analysis of the NMFS Fall Groundfish Survey for Atlantic Croaker off the East Coast of the United States 1972 – 2008); spreadsheet of analysis of NMFS survey data focusing on numbers and CPUE by depth strata.

Outcome: The response had a material effect on the Panel's consideration of the survey and its interpretation and also in the development of a research recommendation.

6) *Confidence intervals on model results in tables and some plots including base model (including SSB & F & relative ratios).*

   Rationale for request: The Panel wished to understand the variability of results around the point estimates.

   Responses (R06): Spreadsheet and PowerPoint presentation with tables and figures showing SSB, F and relative ratios.

   Outcome: Future plots contained CIs where possible, aiding interpretation of the results.

7) *Clarify issue of lack of CVs in equations for standardization of residuals. What was actually done?*

   Rationale for request: There was a concern that there was an error in the equations given in the draft assessment document.

   Response: Verbal confirmation that the equations as presented in the paper were used and that the equations were in error.

   Outcome: The error was corrected for all later runs of the model.

8) *Sensitivity runs on the shape of the maturity ogive*
   a. *Values from last assessment, literature review, add one year to NMFS ages*
   b. *Base run, shrimp bycatch run.*

   Rationale for request: There was a concern over the relatively high percentage maturity of fish in the 0-group and the Panel wished to see how sensitive the model outputs were to this estimate.

   Responses (R08): Two spreadsheets and a PowerPoint presentation showing tables and figures of sensitivity to maturity ogive shape and effect of shrimp by-catch.

   Outcome: Confirmation of the sensitivity of the model to the age at maturity input data. This led to further requests and research recommendations.

9) *Confirm maturity at age (critical in interpretation of the shrimp by-catch).*
   a. *Report standard errors + sample sizes on maturity ogive parameters.*

Rationale for request: There was some confusion within the Panel about the aging of croaker. The relationship between age and maturity is a critical one given the relatively young age of fish taken and discarded in the shrimp fishery and that inconsistencies or errors in this could have serious outcomes.

Response (R09): Spreadsheet showing tables of maturity at age from two sources with SE and sample sizes.

Outcome: The age at maturity was confirmed as being handled consistently for all input data. The data sources showed different patterns of maturity. These were used to test sensitivity.

10) *What is the selectivity for the gill nets?*
    a. *Size & age ranges captured over time*

Rationale for request: Increased importance of this gear type over time gave rise to concerns over changing selectivities that may not have been well described by the model.

Responses (R10): PowerPoint presentation and spreadsheet showing tables and graphs showing selectivity in the gill net fishery by length and age through time and for different states.

Outcome: The gillnets were seen to take a changing mix of lengths and ages through time, with larger, older individuals being taken more in recent years.

11) *Sensitivity to year start of model (shorten/lengthen the entire input time series, e.g. start in 1986 and 1975)*

Rationale for request: The Panel wished to see the sensitivity of the model to different start dates and thus input data, which can also correspond to changes in the fishery.

Response (R11): Spreadsheet showing tables and figures of sensitivity to year of start of model (1973, 1975, 1981[base], 1986 and 1991).

Outcome: Sensitivity was seen for some parameters, notable SSB/SSBmsy, but not for others.

12) *Comparison of full annual F and full F_{msy} values (including error/CIs)*

Rationale for request: Overfishing determination should be made with full Fs rather than weighted versions.

Response: Dealt with later – see request 16.

Outcome: Addressed as request 16.

13) *Clarification of values of sigma from the index q-q plots*

Rationale for request: All of the standard deviations of the standardized residuals had been approximately equal to 1. This seemed an unlikely result.

Response: It was not considered further since it had been established that the equations for the standardized residuals were wrong.

Outcome: Equations corrected for all future runs.

14) *Table of SSB ratio estimates from sensitivity runs.*

Rationale for request: To judge the plausibility of the estimates across the different runs.

Response: Some values were shown in a presentation but other more pressing issues needed to be dealt with.

Outcome: Agreed low priority at the time, addressed sufficiently to enable run comparison.

15) *Presentation of trajectories of SSB as % B_0 with B_{msy} and include estimates of B_0 and SSB ratio for baseline run with/without shrimp by-catch.*

Rationale for request: When comparing results across runs with different biomass reference points it is very helpful to place them on a common scale (rather than just looking at ratios of estimates to reference points).

Response: This was noted for presentation of all future runs.

Outcome: Future runs included appropriate comparison.

16) *Presentations of the fully recruited F and number weighted F for all future model runs.*

Rationale for request: Overfishing determinations need to be done with full F

Response: Noted by the Assessment Team for future runs.

Outcome: All future runs presented appropriately.

17) *Add year and proportion by year derived from those samples to the discard sample table from Request (1).*

Rationale for request: The table of discard data prepared in answer to Request 1 lacked year identifier and discard ratio.

Response (R01): Table in spreadsheet updated.

Outcome: Interpretation of presented data improved.

18) *Information/report from the aging workshop and confirmation that ages (and weights) applied in the models are appropriate.*

Rationale for request: The definition of age group 0 created a number of issues, particularly associated with the proportion mature at age. The panel wished confirmation that age had been handled in the same way throughout the preparation of the disparate data sets that feed into the assessment.

Response: Verbal confirmation that all elements where age was fed into the assessment had handled age in the same way.

Outcome: Confidence in age input data consistency maintained.

19) *What are the age/length distributions of croaker in the three depth strata by year from the NMFS survey.*

Rationale for request: As there were no tows in the shallow depth strata in most years, there was a question as to whether this strata could be managed differently or omitted from the analysis but it was important to know in advance whether the shallow strata contained a disproportionate number of small (young) animals.

Response (R19): Spreadsheet containing raw data, tables and plots of length and age frequency by depth strata, year from the NMFS survey.

Outcome: Confirmed fish age/size distribution by depth strata enabling further exploration of survey re-stratification.

20) *Define maximum area of each of the three (0-9, 9-18, 18-27m) depth strata used in the NMFS survey.*

Rationale for request: In the assessment documents, more than one area for each of the depth strata was given. In order to calculate numbers per swept area as an alternative index, the actual area of each strata was required.

Response: Maximum areas for each strata reported. This was done by the Assessment Team and used in the calculation of the area swept indices.

Outcome: These areas were used by the Assessment Team in the calculation of the area swept indices.

21) *Introduce a latititude stratification (aim to have at least two tows in each strata in each year) into the NMFS index.*

Rationale for request: The Panel wished to explore improvements to the index derived from the NMFS survey.

