Northeast Fisheries Science Center Reference Document 09-02A & B

The Northeast Data Poor Stocks Working Group Report

December 8-12, 2008 Meeting

Part A. Skate species complex, Deep sea red crab, Atlantic wolfish, Scup, and Black sea bass
Part B. Weakfish

by Northeast Data Poor Stocks Working Group

January 2009

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08-16 *Assessment of 19 Northeast Groundfish Stocks through 2007: A Report of the 3rd Groundfish Assessment Review Meeting (GARM III) -- Appendixes*, by Northeast Fisheries Science Center. September 2008.

08-17 *Preparation of the Northeast Fisheries Observer Program Gillnet Data for Use in Bycatch Analyses of Protected Species*, by ML Warden and CD Orphanides. August 2008.

08-18 *A Description of the Allocation Procedure Applied to the 1994 to 2007 Commercial Landings data*, by SE Wigley, P Hersey, and JE Palmer. September 2008.

08-19 *11th Flatfish Biology Conference Program and Abstracts, Dec. 3-4, 2008, Water's Edge Resort and Spa, Westbrook, Connecticut*, by Conference Steering Committee: R Mercaldo-Allen (Chair), A Calabrese, D Danila, M Dixon, A Jearld, T Munroe, Deborah Pacileo, C Powell, and S Sutherland. November 2008.

08-20 *Estimated average annual bycatch of loggerhead sea turtles (Caretta caretta) in US Mid-Atlantic bottom otter trawl gear, 1996-2004 (2nd edition)*, by KT Murray. November 2008.

09-01 *Report of the Retrospective Working Group, January 14-16, 2008, Woods Hole, Massachusetts*, by CM Legault, Chair. January 2009.

Northeast Fisheries Science Center Reference Document 09-02a

The Northeast Data Poor Stocks Working Group Report

December 8-12, 2008 Meeting

Part A. Skate species complex, Deep sea red crab, Atlantic wolfish, Scup, and Black sea bass

by Northeast Data Poor Stocks Working Group

NOAA's National Marine Fisheries Service, 166 Water St., Woods Hole MA 02543-1026

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

January 2009

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Foreword to the NE Data Poor Stocks Report

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees/Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies. Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees) formulate management advice, after an assessment has been accepted by the peer review panel.

Reports that are produced following peer review meetings typically include: an *Assessment Report* – a detailed account of the stock assessment; and the review panel report – a summary of the reviewer's opinions and recommendations. Assessment reports are available online at http://www.nefsc.noaa.gov/nefsc/publications/series/crdlist.htm. Review panel reports as well as assessment reports can be found at http://www.nefsc.noaa.gov/nefsc/saw/.

The Northeast "Data Poor Stocks" Working Group (DPWG) was formed in 2007, as part of the SAW process, to perform stock assessments of species that are difficult to assess due to lack of critical data or severe modeling problems. Monkfish was the first stock addressed by DPWG in 2007. The current report describes new work performed in 2008 by the DPWG on the NE skate species complex, deep sea red crab, Atlantic wolfish, scup, black sea bass, and weakfish. The DPWG met in October and November, 2008, and had an integrated peer review meeting during December 8-12, 2008 in Woods Hole at the Northeast Fisheries Science Center.

This Foreword contains a brief summary of the integrated peer review meeting, Terms of Reference, a list of reviewers, the December meeting agenda, and a list of meeting attendees (Tables 1-4). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1-3).

Summary of Peer Review Meeting (December 8-12, 2008):

The Working Group (DPWG) that did the analyses was comprised of NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC. There was also participation by scientists from NOAA's SWFSC and SEFSC.

The Peer Review Panel examined working papers that were focused on Biological Reference Points (BRP) of Northeast skate species, deep sea red crab, Atlantic wolfish, scup, and black sea bass. The Review Panel also provided guidance for scientists to use in future weakfish assessments.

In addition to reviewing BRPs for each stock (with the exception of weakfish), the panel was asked to make a recommendation on the utility of the analyses for stock assessment. In particular the panel was asked to determine if the analyses and amount of peer review were sufficient to make a determination about stock status. If not, the panel was asked to recommend the process for further analyses and review.

The Review Panel accepted new assessment models for red crab, wolfish, scup and black sea bass. This resulted in new BRP recommendations and new estimates of those parameters. New BRPs were not recommended for the skates. However, the Panel generally advocated updating the estimates of skate biomass targets and thresholds (with the exception of Barndoor skate) to include data from recent surveys. Some changes in stock status are implied by the outcome of this peer review. The review panel report can be found at *http://www.nefsc.noaa.gov/nefsc/saw/*.

Table 1. Background and Terms of Reference for the DPWG developed by the Northeast Regional Coordinating Committee (NRCC).

Draft Terms of Reference
Data Poor Stocks Working Group
(written: 10-11-07, updated: 5-9-08**)**

Background

Data poor stocks are problematic for managers because traditional measures of status (biomass and fishing mortality) are not available. A variety of *ad hoc* metrics have been developed to address these issues but a synoptic evaluation of the problem has not been conducted in the Northeast. The term "data poor" will be used to categorize assessments limited by either data or lack of contrast in time series. Fisheries stock assessments require the integration of multiple sources of data including commercial and recreational landings, discards from multiple fleets, fishery independent survey indices, and measures of fishing effort. For some species, one or more of these data sources may not be available or have such low precision that it is not possible to use them in a conventional application within an assessment.

Objectives

1. Constitute and convene a Working Group comprising NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC to:
    a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for the following data poor stocks: Black sea bass; Deep-sea red crab; Scup; Skates; Atlantic wolffish.
    b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
    c. Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depend on, and needs to be consistent with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available.
    d. Comment on what can be done to improve the information, proxies or assessments for each species.
2. For weakfish, provide guidance/suggest methodologies for scientists to use in future assessments.

Participants

The Working Group (WG) will consist of representatives from the staffs of the NEFMC (2), MAFMC (2), ASMFC (2), NERO (3), and NEFSC (5).

Products

The WG product will be a document providing: (a) proposed BRPs and measurable BRP and MSY proxies for the five Northeast stocks/species groups listed in 1(a) above; (b) advice for SSCs to consider when they develop fishing level recommendations for these stocks; (c) advice on what to do about species with identification problems; (d) comments on what is needed to improve the proxies and/or assessments for each species and (e) suggested methodologies for conducting future weakfish stock assessments. Although it is expected that significant uncertainties will be associated with the proposed BRPs, MSYs, and their proxies, the intention is that the recommended values will represent the best available science.

During (or after) the WG's activities, a peer review of some type will be undertaken to ensure that the WG's recommendations and technical approaches are sound.

Table 2. Peer Reviewers of the December 8-12, 2008 "Northeast Data Poor Stocks" Working Group Meeting (See Table 4 for a list of meeting attendees).

Chairman:
Dr. Thomas Miller, Univ. of Maryland Center for Environmental Science, Chesapeake Biological Laboratory

Panelists :
Dr. Robert Muller, Florida Fish and Wildlife Commission
Mr. Robert O'Boyle, Beta Scientific Consulting Inc.
Dr. Andrew Rosenberg, Dept. Natural Resources, Univ. of New Hampshire

Table 3. Northeast Data Poor Stocks Dec. 8-12, 2008 meeting agenda.

Northeast Data Poor Stocks Working Group -- Peer Review Meeting

AGENDA

Last Update: ***3-Dec-08***

Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
8-Dec	12:30	12:40	10	Welcome and Introduction	Weinberg (SAW Chair)
Mon	12:40	13:00	20	Overview of Data Poor Workshop and objectives	Rago (DPWG Chair)
Mon	13:00	13:15	15	Open Remarks, Guidance to Panel	Miller (Review Panel Chair)
Mon	13:15	14:15	60	Skate Complex	Sosebee
Mon	14:15	14:30	15	Break	
Mon	14:30	15:00	30	Skate Stock Recruitment Analyses	Brooks
Mon	15:00	15:30	30	Skate Landings and Discard Estimation	Applegate
Mon	15:30	16:15	45	Discussion--Skates	Miller
Mon	16:15	16:30	15	Break	
Mon	16:30	17:15	45	Red Crab	Chute
Mon	17:15	18:00	45	Red Crab Models: Frequency Analyses, DCAC, Two-point boundary value problem	Chute/Rago
Mon	18:00	18:45	45	Discussion--Red Crab	Miller
Mon	18:45	19:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
9-Dec	***9:00***	9:15	15	Progress review and Order of the Day (Chair)	Miller (Chair)
Tues	9:15	10:00	45	Wolffish	Keith
Tues	10:00	10:45	45	Wolffish Model in SCALE	Nitschke
Tues	10:45	11:00	15	Break	
Tues	11:00	12:00	60	Wolffish--Discussion	Miller
Tues	12:00	13:00	60	Lunch	
Tues	13:00	15:00	120	Revisit on Skates, Red Crab and/or Wolffish	TBD
Tues	15:00	15:15	15	Break	
Tues	15:15	17:45	150	Conclusions: Skates, Red Crab, Wolffish	Miller/Panel
Tues	17:45	18:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
10-Dec	***9:00***	9:15	15	Progress review and Order of the Day (Chair)	Miller
Wed	9:15	10:45	90	Scup	Terceiro
Wed	10:45	11:00	15	Break	
Wed	11:00	12:00	60	Discussion --Scup	Miller
Wed	12:00	13:00	60	Lunch	
Wed	13:00	13:30	30	Discussion--Scup	Miller
Wed	13:30	15:00	90	Black Sea Bass	Shepherd
Wed	15:00	15:15	15	Break	
Wed	15:15	16:45	90	Discussion--Black Sea Bass	Miller
Wed	16:45	17:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
11-Dec	***9:00***	9:15	15	Progress review and Order of the Day	Rago
Thurs	9:15	10:45	90	Black Sea Bass--Conclusions	Miller
Thurs	10:45	11:00	15	Break	
Thurs	11:00	12:30	90	Scup--Conclusions	Miller
Thurs	12:30	13:30	60	Lunch	
Thurs	13:30	14:45	75	Further Discussion: Scup, Black Sea Bass Conclusions	Miller
Thurs	14:45	15:00	15	Break	
Thurs	15:00	16:30	90	Weakfish Assessment Model Summary	Brust (Weakfish Chair)
Thurs	16:30	17:30	60	Weakfish Assessment Discussion	Miller
Thurs	17:30	18:00	30	Summary/Followup (Chair)	Miller
12-Dec	***9:00***	9:15	15	Progress review and Order of the Day	Miller (Chair)
Fri	9:15	10:30	75	Synthesis of Meeting and Recommendations	TBD
Fri	10:30	10:45	15	Break	
Fri	10:45	12:00	75	Report Development and Writing	
Fri	12:00	13:00	60	Lunch	
Fri	13:00	14:30	90	Report Writing	
Fri	14:30	14:45	15	Break	
Fri	14:45	16:00	75	Report Writing	
				Adjourn	

Table 4. List of NE Stocks Data Poor Working Group meeting attendees (November – December, 2008).

Name	Affiliation	Email
Moira Kelly	NERO-SFD	moira.kelly@noaa.gov
Tim Miller	NEFSC	timothy.j.miller@noaa.gov
Mike Palmer	NEFSC	michael.palmer@noaa.gov
Doug Potts	NERO-SFD	douglas.potts@noaa.gov
Dvora Hart	NEFSC	deborah.hart@noaa.gov
Chad Keith	NEFSC	chad.keith@noaa.gov
Tom Nies	NEFMC	tnies@nefmc.org
Alec MacCall	SWFSC	alec.maccall@noaa.gov
Peter Shelley	CLF	pshelley@clf.org
	Umass	
Fiona Hogan	Dartmouth/SEMAST	fhogan@umassd.edu
Gary Shepherd	NEFSC	gary.shepherd@noaa.gov
Katherine Sosebee	NEFSC	katherine.sosebee@noaa.gov
Lisa Hendrickson	NEFSC	lisa.hendrickson@noaa.gov
Toni Kerns	ASMFC	tkerns@asmfc.org
Mike Ruccio	NERO	michael.ruccio@noaa.gov
Rich Seagraves	MAFMC	rseagraves@mafmc.org
Jim Armstrong	MAFMC	jarmstrong@mafmc.org
Josh Moser	NEFSC	josh.moser@noaa.gov
Gred DiDominico	GSSA	
Paul Caruso	MDMF	paul.caruso@state.ma.us
David Burr	MADMF	
Eric Powell	Rutgers University	eric@hsrl.rutgers.edu
Toni Chute	NEFSC	toni.chute@noaa.gov
Rich McBride	NEFSC	rich.mcbride@noaa.gov
Jessica Coakley	MAFMC	jcoakley@mafmc.org
Todd Gedamke	SEFSC	todd.gedamke@noaa.gov
Meredith Cavanaugh	NMFS	meredith.cavanaugh@noaa.gov
Michele Traver	NEFSC	michele.traver@noaa.gov
Andrew Applegate	NEFWC	aapplegate@nefmc.org
Loretta O'Brien	NEFSC	loretta.obrien@noaa.gov
Michael Jones	NEFSC	michael.jones@noaa.gov
Richard Merrick	NEFSC	richard.merrick@noaa.gov
Anne Richards	NEFSC	anne.richards@noaa.gov
Mark Terceiro	NEFSC	mark.terceiro@noaa.gov
Fred Serchuk	NEFSC	fred.serchuk@noaa.gov
Jim Weinberg	NEFSC	james.weinberg@noaa.gov
Laurel Col	NEFSC	laurel.col@noaa.gov
Liz Brooks	NEFSC	liz.brooks@noaa.gov
Paul Nitschke	NEFSC	paul.nitschke@noaa.gov
Chris Legault	NEFSC	chris.legault@noaa.gov

Fiona Hogan	UMASS/SMAST	fhogan@umassd.edu
Susan Wigley	NEFSC	susan.wigley@noaa.gov
Steve Cadrin	NEFSC	steve.cadrin@noaa.gov
Shelly Tallach	GMRI	stallach@gmri.org
Richard Allen	Scientific Systems	rballen@cox.net
Bob Muller	Florida FWC	robert.muller@myfwc.com
Joe DeAlteris	URI	jdealteris@uri.edu
Chet Chaffee	SCS	chaffe3@ahglobal.net
Frank Almeida	NEFSC	frank.almeida@noaa.gov
Andrea Toran	NEFSC	andrea.toran@noaa.gov

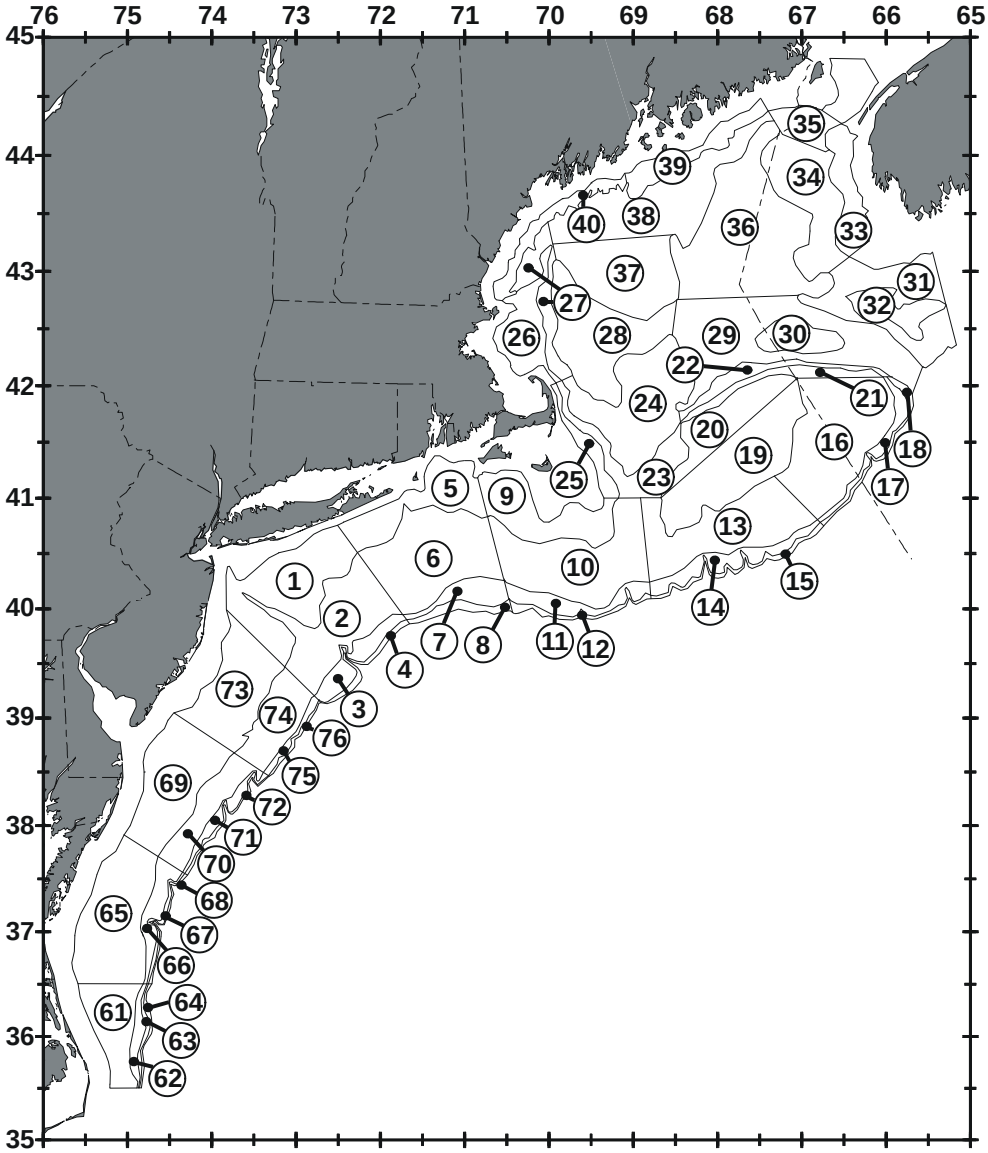

Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

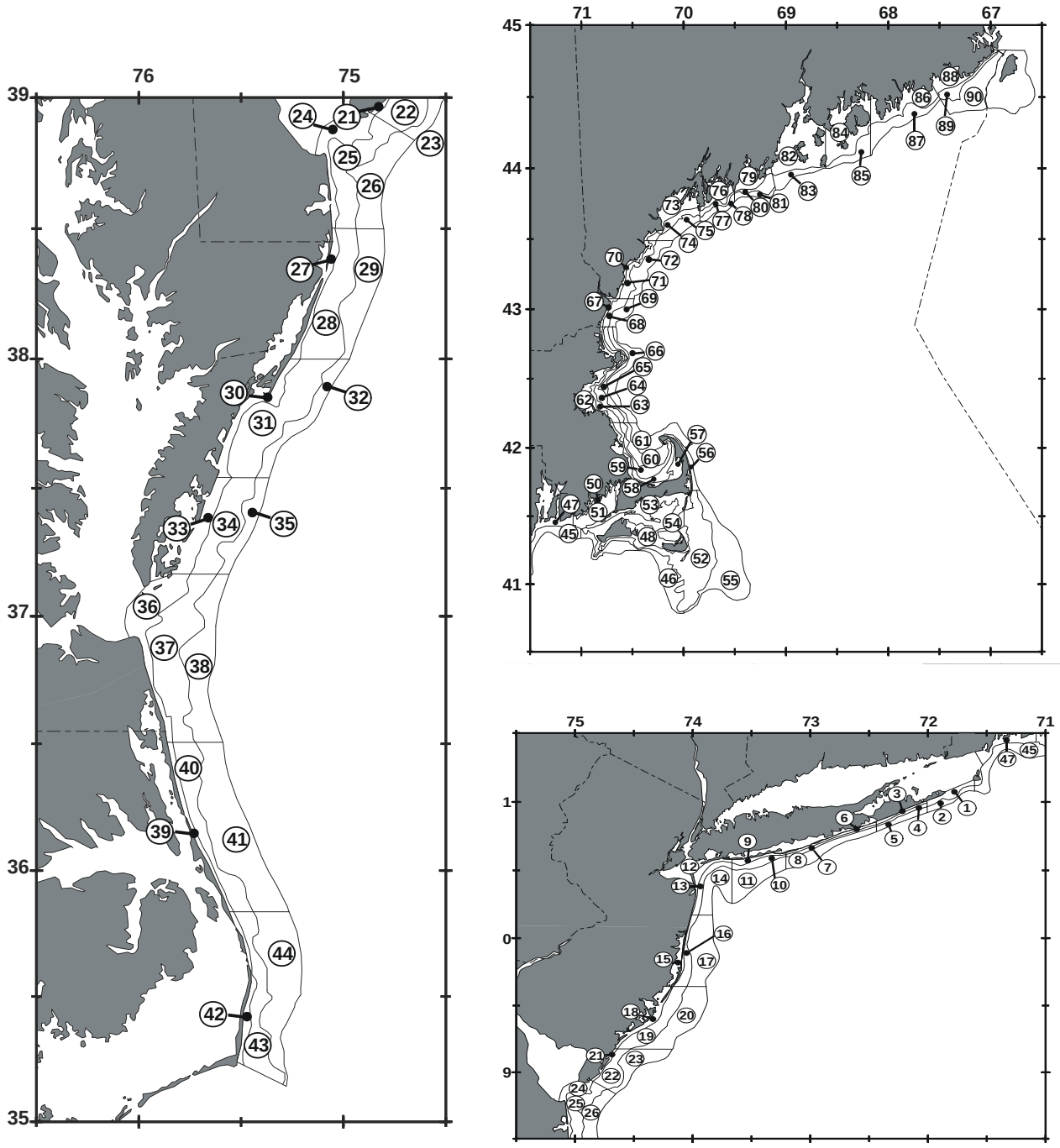

Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

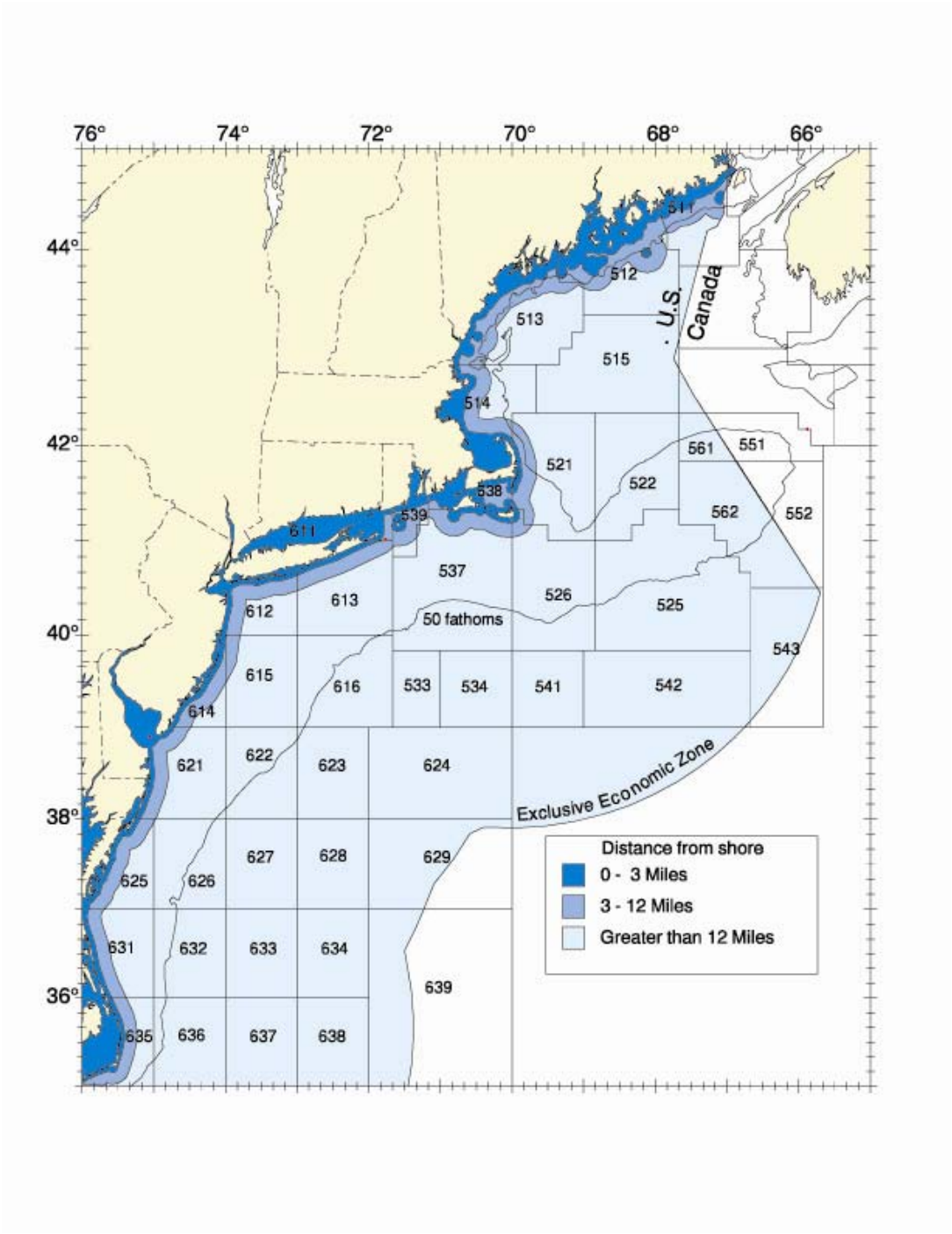

Figure 3. Statistical areas used for reporting commercial catches.

Skate Species Complex: Examination of Potential Biological Reference Points for the Northeast Region

by
Katherine Sosebee[1], Andrew Applegate[2], Elizabeth Brooks[1],
Todd Gedamke[3], and Michele Traver[1]

[1]NEFSC, 166 Water Street, Woods Hole, MA 02543
[2] NEFMC 50 Water Streeet, Newburyport, MA 01950
[3]SEFSC, 75 Virginia Beach Drive, Miami, FL

Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

Executive Summary

The seven species in the Northeast Region (Maine to Virginia) skate complex are: little skate (*Leucoraja erinacea*), winter skate (*L. ocellata*), barndoor skate (*Dipturus laevis)*, thorny skate (*Amblyraja radiata*), smooth skate (*Malacoraja senta*), clearnose skate (*Raja eglanteria*), and rosette skate (*L. garmani*). Landings have generally been increasing since 2000 and the 2007 reported commercial landings of 19,000 mt were the highest on record. Discard estimates from SAW/SARC 44 in 2006 were revised in this assessment based on Standardized Bycatch Reporting Methodology. Most differences were due to inclusion of more trips from the last few years (e.g., Special Access Programs, etc.).

The landings estimates were not disaggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007). Alternative methods to estimate landings by species were developed, each of which has strengths and weaknesses. The Review Panel concluded that progress had been made and future efforts should be encouraged, but that the Panel had insufficient time to explore the alternative methods in detail. Therefore, these approaches will be used in future modeling efforts, and will serve as an indication of the uncertainty in the catch of skates. Discards were also disaggregated to skate species using one method.

Survey indices by species were updated through 2007/2008 and aggregate indices were developed by area. These were used along with the catch data in An Index Method (AIM). Attempts to use this model were unsuccessful. Another model, SEINE (Survival Estimation in Non-Equilibrium Situations Model), was attempted to estimate fishing mortality. While the model estimated fishing mortality, it did so over a very long time period, but was not useful for producing annual estimates.

SPR-based reference points for three skate species, barndoor, winter, and thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships. Future assessments might determine stock status by comparing these depletion levels either with depletion in the surveys or from a stock assessment model that incorporates information about maturity. These results were not accepted for reference points at this time.

Until new models are constructed using the new catch by species information, the existing overfishing definitions, updated through 2007/2008 will remain the best available. For barndoor skate, the current (i.e., non-updated) definition will be retained. Stock status with respect to the updated estimates is described. For skates in general, no new measurable stock status definitions were identified.

Terms of Reference

The following Terms of Reference were provided to the Data Poor Stocks Working Group for peer review in December 2008:

a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for the following data poor stocks: Black sea bass; Deep-sea red crab; Scup; Skates; Atlantic wolffish.

b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.

c. Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depend on, and needs to be consistent

with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available.
d. Comment on what can be done to improve the information, proxies or assessments for each species.

Introduction

The seven species in the Northeast Region (Maine to Virginia) skate complex are distributed along the coast of the northeast United States from near the tide line to depths exceeding 700 m (383 fathoms). The species are: little skate (*Leucoraja erinacea*), winter skate (*L. ocellata*), barndoor skate (*Dipturus laevis)*, thorny skate (*Amblyraja radiata*), smooth skate (*Malacoraja senta*), clearnose skate (*Raja eglanteria*), and rosette skate (*L. garmani*).

In the Northeast region, the center of distribution for the little and winter skates is Georges Bank and Southern New England. The barndoor skate is most common in the Gulf of Maine, on Georges Bank, and in Southern New England. The thorny and smooth skates are commonly found in the Gulf of Maine. The clearnose and rosette skates have a more southern distribution, and are found primarily in Southern New England and the Chesapeake Bight. Skates are not known to undertake large-scale migrations, but they do move seasonally in response to changes in water temperature, moving offshore in summer and early autumn and returning inshore during winter and spring. Members of the skate family lay eggs that are enclosed in a hard, leathery case commonly called a mermaid's purse. Incubation time is 6 to 12 months, with the young having the adult form at the time of hatching (Bigelow and Schroeder 1953).

The first stock assessment for the skate complex was conducted in 1999 at SARC/SAW 30 (NEFSC 2000). At that time there was no Fishery Management Plan (FMP) in place. The National Marine Fisheries Service had been petitioned to list barndoor skate as endangered based on a paper published by Casey and Myers (1998) and was also asked to assess the other species in the complex. SARC 30 found no cause to list barndoor as endangered but recommended that the species remain on the candidate species list as well as to put thorny skate on the candidate species list. Biomass reference points were developed for all seven species and four were listed as overfished. Fishing mortality reference points were developed for winter and little skate and overfishing was occurring for winter skate.

An FMP was developed following SARC 30 by the New England Fishery Management Council (NEFMC) when they were informed of the overfished status of thorny and barndoor (winter and smooth biomass increased in the 1999 autumn survey and were no longer considered overfished). The FMP was implemented in September of 2003 with a primary requirement for mandatory reporting of skate landings by species by both dealers and vessels. Possession prohibitions of barndoor and thorny skate as well as smooth skate in the Gulf of Maine were also provisions of the FMP. A trip limit of 10,000 lbs was implemented for winter skate with a Letter of Authorization for the bait fishery (little skate) to exceed the trip limit. The biomass reference points developed at SARC 30 were maintained, but new fishing mortality reference points were developed.

The last stock assessment for the skate complex was conducted in 2006 at SARC/SAW 44 (NEFSC 2007). Several methods were attempted to develop fishing mortality estimates and biological reference points. These included the Gedamke-Hoenig length-based mortality estimator, length-based yield-per-recruit, spawner-per-recruit, and a length-tuned model. None of

these methods were accepted, although some had promise. SARC 44 did not change the biological reference points.

Commercial Fishery Landings

Skates have been reported in New England fishery landings since the late 1800s. However, commercial fishery landings, primarily from off Rhode Island, never exceeded several hundred metric tons until the advent of distant-water fleets and the industrial fishery during the 1950s and 1960s. Skate landings reached 9,500 mt in 1969, but declined quickly during the 1970s, falling to 800 mt in 1981 (Table 1, Figure 1). Landings then increased substantially; partially in response to increased demand for lobster bait, and more significantly, to the increased export market for skate wings. Landings increased to 12,900 mt in 1993 and then declined somewhat to 7,200 mt in 1995. Landings increased again and the 2007 reported commercial landings of 19,000 mt were the highest on record (Table 1, Figure 1).

United States landings of skates are reported in all months (Table 2). There is a relatively even distribution of landings across months, but the summer months do show a slightly higher percentage, probably due to the increased demand for lobster bait during those months.

Skate landings are primarily from Massachusetts and Rhode Island (mainly New Bedford and Point Judith) with 85-95% of the landings occurring in those two states (Table 3). Landings from other states did occur back through time and the table somewhat reflects better reporting as more states reported in the NMFS database. Also, the difference in total landings between Table B1.1 and B1.3 is likely the result of landings from the industrial fishery not included in the Weighout database. These landings were sampled during the 1960s and 1970s for species composition and prorated. Skates accounted for about 10% of those landings.

Otter trawls are the primary gear used to land skates in the United States, with some landings coming from sink gill nets (Table 4). In the last couple of years, landings from longline gear have increased slightly in importance. The increase in other gear reflects the new reporting system implemented in 2004.

Landings historically were taken from the Georges Bank and Southern New England during the early 1960s as the industrial fishery operated mainly out of Point Judith and the distant-water fleet fished mainly on Georges Bank (Table 5). Landings from Mid-Atlantic increased through the early 2000s while landings from Georges Bank in 2007 were the highest on record.

Landings are generally not reported by species, with over 99% of the landings reported as "unclassified skates" until the FMP was implemented in September of 2003 (Table 6). Wings are most likely taken from winter and thorny skates, the two species currently known to be used for human consumption. Bait landings are presumed to be primarily from little skate, based on areas fished and known species distribution patterns. Landings of barndoor and thorny skate are being reported by the dealers even though there is a possession prohibition for those two species. There are also wings reported for rosette, little and smooth which are known to be too small for wings. The distribution of skate landings by state and species also shows that some species are landed in areas that they do not occur (Table 7). For example, in 2004, barndoor were landed in Virginia which is too far south for barndoor skate.

Commercial Fishery Discards

Discard estimates from SAW/SARC 44 were revised in this assessment. The ratio-estimator used in this assessment is based on the methodology described in Rago et al. (2005)

and updated in Wigley et al 2007. It relies on a d/k ratio where the kept component is defined as the total landings of all species within a "fishery". A fishery is defined as a homogeneous group of vessels with respect to gear type (longline, otter trawl, shrimp trawl, sink gill net, and scallop dredge), quarter (months 1-4, 5-6, 7-8, 9-12), and area fished (GOM, GB, SNE, MA). Mesh size was not used to split out otter trawl trips or sink gill net trips. All trips were included if they occurred within this stratification regardless of whether or not they caught skates.

The discard ratio for skates in stratum h is the sum of discard weight over all trips divided by sum of kept weights over all trips:

$$\hat{R}_h = \frac{\sum_{i=1}^{n_h} d_{ih}}{\sum_{i=1}^{n_h} k_{ih}} \qquad (1)$$

where d_{ih} is the discards for skates within trip i in stratum h and k_{ih} is the kept component of the catch for all species. R_h is the discard rate in stratum h. The stratum weighted discard to kept ratio is obtained by weighted sum of discard ratios over all strata:

$$\hat{R} = \sum_{h=1}^{H} \left(\frac{N_h}{\sum_{h=1}^{H} N_h} \right) \hat{R}_h \qquad (2)$$

The total discard within a strata is simply the product of the estimate discard ratio R and the total landings for the fishery defined as stratum h, i.e., $D_h=R_hK_h$.

Missing cells were inputed using averages of existing cells. If information existed in the same area fished, the annual average discard ratio was applied in the missing cells. If the information was missing in the area fished, but available in the region (i.e. SNE and MA or GOM and GBK), then the annual average for that region was applied. There were some cases for the longline fishery in which the entire year was averaged for all areas or for a span of 12 years (1993-2004). The details of the imputation are given in Appendix 1.

To hindcast the discard estimates back to 1964, a three-year average (the earliest three years of data) of the discards of skates/landings of all species was used. The sensitivity of this estimate was examined using a five-year average and a time-series average (Figure 2). The trends in the total estimates are similar, with the time-series average giving the lowest estimate and the three-year average the highest estimates. Using the three estimates in any future modeling efforts will give some idea of the uncertainty in the data.

Estimated discards by fishery, region and half year for 1964-2007 are summarized in Tables 8-10. The new estimated discards are different than those estimated in SARC/SAW 44 (Figure 3). There are two main reasons for these differences. First, missing cells were imputed in the new method. This should lead to higher values in general. Second, the data for any Special Access Programs for 2005 -2007 were included in the new estimates. These trips showed a higher discard ratio than those outside the closed areas. These should be placed in a separate

stratum, however, there is no easy way to determine if a trip in the dealer database was fishing in an SAP. The coefficients of variation for the otter trawl are generally reasonable, while the scallop dredge estimates are highly variable (Table 11). Alternative stratification schemes were examined to determine if this had any impact on the magnitude of the discard estimates (Appendix 2). When all trips were included the estimates were all fairly similar.

The estimates from 1992-2007 were hind-cast using the first three years of the time series to compare actual estimates and hind-cast estimates (Figure 4). For years when the regulations were similar (mid-1990s), the hind-cast estimates were comparable to the actual estimates. In more recent years, management has changed and the estimates are not and probably should not be comparable.

Recreational Fishery Catch

Aggregate recreational landings of the seven species in the skate complex are relatively insignificant when compared to the commercial landings, never exceeding 300 mt during the 1981-1998 time series of Marine Recreational Fishery Statistics Survey (MRFSS) estimates. Little and clearnose skates are the most frequently landed species of the complex. For little skate, total landings varied between <1000 and 56,000 fish, equivalent to <1 to 15 mt, during 1981-1998. For clearnose skate, total landings varied between 2,000 and 145,000 fish, equivalent to 2 to 232 mt, during 1981-1998. The number of skates reported as released alive averages an order of magnitude higher than the reported landed number. Party/charter boats have historically been undersampled compared to the private/rental boat sector that accounts for most of the recreational catch, and may have a different discard rate. The recreational fishery release mortality rate of skates is unknown, but is likely comparable to that for flounders and other demersal species, which generally ranges from 10-15%. Assuming a 10-15% release mortality rate would suggest that recreational fishery discard mortality is of about the same magnitude as the recreational landings. Data from 1999 through 2005 were similar in magnitude.

Landings by Species Estimation

The landings estimates were not dis-aggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007). Alternative methods to estimate landings by species were developed, each of which has both strengths and weaknesses. Therefore, both sets of estimates were chosen to be used in any future modeling efforts as an indication of the uncertainty in the catch of skates.

The first method used the observer lengths of the kept component of the catch directly. In order to split the data into the bait (whole) and wing components of the fishery, a length cutoff of 60 cm was used, since there is no direct way of determining the disposition of the landings until recently. This seemed justified, since the maximum size in the bait fishery was instituted to also be close to the minimum accepted length for the wing fishery. Examination of the samples by the two main gear types also showed two groups of fish with a trough at about 60 cm (Figure 5). The data were apportioned into two regions, Gulf of Maine to Georges Bank (GOMGBK – Divisions 51 and 52), and Southern New England to Mid-Atlantic (SNEMA – Divisions 53 and Subarea 6). The number of fish measured in these regions was barely sufficient (Table 12) so no further areal division was attempted. Pooling over years within a region was still required to get an adequate number of fish (Figure 6). An average skate length-weight equation was applied to the samples and used to estimate the landings numbers at length for each market category (Figure 7).

Length compositions for each species for the two regions (GOMGBK – Offshore strata 13-30, 36-40, and Inshore strata 56-66; SNEMA – Offshore strata 1-12, 61-76, and Inshore strata 1-55) were estimated. The species length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial landings-at-length to estimate landings-at-length by species. The lengths had to be grouped into 5 cm intervals to avoid zero cells in the survey and all fish greater than 112 cm were set to be barndoor skate.

For the second method, a selectivity ogive was estimated for observed hauls in each skate fishery compared to the applicable surveys during 2004-2007. The data were fit using a three parameter logistic curve via Millar's (1992) SELECT model. Results of these logistic model fits are given in Table 13 and in Figures 8-11. In most cases where the parameters could be estimated, the L50s for winter and little skates were similar to the overall fit for all skate species (with a notable exception of little skates observed in the retained fraction of gillnet catches). Also the ogives by region were very similar to one another within each fishery and gear type. As a result, pooled selectivity ogives for each gear and skate fishery were used to determine the exploitable species composition at size in each survey stratum. In the following table, the L50s for the newly estimated ogives are compared with the PDT's assumed knife edge selectivity ogive.

Fishery	**L50 for selectivity ogive applied to survey weight per tow data**	**PDT assumed knife edge selectivity**
Trawl wing	66.9 cm	> 40 cm
Trawl whole/bait	44.4 cm and < 59 cm	< 59 cm
Gillnet	54.9 cm	> 65 cm

Average proportional weight per tow by three digit statistical area was re-estimated by determining an average stratum weight per tow and then computing an area-weighted average for the sampled strata within each three digit statistical area. While this approach does not readily allow estimation of variance (like a domain estimator), the averages computed in this way satisfy the conditions of the stratified random survey design. These average proportions of survey catch by skate species were then applied to the VTR data by gear type, fishery (product form), and trimester (corresponding to the spring, fall, and winter surveys).

Comparison of the two methods generally shows higher amounts of winter, clearnose, and rosette skate in method one (length composition) compared to the second method (selectivity ogive) and lower amounts of little, smooth, and thorny skate (Tables 14-15; Figures 12-14). Barndoor skate are generally comparable. The length composition method uses the annual length data when possible, but may be ignoring some sub-regional differences due to the low sample sizes. The selectivity ogive method, on the other hand, uses the sub-regional data while assuming that the length composition of the survey, once the skates are fully selected, reflects the length composition of the fishery. The two methods give a range of values and will both be used in any future modeling efforts.

Discards by Species Estimation

The discard estimates were not dis-aggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007).

The observer lengths of the discarded component of the catch were used by gear type. The data were apportioned into two regions, Gulf of Maine to Georges Bank (GOMGBK – Divisions 51 and 52), and Southern New England to Mid-Atlantic (SNEMA – Divisions 53 and Subarea 6). The number of fish measured in these regions was barely sufficient (Table 16) so no further areal division was attempted. Pooling over years, sometimes over the entire time series, within a region was still required to get an adequate number of fish (Figure 15). For longline gear, all samples were used for both regions. An average skate length-weight equation was applied to the samples and used to estimate the discard numbers at length by gear category (Figure 16).

Length compositions for each species for the two regions (GOMGBK – Offshore strata 13-30, 36-40, and Inshore strata 56-66; SNEMA – Offshore strata 1-12, 61-76, and Inshore strata 1-55) were estimated. The species length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial landings-at-length to estimate landings-at-length by species. The lengths had to be grouped into 5 cm intervals to avoid zero cells in the survey and all fish greater than 112 cm were set to be barndoor skate. The estimates by gear type and species are given in Table 17.

Research Survey Data- Total Stock Biomass

Indices of relative abundance have been developed from NEFSC bottom trawl surveys for the seven species in the skate complex, and these form the basis for most of the conclusions about the status of the complex. The NEFSC trawl survey has been conducted in the autumn from the Gulf of Maine to Southern New England since 1963 (Azarovitz 1981) and the Mid-Atlantic was added in 1967. A spring survey was started in 1968 with stations <= 27 m added in 1975. All statistically significant NEFSC gear, door, and vessel conversion factors were applied to little, winter, and smooth skate indices when applicable (Sissenwine and Bowman, 1978; NEFC 1991). Juvenile little and winter skates are not readily distinguished in the field. The numbers of juveniles were split between the two species based on the abundance of the adults in the same tow.

For the aggregate skate complex, the spring survey index of biomass was relatively constant from 1968 to 1980, then increased significantly to peak levels in the mid to late 1980s. The index of skate complex biomass then declined steadily until 1994, but increased until 2000 and has since decreased (Figure 17). If the species in the complex are divided into large (barndoor, winter, and thorny) and small sized skates (little, clearnose, rosette, and smooth), it is evident that the large increase in skate biomass in the mid to late 1980s was dominated by winter and little skate (Figure 17). The biomass of large sized skates steadily declined from the mid-1980s to the mid-1990s and has since been stable. The increase in aggregate skate biomass from the mid-1990s to 2000 was due to an increase in little skate and the subsequent decline is also due to little skate (Figure 17).

Indices were also derived for the aggregate skate complex by region. The index of skate biomass in the Gulf of Maine (Offshore strata 26-30, 36-40) was steady through the mid-1970s, started to decline and is currently among the lowest on record (Figure 18). The index for the Georges Bank region (Offshore strata 13-25) was relatively low at the start of the time series, increased to high levels in the 1980s and has since declined to low levels (Figure 18). For the Southern New England region (Offshore strata 1-12), the index either increased over time (the spring survey) or was stable (the fall survey) (Figure 19). The index for the Mid-Atlantic (Offshore strata 61-76) region has increased over time (Figure 19).

Indices of relative abundance for some of the species have also been developed from MADMF and CTDEP research surveys. Data are also available from the Maine-New Hampshire inshore survey, the ASMFC shrimp trawl survey, the monkfish survey, and the VIMS trawl survey but have not been developed into indices at this time.

The bootstrap methodology of Smith (1997) was continued from the previous SARC and also applied to the MADMF survey but the complete results are not shown. The data are shown to demonstrate what may be available for future modeling work.

Winter skate

In the NEFSC spring survey offshore strata (1968-2008), the annual total catch of winter skate has ranged from 160 fish in 1976 to 1,891 fish in 1985. In the NEFSC autumn survey offshore strata (1963-2007), the annual total catch of winter skate has ranged from 115 fish in 1975 to 1,187 fish in 1984. Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the GOM-MA offshore strata of about 7.9 fish, or 16.4 kg, per tow during 1985; autumn maximum catches equate to indices of 3.7 fish, or 13.3 kg, per tow in 1984 (Tables 18-19).

The catchability of winter skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series, especially for smaller winter skates. NEFSC winter survey (1992-2007) annual catches of winter skate have ranged from 841 fish in 1993 to 4,055 fish in 1996, equating to a maximum stratified mean catch per tow of 43.5 fish, or 25.2 kg, per tow in 1996 (Table 20). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of winter skate abundance and biomass from the NEFSC spring and autumn surveys were stable, but below the time series mean, during the late 1960s and 1970s (Figure 20). Winter skate indices increased to the time series mean by 1980, and then reached a peak during the mid 1980s. Winter skates indices began to decline in the late 1980s. Current NEFSC indices of winter skate abundance are below the time series mean, at about the same value as during the early 1970s. Current NEFSC indices of winter skate biomass are about 20% of the peak observed during the mid 1980s (Figure 20).

The NEFSC scallop dredge survey, as with the winter survey also catches winter skates mostly on Georges Bank and also does not sample in the Gulf of Maine and on the very shallowest portions of Georges Bank. However, the trends in abundance are similar to the trends in the spring and autumn surveys (Figure 21).

Indices of abundance for winter skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008. MADMF biomass indices of winter skate were moderate to high from 1981 through 1987. Thereafter, both spring and autumn indices declined to time series lows in 1989-1991. The spring index rebounded to moderate levels during 1992-1996 before dropping again to low values in the late 1990s and remaining low through 2008 (Figure 22). The autumn index is more erratic, but generally shows the same pattern.

Indices of abundance for winter skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). Annual CTDEP survey catches have ranged from 0 to 115 skates. CTDEP survey indices suggest that after increasing to a time

series high from 1984 through 1989, winter skate in Long Island Sound has declined slightly (Figure 23).

Little skate

In the NEFSC spring surveys (1976-2008), the annual total catch of little skate has ranged from 2,271 fish in 2006 to 16,406 fish in 1999 (Table 21). In the NEFSC autumn surveys (1975-2007), the annual total catch of little skate has ranged from 1,124 fish in 1993 to 6,523 fish in 2003 (Table 22). Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the GOM-MA inshore and offshore strata of about 28 fish, or 10 kg, per tow during 1999; autumn maximum catches equate to indices of 18 fish, or 7.7 kg, per tow in 2003 (Tables 21-22).

The catchability of little skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of little skate have ranged from 8,870 fish in 2003 to 18,418 fish in 1992, equating to a maximum stratified mean catch per tow of 170 fish, or 66 kg, per tow in 1992 (Table 23). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of little skate abundance and biomass from the NEFSC spring and autumn surveys were stable, but below the time series mean, during the 1970s. Little skate spring survey indices began to increase in 1982, reached a peak in 1999, and declined thereafter (Figure 24). Autumn survey indices have been relatively stable over the duration of the time series, with a slight increase in recent years (Figure 24). The application of the NEFSC gear conversion factors to spring survey indices decreased the indices in 1981 and earlier years by 75 percent. This may account for some of the mis-match between the spring and autumn surveys.

The NEFSC scallop dredge survey, as with the winter survey also catches little skates in all areas and also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank, and parts of Southern New England. However, the trends in abundance are similar to the spring and autumn surveys with the indices showing little trend over the time series (Figure 25).

Indices of abundance for little skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008 (Figure 26). MADMF biomass indices of little skate declined through the 1980's to time series lows in 1989 (autumn) and 1991 (spring). Biomass indices quickly rose to high levels in the early 1990's, and have since fluctuated without trend.

Indices of abundance for little skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). Little skate are the most abundant species in the skate complex in Long Island Sound, with annual CTDEP survey catches ranging from 142 to 837 skates. CTDEP survey indices suggest an increase in abundance of little skate in Long Island Sound through 1996 followed by a decline (Figure 27).

Barndoor skate

In the NEFSC spring surveys (1968-2008), the annual total catch of barndoor skate has ranged from 0 fish (several years during the 1970s and 1980s) to 325 fish in 2007 (Table 24). In

the NEFSC autumn surveys (1963-2007), the annual total catch of barndoor skate has ranged from 0 fish (several years in the 1970s and 1980s) to 120 fish in 1963 (Table 25). Calculated on a per tow basis, the autumn survey catches equate to maximum stratified mean number per tow indices for the GOM-SNE offshore strata of about 0.8 fish, or 2.6 kg, per tow in 1963 while the spring maximum is 1.5 fish, or 6.8 kg, per tow in 2007 (Tables 24-25). The spring survey index was driven mainly by one large tow (277 fish; >1500 kg).

The catchability of barndoor skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series and may be particularly higher for smaller skates as in winter skates. NEFSC winter survey (1992-2007) annual catches of barndoor skate have ranged from 0 fish in 1992 to 355 in 2006, equating to a maximum stratified mean catch per tow of 3.2 fish, or 3.0 kg, per tow in 2006 (Table 26). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of barndoor skate abundance and biomass from the NEFSC spring and autumn surveys were at their highest values during early to late 1960s, and then declined to 0 fish per tow during the early 1980s. Since 1990, both spring and autumn survey indices have steadily increased, with the spring survey at the highest value and the autumn survey nearing the peak values found in the 1960s (Figure 28).

The NEFSC scallop dredge survey, as with the winter survey also catches winter skates mostly on Georges Bank and also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank, and parts of Southern New England. However, the trends in abundance are similar to the trends in the spring and autumn surveys showing a large increase since 1992 while the biomass is much noisier (Figure 29).

Thorny skate

In the NEFSC spring surveys (1968-2008), the annual total catch of thorny skate has ranged from 29 fish in 2006 to 574 fish in 1973 (Table 27). In the NEFSC autumn surveys (1963-2007), the annual total catch of thorny skate has ranged from 36 fish in 2005 to 874 fish in 1978 (Table 28). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the GOMSNE offshore strata of about 2 to 3 fish, or about 6.0 kg, per tow during the early 1970s (Tables 27-28).

NEFSC spring and autumn survey indices for thorny skate have declined continuously over the last 40 years. Indices of thorny skate abundance and biomass from the NEFSC spring and autumn surveys were at a peak during the early 1970s, reaching 2.9 fish per tow (5.3 kg per tow) in the spring survey and 1.8 fish per tow (5.9 kg per tow) in the autumn survey. Kulka and Mowbray (1998) indicated a similar period of high abundance for thorny skate in Canadian waters. NEFSC indices of thorny skate abundance have declined steadily since the late 1970s, reaching historically low values by 2005-2007 that are less than 10% of the peak observed in the 1970s (Figure 30).

The NEFSC scallop dredge survey also catches thorny skates primarily on the edges of Georges Bank and a sharp decline followed by no trend (Figure 31). The scallop survey also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank and parts of Southern New England.

Indices of abundance for thorny skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008. MADMF indices of thorny skate biomass have been variable over the time series, but there is a decreasing trend evident in both the spring and autumn time series. The spring index has stabilized around the median of 0.2 kg/tow throughout the 2000's, while the autumn index has been below the median of 0.6 kg/tow since 1994 except for 2001 and 2002 (Figure 32).

Smooth skate

In the NEFSC spring surveys (1968-2008), the annual total catch of smooth skate has ranged from 12 fish in 1996 to 179 fish in 1973 (Table 29). In the NEFSC autumn surveys (1963-2007), the annual total catch of smooth skate has ranged from 10 fish in 1976 to 130 fish in 1978 (Table 30). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the GOM-MA offshore strata of 0.6 to 1.6 fish, or about 0.6 to 0.9 kg, per tow during the 1970s (Tables 29-30).

Indices of smooth skate abundance and biomass from the NEFSC surveys were at a peak during the early 1970s for the spring series and the late 1970s for the autumn series (Figure 33). NEFSC survey indices declined during the 1980s, before stabilizing during the early 1990s at about 25% of the autumn and 50% of the spring survey index values of the 1970s.

The NEFSC scallop dredge survey also catches smooth skates primarily on the edges of Georges Bank and the indices have slightly increased (Figure 34). The scallop survey also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank and parts of Southern New England.

Clearnose skate

In the NEFSC spring surveys (1976-2008), the annual total catch of clearnose skate has ranged from 9 fish in 1979 to 136 fish in 1993 (Table 31). In the NEFSC autumn surveys (1975-2007), the annual total catch of clearnose skate has ranged from 19 fish in 1983 to 221 fish in 2001 (Table 32). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the Mid-Atlantic offshore and inshore strata set of 1.2-1.6 fish, or about 0.8-0.9 kg, per tow during the mid 1990s and 2000s (Tables 31-32).

The catchability of clearnose skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of clearnose skate have ranged from 343 fish in 1999 to 3,086 fish in 1996, equating to a maximum stratified mean catch per tow of 12 fish or 15 kg per tow in 1996 (Table 33). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine, and has been discontinued.

NEFSC spring and autumn survey indices for clearnose skate increased from the mid-1980s through 2000, declined to about average values, and increased slightly in the last few years (Figure 35).

Indices of abundance for clearnose skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). The CTDEP survey had caught

very few clearnose skate, with annual catches ranging from 0 to 20 skates through 1998, but the indices have increased in Long Island Sound over the times series with 100 caught in 2005 (Figure 36).

Rosette skate

In the NEFSC spring surveys (1968-2008), the annual total catch of rosette skate has ranged from 0 fish, in 1970 and1984, to 70 fish in 1977 (Table 34). In the NEFSC autumn surveys (1967-2005), the annual total catch of rosette skate has ranged from 1 fish, most recently in 1982, to 46 fish in 1999 (Table 35). Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the Mid-Atlantic offshore strata set of about 0.6 fish, or about 0.1 kg, per tow during 1977 (Tables 34-35).

The catchability of rosette skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of rosette skate have ranged from 143 fish in 1993 to 1029 fish in 2003, equating to a maximum stratified mean catch per tow of 2.8 fish or 0.7 kg per tow in 2003 (Table 36). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has since been discontinued.

Indices of rosette skate abundance and biomass from the NEFSC surveys were at a peak during 1975-1980, before declining through 1986. NEFSC survey indices for rosette skate increased from 1986 through 2001, declined slightly and recent indices are near the peak values of the late 1970s (Figure 37).

Research Survey Data- Spawning Stock Biomass

Maturity information was available in some form for all species to split the survey length information into mature and immature animals (Table 37). The series chosen for each species was the same as chosen for reference points at SARC30. There is a protracted spawning as females likely lay eggs year round so there is no need to pick a season based on spawning time. The autumn survey was used for all species except little as it is generally the longest. For little skate, the spring series from 1982 on was used to avoid gear conversion issues.

Winter skate SSB generally follows the pattern of the autumn total biomass index with very low values in the 1970s followed by the large expansion of the size composition in the 1980s (Table 38; Figure 38). The index of SSB declined in the mid- to late 1990s, increased slightly, and is currently at low values. Little skate SSB has been fairly stable through the time series with slightly higher values from 1999-2004 than in the 1980s and early 1990s (Table 38; Figure 38). The pattern in barndoor skate SSB indices is much the same as that of total biomass with high values in the early 1960s, followed by very low to nonexistent values in the 1970s and 1980s, and then a consistent increase in the 1990s and 2000s (Table 38; Figure 38). The decline in thorny skate SSB indices is more pronounced than for the total biomass index (Table 38; Figure 38). Smooth skate SSB indices are very variable, but exhibit a slight decline over the time series (Table 38; Figure 38). Clearnose skate SSB has increased over the time period (Table 38; Figure 38). Rosette skate SSB has been variable but has generally increased (Table 38; Figure 38).

Fishing Mortality Estimates

Gedamke and Hoenig (2006) developed a method to estimate mortality from mean length data in nonequilibrium situations, now called Survival Estimation in Non-Equilibrium Situations Model (SEINE, available at http://nft.nefsc.noaa.gov/). It is an extension of the Beverton-Holt length-based mortality estimator that assumes constant recruitment throughout the time series and mortality at fixed levels for certain periods within the time series. The approach allows for the transitory changes in mean length to be modeled as a function of mortality rate changes. After an increase in mortality, mean length will gradually decrease due to larger animals being less prevalent in the population. After a decrease in mortality, mean length will increase slowly due to growth of the fish in the population. The rates of change in both cases depend on the von Bertalanffy growth parameters and the magnitude of change in the mortality rates. Since the method requires only a series of mean length above a user defined minimum size and the von Bertalanffy growth parameters, it can be applied in many data poor situations. Gedamke and Hoenig (2006) demonstrated the utility of this approach using both simulated data and an application to data for goosefish caught in the NEFSC fall groundfish survey.

Most of the information for the six species suggests that there is one break-point in the time series. This is not useful in monitoring the species on an annual basis. Further modeling efforts are required to estimate fishing mortality.

Biological Reference Points

Current Reference Points

The existing biomass reference points were developed at SARC 30 (NEFSC 2000) and maintained at SARC 44 (NEFSC 2007) with B_{MSY} Proxy formulated as the 75th percentile of the given time series of each species, except barndoor (Table 39) and half that value for $B_{threshold}$. It was assumed that all species had at some time passed through B_{MSY} at some point in the time series. For barndoor skate, the mean of the first four years of the autumn survey were used instead, given that biomass had been extremely low during most of the time series. To reduce the variability in the survey estimates, a three-year moving average of the survey indices was proposed to evaluate stock status for all species (Table 40).

The fishing mortality reference points developed at SARC 30 were not accepted by the NEFMC and a different method for evaluating fishing mortality was developed by the Plan Development Team (PDT). The thresholds for fishing mortality are based on annual percentage declines of the three-year average of the NEFSC trawl survey time series chosen for the biomass reference points. The percentages are specified for each species individually based on historical variation within the survey. The thresholds also include what is termed a precautionary "backstop" that indicates that overfishing is occurring if the trawl survey mean weight per tow declines for three consecutive years. The main part of the definition is that overfishing is occurring when the three-year moving average of the given survey biomass index declines by more than the average CV of the time series. The resulting overfishing status determinations are shown in Table 41.

Extension of time series

One alternative biomass reference point is to use the 75th percentile of the series, but to add the nine years of survey data since the last SARC (Table 42). This gives slightly lower

estimates of B_{target} for winter, thorny, and smooth, a much lower estimate for barndoor, and higher estimates for little, clearnose, and rosette.

An Index Method (AIM)

An Index Method (AIM, available at http://nft.nefsc.noaa.gov/) was attempted for all seven species using both spring and autumn surveys. For this method, the replacement ratios, defined as the biomass index in the current year divided by the average biomass indices from the previous 5 years was calculated. Autumn and spring survey biomass indices and total landings and total catch were used to compute the relative exploitation rates, defined as the catch in the current year divided by the 3 year average survey biomass index for the current year and the previous and following years. These relative exploitation rates (or relative F) may be considered a proxy for F. The relationship between replacement ratios and relative F was evaluated by a linear regression of the Log_e replacement ratio on Log_e relative F. None of the relationships were significant and some were actually positive. This method was also attempted for the aggregate skate landings/catch for the four regions. These model runs were also unsuccessful.

SPR- Based Reference Points

SPR-based reference points for three skate species, barndoor, winter, and thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships (Appendix 3). Estimated overfishing reference points for these three species are $F_{25\%}$, $F_{37\%}$, and $F_{46\%}$, respectively. Future assessments could estimate comparable F's from mean length models (SEINE, e.g.), or from age-specific assessment models provided discards and landings could be disaggregated to species level. Estimates of overfished reference points are also SPR based, and are defined in terms of depletion, i.e. the proportion of spawners relative to unexploited levels. For barndoor, winter, and thorny skates, the depletion reference points are 0.20, 0.27, and 0.32, respectively. Future assessments could determine stock status by comparing these depletion levels either with depletion in the surveys or from a stock assessment model that incorporates information about maturity. There are several important caveats for the methods used in this working paper, namely, that a fixed value of M was assumed for all ages, that the errors in variables problem was ignored in fitting the stock recruit relationship (*status quo*), and that no fishing is assumed to occur prior to the age of recruitment. The sensitivity to the assumed M value is addressed by exploring alternative values. If any fishing were to occur prior to the age of recruitment, then the estimated slope at the origin (*a* in the Beverton-Holt function) would be biased low, leading to an SPR reference point having a positive bias.

Reference Point Recommendation

In general for skates, no new measurable alternative BRPs were identified or recommended. Until new models are constructed using the new catch by species information, the existing overfishing definitions, using information updated through 2007/2008 (except for barndoor skate), will remain in place (Table 43; Figure 39). For barndoor skate, the reference point estimates will not be updated through 2007/2008 because barndoor skate survey indices were extremely low during most of the time series and have been increasing recently (Table 40).

Under the current definition, a stock of skates is designated as overfished when the three year moving average of the NEFSC survey index is less than $B_{THRESHOLD}$. For each of the skate stocks, estimates of the three year moving average survey index are provided in Table 40.

Overfished status determinations can be made by comparing the survey index estimates (Table 40) to the recommended biomass-based reference points (Table 43).

The overfishing status determinations are shown in Table 41 (See additional description in the earlier section labeled "Current Reference Points".

Research Recommendations

1) Given the new information on catch by species, efforts should be made to use a more complex model such as Stock Synthesis.
2) The identification of the species composition of the skate catch should be improved.
3) Age and growth studies, for all seven species in the complex, should be continued.
4) Fecundity studies, for all seven species in the complex, are needed. Use of life history models requires these data, and may prove useful in establishing biological reference points for the skate species.
5) Estimates of commercial and recreational fishery discard mortality rates, for different fishing gears and coastal regions and/or bottom types, for all seven species in the complex, are needed.
6) Studies of the stock structure of the species in the skate complex are needed to identify unit stocks. Stock identification studies, especially for barndoor, thorny, winter, and little skate, are needed.

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Skate Complex; Tables

Table 1. Total commercial landings of skate (mt) in NAFO subareas 5 and 6 by country from 1960-2007. U.S. landings are from NAFO database from 1964-1978, weighout from 1979-2007.

	US	USSR	Others	Total
1964	4081	0	2	4083
1965	2343	0	20	2363
1966	2738	0	106	2844
1967	2715	2121	62	4898
1968	2417	3974	92	6483
1969	3045	6410	7	9462
1970	1583	2544	1	4128
1971	900	5000	5	5905
1972	866	7957	0	8823
1973	1191	6754	18	7963
1974	2026	1623	2	3651
1975	752	3216	0	3968
1976	754	412	46	1212
1977	1143	240	35	1418
1978	1130	216	7	1353
1979	1280	79	64	1423
1980	1577	0	73	1650
1981	838	0	9	847
1982	878	0	0	878
1983	3603	0	0	3603
1984	4157	0	0	4157
1985	3984	0	0	3984
1986	4159	0	94	4253
1987	5078	0	0	5078
1988	7255	0	9	7264
1989	6707	0	0	6707
1990	11403	0	0	11403
1991	11332	0	0	11332
1992	12525	0	0	12525
1993	12904	0	0	12904
1994	8783	0	0	8783
1995	7217	0	0	7217
1996	14213	0	0	14213
1997	10945	0	0	10945
1998	13832	0	0	13832
1999	11684	0	0	11684
2000	13360	0	0	13360
2001	13120	0	0	13120
2002	13004	0	0	13004
2003	15005	0	0	15005
2004	16072	0	0	16072
2005	14113	0	0	14113
2006	16158	0	0	16158
2007	19085	0	0	19085

Table 2. U.S. commerical landings (mt, live wt) of skates (all species) by month from 1964-2007.

	Month													
year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
1964	4050.3	2.0	3.9	3.6	3.1	2.0	1.6	0.9	1.3	1.6	2.0	2.1	6.4	4081.0
1965	2304.4	5.4	7.2	7.5	4.3	2.4	0.4	0.6	1.2	0.6	2.3	2.6	4.2	2343.0
1966	2707.1	6.4	7.3	6.0	1.0	0.9	0.2	0.1	0.7	1.7	1.4	2.4	2.9	2738.0
1967	2643.3	15.1	7.3	18.1	7.7	3.0	1.6	0.6	0.4	1.8	6.1	2.9	7.1	2715.0
1968	2381.3	10.3	1.9	5.3	1.3	1.5	1.3	1.5	2.6	3.0	2.8	2.5	1.7	2417.0
1969	2993.4	4.1	6.2	5.7	6.2	2.5	2.3	3.1	3.2	3.0	5.0	5.7	4.6	3045.0
1970	1513.4	6.1	8.6	13.9	7.0	4.1	3.4	5.6	5.3	8.3	4.1	2.1	1.1	1583.0
1971	836.7	4.9	6.2	8.5	7.3	7.7	2.7	3.0	2.8	3.5	8.2	3.9	4.7	900.0
1972	780.1	7.2	6.9	12.1	12.3	9.1	4.9	5.7	7.8	4.3	4.2	5.9	5.5	866.0
1973	1104.1	8.3	3.9	10.4	12.4	7.1	6.7	7.1	7.0	8.1	7.1	4.7	4.1	1191.0
1974	1945.9	5.7	4.9	5.6	12.3	8.0	4.6	4.4	12.3	6.7	5.2	2.6	7.8	2026.0
1975	637.9	7.3	10.1	16.6	16.2	13.0	7.3	6.7	7.6	9.8	5.6	6.9	6.9	752.0
1976	641.8	8.4	12.5	19.2	22.4	9.6	4.3	8.1	4.7	6.9	3.1	6.3	6.8	754.0
1977	994.7	15.4	19.7	27.9	20.0	9.0	8.9	6.8	11.0	7.0	8.8	9.3	4.5	1143.0
1978	827.4	19.3	24.7	11.7	29.8	30.5	46.4	33.9	26.2	23.2	20.9	19.3	16.7	1130.0
1979	787.4	24.8	24.8	46.5	62.6	50.4	28.1	29.4	55.5	38.8	42.1	52.9	36.5	1279.6
1980	961.1	61.5	112.6	121.1	82.8	63.9	27.3	26.4	24.4	22.8	27.4	20.5	25.4	1577.2
1981	509.9	33.9	30.8	54.4	31.1	26.7	25.3	15.1	24.5	23.1	12.3	19.2	31.9	838.4
1982	449.5	30.4	23.3	54.0	47.5	58.2	18.9	25.3	35.1	32.3	34.4	31.3	38.2	878.1
1983	2720.3	84.1	95.9	134.0	95.4	102.3	76.3	44.1	66.1	53.3	37.0	56.6	37.5	3603.0
1984	3325.7	99.4	127.3	134.9	108.6	84.0	36.7	30.9	29.0	25.9	37.0	54.2	63.0	4156.5
1985	3220.7	85.4	85.5	150.6	142.7	31.6	29.9	33.2	29.9	28.8	37.7	59.3	48.6	3984.1
1986	3173.4	98.6	89.7	149.7	147.8	91.8	36.4	33.7	49.0	28.2	72.6	86.3	102.5	4159.5
1987	3638.7	83.8	114.3	207.7	227.0	245.3	106.2	40.3	53.0	33.8	87.6	101.5	139.1	5078.4
1988	5141.7	281.6	338.2	378.7	284.0	150.3	74.5	154.5	137.9	75.0	54.1	66.2	118.8	7255.5
1989	4157.8	240.1	150.3	227.1	454.3	292.6	102.6	142.2	272.3	221.9	174.8	173.0	98.4	6707.3
1990	4252.9	136.6	182.0	424.8	834.4	948.5	1174.9	763.8	818.7	624.4	265.9	542.3	433.4	11402.5
1991	4255.9	464.0	423.8	460.9	606.0	419.8	370.4	658.1	925.7	515.5	565.5	958.9	708.0	11332.3
1992	4782.2	517.3	457.7	510.1	567.1	564.3	816.2	764.4	718.2	862.3	639.1	771.1	555.4	12525.3
1993	4860.4	335.1	265.6	471.2	741.7	875.2	823.2	1005.6	859.1	712.4	535.5	864.0	555.0	12904.0
1994	175.5	338.2	309.8	291.7	501.5	855.1	1238.5	780.9	1263.7	960.6	937.7	787.3	342.9	8783.3
1995	1.0	183.8	285.7	413.6	515.5	752.0	915.7	768.4	752.2	557.7	724.8	897.2	449.7	7217.2
1996	2.3	224.6	229.3	206.5	360.1	1012.0	1389.7	1539.8	1577.6	1720.4	2440.4	2411.8	1098.4	14212.8
1997		530.8	469.9	597.5	395.5	969.4	1127.6	1181.8	1189.6	1062.3	1084.2	1305.2	1031.1	10944.8
1998		518.9	589.8	625.4	814.9	1406.0	1702.2	1643.9	1512.7	1551.5	1224.9	1277.1	964.5	13831.8
1999		511.2	401.0	591.8	678.6	1295.5	1436.2	1039.3	1137.7	1388.8	1055.8	1250.0	898.1	11683.9
2000		667.8	615.2	1024.2	826.2	1187.7	1594.2	1188.5	1534.6	1270.1	946.4	1583.6	921.1	13359.7
2001		802.4	588.6	956.2	967.3	984.0	1058.2	1150.5	1465.1	1197.3	1115.1	1692.1	1143.6	13120.4
2002		742.3	730.7	783.2	1093.9	773.5	1372.6	998.7	1488.6	1247.8	1352.1	1264.4	1156.3	13004.0
2003		548.3	447.6	857.4	1043.7	1006.6	1183.0	1632.9	1867.9	1889.1	1993.3	1563.3	971.9	15004.9
2004		538.1	1278.0	1305.0	1391.0	1155.1	1456.9	2008.8	1557.9	1573.6	1115.7	1541.6	1150.2	16071.8
2005		871.6	1204.4	1077.6	1176.6	1071.0	1314.7	1763.2	1689.3	1336.1	828.5	974.5	805.5	14113.0
2006		939.8	1036.9	1490.8	1564.6	921.8	1250.3	1741.1	1847.2	1071.4	1498.6	1653.3	1142.1	16157.7
2007		778.6	702.9	1225.9	1481.5	1254.7	2524.2	2916.6	2498.0	1587.6	1528.2	1348.4	1238.1	19084.8

Table 3. U.S. commercial landings (mt, live wt) of skates (all species) by state from 1964-2007. Data are from weighout database.

	STATE											
year	CT	DE	ME	MD	MA	NH	NJ	NY	NC	RI	VA	Total
1964					28.2						2.4	30.7
1965					38.1						0.4	38.6
1966					30.1						0.8	30.9
1967					71.1						0.5	71.7
1968					35.7							35.7
1969					51.6							51.6
1970					69.0						0.6	69.6
1971					61.9						1.4	63.3
1972					85.2						0.7	85.9
1973				1.5	80.9						4.6	86.9
1974				8.8	67.2						4.1	80.1
1975				14.9	94.8						4.4	114.1
1976				36.2	74.9						1.1	112.2
1977				62.6	82.0						3.7	148.3
1978				86.9	161.8			2.9			50.9	302.6
1979				181.1	259.0			0.7			51.5	492.2
1980				197.5	297.5			0.4			120.7	616.1
1981				151.2	137.3		2.2	0.8			37.0	328.4
1982				175.0	210.4		3.9	0.1			39.3	428.7
1983				258.8	455.0		3.3	0.6			165.0	882.7
1984				230.8	445.4		2.6	0.7			150.8	0.5	830.8
1985				144.5	409.3		2.3	2.4			204.9	763.3
1986				107.6	363.8		1.1	10.8	55.0		447.2	0.6	986.1
1987				168.9	746.2		20.6	8.9	133.1		361.9	1439.7
1988				81.9	1376.2		51.9	10.5	172.2		420.9	2113.7
1989		12.2		99.8	2030.1		18.6	18.2	107.7		4420.0	0.7	6707.3
1990		146.9		47.1	1.7	5742.0	10.5	8.8	162.4		5282.1	1.1	11402.5
1991		113.3		16.9		5696.1	12.4	125.4	56.9		5310.7	0.6	11332.3
1992		97.0		45.1	0.6	5923.3	10.1	267.2	231.1		5950.1	0.8	12525.3
1993		237.9		167.1	4.1	6118.5	9.5	376.1	168.2		5820.3	2.3	12904.0
1994		175.5		442.9	46.6	6616.4	37.2	186.1	225.3		1047.1	6.4	8783.3
1995		309.3		349.2	45.6	2926.5	24.6	291.4	141.7		3111.5	17.3	7217.2
1996		432.0		267.4	55.8	9016.9	20.3	339.2	164.2		3908.8	8.3	14212.8
1997		357.5		221.0	97.8	3933.4	17.0	794.8	374.5	9.4	5131.4	8.1	10944.8
1998		441.9		162.2	95.6	6325.0	19.1	807.8	575.0	9.1	5372.5	23.6	13831.8
1999		518.3		218.8	63.5	4809.3	26.3	636.8	396.8	2.6	4911.9	99.6	11684.0
2000		493.8		138.0	65.6	6517.8	38.4	564.6	387.7	20.6	4825.0	308.2	13359.7
2001		618.9		138.2	55.5	6683.5	33.2	624.7	366.7	0.1	4536.2	63.4	13120.4
2002		367.6		137.2	52.0	6335.0	24.5	582.4	462.9	0.3	5029.6	12.7	13004.0
2003		433.7		76.4	26.9	8098.0	14.9	448.7	353.3	0.8	5516.6	35.7	15004.9
2004		441.7	0.0	13.3	6.2	10075.9	10.6	374.3	222.7	0.5	4881.0	45.7	16071.8
2005		353.4		10.9	8.4	8988.9	9.4	334.8	157.5	0.5	4219.1	30.3	14113.0
2006		259.6		1.5	14.6	11132.7	11.2	451.6	229.3	0.1	4051.5	5.5	16157.7
2007		256.2		29.9	18.2	13554.4	5.6	524.1	324.9	0.3	4319.4	51.8	19084.8

Table 4. U.S. Commercial landings (mt, live wt) of skates (all species) by gear type from 1964-2007. Landings are from weighout database.

	gear				
year	longline	otter trawl	other	sink gillnet	Total
1964	0.1	30.5		0.0	30.7
1965	0.3	38.2		0.0	38.6
1966		30.9			30.9
1967		71.7			71.7
1968		35.7			35.7
1969		51.5		0.0	51.6
1970	0.6	68.8	0.0	0.2	69.6
1971	1.1	62.0		0.1	63.3
1972	3.7	80.8	0.1	1.3	85.9
1973	7.0	77.9	1.9	0.2	86.9
1974	10.5	64.3	0.2	5.1	80.1
1975	11.7	101.4	0.1	0.8	114.1
1976	16.2	93.3	0.2	2.5	112.2
1977	13.4	126.8	0.9	7.2	148.3
1978	4.4	290.0	3.2	5.0	302.6
1979	18.4	456.0	5.8	12.0	492.2
1980	16.5	577.9	6.0	15.6	616.1
1981	5.1	311.7	1.2	10.4	328.4
1982	2.0	408.4	7.4	10.8	428.7
1983	3.4	846.2	22.5	10.6	882.7
1984	5.0	796.5	19.1	10.3	830.8
1985	3.7	721.5	17.8	20.3	763.3
1986	6.6	954.4	14.2	10.9	986.1
1987	22.4	1384.4	16.1	16.8	1439.7
1988	5.7	2070.7	22.2	15.2	2113.7
1989	30.6	6636.1	27.3	13.4	6707.3
1990	3.8	11339.6	47.7	11.5	11402.5
1991	24.3	11169.9	77.0	61.1	11332.3
1992	21.9	12242.5	35.1	225.8	12525.3
1993	63.4	11913.6	204.6	722.3	12904.0
1994	193.9	7174.3	374.9	1040.1	8783.3
1995	98.6	5725.5	416.2	976.8	7217.2
1996	54.3	12879.6	141.9	1137.1	14212.8
1997	47.6	9157.6	394.0	1345.5	10944.8
1998	53.9	11704.7	449.8	1623.5	13831.8
1999	38.2	10073.7	105.5	1466.6	11684.0
2000	37.7	11444.7	81.7	1795.5	13359.7
2001	13.2	10808.4	46.4	2252.5	13120.4
2002	14.2	9630.3	45.0	3314.5	13004.0
2003	30.0	10553.2	65.1	4356.5	15004.9
2004	24.7	11355.7	665.7	4025.7	16071.8
2005	175.9	9249.8	1078.6	3608.8	14113.0
2006	11.4	10523.0	838.2	4785.0	16157.7
2007	12.2	12531.0	339.1	6202.6	19084.8

Table 5. Landings of skate by region.

	gm	gb	sne	ma
1968	30	2641	3802	10
1969	50	252	8425	735
1970	62	1742	2178	146
1971	51	2681	3014	159
1972	264	5384	3087	88
1973	60	5097	2701	105
1974	63	1116	2359	113
1975	95	2965	722	186
1976	96	450	487	179
1977	126	215	823	254
1978	181	94	871	207
1979	469	215	559	179
1980	609	394	465	182
1981	344	122	272	109
1982	434	165	216	63
1983	486	240	2824	53
1984	445	234	3411	71
1985	372	183	3379	50
1986	309	103	3634	207
1987	585	333	3968	193
1988	1140	404	5394	326
1989	909	1243	4395	160
1990	1076	4905	5249	173
1991	979	4801	5306	246
1992	644	4944	6430	508
1993	982	5143	5826	953
1994	800	5964	1340	680
1995	590	2060	3826	742
1996	579	8210	4579	845
1997	549	3095	5802	1498
1998	1064	5160	5392	2216
1999	909	3997	4390	2388
2000	1050	5517	4508	2284
2001	689	5784	4294	2354
2002	799	4936	4516	2753
2003	491	6811	5575	2129
2004	259	8632	5060	2121
2005	310	6900	5571	1333
2006	337	8367	6173	1280
2007	358	11502	5664	1561

Table 6. U.S. landings (mt, live wt) of skates by species and markey category from 1964-2007. Landings are from weighout database.

	Species and Market Category																	
YEAR	Uncl.	Uncl.	Winter	Winter	Little	Little	Barndoor	Barndoor	Thorny	Thorny	Smooth	Smooth	Clearnose	Clearnose	Rose	Rose	Total	
	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings
1964	30.7																30.7	0.0
1965	38.6																38.6	0.0
1966	30.9																30.9	0.0
1967	71.7																71.7	0.0
1968	35.7																35.7	0.0
1969	51.6																51.6	0.0
1970	69.6																69.6	0.0
1971	63.3																63.3	0.0
1972	85.9																85.9	0.0
1973	86.9																86.9	0.0
1974	80.1		0.0														80.1	0.0
1975	114.1																114.1	0.0
1976	112.2																112.2	0.0
1977	148.3																148.3	0.0
1978	302.6																302.6	0.0
1979	492.2																492.2	0.0
1980	616.1																616.1	0.0
1981	328.4																328.4	0.0
1982	277.2	151.4															277.2	151.4
1983	169.6	713.0															169.6	713.0
1984	68.1	762.8															68.1	762.8
1985	68.3	695.0															68.3	695.0
1986	262.6	723.5															262.6	723.5
1987	87.5	1352.2															87.5	1352.2
1988	74.2	2039.6															74.2	2039.6
1989	4163.1	2544.2															4163.1	2544.2
1990	5002.9	6399.6															5002.9	6399.6
1991	5069.2	6262.5			0.6												5069.7	6262.5
1992	5860.5	6664.7															5860.5	6664.7
1993	5526.6	7377.5	0.0														5526.6	7377.5
1994	703.4	8079.9															703.4	8079.9
1995	3095.1	3985.5			136.6												3231.7	3985.5
1996	3981.5	10230.8	0.4		0.2												3982.0	10230.8
1997	5369.1	5575.6															5369.1	5575.6
1998	5391.8	8440.0			0.0												5391.8	8440.0
1999	5026.7	6655.3					2.1										5028.7	6655.3
2000	3633.2	8690.6	0.0		1036.0	0.1	0.0										4669.1	8690.6
2001	4399.5	8718.5	2.2		0.0	0.1						0.1					4401.7	8718.7
2002	4396.9	8606.9				0.1		0.1									4396.9	8607.1
2003	4327.8	10650.0	0.8	26.0	0.2						0.1						4328.8	10676.0
2004	998.1	8450.3	2.8	2697.5	2867.4	8.6	0.3	0.1	0.0	95.6	1.0	927.2	3.5	16.6		2.7	3873.2	12198.5
2005	417.1	6679.4	59.3	3301.4	3449.6	15.6	0.2	5.4	1.5	126.2	0.6	1.0	33.3		16.6	5.9	3978.2	10134.9
2006	1101.0	8543.5	79.3	2904.6	3138.3	6.4		2.2		137.4	0.6	31.9	189.6		8.5	14.5	4517.2	11640.5
2007	1279.3	11129.7	41.0	2796.4	3479.4	0.3		1.2	11.5	113.4	0.1	26.7	176.1		15.1	14.8	5002.5	14082.4

Table 7. U.S. landings (mt, live wt) of skates by state, species and markey category from 2004-2007.

		Species and Market Category																	
		Uncl.	Uncl.	Winter	Winter	Little	Little	Barndoor	Barndoor	Thorny	Thorny	Smooth	Smooth	Clearnose	Clearnose	Rosette	Rosette	Total	
YEAR	State	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings
2004	CT	369.9	71.8															369.9	71.8
	DE	0.0																0.0	0.0
	ME	0.0	12.2		1.2													0.0	13.3
	MD	1.0	2.4		2.7	0.1												1.1	5.1
	MA	17.7	6482.2	0.2	2467.9	97.5				0.0	83.4	0.1	926.8				0.1	115.5	9960.4
	NH		5.1		5.4						0.1							0.0	10.6
	NJ	1.5	131.2	0.3	135.5	103.0	2.7				0.1							104.8	269.5
	NY	23.3	183.6	1.2	0.6	0.7	0.1				12.0	1.0	0.3					26.1	196.7
	NC		0.5															0.0	0.5
	RI	583.7	1537.3	1.2	84.2	2666.1	5.8										2.6	3251.0	1630.0
	VA	1.1	24.0					0.3	0.1					3.5	16.6			4.9	40.8
	Total	998.1	8450.3	2.8	2697.5	2867.4	8.6	0.3	0.1	0.0	95.6	1.0	927.2	3.5	16.6	0.0	2.7	3873.2	12198.5
2005	CT	275.6	77.7															275.6	77.7
	ME		10.2		0.5		0.2											0.0	10.8
	MD	2.3	6.1															2.3	6.1
	MA	60.2	5699.0	21.7	3071.7	21.1			1.3	1.5	111.6	0.0	0.7					104.5	8884.4
	NH	0.0	9.4															0.0	9.4
	NJ	0.4	120.0	24.4	110.7	45.0	1.1					0.4		32.7				102.9	231.9
	NY	12.3	96.6	0.4	1.6	12.7	0.2	0.2	4.1		12.6	0.0	0.3			16.6		42.2	115.3
	NC		0.5															0.0	0.5
	RI	65.9	630.4	12.8	116.9	3370.9	14.1				2.0	0.2	0.1				5.9	3449.7	769.4
	VA	0.3	29.3											0.7				1.0	29.3
	Total	417.1	6679.4	59.3	3301.4	3449.6	15.6	0.2	5.4	1.5	126.2	0.6	1.0	33.3	0.0	16.6	5.9	3978.2	10134.9
2006	CT	190.5	69.1															190.5	69.1
	ME		1.5															0.0	1.5
	MD	5.0	4.2		2.3	2.2	0.9											7.2	7.4
	MA	834.2	7584.2	62.7	2317.9	196.2	0.2				136.6	0.6					0.0	1093.7	10039.0
	NH		11.2								0.0							0.0	11.2
	NJ	5.3	45.8	0.7	165.9	11.8	2.9						31.8		187.4			17.8	433.9
	NY	11.2	176.0		19.3	10.1			2.2				0.1			8.5	2.1	29.7	199.6
	NC	0.1	0.0															0.1	0.0
	RI	54.7	648.1	15.9	399.2	2918.1	2.4				0.8						12.4	2988.6	1062.9
	VA		3.4											2.2				2.2	3.4
	Total	1101.0	8543.5	79.3	2904.6	3138.3	6.4	0.0	2.2	0.0	137.4	0.6	31.9	2.2	187.4	8.5	14.5	4329.8	11827.9
2007	CT	195.4	60.8															195.4	60.8
	ME		29.9															0.0	29.9
	MD	9.0	6.9		1.5	0.4	0.3											9.4	8.8
	MA	958.0	9993.9	22.7	2390.9	56.3				11.5	103.2		18.0					1048.4	12506.1
	NH		5.3		0.3													0.0	5.6
	NJ	0.1	107.2	1.8	203.4	31.8							8.3	171.6				205.2	318.9
	NY	14.3	247.8	8.3	27.8	3.9			1.2		9.4	0.1	0.3			11.9		38.5	286.4
	NC	0.3																0.3	0.0
	RI	91.7	645.4	8.2	171.5	3387.0					1.1			4.5			14.8	3491.5	832.7
	VA																	0.0	0.0
	Total	1268.7	11097.2	41.0	2795.3	3479.4	0.3	0.0	1.2	11.5	113.7	0.1	26.7	176.1	0.0	11.9	14.8	4988.7	14049.2

Table 8. Estimated discards (mt) of skates (all species) by gear type taken in the Gulf of Maine-Georges Bank region, 1964-2007.

	Half 1				Scallop		Half 2				Scallop		
year	Line Trawl	Otter Trawl	Shrimp Trawl	Sink Gill Net	Dredge	Total Half 1	Line Trawl	Otter Trawl	Shrimp Tra	Sink Gill Net	Dredge	Total Half 2	Grand Total
1964	449	37,255	0	12	5,868	43,583	403	22,824	0	7	6,541	29,775	73,358
1965	498	38,321	0	16	2,284	41,120	522	24,329	0	5	600	25,456	66,575
1966	380	39,624	0	26	742	40,771	491	22,374	0	7	1,506	24,379	65,149
1967	329	30,462	0	21	575	31,387	323	19,148	0	8	2,295	21,775	53,162
1968	259	26,067	0	36	728	27,090	299	18,036	0	10	1,651	19,995	47,085
1969	281	25,173	0	32	1,004	26,490	455	15,909	0	6	1,935	18,305	44,795
1970	308	22,927	0	22	1,228	24,485	415	15,208	0	7	1,890	17,520	42,005
1971	472	21,746	0	21	1,749	23,988	615	14,941	0	8	1,458	17,023	41,011
1972	476	19,491	0	31	1,217	21,215	659	12,401	0	13	1,724	14,796	36,011
1973	569	19,548	0	30	1,758	21,905	640	13,558	0	15	1,502	15,715	37,620
1974	614	17,687	0	57	1,043	19,400	592	11,947	0	24	1,413	13,976	33,377
1975	680	15,631	280	60	1,303	17,953	613	11,792	36	26	2,047	14,514	32,467
1976	464	15,157	66	97	1,650	17,434	353	12,139	0	37	3,115	15,645	33,078
1977	341	19,662	39	166	3,299	23,507	294	14,148	0	47	7,176	21,664	45,171
1978	561	23,070	0	186	4,012	27,828	321	14,383	0	66	7,889	22,658	50,487
1979	779	22,771	26	153	5,275	29,004	508	16,612	0	67	8,454	25,641	54,645
1980	851	28,570	21	185	7,342	36,969	155	18,066	0	96	6,972	25,288	62,258
1981	332	29,786	99	252	8,206	38,676	95	15,643	0	93	9,501	25,332	64,008
1982	302	26,789	124	89	5,632	32,937	74	19,496	7	83	7,936	27,596	60,533
1983	297	29,695	115	113	4,802	35,022	93	16,467	22	69	5,663	22,314	57,336
1984	307	27,882	152	121	3,463	31,925	19	13,640	53	94	4,359	18,165	50,090
1985	263	22,242	225	112	2,308	25,149	52	10,748	70	81	4,720	15,671	40,820
1986	322	19,142	252	166	4,010	23,892	49	8,856	83	87	6,206	15,281	39,173
1987	536	15,330	288	137	3,905	20,197	166	8,272	46	85	7,574	16,144	36,340
1988	561	17,091	183	158	6,175	24,169	199	8,410	46	90	10,002	18,746	42,915
1989	503	18,497	73	37	6,349	25,459	161	8,727	17	1,265	11,105	21,276	46,735
1990	358	23,476	208	347	7,290	31,680	156	9,910	71	940	15,222	26,299	57,979
1991	1,069	11,624	243	99	9,842	22,877	264	8,680	44	628	10,383	19,999	42,876
1992	1,269	8,056	245	162	8,843	18,575	471	2,848	0	518	10,919	14,756	33,331
1993	169	4,528	35	119	4,512	9,362	125	11,482	1	1,406	4,928	17,942	27,305
1994	82	4,912	11	130	2,294	7,429	146	10,132	1	1,382	2,103	13,764	21,193
1995	147	7,492	8	209	398	8,253	152	2,312	1	2,029	1,647	6,141	14,393
1996	123	7,507	26	284	837	8,777	121	1,181	8	1,921	3,029	6,259	15,037
1997	119	3,788	32	110	1,804	5,854	123	3,189	2	987	3,165	7,466	13,320
1998	99	5,276	8	50	2,376	7,809	142	15,784	0	1,930	4,101	21,957	29,767
1999	112	2,870	4	98	1,207	4,292	123	7,146	0	1,799	2,957	12,024	16,316
2000	62	4,490	5	121	2,086	6,764	131	7,584	0	2,100	1,387	11,201	17,965
2001	87	19,242	0	188	518	20,034	92	6,262	0	1,241	582	8,176	28,210
2002	97	11,085	1	135	1,095	12,413	44	5,761	0	1,844	2,030	9,680	22,093
2003	34	11,684	8	253	1,836	13,815	24	9,848	0	1,995	1,975	13,842	27,656
2004	3	11,505	4	269	294	12,075	17	13,832	0	1,027	1,060	15,937	28,012
2005	91	9,468	2	399	594	10,554	54	12,844	0	925	2,212	16,034	26,588
2006	193	8,042	0	173	1,085	9,494	17	9,344	1	1,599	2,408	13,369	22,863
2007	46	10,703	0	378	871	11,999	27	11,158	0	1,439	3,418	16,042	28,041

Table 9. Estimated discards (mt) of skates (all species) by gear type taken in the Southern New England-Mid-Atlantic region, 1964-2007.

	Half 1					Half 2					
year	Line Trawl	Otter Trawl	Sink Gill Net	Scallop Dredge	Total Half 1	Line Trawl	Otter Trawl	Sink Gill Ne	Scallop Dredge	Total Half 2	Grand Total
1964	0	16,916	0	1	16,917	0	12,929	0	494	13,422	30,339
1965	0	20,746	0	2,108	22,854	0	15,053	0	7,343	22,396	45,250
1966	0	23,680	0	5,026	28,707	0	11,657	0	4,067	15,724	44,431
1967	0	26,886	0	2,257	29,143	0	13,933	0	1,771	15,704	44,848
1968	0	30,741	0	2,926	33,667	0	13,895	0	2,516	16,411	50,077
1969	1	30,557	0	1,279	31,837	1	11,827	0	683	12,510	44,348
1970	2	21,694	0	399	22,095	0	10,272	0	462	10,734	32,829
1971	2	13,419	0	91	13,511	0	4,979	0	756	5,735	19,246
1972	2	13,272	0	724	13,999	1	6,373	0	488	6,862	20,860
1973	11	15,425	0	391	15,828	4	6,227	0	173	6,404	22,232
1974	30	19,170	0	706	19,906	11	5,279	0	987	6,277	26,183
1975	30	9,882	0	1,069	10,981	11	5,131	0	2,060	7,202	18,183
1976	17	7,688	0	2,175	9,880	9	7,804	0	3,979	11,792	21,672
1977	9	7,639	0	3,302	10,950	3	7,169	0	1,352	8,525	19,475
1978	185	12,605	0	3,946	16,736	168	8,389	0	4,215	12,772	29,509
1979	86	16,229	0	3,399	19,714	164	10,770	0	2,929	13,862	33,576
1980	170	11,730	0	2,314	14,213	131	10,958	0	2,355	13,444	27,657
1981	180	13,828	0	1,065	15,072	131	10,028	0	976	11,135	26,208
1982	115	17,088	0	1,597	18,800	77	17,764	0	2,699	20,540	39,340
1983	99	20,196	0	3,646	23,941	66	15,883	0	4,480	20,429	44,371
1984	79	21,023	0	4,933	26,035	46	17,034	0	4,046	21,126	47,161
1985	56	18,452	0	4,302	22,809	66	12,401	0	3,220	15,687	38,496
1986	94	18,225	0	3,215	21,534	74	17,119	0	4,117	21,310	42,844
1987	99	21,129	0	8,277	29,504	81	15,105	0	8,492	23,678	53,182
1988	78	18,544	0	7,704	26,326	13	13,960	0	6,365	20,339	46,664
1989	45	19,166	0	12,414	31,625	22	11,537	0	5,363	16,923	48,548
1990	35	26,989	0	10,327	37,352	29	25,810	0	4,662	30,501	67,853
1991	112	11,258	0	8,285	19,655	64	21,176	0	5,567	26,807	46,462
1992	234	5,097	107	4,661	10,100	245	16,761	51	7,177	24,234	34,333
1993	75	3,466	94	5,366	9,000	34	10,309	45	7,260	17,648	26,648
1994	36	59,775	135	4,193	64,140	16	6,039	150	3,250	9,454	73,595
1995	18	15,368	234	8,729	24,349	23	9,305	91	18,394	27,813	52,162
1996	40	8,046	135	7,738	15,960	34	23,207	66	8,544	31,851	47,811
1997	58	2,978	282	9,318	12,636	49	2,957	76	3,779	6,861	19,496
1998	47	22,088	167	4,300	26,601	36	4,876	194	4,372	9,479	36,080
1999	23	920	500	6,023	7,466	17	2,370	140	4,990	7,517	14,983
2000	19	2,341	60	3,241	5,661	23	8,924	52	3,335	12,333	17,994
2001	31	1,750	215	3,260	5,256	38	1,989	51	2,701	4,779	10,035
2002	26	1,049	255	5,190	6,520	82	3,721	2,242	5,691	11,736	18,255
2003	36	6,200	268	6,096	12,600	32	7,549	289	6,108	13,978	26,578
2004	36	2,864	180	5,178	8,258	7	7,629	248	3,099	10,982	19,240
2005	0	4,633	634	5,523	10,789	0	6,115	354	2,419	8,888	19,678
2006	2	2,526	676	4,676	7,880	0	2,846	68	2,507	5,421	13,301
2007	0	3,913	661	5,234	9,808	0	5,334	406	4,161	9,901	19,709

Table 10. Estimated discards (mt) of skates (all species) by gear type, 1964-2007.

	Half 1				Scallop		Half 2				Scallop		
year	Line Trawl	Otter Trawl	Shrimp Trawl	Sink Gill Net	Dredge	Total Half 1	Line Trawl	Otter Trawl	Shrimp Tra	Sink Gill Net	Dredge	Total Half 2	Grand Total
1964	449	54,171	0	12	5,869	60,500	403	35,752	0	7	7,035	43,197	103,696
1965	498	59,067	0	16	4,392	63,974	522	39,381	0	5	7,943	47,852	111,826
1966	380	63,304	0	26	5,768	69,478	491	34,031	0	7	5,573	40,103	109,580
1967	329	57,348	0	21	2,832	60,530	323	33,081	0	8	4,066	37,479	98,009
1968	259	56,808	0	36	3,653	60,756	299	31,931	0	10	4,167	36,406	97,162
1969	283	55,730	0	32	2,283	58,327	455	27,736	0	6	2,617	30,815	89,142
1970	310	44,621	0	22	1,627	46,580	415	25,480	0	7	2,352	28,253	74,833
1971	474	35,165	0	21	1,840	37,499	615	19,920	0	8	2,214	22,758	60,257
1972	478	32,764	0	31	1,941	35,213	659	18,774	0	13	2,211	21,658	56,871
1973	580	34,973	0	30	2,150	37,732	644	19,785	0	15	1,674	22,119	59,852
1974	644	36,856	0	57	1,749	39,306	603	17,226	0	24	2,400	20,253	59,560
1975	710	25,513	280	60	2,371	28,934	624	16,923	36	26	4,106	21,716	50,650
1976	481	22,845	66	97	3,825	27,314	362	19,943	0	37	7,094	27,436	54,750
1977	350	27,301	39	166	6,601	34,457	296	21,317	0	47	8,528	30,189	64,646
1978	746	35,675	0	186	7,958	44,565	489	22,772	0	66	12,104	35,430	79,995
1979	864	39,000	26	153	8,674	48,717	672	27,382	0	67	11,382	39,504	88,221
1980	1,021	40,300	21	185	9,656	51,183	285	29,024	0	96	9,327	38,732	89,915
1981	512	43,614	99	252	9,271	53,749	226	25,671	0	93	10,478	36,467	90,216
1982	417	43,877	124	89	7,228	51,737	151	37,260	7	83	10,635	48,136	99,873
1983	396	49,891	115	113	8,448	58,963	159	32,350	22	69	10,143	42,744	101,707
1984	385	48,904	152	121	8,396	57,959	65	30,674	53	94	8,406	39,292	97,251
1985	318	40,693	225	112	6,609	47,958	117	23,149	70	81	7,940	31,358	79,316
1986	415	37,367	252	166	7,225	45,425	123	25,975	83	87	10,323	36,591	82,016
1987	635	36,459	288	137	12,182	49,701	247	23,377	46	85	16,066	39,821	89,523
1988	639	35,635	183	158	13,879	50,495	212	22,370	46	90	16,366	39,085	89,579
1989	547	37,663	73	37	18,763	57,084	183	20,264	17	1,265	16,469	38,198	95,282
1990	393	50,465	208	347	17,618	69,032	185	35,720	71	940	19,884	56,800	125,832
1991	1,181	22,882	243	99	18,127	42,532	328	29,856	44	628	15,950	46,806	89,338
1992	1,503	13,153	245	269	13,504	28,674	716	19,609	0	569	18,096	38,990	67,664
1993	244	7,994	35	212	9,877	18,362	160	21,791	1	1,452	12,187	35,591	53,953
1994	118	64,688	11	265	6,487	71,569	162	16,171	1	1,532	5,352	23,218	94,788
1995	165	22,860	8	443	9,127	32,602	176	11,617	1	2,120	20,041	33,954	66,556
1996	164	15,554	26	419	8,575	24,737	155	24,388	8	1,987	11,573	38,110	62,848
1997	177	6,766	32	392	11,123	18,489	172	6,146	2	1,062	6,944	14,327	32,816
1998	146	27,363	8	217	6,676	34,410	178	20,659	0	2,124	8,474	31,436	65,846
1999	136	3,790	4	598	7,230	11,758	139	9,516	0	1,939	7,947	19,542	31,299
2000	81	6,831	5	181	5,326	12,425	153	16,508	0	2,152	4,721	23,535	35,959
2001	118	20,992	0	403	3,778	25,290	130	8,250	0	1,292	3,283	12,955	38,245
2002	123	12,134	1	390	6,285	18,933	126	9,482	0	4,087	7,721	21,416	40,348
2003	70	17,884	8	522	7,931	26,415	56	17,397	0	2,284	8,083	27,820	54,235
2004	40	14,369	4	449	5,472	20,333	24	21,461	0	1,275	4,159	26,919	47,252
2005	91	14,100	2	1,033	6,117	21,343	54	18,959	0	1,279	4,630	24,922	46,265
2006	194	10,569	0	849	5,761	17,374	18	12,190	1	1,667	4,916	18,790	36,164
2007	46	14,616	0	1,038	6,105	21,807	27	16,492	0	1,845	7,579	25,943	47,750

Table 11. Coefficients of variation for the discard estimates from the two main gear types.

	Scallop dredge	Otter trawl
1992	164.5	27.6
1993	65.8	24.9
1994	137.2	26.0
1995	84.9	22.4
1996	40.9	36.1
1997	48.2	30.3
1998	116.5	17.5
1999	120.5	19.6
2000	196.7	18.6
2001	109.1	50.8
2002	68.8	8.9
2003	384.3	11.3
2004	70.1	8.2
2005	194.0	5.3
2006	184.8	6.8
2007	94.5	6.0

Table 12. Number of landed skates measured by fishery, region and season. The bait fishery are fish <= 60 cm while the wings are those > 60 cm.

GOM-GBK

		half 1			half 2		
YEAR	bait	wings	half 1 total	bait	wings	half 1 total	Grand Total
1994	27	36	63	19	20	39	102
1995	0	118	118	0	0	0	118
1996	45	38	83	4	14	18	101
1997	0	0	0	1	15	16	16
1998	0	17	17	0	0	0	17
1999	8	160	168	0	251	251	419
2000	43	102	145	0	438	438	583
2001	0	378	378	40	1222	1262	1640
2002	1	591	592	22	2088	2110	2702
2003	4	1304	1308	166	6656	6822	8130
2004	62	1464	1526	114	5931	6045	7571
2005	147	917	1064	146	1543	1689	2753
2006	34	1063	1097	175	7087	7262	8359
2007	232	46	278	39	21	60	338

SNE-MA

		half 1			half 2		
YEAR	bait	wings	half 1 total	bait	wings	half 1 total	Grand Total
1994	0	0	0	155	191	346	346
1995	9	327	336	301	17	318	654
1996	2	408	410	152	128	280	690
1997	295	257	552	14	441	455	1007
1998	27	1462	1489	199	653	852	2341
1999	67	305	372	76	264	340	712
2000	131	335	466	526	69	595	1061
2001	886	502	1388	1359	1967	3326	4714
2002	932	873	1805	95	286	381	2186
2003	540	489	1029	939	2228	3167	4196
2004	811	2542	3353	133	945	1078	4431
2005	706	854	1560	1121	774	1895	3455
2006	1300	563	1863	584	152	736	2599
2007	749	606	1355	2288	332	2620	3975

Table 13. Selectivity parameter estimates for observed skate landings fitted to survey length frequencies using the SELECT model (Millar 1992).

	Winter skate								
	Trawl, wings			Trawl, whole			Gillnet		
	GoM	GB	MA	GoM	GB	MA	GoM	GB	MA
a =	Insufficient data	1.278	Insufficient data	Insufficient data	4.401	-3.800	3.311	2.109	1.595
b =		0.103			0.037	0.148	0.052	0.075	0.094
δ =		0.00042			0.00192	0.01032	0.00147	0.00102	0.00092
L50%		**66.911**			**60.817**	**59.030**	**68.626**	**68.381**	**61.597**
SE		34530.57			901.88	4817.01	689.32	2215.72	2709.99
Range		15.32			43.07	10.66	30.19	20.90	16.81
Log-likelihood		-11.74			-26.84	-14.49	-22.41	-18.90	-15.62
AIC		29.49			59.68	34.98	50.82	43.80	37.23

	Little skate								
	Trawl, wings			Trawl, whole			Gillnet		
	GoM	GB	MA	GoM	GB	MA	GoM	GB	MA
a =	Insufficient data	Insufficient data	Insufficient data	-0.004	2.094	6.287	Insufficient data	-2.141	2.418
b =				0.111	0.125	-0.070		0.106	0.095
δ =				0.01140	0.00082	0.03171		0.10842	0.00154
L50%				**43.46**	**43.04**	**35.57**		**44.23**	**46.73**
SE				774.22	4369.11	82.34		18.53	1967.88
Range				14.18	12.58	-22.80		15.39	16.62
Log-likelihood				-8.38	-5.08	-20.09		-7.42	-6.99
AIC				22.75	16.16	46.18		20.85	19.99

	All landed skates								
	Trawl, wings			Trawl, whole					Gillnet
	GoM	GB	MA	All	GoM	GB	MA	All	GoM
a =	Insufficient data	Insufficient data	Insufficient data	-0.080	2.407	1.800	1.689	5.014	1.030
b =				0.112	0.076	0.065	0.031	0.052	0.100
δ =				0.002	0.003	0.010	0.068	0.001	0.001
L50%				**59.85**	**48.75**	**48.35**	**43.03**	**44.36**	**60.42**
SE				16247.71	1390.32	276.63	27.61	1789.43	231.93
Range				14.05	20.80	24.14	51.36	30.00	15.77
Log-likelihood				-5.28	-19.86	-12.20	-20.96	-11.23	-18.79
AIC				16.55	45.72	30.40	47.92	28.45	43.59

Table 14. Species composition of landings using the length composition method. The first three columns are metric tons, the last three are in pounds.

		market			market		
		bait	wings	Grand Total	bait	wings	Grand Total
1995	winter	1060.72	3392.77	4453.48	2,338,486	7,479,767	9,818,252
	little	1926.66	0.00	1926.66	4,247,565	0	4,247,565
	barndoor	2.08	81.03	83.11	4,584	178,644	183,227
	thorny	0.60	313.97	314.57	1,330	692,180	693,511
	smooth	0.77	0.00	0.77	1,706	0	1,706
	clearnose	214.47	134.01	348.48	472,827	295,431	768,258
	rosette	5.39	0.00	5.39	11,886	0	11,886
	Total	3210.70	3921.77	7132.47	7,078,384	8,646,022	15,724,406
1996	winter	1165.20	8886.34	10051.54	2,568,833	19,591,016	22,159,849
	little	2399.89	0.00	2399.89	5,290,862	0	5,290,862
	barndoor	0.02	336.37	336.39	38	741,568	741,606
	thorny	0.39	759.13	759.51	851	1,673,587	1,674,438
	smooth	0.37	0.00	0.37	822	0	822
	clearnose	377.56	162.33	539.89	832,372	357,871	1,190,243
	rosette	11.01	0.00	11.01	24,268	0	24,268
	Total	3954.44	10144.16	14098.60	8,718,046	22,364,042	31,082,087
1997	winter	1050.68	4303.02	5353.70	2,316,356	9,486,530	11,802,887
	little	3792.04	0.00	3792.04	8,360,013	0	8,360,013
	barndoor	0.01	281.03	281.04	26	619,554	619,580
	thorny	1.38	509.00	510.38	3,046	1,122,149	1,125,195
	smooth	2.64	4.35	6.99	5,815	9,584	15,399
	clearnose	451.84	296.89	748.73	996,134	654,530	1,650,664
	rosette	12.90	0.00	12.90	28,439	0	28,439
	Total	5311.49	5394.28	10705.77	11,709,829	11,892,347	23,602,176
1998	winter	1025.76	7318.49	8344.25	2,261,416	16,134,513	18,395,929
	little	4028.73	0.00	4028.73	8,881,828	0	8,881,828
	barndoor	0.62	160.49	161.12	1,378	353,828	355,205
	thorny	1.91	626.28	628.19	4,205	1,380,710	1,384,915
	smooth	7.83	0.00	7.83	17,264	0	17,264
	clearnose	266.14	181.31	447.45	586,744	399,721	986,465
	rosette	27.33	0.00	27.33	60,253	0	60,253
	Total	5358.33	8286.58	13644.90	11,813,088	18,268,771	30,081,859
1999	winter	1040.52	5826.05	6866.57	2,293,964	12,844,231	15,138,195
	little	3680.41	0.00	3680.41	8,113,912	0	8,113,912
	barndoor	5.59	446.78	452.37	12,324	984,972	997,296
	thorny	0.50	203.22	203.71	1,092	448,014	449,105
	smooth	0.95	1.15	2.09	2,089	2,527	4,617
	clearnose	234.34	90.02	324.36	516,626	198,458	715,084
	rosette	15.35	0.00	15.35	33,841	0	33,841
	Total	4977.65	6567.20	11544.86	10,973,848	14,478,203	25,452,051

Table 14 cont.

		market bait	wings	Grand Total	market bait	wings	Grand Total
2000	winter	833.19	7539.80	8372.99	1,836,873	16,622,407	18,459,279
	little	3334.57	1.45	3336.02	7,351,473	3,197	7,354,670
	barndoor	2.03	492.39	494.42	4,484	1,085,523	1,090,007
	thorny	1.18	465.21	466.39	2,602	1,025,606	1,028,208
	smooth	2.49	5.18	7.67	5,482	11,416	16,899
	clearnose	405.42	96.52	501.95	893,806	212,795	1,106,601
	rosette	19.96	0.00	19.96	44,009	0	44,009
	Total	4598.85	8600.54	13199.39	10,138,729	18,960,944	29,099,673
2001	winter	1057.56	6597.72	7655.28	2,331,521	14,545,480	16,877,001
	little	1700.99	0.00	1700.99	3,750,031	0	3,750,031
	barndoor	5.21	1531.64	1536.85	11,489	3,376,682	3,388,171
	thorny	4.55	190.88	195.42	10,026	420,810	430,836
	smooth	18.78	0.00	18.78	41,397	0	41,397
	clearnose	1558.81	301.26	1860.07	3,436,582	664,174	4,100,756
	rosette	8.61	0.00	8.61	18,992	0	18,992
	Total	4354.50	8621.50	12976.00	9,600,038	19,007,146	28,607,184
2002	winter	1230.90	5863.28	7094.18	2,713,677	12,926,318	15,639,994
	little	2371.81	0.00	2371.81	5,228,949	0	5,228,949
	barndoor	69.34	2054.33	2123.66	152,866	4,529,014	4,681,879
	thorny	2.31	399.32	401.63	5,085	880,356	885,441
	smooth	16.97	0.28	17.24	37,406	608	38,014
	clearnose	588.66	51.55	640.20	1,297,766	113,637	1,411,403
	rosette	10.72	0.00	10.72	23,629	0	23,629
	Total	4290.70	8368.75	12659.45	9,459,378	18,449,932	27,909,310
2003	winter	663.38	9322.73	9986.12	1,462,512	20,553,111	22,015,623
	little	3302.87	0.00	3302.87	7,281,580	0	7,281,580
	barndoor	89.20	765.62	854.82	196,653	1,687,903	1,884,556
	thorny	4.72	298.22	302.94	10,402	657,458	667,861
	smooth	8.11	0.43	8.55	17,890	953	18,843
	clearnose	149.05	186.56	335.61	328,603	411,288	739,891
	rosette	5.82	0.00	5.82	12,834	0	12,834
	Total	4223.16	10573.56	14796.72	9,310,475	23,310,713	32,621,188
2004	winter	1499.08	10288.74	11787.82	3,304,912	22,682,786	25,987,698
	little	1955.26	0.00	1955.26	4,310,621	0	4,310,621
	barndoor	72.65	771.86	844.52	160,176	1,701,668	1,861,844
	thorny	0.82	510.74	511.56	1,809	1,125,978	1,127,787
	smooth	5.63	0.00	5.63	12,410	0	12,410
	clearnose	277.16	67.38	344.54	611,037	148,552	759,590
	rosette	6.80	0.00	6.80	14,998	0	14,998
	Total	3817.42	11638.72	15456.14	8,415,962	25,658,985	34,074,947

Table 14 cont.

		market			market		
		bait	wings	Grand Total	bait	wings	Grand Total
2005	winter	628.98	7021.60	7650.58	1,386,658	15,479,978	16,866,636
	little	3056.36	0.00	3056.36	6,738,126	0	6,738,126
	barndoor	55.49	1920.85	1976.34	122,337	4,234,744	4,357,081
	thorny	1.69	438.17	439.86	3,733	965,997	969,730
	smooth	8.71	1.68	10.39	19,202	3,709	22,911
	clearnose	63.94	104.53	168.47	140,958	230,452	371,410
	rosette	8.97	0.00	8.97	19,773	0	19,773
	Total	3824.14	9486.83	13310.97	8,430,787	20,914,880	29,345,667
2006	winter	1624.28	7632.53	9256.81	3,580,914	16,826,851	20,407,766
	little	2392.33	0.00	2392.33	5,274,186	0	5,274,186
	barndoor	138.00	2494.83	2632.83	304,241	5,500,163	5,804,404
	thorny	2.20	640.77	642.97	4,843	1,412,653	1,417,496
	smooth	15.77	5.73	21.51	34,775	12,637	47,412
	clearnose	248.57	135.92	384.49	547,993	299,656	847,650
	rosette	8.63	0.00	8.63	19,024	0	19,024
	Total	4429.77	10909.79	15339.56	9,765,977	24,051,960	33,817,937
2007	winter	1492.23	11368.57	12860.80	3,289,800	25,063,404	28,353,204
	little	3078.31	0.00	3078.31	6,786,503	0	6,786,503
	barndoor	91.67	1919.79	2011.46	202,088	4,232,420	4,434,509
	thorny	2.23	349.68	351.91	4,914	770,915	775,828
	smooth	8.53	9.30	17.84	18,816	20,512	39,328
	clearnose	193.40	168.33	361.73	426,370	371,098	797,468
	rosette	22.41	0.00	22.41	49,398	0	49,398
	Total	4888.77	13815.67	18704.44	10,777,889	30,458,349	41,236,238

Table 15. Species composition of landings using the selectivity ogive method. The first three columns are metric tons, the last three are in pounds.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
1995	winter	543.41	2013.59	2557.01	1,198,024	4,439,210	5,637,234
	little	2077.88	551.82	2629.69	4,580,935	1,216,547	5,797,481
	barndoor	1.35	43.45	44.80	2,986	95,787	98,773
	thorny	6.53	1149.72	1156.25	14,389	2,534,702	2,549,091
	smooth	0.66	27.36	28.02	1,461	60,313	61,774
	clearnose	5.11	17.49	22.60	11,273	38,553	49,826
	rosette	1.04	0.08	1.11	2,287	170	2,457
	Total	2635.99	3803.50	6439.49	5,811,355	8,385,281	14,196,636
1996	winter	1059.12	7716.89	8776.01	2,334,952	17,012,833	19,347,785
	little	2751.73	842.40	3594.13	6,066,523	1,857,173	7,923,696
	barndoor	0.02	193.10	193.12	54	425,711	425,765
	thorny	6.42	1213.05	1219.47	14,152	2,674,321	2,688,474
	smooth	0.37	72.48	72.85	821	159,794	160,615
	clearnose	5.56	39.14	44.70	12,261	86,285	98,546
	rosette	0.19	0.04	0.23	408	91	499
	Total	3823.41	10077.10	13900.51	8,429,172	22,216,208	30,645,380
1997	winter	659.60	3149.35	3808.94	1,454,161	6,943,124	8,397,285
	little	4623.60	703.24	5326.84	10,193,302	1,550,375	11,743,677
	barndoor	1.13	145.26	146.39	2,496	320,243	322,739
	thorny	6.66	1016.35	1023.01	14,691	2,240,666	2,255,357
	smooth	1.52	53.07	54.59	3,349	117,002	120,352
	clearnose	42.97	114.89	157.86	94,737	253,281	348,018
	rosette	0.12	0.02	0.14	271	40	311
	Total	5335.61	5182.17	10517.78	11,763,007	11,424,732	23,187,739
1998	winter	929.83	4495.66	5425.49	2,049,928	9,911,233	11,961,161
	little	4015.43	960.18	4975.61	8,852,516	2,116,832	10,969,349
	barndoor	4.62	292.51	297.13	10,175	644,877	655,053
	thorny	1.31	2237.44	2238.76	2,899	4,932,717	4,935,616
	smooth	2.75	69.25	72.00	6,073	152,669	158,743
	clearnose	8.63	38.78	47.42	19,034	85,505	104,539
	rosette	0.33	0.19	0.51	726	409	1,135
	Total	4962.91	8094.01	13056.93	10,941,351	17,844,243	28,785,594
1999	winter	920.69	4431.13	5351.83	2,029,784	9,768,974	11,798,758
	little	3914.15	751.91	4666.06	8,629,229	1,657,669	10,286,898
	barndoor	3.67	292.22	295.90	8,096	644,245	652,341
	thorny	1.81	875.62	877.43	4,001	1,930,410	1,934,411
	smooth	3.27	73.44	76.71	7,204	161,916	169,120
	clearnose	5.12	69.83	74.95	11,279	153,955	165,234
	rosette	1.07	1.30	2.37	2,364	2,866	5,230
	Total	4849.79	6495.46	11345.25	10,691,958	14,320,035	25,011,993

Table 15 cont.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
2000	winter	306.95	5023.89	5330.84	676,715	11,075,785	11,752,500
	little	4046.00	954.65	5000.65	8,919,903	2,104,651	11,024,554
	barndoor	2.17	449.67	451.84	4,790	991,345	996,135
	thorny	0.79	1782.98	1783.77	1,736	3,930,806	3,932,542
	smooth	1.61	72.34	73.95	3,550	159,473	163,023
	clearnose	64.17	145.20	209.36	141,463	320,105	461,568
	rosette	6.06	0.95	7.01	13,369	2,085	15,454
	Total	4427.75	8429.67	12857.43	9,761,525	18,584,251	28,345,776
2001	winter	504.29	6011.92	6516.21	1,111,776	13,254,016	14,365,792
	little	3606.10	1105.32	4711.42	7,950,090	2,436,815	10,386,905
	barndoor	3.30	494.71	498.01	7,268	1,090,653	1,097,921
	thorny	16.61	830.96	847.57	36,608	1,831,959	1,868,568
	smooth	13.50	56.53	70.02	29,753	124,618	154,371
	clearnose	28.05	68.36	96.41	61,841	150,707	212,548
	rosette	5.46	0.36	5.82	12,044	793	12,836
	Total	4177.30	8568.16	12745.47	9,209,381	18,889,560	28,098,941
2002	winter	580.15	6003.17	6583.32	1,279,018	13,234,716	14,513,734
	little	3785.75	947.41	4733.17	8,346,161	2,088,690	10,434,851
	barndoor	19.15	325.19	344.34	42,213	716,932	759,145
	thorny	5.68	1190.99	1196.67	12,520	2,625,682	2,638,202
	smooth	15.45	58.01	73.46	34,054	127,890	161,944
	clearnose	8.59	34.30	42.89	18,933	75,627	94,559
	rosette	1.20	0.26	1.46	2,644	565	3,209
	Total	4415.97	8559.33	12975.30	9,735,542	18,870,102	28,605,643
2003	winter	446.47	7174.71	7621.18	984,297	15,817,519	16,801,816
	little	4066.26	1449.03	5515.29	8,964,572	3,194,556	12,159,128
	barndoor	17.10	687.24	704.34	37,705	1,515,097	1,552,803
	thorny	33.21	981.39	1014.60	73,219	2,163,595	2,236,813
	smooth	23.03	39.37	62.39	50,766	86,786	137,552
	clearnose	0.99	69.61	70.60	2,190	153,464	155,654
	rosette	0.89	0.05	0.94	1,953	118	2,071
	Total	4587.95	10401.39	14989.34	10,114,702	22,931,134	33,045,837
2004	winter	669.89	9395.37	10065.26	1,476,861	20,713,238	22,190,099
	little	2856.62	599.49	3456.12	6,297,778	1,321,658	7,619,436
	barndoor	17.00	876.63	893.63	37,479	1,932,636	1,970,115
	thorny	0.32	370.51	370.83	701	816,836	817,537
	smooth	7.77	49.48	57.25	17,138	109,075	126,212
	clearnose	2.72	29.64	32.36	6,002	65,334	71,337
	rosette	0.04	0.31	0.36	91	693	783
	Total	3554.37	11321.43	14875.80	7,836,049	24,959,470	32,795,519

Table 15 cont.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
2005	winter	528.33	6421.31	6949.64	1,164,766	14,156,572	15,321,337
	little	3041.72	1090.08	4131.79	6,705,841	2,403,206	9,109,047
	barndoor	9.30	1255.49	1264.79	20,504	2,767,871	2,788,376
	thorny	6.52	169.88	176.39	14,367	374,512	388,879
	smooth	3.78	153.39	157.17	8,338	338,169	346,507
	clearnose	3.69	25.96	29.65	8,132	57,236	65,368
	rosette	0.14	0.15	0.29	315	334	649
	Total	3593.48	9116.25	12709.73	7,922,263	20,097,900	28,020,163
2006	winter	981.76	6607.23	7589.00	2,164,413	14,566,459	16,730,872
	little	3387.88	1030.19	4418.07	7,469,003	2,271,174	9,740,177
	barndoor	26.84	2816.91	2843.75	59,181	6,210,223	6,269,404
	thorny	13.95	301.22	315.16	30,748	664,068	694,816
	smooth	29.23	287.89	317.11	64,436	634,678	699,114
	clearnose	24.31	20.20	44.51	53,599	44,532	98,131
	rosette	2.62	0.12	2.75	5,780	274	6,054
	Total	4466.60	11063.76	15530.35	9,847,161	24,391,409	34,238,569
2007	winter	752.79	10757.92	11510.70	1,659,612	23,717,145	25,376,757
	little	3824.08	1557.94	5382.02	8,430,648	3,434,679	11,865,327
	barndoor	24.69	452.76	477.45	54,429	998,173	1,052,602
	thorny	7.92	642.53	650.46	17,469	1,416,545	1,434,014
	smooth	5.49	27.79	33.28	12,103	61,265	73,368
	clearnose	32.01	52.32	84.33	70,564	115,340	185,905
	rosette	2.97	0.49	3.45	6,544	1,072	7,616
	Total	4649.94	13491.75	18141.69	10,251,369	29,744,220	39,995,590

Table 16. Number of length samples by region, year, season, and gear type of the discarded component of the skate catch from the Observer Program.

GOM-GBK

	half 1					half 2				
YEAR	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge
1994		0	60	0	0		0		9	332
1995		726	9	55	0		90		37	
1996		626		17	0		107		7	45
1997		265	25	0	9		183		25	0
1998		0		13	1499		60		213	0
1999		0		52	0		77		18	47
2000		464		13	31		393		97	0
2001		1201		80	0		167		58	
2002		752		177	0		6089		224	762
2003	22	7508	186	552	12	0	6949		724	80
2004	41	5783	15	1710	654	56	8229		1703	634
2005	74	19162	29	702	744	13	12705		688	1169
2006	50	8075		459	346	35	8020		404	2500
2007	3	9374		392	703	52	12468		1949	2605

SNE-MDA

	half 1					half 2				
Year	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge
1994		0	na	0	0		619	na	55	354
1995		726	na	55	0		500	na	12	
1996		626	na	17	379		247	na	0	0
1997		265	na	0	52		1323	na	46	179
1998		0	na	13	0		43	na	28	0
1999		0	na	52	0		0	na	10	0
2000		464	na	13	0		922	na	32	86
2001		1201	na	80	0		1664	na	74	
2002		752	na	177	0		1701	na	164	2125
2003	0	7508	na	552	1524	1	520	na	1312	987
2004	0	5783	na	1710	6162	0	2530	na	630	5953
2005	0	19162	na	702	1643	0	3966	na	761	1164
2006	24	8075	na	459	0	1	1743	na	192	3440
2007	0	9374	na	392	1591	0	932	na	39	1319

Table 17. Discards by species, gear type and half year from 1995-2007.

				Half 1 Gear Type					Half 2 Gear Type					Total Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
1995	winter	2575.94	211.38	118.53	0.19	11984.72	6880.52	1517.84	122.18	0.04	4162.79	9456.46	1729.22	240.71	0.23	16147.51
	little	6357.05	202.52	24.02	1.63	7319.12	12516.80	354.22	18.55	0.15	5902.89	18873.85	556.73	42.57	1.78	13222.00
	barndoor	1.30	0.28	2.70	0.00	206.84	19.40	58.80	19.09	0.00	41.05	20.70	59.08	21.79	0.00	247.89
	thorny	19.58	10.29	12.97	3.98	312.32	90.71	115.10	20.03	0.17	159.80	110.29	125.39	33.00	4.15	472.13
	smooth	8.85	9.92	2.35	1.76	286.58	105.69	43.25	2.75	0.18	103.54	114.54	53.17	5.10	1.93	390.12
	clearnose	103.50	5.55	3.11	0.00	2602.62	140.62	17.38	5.30	0.00	1127.79	244.12	22.94	8.41	0.00	3730.41
	rosette	4.49	0.08	0.00	0.00	6.74	163.92	0.30	0.01	0.00	47.64	168.41	0.38	0.01	0.00	54.38
1996	winter	2617.45	257.18	113.66	3.93	7584.85	3057.90	1438.02	163.78	1.89	6713.87	5675.35	1695.20	277.45	5.82	14298.72
	little	5843.77	139.90	29.59	9.58	6076.34	7836.97	354.78	24.93	2.83	13618.24	13680.74	494.68	54.52	12.41	19694.58
	barndoor	4.31	1.23	6.55	0.91	20.03	14.58	26.98	21.44	0.32	11.20	18.90	28.21	27.98	1.23	31.23
	thorny	13.34	4.39	5.28	7.72	87.04	163.38	105.46	12.21	1.65	81.16	176.72	109.84	17.49	9.36	168.20
	smooth	6.50	1.49	0.36	3.93	51.67	164.40	48.39	3.73	0.99	68.15	170.91	49.88	4.09	4.92	119.81
	clearnose	32.84	11.96	7.21	0.00	1635.71	54.04	10.47	7.78	0.00	3555.45	86.88	22.43	14.99	0.00	5191.16
	rosette	3.78	0.05	0.00	0.00	2.41	210.38	0.63	0.04	0.00	189.70	214.17	0.68	0.04	0.00	192.11
1997	winter	2174.14	168.54	114.86	3.09	3543.37	1920.23	778.96	93.34	0.35	2408.23	4094.37	947.50	208.21	3.43	5951.61
	little	8408.50	183.94	31.36	17.02	2598.91	4581.22	234.94	20.66	0.45	3200.03	12989.73	418.88	52.02	17.47	5798.94
	barndoor	211.92	0.69	7.70	0.00	55.31	17.04	19.70	30.77	0.00	9.37	228.96	20.39	38.47	0.00	64.68
	thorny	38.81	2.79	10.44	6.16	148.38	114.96	92.08	16.98	0.74	136.90	153.77	94.87	27.42	6.90	285.29
	smooth	28.61	0.70	0.38	5.68	31.19	189.77	29.38	3.20	0.67	201.79	218.38	30.08	3.58	6.36	232.98
	clearnose	166.51	32.53	11.22	0.00	336.86	53.65	10.84	5.96	0.00	143.34	220.16	43.37	17.17	0.00	480.20
	rosette	25.55	0.46	0.01	0.00	9.96	24.53	0.21	0.02	0.00	8.52	50.08	0.67	0.03	0.00	18.47
1998	winter	1046.54	72.21	84.83	0.15	8171.28	2343.94	1538.36	132.05	0.03	12338.24	3390.47	1610.57	216.89	0.18	20509.53
	Little	5249.09	120.08	32.44	2.93	15693.50	5702.77	490.01	21.50	0.15	6860.44	10951.86	610.10	53.94	3.09	22553.94
	barndoor	10.97	0.66	6.10	0.00	140.29	11.38	10.92	15.65	0.00	68.87	22.35	11.58	21.75	0.00	209.16
	thorny	101.80	1.32	9.48	2.41	350.86	109.09	85.99	3.58	0.17	468.93	210.89	87.31	13.06	2.57	819.79
	smooth	178.62	6.19	4.95	2.49	392.15	33.43	7.78	0.44	0.09	128.80	212.05	13.97	5.38	2.59	520.95
	clearnose	37.82	14.56	7.77	0.00	2414.69	105.83	26.68	3.51	0.00	607.17	143.65	41.24	11.28	0.00	3021.86
	rosette	9.82	0.17	0.02	0.00	32.01	115.28	1.57	0.02	0.00	59.48	125.10	1.74	0.04	0.00	91.49

Table 17 cont.

				Half 1					Half 2					Total		
				Gear Type					Gear Type					Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
1999	winter	703.27	182.27	92.72	0.23	2137.63	1991.81	1393.05	122.37	0.01	5432.98	2695.08	1575.32	215.09	0.24	7570.62
	Little	6369.41	353.58	31.99	0.25	1402.49	5586.79	413.62	20.95	0.04	3082.78	11956.20	767.20	52.94	0.29	4485.26
	barndoor	5.12	0.77	3.99	0.01	18.29	43.56	22.86	26.24	0.00	100.43	48.67	23.63	30.23	0.01	118.72
	thorny	17.03	1.03	1.43	0.87	44.98	116.34	57.38	2.67	0.03	198.34	133.37	58.41	4.10	0.90	243.32
	smooth	33.32	1.55	0.84	2.37	40.50	41.52	16.14	1.25	0.01	153.32	74.84	17.70	2.10	2.38	193.82
	clearnose	49.32	55.01	3.79	0.00	120.89	45.46	23.29	5.64	0.00	472.19	94.77	78.29	9.43	0.00	593.08
	rosette	8.18	0.46	0.00	0.00	1.60	72.41	0.79	0.02	0.00	17.62	80.59	1.25	0.02	0.00	19.23
2000	winter	731.54	82.47	50.29	0.37	3362.87	1203.23	1552.52	87.04	0.01	6321.91	1934.77	1634.99	137.33	0.38	9684.78
	Little	4394.88	83.65	20.58	2.88	2849.42	3297.27	439.12	19.60	0.02	7164.16	7692.16	522.76	40.17	2.90	10013.58
	barndoor	39.56	2.92	5.15	0.00	149.55	4.07	25.12	31.63	0.00	1134.40	43.63	28.04	36.78	0.00	1283.95
	thorny	60.54	1.78	1.58	1.66	116.53	37.45	76.84	9.28	0.04	275.87	97.99	78.62	10.86	1.69	392.40
	smooth	24.56	2.57	0.48	0.40	69.87	45.93	36.43	2.33	0.03	159.76	70.48	39.00	2.80	0.43	229.63
	clearnose	40.04	6.11	2.75	0.00	238.26	28.44	8.28	2.58	0.00	1254.93	68.47	14.38	5.33	0.00	1493.20
	rosette	2.55	0.03	0.00	0.00	2.36	75.76	0.38	0.01	0.00	95.30	78.31	0.42	0.01	0.00	97.66
2001	winter	610.66	178.6	68.39292		10483.5	518.056	1005.6	76.0568		4021.27	1128.72	1184.29	144.45	0.00	14504.81
	little	3062	170	34.11211		8579.03	2516.46	276.27	16.29889		1769.56	5578.50	446.31	50.41	0.00	10348.59
	barndoor	10.19	11.91	4.83		683.64	8.70	125.84	27.58		1034.13	18.89	137.76	32.41	0.00	1717.77
	thorny	12.90	10.27	3.55		779.67	10.38	20.48	0.96		85.23	23.29	30.75	4.51	0.00	864.91
	smooth	12.14	4.35	1.60		324.85	40.60	58.60	3.01		239.16	52.74	62.95	4.61	0.00	564.01
	clearnose	31.40	25.04	4.45		10.37	38.67	42.08	4.73		1045.62	70.07	67.12	9.18	0.00	1055.99
	rosette	5.17	0.25	0.00		1.72	129.82	4.04	0.05		4.37	134.99	4.29	0.06	0.00	6.09
2002	winter	413.56	209.52	62.18	0.09	6012.98	1502.58	3372.67	84.28		5864.64	1916.14	3582.19	146.47	0.09	11877.62
	little	5705.43	63.13	34.63	0.31	3473.59	5737.55	272.85	17.61		1960.72	11442.97	335.98	52.23	0.31	5434.31
	barndoor	38.02	55.00	14.04	0.00	1527.48	79.27	300.10	15.12		369.34	117.28	355.11	29.16	0.00	1896.82
	thorny	18.10	12.38	4.76	0.18	696.08	22.90	21.29	0.35		75.81	41.01	33.67	5.11	0.18	771.88
	smooth	38.86	6.23	3.47	0.21	323.61	55.59	40.72	0.64		112.39	94.44	46.95	4.11	0.21	435.99
	clearnose	26.14	41.39	2.83	0.00	33.79	207.14	53.66	7.16		1038.69	233.28	95.06	9.99	0.00	1072.49
	rosette	6.10	0.00	0.00	0.00	0.10	68.42	0.09	0.06		2.21	74.51	0.10	0.07	0.00	2.31

Table 17 cont.

				Half 1 Gear Type					Half 2 Gear Type					Total Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
2003	winter	1049.56	324.86	39.94	1.04	8936.49	877.36	1545.44	33.89		7232.20	1926.92	1870.30	73.83	1.04	16168.69
	little	6664.13	79.66	17.94	0.60	6948.71	6824.40	309.58	8.50		7902.79	13488.53	389.24	26.44	0.60	14851.49
	barndoor	38.86	79.76	5.25	0.06	702.72	48.35	226.61	8.85		373.64	87.21	306.37	14.10	0.06	1076.36
	thorny	31.42	15.12	1.43	1.64	478.64	94.16	85.95	0.74		469.39	125.58	101.07	2.17	1.64	948.03
	smooth	72.24	9.11	1.05	4.60	460.31	152.53	48.54	0.50		458.02	224.77	57.64	1.54	4.60	918.33
	clearnose	14.15	10.02	3.59	0.00	236.78	26.89	53.38	3.25		847.79	41.05	63.40	6.84	0.00	1084.57
	rosette	12.02	0.05	0.01	0.00	10.15	9.25	0.11	0.00		6.53	21.26	0.16	0.01	0.00	16.68
2004	winter	1521.17	214.72	23.11	0.66	8200.57	1654.52	863.08	14.34	0.02	11645.92	3175.68	1077.80	37.45	0.68	19846.48
	little	3620.75	97.27	9.49	1.99	4591.50	1974.36	233.16	2.45	0.01	6962.03	5595.11	330.43	11.94	2.00	11553.53
	barndoor	58.49	105.04	2.81	0.00	519.91	22.89	77.54	5.39	0.00	657.79	81.38	182.58	8.20	0.00	1177.70
	thorny	5.18	7.67	0.12	0.46	275.00	27.47	35.21	0.37	0.03	369.88	32.65	42.88	0.49	0.49	644.88
	smooth	13.60	15.62	0.14	1.07	571.56	88.88	41.11	0.54	0.11	857.39	102.48	56.72	0.68	1.19	1428.95
	clearnose	211.88	5.65	3.70	0.00	119.12	356.73	16.83	0.62	0.00	806.37	568.61	22.48	4.31	0.00	925.49
	rosette	7.01	0.00	0.00	0.00	2.66	8.61	0.28	0.00	0.00	29.17	15.62	0.29	0.00	0.00	31.83
2005	winter	1964.26	556.59	39.74	0.26	5967.05	1600.00	696.13	26.53	0.01	8071.63	3564.25	1252.72	66.28	0.27	14038.68
	little	3294.29	154.67	17.95	0.28	4855.81	2425.36	290.48	5.60	0.03	8054.99	5719.66	445.15	23.55	0.31	12910.80
	barndoor	379.78	219.52	20.64	0.27	1263.90	277.40	489.30	19.57	0.00	1576.52	657.17	708.83	40.21	0.27	2840.41
	thorny	20.39	21.30	4.98	0.44	478.08	35.54	14.98	0.59	0.01	185.03	55.93	36.28	5.57	0.45	663.11
	smooth	96.95	44.69	7.28	1.15	1136.78	73.48	23.97	0.96	0.05	453.69	170.44	68.65	8.24	1.20	1590.47
	clearnose	293.51	29.28	0.00	0.00	298.89	165.44	58.71	0.00	0.00	478.90	458.95	87.98	0.00	0.00	777.79
	rosette	29.94	0.32	0.00	0.00	12.93	24.68	0.75	0.01	0.00	21.69	54.62	1.07	0.01	0.00	34.61
2006	winter	1870.57	466.42	105.59	0.04	5449.79	1784.91	717.39	89.87	0.09	5404.90	3655.48	1183.81	195.46	0.13	10854.69
	little	3551.05	30.82	37.69	0.05	2755.35	2532.95	206.95	23.42	0.22	4347.21	6084.00	237.77	61.11	0.27	7102.56
	barndoor	166.18	320.57	38.67	0.01	1375.82	227.09	613.16	84.51	0.00	1428.08	393.27	933.73	123.18	0.01	2803.90
	thorny	16.29	2.83	3.31	0.02	125.64	69.86	69.90	7.51	0.13	299.26	86.15	72.72	10.81	0.15	424.89
	smooth	59.35	10.17	7.80	0.04	506.45	89.19	39.94	5.17	0.11	407.48	148.54	50.11	12.97	0.14	913.94
	clearnose	58.37	13.38	0.18	0.00	290.17	165.23	8.55	0.13	0.00	202.28	223.60	21.93	0.32	0.00	492.45
	rosette	3.84	0.01	0.00	0.00	0.42	16.25	0.40	0.00	0.00	25.32	20.09	0.41	0.00	0.00	25.74

Table 17 cont.

		Half 1 Gear Type					Half 2 Gear Type					Total Gear Type				
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
2007	winter	724.50	704.35	22.80	0.04	5826.92	2964.42	1330.14	12.55	0.00	9437.23	3688.92	2034.49	35.35	0.04	15264.15
	Little	5069.34	194.05	10.09	0.10	5200.60	4128.47	238.32	2.57	0.00	4170.34	9197.81	432.37	12.66	0.10	9370.95
	barndoor	135.26	75.39	11.45	0.00	2465.17	167.73	156.75	10.79	0.00	1042.24	303.00	232.13	22.25	0.00	3507.40
	thorny	12.33	5.58	0.69	0.03	172.78	55.58	16.98	0.48	0.02	179.56	67.91	22.56	1.18	0.05	352.35
	smooth	27.01	14.24	1.10	0.08	395.69	101.80	22.13	0.33	0.01	303.58	128.80	36.37	1.42	0.09	699.27
	clearnose	96.347	38.47	0	0	464.41	90.1909	66.433	0	0	1246.24	186.54	104.91	0.00	0.00	1710.65
	rosette	3.0999	0.027	0	0	0.92939	23.916	3.1576	0	0	11.5952	27.02	3.18	0.00	0.00	12.52

Table 18. Abundance and biomass from NEFSC spring surveys for winter skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	2.171	1.640	2.978	0.854	0.530	1.178	2.542	32	42	56	58.6	79	112	36	232
1969	5.913	4.283	7.543	2.790	1.907	3.672	2.119	15	25	53	53.5	79	111	68	640
1970	2.645	1.627	3.663	0.971	0.626	1.317	2.723	37	43	59	61.0	83	103	44	275
1971	3.387	2.066	4.708	1.894	0.873	2.915	1.788	15	30	48	51.8	76	103	41	513
1972	4.620	3.033	6.207	2.602	1.253	3.951	1.776	15	24	48	49.5	74	97	63	634
1973	2.905	2.024	3.786	1.257	0.824	1.689	2.311	21	32	55	55.5	79	100	49	347
1974	2.091	1.352	2.830	0.943	0.505	1.381	2.218	29	34	53	55.6	76	101	46	222
1975	2.395	1.521	3.269	0.893	0.556	1.230	2.682	17	38	59	59.4	79	99	46	227
1976	2.153	1.075	3.231	0.628	0.279	0.978	3.428	22	38	64	63.1	86	97	29	160
1977	3.111	1.815	4.408	0.838	0.513	1.163	3.712	20	29	69	64.7	93	106	35	204
1978	8.275	-0.327	16.877	1.355	0.121	2.589	6.108	43	62	79	78.5	89	96	41	395
1979	1.852	1.095	2.608	0.333	0.206	0.459	5.568	23	35	78	73.5	93	105	50	204
1980	2.990	1.751	4.229	0.538	0.331	0.745	5.559	22	45	78	74.8	97	104	49	187
1981	4.140	2.905	5.376	2.083	1.199	2.966	1.988	15	22	39	47.6	91	104	56	586
1982	5.773	3.876	7.670	2.137	1.195	3.080	2.701	15	26	46	54.9	95	109	64	707
1983	14.329	8.182	20.476	3.264	1.772	4.756	4.391	15	28	67	64.4	96	108	65	817
1984	10.480	6.816	14.144	2.948	1.694	4.201	3.555	15	22	60	59.0	94	106	59	753
1985	16.373	11.119	21.627	7.861	4.653	11.069	2.083	15	22	46	54.3	94	116	65	1891
1986	10.019	6.973	13.064	3.538	2.181	4.894	2.832	15	27	58	62.2	97	108	67	969
1987	13.126	8.428	17.824	4.821	2.926	6.716	2.723	15	29	56	60.8	97	108	69	1221
1988	14.543	10.508	18.577	7.409	4.736	10.082	1.963	15	25	43	53.4	95	107	73	1827
1989	10.141	7.736	12.546	4.252	3.095	5.409	2.385	15	25	59	61.4	94	109	74	1429
1990	7.183	5.184	9.183	5.087	2.657	7.517	1.412	15	27	41	49.9	91	105	67	1678
1991	6.965	4.012	9.918	3.239	1.979	4.499	2.150	17	29	54	58.6	93	107	57	1027
1992	5.988	3.369	8.607	5.208	0.635	9.780	1.150	15	23	42	46.2	82	106	51	1303
1993	4.761	3.392	6.131	4.305	2.561	6.049	1.106	15	25	42	46.5	82	103	62	1118
1994	1.421	0.990	1.852	1.673	1.150	2.196	0.849	20	32	43	46.5	69	99	49	519
1995	2.151	1.340	2.961	1.998	1.231	2.766	1.076	15	34	44	48.4	71	103	49	476
1996	4.547	2.499	6.594	4.470	2.384	6.556	1.017	15	34	46	49.0	68	96	56	1004
1997	3.065	1.325	4.806	1.834	0.987	2.680	1.672	15	23	51	53.5	78	93	39	458
1998	1.504	0.913	2.096	1.045	0.561	1.529	1.439	15	32	51	53.4	79	94	52	341
1999	2.968	1.303	4.632	1.876	0.870	2.883	1.582	16	27	54	54.9	79	100	52	482
2000	4.358	2.273	6.443	1.998	1.041	2.954	2.181	15	34	62	62.2	82	99	57	457
2001	3.496	1.889	5.103	2.350	0.912	3.787	1.488	20	27	44	52.1	82	100	48	556
2002	3.132	1.650	4.614	1.688	0.949	2.426	1.856	15	29	59	58.6	82	93	48	407
2003	2.799	1.471	4.127	2.047	1.164	2.931	1.367	15	29	49	53.4	82	100	61	606
2004	2.446	1.512	3.379	1.547	1.015	2.080	1.581	18	29	50	54.6	85	97	56	356
2005	1.757	0.869	2.645	1.672	0.470	2.874	1.051	15	30	45	48.6	75	97	52	375
2006	3.041	1.020	5.062	3.067	0.465	5.668	0.992	15	24	43	47.2	75	99	55	779
2007	4.732	3.428	6.035	1.798	1.326	2.269	2.632	17	36	63	64.4	93	101	66	547
2008	2.996	1.224	4.767	1.843	0.726	2.959	1.625	16	36	56	57.2	81	95	55	750

Table 19. Abundance and biomass from NEFSC autumn surveys for winter skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1967-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1967	2.159	1.248	3.070	0.825	0.544	1.106	2.617	15	32	56	57.0	83	107	35	213
1968	1.865	1.264	2.466	0.928	0.573	1.284	2.009	15	25	51	51.8	80	100	56	227
1969	1.315	0.856	1.774	0.540	0.351	0.730	2.435	16	37	58	58.3	78	90	36	161
1970	2.996	1.663	4.328	1.357	0.576	2.138	2.208	21	33	54	56.0	77	97	53	331
1971	1.078	0.542	1.615	0.588	0.238	0.938	1.833	18	27	50	50.5	77	93	35	163
1972	2.958	2.113	3.804	2.071	1.413	2.728	1.429	15	24	42	46.9	74	96	64	592
1973	4.686	3.348	6.024	2.238	1.510	2.967	2.093	21	32	54	55.1	78	101	48	662
1974	2.097	1.418	2.777	1.024	0.672	1.376	2.048	17	30	52	53.6	77	103	39	262
1975	1.315	0.682	1.948	0.420	0.260	0.580	3.130	16	24	62	60.9	84	103	31	115
1976	2.655	0.918	4.392	0.766	0.257	1.274	3.468	19	22	70	59.9	83	98	21	190
1977	4.095	2.814	5.376	1.617	1.049	2.185	2.533	15	25	47	54.8	87	100	51	662
1978	4.989	3.778	6.199	1.042	0.777	1.307	4.787	15	36	77	73.6	94	105	94	762
1979	5.121	3.768	6.475	1.290	0.976	1.603	3.971	20	31	75	66.0	93	113	89	975
1980	6.233	3.806	8.660	1.558	1.015	2.100	4.002	15	37	66	66.4	95	108	60	602
1981	5.668	3.726	7.610	1.505	0.916	2.094	3.766	15	25	61	62.3	99	110	54	516
1982	8.306	4.780	11.831	3.889	0.502	7.275	2.136	15	22	35	46.7	92	112	45	950
1983	12.852	5.693	20.012	2.590	1.447	3.733	4.962	16	28	78	70.5	95	108	42	843
1984	13.323	8.465	18.181	3.653	2.450	4.857	3.647	15	21	55	59.0	95	110	52	1187
1985	9.182	6.552	11.811	2.665	1.842	3.488	3.446	15	32	79	69.7	97	107	37	827
1986	15.800	7.184	24.415	4.196	2.496	5.895	3.766	15	34	75	71.5	97	110	46	1089
1987	11.063	8.200	13.925	4.291	2.783	5.800	2.578	15	25	58	60.1	97	109	49	1165
1988	7.564	4.961	10.167	3.126	2.223	4.028	2.420	15	23	49	57.4	97	110	45	888
1989	5.081	3.288	6.874	2.084	1.422	2.745	2.439	15	27	59	61.0	96	106	48	720
1990	7.145	4.658	9.632	2.451	1.397	3.505	2.915	22	33	68	66.5	97	107	44	895
1991	4.724	3.627	5.821	2.631	1.866	3.396	1.796	17	31	48	56.3	94	106	58	941
1992	3.582	2.140	5.024	1.862	1.116	2.608	1.923	22	33	51	57.4	91	103	39	509
1993	1.905	1.280	2.530	1.458	0.965	1.951	1.307	16	33	48	52.8	88	104	50	452
1994	2.120	1.432	2.808	1.925	1.217	2.633	1.101	15	26	44	47.6	84	106	52	503
1995	1.985	1.214	2.757	1.769	1.047	2.491	1.122	17	31	46	49.4	77	102	43	424
1996	2.276	1.615	2.937	1.426	0.985	1.867	1.596	17	35	51	54.9	83	104	44	370
1997	2.455	1.150	3.760	1.611	0.738	2.484	1.524	19	34	54	55.5	79	101	55	415
1998	3.753	2.488	5.018	2.140	1.438	2.843	1.753	19	27	55	56.8	83	101	50	609
1999	5.089	2.080	8.098	2.642	1.320	3.963	1.927	15	31	58	58.0	80	111	53	966
2000	4.378	2.390	6.366	2.535	1.351	3.718	1.727	18	25	56	55.5	82	99	45	756
2001	3.887	2.442	5.333	2.165	1.415	2.914	1.796	15	32	58	57.8	83	98	53	601
2002	5.600	3.417	7.782	2.323	1.535	3.111	2.411	16	33	66	63.9	87	101	55	743
2003	3.386	2.111	4.662	1.498	0.928	2.068	2.260	16	33	62	63.0	87	104	43	435
2004	4.031	2.632	5.430	1.942	1.343	2.542	2.075	15	33	62	60.4	87	102	50	611
2005	2.615	1.791	3.439	1.671	1.005	2.337	1.565	18	31	52	55.1	81	98	54	475
2006	2.484	1.416	3.553	1.759	1.124	2.395	1.412	18	31	50	52.2	78	99	52	619
2007	3.705	2.169	5.241	2.324	1.208	3.440	1.594	15	33	53	55.0	80	94	56	747

Table 20. Abundance and biomass from NEFSC winter surveys for winter skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	31.571	21.666	41.476	39.759	23.811	55.707	0.794	15	24	38	42.4	74	105	62	4042
1993	10.261	6.052	14.469	10.676	2.331	19.021	0.961	15	23	41	44.1	81	106	47	841
1994	14.439	10.586	18.293	14.216	8.465	19.966	1.016	15	29	40	45.4	81	102	33	1079
1995	23.268	14.507	32.029	35.528	18.060	52.996	0.655	15	27	40	42.2	59	104	53	3773
1996	25.239	7.110	43.369	43.515	7.434	79.596	0.580	15	25	40	41.2	56	99	59	4055
1997	11.643	7.287	15.999	12.565	7.109	18.022	0.927	15	27	45	46.9	71	98	46	1414
1998	22.464	15.878	29.050	19.950	13.556	26.344	1.126	15	26	48	49.4	74	105	60	2092
1999	21.089	13.628	28.549	18.380	10.899	25.860	1.147	15	24	49	49.0	74	101	52	1932
2000	11.315	4.814	17.815	5.697	2.799	8.596	1.986	18	27	56	57.6	88	101	33	486
2001	28.634	19.682	37.585	15.555	9.234	21.875	1.841	16	30	58	57.5	84	100	76	2025
2002	28.733	17.246	40.220	15.982	6.565	25.400	1.798	15	24	49	55.1	88	107	53	1849
2003	17.425	7.871	26.979	29.540	-6.318	64.399	0.590	15	15	28	34.8	75	99	34	1662
2004	26.618	13.793	39.444	13.833	9.244	18.422	1.924	15	31	55	58.0	86	102	58	1342
2005	19.424	8.976	29.872	16.081	6.327	25.836	1.208	16	26	48	50.3	76	95	46	972
2006	32.411	12.125	52.697	18.233	9.593	26.874	1.778	15	30	56	57.4	86	102	60	1776
2007	14.689	5.443	23.936	13.020	3.847	22.193	1.128	15	27	48	50.2	73	93	38	1087

Table 21. Abundance and biomass from NEFSC spring surveys for little skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76, and inshore strata 1-66). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1976-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1976	1.308	0.861	1.755	3.218	2.136	4.301	0.406	8	12	40	36.9	48	58	172	4202
1977	1.347	0.882	1.811	3.336	2.177	4.494	0.404	6	19	41	38.7	48	57	160	4218
1978	1.391	0.962	1.821	3.286	2.363	4.209	0.423	8	11	42	37.5	48	62	160	3945
1979	0.650	0.501	0.799	2.182	1.429	2.934	0.298	4	12	31	32.7	48	56	204	5684
1980	2.206	1.705	2.707	5.898	4.384	7.413	0.374	8	12	37	36.0	48	57	224	9031
1981	1.501	1.200	1.803	3.426	2.714	4.137	0.438	6	15	41	38.3	49	55	175	4113
1982	3.627	2.644	4.611	7.214	5.351	9.076	0.503	9	18	43	40.7	49	55	153	3564
1983	5.718	4.017	7.420	13.024	9.215	16.832	0.439	6	16	42	37.9	48	57	167	6365
1984	4.094	2.615	5.574	10.023	6.787	13.258	0.409	7	11	40	35.8	48	55	139	4573
1985	6.265	4.628	7.901	15.175	10.575	19.775	0.413	8	11	40	36.8	48	57	148	6535
1986	2.753	1.712	3.795	8.554	3.399	13.709	0.322	6	14	33	34.5	48	57	153	3512
1987	4.625	3.149	6.102	16.031	10.222	21.839	0.289	8	12	32	33.1	47	55	145	9584
1988	5.083	3.444	6.721	14.593	9.688	19.498	0.348	8	11	36	34.5	48	55	130	4195
1989	6.634	3.434	9.834	21.643	9.844	33.441	0.307	8	13	34	33.4	46	55	144	10760
1990	4.993	2.397	7.589	14.979	5.250	24.708	0.333	8	11	37	34.7	47	56	132	7085
1991	5.990	4.672	7.308	18.731	14.059	23.403	0.320	8	13	34	34.2	47	58	178	11986
1992	5.297	2.477	8.118	16.793	5.234	28.352	0.315	8	16	33	34.1	46	57	136	6392
1993	7.524	5.187	9.862	22.361	15.110	29.611	0.336	9	12	36	35.0	47	54	160	9574
1994	3.622	2.425	4.819	9.365	6.297	12.434	0.387	9	19	39	37.3	46	54	154	8548
1995	2.872	2.024	3.720	7.574	5.215	9.933	0.379	8	10	39	36.1	47	59	148	3801
1996	7.574	5.522	9.626	18.185	12.647	23.722	0.417	7	17	41	38.3	48	58	168	9086
1997	2.708	2.231	3.184	6.671	5.504	7.837	0.406	9	13	40	37.8	48	54	151	4840
1998	7.471	6.156	8.787	20.938	16.232	25.644	0.357	7	17	37	35.8	47	56	195	15710
1999	9.978	7.688	12.267	28.377	20.345	36.409	0.352	8	12	38	35.4	47	56	157	16406
2000	8.596	6.647	10.545	19.677	15.270	24.083	0.437	9	21	41	38.9	47	57	179	15367
2001	6.835	4.297	9.372	15.347	9.900	20.794	0.445	8	18	42	39.5	48	58	154	6978
2002	6.444	4.546	8.341	16.280	11.306	21.254	0.396	8	11	42	37.7	48	57	154	11983
2003	6.486	4.505	8.486	15.116	10.195	20.036	0.429	9	22	42	40.1	48	55	169	6919
2004	7.219	5.374	9.064	17.039	11.917	22.162	0.424	7	25	42	39.9	47	57	147	9866
2005	3.241	2.305	4.177	7.328	5.515	9.141	0.442	8	13	43	38.9	48	53	138	3108
2006	3.323	1.892	4.753	7.878	4.544	11.211	0.422	7	11	42	38.4	48	55	138	2771
2007	4.459	3.031	5.887	9.081	6.385	11.778	0.491	9	16	44	41.1	48	58	159	5538
2008	7.339	4.537	10.142	16.659	9.678	23.641	0.441	9	17	42	39.1	47	58	149	11863

Table 22. Abundance and biomass from NEFSC autumn surveys for little skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76, and inshore strata 1-66). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1975-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1975	2.379	1.508	3.249	4.858	3.063	6.654	0.490	10	18	43	40.3	49	56	118	1386
1976	2.185	1.582	2.788	4.576	3.278	5.875	0.477	8	22	43	40.6	48	58	74	1421
1977	3.172	2.271	4.072	6.589	4.683	8.495	0.481	9	22	43	40.7	49	56	122	2438
1978	2.938	2.140	3.736	5.613	3.947	7.279	0.523	10	22	44	42.0	49	62	144	3171
1979	2.902	2.343	3.461	5.944	4.790	7.098	0.488	8	21	44	41.0	49	58	177	4597
1980	2.312	1.768	2.855	5.055	4.102	6.008	0.457	9	13	43	37.9	49	55	142	2451
1981	2.779	2.175	3.382	5.847	4.479	7.215	0.475	9	19	43	39.9	49	58	111	1728
1982	5.799	2.673	8.925	15.391	6.979	23.803	0.377	9	18	36	36.4	48	56	123	3848
1983	1.990	1.340	2.639	5.244	3.268	7.219	0.379	8	17	38	36.6	49	55	100	1313
1984	2.483	1.688	3.279	5.487	3.789	7.185	0.453	10	13	43	38.3	49	56	95	1350
1985	2.423	1.629	3.217	6.103	4.006	8.199	0.397	9	17	40	37.5	49	58	119	2761
1986	1.502	1.125	1.879	4.203	2.759	5.648	0.357	10	16	36	35.7	49	55	96	1240
1987	2.311	1.532	3.090	8.104	4.084	12.124	0.285	10	14	31	32.4	48	55	96	2093
1988	1.177	0.663	1.692	3.524	2.144	4.903	0.334	9	13	34	33.8	48	56	80	1128
1989	2.321	1.091	3.552	6.698	3.574	9.823	0.347	5	13	38	35.2	48	56	100	2288
1990	1.242	0.802	1.681	3.204	1.913	4.495	0.388	9	17	40	37.3	48	54	98	1183
1991	3.552	1.494	5.610	8.854	3.301	14.408	0.401	11	24	40	39.3	47	55	102	2866
1992	1.542	1.126	1.958	4.294	2.993	5.595	0.359	6	14	38	36.0	49	63	107	1460
1993	1.180	0.805	1.555	3.136	2.174	4.099	0.376	10	14	41	36.3	49	55	115	1124
1994	1.906	1.349	2.463	4.329	3.102	5.556	0.440	9	18	42	39.4	49	59	131	1729
1995	2.682	1.795	3.569	5.527	3.739	7.316	0.485	9	21	43	41.2	48	56	118	2058
1996	2.239	1.504	2.973	5.146	3.582	6.711	0.435	9	13	42	38.1	49	60	112	1878
1997	2.148	1.533	2.763	4.825	3.407	6.243	0.445	10	21	43	40.0	49	60	109	1757
1998	2.704	1.968	3.441	5.914	4.237	7.591	0.457	10	20	43	40.2	49	57	129	1713
1999	3.210	2.344	4.076	7.698	5.042	10.355	0.417	6	21	41	38.4	48	58	143	2289
2000	2.550	1.607	3.493	5.711	3.761	7.661	0.447	10	22	43	40.1	49	63	116	1759
2001	2.845	2.032	3.658	6.044	4.265	7.823	0.471	10	22	43	41.4	49	57	130	1985
2002	3.375	2.371	4.379	7.358	5.170	9.545	0.459	9	23	43	40.8	49	54	135	2515
2003	7.740	5.218	10.261	18.199	11.697	24.702	0.425	10	18	41	39.3	48	55	141	6523
2004	2.265	1.388	3.141	4.556	2.714	6.399	0.497	8	26	43	42.3	49	57	122	2270
2005	3.766	2.281	5.252	7.606	4.698	10.515	0.495	9	21	44	41.8	49	55	122	2437
2006	3.551	2.492	4.611	7.339	5.154	9.524	0.484	9	20	43	41.4	49	57	130	3349
2007	2.030	1.199	2.861	5.111	2.997	7.225	0.397	10	13	42	36.6	49	55	118	1439

Table 23. Abundance and biomass from NEFSC winter surveys for little skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	66.321	50.335	82.306	170.155	127.459	212.852	0.390	9	21	39	38.0	47	62	89	18418
1993	56.377	43.992	68.761	166.927	120.808	213.045	0.338	9	19	36	35.8	46	53	94	16026
1994	49.812	37.387	62.236	131.570	95.199	167.940	0.379	10	20	39	37.5	47	60	67	10113
1995	57.368	39.311	75.424	138.769	87.458	190.081	0.413	8	24	40	39.1	47	53	95	14530
1996	64.056	47.616	80.495	150.579	108.945	192.213	0.425	9	15	41	38.7	47	62	102	15701
1997	51.901	39.986	63.816	117.751	92.288	143.214	0.441	9	23	42	40.2	47	58	92	12084
1998	57.512	49.249	65.775	138.503	111.869	165.136	0.415	9	20	41	38.7	47	57	105	14492
1999	58.566	46.296	70.837	138.876	104.459	173.292	0.422	6	22	41	39.3	48	55	99	14740
2000	50.725	37.806	63.643	115.572	87.597	143.547	0.439	8	20	42	39.5	47	53	92	10722
2001	47.429	38.584	56.274	105.749	85.050	126.447	0.449	8	11	42	39.7	48	63	120	12956
2002	63.321	49.704	76.937	149.228	116.464	181.993	0.424	8	23	42	40.2	48	56	110	17329
2003	63.943	44.340	83.546	151.185	105.428	196.943	0.423	9	24	41	40.0	48	54	62	8870
2004	71.803	50.398	87.208	162.456	128.807	196.106	0.442	10	25	41	40.5	47	54	94	13822
2005	64.149	45.820	82.478	140.444	93.239	187.648	0.457	9	25	42	40.9	47	54	68	9544
2006	59.254	48.374	70.134	116.433	96.399	136.467	0.509	9	23	43	42.1	49	55	87	12687
2007	48.498	33.785	63.210	106.848	70.103	143.593	0.454	9	22	43	40.8	48	58	86	9258

Table 24. Abundance and biomass from NEFSC spring surveys for barndoor skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.374	0.075	0.673	0.138	0.026	0.249	2.716	41	46	61	71.7	115	118	10	21
1969	0.658	-0.364	1.681	0.145	-0.011	0.301	4.539	33	42	70	83.1	119	120	8	22
1970	0.111	0.033	0.188	0.047	0.017	0.078	2.350	45	44	62	68.2	104	105	9	10
1971	0.116	0.018	0.214	0.102	0.021	0.183	1.134	26	31	59	57.1	69	80	8	20
1972	0.222	0.028	0.416	0.023	0.005	0.041	9.617	63	62	119	104.7	123	124	6	6
1973	0.010	-0.001	0.022	0.017	0.000	0.034	0.621	51	51	51	54.1	59	60	3	3
1974	0.020	-0.005	0.045	0.017	-0.002	0.037	1.146	43	43	58	53.3	59	60	3	3
1975	0.001	-0.001	0.003	0.001	-0.001	0.003	0.900	60	60	60	60.0	60	60	1	1
1976	0.010	-0.010	0.030	0.006	-0.005	0.017	1.800	61	61	61	61.0	61	61	1	1
1977	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1978	0.015	-0.009	0.040	0.016	-0.006	0.039	0.933	51	50	55	56.3	61	62	2	3
1979	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1980	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1981	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1982	0.002	-0.001	0.005	0.002	-0.002	0.005	1.000	54	54	54	54.0	54	54	1	1
1983	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1984	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1985	0.001	0.000	0.002	0.007	-0.004	0.017	0.076	20	20	20	24.6	37	38	2	2
1986	0.003	-0.001	0.007	0.011	-0.004	0.026	0.250	33	33	41	37.5	41	42	2	2
1987	0.002	-0.002	0.006	0.007	-0.006	0.020	0.300	37	37	37	37.0	37	37	1	1
1988	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1989	0.007	-0.007	0.021	0.006	-0.006	0.019	1.100	60	60	60	60.0	60	60	1	1
1990	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1991	0.002	-0.002	0.006	0.007	-0.006	0.020	0.300	38	38	38	38.0	38	38	1	1
1992	0.136	-0.117	0.389	0.013	-0.006	0.032	10.397	41	41	117	98.2	124	125	2	4
1993	0.032	0.024	0.039	0.028	0.005	0.051	1.147	31	31	37	45.3	89	90	5	5
1994	0.084	-0.023	0.191	0.029	-0.001	0.059	2.926	46	46	65	70.1	120	121	4	6
1995	0.015	-0.007	0.037	0.012	-0.005	0.029	1.254	55	55	63	59.6	63	64	2	2
1996	0.062	-0.039	0.162	0.025	-0.003	0.054	2.465	23	23	66	63.2	111	112	4	6
1997	0.077	0.006	0.148	0.035	0.007	0.063	2.216	39	39	67	68.7	89	90	6	7
1998	0.169	-0.024	0.363	0.061	0.015	0.106	2.799	26	26	60	64.4	122	123	8	15
1999	0.279	-0.102	0.660	0.052	0.011	0.094	5.343	28	28	74	80.9	125	126	8	11
2000	0.473	0.246	0.699	0.138	0.076	0.200	3.419	19	20	68	71.4	125	127	14	29
2001	0.170	0.032	0.307	0.141	0.048	0.234	1.200	20	20	52	54.8	77	115	13	30
2002	0.477	0.233	0.721	0.129	0.047	0.212	3.690	35	35	66	77.3	127	133	13	26
2003	0.885	0.341	1.429	0.302	0.172	0.432	2.928	19	19	54	64.0	126	132	23	64
2004	0.103	0.039	0.167	0.111	0.032	0.189	0.928	19	19	55	50.6	81	89	12	24
2005	0.670	0.120	1.221	0.319	0.073	0.565	2.101	26	33	68	68.1	109	122	15	59
2006	1.706	-0.995	4.407	0.586	-0.087	1.260	2.910	19	19	69	69.9	123	134	22	196
2007	6.711	6.606	6.816	1.451	1.331	1.572	4.624	20	35	73	83.4	128	133	23	325
2008	1.370	-0.678	3.419	0.519	-0.059	1.096	2.641	28	33	67	70.9	113	133	17	140

Table 25. Abundance and biomass from NEFSC autumn surveys for barndoor skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	2.633	1.604	3.663	0.762	0.468	1.056	3.458	28	44	69	74.6	121	136	47	120
1964	1.212	0.489	1.934	0.400	0.229	0.570	3.030	40	41	69	72.7	112	122	32	63
1965	1.822	1.115	2.528	0.695	0.441	0.949	2.622	27	42	67	69.9	111	134	36	95
1966	0.811	0.394	1.229	0.459	0.243	0.675	1.767	23	38	60	63.0	88	115	26	62
1967	0.438	-0.025	0.901	0.064	0.017	0.111	6.844	45	52	65	81.0	119	120	10	14
1968	0.285	0.123	0.447	0.132	0.067	0.198	2.150	42	42	67	69.1	96	132	18	29
1969	0.054	-0.003	0.111	0.035	-0.006	0.076	1.551	51	51	62	62.0	73	74	5	8
1970	0.066	-0.046	0.178	0.011	-0.005	0.027	5.868	66	66	65	89.1	128	129	2	2
1971	0.170	-0.051	0.392	0.117	-0.077	0.311	1.455	35	35	53	54.6	63	120	6	19
1972	0.096	-0.073	0.265	0.012	-0.001	0.026	7.751	59	59	70	90.3	132	133	3	3
1973	0.004	-0.001	0.009	0.008	-0.003	0.019	0.474	41	41	47	48.7	52	53	2	3
1974	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1975	0.017	-0.016	0.049	0.010	-0.010	0.031	1.600	70	70	70	70.0	70	70	1	2
1976	0.047	0.002	0.091	0.058	-0.003	0.119	0.810	50	50	51	54.6	61	62	7	10
1977	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1978	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1979	0.009	-0.008	0.026	0.003	-0.003	0.009	3.000	78	78	78	78.0	78	78	1	1
1980	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1981	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1982	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1983	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1984	0.010	-0.004	0.024	0.003	0.000	0.007	2.900	61	61	84	73.0	84	85	2	2
1985	0.004	-0.004	0.012	0.002	-0.002	0.005	2.300	70	70	70	70.0	70	70	1	1
1986	0.029	-0.018	0.077	0.015	-0.002	0.032	2.008	22	22	52	51.0	90	91	3	3
1987	0.014	-0.005	0.032	0.012	-0.004	0.027	1.200	53	53	63	58.5	63	64	2	2
1988	0.007	-0.005	0.020	0.009	-0.005	0.022	0.850	34	34	33	44.8	76	77	2	2
1989	0.005	-0.005	0.014	0.002	-0.002	0.007	2.100	71	71	71	71.0	71	71	1	1
1990	0.028	-0.022	0.078	0.010	-0.005	0.024	2.964	60	60	66	76.3	95	96	2	3
1991	0.031	0.000	0.062	0.020	0.000	0.040	1.579	54	54	61	61.3	73	74	4	5
1992	0.002	-0.002	0.007	0.004	-0.004	0.013	0.550	46	46	51	49.0	51	52	1	2
1993	0.141	-0.040	0.321	0.023	0.004	0.042	6.180	45	45	74	86.6	127	128	5	6
1994	0.035	0.001	0.069	0.044	0.006	0.082	0.790	33	33	47	49.4	75	76	6	9
1995	0.111	-0.009	0.231	0.040	-0.006	0.085	2.810	48	48	62	70.9	113	114	4	10
1996	0.042	-0.020	0.104	0.023	0.000	0.046	1.841	25	25	61	59.8	92	93	4	5
1997	0.105	-0.024	0.234	0.026	0.004	0.047	4.065	36	36	79	73.3	124	125	5	5
1998	0.089	-0.036	0.214	0.026	0.002	0.050	3.453	48	48	71	73.9	120	121	4	5
1999	0.300	0.051	0.549	0.085	0.041	0.130	3.511	23	23	54	68.0	120	121	13	15
2000	0.288	0.054	0.521	0.054	0.023	0.085	5.360	29	29	89	85.5	121	122	12	15
2001	0.543	0.050	1.036	0.149	0.052	0.247	3.635	24	40	75	75.5	121	126	16	34
2002	0.778	0.351	1.205	0.269	0.130	0.407	2.893	26	27	59	68.0	119	129	24	59
2003	0.553	0.255	0.852	0.251	0.157	0.345	2.203	22	22	48	57.1	115	120	29	55
2004	1.295	0.677	1.913	0.229	0.122	0.336	5.662	42	47	80	90.1	124	128	23	58
2005	1.036	0.482	1.590	0.360	0.207	0.513	2.877	18	25	64	68.1	118	132	29	73
2006	1.168	0.392	1.945	0.435	0.169	0.701	2.687	19	29	58	65.5	118	127	35	102
2007	0.798	0.387	1.208	0.305	0.125	0.485	2.617	26	33	59	67.0	126	140	24	71

Table 26. Abundance and biomass from NEFSC winter surveys for barndoor skate for the Georges Bank to Mid-Atlantic region (offshore strata1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	0.000	0.000	0.000	0.000	0.000	0.000	-	-			-		-	0	0
1993	0.123	-0.066	0.311	0.052	0.004	0.100	2.358	20	20	65	57.3	119	120	4	6
1994	0.185	-0.027	0.397	0.080	0.011	0.148	2.328	21	21	60	63.5	102	103	5	7
1995	0.362	0.121	0.603	0.198	0.056	0.340	1.828	33	33	62	63.6	88	109	11	24
1996	0.291	0.079	0.503	0.203	0.054	0.352	1.434	19	20	61	56.4	85	92	12	23
1997	0.618	0.208	1.028	0.275	0.032	0.519	2.247	35	38	65	67.7	112	117	10	28
1998	0.455	0.146	0.765	0.464	0.092	0.837	0.980	20	26	41	46.8	83	123	12	57
1999	1.053	0.347	1.760	0.709	0.318	1.099	1.486	23	27	46	53.2	113	124	22	81
2000	2.718	0.153	5.284	1.081	0.518	1.643	2.515	19	19	56	62.8	122	126	12	69
2001	1.373	0.375	2.370	0.929	0.168	1.691	1.477	19	30	60	58.7	95	127	21	107
2002	2.126	0.506	3.746	0.950	0.441	1.459	2.238	18	29	58	63.9	119	126	24	123
2003	0.872	0.429	1.316	0.776	0.227	1.324	1.125	26	31	46	52.0	90	131	11	47
2004	3.397	1.214	5.581	1.786	0.972	2.601	1.902	18	30	53	60.9	116	130	23	247
2005	1.061	0.542	1.581	1.23101	0.703	1.759	0.862	18	19	44	47.8	84	102	21	103
2006	3.015	1.519	4.511	3.171	1.622	4.719	0.951	20	29	51	52.9	78	111	37	355
2007	1.847	0.815	2.878	2.318	0.199	4.438	0.797	20	30	44	48.5	80	118	25	220

Table 27. Abundance and biomass from NEFSC spring surveys for thorny skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	3.181	2.137	4.225	1.600	1.067	2.134	1.987	12	16	44	47.8	91	105	60	252
1969	4.526	3.186	5.865	1.680	1.161	2.199	2.694	12	13	47	51.1	98	109	64	294
1970	4.202	3.229	5.174	1.990	1.478	2.502	2.112	12	16	41	48.2	95	110	84	363
1971	3.683	2.475	4.891	1.974	1.473	2.475	1.866	12	15	44	47.8	95	116	81	424
1972	4.984	3.757	6.212	2.219	1.773	2.665	2.246	12	16	47	50.7	94	110	91	443
1973	6.622	4.867	8.377	3.562	2.640	4.483	1.859	12	15	44	47.9	91	108	75	574
1974	3.774	2.939	4.608	2.450	1.938	2.962	1.540	9	14	43	45.8	87	106	81	376
1975	3.189	2.222	4.157	1.360	0.990	1.731	2.344	10	15	46	50.5	95	102	62	192
1976	2.895	2.041	3.750	1.671	1.281	2.060	1.733	13	15	43	47.2	90	106	79	339
1977	1.623	1.175	2.070	0.942	0.675	1.209	1.722	12	15	42	48.1	89	111	74	213
1978	1.250	0.806	1.695	0.800	0.579	1.020	1.564	10	15	49	46.8	83	97	71	191
1979	1.079	0.729	1.429	0.582	0.410	0.754	1.853	12	17	51	50.5	84	102	68	163
1980	2.105	1.308	2.901	1.319	0.880	1.757	1.596	11	13	37	43.6	92	100	60	250
1981	2.700	2.065	3.335	1.535	1.139	1.930	1.760	9	13	47	48.1	87	100	60	255
1982	2.345	1.685	3.004	1.144	0.878	1.411	2.049	10	17	53	52.4	85	97	62	218
1983	2.142	1.398	2.886	0.968	0.728	1.209	2.212	12	15	52	52.3	91	103	55	156
1984	1.453	0.818	2.087	0.608	0.462	0.755	2.389	12	16	51	53.0	96	100	40	97
1985	3.074	2.124	4.024	1.413	1.060	1.766	2.175	11	14	44	48.4	95	102	59	209
1986	2.619	1.974	3.263	1.718	1.377	2.058	1.525	10	15	38	44.0	83	98	69	276
1987	1.469	0.805	2.133	0.852	0.646	1.058	1.724	14	16	42	46.6	87	109	53	141
1988	1.173	0.735	1.612	1.106	0.766	1.446	1.061	11	14	32	38.5	82	98	59	176
1989	1.481	0.793	2.169	1.221	0.801	1.640	1.213	11	15	34	40.0	84	101	57	175
1990	1.565	0.833	2.296	1.097	0.688	1.506	1.427	14	16	39	44.5	82	99	49	167
1991	1.542	0.945	2.139	0.858	0.569	1.147	1.797	11	13	47	48.5	89	99	47	132
1992	1.092	0.621	1.564	0.612	0.384	0.840	1.784	14	15	47	48.4	89	102	31	86
1993	0.700	0.366	1.034	0.486	0.327	0.646	1.440	13	13	36	42.0	91	105	37	79
1994	0.435	0.242	0.629	0.439	0.270	0.609	0.991	12	12	37	39.3	67	92	39	80
1995	0.564	0.307	0.821	0.384	0.236	0.533	1.467	9	12	42	45.8	84	92	31	66
1996	0.371	0.178	0.563	0.321	0.106	0.535	1.156	12	12	36	40.8	80	93	24	63
1997	0.422	0.117	0.727	0.270	0.153	0.387	1.560	15	20	47	47.9	82	87	25	47
1998	0.480	0.209	0.752	0.334	0.236	0.431	1.440	12	14	35	40.8	89	98	42	85
1999	0.369	0.093	0.646	0.255	0.163	0.347	1.448	11	17	40	46.2	83	89	26	44
2000	0.423	0.166	0.680	0.470	0.013	0.927	0.900	12	12	24	34.0	82	89	28	103
2001	0.493	0.217	0.769	0.221	0.080	0.362	2.234	14	33	56	57.7	80	92	16	35
2002	0.333	0.138	0.529	0.248	0.127	0.369	1.340	13	15	38	42.0	88	93	24	53
2003	0.594	0.268	0.920	0.332	0.203	0.461	1.790	19	19	50	50.9	86	102	30	57
2004	0.368	0.178	0.557	0.212	0.128	0.296	1.731	15	15	47	49.3	91	95	22	48
2005	0.435	0.154	0.716	0.371	0.167	0.576	1.171	16	17	44	44.4	76	89	19	62
2006	0.201	0.035	0.366	0.186	0.020	0.352	1.079	12	14	41	41.9	83	87	15	29
2007	0.390	0.144	0.635	0.430	0.228	0.632	0.907	9	11	24	32.3	88	98	26	99
2008	0.255	0.088	0.422	0.184	0.086	0.281	1.387	10	12	37	41.5	90	94	20	39

Table 28. Abundance and biomass from NEFSC autumn surveys for thorny skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	5.371	3.788	6.954	1.672	1.305	2.039	3.213	10	15	60	60.4	99	107	65	297
1964	4.403	3.273	5.534	1.651	1.110	2.192	2.667	10	14	49	52.7	96	110	66	278
1965	4.474	3.268	5.681	1.825	1.243	2.408	2.451	10	14	45	49.6	95	107	55	352
1966	7.971	6.163	9.780	2.371	1.855	2.886	3.362	9	13	61	59.4	95	112	72	364
1967	2.712	1.422	4.001	0.982	0.383	1.580	2.763	12	14	49	52.5	95	100	54	165
1968	4.421	3.321	5.521	1.440	1.040	1.840	3.071	12	16	55	57.5	97	107	59	217
1969	5.715	4.320	7.110	1.833	1.359	2.307	3.117	12	14	55	56.7	97	106	72	289
1970	7.347	5.630	9.065	2.216	1.474	2.958	3.316	8	19	57	60.4	98	109	77	403
1971	5.357	4.149	6.565	1.434	1.095	1.774	3.735	12	18	63	64.1	99	111	69	284
1972	4.119	2.974	5.263	1.717	1.302	2.132	2.399	12	16	51	53.1	94	105	75	306
1973	4.564	3.227	5.902	1.536	1.134	1.939	2.971	12	17	59	61.2	95	111	72	274
1974	3.038	2.166	3.910	1.392	1.025	1.759	2.182	10	14	50	51.1	89	111	79	293
1975	2.474	1.483	3.464	1.027	0.716	1.338	2.409	10	12	47	50.0	94	106	70	232
1976	1.720	1.003	2.437	0.798	0.543	1.052	2.157	12	15	44	49.1	91	103	57	143
1977	3.221	2.513	3.928	1.548	1.223	1.874	2.080	10	13	49	50.7	89	107	108	446
1978	4.291	3.473	5.109	2.145	1.643	2.648	2.000	10	16	49	51.1	88	107	155	874
1979	3.612	2.750	4.474	1.283	0.864	1.702	2.815	11	21	59	59.5	89	101	134	486
1980	4.601	3.344	5.859	1.882	1.484	2.280	2.445	11	14	54	54.4	90	100	84	416
1981	3.339	2.551	4.127	1.305	0.957	1.653	2.559	12	15	55	57.1	90	103	71	223
1982	0.646	0.312	0.981	0.393	0.194	0.592	1.644	11	13	33	43.0	85	96	31	83
1983	2.409	1.553	3.266	0.833	0.589	1.077	2.892	15	20	56	58.8	93	108	49	121
1984	2.887	1.978	3.795	1.270	0.975	1.565	2.272	10	13	48	49.8	94	107	70	211
1985	2.877	1.765	3.988	1.438	1.094	1.783	2.000	12	16	49	49.6	87	103	66	260
1986	1.629	1.068	2.189	1.019	0.771	1.268	1.598	11	15	35	44.2	83	101	61	183
1987	0.944	0.590	1.297	0.841	0.600	1.082	1.123	12	14	36	40.2	78	92	49	143
1988	1.488	0.998	1.978	1.099	0.702	1.497	1.354	13	15	31	41.5	84	101	56	208
1989	1.883	0.980	2.786	1.129	0.787	1.471	1.668	12	14	40	46.2	85	101	63	198
1990	1.704	1.090	2.318	1.040	0.744	1.335	1.639	12	17	42	47.2	85	95	53	202
1991	1.632	0.519	2.745	0.921	0.591	1.251	1.772	13	15	47	49.5	86	108	54	153
1992	0.962	0.551	1.373	0.775	0.461	1.088	1.242	12	13	36	41.2	83	99	48	144
1993	1.658	0.639	2.676	0.901	0.440	1.361	1.840	12	13	47	47.8	91	101	50	157
1994	1.509	0.343	2.675	0.981	0.311	1.652	1.538	13	17	45	46.9	84	97	41	170
1995	0.783	0.331	1.235	0.639	0.183	1.095	1.226	13	14	39	42.2	72	99	37	107
1996	0.814	0.360	1.269	0.602	0.362	0.842	1.352	14	14	39	43.3	85	99	37	102
1997	0.849	0.405	1.293	0.404	0.241	0.567	2.101	12	20	50	52.3	83	99	33	79
1998	0.648	0.297	0.999	0.307	0.145	0.468	2.113	13	14	51	52.4	87	93	30	60
1999	0.479	0.249	0.710	0.326	0.195	0.457	1.469	13	14	41	46.3	87	94	38	72
2000	0.832	0.391	1.274	0.374	0.239	0.510	2.224	13	17	49	52.7	92	102	27	70
2001	0.332	0.087	0.577	0.294	0.157	0.430	1.129	16	17	44	44.1	74	82	23	60
2002	0.436	0.188	0.684	0.260	0.126	0.393	1.679	14	15	35	44.2	85	95	25	52
2003	0.742	0.450	1.035	0.930	0.168	1.691	0.798	12	14	23	34.2	74	89	34	175
2004	0.710	0.272	1.148	0.358	0.167	0.550	1.980	14	18	45	50.1	87	90	23	65
2005	0.224	0.092	0.357	0.205	-0.034	0.443	1.096	13	18	39	42.6	76	90	17	36
2006	0.726	0.385	1.066	0.254	0.154	0.354	2.857	13	15	51	54.6	93	94	27	52
2007	0.316	0.083	0.549	0.296	0.072	0.520	1.068	10	13	19	34.6	84	92	22	45

Table 29. Abundance and biomass from NEFSC spring surveys for smooth skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.211	0.080	0.342	0.484	0.129	0.838	0.436	12	24	41	42.1	58	64	17	41
1969	0.377	0.193	0.562	0.834	0.521	1.147	0.452	11	19	48	43.3	58	63	28	82
1970	0.346	0.134	0.557	0.702	0.376	1.028	0.492	9	14	47	40.9	57	61	25	68
1971	0.800	0.395	1.205	1.185	0.650	1.719	0.675	9	20	51	48.2	61	63	40	114
1972	0.621	0.355	0.886	1.016	0.582	1.450	0.611	14	20	47	44.3	59	64	34	122
1973	1.000	0.745	1.255	1.907	1.401	2.414	0.524	9	24	45	44.2	59	65	51	179
1974	1.092	0.594	1.590	2.003	1.109	2.896	0.545	9	9	47	42.7	59	63	47	172
1975	0.240	0.133	0.346	0.383	0.224	0.543	0.626	19	25	49	46.8	59	61	22	37
1976	0.534	0.413	0.655	1.150	0.870	1.429	0.464	12	16	43	39.8	57	60	49	134
1977	0.122	0.066	0.178	0.302	0.158	0.445	0.405	15	18	40	41.4	57	60	28	45
1978	0.251	0.144	0.358	0.413	0.258	0.567	0.609	24	26	50	46.7	58	61	33	56
1979	0.218	0.097	0.340	0.410	0.163	0.657	0.533	15	19	39	40.2	54	61	27	54
1980	0.484	0.316	0.651	0.948	0.625	1.271	0.510	16	20	42	41.9	56	60	42	84
1981	0.358	0.227	0.489	0.782	0.513	1.050	0.458	8	13	38	37.2	57	65	38	70
1982	0.152	0.057	0.247	0.225	0.092	0.357	0.677	11	10	52	45.6	57	64	14	23
1983	0.363	0.219	0.507	0.531	0.335	0.727	0.683	11	21	50	47.9	57	69	25	50
1984	0.065	0.010	0.120	0.124	0.026	0.221	0.523	19	20	48	39.8	59	60	9	13
1985	0.211	0.136	0.286	0.450	0.298	0.602	0.469	18	20	41	40.4	57	63	31	59
1986	0.250	0.137	0.362	0.466	0.256	0.677	0.536	20	24	48	46.7	59	65	30	93
1987	0.069	0.029	0.108	0.105	0.044	0.166	0.655	43	42	48	50.2	59	62	12	15
1988	0.115	0.044	0.186	0.328	0.175	0.480	0.350	11	13	36	36.3	57	60	24	49
1989	0.225	0.107	0.343	0.620	0.402	0.838	0.363	13	15	37	38.8	60	63	30	88
1990	0.152	0.010	0.294	0.294	0.080	0.509	0.515	11	16	46	44.0	57	62	18	40
1991	0.137	0.073	0.200	0.237	0.136	0.337	0.576	11	17	49	47.1	59	62	22	34
1992	0.063	0.025	0.101	0.104	0.035	0.172	0.608	22	40	49	48.5	56	57	12	16
1993	0.086	0.021	0.151	0.214	0.020	0.408	0.403	21	23	42	41.2	56	58	14	35
1994	0.098	0.043	0.153	0.176	0.082	0.269	0.558	29	29	47	47.1	56	58	15	30
1995	0.101	0.050	0.152	0.234	0.119	0.349	0.432	9	20	42	41.9	55	59	18	33
1996	0.036	0.014	0.058	0.084	0.038	0.129	0.429	20	19	48	43.8	53	59	10	12
1997	0.037	0.015	0.059	0.122	0.035	0.208	0.307	17	20	36	38.9	55	58	11	22
1998	0.200	0.089	0.311	0.410	0.206	0.613	0.489	9	19	46	44.6	56	60	28	77
1999	0.243	0.068	0.418	0.925	-0.074	1.924	0.262	18	20	32	35.6	51	65	23	111
2000	0.060	0.025	0.095	0.220	-0.021	0.460	0.272	10	10	27	30.9	59	62	13	30
2001	0.058	0.020	0.096	0.125	0.058	0.192	0.466	19	28	46	44.6	57	60	16	25
2002	0.184	0.096	0.271	0.482	0.297	0.667	0.381	10	13	45	40.4	55	61	26	78
2003	0.224	0.161	0.287	0.642	0.429	0.348	0.348	14	19	40	40.4	55	59	36	95
2004	0.262	0.141	0.383	0.650	0.278	1.022	0.403	12	19	43	42.3	56	60	32	125
2005	0.457	0.125	0.788	1.207	0.288	2.126	0.378	10	27	42	42.4	53	60	22	178
2006	0.203	0.005	0.401	0.531	-0.009	1.072	0.382	19	21	41	41.3	56	62	22	71
2007	0.125	0.035	0.214	0.294	0.095	0.494	0.423	16	21	46	41.9	57	60	18	64
2008	0.340	0.075	0.604	1.050	0.156	1.945	0.323	9	14	38	36.8	55	59	20	168