Response (R21): A PowerPoint presentation and spreadsheet with tables, plots and maps describing an alternative post-stratification index.

Outcome: This re-stratification of the NMFS survey was applied in future runs of the model.

22) *Recalculate the NMFS index based on total numbers calculated from the total area and swept area in each of the depth/latitude strata. Show comparison.*

Rationale for request: The Panel wanted area-swept estimates from a constant survey area each year to be used in model runs. This ensures a consistent time-series and enables the estimated q to be used as a diagnostic (i.e. is it too small or too large?)

Response (R22): Two PowerPoint presentations and a spreadsheet describing an index based on the NMFS survey calculated by the new depth-latitude strata.

Outcome: Swept area estimates were developed for use in model runs.

23) *New base-line run using reworked NMFS index from (22) above.*

Rationale for request: To assess whether the re-worked NMFS index improved the fit of the model or made an appreciable difference to the model output.

Response: Dealt with under request 29.

Outcome: Addressed by request 29.

24) *List of reference material used in the assessment process in Word format.*

Rationale for request: To facilitate report writing for all participants.

Response (R24): Word bibliography prepared.

Outcome: Reference list in requested format provided and updated on the ftp site.

25) There was no request number 25.

26) *For all future runs provide at least the following:*
    a. *SSB trajectories with se*
    b. *Absolute and % B0*

        i. *Reference points on both graphs (actual reference points not the ratio)*
    c. *Full F trajectories with reference points (actual reference points not the ratio)*

Rationale for request: To put runs with different reference points on a consistent scale to enable comparison.

Response: Noted by the Assessment Team.

Outcome: Future model runs included appropriate elements where time permitted.

27) *Two runs: 1 with and 1 without shrimp discard with the following changes:*
    a. *without the recreational CPUE index*
    b. *Starting year of the model needs to be moved so the model can estimate the initial age structure*
        i. *Is there code in the model for estimating the initial age structure?*
    c. *Add NMFS age data to model*
        ii. *Use # of tows as effective sample size*
    d. *Commercial landings at age effective sample size – use number of trips*
    e. *Use maturity schedule from the last assessment*
    f. *Estimate all selectivities in the model (fix some parameters if necessary).*

Rationale for request: This was an attempt to get a defensible run to enable some conclusions to be made with regard to stock status.

Response: (b) request misunderstood, compromising model runs. (d) effective sample size set to 200 as trip numbers not currently available.

Outcome: Request reformulated as request 29.

28) *Clarify retrospective pattern changes in the final year*.

Rationale for request: The Panel wished to be able to consider the retrospective analyses for pattern.

Response: Retrospective patterns were presented.

Outcome: The significance of the retrospective patterns were discussed.

29) *Two runs: 1 with and 1 without shrimp discard with the following changes:*
a. *without the recreational CPUE index*
b. *Use two depth and latitude swept-area NMFS survey index.*
c. *starting year of the model needs to be moved to a later year when data are available from which the model can estimate the initial age structure*
    iii. *is there code in the model for estimating the initial age structure?*
d. *Add age data to model from the NMFS survey*
    iv. *Use # of tows as effective sample size or cap at 200 if data unavailable.*

e. *Use the commercial landings age data with an effective sample size of the number of trips*
f. *Use maturity schedule from previous assessment (lower % age maturity at age 0)*
g. *Estimate all selectivities in the model (fix some parameters if necessary).*

Rationale for request: This was a second attempt (request 27) to get a defensible run to enable some conclusions to be made with regard to stock status.

Response: Runs showing the requested information were conducted and presented.

Outcome: The runs provided the Panel with a better understanding of the performance of the assessment under review.

30) *For the (corrected) base model, provide:*

a. *the estimated q, with confidence intervals, for the NMFS trawl survey;*
b. *the selectivity used to estimate Fmsy.*

Rationale for request: (a) the scale of the estimated q can be used as a diagnostic to judge the reliability of the trawl survey; (b) to compare the composite selectivities assumed in Fmsy calculations with and without shrimp bycatch.

Response: Data from requested runs provided in tabular and graphical formats.

Outcome: (a) improved model fit to the trawl survey; (b) selectivities little different.

31) *Do a run including the shrimp bycatch estimates in the base model and provide the resulting selectivity used to estimate Fmsy for this run.*

Rationale for request: To compare the composite selectivities assumed in Fmsy calculations with and without shrimp bycatch.

Response: Data from requested runs provided in tabular and graphical formats.

Outcome: Selectivities little different.

32) *Profile across the potential levels of shrimp-fishery F to examine the potential effect on Fmsy and stock status i.e. - Fmsy and current F relative Fmsy for a range of shrimp-fishery Fs, each level held constant while calculating Fmsy (bearing in mind that the shrimp fishery has a selection pattern which catches age-0 and older ages). Please document methods along with the results*

Rationale for request: To better understand the impact of the croaker catch in the shrimp fisheries and how this affects our understanding of Fmsy and stock status for croaker.

Response: Methods and results were clearly documented. However, the Fmsy calculations were not as requested. The shrimp fishery catches a range of age classes: age-0 are assumed discarded and other ages are assumed landed. In the calculation of Fmsy the Panel requested that the F from the shrimp fishery (which applies to a range of croaker age-classes) be held constant while the directed effort be optimized to find Fmsy. This was not done, instead a single average selectivity was used in the Fmsy calculations with a single F.

Outcome: The issue of Fmsy calculation was incorporated into a research recommendation (see short term research recommendation g).

Effect of Shrimp-Trawl Fishing Mortality on F_{MSY} and Stock Status for Atlantic Croaker

Prepared by Katie Drew and Laura Lee, May 2010

Approved by the ASMFC Atlantic Croaker Technical Committee, June 2010

Motivation

Atlantic croakers are one of the major components of shrimp-trawl bycatch. Most of the Atlantic croakers that occur as bycatch are age 0, but older fish are also caught. Marketable fish may be landed (and thus included in the reported commercial landings), but the magnitude of the discards from this fishery is highly uncertain. Without a reliable estimate of the shrimp-trawl discards, it is not possible to determine the degree of mortality attributed to bycatch. This introduces uncertainty into estimates of total mortality and stock status. As such, the SEDAR 20 review panel requested that the impact of potential levels of shrimp-trawl fishing mortality on F_{MSY} and stock status be evaluated.

The base run of the 2010 ASMFC Atlantic croaker stock assessment model estimated F_{MSY} using a single average selectivity pattern based on the catch-weighted selectivities at age estimated for the last three years in the assessment time series and combined across all fleets—commercial landings (including landed bycatch from shrimp-trawls), commercial discards and scrap/bait landings, recreational harvest, and recreational discards (Figure 1). Shrimp-trawl discards were included as an additional fleet in sensitivity runs. The use of this composite selectivity pattern means that the effort in all fisheries is scaled by the same proportion in the estimation of F_{MSY}:

$$Z_{MSY} = s_{MSY} \times F_{MSY} + M$$

where s_{MSY} represents the composite selectivity vector.

The shrimp-trawl discards of Atlantic croaker were assumed to be entirely age-0 fish (i.e., selectivity equal to 1 for age-0 and equal to 0 for all other ages). As a result, the composite selectivity pattern gives more weight to age-0 selectivity when the shrimp-trawl discard estimates are included in the model (Figure 1).

Given the independence of the directed Atlantic croaker fisheries and the shrimp-trawl fishery, the review panel felt a better approach would be to hold shrimp-trawl fishing mortality constant while optimizing effort in the directed fisheries to find F_{MSY}.

Methods

The model splits the shrimp-trawl bycatch into two components, a landed component (marketable fish, included with the rest of the commercial landings), and a discard component (assumed to be all age-0 and treated as a separate fleet). Hence, the terms shrimp-trawl fishery, fleet, or fishing mortality used below refer only to the discard component of shrimp-trawl croaker bycatch.

The reference point calculations were modified by treating the directed fisheries and the shrimp-trawl fishery as separate mortality components:

$$Z_{MSY} = (s_{\text{Directed,MSY}} \times F_{\text{Directed,MSY}}) + (s_{\text{Shrimp Trawl,MSY}} \times F_{\text{Shrimp Trawl,MSY}}) + M$$

Using this method, only the directed fisheries fishing mortality is scaled to estimate F_{MSY} while the shrimp-trawl F is held constant.

The impact of shrimp-trawl fishing mortality on F_{MSY} and stock status was evaluated using a profiling approach, in which shrimp-trawl fishing mortality was held constant at values ranging from 0 to 1.0 year^{-1} over a series of alternate runs. The fixed values included the recent 3-year, 5-year, and 21-year average shrimp-trawl F estimated by the model.

The profile analyses were performed assuming different levels of shrimp-trawl discards, ranging from no discards to 10 times the original shrimp-trawl discard estimates. The original shrimp-trawl discard estimates are shown with the directed fisheries catch estimates in Figure 2. In this set of runs, the model was allowed to estimate annual shrimp-trawl F as another fleet in the model.

In a second set of runs, a time-series of shrimp-trawl F estimates was given as input to the model rather than estimated and was treated as an extra component of Z:

$$Z = M + F_{directed} + F_{shrimp\text{-}trawl}$$

The fixed F time-series were based on the model estimates of shrimp-trawl F from the run using the original estimates of discards. These original estimates were scaled up and down, ranging from 0x to 4x (Figure 3) for the profile runs. F_{MSY} was estimated the same way, with the shrimp-trawl F component equal to the 3-year, 5-year, and 10-year average, as well as to fixed values that were the same across runs.

In all cases, selectivity of these shrimp-trawl discards was assumed to be entirely on age-0 (that is, 1 for age-0 and 0 for ages 1+).

Standard deviations of the estimates were calculated within ADMB; however, these estimates are considered biased low.

Results

Estimates of F_{MSY} decreased as the fixed value of shrimp-trawl F increased (Tables 1–4; Figures 4-5). All results suggest that overfishing was not occurring in the Atlantic croaker stock in 2008, with the estimates of directed F_{2008} less than corresponding estimates of F_{MSY} in all runs.

The value of the shrimp-trawl F used in the MSY calculations had more of an effect on the estimates of F_{MSY} than the inputs of fixed F or discards used in the population model (Figure 4, 5). Increasing levels of shrimp-trawl F and discards resulted in increased estimates of virgin and time-series average recruitment (Figure 6), and decreasing estimates of directed F (Figure 7). As a result, although estimates of F_{MSY} were similar at the same fixed level of shrimp-trawl F in the MSY calculations, estimates of $F_{Directed,\ 2008}$ relative to F_{MSY} decreased as the level of shrimp-trawl discards and F used in the model increased (Figure 4, 5).

Conclusions

Although increasing the fixed shrimp-trawl F in the model reduced the estimate of F_{MSY}, the directed F in 2008 was below F_{MSY} in all cases¸ indicating overfishing is not occurring.

Table 1. Estimates of F_{MSY} and relative stock status (standard deviations in parentheses) over a range of fixed shrimp-trawl fishing mortalities

		$F_{shmip\text{-}trawl}$ in MSY calculations	F_{MSY}		$F_{\mathrm{Directed,2008}}/F_{\mathrm{MSY}}$	
Fixed Shrimp-Trawl F in model (relative to base estimates)	**0x**	Average (0.0)	0.365	(0.004)	0.189	(0.020)
		0.157 (all runs)	0.350	(0.004)	0.196	(0.020)
	0.1x	21-yr avg (0.045)	0.363	(0.004)	0.195	(0.020)
		3-yr avg (0.012)	0.366	(0.004)	0.193	(0.020)
		5-yr avg (0.0087)	0.367	(0.004)	0.193	(0.020)
		0.157 (all runs)	0.352	(0.004)	0.201	(0.020)
	0.5x	21-yr avg (0.226)	0.346	(0.004)	0.178	(0.018)
		3-yr avg (0.060)	0.363	(0.004)	0.170	(0.017)
		5-yr avg (0.043)	0.364	(0.004)	0.169	(0.017)
		0.157 (all runs)	0.353	(0.004)	0.174	(0.018)
	1x	21-yr avg (0.451)	0.322	(0.003)	0.158	(0.017)
		3-yr avg (0.120)	0.359	(0.004)	0.142	(0.015)
		5-yr avg (0.087)	0.362	(0.004)	0.140	(0.015)
		0.157 (all runs)	0.355	(0.004)	0.143	(0.015)
	1.5x	21-yr avg (0.677)	0.278	(0.002)	0.119	(0.015)
		3-yr avg (0.181)	0.332	(0.002)	0.100	(0.013)
		5-yr avg (0.130)	0.337	(0.002)	0.098	(0.013)
		0.157 (all runs)	0.334	(0.002)	0.099	(0.013)
	2x	21-yr avg (0.902)	0.266	(0.002)	0.122	(0.015)
		3-yr avg (0.241)	0.345	(0.003)	0.094	(0.012)
		5-yr avg (0.174)	0.352	(0.003)	0.092	(0.011)
		0.157 (all runs)	0.354	(0.003)	0.092	(0.011)
	4x	21-yr avg (1.804)	0.150	(0.001)	0.127	(0.018)
		3-yr avg (0.482)	0.310	(0.002)	0.061	(0.009)
		5-yr avg (0.348)	0.326	(0.002)	0.058	(0.008)
		0.157 (all runs)	0.348	(0.002)	0.055	(0.008)

Table 2. Estimates of F_{MSY} and stock status (standard deviations in parentheses) over a range of assumed shrimp-trawl discards levels. To calculate F_{MSY}, shrimp-trawl F was fixed at the model-estimated shrimp-trawl fishing mortality averaged over the three most recent years in the model time series.