Table 30. Abundance and biomass from NEFSC autumn surveys for smooth skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	0.498	0.306	0.689	0.543	0.282	0.804	0.917	9	20	48	43.9	58	62	26	53
1964	0.326	0.152	0.501	0.360	0.209	0.512	0.906	9	20	42	41.7	59	64	19	35
1965	0.475	0.140	0.811	1.221	0.440	2.001	0.389	11	16	35	38.1	56	64	27	94
1966	0.323	0.175	0.471	0.867	0.519	1.216	0.372	13	17	37	38.6	58	59	28	60
1967	0.152	0.036	0.268	0.293	0.118	0.469	0.518	22	24	48	46.5	62	69	16	27
1968	0.385	0.211	0.559	0.665	0.375	0.955	0.579	17	20	48	45.9	58	62	24	56
1969	0.290	0.131	0.449	0.604	0.282	0.925	0.481	12	16	41	39.6	58	64	21	50
1970	0.232	0.121	0.343	0.530	0.289	0.771	0.437	9	13	45	38.3	59	62	25	50
1971	0.157	0.077	0.238	0.250	0.120	0.379	0.631	17	36	53	51.0	57	59	18	27
1972	0.332	0.185	0.478	0.499	0.285	0.713	0.664	16	24	49	49.8	62	64	30	52
1973	0.311	0.199	0.423	0.506	0.344	0.667	0.614	17	22	48	46.9	58	60	32	56
1974	0.123	0.055	0.192	0.180	0.088	0.273	0.684	11	11	50	48.5	60	63	13	21
1975	0.076	0.029	0.123	0.104	0.043	0.165	0.727	21	30	49	46.7	56	57	12	15
1976	0.039	0.004	0.074	0.077	0.020	0.135	0.501	17	36	41	43.9	52	60	9	10
1977	0.376	0.274	0.478	0.600	0.443	0.757	0.627	19	24	48	44.9	56	61	50	84
1978	0.450	0.240	0.661	0.635	0.359	0.912	0.709	8	25	50	48.0	59	66	49	130
1979	0.182	0.075	0.288	0.239	0.116	0.362	0.761	9	29	50	48.7	60	62	31	60
1980	0.343	0.167	0.519	0.522	0.254	0.789	0.658	15	23	52	46.4	58	62	37	60
1981	0.119	0.039	0.199	0.167	0.069	0.264	0.715	23	26	49	48.1	60	61	13	18
1982	0.039	0.007	0.071	0.074	0.025	0.123	0.521	9	9	49	41.9	63	64	11	11
1983	0.146	0.056	0.236	0.255	0.085	0.426	0.573	14	14	46	40.9	57	59	12	24
1984	0.199	0.106	0.292	0.389	0.171	0.607	0.512	14	22	37	39.2	58	71	23	39
1985	0.210	0.088	0.332	0.340	0.180	0.500	0.617	12	15	51	45.2	59	63	28	64
1986	0.209	0.118	0.300	0.392	0.216	0.567	0.534	13	21	47	45.0	63	66	24	63
1987	0.095	0.045	0.145	0.164	0.081	0.247	0.581	15	15	48	44.8	60	61	19	28
1988	0.284	0.103	0.465	0.446	0.223	0.670	0.637	20	20	51	48.3	59	65	27	90
1989	0.128	0.072	0.185	0.336	0.194	0.478	0.382	13	16	33	36.8	59	62	27	52
1990	0.194	0.120	0.268	0.332	0.202	0.462	0.584	16	23	48	46.4	58	62	27	45
1991	0.167	0.070	0.265	0.335	0.188	0.482	0.500	18	20	46	43.9	57	62	25	59
1992	0.126	0.024	0.228	0.316	0.120	0.511	0.400	12	18	43	40.0	58	60	16	56
1993	0.227	0.107	0.346	0.818	0.273	1.362	0.277	13	13	26	32.6	56	62	29	123
1994	0.099	0.030	0.169	0.269	0.105	0.433	0.370	11	11	36	38.0	57	59	17	36
1995	0.189	0.115	0.263	0.764	0.315	1.214	0.247	10	13	30	32.6	56	59	29	119
1996	0.176	0.093	0.260	0.421	0.249	0.594	0.418	15	18	46	41.6	56	59	26	55
1997	0.232	0.117	0.347	0.449	0.232	0.665	0.517	16	21	47	45.2	60	64	20	59
1998	0.028	0.005	0.051	0.108	0.021	0.194	0.263	18	17	29	35.2	51	53	11	18
1999	0.070	0.032	0.109	0.110	0.050	0.171	0.638	22	22	50	48.7	60	62	16	22
2000	0.154	0.083	0.226	0.318	0.190	0.447	0.485	10	11	45	42.3	59	73	27	55
2001	0.287	0.169	0.405	0.565	0.349	0.781	0.507	17	23	49	46.5	58	62	29	84
2002	0.111	0.067	0.155	0.209	0.140	0.278	0.533	15	24	50	46.2	60	62	25	32
2003	0.190	0.076	0.304	0.646	0.248	1.045	0.294	10	14	39	36.3	52	62	30	84
2004	0.214	0.126	0.303	0.467	0.283	0.652	0.458	18	24	47	45.3	55	59	29	58
2005	0.131	0.039	0.224	0.291	0.143	0.439	0.451	15	17	47	43.1	59	62	18	44
2006	0.211	0.106	0.316	0.387	0.230	0.544	0.545	10	14	50	45.6	59	62	27	56
2007	0.089	0.048	0.131	0.198	0.107	0.289	0.451	16	24	47	43.6	58	71	19	31

Table 31. Abundance and biomass from NEFSC spring surveys for clearnose skate for the Mid-Atlantic region (offshore strata 61-76, inshore strata 15-44). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1976-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1976	0.100	0.020	0.179	0.129	0.040	0.218	0.770	26	26	43	48.5	66	67	8	12
1977	0.509	0.297	0.722	0.500	0.260	0.741	1.017	23	23	56	52.5	63	64	17	41
1978	0.211	-0.094	0.516	0.237	-0.057	0.530	0.893	20	20	57	52.2	68	69	8	21
1979	0.109	0.010	0.209	0.125	0.004	0.247	0.875	25	25	42	50.3	77	78	6	9
1980	0.319	0.100	0.538	0.456	0.136	0.775	0.700	25	25	41	45.1	64	69	14	44
1981	0.891	-0.141	1.923	0.606	0.106	1.107	1.469	24	26	60	55.9	67	72	10	44
1982	0.328	0.165	0.491	0.368	0.126	0.610	0.892	30	32	52	53.6	66	71	14	40
1983	0.138	0.005	0.270	0.127	0.003	0.252	1.081	13	13	58	51.3	65	66	7	11
1984	0.380	0.103	0.658	0.288	0.018	0.557	1.321	48	48	62	60.7	70	74	11	25
1985	0.493	-0.166	1.151	0.436	-0.203	1.076	1.129	48	48	58	59.3	69	72	10	37
1986	0.155	0.035	0.274	0.232	0.038	0.427	0.666	27	27	44	44.8	68	69	11	15
1987	0.306	0.150	0.463	0.202	0.109	0.204	1.519	49	51	63	61.9	69	72	16	20
1988	0.340	0.171	0.508	0.300	0.097	0.502	1.134	44	44	58	57.1	67	71	11	19
1989	0.424	0.258	0.590	0.415	0.275	0.554	1.023	25	25	58	52.3	68	72	14	40
1990	0.501	0.283	0.719	0.420	0.243	0.597	1.192	30	30	59	56.2	67	72	15	52
1991	0.690	0.463	0.918	0.543	0.354	0.731	1.272	27	27	62	58.8	68	71	23	59
1992	0.748	0.324	1.172	0.489	0.218	0.760	1.529	46	46	63	63.0	68	80	23	47
1993	0.856	0.479	1.233	0.656	0.216	1.096	1.305	21	33	63	58.6	70	74	12	136
1994	0.319	0.052	0.585	0.188	0.043	0.333	1.699	51	57	65	66.0	73	74	8	24
1995	0.669	0.361	0.977	0.464	0.261	0.666	1.443	46	46	67	62.4	68	74	18	32
1996	1.224	0.194	2.254	0.948	0.255	1.641	1.291	13	27	62	59.8	70	75	30	95
1997	1.290	0.885	1.695	0.972	0.542	1.403	1.326	33	39	63	61.3	71	78	22	80
1998	0.903	0.674	1.133	0.667	0.369	0.964	1.355	26	38	62	60.2	70	74	29	81
1999	0.943	0.647	1.238	0.862	0.470	1.255	1.093	26	28	59	57.3	67	72	19	54
2000	1.391	1.046	1.736	1.140	0.789	1.491	1.221	24	40	59	59.4	70	76	31	126
2001	1.380	0.674	2.087	1.097	0.456	1.738	1.258	42	49	62	60.8	68	72	19	74
2002	0.836	0.281	1.392	0.617	0.241	0.993	1.355	29	42	62	60.5	69	74	23	59
2003	0.622	0.366	0.879	0.448	0.265	0.631	1.389	49	49	62	62.7	75	76	16	35
2004	0.433	0.050	0.815	0.376	0.049	0.703	1.151	35	35	59	56.2	70	72	9	23
2005	0.569	0.030	1.109	0.414	0.008	0.820	1.374	42	42	61	61.2	70	73	11	27
2006	0.567	0.189	0.946	0.420	0.179	0.661	1.350	36	41	63	60.7	68	72	18	39
2007	0.857	0.406	1.308	0.745	0.273	1.217	1.150	28	30	60	58.4	69	73	19	48
2008	1.188	0.603	1.773	0.846	0.370	1.322	1.404	27	43	62	62.4	72	79	30	103

Table 32. Abundance and biomass from NEFSC autumn surveys for clearnose skate for the Mid-Atlantic region (offshore strata 61-76, inshore strata 15-44). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th,and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1975-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1975	0.237	0.086	0.388	0.246	0.133	0.360	0.961	21	21	53	50.3	63	66	31	49
1976	0.302	0.189	0.415	0.348	0.236	0.459	0.869	18	34	52	52.1	64	69	26	54
1977	0.768	0.288	1.248	0.742	0.281	1.203	1.035	15	37	57	55.4	65	68	32	106
1978	0.156	0.073	0.240	0.224	0.086	0.363	0.697	10	10	44	40.8	64	66	14	23
1979	0.419	0.116	0.721	0.346	0.146	0.545	1.211	22	24	56	55.4	67	71	27	46
1980	0.685	0.408	0.961	0.549	0.322	0.775	1.248	33	37	59	58.1	69	72	32	80
1981	0.171	0.081	0.260	0.179	0.087	0.271	0.954	27	27	55	51.5	65	68	19	28
1982	0.213	0.099	0.326	0.183	0.095	0.271	1.163	32	43	59	58.3	67	72	26	37
1983	0.141	0.027	0.254	0.127	0.043	0.210	1.110	16	16	57	52.2	64	70	15	19
1984	0.178	0.064	0.293	0.189	0.063	0.315	0.945	34	37	53	54.0	67	83	20	32
1985	0.306	0.173	0.439	0.315	0.182	0.447	0.974	32	41	56	54.9	66	71	23	42
1986	0.545	-0.038	1.027	0.591	0.091	1.092	0.921	23	23	59	52.6	64	71	31	62
1987	0.320	0.176	0.465	0.289	0.167	0.412	1.107	15	41	56	55.5	69	70	23	42
1988	0.335	0.157	0.513	0.329	0.163	0.495	1.019	33	37	57	56.0	66	71	19	60
1989	0.273	0.075	0.471	0.324	0.064	0.584	0.843	37	37	52	52.7	63	70	20	39
1990	0.402	0.157	0.646	0.306	0.114	0.499	1.311	16	41	60	57.9	69	72	17	50
1991	0.922	0.279	1.566	0.816	0.339	1.294	1.130	35	39	58	57.1	69	71	35	119
1992	0.345	0.185	0.505	0.312	0.185	0.440	1.104	16	42	59	56.7	67	69	22	48
1993	0.495	0.145	0.844	0.474	0.188	0.759	1.044	35	40	57	56.8	66	73	27	104
1994	0.938	0.479	1.398	0.842	0.494	1.190	1.115	35	40	57	57.1	66	73	35	129
1995	0.331	0.189	0.473	0.426	0.233	0.618	0.777	14	14	51	45.5	66	72	25	63
1996	0.430	0.194	0.666	0.369	0.163	0.576	1.165	29	45	59	58.8	68	72	20	42
1997	0.614	0.296	0.932	0.484	0.281	0.688	1.269	43	43	61	60.2	69	77	27	60
1998	1.121	0.115	2.128	1.096	0.124	2.068	1.023	34	43	57	57.5	68	73	32	98
1999	1.053	0.536	1.570	0.928	0.525	1.332	1.134	15	32	61	57.8	69	71	41	84
2000	1.032	0.422	1.642	0.795	0.353	1.238	1.298	14	47	60	60.5	69	74	29	61
2001	1.614	1.092	2.136	1.494	0.984	2.004	1.081	13	15	59	55.2	68	73	41	221
2002	0.891	0.372	1.411	0.863	0.317	1.409	1.033	14	38	55	56.0	68	73	27	63
2003	0.661	0.417	0.906	0.640	0.456	0.823	1.034	15	30	54	54.5	71	78	38	81
2004	0.709	0.201	1.217	0.590	0.172	1.008	1.201	37	43	62	60.1	69	75	18	55
2005	0.524	0.192	0.855	0.452	0.207	0.697	1.159	26	37	62	59.6	71	74	30	71
2006	0.533	0.257	0.809	0.654	0.347	0.961	0.816	13	37	53	52.6	64	71	35	77
2007	0.853	0.430	1.276	0.788	0.386	1.191	1.082	13	34	60	57.9	67	74	25	74

Table 33. Abundance and biomass from NEFSC winter surveys for clearnose skate for the Georges Bank to Mid-Atlantic region (offshore strata1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	5.622	3.247	7.997	5.247	2.974	7.519	1.072	23	26	59	54.7	67	93	22	551
1993	6.013	3.818	8.208	5.973	3.852	8.093	1.007	22	33	57	54.3	67	81	23	716
1994	8.854	4.037	13.672	7.692	2.152	13.233	1.151	27	33	60	57.5	69	77	16	639
1995	7.924	2.521	13.327	6.247	1.301	11.194	1.268	24	45	61	60.2	69	76	23	737
1996	14.725	8.266	21.183	11.555	6.347	16.762	1.274	22	40	61	60.0	69	77	32	3086
1997	5.522	3.154	7.890	5.069	2.158	7.980	1.089	22	35	59	56.2	70	76	32	682
1998	6.031	4.470	7.592	4.878	3.195	6.560	1.236	22	36	60	58.3	71	88	32	1091
1999	3.826	2.335	5.317	3.022	1.586	4.459	1.266	23	37	61	59.6	70	76	30	343
2000	10.102	5.693	14.510	8.864	4.579	13.150	1.140	25	42	59	58.2	69	93	43	1449
2001	8.316	5.624	11.008	6.599	4.240	8.957	1.260	25	43	61	60.6	69	86	41	1300
2002	12.223	8.343	16.102	8.864	5.886	11.843	1.379	23	39	63	61.6	70	74	51	1704
2003	19.637	13.819	25.455	15.769	10.902	20.635	1.245	23	39	62	59.1	70	81	36	2260
2004	11.566	7.743	15.389	10.162	6.344	13.979	1.138	20	35	60	58.1	70	80	38	1880
2005	6.036	3.837	8.235	5.078	2.425	7.731	1.189	24	44	60	59.1	70	82	26	1047
2006	11.723	4.862	18.585	11.085	4.693	17.477	1.058	23	35	57	56.7	70	77	41	1916
2007	15.151	10.623	19.679	11.760	8.466	15.054	1.288	25	44	62	60.5	70	82	51	1731

Table 34. Abundance and biomass from NEFSC spring surveys for rosette skate for the Mid-Atlantic region (offshore strata 61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.005	-0.002	0.012	0.014	0.000	0.029	0.356	33	33	33	34.4	35	36	3	3
1969	0.001	-0.001	0.002	0.003	-0.003	0.010	0.200	37	37	37	37.0	37	37	1	1
1970	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1971	0.005	-0.005	0.014	0.010	-0.009	0.028	0.500	57	57	57	57.0	57	57	1	1
1972	0.000	0.000	0.001	0.003	-0.003	0.010	0.100	35	35	35	35.0	35	35	1	1
1973	0.006	-0.001	0.012	0.023	-0.006	0.052	0.240	38	38	38	38.6	41	42	4	5
1974	0.005	-0.005	0.015	0.025	-0.024	0.074	0.200	41	41	41	41.0	41	41	1	1
1975	0.001	-0.001	0.003	0.005	-0.005	0.014	0.200	38	38	38	38.5	39	39	1	2
1976	0.007	0.000	0.015	0.035	-0.003	0.073	0.208	31	31	36	36.9	44	45	4	6
1977	0.102	0.019	0.186	0.552	0.107	0.998	0.185	20	26	32	33.6	37	42	11	70
1978	0.010	0.001	0.019	0.041	0.008	0.074	0.232	12	25	35	35.3	40	41	7	10
1979	0.007	0.005	0.009	0.040	0.031	0.048	0.171	13	13	34	31.6	40	41	4	10
1980	0.072	0.030	0.115	0.373	0.167	0.580	0.194	26	27	34	35.3	41	42	15	47
1981	0.013	0.001	0.025	0.057	0.006	0.109	0.231	19	28	37	36.3	41	42	6	17
1982	0.025	0.010	0.040	0.108	0.043	0.174	0.234	22	25	37	37.4	43	44	11	20
1983	0.002	-0.001	0.004	0.012	-0.006	0.029	0.147	29	29	34	34.2	35	36	2	5
1984	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1985	0.005	-0.001	0.011	0.059	0.040	0.079	0.080	17	17	18	21.0	29	42	3	9
1986	0.002	-0.002	0.006	0.012	-0.008	0.031	0.182	32	32	35	35.3	35	36	2	2
1987	0.003	-0.002	0.009	0.017	-0.012	0.046	0.200	35	35	36	36.7	36	37	2	2
1988	0.020	-0.001	0.041	0.111	-0.002	0.223	0.180	26	26	35	32.8	35	36	4	6
1989	0.010	-0.004	0.025	0.051	-0.036	0.137	0.200	28	28	34	34.6	40	41	2	15
1990	0.010	-0.004	0.024	0.049	-0.022	0.121	0.200	36	36	35	36.0	35	36	3	3
1991	0.036	0.014	0.058	0.143	0.057	0.228	0.253	19	33	37	37.2	40	42	7	19
1992	0.014	-0.001	0.029	0.063	0.012	0.113	0.223	24	24	37	36.0	40	41	5	5
1993	0.009	0.007	0.011	0.037	0.030	0.043	0.255	38	38	37	38.6	39	40	2	5
1994	0.005	0.001	0.009	0.021	0.006	0.035	0.243	36	36	38	38.7	40	41	4	4
1995	0.010	0.000	0.020	0.056	0.003	0.110	0.173	19	19	35	32.9	36	37	3	5
1996	0.014	-0.011	0.039	0.095	-0.013	0.203	0.149	9	9	35	29.3	42	43	5	19
1997	0.028	0.022	0.033	0.138	0.091	0.186	0.200	30	30	34	35.6	41	42	4	25
1998	0.038	0.007	0.068	0.132	0.041	0.223	0.287	32	33	38	38.0	41	42	11	15
1999	0.043	0.003	0.083	0.206	0.012	0.399	0.211	15	29	37	36.7	42	43	9	16
2000	0.026	0.009	0.043	0.106	0.040	0.171	0.247	30	32	37	38.0	41	42	7	15
2001	0.010	-0.005	0.025	0.041	-0.012	0.095	0.244	21	21	40	38.2	40	41	4	4
2002	0.019	-0.007	0.045	0.076	-0.029	0.180	0.252	12	12	38	34.1	39	40	3	5
2003	0.028	-0.002	0.057	0.115	0.003	0.226	0.241	9	24	38	37.0	39	41	5	17
2004	0.023	-0.009	0.055	0.084	-0.025	0.193	0.276	30	32	39	39.2	40	41	3	7
2005	0.050	-0.029	0.128	0.216	-0.131	0.564	0.229	13	31	37	36.7	40	41	5	21
2006	0.012	0.007	0.016	0.051	0.020	0.081	0.230	25	25	39	35.5	40	41	5	8
2007	0.006	0.001	0.010	0.033	0.008	0.058	0.167	18	18	31	32.3	39	40	8	11
2008	0.024	-0.008	0.057	0.172	-0.044	0.388	0.142	7	7	27	29.9	38	41	4	24

Table 35. Abundance and biomass from NEFSC autumn surveys for rosette skate for the Mid-Atlantic region (offshore strata 61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1967-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1967	0.019	0.002	0.037	0.117	0.010	0.224	0.166	10	18	34	34.3	39	42	7	17
1968	0.003	-0.001	0.008	0.023	-0.019	0.065	0.135	28	28	28	28.9	37	38	2	2
1969	0.002	-0.002	0.006	0.010	-0.009	0.028	0.200	38	38	38	38.0	38	38	1	1
1970	0.009	-0.006	0.024	0.033	-0.025	0.090	0.276	39	39	39	39.5	39	40	2	3
1971	0.001	-0.001	0.004	0.006	-0.005	0.016	0.250	40	40	40	40.5	40	41	1	2
1972	0.016	0.001	0.032	0.058	0.021	0.094	0.285	12	12	34	34.2	40	41	7	8
1973	0.012	-0.008	0.032	0.053	-0.016	0.122	0.224	16	16	28	29.0	40	41	3	5
1974	0.012	-0.002	0.026	0.079	-0.014	0.171	0.156	23	23	34	33.8	40	41	4	11
1975	0.004	-0.001	0.009	0.034	-0.001	0.070	0.122	25	25	34	33.6	38	39	4	8
1976	0.024	0.003	0.045	0.149	0.016	0.281	0.163	28	28	33	33.7	37	40	7	21
1977	0.020	-0.002	0.043	0.087	-0.011	0.185	0.231	31	31	33	35.2	40	41	5	8
1978	0.007	-0.007	0.022	0.015	-0.014	0.043	0.500	39	39	39	39.0	39	39	1	1
1979	0.010	-0.004	0.025	0.043	-0.016	0.101	0.242	22	22	35	36.1	39	40	3	6
1980	0.090	0.042	0.138	0.312	0.120	0.505	0.287	14	25	38	36.6	41	42	10	24
1981	0.079	0.011	0.148	0.296	0.052	0.539	0.268	27	28	37	37.5	41	43	10	45
1982	0.006	-0.006	0.018	0.020	-0.019	0.059	0.300	39	39	39	39.0	39	39	1	1
1983	0.001	-0.001	0.003	0.010	-0.010	0.030	0.100	12	12	12	20.7	36	37	1	3
1984	0.029	0.005	0.053	0.128	0.033	0.223	0.229	13	26	36	35.6	39	40	7	16
1985	0.005	0.004	0.007	0.036	0.019	0.054	0.146	14	14	25	28.0	35	36	5	6
1986	0.003	0.001	0.004	0.009	0.005	0.013	0.300	37	37	37	38.2	39	40	3	3
1987	0.028	0.006	0.050	0.112	0.040	0.183	0.253	11	15	38	32.7	41	42	7	10
1988	0.021	0.000	0.043	0.093	-0.002	0.188	0.228	30	30	32	35.0	41	42	5	8
1989	0.018	-0.005	0.041	0.046	-0.012	0.105	0.378	33	33	33	33.5	36	37	3	4
1990	0.023	-0.004	0.049	0.099	0.001	0.198	0.228	32	32	37	37.7	41	42	5	10
1991	0.005	-0.004	0.014	0.021	-0.009	0.051	0.237	15	15	34	31.4	34	35	3	3
1992	0.035	0.006	0.064	0.170	0.033	0.308	0.203	25	25	35	35.3	41	42	9	11
1993	0.021	0.005	0.037	0.102	0.033	0.170	0.211	25	25	37	35.1	40	41	4	8
1994	0.073	0.000	0.146	0.301	0.006	0.597	0.242	27	27	37	36.8	42	43	6	21
1995	0.039	-0.005	0.084	0.174	-0.009	0.358	0.227	19	24	35	35.1	38	39	7	13
1996	0.043	-0.014	0.100	0.273	-0.127	0.674	0.158	7	19	32	31.6	38	42	7	21
1997	0.013	0.000	0.026	0.074	-0.014	0.162	0.176	31	31	33	34.0	42	43	4	6
1998	0.050	-0.008	0.108	0.208	-0.042	0.458	0.241	33	33	37	38.1	40	41	7	22
1999	0.067	0.038	0.096	0.380	0.182	0.578	0.177	12	18	34	32.6	41	42	8	46
2000	0.033	-0.006	0.073	0.134	-0.015	0.283	0.248	26	30	35	36.5	39	40	7	10
2001	0.121	-0.007	0.249	0.472	-0.016	0.961	0.257	11	34	39	38.6	43	44	10	28
2002	0.052	0.009	0.095	0.347	0.045	0.648	0.150	8	8	30	28.0	40	42	11	29
2003	0.033	0.016	0.051	0.136	0.071	0.200	0.247	33	33	36	37.4	39	41	7	18
2004	0.048	0.003	0.092	0.231	0.030	0.432	0.206	19	29	35	35.5	37	40	8	29
2005	0.065	0.001	0.129	0.286	-0.004	0.575	0.227	30	30	35	36.4	39	40	7	24
2006	0.058	0.015	0.101	0.211	0.062	0.361	0.275	35	35	38	39.6	42	43	10	23
2007	0.070	0.002	0.137	0.268	0.037	0.499	0.260	24	24	38	37.4	40	41	7	17

Table 36. Abundance and biomass from NEFSC winter surveys for rosette skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	0.264	0.138	0.390	1.125	0.619	1.632	0.235	16	27	36	36.4	41	45	15	230
1993	0.149	0.048	0.251	0.663	0.197	1.130	0.225	26	29	36	36.7	39	41	9	143
1994	0.199	0.148	0.249	0.761	0.608	0.914	0.261	16	28	37	36.8	40	44	15	162
1995	0.195	0.066	0.323	0.774	0.273	1.275	0.252	19	32	37	37.9	41	42	23	197
1996	0.324	0.121	0.526	1.410	0.443	2.376	0.230	19	28	36	36.3	40	46	23	899
1997	0.258	-0.051	0.567	1.079	-0.194	2.353	0.239	13	30	36	36.9	40	44	21	238
1998	0.160	0.102	0.219	0.664	0.421	0.907	0.241	15	30	36	36.5	40	45	21	350
1999	0.271	0.043	0.500	1.151	0.082	2.220	0.236	24	27	37	36.6	41	44	25	228
2000	0.344	0.198	0.491	1.357	0.725	1.989	0.254	8	28	37	37.5	43	47	34	740
2001	0.437	0.185	0.690	1.718	0.797	2.640	0.254	9	24	38	37.6	41	46	36	790
2002	0.723	0.140	1.307	2.655	0.603	4.708	0.272	8	29	38	38.3	42	47	34	913
2003	0.670	0.195	1.144	2.774	0.802	4.745	0.242	8	26	37	36.9	41	47	28	1029
2004	0.300	0.171	0.429	1.192	0.653	1.730	0.252	16	31	37	37.8	41	46	29	784
2005	0.189	0.090	0.289	0.716	0.357	1.076	0.264	12	30	38	38.2	43	45	19	281
2006	0.437	0.209	0.665	1.738	0.821	2.654	0.251	8	31	37	37.7	42	45	28	513
2007	0.634	0.262	1.006	2.446	1.110	3.781	0.259	9	33	38	38.2	41	44	28	750

Table 37. Estimates of size at 50% maturity, length-weight parameters (Wigley et al 2003) and Von Bertalanffy Parameter estimates used to estimate SSB and to calculate Hoenig (1987) mortality estimates. Smooth skate data in parentheses are female values. Clearnose data in parentheses are in disk width.

Species (Study)	L50	ln(a)	b	Linf	K	t0 (L0)
Winter (Frisk 2004)	76	-13.1531	3.3199	122.1	0.07	-2.06
Little (Frisk 2004)	44	-12.4462	3.128	56.1	0.19	-1.17
Barndoor (Gedamke 2005)	116	-13.3224	3.2919	166.3	0.14	-1.2912
Thorny (Sulikowski 2005, 2006)	88	-12.088	3.1197	124.0	0.12	-0.35
Smooth (Sosebee 2005; Natanson et al 2007)	50	-13.0139	3.1812	75.4 (69.6)	0.12	11 cm (10cm)
Clearnose(Gelsleichter 1998; Sosebee 2005)	66	-13.8683	3.4235	94.3(61.8)	0.17	-0.88
Rosette (Sosebee 2005)	34	-12.5504	3.0718			

Table 38. Estimates of spawning stock biomass indices from NEFSC surveys using sizes at 50% maturity as knife-edge cutpoints.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
1963			0.796	3.934	0.202		
1964			0.227	2.799	0.091		
1965			0.135	2.848	0.297		
1966			0.000	4.673	0.218		
1967	0.553		0.063	1.411	0.126		0.022
1968	0.338		0.073	2.857	0.229		0.001
1969	0.183		0.000	3.668	0.190		0.002
1970	0.534		0.060	5.155	0.152		0.009
1971	0.151		0.047	3.921	0.134		0.002
1972	0.464		0.077	2.593	0.244		0.010
1973	0.892		0.000	2.987	0.189		0.001
1974	0.377		0.000	1.368	0.080		0.013
1975	0.327		0.000	1.344	0.039	0.003	0.005
1976	1.117		0.000	0.943	0.015	0.019	0.020
1977	1.863		0.000	1.450	0.201	0.076	0.015
1978	3.008		0.000	1.514	0.288	0.007	0.004
1979	3.400		0.000	1.569	0.112	0.073	0.009
1980	3.663		0.000	1.972	0.217	0.166	0.070
1981	3.513		0.000	1.312	0.079	0.016	0.070
1982	4.203	2.744	0.000	0.261	0.035	0.038	0.005
1983	7.598	4.058	0.000	1.065	0.073	0.006	0.001
1984	7.253	2.655	0.000	1.480	0.095	0.041	0.024
1985	8.514	4.184	0.000	1.077	0.169	0.069	0.003
1986	12.279	1.599	0.000	0.653	0.152	0.030	0.002
1987	7.768	2.168	0.000	0.209	0.062	0.085	0.021
1988	5.594	2.936	0.000	0.521	0.207	0.072	0.011
1989	3.753	2.832	0.000	0.709	0.073	0.028	0.002
1990	6.129	2.983	0.000	0.790	0.122	0.072	0.023
1991	3.499	2.854	0.000	0.734	0.116	0.341	0.003
1992	2.083	2.384	0.000	0.292	0.079	0.080	0.033
1993	1.012	3.875	0.134	0.700	0.146	0.110	0.018
1994	0.841	1.742	0.000	0.434	0.072	0.184	0.063
1995	0.536	1.706	0.000	0.189	0.081	0.097	0.033
1996	0.793	4.551	0.000	0.318	0.128	0.083	0.029
1997	0.664	1.601	0.052	0.333	0.167	0.269	0.009
1998	1.576	3.634	0.062	0.319	0.016	0.234	0.051
1999	1.331	5.078	0.118	0.145	0.062	0.442	0.055
2000	1.753	4.424	0.048	0.420	0.102	0.371	0.028
2001	1.397	4.783	0.250	0.066	0.226	0.376	0.129
2002	3.154	4.858	0.366	0.196	0.094	0.261	0.034
2003	1.912	4.401	0.161	0.233	0.106	0.353	0.032
2004	2.222	4.340	0.773	0.365	0.146	0.259	0.043
2005	1.005	2.455	0.285	0.047	0.082	0.253	0.057
2006	0.638	2.472	0.477	0.482	0.180	0.042	0.060
2007	1.033	3.555	0.353	0.207	0.071	0.228	0.065
2008		5.048					

Table 39. Current (i.e., not updated) estimates of biomass-based reference points for skates. The estimates for barndoor are an average of 1963-1966 biomass estimates.

	B_{MSY}	$B_{THRESHOLD}$
Winter	6.46	3.43
Little	6.54	3.27
Barndoor	1.62	0.81
Thorny	4.41	2.2
Smooth	0.31	0.16
Clearnose	0.56	0.28
Rosette	0.029	0.015

Table 40. Three-year moving average of the chosen time series from 1965-2008.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
1965			1.89	4.75	0.43		
1966			1.28	5.62	0.37		
1967			1.02	5.05	0.32		
1968			0.51	5.03	0.29		
1969	1.78		0.26	4.28	0.28		0.008
1970	2.06		0.13	5.83	0.30		0.005
1971	1.80		0.10	6.14	0.23		0.004
1972	2.34		0.11	5.61	0.24		0.009
1973	2.91		0.09	4.68	0.27		0.010
1974	3.25		0.03	3.91	0.26		0.014
1975	2.70		0.01	3.36	0.17		0.009
1976	2.02		0.02	2.41	0.08		0.014
1977	2.69		0.02	2.47	0.16	0.44	0.016
1978	3.91		0.02	3.08	0.29	0.41	0.017
1979	4.74		0.00	3.71	0.34	0.45	0.013
1980	5.45		0.00	4.17	0.33	0.42	0.036
1981	5.67		0.00	3.85	0.21	0.43	0.060
1982	6.74		0.00	2.86	0.17	0.36	0.058
1983	8.94		0.00	2.13	0.10	0.18	0.029
1984	11.49	4.48	0.00	1.98	0.13	0.18	0.012
1985	11.79	5.36	0.00	2.72	0.19	0.21	0.012
1986	12.77	4.37	0.01	2.46	0.21	0.34	0.012
1987	12.02	4.55	0.02	1.82	0.17	0.39	0.012
1988	11.48	4.15	0.02	1.35	0.20	0.40	0.017
1989	7.90	5.45	0.01	1.44	0.17	0.31	0.022
1990	6.60	5.57	0.01	1.69	0.20	0.34	0.020
1991	5.65	5.87	0.02	1.74	0.16	0.53	0.015
1992	5.15	5.43	0.02	1.43	0.16	0.56	0.021
1993	3.40	6.27	0.06	1.42	0.17	0.59	0.020
1994	2.54	5.48	0.06	1.38	0.15	0.59	0.043
1995	2.00	4.67	0.10	1.32	0.17	0.59	0.045
1996	2.13	4.69	0.06	1.04	0.15	0.57	0.052
1997	2.24	4.38	0.09	0.82	0.20	0.46	0.032
1998	2.83	5.92	0.08	0.77	0.15	0.72	0.035
1999	3.77	6.72	0.16	0.66	0.11	0.93	0.043
2000	4.41	8.68	0.23	0.65	0.08	1.07	0.050
2001	4.45	8.47	0.38	0.55	0.17	1.23	0.074
2002	4.62	7.29	0.54	0.53	0.18	1.18	0.069
2003	4.29	6.59	0.62	0.50	0.20	1.06	0.069
2004	4.34	6.72	0.88	0.63	0.17	0.75	0.044
2005	3.34	5.65	0.96	0.56	0.18	0.63	0.049
2006	3.04	4.59	1.17	0.55	0.19	0.59	0.057
2007	2.93	3.67	1.00	0.42	0.14	0.64	0.064
2008		5.04					

Table 41. Fishing mortality overfishing definition for skates based on the average coefficient of variation in the survey. The percentages are percent change from one three-year moving average to the next. The shaded cells indicate overfishing is ocurring.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
	-20%	-20%	-30%	-20%	-30%	-30%	-60%
1992	-8.8	-7.6	-3.8	-17.6	-0.4	4.5	37.7
1993	-33.9	15.6	180.7	-1.1	6.7	5.6	-2.0
1994	-25.5	-12.6	2.0	-2.9	-13.0	0.9	110.9
1995	-21.0	-14.8	61.3	-4.3	13.8	-0.8	3.8
1996	6.2	0.4	-34.3	-21.4	-9.8	-3.6	16.4
1997	5.3	-6.5	37.3	-21.2	28.6	-19.1	-38.4
1998	26.3	35.0	-8.6	-5.5	-26.9	57.5	11.1
1999	33.2	13.5	109.2	-14.5	-24.2	28.8	22.5
2000	17.0	29.2	37.1	-0.9	-23.6	15.0	15.3
2001	1.0	-2.4	66.0	-16.1	102.3	15.4	47.1
2002	3.8	-13.9	42.5	-2.6	8.1	-4.4	-6.9
2003	-7.2	-9.6	16.5	-5.6	6.5	-10.5	0.2
2004	1.1	1.9	40.7	25.0	-12.4	-28.6	-35.4
2005	-22.9	-15.9	9.8	-11.2	3.7	-16.2	9.7
2006	-9.0	-18.7	21.3	-1.0	3.9	-6.8	16.8
2007	-3.6	-20.0	-14.2	-23.7	-22.4	8.1	12.7
2008		37.2					

Table 42. Estimates of biomass-based reference points for skates updated through 2007/2008.

	B_{MSY}	$B_{THRESHOLD}$
Winter	5.60	2.80
Little	7.03	3.51
Barndoor	0.44	0.22
Thorny	4.12	2.06
Smooth	0.29	0.14
Clearnose	0.77	0.38
Rosette	0.048	0.024

Table 43. Recommendation for new biomass-based reference points for skates updated through 2007/2008. The estimates for barndoor are an average of 1963-1966 biomass estimates.

	B_{MSY}	$B_{THRESHOLD}$
Winter	5.60	2.80
Little	7.03	3.51
Barndoor	1.62	0.81
Thorny	4.12	2.06
Smooth	0.29	0.14
Clearnose	0.77	0.38
Rosette	0.048	0.024

Skate Complex; Figures

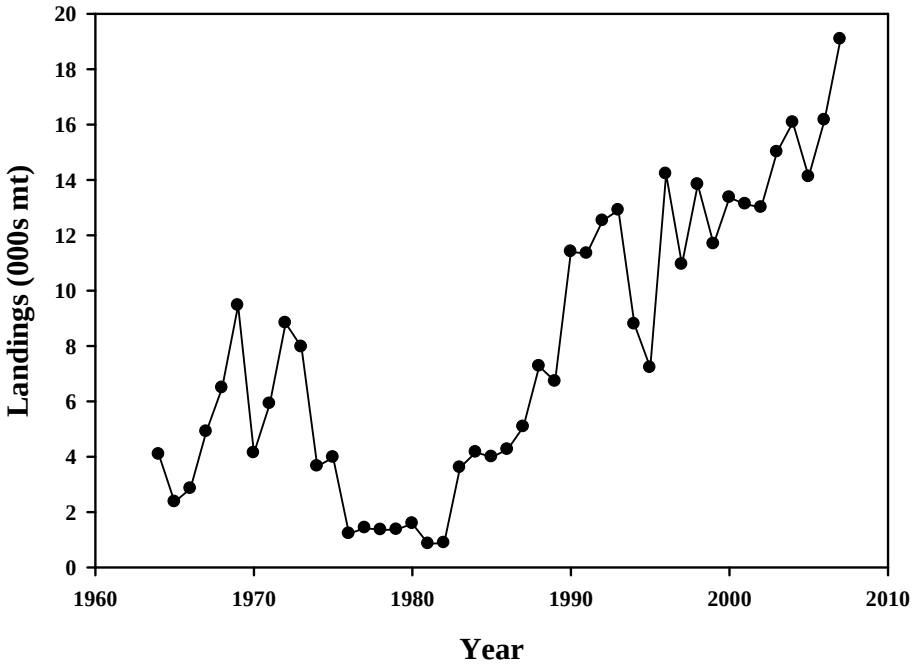


Figure 1. Total reported landings of skates in NAFO subareas 5 and 6.

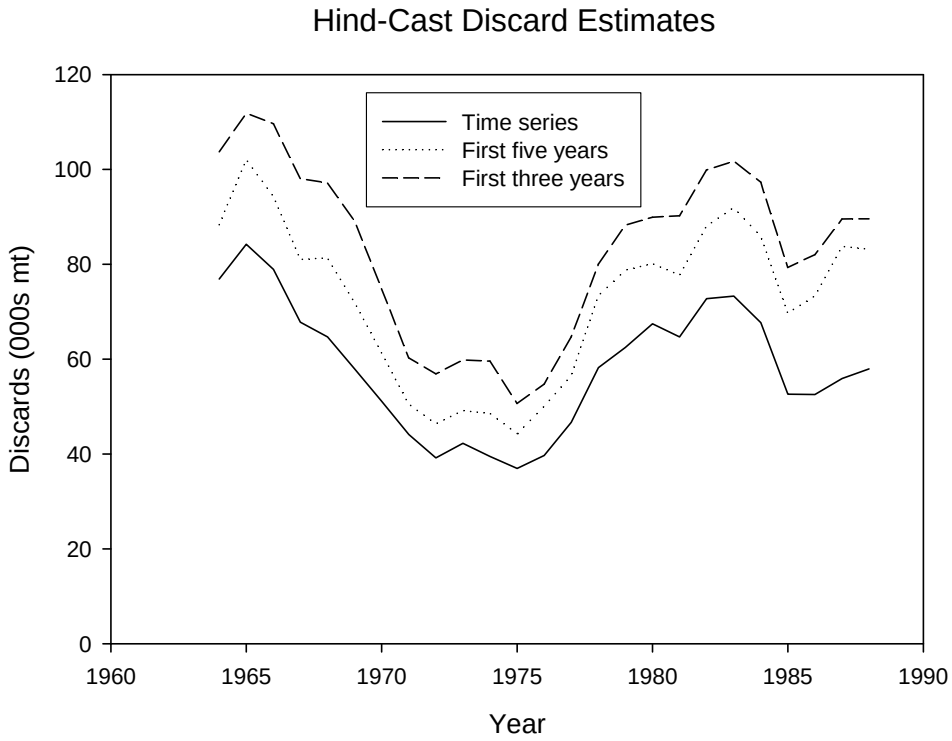


Figure 2. Estimates of discards hind-cast using three different methods.

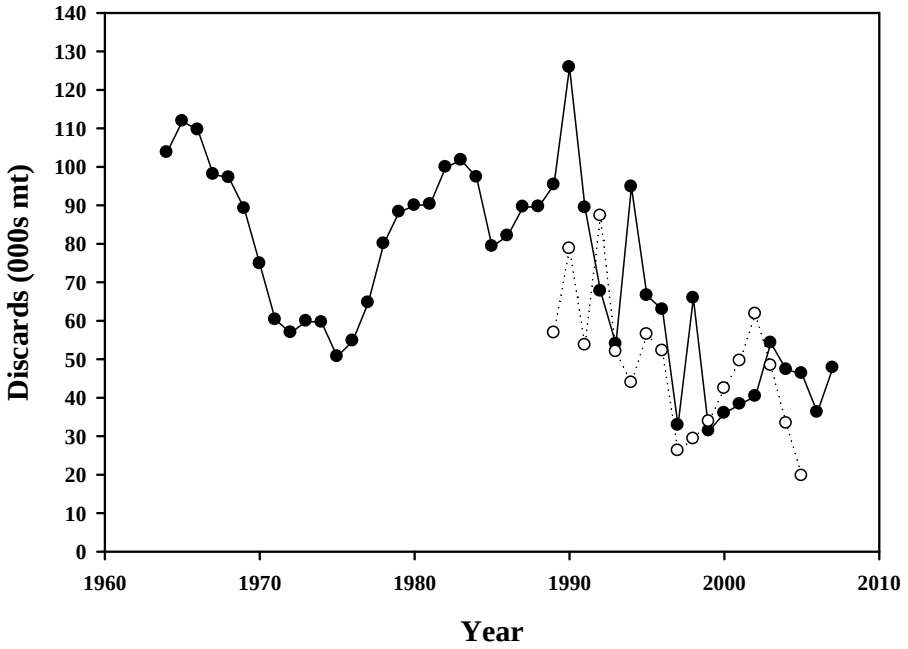


Figure 3. Total discards of skates in NAFO subareas 5 and 6. The closed circles represent the new estimates which include all sources. The circles from 1964-1988 are hind-cast using the first three years. The open circles are the SARC44 estimates which did not impute missing information and/or

ir

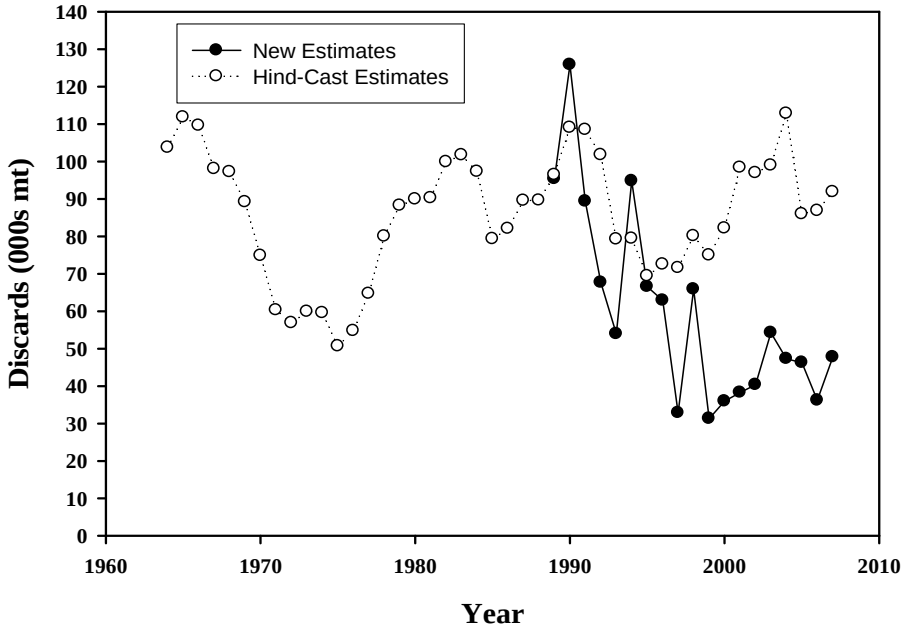


Figure 4 Estimates of discards comparing hind-cast estimates (first three years) for the entire time series.

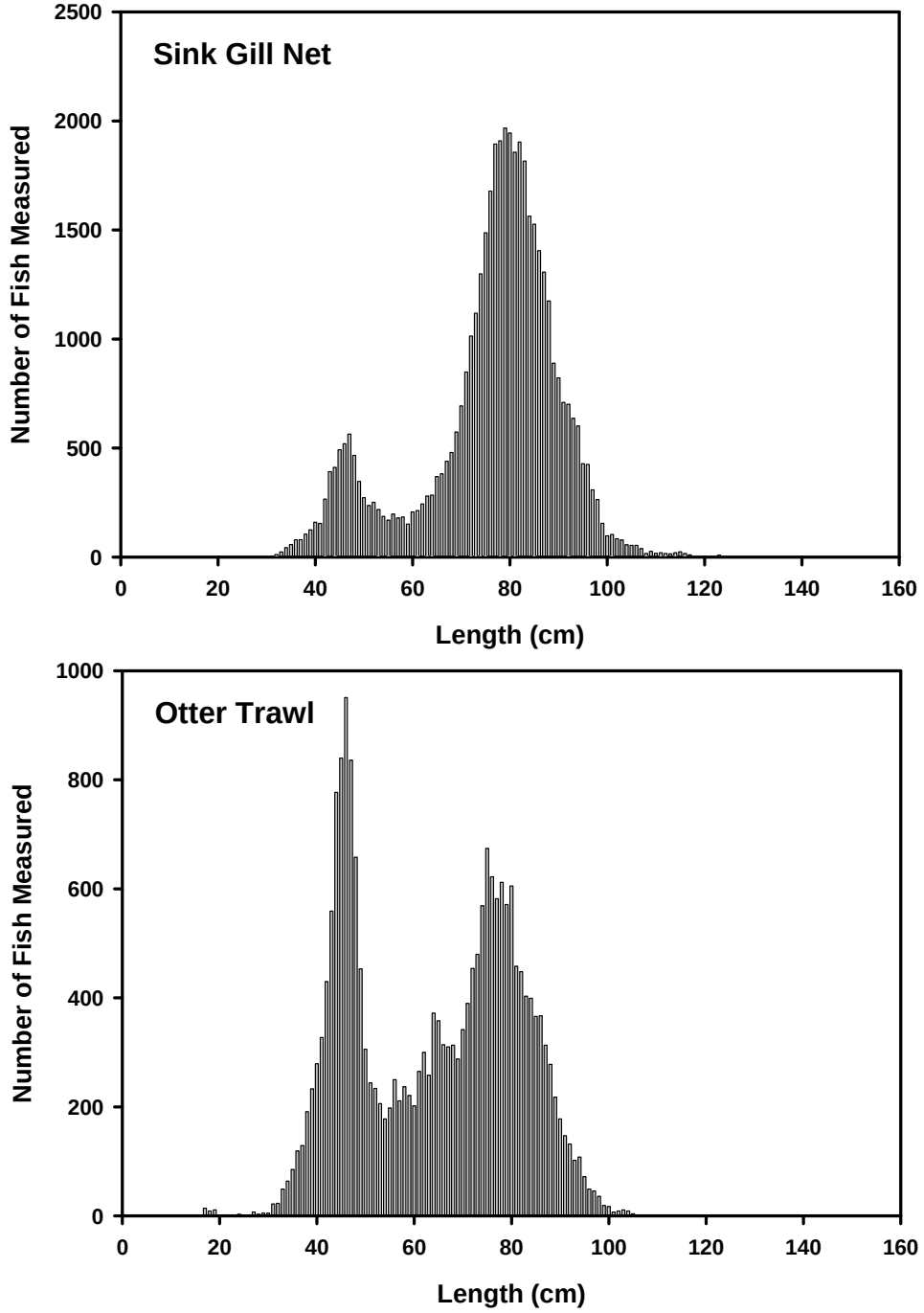


Figure 5. Length composition of the kept skate measured by the Observer Program by gear type.

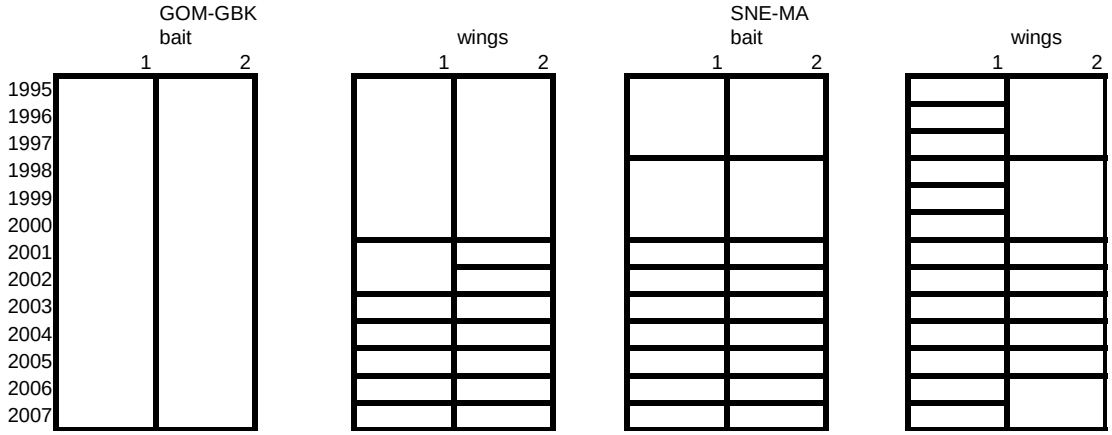


Figure 6. Pooling scheme used to derive length compositions for the landed component of the skate catch

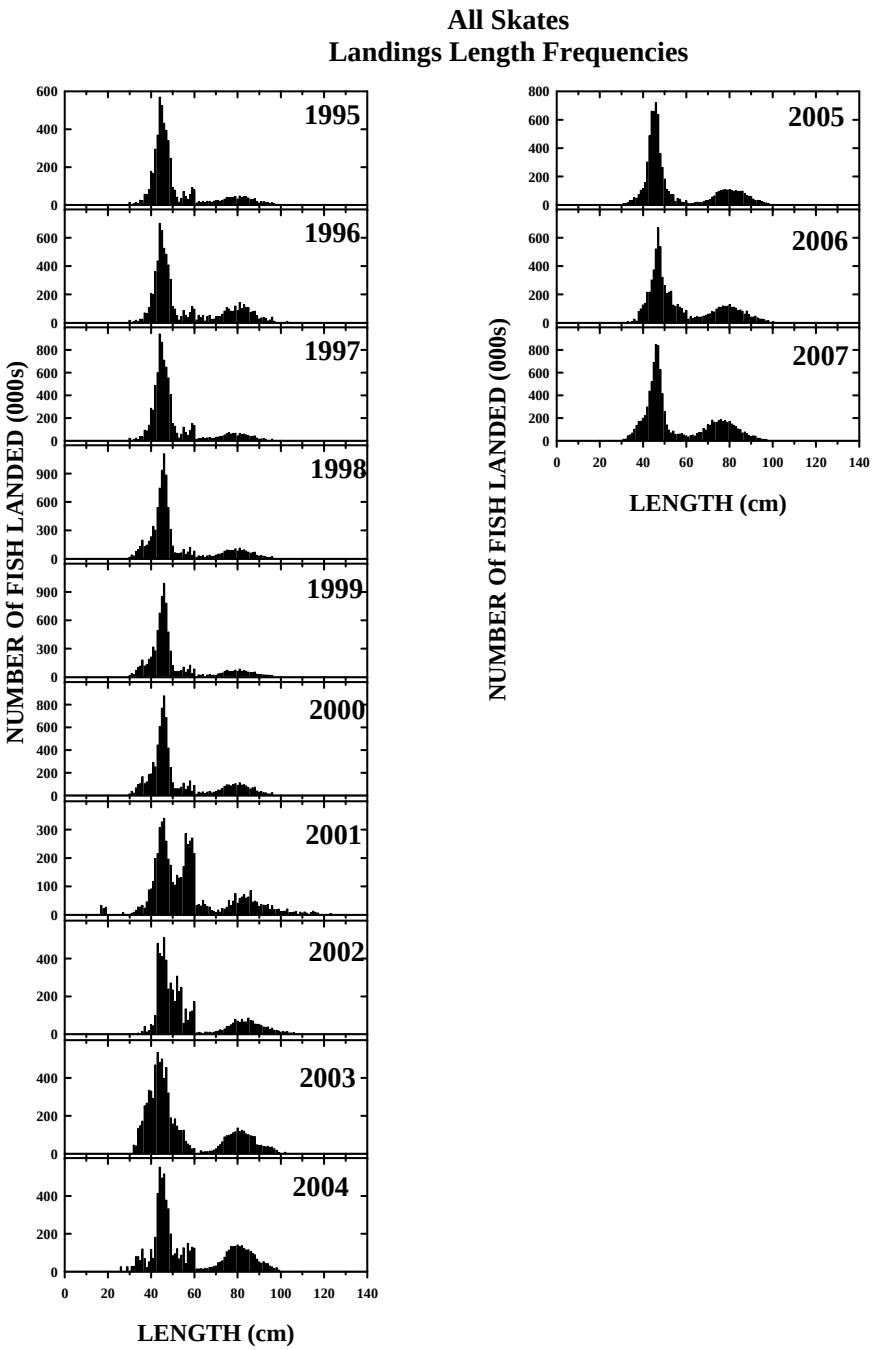


Figure 7. Skate length composition from commercial landings data, 1995-2007.

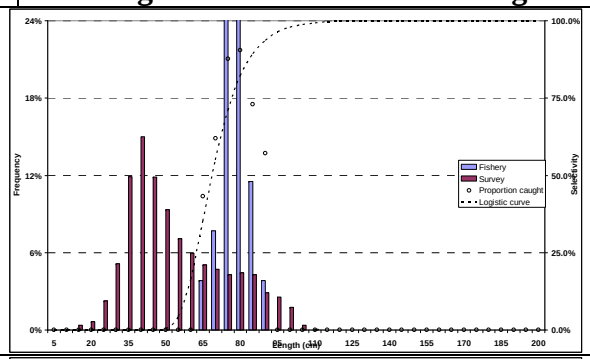
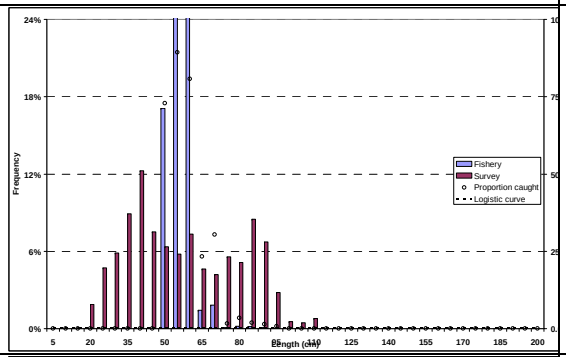
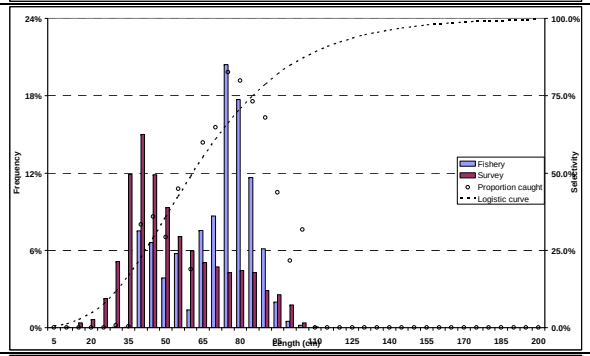
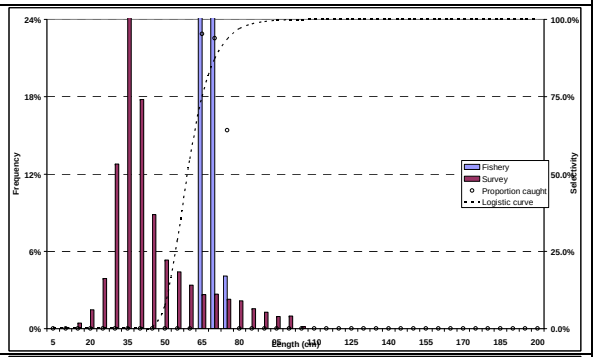
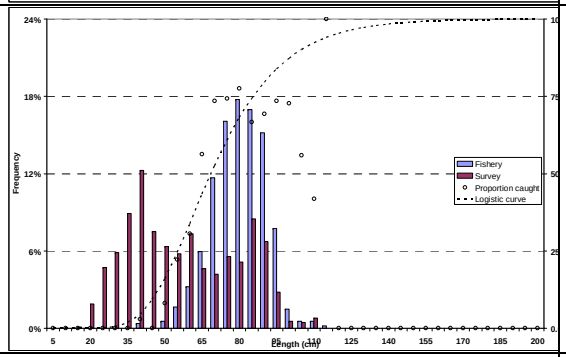
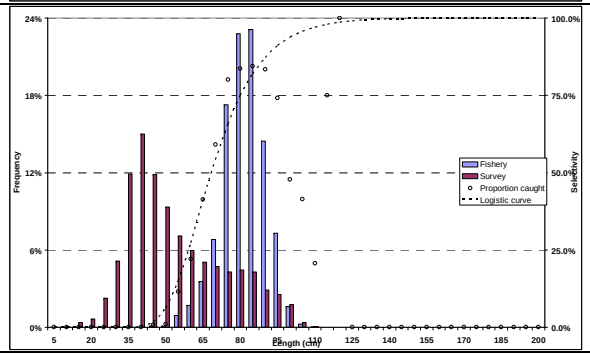
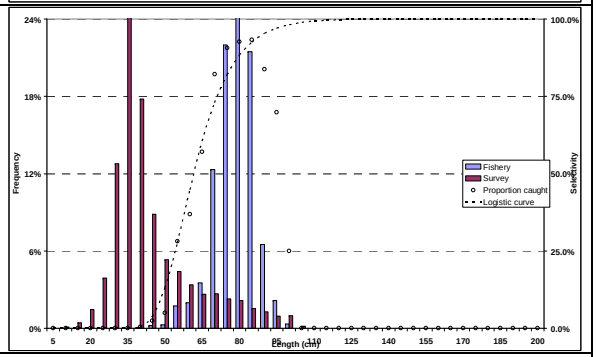
	Gulf of Maine	Georges Bank/Southern New England	Mid-Atlantic
Winter Trawl Wings	**Insufficient data**		**Insufficient data**
Winter Trawl Whole			
Winter Gillnet			

Figure 8. Selectivity of observed winter skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992).

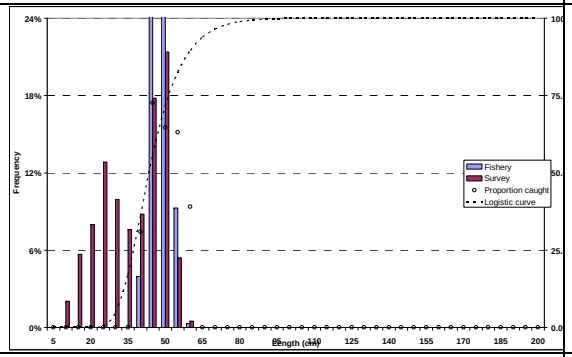
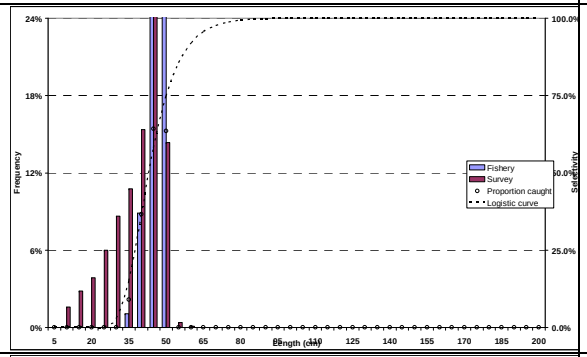
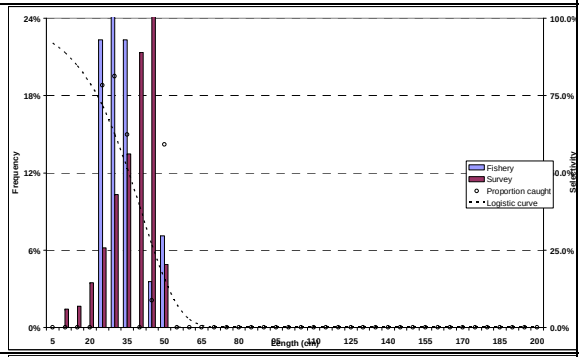
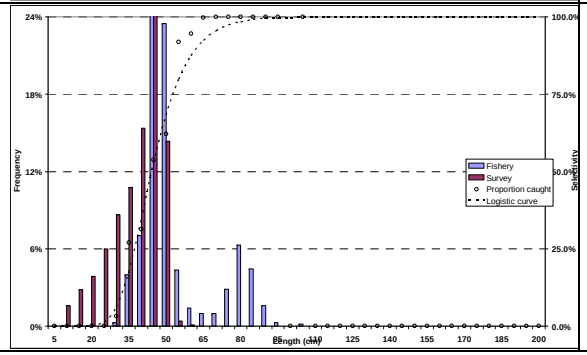
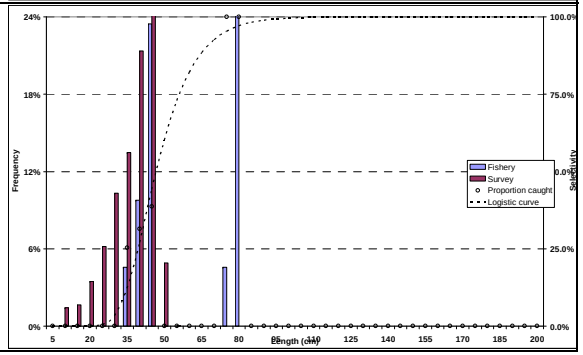
	Gulf of Maine	Georges Bank/Southern New England	Mid-Atlantic
Little Trawl Wings	**Insufficient data**	**Insufficient data**	**Insufficient data**
Little Trawl Whole			
Little Gillnet	**Insufficient data**		

Figure 9. Selectivity of observed little skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992).

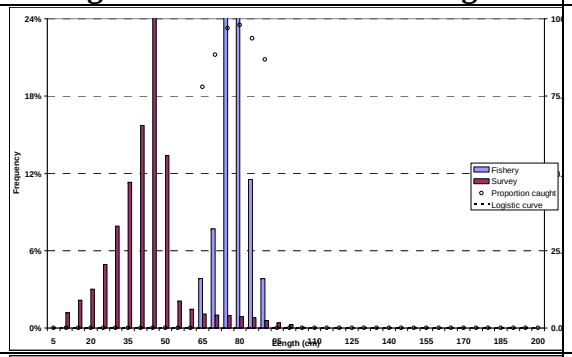
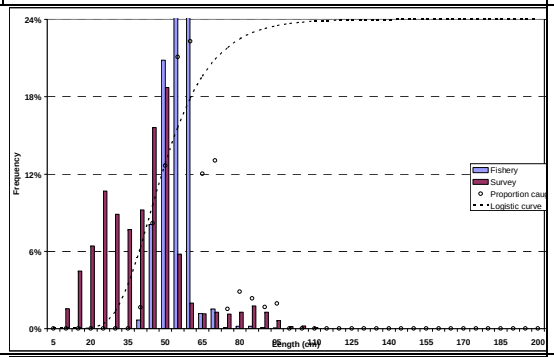
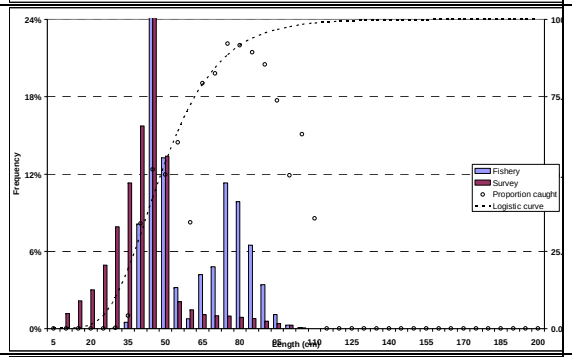
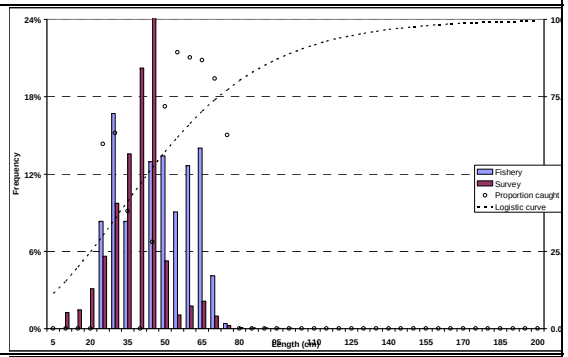
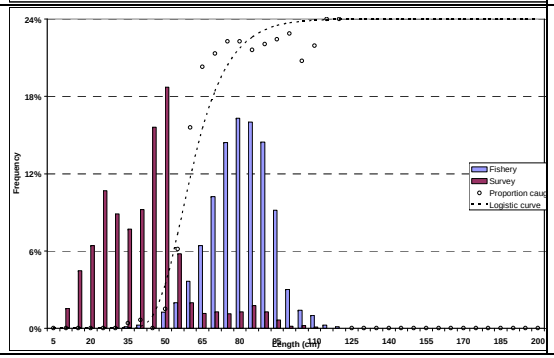
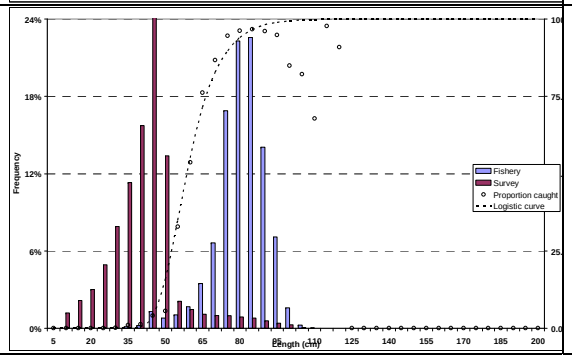
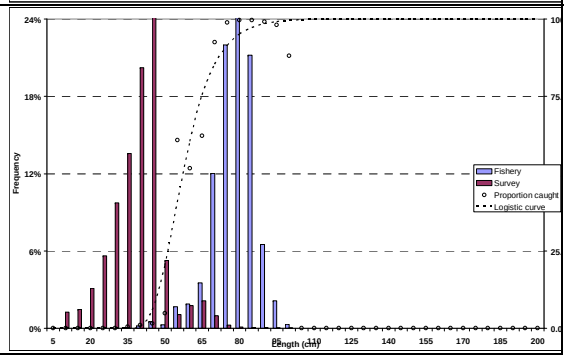
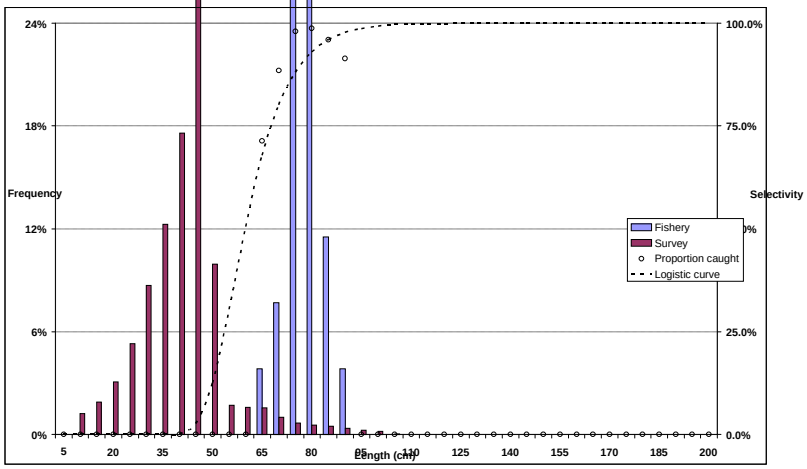
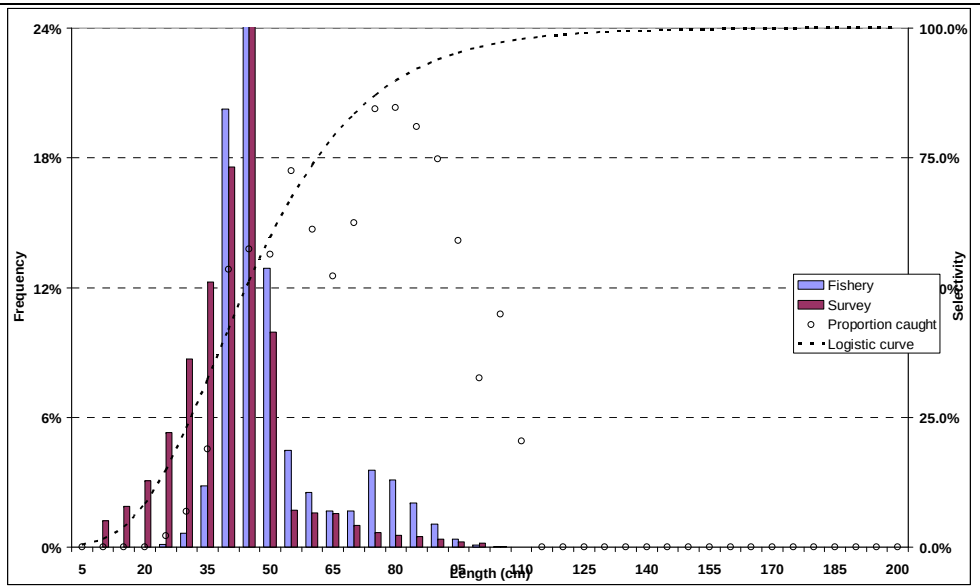
	Gulf of Maine	Georges Bank/Southern New England	Mid-Atlantic
Clearnose, Little, Rosette, & Winter Trawl Wings	**Insufficient data**		**Insufficient data**
Clearnose, Little, Rosette, & Winter Trawl Whole			
Clearnose, Little, Rosette, & Winter Gillnet			

Figure 10. Selectivity of observed aggregate skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992). Survey size frequency is for clearnose, little, rosette, and winter skates.

	All regions
Clearnose, Little, Rosette, & Winter Trawl Wings	

Clearnose, Little, Rosette, & Winter Trawl Whole



Clearnose, Little, Rosette, & Winter Gillnet

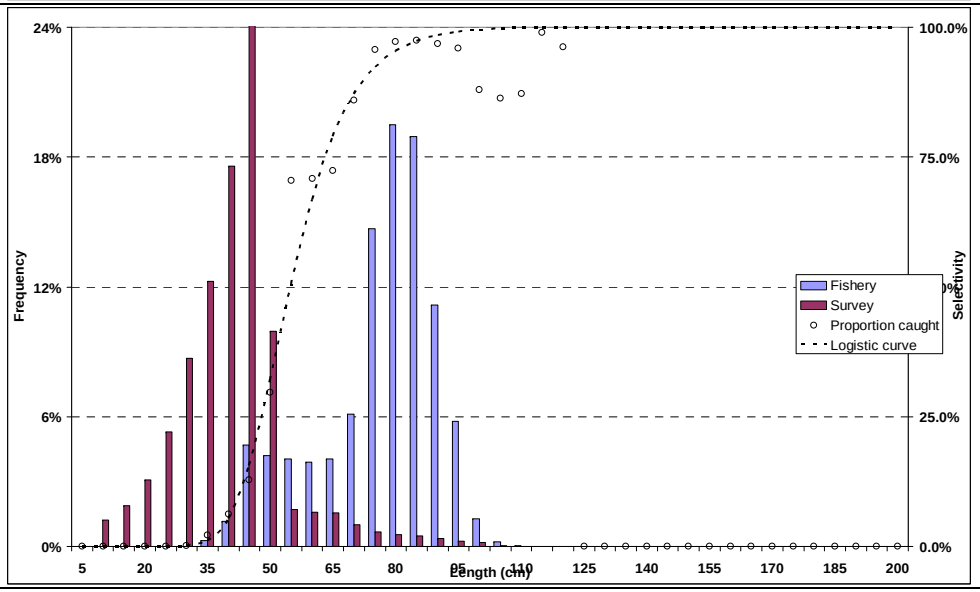
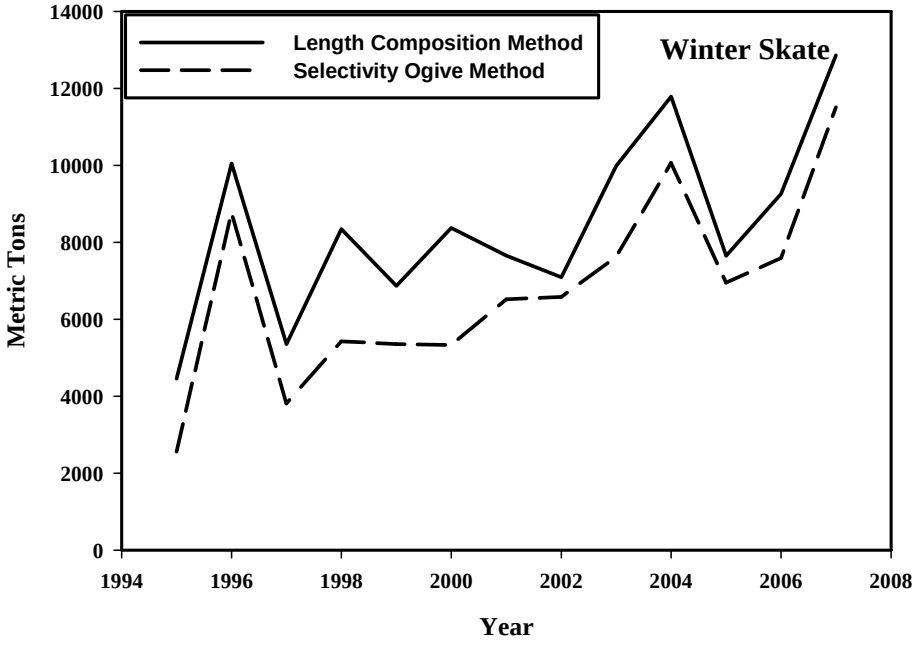


Figure 11. Selectivity of observed aggregate skate landings by gear and product type, 2004-2007, estimated with the SELECT model (Millar 1992). Survey size frequency is for clearnose, little, rosette, and winter skates



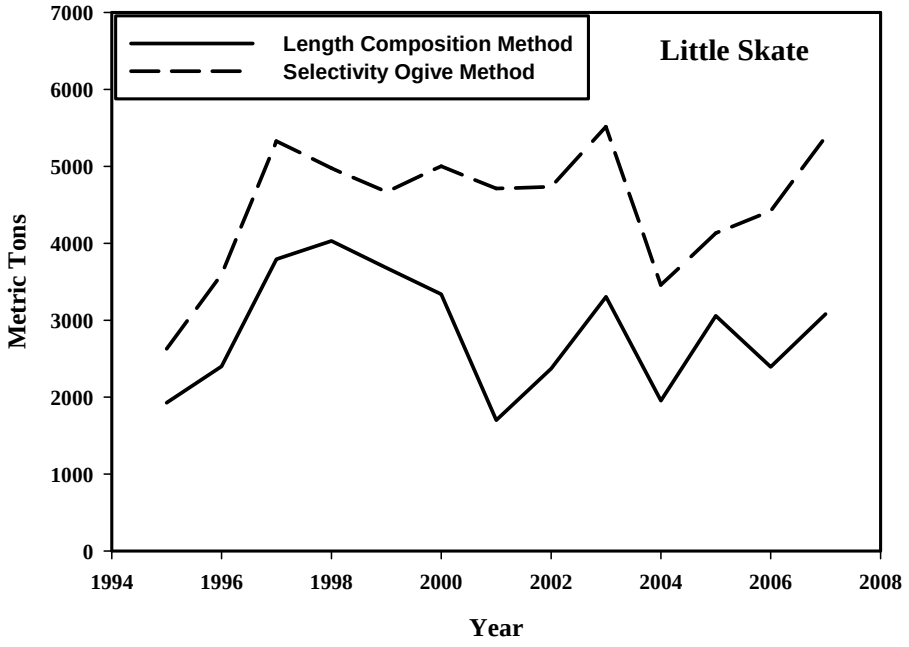
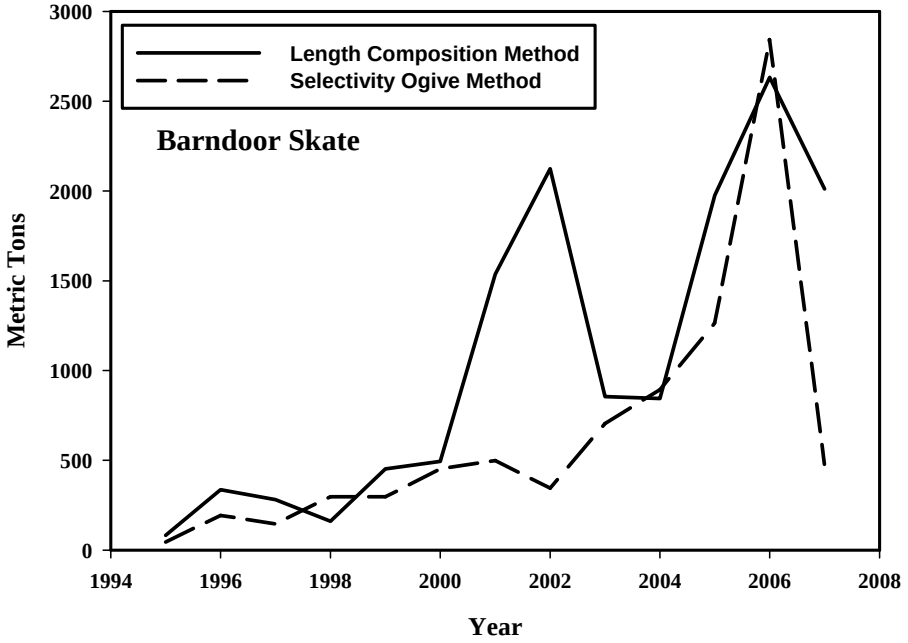


Figure 12. Comparison of landings for winter and little skate using two different methods.



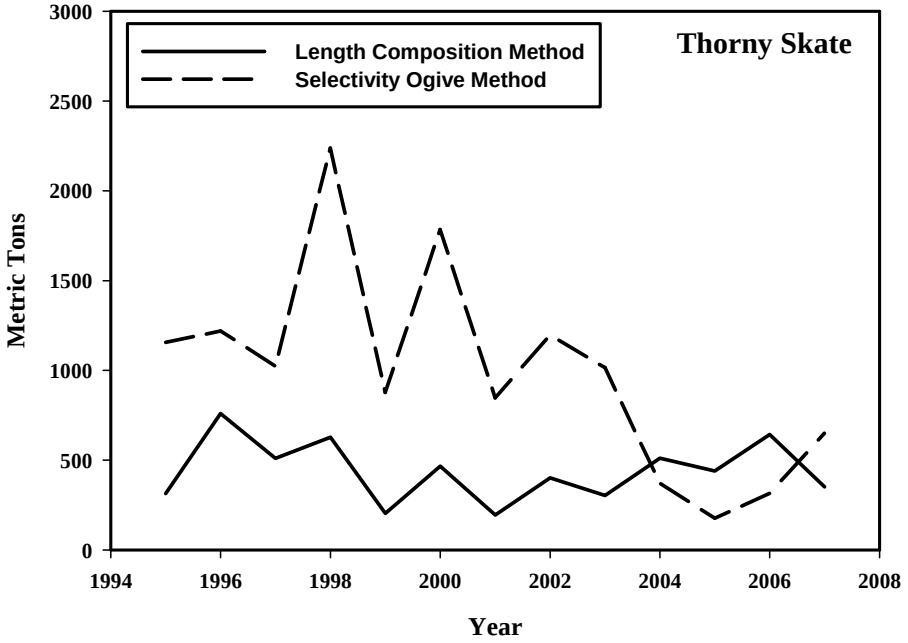


Figure 13. Comparison of landings for barndoor and thorny skate using two different methods.

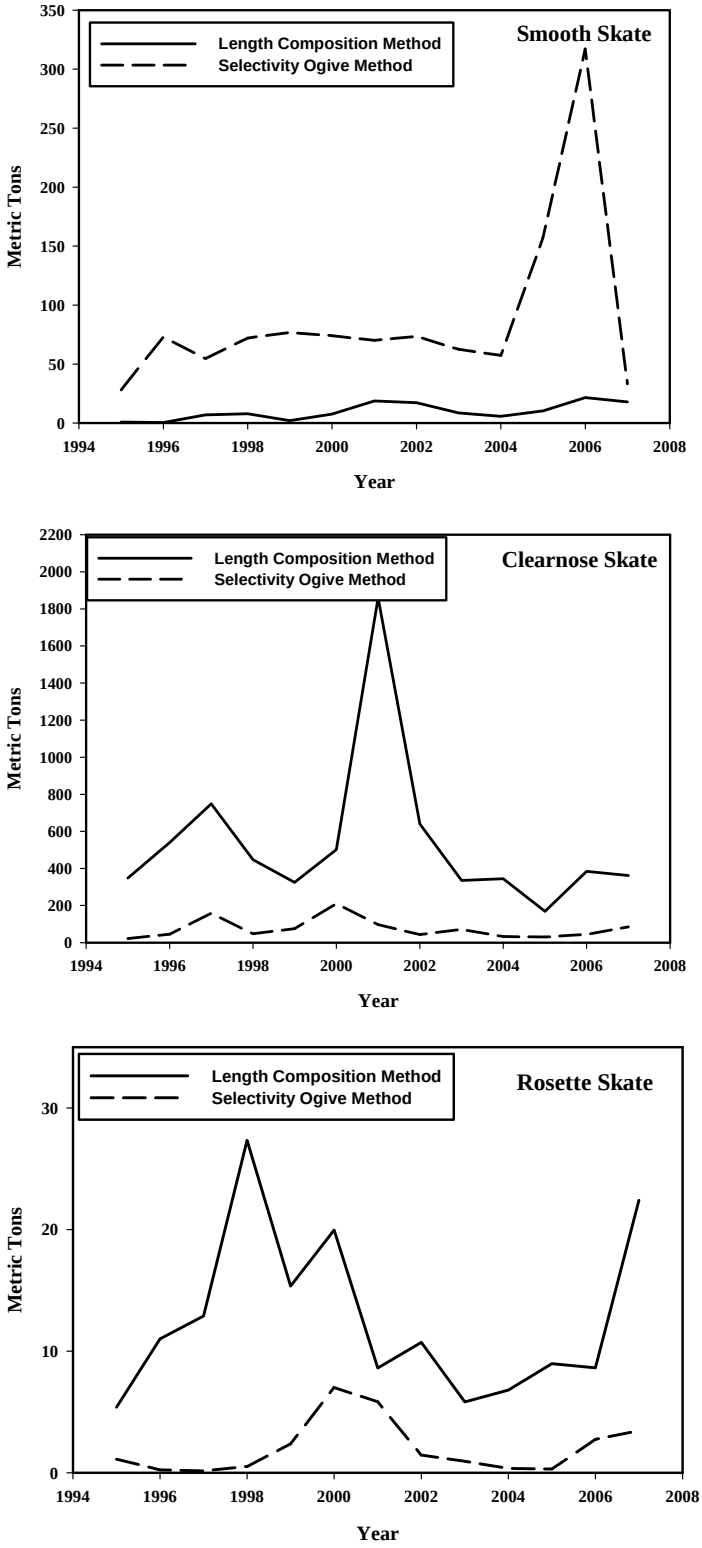


Figure 14. Comparison of landings for smooth, clearnose, and rosette skate using two different methods.

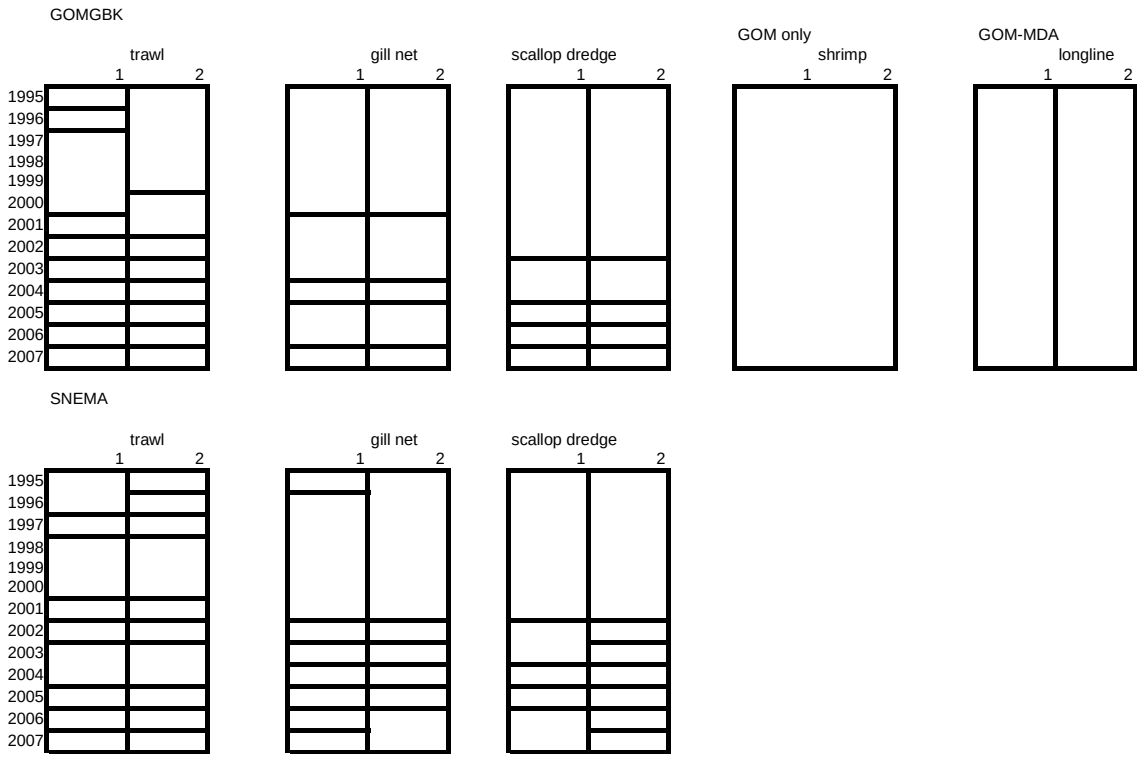


Figure 15. Pooling scheme used to derive the length composition of the discarded component of the skate catch.

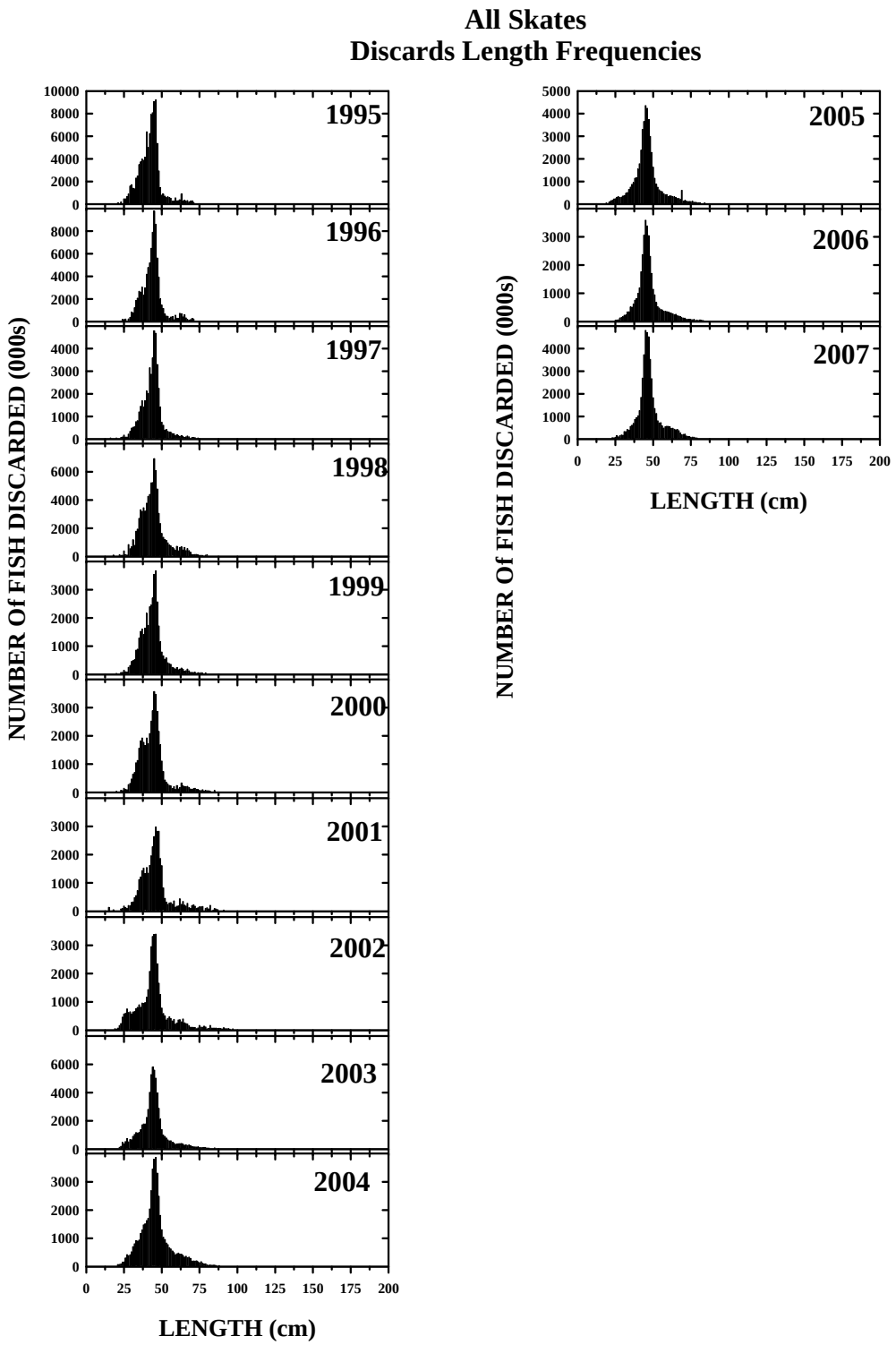


Figure 16. Skate length composition from commercial discard data, 1995-2007.

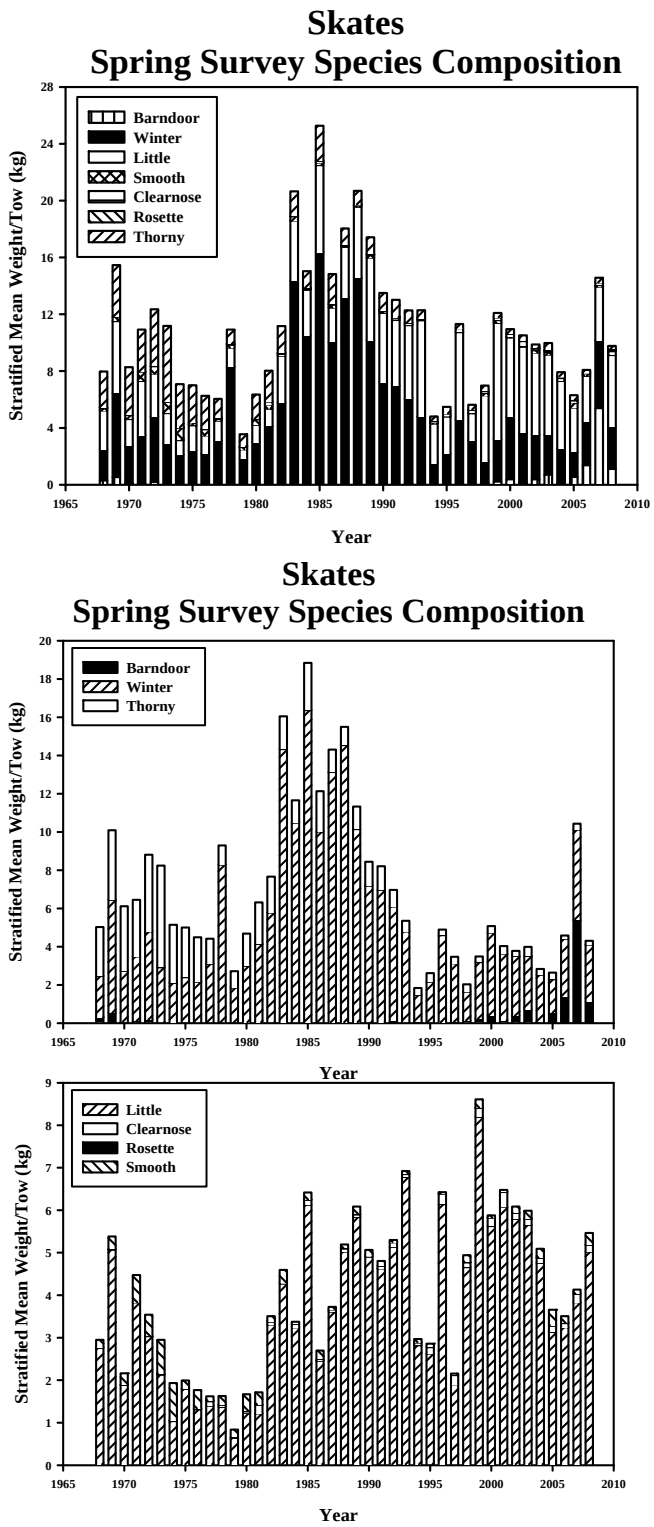


Figure 17. Species composition of skates from the spring survey. The top panel is all skates, the middle panel shows the composition of large species (>100 cm maximum length) while the bottom panel shows the composition of the small species (maximum length < 100cm).

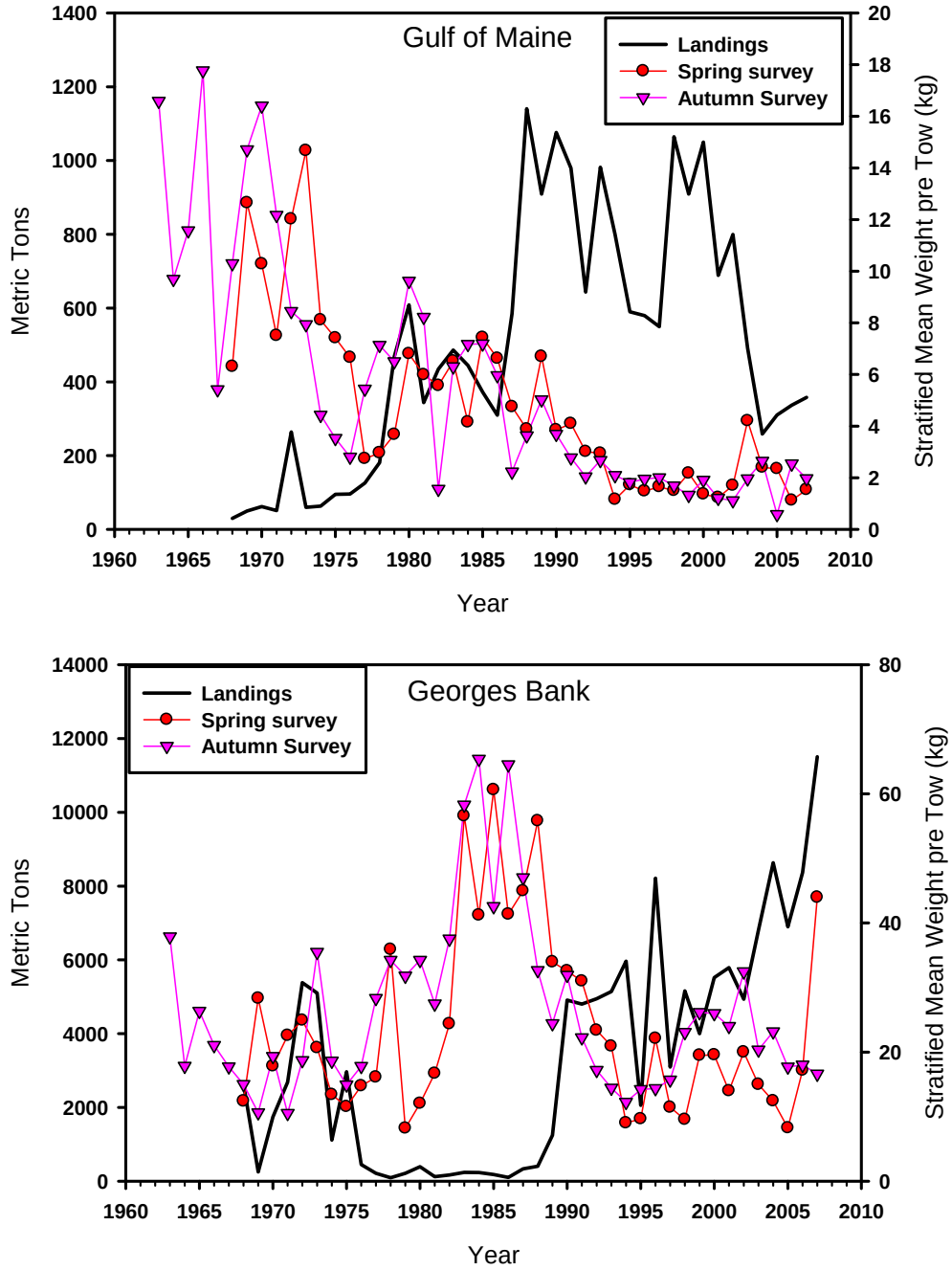


Figure 18. Landings and survey indices of skates from the Gulf of Maine (top panel) and Georges Bank (bottom panel).

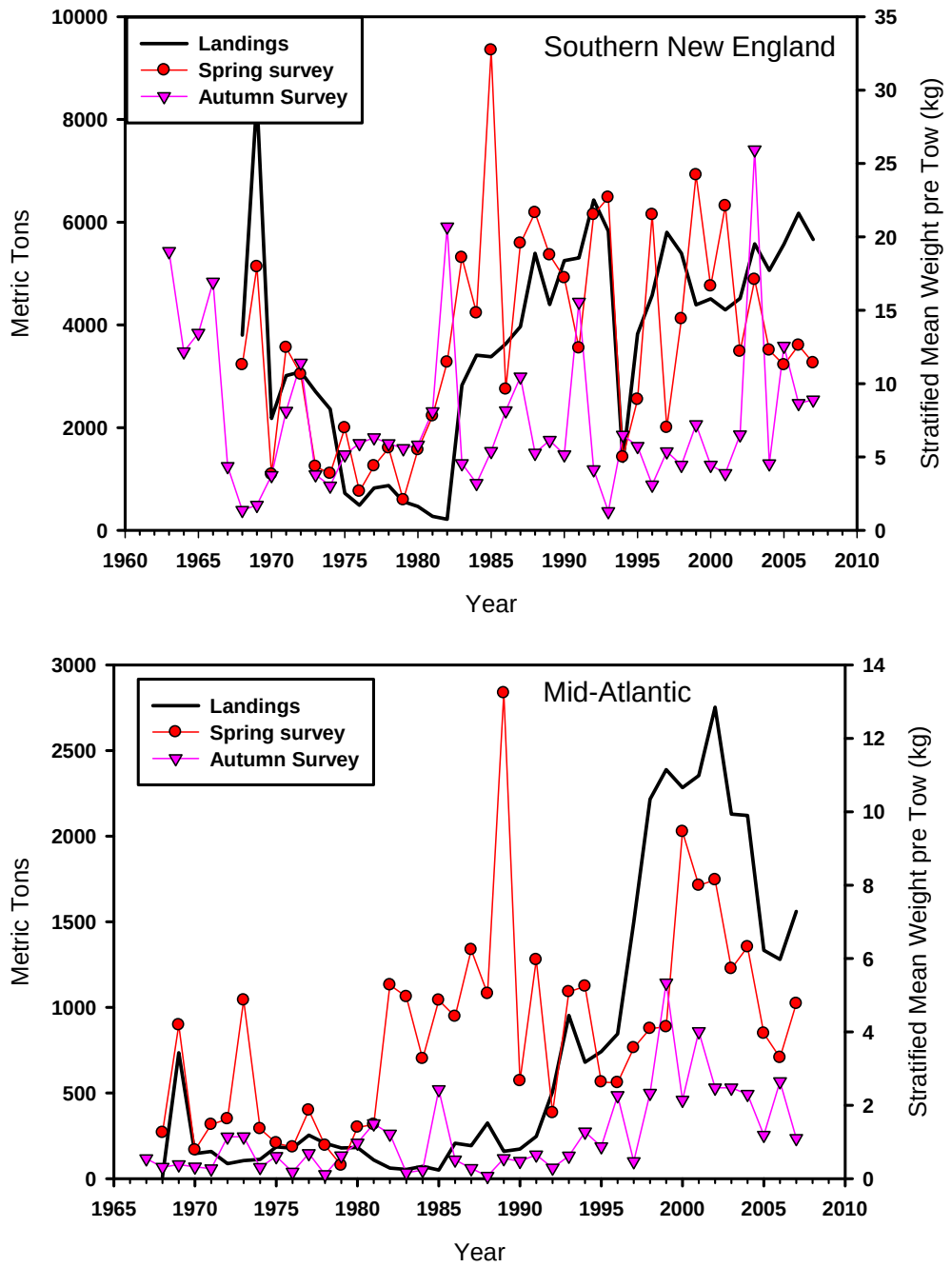


Figure 19. Landings and survey indices of skates from Southern New England (top panel) and the Mid-Atlantic (bottom panel).

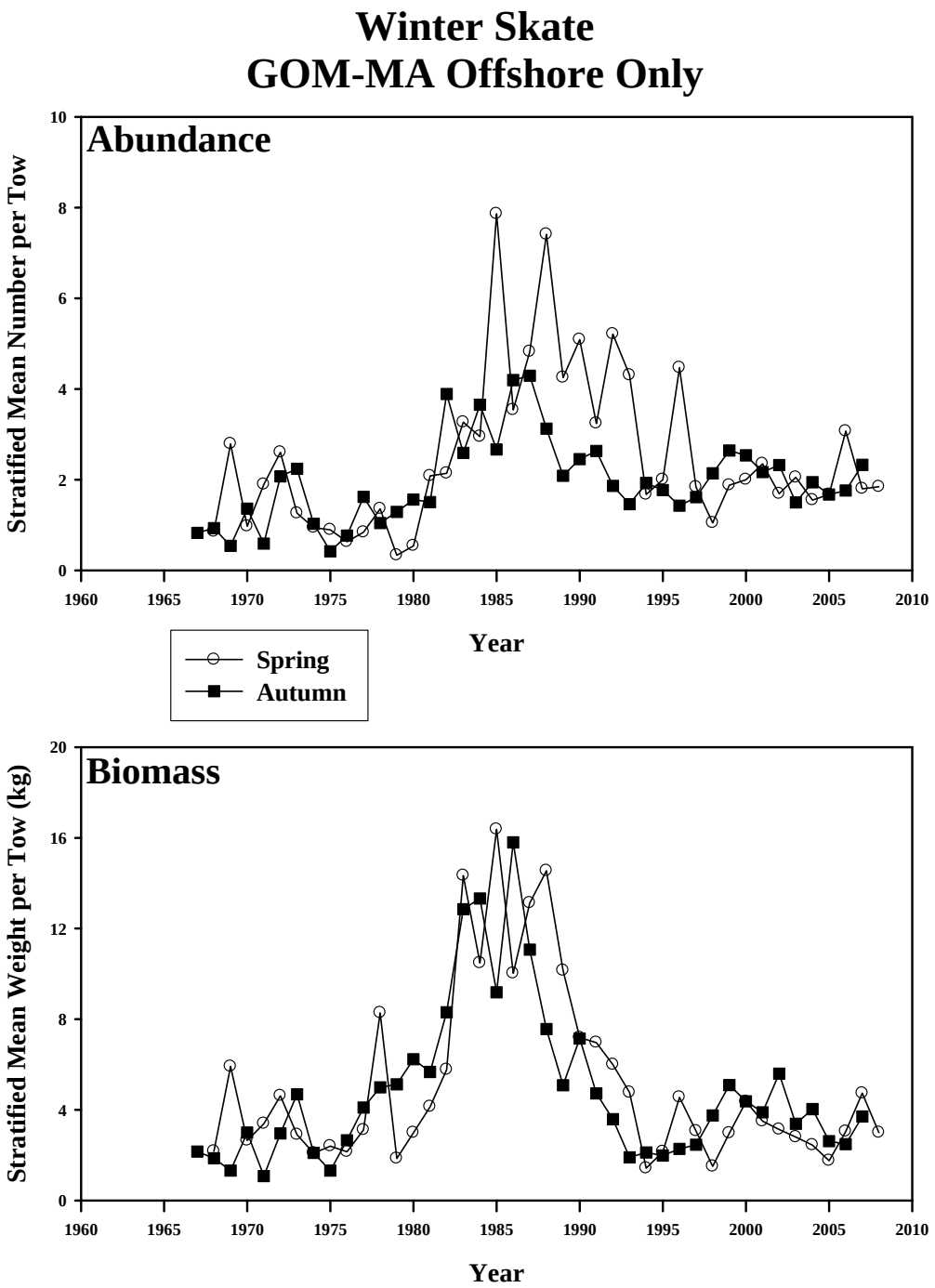


Figure 20. Abundance and biomass of winter skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1967-2008 in the Gulf of Maine to Mid-Atlantic offshore region.

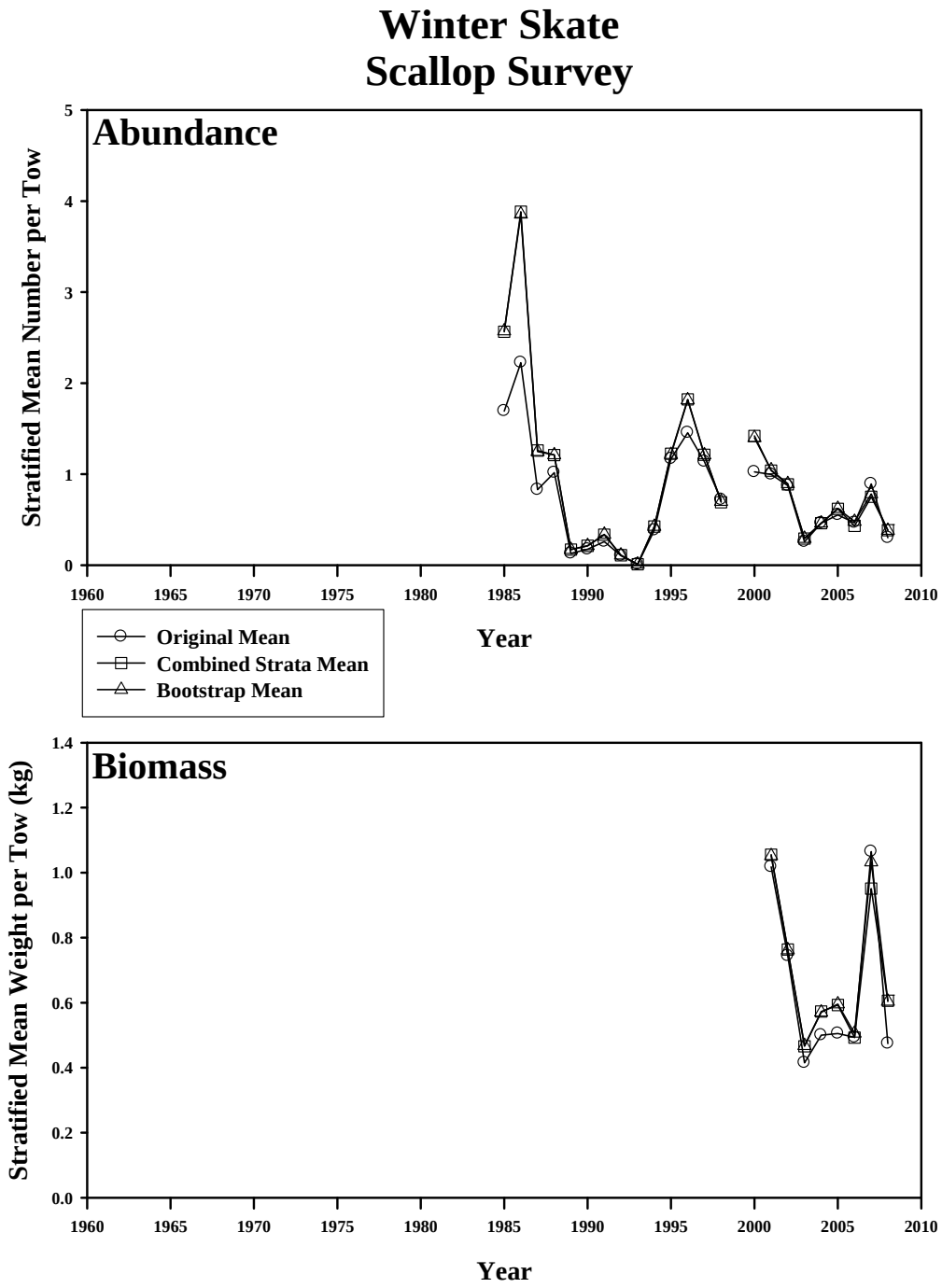


Figure 21. Abundance and biomass of winter skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

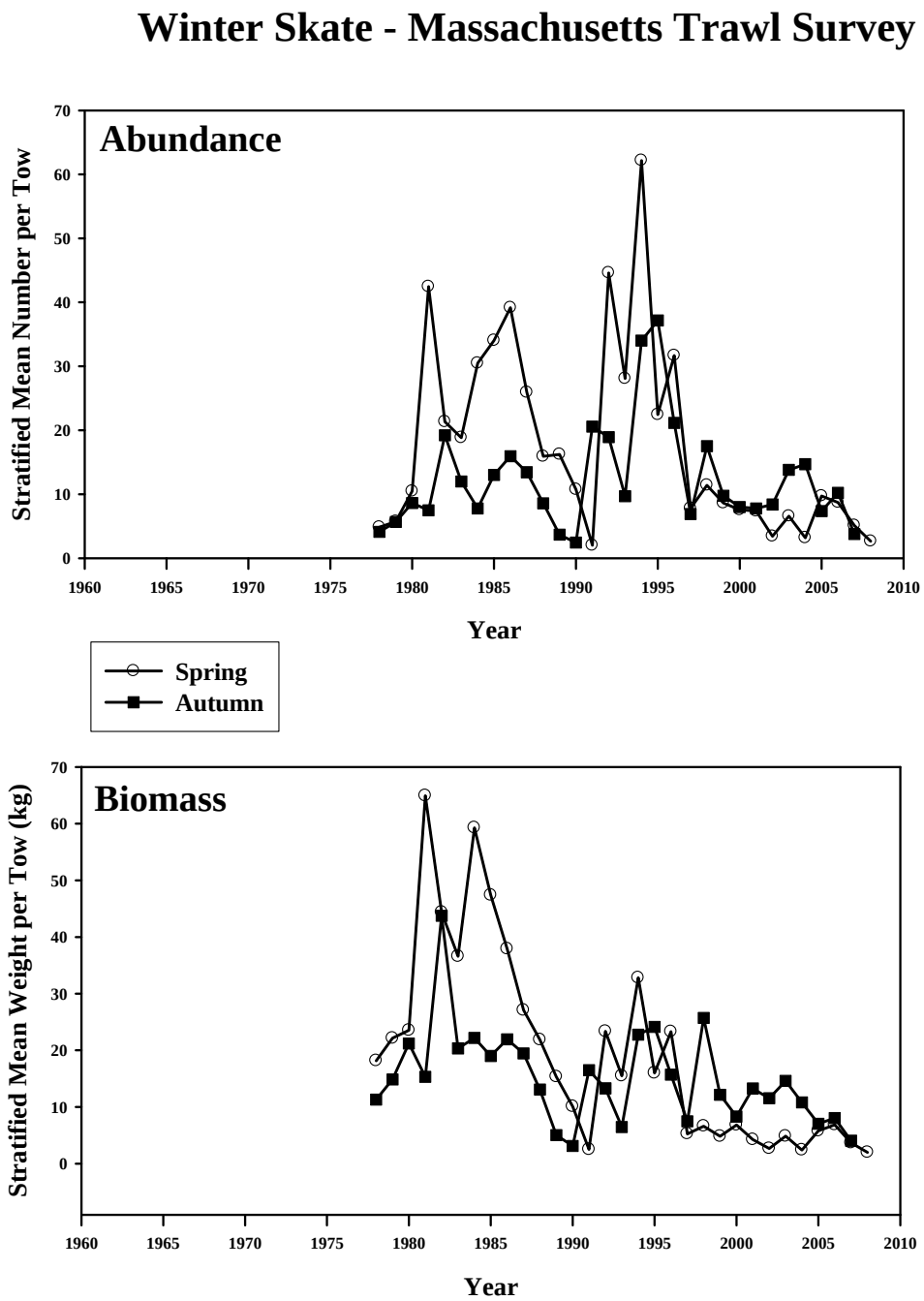


Figure 22. Abundance and biomass of winter skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (strata 11-36).

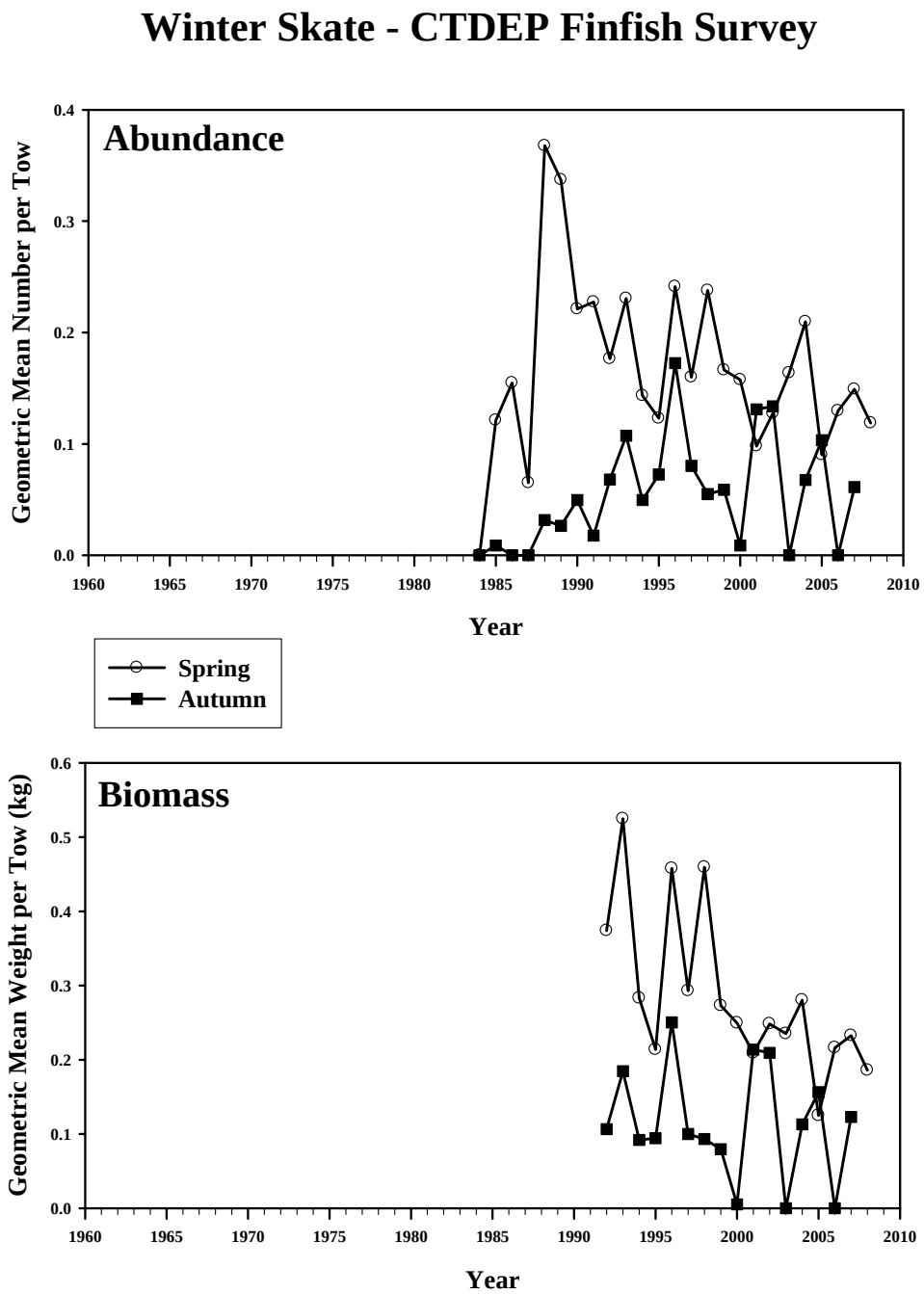


Figure 23. Abundance and biomass of winter skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters, 1984-2008.

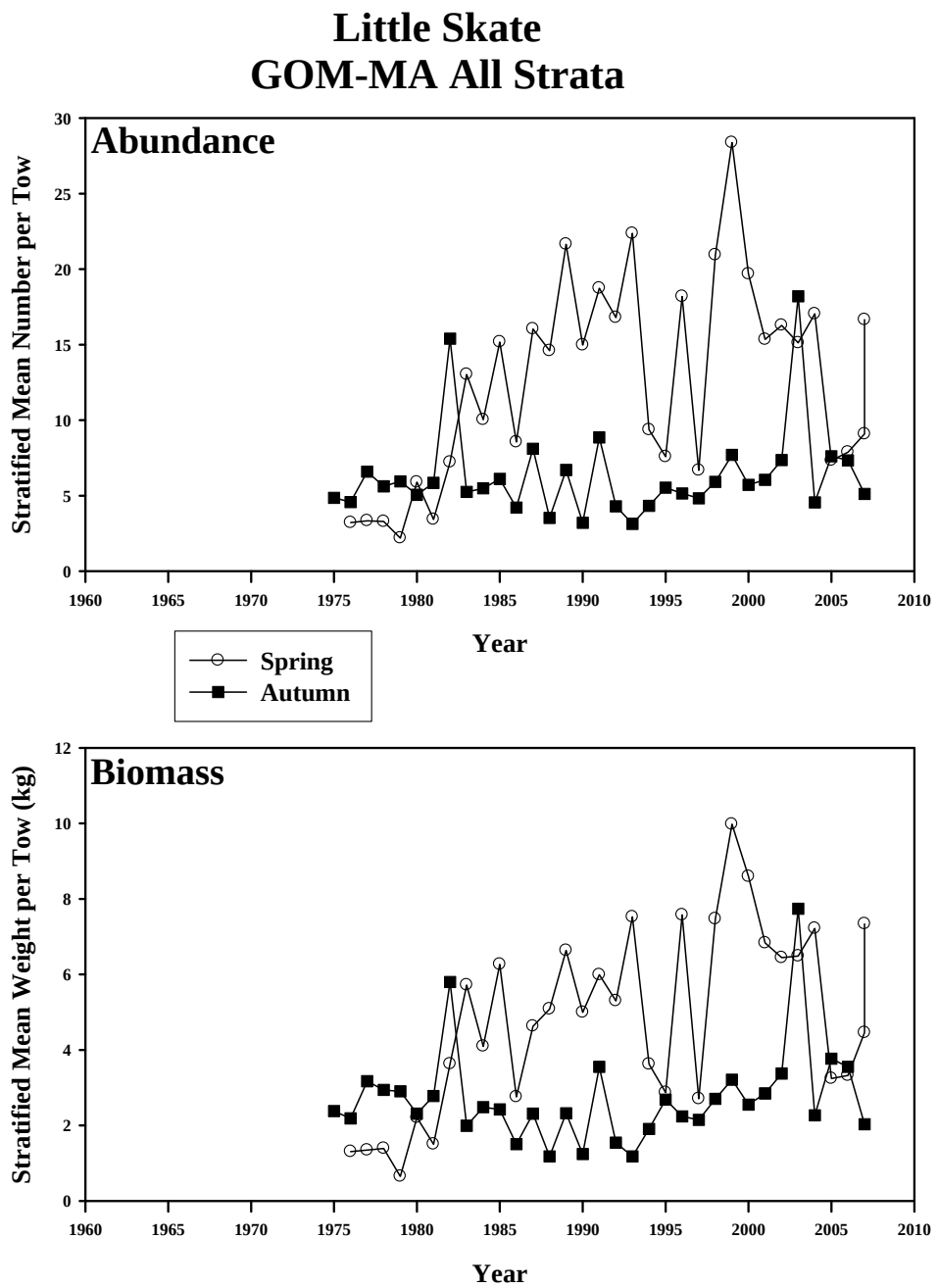


Figure 24. Abundance and biomass of little skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1975-2008 in the Gulf of Maine to Mid-Atlantic offshore and inshore regions.

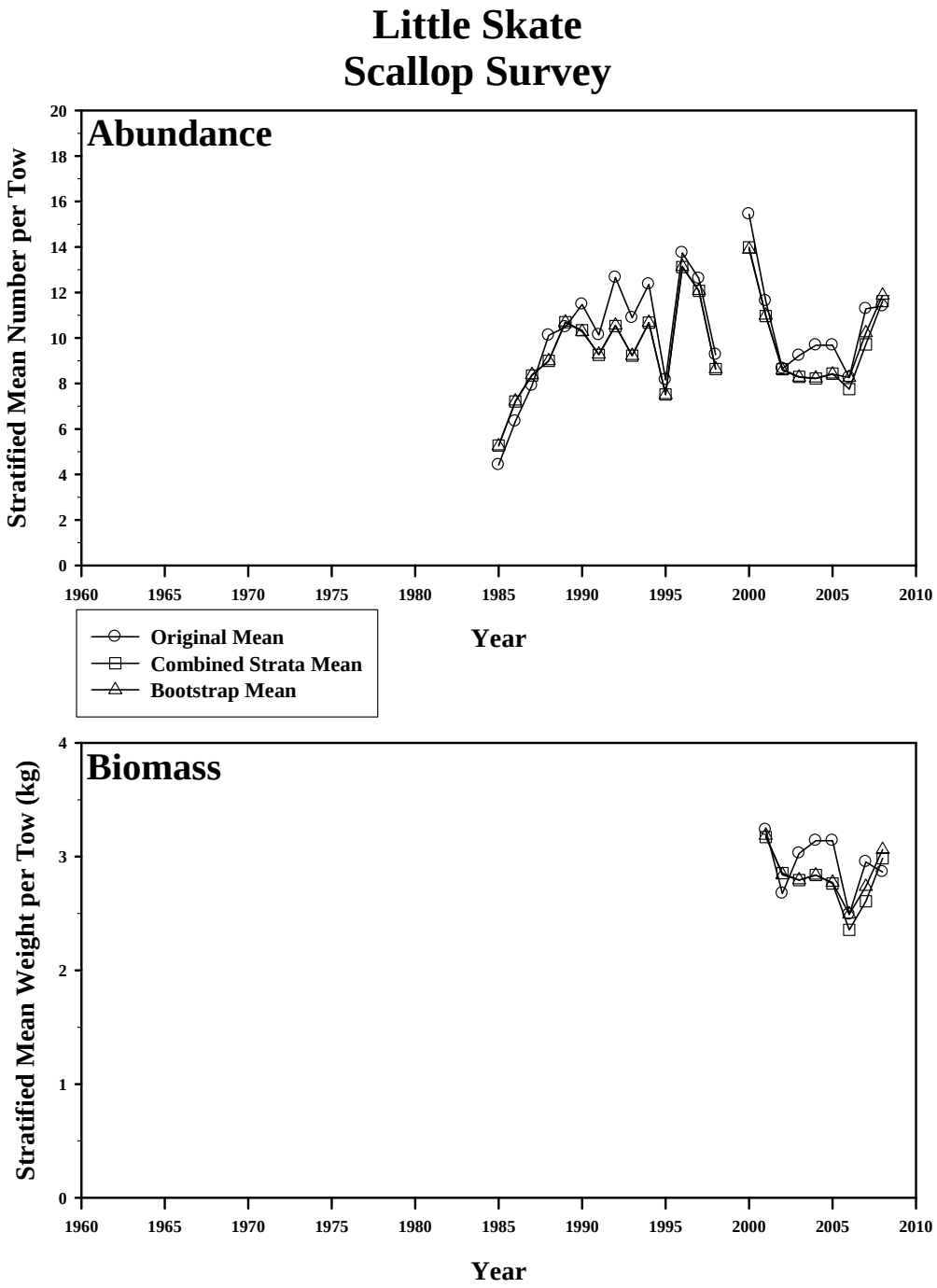


Figure 25. Abundance and biomass of little skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

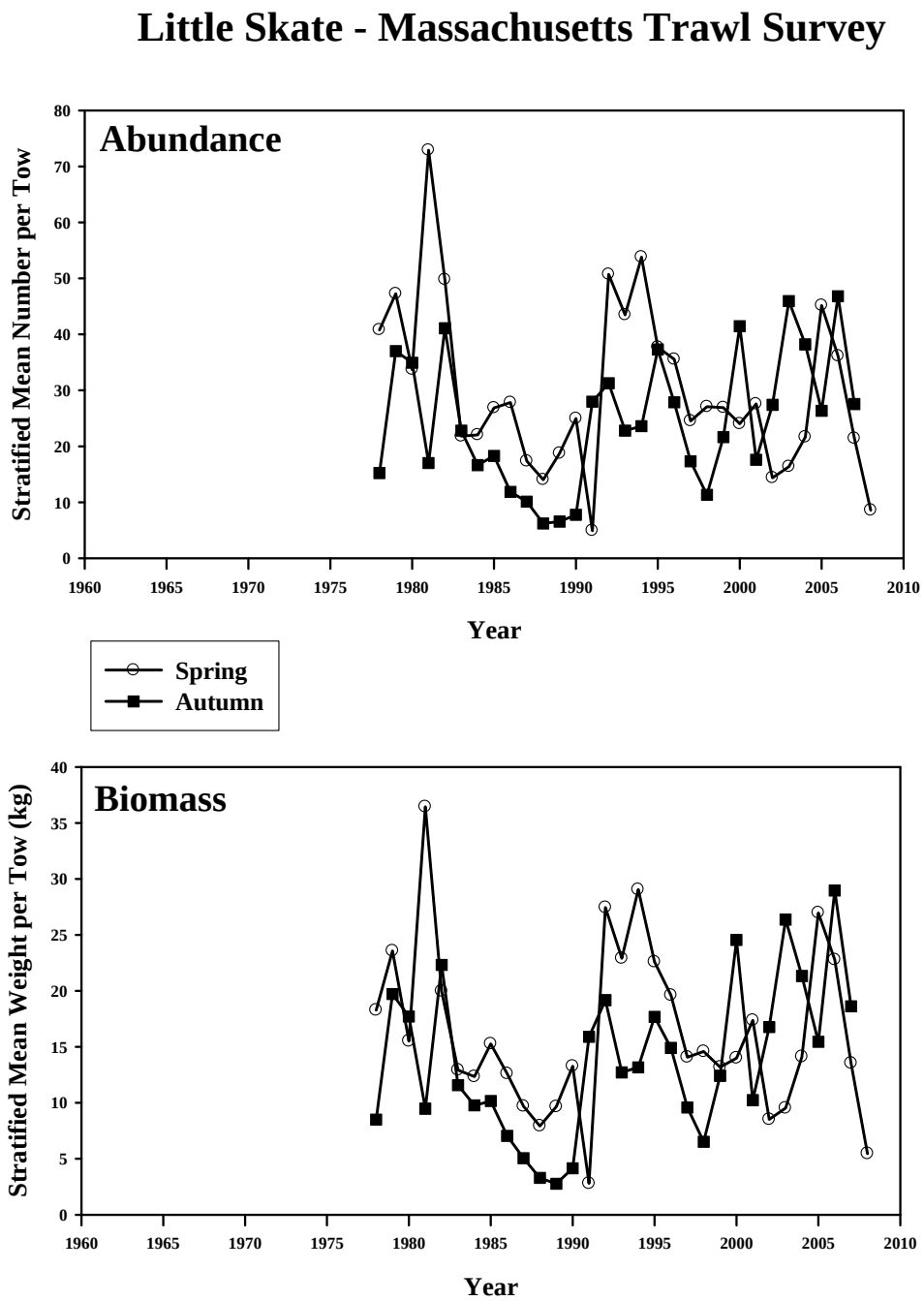


Figure 26. Abundance and biomass of little skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (Strata 11-36).

Little Skate - CTDEP Finfish Survey

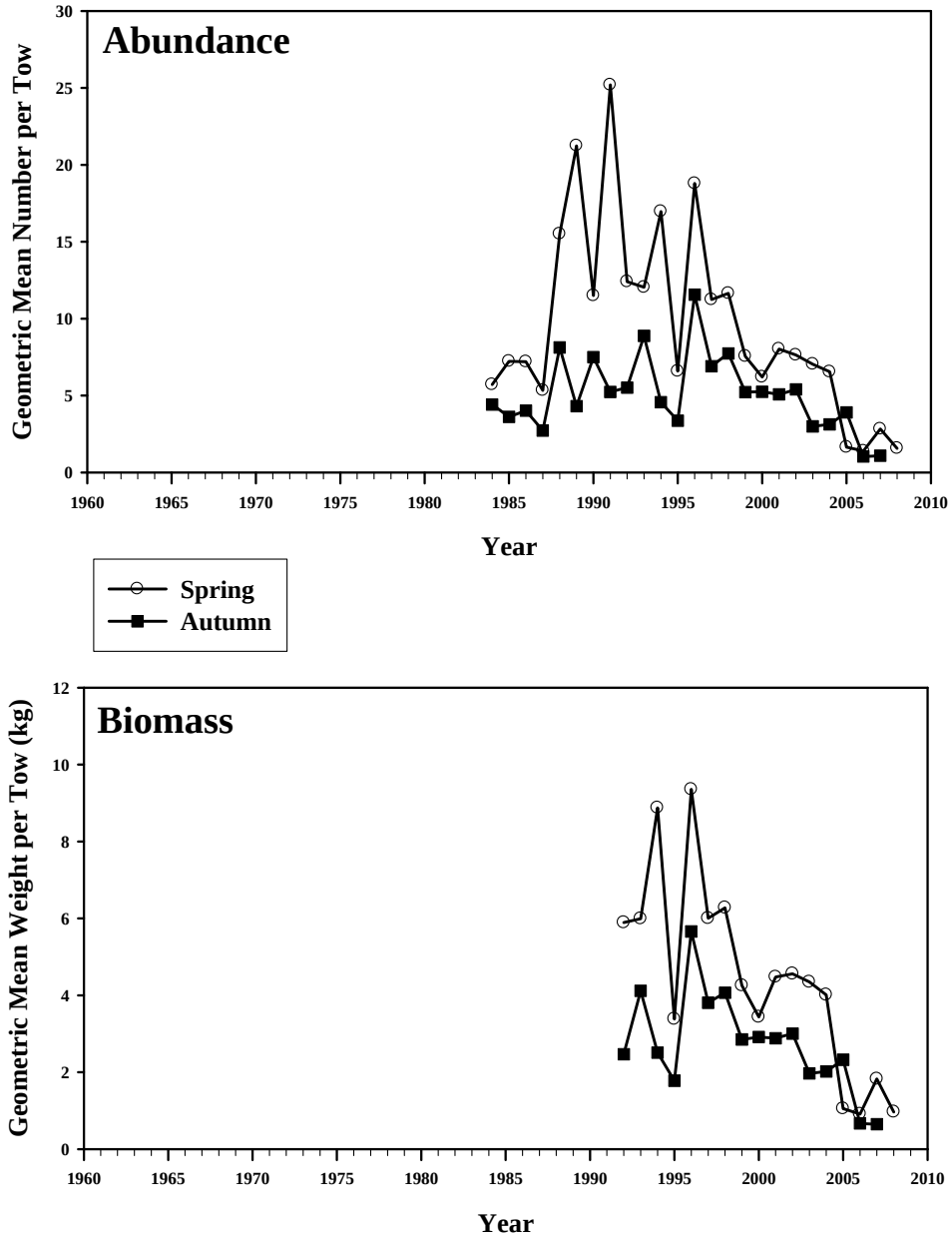


Figure 27. Abundance and biomass of little skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters, 1984-2008.

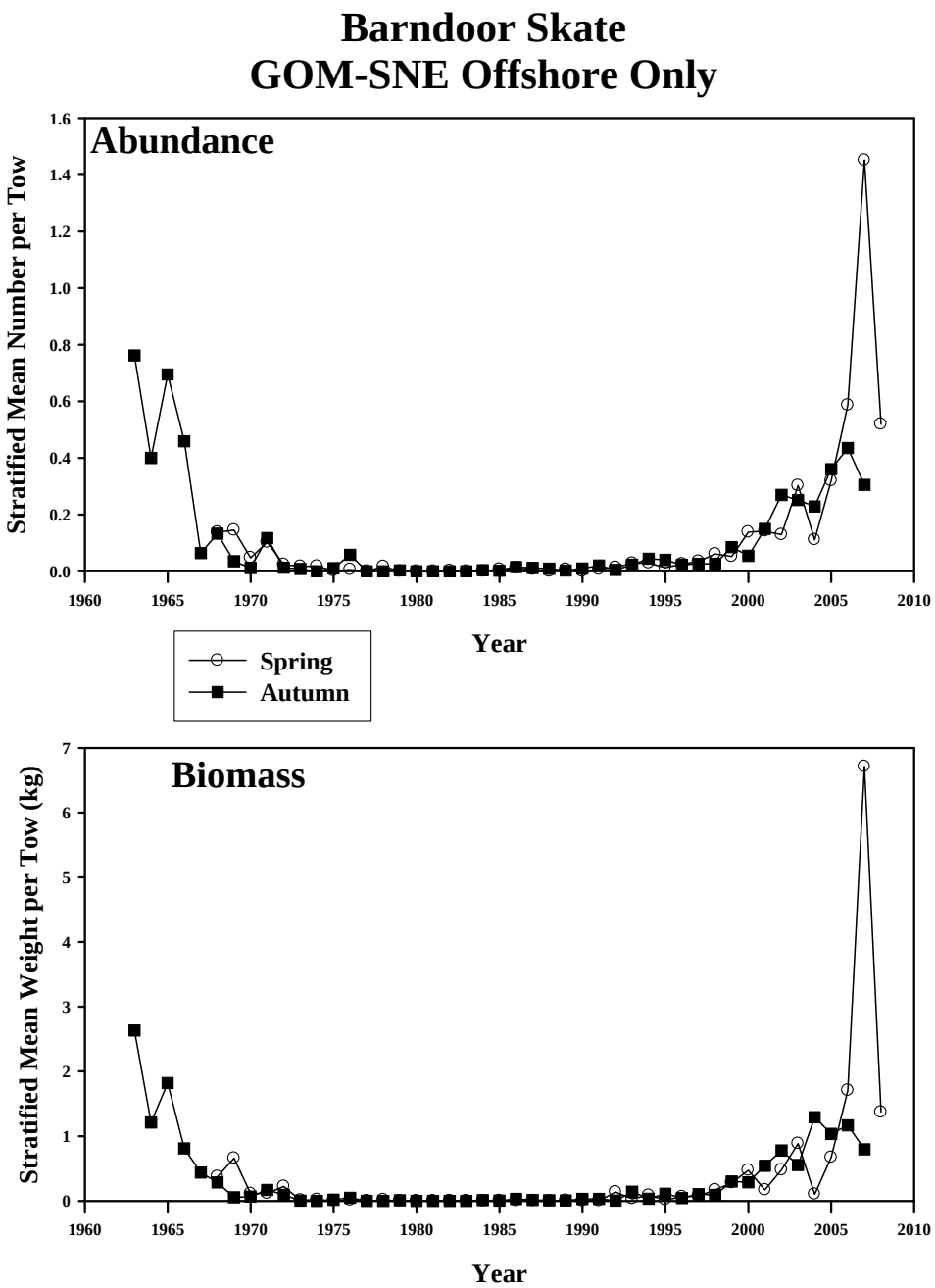


Figure 28. Abundance and biomass of barndoor skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine-Southern New England offshore region.

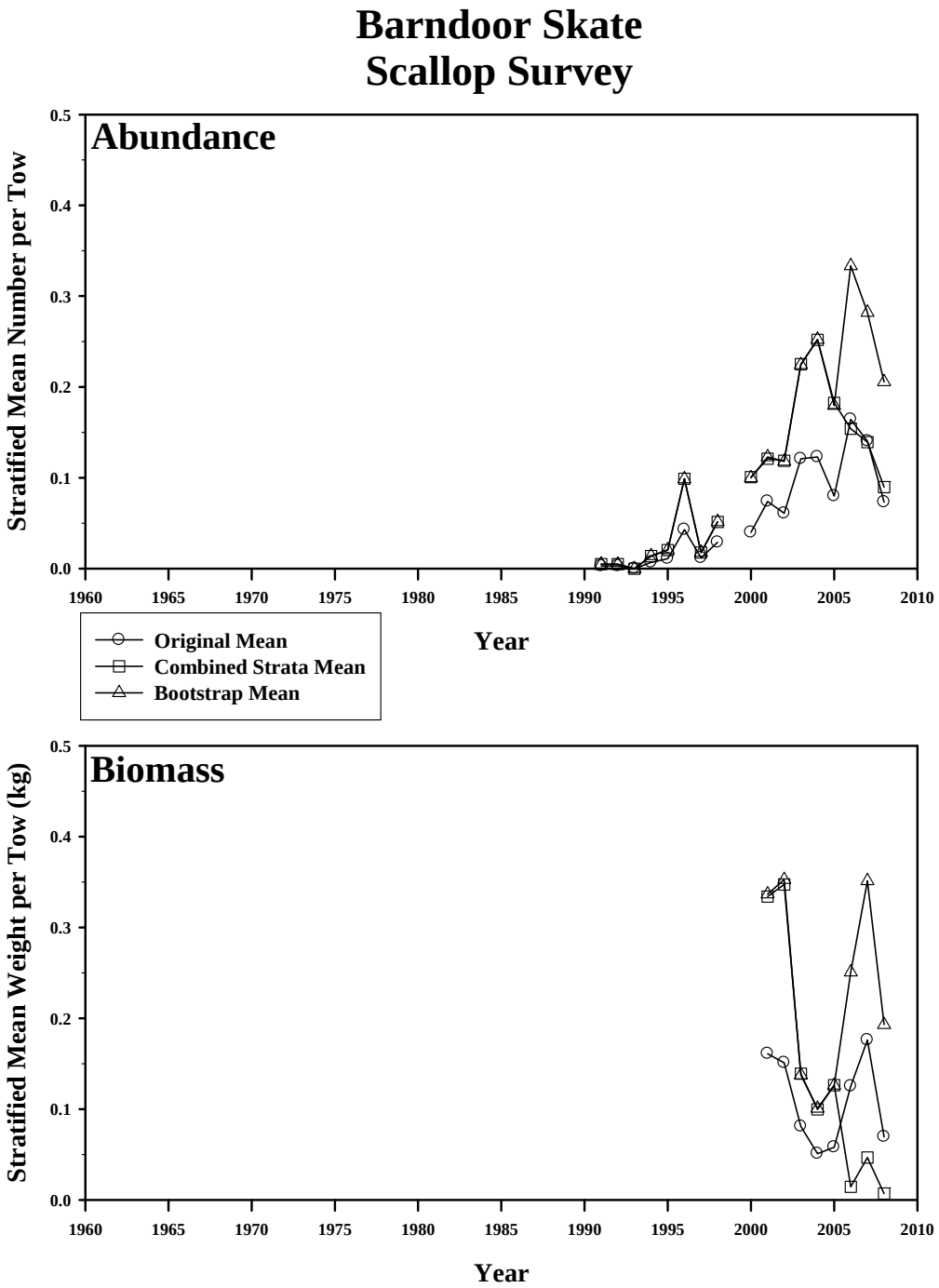


Figure 29. Abundance and biomass of barndoor skate from the NESFC scallop dredge surveys from 1992-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

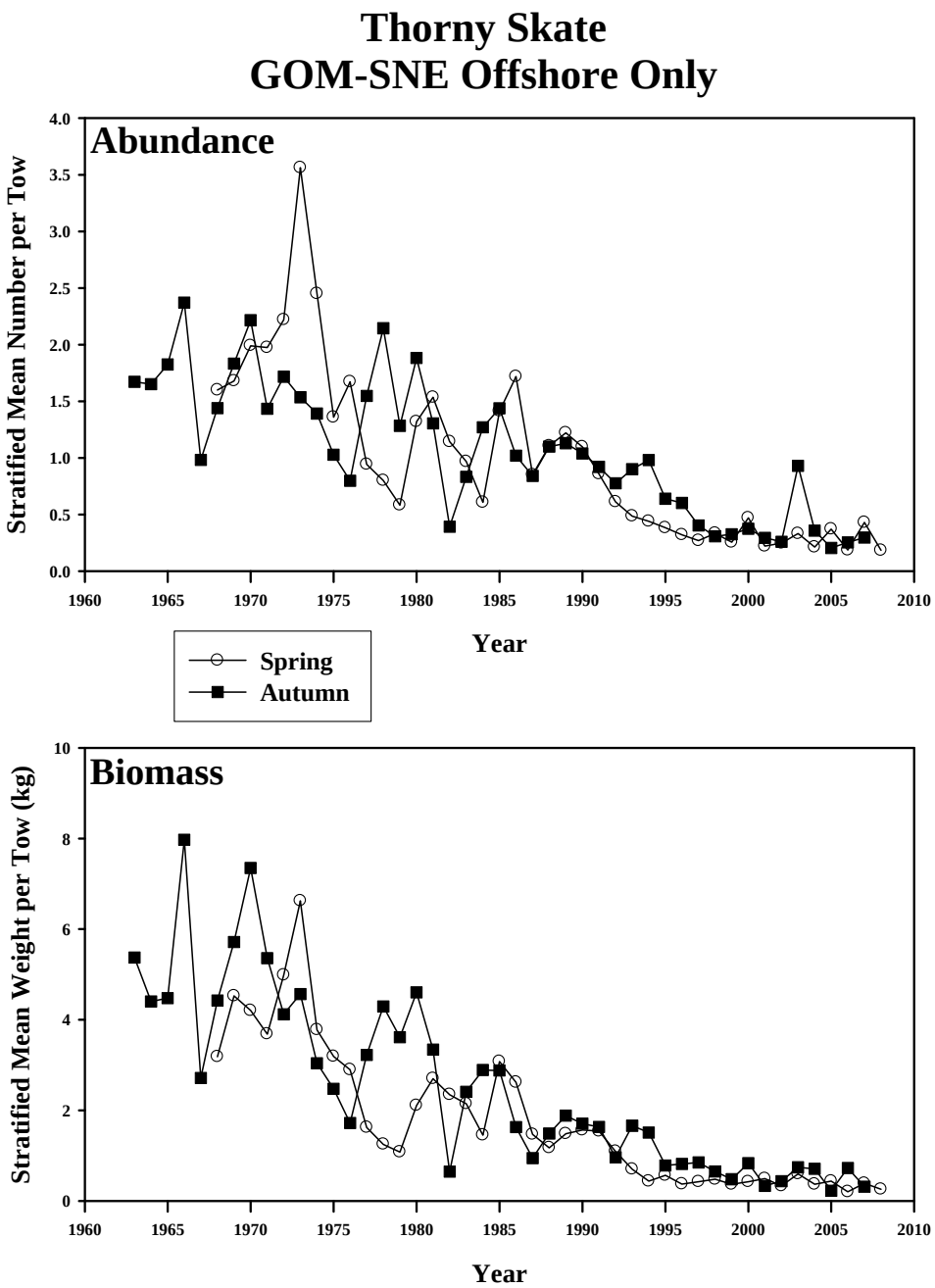


Figure 30. Abundance and biomass of thorny skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine to Southern New England offshore region.

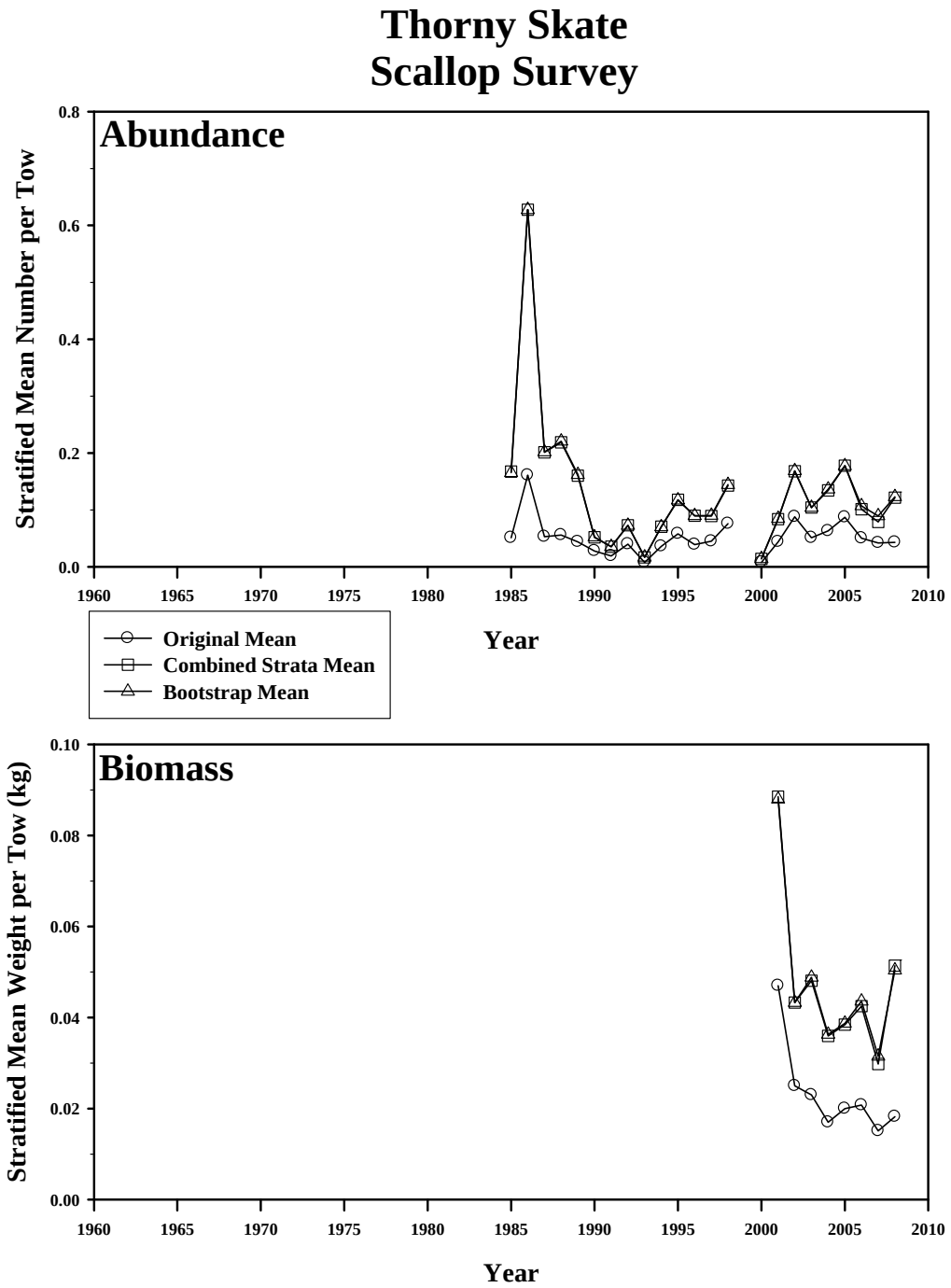


Figure 31. Abundance and biomass of thorny skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

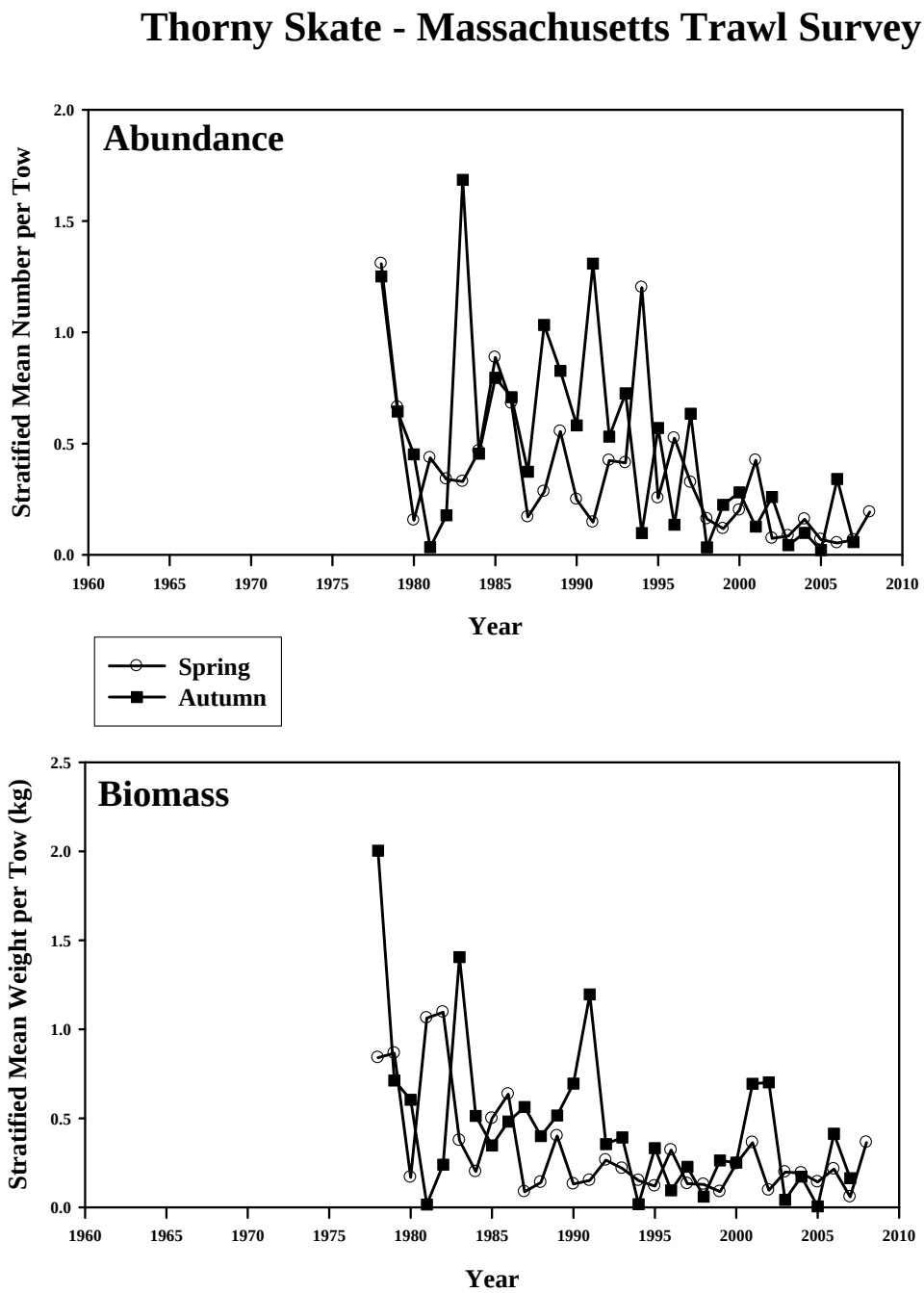


Figure 32. Abundance and biomass of thorny skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (Strata 25-36).

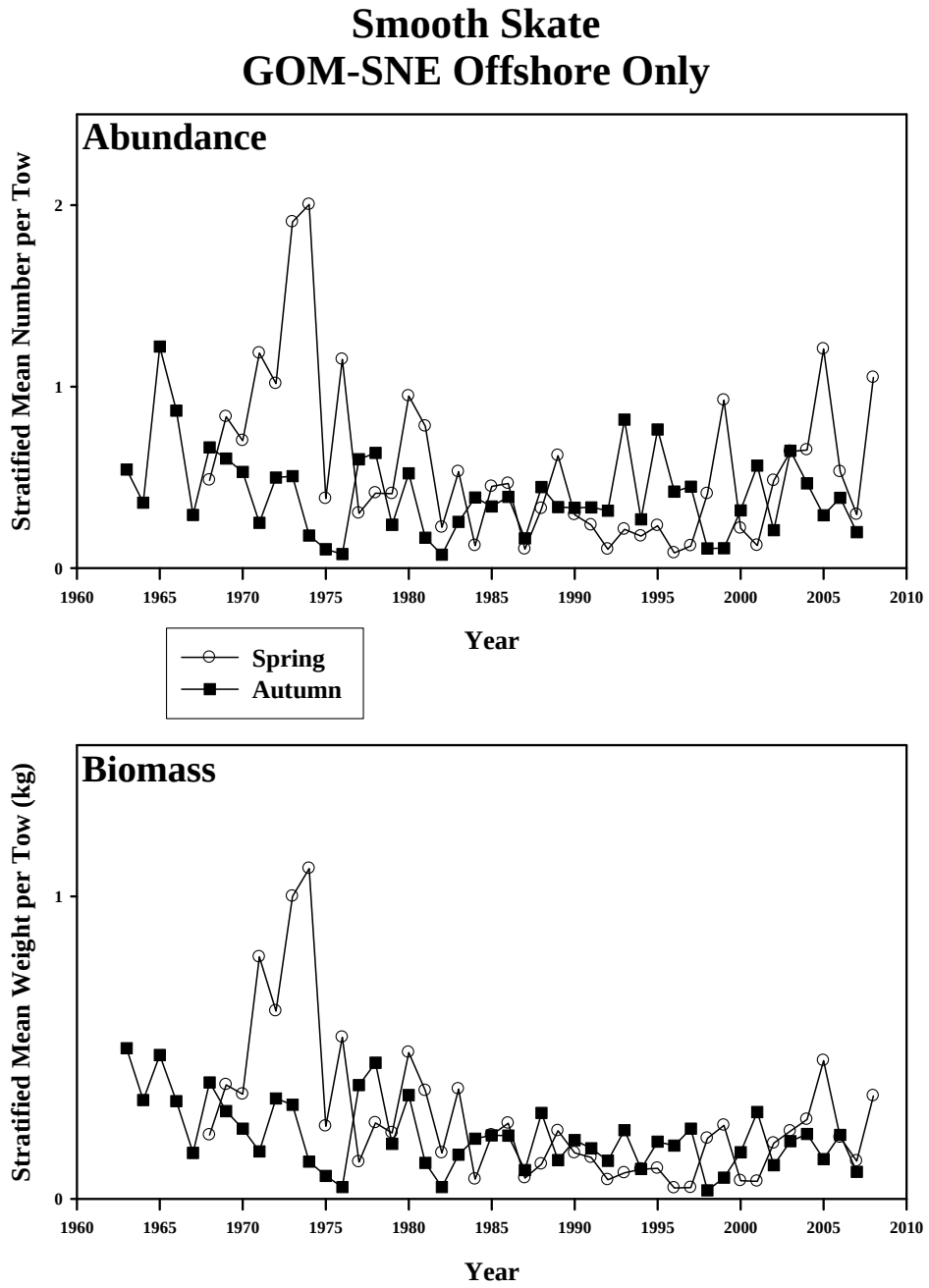


Figure 33. Abundance and biomass of smooth skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine to Southern New England offshore region.

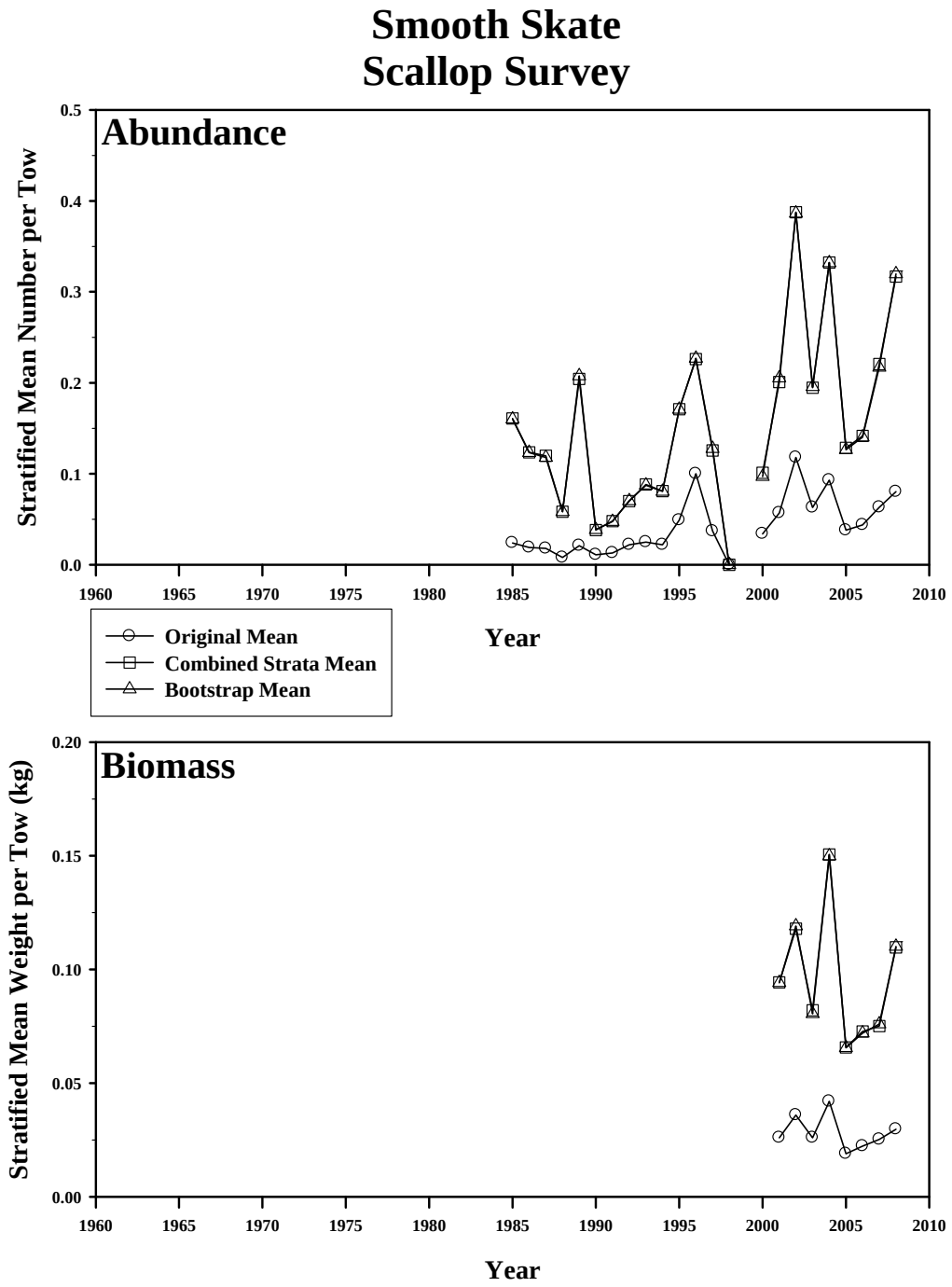


Figure 34. Abundance and biomass of smooth skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

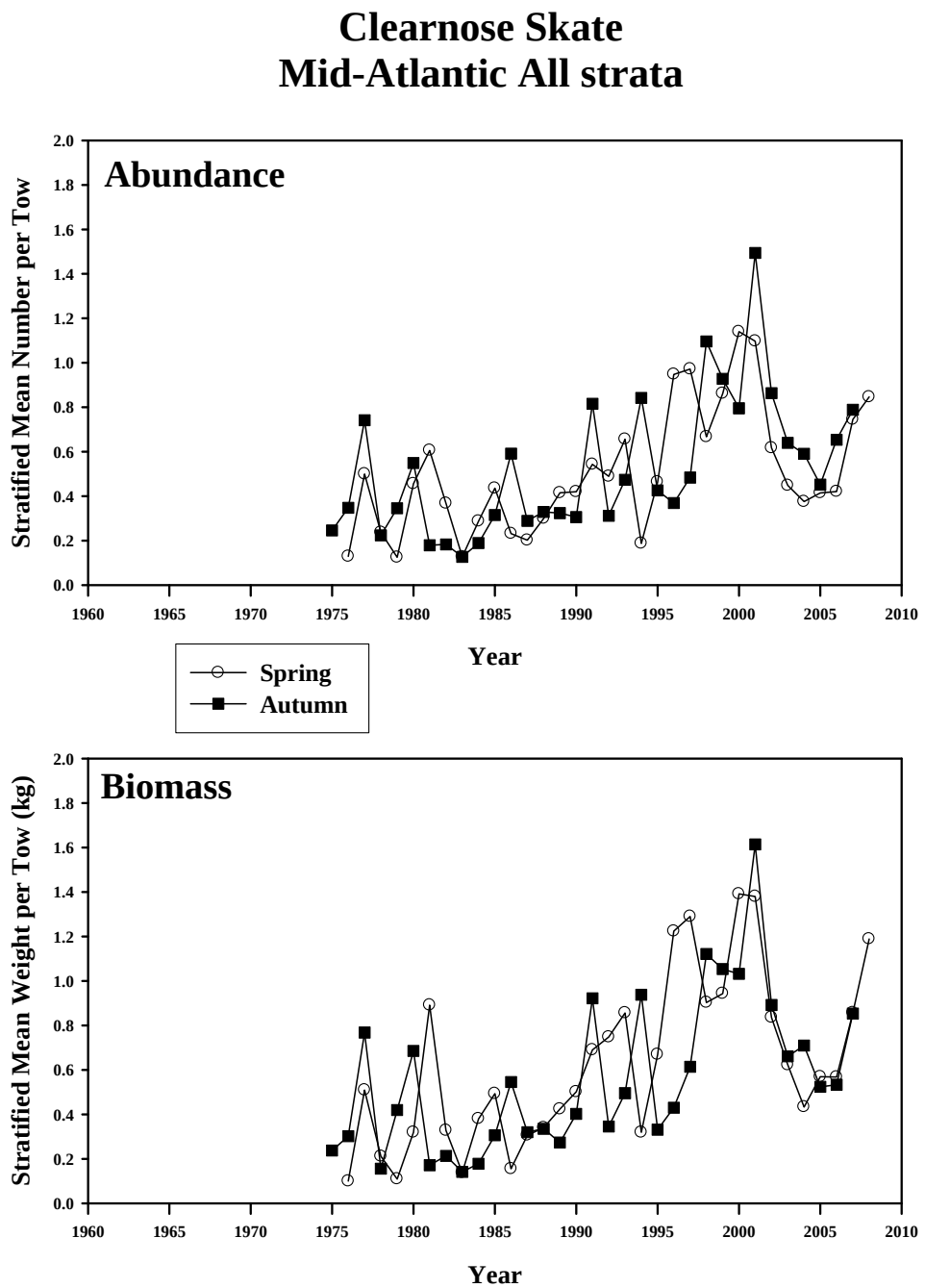


Figure 35. Abundance and biomass of clearnose skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1975-2008 in the Mid-Atlantic offshore and inshore regions.

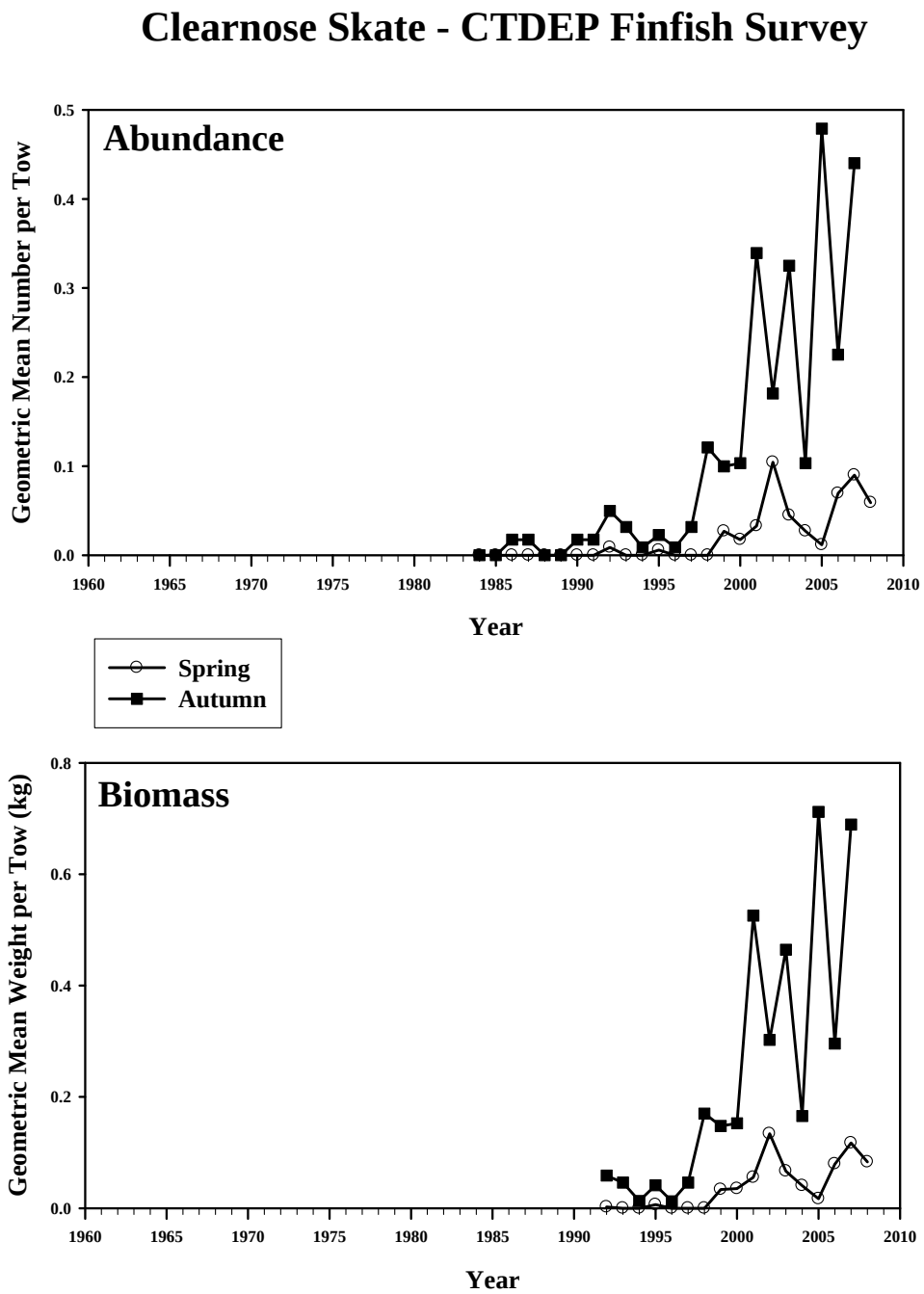


Figure 36. Abundance and biomass of clearnose skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters 1984-2008.

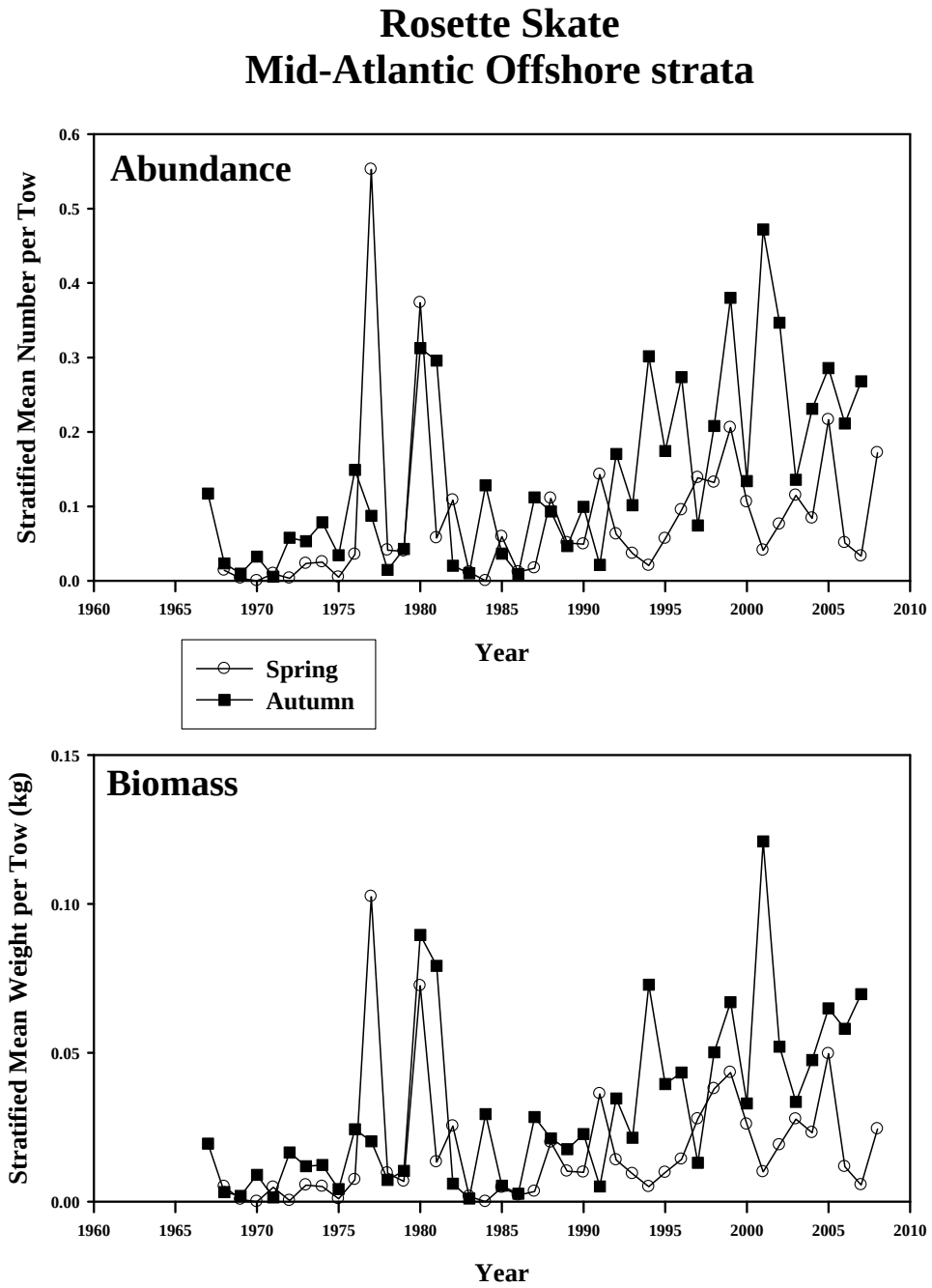


Figure 37. Abundance and biomass of rosette skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1967-2008 in the Mid-Atlantic offshore region.

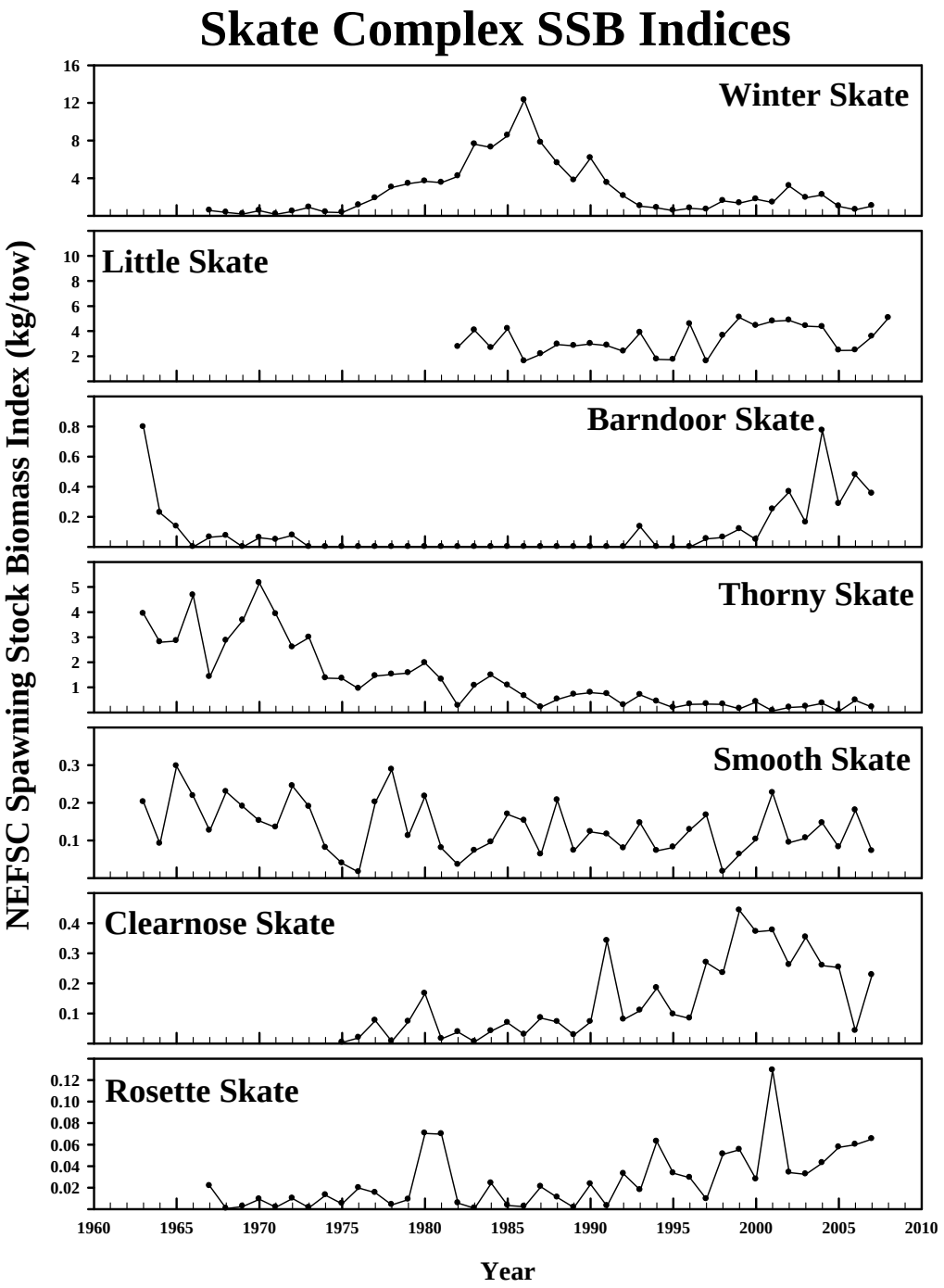


Figure 38. NEFSC survey spawning stock biomass indices (kg/tow).

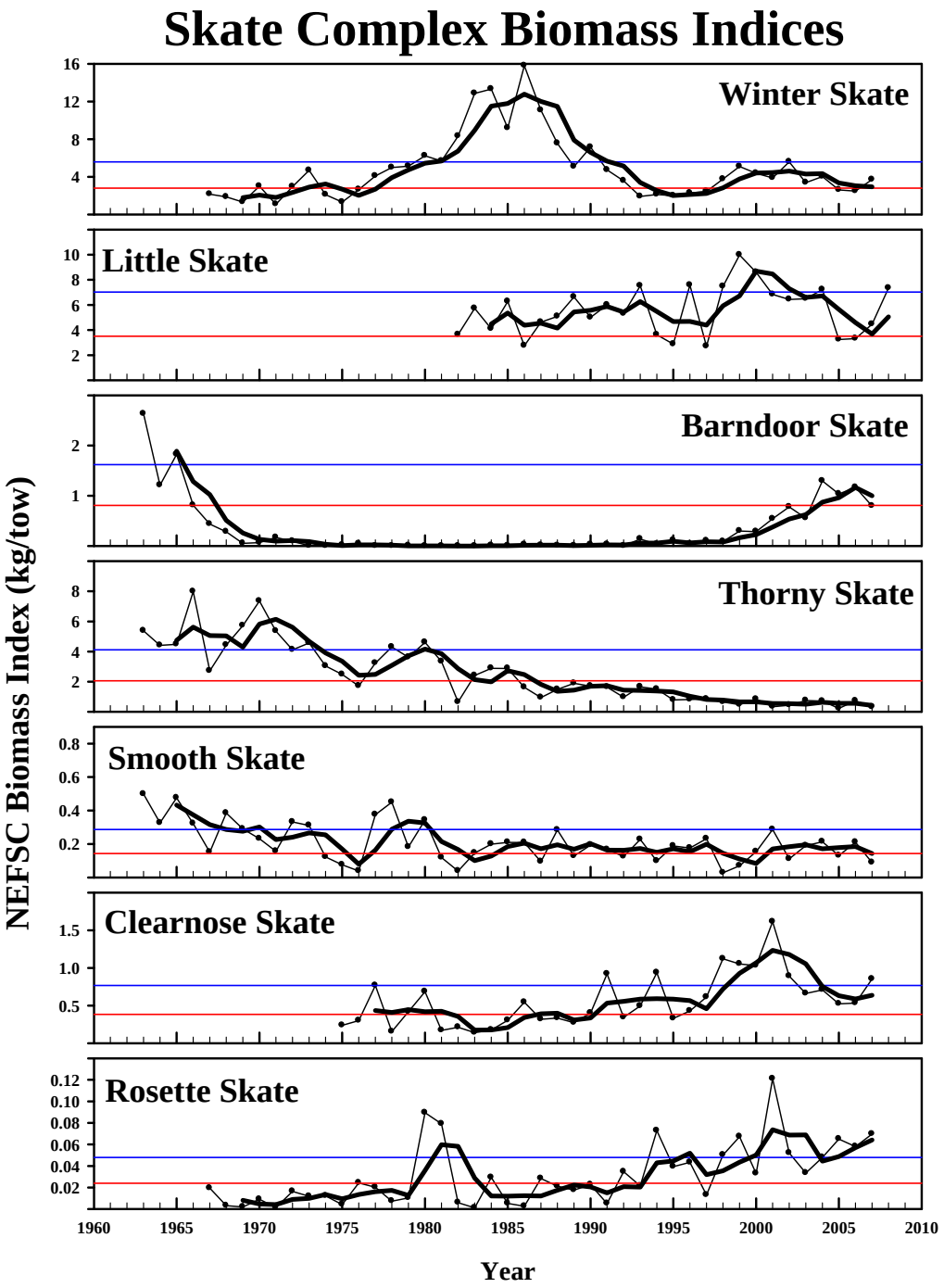


Figure 39. NEFSC survey biomass indices (kg/tow). Thin lines with symbols are annual indices, thick lines are 3-year moving averages, and the thin horizontal line are the biomass target and threshold.

January 13, 2009

Skate Complex
Skate Appendix 1

by
Data Poor Stocks Working Group
National Marine Fisheries Service
Northeast Fisheries Science Center

Data Poor Working Group Meeting
Woods Hole, MA

December 8-12, 2008

Table 1. Discard estimates by stratum for the longline fishery.

mean within areaf | mean within combined region (ie sne-ma) | average across year | average - 1993-2004

YEAR	QTR	areaf	kept	discards	dkratio	mt kept	total discards
1991	1	GBK	15961.0	12350.0	0.7738	970.0	750.53
1991	2	GBK	18109.7	5863.3	0.3296	485.1	159.90
1991	3	GBK	18109.7	5863.3	0.3296	442.3	145.79
1991	4	GBK	27562.0	4796.0	0.1740	393.9	68.55
1991	1	GOM	18109.7	5863.3	0.3296	359.8	118.61
1991	2	GOM	18109.7	5863.3	0.3296	122.1	40.24
1991	3	GOM	18109.7	5863.3	0.3296	131.6	43.38
1991	4	GOM	10806.0	444.0	0.0411	141.7	5.82
1991	1	MA	18109.7	5863.3	0.3296	164.1	54.08
1991	2	MA	18109.7	5863.3	0.3296	58.6	19.32
1991	3	MA	18109.7	5863.3	0.3296	26.5	8.72
1991	4	MA	18109.7	5863.3	0.3296	124.5	41.02
1991	1	SNE	18109.7	5863.3	0.3296	84.9	27.99
1991	2	SNE	18109.7	5863.3	0.3296	32.2	10.60
1991	3	SNE	18109.7	5863.3	0.3296	15.5	5.10
1991	4	SNE	18109.7	5863.3	0.3296	28.1	9.25
1992	1	GBK	30379.5	27527.0	0.9061	1116.6	1011.79
1992	2	GBK	1922.0	426.0	0.2216	632.5	140.19
1992	3	GBK	16579.3	7918.8	0.3095	460.6	142.54
1992	4	GBK	16579.3	7918.8	0.3095	499.4	154.55
1992	1	GOM	33786.8	3722.0	0.1102	800.8	88.22
1992	2	GOM	16579.3	7918.8	0.3095	93.9	29.05
1992	3	GOM	16579.3	7918.8	0.3095	176.6	54.66
1992	4	GOM	16579.3	7918.8	0.3095	386.0	119.45
1992	1	MA	16579.3	7918.8	0.3095	226.1	69.98
1992	2	MA	229.0	0.0	0.0000	64.9	0.00
1992	3	MA	16579.3	7918.8	0.3095	111.6	34.55
1992	4	MA	16579.3	7918.8	0.3095	124.0	38.38
1992	1	SNE	16579.3	7918.8	0.3095	330.0	102.11
1992	2	SNE	16579.3	7918.8	0.3095	200.3	62.00
1992	3	SNE	16579.3	7918.8	0.3095	151.1	46.76
1992	4	SNE	16579.3	7918.8	0.3095	403.4	124.83
1993	1	GBK	32995.7	394.5	0.0679	1220.1	82.89
1993	2	GBK	32995.7	394.5	0.0679	579.3	39.36
1993	3	GBK	32995.7	394.5	0.0679	587.7	39.93
1993	4	GBK	32995.7	394.5	0.0679	606.0	41.17
1993	1	GOM	296.0	26.0	0.0878	380.0	33.38
1993	2	GOM	32995.7	394.5	0.0679	193.9	13.17
1993	3	GOM	32995.7	394.5	0.0679	247.8	16.84
1993	4	GOM	32995.7	394.5	0.0679	404.4	27.47
1993	1	MA	4205.0	0.0	0.0000	138.0	0.00
1993	2	MA	32995.7	394.5	0.0679	96.8	6.57
1993	3	MA	578.0	0.0	0.0000	45.3	0.00
1993	4	MA	32995.7	394.5	0.0679	116.7	7.93
1993	1	SNE	32995.7	394.5	0.0679	569.6	38.70

Table 1. cont.

1993	2	SNE	32995.7	394.5	0.0679	434.8	29.54
1993	3	SNE	32995.7	394.5	0.0679	146.9	9.98
1993	4	SNE	32995.7	394.5	0.0679	239.3	16.26
1994	1	GBK	481.0	0.0	0.0000	989.6	0.00
1994	2	GBK	32995.7	394.5	0.0679	568.2	38.60
1994	3	GBK	32995.7	394.5	0.0679	512.1	34.79
1994	4	GBK	32995.7	394.5	0.0679	676.0	45.92
1994	1	GOM	32995.7	394.5	0.0679	268.2	18.22
1994	2	GOM	32995.7	394.5	0.0679	365.9	24.86
1994	3	GOM	32995.7	394.5	0.0679	649.2	44.10
1994	4	GOM	32995.7	394.5	0.0679	314.0	21.33
1994	1	MA	64.4	0.0	0.0000	101.9	0.00
1994	2	MA	32995.7	394.5	0.0679	50.3	3.42
1994	3	MA	32995.7	394.5	0.0679	3.0	0.20
1994	4	MA	32995.7	394.5	0.0679	1.5	0.11
1994	1	SNE	32995.7	394.5	0.0679	382.1	25.96
1994	2	SNE	32995.7	394.5	0.0679	104.5	7.10
1994	3	SNE	32995.7	394.5	0.0679	69.4	4.71
1994	4	SNE	32995.7	394.5	0.0679	160.6	10.91
1995	1	GBK	32995.7	394.5	0.0679	948.1	64.41
1995	2	GBK	32995.7	394.5	0.0679	691.6	46.98
1995	3	GBK	32995.7	394.5	0.0679	436.9	29.68
1995	4	GBK	32995.7	394.5	0.0679	811.2	55.11
1995	1	GOM	32995.7	394.5	0.0679	221.9	15.08
1995	2	GOM	32995.7	394.5	0.0679	297.2	20.19
1995	3	GOM	32995.7	394.5	0.0679	463.0	31.45
1995	4	GOM	32995.7	394.5	0.0679	529.8	35.99
1995	1	MA	0.0	0.0		135.2	0.00
1995	2	MA	32995.7	394.5	0.0679	64.3	4.37
1995	3	MA	32995.7	394.5	0.0679	43.5	2.96
1995	4	MA	32995.7	394.5	0.0679	46.3	3.14
1995	1	SNE	32995.7	394.5	0.0679	186.3	12.66
1995	2	SNE	32995.7	394.5	0.0679	15.5	1.05
1995	3	SNE	32995.7	394.5	0.0679	30.3	2.06
1995	4	SNE	32995.7	394.5	0.0679	223.0	15.15
1996	1	GBK	32995.7	394.5	0.0679	649.6	44.13
1996	2	GBK	32995.7	394.5	0.0679	576.0	39.13
1996	3	GBK	32995.7	394.5	0.0679	380.5	25.85
1996	4	GBK	32995.7	394.5	0.0679	841.8	57.19
1996	1	GOM	32995.7	394.5	0.0679	325.5	22.11
1996	2	GOM	32995.7	394.5	0.0679	263.6	17.91
1996	3	GOM	32995.7	394.5	0.0679	171.4	11.64
1996	4	GOM	32995.7	394.5	0.0679	394.5	26.80
1996	1	MA	32995.7	394.5	0.0679	120.9	8.21
1996	2	MA	32995.7	394.5	0.0679	79.5	5.40
1996	3	MA	32995.7	394.5	0.0679	76.5	5.20
1996	4	MA	32995.7	394.5	0.0679	109.2	7.42
1996	1	SNE	32995.7	394.5	0.0679	319.5	21.70
1996	2	SNE	32995.7	394.5	0.0679	74.9	5.09

Table 1 cont.

1996	3	SNE	32995.7	394.5	0.0679	86.0	5.84
1996	4	SNE	32995.7	394.5	0.0679	221.9	15.08
1997	1	GBK	32995.7	394.5	0.0679	416.1	28.27
1997	2	GBK	32995.7	394.5	0.0679	662.5	45.01
1997	3	GBK	32995.7	394.5	0.0679	306.6	20.83
1997	4	GBK	32995.7	394.5	0.0679	645.3	43.84
1997	1	GOM	32995.7	394.5	0.0679	342.2	23.25
1997	2	GOM	32995.7	394.5	0.0679	336.1	22.83
1997	3	GOM	32995.7	394.5	0.0679	292.0	19.84
1997	4	GOM	32995.7	394.5	0.0679	563.6	38.29
1997	1	MA	32995.7	394.5	0.0679	86.7	5.89
1997	2	MA	32995.7	394.5	0.0679	113.0	7.68
1997	3	MA	32995.7	394.5	0.0679	98.4	6.68
1997	4	MA	32995.7	394.5	0.0679	134.7	9.15
1997	1	SNE	32995.7	394.5	0.0679	463.8	31.51
1997	2	SNE	32995.7	394.5	0.0679	185.6	12.61
1997	3	SNE	32995.7	394.5	0.0679	119.8	8.14
1997	4	SNE	32995.7	394.5	0.0679	370.9	25.20
1998	1	GBK	32995.7	394.5	0.0679	661.8	44.96
1998	2	GBK	32995.7	394.5	0.0679	276.2	18.77
1998	3	GBK	32995.7	394.5	0.0679	358.4	24.35
1998	4	GBK	32995.7	394.5	0.0679	1137.5	77.27
1998	1	GOM	32995.7	394.5	0.0679	254.2	17.27
1998	2	GOM	32995.7	394.5	0.0679	271.8	18.46
1998	3	GOM	32995.7	394.5	0.0679	205.0	13.93
1998	4	GOM	32995.7	394.5	0.0679	384.4	26.12
1998	1	MA	32995.7	394.5	0.0679	173.2	11.77
1998	2	MA	32995.7	394.5	0.0679	62.7	4.26
1998	3	MA	115.0	10.0	0.0870	43.3	3.77
1998	4	MA	32995.7	394.5	0.0679	255.6	17.36
1998	1	SNE	32995.7	394.5	0.0679	322.8	21.93
1998	2	SNE	32995.7	394.5	0.0679	133.3	9.06
1998	3	SNE	32995.7	394.5	0.0679	94.1	6.39
1998	4	SNE	32995.7	394.5	0.0679	127.8	8.69
1999	1	GBK	32995.7	394.5	0.0679	805.6	54.73
1999	2	GBK	32995.7	394.5	0.0679	589.2	40.02
1999	3	GBK	32995.7	394.5	0.0679	482.1	32.75
1999	4	GBK	32995.7	394.5	0.0679	1145.9	77.85
1999	1	GOM	32995.7	394.5	0.0679	84.0	5.71
1999	2	GOM	32995.7	394.5	0.0679	177.1	12.03
1999	3	GOM	32995.7	394.5	0.0679	64.3	4.37
1999	4	GOM	32995.7	394.5	0.0679	112.8	7.66
1999	1	MA	32995.7	394.5	0.0679	103.8	7.05
1999	2	MA	32995.7	394.5	0.0679	57.4	3.90
1999	3	MA	32995.7	394.5	0.0679	37.4	2.54
1999	4	MA	32995.7	394.5	0.0679	112.4	7.64
1999	1	SNE	32995.7	394.5	0.0679	109.1	7.41
1999	2	SNE	32995.7	394.5	0.0679	70.4	4.78
1999	3	SNE	32995.7	394.5	0.0679	42.0	2.86

Table 1 cont.

1999	4	SNE	32995.7	394.5	0.0679	54.1	3.67
2000	1	GBK	32995.7	394.5	0.0679	474.0	32.20
2000	2	GBK	32995.7	394.5	0.0679	309.0	20.99
2000	3	GBK	32995.7	394.5	0.0679	1545.6	105.00
2000	4	GBK	32995.7	394.5	0.0679	200.5	13.62
2000	1	GOM	32995.7	394.5	0.0679	64.0	4.35
2000	2	GOM	32995.7	394.5	0.0679	65.6	4.46
2000	3	GOM	32995.7	394.5	0.0679	98.6	6.70
2000	4	GOM	32995.7	394.5	0.0679	80.5	5.47
2000	1	MA	32995.7	394.5	0.0679	108.4	7.36
2000	2	MA	32995.7	394.5	0.0679	36.7	2.49
2000	3	MA	32995.7	394.5	0.0679	43.3	2.94
2000	4	MA	32995.7	394.5	0.0679	168.6	11.45
2000	1	SNE	32995.7	394.5	0.0679	79.3	5.38
2000	2	SNE	32995.7	394.5	0.0679	60.6	4.12
2000	3	SNE	32995.7	394.5	0.0679	65.6	4.46
2000	4	SNE	32995.7	394.5	0.0679	54.5	3.71
2001	1	GBK	32995.7	394.5	0.0679	446.2	30.31
2001	2	GBK	32995.7	394.5	0.0679	739.7	50.25
2001	3	GBK	32995.7	394.5	0.0679	438.0	29.76
2001	4	GBK	32995.7	394.5	0.0679	805.7	54.73
2001	1	GOM	32995.7	394.5	0.0679	34.8	2.36
2001	2	GOM	32995.7	394.5	0.0679	53.5	3.64
2001	3	GOM	32995.7	394.5	0.0679	21.9	1.48
2001	4	GOM	32995.7	394.5	0.0679	87.4	5.94
2001	1	MA	32995.7	394.5	0.0679	177.3	12.04
2001	2	MA	32995.7	394.5	0.0679	124.3	8.45
2001	3	MA	32995.7	394.5	0.0679	109.9	7.47
2001	4	MA	32995.7	394.5	0.0679	304.8	20.71
2001	1	SNE	32995.7	394.5	0.0679	123.9	8.42
2001	2	SNE	32995.7	394.5	0.0679	32.6	2.22
2001	3	SNE	32995.7	394.5	0.0679	47.2	3.21
2001	4	SNE	32995.7	394.5	0.0679	91.9	6.24
2002	1	GBK	32995.7	394.5	0.0679	619.8	42.10
2002	2	GBK	32995.7	394.5	0.0679	451.4	30.67
2002	3	GBK	683.0	145.0	0.2123	113.1	24.00
2002	4	GBK	6362.0	208.0	0.0327	527.0	17.23
2002	1	GOM	32995.7	394.5	0.0679	105.1	7.14
2002	2	GOM	32995.7	394.5	0.0679	246.4	16.74
2002	3	GOM	32995.7	394.5	0.0679	36.7	2.49
2002	4	GOM	1.5	0.0	0.0000	63.6	0.00
2002	1	MA	32995.7	394.5	0.0679	204.3	13.88
2002	2	MA	32995.7	394.5	0.0679	78.7	5.34
2002	3	MA	32995.7	394.5	0.0679	70.4	4.78
2002	4	MA	32995.7	394.5	0.0679	163.9	11.13
2002	1	SNE	32995.7	394.5	0.0679	53.2	3.62
2002	2	SNE	32995.7	394.5	0.0679	45.7	3.11
2002	3	SNE	32995.7	394.5	0.0679	69.3	4.71
2002	4	SNE	937.0	427.0	0.4557	135.3	61.64

Table 1 cont.

2003	1	GBK	4138.0	643.0	0.1554	140.9	21.89
2003	2	GBK	32995.7	394.5	0.0679	16.6	1.13
2003	3	GBK	32995.7	394.5	0.0679	195.3	13.26
2003	4	GBK	6300.0	0.0	0.0000	747.4	0.00
2003	1	GOM	9886.9	567.0	0.0573	170.8	9.79
2003	2	GOM	32995.7	394.5	0.0679	17.7	1.20
2003	3	GOM	32995.7	394.5	0.0679	47.8	3.24
2003	4	GOM	32995.7	394.5	0.0679	110.9	7.53
2003	1	MA	32995.7	394.5	0.0679	205.0	13.93
2003	2	MA	32995.7	394.5	0.0679	141.6	9.62
2003	3	MA	32995.7	394.5	0.0679	145.2	9.86
2003	4	MA	32995.7	394.5	0.0679	215.0	14.60
2003	1	SNE	32995.7	394.5	0.0679	137.4	9.34
2003	2	SNE	32995.7	394.5	0.0679	41.2	2.80
2003	3	SNE	32995.7	394.5	0.0679	26.5	1.80
2003	4	SNE	32995.7	394.5	0.0679	85.6	5.81
2004	1	GBK	684.0	9.0	0.0132	105.8	1.39
2004	2	GBK	32995.7	394.5	0.0679	4.5	0.31
2004	3	GBK	18336.1	638.0	0.0348	87.0	3.03
2004	4	GBK	533137.1	4358.3	0.0082	669.8	5.48
2004	1	GOM	6638.8	70.0	0.0105	142.1	1.50
2004	2	GOM	32995.7	394.5	0.0679	4.1	0.28
2004	3	GOM	32995.7	394.5	0.0679	66.1	4.49
2004	4	GOM	32995.7	394.5	0.0679	62.0	4.21
2004	1	MA	32995.7	394.5	0.0679	148.2	10.07
2004	2	MA	32995.7	394.5	0.0679	43.2	2.94
2004	3	MA	32995.7	394.5	0.0679	61.7	4.19
2004	4	MA	1144.0	0.0	0.0000	218.6	0.00
2004	1	SNE	32995.7	394.5	0.0679	316.8	21.52
2004	2	SNE	32995.7	394.5	0.0679	23.6	1.61
2004	3	SNE	32995.7	394.5	0.0679	38.0	2.58
2004	4	SNE	14802.0	0.0	0.0000	161.3	0.00
2005	1	GBK	25875.8	2416.0	0.0934	276.1	25.78
2005	2	GBK	103532.8	29924.0	0.2890	130.7	37.79
2005	3	GBK	52318.8	5492.0	0.1050	216.7	22.75
2005	4	GBK	625960.6	21498.1	0.0343	850.2	29.20
2005	1	GOM	36869.1	1932.0	0.0524	465.7	24.40
2005	2	GOM	4250.0	101.0	0.0238	132.7	3.15
2005	3	GOM	5209.4	62.0	0.0119	128.5	1.53
2005	4	GOM	12918.0	11.5	0.0009	154.8	0.14
2005	1	MA	24285.0	0.0	0.0000	930.0	0.00
2005	2	MA	24285.0	0.0	0.0000	315.1	0.00
2005	3	MA	24285.0	0.0	0.0000	381.1	0.00
2005	4	MA	11009.0	0.0	0.0000	325.1	0.00
2005	1	SNE	37561.0	0.0	0.0000	733.2	0.00
2005	2	SNE	24285.0	0.0	0.0000	62.4	0.00
2005	3	SNE	24285.0	0.0	0.0000	124.5	0.00
2005	4	SNE	13904.0	0.0	0.0000	251.3	0.00
2006	1	GBK	5382.3	2678.0	0.4976	329.8	164.08

Table 1 cont.

2006	2	GBK	15863.0	3717.0	0.2343	77.5	18.16
2006	3	GBK	725.0	0.0	0.0000	20.6	0.00
2006	4	GBK	122382.7	6628.4	0.0542	282.3	15.29
2006	1	GOM	29380.8	1181.6	0.0402	251.9	10.13
2006	2	GOM	11947.3	469.9	0.0264	11.4	0.30
2006	3	GOM	591.0	0.0	0.0000	9.3	0.00
2006	4	GOM	5870.0	228.0	0.0388	49.7	1.93
2006	1	MA	26623.8	1.5	0.0001	190.4	0.01
2006	2	MA	25933.5	3.0	0.0001	120.0	0.01
2006	3	MA	25392.0	48.0	0.0015	161.2	0.24
2006	4	MA	27314.0	0.0	0.0000	354.7	0.00
2006	1	SNE	36898.8	281.0	0.0076	206.0	1.57
2006	2	SNE	23469.9	96.0	0.0030	63.5	0.19
2006	3	SNE	28359.0	0.0	0.0000	74.9	0.00
2006	4	SNE	5152.0	7.0	0.0014	171.9	0.23
2007	1	GBK	19980.8	7508.0	0.3758	40.3	15.15
2007	2	GBK	13550.6	618.0	0.0456	85.2	3.89
2007	3	GBK	704.0	57.0	0.0810	94.2	7.62
2007	4	GBK	162247.8	8277.1	0.0510	302.4	15.43
2007	1	GOM	15599.3	1455.8	0.0933	292.0	27.25
2007	2	GOM	1315.8	45.0	0.0342	3.7	0.13
2007	3	GOM	679.2	61.8	0.0910	37.8	3.44
2007	4	GOM	15414.0	78.1	0.0051	88.5	0.45
2007	1	MA	13696.6	0.0	0.0000	148.8	0.00
2007	2	MA	13696.6	0.0	0.0000	111.8	0.00
2007	3	MA	21468.9	0.0	0.0000	192.4	0.00
2007	4	MA	2793.0	0.0	0.0000	480.6	0.00
2007	1	SNE	13696.6	0.0	0.0000	188.6	0.00
2007	2	SNE	13696.6	0.0	0.0000	77.3	0.00
2007	3	SNE	13696.6	0.0	0.0000	38.3	0.00
2007	4	SNE	16828.0	0.0	0.0000	85.9	0.00

Table 2. Discard estimates by stratum for the otter trawl fishery.

average within areaf

YEAR	QTR	areaf	ksums	dsums	dkratio	cf_totalmt	disc
1989	1	GBK	117519.0	94262.0	0.8021	15772.5	12651.1
1989	2	GBK	210790.2	57319.0	0.2719	10299.5	2800.7
1989	3	GBK	454241.8	129818.0	0.2858	8532.2	2438.4
1989	4	GBK	252775.0	97525.0	0.3858	11330.0	4371.3
1989	1	GOM	48544.0	16810.0	0.3463	6779.9	2347.8
1989	2	GOM	27026.8	4486.0	0.1660	4201.0	697.3
1989	3	GOM	50683.0	6507.0	0.1284	3824.7	491.0
1989	4	GOM	42992.8	8354.0	0.1943	7340.8	1426.4
1989	1	MA	203087.8	43259.0	0.2130	19939.2	4247.2
1989	2	MA	52984.0	1248.0	0.0236	4127.6	97.2
1989	3	MA	11208.1	5721.0	0.5104	6179.5	3154.2
1989	4	MA	109527.0	15869.0	0.1449	12396.1	1796.0
1989	1	SNE	80602.4	136040.0	1.6878	7660.9	12930.0
1989	2	SNE	64276.6	19099.0	0.2971	6365.3	1891.4
1989	3	SNE	20408.4	23176.0	1.1356	2033.9	2309.8
1989	4	SNE	157064.6	89395.0	0.5692	7514.9	4277.2
1990	1	GBK	169125.7	175388.0	1.0370	16371.4	16977.6
1990	2	GBK	200458.5	67116.0	0.3348	12978.9	4345.5
1990	3	GBK	140104.7	17486.0	0.1248	11239.0	1402.7
1990	4	GBK	198538.0	55702.0	0.2806	16617.9	4662.3
1990	1	GOM	1822.0	448.0	0.2459	5568.7	1369.3
1990	2	GOM	23842.0	3089.0	0.1296	6045.3	783.2
1990	3	GOM	27414.7	765.0	0.0279	7291.1	203.5
1990	4	GOM	75133.5	21051.0	0.2802	12997.3	3641.6
1990	1	MA	262107.9	37787.0	0.1442	16534.5	2383.7
1990	2	MA	18160.1	1863.0	0.1026	4986.0	511.5
1990	3	MA	11400.1	4375.0	0.3838	7225.0	2772.7
1990	4	MA	107716.6	45878.0	0.4259	15494.3	6599.2
1990	1	SNE	95622.5	246951.0	2.5826	9198.6	23755.8
1990	2	SNE	234679.7	18902.0	0.0805	4201.0	338.4
1990	3	SNE	24171.4	3174.0	0.1313	2545.7	334.3
1990	4	SNE	77514.8	141495.0	1.8254	8822.3	16104.1
1991	1	GBK	286394.1	98774.0	0.3449	16731.6	5770.5
1991	2	GBK	81042.4	32320.0	0.3988	12068.2	4812.8
1991	3	GBK	265911.0	19991.0	0.0752	9653.7	725.8
1991	4	GBK	321971.0	166273.0	0.5164	12115.9	6256.9
1991	1	GOM	29317.0	3598.0	0.1227	6247.8	766.8
1991	2	GOM	44616.2	1855.0	0.0416	6581.6	273.6
1991	3	GOM	31819.0	2640.0	0.0830	7495.0	621.9
1991	4	GOM	300163.0	25951.0	0.0865	12435.0	1075.1
1991	1	MA	638472.8	6016.0	0.0094	26490.5	249.6
1991	2	MA	19918.0	8849.0	0.4443	5490.1	2439.1
1991	3	MA	7639.0	12186.0	1.5952	8983.1	14330.0
1991	4	MA	1221565.0	255263.0	0.2090	15782.6	3298.0
1991	1	SNE	144929.0	102308.0	0.7059	9132.3	6446.7
1991	2	SNE	104618.7	47207.0	0.4512	4703.6	2122.4

Table 2 cont.

1991	3	SNE	76042.7	27575.0	0.3626	3685.5	1336.4
1991	4	SNE	269344.8	69244.0	0.2571	8602.9	2211.7
1992	1	GBK	211715.5	100398.0	0.4742	12897.5	6116.1
1992	2	GBK	127642.0	12823.0	0.1005	11609.2	1166.3
1992	3	GBK	109207.0	3158.0	0.0289	9223.0	266.7
1992	4	GBK	224868.0	38302.0	0.1703	11227.9	1912.5
1992	1	GOM	219231.0	22429.0	0.1023	6679.5	683.4
1992	2	GOM	51966.3	728.0	0.0140	6444.1	90.3
1992	3	GOM	42787.0	1023.0	0.0239	7549.5	180.5
1992	4	GOM	107219.0	5166.0	0.0482	10138.2	488.5
1992	1	MA	432338.9	47195.0	0.1092	27963.5	3052.6
1992	2	MA	3688.0	75.0	0.0203	7562.2	153.8
1992	3	MA	4008.1	850.0	0.2121	10730.1	2275.5
1992	4	MA	264680.4	161108.0	0.6087	16932.3	10306.5
1992	1	SNE	260659.6	6965.0	0.0267	9872.3	263.8
1992	2	SNE	25181.0	9938.0	0.3947	4122.2	1626.9
1992	3	SNE	157759.0	36466.0	0.2312	2338.8	540.6
1992	4	SNE	114864.2	67854.0	0.5907	6158.5	3638.0
1993	1	GBK	134660.8	15600.0	0.1158	9861.9	1142.5
1993	2	GBK	127030.0	32601.0	0.2566	9047.7	2322.0
1993	3	GBK	160014.0	3233.0	0.0202	9184.4	185.6
1993	4	GBK	79910.0	59777.0	0.7481	13966.0	10447.3
1993	1	GOM	36155.0	5288.0	0.1463	5540.6	810.4
1993	2	GOM	53969.0	2862.0	0.0530	4782.4	253.6
1993	3	GOM	18086.0	446.0	0.0247	5934.0	146.3
1993	4	GOM	69066.0	5482.0	0.0794	8854.3	702.8
1993	1	MA	292580.3	7047.0	0.0241	24397.6	587.6
1993	2	MA	871.0	39.0	0.0448	5242.9	234.8
1993	3	MA	4335.0	205.0	0.0473	12974.8	613.6
1993	4	MA	65343.2	29027.0	0.4442	13454.6	5976.8
1993	1	SNE	128829.0	7757.0	0.0602	6354.0	382.6
1993	2	SNE	22059.2	14224.0	0.6448	3506.2	2260.8
1993	3	SNE	43748.0	37881.0	0.8659	1693.1	1466.0
1993	4	SNE	280056.4	72207.0	0.2578	8737.8	2252.9
1994	1	GBK	436769.0	88920.0	0.2036	8945.5	1821.2
1994	2	GBK	72759.5	33874.0	0.4656	5641.3	2626.4
1994	3	GBK	46292.5	11055.0	0.2388	6584.7	1572.5
1994	4	GBK	35845.9	31958.0	0.8915	8935.1	7966.0
1994	1	GOM	24887.0	738.0	0.0297	5544.9	164.4
1994	2	GOM	3141.0	220.0	0.0700	4287.4	300.3
1994	3	GOM	14080.0	1000.0	0.0710	5197.5	369.1
1994	4	GOM	21317.4	554.0	0.0260	8638.0	224.5
1994	1	MA	381053.6	37798.0	0.0992	20620.1	2045.4
1994	2	MA	6763.5	36765.0	5.4358	9182.5	49914.0
1994	3	MA	23752.0	1130.0	0.0476	11546.8	549.3
1994	4	MA	138197.2	18468.6	0.1336	15207.5	2032.3
1994	1	SNE	294069.2	1267.0	0.0043	8344.8	36.0
1994	2	SNE	1871.0	4222.0	2.2565	3447.9	7780.2
1994	3	SNE	2871.0	204.0	0.0711	3812.2	270.9

Table 2 cont.

1994	4	SNE	47233.3	15154.0	0.3208	9931.6	3186.4
1995	1	GBK	398782.6	165691.7	0.4155	7122.9	2959.5
1995	2	GBK	100454.1	76175.0	0.7583	5439.9	4125.1
1995	3	GBK	42319.5	5071.0	0.1198	4323.4	518.1
1995	4	GBK	106802.9	25099.0	0.2350	6558.7	1541.3
1995	1	GOM	177529.2	8604.4	0.0485	5299.9	256.9
1995	2	GOM	37469.2	1324.0	0.0353	4249.4	150.2
1995	3	GOM	73591.3	818.2	0.0111	4344.0	48.3
1995	4	GOM	127430.2	3981.0	0.0312	6542.1	204.4
1995	1	MA	265025.8	167568.1	0.6323	17081.4	10800.0
1995	2	MA	38774.2	11692.0	0.3015	6733.4	2030.4
1995	3	MA	155938.2	16521.1	0.1059	9038.7	957.6
1995	4	MA	175000.0	96826.8	0.5533	12480.0	6905.1
1995	1	SNE	38708.1	3904.0	0.1009	8666.6	874.1
1995	2	SNE	4411.8	2159.0	0.4894	3399.2	1663.5
1995	3	SNE	9451.3	1015.0	0.1074	4432.9	476.1
1995	4	SNE	88329.5	12063.0	0.1366	7074.4	966.1
1996	1	GBK	184663.6	113637.0	0.6154	7858.4	4835.9
1996	2	GBK	117595.1	37819.0	0.3216	7171.7	2306.4
1996	3	GBK	0.0	0.0		6840.9	0.0
1996	4	GBK	209964.4	16941.0	0.0807	11369.5	917.3
1996	1	GOM	61714.6	2034.0	0.0330	4742.3	156.3
1996	2	GOM	69868.1	3330.0	0.0477	4379.7	208.7
1996	3	GOM	63234.1	6.2	0.0001	4269.6	0.4
1996	4	GOM	141362.8	4941.7	0.0350	7532.8	263.3
1996	1	MA	479520.5	107702.1	0.2246	24713.8	5550.8
1996	2	MA	264761.7	9485.0	0.0358	6571.0	235.4
1996	3	MA	965224.6	3855.3	0.0040	7059.7	28.2
1996	4	MA	944748.5	69812.6	0.0739	11609.4	857.9
1996	1	SNE	10668.2	1410.0	0.1322	7603.4	1004.9
1996	2	SNE	48753.8	14780.0	0.3032	4140.8	1255.3
1996	3	SNE	5599.4	11266.0	2.0120	3906.9	7860.7
1996	4	SNE	77863.0	112269.0	1.4419	10028.6	14460.1
1997	1	GBK	227488.1	54825.9	0.2410	7139.8	1720.7
1997	2	GBK	170456.4	34555.0	0.2186	6615.0	1446.1
1997	3	GBK	222203.6	32189.0	0.1449	4697.8	680.5
1997	4	GBK	61677.5	16650.0	0.2700	8173.5	2206.4
1997	1	GOM	95497.2	12207.0	0.1278	4563.5	583.3
1997	2	GOM	542.0	6.0	0.0111	3408.8	37.7
1997	3	GOM	16785.2	71.0	0.0042	2774.3	11.7
1997	4	GOM	37608.1	4094.7	0.0477	6084.7	290.3
1997	1	MA	565473.0	44438.5	0.0786	19625.7	1542.3
1997	2	MA	1007214.8	17920.1	0.0326	3915.8	127.6
1997	3	MA	2280771.0	6448.3	0.0028	11231.8	31.8
1997	4	MA	175400.4	2873.5	0.0164	16504.1	270.4
1997	1	SNE	107043.1	13335.0	0.1246	8470.6	1055.2
1997	2	SNE	19773.8	1151.0	0.0582	4338.8	252.6
1997	3	SNE	148705.0	78903.0	0.5306	4355.4	2311.0
1997	4	SNE	74102.4	3041.0	0.0410	8380.8	343.9

Table 2 cont.

1998	1	GBK	114649.0	19374.5	0.1690	9249.6	1563.1
1998	2	GBK	54096.1	17653.8	0.4888	6539.3	3196.5
1998	3	GBK	21141.4	3131.0	0.1481	6382.8	945.3
1998	4	GBK	26497.8	30456.0	1.1494	10561.3	12138.9
1998	1	GOM	20993.4	1933.0	0.0921	4942.6	455.1
1998	2	GOM	3021.6	71.0	0.0235	2594.6	61.0
1998	3	GOM	19.0	11.0	0.5789	2411.0	1395.9
1998	4	GOM	8011.3	671.7	0.2315	5630.4	1303.5
1998	1	MA	395451.2	20314.5	0.0514	23801.8	1222.7
1998	2	MA	733.3	1455.0	1.9842	9736.8	19319.3
1998	3	MA	348354.9	39500.0	0.1134	14521.9	1646.6
1998	4	MA	111097.6	12894.0	0.1161	10795.8	1253.0
1998	1	SNE	74163.6	5339.0	0.0720	10848.1	780.9
1998	2	SNE	507.4	93.0	0.1833	4171.6	764.6
1998	3	SNE	28215.2	1813.0	0.0643	4222.3	271.3
1998	4	SNE	11191.0	2065.0	0.1845	9238.2	1704.7
1999	1	GBK	89278.8	383.0	0.0043	11941.5	51.2
1999	2	GBK	70345.7	26052.0	0.3703	7255.9	2687.2
1999	3	GBK	41587.0	16863.0	0.4055	7114.1	2884.7
1999	4	GBK	126953.2	53410.0	0.4207	9847.4	4142.8
1999	1	GOM	27103.3	275.2	0.0229	3908.0	89.5
1999	2	GOM	454.9	9.0	0.0198	2124.4	42.0
1999	3	GOM	7163.2	300.5	0.0420	1932.4	81.1
1999	4	GOM	73691.8	516.1	0.0070	5311.1	37.2
1999	1	MA	1013097.0	10230.0	0.0101	17301.2	174.7
1999	2	MA	35400.0	4903.0	0.1385	4809.8	666.2
1999	3	MA	178663.2	1582.0	0.0089	7405.0	65.6
1999	4	MA	249211.4	27940.0	0.1121	13499.0	1513.4
1999	1	SNE	152117.7	918.0	0.0060	8584.7	51.8
1999	2	SNE	37805.6	297.0	0.0079	3448.9	27.1
1999	3	SNE	73651.9	1449.0	0.0383	3281.6	125.6
1999	4	SNE	31032.6	3132.0	0.1009	6597.4	665.8
2000	1	GBK	501596.7	61654.5	0.1229	13462.5	1654.8
2000	2	GBK	83110.4	24463.0	0.2943	6144.5	1808.6
2000	3	GBK	151326.8	29832.0	0.1971	5143.5	1014.0
2000	4	GBK	389648.5	211490.0	0.5428	11464.9	6222.8
2000	1	GOM	61838.6	9326.0	0.1508	4204.0	634.0
2000	2	GOM	75118.8	8142.0	0.1084	3622.9	392.7
2000	3	GOM	121344.3	1973.0	0.0163	3294.2	53.6
2000	4	GOM	88946.2	4701.0	0.0529	5555.4	293.6
2000	1	MA	1383068.8	54066.0	0.0391	15666.5	612.4
2000	2	MA	224847.0	27600.0	0.1228	4468.3	548.5
2000	3	MA	867161.0	9318.0	0.0107	8165.7	87.7
2000	4	MA	129964.5	57963.0	0.4460	11506.8	5131.9
2000	1	SNE	26945.5	2520.0	0.0935	6498.4	607.7
2000	2	SNE	27953.0	4273.0	0.1529	3743.4	572.2
2000	3	SNE	289.9	54.0	0.1863	4355.6	811.5
2000	4	SNE	50400.0	23473.0	0.4657	6211.3	2892.8
2001	1	GBK	502325.9	567152.5	1.1291	15645.4	17664.5

Table 2 cont.

2001	2	GBK	163268.7	23552.0	0.1443	7396.8	1067.0
2001	3	GBK	179922.9	29426.0	0.1635	6675.5	1091.8
2001	4	GBK	429590.9	132451.0	0.3083	15368.5	4738.4
2001	1	GOM	39995.0	2465.0	0.0616	4963.4	305.9
2001	2	GOM	87230.2	4889.0	0.0560	3651.8	204.7
2001	3	GOM	50757.2	3269.0	0.0644	2783.3	179.3
2001	4	GOM	271527.6	9978.0	0.0367	6863.4	252.2
2001	1	MA	3117272.2	13786.0	0.0044	12403.5	54.9
2001	2	MA	53707.4	3795.0	0.0707	3036.1	214.5
2001	3	MA	586146.4	7925.5	0.0135	4713.0	63.7
2001	4	MA	236560.3	14662.5	0.0620	9509.3	589.4
2001	1	SNE	118525.2	4803.0	0.0405	9405.5	381.1
2001	2	SNE	4475.0	1444.0	0.3227	3407.2	1099.5
2001	3	SNE	3995.0	456.0	0.1141	3987.4	455.1
2001	4	SNE	33110.6	7189.0	0.2171	4054.6	880.3
2002	1	GBK	285255.2	130977.0	0.4592	16750.6	7691.2
2002	2	GBK	321494.8	135567.5	0.4217	7098.2	2993.1
2002	3	GBK	853066.8	263641.2	0.3091	5735.8	1772.6
2002	4	GBK	1850673.9	534334.8	0.2887	11038.8	3187.2
2002	1	GOM	211295.9	6556.0	0.0310	6421.0	199.2
2002	2	GOM	16769.4	1546.0	0.0922	2186.5	201.6
2002	3	GOM	230292.9	16668.9	0.0724	3351.7	242.6
2002	4	GOM	292352.7	27891.6	0.0954	5858.3	558.9
2002	1	MA	636320.1	41276.0	0.0649	10552.9	684.5
2002	2	MA	14028.4	1118.5	0.0797	2976.1	237.3
2002	3	MA	217428.1	12693.0	0.0584	5233.4	305.5
2002	4	MA	88761.5	19159.0	0.2158	9490.7	2048.5
2002	1	SNE	36892.0	3.0	0.0001	6232.9	0.5
2002	2	SNE	30767.5	1388.0	0.0451	2814.1	126.9
2002	3	SNE	2765.5	224.0	0.0810	2226.0	180.3
2002	4	SNE	36505.7	12143.0	0.3326	3566.9	1186.5
2003	1	GBK	2025154.8	1165520.9	0.5755	14506.5	8348.8
2003	2	GBK	913155.6	287681.7	0.3150	8159.6	2570.6
2003	3	GBK	764077.2	360934.0	0.4724	6512.7	3076.5
2003	4	GBK	1488066.9	671086.7	0.4510	13722.5	6188.6
2003	1	GOM	816958.4	62916.9	0.0770	7344.1	565.6
2003	2	GOM	296503.7	23768.3	0.0802	2477.7	198.6
2003	3	GOM	206323.8	17607.8	0.0853	2939.0	250.8
2003	4	GOM	491413.8	27891.4	0.0568	5860.4	332.6
2003	1	MA	264353.0	49131.7	0.1859	12727.0	2365.4
2003	2	MA	44843.7	7188.0	0.1603	2450.4	392.8
2003	3	MA	2116191.0	10965.9	0.0052	3789.2	19.6
2003	4	MA	805656.0	84646.5	0.1051	8999.7	945.6
2003	1	SNE	66694.2	47740.5	0.7158	4730.9	3386.5
2003	2	SNE	24570.5	864.0	0.0352	1580.9	55.6
2003	3	SNE	2574.3	5833.5	2.2660	1960.4	4442.3
2003	4	SNE	71582.1	24892.0	0.3477	6158.4	2141.5
2004	1	GBK	1906366.7	850612.0	0.4462	13896.7	6200.6
2004	2	GBK	1196759.3	679946.0	0.5682	7900.6	4488.8

Table 2 cont.

2004	3	GBK	1310535.8	812051.2	0.6196	9243.2	5727.4
2004	4	GBK	2329145.1	1308189.5	0.5617	11898.2	6682.7
2004	1	GOM	663041.1	32656.5	0.0493	5842.7	287.8
2004	2	GOM	111970.8	13358.7	0.1193	4420.4	527.4
2004	3	GOM	140897.7	5950.6	0.0422	8207.7	346.6
2004	4	GOM	789168.0	93840.7	0.1189	9043.0	1075.3
2004	1	MA	1315546.7	84251.6	0.0640	13442.2	860.9
2004	2	MA	309818.9	24332.0	0.0785	10123.4	795.1
2004	3	MA	1688970.5	38723.0	0.0229	16252.8	372.6
2004	4	MA	2167080.6	96405.2	0.0445	14202.6	631.8
2004	1	SNE	163708.3	18157.0	0.1109	6955.0	771.4
2004	2	SNE	103306.4	17879.5	0.1731	2524.4	436.9
2004	3	SNE	39012.3	28424.5	0.7286	2811.4	2048.4
2004	4	SNE	111008.8	96013.5	0.8649	5290.5	4575.9
2005	1	GBK	7807344.5	4202547.8	0.5383	9767.2	5257.5
2005	2	GBK	4814352.4	2749110.2	0.5710	6521.3	3723.8
2005	3	GBK	2242281.5	1610769.3	0.7184	5950.3	4274.5
2005	4	GBK	5070013.8	3456805.2	0.6818	10262.1	6996.8
2005	1	GOM	1460432.0	86059.9	0.0589	5309.4	312.9
2005	2	GOM	366527.9	22120.3	0.0604	2874.2	173.5
2005	3	GOM	363672.6	24488.2	0.0673	4164.6	280.4
2005	4	GOM	905399.7	157153.5	0.1736	7443.5	1292.0
2005	1	MA	1406306.4	63760.8	0.0453	16560.4	750.8
2005	2	MA	150171.1	49163.0	0.3274	4843.3	1585.6
2005	3	MA	293991.1	45674.3	0.1554	7761.4	1205.8
2005	4	MA	1050916.6	115930.0	0.1103	10842.3	1196.0
2005	1	SNE	575564.0	96978.0	0.1685	5434.7	915.7
2005	2	SNE	59569.3	56647.1	0.9509	1451.7	1380.5
2005	3	SNE	167366.8	105007.1	0.6274	1783.4	1118.9
2005	4	SNE	279194.2	181264.2	0.6492	3996.5	2594.7
2006	1	GBK	3424697.6	2457176.4	0.7175	7699.6	5524.4
2006	2	GBK	1622453.8	731960.0	0.4511	4057.1	1830.3
2006	3	GBK	1933865.4	1412239.9	0.7303	4459.1	3256.3
2006	4	GBK	1578415.8	1128798.5	0.7151	7837.4	5604.9
2006	1	GOM	711124.0	75375.0	0.1060	4452.7	472.0
2006	2	GOM	19006.0	3383.0	0.1780	1211.8	215.7
2006	3	GOM	92619.0	7354.8	0.0794	2978.2	236.5
2006	4	GOM	198574.3	15191.4	0.0765	3213.8	245.9
2006	1	MA	1871943.9	62970.2	0.0336	32892.0	1106.5
2006	2	MA	1647404.2	59383.5	0.0360	4259.7	153.5
2006	3	MA	1991620.9	40898.7	0.0205	9085.0	186.6
2006	4	MA	1096588.4	87026.7	0.0794	13777.2	1093.4
2006	1	SNE	860190.4	149848.5	0.1742	6488.1	1130.2
2006	2	SNE	87581.6	6228.5	0.0711	1913.9	136.1
2006	3	SNE	85786.2	23498.0	0.2739	2553.5	699.4
2006	4	SNE	227163.2	52487.5	0.2311	3750.6	866.6
2007	1	GBK	2716869.7	1847037.5	0.6798	10413.1	7079.3
2007	2	GBK	2002073.1	1113493.0	0.5562	5199.6	2891.8
2007	3	GBK	1385278.3	1471099.1	1.0620	4478.8	4756.3

Table 2 cont.

2007	4	GBK	3181301.6	2050467.9	0.6445	9427.9	6076.6
2007	1	GOM	732365.3	112054.9	0.1530	4161.4	636.7
2007	2	GOM	290266.9	17910.3	0.0617	1546.3	95.4
2007	3	GOM	358148.5	10986.0	0.0307	2091.2	64.1
2007	4	GOM	611896.9	49552.7	0.0810	3220.8	260.8
2007	1	MA	962031.0	104525.7	0.1087	11354.0	1233.6
2007	2	MA	93576.9	51220.5	0.5474	1957.8	1071.6
2007	3	MA	1939160.2	97902.8	0.0505	4913.8	248.1
2007	4	MA	1735005.5	369938.7	0.2132	10653.6	2271.6
2007	1	SNE	564348.9	100567.6	0.1782	5368.0	956.6
2007	2	SNE	102264.1	42452.0	0.4151	1569.1	651.3
2007	3	SNE	260652.2	124886.5	0.4791	2211.9	1059.8
2007	4	SNE	251575.7	96107.7	0.3820	4593.7	1754.9

Table 3. Discard estimates by stratum for the shrimp trawl fishery.

average within areaf across mesh | average across comb region (ie sne-ma) | Average 1995-2007

YEAR	QTR	areaf	kept	discards	dkratio	mt kept	Total discards
1989	1	GBK	761.0	0.0	0.0000		0.0000
1989	1	GOM	37722.0	763.0	0.0202	3213.4194	64.9976
1989	2	GOM	8980.0	380.0	0.0423	198.7805	8.4117
1989	4	GOM	12558.0	227.0	0.0181	931.1231	16.8311
1990	1	GBK	17384.3	917.7	0.0582	16.6527	0.9694
1990	2	GBK	17384.3	917.7	0.0582	37.1733	2.1640
1990	1	GOM	37744.0	1877.0	0.0497	4014.9878	199.6644
1990	2	GOM	7437.0	82.0	0.0110	478.8901	5.2802
1990	4	GOM	6972.0	794.0	0.1139	619.7042	70.5745
1991	1	GBK	691.0	200.0	0.2894	51.3303	14.8568
1991	1	GOM	54049.0	3704.0	0.0685	3144.6289	215.5025
1991	2	GOM	8673.0	330.0	0.0380	339.8328	12.9303
1991	4	GOM	6233.0	807.0	0.1295	340.0274	44.0241
1992	1	GBK	27845.0	2040.7	0.0263	49.5051	1.3012
1992	1	GOM	78834.0	6117.0	0.0776	3137.5987	243.4570
1992	2	GOM	725.0	0.0	0.0000	98.3130	0.0000
1992	4	GOM	3976.0	5.0	0.0013	161.2525	0.2028
1993	1	GBK	2300.0	0.0	0.0000		0.0000
1993	1	GOM	62135.0	1145.0	0.0184	1885.0247	34.7365
1993	2	GOM	33122.5	579.5	0.0109	5.0068	0.0547
1993	4	GOM	4110.0	14.0	0.0034	316.2319	1.0772
1994	1	GBK	41229.5	168.5	0.0027	23.0974	0.0618
1994	4	GBK	41229.5	168.5	0.0027	0.0454	0.0001
1994	1	GOM	72823.0	329.0	0.0045	2419.8023	10.9322
1994	3	GOM	41229.5	168.5	0.0027	9.1372	0.0244
1994	4	GOM	9636.0	8.0	0.0008	897.0524	0.7448
1995	1	GBK	48706.0	67.9	0.0010	22.2133	0.0233
1995	4	GBK	48706.0	67.9	0.0010	5.4626	0.0057
1995	1	GOM	74054.0	126.8	0.0017	4426.6070	7.5795
1995	2	GOM	48706.0	67.9	0.0010	5.4390	0.0057
1995	3	GOM	48706.0	67.9	0.0010	12.4094	0.0130
1995	4	GOM	23358.0	9.0	0.0004	1359.4640	0.5238
1996	1	GBK	15813.3	53.7	0.0032	42.2716	0.1340
1996	1	GOM	32304.0	128.7	0.0040	6560.2339	26.1361
1996	2	GOM	9342.0	0.7	0.0001	979.4293	0.0734
1996	4	GOM	5794.0	31.6	0.0055	1416.1748	7.7237
1997	1	GBK	1590.0	1.0	0.0006	24.8224	0.0156
1997	4	GBK	10800.0	63.5	0.0035	3.0699	0.0106
1997	1	GOM	20010.0	125.9	0.0063	4761.5655	29.9591
1997	2	GOM	10800.0	63.5	0.0035	629.2601	2.1775
1997	3	GOM	10800.0	63.5	0.0035	15.0107	0.0519
1997	4	GOM	10800.0	63.5	0.0035	630.9021	2.1832
1998	1	GOM	26486.6	53.8	0.0026	2875.1596	7.4407
1998	2	GOM	26486.6	53.8	0.0026	219.7514	0.5687
1998	3	GOM	26486.6	53.8	0.0026	9.0877	0.0235

Table 3 cont.

1998	4	GOM	26486.6	53.8	0.0026	159.0295	0.4116
1999	1	GBK	26486.6	53.8	0.0026	12.9020	0.0334
1999	1	GOM	26486.6	53.8	0.0026	1177.4074	3.0470
1999	2	GOM	26486.6	53.8	0.0026	229.1803	0.5931
1999	3	GOM	26486.6	53.8	0.0026	32.2999	0.0836
1999	4	GOM	26486.6	53.8	0.0026	0.9453	0.0024
2000	1	GOM	26486.6	53.8	0.0026	2067.9439	5.3517
2000	3	GOM	26486.6	53.8	0.0026	22.0582	0.0571
2000	4	GOM	26486.6	53.8	0.0026	12.6198	0.0327
2001	1	GBK	26486.6	53.8	0.0026	0.2155	0.0006
2001	1	GOM	4950.0	0.0	0.0000	812.8656	0.0000
2001	2	GOM	26486.6	53.8	0.0026	0.0408	0.0001
2002	1	GOM	26486.6	53.8	0.0026	307.5170	0.7958
2003	1	GOM	14519.3	135.6	0.0093	855.2058	7.9870
2003	2	GOM	26486.6	53.8	0.0026	0.2572	0.0007
2004	1	GBK	21444.0	84.7	0.0039	0.2132	0.0008
2004	1	GOM	21444.0	84.7	0.0039	1065.2263	4.2075
2004	2	GOM	21444.0	84.7	0.0039	3.5045	0.0138
2004	3	GOM	21444.0	84.7	0.0039	1.8715	0.0074
2004	4	GOM	21444.0	84.7	0.0039	42.6259	0.1684
2005	1	GOM	27219.2	78.8	0.0029	835.6192	2.4191
2005	4	GOM	27219.2	78.8	0.0029	39.6508	0.1148
2006	4	GBK	43012.6	12.1	0.0007	1.6806	0.0012
2006	1	GOM	77625.1	14.1	0.0002	846.9831	0.1538
2006	3	GOM	43012.6	12.1	0.0007	1.4678	0.0010
2006	4	GOM	8400.0	10.1	0.0012	445.9153	0.5362
2007	2	GBK	50203.0	6.6	0.0001	26.7878	0.0035
2007	3	GBK	50203.0	6.6	0.0001	17.6080	0.0023
2007	4	GBK	50203.0	6.6	0.0001	1.8538	0.0002
2007	1	GOM	50203.0	6.6	0.0001	1828.3506	0.2404
2007	2	GOM	50203.0	6.6	0.0001	40.7557	0.0054
2007	3	GOM	50203.0	6.6	0.0001	57.4321	0.0076
2007	4	GOM	50203.0	6.6	0.0001	281.7607	0.0370

Table 4. Discard estimates by stratum for the sink gill net fishery.

average within areaf average across comb region (ie sne-ma)

YEAR	QTR	areaf	ksums	dsums	dkratio	cf_totalmt	disc
1989	1	GBK	22453.7	245.0	0.0084	586.7	5.0
1989	2	GBK	3410.0	11.0	0.0032	1039.2	3.4
1989	3	GBK	30690.0	140.0	0.0046	2108.0	9.6
1989	4	GBK	33261.1	584.0	0.0176	1194.9	21.0
1989	1	GOM	98651.0	716.5	0.0055	2085.5	11.5
1989	2	GOM	98651.0	716.5	0.0055	3209.8	17.7
1989	3	GOM	13516.0	47.0	0.0035	4023.2	14.0
1989	4	GOM	183786.0	1386.0	0.0075	6232.1	47.0
1989	1	MA	106.3	0.0	0.0000	1079.2	0.0
1989	2	MA	106.3	0.0	0.0000	769.4	0.0
1989	3	MA	106.3	0.0	0.0000	820.8	0.0
1989	4	MA	106.3	0.0	0.0000	1222.8	0.0
1989	1	SNE	106.3	0.0	0.0000	324.1	0.0
1989	2	SNE	106.3	0.0	0.0000	38.1	0.0
1989	3	SNE	106.3	0.0	0.0000	83.9	0.0
1989	4	SNE	106.3	0.0	0.0000	264.0	0.0
1990	1	GBK	4037.0	58.0	0.0144	306.3	4.4
1990	2	GBK	8856.0	119.0	0.0134	1017.9	13.7
1990	3	GBK	104237.1	29.0	0.0003	1598.3	0.4
1990	4	GBK	59828.1	122.0	0.0020	869.0	1.8
1990	1	GOM	31339.0	3354.0	0.1070	1775.3	190.0
1990	2	GOM	23717.0	1114.0	0.0470	2967.6	139.4
1990	3	GOM	94015.6	323.0	0.0034	6385.8	21.9
1990	4	GOM	72931.2	655.0	0.0090	5447.0	48.9
1990	1	MA	2261.4	0.0	0.0000	1180.8	0.0
1990	2	MA	255.7	0.0	0.0000	541.7	0.0
1990	3	MA	2261.4	0.0	0.0000	670.5	0.0
1990	4	MA	4267.1	0.0	0.0000	1384.0	0.0
1990	1	SNE	1138.4	0.0	0.0000	363.8	0.0
1990	2	SNE	1138.4	0.0	0.0000	1060.2	0.0
1990	3	SNE	1138.4	0.0	0.0000	238.4	0.0
1990	4	SNE	1138.4	0.0	0.0000	1155.4	0.0
1991	1	GBK	6139.0	32.0	0.0052	166.8	0.9
1991	2	GBK	100725.3	730.0	0.0072	833.0	6.0
1991	3	GBK	221500.1	4243.0	0.0192	1248.6	23.9
1991	4	GBK	78760.0	3517.0	0.0447	539.7	24.1
1991	1	GOM	21516.0	882.0	0.0410	1258.5	51.6
1991	2	GOM	338493.2	4779.0	0.0141	2867.9	40.5
1991	3	GOM	1032744.5	8763.0	0.0085	4929.0	41.8
1991	4	GOM	576265.9	3962.0	0.0069	3354.7	23.1
1991	1	MA	1947.7	0.0	0.0000	1441.7	0.0
1991	2	MA	3226.6	0.0	0.0000	1042.6	0.0
1991	3	MA	2587.1	0.0	0.0000	894.0	0.0
1991	4	MA	2587.1	0.0	0.0000	2591.0	0.0
1991	1	SNE	657.0	0.0	0.0000	1954.6	0.0
1991	2	SNE	657.0	0.0	0.0000	1629.6	0.0
1991	3	SNE	1057.0	0.0	0.0000	110.3	0.0

Table 4 cont.

1991	4	SNE	257.0	0.0	0.0000	2105.3	0.0
1992	1	GBK	8797.0	466.0	0.0530	119.9	6.4
1992	2	GBK	64292.0	805.0	0.0125	582.4	7.3
1992	3	GBK	257302.9	558.0	0.0022	1262.9	2.7
1992	4	GBK	26579.0	1041.0	0.0392	480.8	18.8
1992	1	GOM	83433.0	8691.0	0.1042	1018.6	106.1
1992	2	GOM	327513.2	5495.0	0.0168	2507.2	42.1
1992	3	GOM	619171.0	2005.0	0.0032	5062.0	16.4
1992	4	GOM	422764.0	1933.0	0.0046	3928.4	18.0
1992	1	MA	159421.1	0.0	0.0000	1552.6	0.0
1992	2	MA	159421.1	0.0	0.0000	1284.1	0.0
1992	3	MA	159421.1	0.0	0.0000	855.9	0.0
1992	4	MA	159421.1	0.0	0.0000	2243.4	0.0
1992	1	SNE	24339.0	381.0	0.0157	994.4	15.6
1992	2	SNE	158927.0	8499.0	0.0535	1717.9	91.9
1992	3	SNE	12277.0	824.0	0.0671	63.8	4.3
1992	4	SNE	116631.4	2077.0	0.0178	2636.8	47.0
1993	1	GBK	10907.0	190.0	0.0174	134.9	2.4
1993	2	GBK	35533.1	177.0	0.0050	604.0	3.0
1993	3	GBK	184496.5	419.0	0.0023	994.0	2.3
1993	4	GBK	79788.8	1556.0	0.0195	1368.6	26.7
1993	1	GOM	65333.1	3277.0	0.0502	1164.5	58.4
1993	2	GOM	195803.4	3330.0	0.0170	3220.8	54.8
1993	3	GOM	220513.3	474.0	0.0021	6614.9	14.2
1993	4	GOM	322639.1	1296.0	0.0040	5316.5	21.4
1993	1	MA	88819.2	0.0	0.0000	2446.1	0.0
1993	2	MA	39302.1	19.0	0.0007	1684.6	1.2
1993	3	MA	1798.0	0.0	0.0000	1248.5	0.0
1993	4	MA	27289.0	57.0	0.0021	3380.6	7.1
1993	1	SNE	17184.0	759.0	0.0442	491.1	21.7
1993	2	SNE	66155.0	2719.0	0.0411	1719.1	70.7
1993	3	SNE	7014.0	1190.0	0.1697	135.3	23.0
1993	4	SNE	116496.0	1243.0	0.0107	1419.2	15.1
1994	1	GBK	11743.0	78.0	0.0066	117.4	0.8
1994	2	GBK	50530.1	0.0	0.0000	803.0	0.0
1994	3	GBK	102328.1	7.0	0.0001	1897.1	0.1
1994	4	GBK	32304.7	501.0	0.0155	1330.6	20.6
1994	1	GOM	12656.0	1302.0	0.1029	1172.1	120.6
1994	2	GOM	9843.3	30.0	0.0030	2806.3	8.6
1994	3	GOM	47074.7	24.0	0.0005	6382.9	3.3
1994	4	GOM	64128.1	814.0	0.0127	3814.1	48.4
1994	1	MA	424842.9	2959.0	0.0070	2214.1	15.4
1994	2	MA	62247.1	206.0	0.0033	1410.4	4.7
1994	3	MA	46100.8	31.0	0.0007	1614.0	1.1
1994	4	MA	290493.6	3790.5	0.0130	3221.9	42.0
1994	1	SNE	15407.0	216.0	0.0140	653.6	9.2
1994	2	SNE	1780.0	122.0	0.0685	1542.2	105.7
1994	3	SNE	39030.0	2901.7	0.0554	282.8	15.7
1994	4	SNE	99903.1	8367.0	0.0838	1085.2	90.9

Table 4 cont.

1995	1	GBK	5379.6	165.0	0.0307	239.6	7.3
1995	2	GBK	107372.2	350.0	0.0033	1658.3	5.4
1995	3	GBK	154650.9	432.0	0.0028	1825.6	5.1
1995	4	GBK	44697.3	597.0	0.0134	1793.9	24.0
1995	1	GOM	16330.9	1583.1	0.0969	1365.0	132.3
1995	2	GOM	29104.0	532.5	0.0183	3486.5	63.8
1995	3	GOM	80281.6	216.0	0.0027	6267.8	16.9
1995	4	GOM	39633.4	1990.0	0.0502	4241.2	213.0
1995	1	MA	755815.3	10447.5	0.0138	2503.3	34.6
1995	2	MA	125150.4	1229.0	0.0098	1809.5	17.8
1995	3	MA	52056.3	216.0	0.0041	847.1	3.5
1995	4	MA	262332.0	3379.3	0.0129	3991.1	51.4
1995	1	SNE	8833.0	678.0	0.0768	595.0	45.7
1995	2	SNE	31651.4	1999.0	0.0632	2150.8	135.8
1995	3	SNE	3936.0	447.0	0.1136	172.4	19.6
1995	4	SNE	33918.5	468.0	0.0138	1204.2	16.6
1996	1	GBK	10373.0	365.0	0.0352	200.0	7.0
1996	2	GBK	25715.0	64.0	0.0025	1371.7	3.4
1996	3	GBK	112924.3	861.0	0.0076	1572.6	12.0
1996	4	GBK	33751.5	361.1	0.0107	1875.5	20.1
1996	1	GOM	22662.2	4893.8	0.2159	1081.5	233.6
1996	2	GOM	15555.1	266.0	0.0171	2323.0	39.7
1996	3	GOM	32440.7	140.0	0.0043	6154.5	26.6
1996	4	GOM	75904.3	111.9	0.0015	4372.9	6.4
1996	1	MA	800368.3	12530.5	0.0157	5261.4	82.4
1996	2	MA	148496.3	1423.4	0.0096	3097.0	29.7
1996	3	MA	42831.4	280.0	0.0065	1745.6	11.4
1996	4	MA	214088.6	1649.0	0.0077	5262.4	40.5
1996	1	SNE	18515.5	75.0	0.0041	386.4	1.6
1996	2	SNE	9094.5	116.0	0.0128	1681.4	21.4
1996	3	SNE	1277.3	0.0	0.0000	216.0	0.0
1996	4	SNE	1110.9	15.0	0.0135	1044.4	14.1
1997	1	GBK	20931.9	102.0	0.0049	428.3	2.1
1997	2	GBK	5213.2	44.0	0.0084	1641.7	13.9
1997	3	GBK	5882.0	3.0	0.0005	1166.1	0.6
1997	4	GBK	7335.2	59.0	0.0080	978.7	7.9
1997	1	GOM	4971.0	236.7	0.0476	1335.0	63.6
1997	2	GOM	25021.5	311.7	0.0125	2471.6	30.8
1997	3	GOM	29352.1	3.0	0.0001	4699.3	0.5
1997	4	GOM	44359.9	78.6	0.0018	3821.1	6.8
1997	1	MA	711796.5	13753.7	0.0193	7893.1	152.5
1997	2	MA	138710.4	6381.0	0.0460	2791.0	128.4
1997	3	MA	54975.6	11.0	0.0002	1862.2	0.4
1997	4	MA	176529.4	1573.0	0.0089	5587.1	49.8
1997	1	SNE	22081.1	47.5	0.0022	398.9	0.9
1997	2	SNE	7321.8	0.0	0.0000	1130.0	0.0
1997	3	SNE	3082.4	94.0	0.0305	160.5	4.9
1997	4	SNE	22597.5	470.0	0.0208	989.9	20.6
1998	1	GBK	13254.0	289.0	0.0218	428.2	9.3

Table 4 cont.

1998	2	GBK	13539.2	21.0	0.0016	1012.1	1.6
1998	3	GBK	103634.0	2259.0	0.0218	783.5	17.1
1998	4	GBK	81759.1	317.4	0.0039	1880.9	7.3
1998	1	GOM	8246.3	173.1	0.0210	1544.7	32.4
1998	2	GOM	65996.6	216.0	0.0033	2135.8	7.0
1998	3	GOM	49801.2	34.0	0.0007	5544.6	3.8
1998	4	GOM	193863.8	1266.7	0.0065	4330.9	28.3
1998	1	MA	748403.1	6338.5	0.0085	7460.2	63.2
1998	2	MA	76002.7	1863.0	0.0245	3902.1	95.6
1998	3	MA	2258.0	64.0	0.0283	1692.5	48.0
1998	4	MA	77028.3	1279.1	0.0166	7274.9	120.8
1998	1	SNE	1614.1	3.0	0.0019	408.4	0.8
1998	2	SNE	20995.3	120.0	0.0057	1211.2	6.9
1998	3	SNE	19049.8	229.0	0.0080	162.2	1.3
1998	4	SNE	34540.0	563.9	0.0163	1486.6	24.3
1999	1	GBK	17467.9	1572.2	0.0900	605.4	54.5
1999	2	GBK	41630.0	126.0	0.0030	1612.3	4.9
1999	3	GBK	58207.3	189.0	0.0032	1217.7	4.0
1999	4	GBK	28471.6	114.0	0.0040	1695.2	6.8
1999	1	GOM	22623.7	188.7	0.0083	1176.5	9.8
1999	2	GOM	33414.6	507.9	0.0152	1910.8	29.0
1999	3	GOM	94138.0	271.1	0.0029	2414.2	7.0
1999	4	GOM	176380.0	6468.1	0.0367	2529.0	92.7
1999	1	MA	63037.4	1342.0	0.0213	8640.0	183.9
1999	2	MA	18830.8	1496.5	0.0795	3584.5	284.9
1999	3	MA	5370.5	0.0	0.0000	1480.7	0.0
1999	4	MA	25202.0	383.5	0.0152	4889.5	74.4
1999	1	SNE	8739.8	122.0	0.0140	885.0	12.4
1999	2	SNE	8818.0	119.0	0.0135	1406.2	19.0
1999	3	SNE	7389.7	169.0	0.0284	338.3	9.6
1999	4	SNE	4611.2	266.0	0.0577	973.9	56.2
2000	1	GBK	21170.1	331.8	0.0157	709.6	11.1
2000	2	GBK	17915.7	683.3	0.0381	976.1	37.2
2000	3	GBK	19154.2	9308.0	0.4860	1119.1	543.8
2000	4	GBK	51549.7	4942.1	0.0959	1504.5	144.2
2000	1	GOM	23536.8	341.9	0.0145	1103.9	16.0
2000	2	GOM	30212.8	957.8	0.0317	1776.8	56.3
2000	3	GOM	34168.9	242.6	0.0071	2376.4	16.9
2000	4	GOM	38219.2	446.7	0.0117	2964.0	34.6
2000	1	MA	49061.9	16.0	0.0003	6565.2	2.1
2000	2	MA	15007.2	79.0	0.0053	2654.3	14.0
2000	3	MA	12557.5	0.0	0.0000	1958.7	0.0
2000	4	MA	62224.3	533.0	0.0086	4986.7	42.7
2000	1	SNE	9597.0	222.0	0.0231	918.0	21.2
2000	2	SNE	22779.3	738.0	0.0324	697.5	22.6
2000	3	SNE	13675.7	355.3	0.0226	100.6	2.3
2000	4	SNE	8650.7	106.0	0.0123	579.9	7.1
2001	1	GBK	23497.4	1354.3	0.0576	875.6	50.5
2001	2	GBK	20554.2	380.0	0.0185	953.7	17.6

Table 4 cont.

2001	3	GBK	8626.2	81.0	0.0094	1118.3	10.5
2001	4	GBK	21143.6	1650.0	0.0780	1180.4	92.1
2001	1	GOM	4458.5	88.0	0.0197	913.8	18.0
2001	2	GOM	24667.5	1391.0	0.0564	1802.7	101.7
2001	3	GOM	27845.6	314.0	0.0113	2129.1	24.0
2001	4	GOM	15130.2	145.5	0.0096	2701.6	26.0
2001	1	MA	73646.7	287.0	0.0039	4166.3	16.2
2001	2	MA	26561.1	168.9	0.0064	2656.1	16.9
2001	3	MA	4520.2	0.0	0.0000	1374.3	0.0
2001	4	MA	27136.9	143.0	0.0053	5366.6	28.3
2001	1	SNE	3451.0	0.0	0.0000	296.6	0.0
2001	2	SNE	4886.0	896.0	0.1834	992.5	182.0
2001	3	SNE	55.0	0.0	0.0000	162.7	0.0
2001	4	SNE	5146.0	82.0	0.0159	1455.3	23.2
2002	1	GBK	9228.4	308.0	0.0334	960.7	32.1
2002	2	GBK	32100.7	3809.0	0.1187	691.9	82.1
2002	3	GBK	10484.5	235.0	0.0224	986.8	22.1
2002	4	GBK	23319.1	701.4	0.0301	1696.6	51.0
2002	1	GOM	34205.3	55.0	0.0016	1337.1	2.2
2002	2	GOM	27988.8	441.1	0.0158	1198.4	18.9
2002	3	GOM	21374.4	1106.5	0.0518	1789.4	92.6
2002	4	GOM	45843.6	611.0	0.0133	2488.4	33.2
2002	1	MA	37080.4	1069.0	0.0288	4219.3	121.6
2002	2	MA	5868.0	90.0	0.0153	2569.0	39.4
2002	3	MA	2315.9	0.0	0.0000	1376.1	0.0
2002	4	MA	29532.6	95.0	0.0032	4375.4	14.1
2002	1	SNE	10840.5	381.0	0.0351	1141.9	40.1
2002	2	SNE	9468.0	428.0	0.0452	1186.8	53.6
2002	3	SNE	963.0	20.0	0.0208	169.1	3.5
2002	4	SNE	6070.0	10329.0	1.7016	1307.3	2224.5
2003	1	GBK	4577.5	1311.1	0.2864	652.0	186.8
2003	2	GBK	43470.1	818.8	0.0188	356.4	6.7
2003	3	GBK	88411.1	3181.0	0.0360	1988.6	71.5
2003	4	GBK	177024.0	3756.3	0.0212	1881.1	39.9
2003	1	GOM	16371.3	481.0	0.0294	1262.1	37.1
2003	2	GOM	88920.5	1586.0	0.0178	1282.3	22.9
2003	3	GOM	140135.5	1562.9	0.0112	1866.6	20.8
2003	4	GOM	169528.6	1429.1	0.0084	2504.9	21.1
2003	1	MA	19277.5	483.0	0.0251	3761.1	94.2
2003	2	MA	22960.6	85.5	0.0037	3871.1	14.4
2003	3	MA	15101.8	0.0	0.0000	1356.5	0.0
2003	4	MA	27781.5	671.0	0.0242	4402.7	106.3
2003	1	SNE	21451.2	1487.0	0.0693	1023.0	70.9
2003	2	SNE	95480.1	4352.0	0.0456	1948.2	88.8
2003	3	SNE	28536.0	1581.1	0.0554	317.6	17.6
2003	4	SNE	135270.5	13896.6	0.1027	1608.6	165.3
2004	1	GBK	81315.1	5199.0	0.0639	3067.2	196.1
2004	2	GBK	129247.6	2860.5	0.0221	822.7	18.2
2004	3	GBK	374557.7	17328.5	0.0463	1744.6	80.7

Table 4 cont.

2004	4	GBK	270667.2	18566.0	0.0686	868.8	59.6
2004	1	GOM	85320.3	2177.7	0.0255	1491.0	38.1
2004	2	GOM	50461.3	907.2	0.0180	927.6	16.7
2004	3	GOM	383048.0	3395.8	0.0089	1855.8	16.5
2004	4	GOM	702958.2	14946.0	0.0213	2891.6	61.5
2004	1	MA	3046.2	0.0	0.0000	4538.0	0.0
2004	2	MA	3174.0	0.0	0.0000	1957.1	0.0
2004	3	MA	24512.5	1109.5	0.0165	1198.8	19.8
2004	4	MA	67317.3	3328.4	0.0494	3915.3	193.6
2004	1	SNE	207015.0	7432.5	0.0359	3361.1	120.7
2004	2	SNE	145289.2	6361.6	0.0438	1347.6	59.0
2004	3	SNE	3084.4	77.5	0.0251	131.5	3.3
2004	4	SNE	76143.0	4066.9	0.0534	579.3	30.9
2005	1	GBK	23149.2	17751.8	0.7668	395.2	303.0
2005	2	GBK	8228.8	56.0	0.0068	326.5	2.2
2005	3	GBK	387916.7	17402.0	0.0449	1476.1	66.2
2005	4	GBK	260812.3	30642.3	0.1175	816.7	96.0
2005	1	GOM	78700.7	3997.6	0.0508	1268.2	64.4
2005	2	GOM	39841.1	1358.5	0.0341	857.1	29.2
2005	3	GOM	473344.6	4407.0	0.0093	2259.6	21.0
2005	4	GOM	721567.1	5408.5	0.0075	2766.7	20.7
2005	1	MA	22404.2	555.0	0.0248	5461.8	135.3
2005	2	MA	163104.8	17011.0	0.1043	2885.5	300.9
2005	3	MA	9684.2	366.0	0.0378	1627.0	61.5
2005	4	MA	58178.3	3033.5	0.0521	4218.2	219.9
2005	1	SNE	28835.0	1689.0	0.0586	779.4	45.7
2005	2	SNE	85795.2	7663.3	0.0893	1700.7	151.9
2005	3	SNE	74307.2	7851.0	0.1057	357.9	37.8
2005	4	SNE	104448.1	6386.0	0.0611	569.0	34.8
2006	1	GBK	44571.9	1004.2	0.0225	505.5	11.4
2006	2	GBK	3979.8	911.0	0.2289	427.2	97.8
2006	3	GBK	96432.4	5581.0	0.0579	2044.7	118.3
2006	4	GBK	90164.1	8982.2	0.0996	1449.4	144.4
2006	1	GOM	82164.8	4076.8	0.0496	928.5	46.1
2006	2	GOM	11490.3	348.8	0.0304	598.9	18.2
2006	3	GOM	35246.8	271.1	0.0077	1835.5	14.1
2006	4	GOM	177169.4	992.2	0.0056	3050.9	17.1
2006	1	MA	41258.2	1454.5	0.0353	3138.0	110.6
2006	2	MA	18235.7	1563.0	0.0857	1662.8	142.5
2006	3	MA	20961.0	55.0	0.0026	666.8	1.7
2006	4	MA	34747.8	776.0	0.0223	2173.8	48.5
2006	1	SNE	59437.3	3969.0	0.0668	1173.6	78.4
2006	2	SNE	9257.0	3059.0	0.3305	1042.1	344.4
2006	3	SNE	3466.3	438.0	0.1264	130.5	16.5
2006	4	SNE	4979.8	7.5	0.0015	539.4	0.8
2007	1	GBK	13029.1	8109.6	0.6224	497.4	309.6
2007	2	GBK	27562.6	902.0	0.0327	1017.4	33.3
2007	3	GBK	471464.1	32418.6	0.0688	2927.8	201.3
2007	4	GBK	327498.6	27336.1	0.0835	1174.2	98.0

Table 4 cont.

2007	1	GOM	95553.5	1742.9	0.0182	976.4	17.8
2007	2	GOM	19165.0	358.5	0.0187	918.0	17.2
2007	3	GOM	54180.0	699.2	0.0129	1723.1	22.2
2007	4	GOM	226349.7	2411.7	0.0107	3896.9	41.5
2007	1	MA	24863.2	629.3	0.0253	5147.9	130.3
2007	2	MA	30796.9	3589.5	0.1166	3028.1	352.9
2007	3	MA	11744.1	154.5	0.0132	1726.3	22.7
2007	4	MA	35426.4	668.2	0.0189	4732.4	89.3
2007	1	SNE	101559.1	12113.1	0.1193	845.4	100.8
2007	2	SNE	25749.0	1942.5	0.0754	1014.5	76.5
2007	3	SNE	3710.3	149.0	0.0402	222.5	8.9
2007	4	SNE	32680.2	13702.3	0.4193	679.9	285.1

Table 5. Discard estimates by stratum for the scallop dredge fishery.

average within areaf

average across comb region (ie sne-ma)

YEAR	QTR	areaf	trp	kept	discards	dkratio	mt kept	total discards
1992	1	GBK	GEN	50291.2	14561.0	0.2508	31.6	7.9
1992	2	GBK	GEN	50291.2	14561.0	0.2508	5.9	1.5
1992	3	GBK	GEN	50291.2	14561.0	0.2508	7.6	1.9
1992	4	GBK	GEN	50291.2	14561.0	0.2508	45.2	11.3
1992	1	GBK	LIM	37455.6	6519.0	0.1740	21901.7	3811.9
1992	2	GBK	LIM	86300.4	23051.0	0.2671	16714.3	4464.4
1992	3	GBK	LIM	6944.1	1275.0	0.1836	18107.8	3324.8
1992	4	GBK	LIM	111608.7	39436.0	0.3533	18596.8	6571.0
1992	1	GOM	GEN	50291.2	14561.0	0.2508	47.7	12.0
1992	2	GOM	GEN	50291.2	14561.0	0.2508	24.7	6.2
1992	3	GOM	GEN	50291.2	14561.0	0.2508	24.1	6.0
1992	4	GOM	GEN	50291.2	14561.0	0.2508	43.4	10.9
1992	1	GOM	LIM	50291.2	14561.0	0.2508	2086.3	523.3
1992	2	GOM	LIM	50291.2	14561.0	0.2508	62.5	15.7
1992	3	GOM	LIM	50291.2	14561.0	0.2508	187.2	46.9
1992	4	GOM	LIM	9147.1	2524.0	0.2759	3429.0	946.2
1992	1	MA	GEN	26547.6	9060.2	0.4585	29.3	13.4
1992	2	MA	GEN	26547.6	9060.2	0.4585	26.8	12.3
1992	3	MA	GEN	26547.6	9060.2	0.4585	18.0	8.3
1992	4	MA	GEN	26547.6	9060.2	0.4585	43.6	20.0
1992	1	MA	LIM	19225.3	5127.0	0.2667	13260.1	3536.2
1992	2	MA	LIM	38383.6	4037.0	0.1052	8296.8	872.6
1992	3	MA	LIM	41502.6	4989.0	0.1202	8151.2	979.9
1992	4	MA	LIM	42997.7	23748.0	0.5523	9604.1	5304.4
1992	1	SNE	GEN	26547.6	9060.2	0.4585	14.7	6.7
1992	4	SNE	GEN	26547.6	9060.2	0.4585	2.4	1.1
1992	1	SNE	LIM	3488.0	2360.0	0.6766	245.0	165.8
1992	2	SNE	LIM	26547.6	9060.2	0.4585	117.7	54.0
1992	3	SNE	LIM	26547.6	9060.2	0.4585	108.5	49.7
1992	4	SNE	LIM	13688.2	14100.0	1.0301	790.1	813.9
1993	1	GBK	GEN	69938.1	14547.0	0.2001	20.4	4.1
1993	2	GBK	GEN	69938.1	14547.0	0.2001	18.8	3.8
1993	3	GBK	GEN	69938.1	14547.0	0.2001	1.4	0.3
1993	4	GBK	GEN	69938.1	14547.0	0.2001	2.7	0.5
1993	1	GBK	LIM	66175.0	15317.0	0.2315	12972.9	3002.7
1993	2	GBK	LIM	80588.9	7761.0	0.0963	8057.1	775.9
1993	3	GBK	LIM	43354.5	6788.0	0.1566	8084.3	1265.8
1993	4	GBK	LIM	89633.9	28322.0	0.3160	9741.0	3077.9
1993	1	GOM	GEN	69938.1	14547.0	0.2001	68.5	13.7
1993	2	GOM	GEN	69938.1	14547.0	0.2001	1.9	0.4
1993	3	GOM	GEN	69938.1	14547.0	0.2001	3.9	0.8
1993	4	GOM	GEN	69938.1	14547.0	0.2001	50.8	10.2
1993	1	GOM	LIM	69938.1	14547.0	0.2001	3048.1	609.9
1993	2	GOM	LIM	69938.1	14547.0	0.2001	505.6	101.2
1993	3	GOM	LIM	69938.1	14547.0	0.2001	134.0	26.8
1993	4	GOM	LIM	69938.1	14547.0	0.2001	2725.3	545.3

Table 5 cont.

1993	1	MA	GEN	38607.5	18893.3	0.7720	17.5	13.5
1993	2	MA	GEN	38607.5	18893.3	0.7720	3.5	2.7
1993	3	MA	GEN	38607.5	18893.3	0.7720	20.7	16.0
1993	4	MA	GEN	38607.5	18893.3	0.7720	53.8	41.5
1993	1	MA	LIM	96891.4	51649.0	0.5331	7909.9	4216.4
1993	2	MA	LIM	71762.1	14807.0	0.2063	4591.2	947.3
1993	3	MA	LIM	23586.3	12465.0	0.5285	4652.4	2458.7
1993	4	MA	LIM	31743.4	24792.0	0.7810	5251.9	4101.8
1993	1	SNE	GEN	38607.5	18893.3	0.7720	9.0	6.9
1993	2	SNE	GEN	38607.5	18893.3	0.7720	22.8	17.6
1993	3	SNE	GEN	38607.5	18893.3	0.7720	5.7	4.4
1993	4	SNE	GEN	38607.5	18893.3	0.7720	2.8	2.1
1993	1	SNE	LIM	3955.1	1147.0	0.2900	346.9	100.6
1993	2	SNE	LIM	38607.5	18893.3	0.7720	78.7	60.7
1993	3	SNE	LIM	38607.5	18893.3	0.7720	68.4	52.8
1993	4	SNE	LIM	3707.0	8500.0	2.2929	254.0	582.4
1994	1	GBK	GEN	37743.1	7367.8	0.2589	4.8	1.3
1994	2	GBK	GEN	37743.1	7367.8	0.2589	1.0	0.3
1994	4	GBK	GEN	37743.1	7367.8	0.2589	1.0	0.3
1994	1	GBK	LIM	6226.1	1147.0	0.1842	3979.7	733.2
1994	2	GBK	LIM	43256.7	7210.0	0.1667	2855.3	475.9
1994	3	GBK	LIM	33287.5	12404.0	0.3726	3220.2	1199.9
1994	4	GBK	LIM	132915.5	20306.0	0.1528	2961.9	452.5
1994	1	GOM	GEN	37743.1	7367.8	0.2589	46.7	12.1
1994	2	GOM	GEN	37743.1	7367.8	0.2589	17.1	4.4
1994	3	GOM	GEN	37743.1	7367.8	0.2589	7.5	2.0
1994	4	GOM	GEN	37743.1	7367.8	0.2589	1117.0	289.2
1994	1	GOM	LIM	4347.1	2530.0	0.5820	1754.9	1021.4
1994	2	GOM	LIM	37743.1	7367.8	0.2589	176.0	45.6
1994	3	GOM	LIM	37743.1	7367.8	0.2589	86.7	22.4
1994	4	GOM	LIM	6426.1	610.0	0.0949	1437.5	136.5
1994	1	MA	GEN	109751.8	19117.9	0.5178	220.0	113.9
1994	2	MA	GEN	109751.8	19117.9	0.5178	586.9	303.9
1994	3	MA	GEN	109751.8	19117.9	0.5178	295.0	152.8
1994	4	MA	GEN	109751.8	19117.9	0.5178	343.9	178.1
1994	1	MA	LIM	291785.5	52137.0	0.1787	13240.8	2365.9
1994	2	MA	LIM	40392.6	5693.0	0.1409	8982.1	1266.0
1994	3	MA	LIM	86889.7	883.1	0.0102	8358.9	85.0
1994	4	MA	LIM	122573.3	22078.5	0.1801	12326.9	2220.4
1994	1	SNE	GEN	109751.8	19117.9	0.5178	7.2	3.7
1994	2	SNE	GEN	109751.8	19117.9	0.5178	50.9	26.3
1994	1	SNE	LIM	109751.8	19117.9	0.5178	195.2	101.1
1994	2	SNE	LIM	109751.8	19117.9	0.5178	24.4	12.6
1994	4	SNE	LIM	7118.0	14798.0	2.0790	295.1	613.5
1995	1	GBK	GEN	35218.7	4671.0	0.1330	1.1	0.1
1995	1	GBK	LIM	6959.1	1098.0	0.1578	868.0	136.9
1995	2	GBK	LIM	35218.7	4671.0	0.1330	425.7	56.6
1995	3	GBK	LIM	44731.1	11497.0	0.2570	4489.5	1153.9
1995	4	GBK	LIM	62540.7	5166.0	0.0826	3713.5	306.7

Table 5 cont.

1995	1	GOM	GEN	35218.7	4671.0	0.1330	737.5	98.1
1995	2	GOM	GEN	35218.7	4671.0	0.1330	18.1	2.4
1995	3	GOM	GEN	35218.7	4671.0	0.1330	5.5	0.7
1995	4	GOM	GEN	35218.7	4671.0	0.1330	553.6	73.6
1995	1	GOM	LIM	35218.7	4671.0	0.1330	367.4	48.9
1995	2	GOM	LIM	35218.7	4671.0	0.1330	411.4	54.7
1995	3	GOM	LIM	35218.7	4671.0	0.1330	547.1	72.8
1995	4	GOM	LIM	26643.9	923.0	0.0346	1140.0	39.5
1995	1	MA	GEN	162275.3	54457.4	0.7607	356.6	271.3
1995	2	MA	GEN	162275.3	54457.4	0.7607	232.9	177.1
1995	3	MA	GEN	162275.3	54457.4	0.7607	118.8	90.4
1995	4	MA	GEN	162275.3	54457.4	0.7607	101.6	77.3
1995	1	MA	LIM	424321.9	83199.8	0.1961	17547.8	3440.7
1995	2	MA	LIM	107649.9	32633.8	0.3031	15124.0	4584.8
1995	3	MA	LIM	78172.3	5807.0	0.0743	6990.4	519.3
1995	4	MA	LIM	38957.1	96189.0	2.4691	7096.1	17521.0
1995	2	SNE	GEN	162275.3	54457.4	0.7607	0.1	0.1
1995	3	SNE	GEN	162275.3	54457.4	0.7607	66.4	50.5
1995	4	SNE	GEN	162275.3	54457.4	0.7607	0.4	0.3
1995	1	SNE	LIM	162275.3	54457.4	0.7607	232.4	176.8
1995	2	SNE	LIM	162275.3	54457.4	0.7607	102.9	78.3
1995	3	SNE	LIM	162275.3	54457.4	0.7607	74.6	56.8
1995	4	SNE	LIM	162275.3	54457.4	0.7607	102.9	78.3
1996	1	GBK	GEN				78.4	0.0
1996	2	GBK	GEN	91775.8	11306.1	0.1461	11.8	1.7
1996	3	GBK	GEN	91775.8	11306.1	0.1461	14.5	2.1
1996	4	GBK	GEN	91775.8	11306.1	0.1461	79.8	11.7
1996	1	GBK	LIM	193963.0	18448.6	0.0951	2333.8	222.0
1996	2	GBK	LIM	73941.0	9214.4	0.1246	2869.5	357.6
1996	3	GBK	LIM	140909.2	13983.1	0.0992	5825.1	578.1
1996	4	GBK	LIM	82763.7	19698.7	0.2380	8059.0	1918.1
1996	1	GOM	GEN	91775.8	11306.1	0.1461	350.1	51.2
1996	2	GOM	GEN	91775.8	11306.1	0.1461	45.3	6.6
1996	3	GOM	GEN	91775.8	11306.1	0.1461	217.7	31.8
1996	4	GOM	GEN	91775.8	11306.1	0.1461	323.5	47.3
1996	1	GOM	LIM	58226.0	6312.0	0.1084	794.6	86.1
1996	2	GOM	LIM	91775.8	11306.1	0.1461	763.3	111.5
1996	3	GOM	LIM	91775.8	11306.1	0.1461	531.9	77.7
1996	4	GOM	LIM	851.7	180.0	0.2113	1711.8	361.8
1996	1	MA	GEN	103404.7	40576.2	0.7423	143.5	106.5
1996	2	MA	GEN	103404.7	40576.2	0.7423	242.2	179.8
1996	3	MA	GEN	103404.7	40576.2	0.7423	85.0	63.1
1996	4	MA	GEN	103404.7	40576.2	0.7423	135.7	100.7
1996	1	MA	LIM	254269.2	51641.0	0.2031	12247.5	2487.4
1996	2	MA	LIM	139290.9	52641.5	0.3779	12782.6	4830.8
1996	3	MA	LIM	133185.7	32433.2	0.2435	8449.0	2057.5
1996	4	MA	LIM	83422.2	93504.9	1.1209	4974.9	5576.1
1996	1	SNE	GEN	103404.7	40576.2	0.7423	24.1	17.9
1996	2	SNE	GEN	103404.7	40576.2	0.7423	9.3	6.9

Table 5 cont.

1996	4	SNE	GEN	103404.7	40576.2	0.7423	5.3	3.9
1996	1	SNE	LIM	103404.7	40576.2	0.7423	111.8	83.0
1996	2	SNE	LIM	103404.7	40576.2	0.7423	34.6	25.7
1996	3	SNE	LIM	1867.1	2236.0	1.1976	184.5	221.0
1996	4	SNE	LIM	8393.0	11000.8	1.3107	398.3	522.0
1997	1	GBK	GEN	71654.1	13615.5	0.1640	62.5	10.2
1997	2	GBK	GEN	71654.1	13615.5	0.1640	2.2	0.4
1997	3	GBK	GEN	71654.1	13615.5	0.1640	2.8	0.5
1997	4	GBK	GEN	71654.1	13615.5	0.1640	33.7	5.5
1997	1	GBK	LIM	118384.4	12318.9	0.1041	6089.8	633.7
1997	2	GBK	LIM	97509.7	13445.1	0.1379	5545.3	764.6
1997	3	GBK	LIM	79412.4	32942.9	0.4148	4835.8	2006.0
1997	4	GBK	LIM	97398.0	18331.6	0.1882	5211.2	980.8
1997	1	GOM	GEN	71654.1	13615.5	0.1640	516.5	84.7
1997	2	GOM	GEN	71654.1	13615.5	0.1640	64.8	10.6
1997	3	GOM	GEN	71654.1	13615.5	0.1640	63.4	10.4
1997	4	GOM	GEN	71654.1	13615.5	0.1640	246.8	40.5
1997	1	GOM	LIM	34113.0	4646.7	0.1362	1698.9	231.4
1997	2	GOM	LIM	71654.1	13615.5	0.1640	417.6	68.5
1997	3	GOM	LIM	71654.1	13615.5	0.1640	709.9	116.4
1997	4	GOM	LIM	3107.0	8.0	0.0026	2049.2	5.3
1997	1	MA	GEN	1017.1	795.0	0.7816	75.3	58.8
1997	2	MA	GEN	280.0	550.0	1.9643	182.7	358.9
1997	3	MA	GEN	63184.8	28637.5	1.1428	135.4	154.8
1997	4	MA	GEN	63184.8	28637.5	1.1428	149.1	170.4
1997	1	MA	LIM	185187.6	96703.0	0.5222	7755.5	4049.9
1997	2	MA	LIM	97013.5	58382.0	0.6018	6919.4	4164.1
1997	3	MA	LIM	59890.5	14226.0	0.2375	4788.9	1137.5
1997	4	MA	LIM	98861.3	29649.3	0.2999	5276.8	1582.5
1997	1	SNE	GEN	63184.8	28637.5	1.1428	11.7	13.3
1997	3	SNE	GEN	63184.8	28637.5	1.1428	36.1	41.3
1997	4	SNE	GEN	63184.8	28637.5	1.1428	33.7	38.5
1997	1	SNE	LIM	63184.8	28637.5	1.1428	118.1	134.9
1997	2	SNE	LIM	43.7	157.0	3.5926	149.9	538.5
1997	3	SNE	LIM	63184.8	28637.5	1.1428	194.9	222.7
1997	4	SNE	LIM	63184.8	28637.5	1.1428	377.2	431.1
1998	1	GBK	GEN	54814.9	16487.8	0.2686	13.6	3.6
1998	2	GBK	GEN	54814.9	16487.8	0.2686	13.8	3.7
1998	3	GBK	GEN	54814.9	16487.8	0.2686	1.2	0.3
1998	4	GBK	GEN	54814.9	16487.8	0.2686	10.6	2.9
1998	1	GBK	LIM	54814.9	16487.8	0.2686	4903.1	1316.9
1998	2	GBK	LIM	46777.6	6201.0	0.1326	4105.2	544.2
1998	3	GBK	LIM	20064.1	7128.0	0.3553	4911.3	1744.8
1998	4	GBK	LIM	124771.5	46771.0	0.3749	5428.4	2034.9
1998	1	GOM	GEN	54814.9	16487.8	0.2686	350.0	94.0
1998	2	GOM	GEN	54814.9	16487.8	0.2686	55.9	15.0
1998	3	GOM	GEN	54814.9	16487.8	0.2686	50.0	13.4
1998	4	GOM	GEN	54814.9	16487.8	0.2686	149.2	40.1
1998	1	GOM	LIM	54814.9	16487.8	0.2686	1255.2	337.1

Table 5 cont.

1998	2	GOM	LIM	54814.9	16487.8	0.2686	228.0	61.2
1998	3	GOM	LIM	54814.9	16487.8	0.2686	57.5	15.5
1998	4	GOM	LIM	27646.3	5851.0	0.2116	1179.8	249.7
1998	1	MA	GEN	27193.7	10898.2	0.4998	149.5	74.7
1998	2	MA	GEN	209.1	240.0	1.1477	127.9	146.8
1998	3	MA	GEN	27193.7	10898.2	0.4998	192.8	96.4
1998	4	MA	GEN	16905.3	13181.0	0.7797	139.6	108.8
1998	1	MA	LIM	24099.0	5711.0	0.2370	7089.8	1680.2
1998	2	MA	LIM	112632.5	41451.5	0.3680	5633.0	2073.1
1998	3	MA	LIM	17567.8	6319.0	0.3597	3980.5	1431.8
1998	4	MA	LIM	18657.1	9355.0	0.5014	5213.8	2614.3
1998	1	SNE	GEN	27193.7	10898.2	0.4998	121.8	60.9
1998	2	SNE	GEN	27193.7	10898.2	0.4998	18.0	9.0
1998	3	SNE	GEN	27193.7	10898.2	0.4998	56.3	28.2
1998	4	SNE	GEN	27193.7	10898.2	0.4998	3.5	1.7
1998	1	SNE	LIM	27193.7	10898.2	0.4998	235.3	117.6
1998	2	SNE	LIM	27193.7	10898.2	0.4998	275.5	137.7
1998	3	SNE	LIM	27193.7	10898.2	0.4998	144.5	72.2
1998	4	SNE	LIM	285.0	30.0	0.1053	181.3	19.1
1999	1	GBK	GEN	369905.3	32992.6	0.0851	86.5	7.4
1999	2	GBK	GEN	369905.3	32992.6	0.0851	216.7	18.4
1999	3	GBK	GEN	369905.3	32992.6	0.0851	208.2	17.7
1999	4	GBK	GEN	369905.3	32992.6	0.0851	27.4	2.3
1999	1	GBK	LIM	369905.3	32992.6	0.0851	5313.5	452.2
1999	2	GBK	LIM	195274.1	13165.0	0.0674	9508.8	641.1
1999	3	GBK	LIM	614597.1	57555.3	0.0936	13175.9	1233.9
1999	4	GBK	LIM	299844.6	28257.5	0.0942	16243.1	1530.8
1999	1	GOM	GEN	369905.3	32992.6	0.0851	244.8	20.8
1999	2	GOM	GEN	369905.3	32992.6	0.0851	37.7	3.2
1999	3	GOM	GEN	369905.3	32992.6	0.0851	689.6	58.7
1999	4	GOM	GEN	369905.3	32992.6	0.0851	470.3	40.0
1999	1	GOM	LIM	369905.3	32992.6	0.0851	723.5	61.6
1999	2	GOM	LIM	369905.3	32992.6	0.0851	32.7	2.8
1999	3	GOM	LIM	369905.3	32992.6	0.0851	13.3	1.1
1999	4	GOM	LIM	369905.3	32992.6	0.0851	848.4	72.2
1999	1	MA	GEN	40167.7	12772.8	0.3235	63.2	20.4
1999	2	MA	GEN	40167.7	12772.8	0.3235	100.5	32.5
1999	3	MA	GEN	7301.1	3450.0	0.4725	65.0	30.7
1999	4	MA	GEN	6453.1	268.0	0.0415	195.3	8.1
1999	1	MA	LIM	40167.7	12772.8	0.3235	11180.6	3617.1
1999	2	MA	LIM	128464.8	27604.0	0.2149	10468.4	2249.4
1999	3	MA	LIM	40581.7	21755.0	0.5361	4921.5	2638.3
1999	4	MA	LIM	36516.6	21910.0	0.6000	3704.5	2222.7
1999	1	SNE	GEN	40167.7	12772.8	0.3235	0.7	0.2
1999	3	SNE	GEN	40167.7	12772.8	0.3235	7.4	2.4
1999	4	SNE	GEN	40167.7	12772.8	0.3235	0.4	0.1
1999	1	SNE	LIM	40167.7	12772.8	0.3235	287.0	92.9
1999	2	SNE	LIM	21688.8	1650.0	0.0761	133.6	10.2
1999	3	SNE	LIM	40167.7	12772.8	0.3235	204.2	66.1

Table 5 cont.

1999	4	SNE	LIM	40167.7	12772.8	0.3235	66.8	21.6
2000	1	GBK	GEN	3457047.2	186667.1	0.0746	92.6	6.9
2000	2	GBK	GEN	3457047.2	186667.1	0.0746	175.4	13.1
2000	3	GBK	GEN	3457047.2	186667.1	0.0746	200.9	15.0
2000	4	GBK	GEN	21015.3	152.0	0.0072	370.3	2.7
2000	1	GBK	LIM	3457047.2	186667.1	0.0746	4192.9	312.7
2000	2	GBK	LIM	1177880.0	218514.9	0.1855	9072.3	1683.0
2000	3	GBK	LIM	4167318.0	354352.8	0.0850	12036.1	1023.4
2000	4	GBK	LIM	8461975.4	173648.5	0.0205	15449.1	317.0
2000	1	GOM	GEN	3457047.2	186667.1	0.0746	126.1	9.4
2000	2	GOM	GEN	3457047.2	186667.1	0.0746	156.0	11.6
2000	3	GOM	GEN	3457047.2	186667.1	0.0746	133.1	9.9
2000	4	GOM	GEN	3457047.2	186667.1	0.0746	37.1	2.8
2000	1	GOM	LIM	3457047.2	186667.1	0.0746	559.5	41.7
2000	2	GOM	LIM	3457047.2	186667.1	0.0746	95.5	7.1
2000	3	GOM	LIM	3457047.2	186667.1	0.0746	17.1	1.3
2000	4	GOM	LIM	3457047.2	186667.1	0.0746	192.9	14.4
2000	1	MA	GEN	6530.1	625.0	0.0957	320.2	30.6
2000	2	MA	GEN	11461.2	3415.0	0.2980	516.4	153.9
2000	3	MA	GEN	117173.4	16514.3	0.1416	282.2	39.9
2000	4	MA	GEN	29437.1	6616.0	0.2248	430.0	96.6
2000	1	MA	LIM	413530.5	65296.3	0.1579	19122.7	3019.5
2000	2	MA	LIM	648.1	0.0	0.0000	19744.1	0.0
2000	3	MA	LIM	170769.5	6511.8	0.0381	12072.2	460.3
2000	4	MA	LIM	187837.4	33136.0	0.1764	15440.1	2723.8
2000	1	SNE	GEN	2001.7	88.7	0.0554	98.7	5.5
2000	4	SNE	GEN	2001.7	88.7	0.0554	0.4	0.0
2000	1	SNE	LIM	2001.7	88.7	0.0554	567.1	31.4
2000	2	SNE	LIM	1381.8	115.0	0.0832		0.0
2000	3	SNE	LIM	1762.5	138.0	0.0783	175.7	13.8
2000	4	SNE	LIM	2860.9	13.0	0.0045	61.6	0.3
2001	1	GBK	GEN	730341.6	17320.0	0.0249	443.5	11.0
2001	2	GBK	GEN	730341.6	17320.0	0.0249	494.3	12.3
2001	3	GBK	GEN	730341.6	17320.0	0.0249	280.5	7.0
2001	4	GBK	GEN	730341.6	17320.0	0.0249	95.3	2.4
2001	1	GBK	LIM	1368169.2	32211.0	0.0235	10806.5	254.4
2001	2	GBK	LIM	92514.0	2429.0	0.0263	7261.0	190.6
2001	3	GBK	LIM	730341.6	17320.0	0.0249	12396.2	308.7
2001	4	GBK	LIM	730341.6	17320.0	0.0249	9160.7	228.1
2001	1	GOM	GEN	730341.6	17320.0	0.0249	216.6	5.4
2001	2	GOM	GEN	730341.6	17320.0	0.0249	1535.0	38.2
2001	3	GOM	GEN	730341.6	17320.0	0.0249	538.2	13.4
2001	4	GOM	GEN	730341.6	17320.0	0.0249	408.6	10.2
2001	1	GOM	LIM	730341.6	17320.0	0.0249	74.0	1.8
2001	2	GOM	LIM	730341.6	17320.0	0.0249	146.9	3.7
2001	3	GOM	LIM	730341.6	17320.0	0.0249	81.9	2.0
2001	4	GOM	LIM	730341.6	17320.0	0.0249	412.4	10.3
2001	1	MA	GEN	1680313.3	67121.0	0.0477	450.6	21.5
2001	2	MA	GEN	1680313.3	67121.0	0.0477	430.1	20.5

Table 5 cont.

2001	3	MA	GEN	1680313.3	67121.0	0.0477	518.2	24.7
2001	4	MA	GEN	1680313.3	67121.0	0.0477	265.9	12.7
2001	1	MA	LIM	207896.6	17123.0	0.0824	27830.9	2292.2
2001	2	MA	LIM	3522211.6	107337.1	0.0305	30088.7	916.9
2001	3	MA	LIM	2152093.3	81877.5	0.0380	21323.6	811.3
2001	4	MA	LIM	2516352.0	129157.5	0.0513	36061.8	1851.0
2001	1	SNE	GEN	1680313.3	67121.0	0.0477	0.2	0.0
2001	2	SNE	GEN	1680313.3	67121.0	0.0477	2.6	0.1
2001	3	SNE	GEN	1680313.3	67121.0	0.0477	0.0	0.0
2001	4	SNE	GEN	1680313.3	67121.0	0.0477	8.3	0.4
2001	1	SNE	LIM	3013.0	110.0	0.0365	131.4	4.8
2001	2	SNE	LIM	1680313.3	67121.0	0.0477	84.2	4.0
2001	3	SNE	LIM	1680313.3	67121.0	0.0477	10.5	0.5
2001	4	SNE	LIM	1680313.3	67121.0	0.0477	7.3	0.3
2002	1	GBK	GEN	318272.9	16620.7	0.0620	129.0	8.0
2002	2	GBK	GEN	318272.9	16620.7	0.0620	155.5	9.6
2002	3	GBK	GEN	318272.9	16620.7	0.0620	223.7	13.9
2002	4	GBK	GEN	318272.9	16620.7	0.0620	112.0	6.9
2002	1	GBK	LIM	318272.9	16620.7	0.0620	5761.6	356.9
2002	2	GBK	LIM	318272.9	16620.7	0.0620	9314.7	577.1
2002	3	GBK	LIM	368114.9	28007.5	0.0761	18366.3	1397.4
2002	4	GBK	LIM	581835.7	21500.1	0.0370	15534.0	574.0
2002	1	GOM	GEN	318272.9	16620.7	0.0620	756.8	46.9
2002	2	GOM	GEN	318272.9	16620.7	0.0620	406.6	25.2
2002	3	GOM	GEN	318272.9	16620.7	0.0620	251.4	15.6
2002	4	GOM	GEN	4868.1	354.5	0.0728	147.3	10.7
2002	1	GOM	LIM	318272.9	16620.7	0.0620	1144.7	70.9
2002	2	GOM	LIM	318272.9	16620.7	0.0620	11.7	0.7
2002	3	GOM	LIM	318272.9	16620.7	0.0620	108.6	6.7
2002	4	GOM	LIM	318272.9	16620.7	0.0620	82.3	5.1
2002	1	MA	GEN	1479173.1	122872.0	0.1024	420.7	43.1
2002	2	MA	GEN	1479173.1	122872.0	0.1024	818.0	83.7
2002	3	MA	GEN	1479173.1	122872.0	0.1024	762.8	78.1
2002	4	MA	GEN	9769.2	1792.0	0.1834	1715.0	314.6
2002	1	MA	LIM	1622662.7	122137.0	0.0753	39750.2	2992.0
2002	2	MA	LIM	1654031.2	100861.0	0.0610	33889.7	2066.6
2002	3	MA	LIM	1691190.7	174917.1	0.1034	23042.3	2383.2
2002	4	MA	LIM	2418211.5	214653.0	0.0888	32696.2	2902.3
2002	1	SNE	GEN	1479173.1	122872.0	0.1024	1.0	0.1
2002	2	SNE	GEN	1479173.1	122872.0	0.1024	4.1	0.4
2002	3	SNE	GEN	1479173.1	122872.0	0.1024	2.2	0.2
2002	4	SNE	GEN	1479173.1	122872.0	0.1024	1.7	0.2
2002	1	SNE	LIM	1479173.1	122872.0	0.1024	35.7	3.7
2002	3	SNE	LIM	1479173.1	122872.0	0.1024	106.1	10.9
2002	4	SNE	LIM	1479173.1	122872.0	0.1024	11.5	1.2
2003	1	GBK	GEN	183288.2	13948.4	0.0888	188.7	16.8
2003	2	GBK	GEN	183288.2	13948.4	0.0888	392.9	34.9
2003	3	GBK	GEN	183288.2	13948.4	0.0888	663.4	58.9
2003	4	GBK	GEN	19728.3	2844.0	0.1442	431.6	62.2

Table 5 cont.

2003	1	GBK	LIM	249438.1	4599.0	0.0184	8836.7	162.9
2003	2	GBK	LIM	159227.5	24910.0	0.1564	9834.4	1538.5
2003	3	GBK	LIM	98491.0	9761.3	0.0991	13445.5	1332.6
2003	4	GBK	LIM	572128.5	41546.2	0.0726	6749.3	490.1
2003	1	GOM	GEN	716.0	30.0	0.0419	665.4	27.9
2003	2	GOM	GEN	183288.2	13948.4	0.0888	309.2	27.4
2003	3	GOM	GEN	183288.2	13948.4	0.0888	164.8	14.6
2003	4	GOM	GEN	183288.2	13948.4	0.0888	131.2	11.6
2003	1	GOM	LIM	183288.2	13948.4	0.0888	100.7	8.9
2003	2	GOM	LIM	183288.2	13948.4	0.0888	206.3	18.3
2003	3	GOM	LIM	183288.2	13948.4	0.0888	8.7	0.8
2003	4	GOM	LIM	183288.2	13948.4	0.0888	43.3	3.8
2003	1	MA	GEN	13839.7	681.0	0.0492	2210.3	108.8
2003	2	MA	GEN	2864.0	475.0	0.1658	1038.3	172.2
2003	3	MA	GEN	16803.3	6195.0	0.3687	1609.2	593.3
2003	4	MA	GEN	28628.5	315.0	0.0110	2055.3	22.6
2003	1	MA	LIM	1738457.1	169608.8	0.0976	33207.8	3239.8
2003	2	MA	LIM	1809350.1	112134.5	0.0620	41415.9	2566.8
2003	3	MA	LIM	1912523.4	125992.5	0.0659	29962.6	1973.9
2003	4	MA	LIM	3431011.6	254800.5	0.0743	46569.2	3458.4
2003	1	SNE	GEN	914442.6	67316.9	0.1299	8.1	1.1
2003	2	SNE	GEN	914442.6	67316.9	0.1299	1.5	0.2
2003	3	SNE	GEN	914442.6	67316.9	0.1299	3.6	0.5
2003	4	SNE	GEN	914442.6	67316.9	0.1299	21.5	2.8
2003	1	SNE	LIM	187199.1	1481.0	0.0079	265.3	2.1
2003	2	SNE	LIM	914442.6	67316.9	0.1299	35.8	4.6
2003	4	SNE	LIM	3749.0	1486.0	0.3964	142.7	56.6
2004	1	GBK	GEN	903834.1	41687.0	0.0599	347.4	20.8
2004	2	GBK	GEN	903834.1	41687.0	0.0599	478.6	28.7
2004	3	GBK	GEN	903834.1	41687.0	0.0599	219.3	13.1
2004	4	GBK	GEN	34306.1	2300.2	0.0670	574.1	38.5
2004	1	GBK	LIM	145522.9	6479.0	0.0445	4375.4	194.8
2004	2	GBK	LIM	903834.1	41687.0	0.0599	736.0	44.1
2004	3	GBK	LIM	903834.1	41687.0	0.0599	2782.7	166.7
2004	4	GBK	LIM	4320027.3	197057.4	0.0456	18164.4	828.6
2004	1	GOM	GEN	696.0	2.0	0.0029	126.6	0.4
2004	2	GOM	GEN	903834.1	41687.0	0.0599	69.2	4.1
2004	3	GOM	GEN	903834.1	41687.0	0.0599	44.8	2.7
2004	4	GOM	GEN	18618.0	2596.5	0.1395	62.4	8.7
2004	1	GOM	LIM	903834.1	41687.0	0.0599	13.6	0.8
2004	2	GOM	LIM	903834.1	41687.0	0.0599	4.8	0.3
2004	3	GOM	LIM	903834.1	41687.0	0.0599	7.6	0.5
2004	4	GOM	LIM	903834.1	41687.0	0.0599	17.9	1.1
2004	1	MA	GEN	1850198.5	88558.9	0.1417	2108.4	298.7
2004	2	MA	GEN	11665.2	1152.0	0.0988	1469.8	145.1
2004	3	MA	GEN	51917.9	6628.5	0.1277	1746.8	223.0
2004	4	MA	GEN	75295.0	7013.5	0.0931	2082.7	194.0
2004	1	MA	LIM	3512382.0	218198.2	0.0621	52059.4	3234.1
2004	2	MA	LIM	4242871.1	152827.9	0.0360	40819.4	1470.3

Table 5 cont

2004	3	MA	LIM	3747024.5	140658.8	0.0375	28934.5	1086.2
2004	4	MA	LIM	5005748.4	270046.3	0.0539	27941.7	1507.4
2004	1	SNE	GEN	1850198.5	88558.9	0.1417	121.9	17.3
2004	2	SNE	GEN	1850198.5	88558.9	0.1417	18.2	2.6
2004	3	SNE	GEN	1850198.5	88558.9	0.1417	179.7	25.5
2004	4	SNE	GEN	4403.1	155.0	0.0352	162.2	5.7
2004	1	SNE	LIM	1850198.5	88558.9	0.1417	59.7	8.5
2004	2	SNE	LIM	1850198.5	88558.9	0.1417	8.7	1.2
2004	3	SNE	LIM	1850198.5	88558.9	0.1417	235.7	33.4
2004	4	SNE	LIM	479.0	350.0	0.7307	33.0	24.1
2005	1	GBK	GEN	41555.5	907.1	0.0218	156.3	3.4
2005	2	GBK	GEN	21770.8	260.5	0.0120	761.2	9.1
2005	3	GBK	GEN	33530.6	1006.0	0.0300	1251.3	37.5
2005	4	GBK	GEN	6791.4	148.0	0.0218	1262.2	27.5
2005	1	GBK	LIM	1555423.6	45189.8	0.0291	11253.2	326.9
2005	2	GBK	LIM	506638.5	28918.0	0.0571	4017.4	229.3
2005	3	GBK	LIM	3279688.8	158732.0	0.0484	25084.8	1214.1
2005	4	GBK	LIM	4234053.2	177304.3	0.0419	21842.3	914.7
2005	1	GOM	GEN	11563.2	586.9	0.0508	261.5	13.3
2005	2	GOM	GEN	11563.2	586.9	0.0508	128.6	6.5
2005	3	GOM	GEN	11563.2	586.9	0.0508	162.7	8.3
2005	4	GOM	GEN	11563.2	586.9	0.0508	165.1	8.4
2005	1	GOM	LIM	11563.2	586.9	0.0508	86.0	4.4
2005	2	GOM	LIM	11563.2	586.9	0.0508	16.2	0.8
2005	3	GOM	LIM	11563.2	586.9	0.0508	8.7	0.4
2005	4	GOM	LIM	11563.2	586.9	0.0508	18.7	1.0
2005	1	MA	GEN	61095.5	13888.0	0.2273	2243.3	509.9
2005	2	MA	GEN	49746.3	3487.0	0.0701	1595.9	111.9
2005	3	MA	GEN	105742.2	7938.0	0.0751	2087.8	156.7
2005	4	MA	GEN	198930.7	30837.0	0.1550	2610.5	404.7
2005	1	MA	LIM	2664400.4	179014.5	0.0672	32820.5	2205.1
2005	2	MA	LIM	1606428.9	97359.5	0.0606	37930.8	2298.8
2005	3	MA	LIM	1041484.0	92504.5	0.0888	10527.7	935.1
2005	4	MA	LIM	911974.9	58671.5	0.0643	10021.0	644.7
2005	1	SNE	GEN	5845.1	1536.0	0.2628	225.5	59.3
2005	2	SNE	GEN	3141.7	920.7	0.3310	321.8	106.5
2005	3	SNE	GEN	3141.7	920.7	0.3310	292.9	97.0
2005	4	SNE	GEN	3076.1	1026.0	0.3335	251.7	84.0
2005	1	SNE	LIM	3141.7	920.7	0.3310	200.2	66.3
2005	2	SNE	LIM	3141.7	920.7	0.3310	499.1	165.2
2005	3	SNE	LIM	504.0	200.0	0.3968	73.0	29.0
2005	4	SNE	LIM	3141.7	920.7	0.3310	204.2	67.6
2006	1	GBK	GEN	1512131.0	50721.1	0.0430	830.6	35.8
2006	2	GBK	GEN	26456.1	274.4	0.0104	1566.4	16.2
2006	3	GBK	GEN	26567.8	2245.6	0.0845	1082.4	91.5
2006	4	GBK	GEN	45981.8	2645.6	0.0575	1305.6	75.1
2006	1	GBK	LIM	1052972.5	43136.0	0.0410	11703.4	479.4
2006	2	GBK	LIM	1776873.6	29162.4	0.0164	31707.2	520.4
2006	3	GBK	LIM	4908723.7	59263.8	0.0121	44152.5	533.1

Table 5 cont.

2006	4	GBK	LIM	2747341.3	218319.9	0.0795	21441.8	1703.9
2006	1	GOM	GEN	1512131.0	50721.1	0.0430	228.7	9.8
2006	2	GOM	GEN	1512131.0	50721.1	0.0430	314.2	13.5
2006	3	GOM	GEN	1512131.0	50721.1	0.0430	64.3	2.8
2006	4	GOM	GEN	1512131.0	50721.1	0.0430	36.7	1.6
2006	1	GOM	LIM	1512131.0	50721.1	0.0430	107.0	4.6
2006	2	GOM	LIM	1512131.0	50721.1	0.0430	128.6	5.5
2006	3	GOM	LIM	1512131.0	50721.1	0.0430	1.7	0.1
2006	4	GOM	LIM	1512131.0	50721.1	0.0430	11.4	0.5
2006	1	MA	GEN	19798.3	1046.5	0.0529	3376.0	178.5
2006	2	MA	GEN	262927.9	39213.7	0.1556	2295.4	357.3
2006	3	MA	GEN	11021.8	2654.0	0.2408	1999.7	481.5
2006	4	MA	GEN	167288.2	61724.6	0.3690	2107.8	777.7
2006	1	MA	LIM	201969.6	19943.0	0.0987	24214.1	2391.0
2006	2	MA	LIM	262927.9	39213.7	0.1556	9894.9	1540.1
2006	3	MA	LIM	66415.1	2655.0	0.0400	1594.3	63.7
2006	4	MA	LIM	1111074.6	147259.0	0.1325	7411.1	982.2
2006	1	SNE	GEN	4205.3	620.7	0.1641	321.2	52.7
2006	2	SNE	GEN	4205.3	620.7	0.1641	613.7	100.7
2006	3	SNE	GEN	5919.8	897.0	0.1515	697.4	105.7
2006	4	SNE	GEN	2826.0	959.0	0.3393	81.8	27.8
2006	1	SNE	LIM	4205.3	620.7	0.1641	200.0	32.8
2006	2	SNE	LIM	4205.3	620.7	0.1641	138.3	22.7
2006	3	SNE	LIM	4205.3	620.7	0.1641	285.5	46.9
2006	4	SNE	LIM	4205.3	620.7	0.1641	132.6	21.8
2007	1	GBK	GEN	3870.1	6.0	0.0016	532.5	0.8
2007	2	GBK	GEN	358236.7	4589.8	0.0128	1451.1	18.6
2007	3	GBK	GEN	288991.1	7412.7	0.0257	1733.7	44.5
2007	4	GBK	GEN	1247.0	384.0	0.3079	757.2	233.2
2007	1	GBK	LIM	593878.9	41340.9	0.0696	6329.5	440.6
2007	2	GBK	LIM	2849421.4	46885.3	0.0165	23308.7	383.5
2007	3	GBK	LIM	3884526.0	140290.9	0.0361	27790.1	1003.6
2007	4	GBK	LIM	2561393.5	380441.5	0.1485	14195.1	2108.4
2007	1	GOM	GEN	2047.0	161.8	0.0764	233.1	17.8
2007	2	GOM	GEN	1866.0	87.0	0.0466	118.9	5.5
2007	3	GOM	GEN	2047.0	161.8	0.0764	67.9	5.2
2007	4	GOM	GEN	2228.0	236.5	0.1061	97.4	10.3
2007	1	GOM	LIM	2047.0	161.8	0.0764	49.1	3.7
2007	2	GOM	LIM	2047.0	161.8	0.0764	8.3	0.6
2007	3	GOM	LIM	2047.0	161.8	0.0764	110.6	8.4
2007	4	GOM	LIM	2047.0	161.8	0.0764	56.2	4.3
2007	1	MA	GEN	70251.7	10615.7	0.1511	4568.1	690.3
2007	2	MA	GEN	29147.2	1961.5	0.0673	3812.6	256.6
2007	3	MA	GEN	78997.6	5916.0	0.0749	3056.1	228.9
2007	4	MA	GEN	85023.5	9005.0	0.1059	3266.0	345.9
2007	1	MA	LIM	2004191.4	123968.2	0.0619	42576.1	2633.5
2007	2	MA	LIM	2129420.5	79156.8	0.0372	31869.6	1184.7
2007	3	MA	LIM	1126763.4	68026.4	0.0604	13663.4	824.9
2007	4	MA	LIM	2908179.8	194294.7	0.0668	24775.2	1655.2

Table 5 cont.

2007	1	SNE	GEN	2468.6	518.0	0.8185	68.3	55.9
2007	2	SNE	GEN	1926.0	240.0	0.1246	299.0	37.3
2007	3	SNE	GEN	2468.6	518.0	0.8185	361.5	295.9
2007	4	SNE	GEN	7787.3	1657.0	0.2128	395.9	84.2
2007	1	SNE	LIM	126.0	100.0	0.7936	19.2	15.3
2007	2	SNE	LIM	2468.6	518.0	0.8185	440.7	360.7
2007	3	SNE	LIM	2468.6	518.0	0.8185	225.0	184.1
2007	4	SNE	LIM	35.0	75.0	2.1428	252.8	541.7

Skates:
Discard Estimations
Appendix 2

By
Andrew Applegate
New England Fishery Management Council
Newburyport, MA

Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

This Working Paper was distributed for pre-dissemination peer review at the NE Data Poor Stocks Peer Review Meeting, December 8-12, 2008. It does not represent any final NOAA agency determination or policy. Some comments in the Peer Review Panel's Report of the Data Poor Stock Working Group are in response to this WP.

New England Fishery Management Council
50 WATER STREET | NEWBURYPORT, MASSACHUSETTS 01950 | PHONE 978 465 0492 | FAX 978 465 3116
John Pappalardo, *Chairman* | Paul J. Howard, *Executive Director*

MEMORANDUM

DATE: **December 11, 2008**

TO: Data Poor Assessment Workshop

FROM: Andrew Applegate

SUBJECT: **Discard estimation**

During the Data Poor Assessment Workshop (DPWS), new skate discard estimates were presented which differed substantially (see Figure 1) from those estimated during SAW44 and updated by the Skate PDT during the development of Amendment 3. Most of the differences were thought to be associated with filling unmatched trips with average DK (live weight ratio of observed discarded skates to the observed kept of all species). Like the SAW44 estimate, a three level stratification was applied to observed trips and dealer landings (obtained from the area allocation "AA" tables). The stratification included gear (longline, limited access scallop dredge, general category scallop dredge, shrimp trawl, sink gillnet, and fish trawl), region (Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic) and quarter (1-4).

The new estimates had the same trend as the previous ones through 2002, but differed substantially from 2003 to 2006 (Figure 1). Most filled DK rations, however, were concentrated in earlier years (Figures 4-7), the largest difference arising from longline gear in 1991 and 1992 and trawl gear in 1998. The cause of the differences for 2003-2006 were not apparent. These more recent discard estimates are critically important because the Council uses the last three years of the discard time series (2004-2006) to reduce the allowable catch limits and set landings targets. Based on the earlier estimates, it was believed that discards had declined substantially due to regulatory effects. The new estimated discards do not show this decline.

To explore the source of these important differences the sea sampling and dealer data were analyzed independently using a different stratification schema to potentially reduce the effects of oversampling of the US/CA area, access area, and special access program trips which are distributed in special areas. Also mesh categories were also introduced to account for DK differences that might be caused by small (< 5.5 inches), large (5.5 to 8 inches), and very large mesh (> 8 inches) for trawl and sink gillnets. A seasonal stratification was also applied (fall 07-10, spring 03-06, and winter 11-02) to comport with the three annual finfish NMFS trawl surveys so that the aggregate discard estimates could be allocated by species. A four level stratification was applied to both data sets: gear (longline, scallop dredge, scallop trawl, sink gillnet, fish trawl, shrimp trawl, and other), sub-region (Delmarva, E. Georges Bank, E. Gulf of Maine, NY Bight, Offshore, S. Channel, Southern New England, and Other), season (see above), and mesh

(see above). Dealer data that matched observed DK ratios from observed trips accounted for about 65-75% of total landings. Where DK matches did not exist, the DK ratio for a two level stratification (gear and sub-region) was applied. Together, the combined matches accounted for 95-99% of total landings. The remaining unmatched trips were for combinations that generally seemed to be associated with low skate discards and the DK ratios were assumed to be zero. No general linear modeling was applied (see analysis below for further discussion) at the time of these discard estimates.

Similar to the NEFSC estimates, the ratio of sums (DK) were applied to total live weight landings of all species on the dealer reports. A simplified method was also applied which discards are the multiplicative product of the observed skate discards per trip times the number of trips landed by dealers. For both, discard 95% confidence levels were computed by bootstrapping the trips (10% of trips in 100 iterations) to obtain a standard deviation for the DK mean by gear. The discard estimates in each 'cell' were then calculated over 1000 iterations with a log normal distribution on DK with a mean μ and a standard deviation σ.

The alternative discard estimates (Figure 2) tend to agree reasonably well with the NEFSC estimates since 1999, and particularly well for estimates since 2003. Before 1998, the discard estimates diverge due to low sample size, but generally all estimates show a declining trend from 1996-1999.

These discard estimates did not however reveal the source of the error in the SAW44 discard estimates. Further exploration of the discard rates was conducted to try to understand why skate discards do not appear to be declining despite more restrictive groundfish regulations during the recent period. For vessels using trawls, skate discards per haul, trip, and kept landings increased from 2000 to 2008 (Figure 9). A similar pattern was observed for vessels using sink gillnets (Figure 10). Observed skate discard rates declined for vessels using scallop dredges (Figure 11). In all three cases, the trends could be caused by oversampling trips in special access programs that could have skate discard rates that differ from regular trips.

Skate discards for vessels landing more than 1000 lbs. of skates (live weight) also increased since 2001 (Figure 12), but appear to level off since 2005 and possible decline in 2008 (a partial year). Skate discard rates for vessels fishing in the Gulf of Maine (Figure 14) and the Mid-Atlantic (Figure 16) appeared to vary without trend (Figure 13) at very low levels particularly since 1999, either per trip or per lb. kept. There appears to be a moderate upward trend in discards in Southern New England (Figure 15) since 2000. Skate discard rates on Georges Bank appear to have trended upward since 2001 (Figure 14), mimicking the overall trend.

When broken out by management program, skate discard rates for regular trawl trips in the Georges Bank region varied without trend from 1989 to 2000, then increased in 2001 and varied at a higher level since that time. In the more recent period, discards averaged 0.3 to 0.6 lbs. of skates per pound kept. In contrast, skate discards on oversampled US/CA area trips were much higher, averaging 0.6 to 0.8 lbs. of skate discards per pound kept.

During the comparison of the discard estimates during the DPWS, it was determined that the SAW44 estimates did not include the US/CA area, scallop access area, and groundfish special access program observed trips. It seems plausible that this omission may have contributed to the estimated declining trend in skate discards that was previously estimated. On the other hand, the high skate discard rates in the US/CA trips may also in some cases be inappropriately applied to non-US/CA area trips, but there is no field in the dealer data to determine trip type. Some post-

stratification of DK rates and dealer landings by sub-region and time could reduce this undue influence on the discard estimation.

Also during the DPWS, it was suggested that a General Linear Model (GLM) analysis should be conducted to determine which type of stratification of observed trips would be better a better model to follow. All three stratifications were analyzed via GLM, plus the NEFSC stratification with only regular management program trips (excluding US/CA area, scallop access area, Multispecies Category B DAS, and special access program trips). All models were significant and one stratification wasn't clearly superior to the other, except that simpler models (i.e. less independent variables) explained a significant amount of the DK variance, but all models had relatively low predictive capability (low R).

More detailed information about the GLM analyses are shown in Tables 2-5. For model 1 (Table 2), the MSE for all independent variables except quarter were significant. Holding the effects of the other independent variables constant, the least squares means increased from 2001 to 2007. Trawl DK rates were substantially higher than other gears and higher in the Southern New England region than the others. Similar trends were observed for a GLM applied to only regular management program observed trips (Table 3).

For model 3 (Table 4), which was applied to unmatched trips in this analysis, all independent variables (year, gear, sub-region) were significant and explained a significant fraction of the DK variation. DK trends for year and gear were similar to those for models 1 and 2. DK rates were high for the E. Georges Bank, NY Bight, and Southern New England sub-regions. All independent variables in model 4 (which was used in this analysis to estimate discards on matched trips) were significant (Table 5), except for season which was retained to comport with the survey data to be used to allocate aggregate discards to species. Holding the effects of the other independent variables constant, the least squares means showed a similar trend for year, but the discard rate for trawls was lower than the other model formulations which did not use mesh as an independent variable. Somewhat counter intuitively, the DK rate was highest for large mesh trawls and gillnets, and lowest for small mesh trawls and gillnets. This may be related to the lower amount of kept for other species compared to the discard of skates for vessels using large mesh. It also suggests that vessels using mesh larger than 8 inches may have a lower skate discard rate – or simply catch more of the target species relative to the amount of skates discarded.

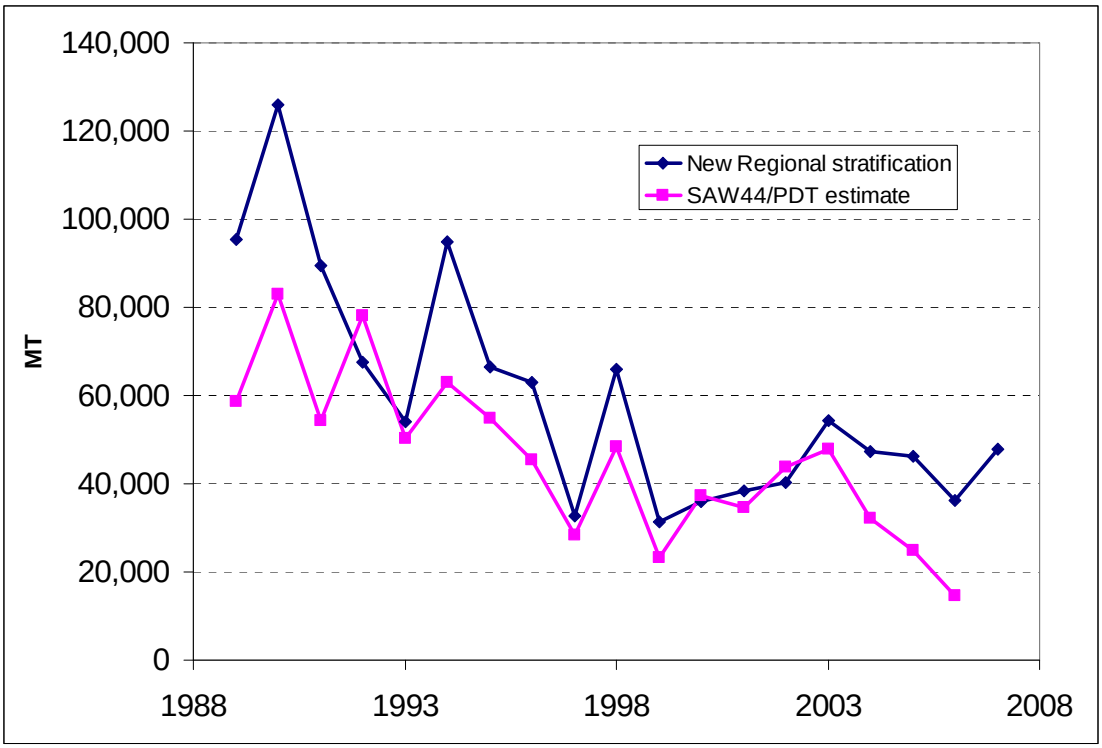


Figure 1. Comparison of new NEFSC discard estimates with SAW44/PDT discard estimates.

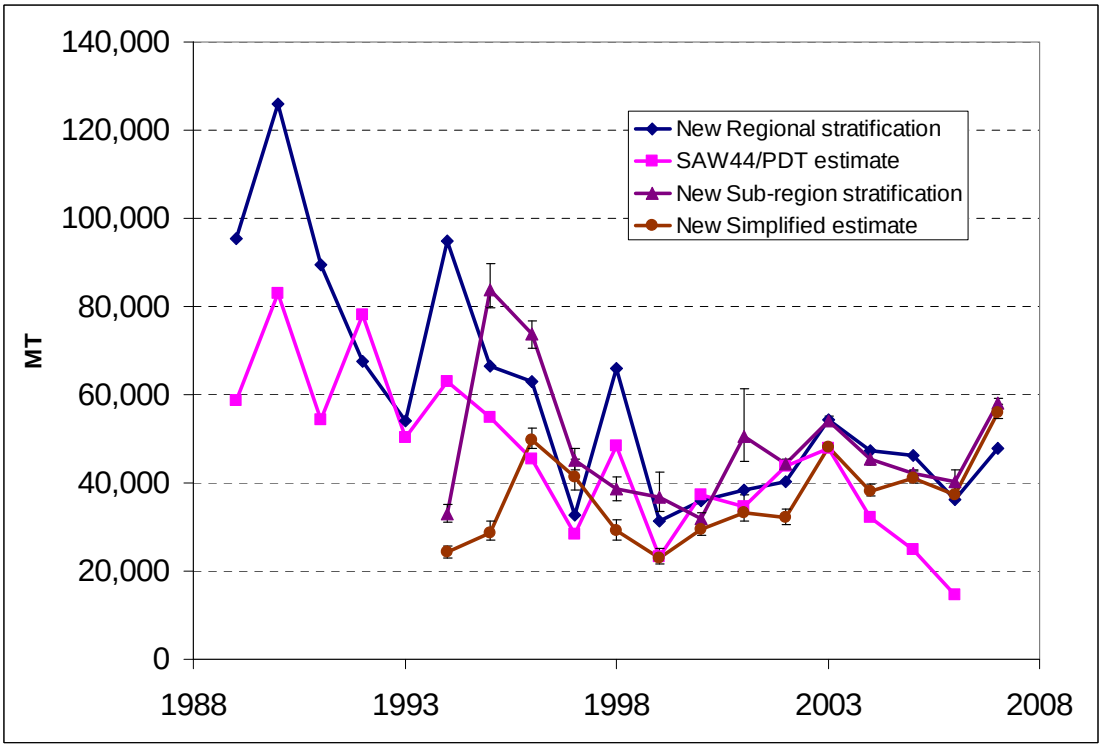


Figure 2. Comparison of discard estimates, including one using a simplified method and a re-stratification at the subregion level (gear, sub-region, season, mesh)

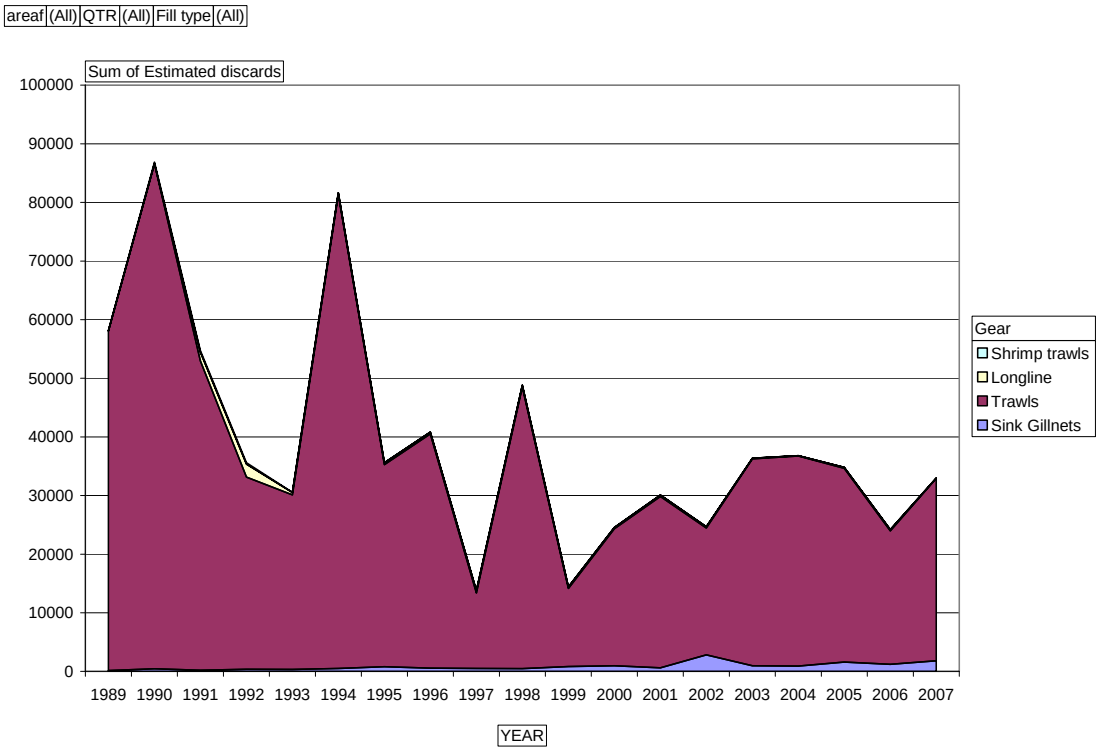


Figure 3. Match trips and all fill types: Estimated discards by gear type via the new NEFSC skate discard estimation.

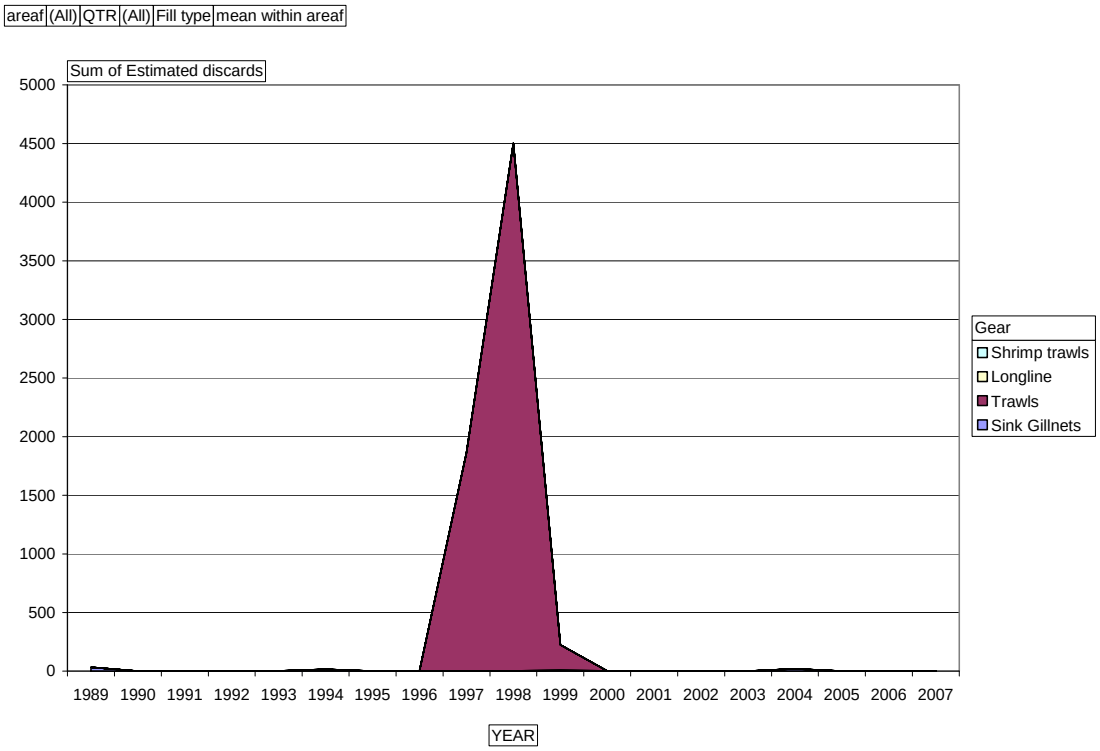


Figure 4. Mean within area fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

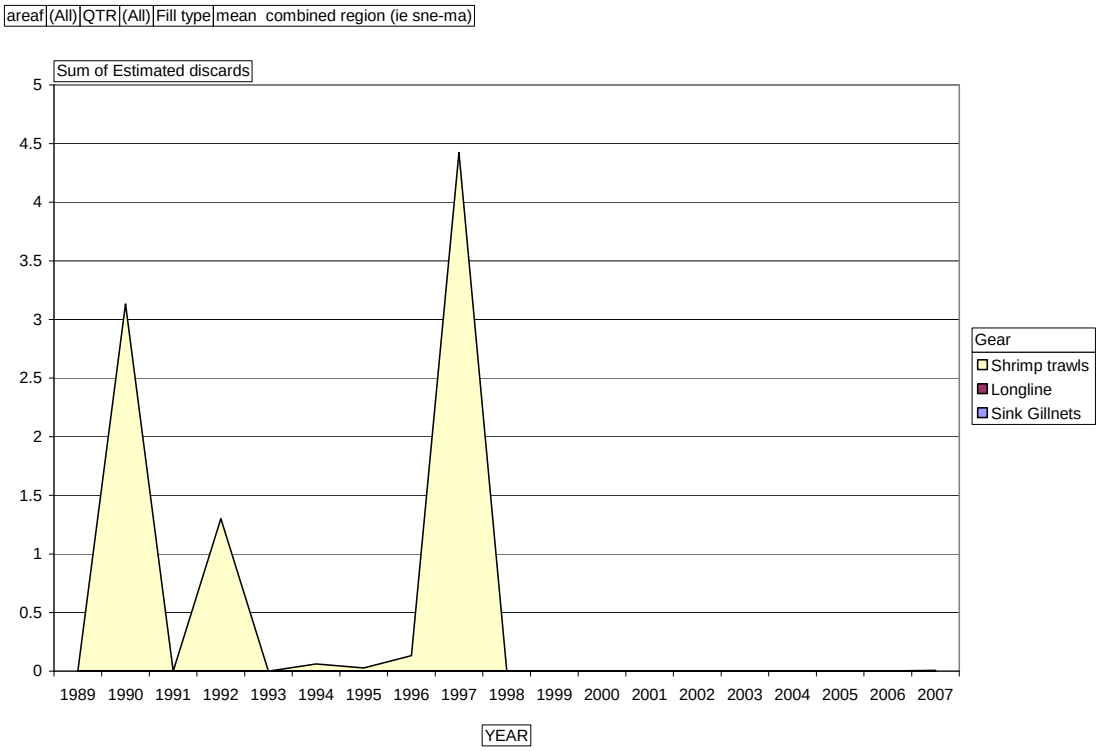


Figure 5. Mean within region fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

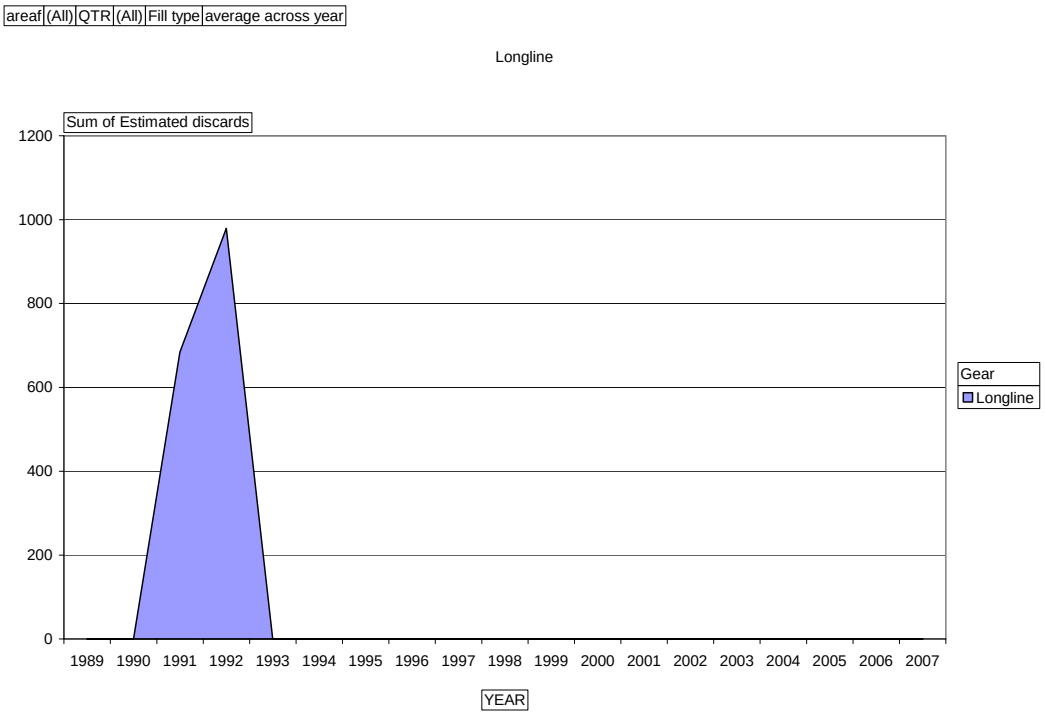


Figure 6. Mean within year fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

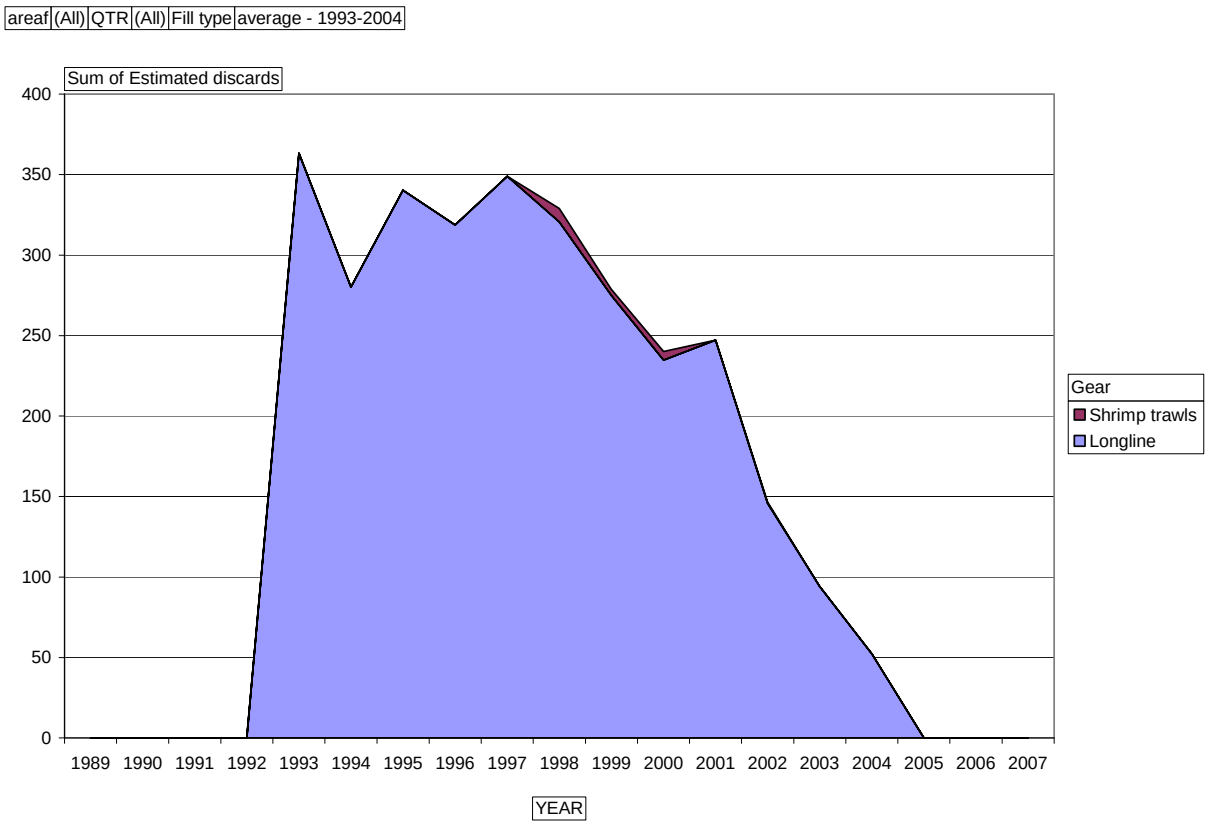


Figure 7. Mean for gear fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

Fill type	None

Average of dkratio		Gear areaf																				
		Longline				Scallop dredges				Shrimp trawls		Sink Gillnets				Trawls				Grand Total
YEAR	QTR	GBK	GOM	MA	SNE	GBK	GOM	MA	SNE	GBK	GOM	GBK	GOM	MA	SNE	GBK	GOM	MA	SNE	
1989	1									0.000	0.020				0.000	0.802	0.346	0.213	1.688	0.438
	2										0.042	0.003			0.000	0.272	0.166	0.024	0.297	0.115
	3											0.005	0.003		0.000	0.286	0.128	0.510	1.136	0.295
	4										0.018	0.018	0.008		0.000	0.386	0.194	0.145	0.569	0.167
1990	1										0.050	0.014	0.107			1.037	0.246	0.144	2.583	0.597
	2										0.011	0.013	0.047	0.000		0.335	0.130	0.103	0.081	0.090
	3											0.000	0.003			0.125	0.028	0.384	0.131	0.112
	4										0.114	0.002	0.009	0.000	0.000	0.281	0.280	0.426	1.825	0.326
1991	1	0.774								0.289	0.069	0.005	0.041	0.000		0.345	0.123	0.009	0.706	0.236
	2										0.038	0.007	0.014	0.000		0.399	0.042	0.444	0.451	0.174
	3											0.019	0.008		0.000	0.075	0.083	1.595	0.363	0.306
	4	0.174	0.041								0.129	0.045	0.007		0.000	0.516	0.086	0.209	0.257	0.147
1992	1	0.906	0.110								0.078	0.053	0.104	0.000	0.016	0.474	0.102	0.109	0.027	0.180
	2	0.222		0.000							0.000	0.013	0.017		0.053	0.100	0.014	0.020	0.395	0.083
	3											0.002	0.003		0.067	0.029	0.024	0.212	0.231	0.081
	4										0.001	0.039	0.005		0.018	0.170	0.048	0.609	0.591	0.185
1993	1		0.088	0.000						0.000	0.018	0.017	0.050	0.000	0.044	0.116	0.146	0.024	0.060	0.047
	2			0.068								0.005	0.017		0.041	0.257	0.053	0.045	0.645	0.141
	3			0.000								0.002	0.002	0.000	0.170	0.020	0.025	0.047	0.866	0.126
	4										0.003	0.020	0.004	0.002	0.011	0.748	0.079	0.444	0.258	0.174
1994	1	0.000		0.000							0.005	0.007	0.103	0.007	0.014	0.204	0.030	0.099	0.004	0.043
	2											0.000	0.003	0.003	0.069	0.466	0.070	5.436	2.257	1.038
	3											0.000	0.001	0.001		0.239	0.071	0.048	0.071	0.061
	4										0.001	0.016	0.013	0.013	0.084	0.892	0.026	0.134	0.321	0.166
1995	1										0.002	0.031	0.097	0.014	0.077	0.415	0.048	0.632	0.101	0.157
	2											0.003	0.018	0.010	0.063	0.758	0.035	0.302	0.489	0.210
	3											0.003	0.003	0.004	0.114	0.120	0.011	0.106	0.107	0.058
	4										0.000	0.013	0.050	0.013	0.014	0.235	0.031	0.553	0.137	0.116
1996	1										0.004	0.035	0.216	0.016	0.004	0.615	0.033	0.225	0.132	0.142
	2										0.000	0.002	0.017	0.010	0.013	0.322	0.048	0.036	0.303	0.083
	3											0.008	0.004	0.007	0.000		0.000	0.004	2.012	0.291
	4										0.005	0.011	0.001	0.008	0.014	0.081	0.035	0.074	1.442	0.186
1997	1									0.001	0.006	0.005	0.048	0.019	0.002	0.241	0.128	0.079	0.125	0.065
	2											0.008	0.012	0.046	0.000		0.011		0.058	0.023
	3											0.001	0.000	0.000	0.030	0.145	0.004	0.003	0.531	0.089
	4											0.008	0.002	0.009	0.021	0.270		0.016	0.041	0.052
1998	1											0.022	0.021	0.008	0.002	0.169	0.092	0.051	0.072	0.055
	2											0.002	0.003	0.025	0.006		0.023	1.984	0.183	0.318
	3			0.087								0.022	0.001	0.028		0.148	0.579	0.113	0.064	0.130
	4											0.004	0.007	0.017	0.016	1.149		0.116	0.185	0.213
1999	1											0.090	0.008	0.021	0.014	0.004		0.010	0.006	0.022
	2											0.003	0.015	0.079	0.013	0.370	0.020	0.139	0.008	0.081
	3											0.003	0.003	0.000		0.405	0.042	0.009		0.077
	4											0.004	0.037	0.015	0.058	0.421	0.007	0.112	0.101	0.094
2000	1											0.016	0.015	0.000	0.023	0.123	0.151	0.039	0.094	0.057
	2											0.038	0.032	0.005	0.032	0.294	0.108	0.123	0.153	0.098
	3											0.486	0.007	0.000		0.197	0.016	0.011	0.186	0.129
	4											0.096	0.012	0.009	0.012	0.543	0.053	0.446	0.466	0.204
2001	1										0.000	0.058	0.020	0.004	0.000	1.129	0.062	0.004	0.041	0.146
	2											0.018	0.056	0.006	0.183	0.144	0.056	0.071	0.323	0.107
	3											0.009	0.011	0.000	0.000	0.164	0.064	0.014	0.114	0.047
	4											0.078	0.010	0.005	0.016	0.308	0.037	0.062	0.217	0.092
2002	1											0.033	0.002	0.029	0.035	0.459	0.031	0.065	0.000	0.082
	2											0.119	0.016	0.015	0.045	0.422	0.092	0.080	0.045	0.104
	3	0.212										0.022	0.052	0.000	0.021	0.309	0.072	0.058	0.081	0.092
	4	0.033	0.000		0.456							0.030	0.013	0.003	1.702	0.289	0.095	0.216	0.333	0.288
2003	1	0.155	0.057			0.018	0.042	0.073	0.008		0.009	0.286	0.029	0.025	0.069	0.576	0.077	0.186	0.716	0.150
	2					0.156		0.114				0.019	0.018	0.004	0.046	0.315	0.080	0.160	0.035	0.096
	3					0.099		0.217				0.036	0.011	0.000	0.055	0.472	0.085	0.005	2.266	0.315
	4	0.000				0.108		0.043	0.396			0.021	0.008	0.024	0.103	0.451	0.057	0.105	0.348	0.130
2004	1	0.013	0.011			0.045	0.003	0.062			0.004	0.064	0.026	0.000	0.036	0.446	0.049	0.064	0.111	0.067
	2							0.067				0.022	0.018	0.000	0.044	0.568	0.119	0.079	0.173	0.116
	3	0.035						0.083				0.046	0.009		0.025	0.620	0.042	0.023	0.729	0.169
	4	0.008		0.000	0.000	0.056	0.139	0.074	0.383			0.069	0.021	0.049	0.053	0.562	0.119	0.044	0.865	0.164
2005	1	0.093	0.052		0.000	0.025	0.051	0.147	0.263		0.003	0.767	0.051	0.025	0.059	0.538	0.059	0.045	0.168	0.140
	2	0.289	0.024			0.035		0.065				0.007	0.034	0.104	0.089	0.571	0.060	0.327	0.951	0.190
	3	0.105	0.012			0.039		0.082	0.397			0.045	0.009	0.038	0.106	0.718	0.067	0.155	0.627	0.168
	4	0.034	0.001	0.000	0.000	0.032		0.110	0.334			0.117	0.007	0.052	0.061	0.682	0.174	0.110	0.649	0.147
2006	1	0.498	0.040		0.008	0.041		0.076			0.000	0.023	0.050	0.035	0.067	0.717	0.106	0.034	0.174	0.130
	2	0.234		0.000		0.013						0.229	0.030	0.086	0.330	0.451	0.178	0.036	0.071	0.139
	3	0.000	0.000		0.000	0.048		0.140	0.152			0.058	0.008	0.003	0.126	0.730	0.079	0.021	0.274	0.114
	4	0.054	0.039	0.000	0.001	0.069		0.251	0.339		0.001	0.100	0.006	0.022	0.002	0.715	0.077	0.079	0.231	0.128
2007	1	0.376	0.093			0.036		0.106	0.794		0.000	0.622	0.018	0.025	0.119	0.680	0.153	0.109	0.178	0.216
	2	0.046	0.034			0.015	0.047	0.052	0.125			0.033	0.019	0.117	0.075	0.556	0.062	0.547	0.415	0.138
	3	0.081	0.091	0.000		0.031		0.068				0.069	0.013	0.013	0.040	1.062	0.031	0.050	0.479	0.142
	4	0.051	0.005	0.000	0.000	0.228	0.106	0.086	1.178			0.083	0.011	0.019	0.419	0.645	0.081	0.213	0.382	0.263
Grand Total		0.183	0.041	0.013	0.058	0.059	0.065	0.102	0.456	0.073	0.022	0.057	0.024	0.017	0.075	0.423	0.086	0.261	0.451	0.160

Figure 8. Observed D/K ratios by stratum, NEFSC estimation.

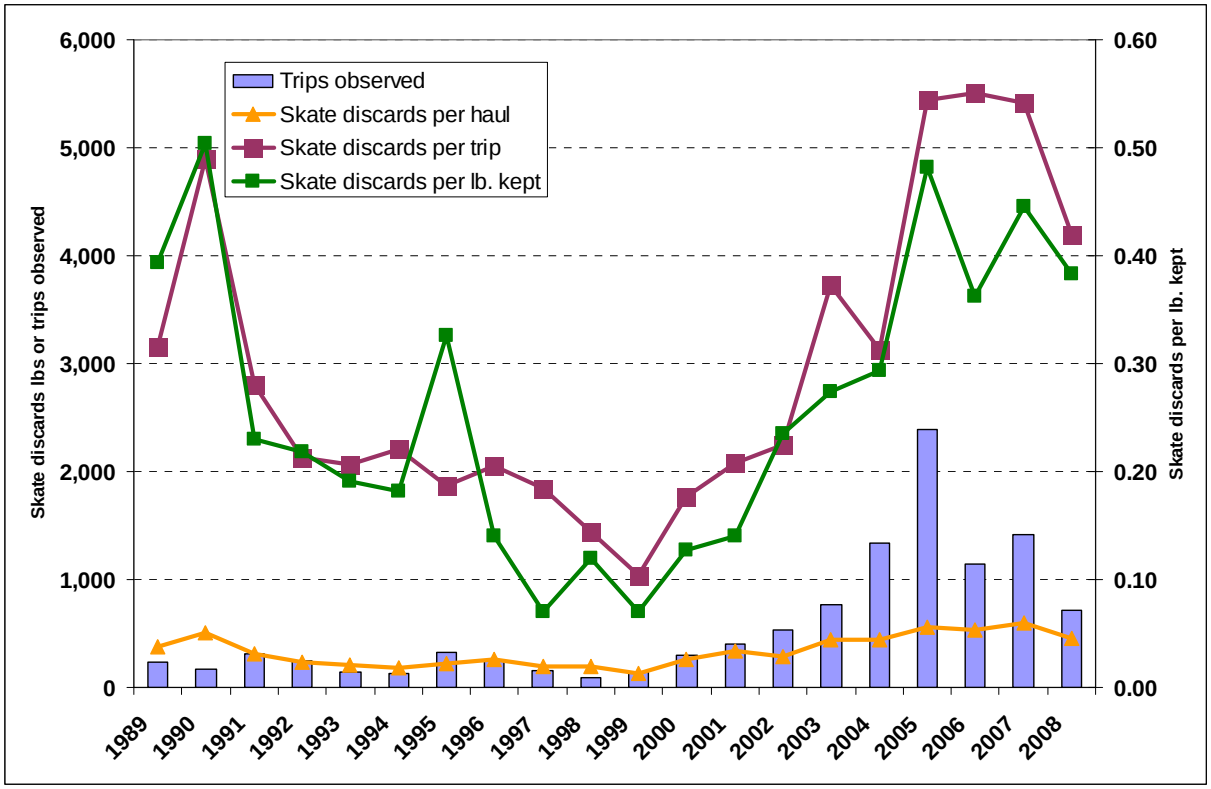


Figure 9. Observed skate discard rate for vessels using trawls.

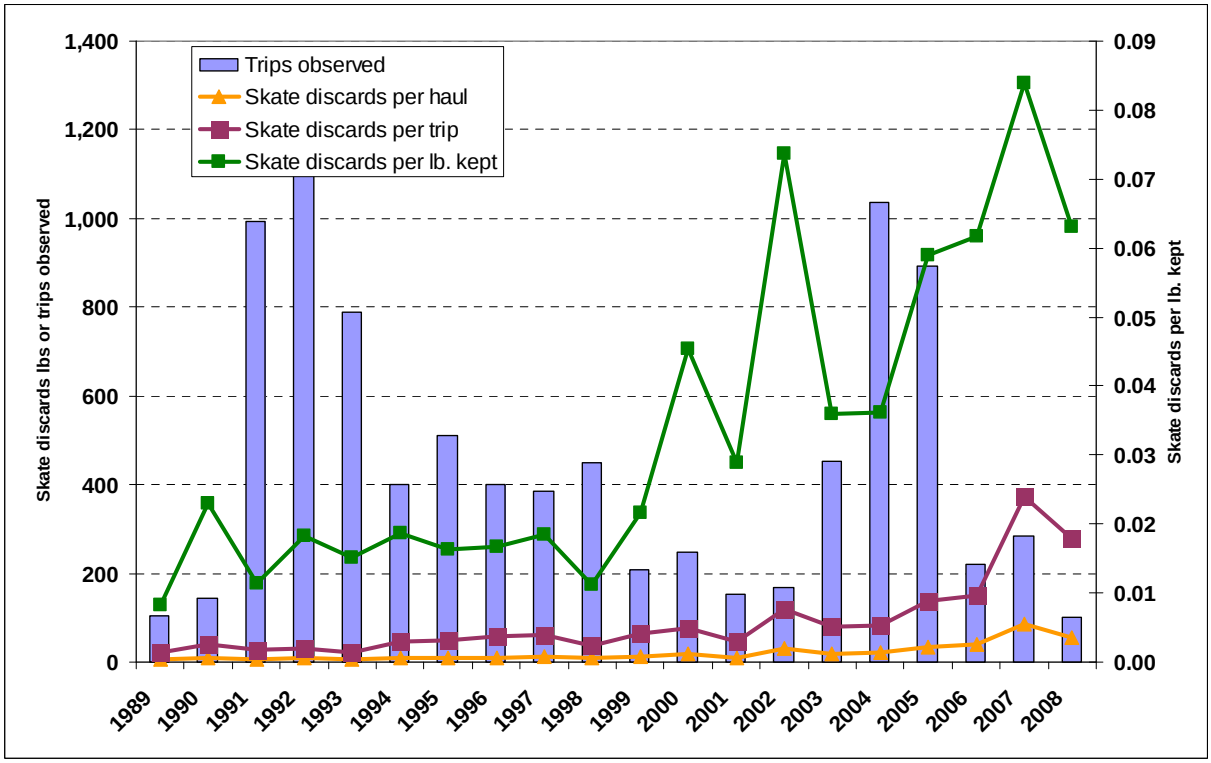


Figure 10. Observed skate discard rate for vessels using sink gillnets.

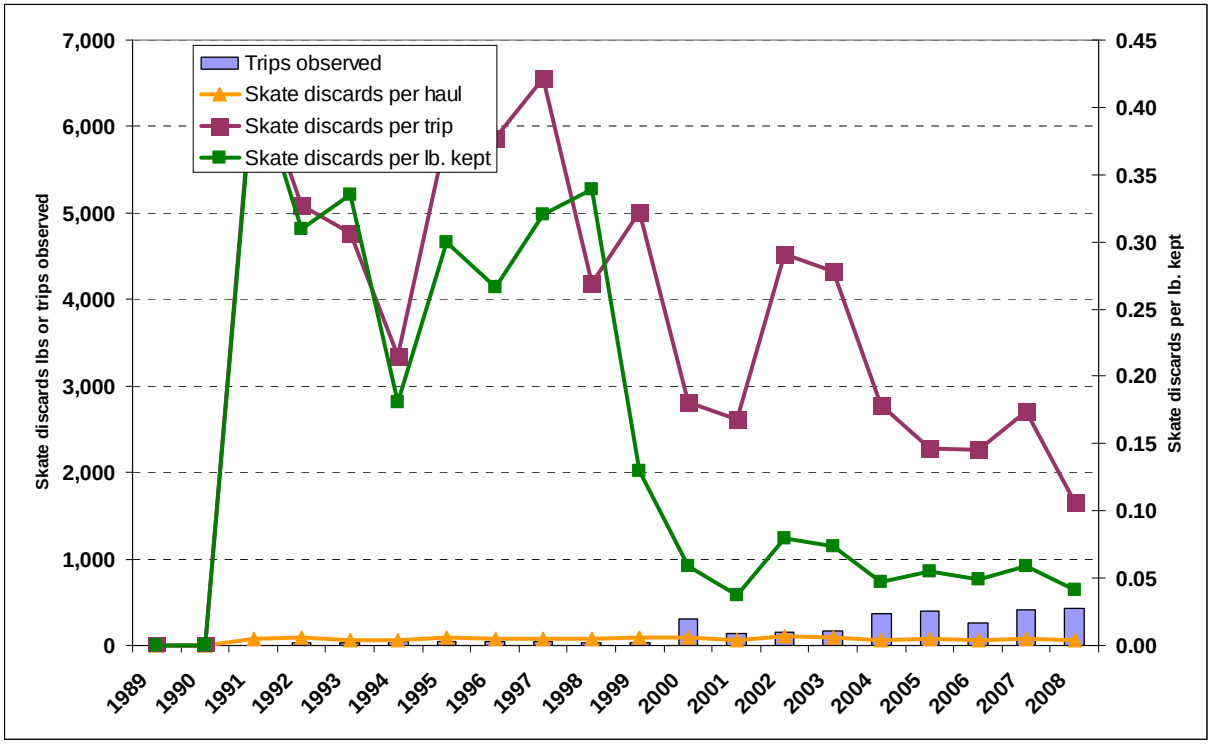


Figure 11. Observed skate discard rate for vessels using scallop dredges.

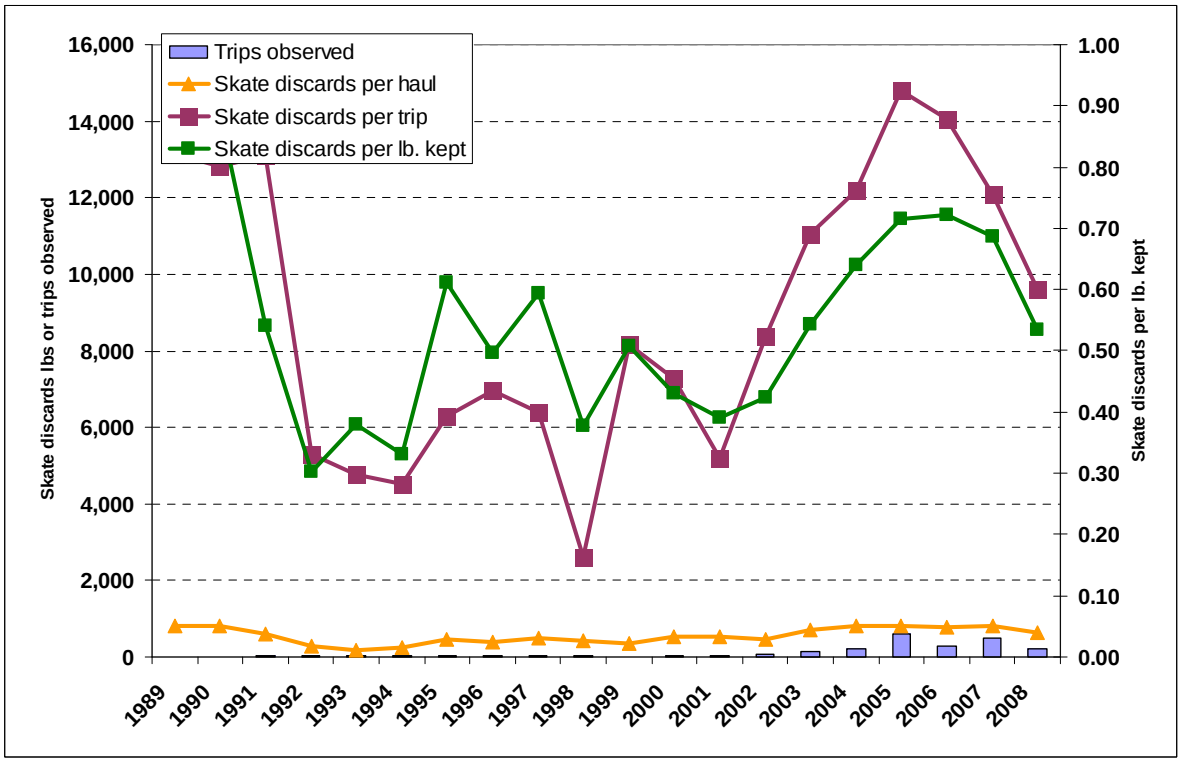


Figure 12. Observed skate discard rate for vessels landing > 1000 lbs. of skate, live weight.

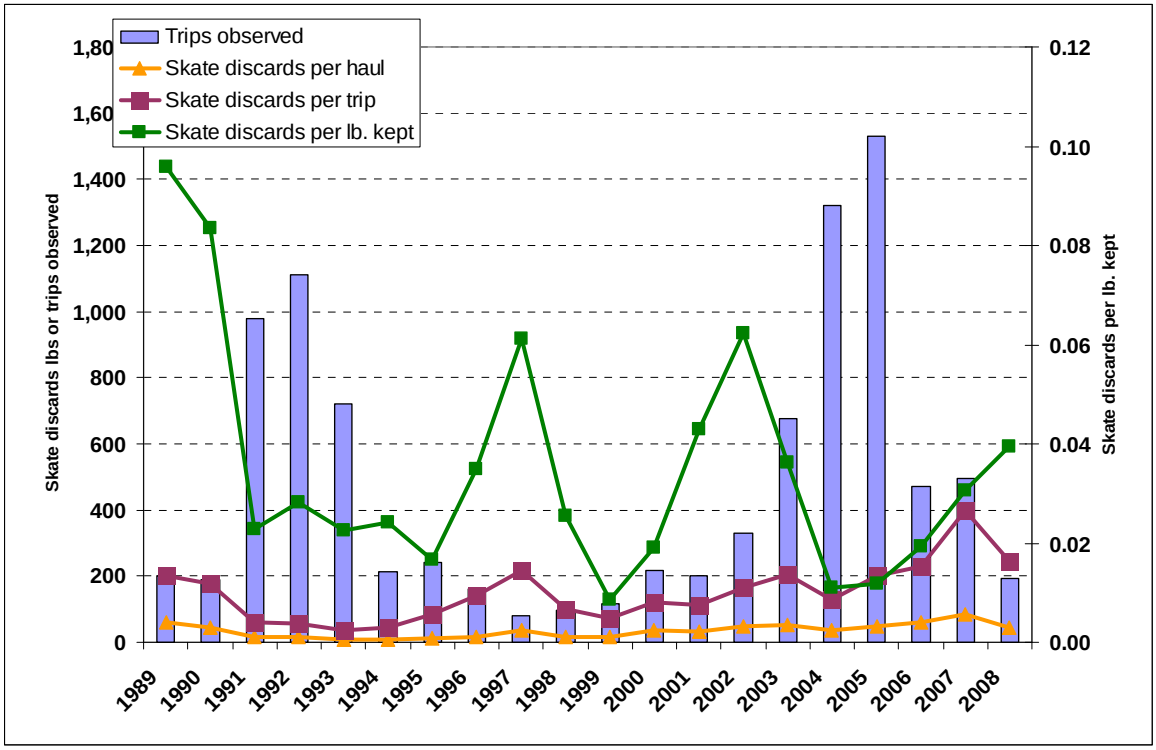


Figure 13. Observed skate discard rate for vessels fishing in the Gulf of Maine.

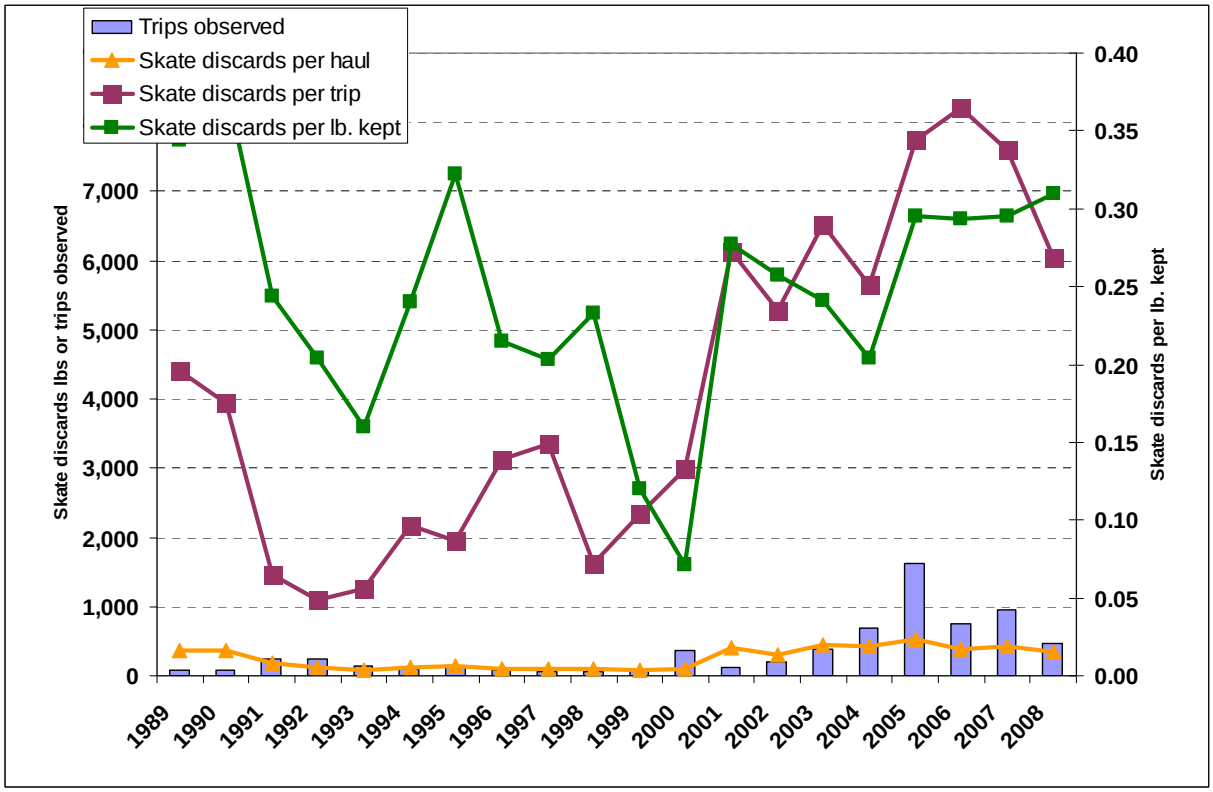


Figure 14. Observed skate discard rate for vessels fishing on Georges Bank.

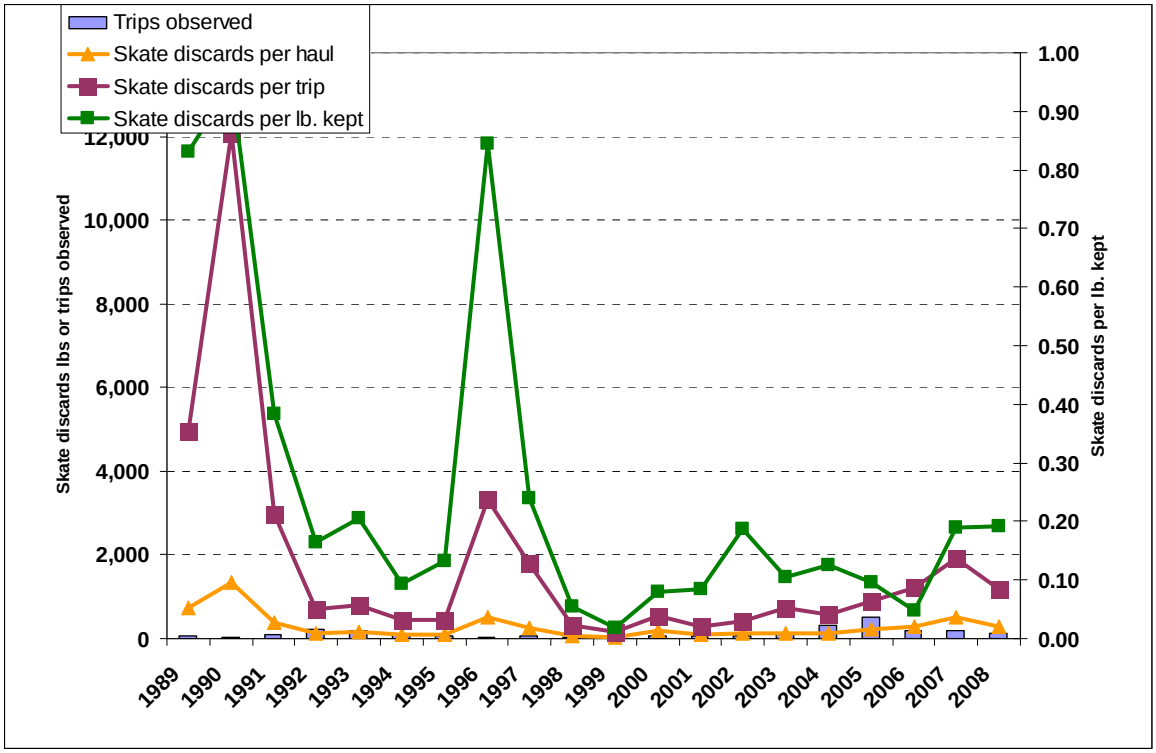


Figure 15. Observed skate discard rate for vessels fishing in Southern New England.

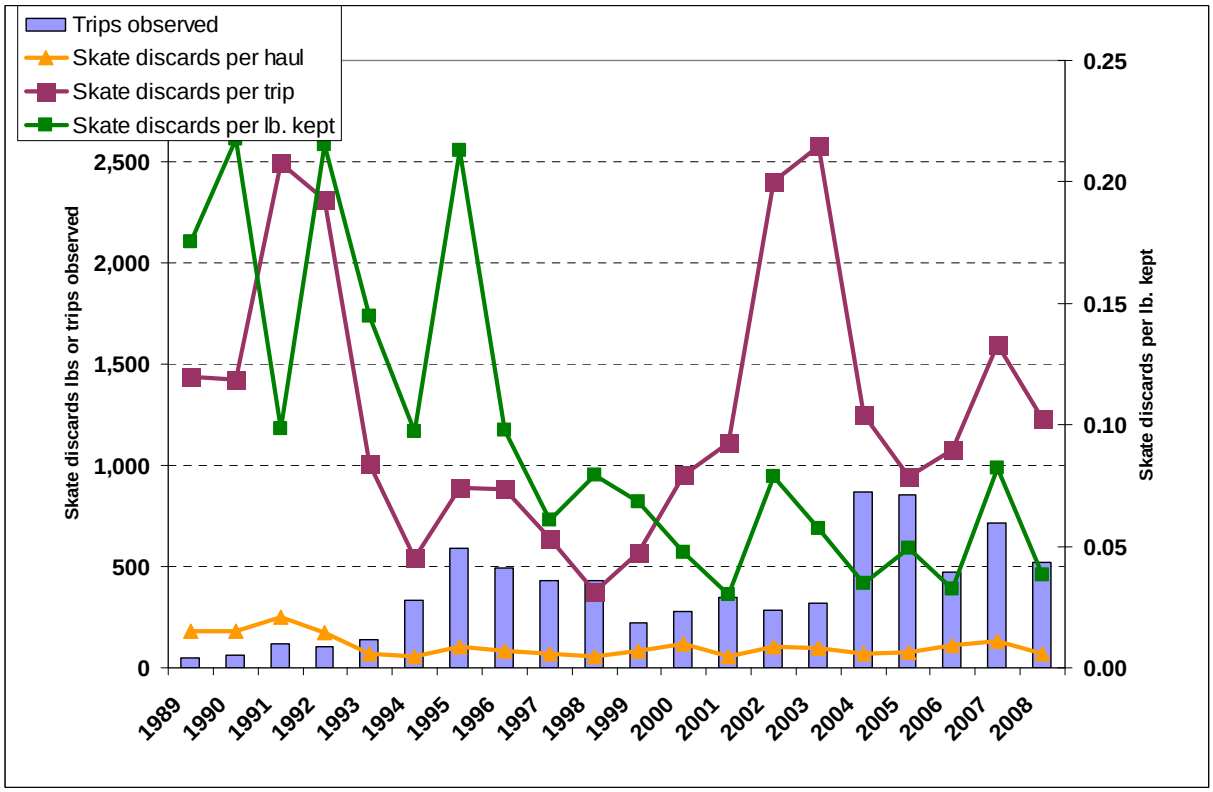


Figure 16. Observed skate discard rate for vessels fishing in the Mid-Atlantic.

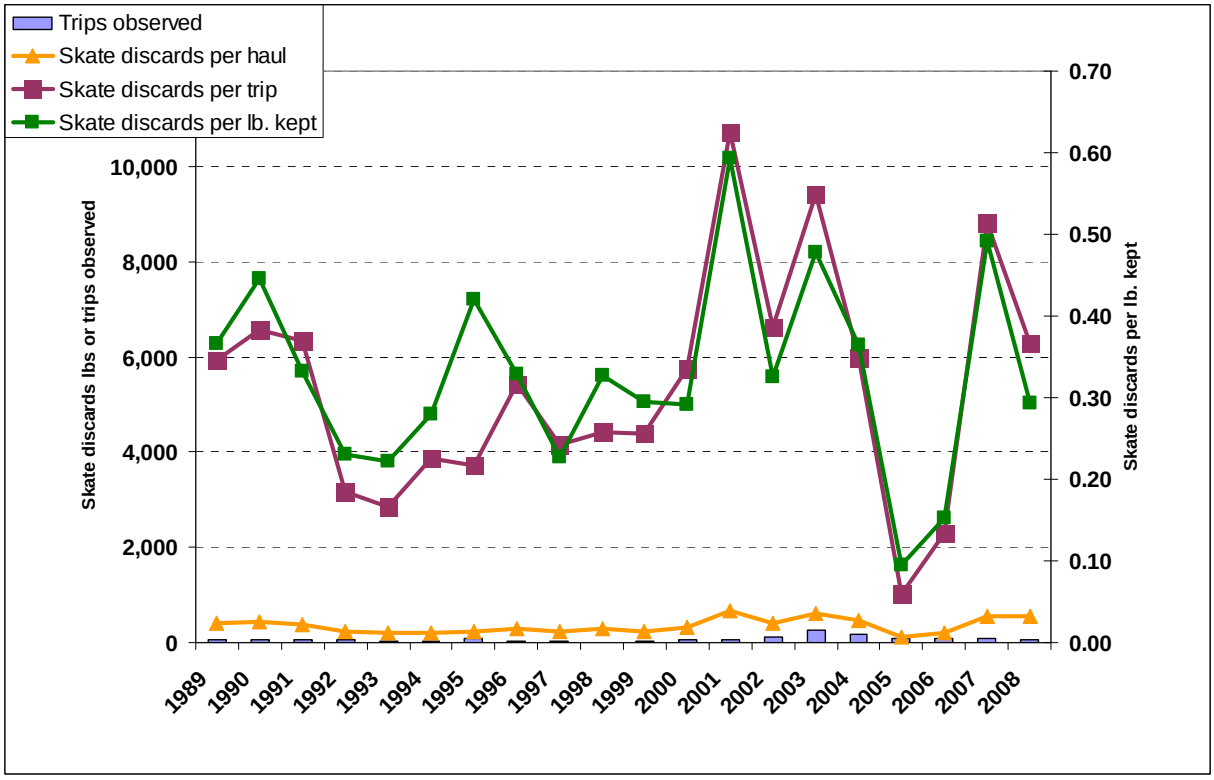


Figure 17. Observed skate discards for vessels using trawls on regular Georges Bank region trips.

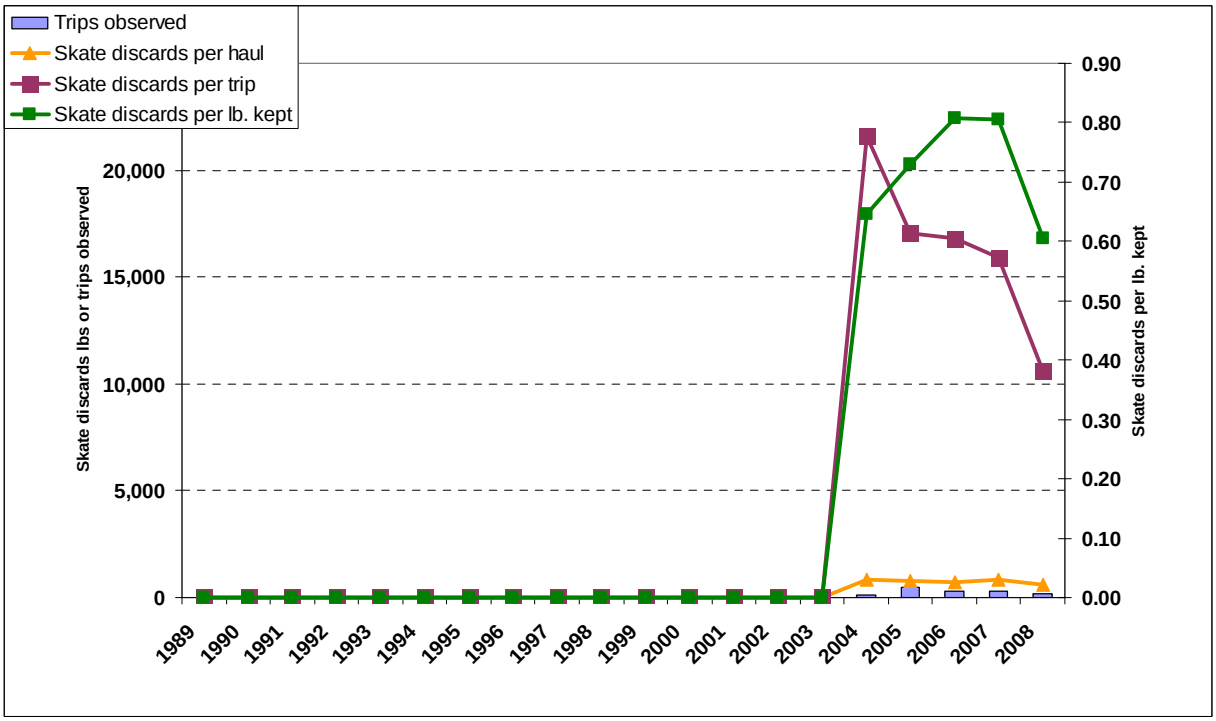


Figure 18. Observed skate discards for vessels using trawls on US/CA trips in the E. Georges Bank sub-region.

Table 1. GLM statistics for various independent variables predictors of average observed DK ratios.

Stratification model	Statistic					
	Multiple R	F-ratio (df)	p-value	Kolmogorov -Smirnov	Durbin-Watson D	AIC
1. NEFSC	0.127	13.45 (24)	0	0.361	1.927	90,347
2. NEFSC regular trips	0.112	7.573 (24)	0	0.378	1.945	69,420
3. Gear/ Sub-region	0.136	14.012 (27)	0	0.358	1.930	92,665
4. Gear/ sub-region/ season/mesh	0.136	9.902 (28)	0	0.368	1.941	71,517

Table 2. GLM statistics and results for Model 1, gear/region/quarter.