Shrimp Trawl			
Discards Level *	**3-year *F***	F_{MSY}	$F_{Directed,2008} / F_{MSY}$
0.10x	0.0165	0.364 (0.004)	0.191 (0.019)
0.50x	0.0691	0.354 (0.004)	0.169 (0.017)
1.0x	0.120	0.343 (0.004)	0.156 (0.016)
1.5x	0.160	0.336 (0.006)	0.144 (0.016)
2.0x	0.198	0.327 (0.007)	0.140 (0.017)
4.0x	0.318	0.300 (0.010)	0.132 (0.018)
10x	0.557	0.241 (0.018)	0.133 (0.025)

Table 3. Estimates of F_{MSY} and stock status (standard deviations in parentheses) over a range of assumed shrimp-trawl discards levels. To calculate F_{MSY}, shrimp-trawl F was fixed at the model-estimated shrimp-trawl fishing mortality averaged over the five most recent years in the model time series.

Shrimp Trawl			
Discards Level *	**5-year *F***	F_{MSY}	$F_{Directed,2008} / F_{MSY}$
0.10x	0.0118	0.365 (0.004)	0.191 (0.019)
0.50x	0.0496	0.359 (0.004)	0.166 (0.017)
1.0x	0.0869	0.351 (0.004)	0.153 (0.016)
1.5x	0.116	0.346 (0.005)	0.140 (0.015)
2.0x	0.143	0.340 (0.005)	0.135 (0.015)
4.0x	0.233	0.322 (0.007)	0.123 (0.016)
10x	0.413	0.280 (0.012)	0.114 (0.019)

* Relative to original shrimp-trawl discards estimates

Table 4. Estimates of F_{MSY} and stock status (standard deviations in parentheses) over a range of assumed shrimp-trawl discards levels. To calculate F_{MSY}, shrimp-trawl F was fixed at the model-estimated shrimp-trawl fishing mortality averaged over the entire model time series (twenty-one years).

Shrimp Trawl			
Discards Level *	**21-year** ***F***	F_{MSY}	$F_{Directed,2008} / F_{MSY}$
0.10x	0.0674	0.353 (0.004)	0.197 (0.020)
0.50x	0.287	0.301 (0.005)	0.198 (0.020)
1.0x	0.451	0.260 (0.006)	0.206 (0.023)
1.5x	0.553	0.236 (0.006)	0.205 (0.024)
2.0x	0.641	0.214 (0.007)	0.214 (0.027)
4.0x	0.881	0.153 (0.009)	0.258 (0.040)
10x	1.26	0.061 (0.012)	0.526 (0.164)

* : Relative to original discards estimates.

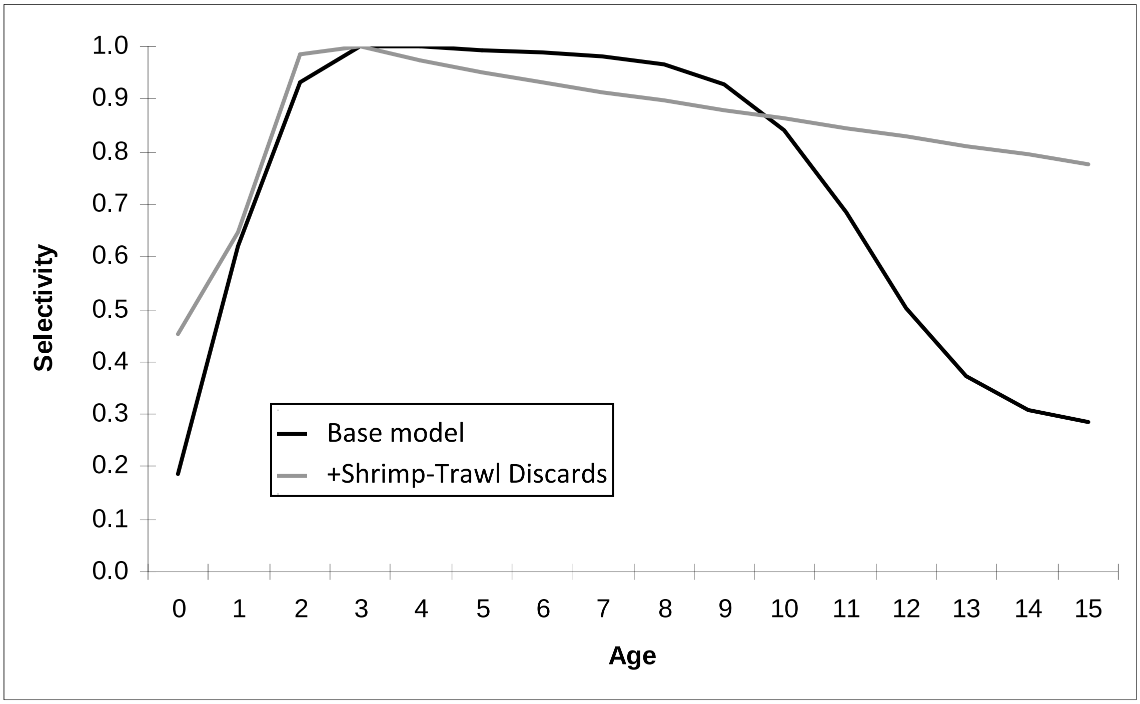

Figure 1. Selectivity pattern used to estimate F_{MSY} in the base run of the model, without and with shrimp-trawl discards.