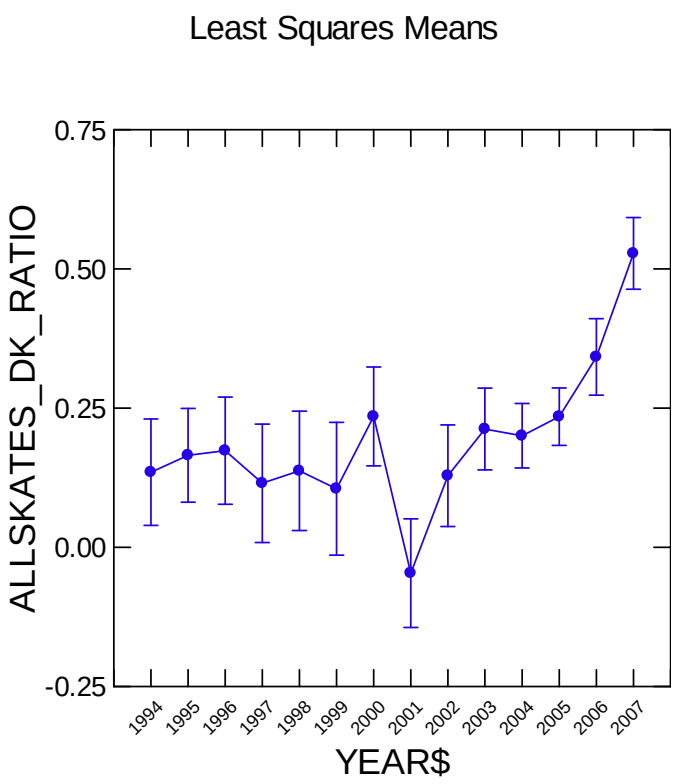
Analysis of Variance

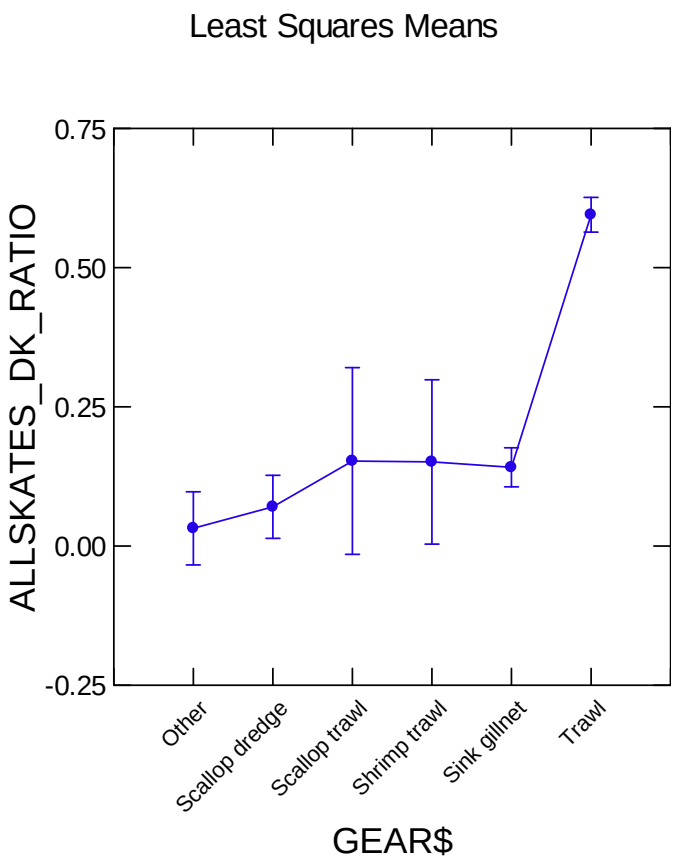
Source	Type III SS	df	Mean Squares	F-ratio	p-value
YEAR$	307.2600	13	23.6354	4.0798	0.0000
GEAR$	1035.3742	5	207.0748	35.7442	0.0000
REGION$	140.1059	3	46.7020	8.0615	0.0000
QTR$	23.3255	3	7.7752	1.3421	0.2587
Error	113738.7331	19633	5.7932		

Estimates of Effects B = $(X'X)^{-1}X'Y$

Factor	Level	ALLSKATES_DK_RA-TIO
CONSTANT		0.1932
YEAR$	1994	-0.0532
YEAR$	1995	-0.0242
YEAR$	1996	-0.0193
YEAR$	1997	-0.0731
YEAR$	1998	-0.0556
YEAR$	1999	-0.0910
YEAR$	2000	0.0417
YEAR$	2001	-0.2394
YEAR$	2002	-0.0589
YEAR$	2003	0.0209
YEAR$	2004	0.0098
YEAR$	2005	0.0469
YEAR$	2006	0.1568
GEAR$	Other	-0.1614
GEAR$	Scallop dredge	-0.1201
GEAR$	Scallop trawl	-0.0262
GEAR$	Shrimp trawl	-0.0413
GEAR$	Sink gillnet	-0.0526

Estimates of Effects B = $(X'X)^{-1}X'Y$		
Factor	**Level**	**ALLSKATES_DK_RATIO**
REGION$	GB	-0.0575
REGION$	GOM	-0.1278
REGION$	MA	0.0080
QTR$	1.000000	-0.0405
QTR$	2.000000	0.0334
QTR$	3.000000	-0.0295




Least Squares Means
ALLSKATES_DK_RATIO
0.75
0.50
0.25
0.00
-0.25
Other
Scallop dredge
Scallop trawl
Shrimp trawl
Sink gillnet
Trawl
GEAR$

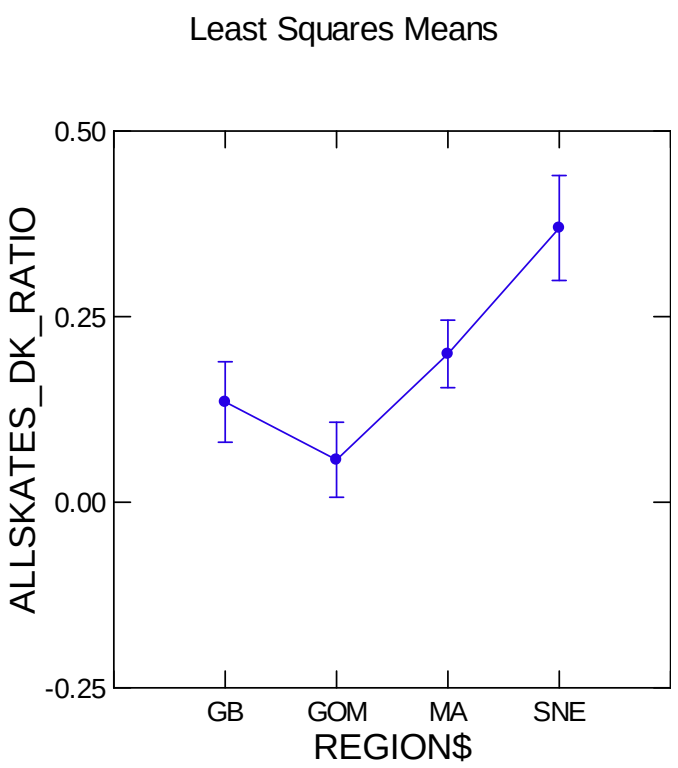

Least Squares Means
ALLSKATES_DK_RATIO
0.50
0.25
0.00
-0.25
GB
GOM
MA
SNE
REGION$

Table 3. GLM statistics and results for Model 2, gear/region/quarter, using only regular management program observed trips.

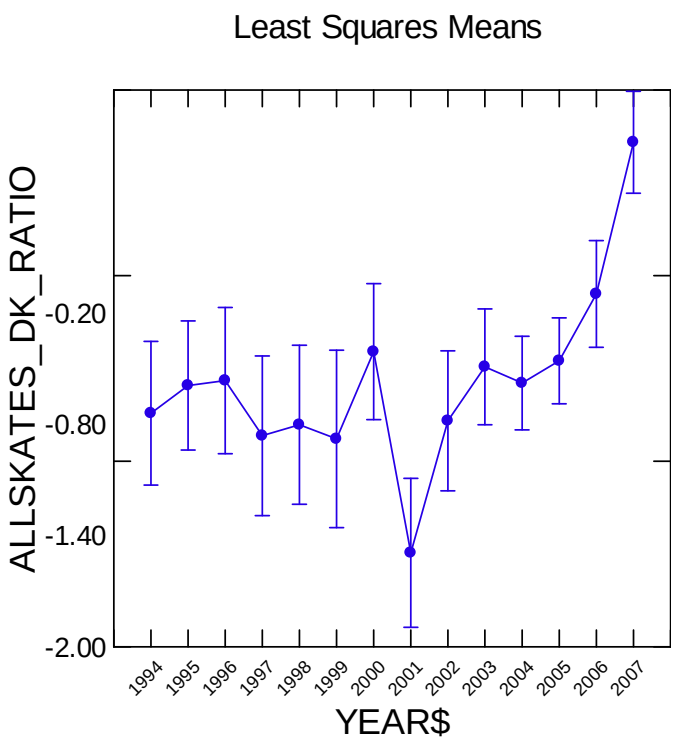
Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
YEAR$	371.1617	13	28.5509	3.8103	0.0000
GEAR$	601.7510	5	120.3502	16.0615	0.0000
REGION$	67.3027	3	22.4342	2.9940	0.0296
QTR$	33.3625	3	11.1208	1.4841	0.2166
Error	106679.1384	14237	7.4931		

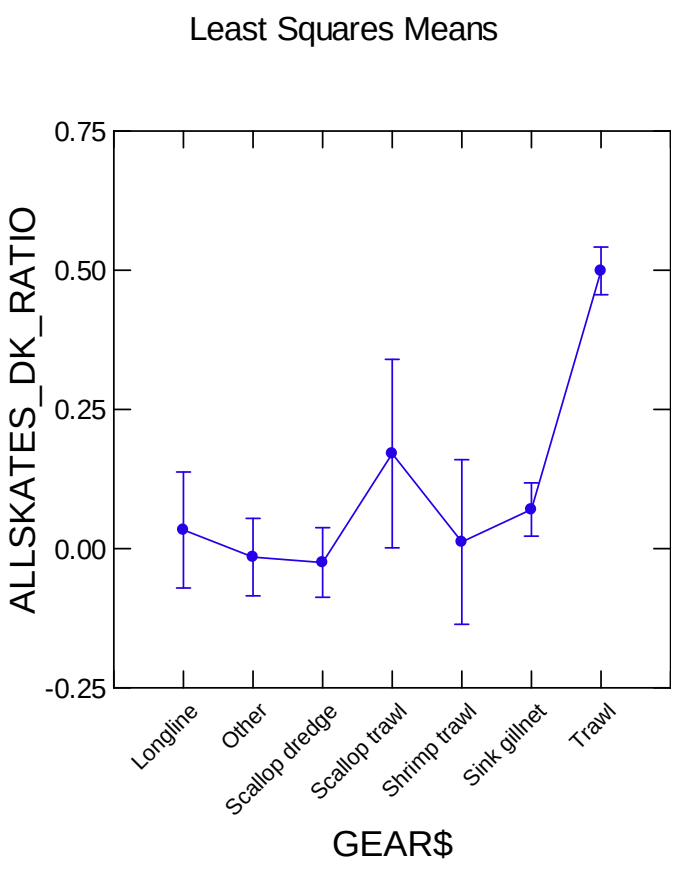
Estimates of Effects $B = (X'X)^{-1}X'Y$		
Factor	**Level**	**ALLSKATES_DK_RATIO**
CONSTANT		0.2075
YEAR$	1994	-0.0629
YEAR$	1995	-0.0254
YEAR$	1996	0.0037
YEAR$	1997	-0.0752
YEAR$	1998	-0.0660
YEAR$	1999	-0.1071
YEAR$	2000	0.0294
YEAR$	2001	-0.2749
YEAR$	2002	-0.0525
YEAR$	2003	0.0028
YEAR$	2004	-0.0375
YEAR$	2005	0.0097
YEAR$	2006	0.1379
GEAR$	Other	-0.1651
GEAR$	Scallop dredge	-0.0354
GEAR$	Scallop trawl	0.0017
GEAR$	Shrimp trawl	-0.1078
GEAR$	Sink gillnet	-0.0570
REGION$	GB	-0.0754
REGION$	GOM	-0.0773
REGION$	MA	-0.0015
QTR$	1.000000	-0.0389
QTR$	2.000000	0.0372
QTR$	3.000000	-0.0556

Table 4. GLM statistics and results for Model 3, DK rates post stratified by gear and sub-region.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
YEAR$	277.7085	13	21.3622	3.8130	0.0000
GEAR$	966.1356	6	161.0226	28.7414	0.0000
SUB_REGION$	378.6510	8	47.3314	8.4483	0.0000
Error	113629.0190	20282	5.6025		

Factor	**Level**	**ALLSKATES_DK_RATIO**
CONSTANT		0.1064
YEAR$	1994	-0.0418
YEAR$	1995	-0.0045
YEAR$	1996	0.0022
YEAR$	1997	-0.0721
YEAR$	1998	-0.0573
YEAR$	1999	-0.0764
YEAR$	2000	0.0412
YEAR$	2001	-0.2299
YEAR$	2002	-0.0521
YEAR$	2003	0.0208
YEAR$	2004	-0.0011
YEAR$	2005	0.0288
YEAR$	2006	0.1189
GEAR$	Longline	-0.0729
GEAR$	Other	-0.1217
GEAR$	Scallop dredge	-0.1314
GEAR$	Scallop trawl	0.0643
GEAR$	Shrimp trawl	-0.0946
GEAR$	Sink gillnet	-0.0362
SUB_REGION$	Delmarva	-0.0171
SUB_REGION$	E. GB	0.1545
SUB_REGION$	E. GM	-0.3530
SUB_REGION$	NY Bight	0.2262
SUB_REGION$	Offshore	-0.2487
SUB_REGION$	Other	0.0182
SUB_REGION$	S. Channel	-0.0531
SUB_REGION$	SNE	0.2751


Least Squares Means
ALLSKATES_DK_RATIO
-0.20
-0.80
-1.40
-2.00
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
YEAR$


Least Squares Means
ALLSKATES_DK_RATIO
0.75
0.50
0.25
0.00
-0.25
Longline
Other
Scallop dredge
Scallop trawl
Shrimp trawl
Sink gillnet
Trawl
GEAR$

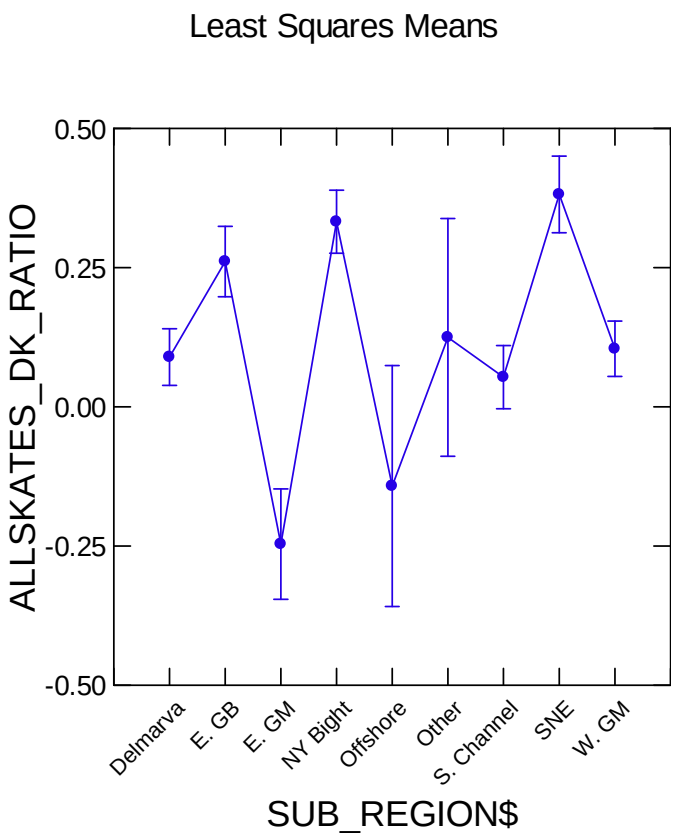
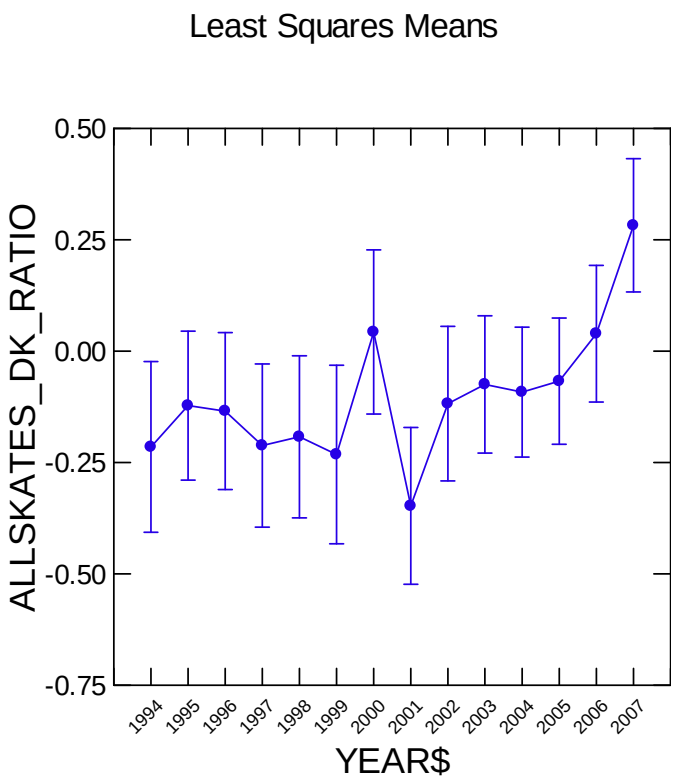
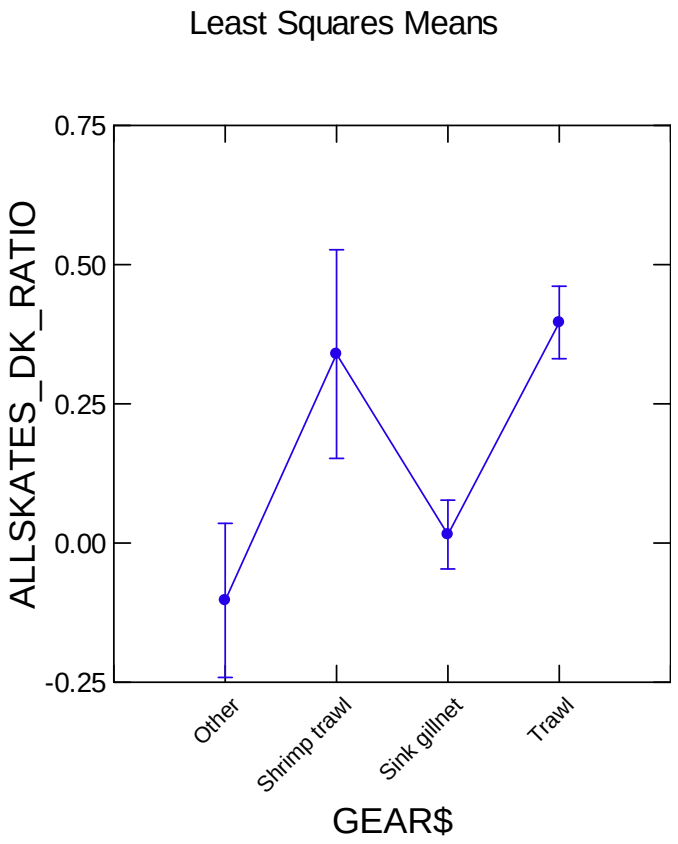

Least Squares Means
0.50
0.25
0.00
-0.25
-0.50
ALLSKATES_DK_RATIO
Delmarva
E. GB
E. GM
NY Bight
Offshore
Other
S. Channel
SNE
W. GM
SUB_REGION$

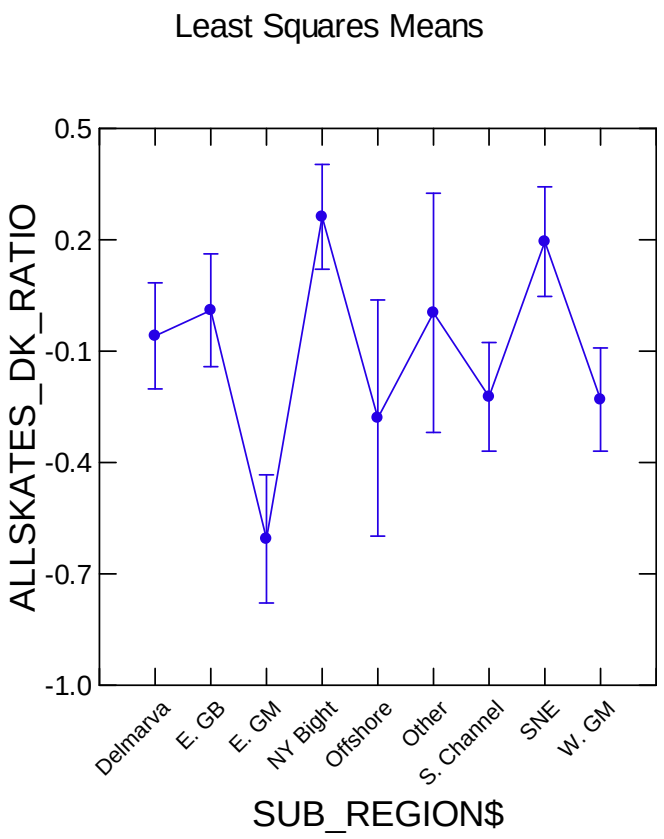
Table 5. GLM statistics and results for Model 4, DK rates post stratified by gear, sub-region, season, and mesh.

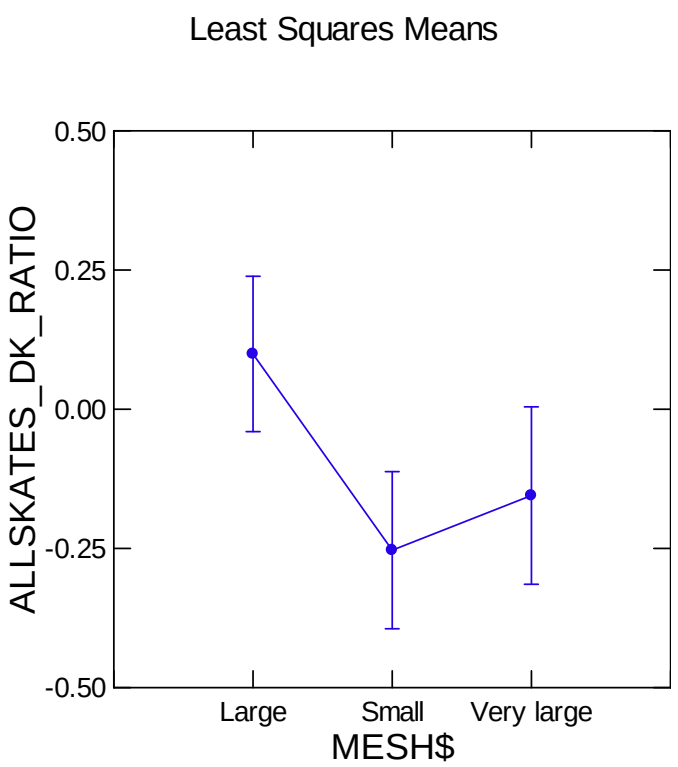
Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
YEAR$	282.2944	13	21.7150	3.0537	0.0002
GEAR$	332.8477	4	83.2119	11.7016	0.0000
SUB_REGION$	518.3715	8	64.7964	9.1120	0.0000
SEASON$	26.4886	2	13.2443	1.8625	0.1553
MESH$	244.0847	2	122.0423	17.1621	0.0000
Error	105372.8981	14818	7.1111		

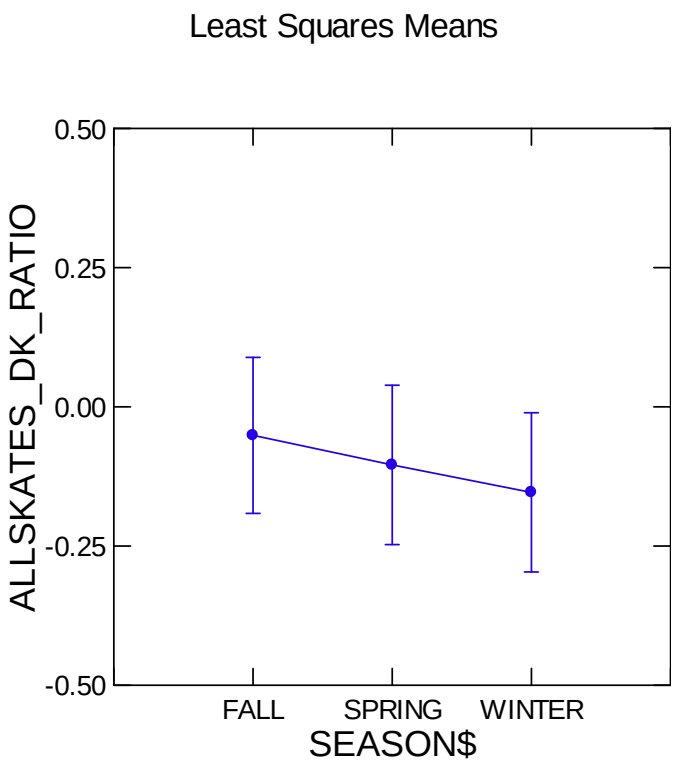
Estimates of Effects $B = (X'X)^{-1}X'Y$		
Factor	**Level**	**ALLSKATES_DK_RATIO**
CONSTANT		0.5507
YEAR$	1994	-0.4975
YEAR$	1995	-0.4047
YEAR$	1996	-0.4169
YEAR$	1997	-0.4944
YEAR$	1998	-0.4748
YEAR$	1999	-0.5144
YEAR$	2000	-0.2394
YEAR$	2001	-0.6300
YEAR$	2002	-0.4004
YEAR$	2003	-0.3571
YEAR$	2004	-0.3743
YEAR$	2005	-0.3498
YEAR$	2006	-0.2432
GEAR$	Other	-0.4991
GEAR$	Shrimp trawl	-0.0567
GEAR$	Sink gillnet	-0.3809
SUB_REGION$	Delmarva	0.1714
SUB_REGION$	E. GB	0.2404
SUB_REGION$	E. GM	-0.3755
SUB_REGION$	NY Bight	0.4924
SUB_REGION$	Offshore	-0.0499
SUB_REGION$	Other	0.2337
SUB_REGION$	S. Channel	0.0072
SUB_REGION$	SNE	0.4252
MESH$	Large	0.2542
MESH$	Small	-0.0982
SEASON$	FALL	0.1023
SEASON$	SPRING	0.0493


Least Squares Means
ALLSKATES_DK_RATIO
0.50
0.25
0.00
-0.25
-0.50
-0.75
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
YEAR$


Least Squares Means
ALLSKATES_DK_RATIO
0.75
0.50
0.25
0.00
-0.25
Other
Shrimp trawl
Sink gillnet
Trawl
GEAR$


Least Squares Means
ALLSKATES_DK_RATIO
0.5
0.2
-0.1
-0.4
-0.7
-1.0
Delmarva
E. GB
E. GM
NY Bight
Offshore
Other
S. Channel
SNE
W. GM
SUB_REGION$


Least Squares Means
ALLSKATES_DK_RATIO
0.50
0.25
0.00
-0.25
-0.50
Large
Small
Very large
MESH$



Draft Working Paper for pre-dissemination peer review only.

Skate Complex
Methodology to determine overfished and overfishing reference points
Appendix 3

By
Elizabeth Brooks[1], Todd Gedamke[2], and Kathy Sosebee[1]
[1]NEFSC, 166 Water Street, Woods Hole, MA 02543
[2]SEFSC, 75 Virginia Beach Drive, Miami, FL 33149

Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

This Working Paper was distributed for pre-dissemination peer review at the NE Data Poor Stocks Peer Review Meeting, December 8-12, 2008. It does not represent any final NOAA agency determination or policy. Some comments in the Peer Review Panel's Report of the Data Poor Stock Working Group are in response to this WP.

Executive Summary

SPR-based reference points for three skate species, Barndoor, Winter, and Thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships. Estimated overfishing reference points for these three species are $F_{25\%}$, $F_{37\%}$, and $F_{46\%}$, respectively. Future assessments could estimate comparable F's from mean length models (SEINE, e.g.), or from age-specific assessment models provided discards and landings could be disaggregated to species level. Estimates of overfished reference points are also SPR based, and are defined in terms of depletion, i.e. the proportion of spawners relative to unexploited levels. For Barndoor, Winter, and Thorny skates, the depletion reference points are 0.20, 0.27, and 0.32, respectively. Future assessments could determine stock status by comparing these depletion levels either with depletion in the surveys (provided information is available to estimate depletion for the first year in the survey) or from a stock assessment model that incorporates information about maturity. The same approach to derive reference points was attempted for Clearnose skate, however the parameter estimates from stock recruit curve were unrealistic.

There are several important caveats for the methods used in this working paper, namely, that a fixed value of M was assumed for all ages, that the errors in variables problem was ignored in fitting the stock recruit relationship (*status quo*), and that no fishing is assumed to occur prior to the age of recruitment. The sensitivity to the assumed M value is addressed by exploring alternative values. If any fishing were to occur prior to the age of recruitment, then the estimated slope at the origin (*a* in the Beverton-Holt function) would be biased low, leading to an SPR reference point having a positive bias.

Introduction

Determination of stock status requires a set of reference points that are measured in the same units as estimates of current stock levels. The *de facto* target reference points are associated with Maximum Sustainable Yield (MSY), with limit reference points being some fraction of the target, typically one-half of the target. When MSY estimates can't be obtained, reference points based on spawning potential ratio (SPR) are a common proxy. There is abundant literature exploring the use of SPR (Goodyear 1977; Gabriel et al. 1989; Goodyear 1993; Mace 1993) and recommending appropriate levels of SPR (Clark 1991; Mace and Sissenwine 1993). Brooks et al. (*in prep.*) suggest that the appropriate level depends on species-specific characteristics, and that the level can be derived analytically from life-history parameters. The ability to express the reference point explicitly in terms of survival, maturity, and fecundity allows the proxy SPR level to be tailored to the species of interest. The appropriateness of the SPR level can be evaluated by inspection of the individual components to determine whether they are biologically realistic, and sensitivity to assumed rates can be calculated directly.

As is discussed in this WP, skate landings are not disaggregated to the species level, and there is uncertainty in the species identification of observed skate discards. The lack of species specific catch poses a major problem to conducting stock assessment analyses. The methods proposed in this working paper for deriving biological reference points use only data from the research surveys conducted by the Northeast Fisheries Science Center, thereby avoiding the potential problems associated with disaggregating the commercial catches.

Methods

Overfishing and overfished reference points are derived in terms of the SPR level that achieves maximum excess recruitment (MER, Goodyear 1980). MER differs from MSY in that

it solves for the maximum yield in numbers rather than in weight. By comparison, $SPR_{MER}<SPR_{MSY}$ because the F that achieves MER is greater. This is due to the fact that MSY is achieved by allowing more fish to survive to older, hence heavier, ages. MER reference points are expressed in terms of maximum lifetime reproduction, $\hat{\alpha}$ (Myers et al., 1997, 1999), where

$$(1) \qquad \hat{\alpha} = a \sum_{age=r}^{A\max} p_{age} E_{age} \prod_{j=1}^{age-1} e^{-M_j} .$$

In (1), r is the age of recruitment, p_{age} is the proportion mature at age, E_{age} is the number of eggs produced at age, M is natural mortality, and a is the slope at the origin in the Beverton-Holt equation

$$(2) \qquad R = \frac{aS}{1 + S/K} .$$

The level of SPR corresponding to MER is given by

$$(3) \qquad SPR_{MER} = \frac{1}{\sqrt{\hat{\alpha}}} .$$

After calculating $\hat{\alpha}$, the resulting SPR_{MER} could be used to determine the overfishing target by calculating $F_{\%SPR}$. An overfished target could similarly be calculated from $\hat{\alpha}$ as

$$(4) \qquad \frac{SSB_{MER}}{SSB_0} = \frac{\sqrt{\hat{\alpha}} - 1}{\hat{\alpha} - 1} .$$

The calculated value in (4) gives a target depletion level, against which current estimates of spawner depletion could be compared.

In order to calculate the reference points, the components of $\hat{\alpha}$ are needed. First, the slope at the origin, a, was obtained by fitting Beverton-Holt curves to NEFSC fall bottom trawl survey data following Gedamke et al. (2009). Annual estimates of mean number of spawners per tow were derived by assuming knife-edged maturity at L_{50}. To obtain a time series of recruitment, the length corresponding to age of full vulnerability to the gear (L_{Crit}) was determined, and this was converted to a mean age from von Bertalanffy growth curves (Table 1).

The stratified mean number of fish per tow above L_{50} (spawners) and for the year class corresponding to L_c (recruits) was then estimated for all years. The vector of mean number of spawners per year was then paired with the vector of mean number of recruits given the appropriate lag (Table 2). For instance, if recruitment was determined to occur at age 4, then a lag of 5 years was taken to account for the additional year spent as an egg. Years with missing data in these lagged pairs were dropped from the analysis. We emphasize that we used spawning number rather than spawning biomass. This is a more realistic approach for elasmobranchs, because they typically produce a few large eggs sacks (or pups, in the case of live bearers).

Counting the number of spawners reflects the fact that there is a finite capacity for egg production and internal storage, whereas using spawning biomass as a proxy implies that fecundity increases by a power function with age. The fall survey was used because it is a longer time series and was more likely to reflect a wider range of observed stock sizes (NEFSC 2000). Beverton-Holt curves were fit in ADMB (Otter Research, Ltd. 2004) assuming log-normal error in recruitment. We note that while the observations of spawners are not measured without error, the errors in variable problem is ignored (*status quo*).

The estimate of a obtained from the Beverton-Holt fits is a compound term that expresses survival from the egg stage (S_{egg}) to the age of recruitment (S_{r-1}) as well as the number of eggs produced per spawner (E), which is assumed to be a constant for all ages:

(5) $$a = ES_{egg}S_0S_1 \cdots S_{r-1}.$$

Given the definition of $\hat{\alpha}$ in (1), the remaining term depends only on the natural mortality rate (M) assumed:

(6) $$\hat{\alpha} = a\sum_{age=r}^{\text{Amax}} p_{age}\prod_{j=1}^{age-r} e^{-M_j} = ae^{-(Amat-r)*M}\sum_{age=Amat}^{\text{Amax}} e^{-(age-Amat)*M} = a\frac{e^{-(Amat-r)*M}}{1-e^{-M}}.$$

The final term above is the closed form solution for the sum of a geometric series, which results for very large *Amax*, the maximum age. If Amax is 30 years or greater, then the difference between the finite sum and the infinite sum is small (Appendix 1). Estimates of an age-constant natural mortality (M) were calculated using four different methods based on life-history parameters: Pauly (1980), Hoenig (1983), and the Jensen (1996) age at maturity and k methods. Estimates ranged from 0.09 to 0.17 yr^{-1}, 0.15 to 0.18 yr^{-1}, and 0.17 to 0.25 yr^{-1} for winter, thorny and barndoor skates, respectively. The base case values used for these three species were 0.15, 0.18, and 0.18, respectively. For the clearnose skate, an M of 0.15 was used based on similarity with the other skates. Note that an estimate of water temperature is required for the Pauly (1980) estimator and we used 8.5 C as reported by Myers et al. (1997).

The reasonableness of the estimate of a can be evaluated by dividing a by E, the total number of eggs produced by a female in a year. The term remaining from this division is the cumulative survival from egg stage to the age of recruitment, $S_{egg}S_0S_1\ldots S_{r-1}$. Assuming that survival is constant at each of these pre-recruit stages, then the annual survival can be calculated as $(S_{egg}S_0S_1\ldots S_{r-1})^{1/r}$.

The sensitivity of $\hat{\alpha}$ and SPR based reference points was explored for a reasonable range of alternative M values that bracketed the estimates discussed above (0.10-0.25). The resulting SPR_{MER} and the level of F that would produce SPR_{MER} were calculated for each of the possible M values. Uncertainty in the reference points arising from uncertainty in a was evaluated with MCMC in AD Model Builder (Otter Research, Ltd, 2004). Two independent chains of length 1E+06 were simulated, with a thinning rate of 1/50. The first 35% of each chain was dropped (burn-in), and the remaining values were retained for analysis.

Results

The results of fitting Beverton-Holt relationships to the observed spawner and recruit data were evaluated by examination of diagnostic plots (Figures 1-4). For Barndoor, Thorny, and Winter skate, the diagnostics are acceptable, and the estimated parameters are reasonable (Table 3). However, for Clearnose skate, the residuals show unacceptable time trends (Figure 4) and the estimates are not reasonable (Tables 3 and 4; steepness of about 0.96).

The estimated precision for the reference points only reflects the precision of the estimated stock-recruit parameters (a and K). Sensitivity of the estimated reference points and the associated fishing mortality rate for alternative values of M are given in Tables 5-7. For higher M, SPR_{MER} and depletion at MER are also higher, which equates to a lower F. This may initially seem counterintuitive, for one often finds that assuming a higher M leads to a higher

estimate of F_{MSY} in a typical stock assessment. However, in this case, the result of a higher M producing a lower $F_{\%SPR}$ is due to the direct impact of M on the unexploited calculation of spawners per recruit (Table 8). It is this parameter that scales *a* to yield $\hat{\alpha}$, from which the reference points are estimated.

Barndoor skate

There were 14 observations of (S_y, R_y) for Barndoor skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 5.78, which gives a maximum lifetime reproduction of 15.61 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.25 and the depletion of spawners at MER (S_{MER}/S_0) is 0.20. The estimated fishing mortality that achieves an SPR of 0.25 is $F_{25\%}$= 0.18. The implied annual survival during the pre-recruit stage is 0.27/year for three years (egg stage to age 2, Table 3). The long right tail in the posterior distribution of the slope at the origin (*a*) reflects the poorer precision of that parameter (CV=50%). By comparison, the reference points were twice as precise.

Winter skate

There were 36 observations of (S_y, R_y) for Winter skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 2.94, which gives a maximum lifetime reproduction of 7.39 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.37 and the depletion of spawners at MER (S_{MER}/S_0) is 0.27. The estimated fishing mortality that achieves an SPR of 0.37 is $F_{37\%}$=0.08. The implied annual survival during the pre-recruit stage is 0.43/year for five years (egg stage to age 4, Table 3). As was the case with barndoor skate, the estimated CV for the slope at the origin (*a*) was twice that of the reference points (0.39 for *a* versus 0.19 and 0.14 for SPR_{MER} and depletion at MER).

Thorny skate

There were 40 observations of (S_y, R_y) for Thorny skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 2.71, which gives a maximum lifetime reproduction of 4.67 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.46 and the depletion of spawners at MER (S_{MER}/S_0) is 0.32. The estimated fishing mortality that achieves an SPR of 0.46 is $F_{46\%}$=0.07. The implied annual survival during the pre-recruit stage is 0.44/year for five years (egg stage to age 4, Table 3). As was the case with barndoor skate, the estimated CV for the slope at the origin (*a*) was twice that of the reference points (0.31 for *a* versus 0.16 and 0.11 for SPR_{MER} and depletion at MER).

Clearnose skate

There were 28 observations of (S_y, R_y) for Clearnose skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 101.10, which gives a maximum lifetime reproduction of 15.61 ($\hat{\alpha}$, Table 3). The diagnostics were not acceptable, and the parameter estimates were unrealistic (steepness=0.96, Table 4); therefore, the estimated reference points are considered inappropriate for management advice. No MCMC simulations were conducted for this species based on the poor initial model fit.

Conclusions

Assessment of skate species has proven to be difficult, due to the aggregated nature of commercial landings and the lack of data on discards for much of the time series. The difficulty

applies equally to the estimation of reference points for skates. The methodology of Gedamke et al. (2008) provided a method to estimate the slope at the origin for Beverton-Holt stock recruit relationships. Management reference points are strongly dependent on the stock recruitment curve, and the slope parameter is a key component in determining appropriate reference points. Combining the slope with other biological parameters, the analytic solutions for SPR_{MER} were derived from results in Brooks et al. (2008, *in preparation*).

Data were sufficient to attempt fitting stock recruit curves to four skate species: Barndoor (14 data points), Thorny (40 data points), Winter (36 data points), and Clearnose skate (28 data points). The diagnostics were acceptable for all but Clearnose skate, and the parameter estimates for the remaining three species appear reasonable. The resulting reference point estimates are on a scale that would be compatible with existing assessment methodology. For example, models such as SEINE (2008; NMFS Toolbox module based on Gedamke and Hoenig, 2006) , or other mean length based models, could provide estimates of fishing mortality, provided the lengths examined included only those above the full vulnerability to the gear. These assessment-based estimates of F could then be compared to the $F_{\%SPR}$ estimated in this working paper to determine the overfishing status. The overfished status could be determined by examining the implied depletion of spawners, for example by examining the final point in the scaled index of mean spawners/tow ($S_y/S_{y=1}$). The scaled index of spawners would be depletion from an unexploited state if it was appropriate to assume that the stock was unexploited in year $y=1$. If that is not the case, then the index could be multiplied by a scalar, d, which reflects a measure (or expert opinion) of the level of depletion in year $y=1$. Alternatively, if algorithms to dissociate the landings and to hindcast discards are developed and agreed upon, then traditional stock assessment methods could be applied to estimate current levels of fishing mortality and stock size.

These SPR reference points were bounded by considering sensitivity across a reasonable range of natural mortality (M) levels.

Beverton-Holt curves were fit, but no Ricker curves were attempted because there is no obvious mechanism that would lead to overcompensation, nor is there data available that would suggest it.

As is common in most stock-recruit curve fitting exercises, the error in observed spawners per tow is ignored. Walters and Ludwig (1981) suggest that the estimation performance from ignoring error in the 'independent' variable is worse if the observations all come from a period where the stock was already heavily exploited. As the time series used in fitting Beverton-Holt curves extends back to the 1960s, it may be that a fairly broad range of spawning stock sizes is reflected in the observations.

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Appendix 1. Evaluation of the bias generated by calculating unexploited spawners per recruit, spr(F=0), as either an infinite sum or by calculating the series only up to the maximum age (Amax). For this exercise, the ratio between terms in the series is $r=e^{-M}$. The infinite sum is $1/(1-r)$ while the sum to Amax is given by $(1-r^{Amax+1})/(1-r)$. The combinations of Alag and M in this illustration correspond to the observed pairs for skate species examined in this document.

Amax	Alag	M	spr(F=0) Sum to Amax	spr(F=0) Infinite sum	% bias (Infinite sum - Sum to Amax)/ Sum to Amax
15	4.5	0.18	2.36	2.70	14%
20	4.5	0.18	2.56	2.70	5%
25	4.5	0.18	2.64	2.70	2%
30	4.5	0.18	2.68	2.70	1%
35	4.5	0.18	2.69	2.70	0%
40	4.5	0.18	2.70	2.70	0%
15	7	0.15	1.86	2.51	35%
20	7	0.15	2.20	2.51	14%
25	7	0.15	2.37	2.51	6%
30	7	0.15	2.44	2.51	3%
35	7	0.15	2.48	2.51	1%
40	7	0.15	2.50	2.51	1%
15	7	0.18	1.38	1.72	25%
20	7	0.18	1.58	1.72	9%
25	7	0.18	1.67	1.72	3%
30	7	0.18	1.70	1.72	1%
35	7	0.18	1.71	1.72	1%
40	7	0.18	1.72	1.72	0%

Table 1. Criteria used to define the age at recruitment (full vulnerability to the survey gear), the age at maturity (assumed to be knife-edged), and the NEFSC bottom trawl survey used to generate paired observations of spawners and recruits.

Parameter	**Barndoor**	**Thorny**	**Winter**	**Clearnose**
Length range at full vulnerability	55-69 cm	46-54 cm	40-44 cm	42-50 cm
Age at full vulnerability (recruitment)	2	4	4	4
Length at full maturity	116	88	76	66
Age at full maturity	6.5	11	11	6
NEFSC survey used (SPRING/FALL)	FALL	FALL	FALL	FALL

Table 2. Pairs of observed number of spawners/tow and number of recruits/tow for Barndoor, Thorny, Winter, and Clearnose skate. The year indicates the year that eggs were spawned. Note that the year differs between the skate species.

Barndoor			Thorny			Winter			Clearnose		
Year	Spawners	Recruits	Year	Spawners	Recruits	Year	Spawners	Recruits	Year	Spawners	Recruits
1963	0.0592	0.1703	1963	0.5141	0.1175	1967	0.1024	0.3502	1975	0.0022	0.0692
1964	0.0194	0.0181	1964	0.3766	0.1723	1968	0.0657	0.2330	1976	0.0106	0.0489
1965	0.0092	0.0572	1965	0.3774	0.2832	1969	0.0448	0.1035	1977	0.0459	0.0350
1967	0.0055	0.0072	1966	0.6772	0.1568	1970	0.1228	0.0197	1978	0.0044	0.0026
1968	0.0047	0.0495	1967	0.1945	0.1997	1971	0.0358	0.0256	1979	0.0414	0.0306
1993	0.0100	0.0039	1968	0.3602	0.2635	1972	0.1025	0.1320	1980	0.0902	0.0516
1997	0.0040	0.0073	1969	0.4592	0.1408	1973	0.2083	0.0442	1981	0.0094	0.0621
1998	0.0053	0.0286	1970	0.6659	0.0716	1974	0.0895	0.1283	1982	0.0216	0.0689
1999	0.0106	0.0747	1971	0.5239	0.0853	1975	0.0688	0.1684	1983	0.0031	0.0627
2000	0.0039	0.0388	1972	0.3609	0.1978	1976	0.2673	0.1504	1984	0.0214	0.0573
2001	0.0219	0.0295	1973	0.4130	0.4055	1977	0.3921	0.2500	1985	0.0395	0.0957
2002	0.0297	0.0890	1974	0.1989	0.1295	1978	0.5990	0.1135	1986	0.0162	0.2069
2003	0.0151	0.0691	1975	0.1850	0.1982	1979	0.6634	0.3065	1987	0.0456	0.0528
2004	0.0642	0.1059	1976	0.1344	0.2253	1980	0.6649	0.2047	1988	0.0413	0.0969
			1977	0.2131	0.0258	1981	0.5778	0.1448	1989	0.0161	0.1828
			1978	0.2172	0.1476	1982	0.7272	0.4153	1990	0.0374	0.0408
			1979	0.2480	0.1543	1983	1.4457	0.3024	1991	0.1917	0.0732
			1980	0.2864	0.1213	1984	1.2900	0.1518	1992	0.0455	0.0653
			1981	0.1973	0.0380	1985	1.4719	0.2345	1993	0.0642	0.3494
			1982	0.0384	0.1114	1986	2.1119	0.3594	1994	0.1021	0.1941
			1983	0.1424	0.0934	1987	1.3070	0.2254	1995	0.0555	0.1712
			1984	0.1925	0.1368	1988	0.9280	0.2203	1996	0.0452	0.2421
			1985	0.1490	0.1241	1989	0.6537	0.3772	1997	0.1473	0.2520
			1986	0.1069	0.1899	1990	1.0601	0.3256	1998	0.1215	0.1001
			1987	0.0321	0.0723	1991	0.6036	0.2136	1999	0.2430	0.0612
			1988	0.0812	0.1316	1992	0.3846	0.1167	2000	0.2059	0.0582
			1989	0.0997	0.2209	1993	0.1721	0.1284	2001	0.2110	0.1417
			1990	0.1313	0.1271	1994	0.1436	0.2063	2002	0.1428	0.1216
			1991	0.1087	0.0782	1995	0.1048	0.2237			
			1992	0.0449	0.0605	1996	0.1557	0.2399			
			1993	0.0963	0.0370	1997	0.1460	0.1339			
			1994	0.0655	0.0481	1998	0.3493	0.0740			
			1995	0.0270	0.0605	1999	0.2881	0.2109			
			1996	0.0450	0.0568	2000	0.4001	0.2149			
			1997	0.0528	0.0214	2001	0.3131	0.2157			
			1998	0.0516	0.1567	2002	0.6870	0.2470			
			1999	0.0197	0.0482						
			2000	0.0605	0.0175						
			2001	0.0127	0.0311						
			2002	0.0303	0.0234						

Table 3. Estimates of Beverton-Holt parameters, and implied annual survival $(S_{egg}S_0 \ldots S_{r-1})^{1/r}$ for the product of total number of eggs per female per year and cumulative survival to recruitment, $S_{egg}S_0 \ldots S_{r-1}$.

Parameter	Barndoor	Thorny	Winter	Clearnose
a (slope at origin)	5.78 (0.50)	2.71 (0.31)	2.94 (0.39)	*19.01 (0.65)*
K	0.01 (1.65)	0.08 (0.48)	0.10 (0.52)	*0.01 (0.80)*
E (Total Number of eggs/female)	80	41	48	40
$S_{egg}S_0 \ldots S_{r-1}$	0.07	0.03	0.04	*0.24*
$(S_{egg}S_0 \ldots S_{r-1})^{1/r}$	0.27	0.51	0.50	0.83

Table 4. Species specific reference points (and CV) for the assumed natural mortality rate (M), the estimated maximum lifetime reproduction ($\hat{\alpha}$), and the implied steepness (steepness is related to $\hat{\alpha}$ as $\hat{\alpha}/(\hat{\alpha}+4)$). No reference points are given for Clearnose skate as diagnostics and estimates were unsatisfactory.

Parameter	Barndoor	Thorny	Winter	Clearnose
M (natural mortality)	0.18	0.18	0.15	*0.15*
$\hat{\alpha}$	15.61 (0.50)	4.67 (0.31)	7.39 (0.39)	101.10 (0.33)
steepness	0.80	0.54	0.65	0.96
SPR_{MER}	0.25 (0.25)	0.46 (0.16)	0.37 (0.19)	N/A
S_{MER}/S_0	0.20 (0.20)	0.32 (0.11)	0.27 (0.14)	N/A

Table 5. Sensitivity of SPR_{MER} reference points to the assumed level of natural mortality (M). For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.16	0.27	0.26
0.15	0.22	0.38	**0.37**
0.18	**0.25**	**0.46**	0.44
0.20	0.28	0.52	0.50
0.25	0.34	0.68	0.66

Table 6. Sensitivity of depletion reference points (S_{MER}/S_0)to the assumed level of natural mortality (M). For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.14	0.21	0.20
0.15	0.18	0.28	**0.27**
0.18	**0.20**	**0.32**	0.31
0.20	0.22	0.34	0.33
0.25	0.26	0.41	0.40

Table 7. Estimated fishing mortality rate (F) that achieves SPR_{MER} given the base value assumed for M. For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.19	0.10	0.10
0.15	0.18	0.08	**0.08**
0.18	**0.18**	**0.07**	0.07
0.20	0.17	0.06	0.06
0.25	0.15	0.04	0.04

Table 8. Effect of Alag (difference in years between maturity and recruitment ages) and M on the unexploited spawners per recruit, spr(F=0).

Alag	M	spr(F=0)
4.5	0.10	6.70
4.5	0.12	5.15
4.5	0.15	3.66
4.5	0.18	2.70
4.5	0.20	2.24
4.5	0.22	1.88
7	0.10	5.22
7	0.12	3.82
7	0.15	2.51
7	0.18	1.72
7	0.20	1.36
7	0.22	1.09

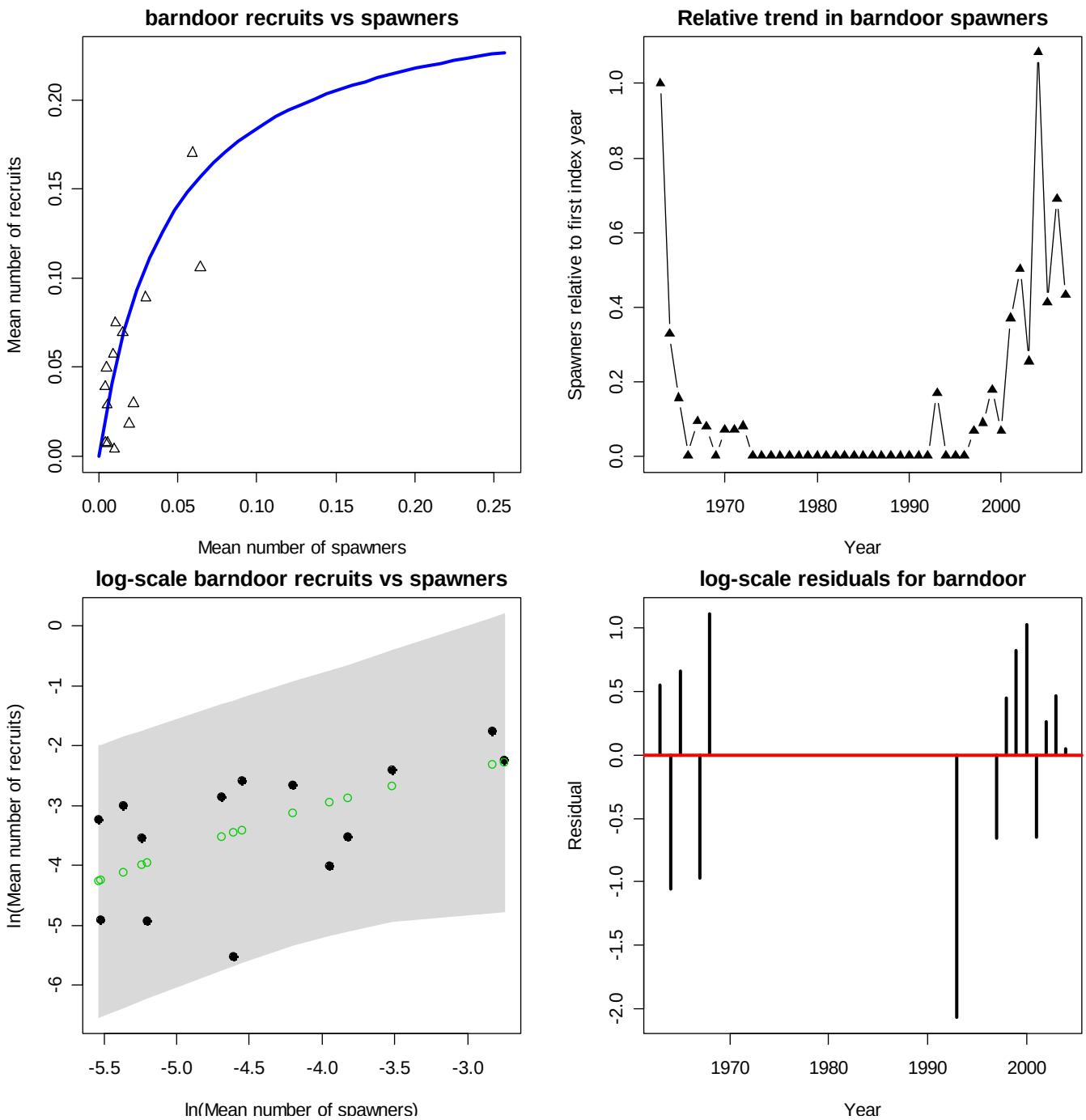

Figure 1. Diagnostic plots for **barndoor** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

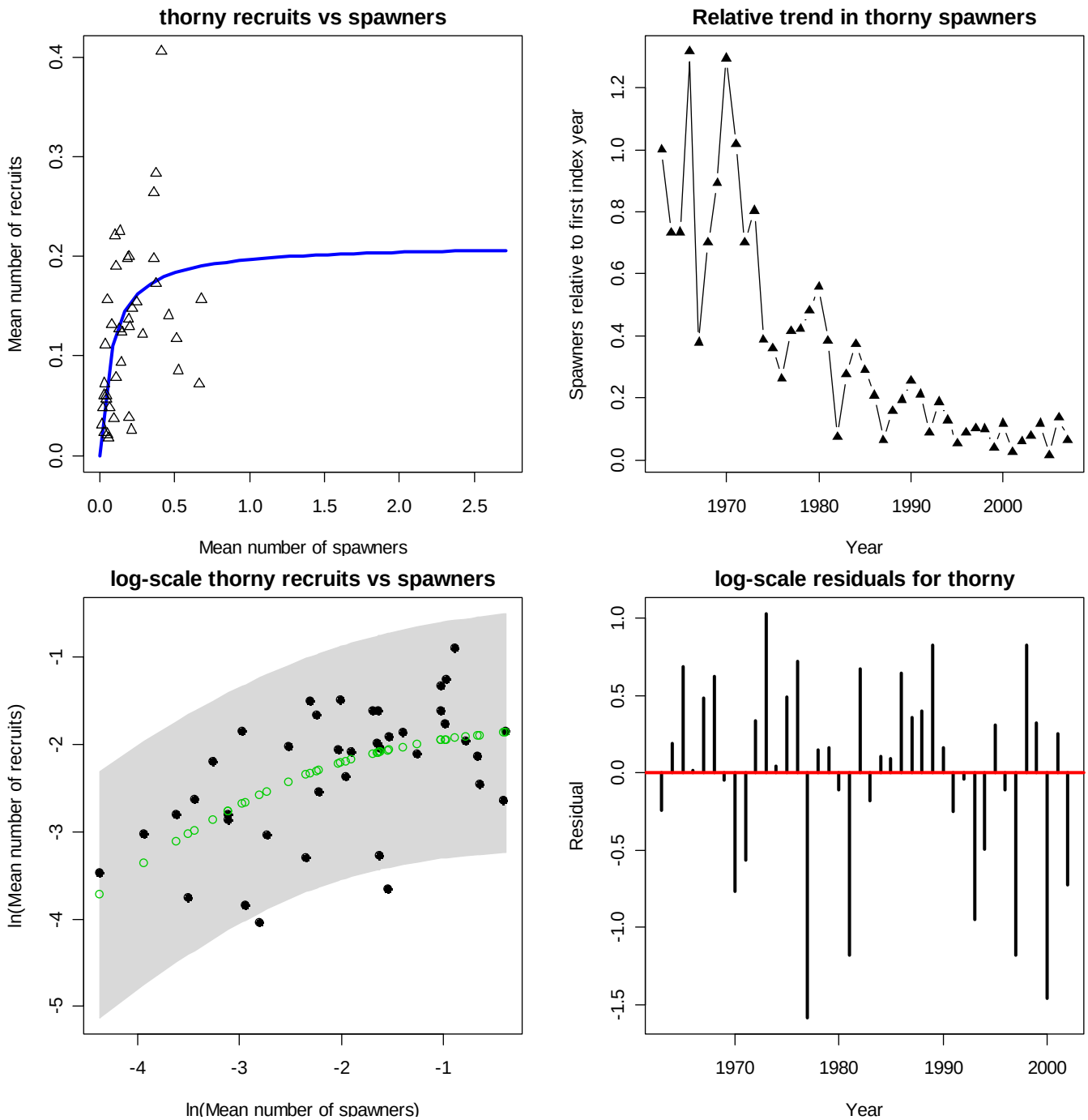

Figure 2. Diagnostic plots for **thorny** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

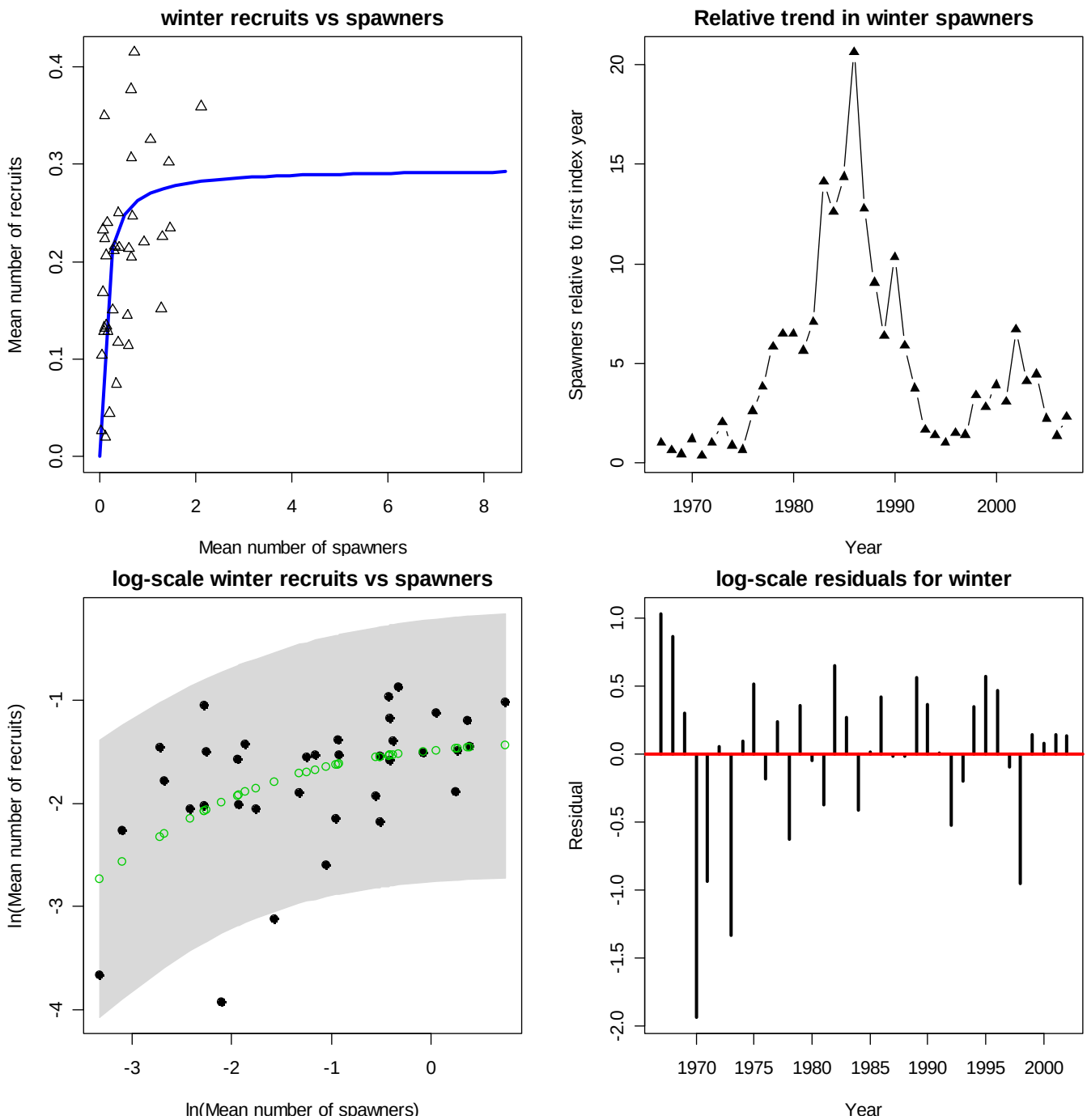

Figure 3. Diagnostic plots for **winter** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

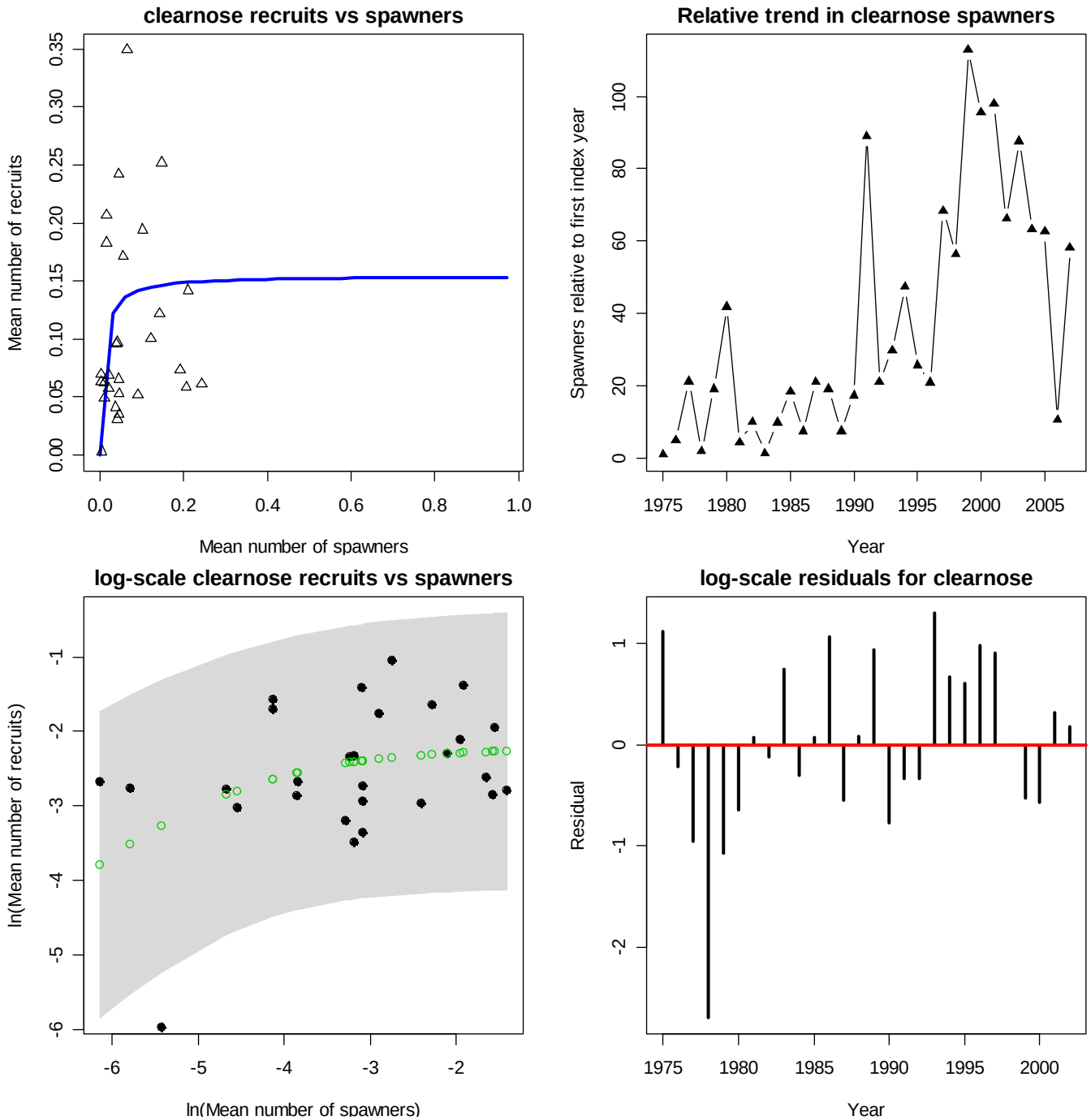

Figure 4. Diagnostic plots for **clearnose** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

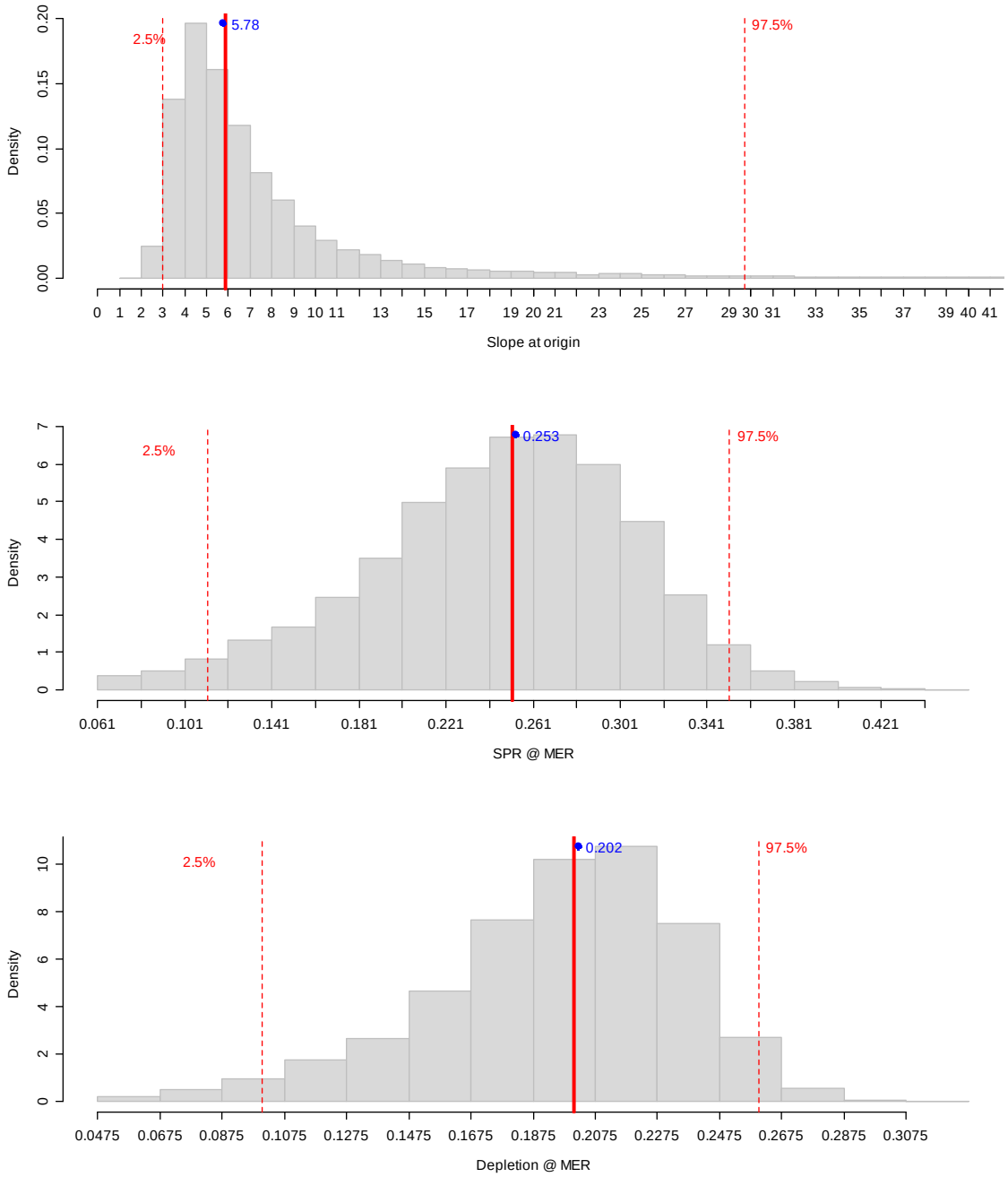

Figure 5. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **barndoor** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5th and 97.5th percentiles are indicated by dashed vertical red lines.

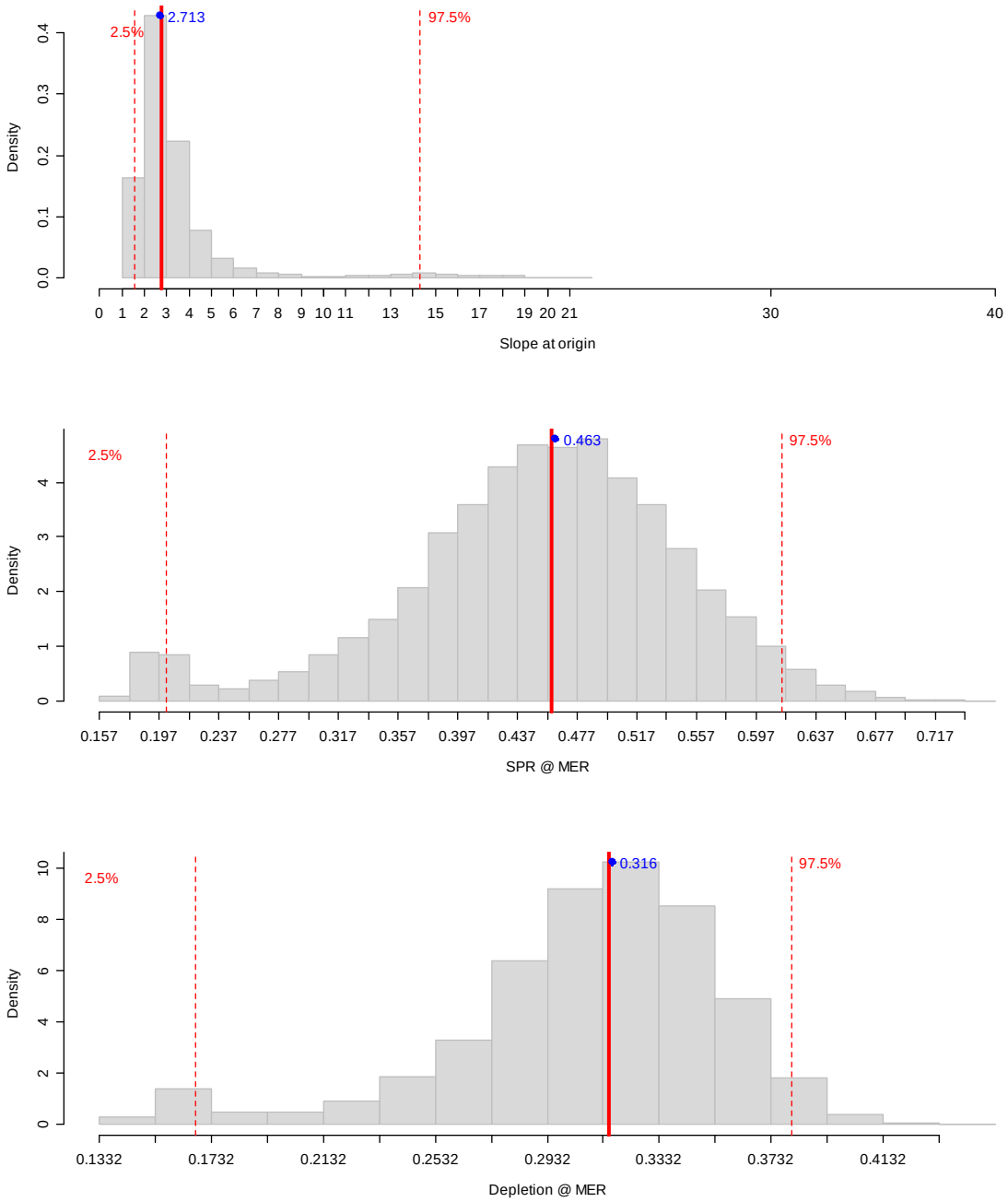

Figure 6. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **thorny** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5th and 97.5th percentiles are indicated by dashed vertical red lines.

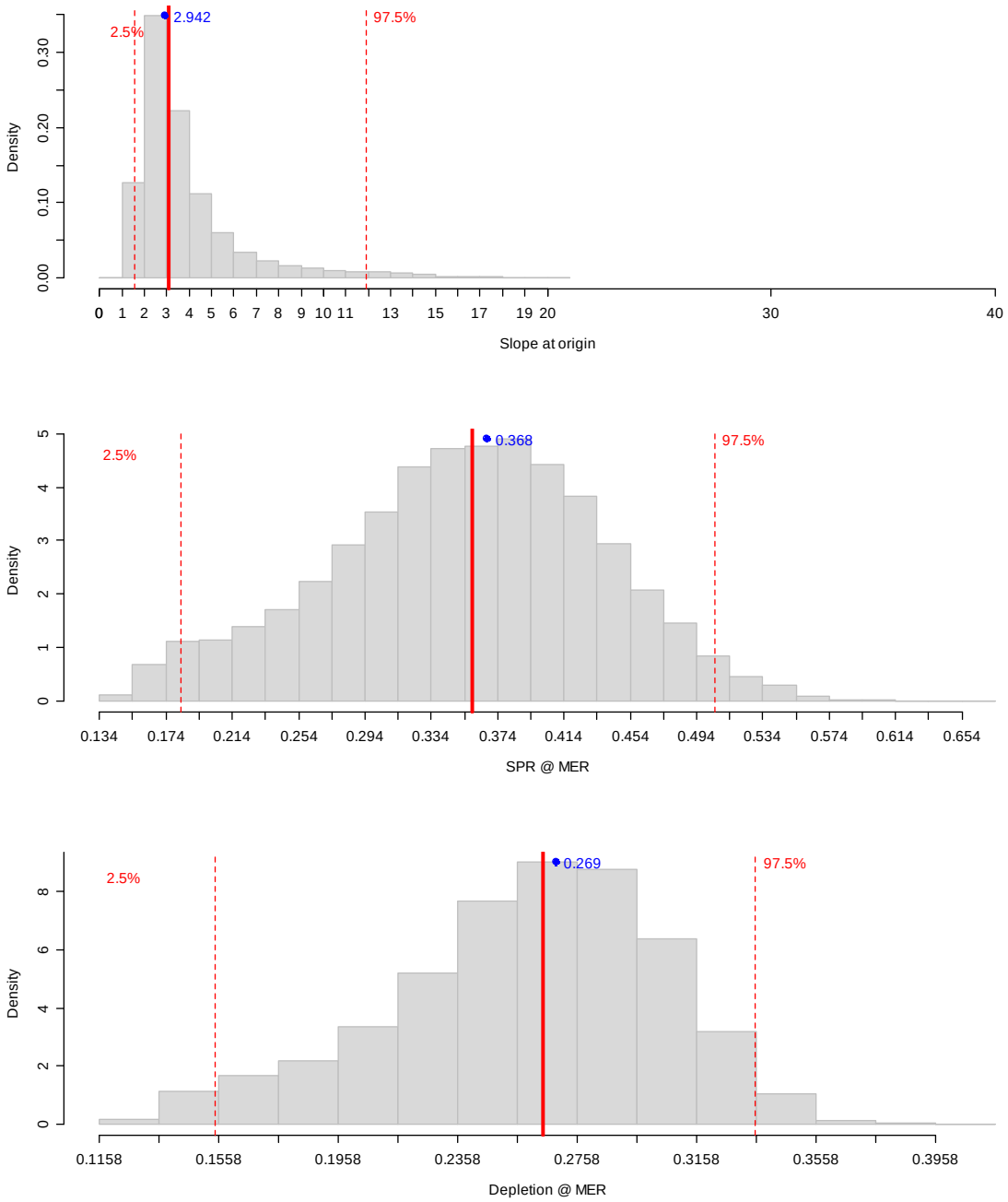

Figure 7. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **winter** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5th and 97.5th percentiles are indicated by dashed vertical red lines.

Deep sea red crab

Deep Sea red crab

A. Chute, L. Jacobson, P. Rago,
(Northeast Fisheries Science Center)

and A. MacCall,
(Southwest Fisheries Science Center, Santa Cruz, CA)

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***Editor's Note: The authors of this red crab report added italicized text to this chapter, summarizing the Peer Review Panel Report (that full report is available at http://www.nefsc.noaa.gov/nefsc/saw/).**

Executive summary

Deep sea red crabs in the northwest Atlantic represent a data-poor stock because they inhabit deep water, are rarely caught in NMFS bottom trawl surveys, require targeted surveys to collect data on abundance, and little is known about their life history. Data from related species has been considered to make assumptions about the life history. Targeted surveys were conducted in 1974 (Wigley et al. 1975) and during 2003-2005 (Wahle et al. 2008). Two stock assessments have been completed for red crabs (Serchuk 1977; NEFSC 2006a).

This male-only fishery began in the late 1970's. Quality of commercial landings data is variable. The most recent targeted survey (2003-2005) found that there had been a significant reduction in abundance of large male crabs since 1974. In 1974 the minimum acceptable marketable size was 114 mm carapace width (CW). In 2008 the minimum market size of landed crabs was less than 90 mm. The size distribution of the females did not change, indicating that the change in male size frequency was due to harvesting. The male red crab carries the female during mating, and the male must be larger than the female for successful mating. The reduction in large males in the population could reduce mating success. Females might not find males of the right size and sperm shortage might occur.

The deep sea red crab fishery management plan (FMP) was implemented in 2002. The FMP set an MSY (2830 mt) based on the biomass of male red crabs over 102 mm in carapace width. Overfishing is considered to be occurring if catch>MSY, or a proxy thereof. The B_{MSY} calculated for the FMP is 18,867 mt of males, and if biomass goes below ½ B_{MSY} then the stock is considered overfished.

Three options for updating B_{MSY} were considered. The first was status quo (i.e., the value in the FMP), the second was to use an updated MSY (provided there was one) to calculate a B_{MSY} proxy, and the third option was to use the biomass of fishable males from the more recent survey as a B_{MSY} proxy. The review panel did not recommend a new B_{MSY} or B_{MSY} proxy, but they were concerned with the change in size of harvested crabs over time. B_{MSY} for red crabs will remain at the default level of 18,867 mt of males.

Several options for updating MSY for red crab were considered. Two models were used, the depletion corrected average catch model (DCAC) (A. MacCall, pers. comm.) and a 2-point boundary model. Runs made over a range of assumed M values (0.05 to 0.15) estimated sustainable catches from 1785-2004 mt. The long-term average catch (1775 mt) was also suggested as a possible MSY proxy. It was also suggested that MSY could be calculated with an updated version of Gulland's (1970) equation with an F_{MSY} to M ratio of 0.8 and the same range of M values, which gave estimates of 549-1740 mt. MSY values from the new options were smaller than the status quo value of 2830 mt.

The panel rejected the current estimate of MSY (2830 mt) as too high, based on observed changes in population size structure since the beginning of the fishery. Based on congruence between average landings and results from the DCAC model, the panel concluded that MSY ranges from 1700-1900 mt of males.

The review panel did not change the overfishing definition for red crab (i.e. overfishing occurs if catch of males >MSY).

Terms of reference (TOR)

a) Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies.

b) Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
c) Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depends on, and needs to be consistent with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available. (This TOR not applicable to red crab)
d) Comment on what can be done to improve the information, proxies or assessments for each species.

Biological characteristics[1]

Information in this section is summarized primarily from Steimle et al. (2001) and Wahle et al. (2008). Deep-sea red crabs (*Chaceon quinquedens*) are a brachyuran crab (family Geryonidae) inhabiting the edge of the continental shelf and slope from Emerald Bank, Nova Scotia, the Gulf of Maine, and south through the mid-Atlantic Bight and into the Gulf of Mexico. According to Weinberg et al. (2003), genetic differences between deep-sea red crabs from southern New England and the Gulf of Mexico indicate that crabs in the two areas belong to different biological populations (figure 1). Red crabs in Southern New England and the Mid-Atlantic Bight (south of Georges Bank) and the Gulf of Maine (north of Georges Bank) are assumed to be the same stock although fishing occurs primarily off Southern New England. Red crabs in the Gulf of Maine are smaller and the bottom is rough so little fishing for red crab occurs there.

Deep-sea red crabs live at depths of 200–1800 m, where temperatures are between 5 and 8 ^{o}C. Adult crabs are segregated incompletely by sex. Adult females generally inhabit shallower water than adult males, and juveniles tend to be deeper than adults, suggesting a deep-to-shallow migration as the crabs mature.

Information on the growth, longevity and mortality of red crabs is scarce. Natural mortality rates were assumed to be 0.2 y^{-1} in Serchuk (1977) and 0.15 y^{-1} in the current Fishery Management Plan (FMP) for Deep-Sea Red Crab. An assumed longevity of 30 or more years corresponds approximately to $M = 0.1\ y^{-1}$ (see below).

On the basis of limited laboratory data, red crabs are believed to require 5–6 years to attain a size of 114 mm carapace width (CW). Male red crabs are estimated to mature at about 75 mm CW and to reach a maximum size of about 180 mm CW. Females begin to mature at somewhat smaller sizes and reach a smaller maximum size of about 136 mm CW.

As in other brachyuran crabs, the mating male is larger than the female and forms a protective "cage" around the female while she molts and becomes receptive to copulation. The protective copulatory period may last as long as 2–3 weeks in red crabs. The minimum size of males relative to females required for successful mating is unknown. Information about sperm storage is not available for female red crabs.

Fishery and management

Red crabs in the US waters outside the Gulf of Mexico are managed as a single stock located primarily in the Mid-Atlantic Bight to Gulf of Maine region, although red crabs in the Gulf of Maine are not considered in calculation of reference points, biomass estimates or other management analyses.

[1] Based on Steimle et al. (2001) and Wahle et al. (2008).

A small experimental fishery for red crabs was established in the early 1970s. Before the initial targeted survey for red crabs (Wigley et al. 1975), fishery catches were small and sporadic. In the 1980s and 1990s, fishing effort was inconsistent due to market demand. A directed fishery for male red crabs and consistent markets developed in the mid-1990s.

The current US fishery for male red crabs has limited entry and as of 2006 consisted of four or fewer vessels 30+ m long. The fishery uses specially designed traps almost exclusively, although small catches are taken also in lobster traps. Fishing occurs year round and catches are made mainly along the continental shelf from the Canadian border (Hague Line), at the eastern end of Georges Bank, to Cape Hatteras, NC, USA, in depths ranging from 400 to 800 m.

Annual US commercial landings of red crabs during the period 1982–2005 ranged from 466 mt (1996) to 4000 mt (2001); there was no fishery in 1994. Since 2002, when the FMP was implemented, landings have been stable at about 2000 t per year. The current fishery is authorized to operate with a target TAC of 2688 mt, and an effort allocation of 780 days at sea. There is no recreational fishery for the species.

Minimum market sizes and fishery size selectivity have decreased since the early 1970s. The minimum market size for male deep sea red crabs in 1974 was 114+ mm CW. The minimum market size for male deep sea red crabs in recent years is about 85 mm CW. Fishery size selectivity has been estimated for the current fishery during 2004-2005 (L_{50}=92 mm CW) but no selectivity estimates are available for earlier years.

Based on limited log book, sea- and port sample information, discards of female and undersize male red crabs appear to average about 30% of total catch but can range from about 10% to 69% of total red crab catch. Discard mortality from being brought to the surface and handled on deck averages about 5%. (Tallack 2007). Bycatch of red crab in fisheries directed at other species is minor.

The major fishery related uncertainties for red crab are discards, discard mortality, as well as historical and recent fishery size composition. In addition, the expected response of the stock to fishing in terms of growth and recruitment is uncertain.

The infrequency of stock assessments is another key uncertainty. Only two stock assessments have been completed for deep-sea red crab off Southern New England (Serchuk 1977; NEFSC 2006a). Both were based on camera/trawl surveys completed just prior to the assessment.

Data availability

The principle fishery data for red crab are landings data from dealer reports starting in 1973, logbooks that start in 1994, size composition data for marketable males from routine port samples, and sea sample data for females and all males from a pilot program involving one vessel during 2004-2005. Landings data from dealer reports for years prior to 1982 are less reliable than data for later years. Landings per unit effort data are available from logbooks and dealer reports but are difficult to interpret. The fishery occurs off south of Georges Bank and virtually no fishery data are available for the Gulf of Maine. As described above, discard estimates based on limited sea-, port and logbook data are available and size selectivity estimates for the recent commercial fishery are available from comparison of sea- and port sample data.

The principle fishery independent data for red crab are from camera sled/bottom trawl surveys conducted during 1974 and 2003-2005 on red crab habitat between Maryland and the eastern tip of Georges Bank (excluding the Gulf of Maine). Camera data provide information about red crab density and bottom tow data provide information and sex- and size composition. The survey data for 2003-2005 are generally combined and treated as one survey. Data from a

variety of research bottom trawl surveys are of limited use for red crab because catches are very low. The NMFS Cooperative Monkfish Survey may provide some useful information about red crab in the Gulf of Maine.

Camera and trawl tows in the 1974 and recent surveys were generally from the same or similar sites and sample locations. The two sets of surveys used bottom trawls of the same design and the same trawling protocols, although different vessels were used. Efforts were made to make camera data from the two surveys as comparable as possible but there is uncertainty about the effective area sampled (and therefore red crab density) by images collected during the 1974 survey. Density estimates from the recent survey are believed to be biased low because crab densities were significantly lower in the foreground (close to the camera sled) than in the background of the sampled area suggesting crabs were avoiding the camera, but the extent of the potential bias is unknown. The most reliable survey data are bottom trawl size compositions from both sets of surveys and density estimates from the most recent surveys.

Current stock status

Information in this section is summarized from NEFSC (2006a). The most recent assessment concluded that overfishing was not occurring because red crab landings during 2005 (2013 mt) were less than an MSY proxy (2830 mt, see below). Recent fishing mortality estimates were available but not used to determine overfishing because no F based reference point or proxy for F_{MSY} was available.

Based on the most recent assessment, average fishing mortality rate (landings / fishable biomass) on male red crabs was estimated to be F=0.055 (SE 0.008) y^{-1} during 2003-2005. This estimate is probably an underestimate because it does not consider potential mortality due to discarding of undersized male crabs and completely omits mortality due to discarding of females. Fishing mortality estimates are calculated using biomass estimates from surveys during 2003-2005, which are relatively certain but possibly biased low due to avoidance of the camera sled. Red crab biomass is appreciable but catches are currently near zero in the Gulf of Maine.

Alternate fishing mortality estimates including discards and based on best available discard estimates for sea- and port samples are given below (Table 1) for males only, females only and males plus females. Results indicate that total fishing mortality (including discards) during 2003-2005 were $F \leq 0.08$ y^{-1} for both sexes and for the sexes combined. The alternative estimates are "worse-case" scenarios because they assume that 50% of discarded red crabs die, whereas the current best estimate of discard mortality indicate that about 5% of discarded red crabs die from being brought to the surface and handled on deck (Tallack 2007). Discard rates (discard/total catch) were from sea- and port samples during 2003-2004 (Table D4.5 in NEFSC 2006a). In this exercise, fishing mortality for red crab was approximated as catch (landings + discards) divided by total biomass and catch divided by 90+ CW biomass (the approximation for F are relatively precise because mortality rates are low). Calculations using total biomass may understate fishing mortality because total biomass includes small size groups probably not taken in traps although potential bias may be small because small crabs have low weight. Calculations using 90+ CW biomass may overstate fishing mortality because red crabs of sizes smaller than 90+ CW make up the bulk of the discard.

Based on the most recent assessment (Table 2), fishable red crab biomass during 2003-2005 was about 36,000 mt. Overfished status was not determined for lack of an adequate B_{MSY} estimate or proxy (see below).

Comparisons of biomass estimates from the two surveys are uncertain due to uncertainty about the effective area sampled by cameras during 1974. However, biomass estimates from the two sets of surveys (table 2) indicate that male fishable biomass (based on current fishery selectivity) increased by about 20% during 1974 to 2003-2005. Female biomass (total, 90+ and 114+ CW) increased substantially by 150%-250%. In contrast, total male biomass increased by only 75% and biomass of large (114+ CW) males decreased by about 43%. Size composition data from the surveys indicates that both male and female red crabs have benefitted from recruitment in recent years (figure 2). The loss of large (114+ CW) male biomass and relatively modest increase biomass of males 90+ mm CW can probably be attributed to size-selective fishing (Weinberg and Keith 2003).

Red crab overfishing definitions

The Magnuson-Stevens act includes the requirement that all FMPs "specify objective and measurable criteria for identifying when the fishery to which the plan applies is overfished." The National Standard Guidelines (NSGs) require the specification of "status determination criteria" (63 FR 24212). These criteria are to be "expressed in a way that enables the Council and Secretary to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished."

The National Standard Guidelines define overfished stock conditions and overfishing. According to the NSGs, an overfished stock is one "whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding." A stock is considered overfished when its size falls below the minimum stock size threshold (MSST). The Magnuson-Stevens Act requires a rebuilding plan for stocks that are overfished. According to the NSGs, overfishing "occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." Overfishing is considered to occur if the maximum fishing mortality threshold (MFMT) is exceeded for one year or more.

Reference point approaches for red crab do not establish a fixed metric or approach to measuring stock biomass or exploitation. Based on the current FMP, overfished stock status and overfishing for red crab should be defined in terms of the best available measures of stock biomass and exploitation or fishing mortality relative to the value of the measures under MSY conditions. Choice of the particular measure or proxy depends on best available data and circumstances but a list of potential proxies and conditions is described in the FMP. In particular, based on the FMP, the red crab stock will be considered to be in an overfished condition if one of the following three conditions is met:

Condition 1 -- The current biomass of red crab is below ½ B_{MSY} in the New England Council's management area (excluding the Gulf of Maine).
Condition 2 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, continues to decline below a baseline level for three or more consecutive years.
Condition 3 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, falls below a minimum threshold level in any single year.
Similarly two potential approaches or proxies for identifying overfishing are described:
Proxy #1: F / F_{MSY} -- It is common for data sparse stocks to estimate trends in fishing mortality as an exploitation ratio, i.e., landings or catch divided by an index of abundance, usually from a survey. As a proxy for F_{MSY}, Councils in the past have

selected an exploitation level that existed during a time with no trend in biomass at an intermediate biomass level.

Proxy #2: Landings / MSY – In the absence of other information, overfishing can be defined as catches in excess of an estimate of MSY. Although crude, provides an indication of current fishing effort relative to MSY conditions.\

The FMP describes a default control rule (figure 3) that could be used by managers, although this has proved impractical due to lack of biomass, exploitation, natural mortality and reference point estimates.

Current reference points

Information in this section is summarized from NEFSC (2006b). The reference point used as a fishing mortality threshold is MSY = 2,830 mt (6.24 million pounds).
The reference point used as a biomass target is B_{MSY} = 18,867 mt (41.6 million pounds) of male red crabs 102+ mm CW (4" CW). The reference point used as a biomass threshold reference point ½ B_{MSY} = 9,434 mt. A suggested CPUE baseline (presumably for use as a target) is 26-29 market-size crabs per trap, before adjustment for an equivalent number of 102 mm (4") CW market-size crabs.

Logic and justifications

In view of survey data limitations and infrequency of stock assessments for red crab, a landings-based BRP (e.g. estimate of MSY) for overall exploitation is appropriate for use as a threshold for exploitation rates in deep-sea red crab.

Serchuk's (1977) original MSY estimate (1,247 mt or 2.75 million lbs) assumed an underlying Schafer surplus production model, and used estimated biomass for male red crabs 114+ mm CW from the 1974 camera/trawl survey as an estimate of virgin biomass B_0 (114 mm CW was the minimum marketable size at that time). Based on the Schaefer surplus production model, MSY= $\frac{1}{2}MB_0$ and it was assumed that $F_{MSY} \cong M$. For the original red crab estimate, M=0.2 y^{-1} and B_0=24,948 mt of male red crabs 114+ mm CW.

The MSY estimate (2,903 mt) currently used by managers was made using the same formula and revised values for M and B_0. The revised value for natural mortality M=0.15 y^{-1} was thought to be a better estimate than M=0.2 y^{-1} for red crab. The original B_0 value was adjusted downward to account for part of the survey being in Canadian waters, adjusted upward to include male crabs 102 mm (4") CW and larger, as compared to the 1974 marketable size of 114 mm (4.5") CW, and adjusted upward again to account for the fact that the area fished is larger than the area surveyed. The adjustments took away biomass which now belongs to Canada, and added biomass to account for the area of the fishery south of the survey boundary to Cape Hatteras.

Reference point weaknesses

In the most recent stock assessments (NEFSC 2006) the current MSY and B_{MSY} estimates for red crabs were criticized and judged unreliable due to uncertainty about biological parameters and the model used to calculate MSY. New estimates were not developed due to lack of information about growth, longevity and trends in abundance.

Relatively little new information has become available since the last assessment. However, limited data for related species (*Geryon maritae*; Mellville-Smith 1989) suggest that M may be as low as 0.1 y^{-1}, which is lower than the previous estimates (0.15 and 0.2 y^{-1}).

The assumption that $F_{MSY}=M$ has been criticized recently. Walters and Martell (2004) suggest that F_{MSY} is lower and approximately $0.8M$ for many species.

The assumption that $B_{MSY} = ½B_0$ (Schaefer surplus production curve) is reasonable if the underlying spawner-recruit relationship is a Ricker curve. However, $B_{MSY} < ½B_0$ if the underlying spawner-recruit relationship is a Beverton-Holt curve. Beverton-Holt recruitment dynamics are more likely for red crab because there is no known biological mechanism that might result in maximum recruitment at intermediate spawning biomass levels.

The current B_{MSY} estimate of 18,867 mt in the FMP is for male red crabs 102+ mm CW (4") which is not representative of current fishery conditions. The current fishery lands male red crabs 80+ mm and the L50 for current fishery selectivity is 92 mm CW.

The survey biomass for 1974 may be a poor estimate of B_0 because of statistical variance in the estimate (variances are not available for the estimate), uncertainty about effective area sampled by the camera sled, or because some fishing had already taken place prior to 1974. The total biomass for male red crabs during 2003-2005 (56,443 mt) exceeds the estimate for 1974 (32,190 mt) despite consistent fishing indicating that the estimate for 1974 is a poor estimate of B_0.

The fishery appears to have substantially reduced the abundance of the largest male red crabs. Smaller male crabs may not be able to mate with large females. There is concern that reduced abundance of large male crabs may lead to sperm limitation and reduced levels of egg production if there are no males left in the population to mate with the larger females.

Landings per unit of fishing effort data (LPUE) are mentioned in the FMP as a baseline stock biomass indicator for red crab but LPUE data have proven difficult to interpret, particularly as long time series (NEFSC 2006a).

Options and recommendations

This section outlines a range of options for exploitation and biomass based biological reference points to be used managing deep-sea red crab in the management area outside the Gulf of Maine.

The exploitation BRPs described here are thresholds specified in terms of landed weight (yield). Yield based approaches are the only practical approach for red crab because the only fishery dependent or fishery independent data routinely available for red crabs are landings. The options for yield based BRPs are intended as proxies for landings at F_{MSY}.

Options outlined below emphasize the most reliable information sources for red crab, which are landings since 1982 and biomass, abundance and size composition data the most recent camera/trawl survey conducted during 2003-2005, and size composition data from the original camera/trawl survey conducted during 1974. Biomass estimates from 1974 are less reliable and more uncertain because of questions about the effective area sampled by cameras in that survey. Uncertainty about biomass estimates makes trend analysis uncertain. Size composition data from 1974 are more reliable and are comparable to size composition data from 2003-2005 because bottom trawls and towing protocols used in 1974 were well documented and because trawls and protocols used in later years were the same.

Fishing for females

All options outlined in this report assume a male only fishery for deep-sea red crab. None are applicable to fishery involving female red crabs. If a female red crab fishery is ever established, then all yield- and biomass based BRPs should be revaluated.

Marketable sizes and fishery selectivity

In laying out options for BRPs, we assume that fishery selectivity in the future will be the same as during 2003-2005. As described above, fishery selectivity for red crab has changed over time. Marketable size males were 114+ mm CW during the late 1970s. Based on the last stock assessment, the selectivity pattern in the current fishery follows a steeply increasing logistic pattern with selectivity near 0% at 80 mm CW, 50% selectivity at 92 mm CW and nearly 100% at 120 mm CW. If fishery selectivity changes, then all yield- and biomass based BRPs should be reevaluated.

OPTIONS for a Gulf of Maine stock

The management area for red crab excludes the Gulf of Maine and this situation complicates the development of biomass based BRPs. Red crabs in the Gulf of Maine (where little or no fishing occurs) and red crabs in the Southern New England and the Mid-Atlantic regions where (fishing occurs) are considered to be a single US stock. It is possible that depletion of red crabs south of Georges Bank might be "hidden" by including some level of unfished biomass in the Gulf of Maine as part of the stock as a whole, to the detriment of the entire stock and the fishery. Thus, the separation of red crabs into one management area and an area with no active management complicates specification and probably reduces the potential benefits of BRPs.

Under these conditions, it may be advisable to manage the areas north (Gulf of Maine) and south (Southern New England and Mid-Atlantic areas) as separate stocks. Red crab are a demersal species that migrate ontogenetically and seasonally from shallow to deep but there is no evidence of strong migratory movement of juveniles and adults along the coast. Thus, localized depletion may occur in red crabs due to continuous fishing in areas south of Georges Bank. The shallow waters and geography of Georges Bank effectively separate the Gulf of Maine from other habitat areas along the US coast. Red crabs in the Gulf of Maine appear to be smaller than red crabs in southern areas where the fishery is occurring, suggesting differences in growth rates and other biological characteristics. However, it is unlikely that red crabs in different areas off the northeast coast of the US differ genetically. It is also likely that recruitment is linked to some extent along the entire US coast due to transport of larvae in currents.

Two options are proposed.

> Option 1: Continue to manage a single US stock of red crabs. The main advantages of this option are minimization and simplicity of regulations. The main disadvantages are loss or potential benefits from BRPs.
>
> Option 2: Manage red crab in the Gulf of Maine and areas south of Georges Bank (Southern New England and Mid-Atlantic regions) as separate stocks.
>
> Under this option, the exploitation BRP used to define overfishing for the Gulf of Maine stock would be F_{MSY} or the best available proxy. BRPs used to define the biomass target and biomass threshold for the Gulf of Maine would be B_{MSY} and $\frac{1}{2}B_{MSY}$ or the best available proxies. F_{MSY} and B_{MSY} for the Gulf of Maine are currently unknown and would have to be determined if interest in a Gulf of Maine red crab fishery develops. One or more special surveys designed to target red crabs would likely be required.

The main disadvantages of this option are increased regulations and complexity although any increases would be modest. The main advantage would be increased benefits of BRPs for red crab in the area were fishing occurs.

The second option (separate stocks) is recommended because the hypothesis of two stocks is scientifically credible, in view of restricted adult movement around Georges Bank and smaller red crabs in the Gulf of Maine, and because the potential utility of BRPs for the fished and unfished stock areas is increased. Under current legislation, BRPs used to define overfishing and overfished stock conditions must apply to entire stocks. Overfishing definitions for parts of stocks, such as the current management area for red crab, are apparently not allowed. Therefore, meaningful BRPs that address only red crab in the current management area appear impractical. *The review panel did not discuss management of deep sea red crabs in the Gulf of Maine.*

OPTIONS to regulate minimum legal size for male red crabs

Minimum size regulations may be desirable and should be evaluated for use in the red crab fishery. Minimum size regulations are used with some success in many crab and lobster fisheries. It is much easier to recommend biomass based reference points once the fishable stock (including minimum size) is clearly established and BRPs for a specified fishable stock are likely to be more meaningful and useful. Moreover, none of the options for exploitation and biomass based BRPs in this report deal effectively with concerns that sperm limitation may result from removal of large males by fishing. Exploitation and biomass based BRPs are indirect approaches to dealing with these potential issues.

Because marketable sizes, fishery selectivity and potential sperm limitation are important, three options for regulating minimum marketable sizes are presented for consideration by managers. Detailed analysis of this topic is an important area for research which should be carried out as soon as possible under any option because the full range of cost and benefits to the stock and fishery have not bet identified.

Option 1: No action. The main advantage is minimal impact on the fishery and minimal management costs. There is no evidence of serious problems in the fishery so no actions to regulate minimum legal size may be necessary. Minimum legal size regulations could be implemented in the future if required. The main disadvantage is the potential for changes in marketable sizes that tend to make BRPs for deep-sea red crabs moot. It is also possible that shifts in marketable sizes could exacerbate loss of large males which may be important for successful reproduction.

Option 2: Implement a minimum legal size for red crab that would leave some larger males in the population yet allow for a significant portion of crabs currently landed to remain marketable. This option would prohibit landings of male red crabs less than a specified CW. This minimum legal size should be close to the current minimum marketable size, such as 85-90 mm CW, to minimize fishery impacts yet large enough to leave males suitable for mating with newly mature females. With this option in place further losses of large males and the potential for sperm limitation in the population might be minimized. BRPs for red crabs would be more meaningful and useful if the fishable stock is defined.

Option 3: Defer minimum legal size regulations until more analysis is carried out to determine the optimum minimum legal size from the fishery and biological perspectives. This option is basically a combination of options 1 and 2.

Option 2 is recommended to increase potential benefits of BRPs and to help avoid potential problems with loss of large males. Impacts on the current fishery would be minimal.

The review panel did not discuss minimum legal size for male red crabs.

Biomass based biological reference points

As described above, biomass based reference points can be outlined for red crabs but data limitations and infrequent assessments will probably undermine their utility. Exploitation (yield-based) reference points are likely to be more important in a practical sense for deep-sea red crabs.

Some MSY analyses and estimates described in this report for red crab assume virgin or near virgin biomass conditions during 1974. Many are basically trend analyses which assume that biomass estimates for 1974 and 2003-2005 are directly comparable. The results of these analyses are uncertain to the extent that biomass estimates for 1974 are uncertain because of questions about the area of the sea floor the camera sled was able to illuminate and photograph clearly during the 1974 survey. Biomass estimates from more recent 2003-2005 surveys are better understood, better documented and the area covered by the cameras is well defined. Recent estimates were affected by some avoidance behavior that resulted in negative bias and some underestimation of stock biomass. Avoidance behavior may affect 1974 estimates as well but uncertainty about the effective area of the camera is most important. Biomass estimates for 1974 are also uncertain because biomass estimates for all but large male crabs were substantially higher for 2003-2005 than for 1974, despite substantial fishery removals during 1974-2003.

OPTIONS for biomass based BRPs

Terms of Reference and NSGs require biomass based BRPs that describe target and threshold biomass levels. It is possible to define biomass based BRPs for red crabs but they are likely to be of little use because of lack of stock assessments, lack of useful survey data and difficulties in interpreting fishery catch rates (LPUE). None of the proposed options for biomass BRPs involve commercial catch rates (LPUE) because they have proven difficult to interpret for red crab (NEFSC 2006).

Three proposed options for B_{MSY} estimates that could be used as target BRPs for red crabs are described below. In each case, the threshold BRP would be ½ of the B_{MSY} estimate or proxy.

Option	B_{MSY} (males only)
1	18,867 mt 102+ mm CW
2	16,904 mt fishable sizes
3	36,253 mt fishable sizes

Option 1: Status quo or no action (Listed in red crab FMP, 2002, Section 3.6.4). This gives a biomass based target B_{MSY} =18,867 mt of male red crabs 102+ mm CW, developed from the approximation $MSY = ½MB_0$ where B_0 was the estimated biomass of male red crabs during 1974 with adjustments for male

biomass at size and for areas not sampled in the survey. The biomass threshold that defines an overfished stock biomass is ½B_{MSY} = 9,434 mt. Weaknesses with Option 1 are described in earlier section of this report "Reference Point Weaknesses". Weaknesses are related to underlying assumptions about the spawner recruit curve, what B_0 represents in terms of virgin biomass, and M.

Option 2: Use the updated estimate of MSY (to be selected, see below) and current fishable biomass from the most recent assessment to estimate B_{MSY}. The biomass threshold that defines overfished stock biomass conditions is ½ B_{MSY}.

The main advantage of Option 2 is ensuring that biomass BRPs are consistent with exploitation based BRPs. If virgin biomass is very uncertain, then it may be better to base biomass reference points on the MSY proxy or estimate of sustainable catch. The main disadvantage is that it necessitates additional information about stock productivity. In addition, it may provide a poor estimate of B_{MSY} if the F_{MSY} proxy is inaccurate or the estimate of sustainable yield is substantially different from MSY.

In particular, assume $F_{MSY} = cM$ where c=0.7 (see below) and the natural mortality rate M= 0.15 y^{-1} (see below), then MSY= F_{MSY} B_{MSY} = 0.7(0.15) B_{MSY} = 0.105 B_{MSY} and B_{MSY} = MSY / 0.105 = 9.52 MSY. For example, if MSY= 1775 mt (the long term average catch and within the range of sustainable yield and MSY proxy options given below), then the biomass target B_{MSY} = 9.52 x 1775 = 16,904 mt fishable biomass and the biomass threshold B_{MSY} /2 = 8,452 mt fishable biomass.

Option 3: Use the most recent estimate of fishable biomass from the last assessment (36,247 mt) as B_{MSY}. The biomass threshold that defines overfished stock biomass conditions is ½ B_{MSY}.

The main advantage of Option 3 is that it is based on the relatively reliable 2003-2005 biomass estimate. As described above, uncertainties about the 1974 biomass estimate for red crab may preclude its use in estimating virgin biomass. The stock shows signs of fishing down (reduction in abundance of large males) expected under fishing at MSY levels. Current fishing mortality rates appear to be relatively low (F=0.055 y^{-1} in the managed stock area ignoring discards and no more than 0.1 y^{-1} including discards). These fishery induced mortality estimates are comparable to the range of F_{MSY} levels (F_{MSY} =0.6 M to 0.8 M, with M=0.1-0.2 y-1) that might be considered for red crabs and potentially sustainable. The main disadvantage is the possibility that current biomass is substantially larger or smaller than B_{MSY}.

Option 2 (use the updated estimate of MSY to specify B_{MSY}) is recommended by the Working Group because virgin biomass is uncertain. Option 1 is not recommended because it involves poor approximations to F_{MSY} and B_{MSY}. Option 3 is not recommended because it implies MSY= F_{MSY} B_{MSY} levels of about 0.7 (0.1) * 36,253 = 2,538 mt per year. This estimate is substantially larger than the long term average catch which has a pronounced effect on the relative abundance of large males.

The Peer Review Panel recommended Option 1 for B_{MSY}. The Panel did not recommend changing B_{MSY} or the B_{MSY} proxy for red crab, due to concerns about the shifting size of

marketable crabs and fishery-induced size frequency changes in the population. A simple biomass-based B_{MSY} proxy would not be reliable under the present circumstances of the fishery.

Options for exploitation based BRPs

All of the options for exploitation based BRPs in this report are specified in terms of landings (yield) because landings are the only data consistently available for the fishery. Landings based BRPs are also desirable for red crabs because they are simple and easy for managers to use outside the formal stock assessment process and without extensive review.

Ideally, all exploitation BRPs for red crabs based on landings would be MSY estimates or proxies to be used as thresholds that define overfishing. In principal, these BRPs are not used as targets. In particular, current NSGs indicate that managers may specify any annual catch limit (ACL) as long as exploitation is below the exploitation threshold BRP. In other words, managers are expected to consider uncertainties and risks in setting ACLs in addition to not exceeding the threshold reference point. In this report, we focus primarily on uncertainties about the reference points themselves and ignore many of the uncertainties managers face in setting ACLs.

A number of the methods used to calculate potential exploitation based BRPs are estimators for "sustainable" catch levels, rather than estimates or proxies for MSY. There is no guarantee that sustainable catch levels calculated for red crab are near MSY. Sustainable yield estimates are often estimates of average catch with or without adjustments for unsustainable "windfall" catches that may occur as virgin stock is fished down towards B_{MSY}. MSY is the maximum sustainable catch level at biomass levels usually less than ½ virgin biomass.

A number of the methods used in this report to calculate potential exploitation based BRPs are equilibrium estimators that assume constant recruitment, growth and mortality over the period of years in the model. Equilibrium estimators are often used in data poor circumstances but they tend to perform poorly in non-equilibrium situations. Size composition data from surveys during 1974 and 2003-2005 indicate changes in recruitment because small male and female red crabs were abundant during the latter survey. Changes in growth and recruitment would, in fact, be expected as the near virgin stock in 1974 was fished down over several decades. Results of the equilibrium estimators are uncertain to the extent that equilibrium assumptions may have been violated.

We used 4 methods to estimate MSY or proxies thereof:

1) Long-term average catch. We can make the argument that if CPUE in pounds per day at sea has been relatively stable and the biomass of currently marketable red crabs hasn't changed much from 1974 to 2005, then the level of fishing on the population since the 1970s must be sustainable. If summed recorded landings from 1973-2007 (35 years) equal 62,132mt, then the mean annual take of red crab has been 1,775mt, which is slightly less than mean landings since 2002.

2) Updated yield equation. The equation used to calculate MSY for the FMP was $Y = (0.5)(M)(B_0) = (0.5)(0.15)(B_0$ of males >114mm). However, $B_{MSY} < ½B_0$ if the underlying spawner-recruit relationship is a Beverton-Holt curve. Beverton-Holt recruitment dynamics are more likely for red crab because there is no known biological mechanism that might result in maximum recruitment at intermediate spawning biomass levels. Secondly, the ratio of F_{MSY} to M at maximum sustainable yield has been found to be less than one for most fisheries (Walters and Martell 2004). A coefficient c should be applied to M that is often 0.8 but for stocks more

vulnerable to overfishing can be as low as 0.5. To update the equation to match the conditions of the current red crab fishery, the B_0 must be for males smaller than the >114mm CW it was originally calculated for. So that leaves the equation Y = (0.4)(c)(M)(B_0 fishable males). We used a range of M values and calculated MSYs based on both the 1974 and 2003-2005 survey biomass of fishable males.

3) Depletion-corrected average catch (DCAC) model. The addition of a second survey allowed us to run two models which use length frequency or abundance data from two points in time to look at potential sustainable yields. The DCAC model input consists of summed annual landings, an estimate of M, an estimate of the F_{MSY} to M ratio, the amount of depletion between the two surveys and the number of years between them. It calculates a sustainable yield of a population after accounting for the "windfall" which occurs at the beginning of a fishery. We ran the model using several different estimates of M. For model details see appendix 2.

4) Two-point boundary model. This approach also uses abundance data from 2 points in time, and was run using various values of M. Estimates of median recruitment of males and females of various sizes, average F, and catch at equilibrium were derived for male and female red crabs from the 1974 and 2003-2005 surveys, and landings from 1974 to 2003. For model details see appendix 3.

Most of the yield based reference points presented in this report (Table 3) are lower than the current estimate of MSY (2830 mt) and target TAC (2688 mt). Most are lower than the observed catches during some years. Most of the estimates are reasonably consistent, possibly because they are based on average landings or because they assume fishable stock biomass levels were similar during 1974 and 2003-2005. The similarity of many of the new MSY estimates (figure 4) to the long-term average catch (from 1973 to 2007, 1775 mt) supports the idea that this level of landings is sustainable. Recent catches from 2002 to 2007 (mean 1853 mt) have been in this range, yet declining over the last few years. We recommend a catch limit that mimics both recent and long term mean annual landings, and suggest the current MSY of 2830 mt is not sustainable.

The review panel agreed that the MSY calculated for the FMP (2,830 mt) is not reliable. If the assumption that the changes in red crab population structure were caused by fishing is true, then previous higher catches have not been at sustainable MSY levels. The review panel concluded that, using the best available scientific information, estimates of MSY for male crabs only was in the range of 1700-1900 mt. The depletion corrected average catch model (DCAC), which estimated MSY to be very similar to the long-term mean catch, was deemed an acceptable model for this rarely-surveyed resource. The panel found no reason to change the overfishing definition of catch>MSY.

The panel noted that the change in the size distribution of landed male crabs over time may introduce uncertainty in the DCAC model. Even though the data were standardized to the same size structure, it is unclear how the removal of smaller and smaller male crabs over time may affect the model estimates of BRPs.

The review panel suggested that BRPs based on size and sex ratio may be useful in the future due to the importance of preventing sperm limitation in the red crab population. Unfortunately, that would require regular surveying, since fishery-dependent data does not give an accurate picture of the whole population as large males are targeted and the crabs are generally segregated by sex.

Since there is evidence the red crab fishery may be moving southward into previously lightly-fished areas as large males are depleted in the traditional fishing areas, the review panel noted the estimated BRPs are for the current area being fished and/or the extent of the surveys.

Scientific risks and uncertainties

Risks and uncertainties regarding BRPs for deep-sea red crabs are described below which are important in the context of choosing among BRP options, and in setting ACLs once BRPs are chosen. Risks to the stock due to overharvest and to the fishery due to foregone harvest are described in general terms but have not been quantified (no formal risk analyses were carried out).

Biomass based BRPs are difficult to evaluate for red crabs at this time due to lack of routinely available information about biomass levels and trends, and infrequent stock assessments. Therefore, risks and uncertainties regarding exploitation based BRPs are particularly important.

The following key uncertainties are listed in approximate order of importance.

a) There is a great deal of uncertainty about fundamental life history parameters in red crab, including longevity and natural mortality, growth and maturity, and reproductive biology. There is also uncertainty about whether red crabs have a terminal molt and the extent to which females can store sperm.
b) There is no available information about the spawner-recruit pattern and recruitment variability in red crab. There is uncertainty about the potential productivity of red crab due to uncertainty about fundamental life history parameters and recruitment.
c) Minimum marketable sizes and fishery size selectivity have changes since the early 1970s and processors now accept smaller male red crabs. There are no management measures regulating minimum size. Thus future fishery selectivity patterns are uncertain.
d) Based on the last stock assessment (NEFSC 2006a; 2006b), there is no evidence of serious problems in the red crab population (fishery induced mortality rates are $< 0.1\ y^{-1}$) and recruitment was apparently occurring during 2003-2005. However, survey size composition data from 1974 and 2003-2005 show reduced abundance of large males (114+ CW) probably due to fishing. There is little uncertainty about reductions in occurrence of large males. There are questions about the potential importance of large males in spawning. In particular, loss of large males may affect reproductive capacity of the red crab stock. These questions have a sound logical basis but have not been fully investigated.
e) Discards of undersize males and females are thought to be about 30% of total catch but the estimates are uncertain. Mortality of discarded crabs was relatively low in a recent study (~5%) but the estimate is uncertain and may be higher during routine fishing.
f) Some of the methods used to calculate biological reference points in this report rely heavily on landings data collected during a period when exploitation levels were relatively low. Historical catches may understate MSY to the extent that fishing mortality has been less than F_{MSY} during recent years. Thus, there is appreciable risk that reference points in this report will result in unnecessarily foregone catches.
g) Some of the methods used to calculate biological reference points in this report involved equilibrium assumptions that may not be justified for red crab. The potential effects of the equilibrium assumptions are uncertain.

h) As noted above, biomass estimates from the camera/trawl survey during 1974 are uncertain because of questions about the effective area searched by camera. Uncertainty in the 1974 biomass estimate increases uncertainty in BRP calculations that evaluate long term biomass trends or use the 1974 survey to characterize virgin or near-virgin stock levels.
i) Recent red crab biomass estimates from surveys during 2003-2005 have a negative bias due to a statistically significant level of red crab avoidance behavior. The magnitudes of red crab avoidance behavior and bias have not been evaluated.
j) There is uncertainty about whether new NEFSC bottom trawl surveys will provide useful information about red crabs. Available data from comparative fishing experiments provide little evidence one way or the other in this regard.
k) Changes in fishing locations have occurred during recent years, presumably due to localized depletion.

The review panel, in their report under "advice about scientific uncertainties" emphasized what they thought were the most significant sources of uncertainty. Under "observation uncertainty", they listed aspects of the biology, the survey and the fishery for red crab. Regarding red crab biology, the most significant sources of uncertainty were the lack of basic knowledge of life history, especially maximum age, growth per molt, intermolt period, and the occurrence of a terminal molt. Seasonal changes in distribution were also noted as a source of possible uncertainty.

Uncertainties involving the surveys exist because only two have been conducted (30 years apart). Also, there are concerns about comparability of the two surveys because of uncertainty about how crab counts from the illuminated area in the first survey were expanded and extrapolated to estimate the number of crabs in the entire region.

There is also uncertainty surrounding the fishery and the distribution of effort both spatially and temporally, and whether the distribution of the crabs was affecting the behavior of the fishery. The panel noted that an assumption of all the red crab analyses was that the pattern of harvest was from a stationary population.

In terms of "process uncertainty", the panel emphasized several possible sources. The first was that there is no knowledge of the influence of male to female ratios, in both number and size, on reproductive potential. The removal of a significant portion of the large males over time may have significant consequences on the population as males must be larger than females to mate. Other process uncertainties are the fact that the fishery may be changing its distribution and thus changing availability patterns, and the unreliability of the VTR discard data.

Research recommendations

a) Establish a regular schedule for surveys that provide useful information about deep-sea red crab. This is the most important research recommendation for red crabs.
b) Develop practical survey approaches for red crab in deep water. Recent cooperative work indicates that towed body video surveys are accurate and useful for sea scallops. It is likely that the same equipment and approaches would be useful for deep-sea red crab.
c) Evaluate the importance of large male red crabs in reproduction considering the size distribution and molting cycle of females, sperm storage, length of the mating season, duration of copulation and other key parameters.
d) Studies to refine estimates of growth parameters, longevity, natural mortality and reproductive parameters are needed.

e) Place scientific observers on board fishing vessels during routine fishing trips to collect data about discards.

The review panel recommended several additional research needs and general suggestions which would reduce the uncertainties in the BRPs:

a) Consider additional fishery-independent surveys, with continued industry support and involvement. These cooperative surveys might include standardized trap-based sampling or HABCAM (cameara) surveys. The panel noted that the industry is already supporting a sizeable tagging program.

b) Additional information on relative sizes of mating pairs and its consequences on reproductive potential (sperm limitation) would allow for the inclusion of additional size-based BRPs

i) Consider simulation modeling to explore the response of the population sex ratio to different exploitation patterns to determine whether sex ratios may serve as a tool to inform management on current catch rates. The review team noted that such an approach would only work if knowledge of the population wide sex ratio was indexed.

c) Studies of brood production, incubation period, and pattern of sperm storage would be helpful.

d) Studies to refine growth (intermolt period and growth per molt) and longevity estimates would improve understanding of stock dynamics.

e) Assessment of whether females, in particular, exhibit a terminal molt would help development of growth models.

f) Information on movement and behavior of crabs within their range would be of utility.

g) Abundance-habitat relationships.

h) Role of economic factors in crab and other fisheries may alter distribution and interpretation of fishing effort.

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Deep sea red crab; Tables

Table 1. Total annual mortality due to fishing (landings and mortal discard) during 2003-2005, by sex.

	Males	**Females**	**Total**
Average 2003-2005 landings (mt)	1,992	0	1,992
Discard/(total male + female catch)	0.11	0.18	0.29
Catch (mt, includes all discards)	2,238	2,429	4,667
Discard (mt)	246	2,429	2,675
Discard mortality rate (5 x best estimate)		0.5	
Mortal discard (mt)	123	1,215	1,338
Landings + mortal discard (mt)	2,115	1,215	3,330
Total biomass (mt)	56,443	74,689	131,132
90+ CW biomass (mt)	38,220	55,279	93,499
F relative to total biomass	0.04	0.02	0.03
F relative to 90+ biomass	0.06	0.02	0.04

Table 2: Biomass estimates, standard errors and CVs from deep-sea red crab camera/bottom trawl surveys. The standard errors for 1974 estimates are approximations based on the assumption that CVs for variability among samples was the same during 1974 as during 2003 to 2005. The differences in CVs between the two periods are due do differences in assumed effective sample size.

		Males			Females			Total		
Year	Size groups (mm CW)	Biomass (mt)	SE (mt)	CV	Biomass (mt)	SE (mt)	CV	Biomass (mt)	SE (mt)	CV
1974	90+ mm	29,991	6,298	0.21	15,654	3,719	0.24	45,645	7,314	0.16
	114+ mm	23,794	4,303	0.18	2,106	433	0.21	25,900	4,325	0.17
	Fishable	30,302	6,363	0.21	NA	NA	NA	NA	NA	NA
	All	32,190	5,001	0.16	20,674	5,221	0.25	52,864	7,230	0.14
2003 to 2005	90+ mm	38,220	4,298	0.11	55,279	7,033	0.13	93,499	8,242	0.09
	114+ mm	13,770	1,334	0.10	5,224	576	0.11	18,994	1,453	0.08
	Fishable	36,247	4,612	0.13	NA	NA	NA	NA	NA	NA
	All	56,443	4,646	0.08	74,689	10,102	0.14	131,132	11,119	0.08

Table 3. Summary of exploitation based BRPs as MSY or MSY proxy options.

Method	Method or model	Result	Estimate or range of estimates	Uses 1974 survey Information?	Equilibrium estimator?
1	Status quo MSY	MSY	2830 mt	Yes	No
2	Long term sustainable catch	Sustainable yield	1775 mt	No	Yes
3	Updated yield equation applied to 1974 biomass	MSY	549 - 1646 mt	No	No
4	Updated yield equation applied to 2003-2005 biomass	MSY	580 - 1740 mt	No	No
5	DCAC model	Sustainable yield	1785 - 1862 mt	Yes	Yes
6	2-point boundary model	Equilibrium catch	1987 - 2044 mt	Yes	Yes

Deep sea red crab; Figures

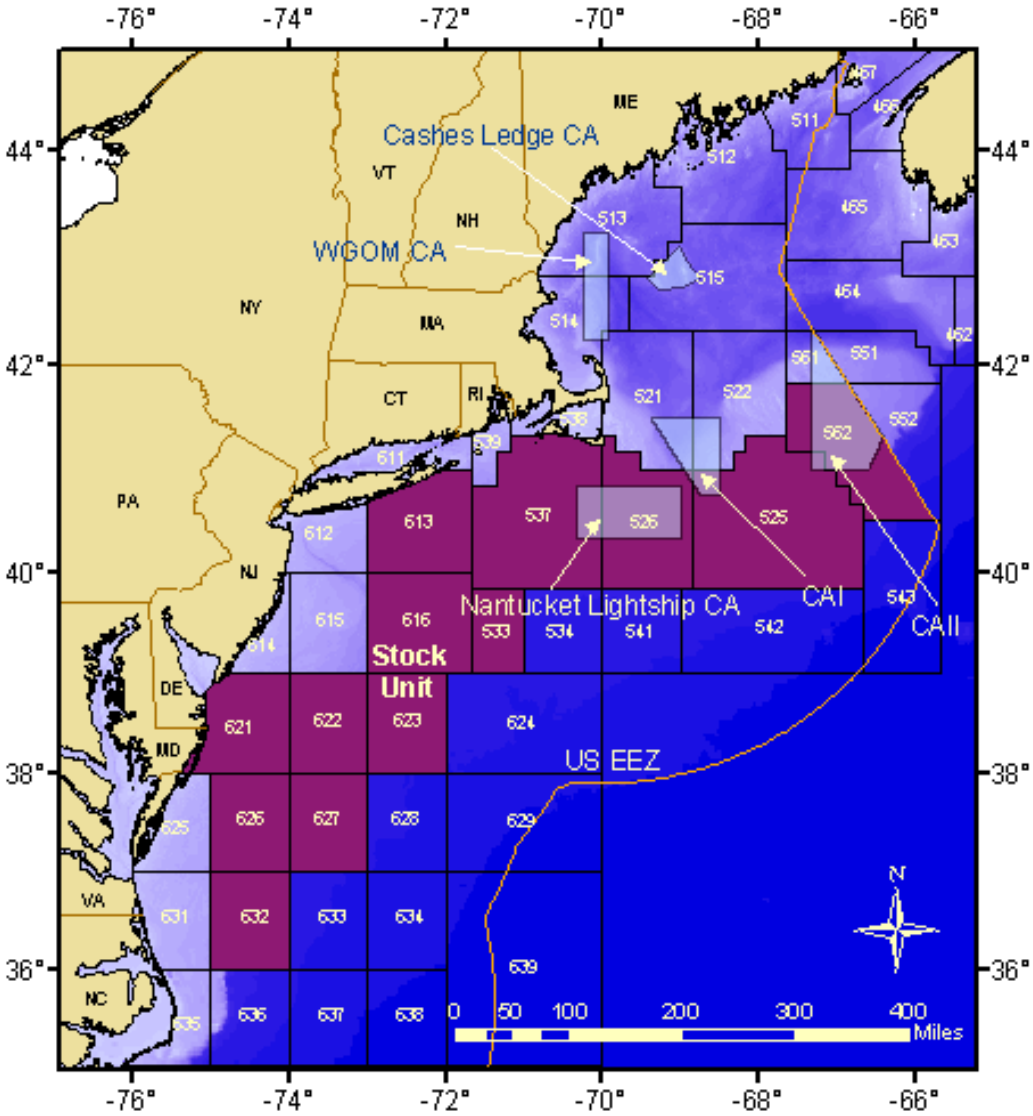

Figure 37.1. Statistical areas used to define the deep sea red crab stock.

Figure 1. The management area used by the New England Fishery Management Council for deep-sea red crab. The portion of the stock in the Gulf of Maine is excluded.

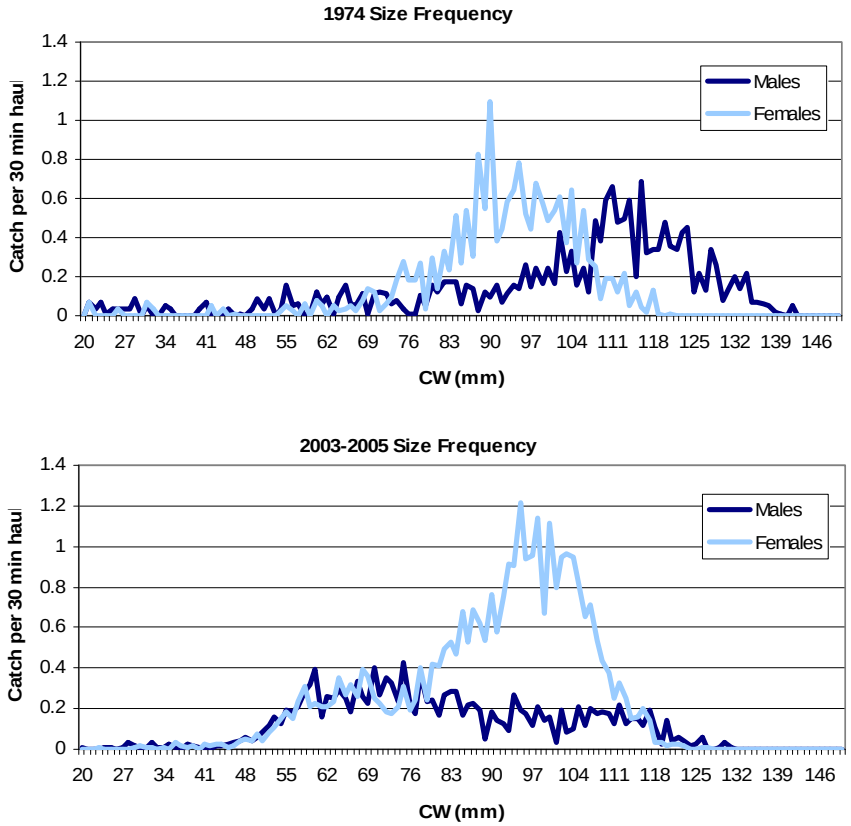

Figure 2. Catch per 30-minute trawl by size in the 1974 survey (top) and 2003-2005 surveys.

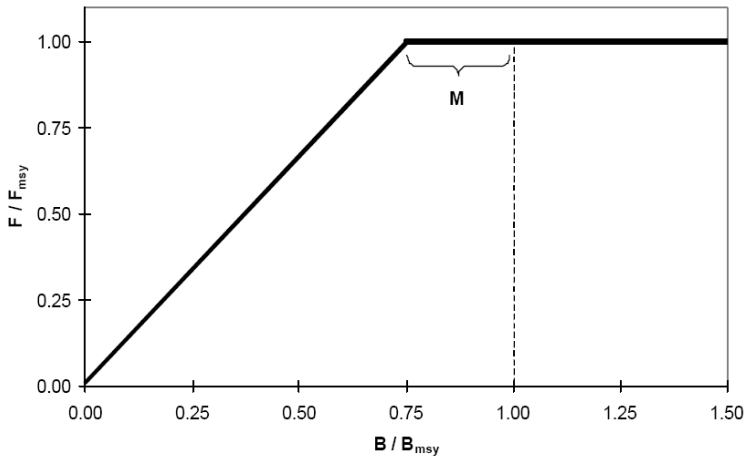

Figure 3**.** Default MSY control rule in the FMP for deep-sea red crab.

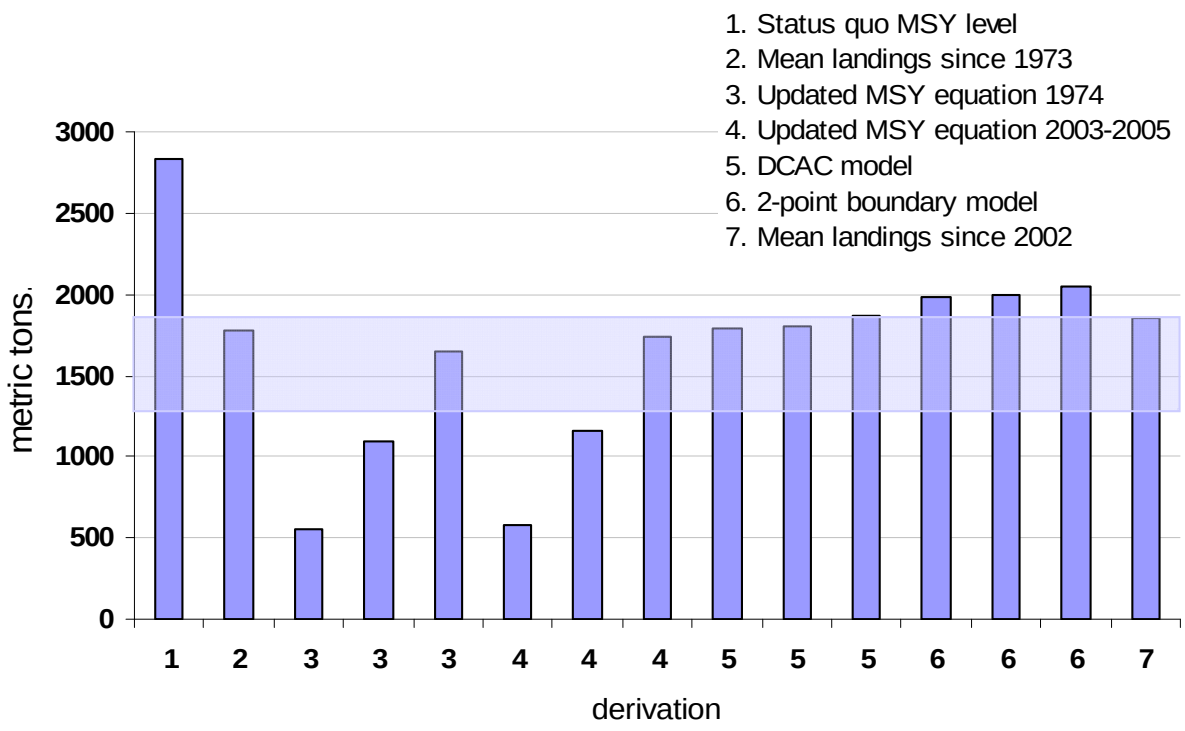

Figure 4. Summary of estimates of sustainable yield for red crab estimated using various methods. The upper boundary of the shaded area is the mean annual landings of red crab since 2002 and the lower boundary represents landings during 2007.

Deep sea red crab; Appendix 1

Red crab size composition analysis

Based on the ratio of minimum mature size, and ratio of mean size in 1974, we assume that males must be at least 25% larger than females to mate successfully (alternative assumptions could be explored). This analysis examines the impact of the fishery on the size structure of the population, specifically with regard to the ratio of number of males to the number of females small enough for the males to fertilize.

Direct analysis of survey results has the benefit of being able to explore the sex ratio in terms of observed densities of crabs, but lacks the ability to interpret those results in terms of a reference point of no fishing. It may be possible to interpret the 1974 survey as representing size distributions under light fishing, so that 1974 could serve directly as a reference distribution.

Direct analysis of survey densities

Table 1a shows summary statistics of mature red crabs from the 1974 and 2003-2005 surveys. Females are assumed to mature at 70mm, and males at 90mm. The densities of mature male crabs per 30-minute tow declined slightly, but the density of female crabs increased substantially in the later survey. This poses some difficulty for interpretation, with the main hypotheses being that it is due to imprecision (including differences in survey locations—all this needs to be explored), or alternatively that it is due to exploitation effects on a population that otherwise would have been more abundant in the later period. If the 1974 ratio of males to females is applied to the density of females in 2003-2005, the expected male density would have been approximately 30, in which case the relatively low observed value of 15 is presumably due to exploitation effects. Mean size of females is similar in the two surveys, but mean size of males declined as would be expected from exploitation effects including a shift of minimum marketable size from 114mm to 90mm. By tabulating the sum of densities of females smaller than the minimum sized female each male size class is capable of mating with, table 1a below shows the mean number of females available to the males, weighted by the size frequency of males. In order to maintain a similar level of fertilization, the average male in 2003-2005 must mate with 2.33 times the number of females that it did in 1974. If the1974 size composition already showed exploitation effects, the population impact is greater than is shown in table 1a.

Table 1a. Summary of size composition analysis.

Survey date	1974		2003-2005	
	males	females	males	females
Size at maturity (mm)	90	70	90	70
total density (n per 30-min tow)	17.2	17.8	15.0	31.3
mean size of mature crabs (mm)	113.8	94.1	105.7	95.1
mean ratio of size-dependent available females to males	25.3		58.9	

Deep sea red crab; Appendix 2

Depletion-Adjusted Average Catch Model

Alec MacCall, NMFS/SWFSC/FED (draft 9/6/07)

Unlike the classic fishery problem of estimating MSY, data-poor fishery analysis must be content simply to estimate a yield that is likely to be sustainable. While absurdly low yield estimates would have this property, they are of little practical use. Here, the problem is to identify a moderately high yield that is sustainable, while having a low chance that the estimated yield level greatly exceeds MSY and therefore is a dangerous overestimate that could inadvertently cause overfishing and potentially lead to resource depletion before the error can be detected in the course of fishery monitoring and management.

Perhaps the most direct evidence for a sustainable yield would be a prolonged period over which that yield has been taken without indication of a reduction in resource abundance.

The estimate of sustainable yield would be nothing more than the long-term average annual catch over that period. However, it is rare that a resource is exploited without some change in underlying abundance. If the resource declines in abundance (which is necessarily the case for newly-developed fisheries), a portion of the associated catch stream is derived from that one-time decline, and does not represent potential future yield supported by sustainable production. If that non-sustainable portion is mistakenly included in the averaging procedure, the average will tend to overestimate the sustainable yield. This error has been frequently made in fishery management. Based on these concepts, we present a simple method for estimating sustainable catch levels when the data available are little more than a time series of catches. The method needs extensive testing, both on simulated data and on cases where reliable assessments exist for comparison. So far, test cases indicate that it may be a robust calculation.

The Windfall/Sustainable Yield Ratio

The old potential yield formula Ypot = 0.5*M* $B_{UNFISHED}$ (Alverson and Pereyra, 1969; Gulland, 1970) is based on combining two approximations: 1) that B_{MSY} occurs at 0.5*$B_{UNFISHED}$, and 2) that F_{MSY} = M. In this and the following calculations fishing mortality rate (F) and exploitation rate are treated as roughly equivalent.

However, it is possible to take the potential yield rationale one step farther, and calculate the ratio of the one-time "windfall" harvest (W) due to reducing the abundance from $B_{UNFISHED}$ to the assumed B_{MSY} level. After that reduction in biomass has occurred, a tentatively sustainable annual yield Y is given by the potential yield formula. So we have the following simple relationships:

Y = 0.5*M* $B_{UNFISHED}$, and

W = 0.5* $B_{UNFISHED}$.

Under the potential yield assumptions, the ratio of one-time windfall yield to sustainable yield is the windfall/sustainable yield ratio (or simply the "windfall ratio") W/Y = 1/M. For example, if M = 0.1, the windfall is equal to 10 units of annual sustainable yield.

An Update

The assumptions underlying the potential yield formula are out-of-date, and merit reconsideration. Most stock-recruitment relationships indicate that MSY of fishes occurs somewhat below the level of 0.5*

$B_{UNFISHED}$. We replace the value of 0.5 with a value of 0.4 as a better approximation of common stock-recruitment relationships.

The F_{MSY} = M assumption also requires revision, as fishery experience has shown it tends to be too high, and should be replaced by a F_{MSY} = c*M assumption (Deriso, 1982; Walters and Martell, 2004). Walters and Martell suggest that coefficient c is commonly around 0.8, but may be 0.6 or less for vulnerable stocks. Figure 1 shows the distribution of c values for West Coast groundfish stocks assessed in 2005. The average of c for those West Coast species is 0.62, but there is a substantial density of lower values. Because the risk is asymmetrical (ACLs are specifically intended to prevent overfishing), use of the average value is risk-prone. Consequently, we have used a value of c=0.5 in the following calculations.

The yield that is potentially sustainable under these revised assumptions is

$Y = 0.4* B_{UNFISHED} *c*M,$

or for c = 0.5,

$Y = 0.2* B_{UNFISHED} *M.$

The windfall is based on the reduction in abundance from the beginning of the catch time series to the end of the series,

$W = Bbegin - Bend = DELTA* B_{UNFISHED}$,

where DELTA is the fractional reduction in biomass from the beginning to the end of the time series, relative to unfished biomass. The analogous case to the potential yield formula is Bbegin = $B_{UNFISHED}$, and Bend = 0.4* $B_{UNFISHED}$, in which case DELTA = 0.6. In practice, Bbegin is rarely $B_{UNFISHED}$, and DELTA is unlikely to be known explicitly. Although data may be insufficient for use of conventional stock assessment methods, an estimate (or range) of DELTA based on expert opinion is sufficient for this calculation. The windfall ratio is now

W/Y = DELTA/(0.4*c*M),

or in the case of c=0.5,

W/Y = DELTA/(0.2*M).

For example, in the case of fishing down from $B_{UNFISHED}$ to near B_{MSY} where DELTA=0.6, if c = 0.5, W/Y = 3/M. Thus the revised calculation gives a much larger estimate of the windfall ratio. For the previous example of M = 0.1, the windfall ratio is now estimated at 30 units of sustainable annual yield.

A Sustainable Yield Calculation

Assume that in addition to the windfall associated with reduction in stock size, each year produces one unit of annual sustainable yield. The cumulative number of annual sustainable yield units harvested from the beginning to the end of the time series is n + W/Y, where n is the length of the series. In this calculation it should not matter when the reduction in abundance actually occurs in the time

series because assumed production is not a function of biomass. Of course, in view of the probable domed shape of the true production curve, the temporal pattern of exploitation may influence the approximation.

The estimate of annual sustainable yield (Ysust) is

Ysust = sum(C)/(n + W/Y).
In the special case of no change in biomass, DELTA = 0, W/Y = 0, and Ysust is the historical average catch. If abundance increases, DELTA is negative, W/Y is negative, and Ysust will be larger than the historical average catch.

Examples

The widow rockfish fishery began harvesting a nearly unexploited stock in 1981 and for the first three years, fishing was nearly unrestricted (Table 1). Reliable estimates of sustainable yield based on conventional stock assessments were not available for many years afterward. By the mid-1990s, stock assessments were producing estimates of sustainable yield ca. 5000 mtons, with indications that abundance had fallen to 20-33% of $B_{UNFISHED}$.

Application of depletion-corrected catch averaging indicates good performance of the method within a few years of the beginning of the fishery. Two alternative calculations are given in Table 1. The first calculation assumes M = 0.15, c = 0.5, and that biomass was near B_{MSY} at the end of the time period, so that DELTA = 0.6. The second calculation is closer to the most recent stock assessment (He et al., 2007) and assumes M = 0.125, c = 0.5, DELTA = 0.75 (ending biomass in year 2000 is about 25% of $B_{UNFISHED}$).

Other examples would be worth exploring, especially were they can be compared with "ground truth" from a corresponding formal stock assessment.

Low biomasses

The yields given by these calculations can only be sustained if the biomass is at or above B_{MSY}. If the resource has fallen below B_{MSY}, the currently sustainable yield (Ycurrent) is necessarily smaller. A possible approximation would be based on the ratio of Bcurrent to B_{MSY},

Ycurrent = Ysust*(Bcurrent/ B_{MSY}) if Bcurrent< B_{MSY}

Implementation

This method is most useful for species with low natural mortality rates; stocks with low mortality rates tend to pose the most serious difficulties in rebuilding from an overfished condition. As natural mortality rate increases (M > 0.2), the windfall ratio becomes relatively small, and the depletion correction has little effect on the calculation.

The relationship between F_{MSY} and M may vary among taxonomic groups of fishes, and among geographic regions, and would be a good candidate for meta-analysis. Uncertainty in parameter values can be represented by probability distributions. A Monte Carlo sampling system such as WinBUGS can easily estimate the output probability distribution resulting from specified distributions of the inputs.
With minor modifications, this method could also be applied to marine mammal populations. Although estimation of sustainable yields is not a central issue for marine mammals nowadays, the method would be especially well suited to analysis of historical whaling data, for example.

References

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Deep sea red crab; Appendix 3

2-point boundary model

Estimation of Average Recruitment, Biomass Weighted F, and Equilibrium Catch

Two quantitative surveys of red crab abundance and long-term record of landings provide an opportunity to estimate the average recruitment necessary to support the observed time series of catch. This is accomplished by using a simple mass balance equation with boundary conditions defined as the initial and final survey values.

Process Equation

Let B_t represent the biomass at time t and specify the boundary conditions B_0 and B_T. The biomass at time t+1 can be expressed as

$$B_{t+1} = (B_t - C_t + R_t)S \qquad (1)$$

Where C_t is the total catch and R_t is total recruitment of biomass to the population. The parameter S can be thought of as either the survival rate = e^{-M} or the difference between the instantaneous rate of growth G and M or $S=e^{-(G-M)}$. For this application it was assumed that increments to population biomass via growth are included in the Rt term; therefore $S=e^{-M}$ No information is available to estimate the annual recruitment to the population but Eq. 1 can be simplified by let R_t equal a constant, say R.

$$B_{t+2} = (B_{t+1} - C_{t+1} + R)S \qquad (2)$$

Substituting Eq. 1 into 2 recursively leads to

$$B_{t+2} = ((B_t - C_t + R)S - C_{t+1} + R)S$$

$$B_{t+3} = (B_{t+2} - C_{t+2} + R)S$$

$$B_{t+3} = (((B_t - C_t + R)S - C_{t+1} + R)S - C_{t+2} + R)S$$

….

$$B_{t+T} = B_t S^{T-1} + \sum_{j=1}^{T-1} S^j R - \sum_{j=1}^{T-1} C_j S^{T-j} \qquad (3)$$

If we let B_t=B(0), B_{t+T}=B(T) and assume S then it is possible to estimate R as the average recruitment necessary to satisfy Eq. 3.

$$R = \frac{B(T) - B(0)S^{T-1} + \sum_{j=1}^{T-1} C_j S^{T-j}}{\sum_{j=1}^{T-1} S^j} \qquad (4)$$

Given the average recruitment R, the year-specific F_t can be estimated as

$$\hat{F}_t \approx \frac{C_t}{B_t + R} \qquad (5)$$

The estimates of year specific F_t are unreliable since they depend on the average recruitment estimate R. However, the average F over the period can be estimated as

$$\overline{F} = \sum_{j=1}^{T-1} \frac{\hat{F}_j}{T-1} \qquad (6)$$

The average catch sufficient to maintain the population at its current size can be estimated by setting $B_{T+1}=B_T$ in Eq. 1 and solving for C as

$$\begin{aligned} B_T &= \left(B_T - \overline{C}_{EQ} + R\right)S \\ \overline{C}_{EQ} &= R - \frac{B_T\left(1-S\right)}{S} \end{aligned} \qquad (7)$$

Eq. 4, 6 and 7 can now be used to estimate the average recruitment necessary to support the total removals between time t and t+T, the average biomass weighted F experienced by the population, and the average catch necessary to maintain the population at its current value of B_T.

Incorporating the Uncertainty in Population Size

The uncertainty in initial and final population sizes has important implications for the uncertainty in the average R, Fbar and C_{EQ}. This uncertainty can be approximated by convolving the distribution of initial population size with the final population size. Assume that the survey mean estimates are normally distributed. Let $B_t \sim N(\mu_t\ \sigma_t^2)$, $B_{t+T} \sim N(\mu_{t+T}\ \sigma_{t+T}^2)$ and $\Phi(.)$ define the cdf of the normal distribution. The inverse of the normal cdf, say $\Phi^{-1}(.)$, can be used to define population estimates for equal probability intervals

$$\begin{aligned} B_{t,\alpha} &= \Phi^{-1}\left(\mu_t, \sigma_t^2, \alpha\right), \quad \alpha = \alpha_{\min}, \ldots \alpha_{\max} \\ B_{T,\beta} &= \Phi^{-1}\left(\mu_T, \sigma_T^2, \beta\right), \quad \beta = \beta_{\min}, \ldots \beta_{\max} \end{aligned} \qquad (8)$$

Define $R_{\alpha,\beta}$ as the average recruitment obtained by substituting $B_{t,\alpha}$ and $B_{T,\beta}$ in Eq. 4 for B(0) and B(T) respectively. The sampling distribution of R and by extension, Fbar and Cbar, can now be obtained by simply matching all possible values of α with all possible values of β. More economically, one can define a small step size, say δ and evaluate $R_{\alpha,\beta}$ for equal

increments between the minimum and maximum values of the cdf. The sampling distribution of R, Fbar, and Ceq is just the collection of discrete estimates since all estimates $R_{\alpha,\beta}$ have equal probabilities of occurrence = δ^2 and the sum of all δ^2 's is one.

Application to Red Crab

Estimates of R, Fbar, and C_{EQ} were derived for male and female red crab from the 1974 and 2004 fishery independent surveys (Table A3-1) and landings from 1974 to 2003 (Table A3-2). The distributions of R, Fbar and CEQ were based on convolution of 51 equal probability cut points representing a 95% confidence interval for the initial and final year biomass estimates. The convolution distribution was based on 2601 (i.e. 51 x 51) evaluations of Eq. 4. Annual survival for the base runs was assumed to be 0.86 (i.e., M=0.15)

Model results suggest that the median male recruitment is about 8500 mt per year. Historical average F between 1974 and 2004 was about 0.04 (Table A3-3). Given the population size in 2004, catches of 2,060 mt would keep the population at its current size of about 36,000 mt. This is about 16% higher than the average catch between 1973 and 2007 but 10% less than landings since 2000.

Between 1974 and 2004 the female population (>90 mm CW) increased nearly four-fold from 15 kt to 55 kt. Under the assumption that fishing mortality on the females was essentially zero, the estimated median recruitment was 9837 mt. The confidence intervals for median recruitment levels for males and females overlap which suggest comparable rates of biomass recruitment. The parameters for average recruitment and survival are confounded and the small differences in average recruitment estimates between male and female recruitment could be due to slightly different mortality rates or growth rates between sexes. For example, assuming an M=0.13 for females results in a median R of 7,810 mt that is about the same as the median R for males when M=0.15.

The sensitivity of the R, Fbar and C_{EQ} to changes in M are illustrated in Tables A3-4 to A3-6. Estimated average recruitment increases about three-fold as M increases (or S declines) from 0.05 to 0.20. The estimated equilibrium catch is relatively unchanged remaining at about 2,000 mt. Figures A3-1 and A3-2 demonstrate that as S approaches 1 the long-term catch equals the estimated average recruitment.

Table A3-1. Estimated survey biomass of male and female red crab, 1974 and 2004.

Category	Initial Biomass (SE)	Final Biomass (SE)
Fishable Biomass of Males	30,302 (6,363)	36,247 (4,612)
Female Biomass (>90 mm CW)	15,654 (3,719)	55,279 (7,033)

Table A3-2. Summary of annual landings (mt) of red crab in US.

Year	Landings (mt)
73	112.5
74	503.1
75	307.3
76	637.9
77	1244.6
78	1247.6
79	1210.8
80	2481.2
81	3031.8
82	2445.6
83	3252.4
84	3875.0
85	2236.7
86	1248.7
87	2110.3
88	3592.7
89	2393.2
90	1526.7
91	1791.0
92	1061.2
93	1439.9
94	0.3
95	572.0
96	465.6
97	1725.2
98	1501.1
99	1869.2
00	3129.4
01	4002.7
02	2142.5
03	1920.0
04	2040.3
05	2013.2
06	1716.0
07	1284.0

Table A3-3. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.15 (S=0.861).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	7,928 (6.856, 9,068)	0.042 (0.036, 0.049)	2,044 (2,023, 2,064)
Female Biomass (>90 mm CW)	9,044 (7,408, 10,785)	0	72 (52, 93)

Table A3-4. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.05 (S=0.95).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	3,850 (3,402, 4,324)	0.047 (0.041, 0.054)	1,987 (1,819, 2,152)
Female Biomass (>90 mm CW)	3,427 (2,766, 4,127)	0	584 (419, 757)

Table A3-5. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.1 (S=0.905).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	5,819 (5,095, 6587)	0.044 (0.038, 0.051)	1,996 (1,932, 2,058)
Female Biomass (>90 mm CW)	6,049 (4,945, 7,224)	0	219 (157, 283)

Table A3-6. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.2 (S=0.819).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	10,159 (8,704, 11,707)	0.039 (0.034, 0.046)	2,110 (2,104, 2,116)
Female Biomass (>90 mm CW)	12,297 (10,077, 14,658)	0	22 (16, 28)

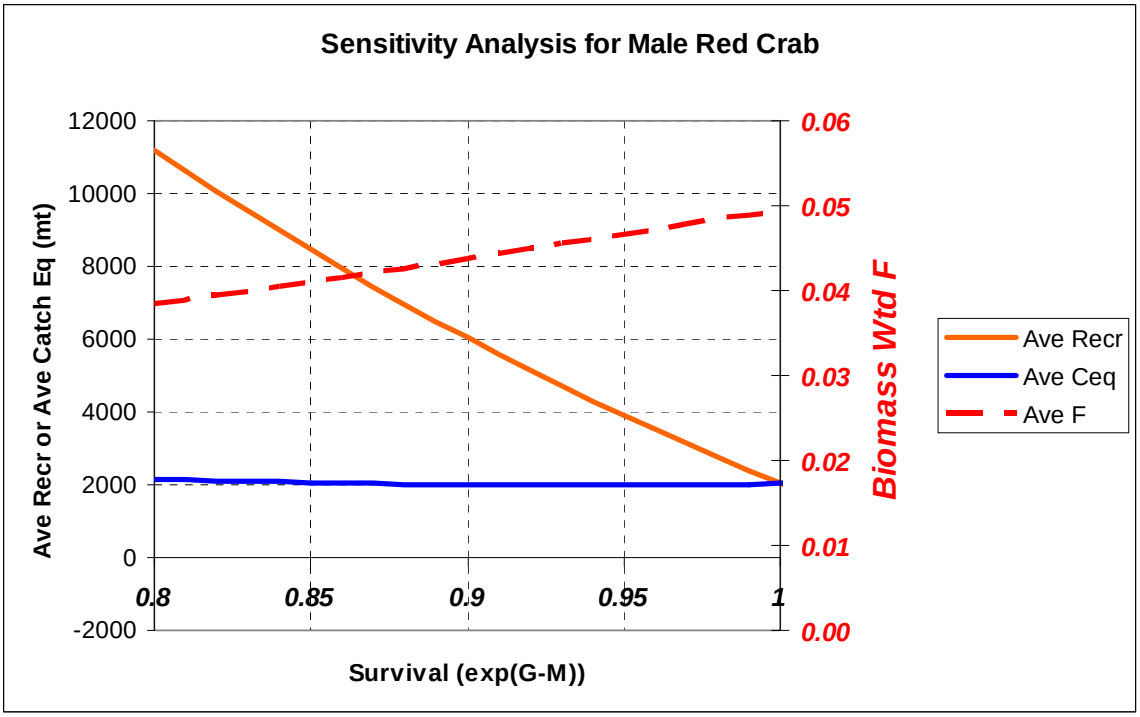

Fig A3-1. Sensitivity analysis of recruitment, average F and equilibrium catch for male red crab to varying levels of survival rate.

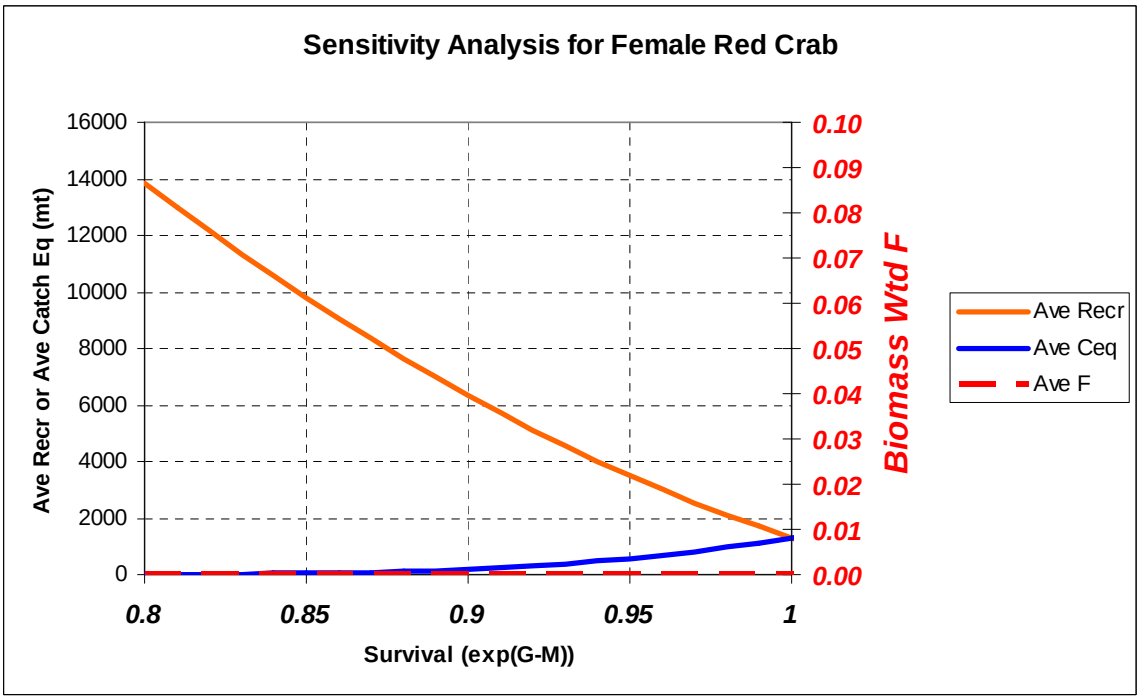

Fig. A3-2. Sensitivity analysis of recruitment, average F and equilibrium catch for female red crab to varying levels of survival rate.

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Atlantic wolffish

Charles Keith and Paul Nitschke
Northeast Fisheries Science Center

Northeast Data Poor Stocks Working Group Meeting
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Executive Summary

Atlantic wolffish in the Gulf of Maine and Georges Bank regions inhabit the southern edge of the species distribution. Analyses herein were limited to the stock component completely within United States waters, which excluded some historically important transboundary portions of Georges Bank. There is currently no fishery management plan for the Atlantic wolffish in U.S. waters. Wolfish are associated with rough topography. Catchability of wolffish is low in NEFSC trawl surveys due to this habitat preference. Atlantic wolffish are long-lived (22 years), late maturing, and of low fecundity. Males guard the eggs in nests in the fall. Larger wolffish are caught in the spring survey compared to the fall, perhaps due to nest guarding behavior. All fishery independent survey indices show a declining trend in abundance over the time series. The commercial catch has also declined steadily since 1983. However there is no size truncation in the catch over the time series. A wolffish growth study from the 1980s in the Gulf of Maine and Georges Bank region was done by Nelson and Ross (1992). The DCAC model, AIM model, and simple exploitation ratios were examined for this assessment and presented to the Data Poor Stocks Peer Review Panel. A forward projection model, Statistical Catch At Length (SCALE), which tunes to size and age data from trawl survey recruitment and adult indices, total catch, and catch size distributions along with overall growth information, was developed for this assessment. This model was accepted by the Peer Review Panel as a basis for determining the biological reference points (BRPs) for Atlantic wolffish. The SCALE model had difficulty estimating selectivity due to the sparse data. Two different selectivity regimes were chosen to determine BRPs and their influence on stock status, using $F_{40\%}$ as a proxy for F_{MSY}. The maturation schedule of wolffish in U.S. waters is uncertain and this influences BRPs derived from the SCALE model. The sensitivity of these non-parametric BRPs was tested with a range of knife edge maturity cutoffs. Early Data-Poor Stocks Working Group meetings indicated that, given the wolffish life history, $F_{50\%}$ may be an appropriate proxy for F_{MSY} and this was presented as a third option to the Panel. Based on all SCALE model runs, the stock in 2007 is at a low biomass level (23% to 45% of B_{MSY}) and is overfished (*assuming a $B_{THRESHOLD}$ of ½ B_{MSY}). The Peer Review Panel concluded that $F_{40\%}$ is a reasonable F_{MSY} proxy and that its value is probably <0.35. The overfishing status is uncertain, and the ratio of F_{2007} to F_{MSY} falls in the range of 56% to 158%. MSY is likely in the range of 138-149 mt and SSB_{MSY} is likely in the range of 794-1,011 mt.

(*Editor's note: This assumption about the definition of $B_{THRESHOLD}$ was confirmed with the Chairman of the Peer Review Panel after the December meeting.)

Section 1. Provide the current exact, legal definitions for overfished and overfishing given in the FMP (if the definition was revised with an official FMP amendment, then give that def.). (NEFSC staff should consult with appropriate RO and Council staff that is on the DPWG to get this info).

NONE

Section 2. List the current Biological Reference Points (parameters and values). (e.g., the proxy for B_{MSY} is the 3-yr average of survey catch per tow from years 19xx to 19yy. The estimate is zzz kg/tow). Include the targets and thresholds for both overfishing and overfished, if those definitions exist.

NONE

Section 3. Explain the logic/justification for why the current definitions were adopted.

NA

Section 4. Explain weaknesses with the current definitions (e.g., not easily measured, not logical, outdated, etc.). If they are OK, say so.

NA

Section 5. (If a change to the BRPs is being recommended by the WG:) Recommend biological reference points (BRPs) and measurable BRP and MSY proxies. Provide justification for the recommendation. Be as specific as possible. If something might be proposed that is not yet measurable, then make that clear and explain what is needed to make it measurable.
A range of biological reference points were available to the Data Poor Stocks Review Panel via the forward projecting SCALE model under various model scenarios. Non-parametric biological reference points (BRP) were developed for both the selectivity L_{50} = 90 run (Run 1) and the slope = 0.15 run (Run 2) within the SCALE model using $F_{40\%}$ as a proxy for F_{MSY}. A range of knife edge maturity values were used in estimating the BRPs. Maturity as 40+ cm, a 65+ cm and 75+ cm cutoffs were used as bounds taken from NEFSC survey results and literature. The Data Poor Working Group suggested $F_{50\%}$, may be an appropriate proxy for a species which is long lived, late maturing and has low fecundity. $F_{50\%}$ BRPs were then developed for the slope =0.15 scenario. SCALE Run 2 was accepted by the Data Poor Stocks Peer Review Panel.

SCALE run	1			2			3		
Selectivity	L_{50} = 90			slope = 0.15			slope = 0.15		
Length of maturity	40	65	75	40	65	75	40	65	75
F_{MSY} proxy	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{50\%}$	$F_{50\%}$	$F_{50\%}$
F_{MSY}	0.70	0.51	0.39	0.35	0.25	0.20	0.195	0.154	0.128
F_{max}	> 0.8	> 0.8	> 0.8	0.60	0.60	0.60	0.60	0.60	0.60
YPR	0.871	0.841	0.809	0.854	0.829	0.788	0.783	0.728	0.678
SSB per Recruit	5.987	5.247	4.686	5.792	5.166	4.548	7.629	6.796	6.050
Initial Recruits (000s)	171	171	171	175	175	175	172	172	172
MSY (mt)	149	144	138	149	145	138	135	125	117
SSB_{MSY} (mt)	1,024	898	802	1,011	902	794	1,314	1,171	1,042
SSB_{07} (mt)	405	293	209	457	339	249	447	330	242
F_{07}	0.516	0.516	0.516	0.195	0.195	0.195	0.202	0.202	0.202
SSB_{07}/SSB_{MSY}	40%	33%	26%	45%	38%	31%	34%	28%	23%
F_{07}/F_{MSY}	74%	101%	132%	56%	78%	98%	104%	131%	158%

Section 6. Provide supporting information for Section 5.

Basic Biology and Ecology

Geographic Range

Atlantic wolffish (*Anarhichas lupus*) can be found in northern latitudes of the eastern and western North Atlantic Ocean (Figure 1). In the north and eastern Atlantic they range from eastern Greenland to Iceland, along northern Europe and the Scandinavian coast extending north and west to the Barents and White Sea's. In the northwest Atlantic they are found from Davis Straits off of western Greenland, along Newfoundland and Labrador and continue southward through the Canadian Maritime Provinces to Cape Cod, USA. They are found infrequently in southern New England to New Jersey (Collete and Klein-MacPhee 2002). Northeast Fishery Science Centers Bottom Trawl surveys have only encountered 1 fish southwest of Martha's Vineyard, Massachusetts since 1963.

Habitats

Atlantic wolffish are demersal and prefer complex habitats with large stones and rocks which provide shelter and nesting sites (Pavlov and Novikov 1993). They are occasionally seen in soft sediments such as sand or mud substrate and likely forage for food sources in these habitats (Collete and Klein-MacPhee 2002; Falk-Petersen and Hansen 1991). They are believed to be relatively sedentary and populations localized. Tagging studies from Newfoundland, Greenland and Iceland indicate that most individuals were recaptured within short distances, ~8km, of the original tagging sites (Templeman 1984; Riget and Messtorff 1988; Jonsson 1982). Three significantly longer migrations were reported in Newfoundland ranging from 338 – 853 km (Templeman 1984).

Atlantic wolffish occupy varying depth ranges across its geographic range. In the Gulf of Maine they inhabit depths of 40 – 240 m, in Greenland and Newfoundland 0 – 600 m, in Iceland 8 – 450 m and in Norway and the Barents Sea from 10 – 215 m (Riget and Messtorff 1988; Albikovskaya 1982; Templeman 1984; Jonsson 1982; Falk-Petersen and Hansen 1991). In U.S. waters, abundance appears to be highest in the southwestern portion of the Gulf of Maine, from Jefferies Ledge to the Great South Channel, corresponding to the 100 m depth contour (Nelson and Ross 1992). Similarly, abundance is highest in the Browns Bank, Scotian shelf and northeast peak of Georges Bank areas in the Canadian portion of the Gulf of Maine (Nelson and Ross 1992). Atlantic wolffish in Newfoundland and Icelandic waters were identified as most abundant in depths 101 – 350 m and 40 - 180 m, respectively (Albikovskaya 1982; Jonsson 1982).

Temperature ranges where Atlantic wolffish occurs also deviate slightly with geographic region. Historically in the Gulf of Maine they have been associated with temperatures ranging from 0 – 11.1°C (Bigelow and Schroeder 1953). Bottom temperatures collected from NEFSC bottom trawl surveys where wolffish were encountered range from 0 – 10°C in spring and 0 – 14.3°C in fall. In Newfoundland wolffish thermal habitat ranged from -1.9 – 11.0 °C, Norway from -1.3 - 11 °C and in Iceland and Northern Europe -1.3 – 10.2 °C (Collete and Klein-MacPhee 2002; Falk-Petersen and Hansen 1991; Jonsson 1982). Laboratory studies indicate wolffish can survive a wide span of temperatures -1.7 – 17.0°C and that feeding is negatively correlated with the higher temperature extremes (Hagen and Mann 1992; King et al. 1989).

Reproduction

In general Atlantic wolffish are solitary in habit, except during mating season when bonded pairs form in spring/summer depending on geographic location (Collete, Klein-MacPhee 2002; Keats et al 1985; Pavlov and Novikov 1993). Spawning is believed to occur in September through October in the Gulf of Maine but is likely to depend on temperature and possibly photoperiod (Collete and Klein-MacPhee 2002; Pavlov and Moksness 1994). Spawning is reported to occur from August – September in Nova Scotia, during autumn in Newfoundland, September – October in Iceland, July – October in Norway, and late summer – early autumn in the White Sea (Keats et al. 1985; Templeman 1986; Jonsson 1982; Falk-Petersen, Hansen 1991; Pavlov, Novikov 1993). In the Gulf of Maine there is weak indication of a seasonal migration as wolffish may travel from shallow to deep in autumn and then deep to shallow in spring (Nelson and Ross 1992). Similar migrations occur in Iceland and the White Sea where wolffish migrate to colder temperatures before the spawning season (Pavlov and Novikov 1993; Jonsson 1982). Atlantic wolffish have the lowest fecundity compared to their relatives, the spotted wolffish (*Anarhichas minor*) and the northern wolffish (*Anarhichas denticulus*). Fecundity is related to fish size and body mass in this species and increases exponentially with length. Newfoundland mean fecundity estimates, combined from several NAFO statistical areas, range from 2,440 eggs at 40 cm to 35,320 eggs at 120 cm (Templeman 1986). In Norway a female at 60 cm produces approximately 5,000 eggs while a female 80-90 cm will lay 12,000 eggs (Falk-Petersen and Hansen 1991). Potential fecundity of wolffish in Iceland was measured between 400 and 16,000 eggs for fish at lengths of 25 and 83 cm respectively (Gunnarsson et al. 2006). Mature eggs are large measuring 5.5 – 6.8 mm in diameter (Colette and Klein-MacPhee 2002). Male Atlantic wolffish have small testes and produce small amounts of sperm peaking during late summer and autumn. These data along with morphological development of a papilla on the urogenital pore during spawning suggest internal fertilization (Pavlov and Novikov 1993; Pavlov and Moksness 1994, Johannessen et al 1993). Males have been observed guarding egg clusters for several months but it is not certain if they continue until hatching (Keats et al. 1985; Collete and Klein-MacPhee 2002). Hatching may take 3 to 9 months depending on temperature (Collete and Klein-MacPhee 2002).

Food Habits

The diet of Gulf of Maine and Georges Bank wolffish consist primarily of bivalves, gastropods, decapods and echinoderms (Nelson. Ross 1992). Wolffish possess specialized teeth, including protruding canine tusks (hence its name) and large rounded molars, which allow for removal of organisms from the sea floor and crushing of hard shelled prey (Collete and Klein-MacPhee 2002). Due to diet teeth are replaced annually (Albikovskaya 1983; Collete and Klein-MacPhee 2002). Fish have also been reported as an important food source in other regions along with amphipods and euphausiid shrimp for smaller individuals, 1 – 10 cm (Collete and Klein-MacPhee 2002; Albikovskaya 1983; Bowman et al. 2000). Travel between shelters and feeding grounds occurs during feeding periods as evidenced by crushed shells and debris observed in the vicinity of occupied shelters (Collete and Klein-MacPhee 2002; Pavlov and Novikov 1993). Fasting does occur for several months while replacing teeth, spawning and nest guarding occurs (Collete and Klein-MacPhee 2002).

Size

In the Gulf of Maine and Georges Bank regions individuals may attain lengths of 150 cm and weights of 18 kg (Goode 1884; Idoine 1998). Northeast Fishery Science Center bottom trawl surveys have captured animals ranging in size from 3 – 137 cm in spring and 4 – 120 cm in fall and with a maximum weight of 11.77 kg.

Age and Growth

Mean length at age for Atlantic wolffish in the Gulf of Maine was determined to be 22 years at 98 cm and 0 years at 4 cm (Nelson, Ross 1992). Fish over 100 cm were not sampled extensively in this study, 10 fish from 100-118 cm. Ages in the Gulf of Maine are comparable to wolffish ages in other regions, such as 21 years in east Iceland and 23 years in Norway (Gunnarsson et al. 2006; Falk-Petersen and Hansen 1991). Age 0 fish grow quickly in Icelandic waters and may reach 10.5 cm in the first year (Jonsson 1982). Gulf of Maine wolffish growth rates are faster than wolffish in Iceland, but grow fastest in the North Sea region (Nelson and Ross 1992; Liao and Lucas 2000). Growth in the Gulf of Maine for both male and female wolffish was best estimated using a Gompertz growth function, $L\infty = 98.9$ cm, $K = 0.22$ and $t_0 = 4.74$ (Nelson and Ross 1992). Female growth from Iceland has been modeled using a logistic growth function and coefficients estimated using non-linear optimization (Gauss-Newton method), results from the east and west regions were: $L\infty = 90.919$, $K = 0.230$ and $t_0 = 8.837$ and $L\infty = 70.046$, $K = 0.378$ and $t_0 = 4.691$, respectively (Gunnarsson et al. 2006). Von Bertalanffy growth parameters for the North Sea population of wolffish were $L\infty = 111.2$, $K = 0.12$ and $t_0 = -0.43$ and $L\infty = 115.1$, $K = 0.11$ and $t_0 = -0.39$, for males and females respectively (Liao and Lucas 2000).

Maturity

In the Gulf of Maine individuals are believed to reach maturity by age 5-6 when they reach approximately 47 cm total length (Nelson, Ross 1992; Templeman 1986). Size at fifty percent maturity (L_{50}) of females varies latitudinally which is likely due to the effects of temperature. Templeman (1986) showed that northern fish mature at smaller sizes than faster growing southern fish in Newfoundland. L_{50} was reported as 51.4 cm in the northern area, 61.0 cm in the intermediate region and 68.2 cm in the south. In a study somewhat contradictory to Templeman 1986, Atlantic wolffish in east Iceland, where water temperatures are colder, had larger L_{50} values than fish in the relatively warmer waters of east Iceland (Gunnarsson et al. 2006). Authors indicate that maturity may be difficult to determine using visual methods in females because of large eggs size in this species. Second generation eggs are visible in young, immature fish when the reach the cortical alveolus stage but they may not be able to spawn for several more years (Gunnarsson et al. 2006; Templeman 1986).

The US Fishery

Landings and Total Catch

NMFS Commercial Fishery Databases contain historical and current catch and effort information of Atlantic wolffish, 1963 - 2007. Data presented here are only from fishery statistical reporting areas that are completely or almost entirely within US territorial waters throughout the time series (Figure 2). The International Court of Justice in 1984 established the maritime boundary in the Gulf of Maine, known as the Hague Line, which divided US and

Canadian Exclusive Economic Zones (ICJ 1984). In 1985 fishery statistical areas 523 and 524, which overlapped the US/Canada boundary in the Georges Bank region, were separated into distinct areas 551, 552, 561 and 562 Figure 2). Disaggregating United States and Canadian landings data in areas 523 and 524 prior to 1985 was not possible so they are not reported here. Also not reported are landings in the newly created areas in US waters because they do not span the entire time frame.

US landings increased until it peaking in 1983 at 498.1 metric tons (mt) and then decline steadily until 2007, the latest complete year available, where landings were 28.7 mt (Figure 3 and Table 1). In the US, Atlantic wolffish are taken primarily as bycatch in the otter trawl fishery. Over all years, percent commercial landings of wolffish were dominated by otter trawl gear (92.24%), followed by fixed gillnets (3.76%) and bottom tending longlines (2.83%) (Figure 4). However, otter trawls have decreased in importance over time as evidenced by increased reported landings of gillnets and longlines (Appendix 1). Otter trawl gear accounted for a minimum of 74% to a maximum of 99% of the wolffish landings from 1964 to 2007 (Appendix 1). Fixed gill nets and bottom tending longline fisheries account for the majority of remaining landings.

Reported US commercial wolffish landings come primarily from fishery statistical areas 513, 514, 515, 521 and 522 (Figure 5 and Table 2). Landings have fluctuated between statistical areas over time and spatial differences may be difficult to interpret due to management actions, such as permanent closures and rolling time closures, in the Gulf of Maine.

Commercial fishery discards from the Northeast Fisheries Observer Program database were estimated for the period 1989-2007 from US only statistical areas based on the Standardized Bycatch Reporting Methodology combined ratio estimation (Wigley et al 2007). Discards appear to be a small component of the overall catch of Atlantic wolffish (Figure 7 and Table 1). The maximum estimated discards in any one year are 26.98 mt, 1989 (Table 3). Otter trawls account for 98.3% of the total discarded wolffish from all years. Discards appear to be increasing in the gillnet sector, which reported approximately 17% of the total wolffish discarded for 2007 (Table 3).

Recreational catch data was retrieved from the MRFSS database (Figure 6 and Table 4). Landings are reported in total number of fish and total weight per year. Landings include both A and B1 fish, these are fish permanently removed from the population. B2 fish are discarded live and are assumed to have survived. Adjusted landings were developed because average weight of an individual wolffish was highly variable. Average weight (kg) was calculated based on the reported numbers of landed fish (A + B1) divided by the reported landed weight (kg). A grand mean was calculated from average weights and used in the new adjusted landings values. Adjusted landing are less variable than the original reported values and are likely to describe the recreational portion of total catch. Recreational catches have become more significant in recent years as commercial landings have steadily declined (Figure 7 and Table 1). Recreational catch makes up 30% of the total catch and is almost half a large as commercial landings for 2007 (Table 1).

Total Catch is comprised of reported landings, estimates of commercial discards from the primary fishery sectors and recreational catch from US waters as previously described (Figure 7 and Table 1). Recreational catches begin in 1981 and discard estimates begin in 1989. Total US catch peaked in 1983 with 510.82 mt and has decreased steadily reaching a low of 42.43 mt in 2007.

Commercial Lengths Data and CPUE

Fishery observers collect length samples at sea opportunistically providing information on the size structure of the population. Observer lengths have been collected since 1989. Sample sizes from early in the time series are low but have exceeded 100 samples per year during 2003-2007 (Table 5). Median length has been variable over time but increased slightly during the 2003-2007 period indicating that larger fish are being harvested (Figure 8). Differences in length composition by commercial gear types were also plotted (Figure 9). Sample sizes are small in all gears except for otter trawl and gillnet, where size distributions and median values are similar (Table 6).

Commercial lengths from port samples have been taken irregularly during the span of the commercial fishery. A significant amount of samples were collected during 1982 – 1985 and have also been taken consistently since 2001. Commercial port sample length distributions were plotted by year (Figure 10). An increase in median length can be seen during the 2001 – 2007 time period. The median has increased from 75 cm in 2001 to 84 cm in 2007 (Table 7). This data suggests that size in the commercial fishery may be increasing as the 95% confidence intervals from the 2001-2003 period do not overlap with the 2004-2007 period. Differences were then examined to see if the increase could be explained by major gear type since longlines, and gill nets have become a larger component of the fishery (Figure11). Slight differences were observed in the size compositions of the various gears but this may be an artifact of low sample size of commercial gears other than otter trawls (Table 8). Commercial length samples were also plotted by statistical area to determine if any geographic trend in size could be seen (Figure 12). The primary fishery areas, 512-522, show similar length distributions. Areas 526 and 537 had anomalous length distributions but also had low sample sizes (Table 9).

Indices of catch per unit of effort (CPUE) were calculated from fishery observer trips and self reported Vessel Trip Reports (VTRs) in party and charter boat sectors for Atlantic wolffish. Observer CPUE was estimated for 1989-2007 in the longline, gillnet and otter trawl fisheries for US statistical areas 512-515, 521-522, 525-526 and 537 (Table 10). CPUE was calculated based on the ratio: sum of kept wolffish per year / sum of days fished per year. Observer CPUE has declined in the 3 fishing sectors reviewed (Figure 13). Atlantic wolffish CPUE for the longline fishery is plotted on the second y-axis as it is significantly higher than the otter trawl and gillnet sectors.

Party and Charter boat CPUE have also declined (Figure 14; Table 11). These indices were calculated from the number wolffish reported landed on VTRs and angler days fished. Angler days fished was estimated by number anglers * hours fished / 24 per year for all party and charter trips in areas 514 and 515.

Research Vessel Survey Data

Survey Length, Weight and Maturity

Atlantic wolffish catches were grouped by decade to reduce data gaps in length frequency plots. Distributions were plotted using proportion at length and number at length (Figures 15 and 16). The numbers at length graphs show an overall reduction in numbers by decade across the length range of Atlantic wolffish. The proportion at length graphs indicate that different size fish are available to the bottom trawl gear in spring and fall. In general, spring survey encounters larger individuals (>= 50 cm) and the fall survey captures smaller individuals ranging from 10-30 cm.

The spring survey also captures a unique distribution of small individuals, less than or equal to 7 cm, and may be used as a juvenile index.

Length weight relationships were developed for Atlantic wolffish from NEFSC bottom trawl survey data. Spring and fall survey data were combined to create one relationship for both male and female fish as no differences were found between seasons or sexes (Figure 17). Linear regression of log transformed data provided a good fit, $R^2 = 0.996$.

A logistic maturity ogive was developed for female Atlantic wolffish based on spring and fall survey vessel data (Figure 18). L_{50} was estimated at approximately 35 cm from these data. This L_{50} for female wolffish is lower than estimates reported in Newfoundland and Iceland where females containing second generation eggs were considered immature (Templeman 1986; Gunnarsson et al. 2006). NEFSC maturity data is based on visual inspection of the reproductive organs. Fish are classified into 1 of 7 stages of maturity (Burnett et al 1989). Fish classifications for females include immature, developing, ripe, eyed (unique for redfish), ripe and running, spent and resting. This analysis considered fish that were in the developing through resting stages as a mature and immature were those fish that contained no visible eggs. Size at maturity may be difficult to interpret for wolffish from these data as they may have an additional developing stage, or a set of second generation eggs which may last for several years, where fish are reproductively immature (Gunnarsson et al. 2006). These immature fish would likely be classified as developing in NEFSC surveys and were considered mature in the ogive thereby reducing the size at 50% mature.

Biomass and Abundance

Atlantic wolffish are encountered infrequently on NEFSC bottom trawl surveys. Strata used in wolffish analyses were limited to offshore areas completely or almost completely within US waters (Figure 19). Some historically important strata were excluded from this analysis, specifically on the Canadian portion of Georges Bank, but due to the sedentary nature of this fish it is believed to have not affected the estimation of the indices or overall trends in US waters (Figures 20 &21). Sampling effort per survey stratum in the Gulf of Maine has remained relatively consistent over most of the time series (Figure 22). The timing of the surveys in the Gulf of Maine has also been consistent during the spring and fall. Inshore sampling did not commence until the mid 1970's and was therefore not used. Higher sampling intensity did occur in portions of the 1970's and 1980's in select survey stratum but elevated abundance and biomass are not likely due to increased sampling effort (Figure 23).

In general the NEFSC spring and fall bottom trawl survey indices show abundance and biomass of Atlantic wolffish has declined over the last two to three decades (Figure 24.). The spring survey typically encounters higher abundance and biomass than the fall survey and was considered by the Data Poor Working Group to be optimal for assessing resource trends (Table 1). Survey differences may be attributed to wolffish being less available to the sampling gear while nest guarding in the fall (Colette and Klein-MacPhee 2002). Inter-annual variability among both surveys is high.

The spring biomass index averaged 0.786 kg/tow and ranged between 0.38 and 1.44 kg/tow from 1968 to 1988. Since the mid to late 1980's the resource has steadily declined. The average spring biomass index for 1989-2007 was 0.143 kg/tow, only 18% of the 1968-1988 average, and ranged from 0.0 kg/tow to 0.42 kg/tow. The fall biomass index shows little trend over time and is relatively low over most of the time series (Figure 24). A large anomalous peak in biomass

appears in 1982 but is not seen again in subsequent years. Since the mid 1990's wolffish biomass has fluctuated with a slightly declining trend.

Abundance indices in both surveys show a decline in stratified mean number per tow since the mid 1990's. 3 year centered moving average plots of abundance and biomass removes the inter-annual variability within the indices and depicts an overall declining trend in the resource (Figure 25).

Spring and fall percent positive Atlantic wolffish catch was plotted by year (Figure 26). This type of index for species rarely captured can be a good indicator of how frequently rare events occur over time. These indices indicate that the number of survey tows catching at least one wolffish has decreased with time in both the spring and fall. The spring index shows an almost continuous declining trend since the late 1970's/early 1980's, averaging around 12% and dropping to approximately 2%. The fall index appears relatively stable from the mid 1960's through the early 1990's, fluctuating around 6 %. It then declines quickly from 1993 to 1996 and becomes relatively stable again near 2 % until 2007 where it reaches zero.

The spatial distribution of Atlantic wolffish has contracted according to the spring and fall bottom trawl surveys. Data were grouped by decade and survey catch in numbers were displayed using GIS (Figures 27 and 28). The spring survey shows high catch along Jefferies Ledge, Stellwagen Bank National Marine Sanctuary and off outer Cape Cod through the Great South Channel during the 1970's and 1980's. Catches in the 1990's extend across a similar area but appear with less abundance and frequency. Highest catches during the 2000's are limited to Stellwagen Bank region. A similar pattern emerges from fall survey catches and the resource appears to be more concentrated within the Jefferies Ledge and Stellwagen Bank regions. During the 1990's and 2000's catches are smaller and appear less frequently in the fall.

Modeling Results

SCALE Model

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At LEngth (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions (NOAA Fisheries Toolbox 2008a). The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information,

abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of mean length at age are essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time. A depiction of model assumed population growth at age using the input mean lengths at age and variation can be seen in table 12 and Figure 29).

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model can not account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^{*}_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^{*}_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov's catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len}\, F_y\, PR_{len}\left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{\left(F_y \;\; PR_{len}\right) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\text{Vrec})^2$ is than used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L}_{\text{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\text{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y}_{\text{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch_lf} = -N_{eff} \sum_{y}\left(\sum_{inlen}^{L_\infty}\left(\left(C_{y,len}+1\right)\ln\left(1+\sum_{a} C_{pred,y,a,len}\right) - \ln\left(C_{y,len}+1\right)\right)\right)$$

$$\mathrm{L}_{\text{vrec}} = \sum_{y=2}^{Nyears} \left(Vrec_y\right)^2 = \sum_{y=2}^{Nyears} \left(R_1 - R_y\right)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{rec_i, inage_i, y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y, inage_i, len} * q_{rec\,i} \right) \right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{adult_i, inlen+_i, y}\right) - \left(\sum_{a} \sum_{inlen_i}^{L_\infty} \ln\left(N_{pred, y, a, len} * q_{adult\,i}\right) \right) \right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf} \left[-N_{eff} \sum_{y} \left(\sum_{inlen_i}^{L_\infty} \left(\left(I_{lf_i, y, len} + 1\right) \ln\left(1 + \sum_{a} N_{pred, y, a, len} \right) - \ln\left(I_{lf_i, y, len} + 1\right) \right) \right) \right]$$

In equation L_{catch_lf} calculations of the sum of length are made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length are used in the calculation.

$$Obj\ \ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Wolffish SCALE Model Configuration and results

Mean lengths at age and variation in mean length at age were based on fish collected during the 1980s from Nelson and Ross (1992). A Gompertz relationship had the best fit using all ages. We have re-estimated a von Bertalanffy relationship using data limited to fish older than 4 with L-infinity fixed at 110 cm (Figure 30). The mean lengths from Nelson and Ross's Gompertz relationship for fish younger than age 5 were also used in the SCALE model. The mean lengths from the younger fish do not have a large effect on the SCALE model results. In the final growth model we fixed L-infinity (110) at a slightly higher value than what was estimated by the Gompertz (98.9) model because few larger and older fish exist in Nelson and Ross's study and the SCALE model had difficultly predicting larger fish that are in seen in the catch length frequency distributions. A North Sea wolffish growth study estimated L-infinity at 111 for males and 115 for females (Liao and Lucas, 2000). Figure 31 shows the predicted catch length distribution under low Fs (F=0.001) assuming different L-infinities. A standard deviation of 6 was used for fish older then age-7. The assumed variation around the mean lengths at age can be seen in Table 12 and Figure 29. Nelson and Ross's oldest fish was 22 years. The age matrix was dimensioned from ages 1 to 30 with an assumed natural mortality of 0.15.