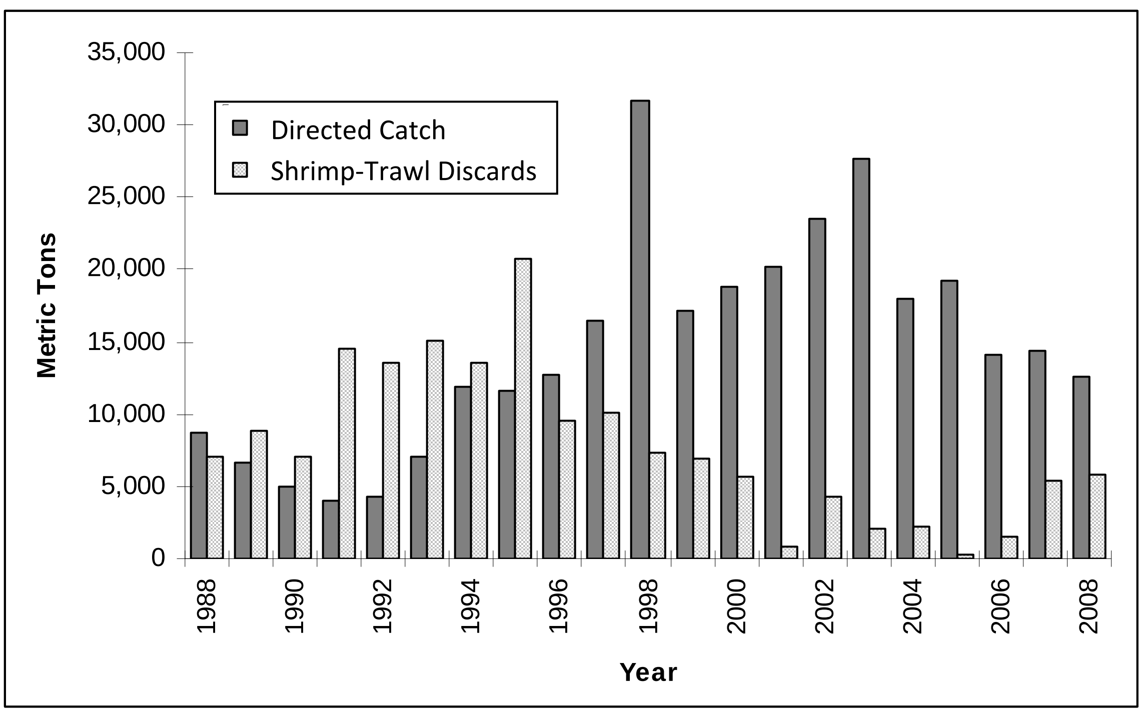

Figure 2. Annual directed fisheries catch estimates (commercial landings, commercial scrap/bait, recreational harvest, and recreational discards) and original shrimp-trawl discard estimates for Atlantic croaker, 1988–2008.

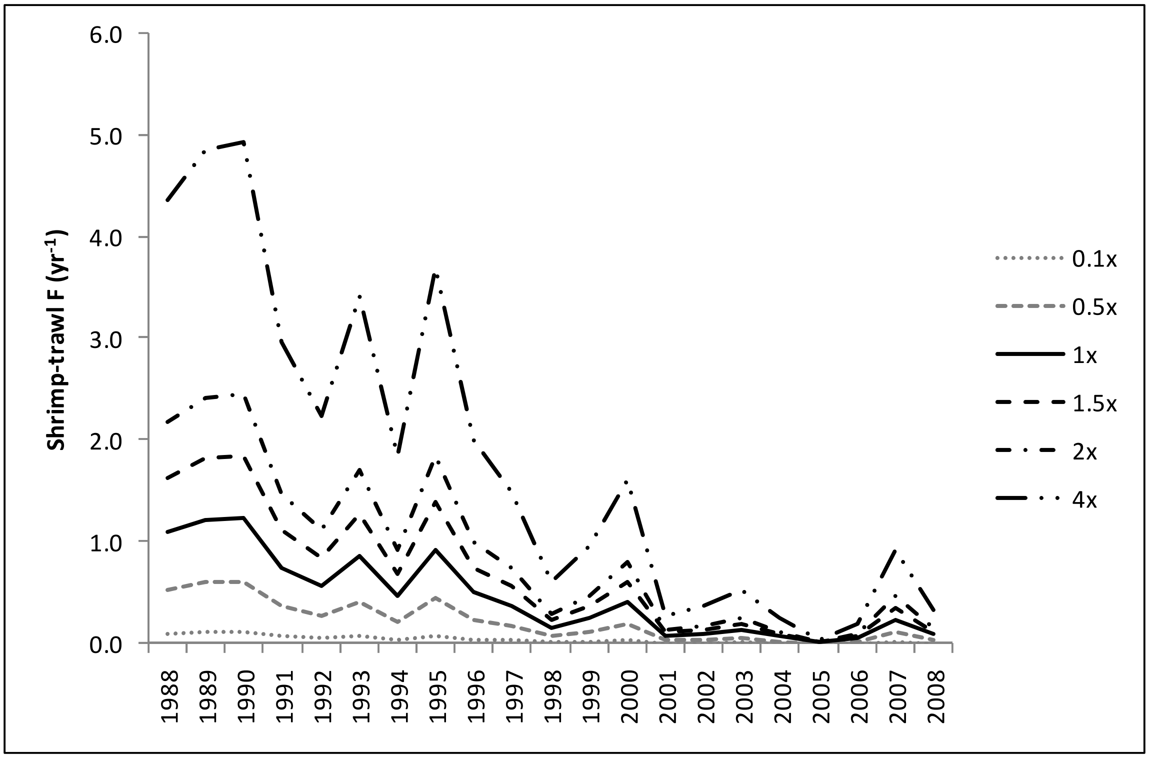

Figure 3. Fixed levels of shrimp-trawl *F* used as input to the model, relative to the values estimated with the original shrimp-trawl discards (1x).