Only one recruitment index exists in the SCALE model (Figure 32). The spring NEFSC survey shows a distinct mode between 1 and 7 cm. This index was tuned to age-1. The recruitment

index suffers from zero catches in many years and at times in blocks of several years. A 40+ cm index was developed from the NEFSC spring, NEFSC fall and the MDMF spring survey (Figure 33). All three surveys show declining trends in abundance with the indices also suffering from zero catches at the end of the time series. The survey length frequency distributions are limited due to the low numbers of wolffish caught in the surveys. There is concern that biomass may have fallen below detection in the surveys. Preliminary evidence suggests the Bigelow survey may also suffer from the same low catchablility issue. Survey indices were scaled using the approximate area of survey coverage divided by the average coverage of a survey tow (Table 13). The area swept estimates can provide some insight from estimated survey efficiencies using the estimated Qs in the SCALE model.

Zero catches were set to missing in the SCALE model. Setting zeros to the smallest value in the time series appears to have a large unsubstantiated influence on the model results. The age-1 recruitment series was given a relatively low weight (Table 14). Setting the weight to high on the recruitment index will force SCALE to fit the recruitment index very closely but the model is less constrained in estimating recruitment for years where recruitment information is missing which can produce unrealistic results. The age-1 index was used more as a guide with setting the penalty on recruitment variation. The penalty on recruitment variation was set high enough to produce recruitment variation within the bounds of what was observed in the recruitment index. The model has to estimate a declining trend in recruitment to fit the decline in the 40+ cm indices and the declining trend in the catch since 1983. The recruitment index was used as guidance on whether recruitment failure has occurred for the wolffish stock. Sensitivity of the model to the weighting on the recruitment index and the penalty on variation in recruitment can be seen in Figures 34 through 37.

The catch length frequency distributions are an important component of the SCALE model. Observer trawl kept length sampling and port samples where combined to characterize the catch size distributions. Catch length frequency information exists from 1982 to 1985 and from 2001 to 2007. A single selectivity block over the time series was used due to the lack of a distinct shift in the size distribution and due to the lack of size information in many years. There is no indication of size truncation in the catch length frequency distributions over time.

The lack of data prevents the SCALE model from estimating a reliable logistic selectivity curve. The SCALE model estimates a very flat selectivity curve that produces a L-50 at very large sizes. There is a tradeoff in the SCALE model between the estimated selectivity and fishing mortality rates. Two different selectivity regimes were chosen to determine its influence of stock status determination (Figure 38). Run one had a relativity flat selectivity curve which was allowed to hit the L-50 bound of 90 cm. Run two was setup to hit the slope parameter bound of 0.15 which produces a steeper selectivity function with a lower L-50 estimate. Results of the two selectivity runs are summarized in Figures 39-42 and Table 14.

The SCALE model time series starts in 1968 with the beginning of the NEFSC spring index. The SCALE model estimates virgin conditions at the beginning of the time series with a low Fstart estimate (0.001) in 1968 when the catch was low. A strong retrospective pattern did not exist with the Slope = 0.15 run (Figure 43). The sensitivity of the assumed L-infinity for growth on the model estimated Fs and recruitment can be seen in Figure 44.

Non-parametric biological reference points (BRP) were developed for both the selectivity L-50 = 90 run (Run 1) and the slope = 0.15 run (Run 2) within the SCALE model using $F_{40\%}$ as a Proxy for F_{MSY} (Table 15). A range of knife edge maturities values were used in estimating the BRPs. Maturity as 40+ cm fish was used to correspond to NEFSC survey maturity results, a 65+

cm and 75+ cm cutoffs were used as bounds taken from the Gunnarsson et al (2006) and Templeman (1986). Templeman found maturation occurring at larger sizes in lower latitudes. However Gunnarsson et al (2006) found maturation occurring at larger sizes in the colder waters on the eastern side of Iceland compared to the western side. The Data Poor Stocks Working Group suggested that $F_{50\%}$ may be a better proxy of F_{MSY} for a species that is long lived, late maturing, and has low fecundity. $F_{50\%}$ BRPs were developed for the Slope = 0.15 run (Table 15 and Figure 45). The $F_{50\%}$ BRPs are based on run 3 incorporating some minor fixes to the catch and catch length frequency (1986) data which were found after the working group meeting (Figures 46-48). Based on all SCALE model runs, the wolfish stock in 2007 is at a low biomass (23% to 45% of B_{MSY}) and is overfished (*assuming a $B_{THRESHOLD}$ of ½ B_{MSY}). The overfishing status determination was more uncertain with F_{2007} to F_{MSY} ratios ranging from 56% to 158%. The Peer Review Panel concluded that $F_{40\%}$ is reasonable and justifiable and that the F_{MSY} proxy < 0.35 is most probable. Therefore, MSY is likely in the range of 138-149 mt and SSB_{MSY} are likely between 794-1,011 mt.
(*This assumption was confirmed by the Chairman of the Peer Review Panel after the December meeting.)

Exploitation Ratios

Exploitation indices were created from reported wolffish catch and spring and fall biomass estimates (Figures 49; Table 1). Exploitation appears to have increased and could indicate this species is being over harvested even at low level commercial catches. Due to low survey catches some values cannot be shown on the chart. The spring exploitation index peaks at a value of 2,135.2 in 2004 and fall exploitation index contains 2 high points at approximately 20.1 in 1998 and 35.2 in 2006. Exploitation ratios were informative to the Review Panel but were considered to be highly variable.

DCAC Model

The DCAC model input consists of summed annual catch, an estimate of *M*, an estimate of the F_{MSY} to *M* ratio, the ratio of catch depletion over time and the number of years being analyzed (NOAA Fisheries Toolbox 2008b). It calculates a sustainable yield of a population after accounting for the "windfall" which occurs at the beginning of a fishery. When natural mortality is high, the DCAC model is the same as calculating the average landings. We conducted a sensitivity analysis of the delta depletion parameter over several time blocks to look at potential sustainable yields (Figure 50; Table 16). All of the time blocks cover the majority of the fishery and include high, moderate and low catch levels. The depletion-corrected average catch was significantly lower than the uncorrected average catch in each time block. Time block did not affect the DCAC but the delta depletion ratio has strong influence. DCAC results ranged from 138.8 mt to 176.6 mt and the Data Poor Stocks Review Panel believed were comparable to and supportive of the MSY values derived from the SCALE model.

AIM – An Index Method

The relationship between total catch of Atlantic wolffish and the spring biomass was explored using the An Index Method (AIM) model (NEFSC 2002 and NOAA Fisheries Toolbox 2008c). Both catch and the survey index have been declining over time with little response of the spring index to declining catches (Figure 51). The linear regression between the $\log_e$ replacement ratio and $\log_e$ relative F was not significant in a randomization test, critical value -0.385 and a

significance level of 0.134 (Figure 52). This model was considered insufficient for providing results on Atlantic wolffish by the Review Panel.

Section 7. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.

Major sources of uncertainty include:

1. Life history – size at maturity, age composition, L∞ within the Gulf of Maine
2. Catchability in NEFSC bottom trawl surveys
3. Commercial length compositions and impacts to SCALE Model
4. Interpretation of 0 catches in recent years – modeling implications
5. Discard information from commercial fisheries
6. Habitat association is poorly known

The Data Poor Stocks Review Panel expanded upon this list of uncertainties. They included natural mortality, maximum age, fecundity and the connectivity of populations on Georges Bank and in the Gulf of Maine for important biological uncertainties. They included scientific uncertainty of the survey indices because populations are at the southern extent of the species range and may exhibit wide changes in distribution. Uncertainties from fisheries data include unknown harvest by foreign fleets and the extent of unreported catches and discards. The Review Panel believed that process uncertainty resulted from the lack of size truncation in commercially harvested fish, which indicated that fishing effort alone may not be responsible for changes in abundance. They suggest lack of preferable habitat may be considered as a viable alternative hypothesis. Model uncertainties include high survey catchability coefficients for pre and fully recruited sizes and the sensitivity of BRPs to maturity ogives and fishery selectivity curves. The Review Panel concluded that stock projections would be unreliable and should not be conducted because of the interpretation of zero catches in the survey data.

Section 8. If applicable, consider developing BRPs for species groups

NA

Section 9. Comment on what can be done to improve the information, proxies or assessments for each species.

Much work could be done to improve information on the basic biology of Atlantic wolffish in the Gulf of Maine. Age and growth data from both commercial and fishery independent sources needs to be collected to improve life history information, specifically L infinity. Conduct a maturity study based on egg size or first generation eggs in female wolffish to improve size at maturity estimates. Estimate fecundity for Gulf of Maine wolffish. Conduct tagging studies to confirm populations are sedentary and localized. Collect fishery observer data from more fishery sectors including the offshore lobster fishery. Comparative studies on wolffish catchability in multiple habitats, including complex rock habitat, with NEFSC survey gear and commercial gear types. A fishery independent index for wolffish should be developed for assessing potential biomass located in rocky habitats.

The Review Panel prioritized a list of research recommendations, including those mentioned above, to reduce uncertainty surrounding the biology, population dynamics and biological reference points of Atlantic wolffish.

1. Exploration of the relationship between survey catch per tow and habitat complexity and environmental signals should continue. These studies will aid understanding of the relationship between survey estimates and population abundance.
2. Age and growth studies for wolffish in the NE/GOM region should be conducted to refine estimates of $L\infty$.
3. Maturity ogive data are currently based on simple presence of eggs in females, and do not account for functional maturity which requires presence of larger eggs. The review team believed the current approach is inadequate. Regional maturity ogives should be developed.
4. The review team recommended that a fixed gear survey be considered to assess abundance in non trawlable habitats.
5. Tagging studies should be conducted to explore and quantify the vagility of wolffish to help improve understanding of population structure and connectivity.

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Atlantic wolffish; Tables

Table 1. Summary table of total catch, commercial landings, recreational catch, discards and NEFSC survey indices.

YEAR	MRFSS (mt)	CFDBS (mt) US Only	Discard OT LL GN (mt) US Only	Total Catch (mt) US Only	Total Catch (1000 mt) US Only	Spring Biomass Index (kg/tow) US Only	Spring Exploitation Index US Only	Fall Biomass Index (kg/tow) US Only	Fall Exploitation Index US Only	Spring Abundance Index US only	Fall Abundance Index US only
1963	--	--	--	--	--	--	--	0.00	0.00	--	0.03
1964	--	51.86	--	51.86	0.05	--	--	0.18	0.28	--	0.09
1965	--	75.53	--	75.53	0.08	--	--	0.30	0.25	--	0.31
1966	--	79.12	--	79.12	0.08	--	--	0.17	0.47	--	0.33
1967	--	67.85	--	67.85	0.07	--	--	0.23	0.29	--	0.09
1968	--	52.72	--	52.72	0.05	0.38	0.14	0.41	0.13	0.07	0.15
1969	--	74.06	--	74.06	0.07	1.11	0.07	0.03	2.19	0.15	0.01
1970	--	70.23	--	70.23	0.07	1.12	0.06	0.36	0.20	0.18	0.08
1971	--	78.38	--	78.38	0.08	0.60	0.13	0.16	0.49	0.14	0.12
1972	--	110.65	--	110.65	0.11	0.51	0.22	0.16	0.69	0.34	0.13
1973	--	110.06	--	110.06	0.11	0.87	0.13	0.13	0.83	0.14	0.34
1974	--	160.02	--	160.02	0.16	1.11	0.14	0.10	1.66	0.53	0.23
1975	--	142.03	--	142.03	0.14	0.92	0.15	0.03	4.39	0.14	0.04
1976	--	182.31	--	182.31	0.18	0.53	0.34	0.05	3.94	0.10	0.07
1977	--	178.61	--	178.61	0.18	0.62	0.29	0.08	2.10	0.22	0.04
1978	--	274.53	--	274.53	0.27	1.17	0.23	0.54	0.51	0.30	0.47
1979	--	297.78	--	297.78	0.30	0.71	0.42	0.10	2.91	0.21	0.05
1980	--	374.88	--	374.88	0.37	0.70	0.54	0.18	2.08	0.30	0.14
1981	0.81	304.64	--	305.44	0.31	0.63	0.49	1.14	0.27	0.31	0.26
1982	23.12	344.91	--	368.03	0.37	0.68	0.54	0.19	1.92	0.19	0.05
1983	11.90	498.92	--	510.82	0.51	0.74	0.69	0.33	1.53	0.13	0.25
1984	13.18	424.25	--	437.44	0.44	0.47	0.92	0.07	6.13	0.12	0.04
1985	15.95	399.14	--	415.10	0.42	0.74	0.56	0.32	1.30	0.28	0.19
1986	7.24	358.24	--	365.49	0.37	1.44	0.25	0.37	0.99	0.24	0.10
1987	37.71	301.70	--	339.40	0.34	0.91	0.37	0.06	5.36	0.25	0.04
1988	9.03	229.33	--	238.36	0.24	0.54	0.44	0.10	2.37	0.20	0.11
1989	20.49	211.76	26.98	259.23	0.26	0.40	0.64	0.11	2.43	0.27	0.14
1990	29.17	171.53	2.63	203.32	0.20	0.17	1.22	0.21	0.95	0.06	0.11
1991	16.86	202.56	1.95	221.37	0.22	0.36	0.61	0.30	0.75	0.05	0.13
1992	10.73	195.46	19.18	225.37	0.23	0.11	1.96	0.18	1.23	0.14	0.13
1993	20.11	211.93	13.38	245.41	0.25	0.42	0.58	0.41	0.60	0.13	0.19
1994	18.54	206.56	0.11	225.21	0.23	0.14	1.62	0.28	0.81	0.21	0.11
1995	20.45	204.03	5.77	230.25	0.23	0.20	1.17	0.27	0.86	0.12	0.15
1996	12.33	157.84	4.53	174.70	0.17	0.17	1.05	0.01	12.40	0.11	0.01
1997	20.21	136.88	7.82	164.91	0.16	0.04	4.01	0.21	0.79	0.05	0.07
1998	16.84	130.11	2.25	149.19	0.15	0.10	1.43	0.01	20.79	0.04	0.01
1999	8.54	110.11	0.35	119.00	0.12	0.06	2.00	0.19	0.64	0.04	0.05
2000	12.40	86.79	0.54	99.74	0.10	0.21	0.48	0.03	3.99	0.03	0.01
2001	16.67	107.05	6.47	130.19	0.13	0.06	2.07	0.12	1.06	0.03	0.04
2002	9.82	66.03	13.10	88.96	0.09	0.08	1.06	0.07	1.24	0.06	0.03
2003	24.23	55.82	3.82	83.87	0.08	0.18	0.46	0.08	0.99	0.09	0.08
2004	12.45	53.05	1.58	67.08	0.07	0.00	2135.24	0.02	3.25	0.02	0.01
2005	10.73	51.73	1.31	63.76	0.06	0.00	0.00	0.02	3.28	0.00	0.05
2006	17.86	36.31	1.45	55.62	0.06	0.00	0.00	0.00	35.23	0.00	0.04
2007	12.87	28.72	0.84	42.43	0.04	0.01	4.58	0.00	--	0.02	0.00
2008	--	--	--	--	--	--	--	--	--	--	--

Table 2. Percent US Commercial Landings of Atlantic wolffish by Statistical Area and Year

YEAR	512	513	514	515	521	522	525	526	537	Grand Total
1964	3.12	4.04	37.04	3.23	27.92	19.68	4.20	0.76	0.00	100
1965	8.06	3.35	29.81	0.92	29.43	25.04	0.72	2.64	0.04	100
1966	1.04	5.00	40.12	0.98	30.95	16.79	1.47	3.60	0.05	100
1967	1.45	17.26	35.79	1.27	29.84	13.21	0.49	0.70	0.00	100
1968	1.72	10.96	32.65	0.55	37.79	12.71	2.55	0.97	0.10	100
1969	0.86	12.90	43.91	1.74	24.19	14.83	1.31	0.26	0.01	100
1970	1.12	11.05	41.51	1.25	31.19	13.03	0.19	0.63	0.03	100
1971	1.85	8.22	42.60	1.63	26.38	16.63	0.85	1.11	0.73	100
1972	1.07	8.43	33.74	0.31	32.11	17.62	2.50	3.95	0.28	100
1973	0.74	10.16	42.75	0.80	33.97	8.85	1.32	1.41	0.00	100
1974	0.74	8.16	37.03	0.21	37.61	12.80	1.21	2.21	0.02	100
1975	1.36	10.36	41.55	2.50	33.34	9.56	0.60	0.50	0.23	100
1976	1.70	12.99	34.29	1.53	32.27	13.75	1.06	2.40	0.00	100
1977	1.34	10.35	37.32	2.02	41.23	6.41	0.58	0.69	0.06	100
1978	3.71	14.34	35.40	2.37	34.21	8.93	0.36	0.53	0.15	100
1979	3.10	17.30	28.31	3.09	36.66	10.77	0.16	0.61	0.00	100
1980	2.94	21.78	21.63	7.24	33.58	11.75	0.49	0.57	0.00	100
1981	3.99	22.82	24.83	6.61	28.63	11.73	0.39	0.80	0.21	100
1982	7.88	22.65	23.83	10.27	26.92	7.67	0.35	0.19	0.24	100
1983	4.65	25.89	28.51	13.92	19.84	6.35	0.22	0.57	0.06	100
1984	4.46	28.29	16.08	16.53	23.95	9.41	0.70	0.49	0.09	100
1985	6.17	25.18	14.83	19.47	26.63	7.09	0.21	0.35	0.05	100
1986	8.92	25.29	14.59	18.43	24.31	7.10	0.78	0.52	0.06	100
1987	5.90	25.25	17.55	18.22	25.56	6.91	0.18	0.42	0.01	100
1988	5.82	26.08	15.75	9.69	32.96	8.31	0.26	1.11	0.00	100
1989	6.39	22.29	11.78	8.76	41.19	8.01	0.10	1.37	0.13	100
1990	7.90	29.96	15.65	8.59	29.71	5.05	0.83	2.02	0.30	100
1991	6.08	24.30	16.41	16.68	25.59	9.10	0.33	1.22	0.29	100
1992	5.74	24.38	15.56	18.10	23.29	10.64	0.49	1.25	0.55	100
1993	3.73	20.35	15.56	20.61	19.51	17.49	0.83	1.49	0.42	100
1994	4.32	18.85	15.44	15.27	28.65	15.68	0.39	1.20	0.19	100
1995	2.26	14.92	20.65	17.80	28.26	14.39	0.29	1.04	0.39	100
1996	2.16	15.06	25.96	13.82	28.98	12.18	0.63	0.97	0.24	100
1997	1.82	13.48	24.10	11.09	33.59	13.72	0.54	0.43	1.23	100
1998	1.87	9.25	35.34	10.08	29.92	11.24	0.44	1.58	0.28	100
1999	1.18	9.34	18.35	7.91	41.27	17.39	0.83	2.66	1.06	100
2000	1.53	13.68	29.21	8.72	29.39	14.38	0.90	0.59	1.61	100
2001	0.96	9.84	18.99	5.81	34.47	26.30	0.83	0.60	2.21	100
2002	1.36	11.77	28.52	6.17	35.49	14.24	1.05	0.28	1.13	100
2003	1.91	14.05	35.62	5.81	29.78	7.93	1.18	0.25	3.47	100
2004	3.91	16.86	39.49	6.92	24.22	5.78	0.18	0.18	2.46	100
2005	2.58	20.06	40.80	12.93	16.14	6.22	0.61	0.64	0.03	100
2006	2.56	16.84	42.28	8.33	20.32	8.85	0.31	0.10	0.41	100
2007	3.29	14.39	39.78	10.08	23.84	7.30	0.85	0.34	0.12	100
Grand Total	4.11	19.26	24.64	10.28	29.20	10.70	0.59	0.94	0.27	100

Table 3. Commercial Discard Estimates for Atlantic wolffish US waters only

	Metric Tons				Percent		
YEAR	LL	OT	GN	Grand Total	LL	OT	GN
1989	0.00	26.98	0.00	26.98	0.00	100.00	0.00
1990	0.00	2.63	0.00	2.63	0.00	100.00	0.00
1991	0.00	1.95	0.00	1.95	0.00	100.00	0.00
1992	0.51	18.67	0.00	19.18	2.66	97.34	0.00
1993	0.00	13.38	0.00	13.38	0.00	100.00	0.00
1994	0.00	0.11	0.00	0.11	0.00	100.00	0.00
1995	0.00	5.77	0.00	5.77	0.00	100.00	0.00
1996	0.00	4.53	0.00	4.53	0.00	100.00	0.00
1997	0.00	7.11	0.71	7.82	0.00	90.91	9.09
1998	0.00	2.25	0.00	2.25	0.00	100.00	0.00
1999	0.00	0.35	0.00	0.35	0.00	100.00	0.00
2000	0.00	0.49	0.06	0.54	0.00	89.28	10.72
2001	0.00	6.47	0.00	6.47	0.00	100.00	0.00
2002	0.00	13.10	0.00	13.10	0.00	100.00	0.00
2003	0.00	3.67	0.15	3.82	0.00	96.01	3.99
2004	0.00	1.34	0.23	1.58	0.00	85.28	14.72
2005	0.00	1.22	0.09	1.31	0.00	93.37	6.63
2006	0.03	1.42	0.00	1.45	1.90	98.10	0.00
2007	0.01	0.69	0.14	0.84	0.65	82.16	17.19
Grand Total	0.54	112.13	1.39	114.06	0.48	98.31	1.21

Table 4. Atlantic wolffish recreational catch summary from MRFSS database, 1981-2007.

Year	Landed # (A + B1)	Discarded # (live) (B2)	Landed kg (A + B1)	Landed MT	Ave Wt kg	Adjusted Landed kg	Adj Landed MT
1981	334	0	unk	unk		806.38	0.81
1982	9,576	2,789	4,952	4.952	0.52	23,119.43	23.12
1983	4,930	88	16,776	16.776	3.40	11,902.54	11.90
1984	5,461	366	12,740	12.74	2.33	13,184.54	13.18
1985	6,607	0	14,428	14.428	2.18	15,951.34	15.95
1986	3,000	0	unk	unk		7,242.93	7.24
1987	15,618	691	31,733	31.733	2.03	37,706.68	37.71
1988	3,740	574	3,748	3.748	1.00	9,029.52	9.03
1989	8,486	6,956	21,415	21.415	2.52	20,487.83	20.49
1990	12,081	386	9,628	9.628	0.80	29,167.27	29.17
1991	6,984	7,180	14,250	14.25	2.04	16,861.54	16.86
1992	4,446	213	4,985	4.985	1.12	10,734.02	10.73
1993	8,329	1,544	11,969	11.969	1.44	20,108.78	20.11
1994	7,681	820	10,526	10.526	1.37	18,544.31	18.54
1995	8,470	2,027	32,287	32.287	3.81	20,449.20	20.45
1996	5,105	5,841	10,391	10.391	2.04	12,325.05	12.33
1997	8,369	833	37,474	37.474	4.48	20,205.35	20.21
1998	6,974	5,029	19,760	19.76	2.83	16,837.39	16.84
1999	3,538	2,389	4,741	4.741	1.34	8,541.83	8.54
2000	5,138	4,463	11,592	11.592	2.26	12,404.72	12.40
2001	6,905	4,841	15,628	15.628	2.26	16,670.81	16.67
2002	4,069	1,953	17,996	17.996	4.42	9,823.82	9.82
2003	10,035	1,204	42,207	42.207	4.21	24,227.59	24.23
2004	5,158	6,237	9,573	9.573	1.86	12,453.01	12.45
2005	4,445	481	14,955	14.955	3.36	10,731.60	10.73
2006	7,397	9,513	28,614	28.614	3.87	17,858.65	17.86
2007	5,329	8,678	15,253	15.253	2.86	12,865.85	12.87
2008							

Grand Mean Average Weight (kg) = **2.41**

Table 5. Summary Statistics of Commercial Observer Length Samples by Year, 1989-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1989	72	74.25	5.91	4	70 - 83
1991	77	81.89	13.25	9	70 - 114
1992	45.5	49.14	10.93	70	39 - 80
1993	61.5	64.58	11.01	24	49 - 86
1994	73	72.80	10.36	25	45 - 95
1995	62.5	62.00	18.08	20	21 - 102
1996	75	72.76	10.96	25	42 - 94
1997	81	78.38	12.52	13	47 - 92
1998	89	85.58	9.89	19	67 - 99
1999	83	82.14	11.28	7	65 - 94
2000	77	77.30	7.19	50	60 - 89
2001	76	75.69	10.86	74	52 - 96
2002	82	81.75	10.64	53	63 - 110
2003	77	73.78	13.41	186	31 - 113
2004	75	74.35	12.40	253	41 - 115
2005	81	80.23	11.38	264	29 - 107
2006	82	82.34	12.04	163	54 - 111
2007	83	81.59	12.48	129	44 - 105

Table 6. Summary Statistics of Commercial Observer Length Samples by major gear type.

Gear Type	Gear Code	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline Bottom	10	73.5	71.91	14.04	22	71-96
Otter Trawl Fish	50	78.0	76.21	14.75	1000	21-115
Gillnet Fixed	100	77.0	76.32	11.82	335	36-114
Gillnet Drift	117	78.5	77.71	9.90	14	64-99
Scallop Dredge	132	69.0	67.64	14.66	11	46-94
Offshore Lobster	200	71	66.17	13.83	6	42-79

Table 7. Commercial Port Sample Summary Statistics by Year, 1982-1985 and 2001-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1982	69	71.71	15.35	354	45-114
1983	78	78.25	14.46	1349	42-128
1984	76	76.10	12.76	445	51-130
1985	77	76.98	11.86	729	47-119
2001	75	76.59	10.11	176	59-110
2002	76	76.34	10.30	297	38-104
2003	76	76.88	11.07	473	52-109
2004	81	80.83	10.72	1159	48-115
2005	82	81.40	9.95	500	54-110
2006	83	83.03	10.36	894	37-111
2007	84	83.55	10.01	800	51-108

Table 8. Commercial Port Samples Summary Statistics by Gear Type

Gear Type	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline	71	71.08	8.84	134	45-92
Handline	80	79.41	10.90	29	62-99
Otter Trawl Fish	80	80.04	12.63	7041	37-130
Gill Net	76	76.36	11.68	211	51-109

Table 9. Commercial Port Samples Summary Statistics by Fishery Statistical Areas

Statistical Area	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
0	83	83.27	6.13	11	75 - 95
512	83	82.16	10.76	421	37 - 108
513	80	79.70	10.99	1745	46 - 110
514	77	77.69	12.04	1357	42 - 130
515	79	78.50	11.67	1956	44 - 112
521	78	79.19	12.53	894	38 - 119
522	77	77.88	12.39	478	50 - 115
525	82	82.70	9.30	47	57 - 102
526	112	110.72	9.67	79	79 - 128
537	68	68.00	15.43	10	48 - 101

Table 10. Observer based CPUE (sum of kept wolffish per year / sum of days fished per year) for Atlantic wolffish, 1989-2007.

	CPUE Gear Type		
YEAR	LLB	OTF	GNF
1989		2.56	0.58
1990		0.71	2.90
1991	8.80	1.40	1.57
1992	8.52	2.90	1.76
1993	45.65	3.05	2.15
1994		3.89	2.61
1995		1.29	6.03
1996		1.22	3.81
1997		1.82	1.84
1998		1.26	2.08
1999		1.30	1.49
2000		1.32	1.90
2001		1.59	2.04
2002	11.79	1.05	1.79
2003	5.14	0.86	3.03
2004	1.19	0.61	1.72
2005	2.48	0.36	1.88
2006	1.56	0.37	1.70
2007	1.28	0.39	0.95
Grand Total	2.59	0.71	1.98

Table 11. Party and Charter Boat CPUE (number of wolffish / angler days fished) from VTR data for Atlantic wolffish, 1994-2007.

YEAR	CPUE Charter Boats	CPUE Party Boats
1994	0.072	0.015
1995	0.077	0.009
1996	0.068	0.011
1997	0.082	0.013
1998	0.139	0.013
1999	0.039	0.008
2000	0.017	0.005
2001	0.047	0.007
2002	0.019	0.008
2003	0.031	0.006
2004	0.018	0.006
2005	0.015	0.006
2006	0.019	0.004
2007	0.013	0.003

Table 12. Population depiction of distributions around the mean length at age for wolffish used in the SCALE model. Top row shows the input standard deviation at age and the second row has the mean lengths at age.

std	3	3	3.5	4	4.5	5	5.5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
len/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
122																										1	1	1	1	1
121																								1	1	1	2	2	2	2
120																						1	1	2	2	3	3	4	4	4
119																					1	1	2	4	5	6	7	8	8	8
118																				1	2	3	5	7	9	11	13	14	14	15
117																			1	2	4	7	10	14	18	20	23	24	25	24
116																		1	2	4	8	13	20	26	31	35	38	39	39	39
115																		1	4	9	16	25	35	44	52	57	60	61	60	58
114																	1	3	8	17	30	45	60	73	82	88	90	90	87	82
113																	2	6	17	33	54	76	97	113	123	128	128	125	118	110
112																1	4	14	32	59	90	122	148	165	175	177	172	164	152	140
111																2	9	27	58	100	144	184	213	229	235	230	219	204	186	168
110															1	5	19	50	100	160	217	263	291	301	297	283	263	239	215	190
109															2	11	37	89	163	242	310	355	375	374	357	330	299	266	234	204
108															4	22	68	149	251	347	418	454	458	439	405	364	321	280	242	208
107														1	9	42	119	237	365	471	533	549	529	488	435	380	327	279	236	200
106														3	20	78	197	354	504	604	643	628	579	512	442	375	314	262	218	182
105														6	39	137	307	503	657	734	734	680	598	509	424	350	286	233	191	156
104													1	13	74	226	454	674	811	843	792	696	585	479	386	309	246	197	158	127
103													3	28	132	354	634	855	947	916	809	674	541	426	332	258	200	157	123	98
102													6	54	222	523	838	1,026	1,046	941	782	617	474	358	270	204	154	118	91	71
101												1	14	101	354	732	1,048	1,165	1,092	915	714	535	392	285	208	152	113	84	64	49
100												2	29	177	533	969	1,240	1,251	1,079	842	618	439	307	215	151	107	78	57	42	32
99												4	57	294	761	1,213	1,388	1,271	1,009	732	505	340	228	153	104	72	51	36	26	20
98												9	106	462	1,028	1,437	1,469	1,222	892	603	391	250	159	103	68	45	31	22	16	11
97											1	20	188	687	1,312	1,611	1,471	1,111	746	469	286	173	106	66	42	27	18	12	9	6
96											1	41	315	965	1,585	1,707	1,394	955	590	345	198	114	66	40	24	15	10	7	5	3
95											4	81	499	1,284	1,811	1,712	1,249	777	442	241	130	71	39	23	13	8	5	3	2	2
94											9	149	749	1,615	1,958	1,624	1,059	598	313	159	80	41	22	12	7	4	3	2	1	1
93											19	259	1,063	1,921	2,002	1,457	849	435	209	99	47	23	12	6	3	2	1	1		
92										1	40	426	1,427	2,163	1,936	1,237	644	300	133	58	26	12	6	3	2	1	1			
91										2	78	664	1,812	2,303	1,771	993	462	195	80	33	14	6	3	1	1					
90										4	147	979	2,177	2,319	1,533	754	314	120	45	17	7	3	1	1						
89										10	259	1,365	2,474	2,210	1,255	542	201	70	24	9	3	1	1							
88										23	434	1,801	2,660	1,992	972	368	122	39	12	4	1	1								
87										47	687	2,247	2,704	1,698	712	237	70	20	6	2	1									
86									1	93	1,028	2,652	2,601	1,370	494	144	38	10	3	1										
85									3	174	1,455	2,961	2,367	1,045	324	83	20	5	1											
84									6	307	1,950	3,128	2,037	754	201	45	10	2												
83									14	512	2,470	3,125	1,659	515	118	23	4	1												
82									31	809	2,961	2,953	1,278	333	65	11	2													
81									64	1,209	3,358	2,640	931	203	34	5	1													
80								1	125	1,709	3,602	2,233	642	117	17	2														
79								2	231	2,285	3,654	1,787	418	64	8	1														
78								4	402	2,890	3,508	1,352	258	33	4															
77								9	664	3,459	3,185	968	151	16	1															
76								21	1,035	3,915	2,735	655	83	8	1															
75								45	1,528	4,192	2,222	420	43	3																
74								92	2,132	4,246	1,708	254	21	1																
73								175	2,816	4,069	1,242	146	10	1																
72								318	3,517	3,688	854	79	4																	
71							1	545	4,155	3,162	556	41	2																	
70							2	884	4,644	2,565	342	20	1																	
69							4	1,357	4,910	1,968	199	9																		
68							11	1,970	4,911	1,428	110	4																		
67							27	2,705	4,647	981	57	2																		
66							63	3,514	4,159	637	28	1																		
65							134	4,318	3,521	391	13																			
64							268	5,019	2,820	227	6																			
63							502	5,518	2,136	125	2																			
62							880	5,740	1,531	65	1																			
61							1,445	5,647	1,038	32																				
60						1	2,220	5,256	666	15																				
59						3	3,193	4,628	404	7																				
58						10	4,298	3,854	232	3																				
57						28	5,415	3,037	126	1																				
56						71	6,386	2,263	65																					
55						165	7,049	1,595	31																					
54						354	7,284	1,064	14																					
53						701	7,045	671	6																					
52					1	1,281	6,377	401	3																					
51					5	2,162	5,404	226	1																					
50					17	3,369	4,286	121																						
49					50	4,844	3,182	61																						
48					134	6,431	2,211	29																						
47					328	7,880	1,438	13																						
46					725	8,914	876	6																						
45					1,453	9,308	499	2																						
44					2,638	8,973	266	1																						
43				1	4,341	7,984	133																							
42				4	6,470	6,558	62																							
41				16	8,736	4,973	27																							
40				55	10,688	3,481	11																							
39				169	11,845	2,249	4																							
38				460	11,893	1,342	2																							
37				1,106	10,818	739	1																							
36				2,345	8,915	375																								
35				4,391	6,656	176																								
34			1	7,254	4,502	76																								
33			4	10,575	2,759	31																								
32			21	13,606	1,531	11																								
31			89	15,448	770	4																								
30			310	15,479	351	1																								
29			923	13,688	145																									
28			2,333	10,681	54																									
27			5,010	7,356	18																									
26			9,135	4,470	6																									
25		3	14,150	2,398	2																									
24		20	18,616	1,135																										
23		106	20,801	474																										
22		457	19,743	175																										
21		1,584	15,915	57																										
20	1	4,395	10,897	16																										
19	5	9,765	6,337	4																										
18	35	17,376	3,130	1																										
17	178	24,756	1,313																											
16	730	28,243	468																											
15	2,399	25,801	142																											
14	6,311	18,873	36																											
13	13,295	11,055	8																											
12	22,428	5,185	1																											
11	30,295	1,947																												
10	32,767	586																												
9	28,379	141																												
8	19,681	27																												
7	10,929	4																												
6	4,860	1																												
5	1,730																													
4	493																													
3	113																													
2	21																													
1	3																													

Table 13. Survey area coverage, estimated average survey tow coverage, total area divided by the survey footprint and the survey efficiency q estimates for run 1 and 2.

Wolffish	NEFSC			MDMF
	Spr Age 1	Spr 40+	Fall 40+	40+
survey area (nm^2)	25,911	25,911	25,911	1,833
Avg tow area swept	0.0112	0.0112	0.0112	0.003846
Tow duration	30 min	30 min	30 min	20 min
total area / tow area swept	2,313,482	2,313,482	2,313,482	476,573
Q L50 = 90	0.303	0.400	0.203	0.023
Q Slope = 0.15	0.305	0.387	0.196	0.022

Table 14. Wolffish working group SCALE runs. Run 1 was allowed to hit the L-50 bound on selectivity and run 2 hit the selectivity slope bound of 0.15. Run 3 fixed some minor catch and catch length frequency errors and was used to develop F50 BRPs.

Run	1			2			3		
	L_{50} = 90			slope = 0.15			slope = 0.15 (Updated F50% run)		
	weight	qs	Residuals or parameters	weight	qs	Residuals or parameters	weight	qs	Residuals or parameters
total objective function			250.06			253.55			252.57
total catch	10		0.22	10		0.22	10		0.20
catch len freq 1+	500		11.26	500		10.99	500		10.29
Variation in recruit penalty (Vrec)	2		14.12	2		14.80	2		14.85
NEFSC Spr 1 Age-1 1968-2007	2	0.303	8.60	2	0.305	8.83	2	0.310	8.80
NEFSC Spr 40+ 1968-2007	12	0.400	5.78	12	0.387	5.93	12	0.391	5.93
MDMF Spr 40+ 1978-2007	3	0.023	9.70	3	0.022	9.61	3	0.022	9.64
NEFSC Fall 40+ 1968-2007	3	0.203	26.62	3	0.196	26.78	3	0.198	26.70
NEFSC Spr 40+ len freq	5		12.83	5		12.82	5		12.82
Fstart			0.004			0.001			0.001
recruitment year 1 (1968, 000s)			171			175			172
Selectivity Alpha (L50) 1982-1984			90.00			72.89			72.93
Selectivity Beta (slope) 1982-1984			0.09			0.15			0.15

Table 15. Estimated biological reference points based on F40 and F50 for three wolffish SCALE runs. A range of knife edge maturity cutoffs were used (40, 65, and 75 cm).

SCALE run	1			2			3		
Selectivity	L_{50} = 90			slope = 0.15			slope = 0.15		
Length of maturity	40	65	75	40	65	75	40	65	75
F_{MSY} proxy	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{50\%}$	$F_{50\%}$	$F_{50\%}$
F_{MSY}	0.70	0.51	0.39	0.35	0.25	0.20	0.195	0.154	0.128
F_{max}	> 0.8	> 0.8	> 0.8	0.60	0.60	0.60	0.60	0.60	0.60
YPR	0.871	0.841	0.809	0.854	0.829	0.788	0.783	0.728	0.678
SSB per Recruit	5.987	5.247	4.686	5.792	5.166	4.548	7.629	6.796	6.050
Initial Recruits (000s)	171	171	171	175	175	175	172	172	172
MSY (mt)	149	144	138	149	145	138	135	125	117
SSB_{MSY} (mt)	1,024	898	802	1,011	902	794	1,314	1,171	1,042
SSB_{07} (mt)	405	293	209	457	339	249	447	330	242
F_{07}	0.516	0.516	0.516	0.195	0.195	0.195	0.202	0.202	0.202
SSB_{07}/SSB_{MSY}	40%	33%	26%	45%	38%	31%	34%	28%	23%
F_{07}/F_{MSY}	74%	101%	132%	56%	78%	98%	104%	131%	158%

Table 16. Sensitivity analysis of the delta depletion parameter in the Depletion-Corrected Average Catch model (DCAC) over time.

DCAC model - DCAC Average Catch (mt)
Sensitivity Analysis of % reduction on Several Time Periods

	Delta Depletion Ratio										
	50%		**75%**		**90%**		**95%**		Total	Uncorrected	
Base Years	mean	median	mean	median	mean	median	mean	median	Catch	Catch	N Years
1970-1990	175.1	178.5	152.0	154.0	141.1	142.4	137.8	138.8	5422	258.2	21
1970-2000	176.6	180.2	158.0	160.9	148.9	151.4	146.1	148.4	7277.0	234.7	31
1970-2005	166.5	169.9	150.6	153.6	142.7	145.3	140.2	142.7	7711.0	214.2	36
	Confidence Intervals										
	5%	95%	5%	95%	5%	95%	5%	95%			
1970-1990	118.5	220.0	94.9	202.6	84.6	193.5	81.7	190.7			
1970-2000	130.5	210.1	108.4	197.9	98.2	191.4	95.3	189.4			
1970-2005	126.9	194.5	106.9	184.6	97.5	179.2	94.7	177.6			

assumptions:
M = 0.15 std dev = 0.5
Fmsy to M = 1.0 std dev = 0.2
delta depl std dev = 0.1

Atlantic wolffish; Figures

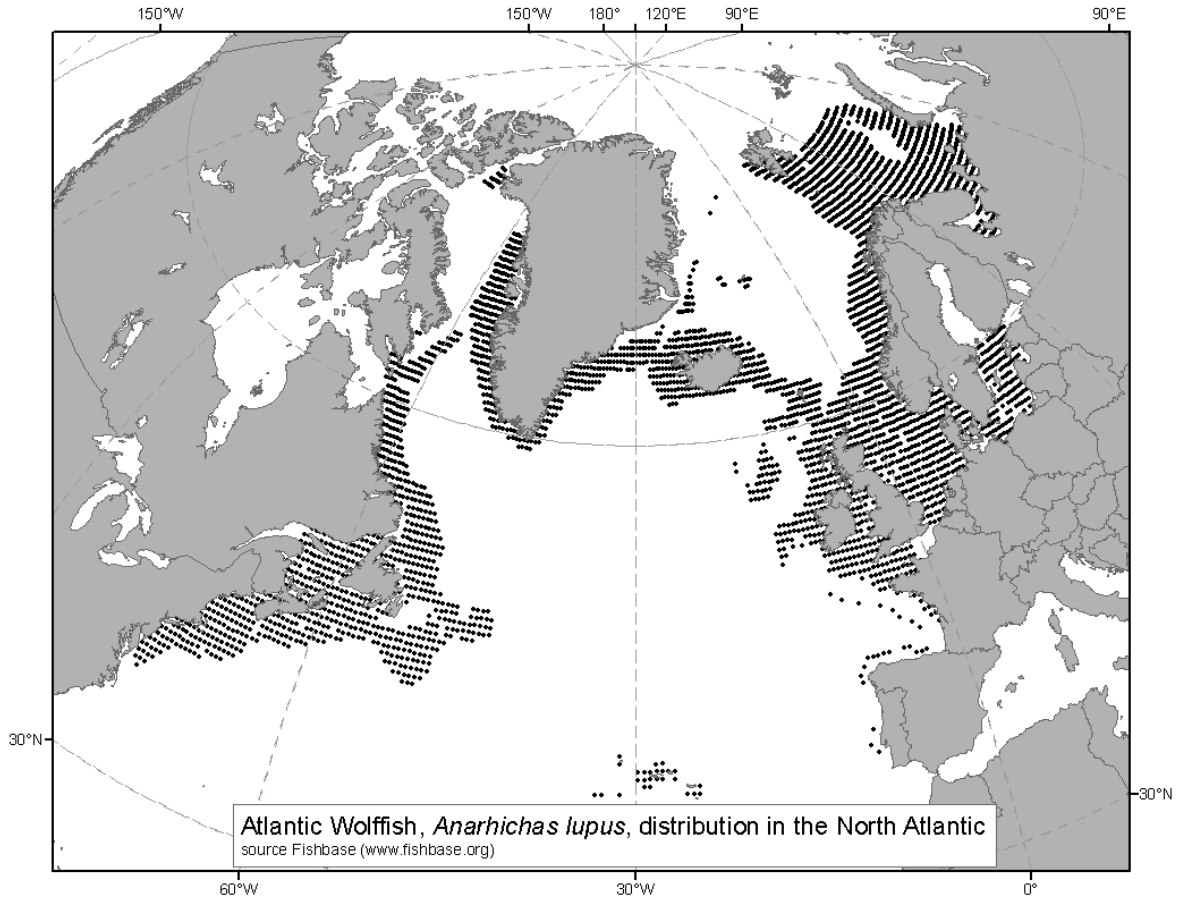


Figure 1. Atlantic wolffish distribution in the North Atlantic Ocean. The US is the southern extent of the geographic range in the western Atlantic.

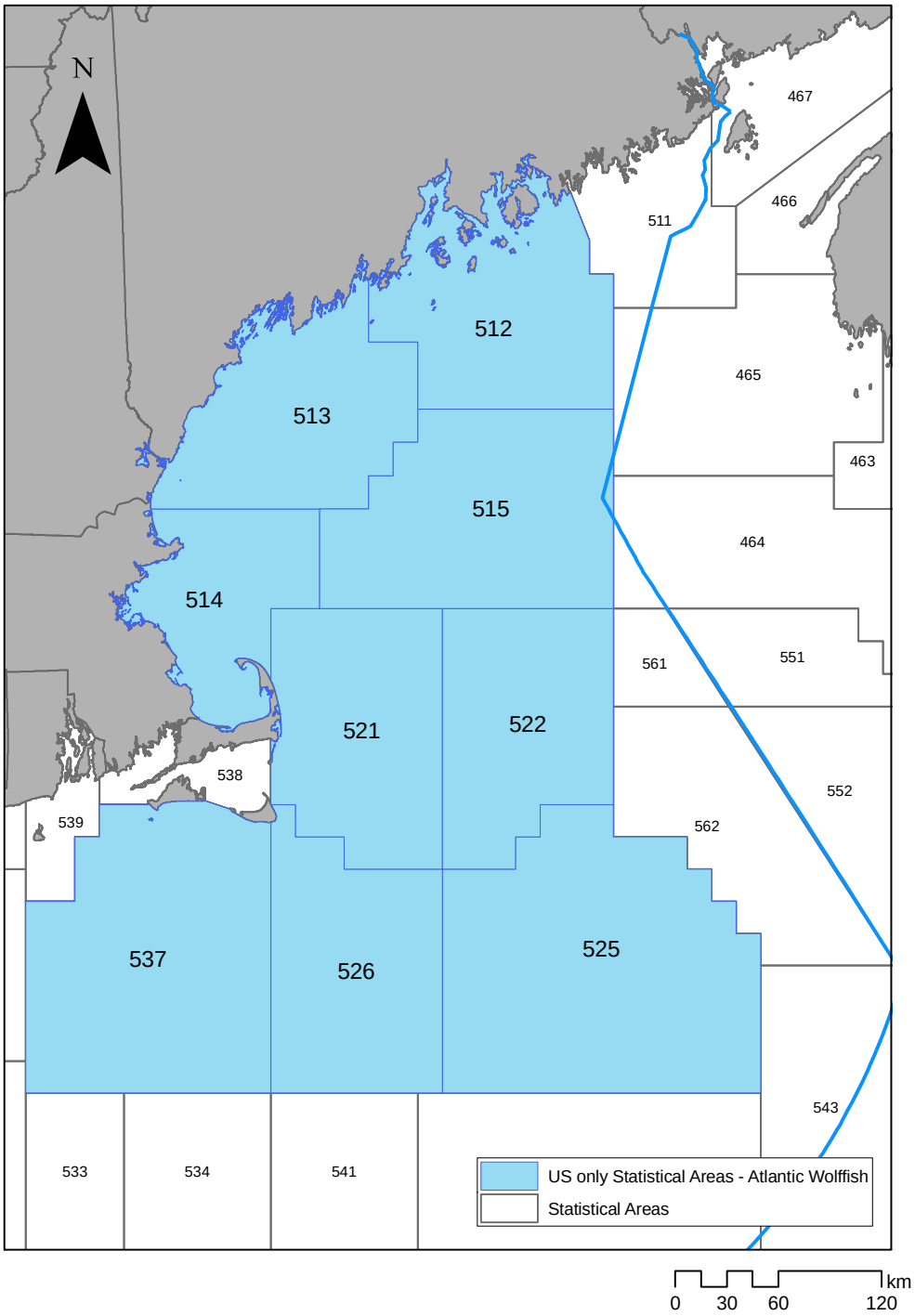


Figure 2. Fishery statistical areas used for Atlantic wolffish landings, catch and discard estimates.

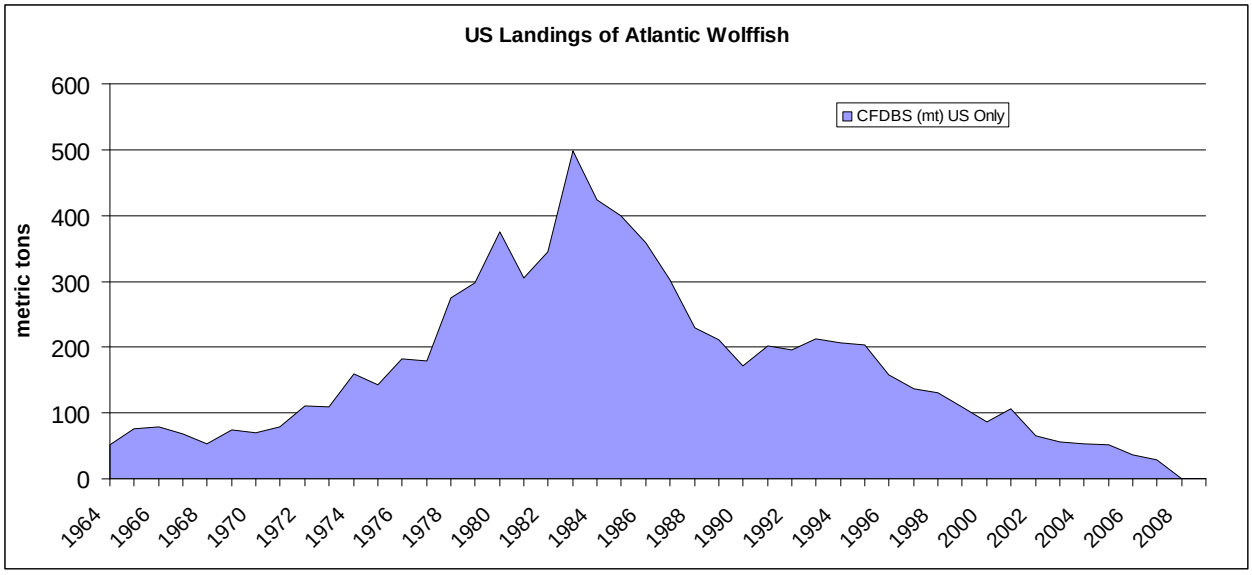


Figure 3. Reported landings of Atlantic wolffish in fishery statistical areas 512-515, 521-522, 525-526 and 537.

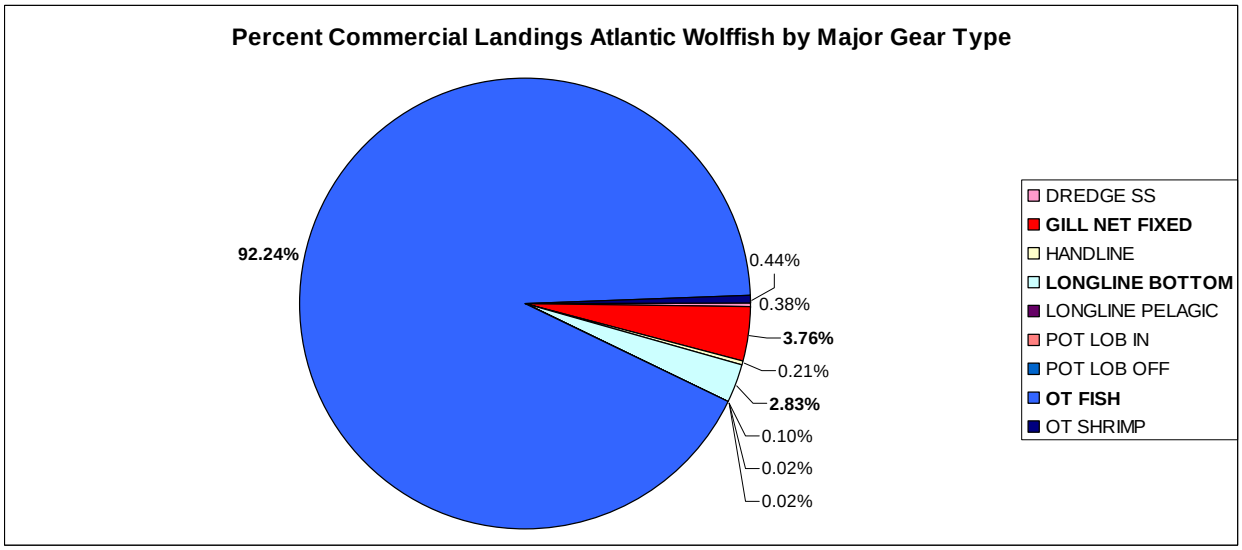


Figure 4. Atlantic wolffish landings by gear type for all years, 1964-2007.

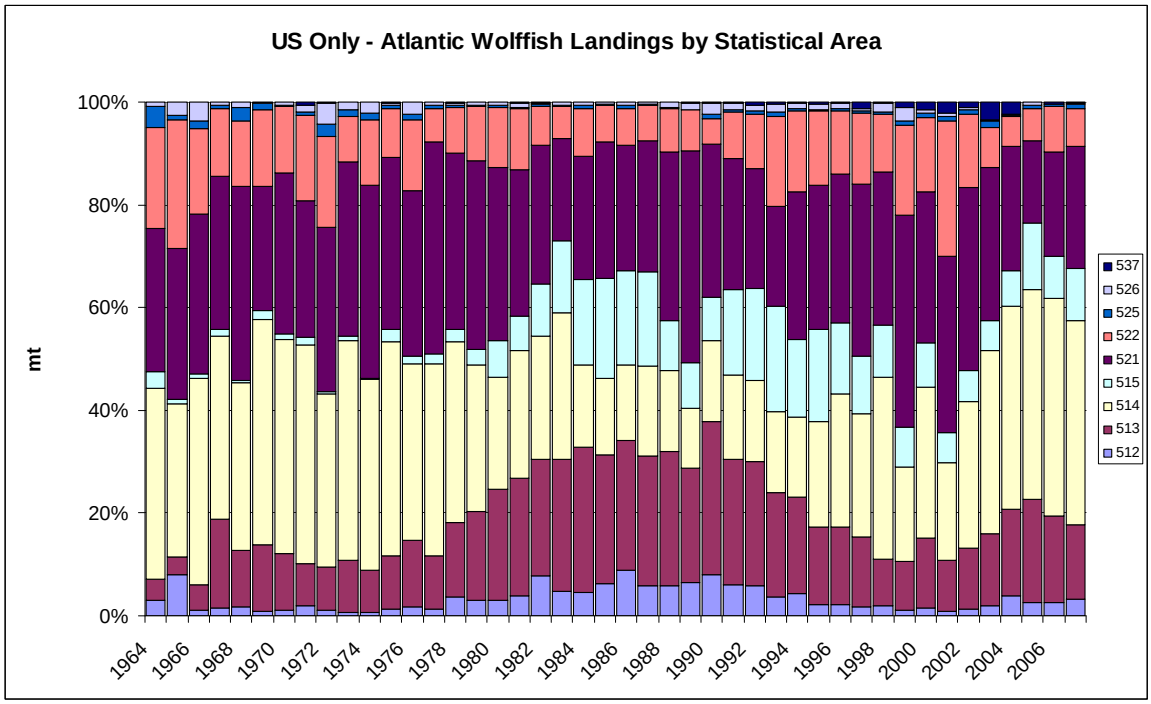


Figure 5. Reported wolffish landings by fishery statistical area in US waters.

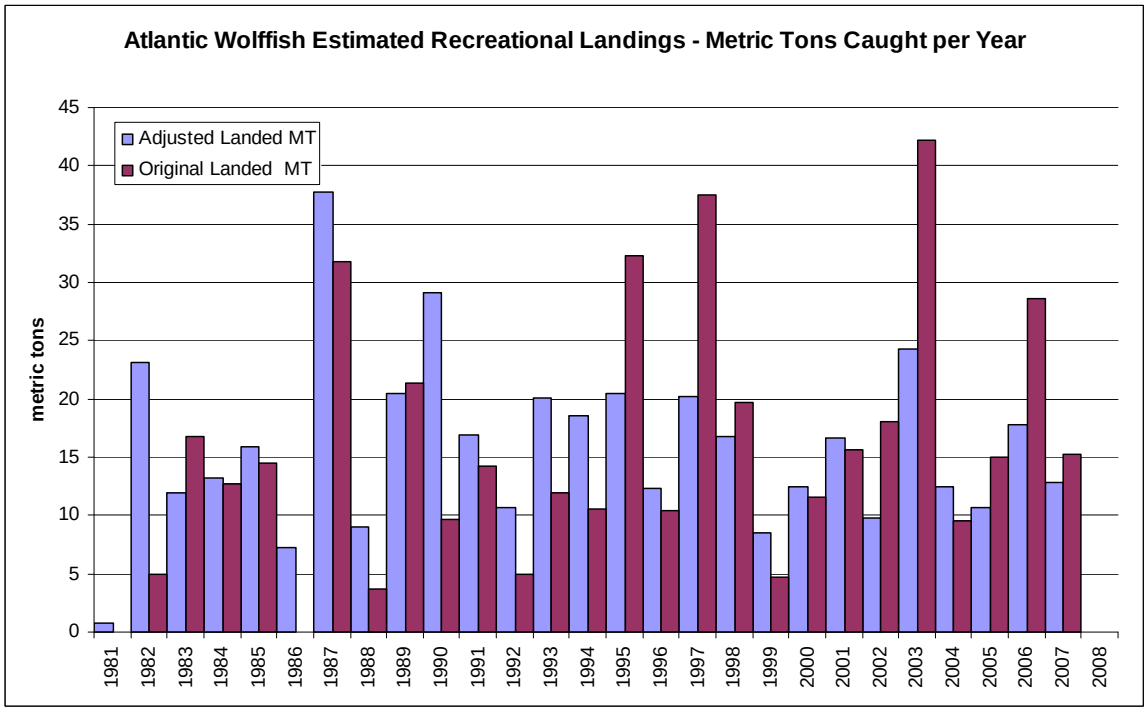


Figure 6. Reported and adjusted recreational landings by year from MRFSS database, 1981-2007.

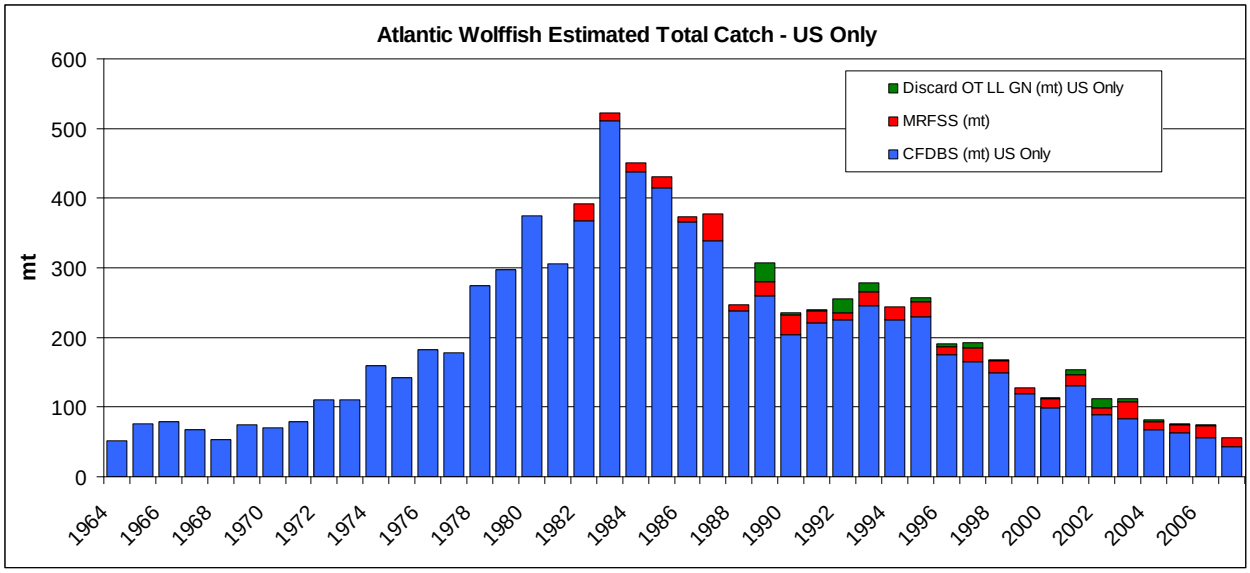


Figure 7. Total catch from reported commercial landings, estimated discards and recreational landings for US only 1964-2007.

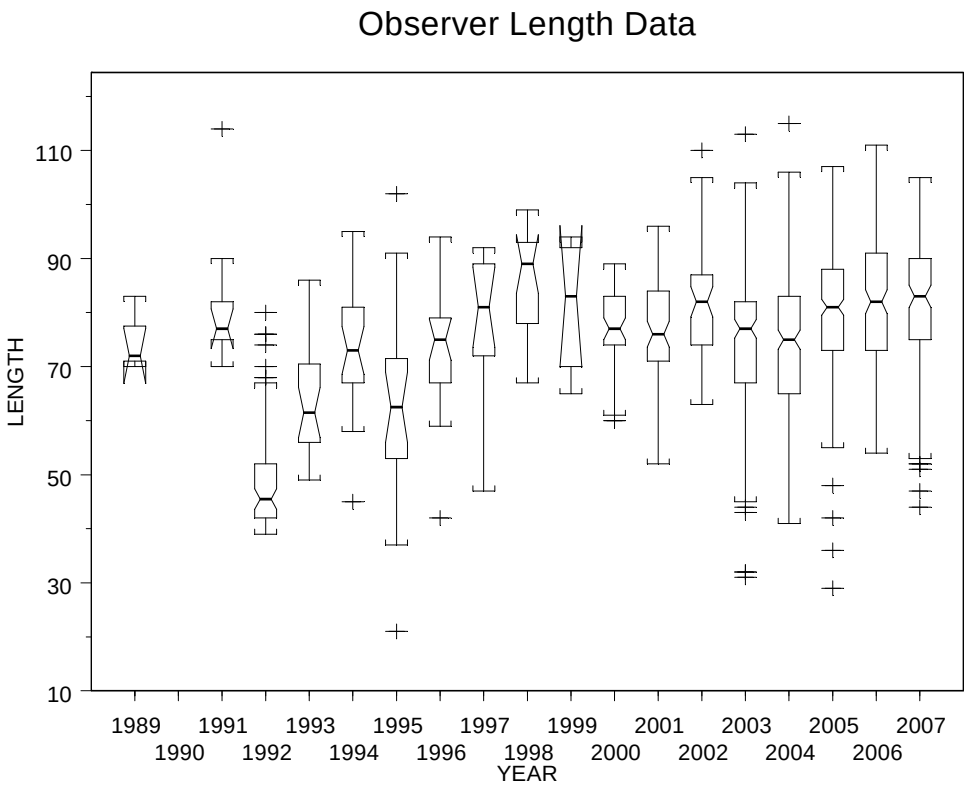


Figure 8. Fishery observer length distribution by year, 1989-2007.

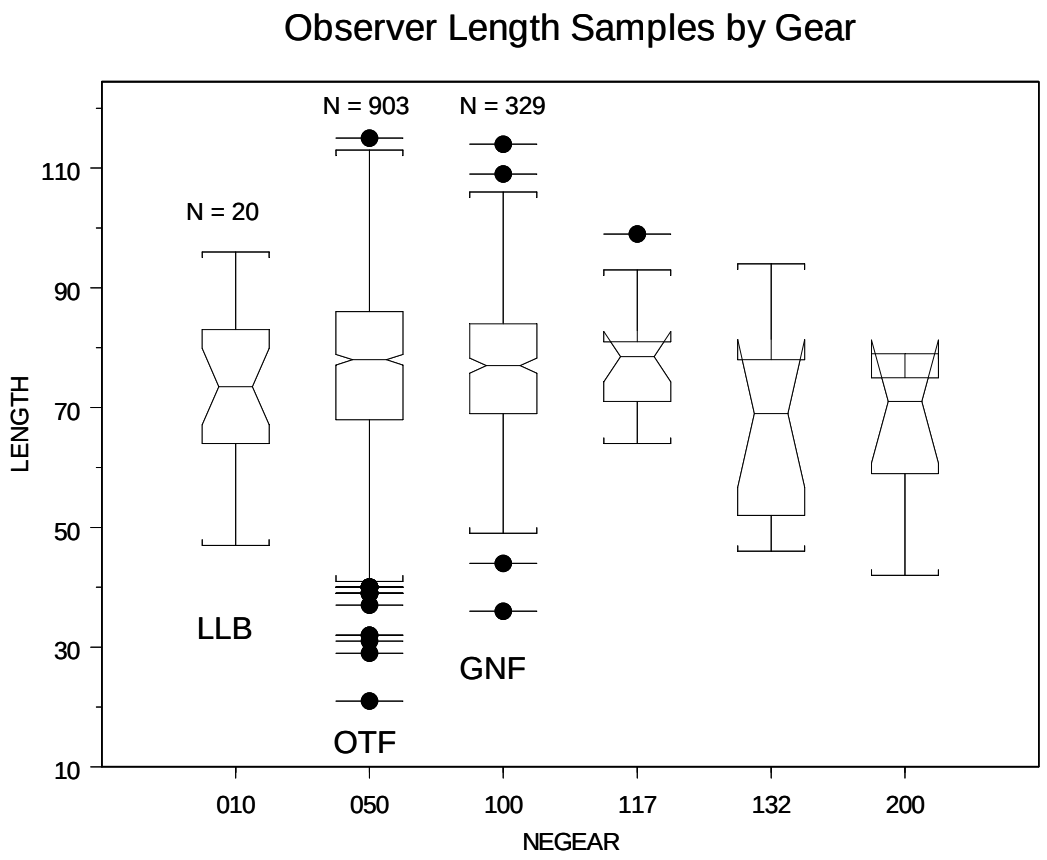


Figure 9. Fishery observer length distribution by major gear type.

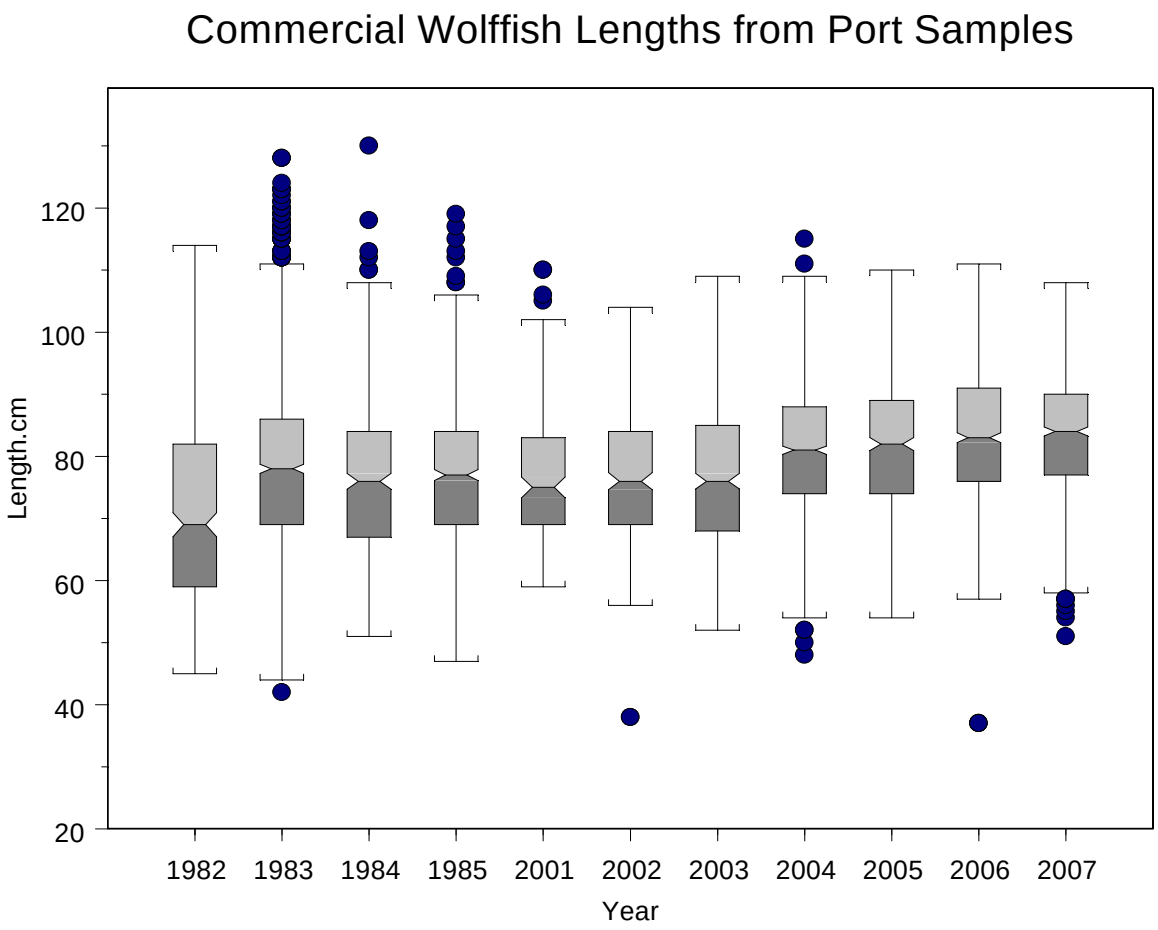


Figure 10. Atlantic wolffish commercial length distributions by year from port samples, 1982-1985 and 2001-2007.

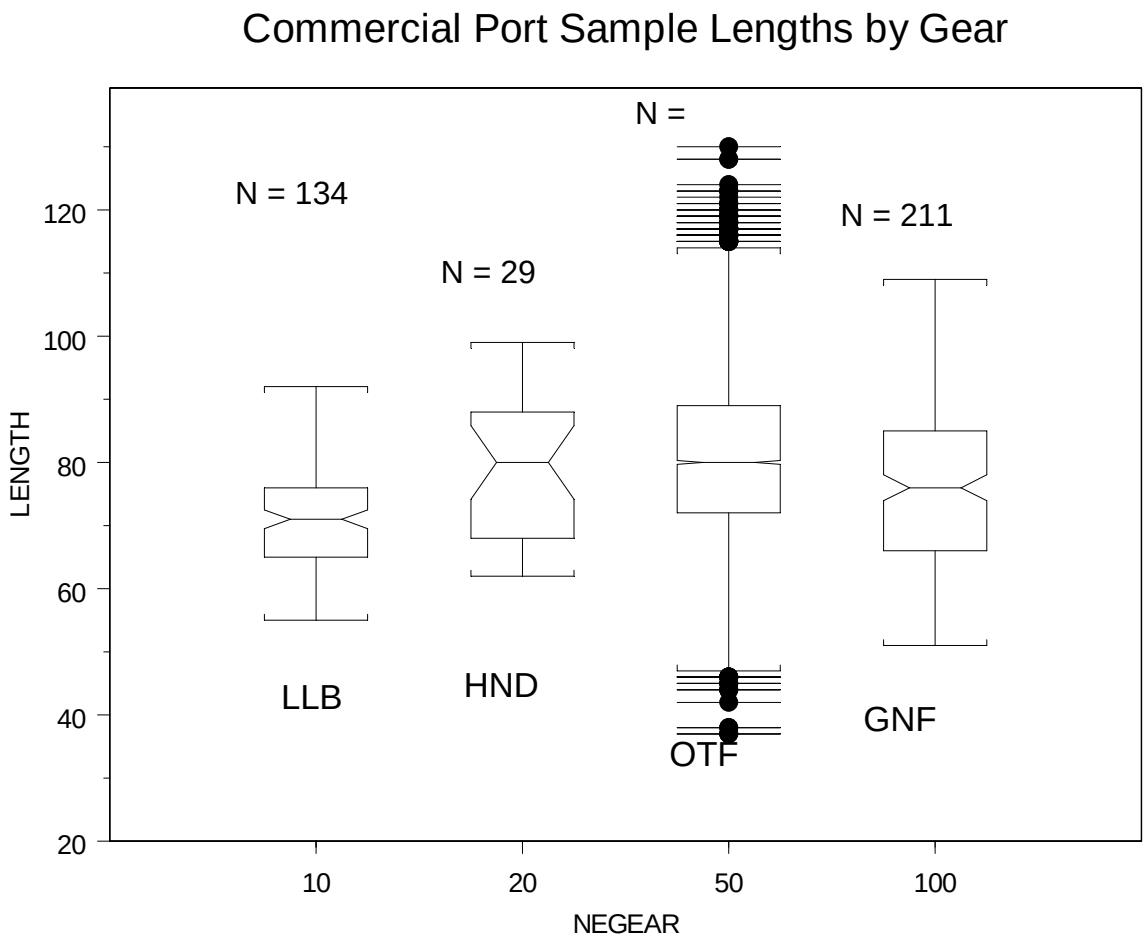


Figure 11. Commercial port sample length distributions by major gear type, all years combined (1982-1985 & 2001-2007).

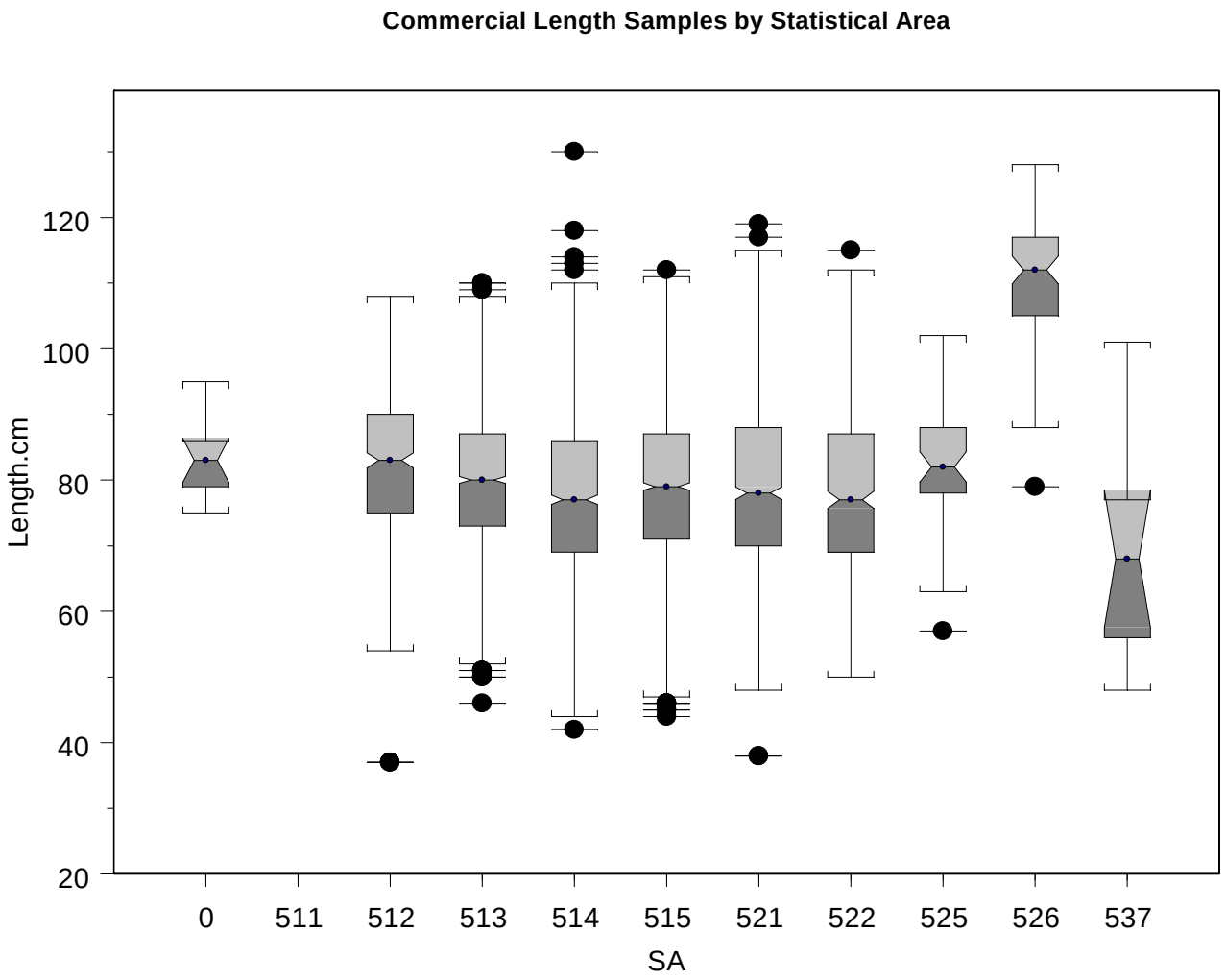


Figure 12. Commercial port sample length distributions by fishery statistical area in US waters, all years combined (1982-1985 & 2001-2007).

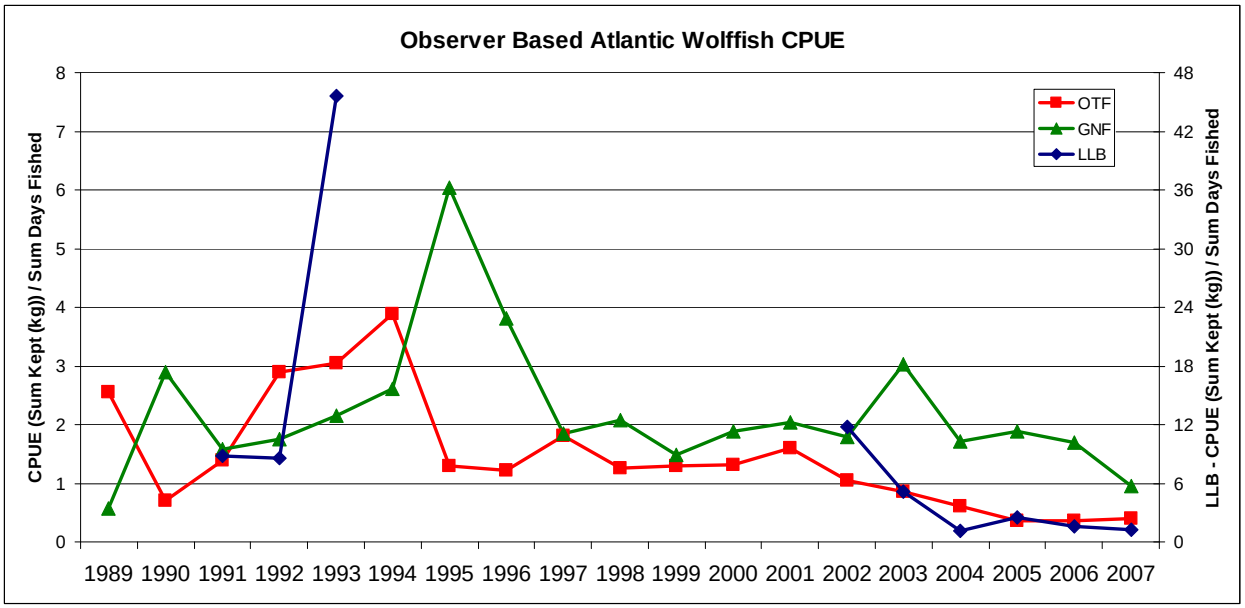


Figure 13. Catch per unit effort of Atlantic wolffish based on observer data in the otter trawl, gillnet and longline fisheries.

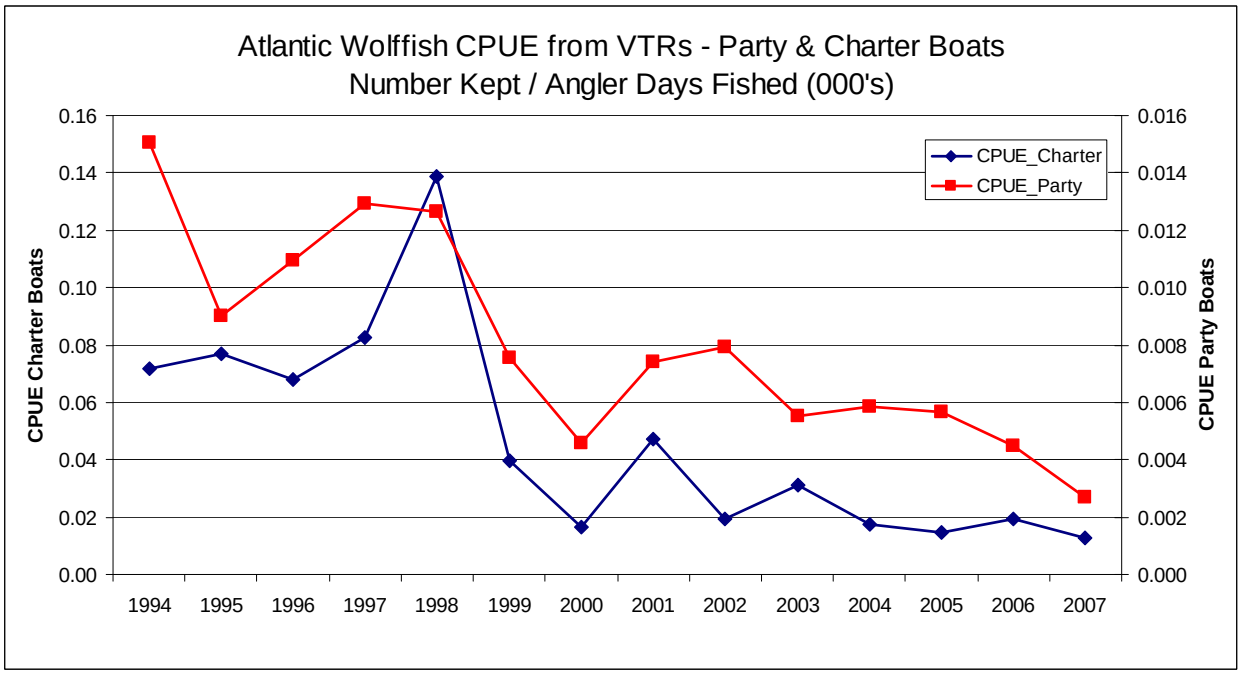


Figure 14. Catch per unit effort of Atlantic wolffish based on VTR data in the party and charter boat sectors.

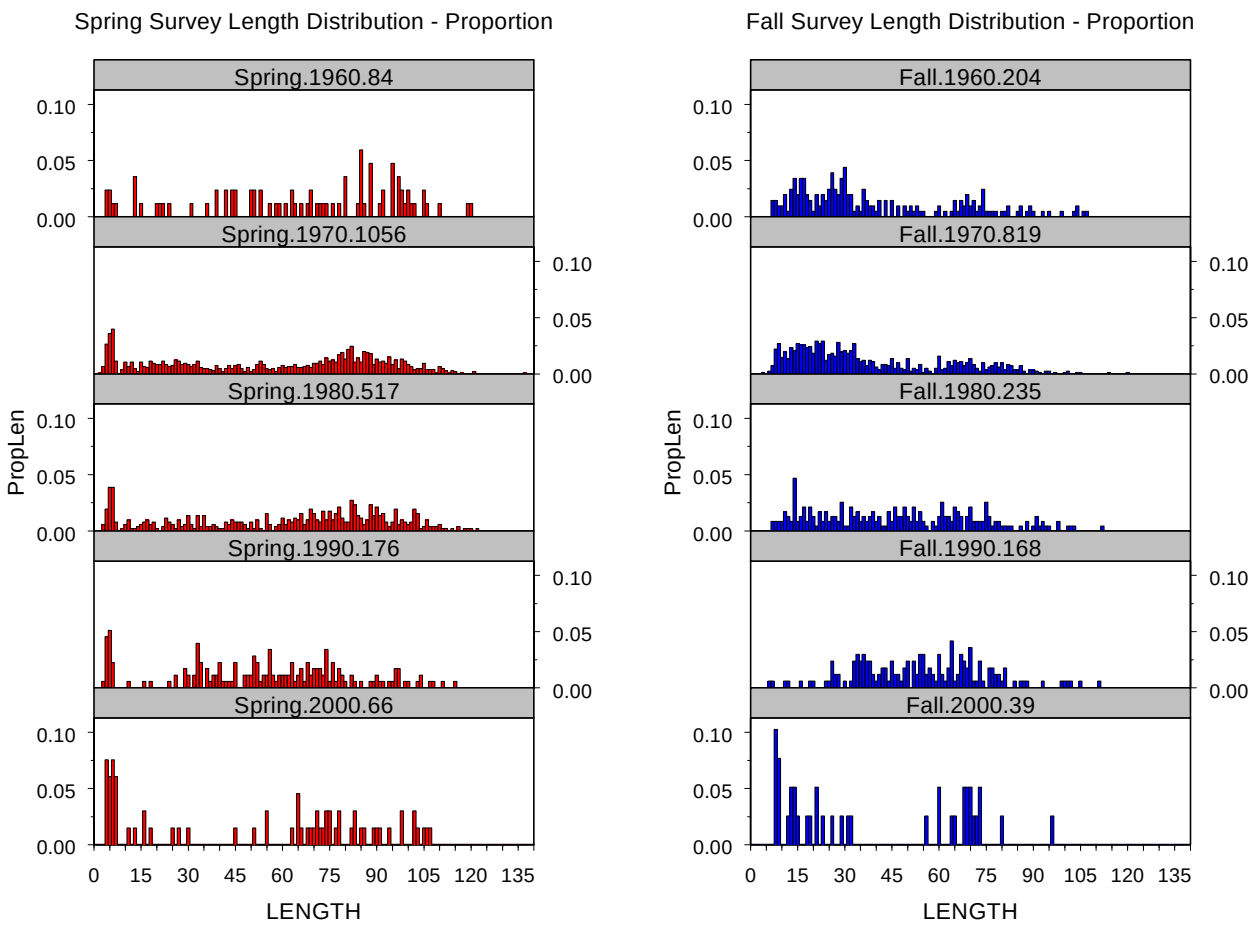


Figure 15. Spring and fall proportional length distributions grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

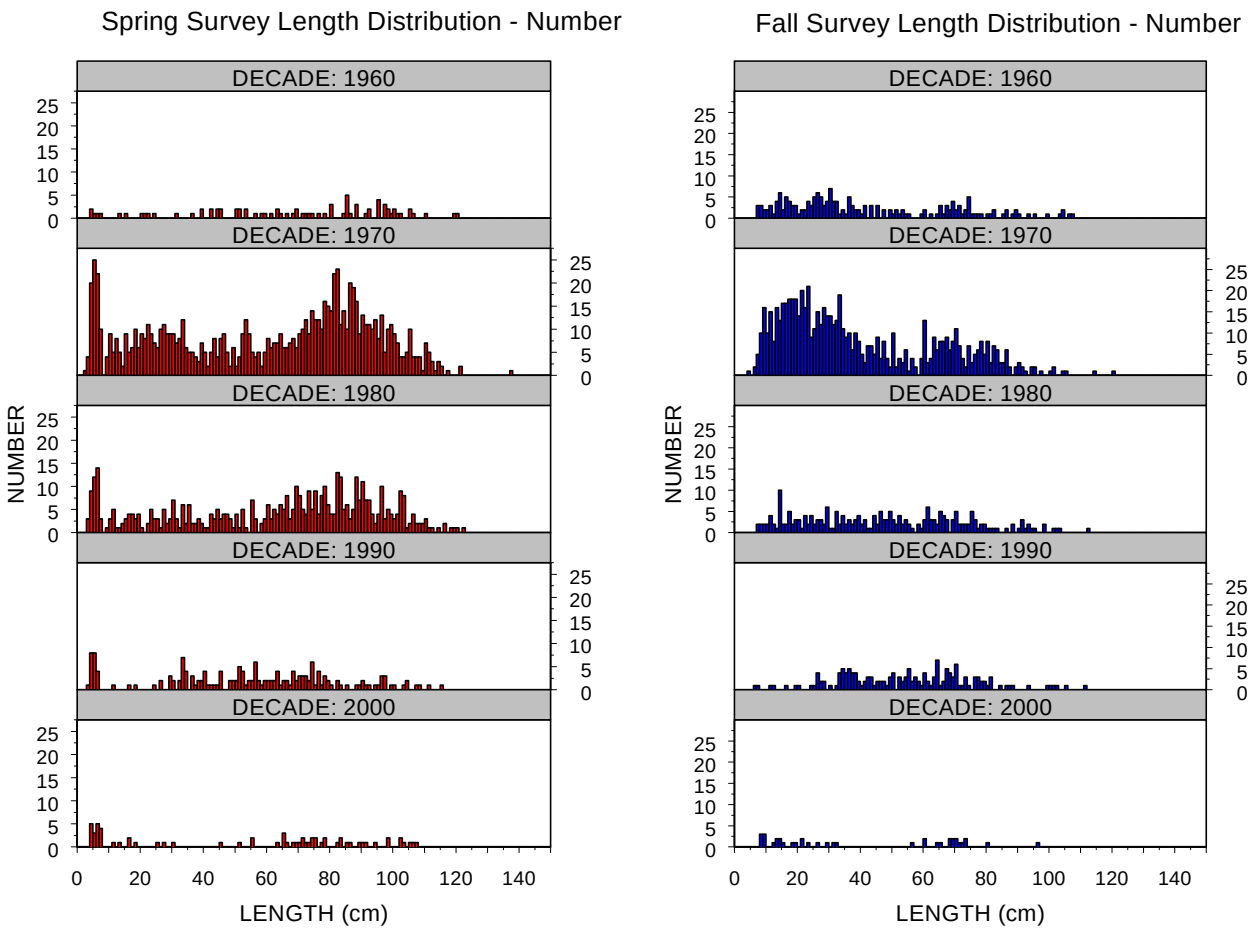


Figure 16. Spring and fall number at length histograms grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

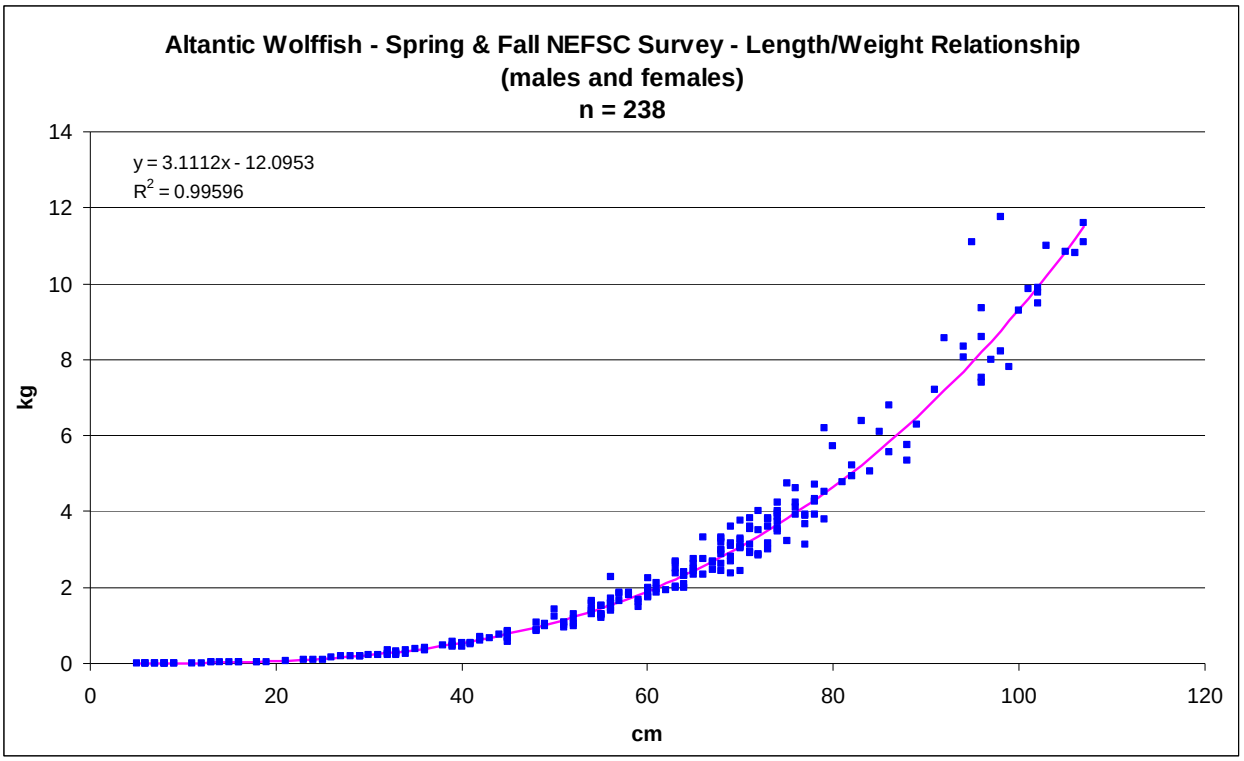


Figure 17. A combined male and female length weight relationship for Atlantic wolffish from NEFSC spring and fall bottom trawl surveys, all years.

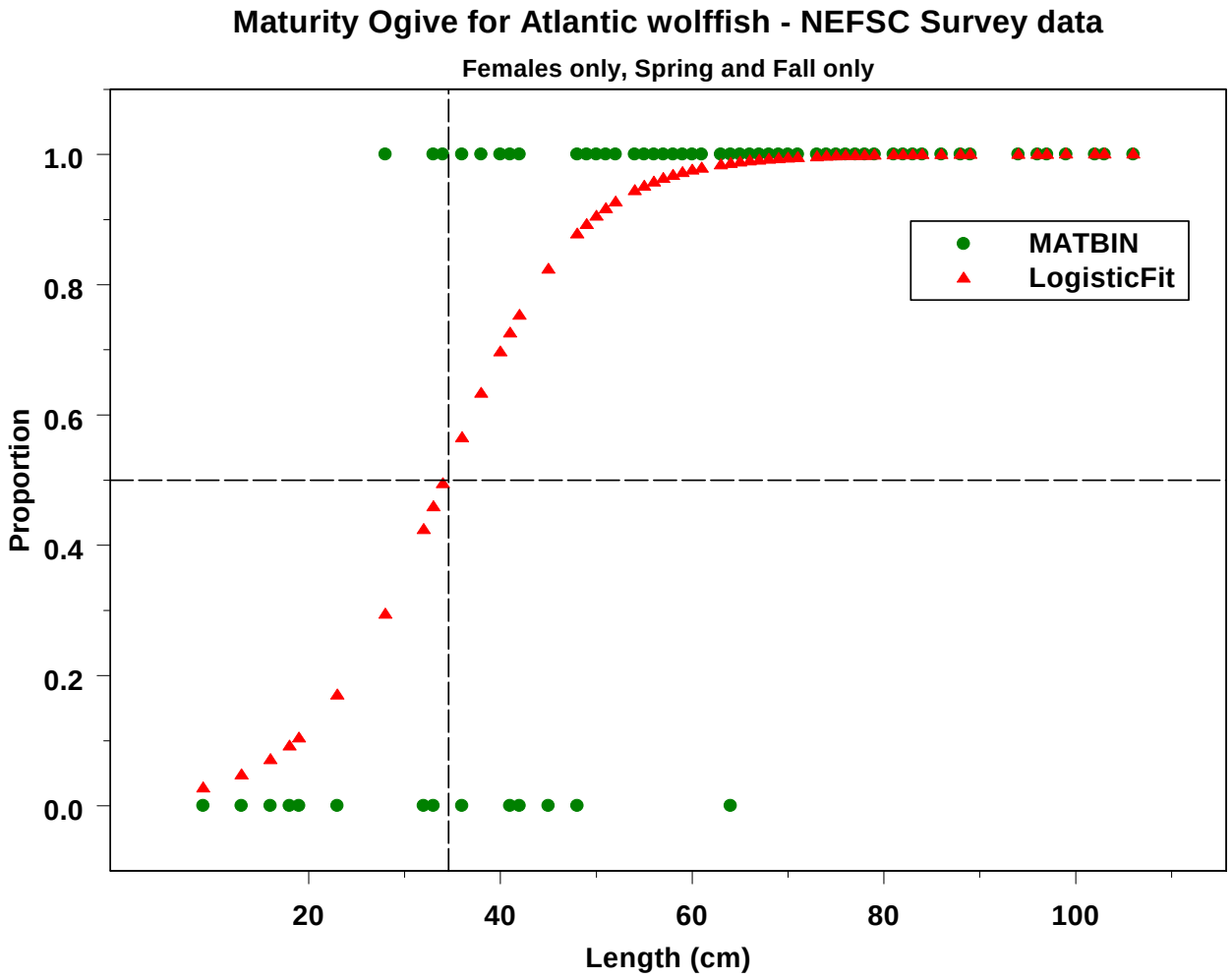


Figure 18. Maturity ogive for female Atlantic wolffish from NEFSC spring and fall data, all years.

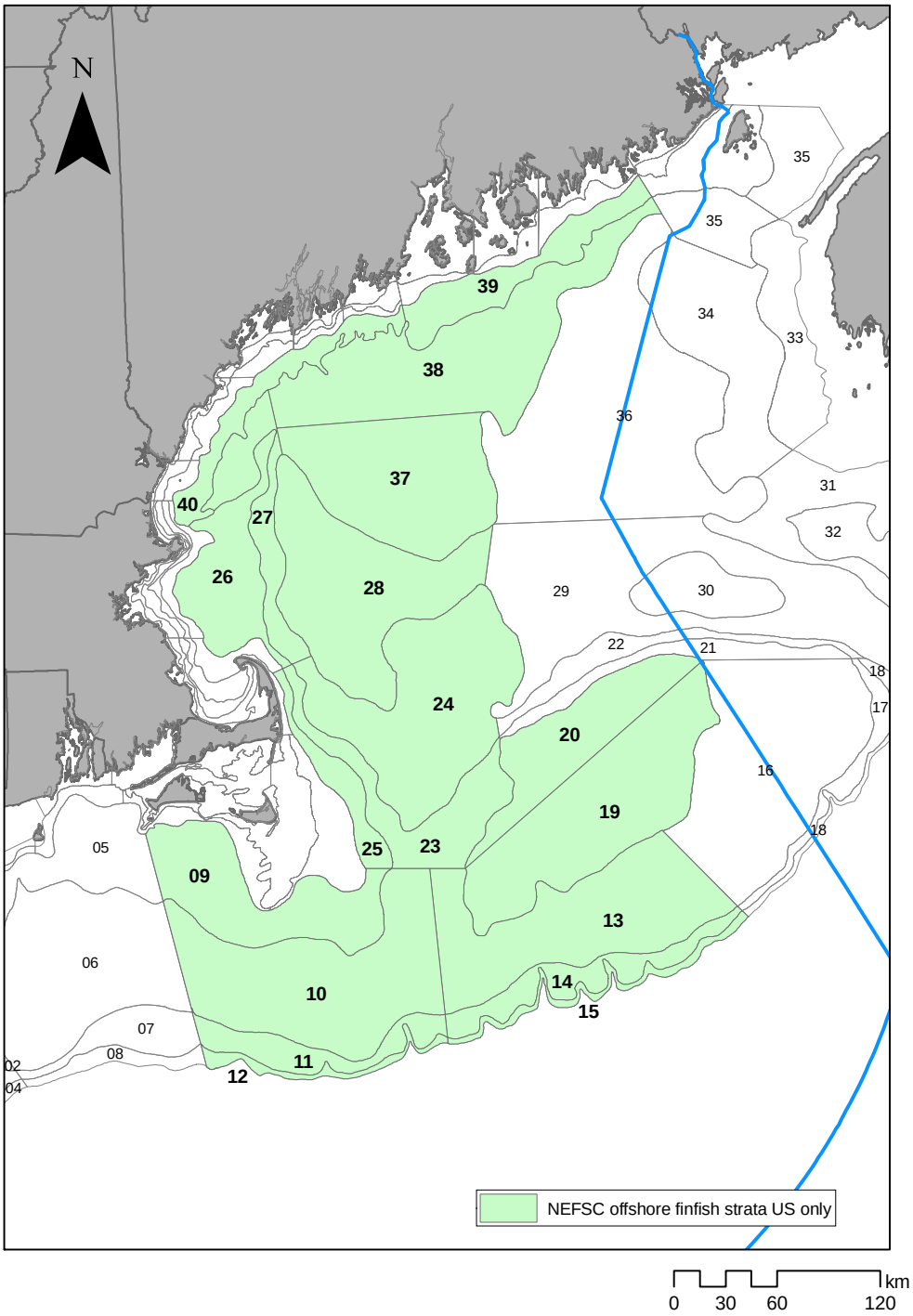


Figure 19. NEFSC survey strata used for Atlantic wolffish abundance and biomass indices.

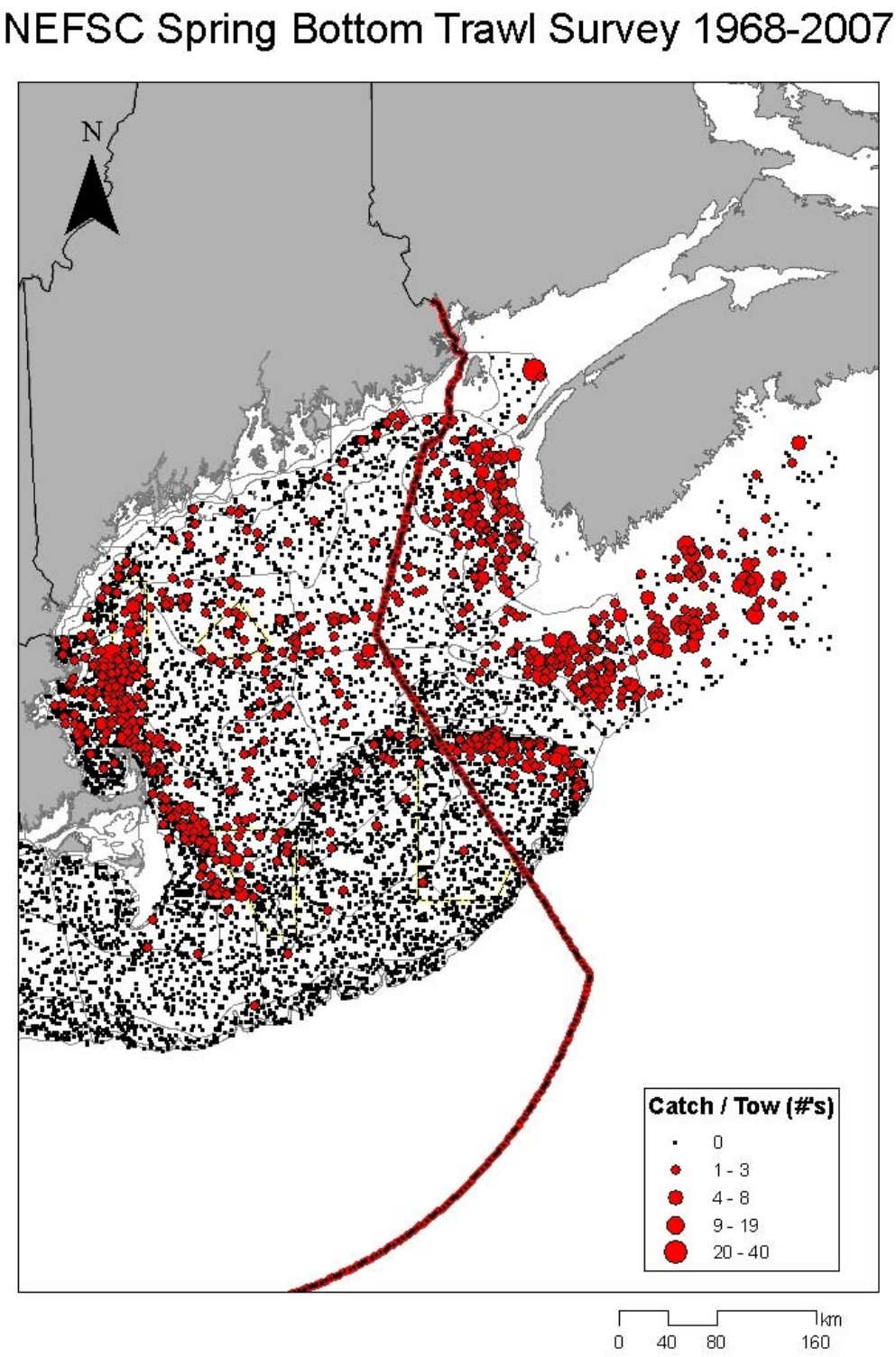


Figure 20. NEFSC spring bottom trawl survey wolffish catches, 1968-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

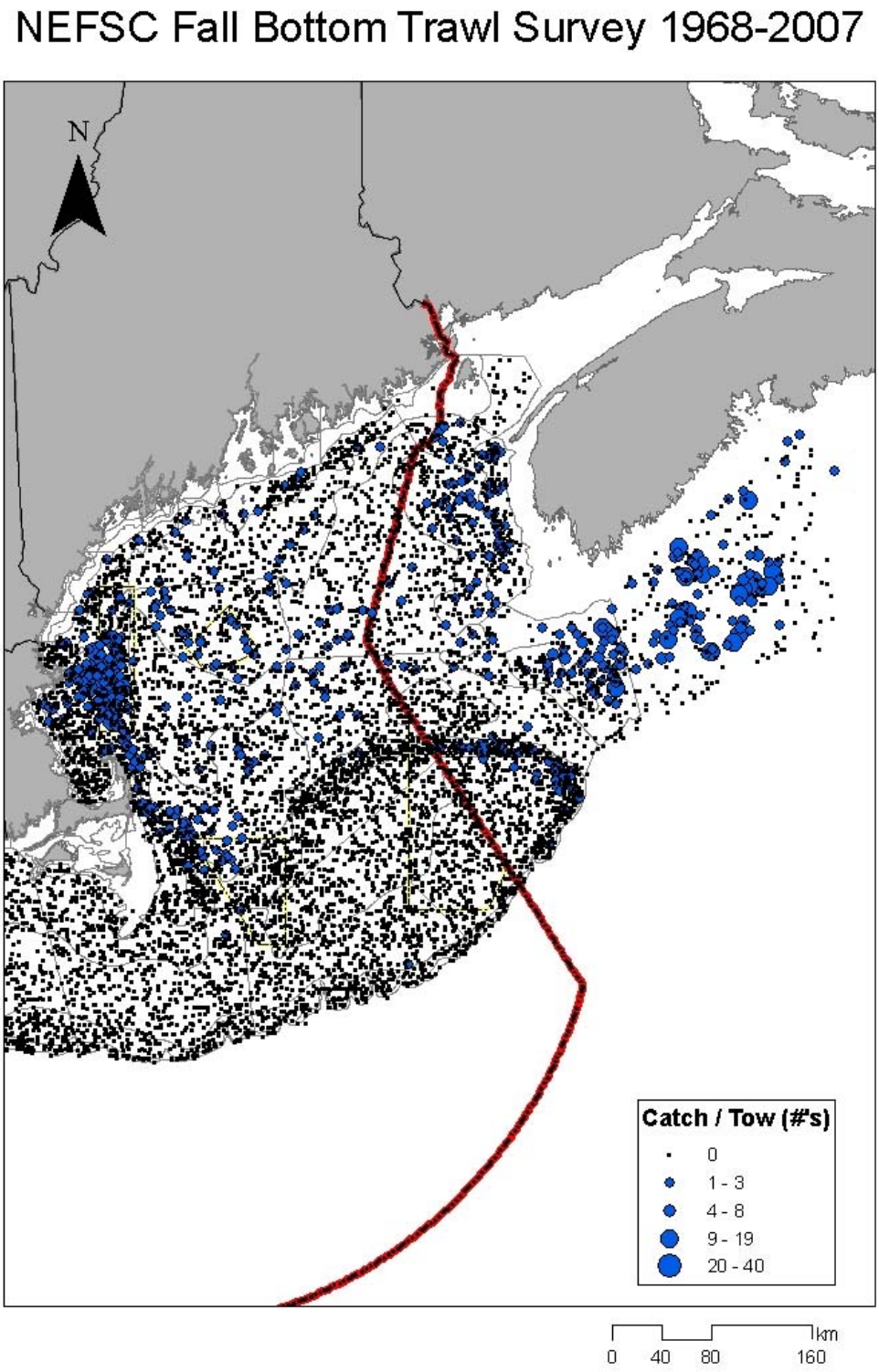


Figure 21. NEFSC fall bottom trawl survey wolffish catches, 1963-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

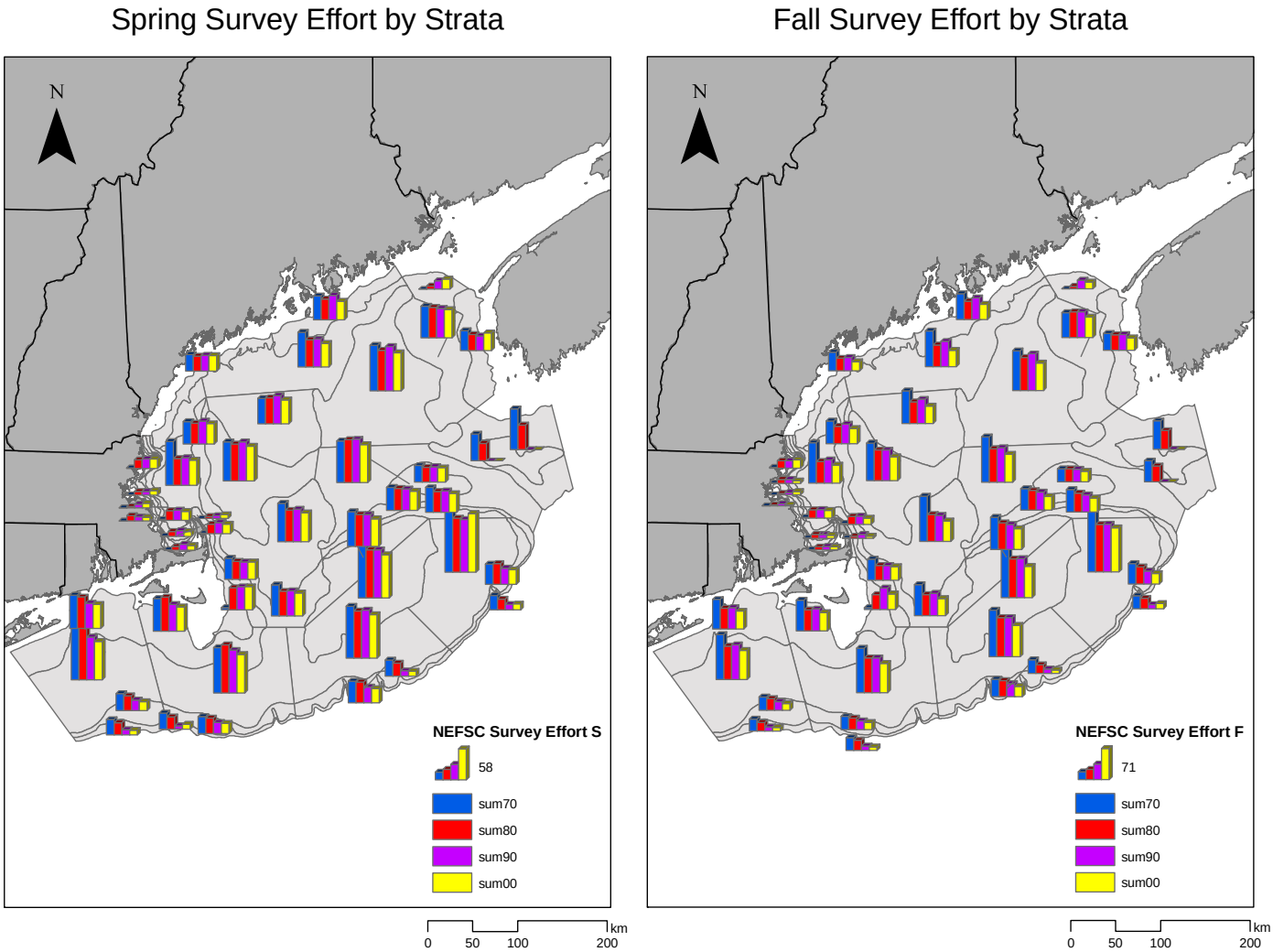


Figure 22. NEFSC spring and fall bottom trawl survey effort by decade per strata. Bars indicate number of stations per strata.

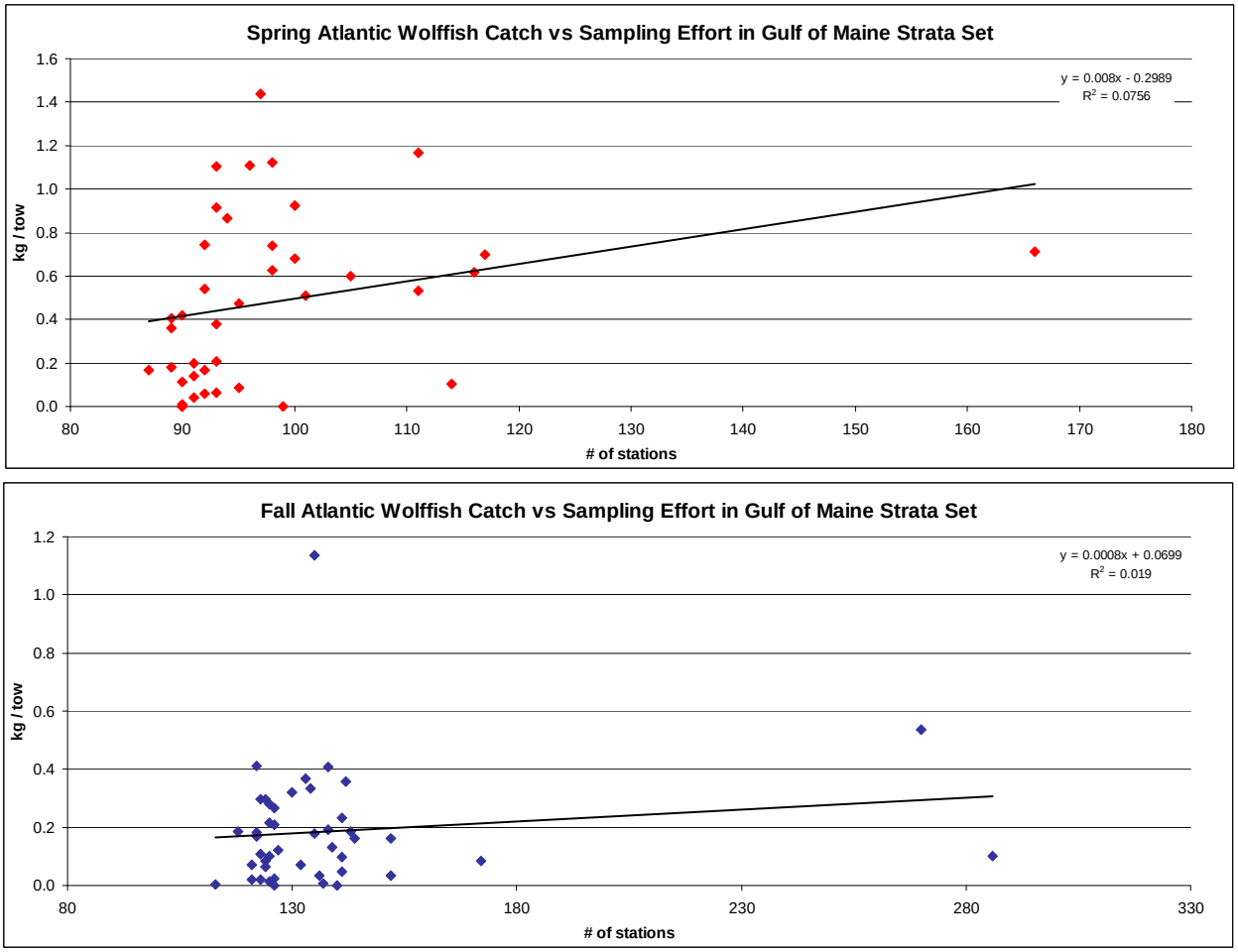


Figure 23. NEFSC sampling effort and biomass of Atlantic wolffish captured.

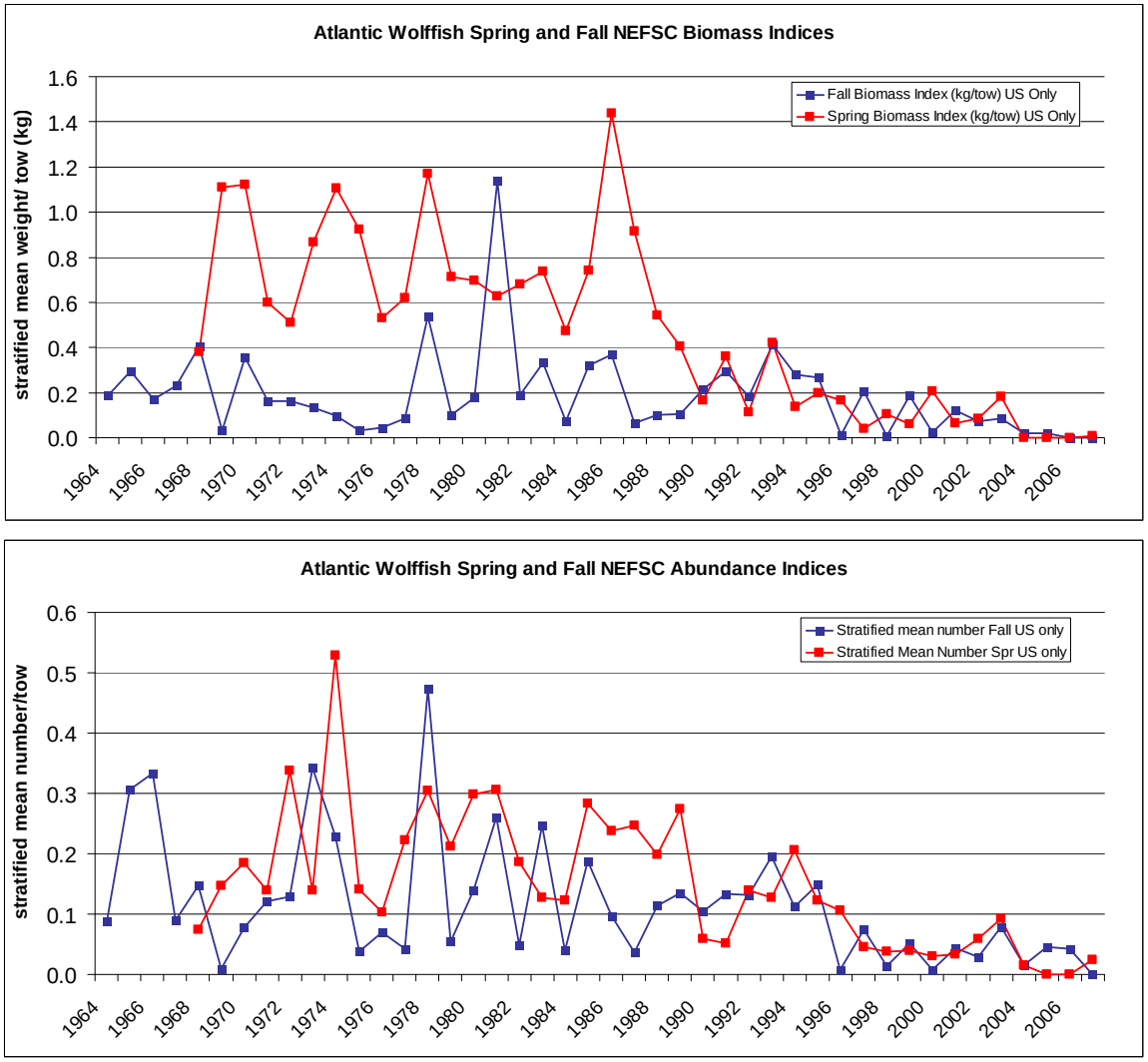
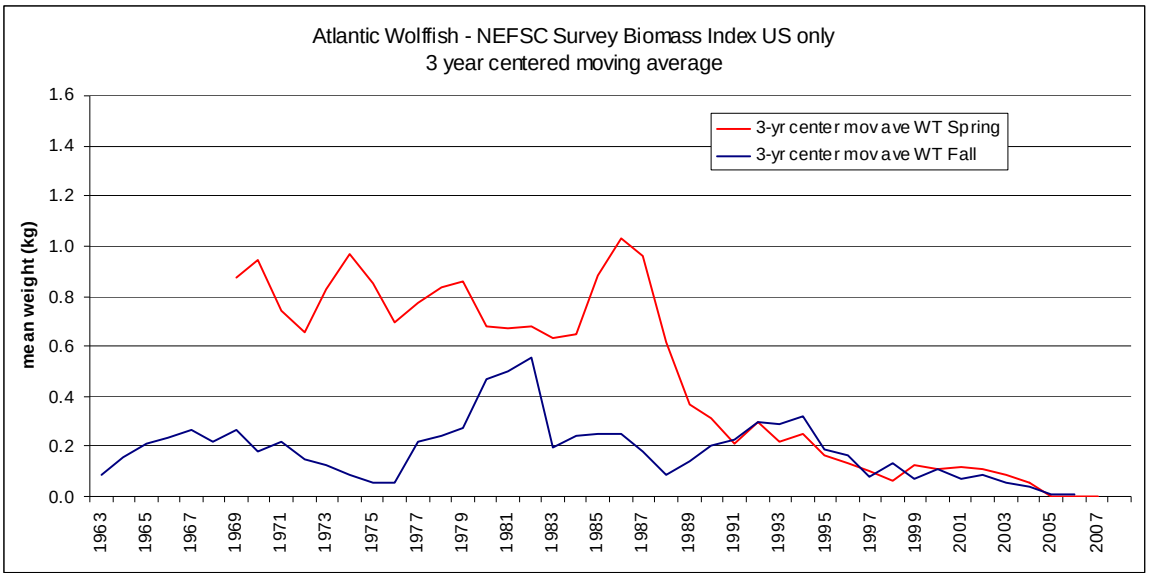


Figure 24. Spring and fall biomass and abundance indices for US only survey strata, 1964-2007.



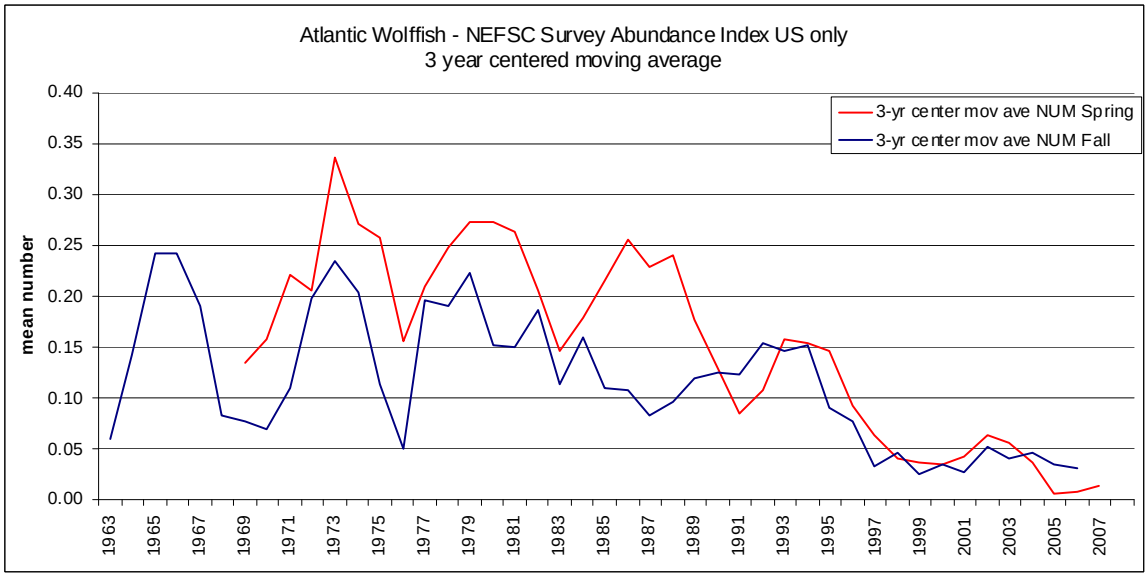
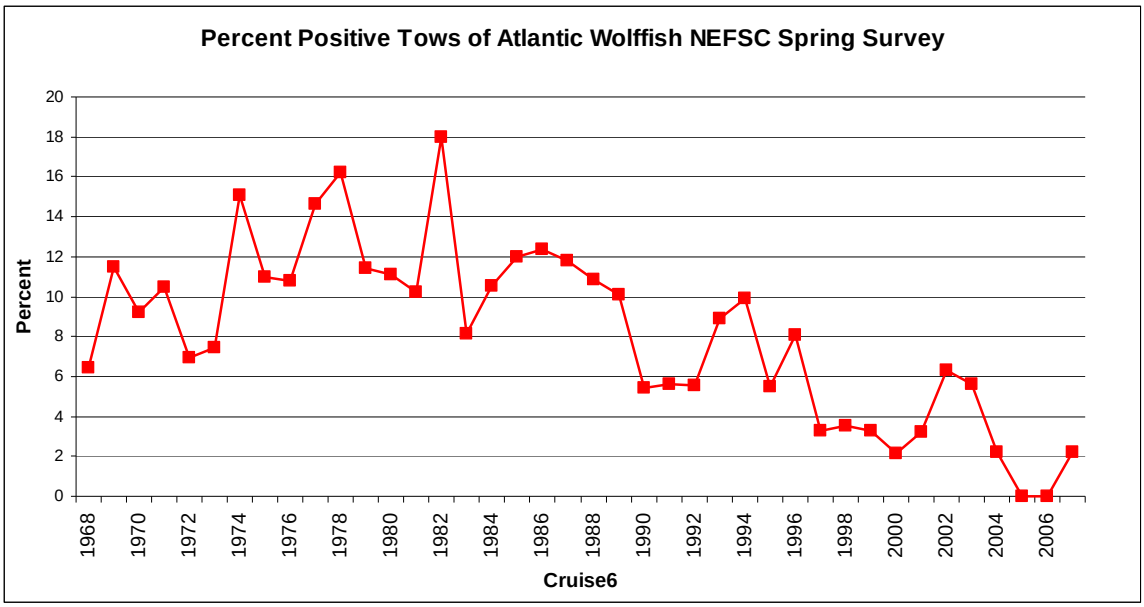


Figure 25. 3 year moving average for NEFSC spring and fall biomass and abundance indices.



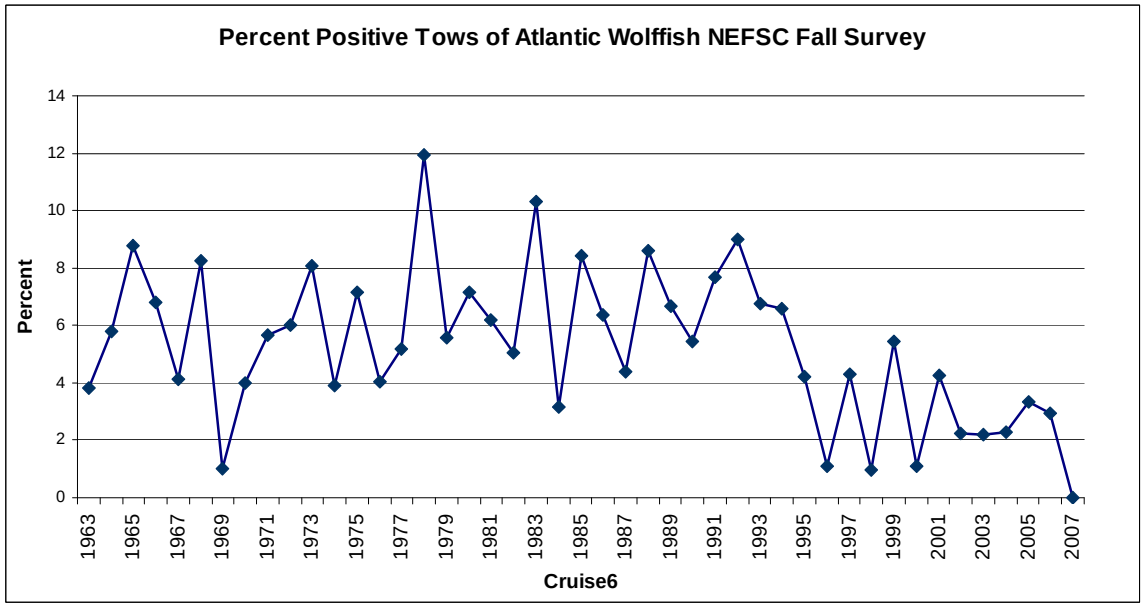


Figure 26. Percent positive Atlantic wolffish catches by year from NEFSC spring and fall bottom trawl surveys.

Spring NEFSC Survey Catches by Decades - US Strata Only

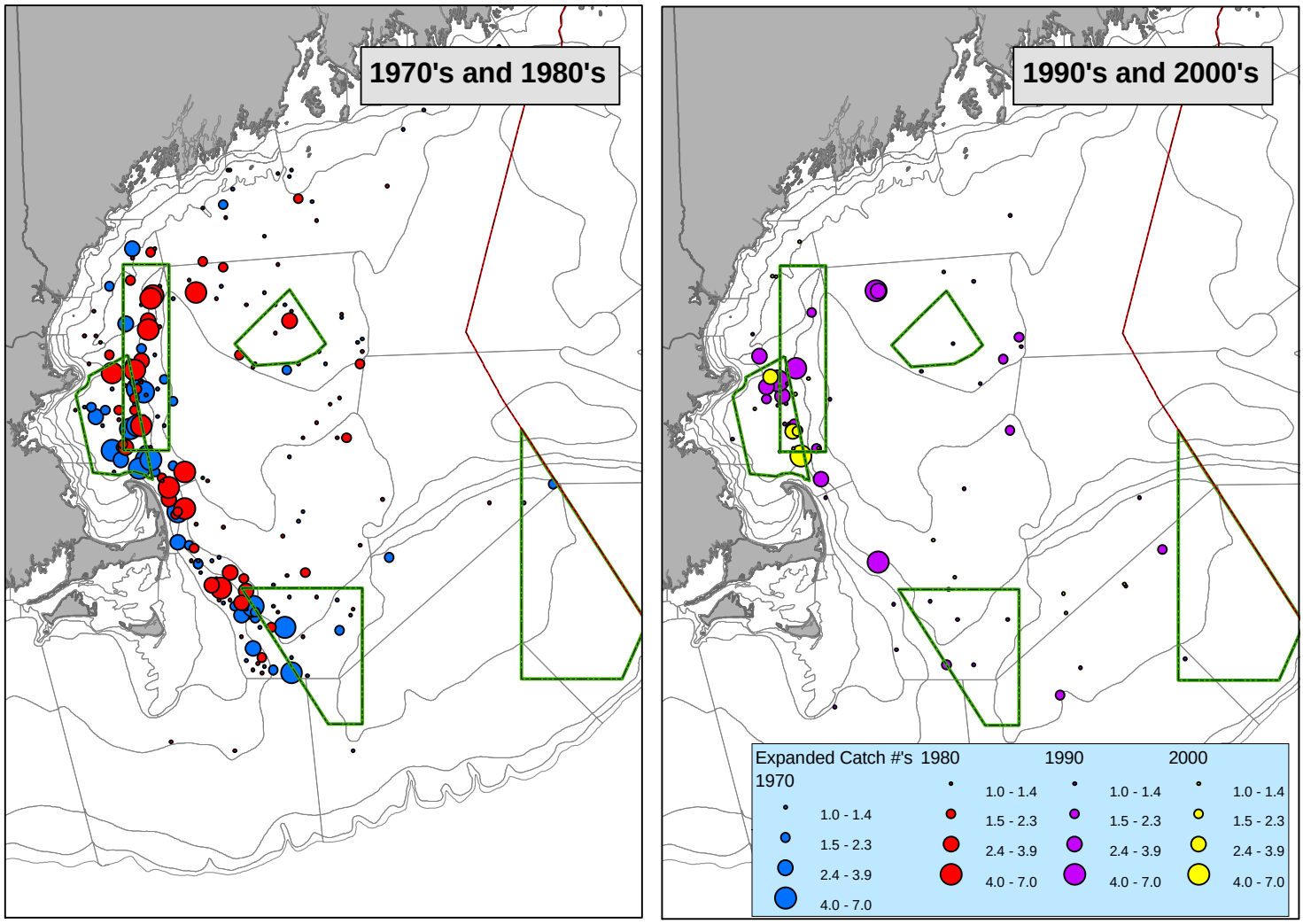


Figure 27. NEFSC spring survey catches by decade.

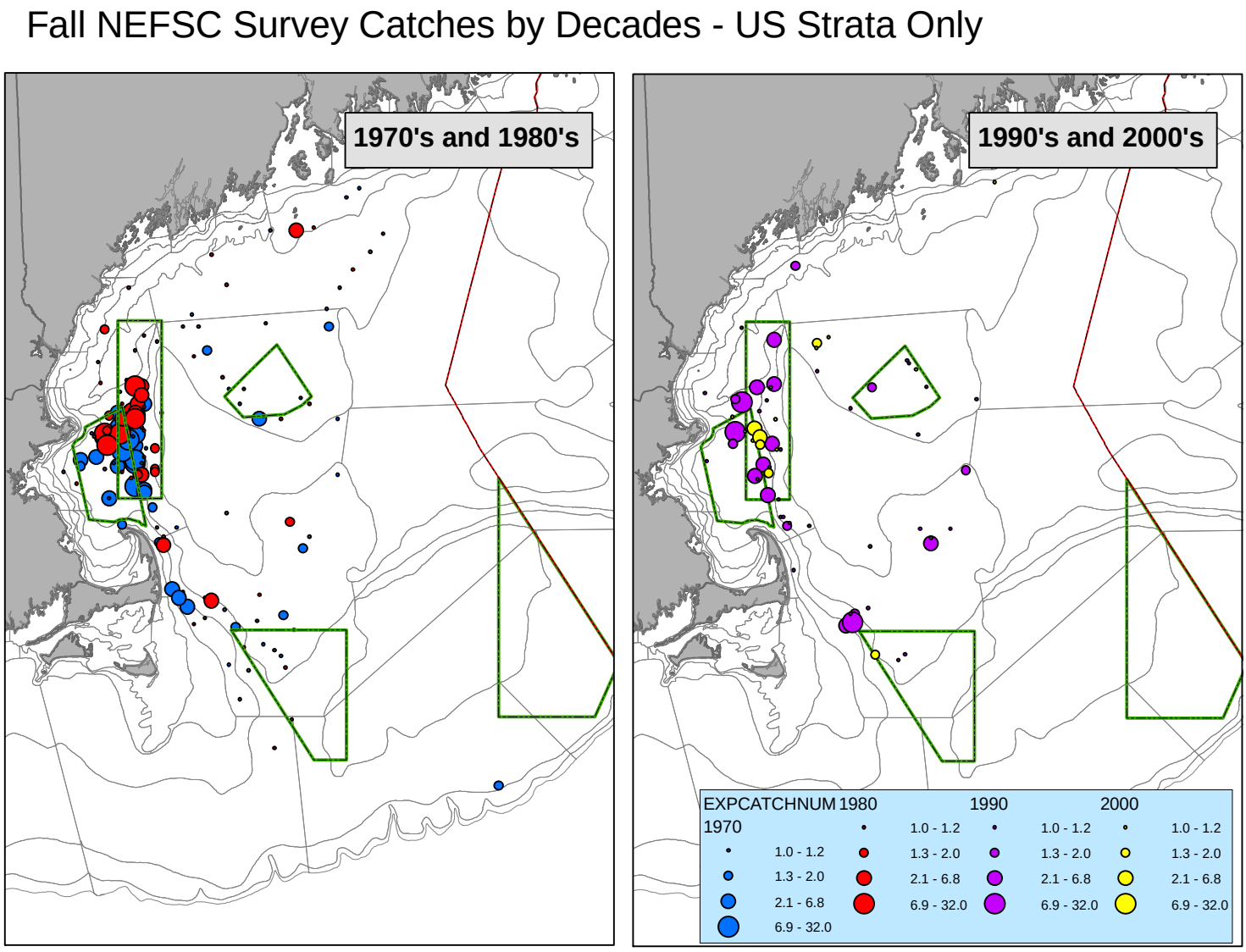


Figure 28. NEFSC fall survey catches by decade.

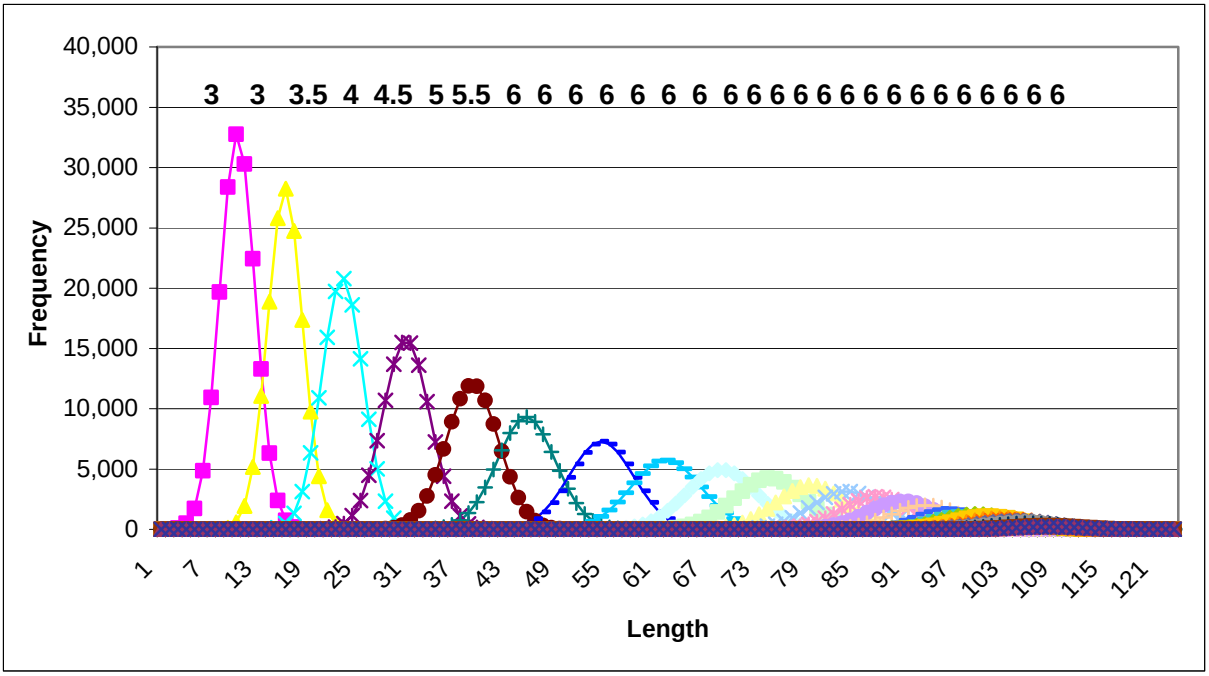


Figure 29. Mean lengths at age distributions assumed for wolffish growth. The input standard deviation is given in the top row of numbers. Ages greater than 7 had a standard deviation of 6.

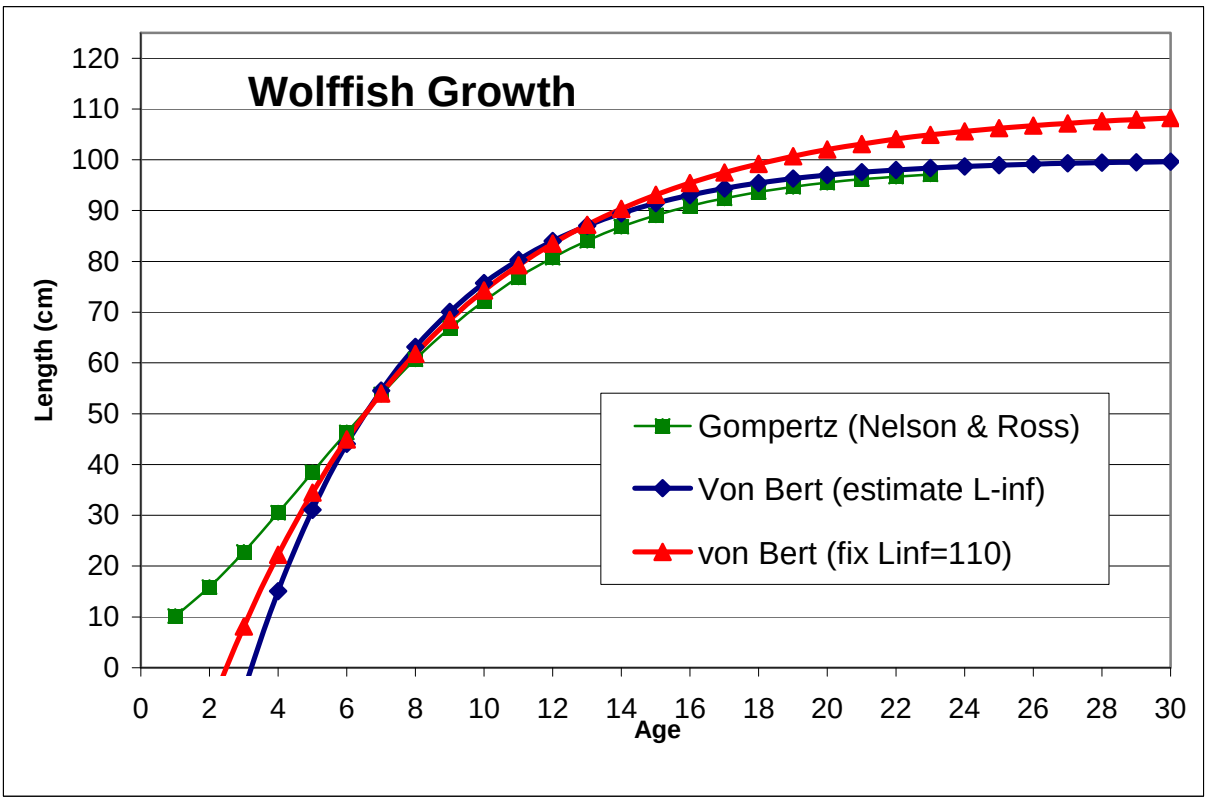


Figure 30. Wolffish estimated growth from Nelson and Ross (1992), von Bertalanffy model limited to 5+ fish, and von Bertalanffy model limited to 5+ fish with fixed L-infinity at 110 cm.

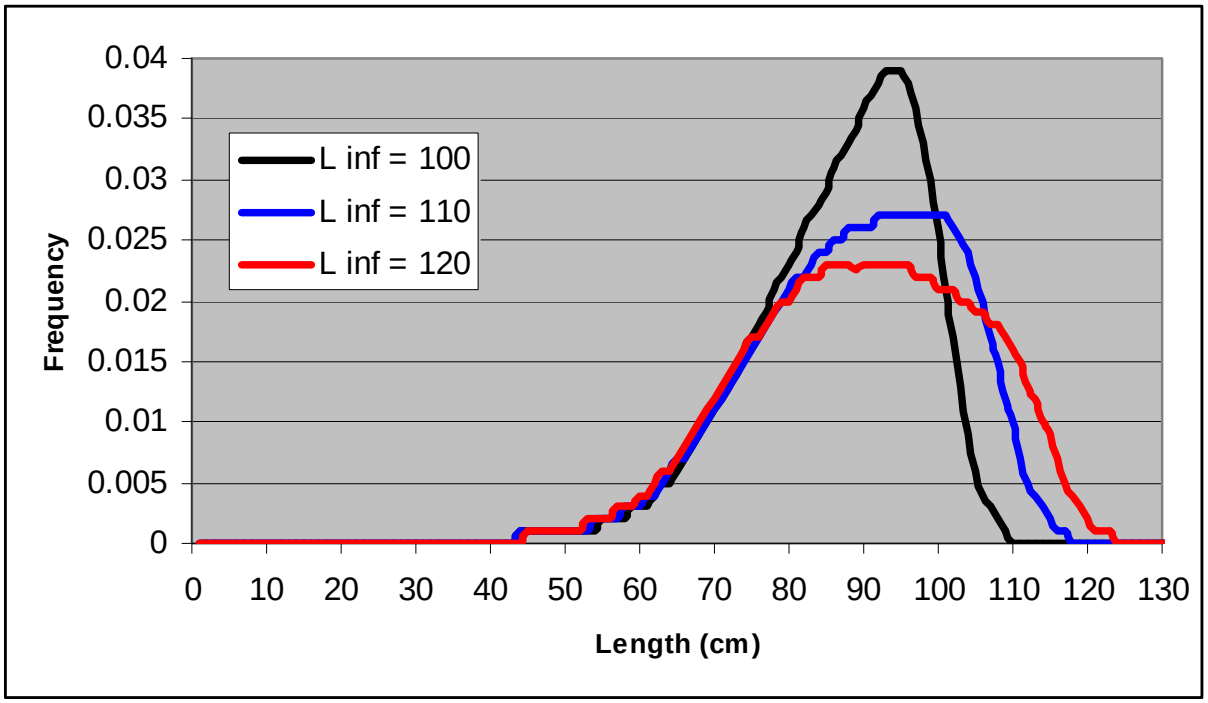


Figure 31. Predicted catch length frequency distributions at low fishing mortality (F = 0.001) with different assumed L-infinity values for growth.

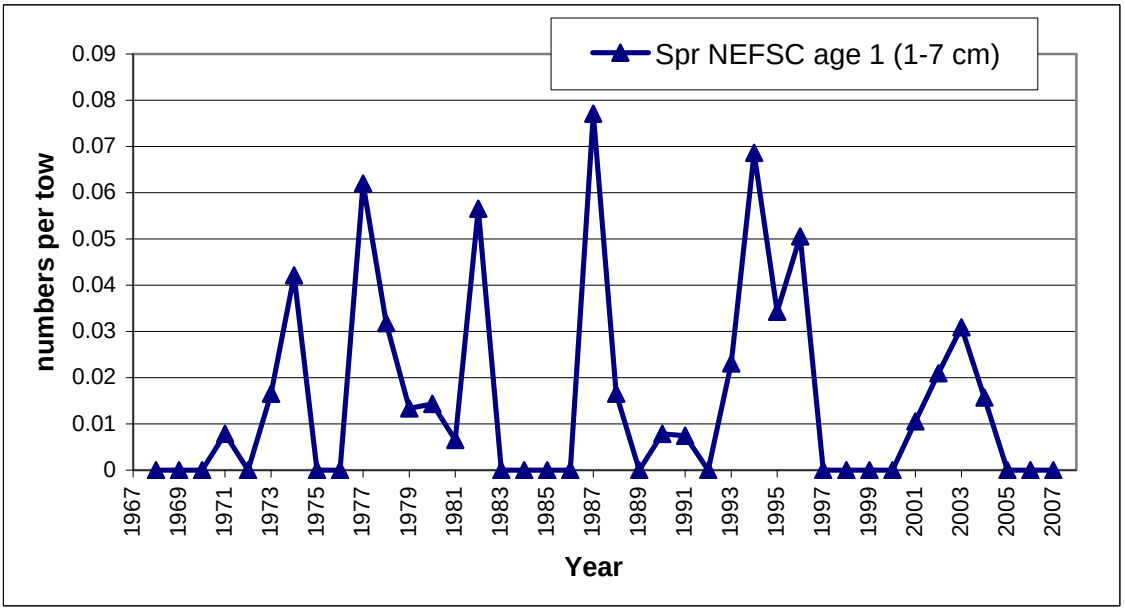


Figure 32. NEFSC spring age-1 stratified mean numbers per tow index. Lengths 1-7 cm was used as a proxy for age-1.

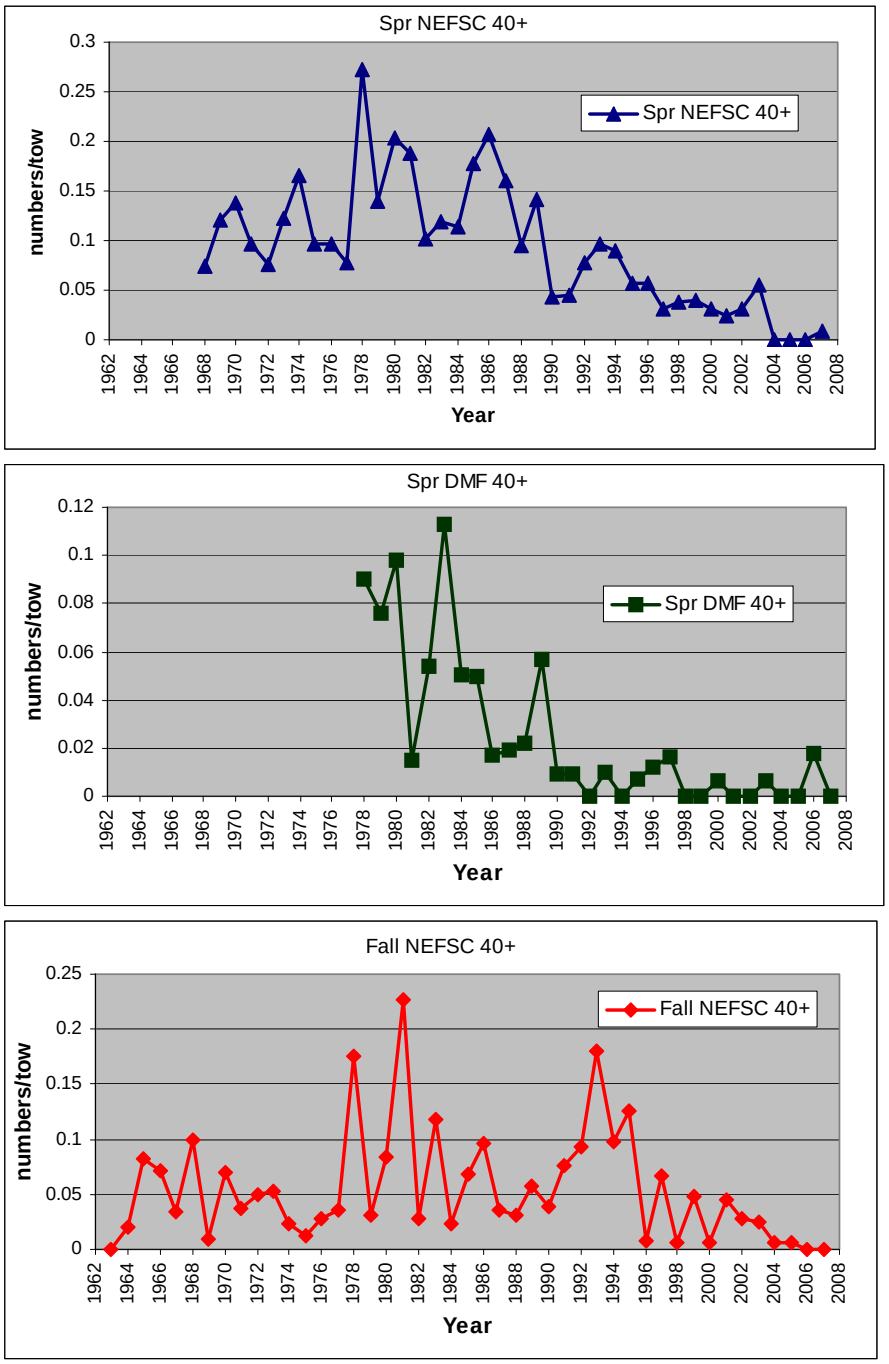


Figure 33. NEFSC spring 40+ cm, MDMF spring 40+ cm, and NEFSC fall 40+ cm stratified numbers per tow survey indices for wolffish.

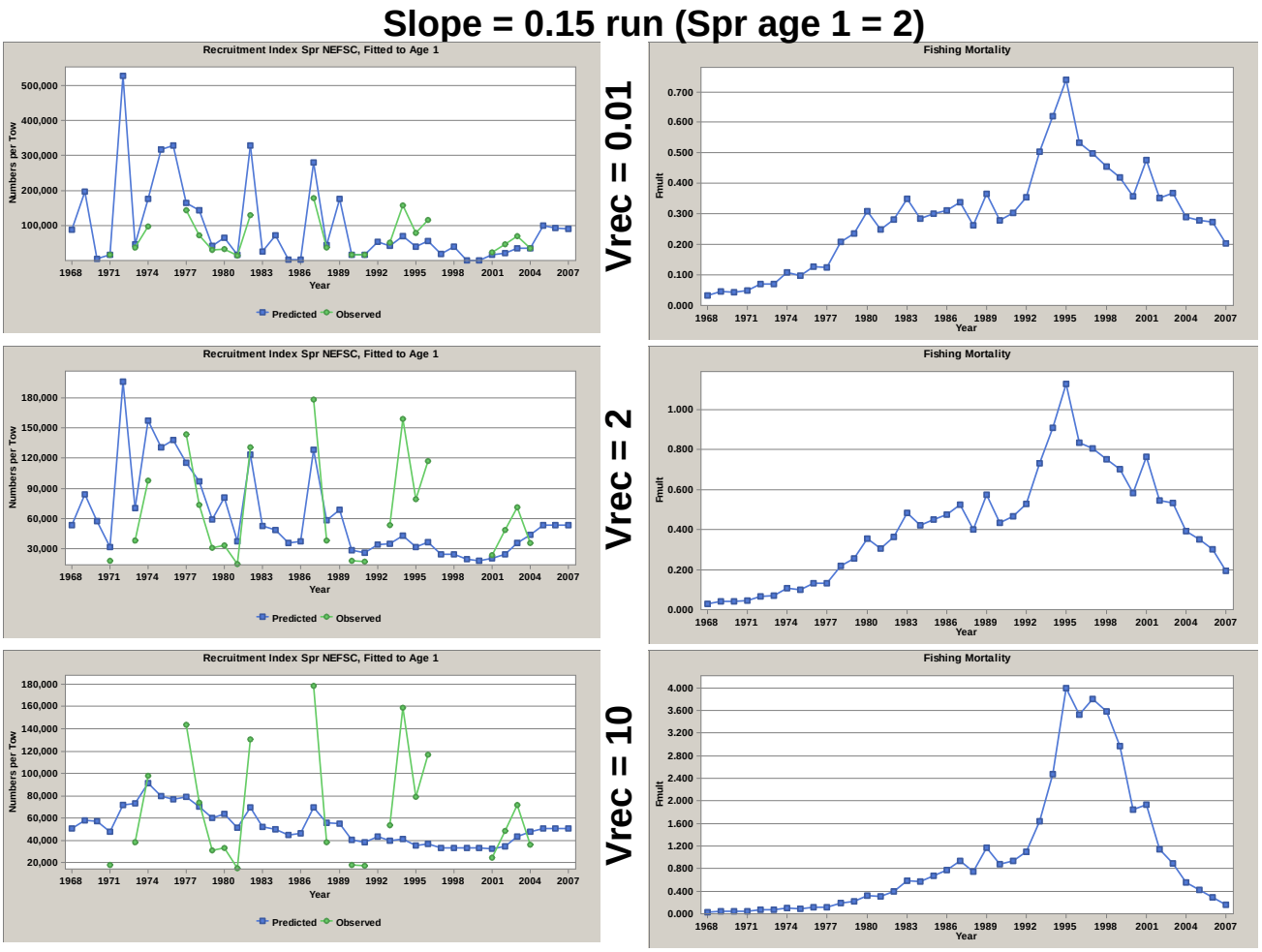


Figure 34. SCALE model sensitivity of fitting the recruitment index and the estimated fishing mortality with different penalty weights on recruitment variation (0.01, 2, 10). The weight on the age-1 recruitment index was fixed at 2.

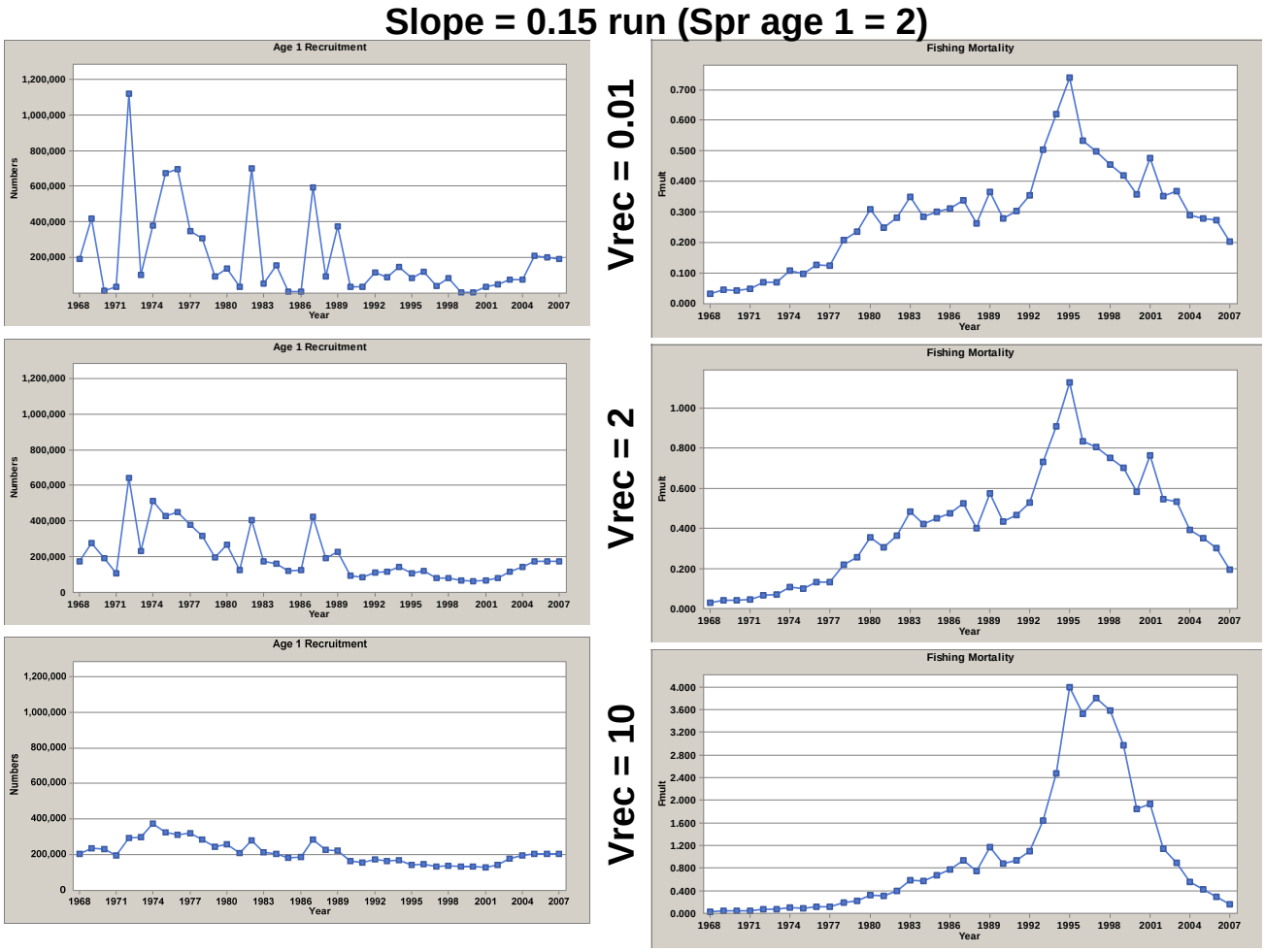


Figure 35. SCALE model sensitivity of estimated recruitment and fishing mortality with different penalty weights on recruitment variation (0.01, 2, 10). The weight on the age-1 recruitment index was fixed at 2.

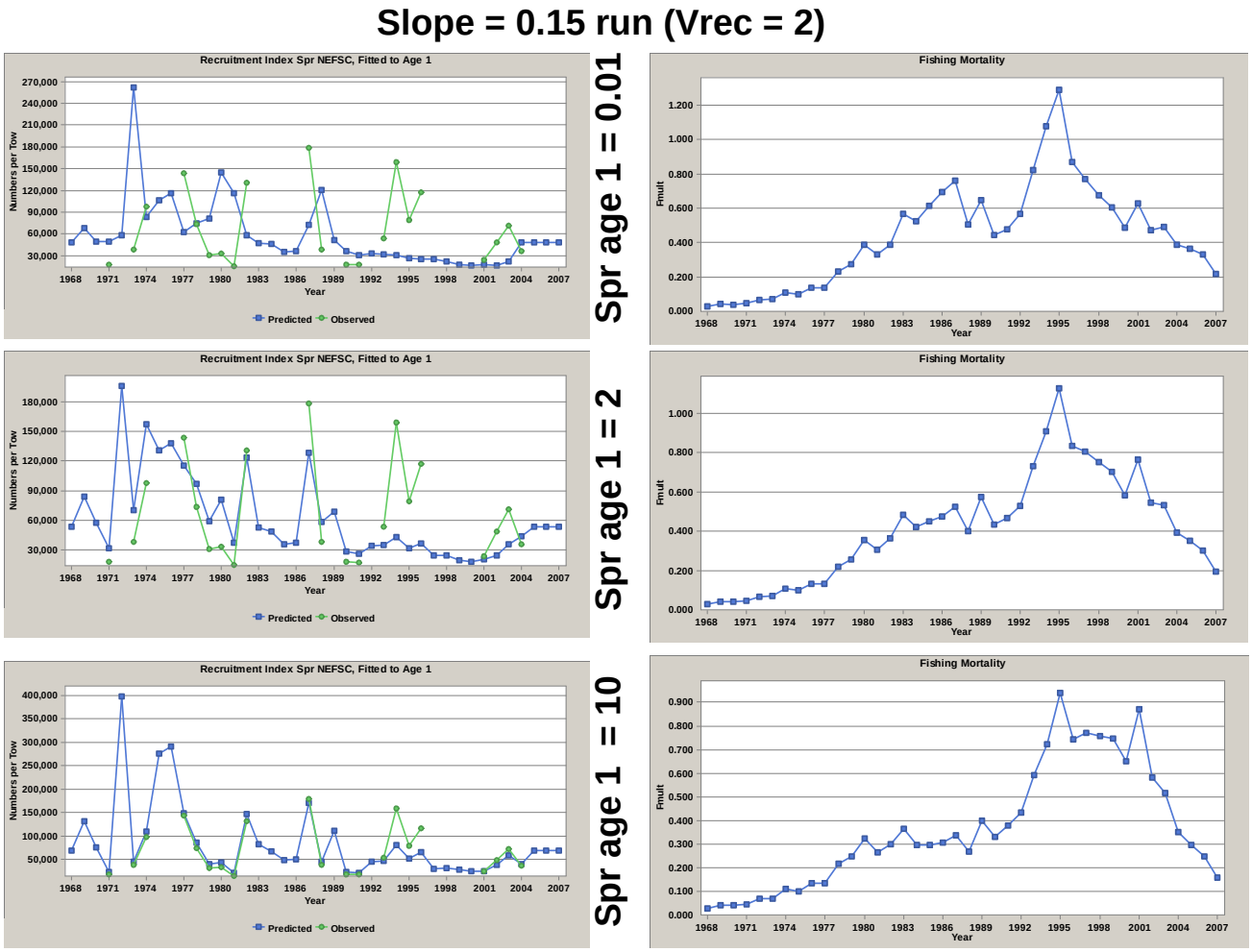


Figure 36. SCALE model sensitivity of fitting the recruitment index and the estimated fishing mortality with different weights on the recruitment index (0.01, 2, 10). The weight on recruitment variation penalty was fixed at 2.

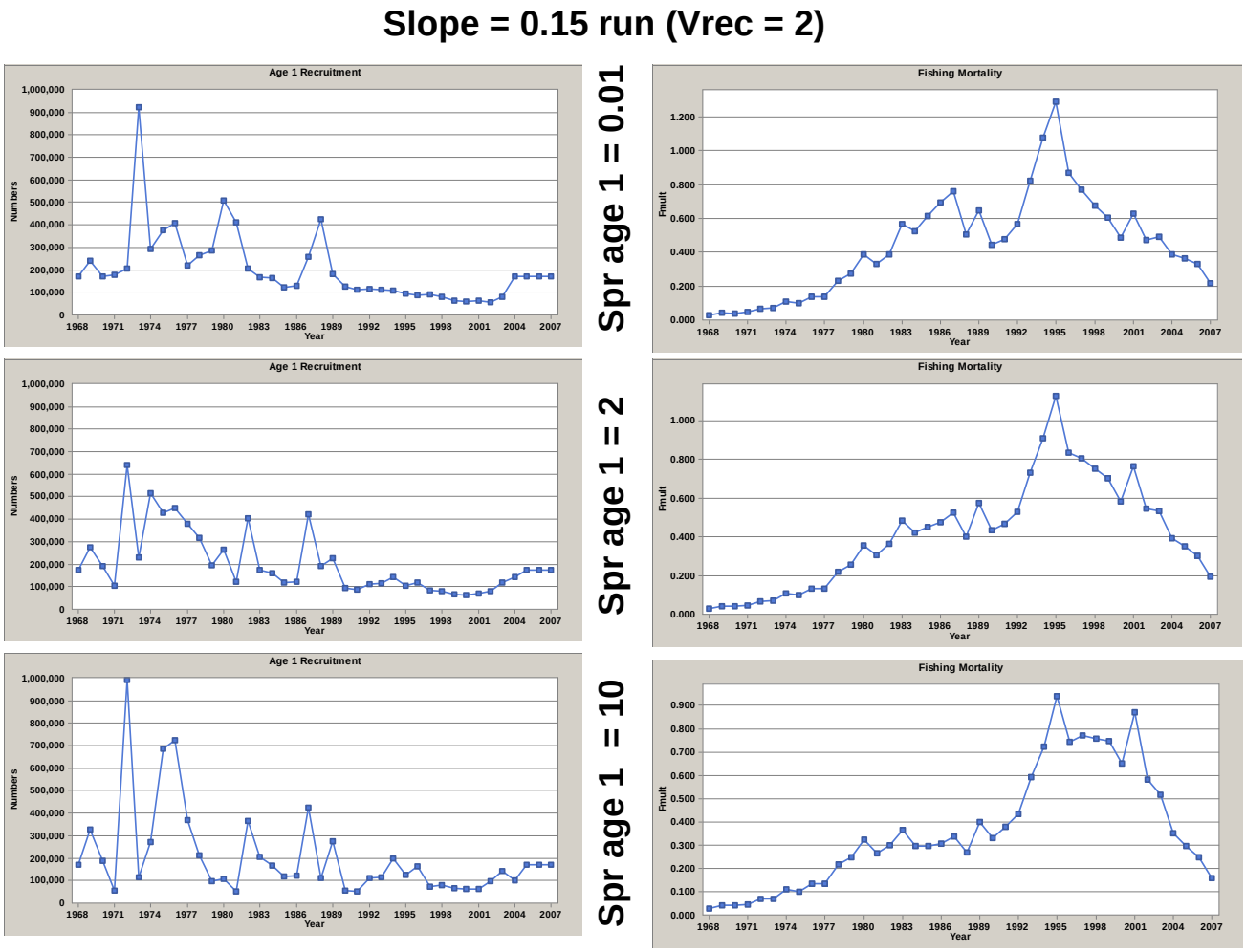


Figure 37. SCALE model sensitivity of estimated recruitment and fishing mortality with different weights on the recruitment index (0.01, 2, 10). The weight on recruitment variation penalty was fixed at 2.

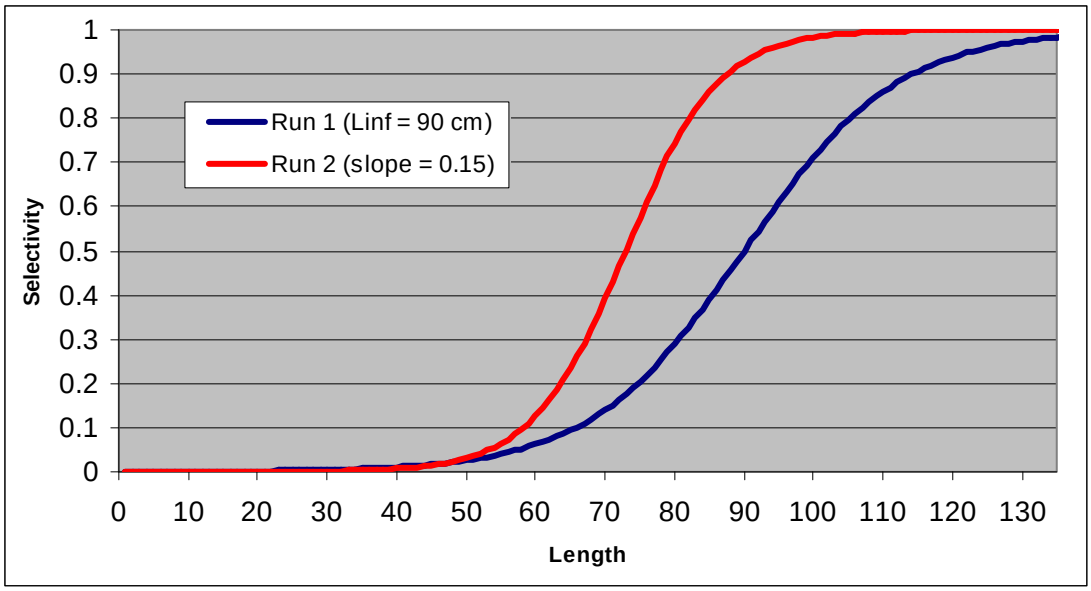


Figure 38. SCALE run 1 selectivity was allowed to hit the L-infinity bound of 90 cm which estimates a relatively flat selectivity curve. SCALE run 2 hits the slope bound of 0.15 which estimated a lower L-infinity.

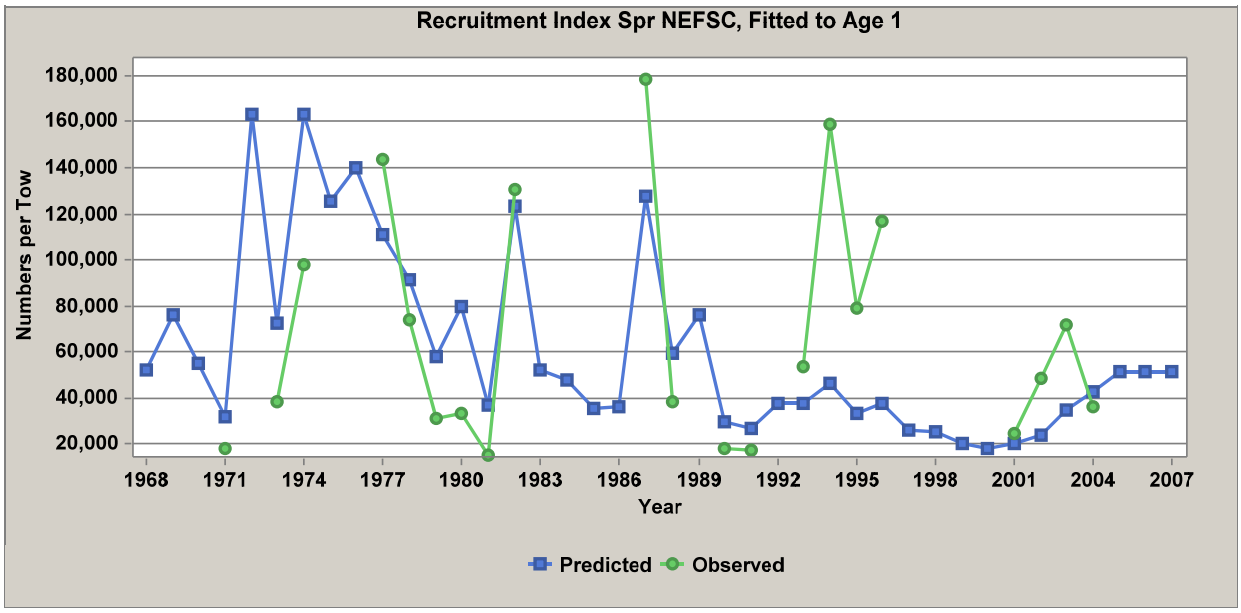


Figure 39. SCALE run 1 (L-infinity = 90 cm) fit to the NEFSC spring age-1 recruitment index.

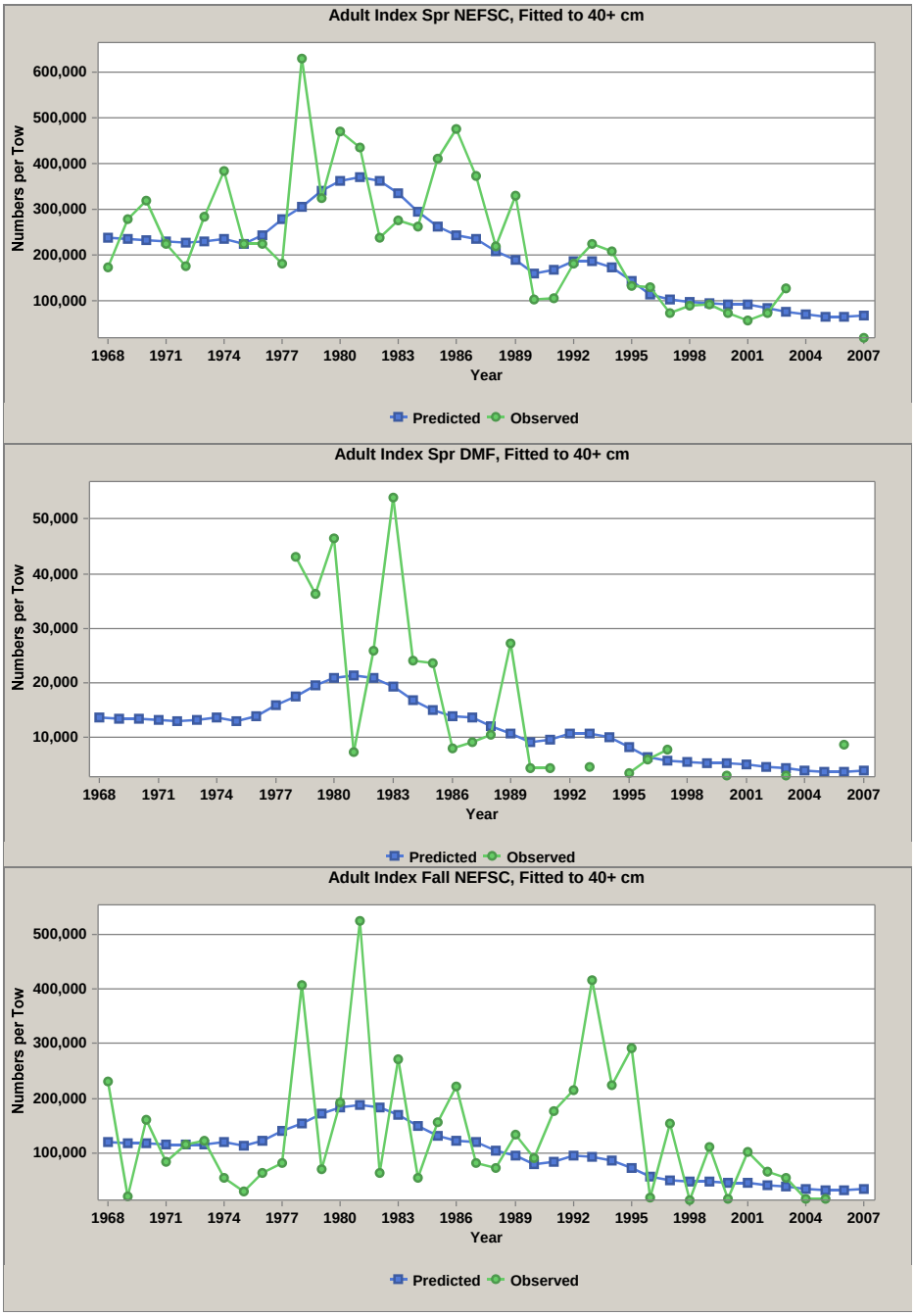


Figure 40. SCALE run 1 (L-infinity = 90 cm) fit to the NEFSC spring 40+ cm, MDMF 40+ cm, and NEFSC fall 40+ cm indices.

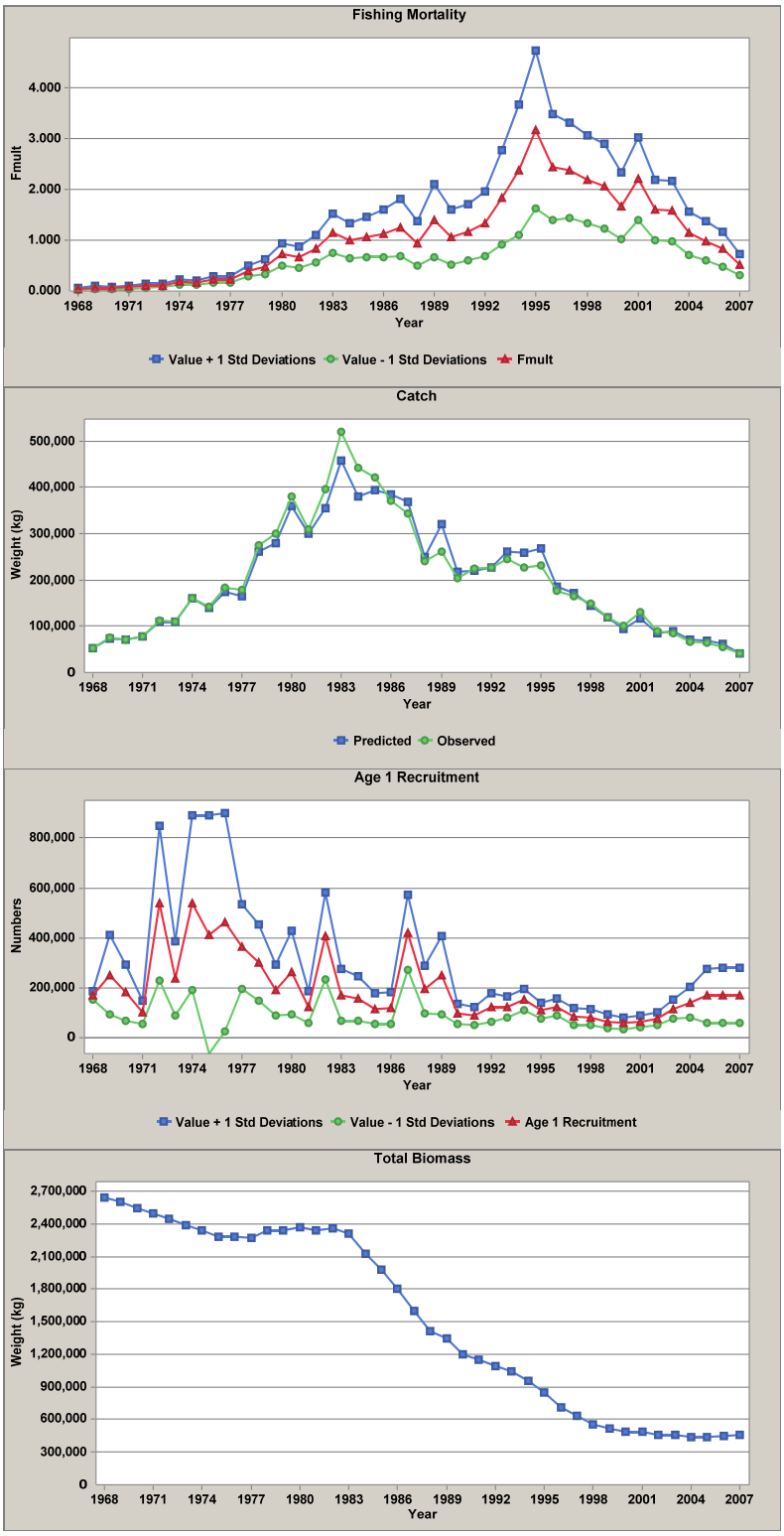


Figure 41. Run 1 (L-infinity = 90 cm) F, fit to the catch, recruitment and total biomass. Plus 1 and minus 1 standard deviations are shown on F and recruitment.

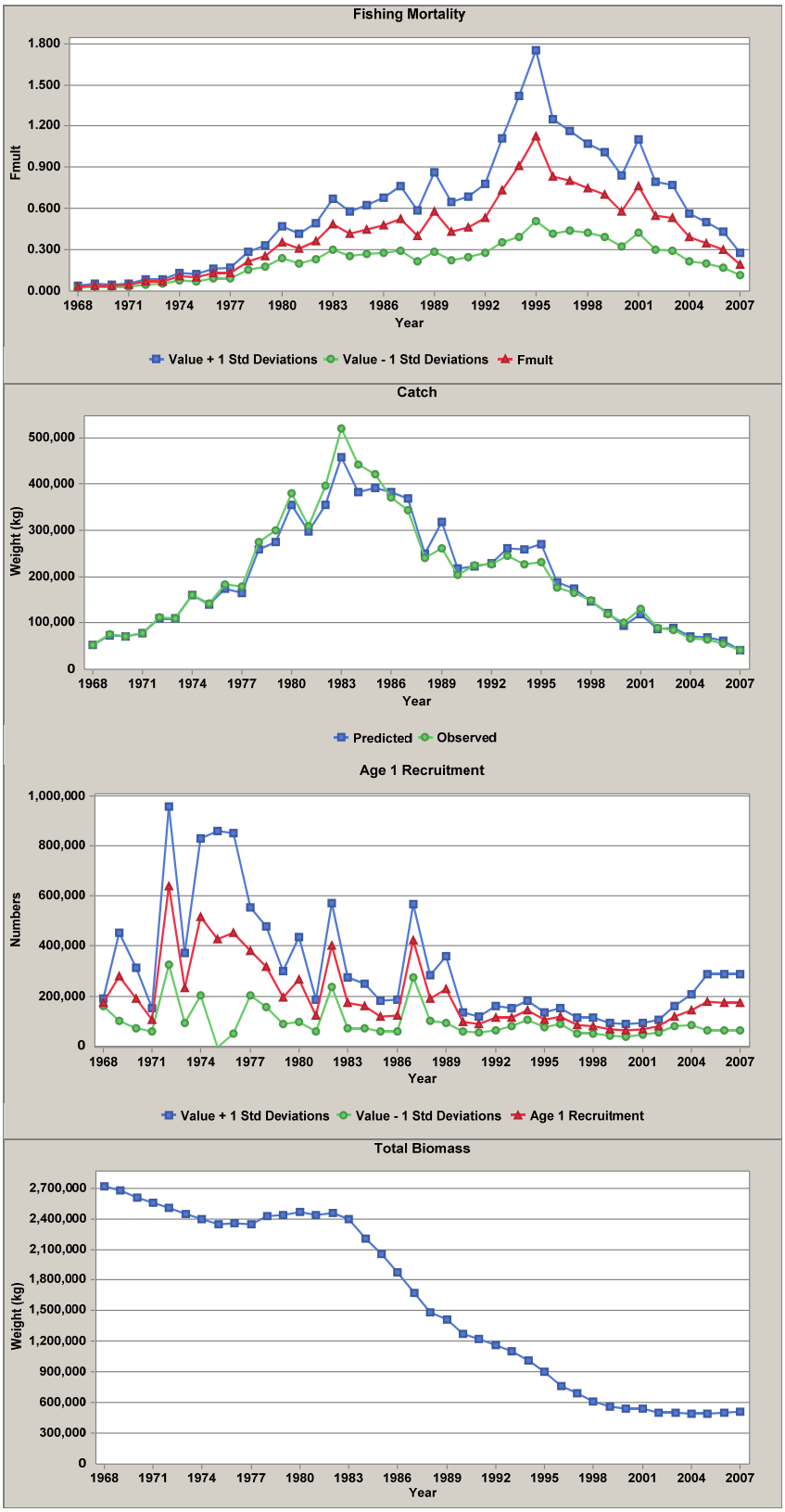


Figure 42. Run 2 (Slope = 0.15) F, fit to the catch, recruitment and total biomass. Plus 1 and minus 1 standard deviations are shown on F and recruitment.