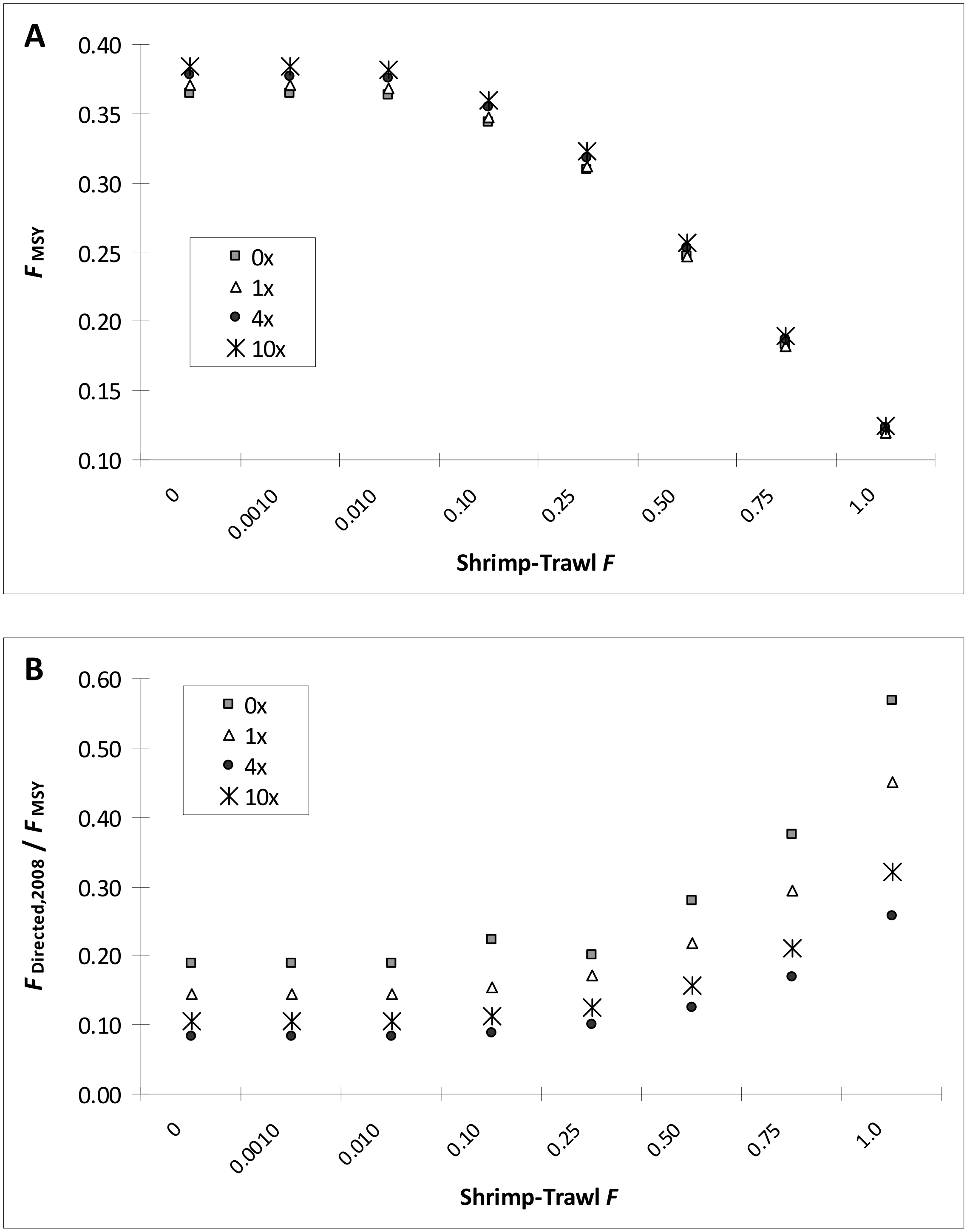

Figure 4. Estimates of (A) F_{MSY} and (B) stock status from profile analyses that used fixed levels of shrimp-trawl F in the F_{MSY} calculations (x-axis) and an input time-series of shrimp-trawl discards equal to 0, 1, 4, and 10 times the original shrimp-trawl discard estimates.

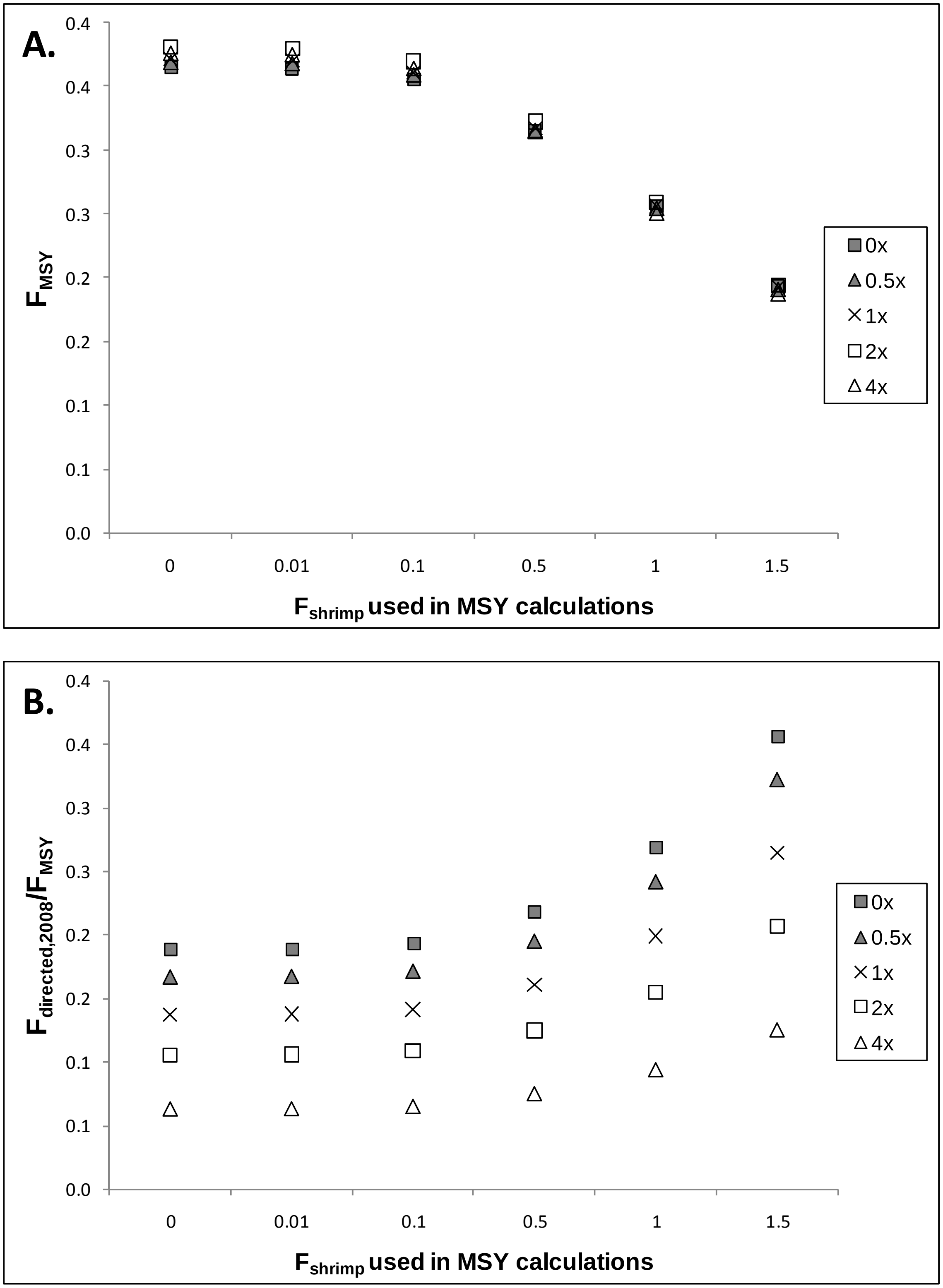

Figure 5. Estimates of (A) F_{MSY} and (B) stock status from profile analysis that used levels of shrimp-trawl F in the F_{MSY} calculations (x-axis) and input time-series of fixed shrimp-trawl F equal to 0 – 4 times the original shrimp-trawl F estimates.