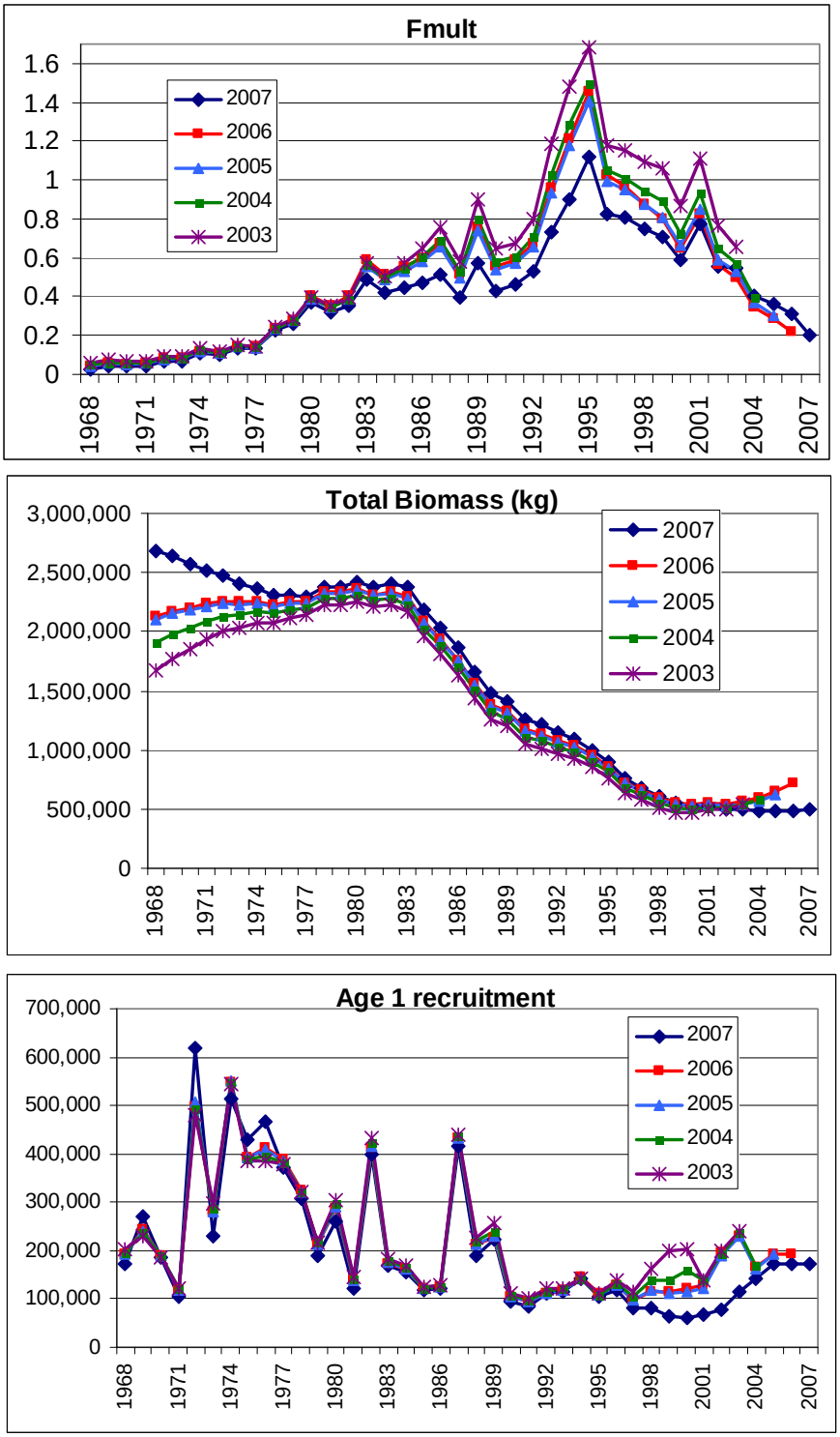


Figure 43. Run 2 (slope = 0.15) retrospective on F, total biomass and age-1 recruitment.

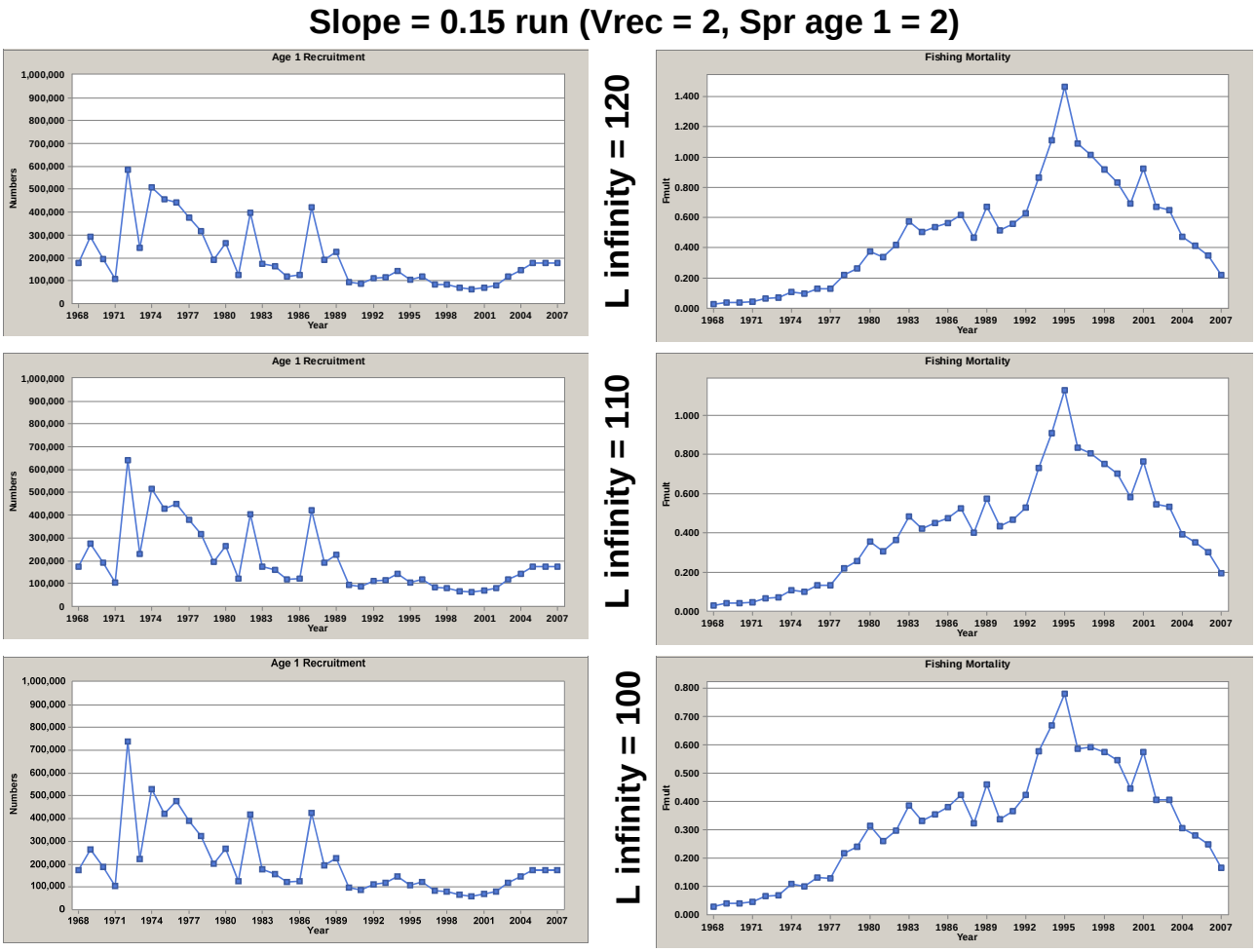


Figure 44. Run 1 (slope = 0.15) sensitivity of recruitment and fishing mortality using three different assumed L-infinity values (100, 110, 120) on growth.

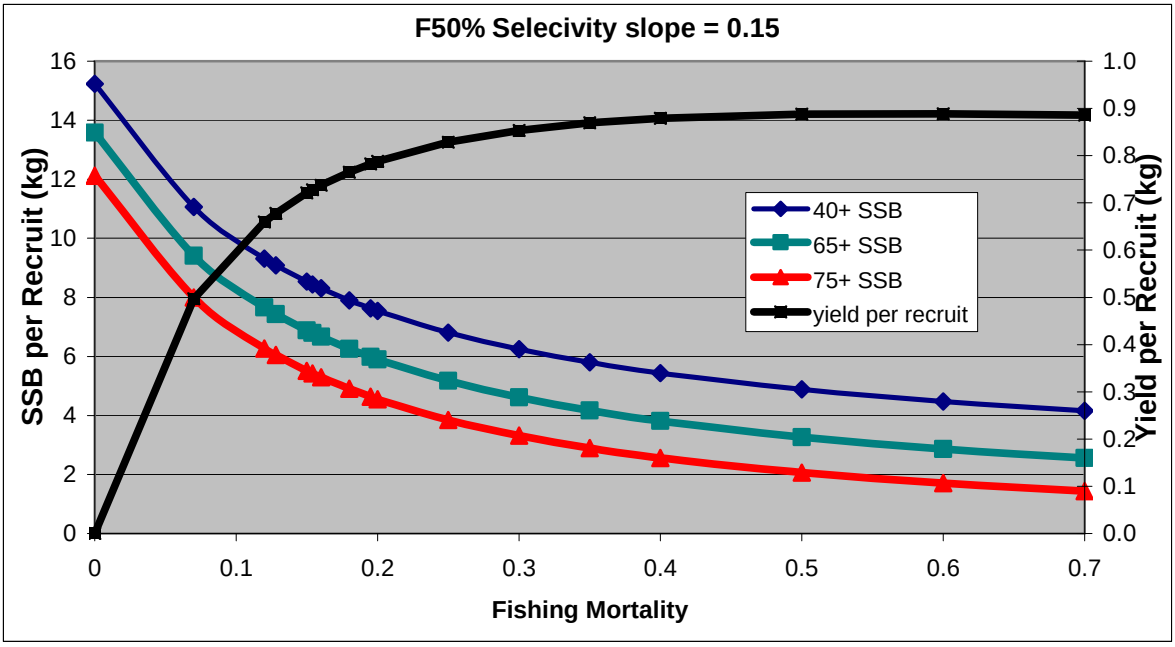


Figure 45. Updated Run 3 SCALE model F50% yield per recruit and spawn stock biomass per recruit curves.

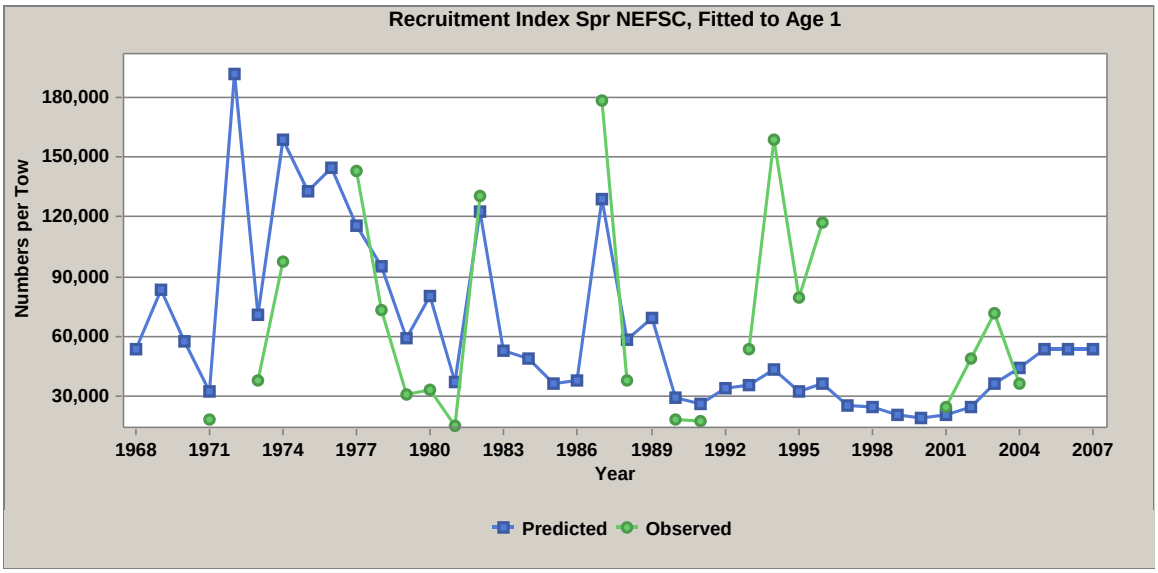


Figure 46. Updated Run 3 (slope = 0.15) SCALE model fit to the NEFSC spring age-1 recruitment index

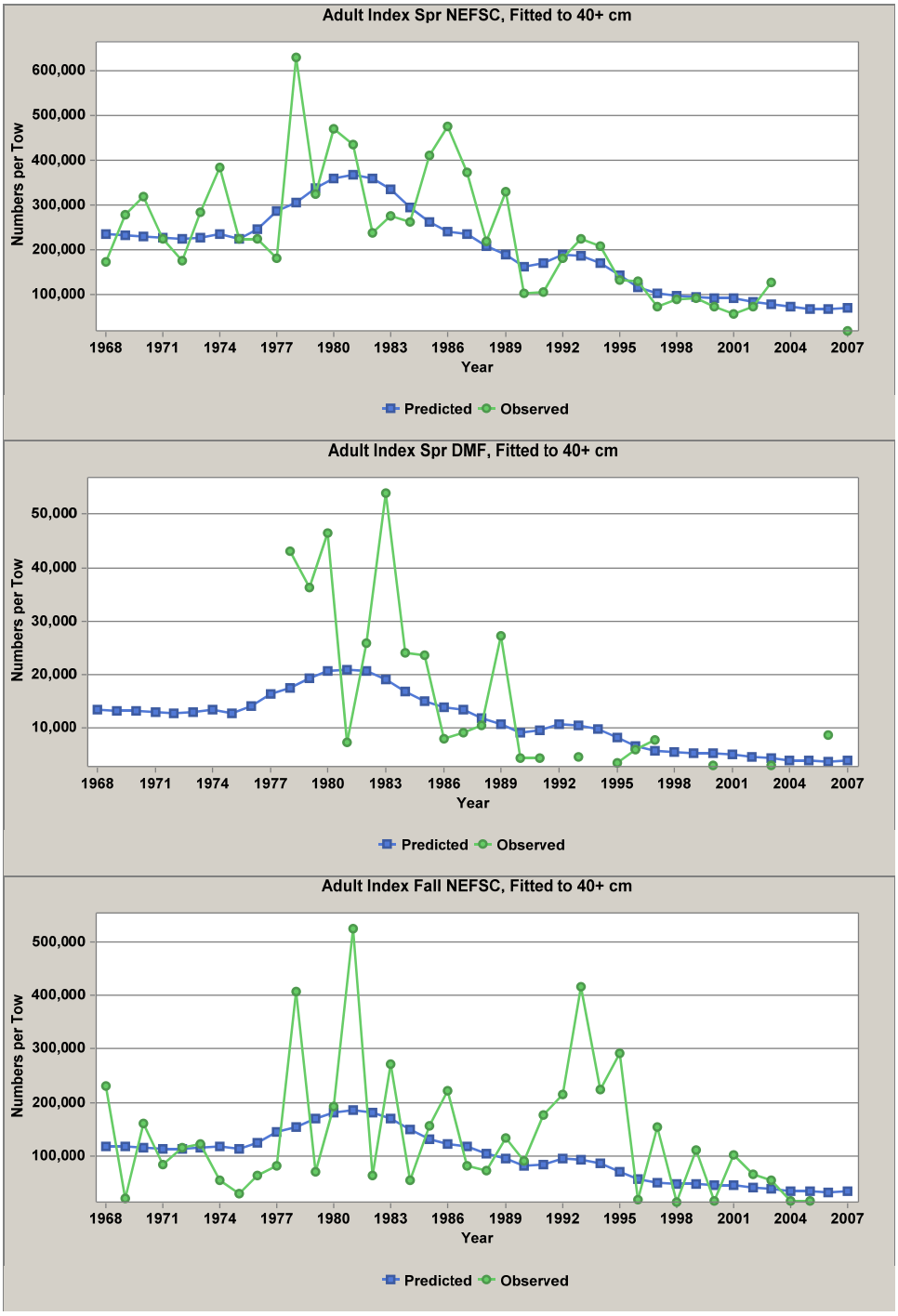


Figure 47. Updated Run 3 (slope = 0.15) SCALE model fit to the NEFSC spring 40+ cm, MDMF 40+ cm, and NEFSC fall 40+ cm indices.

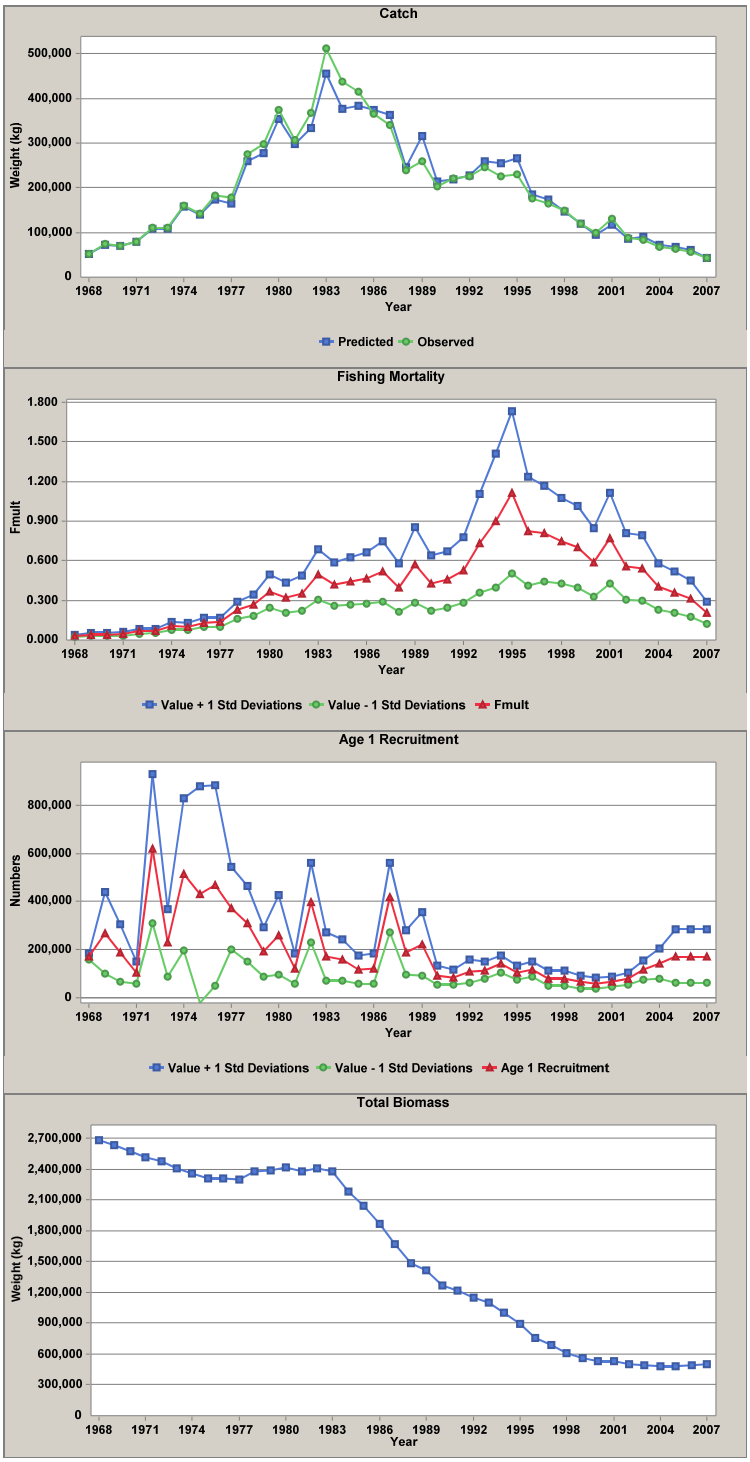


Figure 48. Run 3 (Slope = 0.15) F, fit to the catch, recruitment and total biomass. Plus 1 and minus 1 standard deviation are shown on F and recruitment.

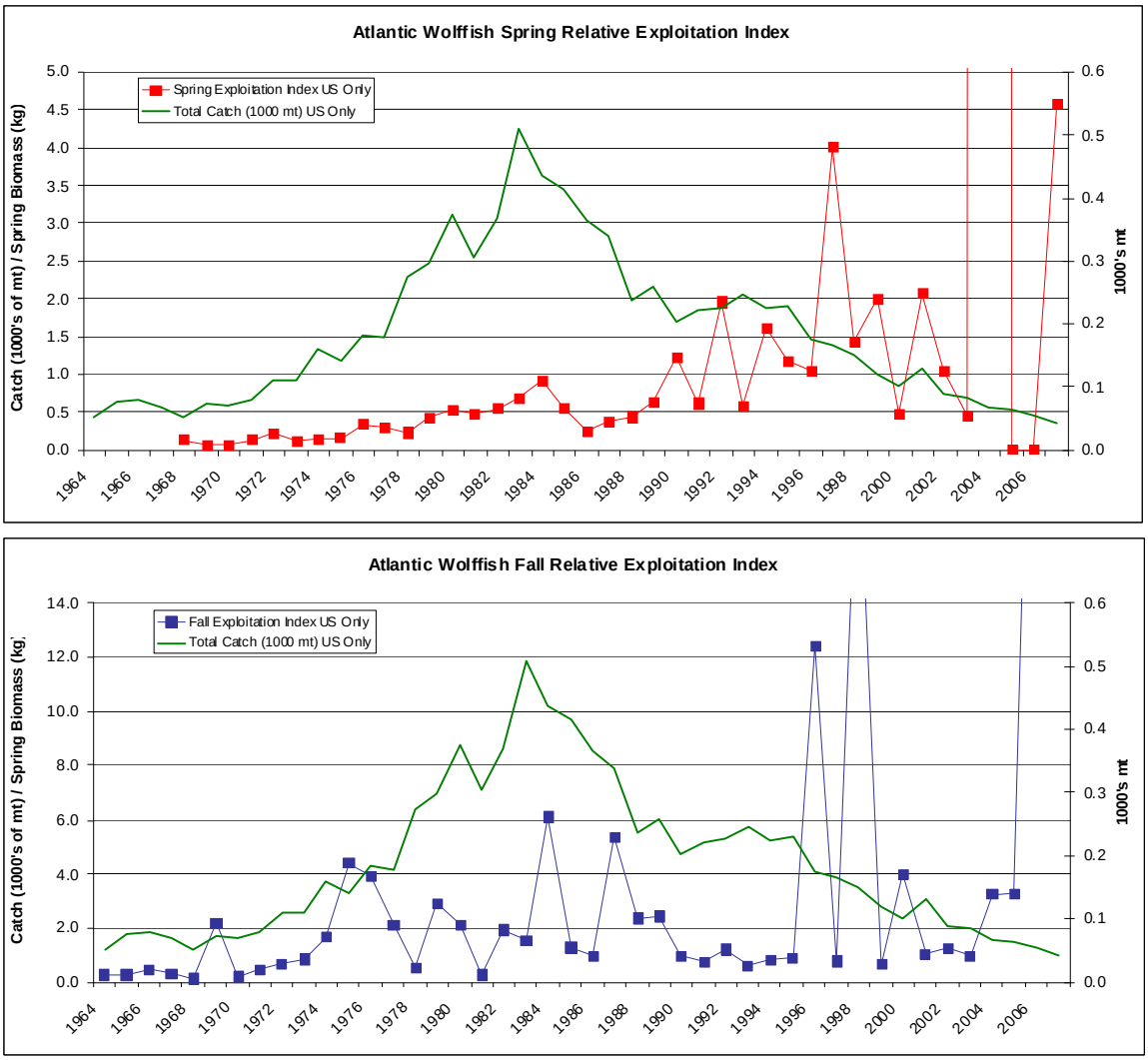


Figure 49. Spring and fall exploitation indices with total catch of Atlantic wolffish.

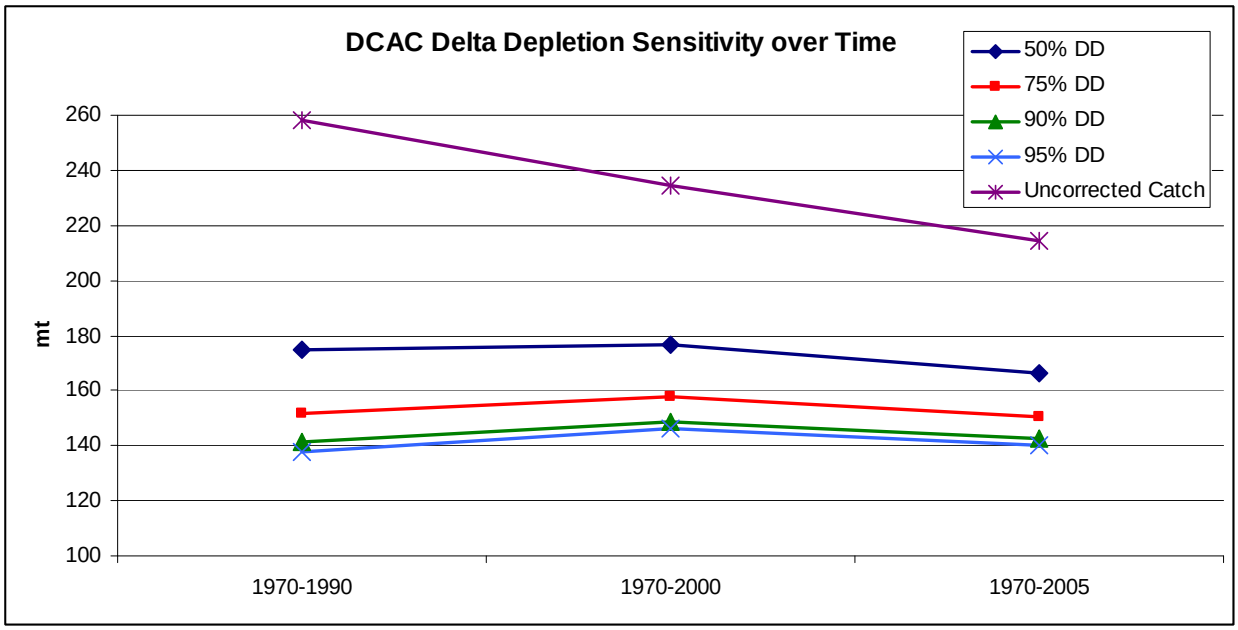


Figure 50. Results of a sensitivity analysis of the depletion ratio from the Depletion-Corrected Average Catch model (DCAC) over time.

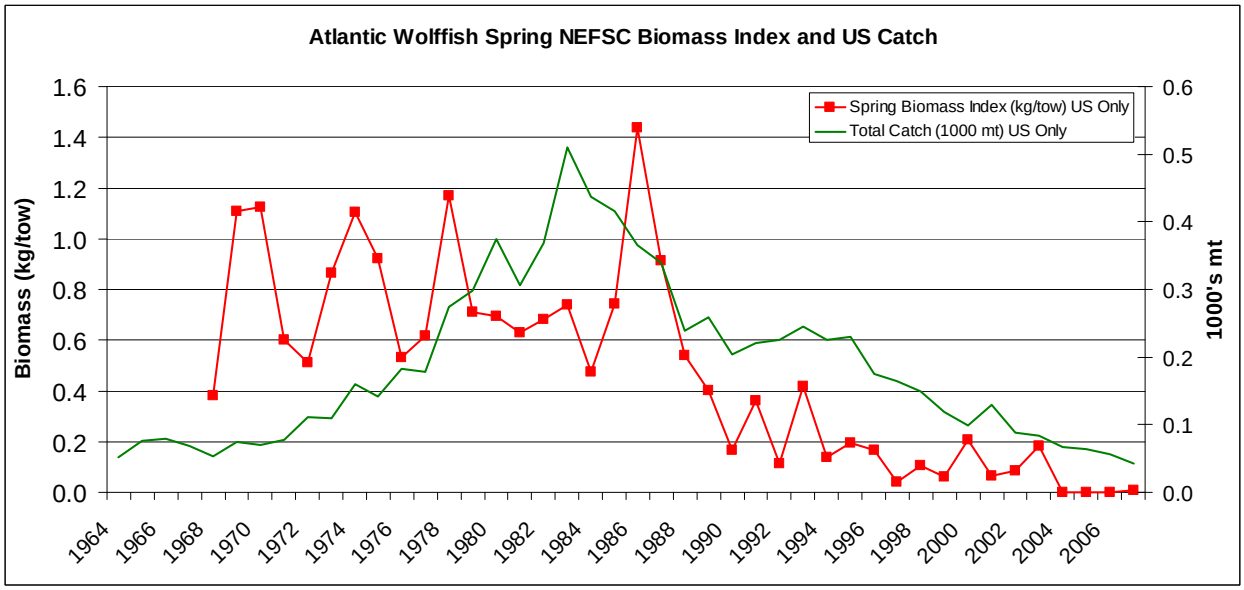
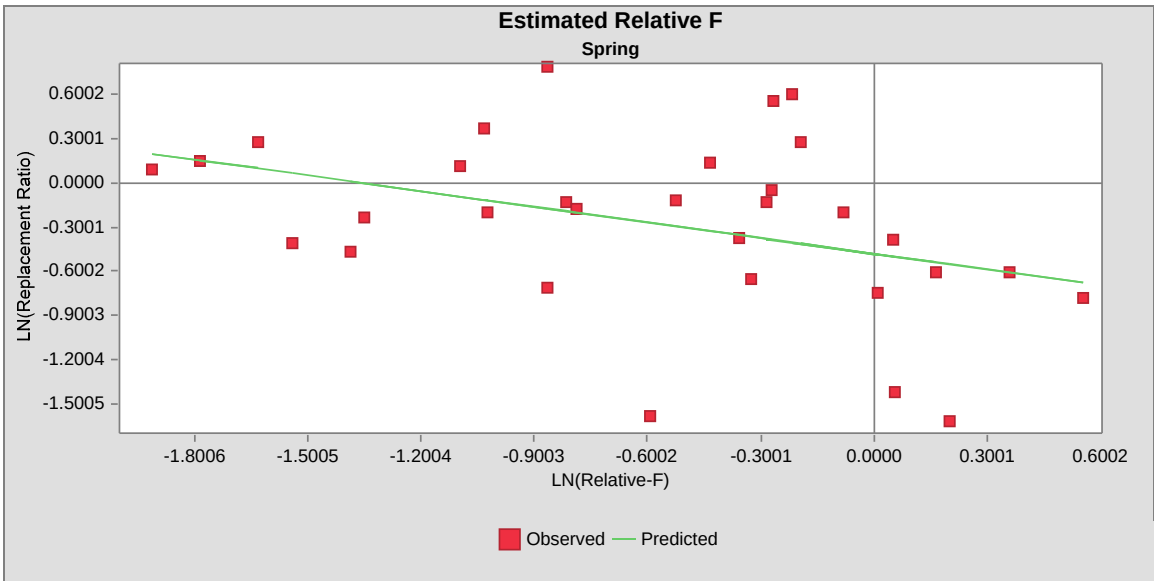


Figure 51. NEFSC spring biomass index and total US catch of Atlantic wolffish used in the AIM (An Index Method) model.

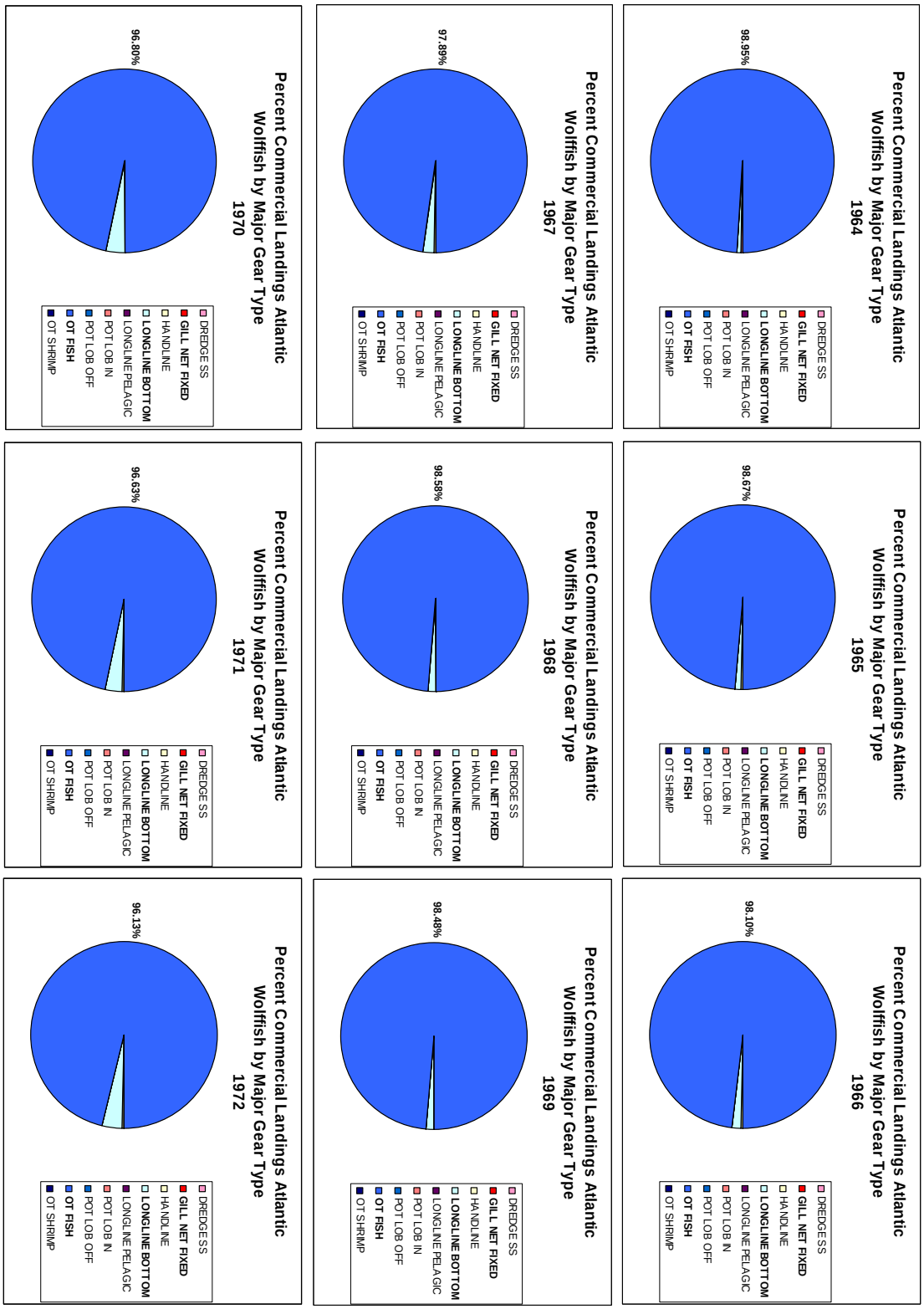


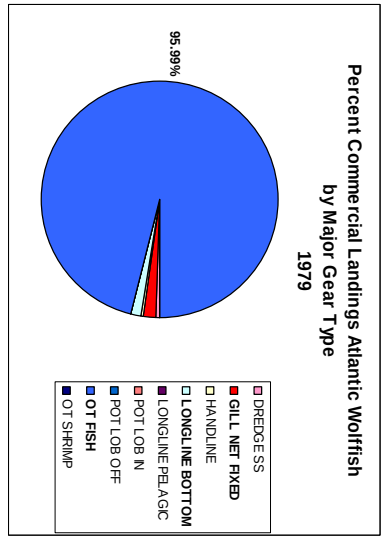
Randomization Test	
	Spring
Critical Value	-0.384824
Significance Level	0.134000

Figure 52. Linear regression of log replacement ratio and log relative F and statistical test results from the AIM model.

Wolffish Appendix 1

Commercial landings of Atlantic wolffish by gear, 1964-2007.




Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1973
95.12%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1974
94.21%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1975
92.83%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1976
97.21%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

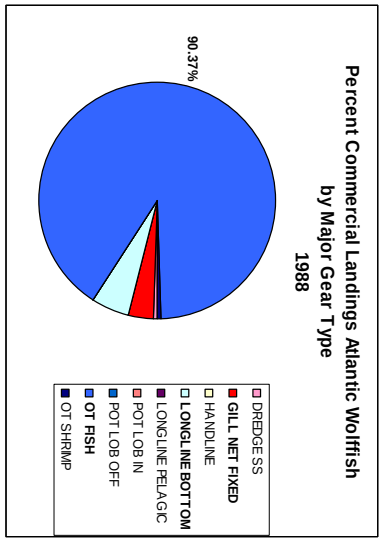
Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1977
97.54%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

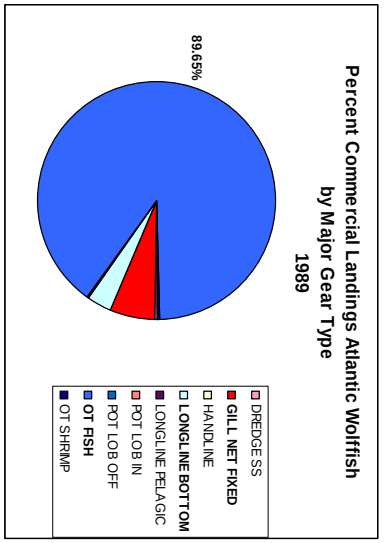
Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1978
95.50%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

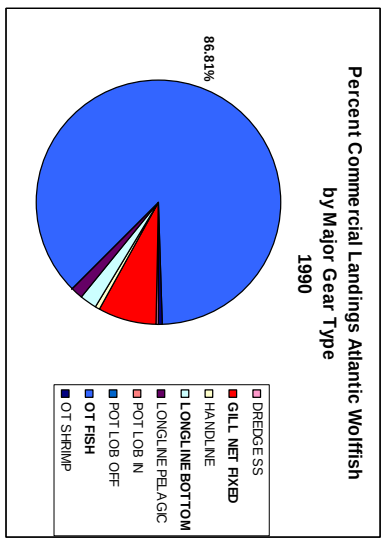
Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1979
95.99%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

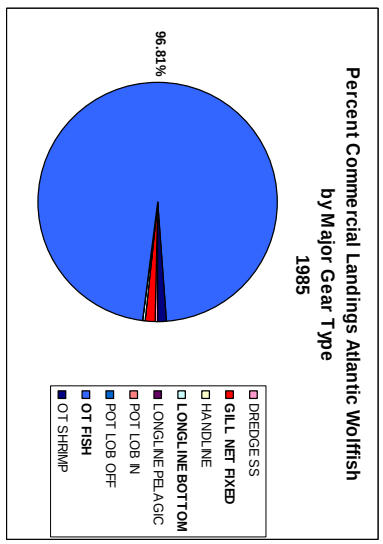
Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1980
95.16%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

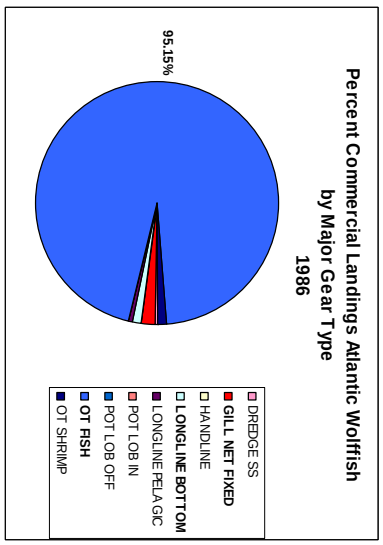
Percent Commercial Landings Atlantic Wolffish by Major Gear Type
1981
95.07%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

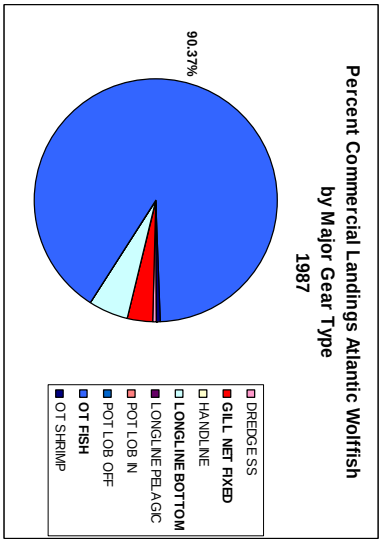

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1988
90.37%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

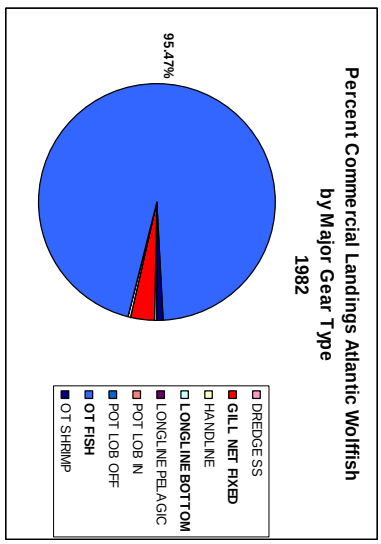

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1989
89.65%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

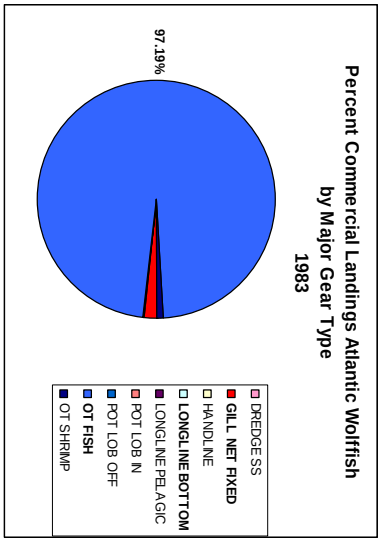

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1990
86.81%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

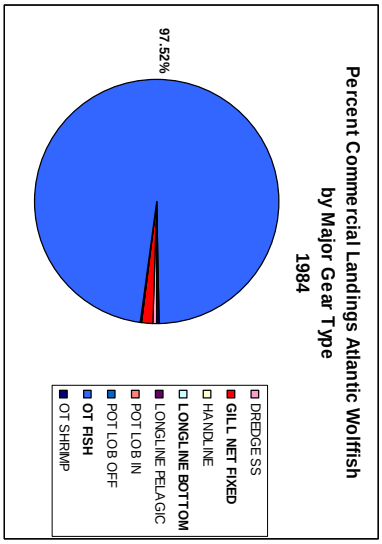

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1985
96.81%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

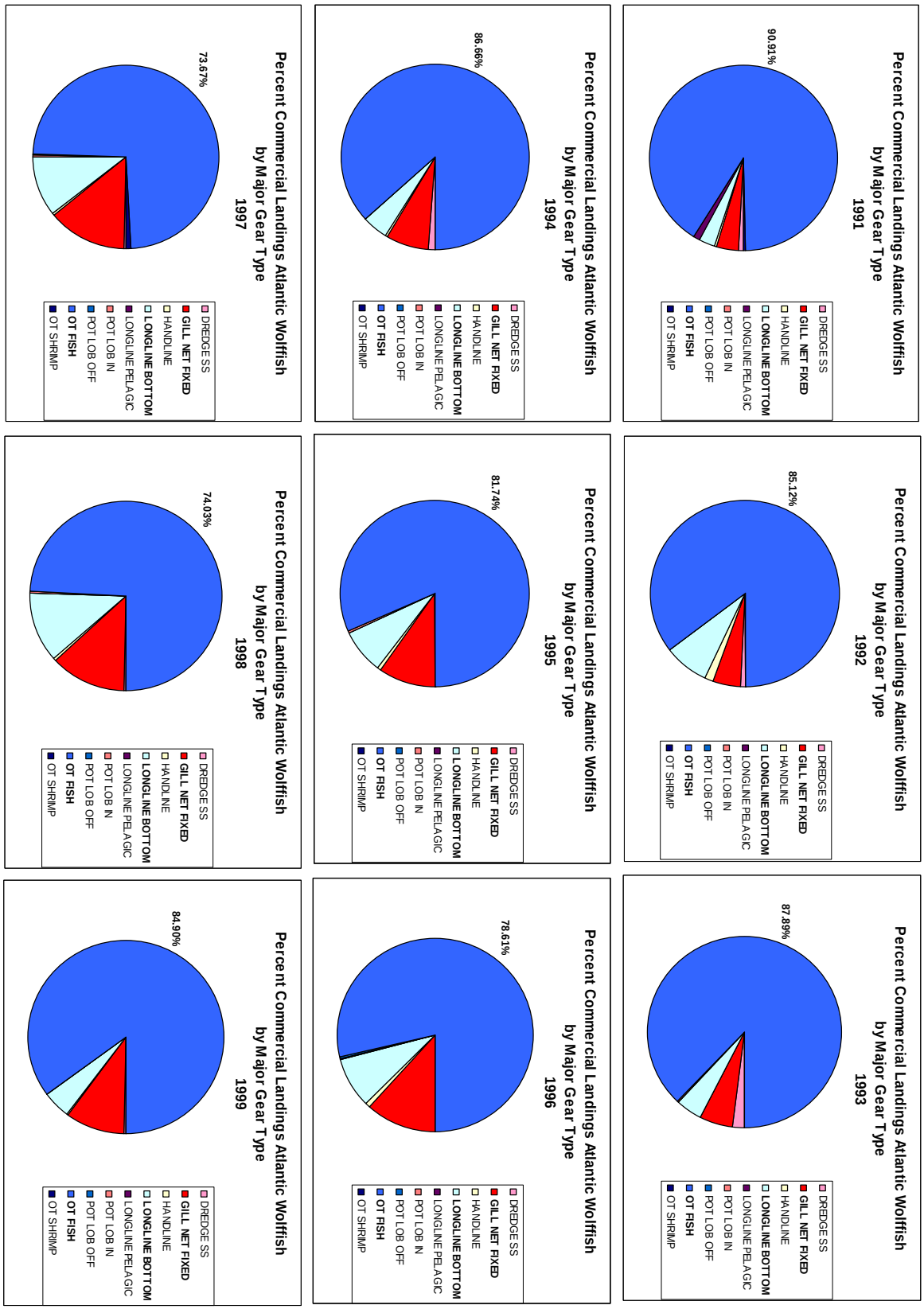

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1986
95.15%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

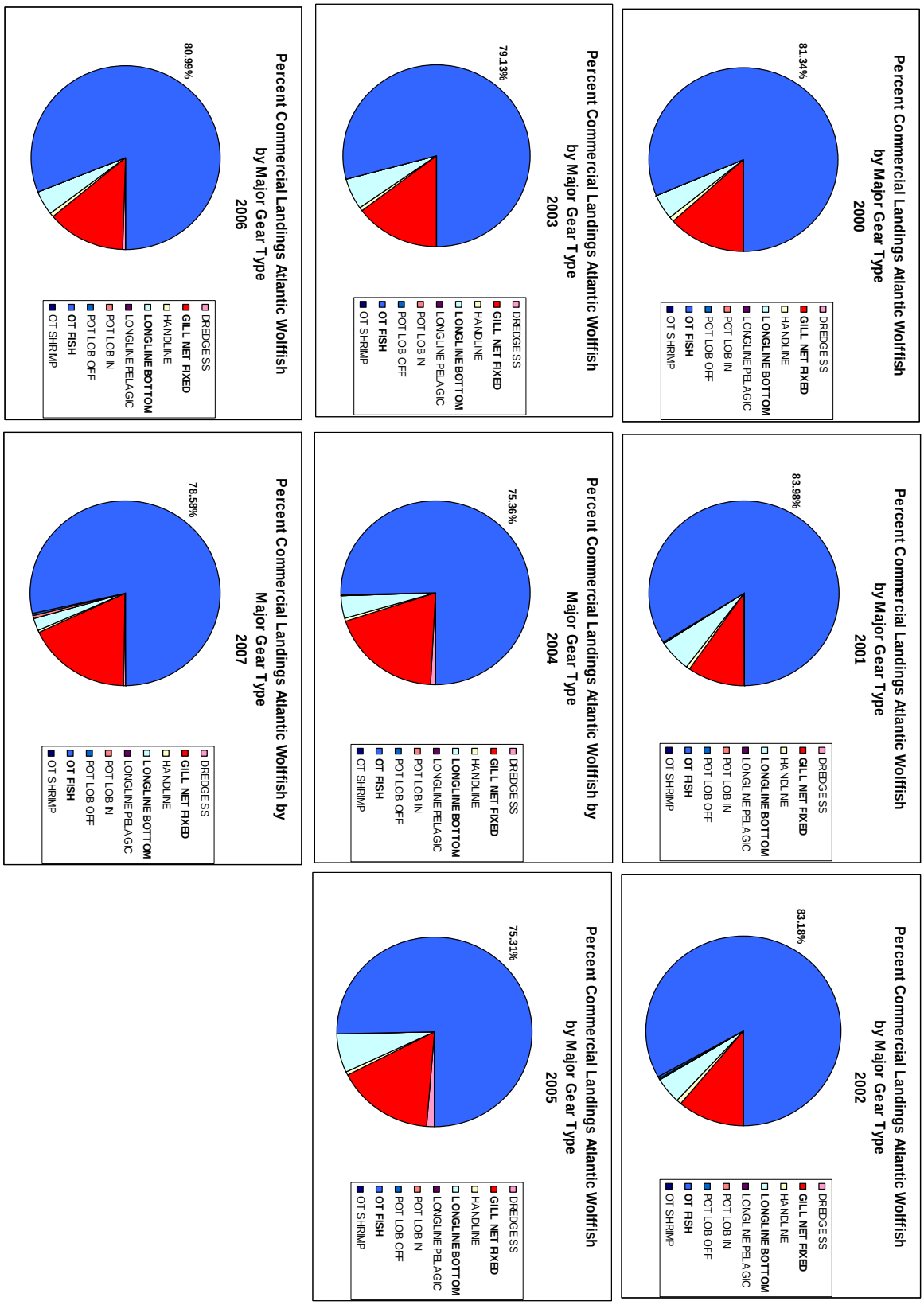

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1987
90.37%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1982
95.47%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1983
97.19%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1984
97.52%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1991
90.91%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1992
85.12%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1993
87.89%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1994
86.66%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1995
81.74%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1996
78.61%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1997
73.67%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1998
74.03%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 1999
84.90%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2000
81.34%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2001
83.98%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2002
83.18%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2003
79.13%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2004
75.36%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2005
75.31%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2006
80.99%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP
Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2007
78.58%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

Scup:
Stock Assessment and
Biological Reference Points for 2008

by

Mark Terceiro
NOAA Fisheries
Northeast Fisheries Science Center
166 Water St.
Woods Hole, MA 02543

Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

Executive Summary

The current biomass reference point for scup relies on the index of Spawning Stock Biomass (SSB) from the NEFSC spring trawl survey. Previous reviews of the stock assessment have indicated that while this index may be the most reliable fishery independent index of scup SSB, it is subject to a relatively high degree of inter-annual variability that reduces its utility as an indicator of stock status. Managers, scientists, and other stakeholders indicated a desire for a more reliable way to monitor the status of scup and support the annual specification of fishery regulations. The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted a revised stock assessment using a statistical catch at age model (ASAP) as the basis for biological reference points and status determination for scup. The new model of scup population dynamics and the recommended reference points represent a more stable approach for monitoring stock status and specifying annual fishery regulations, compared with the current single index-based model. The new model integrates a broad array of fishery and survey input data and should be less sensitive to inter-annual changes in any single data component than the current model.

The Peer Review Panel recommended $F_{40\%}$ as the proxy for F_{MSY}, and the corresponding $SSB_{F40\%}$ as the proxy for SSB_{MSY}. The $F_{40\%}$ proxy for F_{MSY} = 0.177, the proxy estimate for SSB_{MSY} = 92,044 mt, and the proxy estimate for MSY = 16,161 mt (13,134 mt of landings, 3,027 mt of discards). The stock biomass threshold of ½ SSB_{MSY} = ½ $SSB_{F40\%}$ = 46,022 mt = 101.461 million lbs.

The 2007 SSB estimate of 119,343 mt is 30% above SSB_{MSY} = 92,044 mt, indicating the stock was not overfished. The F_{2007} estimate of 0.054 is 31% of F_{MSY} = 0.177, indicating overfishing was not occurring. Total catch (landings plus discards) was 7,867 mt in 2007, about 49% of MSY. The revised status determination represents a significant change from the recent biomass status update conducted in July 2008, which indicated that the stock was overfished in 2007, although not experiencing overfishing. While the accepted long-term MSY estimate appears feasible given historical evidence from the fishery, managers may wish to take an adaptive approach to the specification of fishery quotas in the short-term. Total fishery landings over the last five years (2003-2007) have averaged 6,214 mt (13.7 million lbs). If the stock is fished at $F_{40\%}$ = 0.177 over the long-term, the corresponding annual total MSY landings would be 13,134 mt (29.0 million lbs), more than double the recent five year average. The Peer Review Panel recommended that "…rapid increases in quota to meet the revised MSY would be unwarranted given uncertainties in recruitments. A more gradual increase in quotas is a preferred approach reflective of the uncertainty in the model estimates and stock status."

Term of Reference

The following components of the Terms of Reference for the Northeast Data Poor Stocks Working Group are relevant for scup:

1. Constitute and convene a Working Group comprising NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC to:
    a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for Scup.

b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop allowable biological catches (ABCs) for these stocks.
c. Comment on what can be done to improve the information, proxies or assessments for each species.

Introduction

Scup (*Stenotomus chrysops*) is a schooling continental shelf species of the Northwest Atlantic that is distributed primarily between Cape Cod and Cape Hatteras (Morse 1978). Scup undertake extensive migrations between coastal waters in summer and offshore waters in winter. Scup migrate north and inshore to spawn in spring, with larger scup (age 2 and older) tending to arrive in spring first, followed by smaller scup (Neville and Talbot 1964; Sisson 1974). Larger scup are found during the summer near the mouth of larger bays and in the ocean within 20-fathoms, and often inhabit rough bottom areas. Smaller scup are more likely to be found in shallow, smooth bottom areas of bays during summer (Morse 1978). Scup migrate south and offshore in autumn as the water temperature decreases, arriving in offshore wintering areas by December (Hamer 1970; Morse 1978). Spawning occurs from May through August and peaks in June. About 50% of age-2 scup are sexually mature (about 17 cm total length; Morse 1978), while nearly all scup of age 3 and older are mature. Scup reach a maximum fork length of at least 41 cm and a maximum age of at least 14 years, with a likely maximum of 20 years (Dery and Rearden 1979). Tagging studies (e.g., Neville and Talbot 1964; Cogswell 1960, 1961; Hamer 1970, 1979) have indicated the possibility of two stocks of scup, one in Southern New England waters and another extending south from New Jersey waters. However, the lack of definitive locations for tag return data coupled with distributional data from the NEFSC bottom trawl surveys support the concept of a single unit stock extending from Cape Hatteras north to New England (Mayo 1982).

Overfished and Overfishing Definitions

The Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASMFC) manage scup under Amendment 8 (1997) to the Summer Flounder, Scup, and Black Sea Bass (SFSCBSB) Fishery Management Plan (FMP). The FMP management unit includes all scup from Cape Hatteras, NC northward to the US-Canada border.

Amendment 8 also established a recovery plan for scup under which exploitation rates were to be reduced to 47% (F=0.72) during 1997-1999, to 33% (F=0.45) during 2000-2001, and to 21% (F=0.26) during 2002-2007. These goals were to be attained through implementation of a Total Allowable Catch (TAC) that included a commercial quota and recreational harvest limit, and other regulations including commercial fishery minimum net mesh, trap vent and fish sizes, closed areas, and recreational fishery minimum fish sizes, possession limits, and open seasons.
Amendment 12 (1998) to the FMP established a biomass threshold (a proxy for one-half BMSY) for scup based on the three-year moving average of the NEFSC spring bottom trawl survey index of Spawning Stock Biomass (SSB) during 1977-1979, which was perceived to be a period when the stock was near one-half BMSY (2.77 SSB kg per tow). The scup stock is overfished when the spawning stock biomass index falls below this value. Amendment 12 defined overfishing for

scup to occur when the fishing mortality rate exceeds the threshold fishing mortality of Fmax = 0.26 (proxy for FMSY).

Broad scale Gear Restricted Areas (GRAs) for scup were implemented in November 2000 under the framework provisions of the FMP as a measure to reduce discards of scup in the small mesh fisheries for *Loligo* squid and silver hake. The regulations restricted the use of small mesh trawl gear in areas with high concentrations of small scup during the late fall and winter months. Two Northern Areas off Long Island were implemented for November through January, while a Southern Area off the mid-Atlantic coast was implemented for January through April. The size and boundaries of the GRAs were modified in December 2000 and again in 2005 in response to commercial fishing industry recommendations.

Amendment 14 (July 2007) to the FMP defined the biomass target and implemented a stock rebuilding plan for scup. The stock must be fully rebuilt to the biomass target by January 1, 2015. The proxy for BMSY is two times the 3-year moving average of the NEFSC spring index of SSB during 1977-1979, or 2*2.77 = 5.54 SSB kg per tow. A constant fishing mortality rate (F) of 0.10 (9% exploitation rate) is to be applied in each year of a 7 year rebuilding period; 2008 was year 1 of rebuilding and F=0.10 was applied as the target F. Total Allowable Catch (TAC) of 4,491 mt (9.90 million lbs) and corresponding Total Allowable Landings (TAL) of 3,329 mt (7.34 million lbs) were established for 2008 to achieve the target F.

The current overfished and overfishing definitions are based on revisions to the SFSCBSB FMP through Framework 7 (October 2007), currently use the values established in Amendments 12 (1998) and 14 (July 2007), and are as follows:

AThe maximum fishing mortality threshold for each of the species under the FMP is defined as FMSY (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. Specifically, FMSY is the fishing mortality rate associated with MSY. The maximum fishing mortality threshold (FMSY) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. Exceeding the established fishing mortality threshold constitutes overfishing as defined by the Magnuson-Stevens Act.@

AThe minimum stock size threshold for each of the species under the FMP is defined as one-half BMSY (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. The minimum stock size threshold (one-half BMSY) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. The minimum stock size threshold is the level of productive capacity associated with the relevant one-half MSY level. Should the measure of productive capacity for the stock or stock complex fall below this minimum threshold, the stock or stock complex is considered overfished. The target for rebuilding is specified as BMSY (or reasonable proxy thereof) at the level of productive capacity associated with the relevant MSY level, under the same definition of productive capacity as specified for the minimum stock size threshold.@

Current Biological Reference Points

The current Biological Reference Points for scup are defined as follows in SFSCBSB FMP Amendment 12:

AOverfishing for scup is defined to occur when the fishing mortality rate exceeds the threshold fishing mortality rate of FMSY. Because FMSY cannot be reliably estimated, Fmax is used as a proxy for FMSY. Fmax is 0.26 under current stock conditions. The maximum value of the spring survey index based on a three year moving average (2.77 kg/tow) would serve as a biomass threshold. BMSY cannot be reliably estimated for scup.@ The original definition under Amendment 12 did not explicitly provide the time frame for the biomass threshold calculation. However, the specifics of the definition were provided in the discussion of the National Standards in another section of Amendment 12 as follows: AY 3-year moving average of the NEFSC spring survey catch per tow of spawning stock biomass (1977-1979 average = 2.77 kg/tow).@

Amendment 14 to the SFSCBSB FMP defined a proxy for BMSY for scup as follows: AThe current minimum biomass threshold is the NEFSC spring SSB 3-year index value (1977-1979) of 2.77 kg/tow. Assuming the minimum biomass threshold is a proxy for 2 BMSY, doubling that index value would be a proxy for BMSY. Specifically, NEFSC spring 3-year index value of 5.54 kg/tow would be a proxy for BMSY. A

Background and Justification for Current Biological Reference Points

The last peer-reviewed assessment to include an analytical model was accepted in 1995 by SAW 19 (NEFSC 1995). The assessment featured a Virtual Population Analysis (VPA) modeled in the ADAPT framework (Conser and Powers 1990), included commercial and recreational landings and discards at age estimates, and used state and NEFSC abundance indices for calibration. The 1995 SAW 19 assessment indicated that the instantaneous fishing mortality rate (F) in 1993 was 1.3, and spawning stock biomass was 4,600 mt. A yield per recruit (YPR) analysis indicated that Fmax = 0.236.

The VPA was updated through 1996 and reviewed by SAW 25 (NEFSC 1997), but due to concerns over the low intensity of fishery sampling in the 1990s, uncertainty about the magnitude of commercial discards in the late 1990s, and the ongoing variability of survey indices, the VPA was not accepted as a basis for management decisions. Assessment conclusions were therefore based primarily on trends in NEFSC and state agency survey indices and catch curve analyses using those survey data. The 1997 SAW 25 was able to conclude that in 1996 scup were Aover-exploited and near record low abundance levels.@

The scup assessment was next updated through 1997 and reviewed by SAW 27 (NEFSC 1998). Several configurations of a surplus production model (ASPIC; Prager 1994) were reviewed in addition to an updated VPA, but like the VPA, the ASPIC model results were not accepted due to concerns over the validity of the input fishery and survey data. An updated YPR analysis was accepted and indicated that F_{max} = 0.26. SAW 27 concluded that AA VPA or other analytical model formulation for scup will not be feasible until the quality of the input data, particularly the precision of discard estimates, is significantly improved.@ The 1998 SAW 27 also concluded the scup was Aover exploited and at a low biomass level.@

The 1998 SAW27 Panel recommended the scup assessment be based on the long-term time series of NEFSC trawl survey indices and fishery catches. The Panel noted that commercial landings were sustained near 19,000 mt annually during the mid-1950s to mid-1960s, and concluded that the stock was likely near BMSY during that period (Figure 1). The nearest

subsequent peak in NEFSC survey indices occurred in the late 1970s. Commercial and total fishery catches in the late 1970s were about one-half of those in the 1950s to 1960s, and so the late 1970s were identified as a period when the stock was likely to be near one-half of BMSY (Figures 1-2). The Panel considered the NEFSC spring survey series to be most representative of spawning stock biomass, since older ages were better represented in the age structure than in the NEFSC fall survey or other state agency surveys. The 1998 SAW27 Panel recommended that the three-year moving average of the NEFSC spring bottom trawl survey index of Spawning Stock Biomass (SSB) during 1977-1979 (2.77 SSB kg per tow) be used as the proxy biomass threshold (one-half BMSY) and that Fmax = 0.26 be used as the proxy fishing mortality threshold (FMSY). Those recommendations were subsequently adopted for the BRPs in FMP Amendment 12.

The scup assessment was next updated through 1999 and reviewed by SAW 31 (NEFSC 2000). The assessment continued to be based on trends in research survey indices and fishery catches and indicated that the stock was Aoverfished@ (the NEFSC spring SSB index was much lower than the biomass threshold specified in FMP Amendment 12) and that Aoverfishing@ was occurring (catch curve analyses indicated that F exceeded 1.0, much greater than the FMP Amendment 12 threshold of Fmax = 0.26).

The most recent peer-reviewed assessment of scup included fishery data through 2001 and was reviewed by SAW 35 (NEFSC 2002). The assessment was again based on trends in research survey indices and fishery catches, but indicated that the stock was no longer Aoverfished@ (the NEFSC spring SSB index was above the biomass threshold specified in FMP Amendment 12), although the SAW 35 Panel concluded that Astock status with respect to the overfishing definition cannot currently be evaluated,@ due to the uncertainty of F estimates derived from research survey catch curve calculations. The 2002 SAW 35 Panel found sufficient evidence to conclude that AThe relative exploitation rates have declined in recent years...@ and that ASurvey observations indicated strong recruitment and some rebuilding of age structure.@

Since 2002, the status of the stock has been monitored by the MAFMC Monitoring Committee using trends in research survey indices and fishery catches. A Relative Exploitation Index (REI) based on the annual total fishery landings and the NEFSC spring three-year average SSB index has been used as a proxy for F to monitor status with respect to overfishing and provide guidance to the specification of annual TACs. A projection of the NEFSC spring survey SSB index using assumptions about maturity, partial recruitment to the survey, and the level of future recruitment as indexed by the NEFSC spring survey at age 1 was used in FMP Amendment 14 to forecast stock rebuilding and set the Frebuild target for 2008-2105.

An update to the status monitoring metrics was completed in July 2008 to aid in the specification of fishery regulations for 2009. The update indicated that while the stock was overfished in 2007 (NEFSC spring SSB three-year average index = 1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow), the exploitation rate was at the rebuilding target rate (9%, or about F = 0.10), suggesting that overfishing was not occurring in 2007. However, the stock rebuilding rate was slower than indicated by the Amendment 14 projection, with the NEFSC spring 2007 SSB index (three-year average = 1.16 kg per tow) at only 56% of the forecast 2007 index (2.08 kg per tow).

Need for Revision of the Current Biological Reference Points

The current stock biomass reference point relies on the index of SSB from the NEFSC spring trawl survey. Previous reviews of the scup stock assessment have indicated that while this

index may be the most reliable fishery independent metric of scup SSB, it is subject to a relatively high degree of inter-annual variability and the possibility that positive and negative Aavailability@ events will reduce the utility of the index in monitoring the status of the stock for any given year, in spite of the three-year smoothing protocol (Figure 2). An example of this phenomenon took place in 2002, when an unusually high value of the NEFSC spring SSB index was recorded that did not seem to result from high abundance in 2001, nor translate into a correspondingly high value in 2003. Subsequent reviews concluded that the high 2002 index resulted mainly from an increased availability of fish to the survey, rather than due to a true increase in abundance of the recorded magnitude. However, the high 2002 index lead to a change in official stock status to Anot overfished@ when incorporated into the three-year average SSB index calculation, and then a change back to Aoverfished@ when the 2002 index passed out of the three-year average in 2005 (Figure 2), with accompanying volatility in the annual specification of fishery regulations.

The last four peer reviews of the assessment have rejected analytical models for scup, and indicated that estimates of F based on research survey catch curve analyses are not valid. The Relative Exploitation Index (REI; total fishery landings divided by the NEFSC spring three-year SSB index) used as a proxy for F is also volatile and potentially unreliable if inter-annual changes in the SSB index are suspected to be biologically unrealistic. Finally, the NEFSC survey series using NOAA Ship *Albatross IV* sampling, on which the stock status monitoring is based, ended in November 2008. While efforts are underway to calibrate the *Albatross IV* indices to new indices collected by the NOAA Ship *Henry B. Bigelow*, those efforts may not provide a reliable basis for stock monitoring in the short term. Managers, scientists, and other stakeholders have therefore indicated a desire for a more reliable way to monitor the status of the scup stock and support the annual specification of fishery regulations.

Proposed Biological Reference Points

The following section details the sequence of work that was performed in the series of Data Poor Stocks Working Group meetings during the fall of 2008 to develop the analytical model that is the basis for the accepted BRPs. The section details the two analytical modeling approaches for scup that were pursued. The first was a relatively simple approach, the AIM model, which fits relationships between single abundance index time series and fishery catch time series. The second was a statistical catch at age model incorporating many data components, ASAP. Because the accepted model requires the use of significantly more complex input fishery and research survey data than the current BRPs, a description of those data precedes the model descriptions.

Commercial Landings

US commercial landings averaged over 18,000 mt per year from 1950 to 1965 (peaking at over 22,000 mt in 1960) and declined to less than 10,000 mt per year in the late 1960s. Landings fluctuated between about 5,000 and 10,000 mt from 1970 to the early 1990s and then declined to about 1,200 mt in 2000, less than 6% of the peak observed in 1960. Commercial landings have since increased to average about 4,200 mt during 2003-2007 (Figure 1).

About eighty percent of the commercial landings of scup for the period 1979-2007 were in Rhode Island (38%), New Jersey (26%), and New York (16%; Table 1). The otter trawl is the principal commercial fishing gear, accounting for about 75% of the total catch during 1979-2007 (Table 2). The remainder of the commercial landings is taken by floating trap (11%) and hand

lines (7%), with paired trawl, pound nets, and pots and traps each contributing between 1 and 4%.

Commercial Discards

The NEFSC Observer Program has collected information on landings and discards in the commercial fishery for 1989-2007. Northeast Region (ME-VA) discard estimates were raised to account for North Carolina landings. A discard mortality rate of 100% was assumed because there are no published estimates of scup discard mortality rates. This assumption is based on limited observations and is an important element of uncertainty in the assessment. Past SAW panels have recommended that research be conducted to better characterize the discard mortality rate of scup in different gear types in order to more accurately quantify the absolute magnitude of scup discard mortality (NEFSC 1995, 1997, 1998, 2000, 2002; see also Section 7 of this report AResearch Recommendations@).

Quantifying discards from the commercial fishery is necessary for a reliable scup assessment, but low sample sizes in the past have resulted in uncertain estimates. Concern regarding the uncertainty of discard estimates due to inadequate observer sampling has been expressed in at least five previous SAW reviews of the scup assessment, and those reviews have recommended increases in sampling intensity to increase the accuracy and precision of discard estimates (NEFSC 1995, 1997, 1998, 2000, 2002). Despite the uncertainty of the discard data, recent SAW panels have concluded that commercial discarding of scup has been high during most of the last 20 years, generally approaching or exceeding commercial landings (i.e., about 50% or more of the total commercial catch). Since the implementation of GRAs in 2000, estimated discards as a proportion of the total commercial catch have decreased, averaging about 35%.

Given the uncertainty associated with estimating commercial discards for scup, three different methods for calculating discard estimates have been considered in assessments since 1998:

1) Geometric Mean Discards-to-Landings Ratio (GMDL): Ratios of discards to landings by trip landings level (for trip landings < 300 kg [661 lbs], the Abycatch fishery@; or => 300 kg, the Adirected fishery@) and half year period were calculated and multiplied by the corresponding observed landings from the NEFSC Dealer Report database to provide estimates of discards. Geometric mean rates (re-transformed, uncorrected, mean ln-transformed Discards to Landings [D/L] per trip) were used because the distributions of landings and discards and the ratio of discards to landings on a per-trip basis in the scup fishery are highly variable and positively skewed. Observed trips with both scup landings and discard were used to calculate the per trip discard to landings ratios. Only trips with both non-zero landings and discards could be used for this approach to avoid division by zero. The number of trawl gear trips used to calculate geometric mean discard-to-landings ratios (GMDL) by half year for 1997-2007 ranged from 1 to 104 for trips < 300 kg and from 1 to 35 for trips =>300 kg, with the best sampling occurring since 2003. No trawl gear trips were available for half year two in 1997 and 1999 for trips < 300 kg and for half year two in 1997-2001 for trips => 300 kg. The GMDL calculated for half year one was used to estimate discards for half year two when no trawl gear trips were available in half year two. The GMDL ratios ranged from 0.03 in 2004 (half year two, trips => 300 kg) to 121.71 in 1998 (half year one, trips => 300 kg; Table 3).

The large 1998 Adirected fishery@ discard ratio and subsequent very high annual discard estimate (111,973 mt) was based on one trawl gear trip. About 93% of the discard from that trip was attributable to a single tow in which an estimated 68.2 mt (150,000 lbs) of scup were captured. This tow was not lifted from the water and the captain of the vessel estimated the weight of the catch. There has been debate concerning the validity of the catch weight estimate and whether or not it was representative of other vessels or trips in the fishery. However, the observation was reported by a trained NEFSC observer and was therefore included in the initial calculation of the GMDL estimate of scup discards (Tables 3-4).

2) Aggregate Discards-to-Landings Ratio (AGDL): The second approach for estimating discards considered aggregate discards to landings ratios (summed D/summed L for all trips catching scup in stratum). As in the GMDL method, trips are stratified by trip landings level and half year period. The number of trawl gear trips used to calculate AGDL by half year for 1997-2007 ranged from 14 to 254 for trips < 300 kg and from 1 to 35 for trips => 300 kg, with the best sampling occurring since 2003. There are more trips available for the AGDL calculation for trips < 300 kg than in the GMDL approach, since trips with zero landings can be used. The lowest AGDL ratio calculated was 0.00 in 2001 (no discard observed in 4 trips, half year two, trips => 300 kg). The highest AGDL was 121.71 in 1998 (half year one, trips => 300 kg), the same as that calculated in the GMDL method. The AGDL approach generally provides higher annual estimates of scup discards, with greater inter-annual variability, than the GMDL approach.

3) Mean Differences between Landings and Discards (DELTA): Mean differences (kg) between landings and discard (D = landings - discard, per trip) were also calculated using the same strata as for the other methods. Observed trips in the stratum were used to calculate the mean difference in stratum, which was then applied to the scup landings of trips in the NEFSC Dealer Report database to calculate a discard for each trip (discard = landings -(D)). Calculating differences allows use of trips that had discards but no landings, whereas D/L ratios cannot be calculated in these situations (i.e. zero in the denominator). When discards exceed landings, the difference (D) is negative. As the magnitude of discards is of primary interest, the absolute values of D are used. The number of trawl gear trips used in the DELTA method calculations ranged from 6 to 254 for trips < 300 kg and from 1 to 35 for trips => 300 kg, with the best sampling occurring since 2003. The magnitude of the DELTA values ranged from 10.7 in 2001 (half year two, trips < 300 kg) to 72707 in 1998 (half year one, trips => 300 kg). As before, this large discard estimate is the result of one large discarding event in the Adirected fishery@ that was discussed above. The DELTA approach generally provides lower estimates of scup discards for the Adirected fishery @ but slightly higher estimates for the Abycatch fishery@ compared to the GMDL approach.

Since 2002 the GMDL approach discard estimates have been adopted by the MAFMC Monitoring Committee to monitor trends in fishery catch and evaluate the status of the stock, since the year-to-year trends among the three approaches differed in magnitude but followed similar trends. The large discard event in 1998 affected calculations from each method, resulting in extremely high D/L rates and subsequent discard estimates in 1998 for each approach. The DELTA method yielded estimates that were fairly consistent with the GMDL rates, while the AGDL estimates exhibited generally higher discard estimates with more variability. Previous SAW Working Groups and review panels have expressed most confidence in the estimates produced using the GMDL approach and considered the estimates to be supported by the DELTA rates. The GMDL estimates were used for all subsequent modeling approaches

considered in the assessment. The 1998 estimates from all 3 computational methods was considered infeasible, and replaced by the mean of the 1997 and 1999 GMDL estimates (3,331 mt) in subsequent tabulations of catch and in subsequent modeling (Tables 3-5, and 9).

Recreational Catch

Scup is an important recreational species, with the greatest proportion of catches taken in the states of Massachusetts, Rhode Island, Connecticut and New York. Estimates of the recreational catch in numbers were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) for 1981-2007. These estimates were available for three categories: type A - fish landed and available for sampling, type B1 - fish landed but not available for sampling, and type B2 - fish caught and released alive. The estimated recreational landings (types A and B1) in weight during 1981-2007 averaged about 2,000 mt per year (Table 5). Since 1981, the MRFSS data indicate that the recreational landings have averaged 29% of the commercial and recreational landings total.

The estimated recreational discard in weight during 1984-2007 ranged from 6 mt in 1999 to a high of 185 mt in 2006, while averaging about 72 mt per year (Table 5). The weight of discards has been directly calculated only for those years (1984 and later) for which recreational catch at age has been compiled. In compilations of total fishery catch for earlier years, the recreational discards was assumed to be approximately 2% of the estimated recreational landings, based on the mean discard percentage for 1984-1996 (directly calculated discard weights for years prior to implementation of FMP regulations). No length frequency samples of the scup discard were collected under the MRFSS program before 2005, so recreational discards were assumed to be fish aged 0 and 1, in the same relative proportions and with the same mean weight as the landed catch less than state regulated minimum fish sizes. An inspection of discard length frequency samples from the New York recreational fishery for 1989-1991 indicated that this assumption was reasonable. Since 2005, length samples of the recreational fishery discard have been collected in the MRFSS For Hire Survey sampling. The mortality rate due to discarding in the recreational fishery has been reported to range from 0-15% (Howell and Simpson 1985) and from 0-13.8% (Williams, pers. comm.). Howell and Simpson (1985) found mortality rates were positively correlated with size, due mainly to the tendency for larger fish to take the hook deep in the esophagus or gills. Williams more clearly demonstrated increased mortality with depth of hook location, as well as handling time, but found no association with fish size. Based on these studies, a discard mortality rate in the recreational fishery of 15% appears reasonable and has been used in previous and the current assessments.

Commercial Fishery Landings at Length and Age

The intensity of commercial fishery biological sampling is summarized in Table 6. Annual sampling intensity varied from 27 to 687 mt per 100 lengths, with sampling exceeding the informal threshold criterion of 200 mt per 100 lengths sampled since 1994. For this assessment, commercial fishery landings at age beginning in 1984 have been updated through 2007, with samples generally pooled by market category (pins/small, medium, large/mix, jumbo, and unclassified) and half year period (January-June, July-December), with market category samples pooled on a quarterly basis for 2004-2007. Estimates of commercial fishery landings at age (Figure 3) and mean weights at age are presented in Tables 7-8.

Commercial Fishery Discards at Length and Age

The intensity of length frequency sampling of discarded scup from the NEFSC Observer Program declined in 1992-1995 relative to 1989-1991 (Table 9). Sampling intensity ranged from 489 to 335 mt per 100 lengths sampled in 1992-1995, failing to meet the informal criterion of 200 mt per100 lengths sampled. Sampling intensity improved to 100 mt per 100 lengths in 1996, but then declined to over 200 mt per 100 lengths in 1997-1999. Sampling intensity has generally met the 200 mt per 100 length threshold since 1999. The mean weight of the discard was estimated from length frequency data and a length-weight equation, with the total numbers discarded then estimated by dividing total discard weight by mean fish weight, and the numbers at length then calculated from the length-frequency distribution. Discards at length were aged using a combination of commercial and survey age-length keys, with discards at age dominated by fish aged 0, 1, or 2, depending on the year under consideration. Estimates of commercial fishery discards at age (Figure 4) and mean weights at age are presented in Tables 10-11.

Recreational Fishery Landings at Length and Age

In the recreational fishery, landings sampling intensity varied from 45 to 471 mt per 100 lengths. Sampling in all years except one (1984) during 1981-1987 failed to satisfy the above criterion, but since 1987 the criterion has been met except for 1999-2000 (Table 12). Numbers at length for recreational landings were determined based on available recreational fishery length frequency samples pooled by half year period over all regions and fishing modes, and were converted to numbers at age by applying half year period age-length keys constructed from NEFSC commercial and survey samples. Age-length keys from spring surveys and first and second quarter commercial samples were applied to numbers at length from the first half of the year, while age-length keys from fall surveys and third and fourth quarter commercial samples were applied to numbers at length from the second half of the year. Estimates of recreational fishery landings at age (Figure 5) and mean weights at age are presented in Tables 13-14.

Recreational Fishery Discards at Length and Age

As noted earlier, no length frequency distribution data on scup discard are routinely collected under the MRFSS program prior to 2005, so recreational discards were assumed to be fish less than state minimum sizes, in the same relative proportions at age as the landed catch less than the respective state minimum sizes (i.e., sub-legal fish of ages 0 and 1). This assumption for the coastwide fishery is supported by discard length frequency samples from the New York recreational fishery (1989-1991) and samples collected since 2005 by the MRFSS For-Hire Survey. Since 2005, the MRFSS For-Hire Survey discard samples have been used in concert with the MRFSS sub-legal landed lengths to directly characterize the length frequency of the recreational discard. As noted earlier, a 15% discard mortality rate is assumed. Estimates of recreational fishery discards at age (Figure 6) and mean weights at age are presented in Tables 15-16.

Total Fishery Catch

Estimates of the total fishery catch at age and mean weights at age for 1984-2004 (the time series is limited by the availability of sampled fishery ages) are presented in Tables 17-18.

An extended time series of the total catch of scup has been estimated to provide an historical perspective of the exploitation of scup in the years before fishery aging data were available (Table 19). These estimates include commercial and recreational landings and discards. The catches before 1981 are the least reliable due to uncertainty about a) the level of

domestic commercial fishery discards, b) distant water fleet (DWF) catch, and c) assumptions to estimate the recreational catch (50% reduction from interpolations made in Mayo 1982 for 1960-1978; recreational discards assumed to be 2% of the adjusted recreational landings). For years in which no observer data were collected (prior to 1989), commercial discards were estimated using the mean of GMDL approach ratios for 1989-2001.

Research Vessel Survey Indices

NEFSC

The NEFSC spring and fall surveys provide long time series of fishery-independent indices for scup. The NEFSC spring and fall surveys are conducted annually during March-May and September-November, ranging from just south of Cape Hatteras, NC to Canadian waters. NEFSC spring and fall abundance and biomass indices for scup exhibit considerable inter-annual variability (Table 20). The 2002 spring SSB index (9.24 kg/tow) was about twice the second highest spring SSB index, which was observed in 1977 (4.35 kg/tow)(Figure 7). The spring numeric abundance indices are similar; in 2002, the estimated index of spring abundance is the highest observed in the series (154.86 fish/tow) and about twice the 1970 index (78.50 fish/tow). These dramatic increases were evident across all ages in the estimated 2002 spring numbers at age (Table 21; Figure 8). Fall survey estimates of numbers at age in 2001 did not reflect relatively large values from which corresponding 2002 spring numbers at age might be expected to derive (Table 22, Figure 9) , nor did they translate to exceptional indices of biomass or SSB in fall 2002 or spring 2003. Spring survey SSB and abundance indices decreased subsequent to 2002, but are still above the low values of the late 1990s. Fall survey abundance and biomass have been highly variable since 2002.

The NEFSC winter survey was started in 1992 primarily as a flatfish survey (used a different trawl net than the spring and fall surveys), was conducted during February, and ranged from Cape Hatteras, NC to the southwestern part of Georges Bank. The winter survey 2002 abundance and biomass indices were, like the spring survey, the largest of the time series (Table 23). Similar to the spring estimates, numbers at age estimated for the 2002 winter survey were also exceptionally large (Table 24, Figure 10). Winter survey abundance and biomass decreased subsequent to 2002, but were still above the low values of the late 1990s. The winter trawl series ended in 2007.

As noted in Sections 1-4, indices of scup SSB per tow were developed from the NEFSC spring offshore strata series for use as proxy biomass reference points. The 1998 SAW 27 panel (NEFSC 1998) selected a three-year moving average of the NEFSC spring SSB index as a representative measure of scup SSB, based on the characteristics of the survey age structure, the magnitude of the survey catch, and the trend in the extended series of commercial and total fishery catch estimated back to 1960 (Table 19, Figures 1-2). FMP Amendment 12 defined the biomass threshold reference point as the maximum (at the time) observed value of this three-year moving average: the 1978 value (mean of 1977-1979) of 2.77 SSB kg/tow (Table 20, Figure 2). FMP Amendment 14 defined the target biomass BRP as twice the threshold value of this three-year moving average, or 2 times 2.77 = 5.54 SSB kg/tow.

Massachusetts DMF

The Massachusetts Division of Marine Fisheries (MADMF) has conducted a semi-annual bottom trawl survey of Massachusetts territorial waters in May and September since 1978. Survey coverage extends from the New Hampshire to Rhode Island boundaries and seaward to

three nautical miles including Cape Cod Bay and Nantucket Sound. The study area is stratified into geographic zones based on depth and area. Trawl stations are allocated in proportion to stratum area and are chosen randomly within each stratum. A 20 minute tow at 2.5 knots is made at each station with a 3/4-size North Atlantic two- seam otter trawl (11.9 m headrope, 15.5 m footrope) rigged with a 19.2 m chain sweep with 7.6 cm rubber discs. The net contains a 6.4 mm mesh codend liner to retain small fish. Approximately 95 stations are sampled during each survey. Standard bottom trawl survey techniques are used to process the catch of each species. Generally, the total weight (nearest 0.1 kg) and length frequency (nearest cm) are recorded for each species on standard trawl logs. Collections of age and growth structures, maturity observations, and pathology observations are taken. The MADMF spring survey catches are characterized mainly by scup of ages 1 and 2, while the fall survey often captures large numbers of age 0 fish. The spring biomass and abundance indices dropped sharply from a high in the early 1980s to relatively low levels through the remainder of the time series, with the exception of spikes in 1990, 2000, and 2002, the latter event in common with the NEFSC spring trawl survey (Table 25, Figure 11). The MADMF fall indices can include large numbers of age 0 fish, and on a numeric basis are more variable than the spring indices. The fall biomass index is less variable than the spring, however, and exhibits an increasing trend since the mid 1990s (Figure 12).

Rhode Island DFW

The Rhode Island Division of Fish and Wildlife (RIDFW) has conducted autumn and spring surveys since 1979 based on a stratified random sampling design. Three major fishing grounds are considered in the spatial stratification, including Narragansett Bay, Rhode Island Sound, and Block Island Sound. Stations are either fixed or randomly selected for each stratum. To maintain continuity in the number of stations sampled per stratum each season, an alternate list is generated for substitution in the event of an unexpected hang-up or questionable bottom type. At each station, a 3/4-scale High Rise bottom trawl is towed for 20 minutes at an average speed of 2.5 knots. The net average vertical opening is estimated at 10 feet. The otter trawl doors are 2 ft by 4 ft in dimension, set 7.5 fathoms ahead of the wings of the net. The RIDFW spring survey mainly catches scup of ages 1 and 2. The spring indices show relatively levels of scup abundance and biomass through 1999 followed by a steep increase during 2000-2002, in common with the NEFSC and MADMF indices. No scup were caught in the spring 2003 survey, but the index has since rebounded to pre-2000 levels (Table 26; Figure 11). The RIDFW fall survey is dominated by age 0 scup. Fall abundance indices show a general increase to its 1993 peak, followed by a steep decline until 1998, and a general increase since then, reaching a time series peak in 2007 (Figure 12).

Connecticut DEP

The Connecticut Department of Environmental Protection (CTDEP) trawl survey program was initiated in May 1984 and encompasses both New York and Connecticut waters of Long Island Sound. The stratified random design survey is conducted in the spring (April-June) and fall (September-October). Each survey consists of three cruises, with 40 stations sampled during each cruise, providing a sampling density of one station per 20 square nautical miles per cruise. Prior to 1990, the survey was conducted monthly from April to November. The CTDEP spring indices exhibit relatively low levels through most of the survey period, but have increased substantially since 1999 (Table 27, Figures 11 & 13). The CTDEP fall survey, which often catches large numbers of age-0 scup, indicates that recruitment was relatively stable during most

of the survey period, but fall indices have also increased substantially since 1999 (Table 28, Figures 12 & 14). The age compositions of the CTDEP spring and fall surveys generally include a higher proportion of age 2 and older fish than the other state or NEFSC surveys (Figures 13-14).

New York DEC

The New York Department of Environmental Conservation (NYDEC) initiated a small mesh trawl survey in 1985 to collect fisheries-independent data on the age and size composition of scup in local waters. This survey is conducted in the Peconic Bays, the estuarine waters which lie between the north and south forks of eastern Long Island. Tows are 20 min in duration. The net used has a 16 ft headrope and a 19 ft footrope and is constructed of polypropylene netting with 1.5 in stretch mesh in the body and 1.25 in stretch mesh in the codend. No survey data are available for 2005. The NYDEC survey provides age 0, 1, and 2+ indices of scup abundance. The age 0 indices are generally low over the survey period, with peaks in 2000, 2002, 2003, 2006, and 2007 that may indicate recruitment of strong cohorts in those years (Table 29). In the early years of the survey there often has not been a strong correspondence between the age 0 indices and age 1 and 2+ indices in the following years (Figure 15).

New Jersey BMF

The New Jersey Bureau of Marine Fisheries (NJBMF) conducts a stratified random bottom trawl survey of New Jersey coastal waters from Ambrose Channel south to Cape Henlopen Channel. Latitudinal strata boundaries correspond to those in the NEFSC trawl survey; longitudinal boundaries correspond to the 30, 60, and 90 foot isobaths. Each survey includes two tows per stratum plus one additional tow in each of nine larger strata for a total of 39 tows. A three-in-one trawl with a 100 ft footrope, an 82 ft headrope, 3- 4.7 in mesh throughout most of the body and a 0.25 in mesh codend liner is used. From 1991 to present, the area has been surveyed in January, April, June, August, and October; from 1988-1990, February and December surveys were incorporated instead of the January survey. The NJBMF abundance and biomass indices exhibit variable patterns over the early part of the time series. The index reached a minimum in 1996, and has generally increased since then, reaching time series highs in numbers and biomass in 2007 (Table 29; Figure 11).

Virginia Institute of Marine Science (VIMS)

The Virginia Institute of Marine Science (VIMS) has conducted a juvenile scup survey in lower Chesapeake Bay during June-September since 1988. The VIMS age-0 scup survey shows a general decline in recruitment from relatively high levels with peaks in 1990 and 1993 to relatively low levels from 1994 to 2004, and the indication of stronger year classes in 2006 and 2007 (Table 29).

University of Rhode Island Graduate School of Oceanography (URIGSO)

University of Rhode Island Graduate School of Oceanography (URIGSO) has conducted a standardized, two-station trawl survey in Narragansett Bay and Rhode Island Sound since the 1950s, with consistent sampling since 1963. Irregular length-frequency samples for scup indicate that most of the survey catch is of fish from ages 0 to 2. The aggregate numbers-based index reached a peak in the late 1970s, was relatively low during the late 1990s, reached a

second peak in 2002 in common with the NEFSC, MADMF, RIDFW spring biomass indices, and has since been variable at relatively high level (Table 30, Figure 11).

Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) trawl survey is designed to support bay-specific stock assessment activities at both a single and multispecies scale. While no single gear or monitoring program can collect all of the data necessary for quantitative assessments, ChesMMAP was designed to fulfill data gaps by maximizing the biological and ecological data collected for several recreationally and commercially important species in the bay. Total abundance and biomass indices for scup mainly of age 0 and 1 are available since 2002, and indicate strong recruitment in 2005 and 2006 (Table 31).

Natural Mortality

Instantaneous natural mortality (M) for scup was assumed to be 0.20 (Crecco *et al.* 1981, Simpson *et al.* 1990). The largest/oldest scup sampled in NEFSC surveys (1973, 1978) were fish 38-41 cm (fork length) and 14 years old. The largest/oldest scup in NEFSC commercial fishery samples (1974) was 40 cm (fork length) and 14 years old.

Models of Fishing Mortality and Stock Size

Background Information

The 1998 SAW 27 Panel (NEFSC 1998) rejected an ADAPT VPA for scup as the basis for assessing stock status or as the basis for projections. The panel indicated that the amount of variance in the scup catch at age, particularly for the commercial discards, was unreasonably large. The Panel concluded that the precision of estimates of fishing mortality and stock size from the VPA was unacceptably low and would provide an unreliable basis for any estimates of stock size and fishing mortality rates (NEFSC 1998). The SAW 27 Panel also reviewed a surplus production model for scup developed in the ASPIC framework. The Panel noted that the inability to directly estimate historical commercial fishery discards (1968-1988) and recreational catch (1968-1978) cast uncertainty on the validity of the ASPIC absolute estimates of stock biomass, fishing mortality rates, and biological reference points. Since the ASPIC analysis suffered from many of the same input data inadequacies as the VPA, the SAW 27 Panel rejected the ASPIC analysis as a basis for stock status, projections, or reference points (NEFSC 1998).
State and NEFSC survey indices at age for scup are highly variable. The patterns in proportions at age in survey indices and survey catchability coefficients at age estimated in the VPA suggested that all ages of scup may not be equally available or susceptible to capture by survey trawl gear. As a result, the SAW 27 Panel noted that mortality estimates derived from survey catch at age indices are highly variable and may be positively biased, and are probably not a reliable basis for evaluating fishing mortality rates (NEFSC 1998). These conclusions about the lack of reliability of surplus production, VPA, or catch curve analyses for scup, due mainly to an inability to evaluate the uncertainty of results, have been supported by subsequent SAW Panel reviews of the scup assessment (NEFSC 2000, 2002).

In the absence of reliable analytical model results for scup, the 2000 SAW 31 Panel (NEFSC 2000) developed and the MAFMC Monitoring Committee has subsequently used a Relative Exploitation Index (REI) as a metric for the instantaneous fishing mortality rate (F). The scup REI is computed as the ratio of total fishery landings to the NEFSC spring trawl survey

SSB three year average index. Landings, rather than total catch, are used in the REI because of the relatively high uncertainty of commercial fishery discard estimates. The REI is therefore assumed to reflect the fishing mortality on age 2 and older scup because fishery landings and survey catch in the NEFSC spring SSB index are generally scup of ages 2 and older. The low REI values in the early 1980s were consistent with the Mayo (1982) assessment of scup (Figure 16; note that the REI is plotted on a log scale). There was a general increasing trend in the REI through the mid-1990s followed by a steady decline through 2001, with an increasing trend since 2001.

The 2000 SAW 31 Panel (NEFSC 2000) concluded that A ...catch curve analyses of survey indices indicate that F for ages 0-3 exceeds 1.0...for the 1994-1998 year classes.@ The 2002 SAW 35 Panel (NEFSC 2002) concluded, however, that AThough the relative exploitation rates have declined in recent years, the absolute value of F cannot be determined.@ In recent years, the MAFMC Monitoring Committee has used the REI as part of the assessment information used to recommend an annual Total Allowable Landings (TAL) for the stock. The MAFMC Monitoring Committee has assumed that F in 1999 was equal to 1.0 (NEFSC 2000), equating to an annual exploitation rate of 58%, which in turn equates to the 1999 REI = 62.4. An estimate of the current year exploitation rate has then been developed by assuming the same ratio between the current REI and exploitation rate, to provide advice on an appropriate level for the next year TAL.

The SAW 35 Panel (NEFSC 2002) reviewed an application of the NOAA Fisheries Toolbox model called AAn Index Method,@ or AIM, to scup fishery and survey catch data. That work used the extended total catch series noted earlier, and found that the NEFSC fall survey series provided a better model fit than the NEFSC spring series used as the basis for the biomass reference point and as input to the REI described earlier. The SAW 35 Panel (NEFSC 2002) noted that for scup, the AIM approach had A...considerable promise as a monitoring tool to evaluate stock trajectories and provide valuable information in interim years between analytical assessments@ and A...utility in presenting an integrated picture of stock dynamics for resources where only catch statistics and survey trends are available.@ While this approach was not adopted by the 2002 SAW 35 Panel to monitor the status of the stock, further research using the AIM model was recommended.

As noted earlier, the most recent update of the current stock assessment approach was completed in July 2008 to support the specification of fishery regulations for 2009. The update indicated that while the stock was overfished in 2007 (1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow; Figure 16), the exploitation rate was at about the rebuilding target rate (9%; F = 0.10), suggesting that overfishing was not occurring in 2007. However, the stock rebuilding rate was slower than indicated by the FMP Amendment 14 projection, with the actual 2007 index (2006-2008 three-year average = 1.16 kg per tow) at only 56% of the forecast 2007 index (2.08 kg per tow).

An Index Method (AIM)

The AIM model (NFT 2008a) fits a relationship between time series of relative stock abundance, such as survey indices of abundance or biomass, and fishery catch data that might include landings and discards. Underlying the approach is a linear model of population growth, which characterizes the population response to varying levels of fishing mortality. If the underlying model is valid over the range of densities observed, AIM can be used to estimate the level of relative fishing mortality at which the population is likely to be stable (e.g., a proxy for

FMSY). The approach can be used to construct reference points based on relative abundance indices and catches, and to perform deterministic and stochastic projections to achieve a target stock size.

The basic calculations of the AIM model are two derived quantities, the Replacement Ratio (RR) and Relative F (RF). Replacement ratio is the ratio between the current year observed index and a smoothed value of the index over a given number of the current and previous years (typically 3 to 5), and is a measure of the trend in abundance or biomass of the population. Relative F is the ratio of the observed catch to a centered average index over a given number of years (typically 2 to 3). It should be noted that the application of any smoothing technique reflects a choice between signal and noise, with a greater degree of smoothing eliminating noise but possibly failing to detect a true change in signal (Rago 2001).

When fishing mortality rates exceed to capacity of a population to replace itself the population is expected to decline over time; likewise the population is expected to increase if fishing mortality rates are less than the capacity of a population to replace. In the AIM approach, the RR will have a stable point = 1 when the fishing mortality rate is in balance with recruitment and growth, resulting in a stable population. Robust regression techniques are used in AIM to estimate the RF ($RF_{threshold}$) corresponding to RR = 1. Values of RF in excess of $RF_{threshold}$ are therefore expected to lead to stock decline (i.e., fishing mortality exceeds FMSY), while RF values less than $RF_{threshold}$ would be expected to allow populations to increase. Randomization tests are used to test the null hypothesis that the input fishery catch and survey index time series represent a random ordering of observations with no underlying association, and that in turn the relationship between RR and RF is not spurious.

The AIM approach was tested with data for scup in the 2002 SAW 35 review (NEFSC 2002). An extended series of total catch beginning in 1963 and the NEFSC spring and fall biomass indices through 2001 were used as inputs. In the SAW 35 work, only the NEFSC fall series provided a statistically significant regression between the RR and RF, and results indicated that the RR first increased above 1.0 in 1996, and that the RF during 2000 was lowest of the time series. The SAW 35 work also indicted that re-examination of the reliance on the NEFSC spring survey series as the primary signal of stock abundance was warranted (NEFSC 2002).

The current AIM implementation for scup was tested over a range of degree of smoothing of both the RR and RF to explore the sensitivity of results to those inputs. Also, three different lengths of the extended catch time series (Table 19) were tested: beginning in 1963 (advent of the NEFSC trawl surveys), beginning in 1974 (to include the peak in NEFSC Surveys used as the basis for the current biomass reference point), and beginning in 1981 (to include the least number of assumptions for catch estimates). All of the available NEFSC and state agency survey series of stock biomass and abundance were initially tested for their utility in the AIM approach.

The best (i.e., a significant model at the p = 0.10 level) simple regression fits in AIM were provided by the NEFSC fall, URIGSO, NJBMF annual, and MADMF spring survey series (Figures 17-20). The MADMF and NJBMF series are too short to serve as the sole stock index for scup in the AIM model - neither series captures the historical peaks and trends in biomass. The 1974 and 1981 AIM run configurations suffer from the same shortcoming. The URIGSO, MADMF and NJBMF series also failed to satisfy the randomization test at the p = 0.10 level. These initial results indicated that only the NEFSC fall survey biomass index (Figures 17 and 19) provided acceptable fit statistics and other diagnostics within the AIM model framework.

In an attempt to include the recent information content of the multitude of state agency surveys as well as the historical perspective provided by the long-term NEFSC and URIGSO

series, a model-based index including all of the index series in a GLM framework was developed. Alternative configurations included lognormal, Poisson, and negative binomial error distribution assumptions; Asurvey@ was used as the classification variable, with the Ayear@ classification variable coefficient acting as the index of abundance. The Working Group adopted the GLMALL index with Poisson error (Figure 21) for input to AIM based on the GLM model fit statistics and diagnostics. AIM results for the GLMALL index with Poisson error showed a significant regression model ($p < 0.10$) and feasible Relative F and Replacement Ratio results (Figure 22), but a failed randomization test.

These results suggest that the most appropriate AIM model would include only the NEFSC fall survey biomass index. However, the NEFSC spring and fall *Albatross IV* time series have ended, and even if reliably calibrated indices from the *Henry B. Bigelow* series can be developed (Figure 23), they will likely not be available for at least a few years. Thus, the Working Group concluded that the AIM results provided the impetus to explore a more complex statistical catch at age model (such as ASAP) that is better able to accommodate the numerous sources and relatively high uncertainty of both fishery and survey data for scup.

Age Structured Assessment Program (ASAP) Model

The fishery and research survey data for scup described earlier were used as input for the Age Structured Assessment Program (ASAP) statistical catch at age model in NFT version 2.0.17 (NFT 2008b). NEAMAP survey data were considered by the Data Poor Working Group but were not used to calibrate the scup population model. It was not clear that the NEAMAP data could serve as an abundance index yet given the very short survey time series and the high variance between seasons.

The ASAP model is able to estimate residuals (error) for the fishery catch components as well as for the survey indices used for calibration. The ASAP model also allows control in specifying the selection (partial recruitment) characteristics for both the fisheries and the surveys, in specifying the underlying stock-recruitment relationship, and in the relative emphasis of the different likelihood components that influence the model estimation results.

Initial Runs

The fishery catch data (aggregate catches in weight for 1963-2007; catches at age in number for 1984-2004) were input as four component fisheries (commercial landings, commercial discards, recreational landings, recreational discards; in aggregate weight and as number at age) and associated mean weights at age. Natural mortality (M) was set equal to 0.2, and maturity at age was set as in the SAW 27 assessment (NEFSC 1998) with proportions mature as follows: age 0 = 0.00, age 1 = 0.13, age 2 = 0.75, age 3 = 0.99, and age 4 and older = 1.00. In the initial ALL configuration, the following research survey abundance indices at age were used: NEFSC spring ages 1-4, NEFSC fall ages 0-4, NEFSC winter ages 1-4, CTDEP spring ages 1-6+, CTDEP fall ages 0-5+, NYDEC ages 0-1, and VIMS age 0. Aggregate biomass or abundance indices from the NEFSC winter, spring, and fall, MADMF spring and fall, RIDFW spring and fall, CTDEP spring and fall, NJBMF annual, and VIMS surveys were also used as input in initial runs. Fishery selectivity was estimated for two time periods: 1984-1996 and 1997-2007, with the break roughly coinciding with the advent of substantial regulatory changes in the fisheries (Amendment 8 in 1997 and Amendment 12 in 1998). Other model options (survey CVs, stock-recruit function CVs and lambdas, etc.) were configured to provide

stable and feasible results. Alternative input data model configurations tested included a) only NEFSC surveys, b) only STATE surveys, and c) only NEFSC and URIGSO (NEC-URI) surveys.

The four initial model configurations (ALL, NEFSC, STATE, and NEC-URI) provided comparable time series trends in SSB and F through the late 1990s: high abundance and low F in the early 1960s, a decline and then rebuilding to a period of abundance in the late 1970s, and then a decline in abundance under high Fs in the mid-1980s to mid-1990s resulting in a period of low abundance in the late 1990s. The alternatives differed substantially in the development of the stock since 2000, and in the estimate of current abundance with respect to the previous peak in the late 1970s, mainly as a result of differing estimates of recruitment since the late 1990s (Figures 24-26). The STATE run provided the highest recent estimates of SSB, due to the scaling of recent large year classes (with the notable exception of 2006) about 50% higher than the ALL run and 100% higher than the NEFSC and NEC-URI runs. Comparison of the alternative estimates of SSB and F with ASAP internally calculated BRPs indicates that the stock in 2007 was about two to four times SSBMSY, with Fs at about 20-50% of FMSY (Figure 27).

Modifications to Survey Input Data

The initial runs indicated that the stock should be considered to be fully rebuilt with no overfishing. With a stock at that level of abundance, there is an expectation that both fishery and survey catches would reflect a robust age structure with significant numbers of older fish. There is evidence of expansion of the age structure of the fishery catch since about 2000 (Figures 3-6), likely reflecting the combined effects of a) increasing minimum retention sizes b) more restrictive trip limits in the fisheries, c) recent decreases in quotas/harvest limits and d) real increases in recruitment and subsequently SSB.

However, there is little evidence of substantial expansion of the age structure of the stock in the survey catches (Figures 8-10, 15), except for the CTDEP survey catches (Figures 13-14). Previous and current reviews of the scup research trawl survey data have noted that the catchability and/or availability of age 3 and older fish is likely reduced compared to age 0-2 fish. The NEFSC survey catches likely reflect this higher catchability of ages 0-2 relative to older fish (ages 3 and older), and so the aggregate biomass indices likely reflect mainly the abundance of ages 0-2, but not of ages 3 and older. Examination of the available length and age frequencies suggests the same properties likely apply to the MADMF, RIDFW, URIGSO, NYDEC, and ChesMMAP indices for scup. The CTDEP survey catches, however, are distributed across ages more in line with realistic total mortality rates, suggesting that the CTDEP survey older age indices (ages 3 and older) may be reflective of true abundance, with aggregate indices in turn more reflective of total stock biomass (Figures 13-14).

In an attempt to resolve the inconsistent signals provided by the fishery and survey catches, a number of modifications were made to the input survey data and to the manner in which the survey data are modeled in ASAP. For the NEFSC survey indices at age, input data were limited to the age 0-2 indices. The NEFSC long-term aggregate biomass indices were recompiled with a length cut-off at age 2 (winter = 22 cm; spring = 20 cm; fall = 23 cm; Figures 28-30), and selectivity (selex) within the ASAP model limited to ages 0/1 to 2. The consistency of rank order and trends between the original and modified NEFSC aggregate indices indicates that those series best index the abundance and biomass of ages 0/1 to 2.

For the MADMF, RIDFW, NJBMF, and URIGSO aggregate indices, selectivity within the ASAP model was also limited to ages 0/1 to 2. Alternative runs were made with different inputs and assumptions for the CTDEP indices, to test the inclusion of age 3 and older indices and

aggregate indices, and correspondingly varying the selectivity of the aggregate indices. The newly modified runs are identified as:

Sep08_ALL: All indices, all ages, aggregate index selex for ages 0/1 to 7+
SV0to2: Use only age 0-2 indices, no aggregate indices
SV0to2_AGG0to2 Use only age 0-2 indices, aggregate indices selex for age 0/1 to 2
SV0to2_AGG0to2_CTALL: Use all CT indices, CT aggregate indices selex for ages 0/1 to 7+

The modified runs generally provided a different recent pattern of stock biomass in relation to the early 1960s and late 1970s peaks compared to the four initial runs, and also higher recent biomass in absolute terms. The four initial run estimates of SSB in 2007 ranged from 55,000 mt to 140,000 mt (Figure 24); the four modified run estimates ranged from 90,000 mt to 180,000 mt (Figure 31). The Sep08_ALL run, which includes some additional input data series (URIGSO, ChesMMAP and updated NYDEC) and some modifications to initial settings, provided results closest to the initial ALL run.
The two modified runs with older ages excluded from both the at-age and aggregate indices (SV0to2 and SV0to2_AGG0to2) estimated higher recent recruitment and thus lower recent F and higher recent SSB than the Sept08_ALL run (Figures 31-33). The run including all ages in the CTDEP indices (SV0to2_AGG0to2_CTALL) estimated extremely high recent recruitments (three year classes > 300 million age 0 fish) and correspondingly low F and high SSB. The SV0to2_AGG0to2_CTALL run had the poorest diagnostics of the four runs, in terms of a) large residuals for many of the survey indices, b) relatively poor fits to the estimated commercial and recreational fishery aggregate discards, and c) relatively poor fits to the estimated commercial and recreational fishery discards at age. For those reasons, the SV0to2_AGG0to2_CTALL configuration was not considered further.

The other three runs had comparable residual patterns and fits to the estimated catches. Four objective function components, a) fishery total catch, b) fishery age compositions, c) survey indices (age compositions plus aggregate indices), and d) recruitment deviations, account for 99% of the total objective function for all four modified runs. With the SV0to2_AGG0to2_CTALL excluded, the remaining three runs had comparable objective function distribution and fit diagnostics. Figure 34 shows that restricting the input survey data to only the age 0-2 indices (run SV0to2) shifts more of the influence on the model solution to the fishery catch (total and age composition) components, compared to the other runs that also include aggregate indices (whether restricted to ages 0-2 or allowed to include older ages). The SV0to2 run does not include the long-term aggregate indices that are included in the Sep08_ALL and SV0to2_AGG0to2 runs, fishery independent data that increases the precision of historical stock size estimates in those runs. However, run Sep08_ALL includes indices at age 3 and older that are less likely to be reflective of true abundance than indices for ages 0-2. Therefore, by elimination of configurations with diagnostic or data fit concerns, the SV0to2_AGG0to2 run was carried forward for further examination of the sensitivity of the model to changes in configuration.

The next step was to examine the retrospective performance of the SV0t2_AGG0to2 run to judge its= potential utility to reliably monitor the stock. Six retrospective peels (a seventh,

terminal year 2001 retrospective peel did not converge) indicated that the SV0to2_AGG0to2 run was stable with little retrospective pattern evident in SSB, F, or R (Figure 35).

Sensitivity to Fishery Catch Lambdas (Weighting Factors) and Time Series Length

Next, model sensitivity to fishery catch lambdas (the weighting or emphasis factors on the four aggregate fishery catch components) was examined. The initial and modified runs described earlier were made with lambdas set at 0.10 (i.e., CV = 10%) for all four aggregate fishery catch components. Further sensitivity runs were made with lambda set at 0.10 for commercial landings and 0.20 for the commercial discards, recreational landings, and recreational discards (run CAT20); with 0.10 for commercial landings and 0.30 for the commercial discards, recreational landings, and recreational discards (run CAT30); with 0.10 for commercial landings and 0.60 for the commercial discards, recreational landings, and recreational discards (run CAT60); with 0.10 for commercial landings and lambda changing from 0.30 to 0.10 in 1981 for the commercial discards, recreational landings, and recreational discards (run CAT30to10); and with 0.10 for commercial landings and lambda changing from 0.60 to 0.30 in 1981 for the commercial discards, recreational landings, and recreational discards (run CAT60to30). The 1980/1981 time split coincides with the more reliable estimation of recreational catches.

The results of the SV0to2_AGG0to2 run configuration were sensitive to the catch lambda specifications. The 1980/1981 time split in the CAT30to10 and CAT60to30 runs did not have an important effect on the results. However, the change from lambdas of 0.10 to lambdas of 0.20 and higher did have an important effect on SSB results, as reflected by the Ashift@ from the initial SV0to2_AGG0to2 and CAT30to10 runs (all recent catch lambdas set at 0.10) to the runs with recent commercial discards, recreational landings, and recreational discards lambdas set at 0.20 or higher. Results for F and R were less strongly affected. Lambdas reflecting greater uncertainty of the magnitude of commercial discards and recreational catch resulted in lower recent estimates of SSB and a different relationship between current estimates and previous peaks in SSB in the 1960s and late 1970s (Figure 36-38). This result occurs because the influence of the survey indices in these run configurations is mainly restricted to ages 0-2, and so the magnitude and uncertainty of the input fishery catches has the strongest influence on estimates of recent SSB.

The input assumptions for the age range for which the survey indices can be considered reliable, and the estimate or assumption for the uncertainty of the input fishery catch, both have strong influence on the model results. Based on the work presented earlier, an assumption that most survey indices are likely to be reflective of true abundance only for ages 0 to 2 is appropriate - hence the subsequent work using run SV0to2_AGG0to2 as a basis. Further investigation of the empirical precision of the commercial fishery discards and recreational catches indicated that the precision of commercial fishery discards averaged (unweighted average of annual PSE) 39% for 1997-2007 (Table 4) and 32% for the entire NEFSC Observer Program sample period (1989-2007). The precision of recreational fishery landings (catch types A+B1 numbers) during 1981-2007 averaged 10%; the precision of recreational fishery discards (catch type B2 numbers) during 1981-2007 averaged 12%. A new run, BASE_Nov08, was configured to reflect this empirical information about the uncertainty of the fishery catch for scup, with commercial landings lambda assumed to be 0.10, commercial discards lambda set at 0.32, recreational landings lambda set at 0.10, and recreational discards lambda set at 0.12; for all years 1963-2007. The results of the BASE_Nov08 run were similar to the sensitivity runs

with commercial discard and recreational catch lambdas of 0.20 and greater, indicating that the current magnitude of SSB is about the same as in the 1960s and higher than in the late 1970s, with very low current F and several very large year classes recruiting to the stock since 2000 (Figure 39-41).

A sensitivity exercise was conducted to test the influence of the length of the catch time series modeled. The BASE_Nov08 time series includes a time series of fishery catches extended back to 1963, using ratios to extend the commercial discards (1963-1988) and recreational landings and discards (1963-1980; Table 19). The BASE81_Nov08 run was configured to include only fishery and survey data from 1981-2007, the time period for which most of the fishery catches are reported or estimated from sampling, rather than extrapolated from ratios. The shorter time series provided 10-30% lower estimates of SSB during the early 1980s, and 10-20% higher estimated of SSB since 2003, when compared to the 1963-2007 BASE_Nov08 run (Figure 42). Patterns and levels of F and R were very similar, however (Figures 43-44). The BASE_Nov08 run SSB varied from about 103,000 mt in 1963 to a time-series low of 4,100 mt in 1995 to a time-series high of 107,100 mt in 2007; Fs varied from a high of 1.13 in 1993 to a low of 0.06 in 2007; recruitment varied from a low of 32 million age 0 fish in 1996 to a high 367 million in 2007. The BASE81_Nov08 run SSB varied from a low of 4,200 mt in 1995 to a high of 122,700 mt in 2007; Fs varied from a high of 1.14 in 1994 to a low of 0.06 in 2007; recruitment varied from a low of 35 million age 0 fish in 1996 to 308 million in 2007. Biological Reference Points calculated from the BASE_Nov08 and BASE81_Nov08 runs are presented in Figure 45. Given the similarity of the results, the November 2008 Working Group decided to use to the BASE_Nov08 runs with the full 1963-2007 time series as the basis for further model development.

Sensitivity to 2002 Survey and Commercial Discard Estimates

The next step in model development was to add preliminary fishery catch at age estimates for the four fishery fleets for 2004-2006, which provided model run configuration BASE_C2006. The November 2008 Working Group reviewed the diagnostics of the BASE_C2006 run in detail, and noted that some components of the calendar year 2002 survey data and the 2002 commercial fishery discard aggregate estimate provided large residuals (Figure 46-48). The unusually high values for many survey indices in 2002 has been noted previously, and is presumed to result mainly from increased availability of fish to the surveys, especially during the first half of 2002, rather than true increases in abundance (e.g., Figures 7-8, 11). The same type of availability event may have affected the 2002 commercial fishery discard sampling, resulting in higher than usual discard rates and increased estimated discards at age in 2002 (Figure 4). To explore the sensitivity of the ASAP model for scup to these data, two new runs were configured. The first, BASE_C2006_No02SV, dropped all the calendar year 2002 survey indices (at age and aggregate) from the model fit. The second, BASE_C2006_No02SV_NoCD02, also dropped the 2002 commercial fishery discard estimates at age and used the average of the 2001 and 2003 estimates as a substitute for the 2002 aggregate discard weight.

Figures 49-51 summarize the results of these BASE_C2006 runs. The BASE_C2006 run with fishery catch at age through 2006 provided results very similar to the BASE_Nov08 run with fishery catch at age through 2004, with SSB in 2007 estimated at just over 100,000 mt, F in 2007 estimated at about 0.05, and the large recent recruitments in 2000 and 2007 estimated at 300-400 million fish. Dropping the 2002 survey indices in the BASE_C2006_No02SV run increased the SSB in 2007 to about 125,000 mt, substantially reduced the 2002 recruitment

estimate from about 296 million to 156 million fish, changed the pattern of recruitment so that the 1999 year class (212 million) was larger than the new estimate of the 2000 year class, and increased the estimated of recruitment in 2007 to about 376 million fish. Dropping the 2002 Commercial Discards at age and substituting for the high 2002 aggregate discard in weight in the BASE_C2006_No02SV_No02CD run had relatively little additional effect on results, other than eliminating the large residual for the 2002 estimate, and so the November 2008 Working Group decided to retain the original 2002 commercial fishery discard estimates in subsequent model runs.

The November 2008 Working Group extensively debated whether it was appropriate to exclude the 2002 survey data in a BASE case run for subsequent development. It was noted that the model Acompensated@ for the missing data, changing the rank order of recruitments over the last decade, and increasing the size of the 2007 year class. It was also noted that there may have been other abrupt, but substantial Apositive availability@ events that have occurred in the past (e.g., NEFSC spring survey in 1977, NEFSC fall survey in 1976, 1989, and 1999; Table 20, Figure 7), that were not being considered for exclusion from the analysis. Likewise, there may have been several abrupt, but substantial Anegative availability@ events that have occurred (e.g., NEFSC spring 2003, 2005, and 2007, NEFSC fall 2005), and no exclusion was being considered for those possible events. The November 2008 Working Group found it difficult to develop an objective justification for the exclusion of the 2002 survey data, and so they were retained in subsequent model runs.

Alternative Assumptions for Natural Mortality (M)

A range of alternative assumptions for the instantaneous natural mortality rate (M) was tested in a series of runs derived from the BASE_C2006 run. The values ranged from 0.10 to 0.40, in runs BASE_C2006_M10 to BASE_C2006_M40. A sensitivity profile indicated that the ASAP model for scup fit best (lowest total likelihood value) at M = 0.10 (Figure 52). This was considered a counter-intuitive result, as most members of the November 2008 Working Group expected a higher value of M (e.g., in the 0.3-0.4 range) to perform better, given the maximum observed age in survey and fishery samples of 14 years, and configuration of the model with an oldest age group of 7-plus. Those expectations were not born out by the results, however, and so the November 2008 Working Group retained the initial assumption of M = 0.2 for all ages in subsequent model runs.

Update with final 2004-2007 Catches: BASE_C2007 runs

Final fishery catch at age estimates for 2004-2007 became available in mid-November 2008, after the November 2008 Working Group meeting, and model runs including these data were called BASE_C2007 runs. In the BASE_C2007 and all previous runs, the same mid-year mean weights at age were used for the total catch, January 1 total stock biomass, and June 1 SSB mean weights at age. Once the fishery catches at age were finalized through 2007, mean weights for the January 1 and SSB biomass were re-calculated using the Rivard method (NFT 2008c), to provide run BASE_C2007_RIV. As a final model tuning step, the ratio of the estimated Effective Sample Sizes (ESS) to the input ESS was calculated for the four fishery fleets, and the ratio used to adjust the ESS for the final run, BASE_C2007_T1.

Figures 53-55 summarize comparative results for the runs configured during and since the November 2008 Working Group meeting. The addition of the preliminary 2004-2006 fishery catches at age to the BASE_Nov08 run to create the BASE_C2006 run had a very minor effect

on the results. The addition of the final 2004-2007 catches at age to create the BASE_C2007 run had a slightly larger effect on recent trends, increasing the SSB in 2007 from 103,000 mt to about 113,000 mt, and increasing recruitment in 2000 (from 297 million to 302 million) while decreasing recruitment in 2007 (from 364 million to 305 million). Re-calculation of the mean weights at age in the BASE_C2007_RIV run affected only the SSB estimates by increasing the recent estimates by a few percent, with the SSB in 2007 increasing from 113,000 mt to 121,000 mt. The final tuning of the ESS created the final run BASE_C2007_T1, with a slight decrease in SSB and R in recent years compared to the previous run, and an estimate of SSB in 2007 of 119,000 mt, F of 0.054, and recruitment in 2007 of 308 million fish. The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted the BASE_C2007_T1 ASAP run as the basis for subsequent calculation of biological reference points and status evaluation. Run BASE_C2007_T1 did not exhibit substantial retrospective patterns in SSB, F, or R (Figures 56-58).

Summary estimates, estimated January 1 stock size at age in numbers, and estimated fishing mortality (F) at age from the accepted BASE_C2007_T1 run for 1984-2007 (the years with input fishery catches at age) are provided in Tables 32-34. Spawning stock biomass (SSB) decreased from about 102,000 mt in 1963 to about 50,000 mt in 1969, then increased to about 75,000 mt during the late 1970s (Figure 53). SSB declined through the 1980s and early 1990s to only 4,000 mt in 1995. With greatly improved recruitment and low fishing mortality rates since 2000, SSB has steadily increased since to about 113,000 mt in 2007 (Table 32, Figure 53). There is an 80% chance that SSB in 2007 was between 111,204 and 130,120 mt (Figure 59). Fishing mortality varied between F = 0.100 and F = 0.274 during the 1960s and 1970s (Figure 54). Fishing mortality increased steadily during the 1980s and early 1990s, peaking at F = 1.120 in 1994. Fishing mortality decreased rapidly after 1994, falling to less than F = 0.100 since 2004, with F in 2007 = 0.054 (Table 32, Figure 54). There is an 80% chance that F in 2007 was between 0.048 and 0.060 (Figure 60). Recruitment at age 0 averaged 91.4 million fish during 1963-1983, the period during which recruitment estimates are influenced mainly by the internal ASAP stock-recruitment relationship (Figure 55). Since 1984, recruitment estimates are influenced mainly by the fishery and survey catches at age, and recruitment at age 0 averaged 119.6 million fish during 1984-2007, with the 2000 and 2007 year classes estimated to be the largest of the time series, at 311.2 and 307.9 million age 0 fish (Table 32, Figures 55 and 61).

Recommended Biological Reference Points and Status Determination

The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted the BASE_C2007_T1 ASAP run as the basis for biological reference points and status determination for scup. Biological reference points were calculated using the non-parametric yield and SSB per recruit/long-term projection approach recently adopted for summer flounder (NEFSC 2008a) and New England groundfish stocks (NEFSC 2008b). In the yield and SSB per recruit calculations, the most recent five year averages were used for mean weights and fishery partial recruitment pattern (Table 35). For the projections, the cumulative distribution function of the 1984-2007 recruitments (corresponding to the period of input fishery catches at age) was re-sampled to provide future recruitment estimates (mean = 117.2 million age 0 fish).

The Peer Review Panel recommended $F_{40\%}$ as the proxy for F_{MSY}, and the corresponding $SSB_{F40\%}$ as the proxy for SSB_{MSY}. The F40% proxy for F_{MSY} = 0.177, the proxy estimate for SSB_{MSY} = 92,044 mt, and the proxy estimate for MSY = 16,161 mt (13,134 mt of landings, 3,027

mt of discards). The stock biomass threshold of ½ SSB_{MSY} = ½ $SSB_{40\%}$ = 46,022 mt = 101.461 million lbs.
The 2007 F estimate of 0.054 is 31% of F_{MSY} = 0.177, indicating no overfishing was occurring. The 2007 SSB estimate of 119,343 mt is 30% above SSB_{MSY} = 92,044 mt, indicating the stock was not overfished. Total catch (landings + discards) was 7,867 mt in 2007, about 49% of MSY (Table 36). Estimates of biomass and catch reference points corresponding to F_{MAX} and $F_{35\%}$ are also listed in Table 36 for comparison.

Uncertainty and Risk for Scientific and Statistical Committees (SSCs) to Consider

The accepted ASAP model of scup population dynamics and recommended BRPs provides a more stable tool for monitoring stock status and specifying annual fishery regulations than the current single index-based model. The ASAP model integrates a broad array of fishery and survey input data and should be less sensitive to inter-annual changes in any single data component than the current model. The accepted model results and recommended BRPs indicate that the stock was above the SSB_{MSY} proxy and being fished at below the F_{MSY} proxy in 2007. This status represents a significant change from the July 2008 biomass status update, which indicated that the stock was overfished in 2007 (NEFSC spring SSB three-year average index = 1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow) and rebuilding more slowly than indicated by the Amendment 14 projection (see Section 3). The current REI proxy for F did indicate that F in 2007 was low (about 0.10) and therefore was not experiencing overfishing, in accord with the accepted ASAP model.

The 2007 stock abundance indicated by the accepted model is the result of historically low fishing mortality rates and historically high levels of recruitment since about 2000 (Figures 53-55). Age 0 fish accounted for about 40% of the stock size in 2007 due to the large size of the 2007 year class, but the relative percentages of the age 1 and older fish are within of few percent of what might be expected in the stock if it was fished at Fmax = 0.283 over the long-term (Figure 62). The age 7+ fish accounted for about 6% of the stock size in 2007. The model results indicate that stock has not been fished at low levels of F long enough to accumulate as high a percentage in the age 7+ group (16%) as would be expected if fished at F = 0.05 over the long-term (Figure 62). Since 2000, a high proportion of the SSB has accumulated at ages 3 and older (those expected to be fully mature). The percentage of SSB in 2007 at fully mature ages 3-6 (56%) is near what would be expected if the stock were fished at F = 0.050 over the long-term (46%), while the age 7+ fish accounted for about 35% of the SSB in 2007 (Figure 63).

A retrospective look at historical stock assessments for scup shows that the accepted ASAP model estimates of SSB and R are comparable to those previously estimated for the same time period in the 1995, 1997 and 1998 assessments using ADAPT VPA; estimates of F are somewhat higher in the VPA assessments (NEFSC 1995, 1997, 1998) (Figures 64-66). The 1995 SAW19 assessment was the last accepted peer-reviewed analytical assessment. The analytical components of the 1997 and 1998 assessments were not accepted as valid bases for assessing the stock. The historical analyses used input fishery and research survey data time series beginning in 1984.

The recommended MSY proxy for scup in terms of total catch is 16,161 mt (35.6 million lbs), with total landings of 13,134 mt (29.0 million lbs) and total discards of 3,027 mt (6.7 million lbs). The extended catch series estimated for scup (Table 19) indicates that this MSY proxy is a feasible estimate. Total fishery catch is estimated to have averaged about 34,000 mt

(75.0 million lbs) during 1960-1965, while reported commercial landings alone averaged about 19,000 mt (41.9 million lbs) in that period (Table 19 and Figure 1).

While the accepted long-term MSY estimate appears feasible given historical evidence from the fishery, managers may wish to take an adaptive approach to the specification of fishery quotas in the short-term. Total fishery landings over the last five years (2003-2007) have averaged 6,214 mt (13.7 million lbs). If the stock is fished at F40% = 0.177 over the long-term, the corresponding annual total MSY landings would be 13,134 mt (29.0 million lbs), more than double the recent five year average. The Peer Review Panel recommended that "…rapid increases in quota to meet the revised MSY would be unwarranted given uncertainties in recruitments. A more gradual increase in quotas is a preferred approach reflective of the uncertainty in the model estimates and stock status."

Research Recommendations

Short term analytical tasks

a) Evaluation of indicators of potential changes in stock status that could provide signs to management of potential reductions of stock productivity in the future would be helpful.
b) A management strategy evaluation of alternative approaches to setting quotas would be helpful.

Long term data and analytical needs

a) Current research trawl surveys are likely adequate to index the abundance of scup at ages 0 to2. However, the implementation of new standardized research surveys that focus on accurately indexing the abundance of older scup (ages 3 and older) would likely improve the accuracy of the stock assessment.
b) Continuation of at least the current levels of at-sea and port sampling of the commercial and recreational fisheries in which scup are landed and discarded is critical to adequately characterize the quantity, length and age composition of the fishery catches.
c) Quantification of the biases in the catch and discards, including non-compliance, would help confirm the weightings used in the model. Additional studies would be required to address this issue.
d) The commercial discard mortality rate was assumed to be 100% in this assessment. Experimental work to better characterize the discard mortality rate of scup captured by different commercial gear types should be conducted to more accurately quantify the magnitude of scup discard mortality.

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Scup; Tables

Table 1. Commercial landings (mt) of scup by state. One mt was landed in DE in 1995, included with MD 1995 total. Eight mt was landed in PA in 2004 included with MD 2004 total. Landings include revised Massachusetts landings for 1986-1997.

Year	ME	MA	RI	CT	NY	NJ	MD	VA	NC	Total
1979		782	3,123	92	1,422	2,159	21	397	589	8,585
1980	1	706	2,934	17	1,294	2,310	32	531	599	8,424
1981		523	2,959	44	1,595	2,990	9	1,054	682	9,856
1982		545	3,203	25	1,473	1,746	2	1,042	668	8,704
1983		672	2,583	49	1,103	2,536	13	536	302	7,794
1984		540	2,919	32	904	2,217	6	673	478	7,769
1985		387	3,583	41	861	1,493	17	74	271	6,727
1986		875	2,987	67	893	1,895	14	273	172	7,176
1987	5	735	2,162	301	911	1,817		232	113	6,276
1988	9	536	2,832	359	687	1,334	1	127	58	5,943
1989	32	579	1,401	89	603	1,219	1	45	15	3,984
1990	4	696	1,786	165	755	1,005	4	75	81	4,571
1991	16	553	2,902	287	1,223	1,960	15	56	69	7,081
1992		655	2,676	193	1,043	1,475	17	73	127	6,259
1993		556	1,332	148	729	1,822	10	76	53	4,726
1994		354	1,514	142	688	1,456	7	92	139	4,392
1995		310	1,045	90	511	1,084	2	20	11	3,073
1996		436	773	99	377	1,141	20	72	27	2,945
1997		676	486	50	376	596	1	2	1	2,188
1998		435	361	44	282	758	5	4	7	1,896
1999		300	581	44	206	361		13		1,505
2000		161	461	65	287	232		1		1,207
2001		149	734	45	297	479	1	24		1,729
2002		330	1,668	4	714	419		25	13	3,173
2003		407	1,730	64	839	1,033	21	253	58	4,405
2004		353	1,562	116	865	862	21	203	249	4,231
2005		515	1,553	149	989	880	1	130	50	4,266
2006		493	1,653	135	1,096	632	0	36	17	4,062
2007		501	1,785	118	1,054	714	1	10	13	4,196
mean	11	509	1,906	106	830	1,332	10	212	187	5,074

Table 2. Commercial landings (mt) of scup by major gear types. Midwater paired trawl landings are combined with other gears during 1994 and later. Landings include revised Massachusetts landings for 1986-1997.

Year	Otter trawl	Paired trawl	Floating trap	Pound net	Pots and traps	Hand lines	Other gear	Total mt
1979	6,387	146	1,305	429	26	215	77	8,585
1980	6,192	160	1,559	194	8	303	8	8,424
1981	7,836	79	1,291	246	49	306	49	9,856
1982	6,563	104	1,514	244	9	226	44	8,704
1983	5,861	398	850	390	8	265	22	7,794
1984	5,617	272	1,266	295	8	287	24	7,769
1985	4,856	417	1,022	229	5	182	16	6,727
1986	5,163	540	629	332	9	493	10	7,176
1987	4,607	237	590	193	213	423	13	6,276
1988	4,142	166	1,052	53	44	396	90	5,943
1989	3,174	89	193	74	104	334	16	3,984
1990	3,205	200	505	60	239	340	22	4,571
1991	5,217	152	988	40	258	395	31	7,081
1992	4,371	94	934	67	303	450	40	6,259
1993	3,865	46	166	25	202	402	20	4,726
1994	3,416		331	79	76	340	150	4,392
1995	2,204		331	42	57	215	224	3,073
1996	2,196		229	8	120	374	18	2,945
1997	1,491		86	12	104	489	6	2,188
1998	1,379		11	4	98	390	14	1,896
1999	1,005		140	30	77	184	69	1,505
2000	773		56		78	205	95	1,207
2001	1,088		229	65	52	215	80	1,729
2002	2,084		220		221	450	198	3,173
2003	2,777		723		168	445	292	4,405
2004	3,767		20		121	196	127	4,231
2005	3,475		117		174	448	52	4,266
2006	3,422		106		201	291	42	4,062
2007	3,332		181		279	373	31	4,196
mean	3,775	207	574	141	114	332	65	5,074

Table 3. Summary NEFSC Domestic Observer program data for scup. Geometric mean discards to landings ratios (GMDL; retransformed, mean ln-transformed D/L per trip) are stratified by half-year period (HY1, HY2) and trip landings level (< 300 kg, => 300 kg). N is the number of observed trips with both scup landings and discard, which are used to calculate the per-trip discard to landings ratios. Corresponding dealer landings are from the NEFSC database.

1997		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.8957	17	258	231	0.8221	4	1,244	1,023
HY 2	0.8957	0	279	250	0.8221	0	413	340
Total			537	481			1,657	1,362

1998		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	2.401	7	196	471	121.71	1	920	111,973
HY 2	3.126	10	281	878	121.71	0	496	60,368
Total			477	1,349			1,416	172,341

1999		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	1.742	6	245	427	3.766	2	785	2,956
HY 2	1.742	0	178	310	3.766	0	299	1,126
Total			423	737			1,084	4,082

Table 3 continued .

2000		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	4.5818	13	196	898	0.6018	2	655	394
HY 2	3.5001	1	292	1,022	0.6018	0	63	38
Total		14	488	1,920		2	718	432

2001		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.8916	10	180	160	0.9185	4	1,013	930
HY 2	0.4606	2	307	141	0.9185	0	290	266
Total		14	487	302		4	1,303	1,197

2002		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	2.6088	11	423	1,104	0.0653	2	1,484	97
HY 2	3.4522	12	829	2,862	3.6028	3	437	1,574
Total		23	1,252	3,965		5	1,921	1,671

Table 3 continued .

2003		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.1371	9	315	43	0.2560	2	2,473	633
HY 2	1.4299	4	921	1,317	0.2304	5	696	160
Total		13	1,236	1,360		7	3,169	793

2004		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.3370	40	344	116	0.1685	25	2,353	396
HY 2	0.4200	64	868	365	0.0309	10	550	17
Total		104	1,212	480		35	2,903	413

2005		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.7354	31	292	215	0.0732	7	2,390	175
HY 2	0.2740	67	850	233	0.0563	2	694	39
Total		98	1,142	448		9	3,084	214

Table 3 continued .

2006		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.6621	37	472	313	0.0740	10	1,814	134
HY 2	0.8573	40	814	698	0.2631	10	921	242
Total		77	1,286	1,010		20	2,735	377

2007		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.4821	41	461	222	0.2628	10	2,177	572
HY 2	0.9404	54	892	839	0.3389	7	666	226
Total		95	1,353	1,061		17	2,843	798

Table 4. A summary of landings, discards, and geometric mean discards to landings ratio (GMDL), 1997-2007.

Year	Landings (mt)	GMDL Discards (mt)	GMDL D:L ratio	GMDL Discards PSE (%)
1997	2,188	1,843	0.84	61
1998	1,896	173,690	91.61	32
1999	1,507	4,819	3.20	9
2000	1,207	2,352	1.95	48
2001	1,729	1,499	0.87	32
2002	3,173	5,636	1.78	95
2003	4,405	2,153	0.49	41
2004	4,231	893	0.21	25
2005	4,226	662	0.16	29
2006	4,062	1,387	0.34	27
2007	4,196	1,859	0.44	26

Table 5. Total catch (mt) of scup from Maine through North Carolina. Landings include revised Massachusetts landings for 1986-1997. Commercial discards for 1984-1988 calculated as the geometric mean ratio of discards to landings numbers at age for 1989-1993. Commercial discards estimate for 1998 is the mean of 1997 and 1999 estimates.

Year	Commercial Landings	Commercial Discards	Recreational Landings	Recreational Discards	Total Catch
1981	9,856	n/a	2,636	n/a	12,492
1982	8,704	n/a	2,361	n/a	11,065
1983	7,794	n/a	2,836	n/a	10,630
1984	7,769	2,158	1,096	30	11,053
1985	6,727	4,184	2,764	54	13,729
1986	7,176	2,005	5,264	87	14,532
1987	6,276	2,537	2,811	38	11,662
1988	5,943	1,657	1,936	31	9,567
1989	3,984	2,229	2,521	39	8,773
1990	4,571	3,909	1,878	38	10,396
1991	7,081	3,530	3,668	78	14,357
1992	6,259	5,668	2,001	47	13,975
1993	4,726	1,436	1,450	28	7,640
1994	4,392	807	1,192	37	6,428
1995	3,073	2,057	609	13	5,752
1996	2,945	1,522	978	20	5,465
1997	2,188	1,843	543	8	4,582
1998	1,896	3,331	397	14	5,638
1999	1,505	4,819	856	6	7,186
2000	1,207	2,352	2,469	55	6,083
2001	1,729	1,499	1,933	165	5,326
2002	3,173	5,636	1,644	137	10,590
2003	4,405	2,153	3,848	158	10,564
2004	4,231	893	1,923	134	7,181
2005	4,266	662	1,153	165	6,246
2006	4,062	1,387	1,331	185	6,965
2007	4,196	1,859	1,655	157	7,867
mean	4,820	2,506	1,991	72	9,102

Table 6. Summary of the landed fish sampling intensity for scup in the Northeast Region (NER; ME-VA) commercial fishery.

Year	No. of samples	No. of lengths	NER Landings (mt)	Sampling intensity (mt/100 lengths)
1979	10	1,250	8,585	687
1980	26	3,478	8,424	242
1981	16	2,005	9,856	492
1982	81	9,896	8,704	88
1983	72	7,860	7,794	99
1984	60	6,303	7,769	123
1985	31	3,058	6,727	220
1986	54	5,467	7,176	131
1987	61	6,491	6,276	97
1988	85	8,691	5,943	68
1989	46	4,806	3,984	83
1990	46	4,736	4,571	97
1991	31	3,150	7,081	225
1992	33	3,260	6,259	192
1993	23	2,287	4,726	207
1994	22	2,163	4,392	203
1995	22	2,487	3,073	124
1996	61	6,544	2,945	45
1997	37	3,732	2,188	59
1998	41	4,022	1,896	47
1999	56	6,040	1,505	25
2000	22	2,352	1,207	51
2001	40	3,934	1,729	44
2002	26	2,587	3,173	123
2003	78	6,681	4,405	66
2004	144	13,172	4,231	32
2005	124	9,324	4,266	46
2006	152	12,506	4,062	32
2007	198	15,704	4,196	27

Table 7. Commercial fishery scup landings (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	1	2691	6114	7090	5793	1418	536	251	1	0	0	23895
1985	79	3245	6767	7696	2640	346	520	159	0	0	0	21452
1986	9	301	12321	4773	1004	75	106	337	5	0	0	18931
1987	2	1679	9952	10399	1725	177	124	21	18	0	1	24098
1988	17	423	7709	9526	2424	58	127	39	0	0	0	20323
1989	17	1484	4943	7071	685	22	69	24	0	0	0	14315
1990	0	247	10203	6781	1022	355	149	2	0	0	0	18759
1991	0	2412	12956	10202	2161	409	193	0	0	0	0	28334
1992	21	1577	10883	3737	3797	1243	138	0	0	0	0	21396
1993	1	230	6558	6877	1500	1143	124	0	0	0	0	16432
1994	0	1052	13544	6358	836	82	39	0	0	0	0	21911
1995	0	2198	8345	2878	891	248	31	0	0	0	0	14591
1996	0	346	6343	1640	770	469	62	0	0	0	0	9630
1997	0	131	2080	4089	732	84	97	0	0	0	0	7213
1998	0	340	1453	2373	1092	381	2	0	0	0	0	5641
1999	0	1	1148	2688	527	117	0	0	0	0	0	4481
2000	0	0	661	2144	511	15	0	0	0	0	0	3331
2001	0	31	1635	3033	695	46	6	1	1	0	0	5448
2002	0	124	1219	5051	2132	392	5	0	0	0	0	8922
2003	0	185	863	4627	3323	856	34	0	0	0	0	9889
2004	0	1	844	2406	2826	2089	296	40	4	14	0	8520
2005	0	31	683	1558	2361	2515	807	92	3	3	0	8053
2006	0	89	2233	2231	1119	1477	1219	366	28	3	0	8765
2007	0	91	2787	1390	680	940	590	124	12	0	0	9275

Table 8. Commercial fishery scup landings mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.033	0.155	0.190	0.293	0.344	0.398	0.767	1.044	1.545	0.000	0.000	0.288
1985	0.043	0.134	0.197	0.293	0.409	0.517	0.739	1.042	0.000	0.000	0.000	0.272
1986	0.036	0.140	0.219	0.357	0.676	0.670	1.010	1.246	1.616	0.000	0.000	0.302
1987	0.034	0.136	0.203	0.244	0.407	0.544	0.747	1.194	1.068	0.000	0.000	0.237
1988	0.044	0.123	0.201	0.263	0.441	0.636	0.715	0.982	0.000	0.000	0.000	0.263
1989	0.025	0.144	0.188	0.275	0.367	0.651	0.721	1.036	0.000	0.000	0.000	0.240
1990	0.000	0.140	0.189	0.246	0.367	0.518	0.842	0.846	0.000	1.096	0.000	0.230
1991	0.000	0.187	0.194	0.263	0.389	0.511	0.729	0.000	0.000	0.000	0.000	0.241
1992	0.039	0.173	0.199	0.325	0.419	0.503	0.859	0.000	0.000	1.096	0.000	0.280
1993	0.031	0.140	0.197	0.261	0.442	0.510	0.782	0.000	0.000	0.000	0.000	0.272
1994	0.000	0.203	0.193	0.259	0.430	0.663	0.742	0.000	0.000	0.000	0.000	0.224
1995	0.000	0.161	0.209	0.295	0.396	0.480	0.724	0.000	0.000	0.000	0.000	0.236
1996	0.000	0.206	0.200	0.325	0.468	0.554	0.784	0.000	0.000	0.000	0.000	0.264
1997	0.000	0.227	0.253	0.300	0.386	0.529	0.749	0.000	0.000	0.000	0.000	0.303
1998	0.000	0.200	0.254	0.313	0.459	0.556	0.748	0.000	0.000	0.000	0.000	0.336
1999	0.000	0.075	0.220	0.323	0.497	0.748	0.000	0.000	0.000	0.000	0.000	0.328
2000	0.000	0.000	0.221	0.367	0.504	0.674	0.000	0.000	0.000	0.000	0.000	0.360
2001	0.000	0.229	0.265	0.346	0.476	0.562	0.779	1.003	1.003	0.000	0.000	0.340
2002	0.000	0.231	0.281	0.339	0.465	0.577	0.748	0.000	0.000	0.000	0.000	0.370
2003	0.000	0.228	0.308	0.402	0.505	0.635	0.844	0.000	0.000	0.000	0.000	0.447
2004	0.000	0.182	0.313	0.398	0.518	0.591	0.812	1.002	1.370	1.674	0.000	0.496
2005	0.000	0.196	0.269	0.362	0.471	0.652	0.809	1.044	1.099	1.311	0.000	0.529
2006	0.000	0.213	0.283	0.344	0.460	0.591	0.727	0.915	1.108	1.314	0.000	0.463
2007	0.000	0.217	0.265	0.353	0.470	0.646	0.768	0.894	1.077	1.697	0.000	0.452

Table 9. Summary of sampling for scup in the NEFSC Observer Program. OT =number of otter trawl trips sampled with scup discard lengths. HY1 = first half year; HY2 = second half year. GMDL reflects the estimate of discard based on applying geometric mean observed ratios of discards to landings by trip, stratified by landings level (< 300 kg per trip, = > 300 kg per trip) to reported dealer landings (from Table 4).

Year	OT	Lengths			GMDL Discard	Intensity
	trips	HY1	HY2	Total	(mt)	(mt/100 lengths)
1989	61	4,449	2,910	7,359	2,229	30
1990	52	2,582	781	3,363	3,909	116
1991	91	1,237	1,780	3,017	3,530	117
1992	53	1,158	0	1,158	5,668	489
1993	29	275	154	429	1,436	335
1994	7	99	119	218	807	370
1995	18	162	383	545	2,057	377
1996	27	1,093	435	1,528	1,522	100
1997	45	750	1	751	1,843	245
1998	33	618	64	682	3,331	488
1999	35	586	89	675	4,819	714
2000	62	3,981	762	4,743	2,352	50
2001	67	1,231	229	1,460	1,499	103
2002	65	1,422	866	2,288	5,636	246
2003	72	925	284	1,209	2,153	178
2004	80	1,948	1,051	2,999	893	30
2005	73	797	1,159	1,956	662	34
2006	47	1,486	777	2,263	1,387	61
2007	59	1,313	1,058	2,371	1,859	78

Table 10. Commercial fishery scup discards (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	78	10847	6367	924	21	0	0	0	0	0	0	18237
1985	52773	13093	6534	1060	10	0	0	0	0	0	0	73470
1986	78	1180	14040	602	3	0	0	0	0	0	0	15903
1987	78	6814	12215	1366	5	0	0	0	0	0	0	20478
1988	1552	1698	9242	1339	10	0	0	0	0	0	0	13841
1989	387	8943	13603	813	28	0	0	0	0	0	0	23774
1990	822	8269	17249	2801	0	0	0	0	0	0	0	29141
1991	1794	17231	5397	1733	5	0	0	0	0	0	0	26160
1992	38804	10023	26380	72	0	0	0	0	0	0	0	75279
1993	5386	1549	6960	224	0	0	0	0	0	0	0	14119
1994	6858	3099	3422	74	0	0	0	0	0	0	0	13453
1995	1855	50174	335	108	14	0	0	0	0	0	0	52486
1996	199	3009	5990	691	21	1	0	0	0	0	0	9911
1997	1	618	8250	1871	0	0	0	0	0	0	0	10740
1998	18	17524	11849	1127	247	57	0	0	0	0	0	30822
1999	1338	2563	18123	3139	691	201	0	0	0	0	0	26055
2000	853	11206	4890	1475	55	57	0	0	0	0	0	18536
2001	3536	4232	2647	355	281	207	57	0	0	0	0	11315
2002	9561	22393	5834	4431	518	571	75	0	0	0	0	43383
2003	1480	1578	3779	937	752	503	93	0	0	0	0	9122
2004	545	1397	1423	1176	220	187	8	0	0	0	0	4956
2005	480	893	1879	516	79	47	15	0	0	0	0	3909
2006	4809	8083	2354	642	53	13	16	0	0	0	0	15970
2007	1412	3936	5370	1420	94	41	87	0	0	0	0	12360

Table 11. Commercial fishery scup discards mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.118
1985	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.057
1986	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.126
1987	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.124
1988	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.120
1989	0.039	0.060	0.111	0.198	0.217	0.000	0.000	0.000	0.000	0.000	0.000	0.094
1990	0.026	0.121	0.137	0.187	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.134
1991	0.057	0.127	0.163	0.207	0.252	0.000	0.000	0.000	0.000	0.000	0.000	0.135
1992	0.033	0.078	0.136	0.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075
1993	0.026	0.106	0.154	0.269	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.102
1994	0.024	0.068	0.122	0.198	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060
1995	0.038	0.037	0.229	0.310	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.039
1996	0.033	0.110	0.169	0.240	0.268	0.532	0.000	0.000	0.000	0.000	0.000	0.154
1997	0.020	0.028	0.137	0.362	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170
1998	0.092	0.069	0.147	0.224	0.418	0.564	0.000	0.000	0.000	0.000	0.000	0.108
1999	0.010	0.037	0.158	0.398	0.599	0.690	0.000	0.000	0.000	0.000	0.000	0.183
2000	0.044	0.076	0.195	0.299	0.486	0.768	0.000	0.000	0.000	0.000	0.000	0.127
2001	0.015	0.063	0.168	0.345	0.500	0.670	0.944	0.000	0.000	0.000	0.000	0.108
2002	0.035	0.064	0.201	0.361	0.524	0.757	1.071	0.000	0.000	0.000	0.000	0.123
2003	0.022	0.091	0.212	0.315	0.537	0.784	0.878	0.000	0.000	0.000	0.000	0.236
2004	0.029	0.109	0.166	0.268	0.371	0.453	0.750	0.000	0.000	0.000	0.000	0.180
2005	0.019	0.090	0.154	0.267	0.416	0.652	0.912	0.000	0.000	0.000	0.000	0.153
2006	0.026	0.086	0.166	0.217	0.313	0.549	0.755	0.000	0.000	0.000	0.000	0.087
2007	0.041	0.094	0.163	0.282	0.342	0.597	0.770	0.000	0.000	0.000	0.000	0.148

Table 12. Summary of the landed fish sampling intensity for scup in the recreational fishery (MRFSS sampling).

Year	No. of lengths	Estimated landings (A + B1; mt)	Sampling intensity (mt/100 lengths)
1981	642	2,636	411
1982	1,057	2,361	223
1983	1,384	2,836	205
1984	943	1,096	116
1985	741	2,764	373
1986	2,580	5,264	204
1987	777	2,811	362
1988	2,156	1,936	90
1989	4,111	2,521	61
1990	2,698	1,878	70
1991	4,230	3,668	87
1992	4,419	2,001	45
1993	2,206	1,450	66
1994	1,374	1,192	87
1995	822	609	74
1996	526	978	186
1997	399	543	136
1998	286	397	139
1999	265	856	323
2000	524	2,469	471
2001	1,038	1,933	186
2002	1,006	1,644	163
2003	2,508	3,848	153
2004	1,802	1,923	107
2005	1,794	1,153	64
2006	2,217	1,331	60
2007	2,262	1,655	73

Table 13. Recreational fishery scup landings (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	23	3036	1353	570	182	219	442	86	51	30	66	6058
1985	431	4478	3054	1330	788	441	137	33	0	0	115	10807
1986	538	4353	15570	2617	845	431	87	5	4	57	315	24822
1987	77	2299	4686	1261	824	598	112	0	0	11	46	9914
1988	9	1001	2229	1824	460	216	123	92	20	0	86	6060
1989	311	3978	3371	823	86	235	154	13	0	50	148	9169
1990	169	1352	5091	1102	147	112	36	7	2	3	22	8043
1991	299	4838	3797	3319	700	210	19	0	2	20	68	13272
1992	99	1850	4457	530	672	84	12	6	8	7	30	7755
1993	46	1245	3051	908	254	133	2	2	0	2	7	5650
1994	31	1473	1840	691	95	88	21	6	0	0	0	4245
1995	15	613	1399	225	89	20	3	3	0	0	0	2367
1996	9	351	1467	812	365	54	10	15	0	0	0	3083
1997	32	52	983	562	168	63	33	17	6	0	0	1916
1998	13	223	257	415	248	19	13	23	0	0	0	1211
1999	61	469	2169	359	182	11	0	0	0	0	0	3251
2000	6	912	3443	2113	641	129	0	0	0	0	0	7244
2001	0.3	514	1511	1705	806	244	101	218 0		0	0	5099
2002	7	70	688	1635	1005	179	24	39	0	0	0	3647
2003	0.3	75	1723	2655	3127	1407	350	115	0	0	0	9452
2004	0.9	45	284	1551	1441	1166	470	32	0	0	0	4990
2005	0	13	100	513	700	845	349	26	0	0	0	2546
2006	1	50	658	819	404	431	541	46	0	1	0	2951
2007	3	47	456	1347	775	378	605	206	26	1	0	3844

Table 14. Recreational fishery scup landings mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.044	0.117	0.266	0.373	0.472	0.557	0.678	0.825	0.912	1.002	1.145	0.274
1985	0.038	0.125	0.253	0.340	0.573	0.718	0.913	1.087	0.000	0.000	1.673	0.270
1986	0.052	0.101	0.234	0.374	0.534	0.654	0.801	0.912	1.003	1.003	1.638	0.261
1987	0.029	0.105	0.242	0.381	0.548	0.698	0.737	0.000	0.000	1.003	3.808	0.302
1988	0.026	0.142	0.240	0.325	0.497	0.663	0.794	1.144	1.099	0.000	1.532	0.330
1989	0.035	0.123	0.234	0.376	0.433	0.653	0.696	0.657	0.000	1.003	1.332	0.235
1990	0.057	0.128	0.208	0.325	0.461	0.567	0.761	0.939	1.088	1.202	1.947	0.225
1991	0.064	0.150	0.275	0.361	0.474	0.714	0.675	0.000	1.003	1.003	1.305	0.271
1992	0.092	0.140	0.240	0.373	0.454	0.598	0.804	0.859	1.311	1.003	2.117	0.256
1993	0.087	0.135	0.226	0.336	0.460	0.524	0.912	0.827	0.000	1.026	1.100	0.242
1994	0.054	0.180	0.281	0.357	0.467	0.674	0.905	1.430	0.000	0.000	0.000	0.274
1995	0.065	0.155	0.279	0.450	0.557	0.756	1.044	1.311	0.000	0.000	0.000	0.279
1996	0.093	0.171	0.231	0.368	0.540	0.772	0.876	1.383	0.000	0.000	0.000	0.314
1997	0.083	0.110	0.253	0.299	0.510	0.684	0.819	1.342	0.779	0.000	0.000	0.318
1998	0.072	0.121	0.211	0.312	0.491	0.866	1.066	1.950	0.000	0.000	0.000	0.337
1999	0.095	0.173	0.274	0.451	0.635	0.900	0.000	0.000	0.000	0.000	0.000	0.298
2000	0.075	0.138	0.296	0.424	0.544	0.825	0.000	0.000	0.000	0.000	0.000	0.345
2001	0.092	0.220	0.344	0.485	0.637	0.776	0.875	1.127	0.000	0.000	0.000	0.490
2002	0.110	0.152	0.296	0.427	0.618	0.795	0.932	1.427	0.000	0.000	0.000	0.481
2003	0.092	0.161	0.314	0.416	0.536	0.720	0.908	1.499	0.000	0.000	0.000	0.512
2004	0.094	0.151	0.325	0.437	0.523	0.575	0.858	0.748	0.000	0.000	0.000	0.527
2005	0.000	0.112	0.270	0.384	0.516	0.679	0.881	1.098	0.000	0.000	0.000	0.588
2006	0.092	0.151	0.304	0.411	0.525	0.695	0.883	0.999	0.000	1.311	0.000	0.536
2007	0.111	0.152	0.313	0.418	0.509	0.672	0.882	0.935	1.056	1.322	0.000	0.551

Table 15. Recreational fishery scup discards (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total	Metric tons
1984	2	255	0	0	0	0	0	0	0	0	0	257	30
1985	40	417	0	0	0	0	0	0	0	0	0	457	54
1986	100	807	0	0	0	0	0	0	0	0	0	907	87
1987	12	357	0	0	0	0	0	0	0	0	0	369	38
1988	2	219	0	0	0	0	0	0	0	0	0	221	31
1989	24	308	0	0	0	0	0	0	0	0	0	332	39
1990	36	284	0	0	0	0	0	0	0	0	0	320	38
1991	31	505	0	0	0	0	0	0	0	0	0	536	78
1992	17	325	0	0	0	0	0	0	0	0	0	342	47
1993	8	204	0	0	0	0	0	0	0	0	0	212	28
1994	4	203	0	0	0	0	0	0	0	0	0	207	37
1995	63	135	0	0	0	0	0	0	0	0	0	198	13
1996	44	222	0	0	0	0	0	0	0	0	0	266	20
1997	163	10	0	0	0	0	0	0	0	0	0	173	8
1998	80	139	0	0	0	0	0	0	0	0	0	219	14
1999	208	0	0	0	0	0	0	0	0	0	0	208	6
2000	20	561	25	0	0	0	0	0	0	0	0	606	55
2001	0.3	484	325	0	0	0	0	0	0	0	0	809	165
2002	14	199	381	55	0	0	0	0	0	0	0	649	137
2003	1	168	550	63	0	0	0	0	0	0	0	782	158
2004	7	232	242	211	0	0	0	0	0	0	0	692	134
2005	5	88	232	135	44	46	11	0	0	0	0	561	165
2006	1	143	644	66	0	0	0	0	0	0	0	854	185
2007	20	185	375	124	20	2	1	0	0	0	0	727	

Table 16. Recreational fishery scup discards mean weights at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.044	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.116
1985	0.038	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117
1986	0.052	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096
1987	0.029	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.103
1988	0.026	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.141
1989	0.035	0.123	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117
1990	0.057	0.128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.120
1991	0.064	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.145
1992	0.092	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.138
1993	0.087	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.133
1994	0.054	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.178
1995	0.063	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064
1996	0.075	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075
1997	0.043	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.045
1998	0.061	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.065
1999	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028
2000	0.075	0.087	0.189	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.091
2001	0.092	0.194	0.218	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.204
2002	0.110	0.155	0.238	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.211
2003	0.092	0.141	0.215	0.251	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.202
2004	0.094	0.149	0.206	0.233	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194
2005	0.035	0.114	0.215	0.311	0.481	0.698	0.810	1.110	0.000	0.000	0.000	0.294
2006	0.092	0.148	0.229	0.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.216
2007	0.067	0.127	0.220	0.322	0.408	0.567	0.000	0.000	0.000	0.000	0.000	0.215

Table 17. Total fishery scup catch (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	104	16829	13834	8584	5996	1637	978	337	52	30	66	48447
1985	53323	21233	16355	10086	3438	787	657	192	0	0	115	106186
1986	725	6641	41931	7992	1852	506	193	342	9	57	315	60563
1987	169	11149	26853	13026	2554	775	236	21	18	11	47	54859
1988	1580	3341	19180	12689	2894	274	250	131	20	0	86	40445
1989	739	14712	21917	8707	799	257	223	37	0	50	148	47590
1990	1027	10152	32543	10684	1169	467	185	9	2	3	22	56263
1991	2124	24986	22150	15254	2866	619	212	0	2	20	68	68302
1992	38941	13775	41720	4339	4469	1327	150	6	8	7	30	104772
1993	5441	3228	16569	8009	1754	1276	126	2	0	2	7	36414
1994	6893	5827	18806	7123	931	170	60	6	0	0	0	39816
1995	1933	53120	10079	3211	994	268	34	3	0	0	0	69642
1996	252	3928	13800	3143	1156	524	72	15	0	0	0	22890
1997	196	811	11313	6522	900	147	130	17	6	0	0	20042
1998	111	18226	13559	3915	1587	457	15	23	0	0	0	37893
1999	1607	3033	21440	6186	1400	329	0	0	0	0	0	33995
2000	879	12679	9019	5732	1207	201	0	0	0	0	0	29717
2001	3537	5261	6118	5093	1782	497	164	219	1	0	0	22671
2002	9582	22786	8122	11172	3654	1142	104	39	0	0	0	56601
2003	1481	1823	7007	6629	8432	3041	564	156	5	14	0	29152
2004	553	1675	2793	5344	4487	3442	774	72	4	14	0	19158
2005	465	1025	2894	2722	3184	3453	1182	119	3	3	0	15050
2006	4811	8365	5889	3758	1576	1921	1776	412	28	4	0	28540
2007	1435	4259	8988	5552	2279	1101	1633	796	150	13	0	26206

Table 18. Total fishery scup catch mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.036	0.117	0.168	0.288	0.348	0.419	0.727	0.988	0.924	1.002	1.145	0.222
1985	0.033	0.116	0.179	0.289	0.446	0.629	0.775	1.050	0.000	0.000	1.673	0.122
1986	0.050	0.104	0.193	0.351	0.611	0.656	0.916	1.241	1.344	1.003	1.638	0.236
1987	0.031	0.112	0.174	0.253	0.452	0.663	0.742	1.194	1.068	1.003	3.727	0.206
1988	0.033	0.122	0.169	0.265	0.449	0.657	0.754	1.096	1.099	0.000	1.532	0.223
1989	0.037	0.087	0.147	0.277	0.369	0.653	0.704	0.903	0.000	1.003	1.332	0.165
1990	0.032	0.123	0.164	0.239	0.379	0.530	0.826	0.918	1.088	1.195	1.947	0.179
1991	0.058	0.138	0.201	0.278	0.409	0.580	0.724	0.000	1.003	1.003	1.305	0.206
1992	0.033	0.099	0.164	0.329	0.424	0.509	0.854	0.859	1.311	1.004	2.117	0.131
1993	0.027	0.121	0.184	0.270	0.445	0.512	0.784	0.827	0.000	1.026	1.100	0.200
1994	0.024	0.125	0.189	0.267	0.434	0.669	0.799	1.430	0.000	0.000	0.000	0.174
1995	0.039	0.044	0.219	0.306	0.409	0.501	0.752	1.311	0.000	0.000	0.000	0.088
1996	0.042	0.122	0.190	0.317	0.487	0.577	0.796	1.327	0.000	0.000	0.000	0.221
1997	0.049	0.066	0.168	0.318	0.409	0.595	0.767	1.342	0.779	0.000	0.000	0.231
1998	0.067	0.072	0.160	0.287	0.458	0.570	1.024	1.950	0.000	0.000	0.000	0.149
1999	0.016	0.058	0.173	0.368	0.565	0.718	0.947	1.538	0.000	0.000	0.000	0.212
2000	0.045	0.081	0.235	0.371	0.524	0.798	0.947	1.538	0.000	0.000	0.000	0.205
2001	0.015	0.091	0.240	0.392	0.553	0.712	0.896	1.126	0.000	0.000	0.000	0.253
2002	0.035	0.066	0.223	0.360	0.515	0.701	1.024	1.427	0.000	0.000	0.000	0.186
2003	0.022	0.099	0.247	0.376	0.501	0.708	0.893	1.337	1.241	0.000	0.000	0.396
2004	0.030	0.116	0.230	0.374	0.512	0.578	0.839	0.889	1.370	1.674	0.000	0.412
2005	0.019	0.096	0.190	0.346	0.480	0.659	0.832	1.056	1.099	1.311	0.000	0.433
2006	0.026	0.089	0.233	0.335	0.472	0.614	0.775	0.924	1.108	1.313	0.000	0.253
2007	0.042	0.099	0.205	0.350	0.477	0.653	0.810	0.905	1.073	1.668	0.000	0.316

Table 19. Extended time series of total fishery catch (mt). To estimate commercial discards for 1960-1988, the discards to landings ratio for 1989-1997 = 0.504 was applied to commercial landings. To estimate recreational catch for 1960-1980, 50% of the Mayo 1982 estimates were included.

Year	Comm. Land.	Comm. Disc.	DWF Land.	Rec Catch	Total Catch
1960	22236	11198	0	3765	37,199
1961	20944	10548	0	3716	35,208
1962	20831	10491	0	3667	34,989
1963	18884	9510	5863	3528	37,785
1964	17204	8664	459	3341	29,668
1965	15785	7950	2089	3265	29,089
1966	11960	6023	823	2474	21,280
1967	8748	4406	896	1879	15,929
1968	6630	3339	2251	1473	13,693
1969	5149	2593	485	1107	9,334
1970	4493	2263	288	1003	8,047
1971	3974	2001	889	853	7,717
1972	4203	2117	1647	796	8,763
1973	5024	2530	1783	1118	10,455
1974	7106	3579	958	1,388	13,031
1975	7623	3839	685	1,403	13,550
1976	7302	3677	87	1,183	12,249
1977	8330	4195	28	1,398	13,951
1978	8936	4500	3	1,256	14,695
1979	8585	4324	0	1,198	14,107
1980	8424	4242	16	3,109	15,791
1981	9,856	4964	1	2,636	17,457
1982	8,704	4383	0	2,361	15,448
1983	7,794	3925	0	2,836	14,555
1984	7,769	2158	0	1,126	11,053
1985	6,727	4184	0	2,818	13,729
1986	7,176	2005	0	5,351	14,532
1987	6,276	2537	0	2,849	11,662
1988	5,943	1657	0	1,967	9,567
1989	3,984	2229	0	2,560	8,773
1990	4,571	3909	0	1,916	10,396
1991	7,081	3530	0	3,746	14,357
1992	6,259	5668	0	2,048	13,975
1993	4,726	1436	0	1,478	7,640
1994	4,392	807	0	1,229	6,428
1995	3,073	2,057	0	622	5,752
1996	2,945	1,522	0	998	5,465
1997	2,188	1,843	0	551	4,582
1998	1,896	3,331	0	411	5,638
1999	1,505	4,819	0	862	7,186
2000	1,207	2,352	0	2,524	6,083
2001	1,729	1,499	0	2,098	5,326
2002	3,173	5,636	0	1,781	10,590
2003	4,405	2,153	0	4,006	10,564
2004	4,231	893	0	2,057	7,181
2005	4,266	662	0	1,318	6,246
2006	4,062	1,387	0	1,516	6,965
2007	4,196	1,859	0	1,812	7,867

Table 20. NEFSC spring and fall trawl survey indices for scup. Strata set includes only offshore strata 1-12, 23, 25, and 61-76 for consistency over entire time series. The Fall series strata set excludes inshore strata 1-61 that are included in the 1984 and later indices at age in Table 22.

Year	Spring No./tow	Spring Kg/tow	Spring SSB kg/tow	Spring SSB 3-yr avg	Fall No./tow	Fall Kg/tow
1963					2.12	1.21
1964					118.70	2.23
1965					3.84	0.62
1966					2.00	0.41
1967					29.38	1.46
1968	59.21	2.25	0.94		14.35	0.54
1969	2.26	0.40	0.39	0.88	99.41	4.48
1970	78.50	3.01	1.30	1.09	10.34	0.22
1971	70.91	2.41	1.57	1.28	7.730	0.25
1972	49.80	2.30	0.98	1.21	40.56	2.34
1973	3.62	1.19	1.09	1.38	22.82	0.93
1974	30.28	3.24	2.06	1.92	9.94	1.01
1975	14.01	3.12	2.61	1.73	52.21	3.40
1976	4.09	0.63	0.53	2.50	161.14	7.35
1977	42.46	4.48	4.35	2.49	32.69	1.71
1978	39.85	3.49	2.59	2.77	12.17	1.32
1979	22.42	1.95	1.38	1.69	15.77	0.61
1980	9.31	1.31	1.09	1.12	11.05	0.92
1981	14.72	1.16	0.89	1.00	67.14	3.01
1982	7.88	1.16	1.02	0.65	25.47	1.17
1983	0.80	0.29	0.03	0.46	4.59	0.34
1984	8.52	0.51	0.33	0.24	24.03	1.22
1985	14.67	0.80	0.37	0.68	68.30	3.56
1986	11.74	1.30	1.33	0.98	46.19	1.66
1987	10.82	1.21	1.24	1.10	5.76	0.15
1988	25.41	1.26	0.73	0.66	5.75	0.09
1989	1.63	0.12	0.00	0.35	94.05	3.37
1990	1.17	0.39	0.34	0.26	16.53	0.83
1991	12.61	0.75	0.45	0.32	9.52	0.43
1992	6.79	0.40	0.21	0.32	16.19	1.12
1993	2.93	0.33	0.31	0.18	0.43	0.04
1994	1.54	0.09	0.03	0.15	3.59	0.11
1995	2.90	0.22	0.12	0.06	24.72	0.91
1996	0.53	0.03	0.02	0.08	4.46	0.23
1997	0.91	0.11	0.11	0.06	16.92	0.88
1998	40.04	0.87	0.05	0.08	25.35	0.69
1999	1.70	0.12	0.09	0.08	85.23	2.07
2000	6.71	0.33	0.11	0.25	99.33	4.79
2001	13.03	0.80	0.54	3.30	20.28	1.11
2002	154.86	13.46	9.24	3.31	95.62	3.79
2003	6.01	0.28	0.15	3.74	28.18	0.80
2004	57.58	2.84	1.82	0.69	10.38	0.27
2005	19.22	0.55	0.10	1.32	4.50	0.07
2006	5.71	2.10	2.04	0.76	96.41	1.92
2007	10.60	0.36	0.14	1.16	41.52	2.21
2008	9.68	1.44	1.30			

Table 21. NEFSC spring trawl survey stratified mean number of scup per tow at age. Strata set includes only offshore strata 1-12, 23, 25, and 61-76, corresponding to the spring survey indices in Table 20.

Spring	Age														
Year	0	1	2	3	4	5	6	7	8	9	10	11	Total	age 2+	age 3+
1977		6.62	32.08	3.54	0.16	0.04	0.01	0.01					42.46	35.84	3.76
1978		26.90	4.67	6.50	1.31	0.32	0.12	0.03					39.85	12.95	8.28
1979		15.63	4.04	0.88	1.28	0.37	0.06	0.13	0.02	0.01			22.42	6.79	2.75
1980		2.39	5.61	0.57	0.17	0.25	0.15	0.08	0.08	0.01			9.31	6.92	1.31
1981		10.78	2.16	1.15	0.17	0.14	0.05	0.15	0.12				14.72	3.94	1.78
1982		3.80	1.77	1.39	0.38	0.17	0.13	0.07	0.07	0.10			7.88	4.08	2.31
1983		0.70	0.03	0.06				0.01					0.80	0.10	0.07
1984		6.14	1.97	0.22	0.12	0.07							8.52	2.38	0.41
1985		12.11	2.32	0.20	0.04								14.67	2.56	0.24
1986		1.05	10.26	0.43									11.74	10.69	0.43
1987		4.57	3.60	1.81	0.74	0.04	0.02	0.03	0.01				10.82	6.25	2.65
1988		16.74	8.36	0.17	0.03	0.01	0.03	0.07					25.41	8.67	0.31
1989		0.79	0.74	0.09	0.01								1.63	0.84	0.10
1990		0.12	0.30	0.30	0.18	0.09	0.13	0.05					1.17	1.05	0.75
1991		10.61	0.70	1.11	0.19								12.61	2.00	1.30
1992		5.72	0.88	0.07	0.05	0.06	0.01						6.79	1.07	0.19
1993		0.61	2.02	0.17	0.11	0.02							2.93	2.32	0.30
1994		1.34	0.16	0.04									1.54	0.20	0.04
1995		2.29	0.44	0.11	0.05	0.01							2.90	0.61	0.17
1996		0.44	0.05	0.03	0.01								0.53	0.09	0.04
1997		0.17	0.64	0.10									0.91	0.74	0.10
1998		39.90	0.12	0.02									40.04	0.14	0.02
1999		1.03	0.67										1.70	0.67	0.00
2000		5.93	0.71	0.07									6.71	0.78	0.07
2001		7.90	5.03	0.08		0.02							13.03	5.13	0.10
2002		109.01	15.60	26.67	3.27	0.31							154.86	45.85	30.25
2003		5.08	0.79	0.07	0.06								6.01	0.92	0.14
2004		38.69	16.15	1.31	0.82	0.60							57.58	18.89	2.74
2005		18.26	0.81	0.13	0.02								19.22	0.96	0.15
2006		1.56	0.51	0.80	0.35	0.70	1.69	0.10					5.71	4.15	3.64
2007		9.73	0.41	0.44	0.00	0.01	0.01						10.60	0.87	0.46

Table 22. NEFSC fall trawl survey stratified mean number of scup per tow at age. Strata set includes offshore strata 1-12, 23, 25, 61-76, and inshore strata 1-61.

Fall	Age														
Year	0	1	2	3	4	5	6	7	8	9	10	11	Total	age 2+	age 3+
1984	47.64	9.20	0.34	0.03	0.01		0.01						59.96	0.39	0.05
1985	61.22	11.53	1.10	0.26	0.06	0.05							74.71	1.47	0.37
1986	70.19	6.58	0.57		0.01								77.36	0.58	0.01
1987	49.93	29.85	0.46	0.01									80.45	0.47	0.01
1988	47.44	15.95	0.67	0.10									64.22	0.77	0.10
1989	176.37	25.92	0.66	0.03									202.99	0.69	0.03
1990	77.45	9.21	0.75	0.04									87.46	0.79	0.04
1991	151.62	12.51	0.07	0.02									164.24	0.09	0.02
1992	25.92	14.51	1.66	0.04	0.02								42.15	1.72	0.06
1993	46.78	9.76	0.32										56.86	0.32	0.00
1994	39.54	3.92	0.04	0.01									43.52	0.05	0.01
1995	33.04	2.61	0.08	0.01									35.74	0.09	0.01
1996	24.42	2.86	0.43	0.01									27.73	0.44	0.01
1997	46.91	0.61	0.02		0.01								47.66	0.03	0.01
1998	57.73	9.64	0.09	0.03	0.01								67.50	0.13	0.04
1999	96.06	9.77	1.37	0.07	0.01								107.28	1.45	0.08
2000	98.72	20.60	3.14	0.48	0.11	0.07							123.12	3.80	0.66
2001	91.84	10.32	1.82	0.12	0.04	0.01							104.15	1.99	0.17
2002	180.09	43.31	0.90	0.35	0.04	0.01							224.70	1.30	0.40
2003	53.70	5.66	2.30	1.33	0.82	0.20	0.02						64.02	4.67	2.37
2004	41.83	33.46	1.14	1.70	0.39	0.12	0.04	0.01					78.69	3.40	2.26
2005	27.26	7.94	1.02	0.14	0.04	0.04							36.43	1.23	0.21
2006	146.85	20.08	0.92	0.07	0.05	0.01	0.03	0.01					168.02	1.09	0.17
2007	113.95	40.28	0.60	0.24	0.05	0.03	0.05	0.02					155.22	0.99	0.39

Table 23. NEFSC 1992-2007 Winter trawl survey indices of abundance for scup, offshore survey strata 1-12 and 61-76.

Year	Mean number per tow	Mean kg per tow
1992	65.56	2.87
1993	25.71	2.73
1994	17.09	0.66
1995	69.50	2.26
1996	18.28	1.19
1997	13.90	0.32
1998	46.92	1.20
1999	15.04	0.71
2000	24.21	1.33
2001	55.49	1.58
2002	267.83	7.56
2003	24.16	0.49
2004	380.59	3.82
2005	84.74	1.96
2006	201.96	3.72
2007	101.08	2.95
Mean	88.25	2.21

Table 24. NEFSC 1992-2007 winter trawl survey stratified mean number of scup per tow at age, offshore survey strata 1-12 and 61-76. The 1992, 1993, and 1996 lengths are aged with the corresponding annual spring survey age-length key.

Winter	Age											
Year	0	1	2	3	4	5	6	7	8	Total	age 2+	age 3+
1992		59.78	4.93	0.20	0.09	0.10	0.46			65.56	5.78	0.85
1993		2.51	22.05	0.56	0.57	0.02				25.71	23.19	1.15
1994		16.31	0.73	0.02	0.02	0.01				17.09	0.78	0.05
1995		67.35	1.94	0.15	0.01	0.01	0.02	0.01		69.50	2.15	0.21
1996		12.94	5.31	0.03	0.01					18.28	5.34	0.04
1997		13.27	0.52	0.11						13.90	0.64	0.11
1998		45.62	0.75	0.22	0.21	0.08	0.03	0.01		46.92	1.30	0.55
1999		12.48	2.41	0.12	0.02	0.01				15.04	2.56	0.15
2000		20.28	3.21	0.68	0.03			0.01		24.21	3.93	0.72
2001		48.54	6.48	0.36	0.09	0.02				55.49	6.95	0.47
2002		257.08	7.44	2.96	0.33	0.01	0.01			267.83	10.75	3.31
2003		23.77	0.28	0.07	0.03		0.02			24.16	0.39	0.11
2004		380.22	0.29	0.07	0.01					380.59	0.37	0.08
2005		80.03	4.62	0.09						84.74	4.71	0.09
2006		198.52	2.64	0.66	0.03	0.04	0.07			201.96	3.44	0.80
2007		99.18	1.86	0.02	0.02					101.08	1.90	0.04

Table 25. MADMF trawl survey mean number of scup per tow and mean weight (kg) per tow for spring (survey regions 1-3) and fall (survey regions 1-5). Time series revised in 2008 to account for stratum area changes effective in 2006.

	Spring		Fall	
Year	No./Tow	Kg/tow	No./Tow	Kg/Tow
1978	90.08	31.71	1859.40	14.82
1979	76.14	18.05	1150.16	12.20
1980	189.82	41.39	1183.02	12.53
1981	298.53	17.63	971.87	14.34
1982	10.46	0.98	2153.76	9.17
1983	25.29	3.51	1623.13	12.90
1984	17.90	6.53	963.49	12.29
1985	67.02	3.40	647.63	12.09
1986	44.17	7.35	773.61	9.15
1987	6.05	1.37	561.61	7.72
1988	13.98	2.09	1396.86	14.15
1989	13.32	2.02	580.73	7.77
1990	144.06	21.45	1128.07	7.21
1991	28.73	6.05	1150.71	10.18
1992	14.49	2.52	2440.96	11.54
1993	19.13	4.23	1023.11	10.06
1994	9.71	2.85	820.31	9.84
1995	49.29	2.76	507.02	4.11
1996	5.18	0.68	1019.96	9.15
1997	3.22	0.71	921.21	7.25
1998	1.37	0.21	709.61	6.94
1999	11.61	1.93	1212.23	18.07
2000	307.00	18.02	867.00	11.63
2001	7.28	2.37	1205.60	9.89
2002	281.36	18.77	1137.64	8.32
2003	0.22	0.07	3209.61	14.87
2004	41.71	13.04	1483.56	10.07
2005	9.32	3.25	4005.89	21.53
2006	92.97	22.41	1231.49	9.46
2007	13.30	2.03	1774.23	11.65
2008	145.72	27.89		
Mean	65.76	9.27	1323.78	11.03

Table 26. RIDFW trawl survey mean number of scup per tow and mean weight (kg) per tow for spring and fall.

	Spring		Fall	
Year	No./Tow	Kg/tow	No./Tow	Kg/Tow
1981	12.49	0.40	196.22	2.54
1982	0.43	0.04	63.87	0.70
1983	3.59	0.32	173.63	2.75
1984	13.24	0.88	589.68	10.57
1985	8.30	0.41	74.27	1.51
1986	1.78	0.33	340.06	4.20
1987	0.04	0.01	314.20	4.73
1988	0.23	0.04	804.00	7.10
1989	0.17	0.04	326.86	6.62
1990	0.64	0.15	527.31	5.66
1991	2.93	0.57	655.69	16.62
1992	1.88	0.61	1105.51	9.10
1993	1.12	0.06	1246.35	8.90
1994	2.08	0.53	236.12	3.66
1995	4.33	0.53	423.02	5.03
1996	0.52	0.07	184.73	3.83
1997	1.93	0.15	597.90	6.04
1998	0.15	0.03	150.38	1.89
1999	0.38	0.07	832.22	12.39
2000	84.05	3.54	588.73	9.11
2001	29.68	5.08	1139.17	11.07
2002	174.80	10.28	716.12	9.27
2003	0.00	0.00	1181.83	11.38
2004	2.59	0.45	1616.24	9.58
2005	2.95	1.63	2216.72	21.35
2006	53.12	3.90	765.90	11.26
2007	1.95	0.24	2410.00	23.76
2008				
Mean	15.01	1.12	721.36	8.17

Table 27. CTDEP spring trawl survey mean number of scup per tow at age, total mean number per tow, and total mean weight (kg) per tow.

							Age								Total	Total	Age
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	No./Tow	Kg/Tow	2+
1984	0.49	1.31	0.59	0.30	0.08	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.00	2.80	0.64	2.31
1985	2.94	2.00	0.33	0.24	0.05	0.02	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	5.61	1.22	2.71
1986	4.44	1.65	0.99	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.40	0.78	2.79
1987	0.43	1.65	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	0.37	1.76
1988	1.18	0.30	0.51	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.32	0.88
1989	5.63	0.56	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.77	0.63	0.62
1990	2.56	2.06	0.21	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	0.61	2.30
1991	4.25	1.44	1.26	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.09	0.94	2.80
1992	0.39	1.21	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.48	1.36
1993	0.04	2.29	0.19	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.32	0.49	2.49
1994	0.81	2.03	0.93	0.10	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.58	3.09
1995	12.94	0.39	0.20	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.24	0.65	0.64
1996	5.20	2.48	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.25	0.73	2.56
1997	3.16	2.61	1.68	0.06	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.23	0.75	4.39
1998	10.07	0.58	0.12	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.25	0.75	0.76
1999	2.71	1.75	0.16	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	0.56	2.02
2000	124.51	17.18	4.24	0.20	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.46	4.56	21.71
2001	1.65	18.99	1.57	0.25	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.20	2.85	20.84
2002	49.15	66.61	123.25	17.44	1.29	0.10	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	257.91	13.16	208.76
2003	0.14	4.05	3.28	4.96	0.61	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	13.12	2.28	12.98
2004	0.01	3.97	8.96	4.90	8.21	0.76	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	26.92	3.93	26.90
2005	1.16	1.28	1.06	1.51	1.27	1.94	0.22	0.05	0.00	0.00	0.00	0.00	0.00	0.00	8.49	1.65	7.33
2006	18.48	23.72	5.63	2.07	2.56	3.16	2.90	0.53	0.01	0.00	0.00	0.00	0.00	0.00	59.06	10.41	40.58
2007	7.51	15.86	5.84	1.49	0.55	0.54	0.54	0.39	0.07	0.01	0.00	0.00	0.00	0.00	32.80	3.32	25.29

Table 28. CTDEP fall trawl survey mean number of scup per tow at age, total mean number per tow, and total mean weight (kg) per tow.

							Age					Total	Total	Age
Year	0	1	2	3	4	5	6	7	8	9	10	No/Tow	Kg/Tow	2+
1984	7.99	1.04	0.78	0.52	0.28	0.09	0.02	0.00	0.00	0.00	0.00	10.72	1.36	1.69
1985	25.01	4.71	0.40	0.59	0.19	0.04	0.03	0.00	0.00	0.00	0.00	30.97	2.50	1.25
1986	13.06	9.98	2.50	0.19	0.01	0.01	0.01	0.00	0.00	0.00	0.00	25.76	2.95	2.72
1987	12.47	4.17	1.25	0.58	0.06	0.01	0.01	0.00	0.00	0.00	0.00	18.55	1.79	1.91
1988	31.89	5.71	1.82	0.24	0.03	0.00	0.00	0.00	0.00	0.00	0.00	39.69	2.27	2.09
1989	40.88	22.60	1.51	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	65.08	3.65	1.60
1990	54.34	7.74	6.95	0.40	0.03	0.01	0.01	0.00	0.00	0.01	0.00	69.49	5.00	7.41
1991	291.58	17.03	1.76	1.04	0.15	0.01	0.00	0.00	0.00	0.00	0.00	311.57	8.30	2.96
1992	50.91	26.58	5.54	0.40	0.29	0.01	0.01	0.00	0.00	0.00	0.00	83.74	4.96	6.25
1993	74.06	1.83	1.02	0.12	0.01	0.01	0.00	0.00	0.00	0.00	0.00	77.05	3.72	1.16
1994	90.76	1.12	0.46	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	92.53	3.33	0.65
1995	32.46	26.52	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.13	4.63	0.15
1996	51.50	8.56	1.37	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	61.47	3.68	1.41
1997	31.79	8.68	0.63	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	41.28	2.49	0.81
1998	90.40	12.24	0.54	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	103.27	4.50	0.63
1999	498.18	30.93	8.35	0.19	0.02	0.01	0.00	0.00	0.00	0.00	0.00	537.68	22.72	8.57
2000	250.39	261.45	8.32	0.79	0.14	0.01	0.00	0.00	0.00	0.00	0.00	521.10	30.76	9.26
2001	140.51	16.90	18.42	1.61	0.19	0.03	0.00	0.00	0.00	0.00	0.00	177.66	11.28	20.25
2002	259.90	47.62	23.32	16.81	0.67	0.33	0.05	0.00	0.01	0.00	0.00	348.70	23.69	41.18
2003	52.91	15.35	32.07	22.39	26.44	2.49	0.54	0.02	0.02	0.00	0.00	152.23	28.95	83.96
2004	251.05	4.13	8.34	15.08	5.98	6.25	0.53	0.07	0.01	0.02	0.00	291.46	16.31	36.28
2005	373.32	32.56	8.14	2.44	4.01	1.50	1.69	0.33	0.06	0.00	0.00	424.05	13.79	18.17
2006	52.16	51.02	9.52	2.34	0.26	0.35	0.38	0.68	0.04	0.00	0.00	116.75	10.49	13.57
2007	319.89	118.06	29.34	5.93	0.90	0.23	0.30	0.31	0.31	0.03	0.00	475.30	24.15	37.35

Table 29. NYDEC trawl survey indices at ages 0, 1 and 2 and older (2+); NJBMF trawl survey mean number of scup per tow and mean weight (kg) per tow; VIMS age 0 index.

	NYDEC Trawl			NJBMF Trawl		VIMS
Year	Age 0	Age 1	Age 2+	No/tow	Kg/tow	Age 0
1987	0.33	3.43	0.09			
1988	1.19	1.96	0.05			2.07
1989	0.67	11.02	0.04	72.75	2.75	3.07
1990	5.32	1.30	0.14	74.72	3.77	4.92
1991	13.17	2.31	0.22	200.61	6.17	1.90
1992	15.25	1.54	0.06	227.70	7.16	0.65
1993	0.29	0.72	0.04	256.91	5.21	3.36
1994	6.11	0.36	0.06	86.45	3.30	0.90
1995	0.61	7.49	0.03	27.13	2.08	0.39
1996	0.42	0.94	0.15	30.81	1.04	0.54
1997	20.23	0.74	0.20	52.09	3.82	0.21
1998	73.22	1.46	0.05	220.05	4.88	0.50
1999	35.85	2.25	0.03	209.10	10.30	0.27
2000	186.07	16.73	1.02	260.97	6.56	0.13
2001	83.01	2.99	1.22	163.37	4.32	1.34
2002	346.32	5.47	6.01	565.96	25.65	0.24
2003	266.56	0.38	1.35	804.08	10.19	0.96
2004	40.82	0.92	0.70	449.12	11.70	0.46
2005	n/a	n/a	n/a	147.98	4.19	1.11
2006	122.23	3.12	0.35	943.63	16.52	1.58
2007	109.47	4.18	0.61	1185.54	38.27	2.99
Mean	66.36	3.47	0.62	314.68	8.84	1.38

Table 30. University of Rhode Island Graduate School of Oceanography (URIGSO) trawl survey indices for scup (total catch number).

Year	Number
1963	80
1964	181
1965	100
1966	124
1967	686
1968	217
1969	142
1970	146
1971	523
1972	345
1973	689
1974	543
1975	1243
1976	2591
1977	1806
1978	1112
1979	1033
1980	510
1981	952
1982	478
1983	1477
1984	1374
1985	1411
1986	1062
1987	809
1988	762
1989	2386
1990	953
1991	1841
1992	654
1993	1775
1994	471
1995	682
1996	628
1997	516
1998	551
1999	1830
2000	3978
2001	3225
2002	5380
2003	2047
2004	468
2005	857
2006	4473
2007	2889

Table 31. VIMS ChesMMAP trawl survey indices for scup. Indices are maximum seasonal values (usually July or September) minimum swept area estimates.

Year	Total N	Total B	Age 0 N	Age 1 N
2002	477,359	77,307	324,291	154,625
2003	624,210	61,501	93,089	500,176
2004	2,166,993	146,627	89,384	1,975,035
2005	3,402,832	197,762	1,864,624	673,437
2006	1,318,855	109,652	1,180,618	566,905
2007	894,289	23,183	0	894,289
2008	52,317	3,488	n/a	n/a
Mean	1,480,756	102,672	592,001	794,078

Table 32. Summary results for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

Year	SSB (mt)	Recruits (Age 0; 000s)	F
1984	18,151	108,158	0.533
1985	17,010	78,360	0.608
1986	15,953	60,241	0.779
1987	13,531	48,392	0.676
1988	10,621	91,460	0.701
1989	8,894	66,774	0.695
1990	9,438	114,796	0.673
1991	9,211	100,966	1.027
1992	7,928	39,496	1.068
1993	6,147	45,406	1.109
1994	4,428	75,827	1.120
1995	3,993	36,349	0.920
1996	5,103	30,377	0.758
1997	5,609	87,276	0.487
1998	6,772	123,306	0.329
1999	12,367	217,853	0.206
2000	25,727	311,243	0.149
2001	51,511	194,937	0.080
2002	72,536	114,487	0.186
2003	76,533	108,778	0.111
2004	81,638	171,236	0.079
2005	93,754	116,828	0.061
2006	105,645	219,752	0.057
2007	119,343	307,943	0.054

Table 33. January 1 population number (N, 000s) estimates for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

	Age							
Year	0	1	2	3	4	5	6	7+
1984	108158	61923	30650	8353	3465	3014	4824	13099
1985	78360	80287	40534	14126	4100	1637	1423	8775
1986	60241	56693	49486	16395	6531	1780	710	4704
1987	48392	44866	36176	21410	6555	2350	641	2148
1988	91460	36323	29465	16671	9319	2643	947	1201
1989	66774	69016	24120	13772	7049	3672	1041	887
1990	114796	49652	44341	10620	5925	2780	1448	794
1991	100966	84717	31624	19059	4624	2402	1127	935
1992	39496	72016	49032	10527	5990	1289	670	611
1993	45406	26601	37486	12722	3136	1615	347	365
1994	75827	31708	14804	11151	3641	810	417	196
1995	36349	55377	19198	5296	3162	929	207	163
1996	30377	25410	31416	6090	1802	999	293	122
1997	87276	22335	15998	12939	2438	670	371	158
1998	123306	65699	14356	8195	6455	1218	335	268
1999	217853	94257	44254	8205	4802	3786	714	358
2000	311243	170265	67634	28464	5449	3191	2515	716
2001	194937	247527	128258	47186	20013	3832	2244	2280
2002	114487	156810	192914	96113	35619	15111	2893	3428
2003	108778	68584	55407	47367	65005	24205	10264	4313
2004	171236	86609	51990	39723	34636	47549	17705	10695
2005	116828	138009	67886	39371	30017	26177	35936	21519
2006	219752	94532	109412	52530	30297	23101	20146	44303
2007	307943	177299	74375	83856	40578	23407	17848	49939

Table 34. Fishing mortality (F) estimates for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

	Age							
Year	0	1	2	3	4	5	6	7+
1984	0.098	0.224	0.575	0.512	0.550	0.551	0.551	0.501
1985	0.124	0.284	0.705	0.571	0.634	0.635	0.636	0.564
1986	0.095	0.249	0.638	0.717	0.822	0.822	0.823	0.710
1987	0.087	0.220	0.575	0.632	0.708	0.709	0.709	0.623
1988	0.082	0.209	0.561	0.661	0.731	0.732	0.732	0.649
1989	0.096	0.242	0.620	0.643	0.730	0.731	0.731	0.637
1990	0.104	0.251	0.644	0.632	0.703	0.703	0.704	0.622
1991	0.138	0.347	0.900	0.957	1.077	1.078	1.079	0.945
1992	0.195	0.453	1.149	1.011	1.111	1.112	1.113	0.994
1993	0.159	0.386	1.012	1.051	1.154	1.154	1.155	1.032
1994	0.114	0.302	0.828	1.061	1.166	1.166	1.167	1.040
1995	0.158	0.367	0.948	0.878	0.952	0.953	0.955	0.861
1996	0.108	0.263	0.687	0.715	0.789	0.789	0.790	0.703
1997	0.084	0.242	0.469	0.495	0.494	0.494	0.490	0.460
1998	0.069	0.195	0.359	0.335	0.334	0.334	0.331	0.311
1999	0.046	0.132	0.241	0.209	0.209	0.209	0.207	0.193
2000	0.029	0.083	0.160	0.152	0.152	0.152	0.151	0.139
2001	0.018	0.049	0.089	0.081	0.081	0.081	0.081	0.075
2002	0.312	0.840	1.204	0.191	0.186	0.187	0.185	0.180
2003	0.028	0.077	0.133	0.113	0.113	0.113	0.112	0.104
2004	0.016	0.044	0.078	0.080	0.080	0.080	0.079	0.074
2005	0.012	0.032	0.056	0.062	0.062	0.062	0.061	0.058
2006	0.015	0.040	0.066	0.058	0.058	0.058	0.058	0.054
2007	0.016	0.044	0.073	0.055	0.055	0.055	0.055	0.051

Table 35. 2008 assessment Biological Reference Point input data.

Natural Mortality (M) =				0.20		
Proportion of mortality before spawning =				0.417		
Age	Selectivity on F	Selectivity on M	1-Jan Stock Weights	Catch Weights	1-Jun SSB Weights	Maturity
0	0.21	1.00	0.017	0.028	0.025	0.00
1	0.58	1.00	0.051	0.100	0.089	0.13
2	1.00	1.00	0.142	0.221	0.205	0.75
3	0.91	1.00	0.283	0.356	0.343	0.99
4	0.90	1.00	0.418	0.488	0.476	1.00
5	0.90	1.00	0.564	0.642	0.629	1.00
6	0.90	1.00	0.735	0.830	0.813	1.00
7+	0.90	1.00	1.041	1.041	1.041	1.00

Table 36. Proposed biological reference points and status evaluation for scup from 2008 accepted assessment model BASE_C2007_T1. The Northeast Data Poor Stocks Peer Review Panel adopted F40% = 0.177 as the proxy for FMSY, and SSBF40% = 92,044 mt as the proxy for SSBMSY (in **bold**).

BRP	F	Y/R	SSB/R	SSBproxy	MSYproxy	Landproxy	Discproxy
Fmax	0.283	0.146	0.499	57,759	16,903	12,764	4,139
F35%	0.207	0.142	0.683	80,280	16,615	13,236	3,379
F40%	**0.177**	**0.138**	**0.780**	**92,044**	**16,161**	**13,134**	**3,027**

BRP	SSBproxy	SSB07	%SSBproxy		MSYproxy	Catch07	%MSYproxy
Fmax	57,759	119,343	207%		16,903	7,867	47%
F35%	80,280	119,343	149%		16,615	7,867	47%
F40%	**92,044**	**119,343**	**130%**		**16,161**	**7,867**	**49%**

Scup; Figures

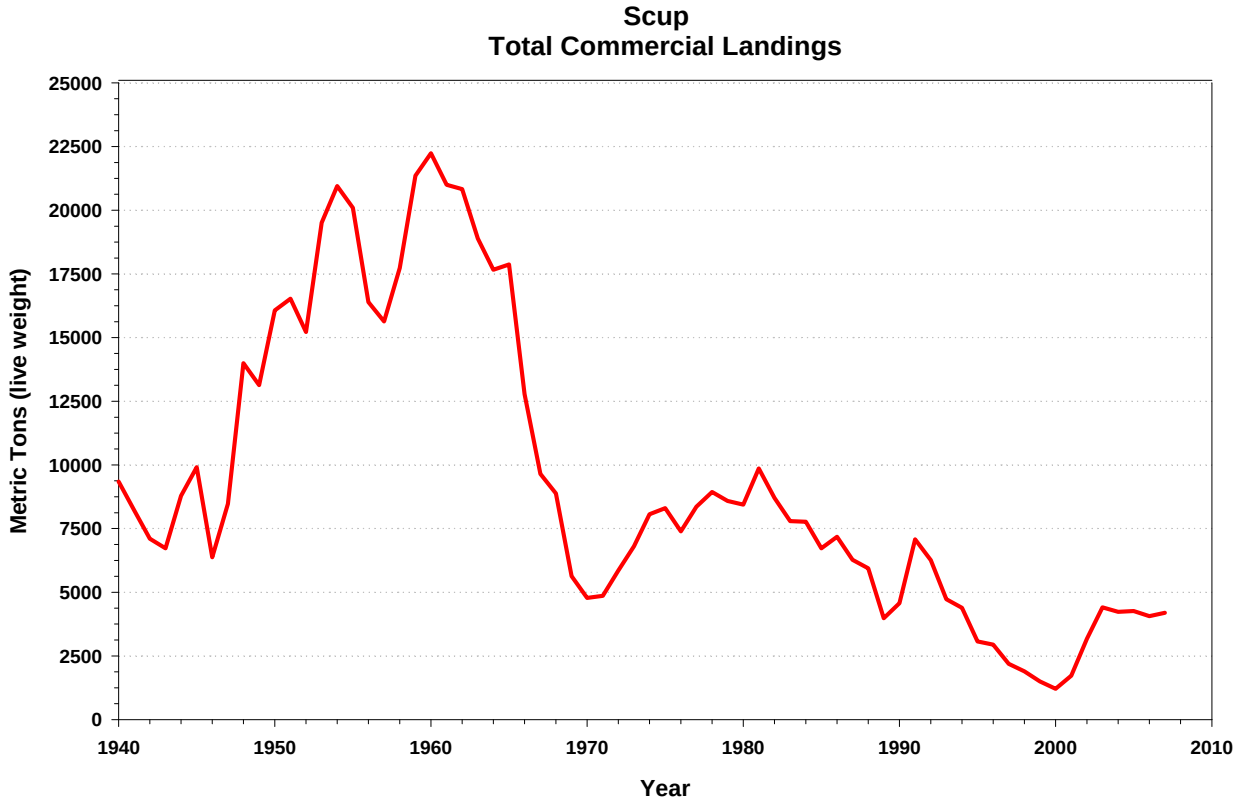


Figure 1. Total commercial fishery landings for scup.

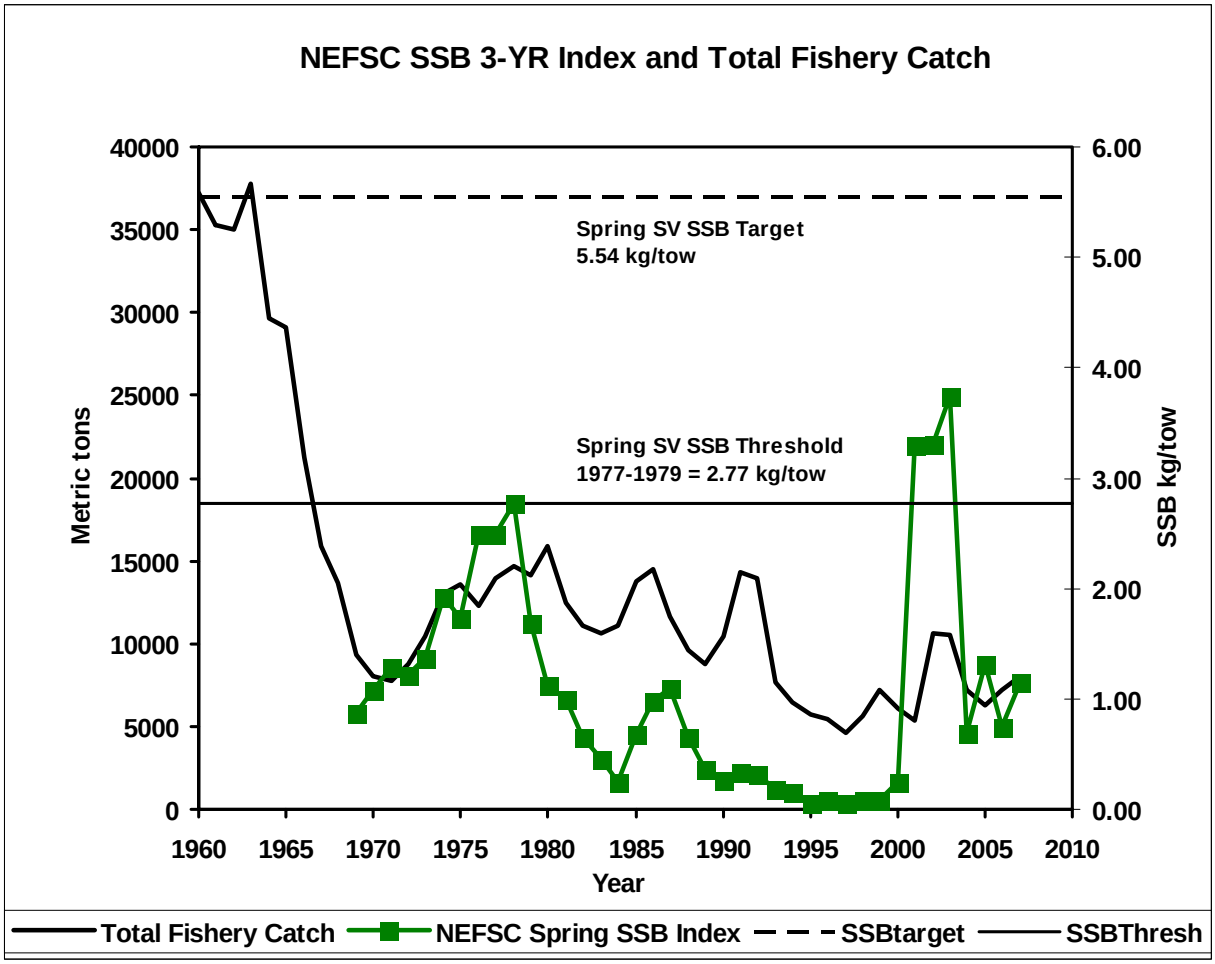


Figure 2. NEFSC Spring survey indices of scup spawning stock biomass per tow (SSB kg/tow) used as proxy target and threshold biomass Biological Reference Points.

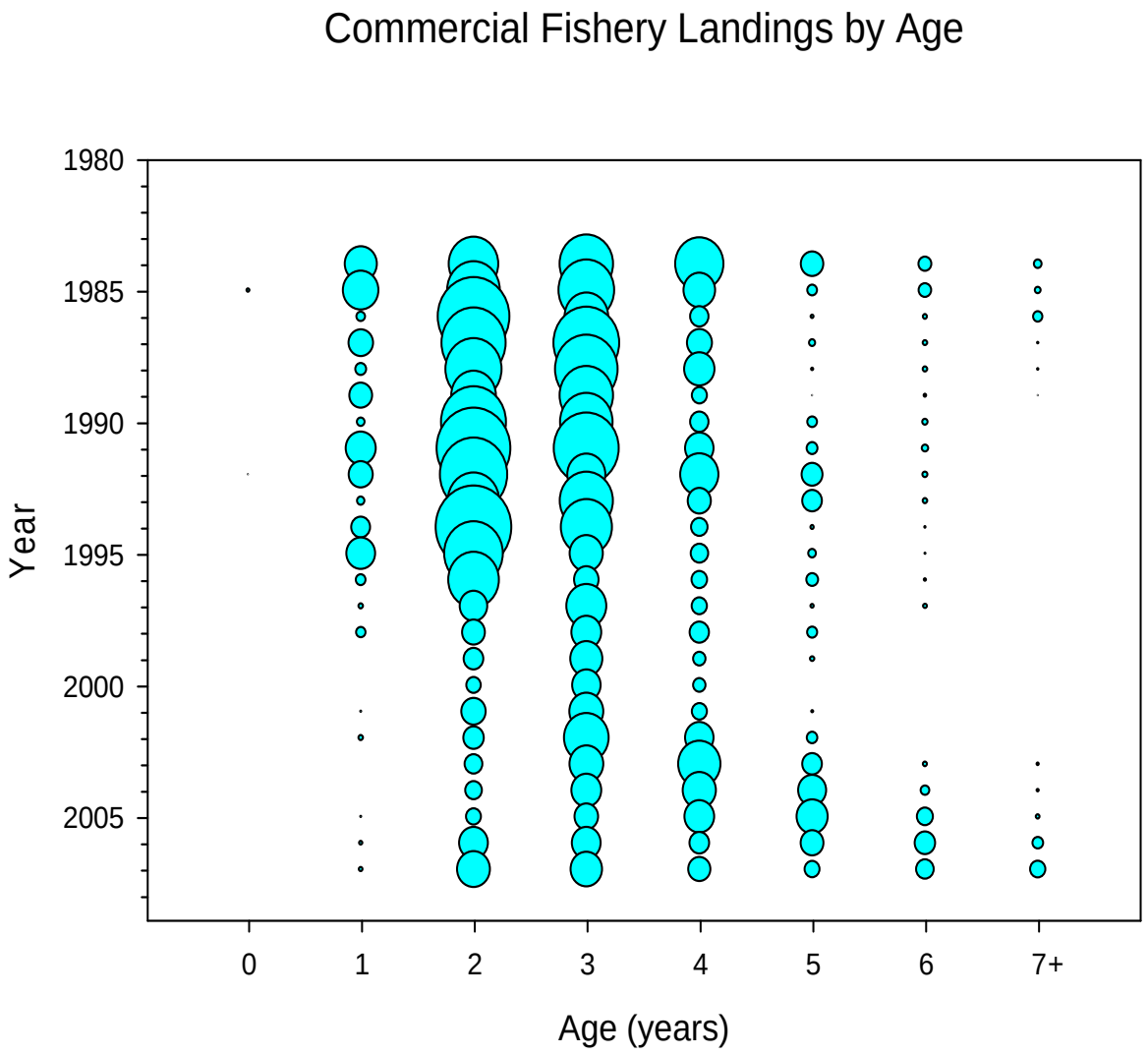


Figure 3. Commercial fishery landings by age for scup.

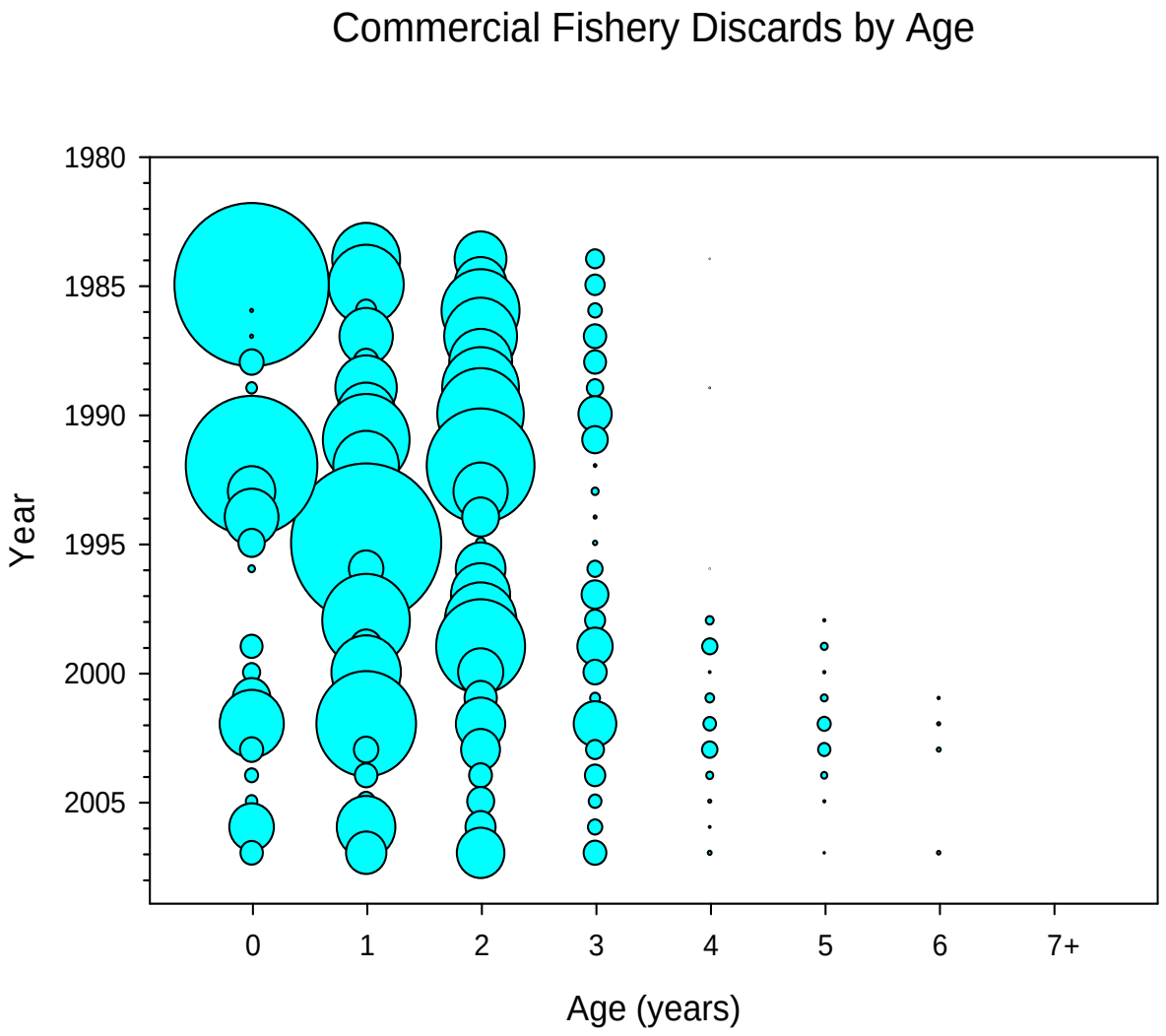


Figure 4. Commercial fishery discards by age for scup.

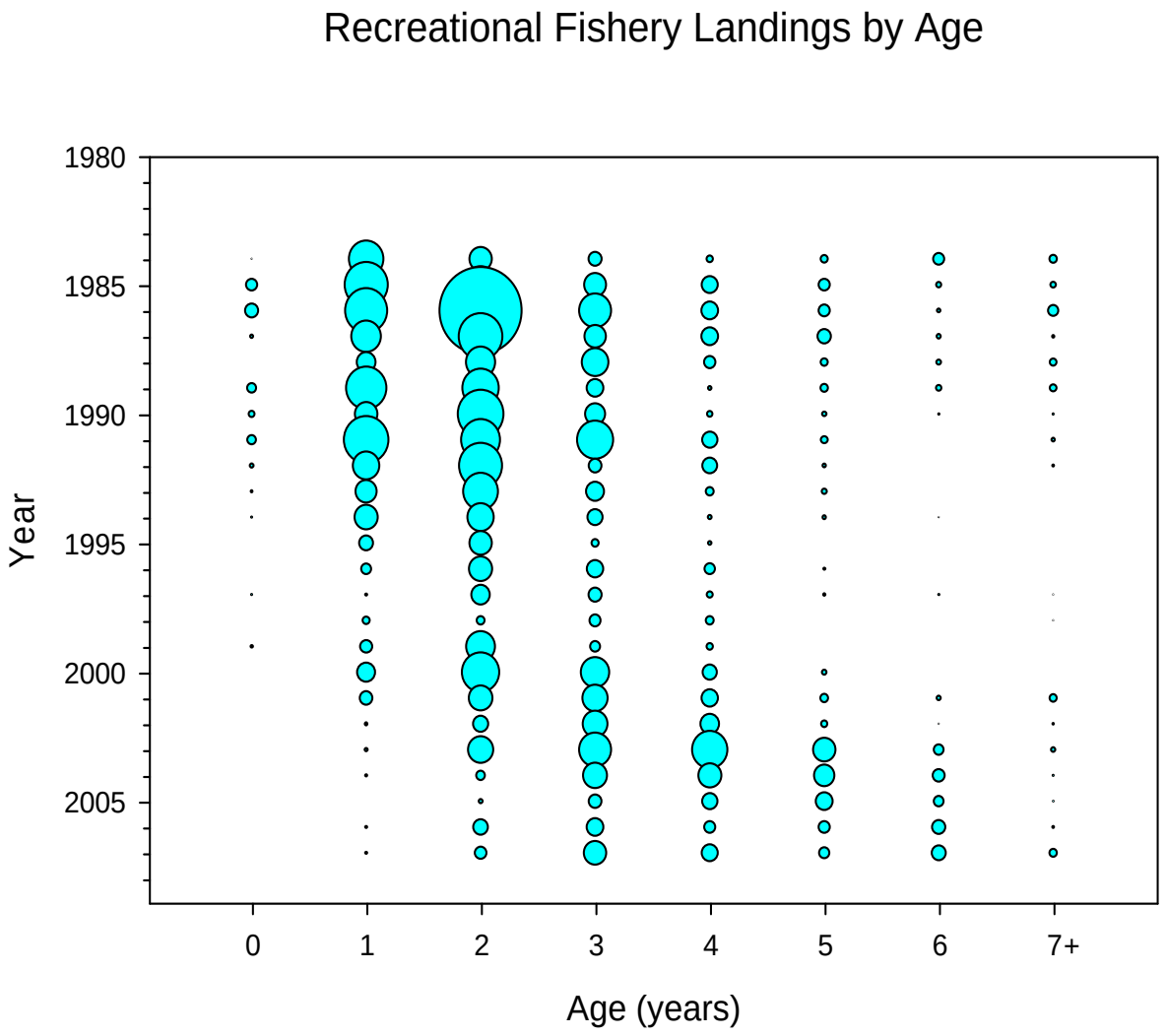


Figure 5. Recreational fishery landings by age for scup.

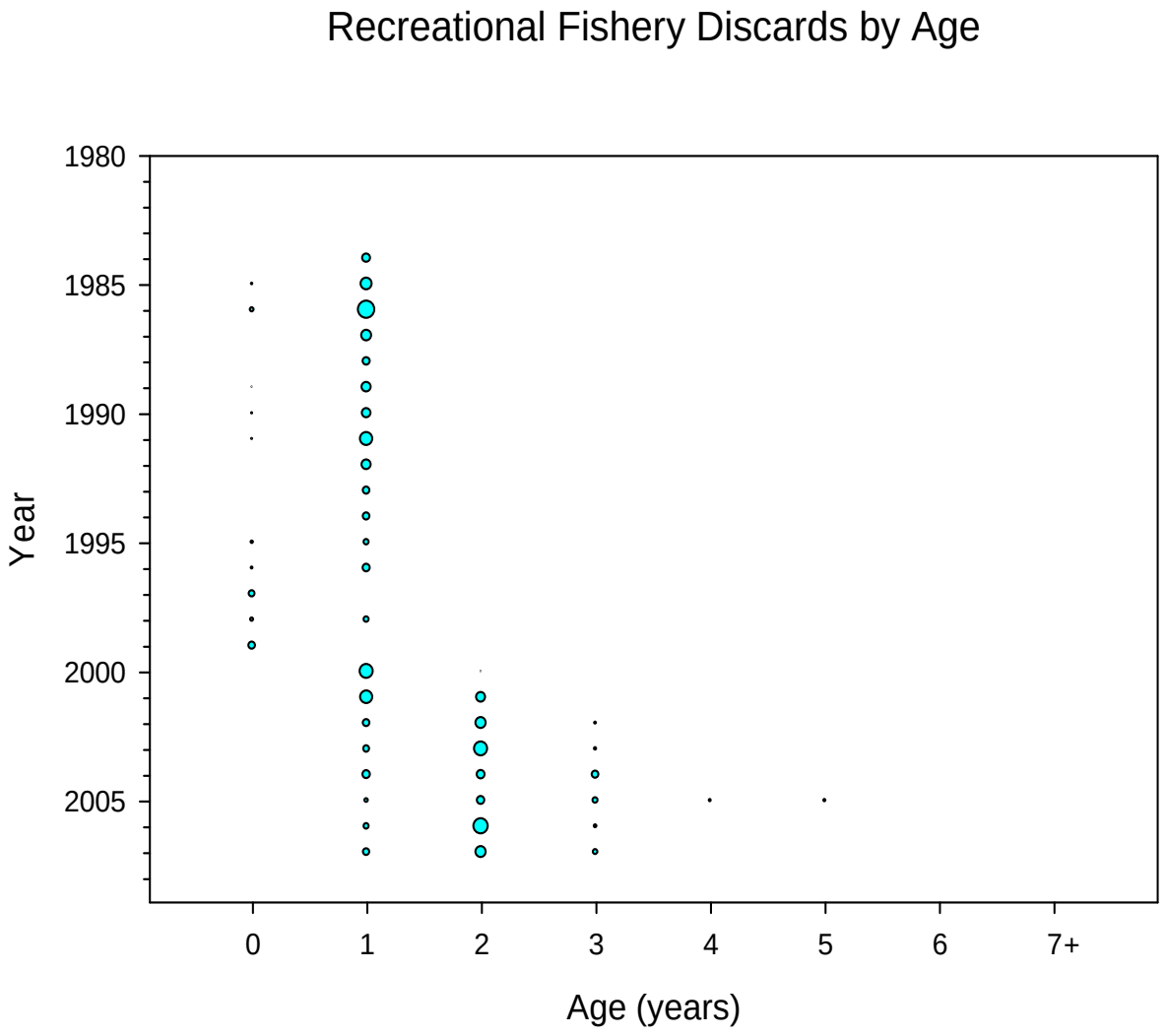


Figure 6. Recreational fishery discards by age for scup.

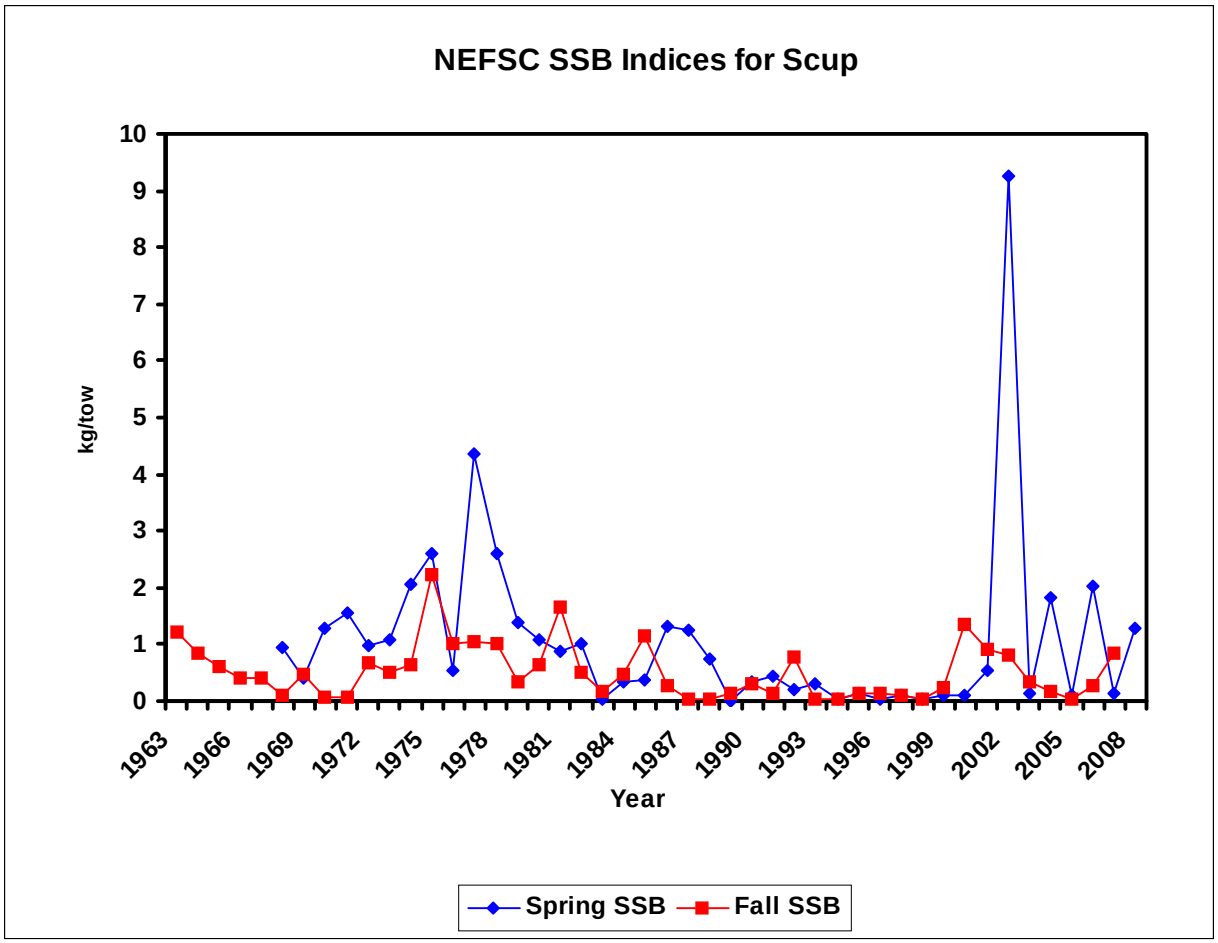


Figure 7. NEFSC spring and fall annual SSB indices for scup.

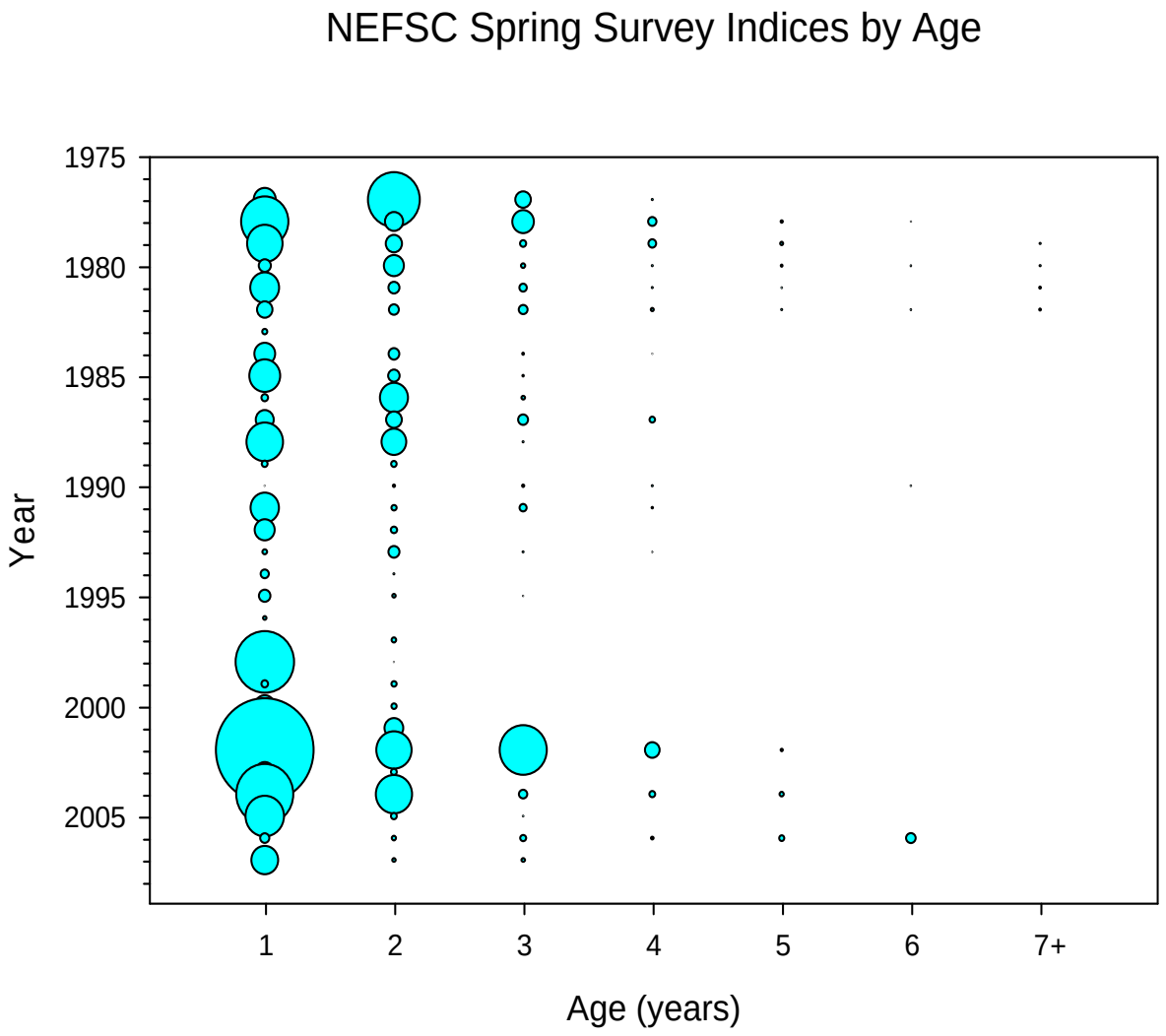


Figure 8. NEFSC Spring survey indices by age for scup.

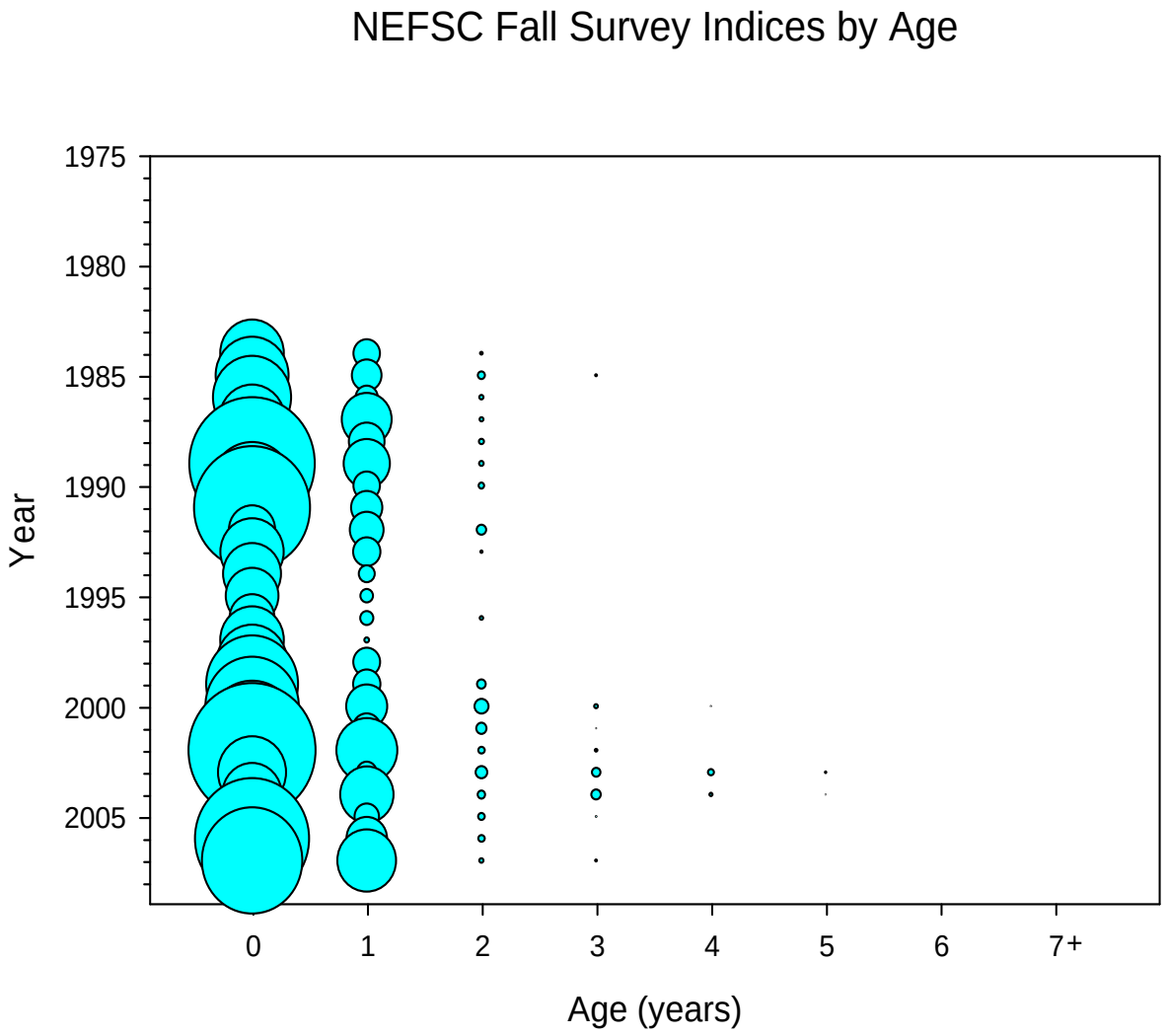


Figure 9. NEFSC Fall survey indices by age for scup.

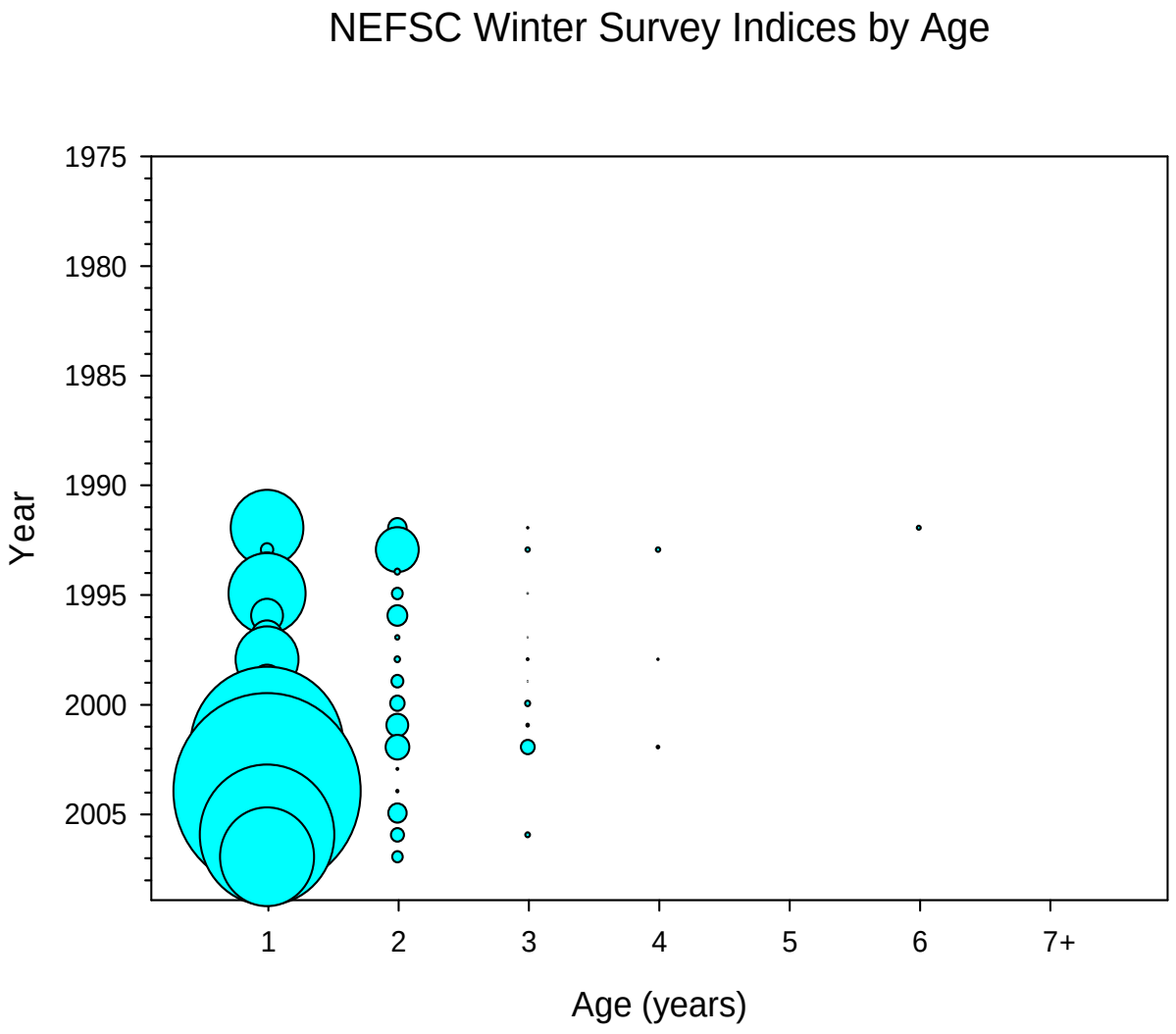


Figure 10. NEFSC Winter survey indices by age for scup.

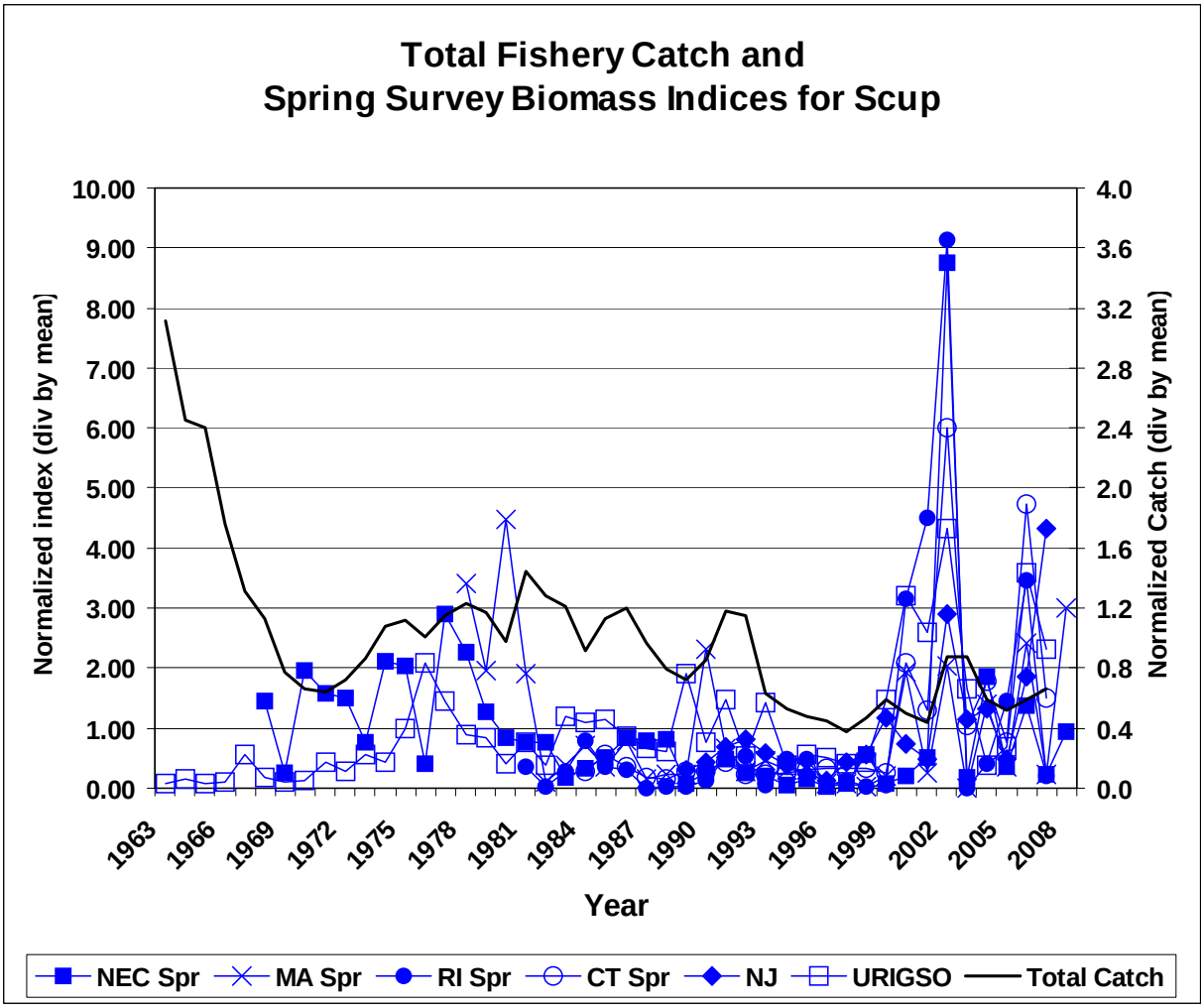


Figure 11. Research survey indices for scup: Spring

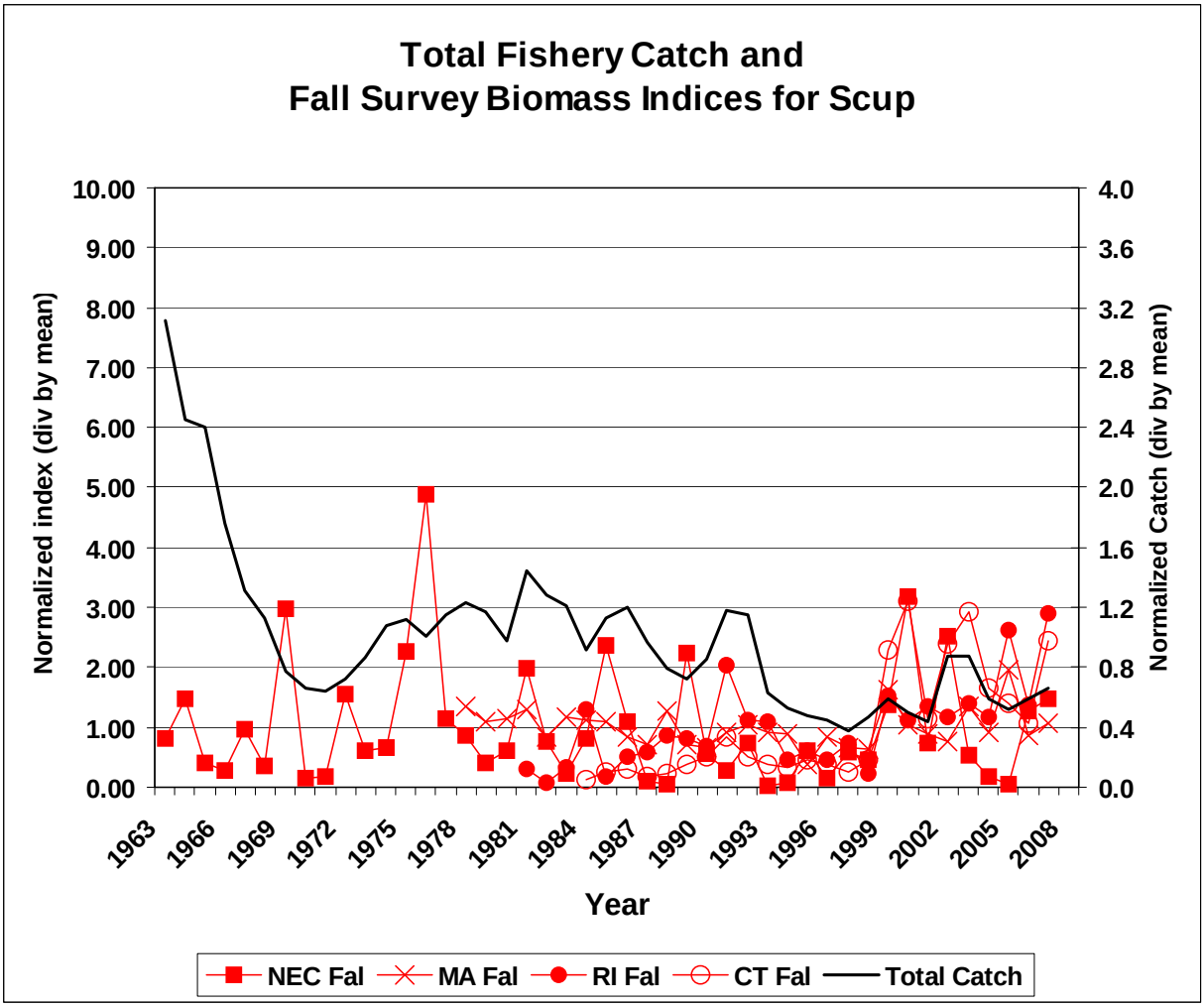


Figure 12. Research survey indices for scup: Fall

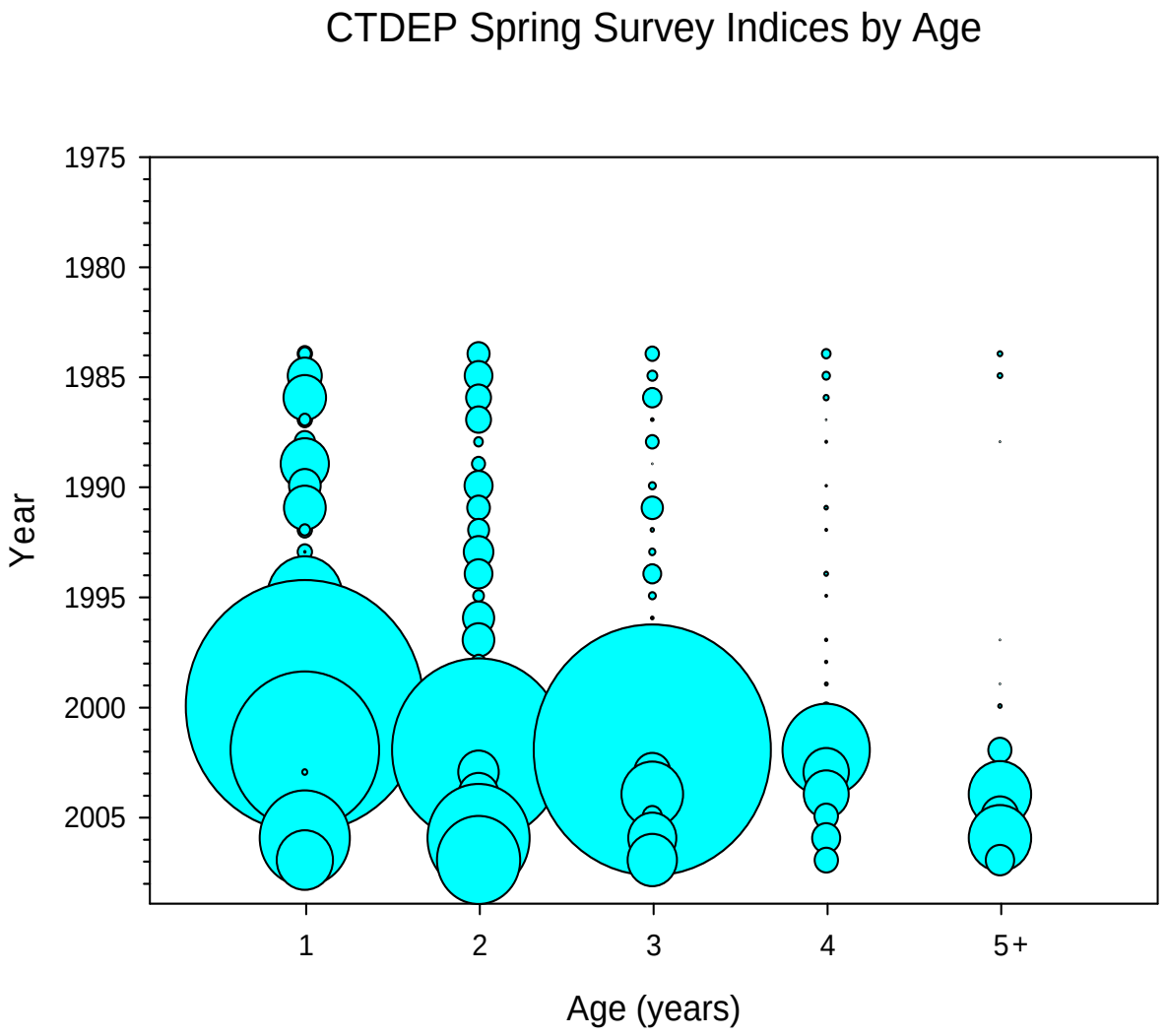


Figure 13. CTDEP Spring survey indices by age for scup.

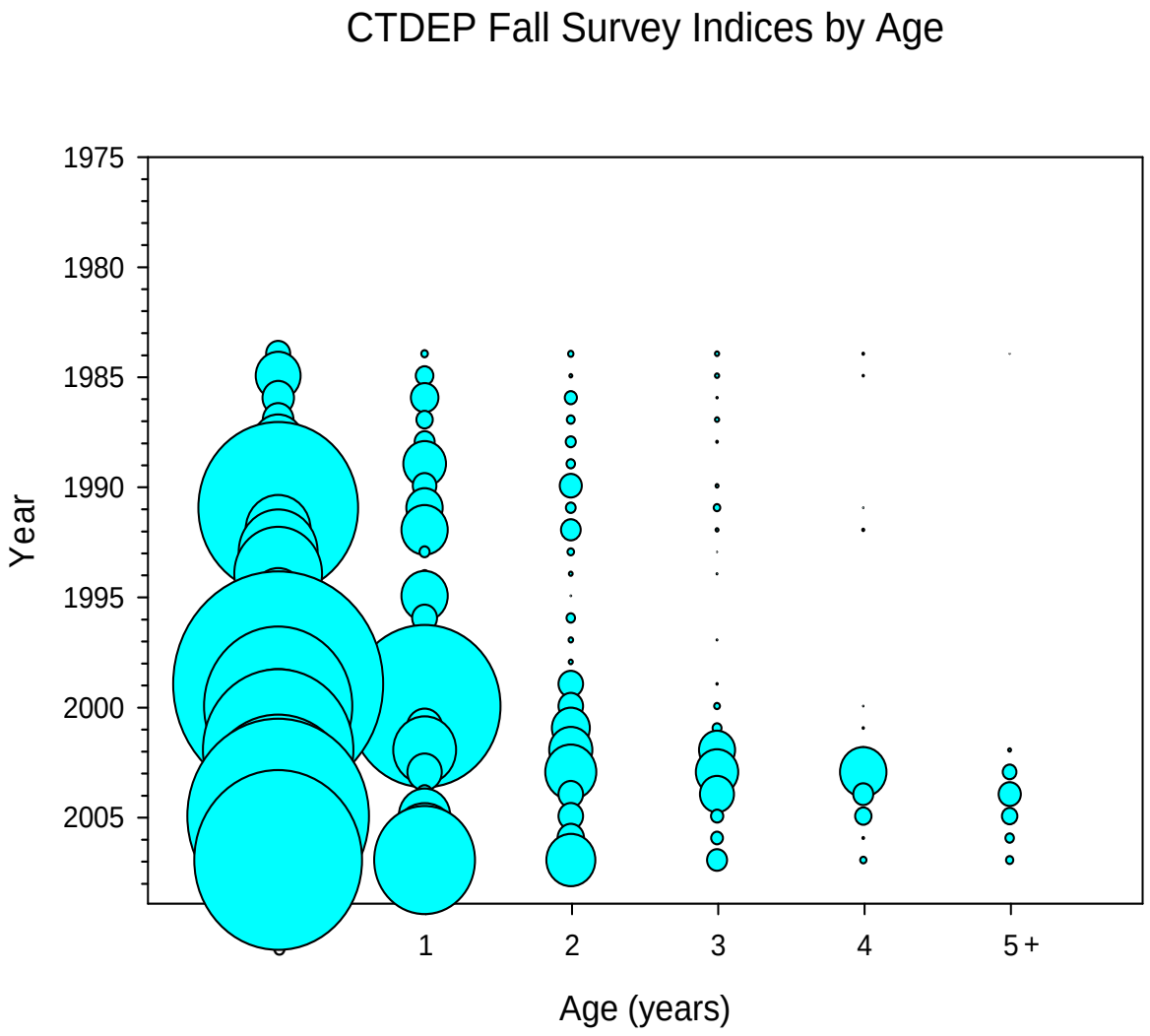


Figure 14. CTDEP Fall survey indices by age for scup.

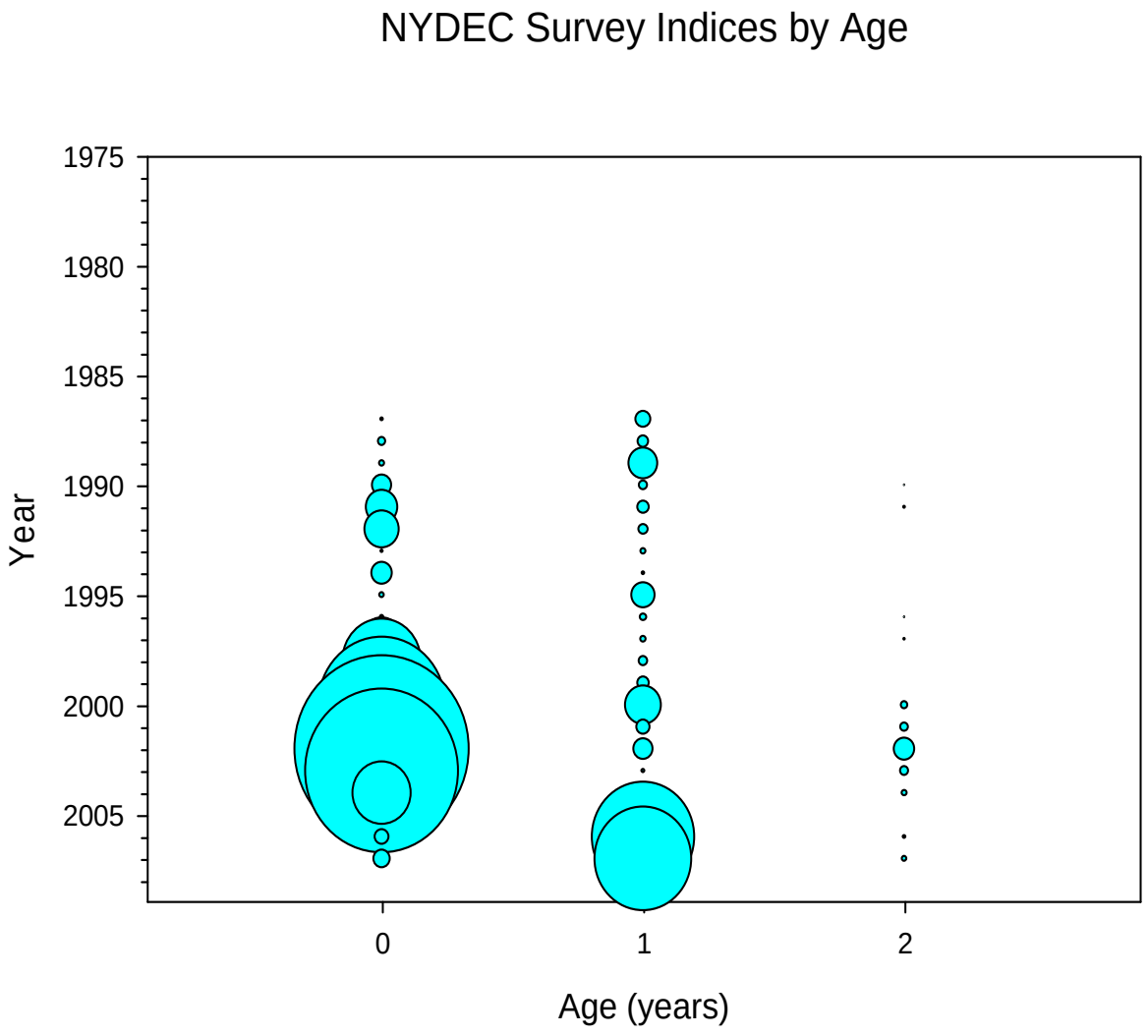


Figure 15. NYDEC survey indices by age for scup.

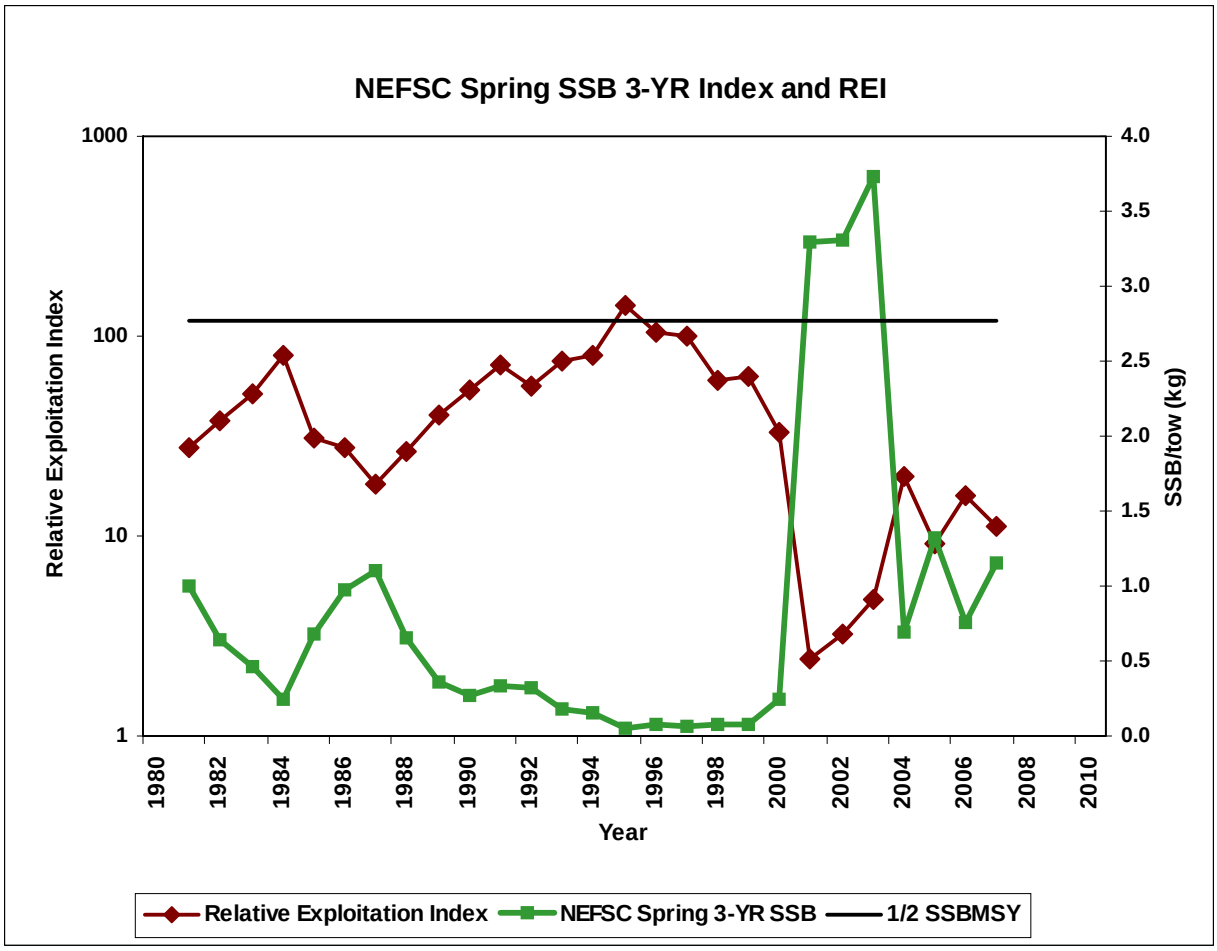
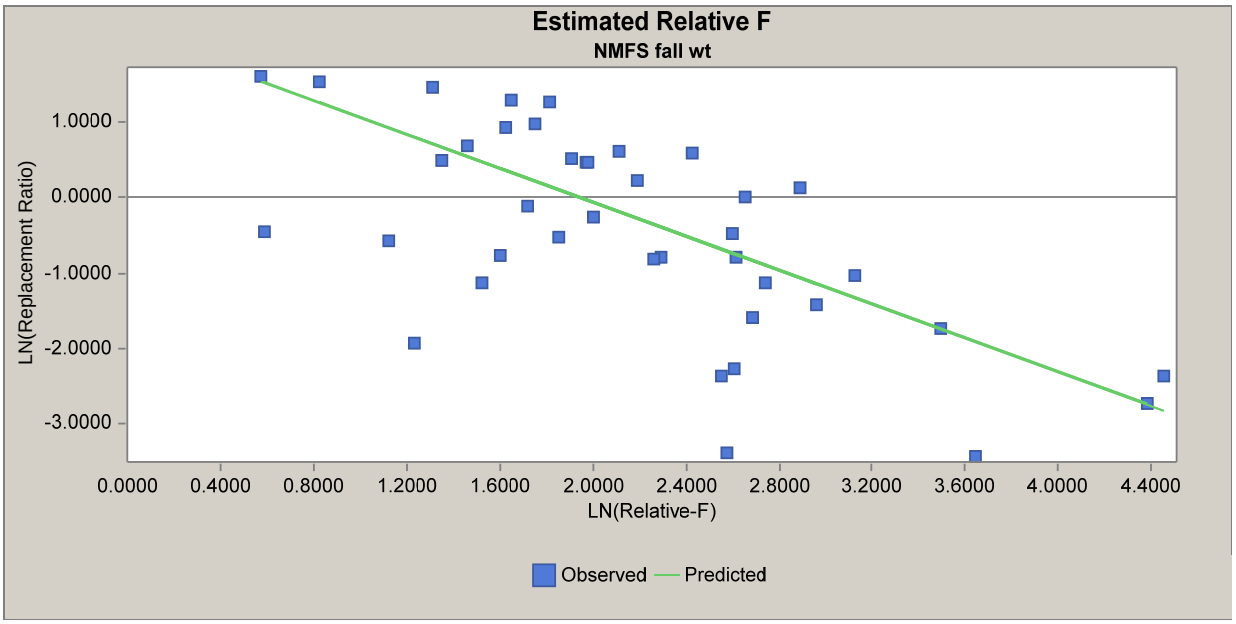


Figure 16. NEFSC Spring survey 3-year average SSB index (biomass metric) and Relative Exploitation Index (REI; fishing mortality rate metric).



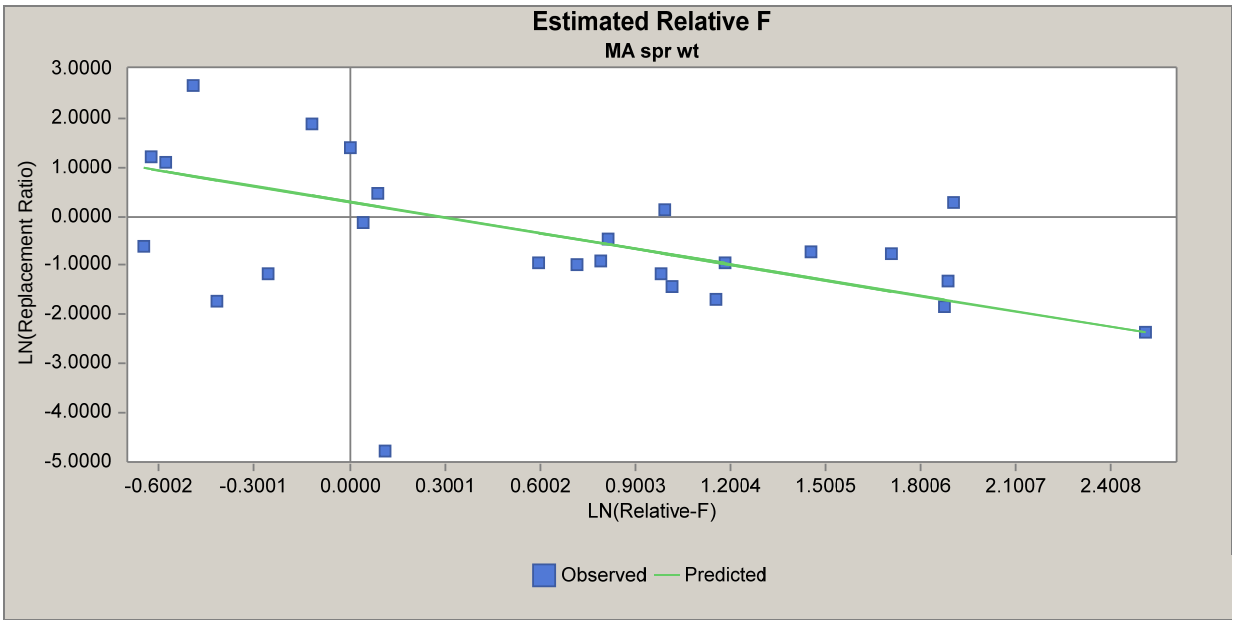
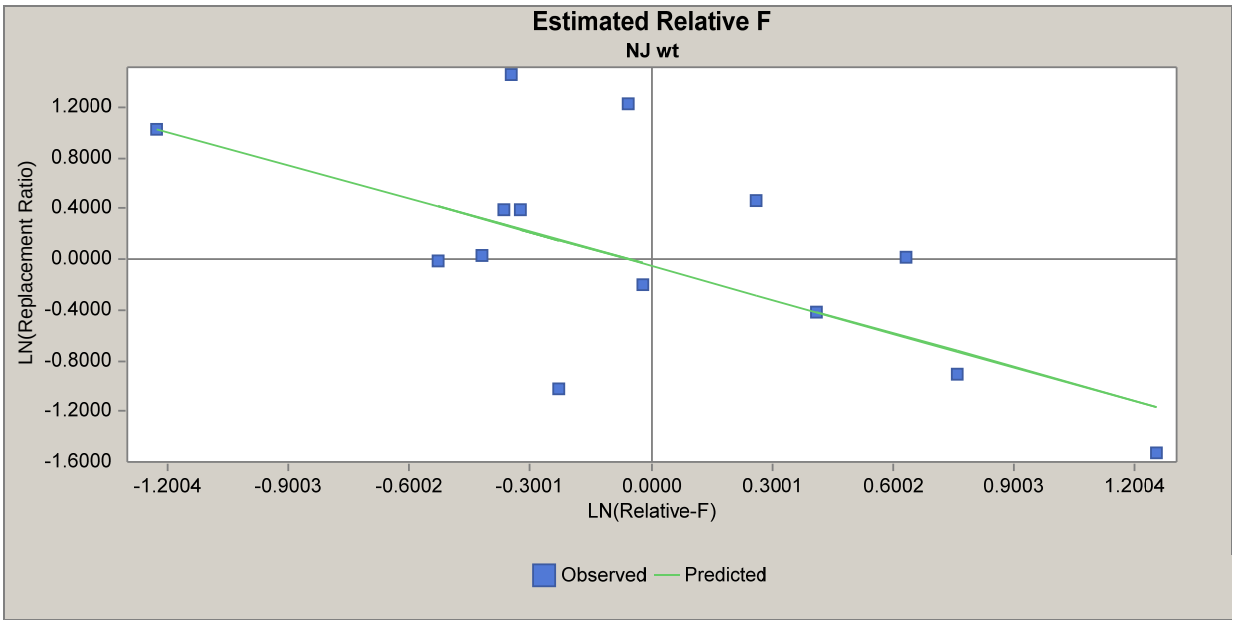


Figure 17. AIM relative F results for the NEFSC Fall and MADMF Spring survey indices.



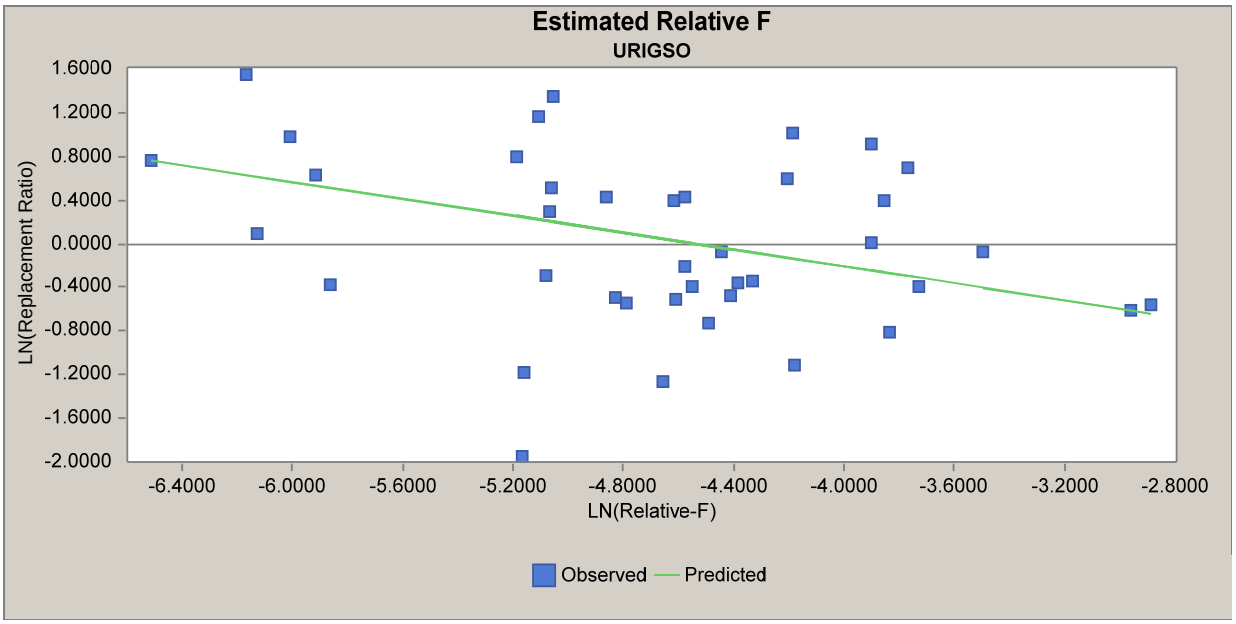
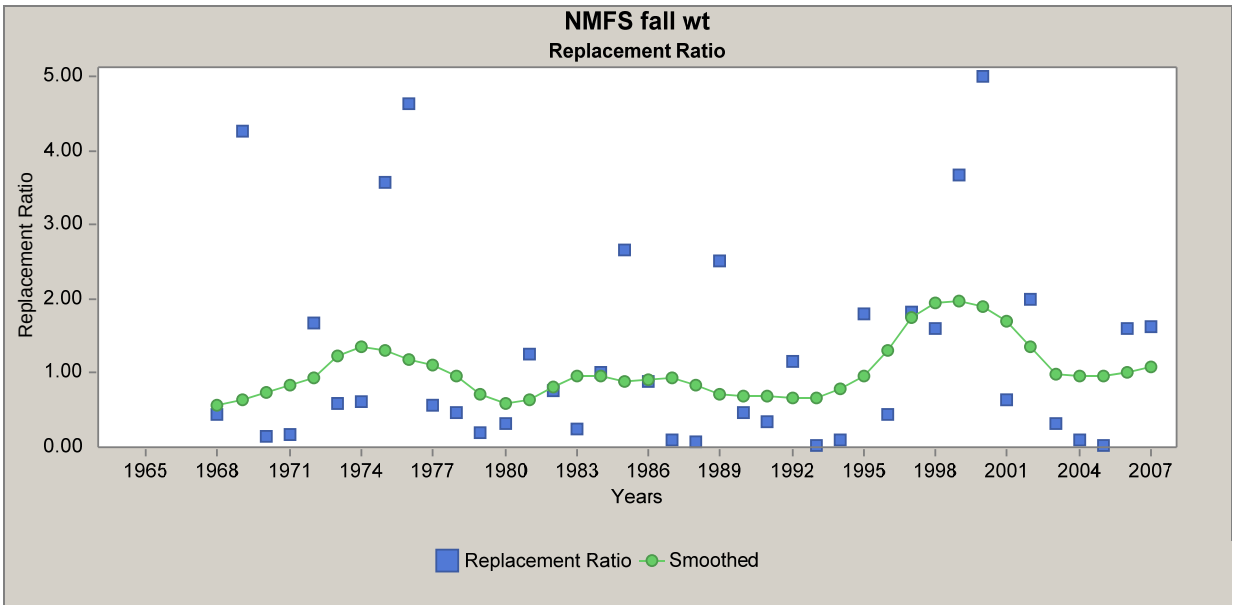


Figure 18. AIM relative F results for the NJBMF Annual and URIGSO indices.



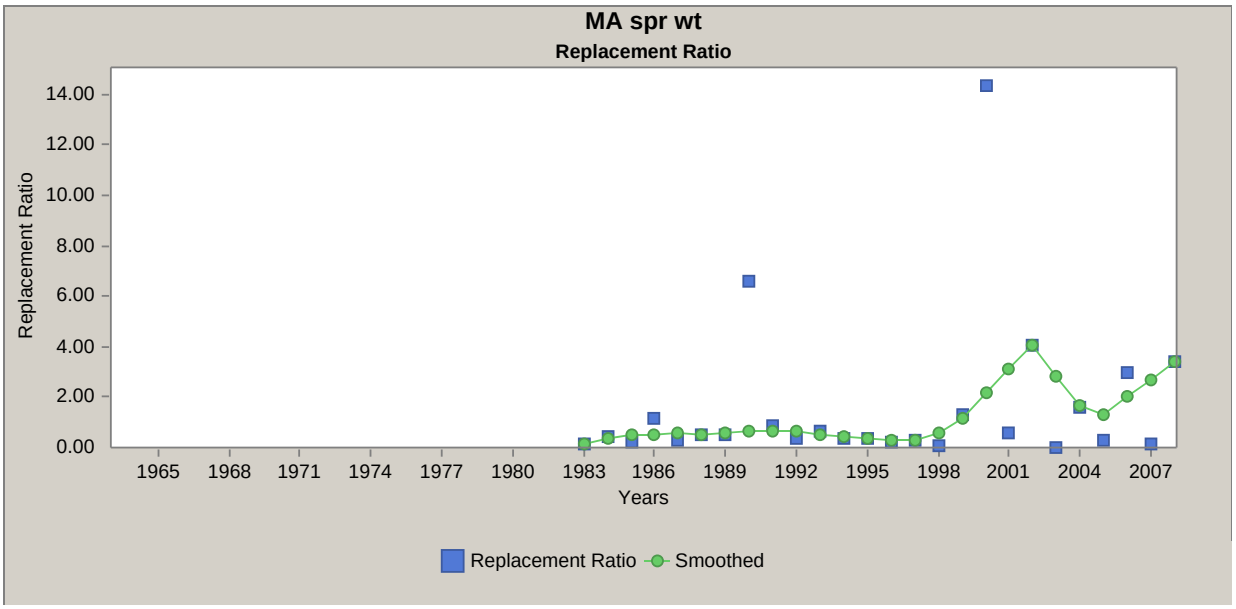
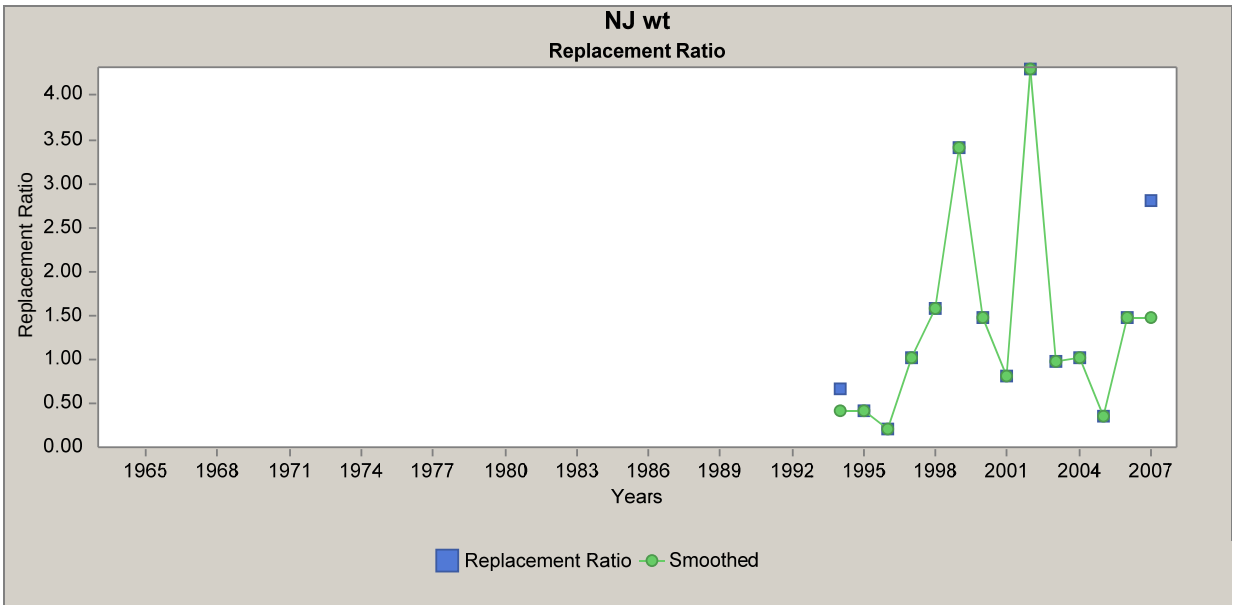


Figure 19. AIM replacement ratio results for NEFSC Fall and MADMF Spring indices.



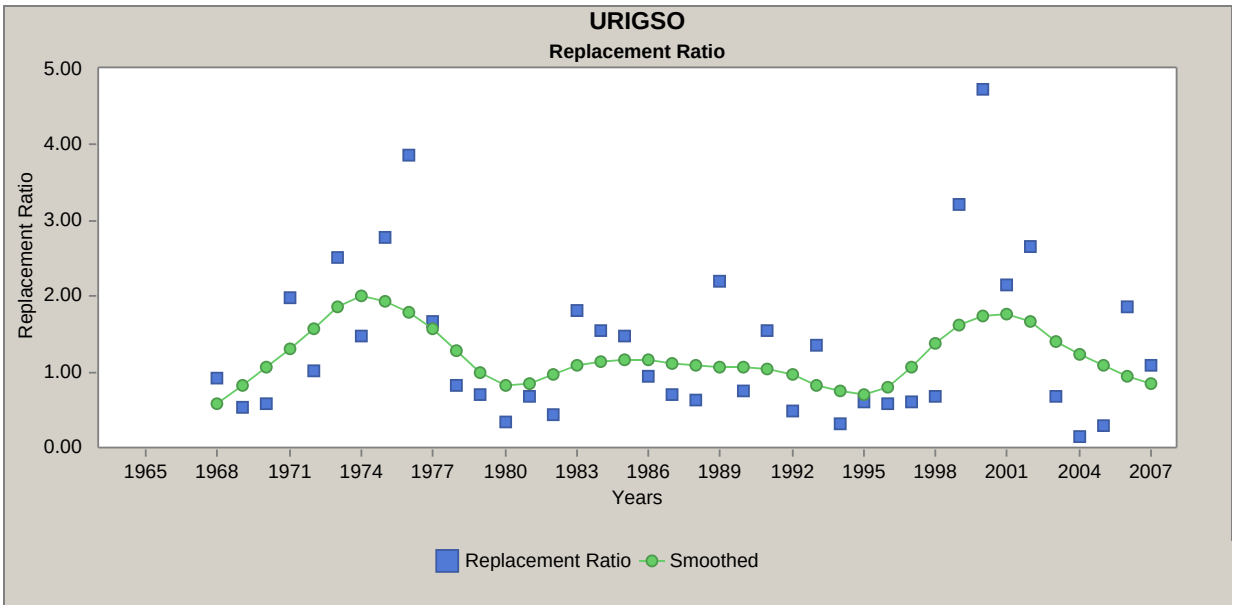


Figure 20. AIM replacement ratio results for NJBMF Annual and URIGSO indices.

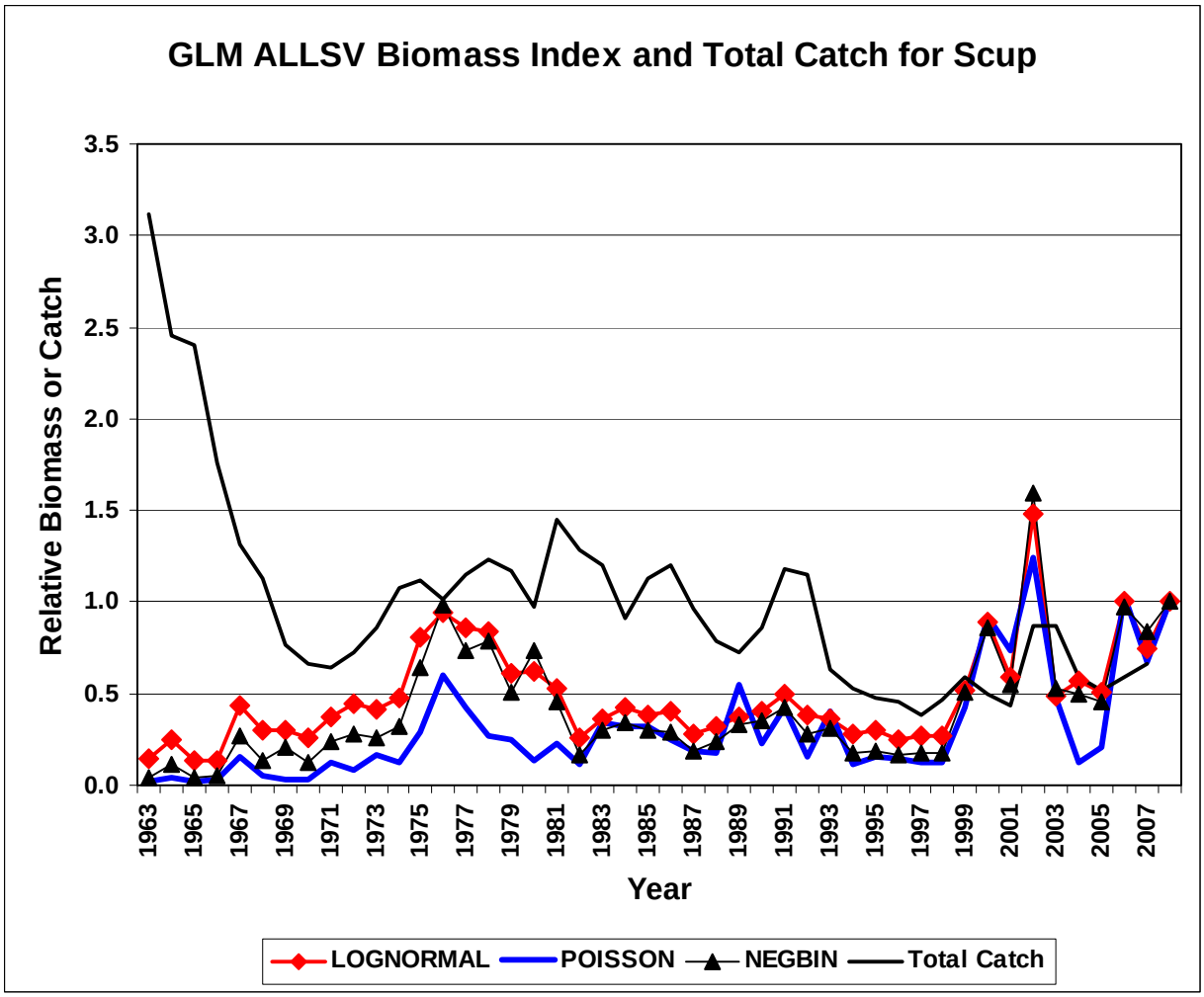
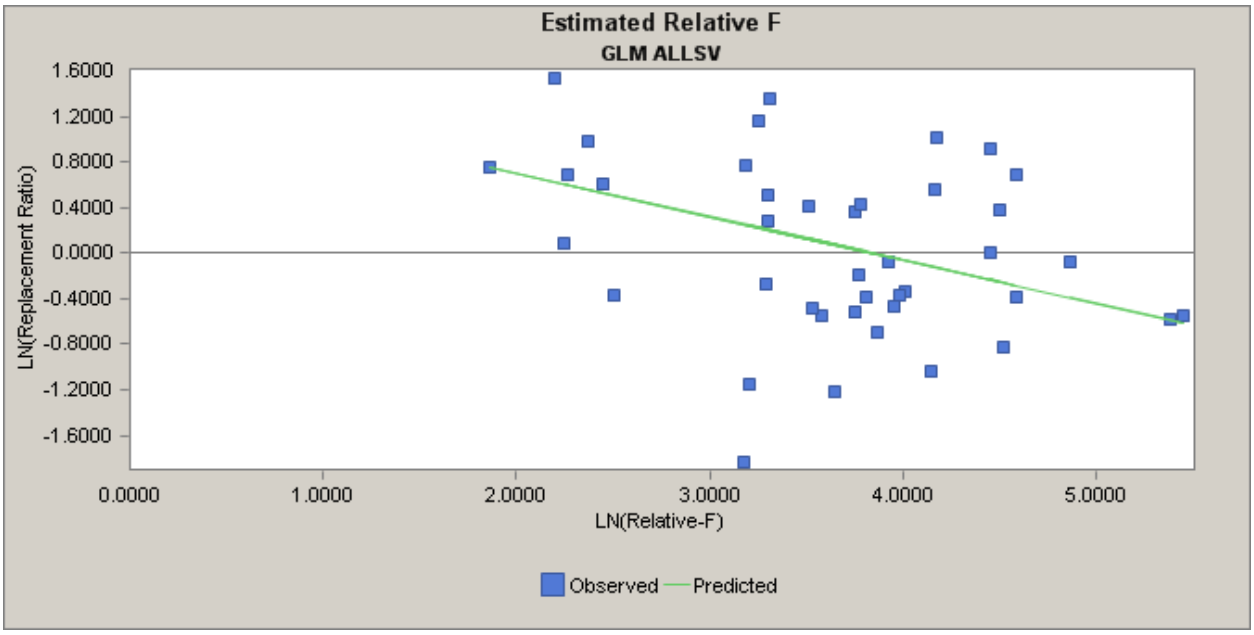


Figure 21. GLM-based biomass index for scup. The Poisson-assumption index was adopted as AIM input.



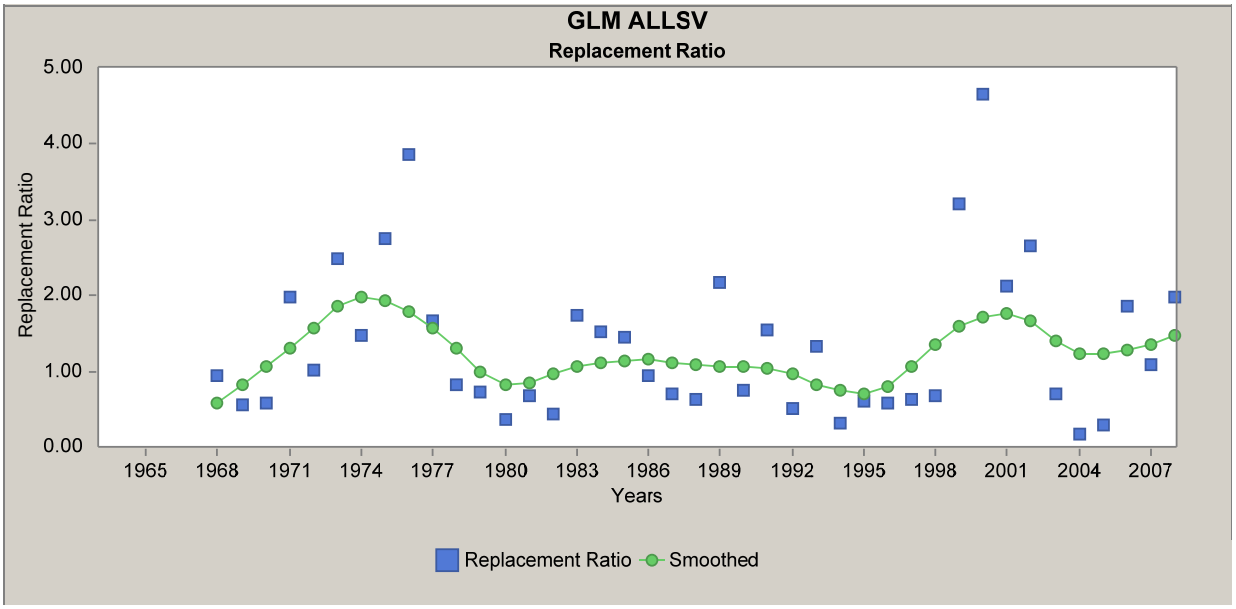


Figure 22. AIM results for the GLM based biomass index for scup.

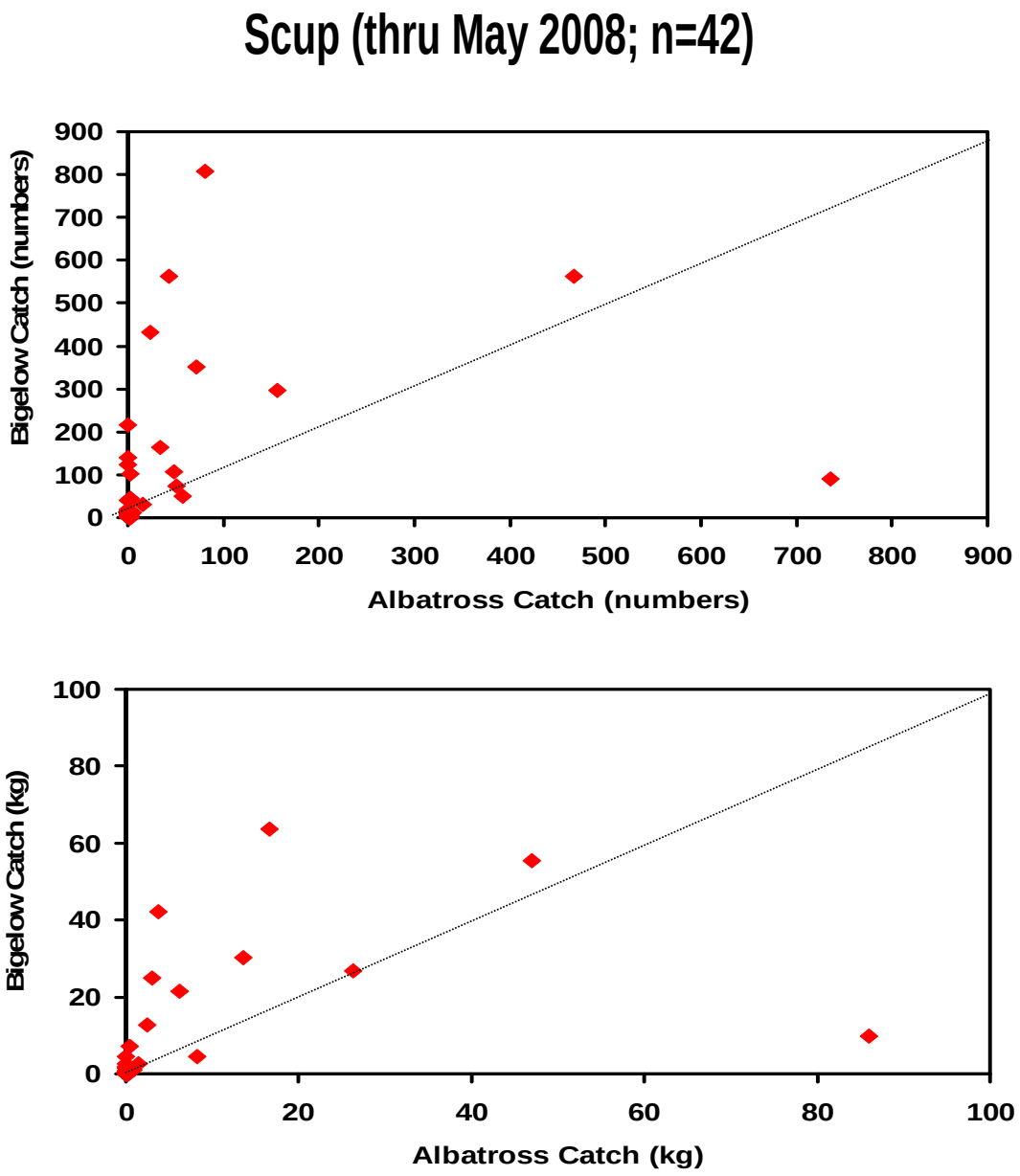


Figure 23. Preliminary NEFSC Survey calibration results for scup.

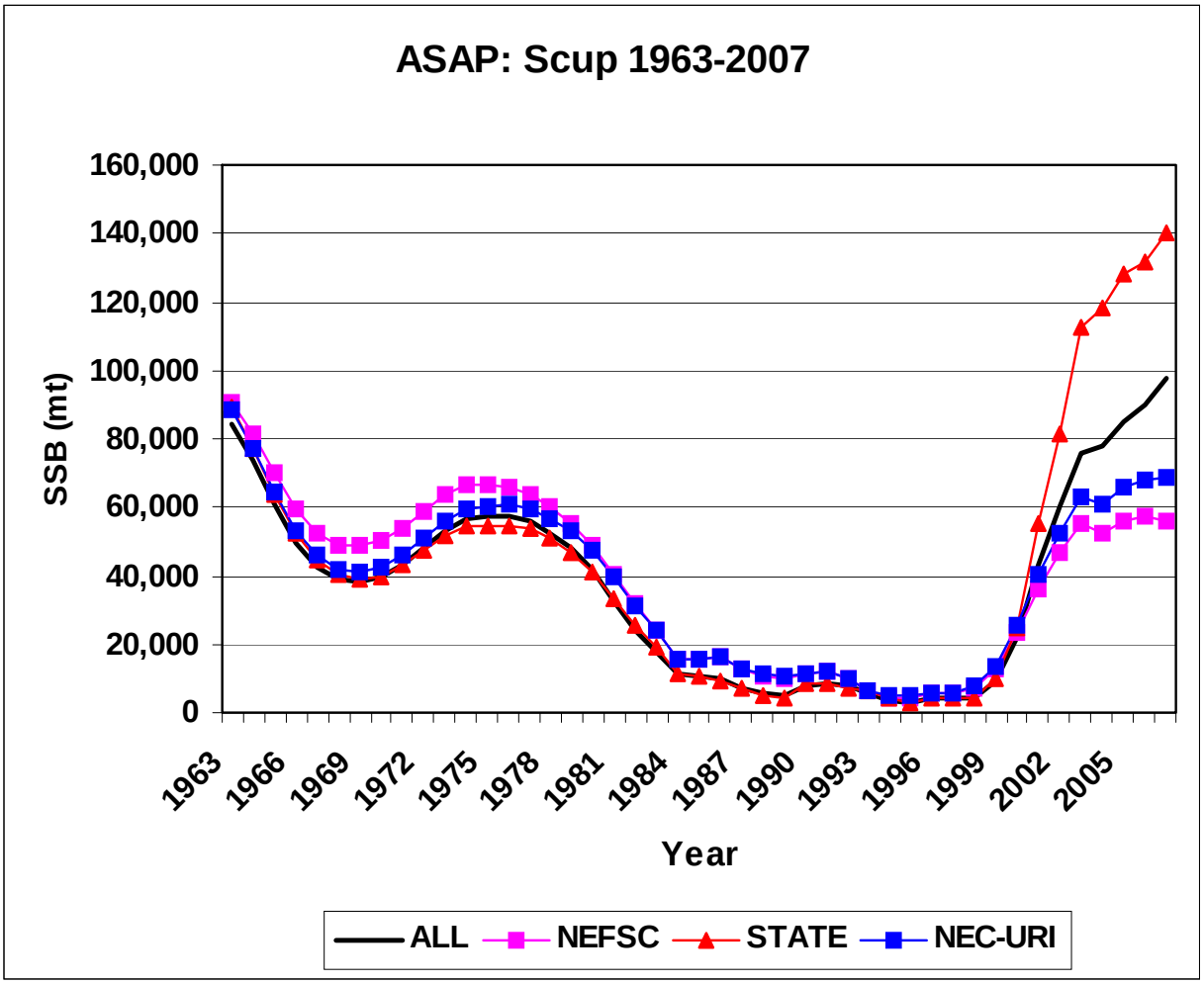


Figure 24. ASAP SSB estimates for the initial four alternative model configurations.

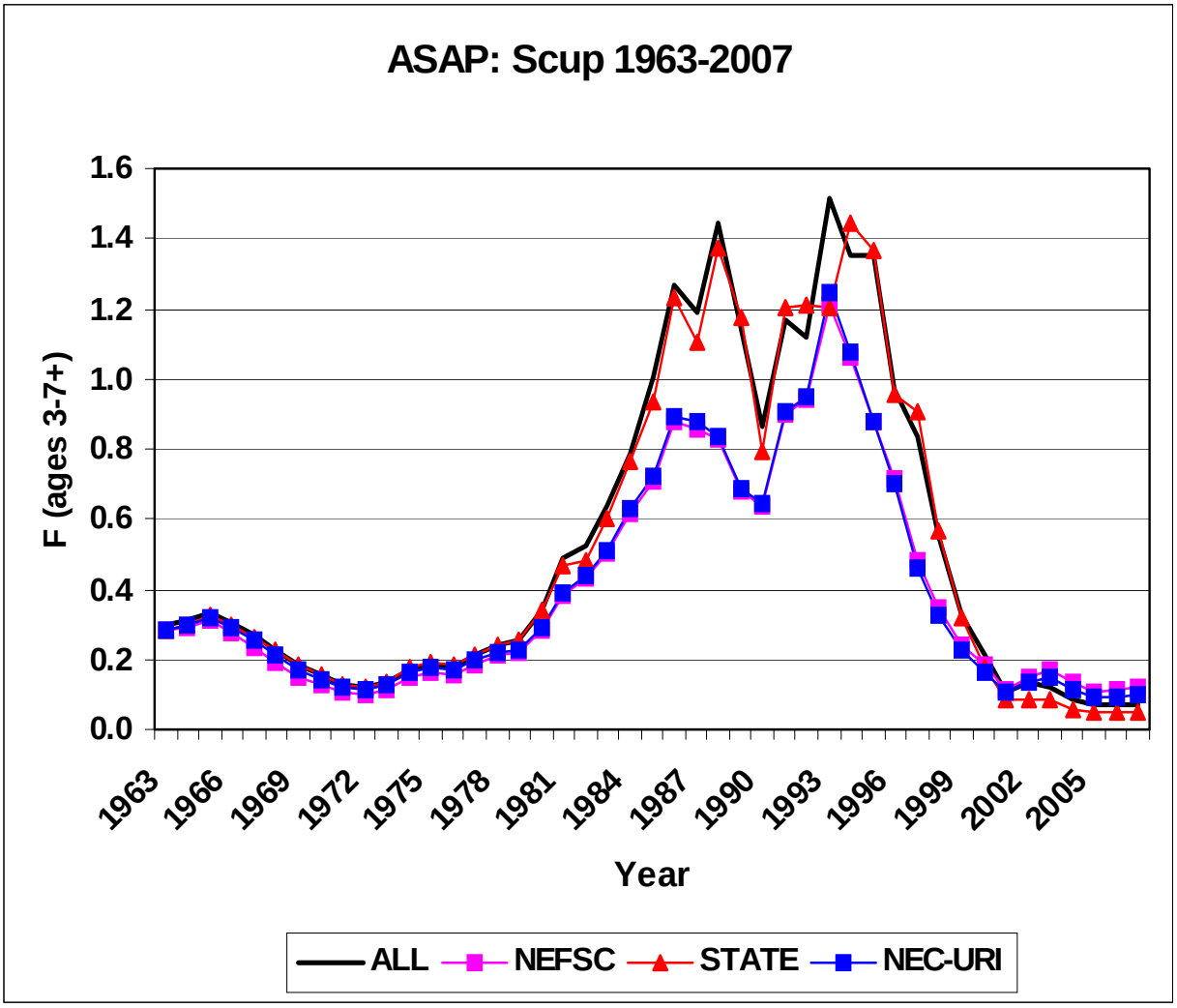


Figure 25. ASAP F estimates for the initial four alternative model configurations.

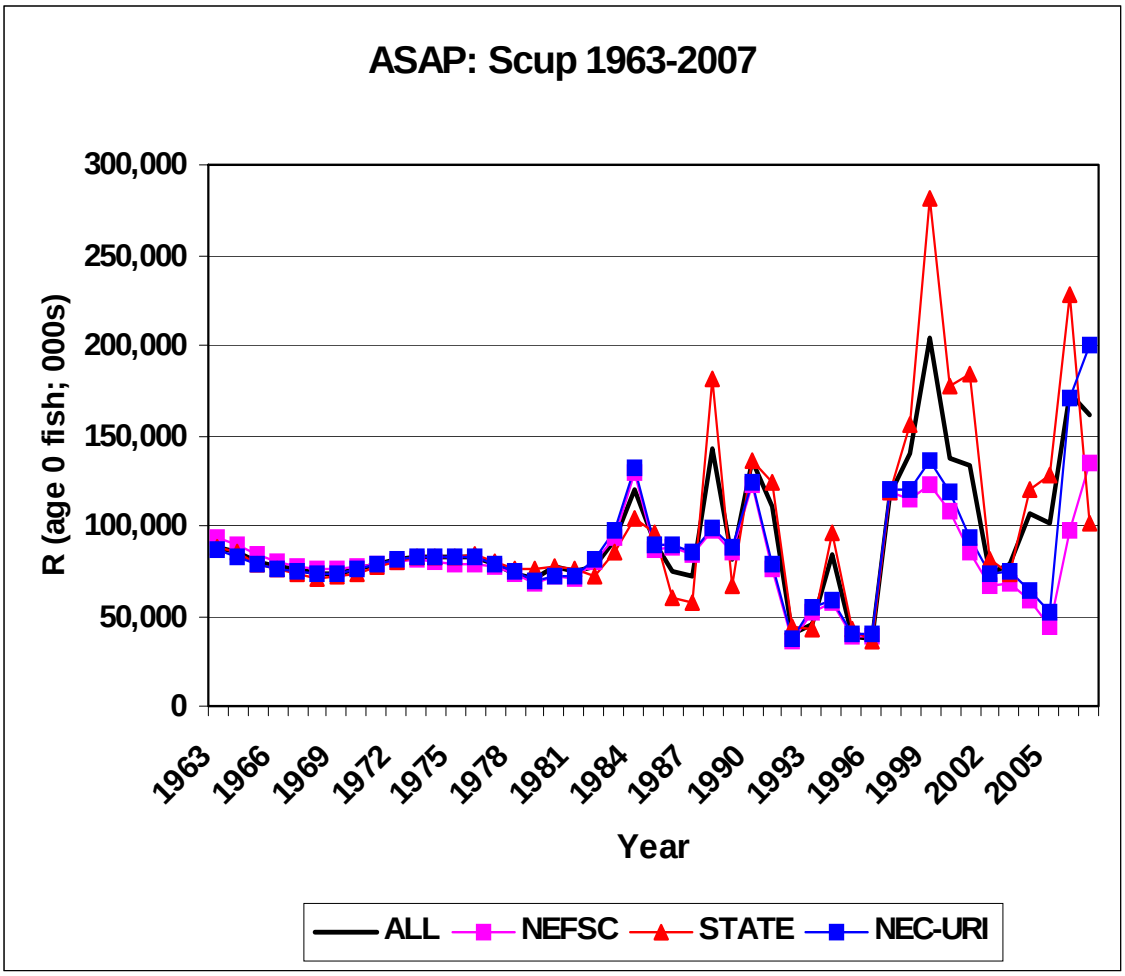


Figure 26. ASAP R (recruitment at age 0) estimates for the initial four alternative model configurations.

RUN ID	SSB63	SSB07	Fhighest	F07	Rhighest	R07	SSBMSY	MSY	FMSY	CATCH07
ALL	84,300	97,700	1.5	0.07	205	161	35600	12300	0.27	8026
NEFSC	90,500	56,300	1.21	0.12	135	135	33000	11000	0.25	8026
STATE	89,000	140,300	1.44	0.05	281	101	35900	12500	0.27	8026
NEC-URI	88,400	68,600	1.25	0.10	200	200	33300	11600	0.27	8026

	SSB07/SSBMSY	F07/FMSY	CAT07/MSY
ALL	2.74	0.26	0.65
NEFSC	1.71	0.48	0.73
STATE	3.91	0.19	0.64
NEC-URI	2.06	0.37	0.69

Figure 27. Initial ASAP results for four alternative run configurations.

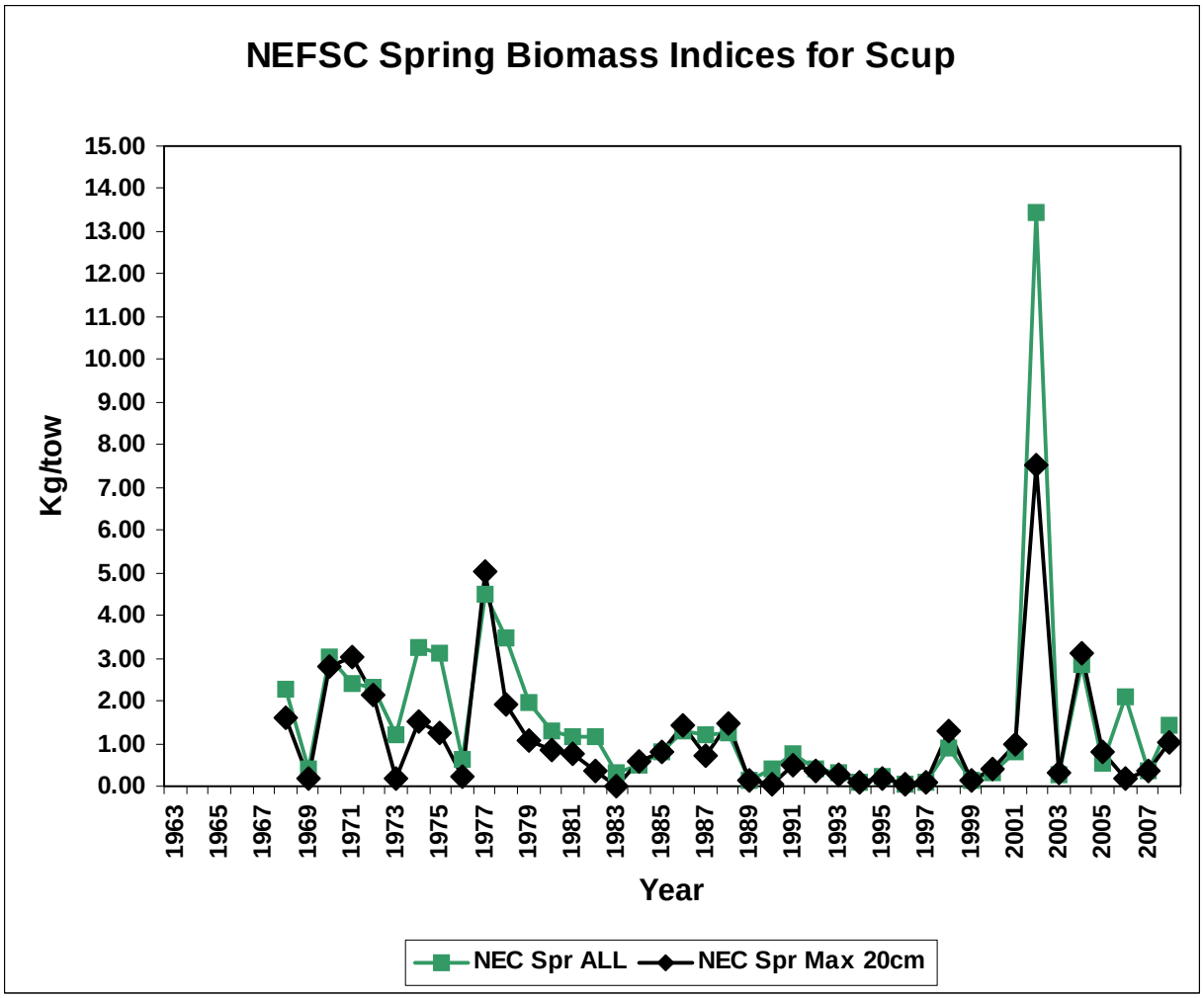


Figure 28. NEFSC Spring trawl survey biomass indices for scup: all sizes, and with a maximum length of 20 cm.

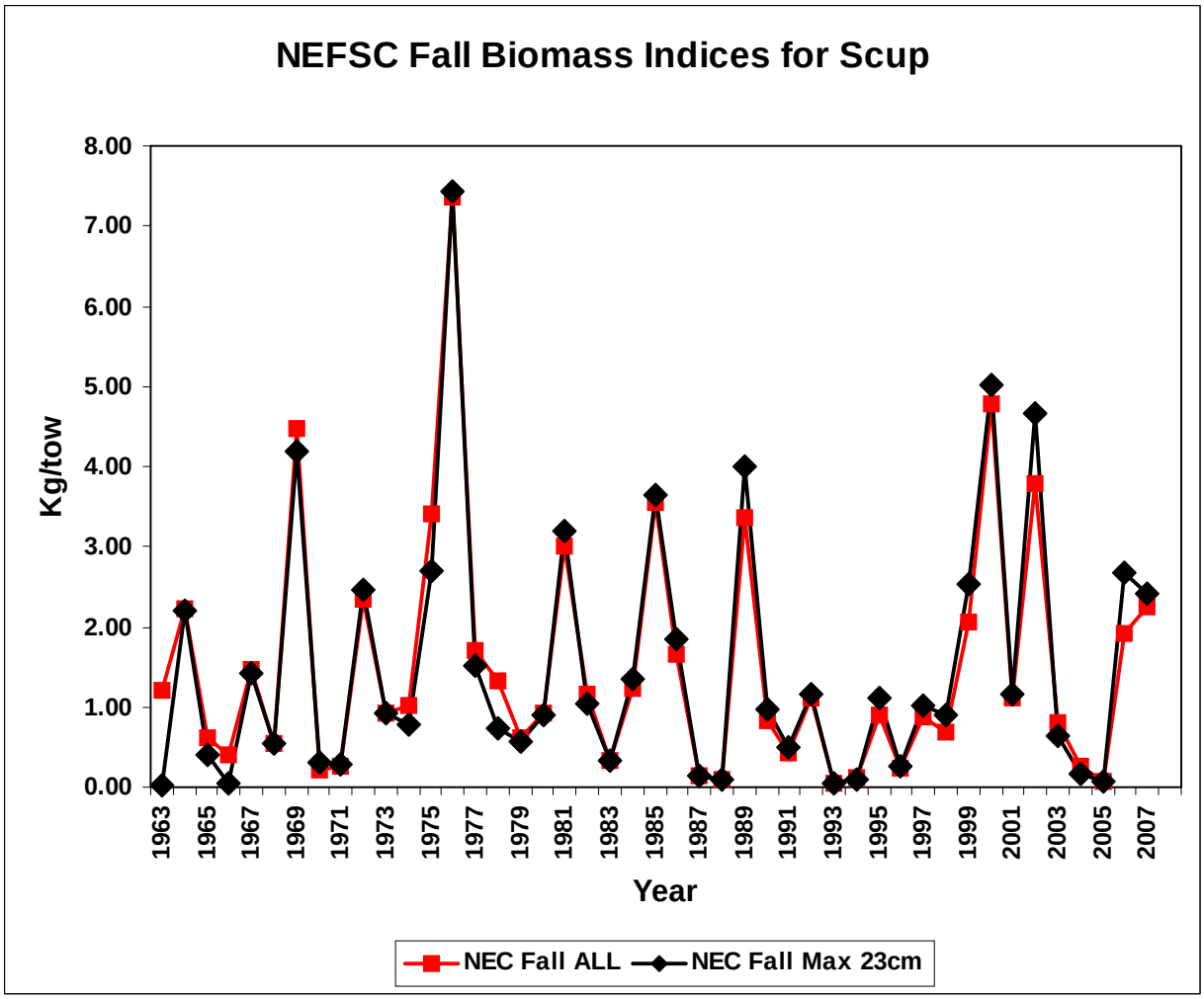


Figure 29. NEFSC Fall trawl survey biomass indices for scup: all sizes, and with a maximum length of 23 cm.

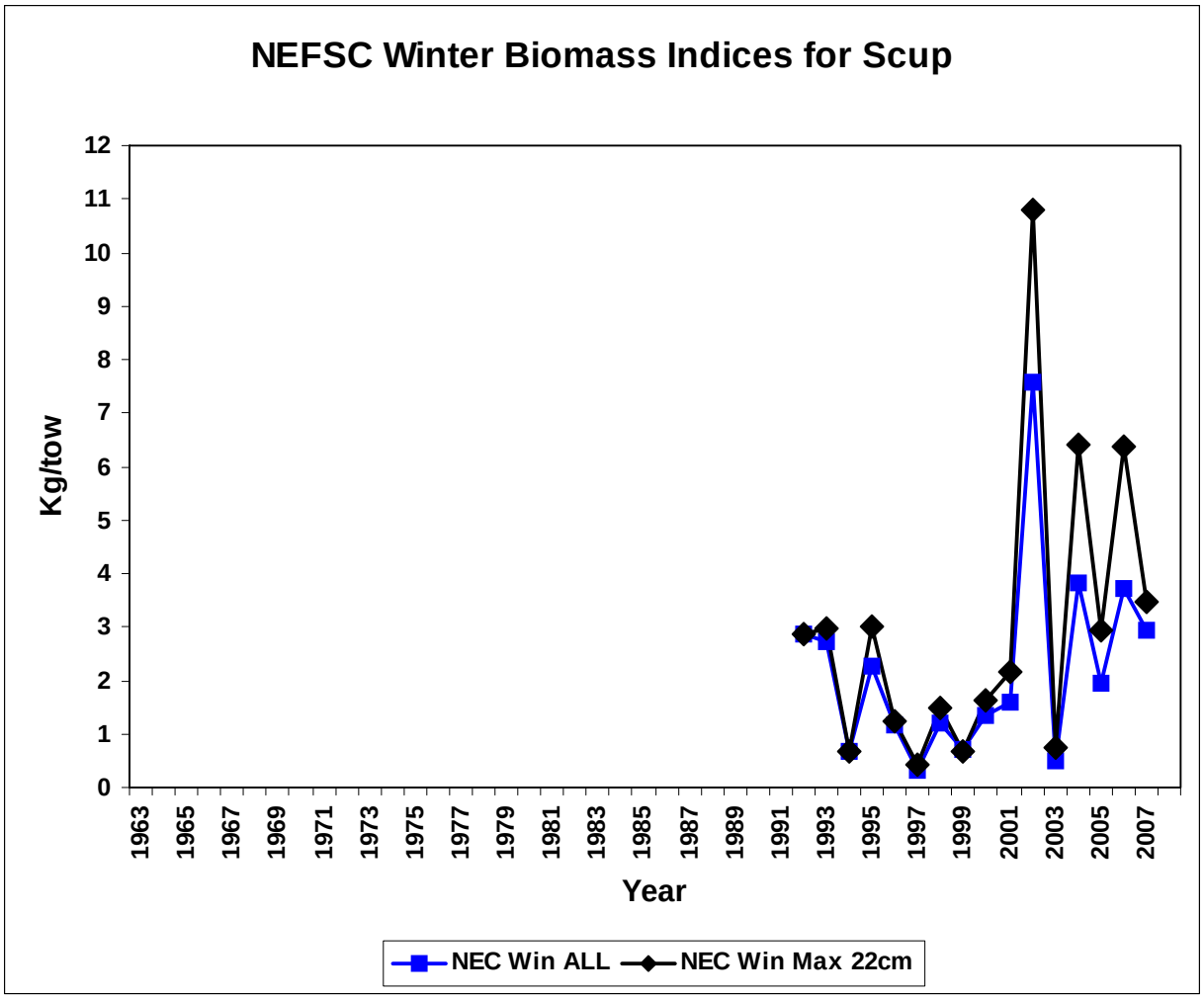


Figure 30. NEFSC Winter trawl survey biomass indices for scup: all sizes, and with a maximum length of 22 cm.

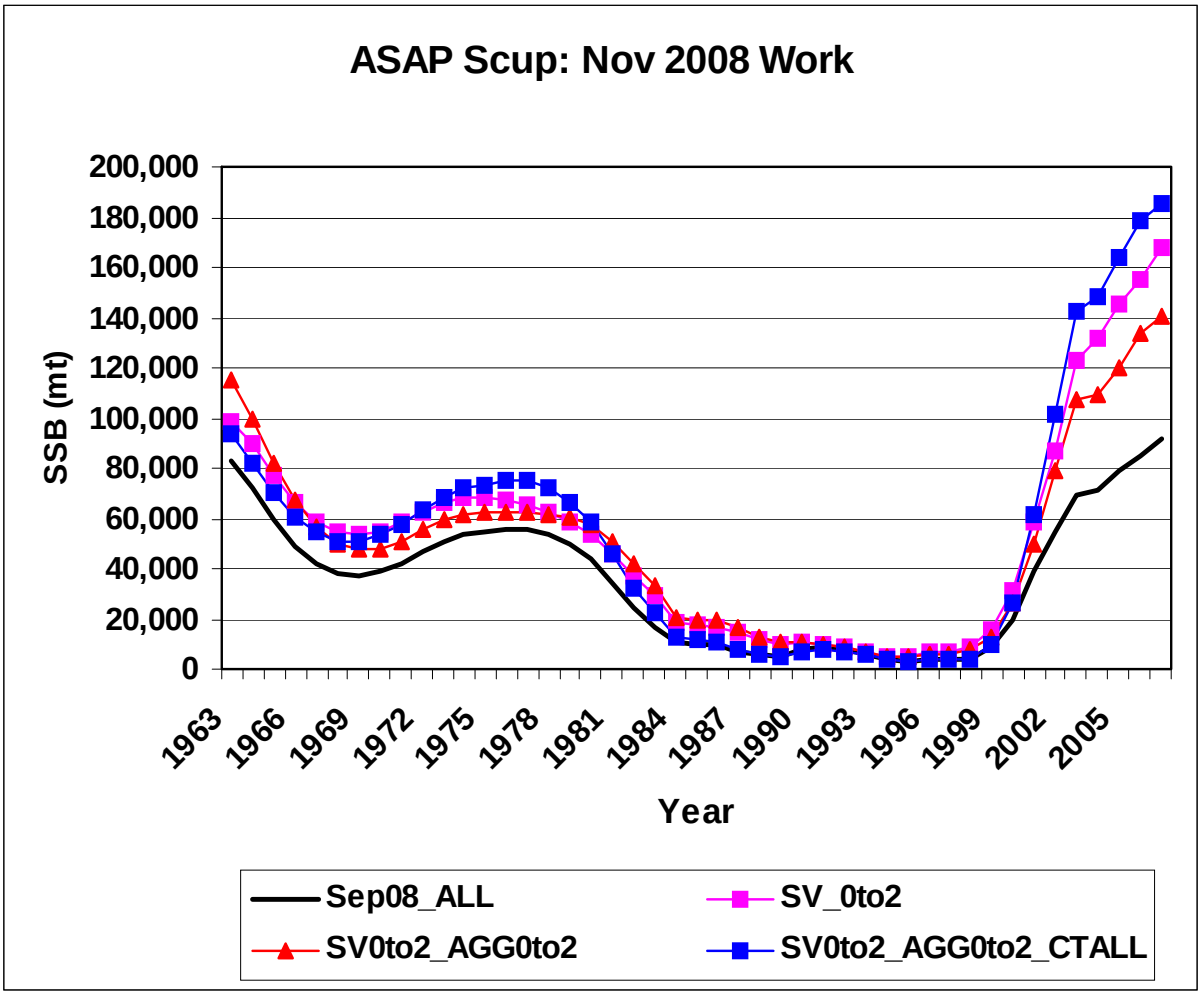


Figure 31. ASAP SSB estimates for the modified survey input model configurations.

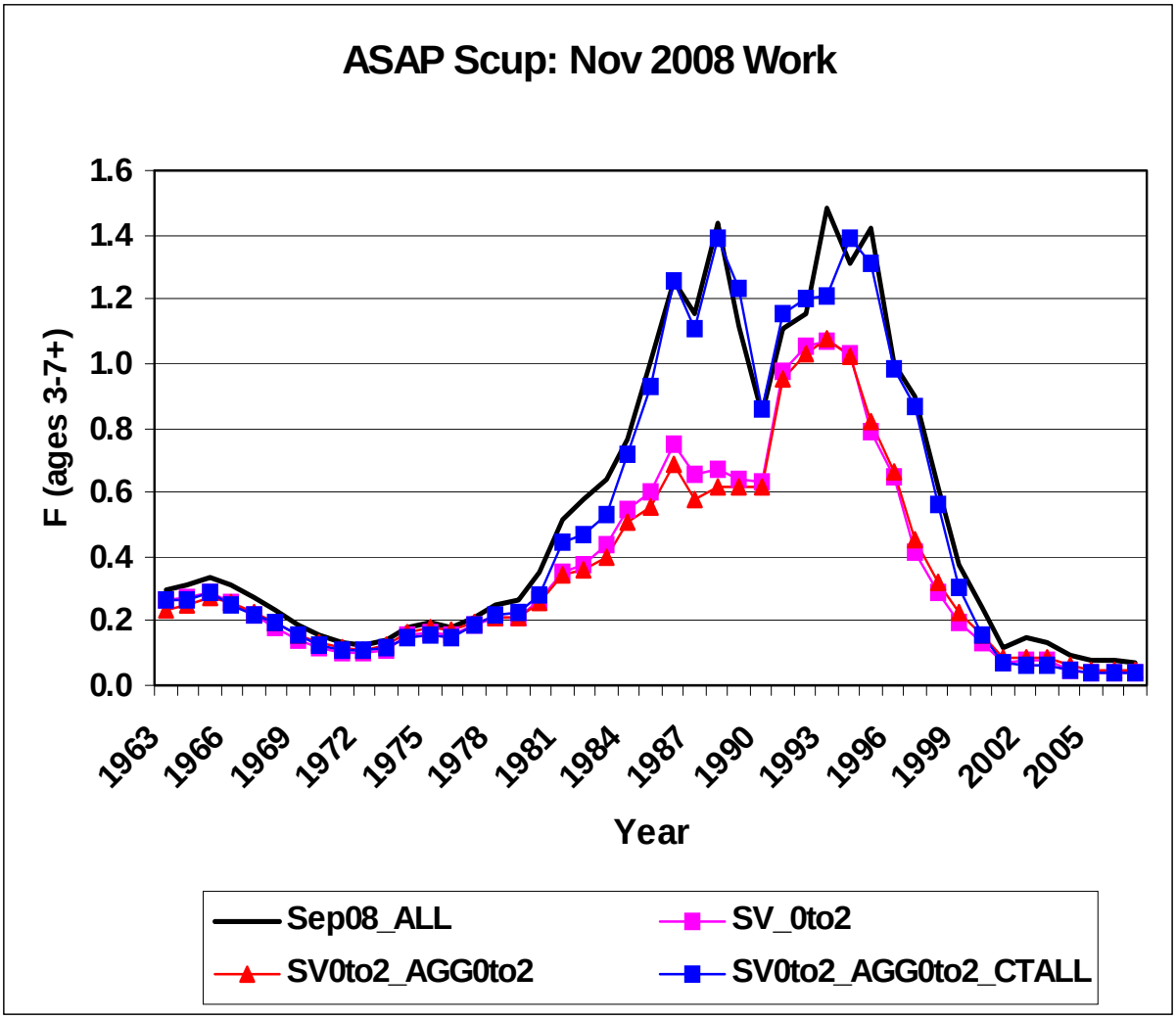


Figure 32. ASAP F estimates for the modified survey input model configurations.

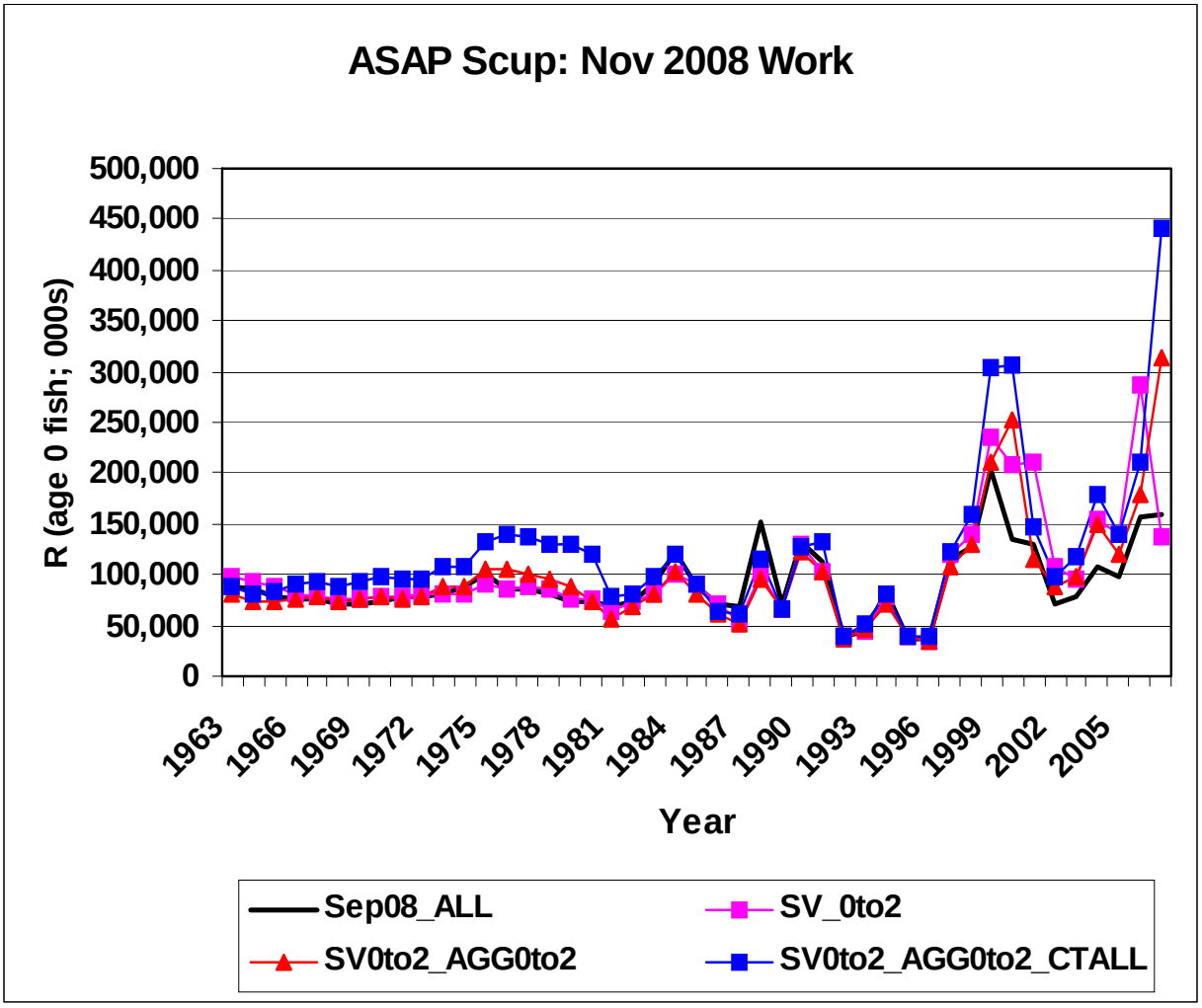


Figure 33. ASAP R (recruitment at age 0) estimates for the modified survey input model configurations.

Objective Function Summary

Absolute RUN ID	Fishery Total Catch	Fishery Age Comp	Survey Indices	Rec Devs	Total
Sep08_ALL	1052	1997	6354	518	9921
SV0to2	1013	1929	2473	528	5943
SV0to2_AGG0to2	1025	1967	5403	537	8932
SV0to2_AGG0to2_CTALL	1159	1996	5597	553	9305

Percent RUN ID	Fishery Total Catch	Fishery Age Comp	Survey Indices	Rec Devs	Total
Sep08_ALL	11%	20%	64%	5%	100%
SV0to2	17%	32%	42%	9%	100%
SV0to2_AGG0to2	11%	22%	60%	6%	100%
SV0to2_AGG0to2_CTALL	12%	21%	60%	6%	100%

Figure 34. Objective function summary for the ASAP modified survey input runs.

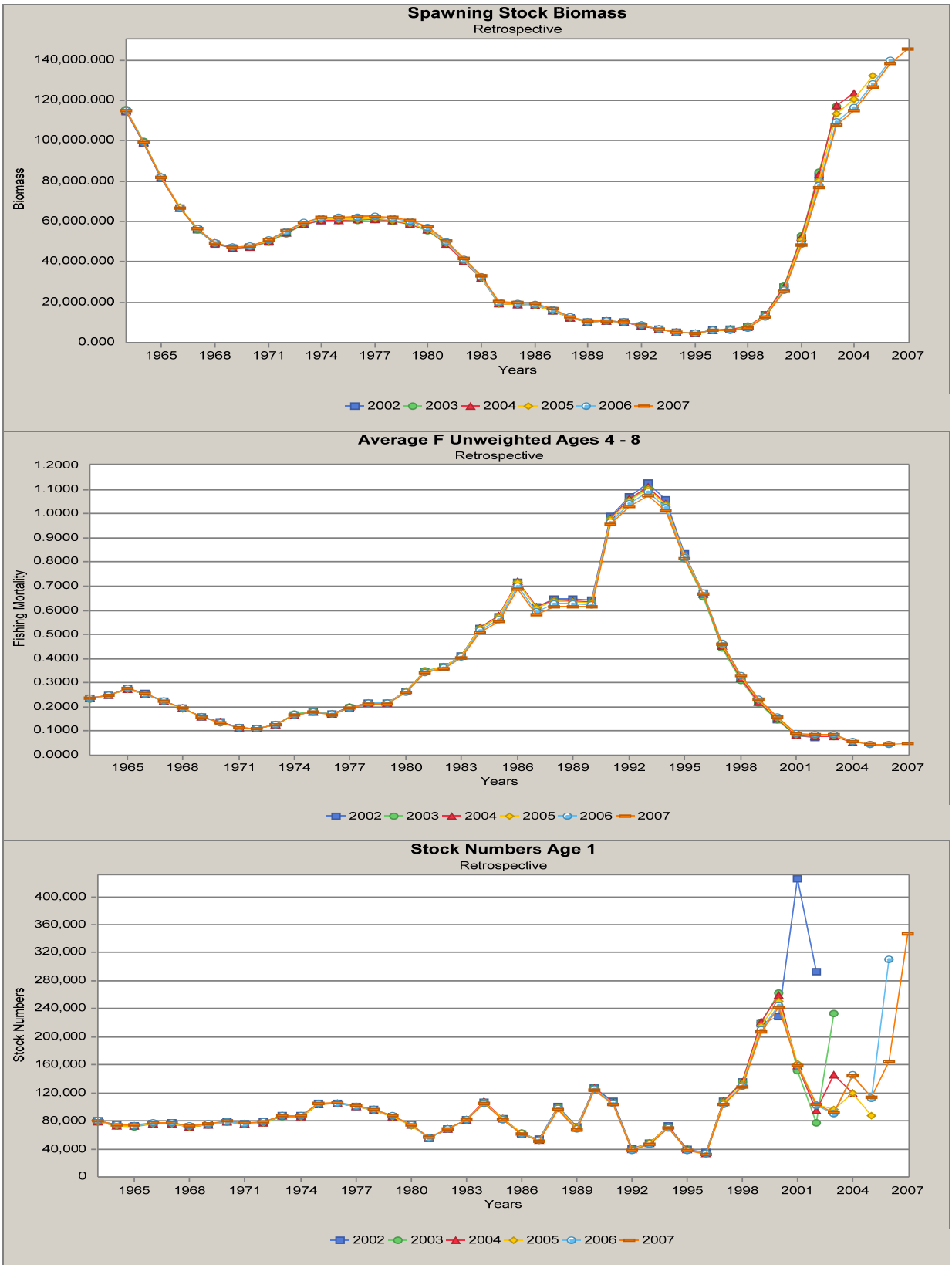


Figure 35. Retrospective results for run SV0to2_AGG0to2.

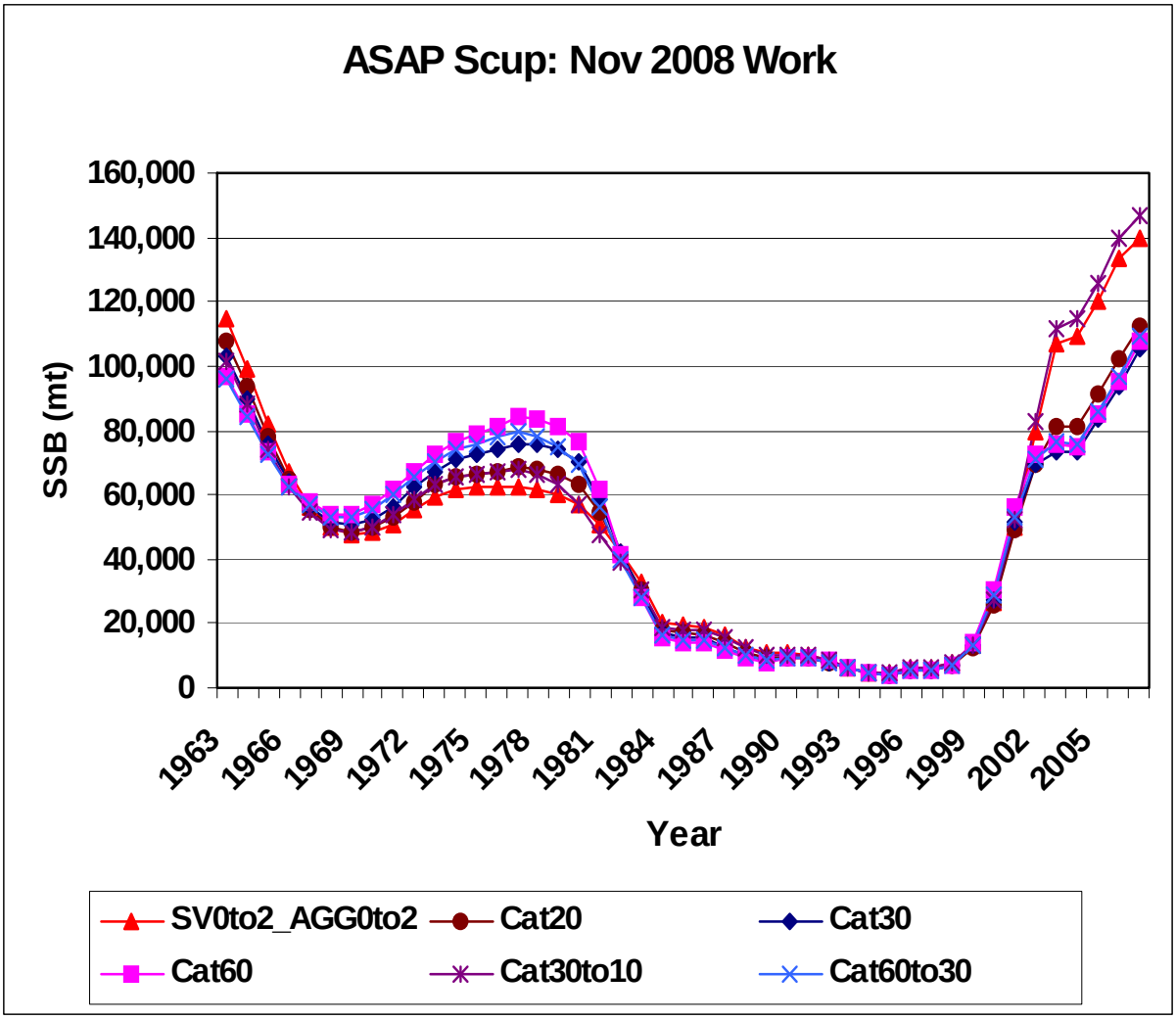


Figure 36. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of SSB.

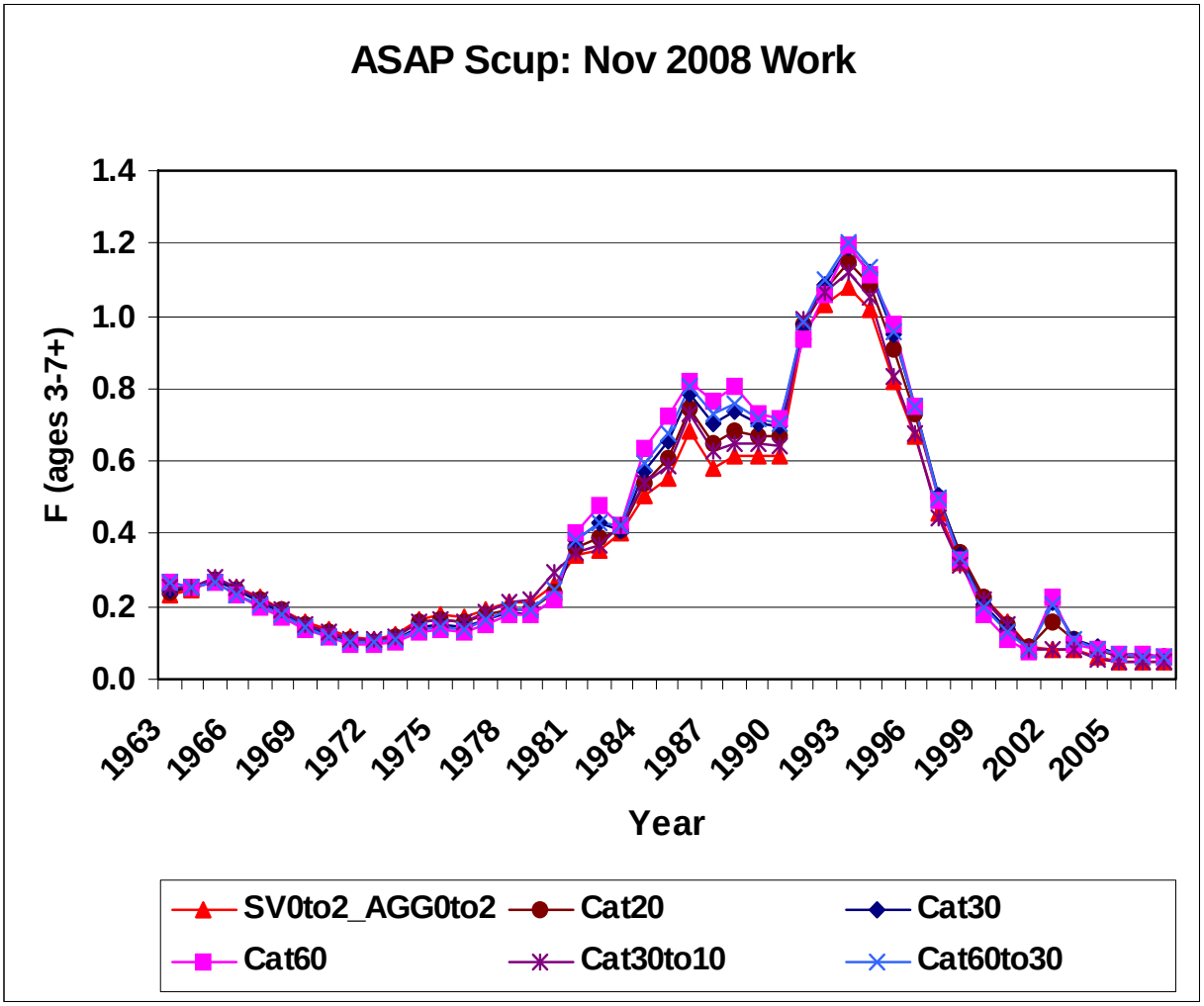


Figure 37. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of F.

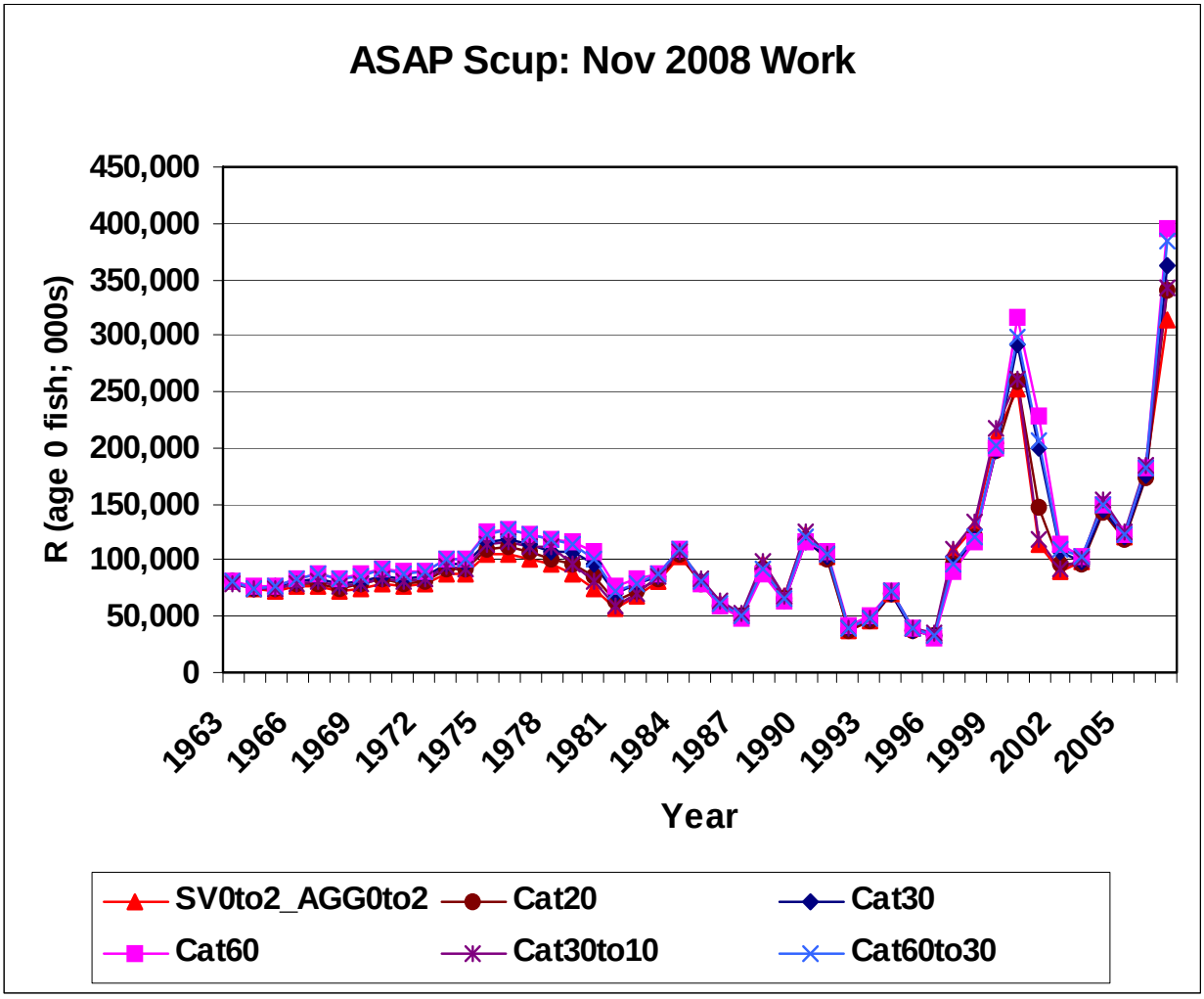


Figure 38. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of F.

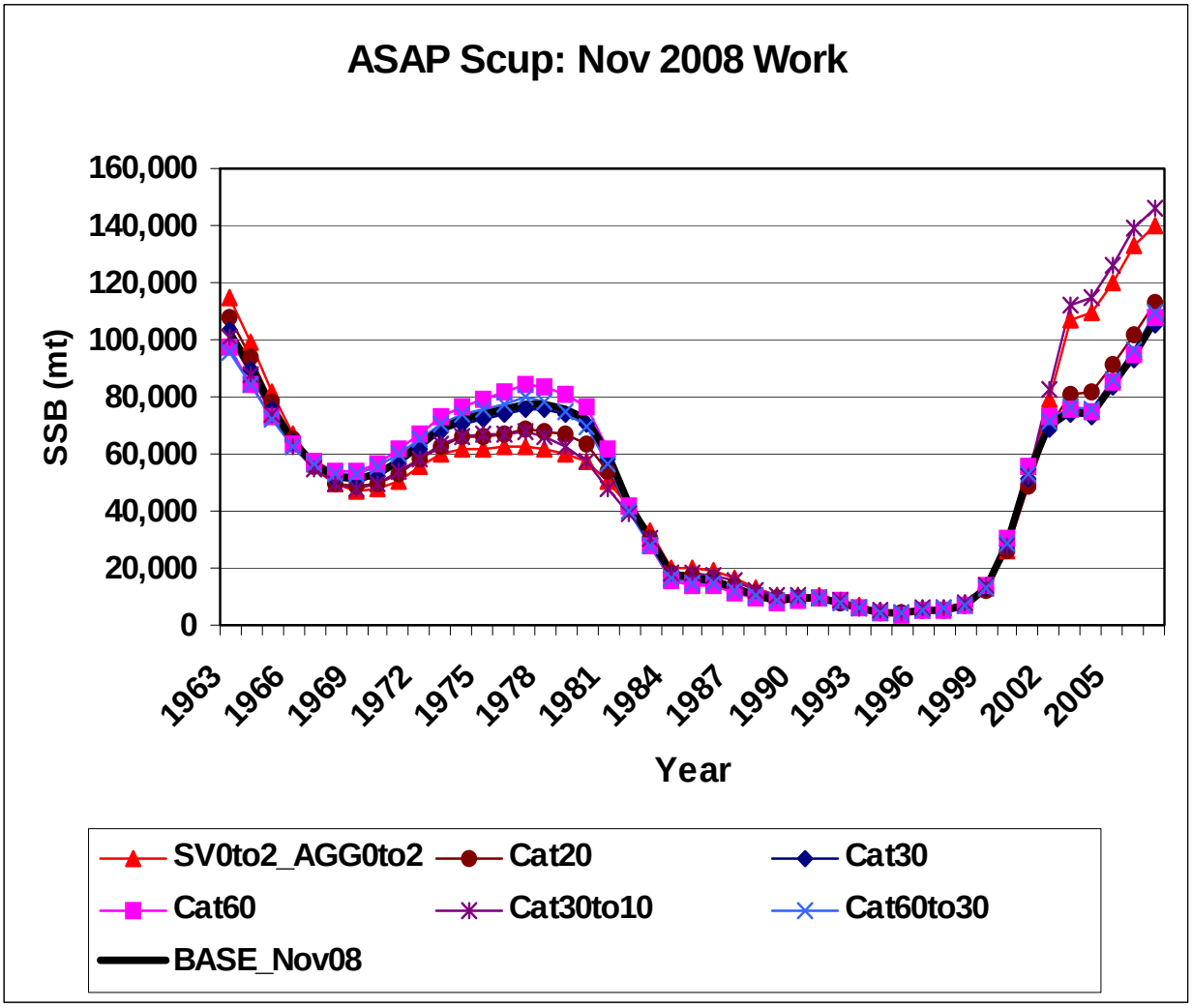


Figure 39. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of SSB from the BASE_Nov08 run.

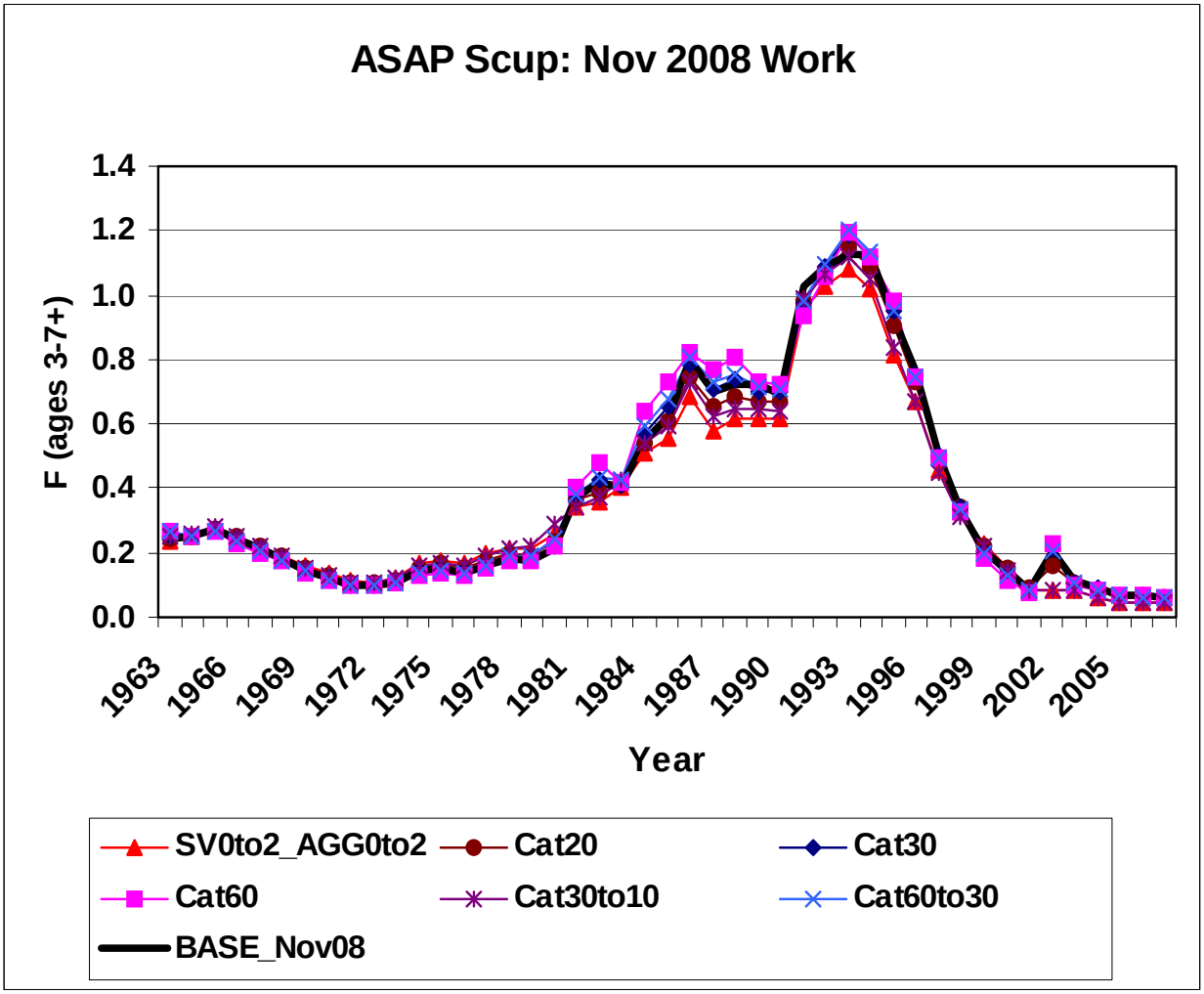


Figure 40. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of F from the BASE_Nov08 run.

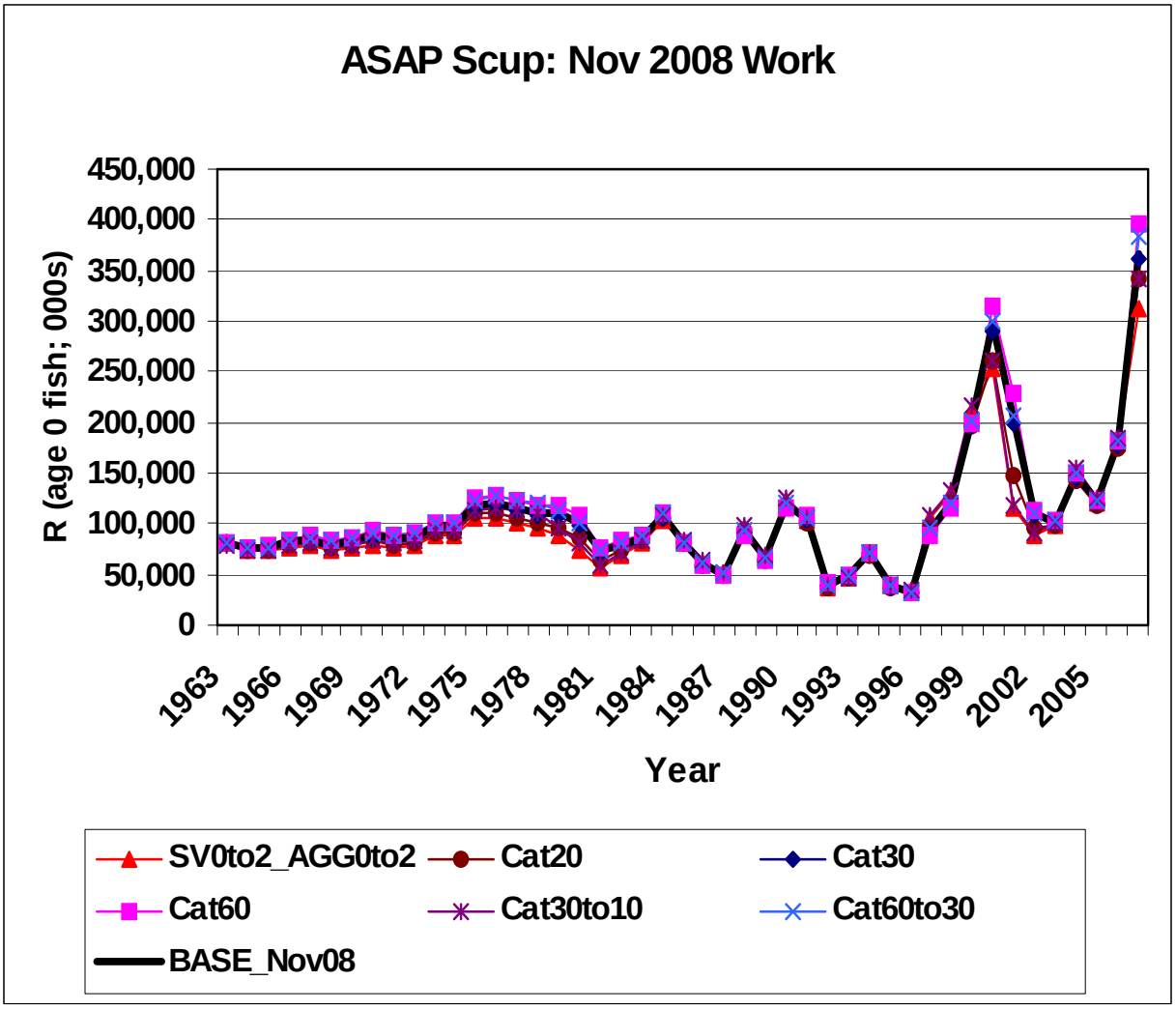


Figure 41. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of R from the BASE_Nov08 run.

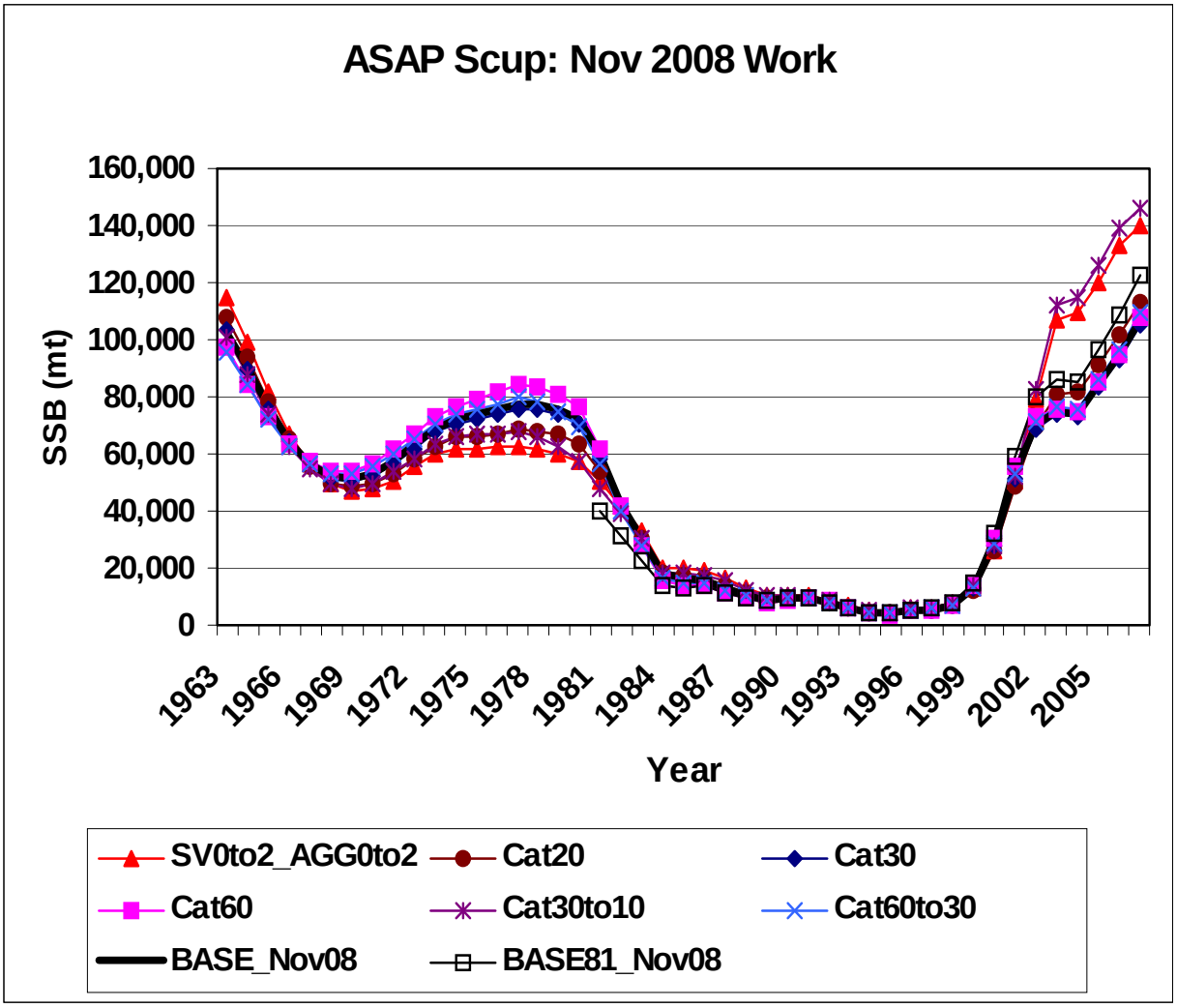


Figure 42. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of SSB.

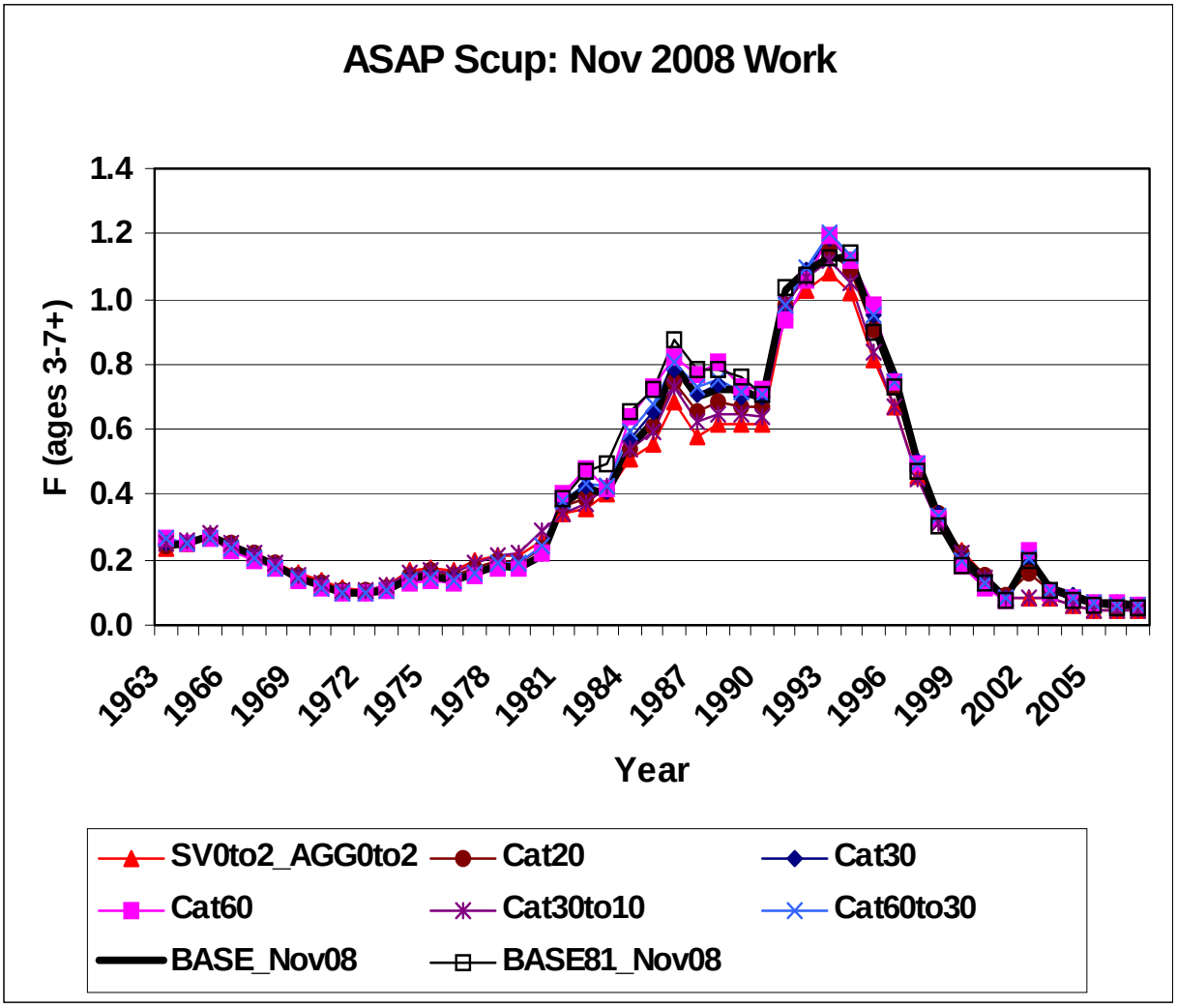


Figure 43. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of F.

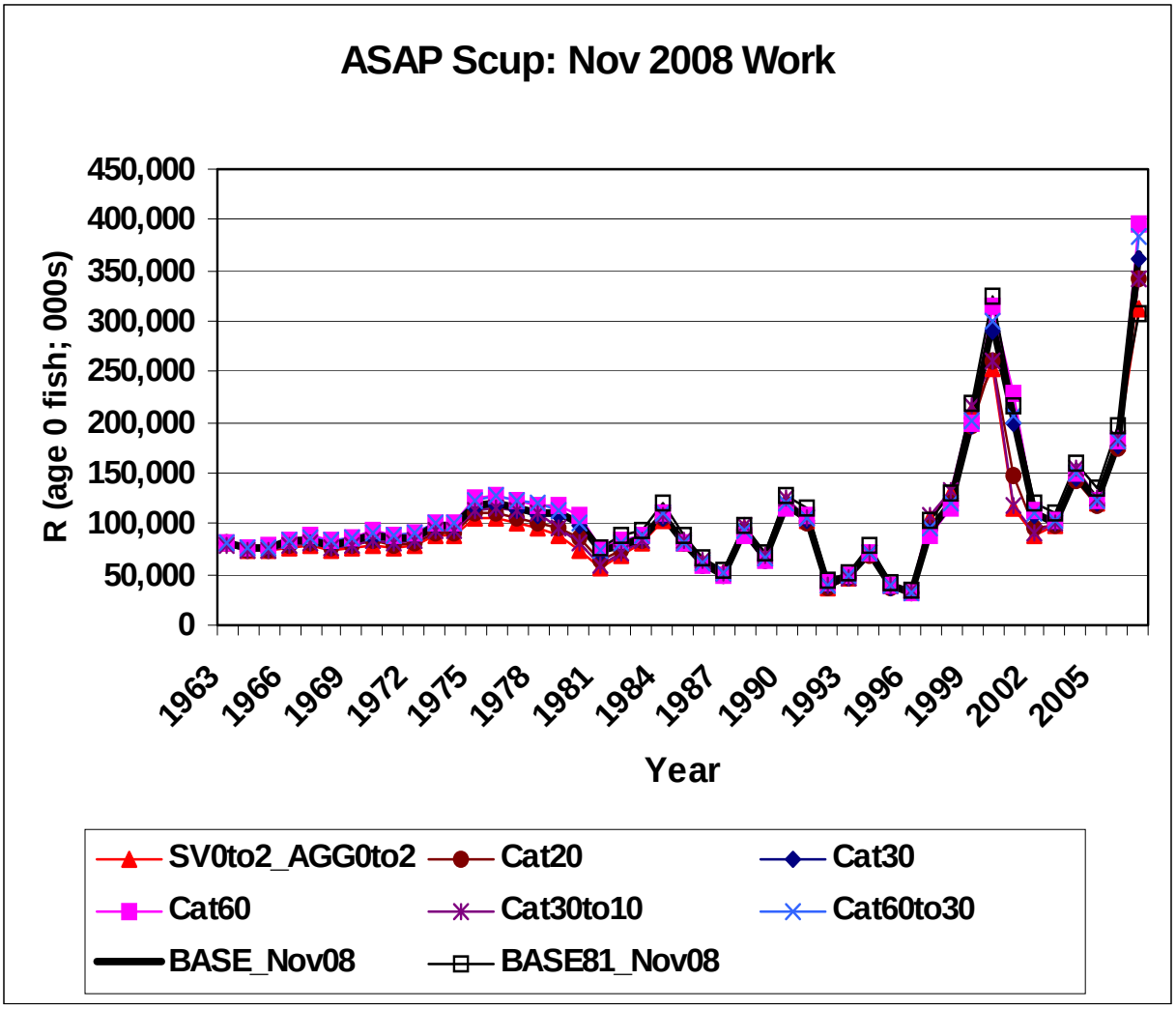


Figure 44. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of R.

SCUP: ASAP "BASE_Nov08" model **Mean R = 119.2 million age 0 fish**

BRP		Y/R	SSB/R	SSB	Catch	Land	Disc
Fmax	0.272	0.155	0.552	62,630	17,601	13,330	4,271
F35%	0.202	0.151	0.745	85,425	17,349	13,823	3,526

SCUP: ASAP "BASE81_Nov08" model **Mean R = 125.4 million age 0 fish**

BRP		Y/R	SSB/R	SSB	Catch	Land	Disc
Fmax	0.292	0.163	0.547	66,142	19,743	15,202	4,541
F35%	0.213	0.158	0.746	91,119	19,440	15,735	3,705

SCUP: ASAP "BASE_Nov08" model

BRP	SSB	SSB07	%SSBMSY	Catch	Catch07	%MSY
Fmax	62,630	107,129	171%	17,601	8,026	46%
F35%	85,425	107,129	125%	17,349	8,026	46%

SCUP: ASAP "BASE81_Nov08" model

BRP	SSB	SSB07	%SSBMSY	Catch	Catch07	%MSY
Fmax	66,142	122,671	185%	19,743	8,026	41%
F35%	91,119	122,671	135%	19,440	8,026	41%

Figure 45. Biological reference points and stock status from ASAP model results, for the full 1963-2007 time series (BASE_Nov08 run) and shorter 1981-2007 time series (BASE81_Nov08 run). Fishing mortality rates (F) for both models were about 0.06, about one-quarter of the Fmax proxy for FMSY.

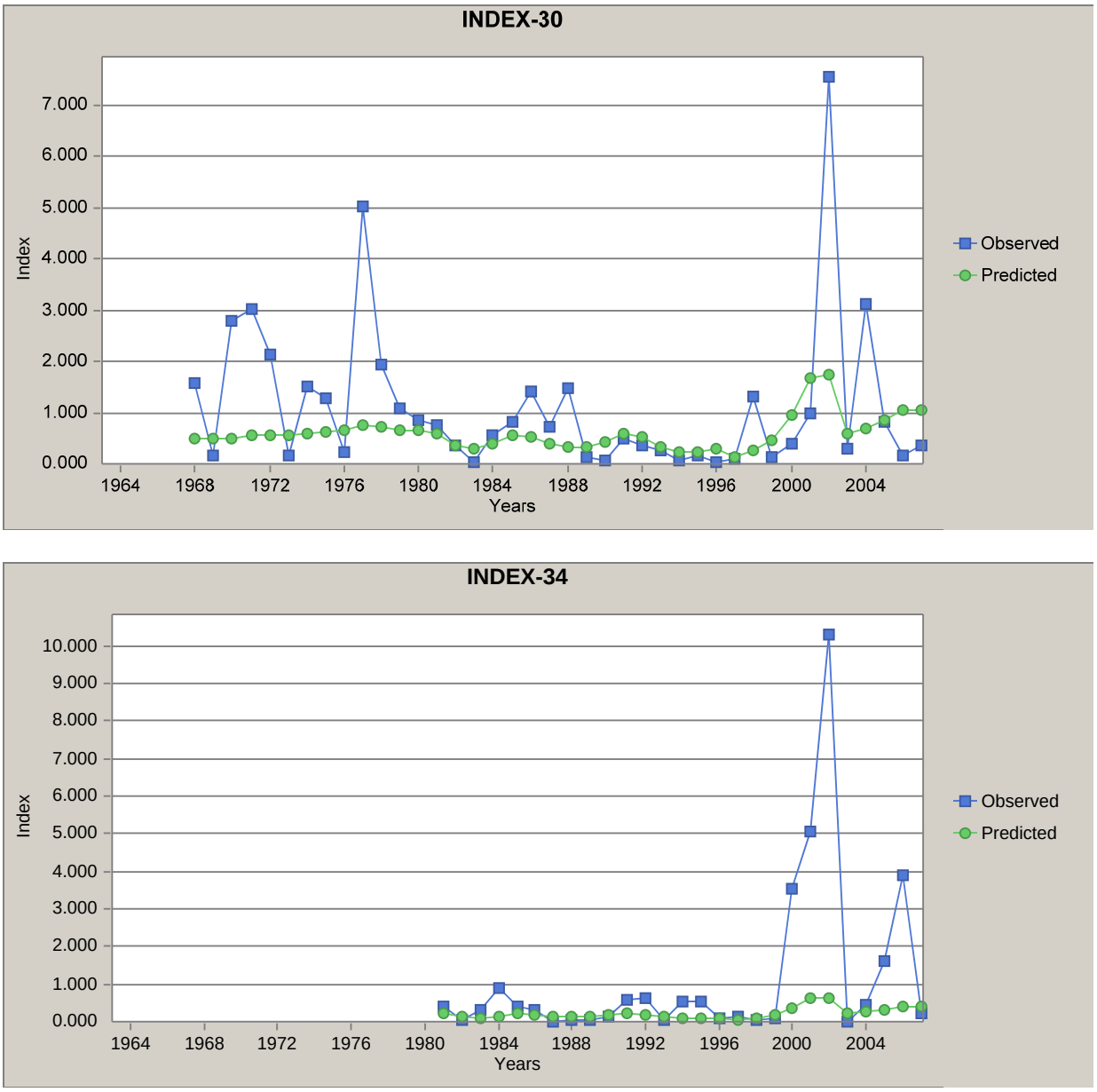


Figure 46. ASAP model BASE_C2006 run fits for the NEFSC Spring survey aggregate biomass index for ages 1-2 (top - Index 30) and RIDFW Spring survey biomass index for ages 1-2 (bottom - Index 34) showing the large residuals for the 2002 indices.

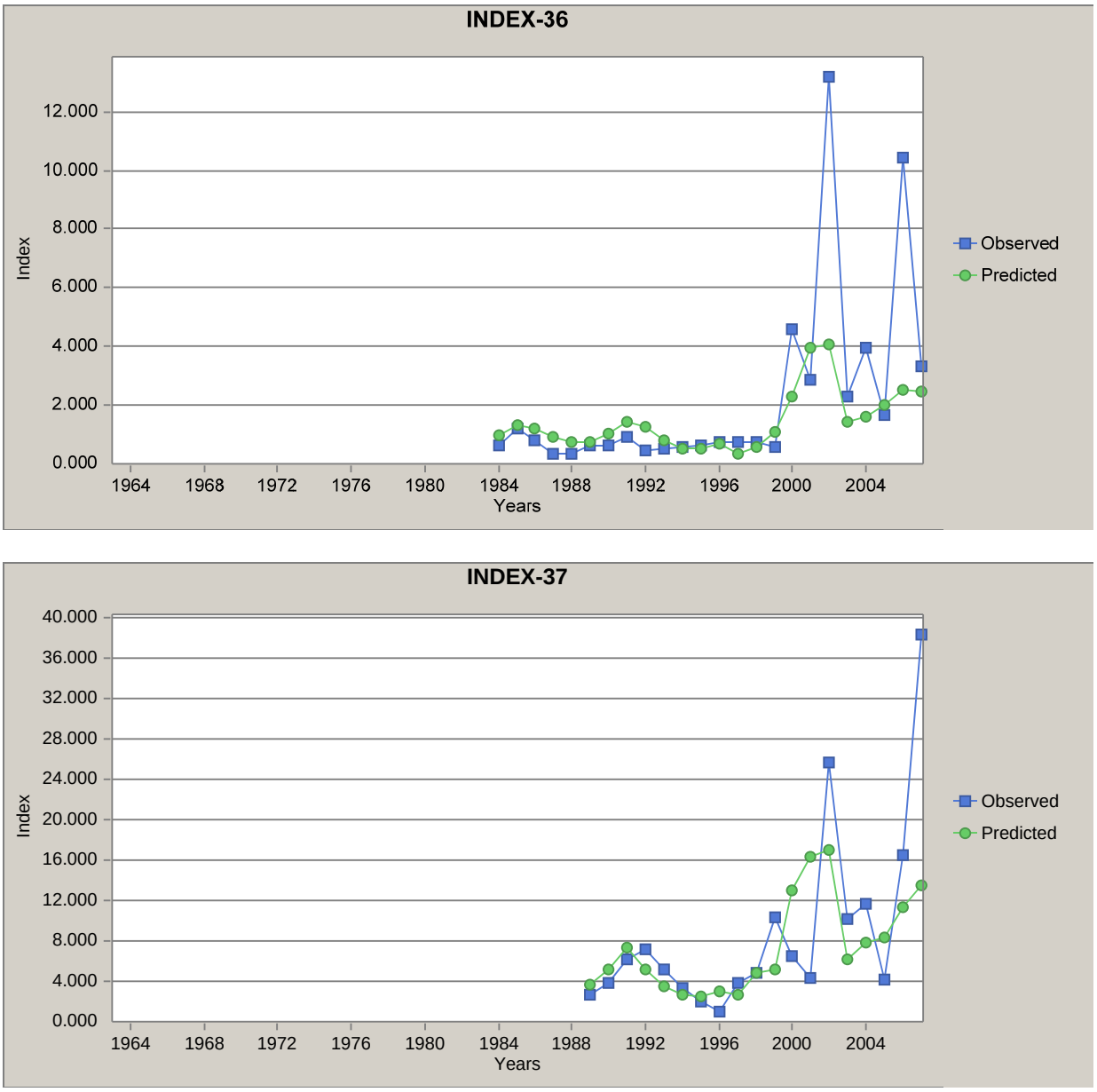


Figure 47. ASAP model BASE_C2006 run fits for the CTDEP Spring survey aggregate biomass index for ages 1-2 (top - Index 36) and NJBMF Annual survey biomass index for ages 1-2 (bottom - Index 37) showing the large residuals for the 2002 indices.