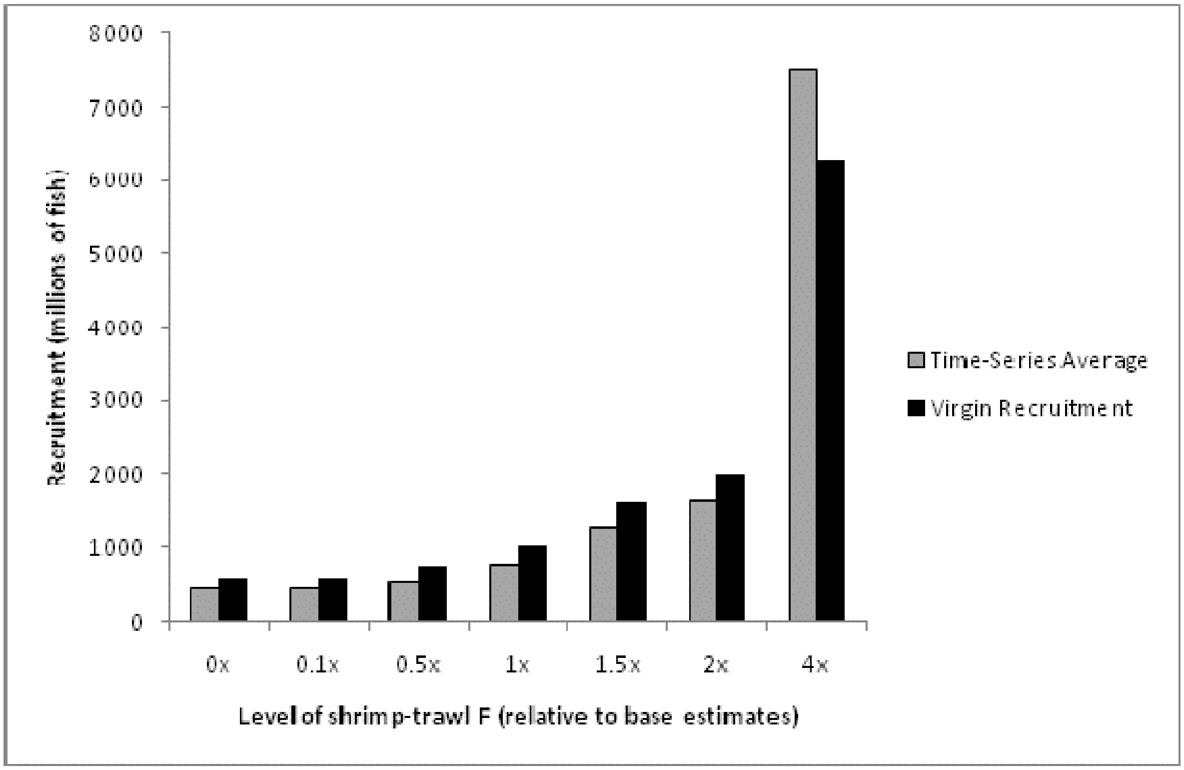

Figure 6. Estimated average and virgin recruitment for different levels of fixed shrimp-trawl F included as input to the model.

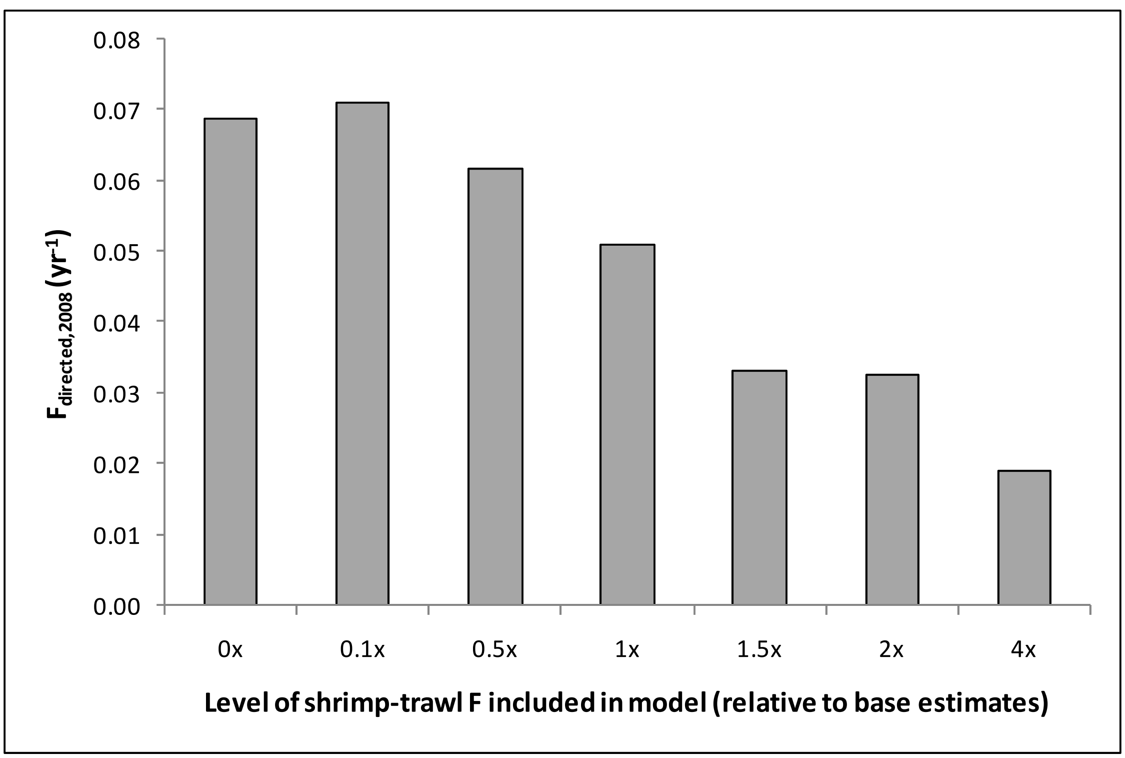

Figure 7. Estimates of $F_{directed,2008}$ for different levels of fixed shrimp-trawl F included as input to the model.

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Memorandum

TO: South Atlantic State-Federal Fisheries Management Board

FROM: Kim McKown, Chair, SEDAR 20 Peer Review Panel

RE: Follow-up Review of 2010 Atlantic Croaker Stock Assessment

DATE: July 14, 2010

The Atlantic Croaker Stock Assessment was peer reviewed through the SouthEast Data and Assessment Review (SEDAR) process in March 2010. During the Review Workshop, the Panel requested a number of additional analyses to better understand the assessment data, methods, and results. One request sought to address the Panel's concern regarding the method used to incorporate shrimp trawl discards in the estimation of F_{MSY}. The calculations were not performed as requested, and therefore the Panel could not provide a recommendation on stock status based on the assessment results.

At its May meeting, the Board tasked the Atlantic Croaker Technical Committee (TC) with conducting additional model runs utilizing the F_{MSY} calculation approach recommended by the Review Panel. Dr. Tim Miller and I, as members of the SEDAR 20 Review Panel, agreed to review new model run results and provide judgment on their accuracy in characterizing the trends and stock status of croaker.

Dr. Miller and I have reviewed the results from the TC's new model run. We agree with the methods used and believe the request for modifying the calculation of F_{MSY} has been adequately addressed. We concur with the new model results that indicate F for the directed fishery is less than F_{MSY} over a wide range of shrimp trawl discard mortality, which indicates that overfishing is not occurring. Based on the results of these sensitivity runs, we recommend that the Board utilize the ratio of F/F_{MSY} to determine overfishing status.

M10-072

Management Advice for Atlantic Croaker Based on the 2010 Stock Assessment

June 2010
ASMFC Atlantic Croaker Technical Committee

The Atlantic Croaker Technical Committee (TC) met on June 24 and 25, 2010 to evaluate the 2010 Atlantic croaker stock assessment, and develop relevant management advice. The TC considered the stock assessment report, the review panel report, the report ("Effect of Shrimp-Trawl Fishing Mortality on F_{MSY} and Stock Status for Atlantic Croaker") from the Stock Assessment Subcommittee (SASC) to the TC completing the last analysis requested by the review panel, and the subset of the review panel's response to that report. The TC accepted the requested analysis report and the subset of the review panel's findings that ratios of F relative to F_{MSY} indicate that overfishing was not occurring, and the ratios are acceptable for use in managing the Atlantic croaker stock. The F/F_{MSY} estimates to be used for management are those from the final base run in the addendum to the stock assessment report in which shrimp discards are not included in the model and the model is for the coastwide stock.

The TC recommends replacing the specific reference point values in Amendment 1, through an addendum, with the following ratio based values:

Overfishing threshold is $F/F_{MSY} = 1$
Overfishing target is $F/(F_{MSY}*0.75) = 1$

Overfished threshold is $SSB/(SSB_{MSY}(1-M)) = 1$
Overfished target is $SSB/SSB_{MSY} = 1$

Overfishing is occurring if F/F_{MSY} is greater than 1 and the stock is considered overfished if $SSB/(SSB_{MSY}(1-M))$ is less than 1.

The TC also recommends discontinuing the use of the Mid-Atlantic and South-Atlantic management regions, and that the reference points be applicable to the entire management unit.

Based on the revised F/F_{MSY} reference points, the stock is currently below the target and threshold; therefore, overfishing is not occurring. The available biological and landings data suggest that it is unlikely the stock is currently overfished. The overfished status can not be determined due to high uncertainty in the shrimp trawl discard estimates. The TC reevaluated the currently available shrimp trawl effort, and shrimp trawl croaker catch-per-unit-effort data, and determined only very modest improvements could be made to the discard estimates due to limited data availability. The level of improvement would not significantly decrease the uncertainty in the estimates. Further analysis of potential improvements to the shrimp trawl discard estimates will be carried out during the next benchmark assessment, but in the absence of better observer data reliable estimates are unlikely. The TC finds no biological basis for additional management restrictions at this time.

To: **Harry Rickabaugh**
Chair, ASMFC Atlantic Croaker Technical Committee (TC)

From: **Linda S. Barker**
Chair, ASMFC Atlantic Croaker Stock Assessment Subcommittee (SASC)

Subject: **Factual Corrections to the SEDAR 20 Review Workshop Report for Atlantic Croaker**

Date: **Monday, June 28, 2010**

Please include this memo as documentation and correction of two erroneous statements made in the SEDAR 20 Review Workshop Report of the 2010 stock assessment for Atlantic Croaker.

I.) Item 2 “Comments on Specific Terms of Reference”, section 1 “Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment“, sub-section b “Report standard error of inputs and use them to inform the model if possible”.

The statement was made that “The Panel was concerned that the effective sample size on the commercial landings at age was too high. They recommend that it be based on the number of biological samples.”

This is not accurate. The SASC did use the number of biological samples in the model.

The Panel’s suggestion at the review workshop was to use trip numbers for the effective sample size. (Part d of Request 2.3.3.27: “Commercial landings at age effective sample size – use number of trips” and Part e of Request 2.3.3.29: “Use the commercial landings age data with an effective sample size of the number of trips.”) It was not possible for the SASC to compile the trip numbers at the workshop. Instead, the SASC and the Panel discussed imposing a maximum sample size and agreed to use an effective sample size equal to 200 in place of any sample size that exceeded 200. This is reflected in the response to Request 2.3.3.27 in the Panel’s report, “effective sample size set to 200 as trip numbers not currently available.”

II.) Item 2 “Comments on Specific Terms of Reference”, section 3 “State and evaluate assumptions made for all models…”, sub-section a “Calculation of M”.

The statement was made that “The assessment uses instantaneous natural mortality rates… The values are averaged across values derived from a series of methodologies...” While the SASC did compare natural mortality values estimated by different methods, the values used in the assessment model were estimated using the approach developed by Lorenzen (2005; see Section 2.4.2 of the stock assessment report). The method requires values for the von Bertalanffy growth parameters. The von Bertalanffy parameter values used were those estimated from a fit of the von Bertalanffy curve to all available data. There was no averaging across methodologies at any step.