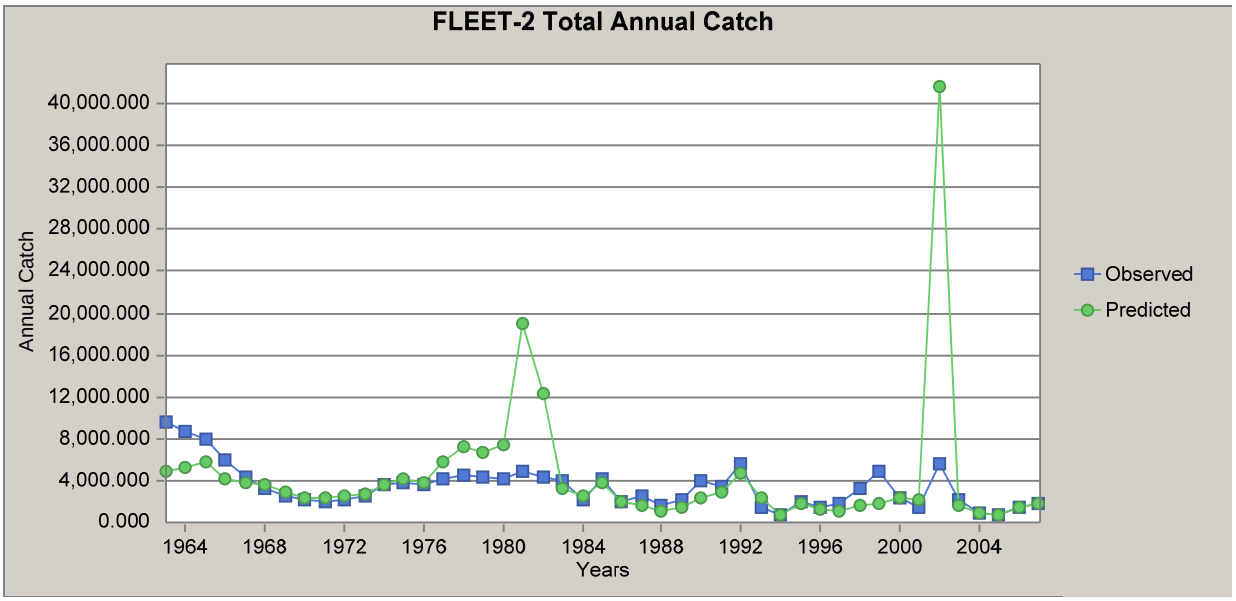


Figure 48. ASAP model BASE_C2006 run fit for Commercial Fishery Aggregate Discards showing the large residual for the 2002 estimate

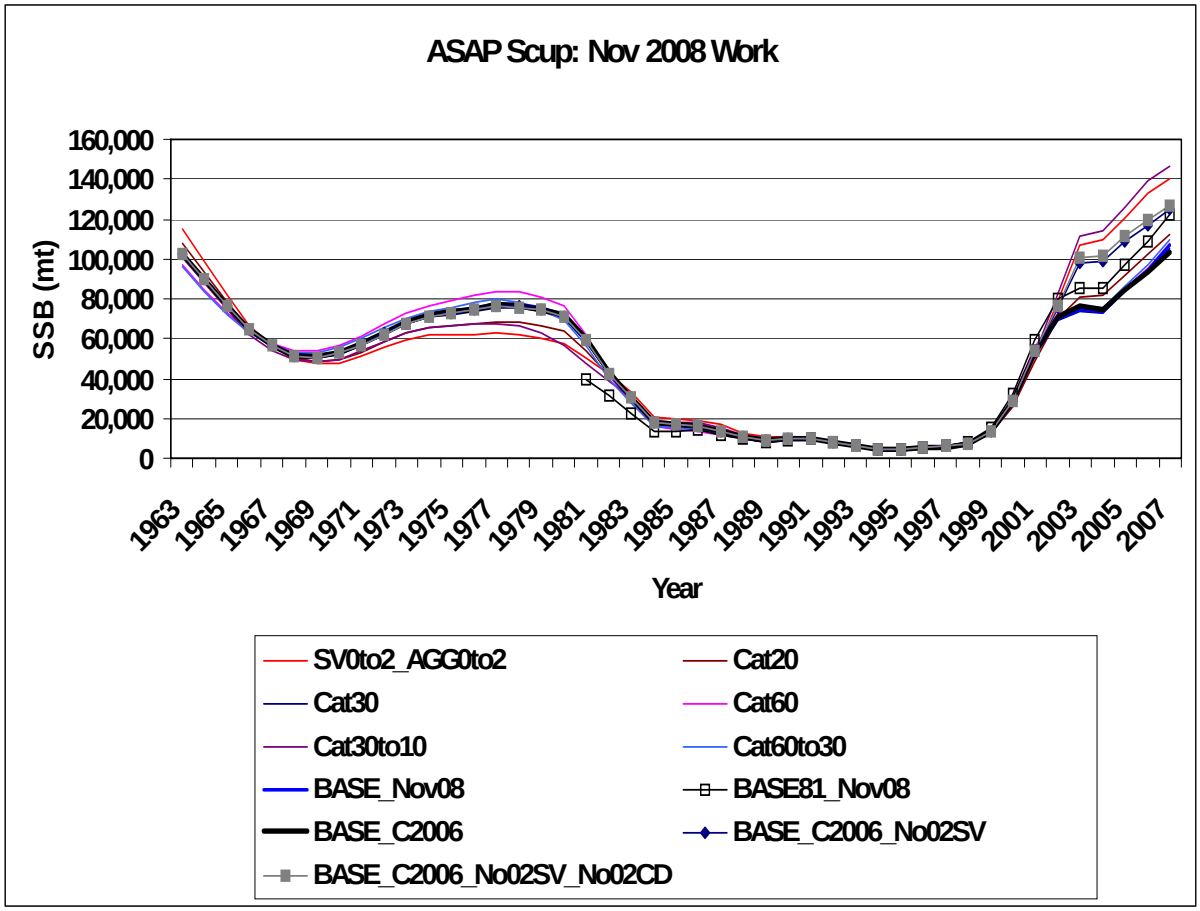


Figure 49. Comparative results for estimated SSB in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

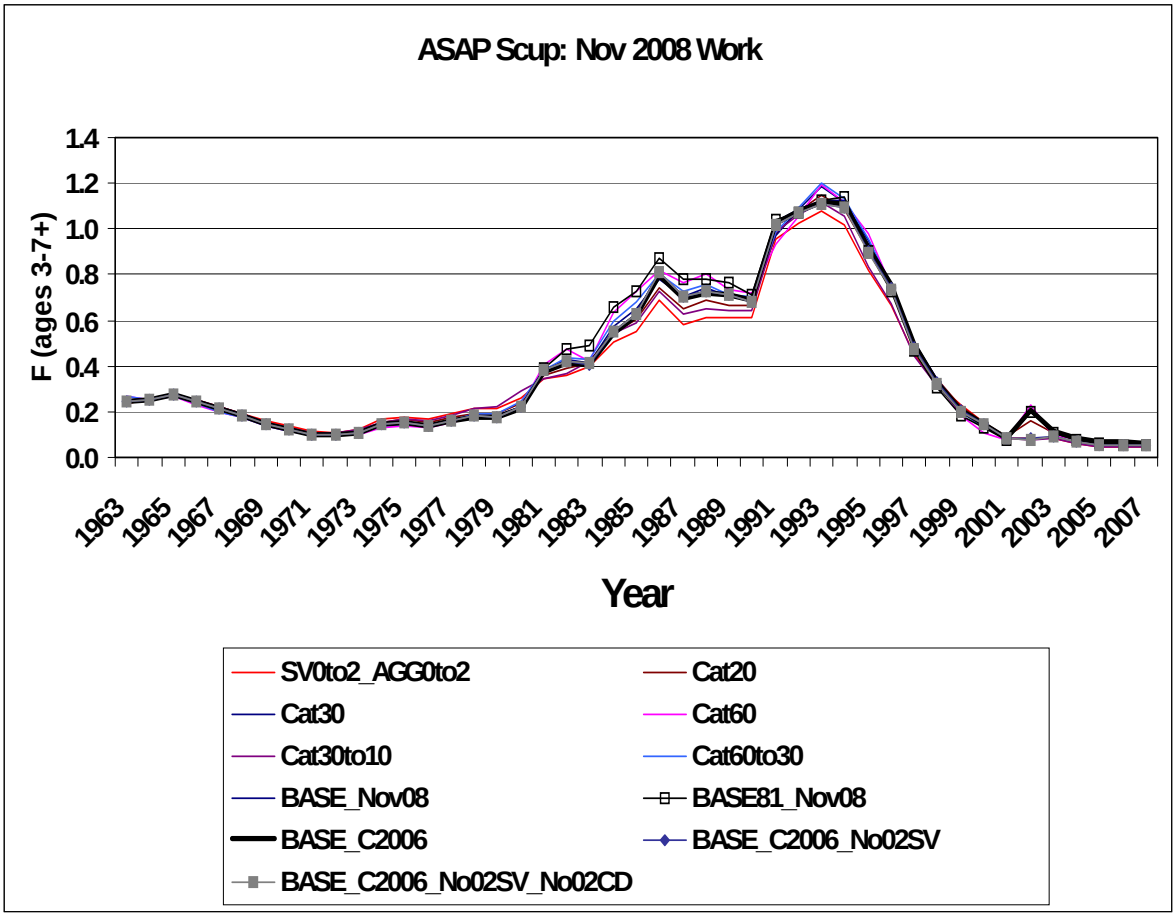


Figure 50. Comparative results for estimated F in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

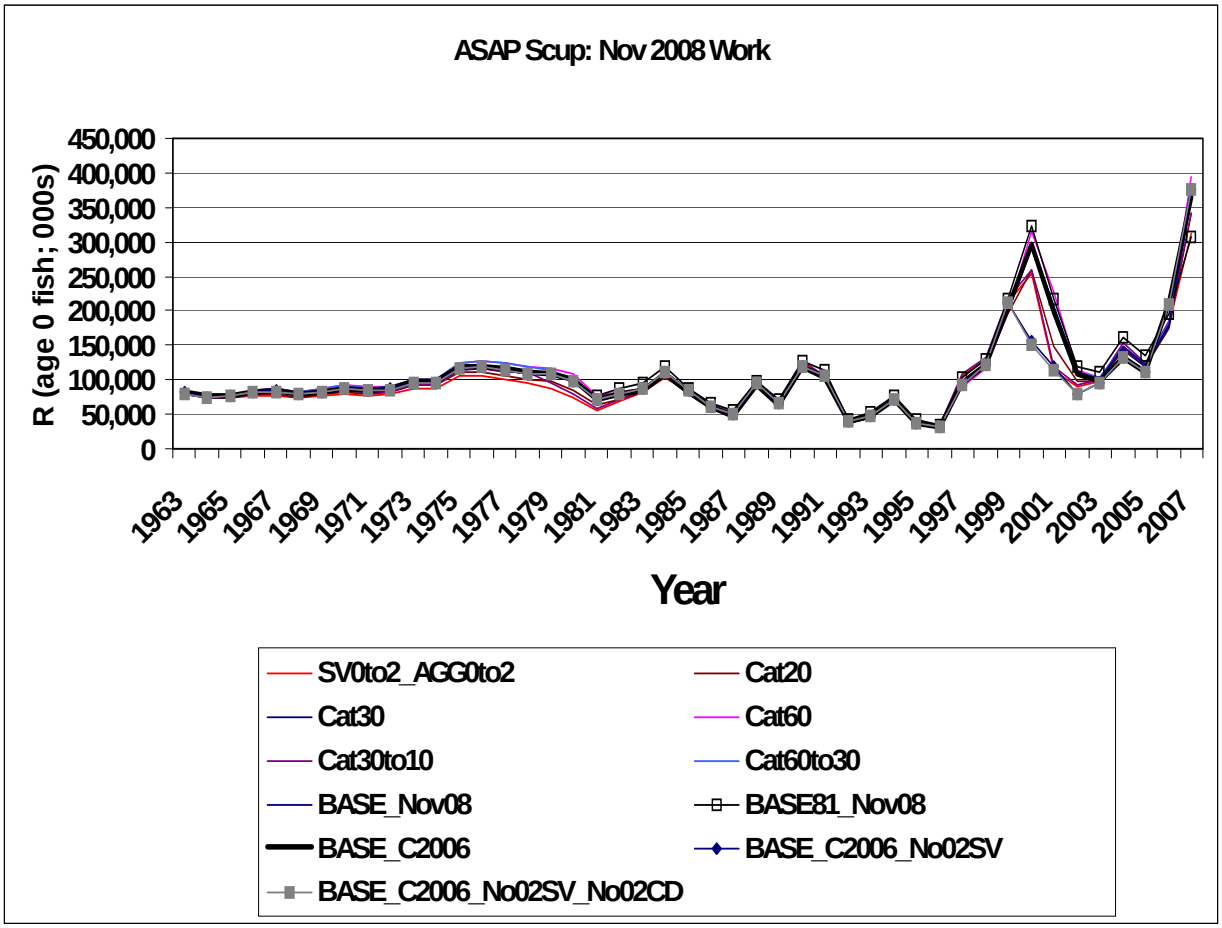


Figure 51. Comparative results for estimated recruitment in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

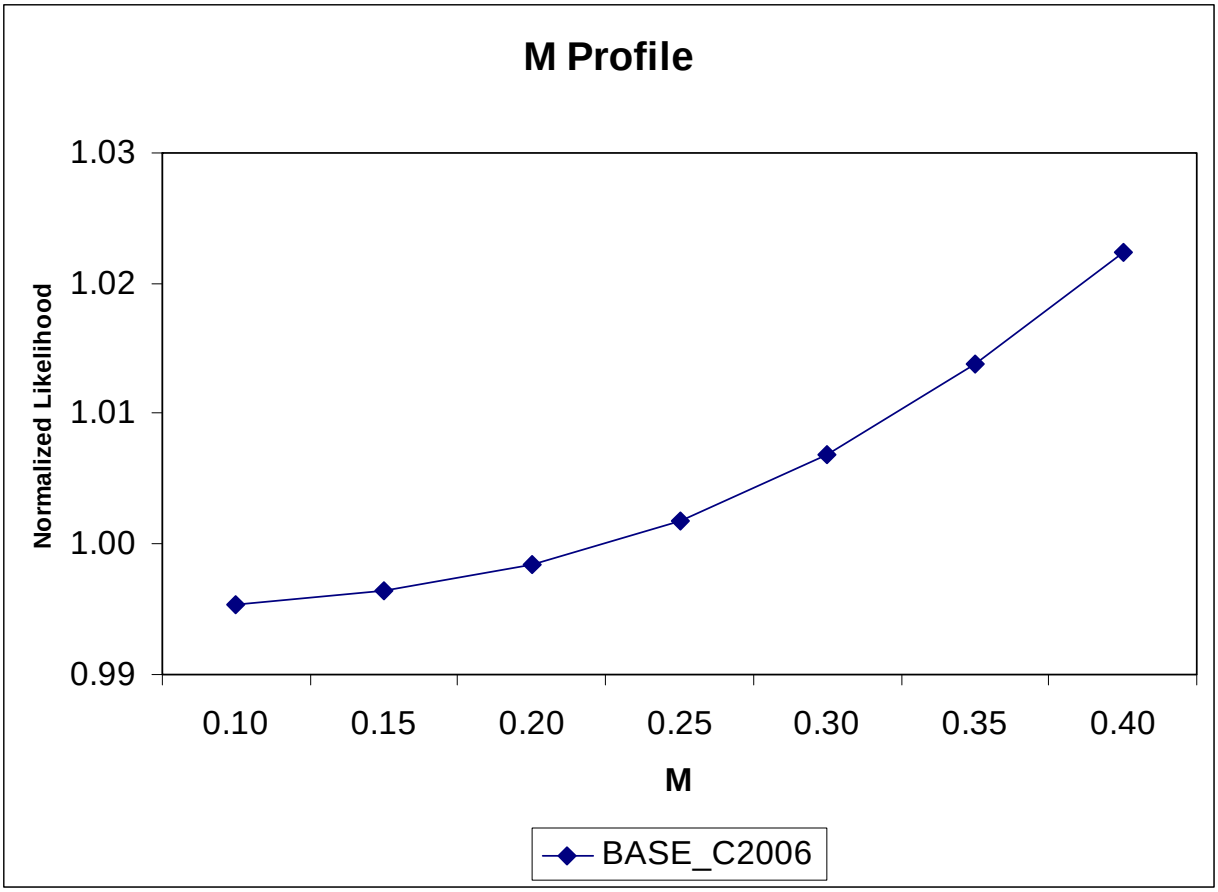


Figure 52. Sensitivity profile of the assumption for natural mortality (M) for the ASAP BASE_C2006 model configuration.

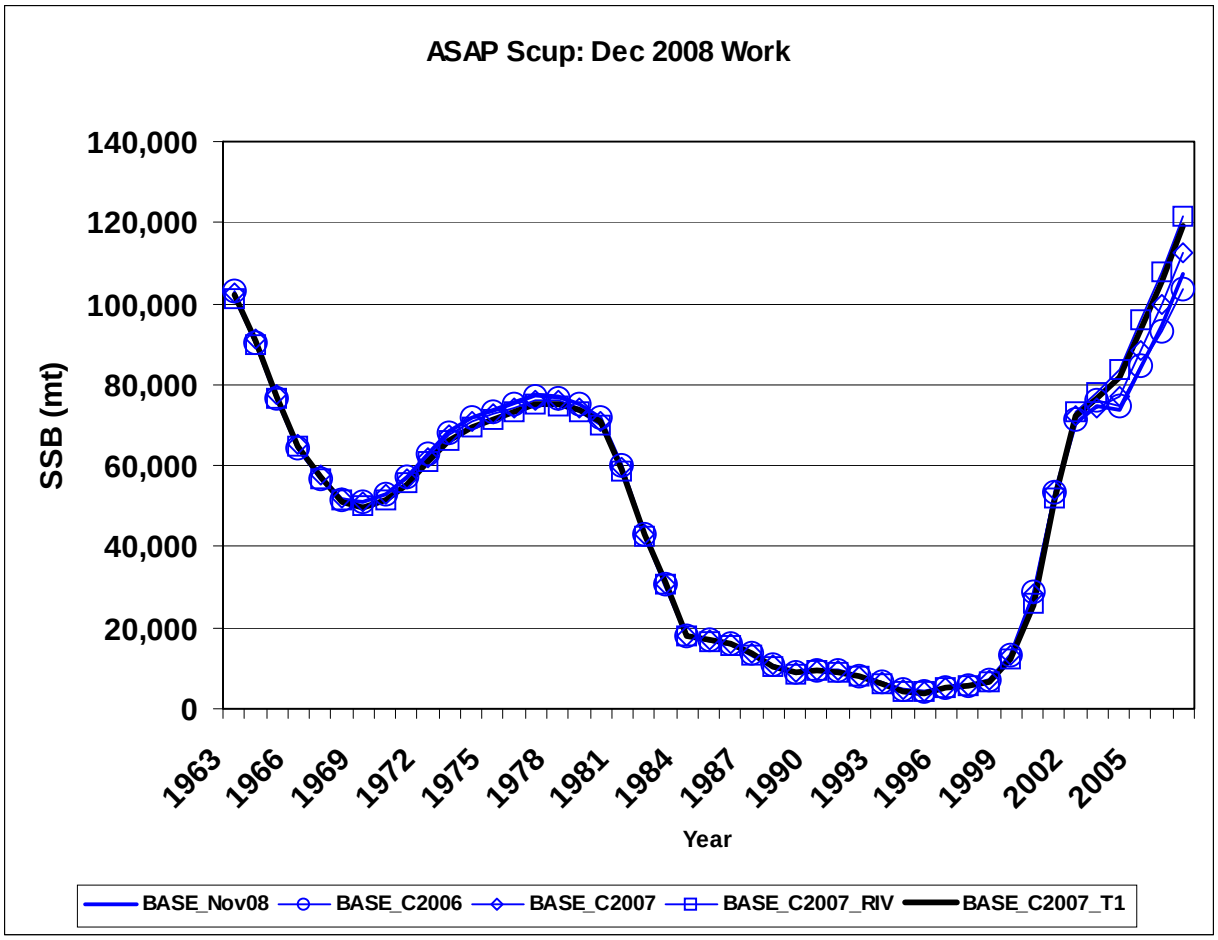


Figure 53. Comparative results for estimated SSB in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

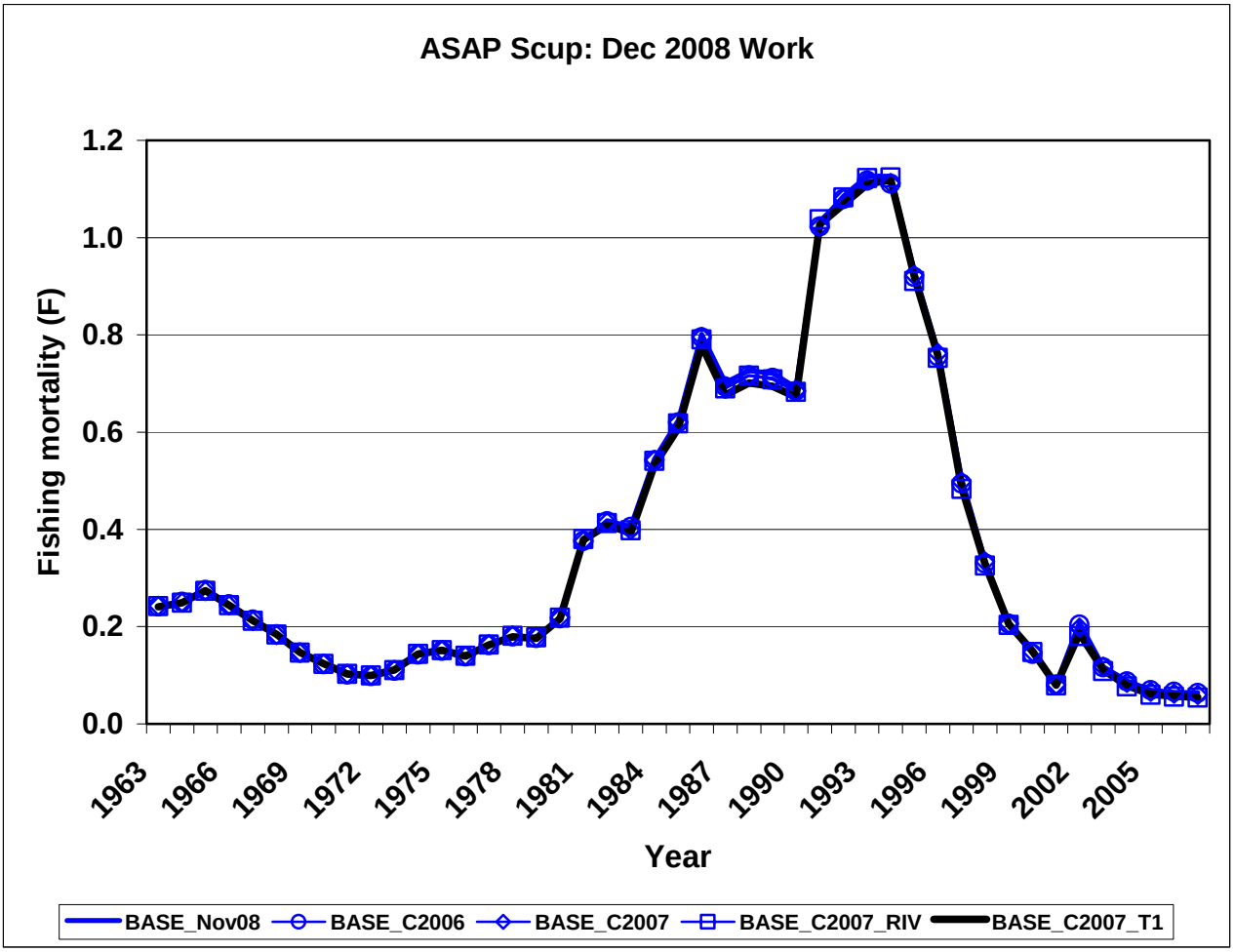


Figure 54. Comparative results for estimated F in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

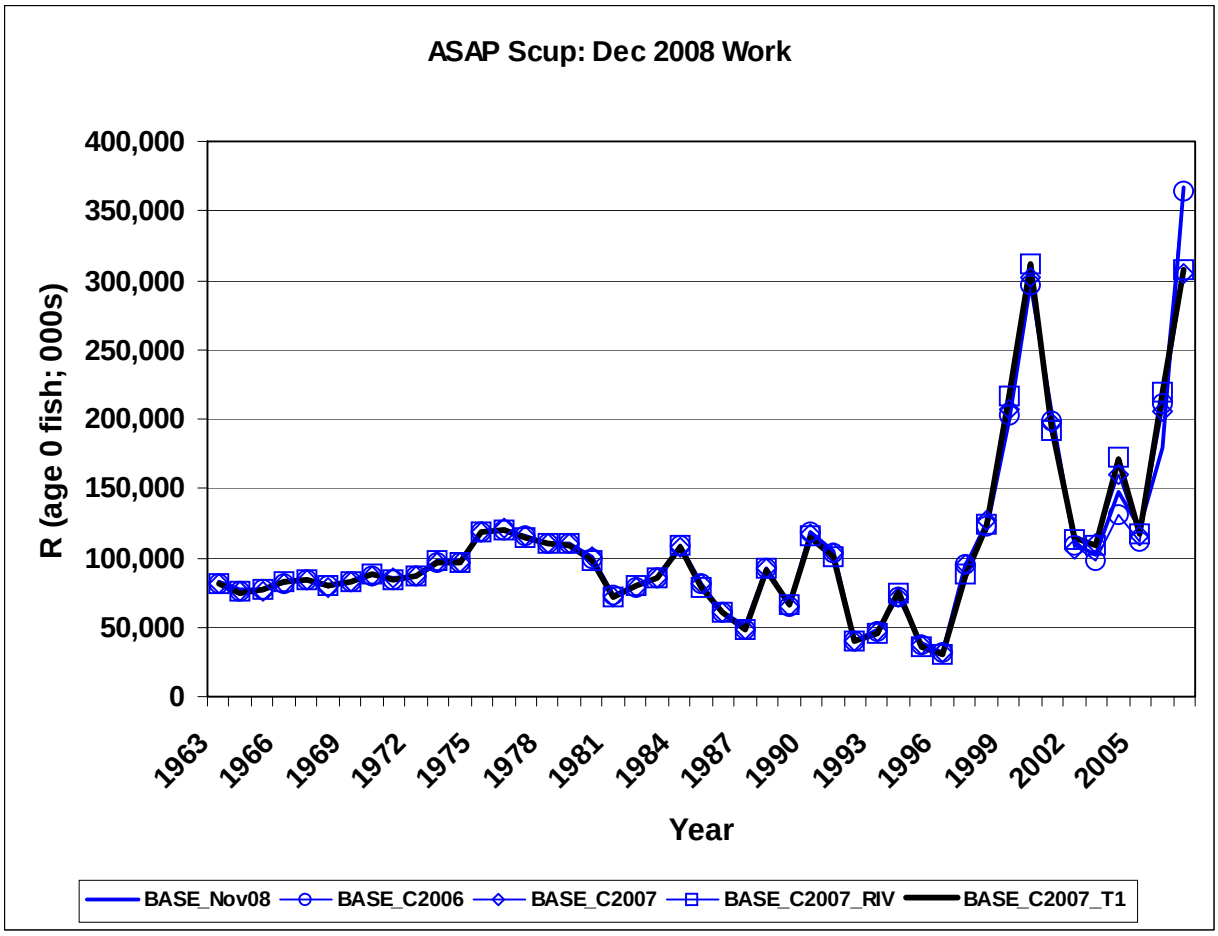


Figure 55. Comparative results for estimated recruitment in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

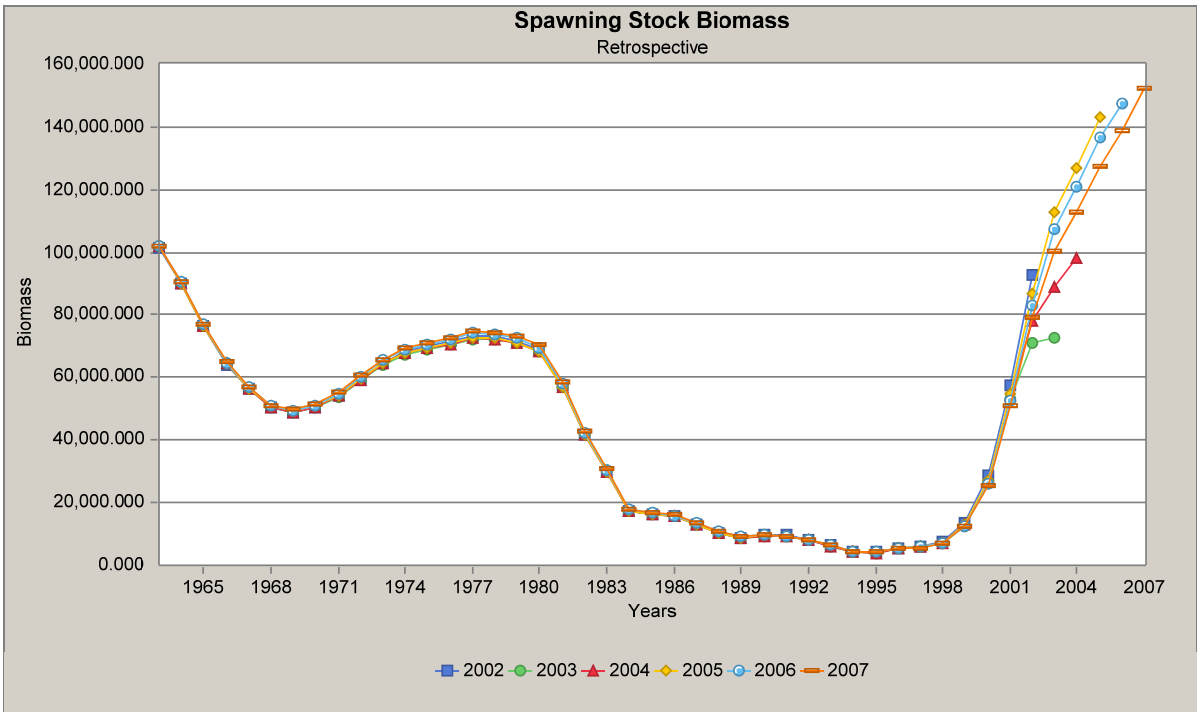


Figure 56. Retrospective analysis for SSB from Scup ASAP accepted model BASE_C2007_T1.

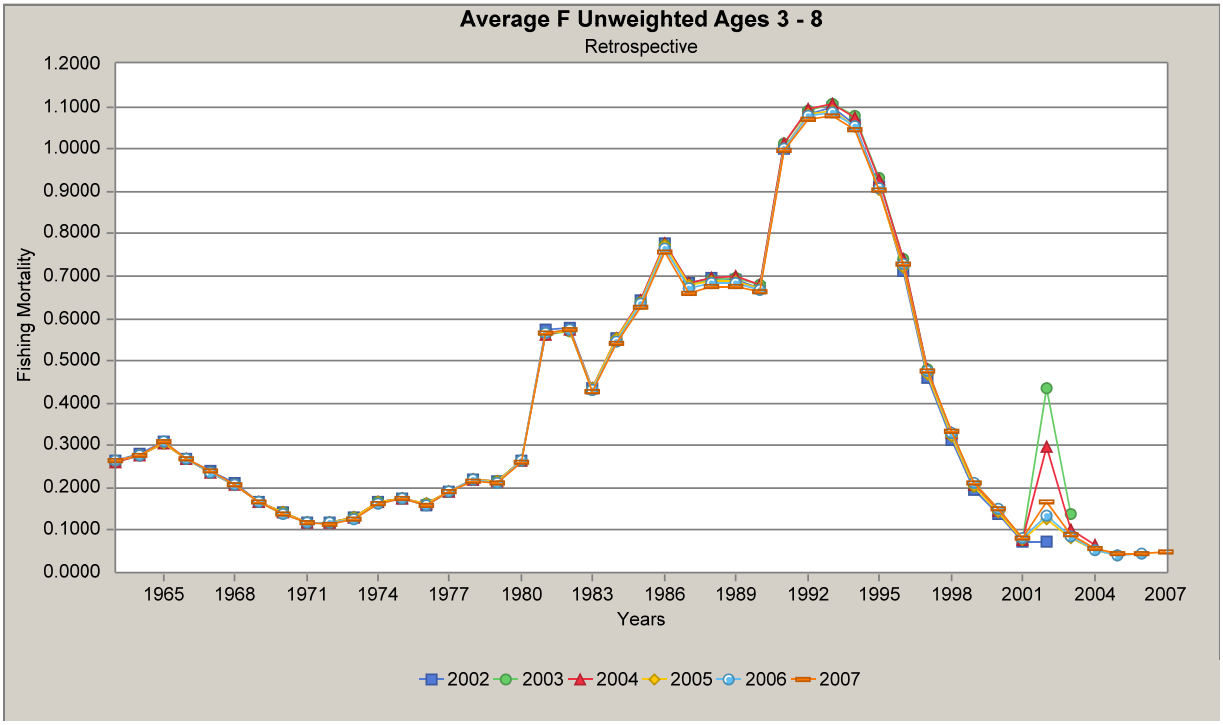


Figure 57. Retrospective analysis for fishing mortality (F) from Scup ASAP accepted model BASE_C2007_T1. Note that model coded ages 3-8 are true ages 2-7+.

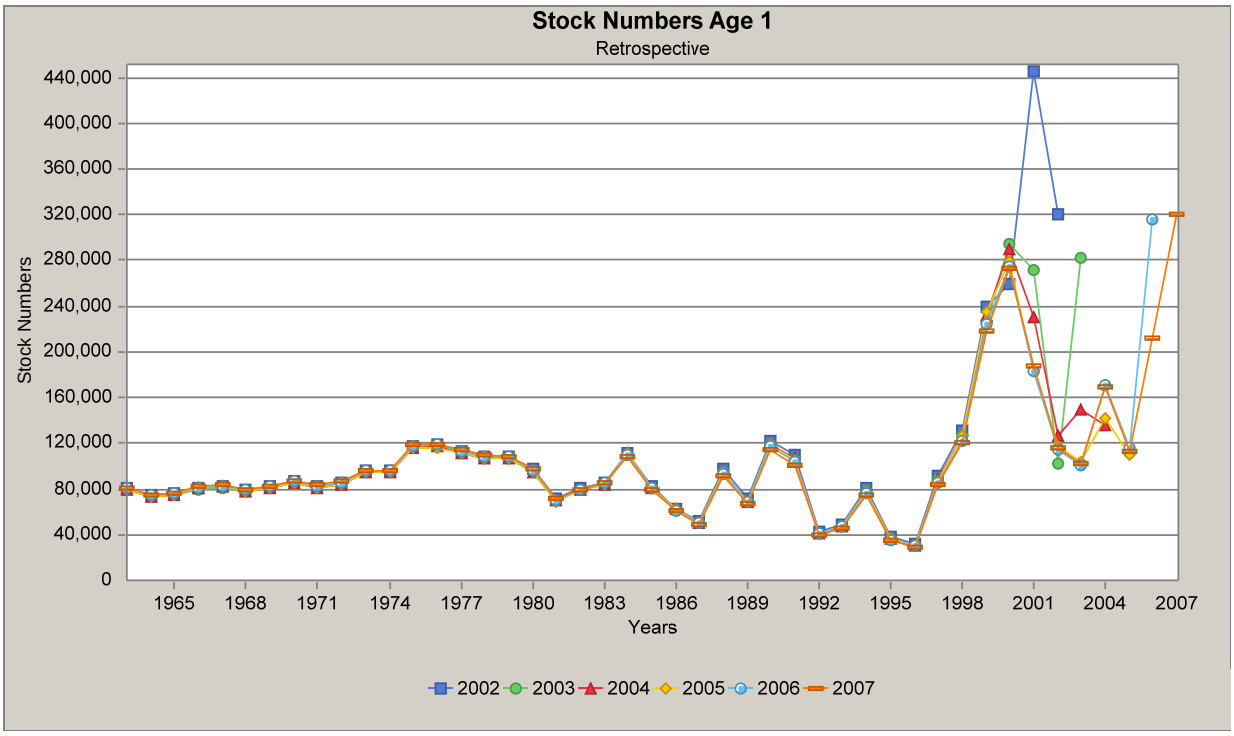


Figure 58. Retrospective analysis for recruitment at age 0 from Scup ASAP accepted model BASE_C2007_T1. Note that model coded age 1 is true age 0.

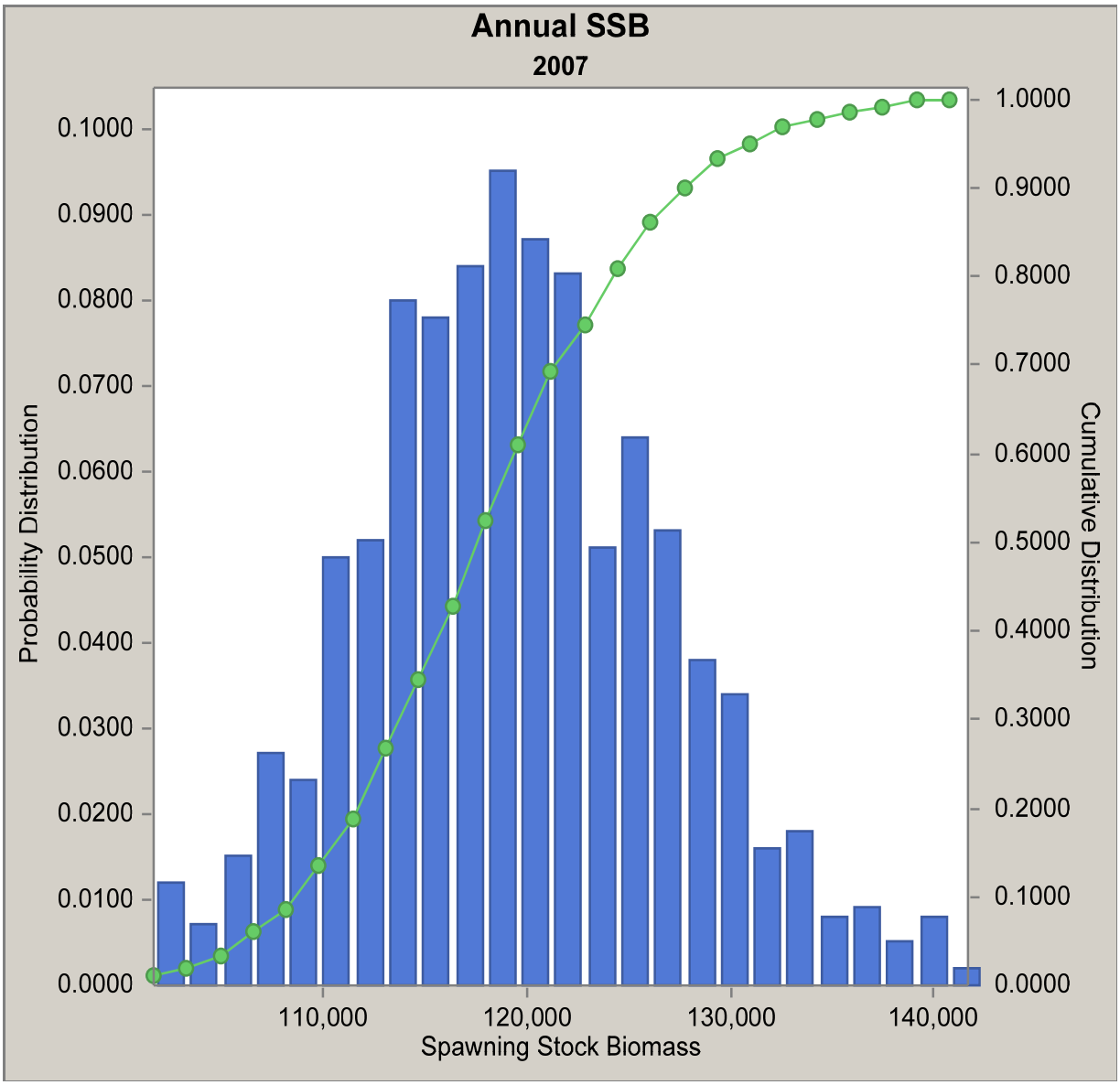


Figure 59. MCMC distribution of SSB in 2007 from the 2008 assessment accepted model BASE_C2007_T1.

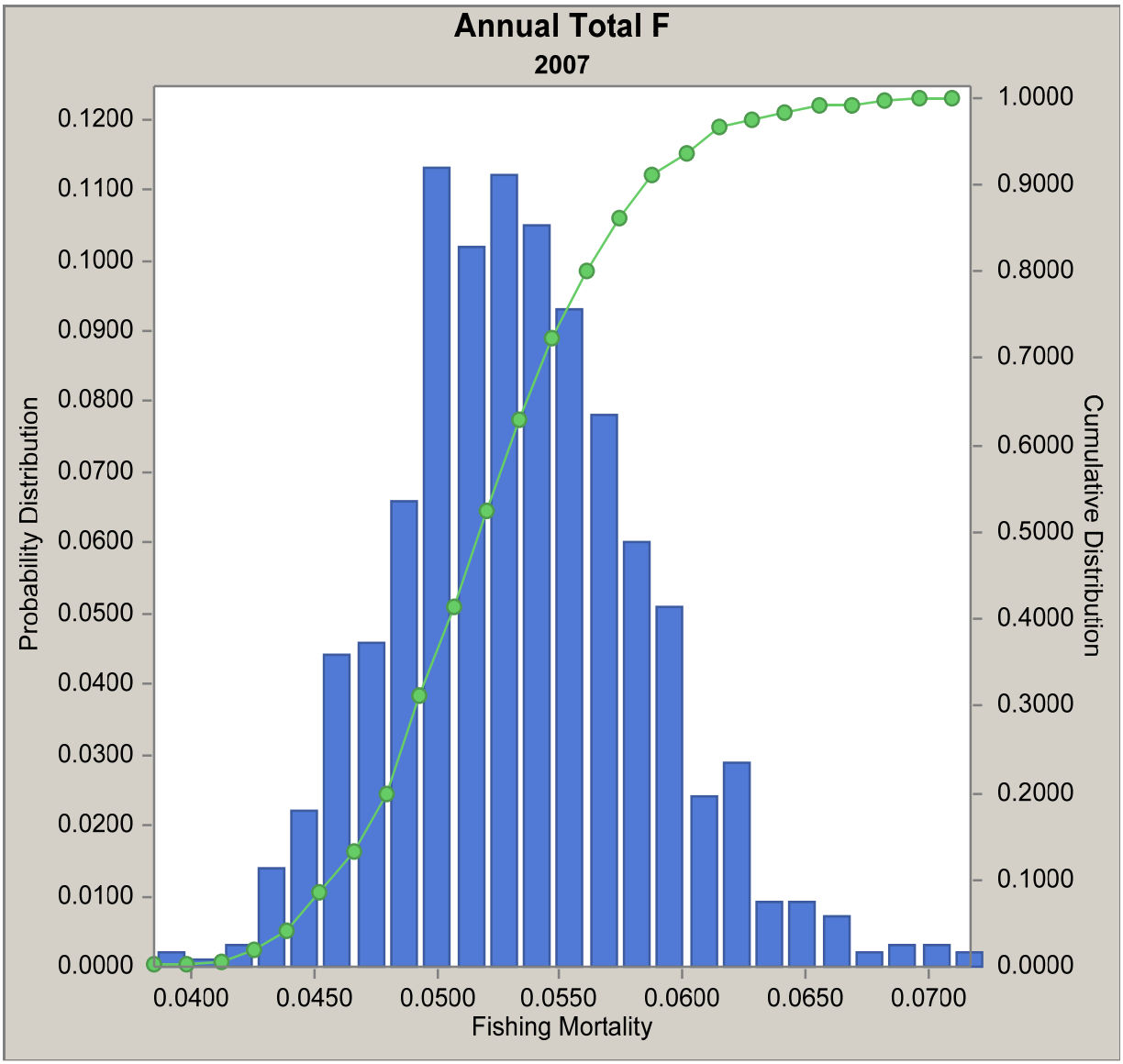


Figure 60. MCMC distribution of F in 2007 from the 2008 assessment accepted model BASE_C2007_T1.

Figure 61. Spawning stock biomass (SSB; metric tons) and recruitment (age 0; 000s) estimates for scup from the 2008 assessment accepted model BASE_C2007_T1.

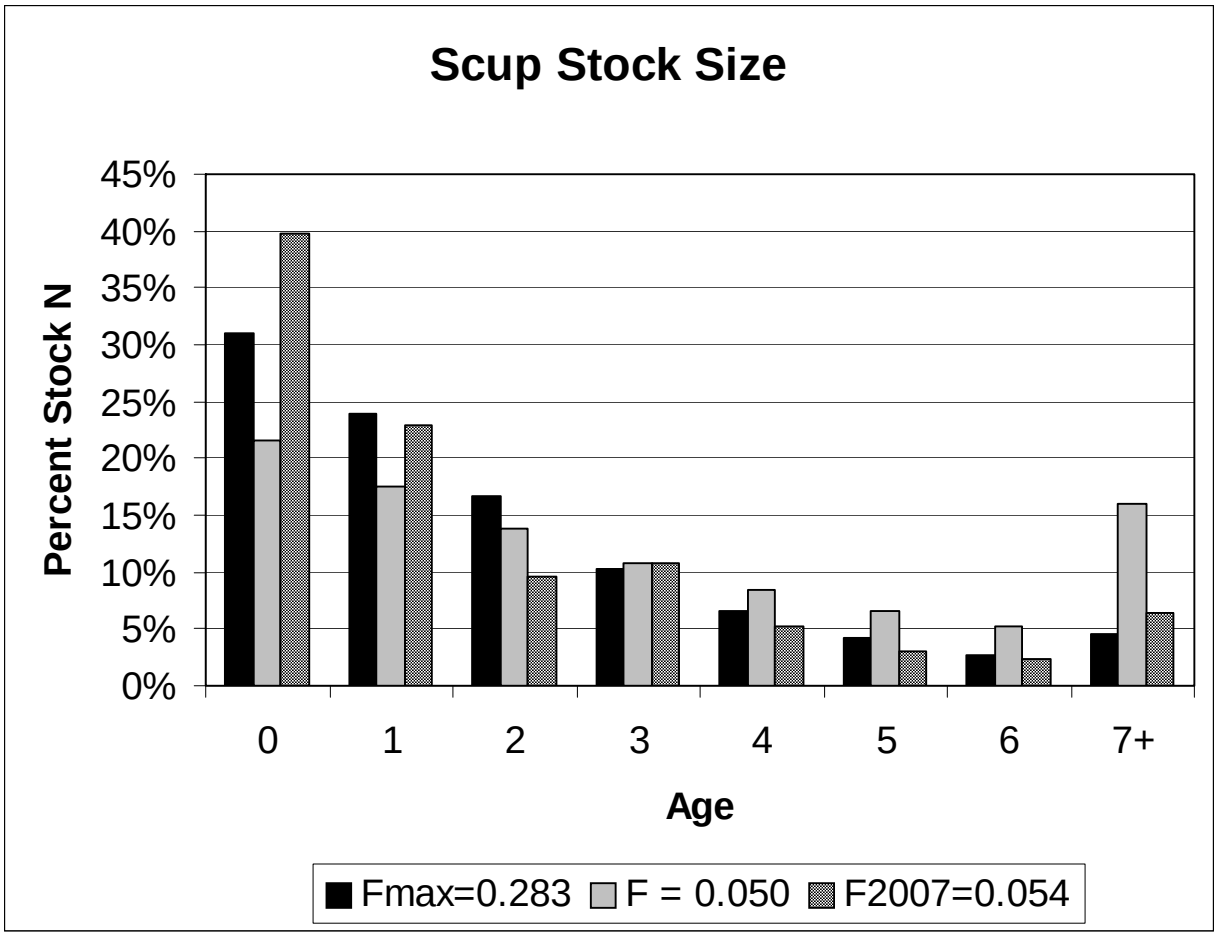


Figure 62. Percentage of scup stock size in numbers expected if the stock were fished at Fmax = 0.283 or F = 0.050 over the long-term, compared with stock size percentages estimated for 2007 at F = 0.054.

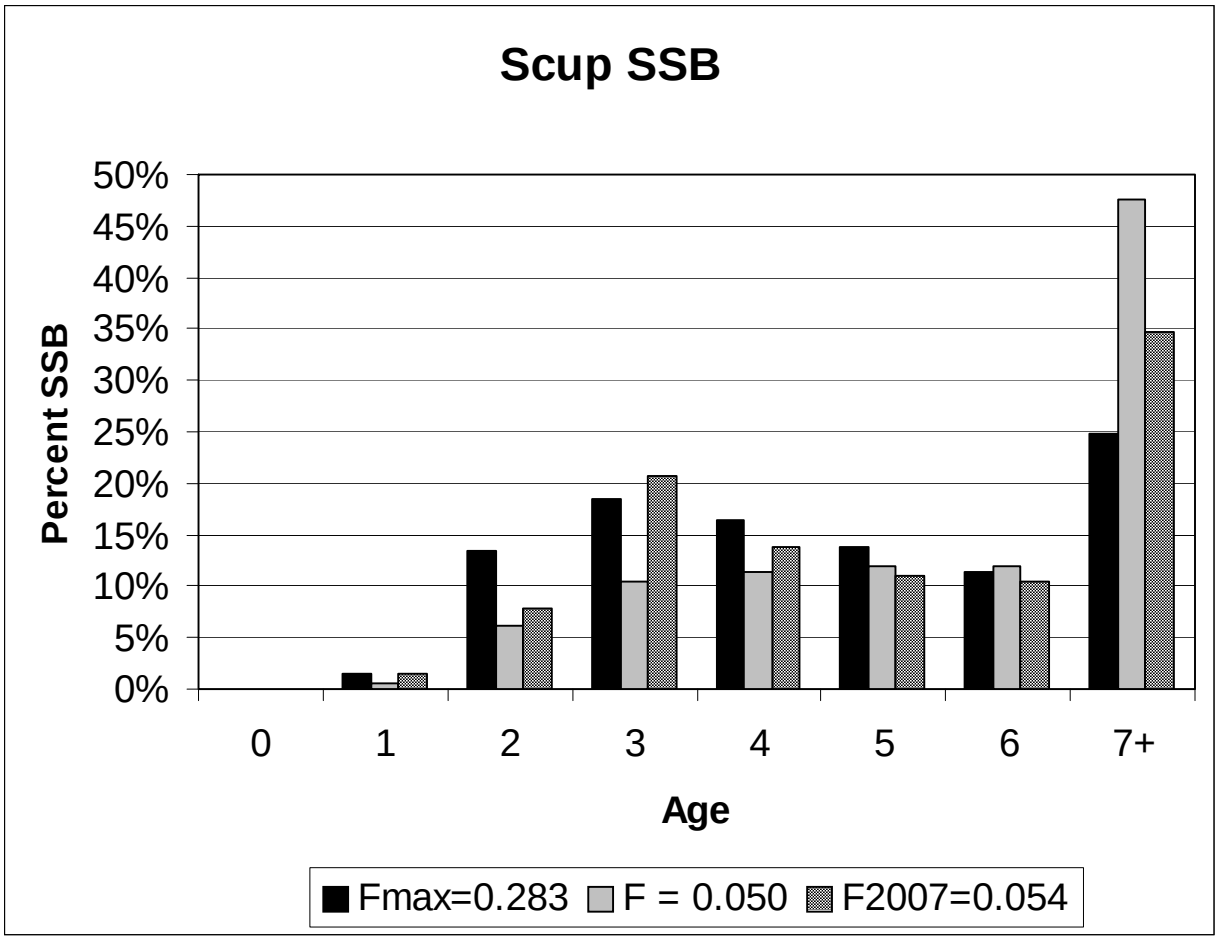


Figure 63. Percentage of SSB in weight expected if the stock were fished at Fmax = 0.283 or F = 0.050 over the long-term, compared with SSB percentages estimated for 2007 at F = 0.054. Fish at ages 3 and older are fully (>99%) mature.

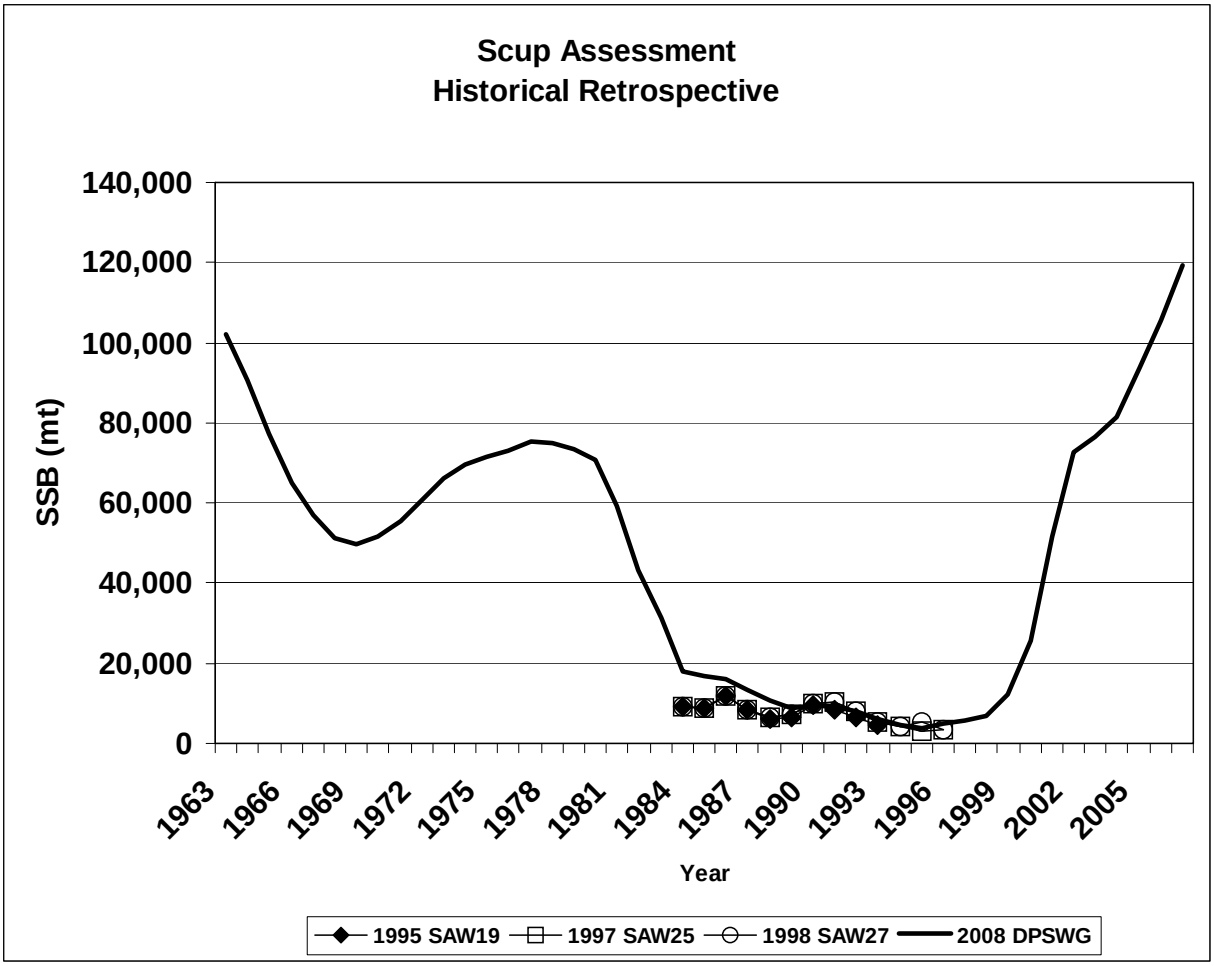


Figure 64. Historical retrospective of previous analytical assessments for scup: SSB. The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

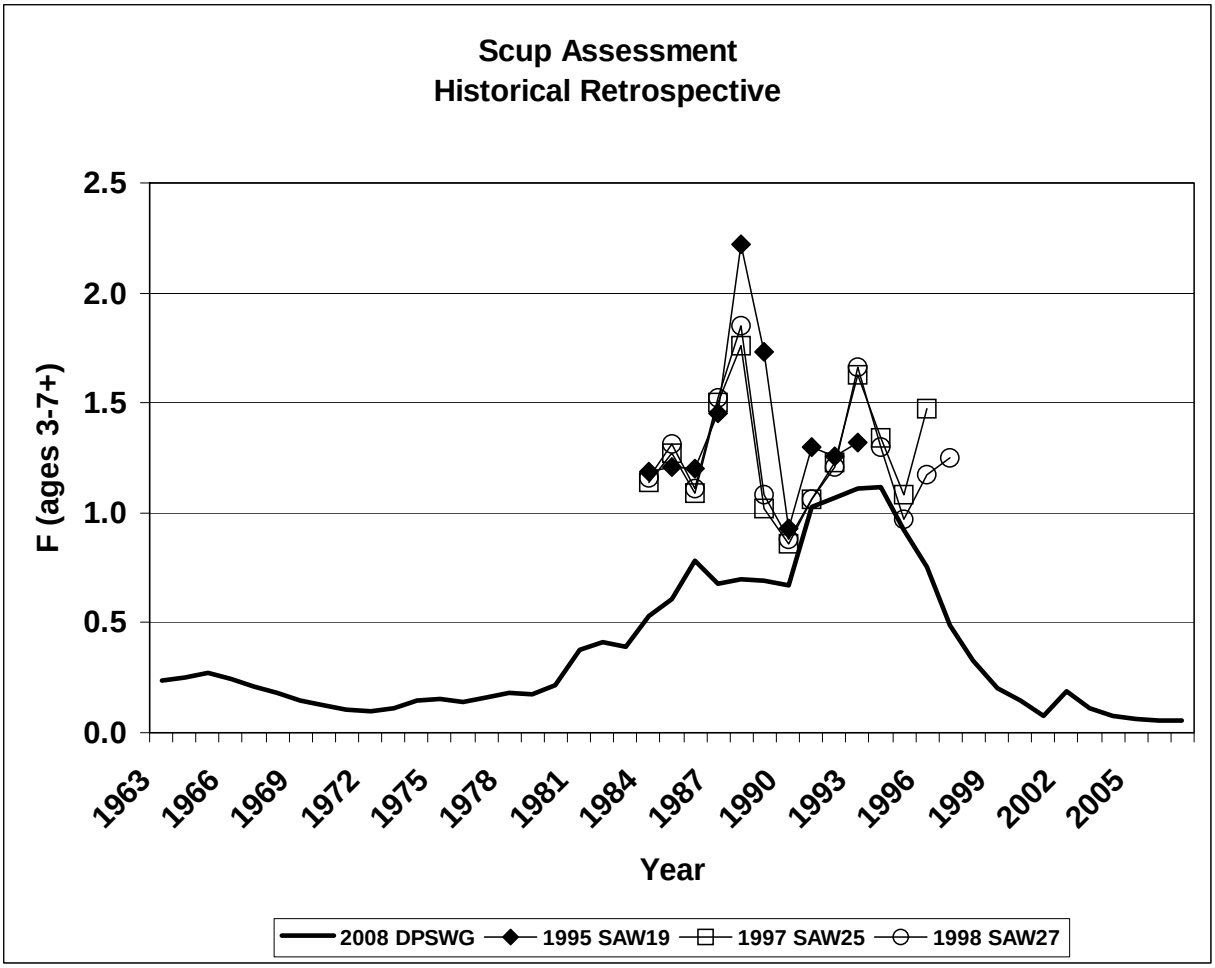


Figure 65. Historical retrospective of previous analytical assessments for scup: Fishing mortality (F). The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

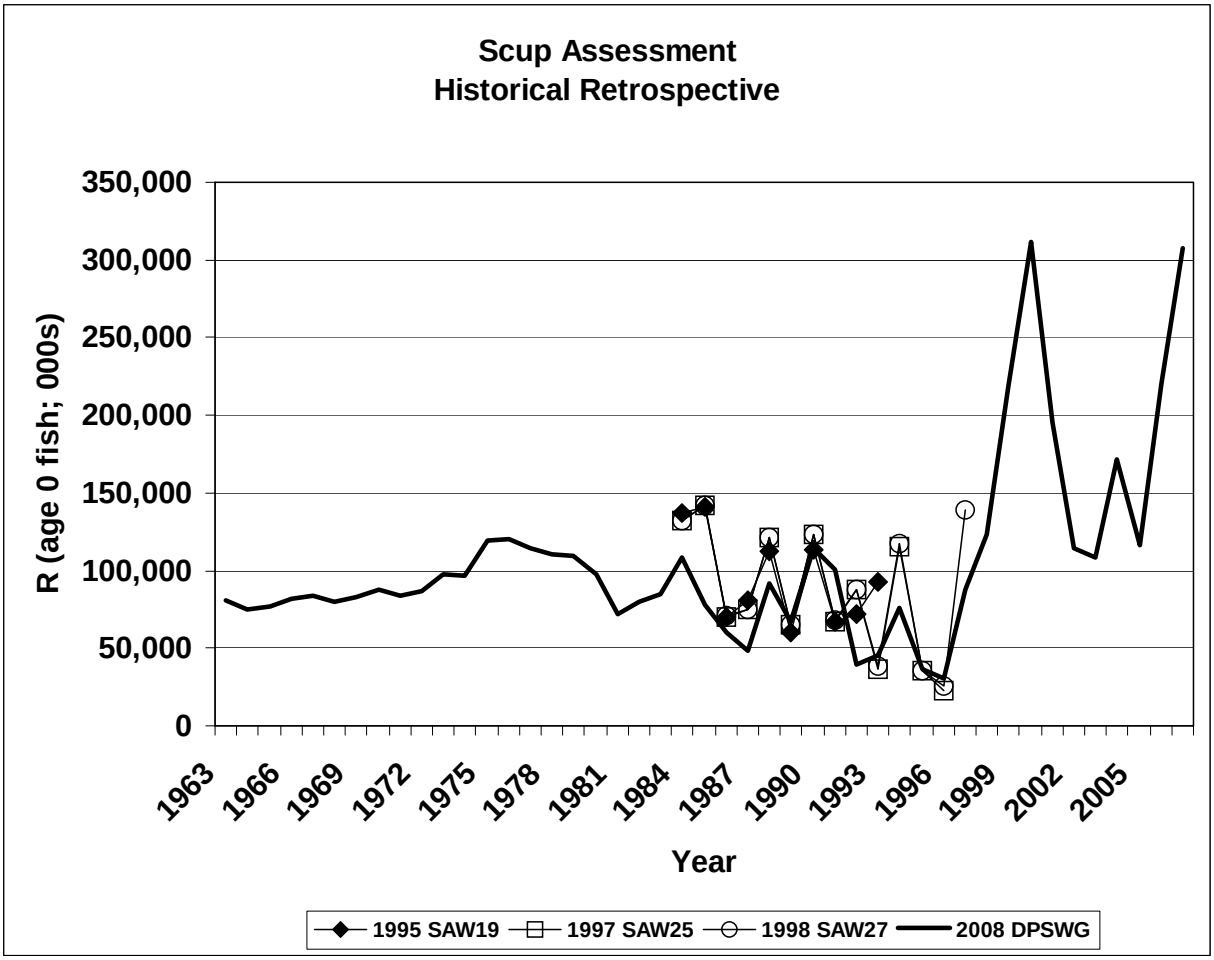


Figure 66. Historical retrospective of previous analytical assessments for scup: Recruitment at age 0 (R). The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

Black Sea Bass

by

Gary Shepherd
National Marine Fisheries Service
Northeast Fisheries Science Center
166 Water St., Woods Hole, MA 02543

Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

Executive Summary

The northern stock of black sea bass (*Centropristis striata*) was evaluated using length-based population models. Under the existing fishery management plan (FMP), black sea bass has been regulated based on annual changes in the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey index. Fishing mortality resulting in maximum sustainable yield was considered equal to F_{MAX} equal to 0.33. Overfishing status was evaluated only with an approximation of F, based on a relative exploitation rate. A new approach was presented to the Data Poor Workshop review panel (December 2008) which involved estimates of fishing mortality and population size determined from changes in the size composition of the population (SCALE model). In addition, a length based yield per recruit model was developed to determine the associated biological reference points. An array of natural mortality estimates was considered, ranging from 0.2 to 0.9, and they were modeled as either a constant value or in the form of a logistic function where M varied with body length. The panel adopted results using a constant M=0.4 as the preferred model. The resulting $F_{40\%}$, as a proxy for F_{MSY}, was equal to 0.42 with an associated SSB equal to 12,537 mt and MSY of 3,903 mt. Assuming a catch of 2,685 mt, F_{2007} was estimated to be 0.48 and SSB equal to 11,478 mt. Therefore the conclusions are that overfishing is occurring, but the stock is not overfished (assuming a biomass threshold equal to ½ B_{MSY}). These new reference points and stock status determinations should be used with caution due to the uncertainty in the natural mortality estimate, the model input parameters, residuals patterns in model fit, and significant uncertainty associated with managing a protogynous species (i.e., individuals change sex from female to male).

Terms of Reference

1. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies.
2. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
3. Comment on what can be done to improve the information, proxies or assessments for each species.

Life History

Black sea bass (*Centropristis striata*) are distributed from the Gulf of Maine to the Gulf of Mexico, however, fish north of Cape Hatteras, NC are considered part of a single fishery management unit. Sea bass are generally considered structure oriented, preferring live-bottom and reef habitats. Within the stock area, distribution changes on a seasonal basis and the extent of the seasonal change varies by location. In the northern end of the range (New York to Massachusetts), sea bass move offshore crossing the continental shelf, then south along the edge of the shelf. By late winter, northern fish may travel as far south as Virginia, however most return to the northern inshore areas by May. Sea bass originating inshore along the Mid-Atlantic coast (New Jersey to Maryland) head offshore to the shelf edge during late autumn, travelling in a southeasterly direction. They return inshore in spring to the general area from which they originated. Black sea bass in the southern end of the stock (Virginia and North Carolina) move

offshore in late autumn/early winter. Given the proximity of the shelf edge, they transit a relatively short distance, due east, to reach over-wintering areas.

Fisheries also change seasonally with changes in distribution. Inshore commercial fisheries are prosecuted primarily with fish pots (baited and unbaited) and handlines. Recreational fisheries generally occur during the period that sea bass are inshore. Once fish move offshore in the winter, they are caught in a trawl fishery targeting summer flounder, scup and *Loligo* squid (Shepherd and Terceiro, 1994). Handline and pot fisheries in the southern areas may still operate during this offshore period. Additionally a small sector of the NJ charter fleet target sea bass offshore during the winter.

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999, Drohan et al. 2007). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949, Mercer 1978). Based on sex ratio at length from NMFS surveys, males constitute approximately 30% of the population by 20 cm, with increasing proportions of males with size (Figure 1). Following transition from female to male, sea bass can follow one of two behavioral pathways; either becoming a dominant male, characterized by a larger size and a bright blue nuccal hump during spawning season, or subordinate males which have few distinguishing features. The initiation of sexual transition appears to be based on visual rather than chemical cues (Dr. David Berlinsky, UNH, Personal communication). In studies of protogny among several coral reef fish species, transition of the largest female to male may occur quickly if the dominate male is removed from the reef, however, similar studies have not been published for black sea bass.

Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters (Drohan et al. 2007). The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory during spawning season (Nelson et al. 2003). The bright coloration of males during spawning season suggests that visual cues may be important in structuring of the social hierarchy.

Black sea bass attain a maximum size around 60 cm and 4 kg. Although age information is limited for the northern stock of black sea bass, growth curves are available from one published study as well as several unpublished studies. Lavenda (1949) suggests a maximum age for females of 8 and age 12 for males. However he noted the presence of large males (>45 cm) in deeper water that may have been older. Available growth curves are listed in Table 1. The Von Bertalanffy parameters were averaged across studies for input to models used in this analysis. (The growth parameters from Caruso, MADMF, appeared to be unique, possibly due to geographic growth differences and were not included in the model average). Although growth information was available for use in models, annual age length keys were not, therefore sea bass modeling efforts are length based rather than age based.

Maturity data is routinely collected on Northeast Fisheries Science Center survey cruises. Proportion mature for all years and sexes combined (n=10,318) was fitted to a logistic model (Figure 2). The model estimate for length at 50% maturity was 20.4 cm with 95% maturity attained by 28 cm.

Fisheries

In the Northwest Atlantic, black sea bass support commercial and recreational fisheries. Prior to WWII in 1939 and 1940, 46-48% of the landings were in New England, primarily in

Massachusetts. After 1940 the center of the fishery shifted south to New York, New Jersey and Virginia. Landings increased to a peak in 1952 at 9,883 mt with the bulk of the landings from otter trawls, then declined steadily reaching a low point in 1971 of 566 mt (Table 2). Historically, trawl fisheries for sea bass have focused on the over-wintering areas near the shelf edge. Inshore pot fisheries, which were primarily in New Jersey, showed a similar downward trend in landings between the peak in 1952 and the late 60s. The large increase in landings during the 1950's appears to be the result of increased landings from otter trawlers, particularly from New York, New Jersey and Virginia (Figure 3). During the same period, a large increase in fish pot effort, and subsequent landings, occurred in New Jersey (Figure 4). In recent years, fish pots and otter trawls account for the majority of commercial landings with increasing contributions from handline fisheries. Landing since 1974 have remained relatively steady around 1400 mt. (Table 2). Recreational landings, available from MFRSS data since 1982, average about 1,600 mt annually (Table 2). Estimates for recreational sea bass landings in1982 and 1986 (4,485 mt and 5,618 mt, respectively) are unusually high, as they are for other species for those years. Similarly, recreational landings for 1998 and 1999 are lower than expected. Although the estimates have been confirmed by MRFSS, they remain suspect.

The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries compared to the decreasing susceptibility to bottom trawl gear commonly used for scientific surveys. In autumn when water temperatures decline, black sea bass migrate offshore to areas along the edge of the continental shelf (Moser and Shepherd 2009). During this offshore period, sea bass are vulnerable to otter trawls as part of a multispecies fishery (Shepherd and Terceiro 1994).

Stock assessment history summary

Black sea bass stock assessments have been reviewed in the SARC/SAW process (SAWs 1, 9, 11, 20, 25, 27, 39 and 43) beginning with an index based assessment in 1991. In 1995 a VPA model was approved and the results generally showed fishing mortalities exceeding 1.0 (estimated using an M=0.2). The VPA was reviewed again in 1997 and at this time was considered too uncertain to determine stock status but indicative of general trends. In 1998, another review was conducted and both VPA and production models were rejected as either too uncertain or inappropriate for use with an hermaphroditic species. A suggestion was made to use an alternative method such as a tag/recapture approach. The NEFSC survey remained the main source of information regarding relative abundance and stock status. A tagging program was initiated in 2002 and the first year results were presented for peer review in 2004. The review panel concluded that a simple tag model using the proportion recovered in the first year at large, as well as an analysis of survey indices, produced acceptable results to determine exploitation rate and stock status. The release of tags continued through 2004 and results of tag models as well as indices were presented for SARC review in 2006. Their findings were that the tag model did not meet the necessary assumptions and the variability in the survey indices created uncertainty which prevented determination of stock status. The panel did not recommend any alternative reference points, however they did recommend continued work on length based analytical models.

Existing Biological Reference Points

Based on revision through Framework 7 to the Summer Flounder, Scup and Black Sea Bass (SFSCBSB) FMP, the status determination criteria is defined for each of the species

managed under the FMP. The maximum fishing mortality threshold for each of the species under the FMP is defined as F_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. Specifically, F_{MSY} is the fishing mortality rate associated with MSY. The maximum fishing mortality threshold (F_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. Exceeding the established fishing mortality threshold constitutes overfishing as defined by the Magnuson-Stevens Act.

The minimum stock size threshold for each of the species under the FMP is defined as ½ B_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. The minimum stock size threshold (½ B_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. The minimum stock size threshold is the level of productive capacity associated with the relevant ½ MSY level. Should the measure of productive capacity for the stock or stock complex fall below this minimum threshold, the stock or stock complex is considered overfished. The target for rebuilding is specified as B_{MSY} (or reasonable proxy thereof) at the level of productive capacity associated with the relevant MSY level, under the same definition of productive capacity as specified for the minimum stock size threshold.

The best scientific information consistent with National Standards 1 and 2, has not recommended revising the definitions for biological reference points set forward under Amendment 12 to the SFSCBSB FMP. Therefore, these reference points and values are defined as follows in Amendment 12: Overfishing for black sea bass is defined to occur when the fishing mortality rate exceeds the threshold fishing mortality rate of F_{MSY}. Because F_{MSY} cannot be reliably estimated, F_{MAX} (0.33) is used as a proxy for F_{MSY}.

The current biomass reference points are a function of the NEFSC spring bottom trawl survey. The current definitions were adopted as a way to measure stock status in the absence of an analytical age-based stock assessment. Commercial landings of black sea bass reached a peak in 1952 at nearly 9900 mt. From that peak through 1965, the landings averaged nearly 4600 mt whereas from 1966 through 1980 commercial landings averaged 1200 mt. The rationale behind the existing reference point was that the substantial landings prior to 1966 likely represented potential yield at B_{MSY}. The landings in the late 1960s-80s were likely more representative of ½ B_{MSY}. NEFSC spring survey indices began in 1968 and it was concluded that the maximum survey indices coinciding with landings in the 1970s were around ½ B_{MSY} and would therefore represent a biological threshold. To limit year to year variation, the spring offshore survey indices were calculated as a 3 point moving average. The 1977-1979 three year moving average of the spring survey value of exploitable stock biomass (index of black sea bass $\geq$ 22 cm = 0.98 kg/tow), would serve as a biomass threshold. B_{MSY} cannot be reliably estimated for black sea bass.

Without an analytical stock assessment, no current fishing mortality estimates are available to compare to the F_{MAX} proxy of F_{MSY} (0.33). A relative index of exploitation is calculated as total landings /spring survey index of exploitable biomass (defined as sea bass $\geq$ 22 cm). Changes in the relative exploitation index are evaluated for development of management

advice. The current definition suffers from the inability to accurately measure fishing mortality relative to F_{MSY}. In addition, reviewers at SARC 43 concluded that the use of the spring offshore survey was not an appropriate measure of relative abundance and was not a valid basis of a biomass reference point. From the SARC 43 reviewer's summary:

"The perception of the status of the stock relative to biomass thresholds is very sensitive to the method used to calculate the survey indices. Not only are the confidence intervals very large, meaning the current biomass is probably indistinguishable from the BRP, but calculating both current biomass and the BRP on a consistent scale (i.e always arithmetic or always logged) can lead to a divergent perceptions of current stock size relative to the BRP. The definition of the biomass threshold was not considered satisfactory. One reviewer questioned whether it was consistent with F_{MAX}. The other pointed out that establishing the biomass threshold as the period of low biomass from which the stock recovered is as plausible as setting the BRP to the early period of high biomass. Given the uncertainty over growth, mortality and selectivity, the estimation of F_{MAX} is uncertain and there is no credible estimate of current fishing mortality with which to compare it. Hence the evaluation of status relative to fishing mortality reference points is not possible."

New analyses

Development of updated biological reference points for black sea bass is hampered not only by a lack of annual age data but also by limited understanding of how black sea bass productivity responds to exploitation. Traditional fisheries models, generally developed for gonochoristic species, may not apply to a protogynous hermaphrodite (Hamilton et al. 2007). Simulation studies of populations exhibiting protogny suggest that conservation of large terminal males is critical for sustainability (Alzono et al. 2008, Brooks et al. 2008, Hamilton et al. 2007, Heppell et al. 2006, Huntsman and Schaaf 1994). The implication is that removal of the terminal male will not only hamper male fertilization success but will induce transitioning of the larger females into males. The consequence is not only removal of male biomass but removal of potential egg production in the larger females. Reduction of dominant males in a population may, in effect, have a similar effect as increasing natural mortality on females.

Tag Release/Recapture model

To evaluate mortality rates, a tag release/recapture study was conducted with 13,794 tagged black sea bass (12,310 legal-size) released between Massachusetts and Cape Hatteras, NC from 2002 to 2004. Of these legal-size releases, 1,683 were recaptured during 2002 to 2007. An instantaneous rates configuration of a Brownie band recovery model was used to estimate both fishing and natural mortality. A seasonal model of fishing mortality, adjusted for non-mixing, and a constant natural mortality best explained the tag recoveries (Shepherd and Moser 2008, *Appendix I*). Fishing mortality estimates ranged between 0.3 and 0.4 whereas the natural mortality estimate was equal to 1.08 (Table 3). The estimate of natural mortality includes the effects of all unaccounted tag losses which could be influenced by an over-estimate of reporting rate (resulting from violation of the assumption that the return rate of high reward tags equaled 100%) or tag attrition (resulting from decreasing legibility of the tags, expulsion of the tags, etc.). An alternative model assuming only 75% reporting of $100 tags and a 9% attrition of tags per season over the recovery period resulted in a decreased estimate of natural mortality of 0.66. Despite uncertainty in the tag model, the results imply that natural mortality of the black sea bass population exceeds 0.2 as used in previous assessments.

Tag recovery data also indicates that extensive seasonal movements occur and are not homogeneous throughout the stock (Moser and Shepherd 2009). During summer months fish throughout the stock remain stationary in coastal areas with very little mixing among adjacent areas. In autumn, offshore migration toward the edge of the continental shelf begins in the north and progresses southward. During the offshore overwintering period on the continental shelf out to the shelf edge, intermixing of fish from various inshore areas is more frequent. Recaptures following spring inshore migrations demonstrate a high degree of site-fidelity with occasional straying to adjacent areas.

Length-based Analytical model

Since annual age information was unavailable, a length based model (SCALE developed by Paul Nitschke, NEFSC) was explored as a method for evaluating sea bass population dynamics. The model details are described in *Appendix II.* SCALE data input included catch time series (mt), NEFSC spring and winter survey recruit and adult indices, growth information, survey length frequencies and catch length frequencies. The model covered the period 1968 to 2007 based on the times series of NEFSC spring offshore surveys.

Commercial length frequencies were compiled beginning with samples in 1984. Sampling was done randomly by market categories and expanded as the ratio of sample weight to total landings, by calendar quarter. Black sea bass were culled as small, medium, large, jumbo or unclassified. In the rare cases where fish were categorized as extra small and extra large, they were combined with small and large, respectively. Total annual length measurements ranged from 300 to 7768 fish with an average of 2956 per year (Table 4).

Commercial discards were estimated since 1989 using a standard approach developed for national standardized by-catch reporting. (Wigley et al., 2008). Observer samples for sea bass were limited to otter trawl trips since 1989. Discard estimates were developed from the ratio of discarded black sea bass in mt to total landings (mt) of all fish species in the comparable statistical area, by half-year periods. Discards from pot and handline fisheries were estimated using the annual ratio of reported discards to landings in vessel trip reports, expanded to total annual landings. Since a component of the pot fishery is prosecuted solely in state waters without a requirement to submit VTR logs, they are not included in the total. A 50% discard survival rate was applied across all commercial gears. Total discards averaged 111 mt annually and represented 17% of reported commercial landings (Table 2). Discards in 1993 and 2004 were well above average at 35% and 62% of landings, respectively.

Complete recreational landings were available from the Marine Recreational Fisheries Statistics Survey (MRFSS) since 1981. Landings for 1968 to 1980 were hindcast based on the relationship between inshore commercial pot and handline landings and recreational landings between 1981 and 1997 (Table 2). In 1998 management regulations were imposed which controlled landings based on quota. The two abnormally large recreational landings in 1982 and 1986 were excluded. The ratio between average recreational landings and pot/handline landings was 2.63. This ratio applied to the commercial pot landings produced the 1968 to 1980 recreational landings. Length frequencies of sea bass were based on dockside sampling by MRFSS staff.

Recreational discard mortalities beginning in 1981 were calculated from MRFSS B2 estimates using a 25% discard mortality rate (Table 2). Discard number was converted to weight assuming comparable mean weight as landings. Between 1981 and 1998 the ratio of discards to landings was relatively constant with an average of 50%. Since 1999, the proportion discarded

has increased dramatically averaging 179% of landed sea bass by weight. With a 25% mortality applied, the weight of discards was approximately 50% of landed weight. Length frequencies for recreational discards were not available for the time series.

Fishery Independent Indices

The NEFSC spring bottom trawl survey conducted since 1968 provided indices of relative abundance in number and weight. The review panel in SARC 43 questioned the use of NEFSC bottom trawl survey indices as an index of relative abundance. During autumn, sea bass are generally inshore on structured bottom that is not conducive to sampling with an otter trawl. Consequently those survey results are not considered indicative of sea bass abundance. However, since the 1930's commercial trawl fisheries have had significant landings of sea bass caught offshore during the winter and early spring on the continental shelf. The spring offshore bottom trawl survey takes place in the same areas suggesting that the use of trawl gear for sampling sea bass at this time of year is no less limited by habitat than commercial trawlers. Comparison of survey length frequencies and length frequencies of commercial landings suggest the selectivity at length is comparable (Figure 5). Additionally, the winter survey time series of relative abundance from 1992 to 2007, which uses a trawl with a chain sweep rather than roller gear, was highly correlated to the spring abundance. Although the catch per tow in the spring survey was low, the correlation to the winter survey as well as the comparable length frequency to the commercial fishery suggests that the survey adequately samples sea bass. Finally, the index of abundance from the spring survey also closely resembles the time series of recreational catch per angler trip estimated from MRFSS dockside sampling (Figure 6).

Concern has been raised in the past that environmental conditions significantly influence catchability of black sea bass in the survey. The relationship between catch and environmental anomalies (water temperature and salinity) was evaluated for the survey time series. There was no apparent pattern in deviations of annual survey catches around the time series mean and anomalous temperature or salinity conditions (Figure 7). Local conditions may alter distributions but the influence on the spring index time series appears to be minimal.

The use of $\log_e$ transformation of the survey indices was also criticized by the SARC 43 review panel. A plot of the mean number per tow by strata against the associated variance shows that the variance increases non-linearly (Figure 8). To reduce the influence of over-dispersion on the estimation of the stratified mean, $\log_e$-transform indices (followed by re-transformation) were used in the model. NEFSC spring survey indices with and without transformation are presented in figures 9a and 9b.

The index of exploitable biomass (defined as fish $\geq$ 22 cm presented as the $\log_e$ re-transformed stratified mean weight per tow) beginning in 1968 increased to a peak value in 1976, followed by a decline to the series low in 1982 (Figure 10). A slight rise in abundance was evident in the late 1980s but was followed by a decade of fluctuations around low levels of abundance. Between 1999 and 2002 the index increased again, peaking with the series high in 2002 (1.07 kg per tow), followed by a steady decline through 2008 when the index dropped to 0.18 kg per tow. The 2008 value of 0.19 is below the long-term average of 0.27 fish per tow. The NEFSC winter survey, initiated in 1992, follows a similar pattern with a peak in the $\log_e$ re-transformed index value for 2003 (1.83 kg/tow) followed by declining indices to 0.40 kg/tow in 2007 (Figure 10).

Juvenile indices of black sea bass from the winter and spring surveys provide some insight into cohort strength. The juveniles appear as clearly defined modes at sizes $\leq$ 14 cm in

the autumn surveys (Figure 11). There appears to be little growth during the winter, as the same distinct size mode appears in the winter and spring survey length frequencies. In the spring, fish $\leq$ 14 cm would be considered one year old. Indices were calculated as the sum of $\log_e$ re-transformed mean #/tow at length for sea bass less than or equal to 14 cm. The indices in both the winter and spring surveys suggest large 1999 and 2001 cohorts (peaks in the 2000 and 2002 surveys) (Figure 12). Both of these modes in the length frequency appear the following year as increases in a mode above 20 cm, which is consistent with known growth rates. The winter and spring surveys show an above average 2002 year class and the spring survey shows a strong 1998 cohort that was below average in the winter survey. The 2007 juvenile index in the winter survey was above average.

SCALE Model input

A critical issue in development of new biological reference points is the choice of natural mortality. In the case of black sea bass this becomes particularly difficult due to the unique life history. Methods have been proposed for estimating M based on longevity (Hoenig 1983, Hewitt and Hoenig 2005). Maximum age has been reported by Lavenda (1949) as 12, although he suggests sea bass may survive for up to 20 years, while the oldest fish in a study by Mercer (1978) was age 9. NMFS spring survey age data collected in the 1980s found a sea bass at age 10. More recently, a trawl caught sea bass of 61 cm and 4 kg was taken in the winter of 2007 off the mouth of the Chesapeake Bay and aged as 9 years using otoliths (Chris Batsavage, pers. comm.). Additionally, a study at VIMS repeating the work of Mercer identified a fish as age 12 (R. Pemberton, pers. comm.) while Caruso (1995) found the oldest fish to be age 7. Applying the Hoenig regression method for maximum age suggests that M could possibly be between 0.37 (age 12) and 0.55 (age 8) (Figure 13). The results of the tag model previously noted suggest a much higher natural mortality of 1.08 for the period 2003-2007. If M were really greater than 1.0 at all sizes, it would be equivalent to a maximum age of 4 in the Hoenig model. However, if the tagging model assumptions of 100% reporting of high reward tags were relaxed to equal 75% and tag attrition of 9% applied, the estimate of M decreases to 0.66. It is clear from multiple approaches that natural mortality of the population is greater than 0.2. As an alternative to a constant natural mortality across sizes, M was also modeled as a logistic function of size (Figure 14). This was an attempt to include both a high natural mortality and a subgroup with a longer potential life expectancy. The point of inflexion corresponded to the approximate age when transition occurs.

Included as input to the SCALE model were spring and winter offshore indices of adult and juvenile abundance. The spring series of stratified $\log_e$ re-transformed mean number per tow included 1968 to 2008 while the comparable indices from the winter survey were 1992 to 2007 (Figure 15). Mean lengths at age were predicted from a growth curve averaged from available studies and length-weight equation parameters were from fitted length-weight data collected on NMFS surveys. Total catch (mt) was commercial landings since 1968, recreational landings since 1981 estimated by MRFSS and 1968 to 1980 estimates derived from commercial inshore fishery landings, recreational discard losses since 1981 and commercial discard estimates since 1989. The model was not restricted to fitting the catch exactly by assuming error in the catch estimates. The model was fitted to survey length frequencies greater than 30 cm to counter the lack of discard length data in the fishery length frequencies. Selectivity periods were chosen based on regulatory changes in the fisheries. The three periods were 1968 to 1997, 1998 to 2000 and 2001 to 2007. The model was allowed to fit the initial fishing mortality in phase two.

Models were developed with a range of natural mortalities under an assumption of either a constant or logistic pattern. Within the logistic model assumption, a variety of logistic model parameters were used to generate a suite of M estimates. A total of 26 various M patterns were evaluated and the SCALE model results are presented in Table 5 and Figures 16-21.

In general, the SCALE model adequately described the length frequency data from the fisheries and the associated catch. The general pattern in the spring and winter survey indices were adequately predicted by the model, although the magnitude of some recruitment events was somewhat reduced. With constant M the model fit as defined by the objective function improved with increasing M until M exceeded 0.8. Similarly the value of the objective function declined with increasing M for the logistic M model. However, reduction in the objective function with increasing M may also be a result of faster removal of fish in the model which ultimately limits variation in model fit. Alternative models using higher M with different values at length are also possible. Within the output for each model run, SCALE produces values for selectivity at length, fishing mortality estimates, biomass and abundance estimates. Annual spawning biomass estimates were developed outside of the model software using population numbers at length multiplied by mean weight at length and proportion mature at length from NEFSC survey data.

New Biological Reference Points

The current overfishing definition for black sea bass is based on F_{MAX} as a proxy for F_{MSY}. The F_{MAX} value was calculated using an M=0.2 and a maximum age of 15 and predicts an F_{MAX}=0.33. The biomass reference point is a 3 year moving average of stratified mean weight per tow of exploitable biomass for 1977-1979. The proposed new reference point incorporates additional fishery and biological information in addition to the NEFSC spring and winter bottom trawl survey indices. Evaluation of natural mortality suggests that M is likely greater than 0.2.

A length based yield per recruit model from the NOAA Fisheries Toolbox was used to develop estimates of reference points. From each of the 26 SCALE models run, the associated M and fishery selectivity parameters were input to the YPR model. Per recruit values from each model run were expanded to population values using the average recruitment from the 1968-2007 time series as estimated by SCALE. Average von Bertalanffy growth parameters from among several studies were used to define growth (Figure 19) and an average selectivity curve from 2001-2007 (Figure 20) was incorporated into the yield per recruit model. Resulting yield per recruit and SSB per recruit at F40% were multiplied by average long-term recruitment (1968-2007) to produce total yield, spawning biomass (sexes combined). These values and F at $F_{40\%}$ were compared to the 2007 SCALE model results (Figures 21 and 22) to evaluate stock status.
Selection of the preferred model for black sea bass was based on a decision matrix using information from recent trends in NEFSC survey indices, comparison of MSY to long term yield and the ratio of 2007 F and total biomass to F and biomass at $F_{40\%}$. The reference point in the existing FMP for sea bass was predicated on the assumption that MSY occurred at some point midway through the decline in landings experienced in the 1950s and 1960s. However, since the decline leveled off in the late 1960s, catch has remained relatively stable around 3,100 mt (the period following implementation of quotas in 1998 was not included in this average). This implies that catches around 3,100 mt may be sustainable, although not necessarily maximum (landings greater than 10,000 mt in 1952 suggests an upper bound of potential landings). Recent trends in survey indices of the entire stock show a steady decline in abundance and biomass since 2003 and 2002, respectively. This declining trend despite restrictive quotas would suggest that

the stock is unlikely at or above any optimal biomass level. Therefore the suite of 26 model runs were judged using the proximity of predicted optimal yield relative to average yield since the 1960s which was assumed to be near MSY and the 2007 model estimates of fishing mortality and biomass relative to the associated biomass and F reference points. Among candidate models, only those with both 2007 F to $F_{40\%}$ ratios between 0.8 and 1.4, and predicted equilibrium yield between 3,900 and 4,200 mt were considered candidates as preferred models. Only three models fulfilled the selection criteria: constant M at 0.4 and two logistic models with starting F=0.6 (Table 6). Since there is currently no empirical evidence to suggest that natural mortality declines as a logistic function of size, the model using constant M=0.4 was chosen as the best model.

The preferred model option with a constant M=0.4 has an F at 40% of maximum spawning potential equal to 0.42 and $F_{0.1}$ of 0.37. F_{MAX} equals 0.975 and is poorly defined. The associated spawning stock biomass per recruit at $F_{40\%}$=0.45 and total biomass per recruit= 0.50 (Figure 23). Applying age 1 recruitment (averaged from 1968 to 2007) of 27,875,990 recruits to per recruit values, total biomass at F=0 is 32,816 mt and at $F_{40\%}$ is 13,977 mt. Spawning biomass (sexes combined) at $F_{40\%}$ equals 12,537 mt. The 2007 estimates of F from the SCALE model using the constant M for 0.4 is 0.48 with an estimated total biomass of 12,892 mt and a spawning stock biomass of 11,478 mt. Using $F_{40\%}$ as a proxy for F_{MSY}, the implication is that 2007 fishing mortality (0.48) exceeds F_{MSY} by 15% and 2007 spawning biomass (11,478 mt) is 8% below B_{MSY}. However, the biomass is above the threshold (1/2 B_{MSY}) and would not be considered overfished. The reference points for M = 0.4 are presented in Table 7.

As a check on the scale of the stock size estimates, yield associated with $F_{40\%}$ (a proxy for MSY) under average recruitment would be 3,903 mt. This compares with the estimated average catch since 1968 of 3,100 mt. In addition, the peak landings in the early 1950s of between 10,000 and 12,000 mt would be well above optimal yield and would expected to result in a declining abundance, as was observed.

Although predicted adult survey indices from model results using a constant M=0.4 followed the general trend of the observed values, residuals patterns show predicted indices greater than observed indices for 2004 to 2007 (Figure 24). This would suggest that the predicted abundance was greater than observed and consequently the model may overestimate predicted abundance. Additionally, the sensitivity of the yield per recruit at length and catch at length models has not been fully evaluated for sensitivity to input values.

Developing biological reference points for hermaphroditic species requires consideration of the unique life history characteristics. Simulation modeling studies have shown that protogyny has little effect on yield per recruit if growth rates between sexes are comparable (Shepherd and Idoine 1993). In contrast, the effect of transitioning can have a significant effect on the calculation of female spawning biomass. However, without information about spawning efficiency the optimal approach is to consider spawning biomass as combined male and female biomass (Brooks et al. 2008). In addition, if the efficiency of spawning is a function of the presence of a dominant male, then conservation of the large males may be critical (Alonzo,S.H. 2008, Heppell et al. 2006). However, the effect of removal of males on the sex ratio, and consequently transition rate from female to male, remains unknown for black sea bass.

Suggested improvements

In order to improve the stock assessment of black sea bass and corresponding biological reference points, additional fishery independent surveys for black sea bass may be necessary. An alternative survey gear for sea bass may be fish pots or hand lines. Since pots could cover a wider area, a stock wide fish trap survey should be developed to evaluate relative abundance. Additionally, experimental and field evaluation of spawning behavior is necessary to better understand the implication of exploitation on sea bass.

Age analysis of NEFSC survey samples is currently underway in cooperation with MA DMF and could potentially improve the assessment models. There is some evidence of regional differences in growth that should be further explored.

Tagging data suggests regional differences in migration pathways and possible sub-populations. Although the assessment model results suggest the overall stock is near F_{MSY} and B_{MSY}, local groups of sea bass could vary from this overall status. Consequently, increased catch in some areas may exacerbate already declining abundance. Consideration should be given to evaluating alternative management approaches that account for regional differences in recruitment patterns and abundance.

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Black sea bass; Tables

Table 1. Black sea bass growth model results and calculated mean lengths at age.

	Caruso	Pemberton	Mercer	NMFS winter	NMFS spring
L_{inf}	71.0	61.8	65.9	46.2	47.7
K	0.20	0.21	0.16	0.36	0.35
t_0	-0.2	0	0	0.40	0.04

age	Mean lengh (cm)					avg (w/o Caruso)
1	15.14	**11.89**	**9.79**	**9.01**	**13.51**	11.05
2	25.26	**21.49**	**18.13**	**20.23**	**23.56**	20.85
3	33.55	**29.25**	**25.23**	**28.08**	**30.66**	28.30
4	40.34	**35.51**	**31.27**	**33.55**	**35.67**	34.00
5	45.89	**40.57**	**36.42**	**37.38**	**39.21**	38.39
6	50.44	**44.66**	**40.80**	**40.05**	**41.71**	41.80
7	54.17	**47.96**	**44.53**	**41.91**	**43.47**	44.47
8	57.22	**50.63**	**47.71**	**43.21**	**44.72**	46.57
9	59.71	**52.79**	**50.41**	**44.12**	**45.60**	48.23
10	61.76	**54.53**	**52.72**	**44.76**	**46.22**	49.56
11	63.43	**55.93**	**54.68**	**45.20**	**46.66**	50.62
12	64.80	**57.07**	**56.35**	**45.51**	**46.97**	51.47

Table 2. Commercial and recreational landings and discards (total) of black sea bass. Italicized landing estimated. Recreational discard losses estimated as 25% of total discards and commercial as 50% of totals presented in the table.

YEAR	Comm landings (mt)	Rec landings (mt)	Rec dicards (mt)	Comm discards (mt)	Total catch (mt)
1939	2,910	*727*			3,637
1940	3,097	*774*			3,871
1941	1,427	*357*			1,784
1942	1,129	*282*			1,411
1943	1,565	*391*			1,956
1944	3,307	*827*			4,133
1945	2,483	*621*			3,103
1946	2,232	*558*			2,790
1947	3,593	*898*			4,492
1948	6,832	*1,708*			8,540
1949	4,555	*1,139*			5,694
1950	5,736	*1,434*			7,170
1951	8,361	*2,090*			10,451
1952	9,883	*2,471*			12,354
1953	6,521	*1,630*			8,151
1954	5,141	*1,285*			6,426
1955	5,130	*1,283*			6,413
1956	5,247	*1,312*			6,559
1957	4,319	*1,080*			5,399
1958	5,241	*1,310*			6,551
1959	3,654	*914*			4,568
1960	3,101	*1,551*			4,652
1961	2,459	*1,230*			3,689
1962	3,554	*1,777*			5,331
1963	3,705	*1,853*			5,558
1964	3,143	*1,572*			4,715
1965	3,481	*1,741*			5,222
1966	1,537	*769*			2,306
1967	1,154	*577*			1,731
1968	1,079	*851*			1,930
1969	1,097	*772*			1,869
1970	970	*1,058*			2,028
1971	566	*540*			1,106
1972	727	*846*			1,573
1973	1,115	*1,145*			2,260
1974	1,023	*1,325*			2,348
1975	1,680	*1,791*			3,471

Table 2 (cont'd). Commercial and recreational landings and discards (total) of black sea bass. Italicized landing estimated. Recreational discard losses estimated as 25% of total discards and commercial as 50% of totals presented in the table.

YEAR	Comm landings (mt)	Rec landings (mt)	Rec dicards (mt)	Comm discards (mt)	Total catch (mt)
1976	1,557	*1,895*			3,452
1977	1,985	*2,267*			4,252
1978	1,662	*1,697*			3,359
1979	1,241	*560*			1,801
1980	977	*1,002*			1,979
1981	1,129	546	65		1,740
1982	1,177	4,485	74		5,735
1983	1,513	1,839	137		3,489
1984	1,965	558	65		2,589
1985	1,551	945	90		2,587
1986	1,901	5,618	229		7,748
1987	1,890	870	79		2,839
1988	1,879	1,295	252		3,426
1989	1,324	1,488	94	217	3,122
1990	1,588	1,248	209	128	3,173
1991	1,272	1,875	247	28	3,421
1992	1,364	1,179	170	246	2,960
1993	1,433	2,189	136	505	4,263
1994	925	1,327	176	46	2,475
1995	935	2,809	373	77	4,194
1996	1,524	1,804	280	770	4,378
1997	1,186	1,926	296	56	3,464
1998	1,163	509	213	238	2,122
1999	1,315	726	393	84	2,517
2000	1,208	1,804	822	96	3,930
2001	1,296	1,545	739	246	3,826
2002	1,571	1,961	818	96	4,447
2003	1,361	1,481	507	139	3,489
2004	1,398	760	314	864	3,335
2005	1,290	846	475	165	2,776
2006	1,271	886	492	57	2,706
2007	1,016	1,026	601	169	2,811

Table 3. Annualized fishing and natural mortality rates determined from tagging model.

	F	M
2002	*	*
2003	0.32	1.08
2004	0.39	1.08
2005	0.41	1.08
2006	0.38	1.08
2007	0.37	1.08

Table 4. Length measurements and landings (mt) from commercial fisheries 1984-2007.

Year	# lengths	Landings (mt)
1984	3841	1965
1985	2509	1551
1986	2922	1901
1987	1545	1890
1988	1376	1879
1989	883	1324
1990	1142	1588
1991	735	1272
1992	605	1364
1993	300	1412
1994	3166	896
1995	3233	925
1996	5295	1472
1997	4414	1186
1998	4171	1163
1999	4650	1315
2000	2196	1208
2001	2196	1296
2002	2196	1571
2003	3684	1361
2004	3684	1398
2005	5265	1290
2006	6000	1271
2007	7768	1016

min	300
avg	3074
max	7768

Table 5. Parameters of natural mortality models and associated objective function from SCALE model.

Base M	alpha	beta	Obj Function
0.40	Constant	Constant	253.14
0.50	Constant	Constant	247.75
0.60	Constant	Constant	243.51
0.40	7.5	-0.175	255.66
0.50	7.5	-0.175	250.40
0.60	7.5	-0.175	245.26
0.70	7.5	-0.175	241.27
0.80	7.5	-0.175	238.60
0.90	7.5	-0.175	237.02
0.60	7.0	-0.175	247.29
0.60	8.0	-0.175	243.92
0.60	7.5	-0.150	243.32
0.60	7.5	-0.200	249.22
0.60	7.0	-0.150	244.17
0.60	7.0	-0.200	252.07
0.60	8.0	-0.150	242.85
0.60	8.0	-0.200	246.71
0.90	7.0	-0.175	237.82
0.90	8.0	-0.175	236.80
0.90	7.5	-0.175	237.02
0.90	7.5	-0.150	236.97
0.90	7.5	-0.200	239.24
0.90	7.0	-0.150	242.36
0.90	7.0	-0.200	242.36
0.90	8.0	-0.150	237.06
0.90	8.0	-0.200	237.51

Table 6. M values, Biological reference points and fishing mortality from SCALE and length-based yield per recruit models.

Base M	alpha	beta	F0.1	Fmax	F40%	YPR 40%	avg recruit	yield (mt)	F2007	F ratio
0.40	Constant	Constant	0.37	0.98	0.42	0.14	27,875,990	3,903	0.48	1.15
0.50	Constant	Constant	0.48	1.60	0.59	0.10	39,765,975	4,133	0.41	0.69
0.60	Constant	Constant	0.60	-	0.85	0.08	57,574,343	4,645	0.38	0.45
0.40	7.5	-0.175	0.15	0.27	0.17	0.19	25,052,388	4,770	0.73	4.30
0.50	7.5	-0.175	0.17	0.36	0.19	0.13	33,945,355	4,301	0.56	2.97
0.60	7.5	-0.175	0.19	0.93	0.22	0.09	47,261,598	4,090	0.47	2.16
0.70	7.5	-0.175	0.23	-	0.25	0.06	66,796,863	4,069	0.41	1.61
0.80	7.5	-0.175	0.28		0.31	0.04	95,096,515	4,240	0.37	1.18
0.90	7.5	-0.175	0.35	-	0.41	0.03	139,831,700	4,786	0.32	0.80
0.60	7.0	-0.175	0.16	0.31	0.11	0.11	43,255,263	4,546	0.52	4.74
0.60	8.0	-0.175	0.25	1.70	0.28	0.08	50,832,843	3,914	0.44	1.58
0.60	7.5	-0.150	0.37	-	0.41	0.08	53,187,988	4,095	0.42	1.03
0.60	7.5	-0.200	0.14	0.22	0.16	0.13	40,430,965	5,286	0.60	3.82
0.60	7.0	-0.150	0.28	1.61	0.31	0.08	50,266,135	3,968	0.44	1.43
0.60	7.0	-0.200	0.13	0.20	0.15	0.17	36,715,080	6,095	0.72	4.90
0.60	8.0	-0.150	0.45	-	0.53	0.08	55,381,775	4,319	0.42	0.79
0.60	8.0	-0.200	0.15	0.28	0.17	0.10	44,361,545	4,627	0.51	2.96
0.90	7.0	-0.175	0.22	-	0.26	0.04	116,861,675	4,410	0.36	1.39
0.90	8.0	-0.175	0.56	-	0.73	0.04	163,941,275	5,987	0.30	0.41
0.90	7.5	-0.175	0.35	-	0.41	0.03	139,831,700	4,786	0.32	0.80
0.90	7.5	-0.150	0.77	-	1.33	0.04	181,211,800	7,448	0.29	0.22
0.90	7.5	-0.200	0.16	0.35	0.19	0.05	101,782,075	4,768	0.39	2.11
0.90	7.0	-0.150	0.60	-	0.84	0.04	158,543,975	6,145	0.31	0.37
0.90	7.0	-0.200	0.14	0.23	0.16	0.06	84,365,165	5,445	0.46	2.86
0.90	8.0	-0.150	0.88	-	1.80	0.04	200,197,775	8,492	0.27	0.15
0.90	8.0	-0.200	0.20	-	0.24	0.04	122,250,403	4,439	0.35	1.47

Table 7. Biological reference points and 2007 status for preferred option of constant M=0.4.

M=0.4 constant

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	1.124	1.177
F0.1	**0.368**	0.135	0.486	0.538
Fmax	0.975	0.152	0.268	0.319
F40%	**0.419**	0.140	0.450	0.501

	yield	SSB	Total Biomass
Fzero	-	31,341	32,816
F0.1	3,774	13,555	14,998
Fmax	4,248	7,472	8,882
F40%	3,903	12,537	13,977

2007 Total Biomass (mt)	12,892
2007 SSB (mt)	11,478
2007 SSB / SSB_{MSY}	92%
2007 F	0.48
2007 F / $F_{40\%}$	115%

Black sea bass; Figures

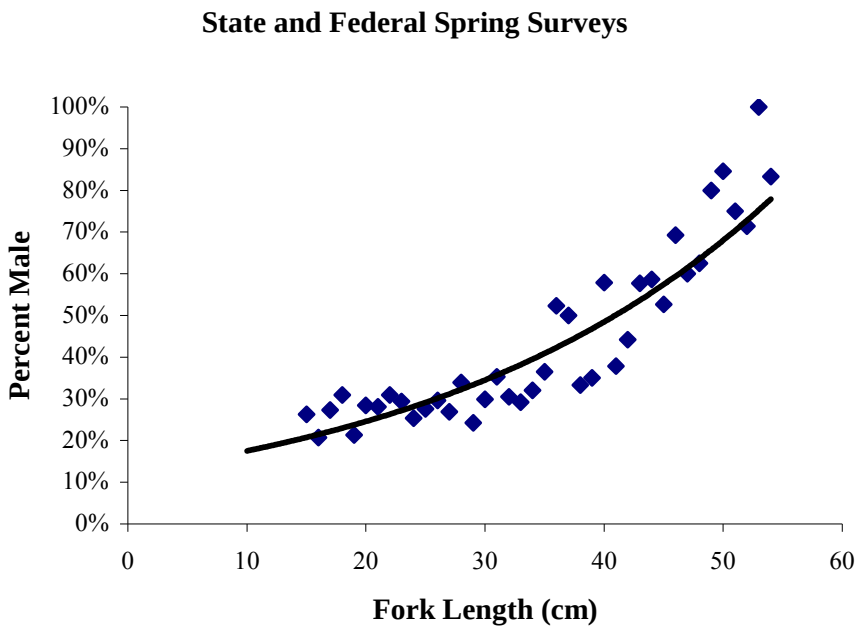

Figure 1. Sex ratio of black sea bass at length (cm) from combined NEFSC and MA DMF spring surveys.

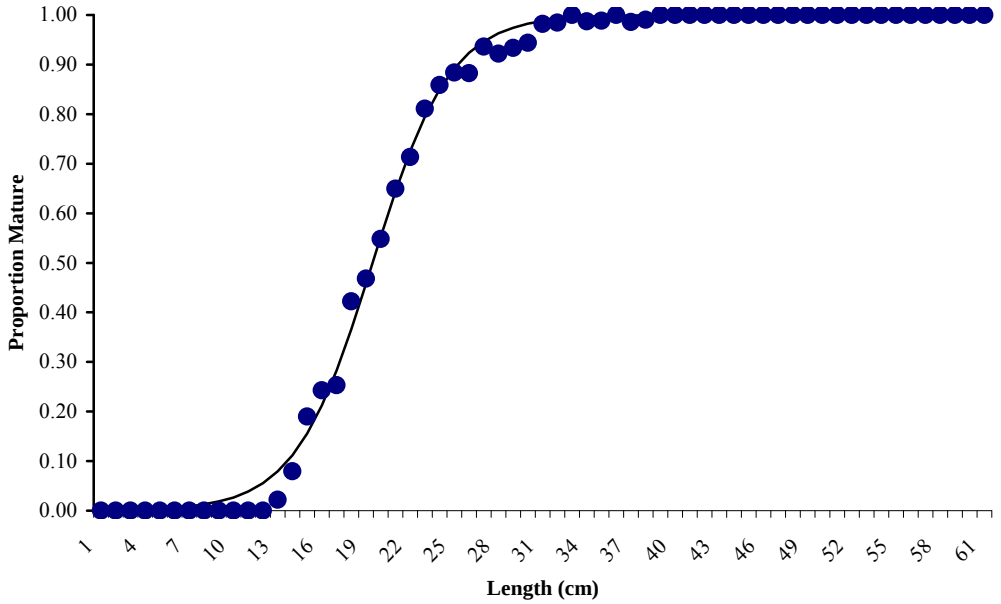

Figure 2. Proportion mature (male and female combined) by length based on samples from NEFSC spring surveys.

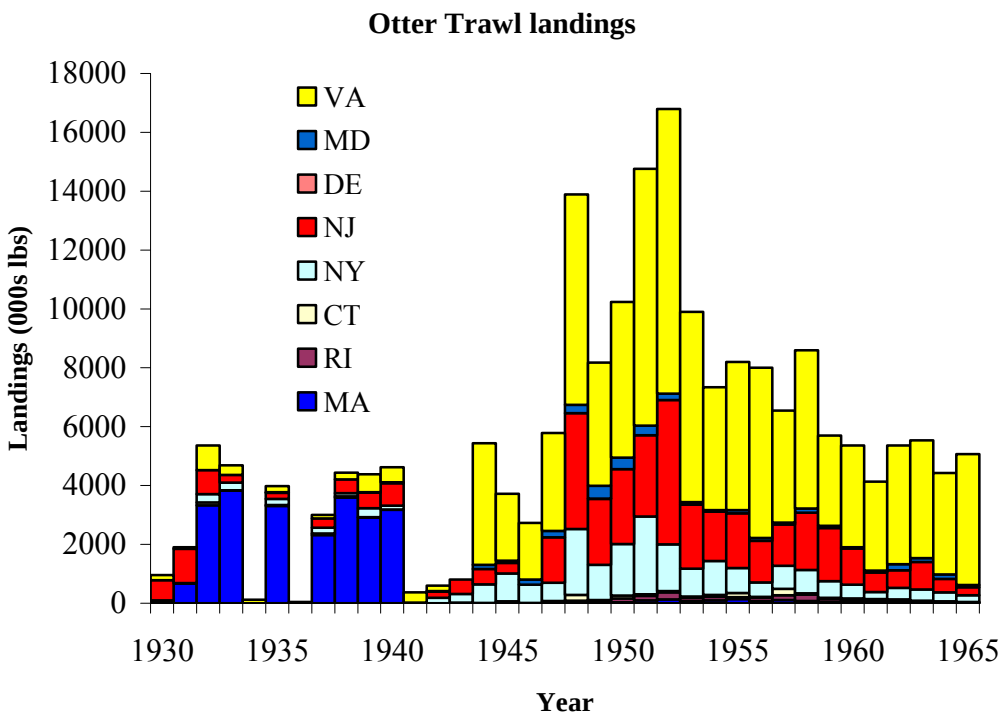

Figure 3. Commercial otter trawl landings (000s lbs) by state for 1930 to 1965. (Source: Fisheries of the U.S.)

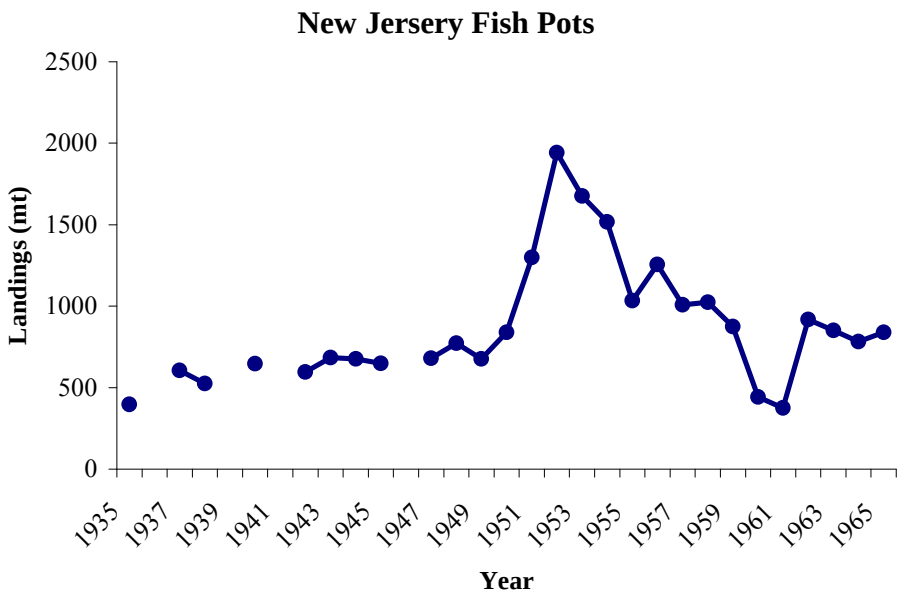

Figure 4. Landings (mt) of sea bass from NJ fish pots, 1935-1965.

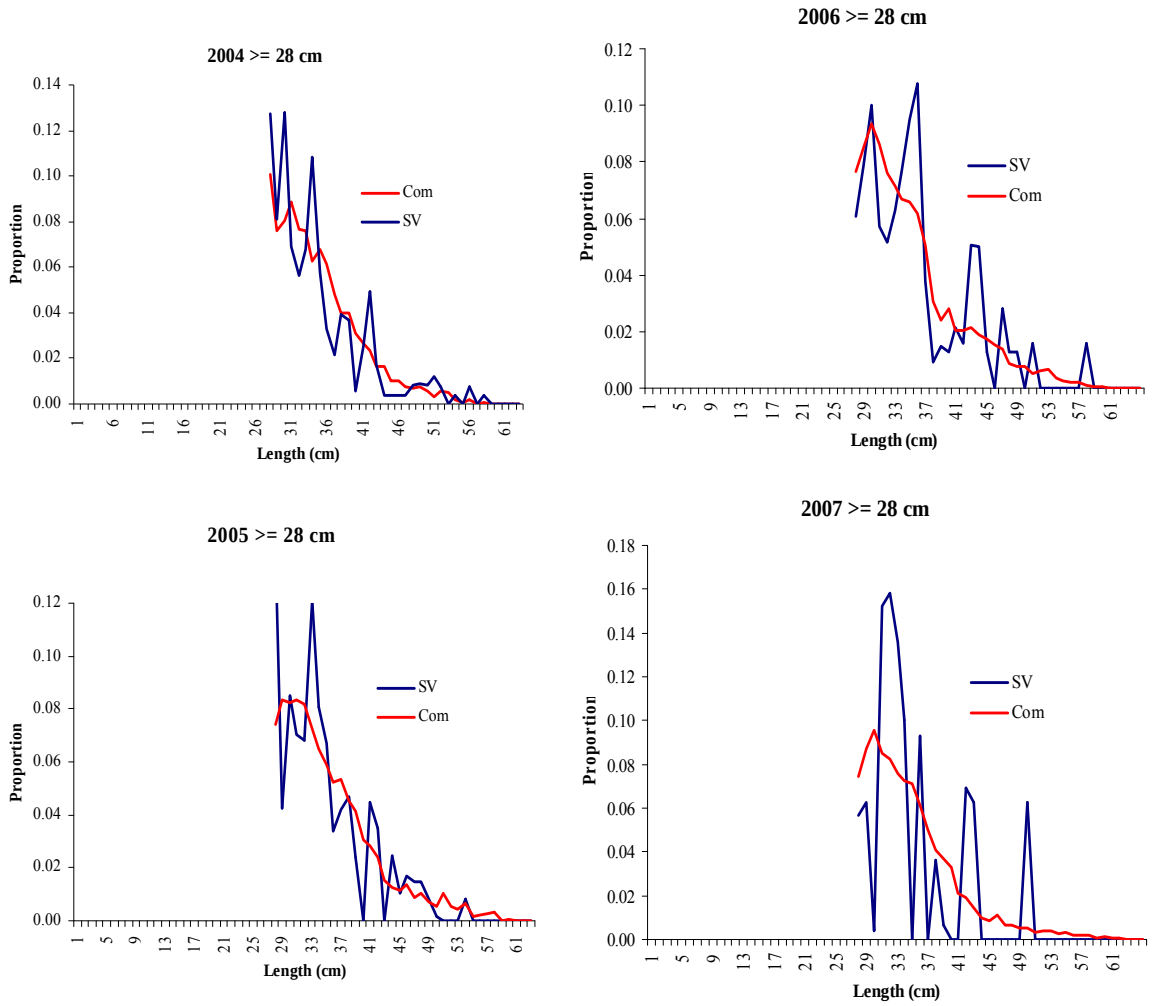

Figure 5. Comparison of proportion at length between commercial fisheries and NEFSC spring offshore survey. Size limited to lengths at full recruitment to the fisheries.

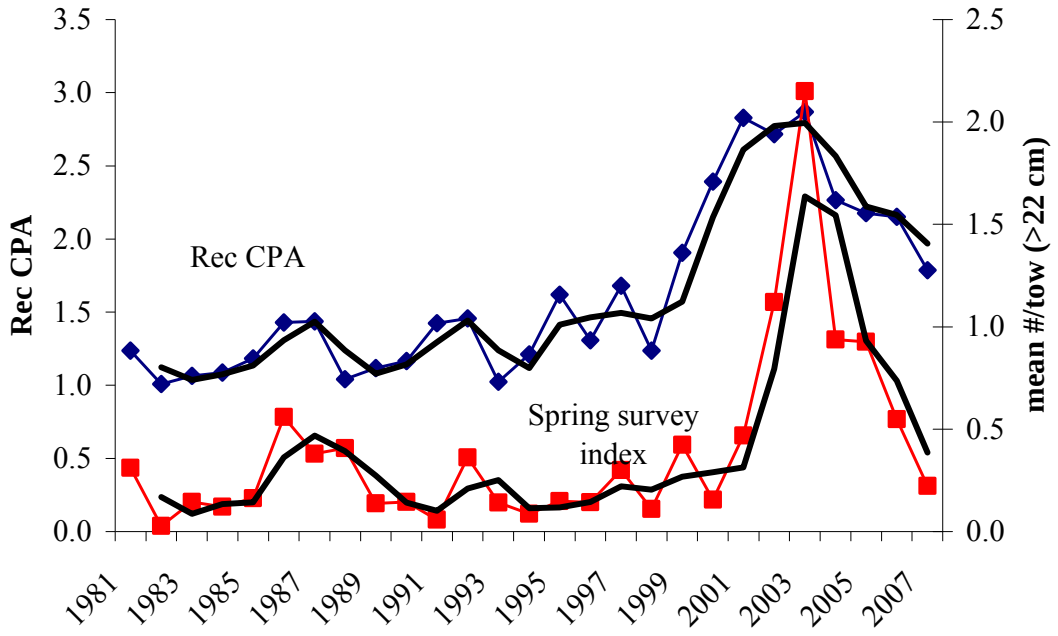

Figure 6. NEFSC Spring offshore survey stratified mean number per tow compared to MRFSS number per angler trip.

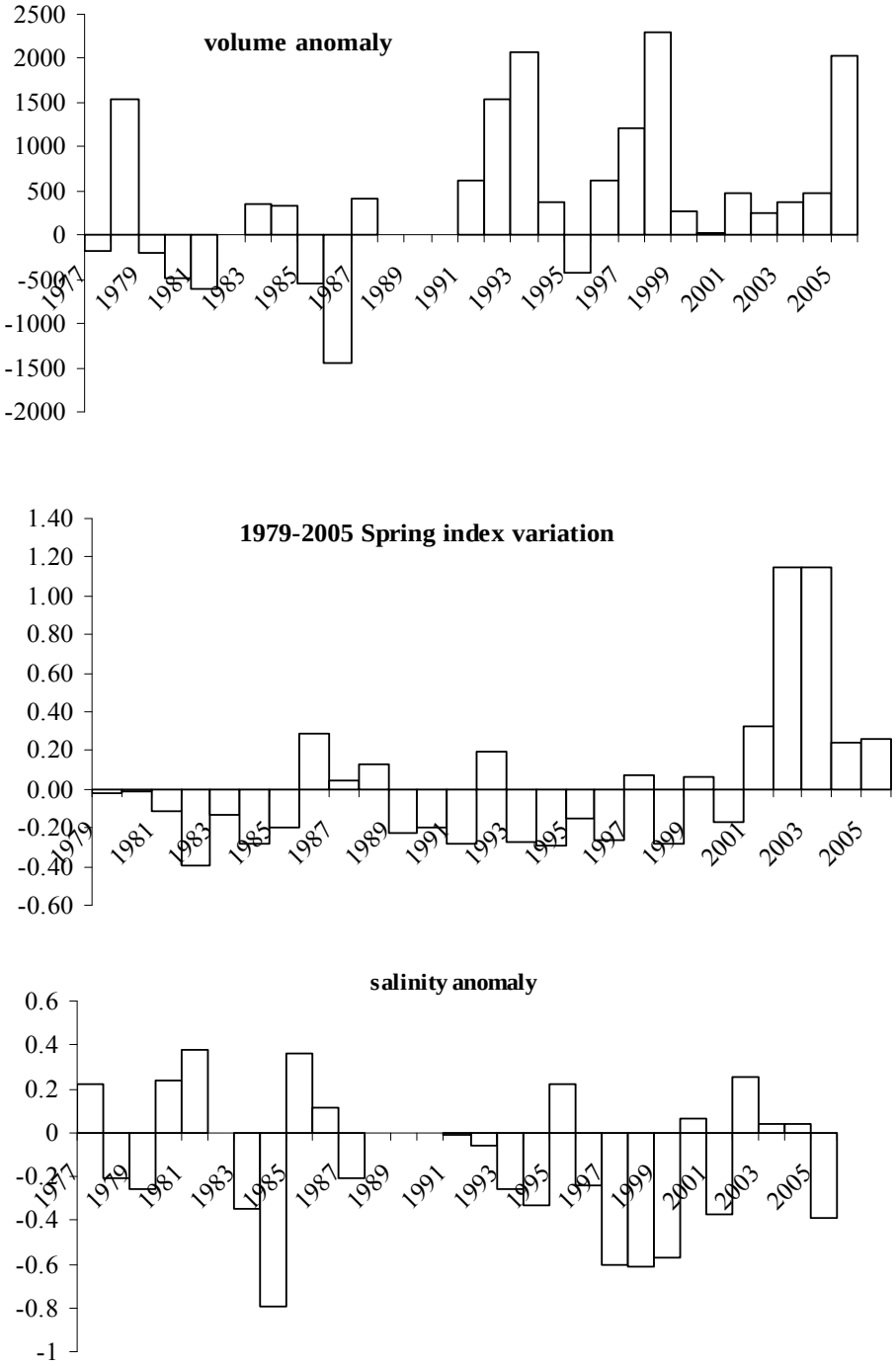

Figure 7. Spring oceanographic anomalies in the mid-Atlantic and variation from the time series mean of NEFSC spring survey indices, 1979-2005.

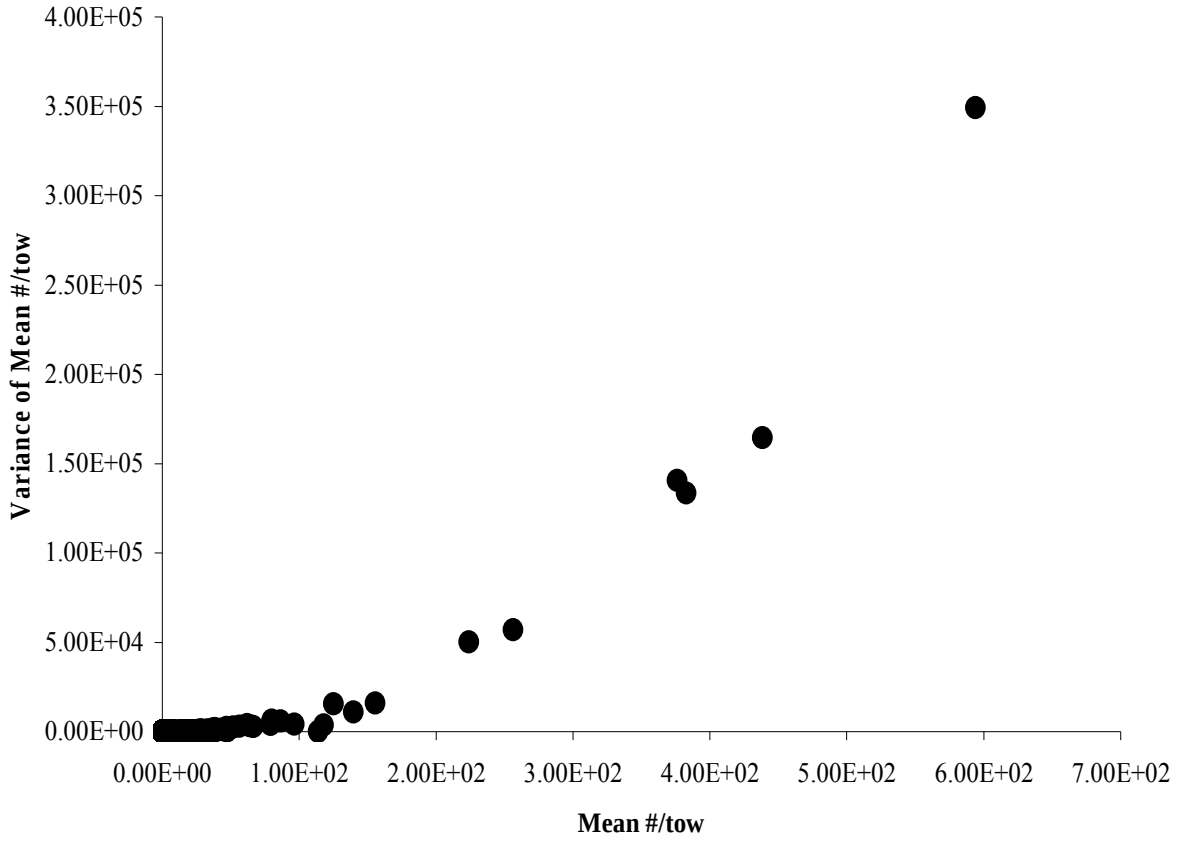

Figure 8. Relationship between black sea bass mean #/tow and associated variance for NEFSC Spring survey.

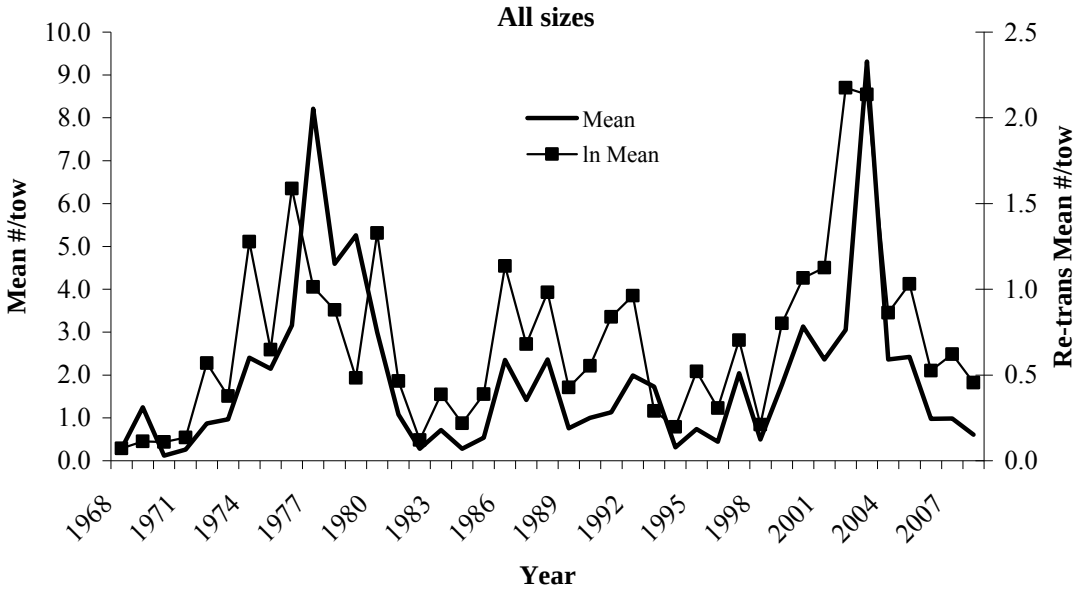

Figure 9a. NEFSC spring offshore stratified mean num/tow and re-transformed $\log_e$ stratified mean num/tow for black sea bass of all sizes.

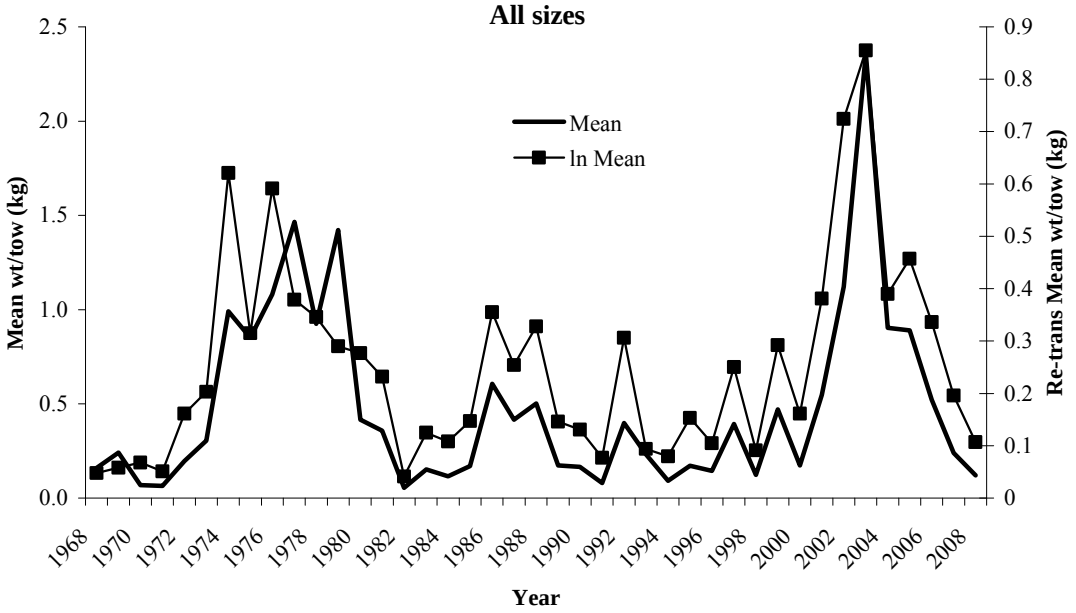

Figure 9b. NEFSC spring offshore stratified mean wt/tow (kg) and re-transformed $\log_e$ stratified mean wt/tow (kg) for biomass of black sea bass, all sizes.

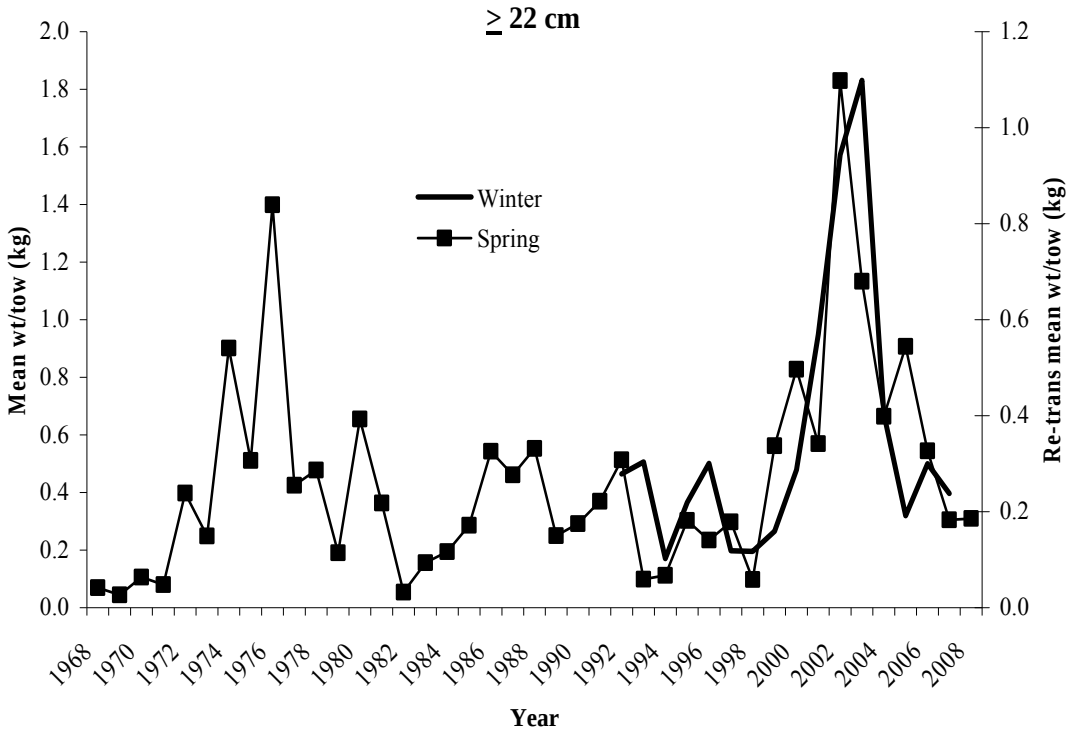

Figure 10. NEFSC spring and winter offshore re-transformed $\log_e$ stratified mean wt/tow (kg) indices for exploitable biomass of black sea bass (≥ 22 cm).

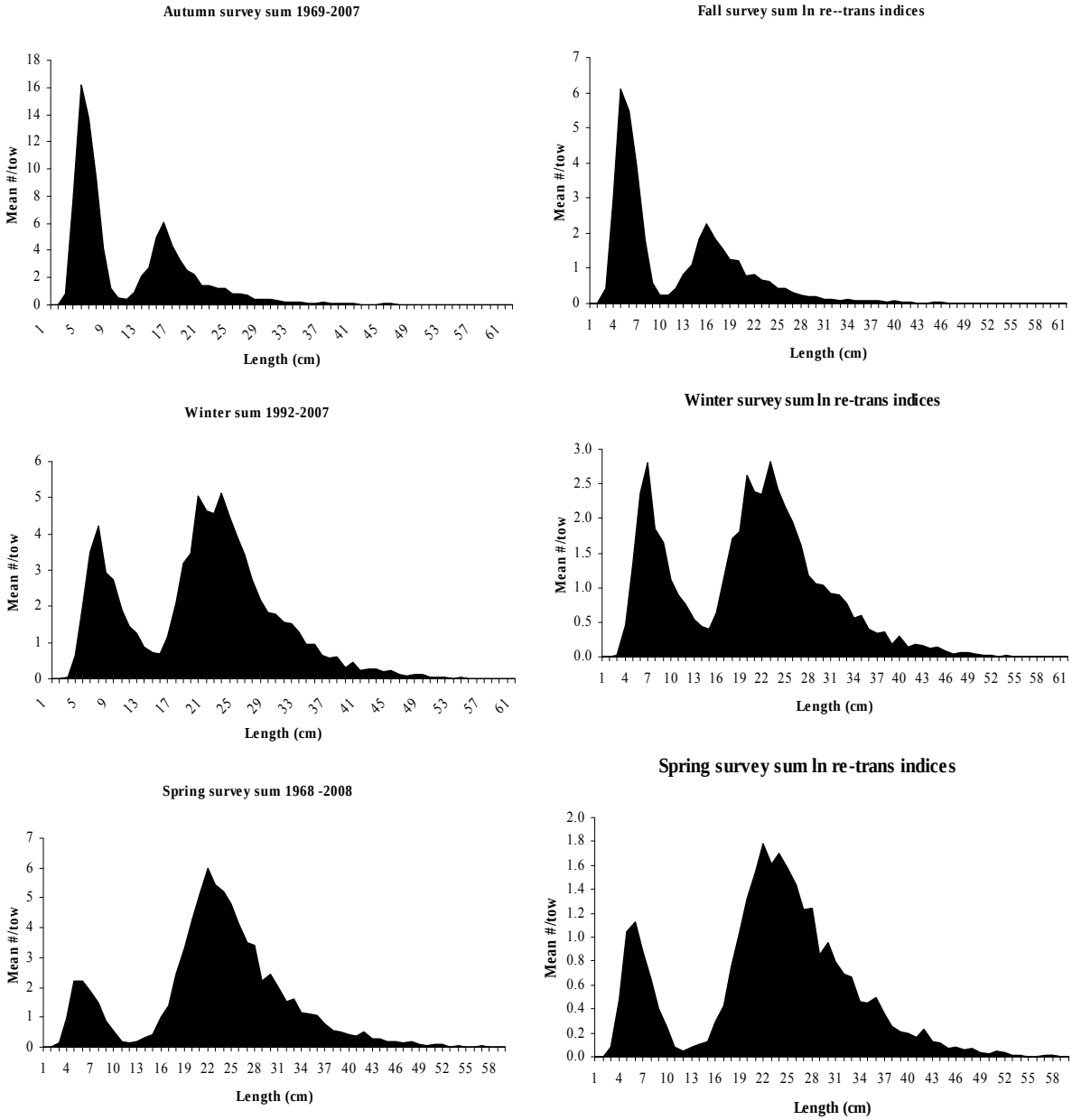

Figure 11. NEFSC spring, winter and autumn length frequencies for combined years showing recruits as first distinctive mode.

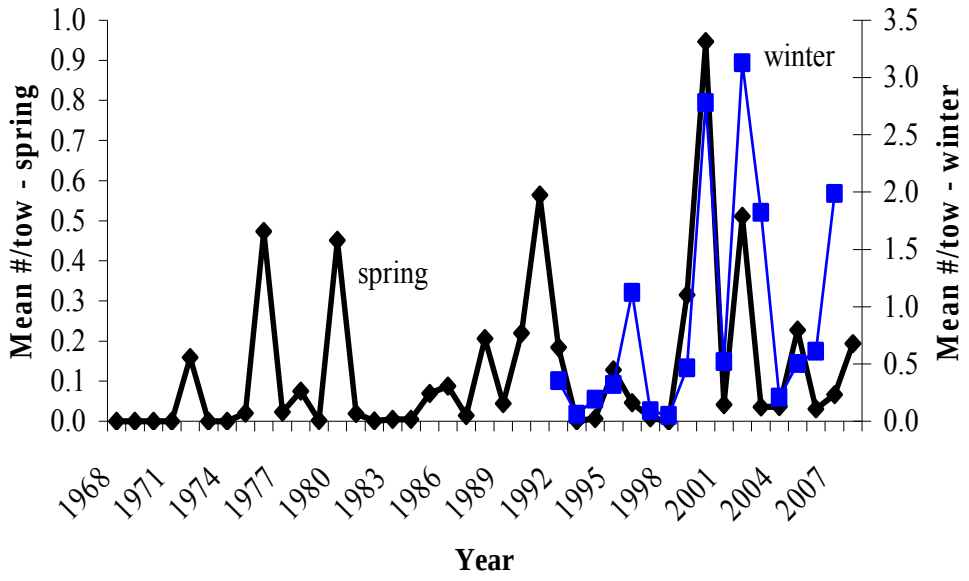

Figure 12. NEFSC spring and winter indices of juvenile abundance (stratified mean #/tow for sea bass ≤ 14 cm).

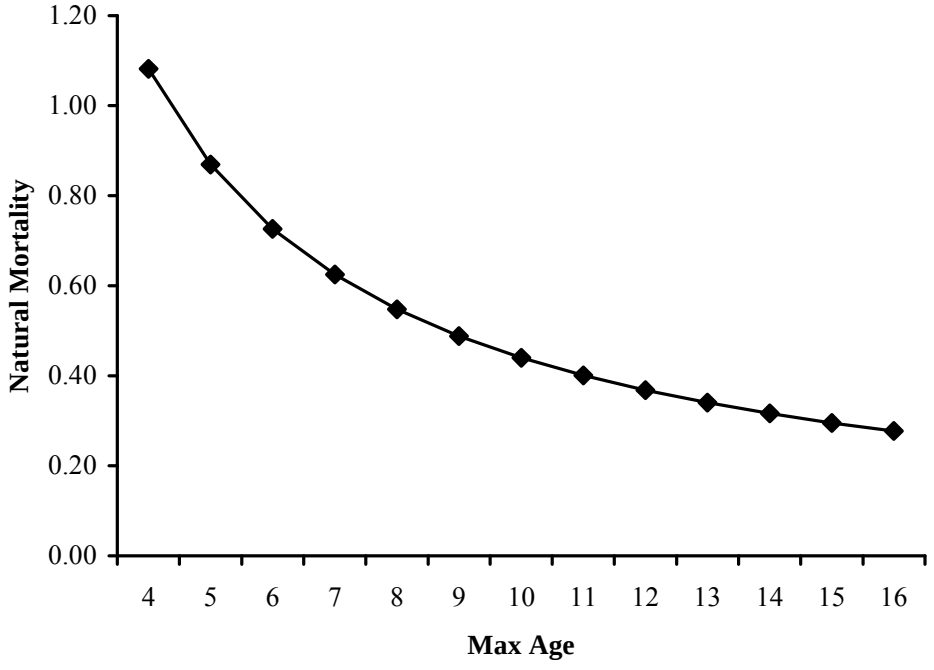

Figure 13. Relationship between maximum age and natural mortality as determined from Hoenig equation.

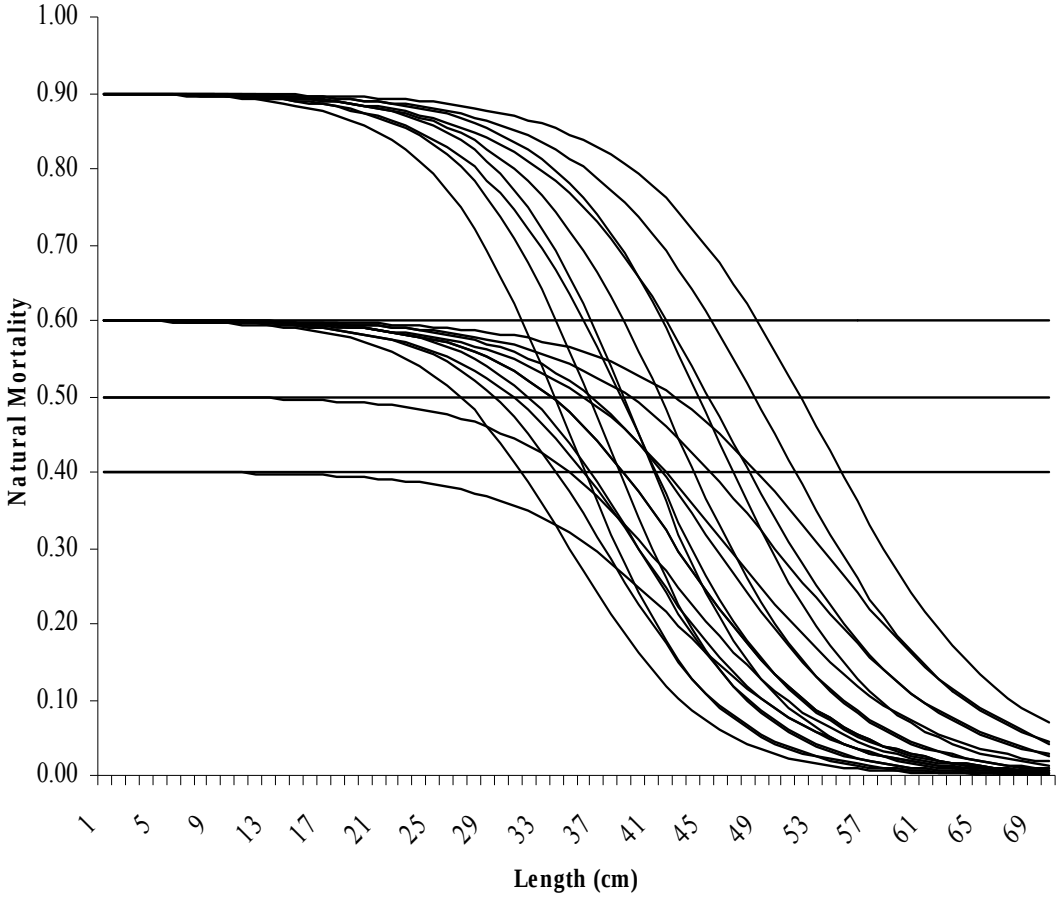

Figure 14. Patterns of natural mortality used in reference point calculations. Logistic models with initial M values of 0.4, 0.5, 0.6 and 0.9 as well as constant M of 0.4, 0.5 and 0.6.

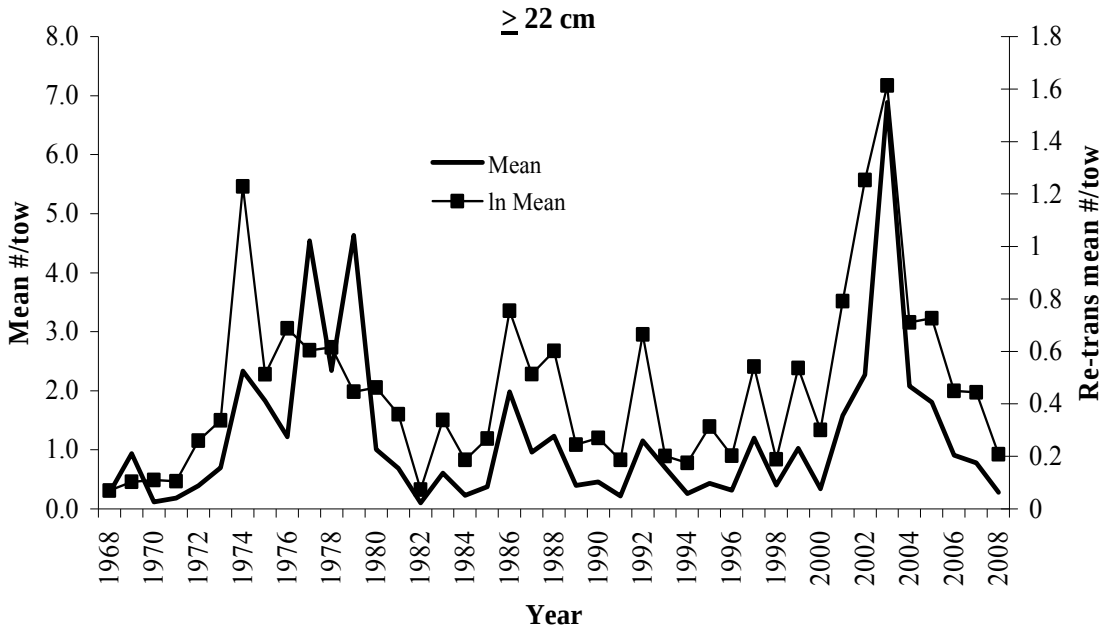

Figure 15. NEFSC spring offshore and winter survey indices (mean #/tow) for black sea bass ≥ 22 cm. Indices of relative abundance used as input to SCALE model.

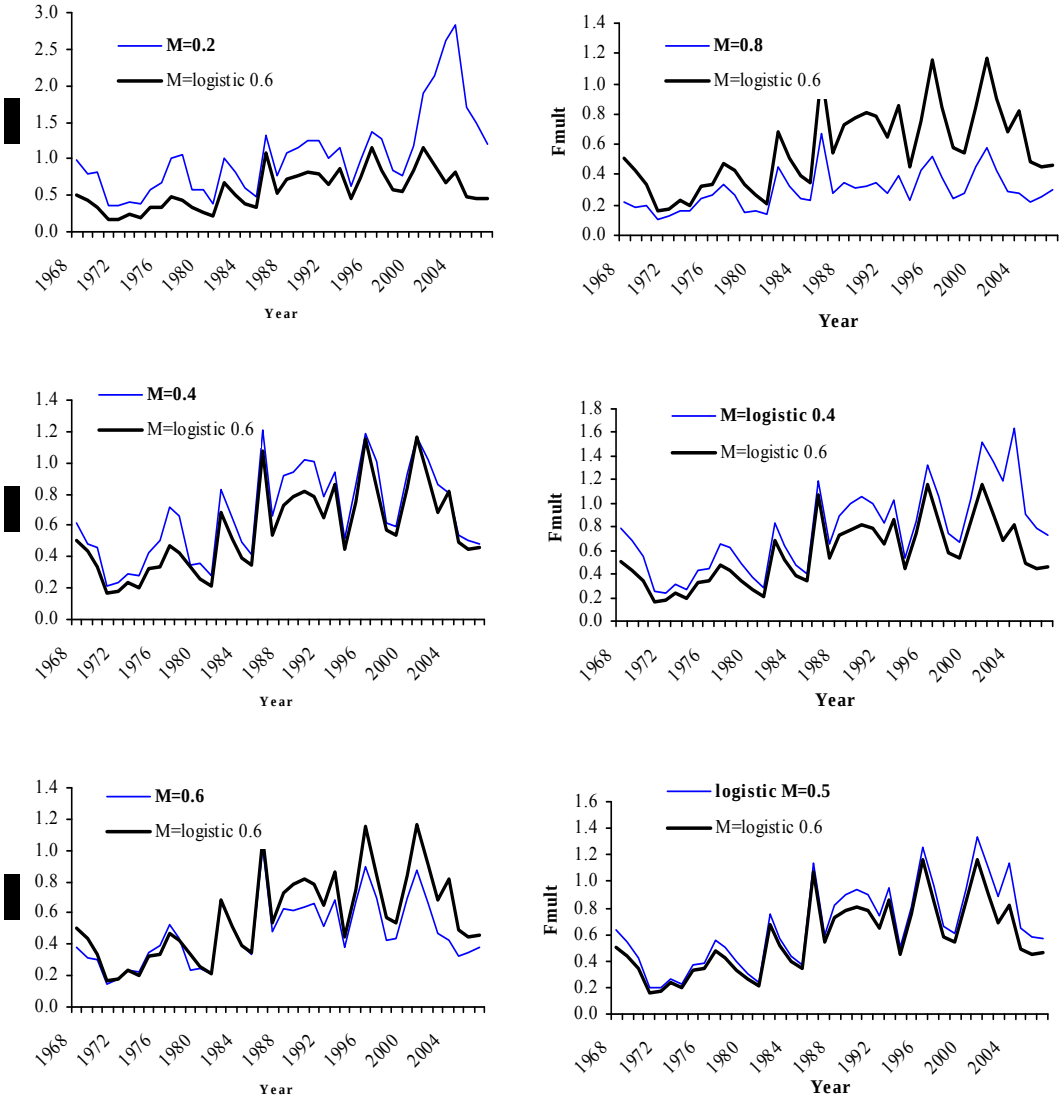

Figure 16. Time series of fishing mortality from the SCALE model under a variety of natural mortality estimates.

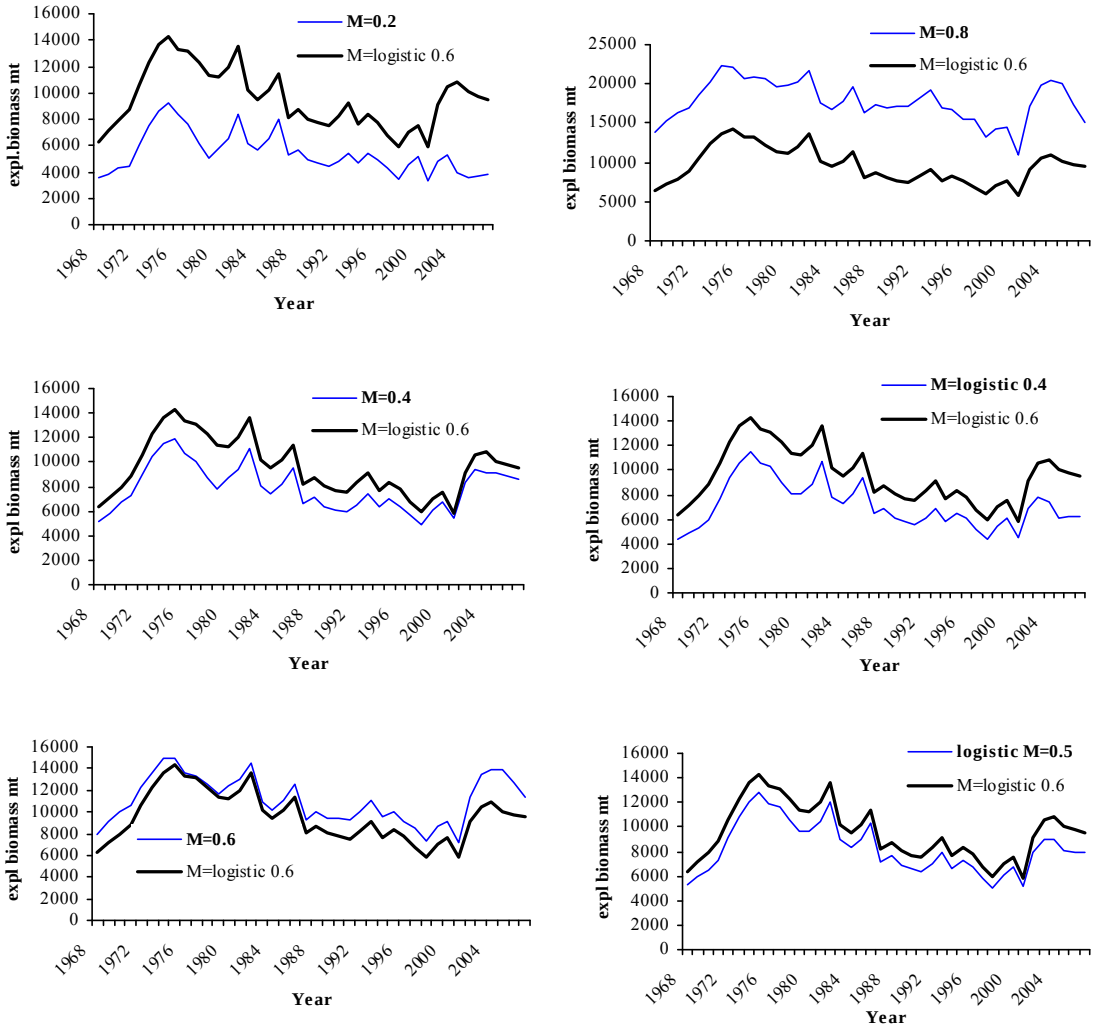

Figure 17. Time series of exploitable biomass (mt) estimates from SCALE under a variety of natural mortalities.

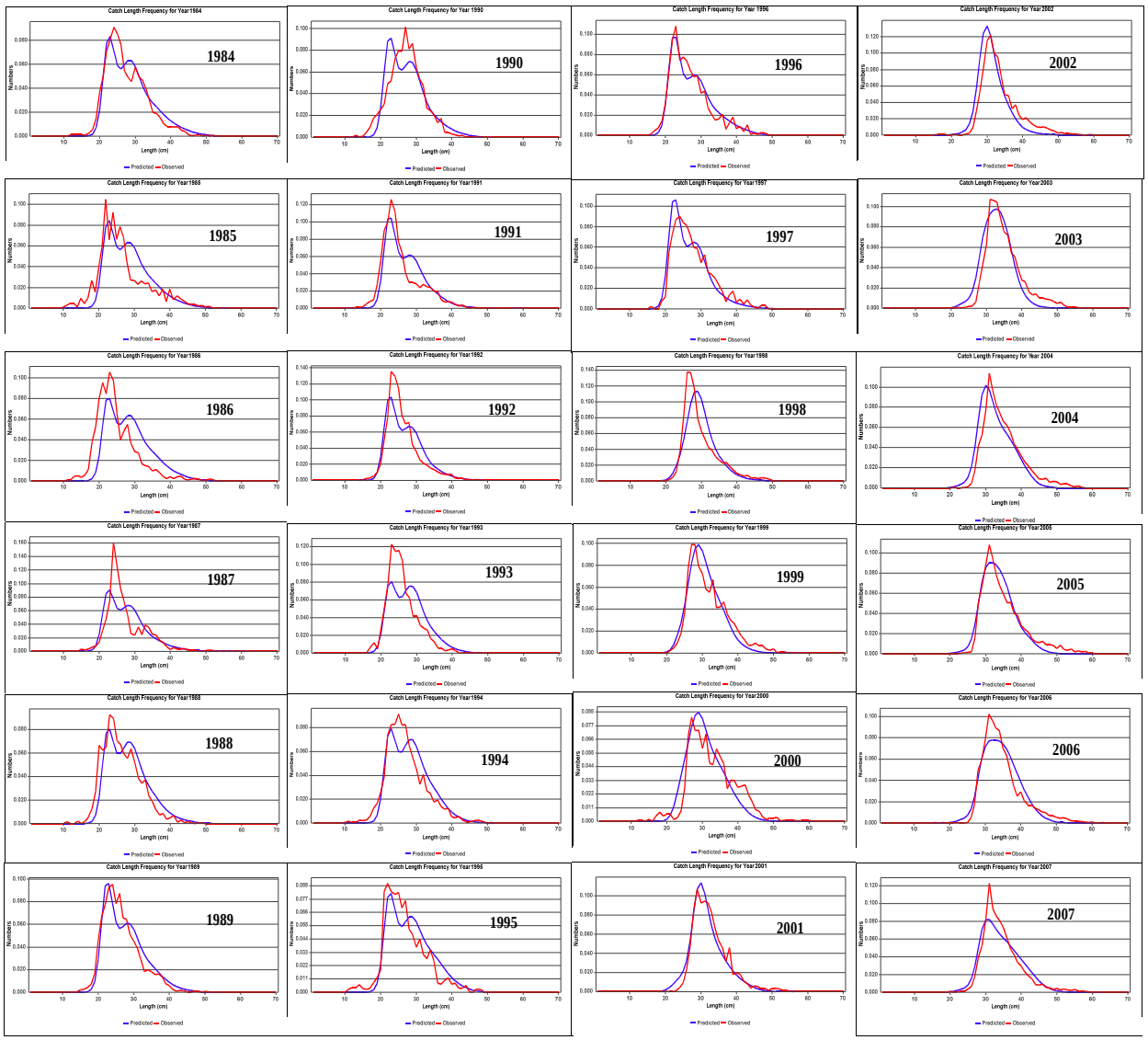

Figure 18. Observed fishery length frequencies 1984-2007 and frequencies predicted by SCALE model using constant M=0.4. Blue equal predicted, red observed.

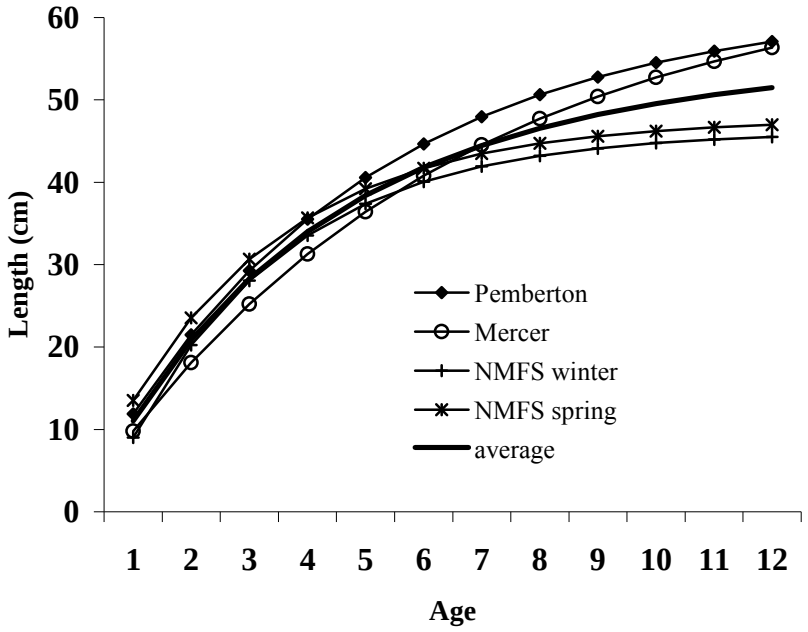

Figure 19. Black sea bass von Bertalanffy growth curves through age 12.

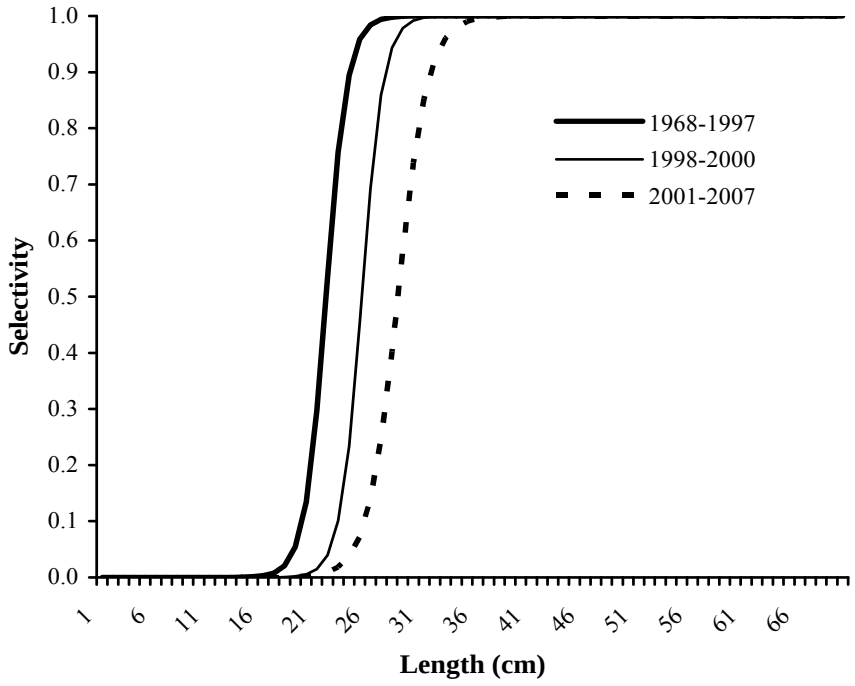

Figure 20. Selectivity patterns for black sea bass from SCALE model, constant M=0.4.

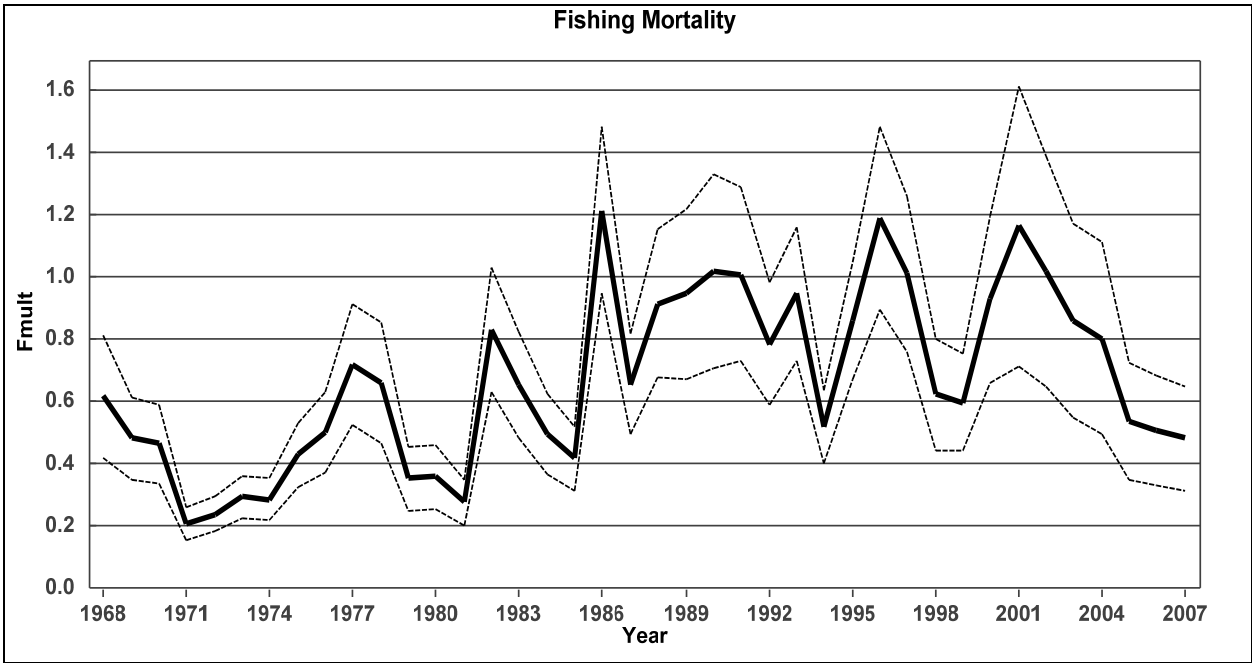

Figure 21. Estimated fishing mortality for black sea bass, 1968-2007 from SCALE model using constant M=0.4.

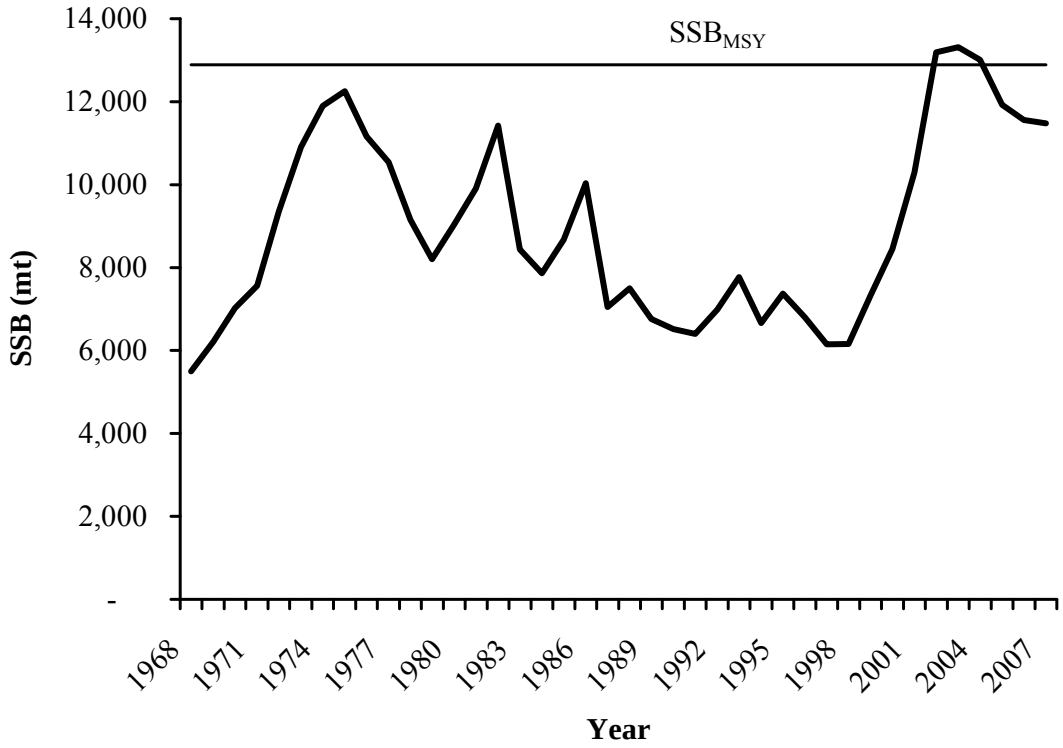

Figure 22. Black sea bass spawning stock biomass from SCALE model using constant M=0.4 and associated SSB_{MSY}.

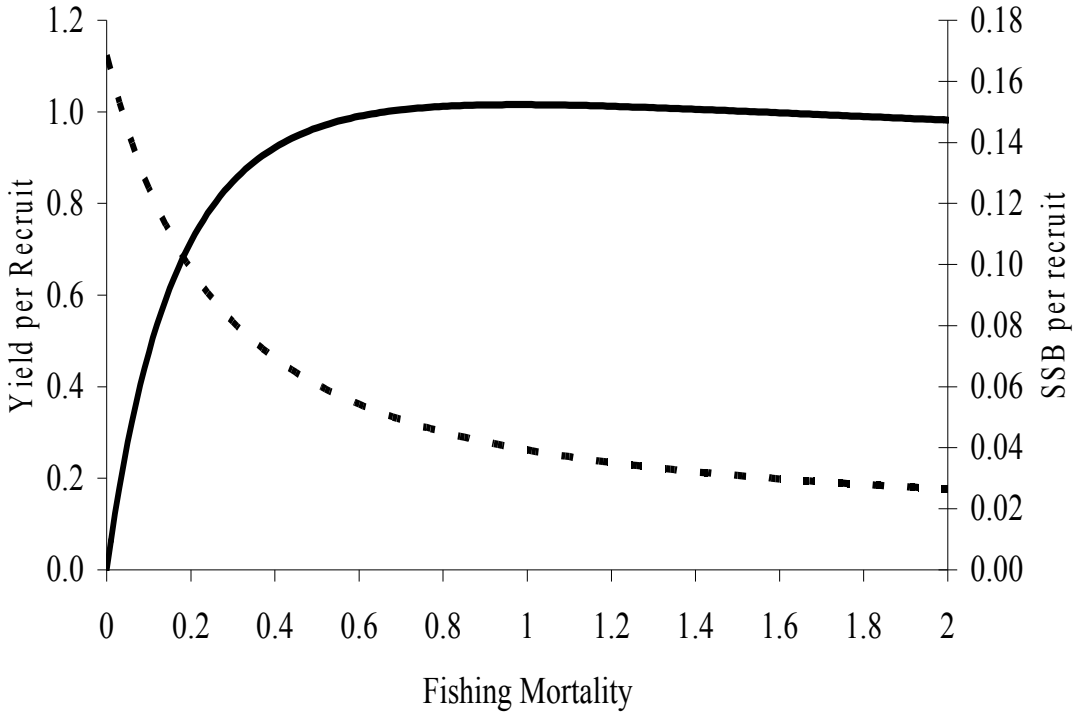

Figure 23. Yield and spawning biomass per recruit for black sea bass at constant M=0.4.

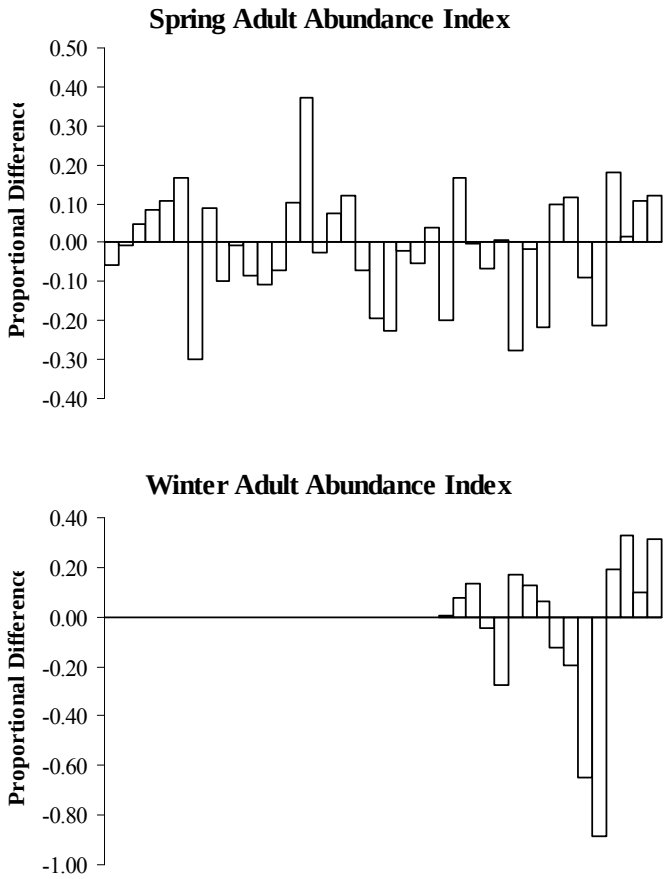

Figure 24. Residual patterns from observed and predicted NEFSC black sea bass survey indices.

Black sea bass
Unpublished manuscript
Appendix 1

Estimates of Fishing and Natural Mortality of Black Sea Bass, *Centropristis striata*, in the Mid-Atlantic based on a Release-Recapture Experiment

Gary R. Shepherd
National Marine Fisheries Service
Woods Hole, MA 02536
gary.shepherd@noaa.gov

and

Joshua Moser
National Marine Fisheries Service
Woods Hole, MA 02536
Joshua.moser@noaa.gov

Black sea bass; Appendix 1

Abstract

Black sea bass in the Mid_Atlantic Bight, are exploited by recreational and commercial fisheries. To evaluate mortality rates, a tag release/recapture study was conducted with 13,794 tagged black sea bass (12,310 legal-size) released between Massachusetts and Cape Hatteras, NC from 2002 to 2004. Of these legal-size releases, 1,683 were recaptured during 2002 to 2007. An instantaneous rates configuration of a Brownie band recovery model was used to estimate both fishing and natural mortality. A seasonal model of fishing mortality, adjusted for non-mixing, and a constant natural mortality best explained the tag recoveries. Fishing mortality estimates were between 0.3 and 0.4 whereas the natural mortality estimate was greater than 1.0. The estimate of natural mortality includes the effects of all unaccounted tag losses, however the results suggest that natural mortality is likely greater than 0.2 which has been assumed based on a maximum age of 15. Higher overall rates of natural mortality could result from increased vulnerability at sexual transition in this hermaphroditic species.

Introduction

Stock assessments of marine fish populations have long been a key component in managing fishery resources. Information regarding past rates of exploitation, along with potential productivity, allow managers to determine how much future exploitation can be allowed. Traditionally, catch based population models have been the tool of choice in stock assessments but in recent years tag based models have been increasingly used either as independent estimates of exploitation (Latour et al. 2001; Lambert et al. 2006; Jiang et al. 2007) or in conjunction with catch data (Polacheck et al. 2006). If implemented within the framework of a properly designed experiment, tagging programs are capable of providing estimates of exploitation and population size as accurately as catch at age models (Pine et al. 2003).

In the Northwest Atlantic, black sea bass (*Centropristis striata*), support both commercial and recreational fisheries. Although black sea bass are distributed from the Gulf of Maine to the Gulf of Mexico, fish north of Cape Hatteras, NC are considered part of a single management unit. Commercial landings for this stock have remained relatively steady around 1400 mt since 1970, although landings in 1952 peaked at 9,900 mt (Shepherd 2007). Recreational landings, available since 1982, average about 1,600 mt annually. The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries while decreasing the susceptibility to bottom trawl gear commonly used for scientific surveys. In autumn when water temperatures decline, black sea bass migrate offshore to areas along the edge of the continental shelf. During this offshore period, sea bass are vulnerable to otter trawl gear as part of a multispecies fishery (Shepherd and Terceiro 1994).

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949; Mercer 1978). Males can follow one of two behavioral pathways, either becoming dominant males, characterized by a larger size and a bright blue nuccal hump during spawning season, or secondary males which have few distinguishing features. Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters. The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory

during spawning season (Nelson et al. 2003). The cue which triggers the transition from females to secondary or dominant male is undocumented, although the bright coloration of males suggests that visual cues may be important in structuring the social hierarchy.

Development of an analytical stock assessment for black sea bass has been hampered by a lack of catch at age information, inadequate fishery independent abundance indices and the unique life history characteristics of this species (NEFSC 2007). A recommendation emanating from an assessment review was to develop a comprehensive coastwide tagging program as an alternative method of determining exploitation on the northern stock and as a way to examine migratory behavior (NEFSC 1998). A secondary goal of the tagging program was to create a cooperative approach to data collection involving both the commercial and recreational industries.

Methods

Tagging protocol

A basic assumption in mark-recapture programs is that the tagged animals will be dispersed equally among untagged animals (Brownie et al. 1985). This can be accomplished either with the tag and release of a single large group, allowing the animals to disperse, or by dispersing the sites of release throughout the tagging area (Ricker 1975). To ensure the greatest geographic dispersal of tagged sea bass throughout the range of the northern stock, we tagged and released fish among coastal states (MA, RI, NY, NJ, DE, MD and VA) relative to state landing quota allocations of the Mid-Atlantic Fishery Management Council (MAFMC). Within each state, tagging sites were distributed at regular spatial intervals.

Sample sizes for releases were determined following the methods of Polacheck and Hearn (2003). A target sample size was 2,500 tags per season based on estimation under a range of exploitation rates (15% to 45%) and assuming a reporting rate of 75%, which demonstrated that any further increase in sample size resulted in minimal reduction in the variance of the exploitation rate. Tagging was conducted annually from 2002 to 2004 within a 30 day period from mid-September to mid-October, as well as a 21day period in May 2003. Several autumn release events occurred within days of this time window, having been delayed by weather. High reward tags ($100) were interspersed among regular tag releases at an approximate rate of 1 per 25 regular tags.

Over the three year period, black sea bass were tagged and released aboard chartered commercial and recreational fishing vessels. Recreational gear was standard hook and line equipment while commercial vessels used fish traps or hook and line gear. Fishing was done in depths ranging from 6 to 46 m and, if necessary, captured fish were placed into a holding tank to await tagging or evaluate condition. The size of fish targeted for tagging were greater than the commercial legal length (28 cm); however, fish as small as 20 cm were tagged. Tag number, date, exact location, total length (to the half-centimeter) and relative condition were recorded for each fish tagged.

The tag type used was a Floy internal anchor tag (FM-84), which has exhibited long term retention in other species (Dunning et al. 1987; Waldman et al. 1991). The tags had a unique identification number, telephone contact number and “Reward” printed on each side and in opposite directions such that the tag number was present at both the base and end of the tag. Tags were either orange, whose reporting was rewarded with a cap, or red which resulted in the $100 reward. In later years of the study, entry into a $250 lottery was offered in lieu of a cap. Tags were inserted into the abdomen below the midpoint of the pectoral fin by removing 2-3

scales and making a 0.5 cm incision into the musculature. Tagged fish were either released immediately or, if necessary, placed into a holding tank for several minutes of observation. Sea bass caught at deeper sites often had extruded swim bladders which were deflated when the abdominal incision was made and tag inserted. Fish judged to be weak or swimming abnormally were not released with a tag.

Recaptured tags were reported by telephone, postal mail, or by an online tag reporting webpage. High reward tags were returned prior to payment. We collected information on the date of capture, fish length, gear type and fishery, port, and longitude and latitude of recapture (or at least some reference point within several miles), condition of the fish at the tag insertion point, and fisherman's contact information.

Tag effects

Tag retention rate and tag induced mortality were determined by holding tagged fish in tanks in three separate studies. The first study was conducted at the Northeast Fisheries Science Center (NEFSC) Woods Hole Aquarium. Fish collected by hook and line were tagged and then placed in a 3,500 L aquarium tank for nine months. A second experiment was conducted in the NEFSC J.J. Howard Laboratory in Sandy Hook, NJ. Fish collected from fish pots were held in 1,500 L for ten to twelve months. A third experiment was conducted by the Rhode Island Department of Environmental Management. Fish collected with fish pots were tagged and held in 1,500 L tanks for twenty-seven days. In each experiment, tag losses and mortality associated with tagging were recorded daily.

Tag Analysis

Black sea bass and their fisheries in the Mid-Atlantic occur during two seasons: May through early October, and late October through April. To account for these seasonal variations and the time of tag releases, the recapture information and subsequent analyses were divided into two periods. One period was May 1st to September 30th and the second period ran from October 1st to April 30th. Tag recapture information was compiled by release cohort and summarized in a recovery matrix as:

$$R = \begin{bmatrix} r_{12} & r_{22} & \cdots & r_{1J} \\ __ & r_{22} & \cdots & r_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ __ & __ & __ & r_{IJ} \end{bmatrix}$$

where r_{IJ} is the number of tags recovered in period J that were released in period I.

An assumption of tag modeling is that the tagged fish are representative of the untagged population. The time series of tag recaptures from a release group can be treated as a catch cohort, and total mortality (F + M or Z) approximated as a catch curve by calculating the slope of the $\log_e$ of recaptures over time (Ricker 1975). The catch curve method was used to evaluate tag recapture consistency across seasons, after adjusting for reporting rate. The negative slopes of the regressions, estimated within Excel, were averaged across all release years for comparison to the full tag model.

Survival estimates from the mark-recapture data were modeled using a variation of the Brownie model parameterized as instantaneous rates (Hoenig et al. 1998a; Hoenig et al. 1998b). The instantaneous rates (IR) model allows for direct estimation of both fishing (F) and natural (M) mortality. Additionally, F in the first recapture interval can be modeled separately to account for incomplete mixing or partial selectivity to the fishery. The model of expected recoveries can be written as:

$$\mathrm{E}(R) = \begin{bmatrix} N_1\phi\lambda_1\mu_1(F_1^*, M) & N_1\phi\lambda_2\mu_2(F_2, M)e^{-(F_1^*+M)} & \cdots\cdots & N_1\phi\lambda_J\mu_J(F_J, M)e^{-(F_1^*+\sum_{k=2}^{J-1}F_k+(J-1)M)} \\ — & N_2\phi\lambda_2\mu_2(F_2^*, M) & \cdots\cdots & N_2\phi\lambda_J\mu_J(F_J, M)e^{-(F_2^*+\sum_{k=3}^{J-1}F_k+(J-2)M)} \\ \vdots & \vdots & \ddots & \vdots \\ — & — & — & N_I\phi\lambda_J\mu_J(F_J, M)e^{-(F_I^*+\sum_{k=I+1}^{J-1}F_k+(J-I)M)} \end{bmatrix}$$

where ϕ is the rate of tag loss at release, λ is the tag reporting rate, F_k is the instantaneous fishing mortality in period k, F* is F during the initial non-mixing period and M is instantaneous rate of natural mortality. In black sea bass fisheries where F and M occur simultaneously, then:

$$\mu_J(F_J, M) = \frac{F_J}{F_J + M}(1 - \exp(-F_J - M))$$

and when $I=J$ then:

$$\mu_J^*(F_J^*, M) = \frac{F_J^*}{F_J^* + M}(1 - \exp(-F_J^* - M))$$

Since the results are assumed to be a multinomial distribution, the optimal solution of model parameters was determined using maximum likelihood estimation. Comparisons between observed and predicted tag recovery frequencies were made with a chi-square goodness of fit test and evaluation of the best model was done using the quasi-likelihood Akaike's information criterion, $QAIC_c$, which accounts for over-dispersion in the data (Anderson et al.1994; Burnham and Anderson 2002). Profile likelihoods were developed for each parameter in the final model and used to calculate 95% confidence intervals (Gimenez et al. 2005). The model parameterization was developed using the solver function in Microsoft Excel.

Since tagging occurred in October or May, the resulting mortality estimates were not calendar year values. Annual fishing and natural mortalities were re-calculated using monthly values (seasonal mortality estimate / # months within the season) and these values re-configured to a calendar year rather than tagging year. Fishing mortality estimates in 2002 only included October to December and were not used in an annual mortality estimate. Results from the final three months of 2007 were assumed equal to the mean of the same period in 2006.

Reporting rate

Although it is possible to estimate reporting rate λ within the model (Jiang et al 2007), we used an empirical estimate based on high reward tag returns:

$$\lambda_J = \left[\frac{(\sum_{J=1} \text{regular tags returned} / \sum_{J=1} \text{regular tags released})}{(\sum_{J=1} \text{high reward tags returned} / \sum_{J=1} \text{high reward tags released})} \right]$$

The ratio was calculated only for the twelve months at large for each release cohort since the recapture ratio of regular tags to high reward tags in the second year is not independent of the reporting rate in the first year. A constant reporting rate was applied to the recaptures after spring 2005. The monetary award that was thought to ensure that return rates approach 100% was $100 (Murphy and Taylor 1991; Pollock et al. 2001; Taylor et al. 2006). The sensitivity of the model results to the assumption of high reward tag reporting rate was evaluated for rates from 25% to 100%.

Tag induced mortality estimates do not account for mortality associated with the capture and release process during tagging. Hooking mortality in black sea bass has been estimated at 5% (Bugley and Shepherd 1991). To account for potential mortality of tagged fish due to hook and line capture, the tag loss rate was inflated by five percent.

Growth

Growth rate of individuals was calculated as the change in length between release and recapture divided by the number of days at large. Since recapture lengths are provided by the public, these lengths were expected to have a greater measurement error than the release measurements taken by trained personnel. The overall average growth per day was estimated for the entire time series of returns, and for the time series following elimination of data from consecutive days at large. Average growth was calculated from the point where the average growth in the time series remained relatively stable.

Results

Between 2002 and 2004, a total of 13,794 black sea bass of all sizes were tagged and released with either regular or high reward tags. Among those released,12,310 fish were greater than or equal to 26 cm and were tagged with regular reward tags (Table 1, Figure 1). These were considered vulnerable to both recreational and commercial size fisheries within one season following release. From October 2002 to September 2007, 1,683 regular tagged sea bass were recaptured and reported (Figure 2), for an overall recapture rate of 13.7%. Tagged fish were recovered throughout the range from recreational fishermen (57.2%), commercial fishermen (39.2%), research trips (1.0%) and unknown sources (2.6%). The average size at release was 32.2 cm ($\pm$ one std. dev of 4.76) whereas the average size at recapture was 35.8 cm ($\pm$ one std. dev of 5.83). The size distributions of released fish were comparable to the size distributions of sea bass harvested by the recreational and commercial fisheries (Figure 3). Average time-at-large was 257 days and the total distance traveled between tagging and recapture locations averaged 27.0 km or 0.35 km day^{-1}.

Tag retention and tag induced mortality in black sea bass were evaluated in three separate experiments. Sixty-eight (68) fish, ranging in size from 26 to 41 cm, were held in aquaria up to twelve months. No mortalities were observed immediately following tag insertion and over the

course of the three experiments, only seven tags were shed (Dr. Mary Fabrizio, NEFSC[2]; Brian Murphy, RIDEM, personal communication). Five of the seven tags were shed within the first several weeks. Tag loss in black sea bass tagged with internal anchor tags was estimated at 10%. In addition, to account for potential hook induced mortalities associated with the initial capture methods, total tag loss and mortality was set at 15%.

Growth of tagged fish was estimated as the difference in size between release and recapture, and the time at large. During the initial days at large, the growth of tagged fish would be expected to be negligible and therefore the difference between length at release and recapture during this period would be due to measurement error. Within the first ten days, the differences in recorded lengths between released and recaptured fish ranged from 0 to 7 cm, averaging 1.1 cm, with the largest discrepancy from legal size fish ($\geq$ 29.5 cm). With increasing time at large, measurement error decreased relative to accumulated growth (Figure 4). Consequently, growth rate declined over the first 90 days but stabilized thereafter. After the initial 90 days, growth averaged 0.012 cm day $^{-1}$ for fish $\geq$26 cm. Assuming constant growth, fish tagged at 26 cm would be expected to attain legal size of 28 cm within 167 days following release.

Estimation of survival in Brownie-type models requires knowledge of the reporting rate of the tags. Included in the tag releases were 662 high reward tagged fish distributed across release periods. Based on the ratio of regular tags to high reward tag recoveries (N=151), seasonal estimates of tag reporting rate ranged from 53% to 80% (Table 2). The rates for the fall-winter period (76%. 80% and 57%) were generally higher than spring-summer (53%, 59% and 62%). Reporting rates in the years without empirical data were held constant at 60%, the average of the last two periods of empirical data. An assumption in reporting rate estimation was 100% reporting of the high reward tags. In the reporting process not all fishermen were willing to provide complete information necessary for payment. Consequently, true reporting rate was unknown but probably slightly less than 100%. The influence of reduced reporting of high reward tags would be an over-estimation of actual reporting rates (Pollock et al. 2001).

An additional model assumption is constant selectivity once the fish reach the size of full recruitment to the fisheries. This assumption was tested using recovery rates by two cm size categories for all data combined (Figure 5). The selectivity for fish greater than 29 cm was tested for a departure from a slope of zero. Results show no significant difference from 0 (Pr = 0.2) indicating a constant selectivity with size.

A simple estimate of total mortality (fishing plus natural mortality) was calculated as the rate of reduction in tag recoveries over time (Figure 6). The rate of decline in recoveries was consistent among release cohorts and total mortality estimates ranged from 1.33 to 1.54. The overall average total mortality using the catch curve method was 1.41. This approach requires a priori information regarding natural mortality to derive fishing mortality. Alternative tagging models, such as the instantaneous rates model, allow partitioning of the sources of mortality and direct estimation of F.

The instantaneous rates non-mixing model can be configured in a variety of ways. Recaptures of fish $\geq$ 29.5 cm were evaluated using seven models which included: (1) a fully parameterized model with time specific F, F* and M; (2) constant F and M with time specific F*; (3) constant F, F* and M; (4) time specific estimates of F* by period, time specific F for periods 1 through 6 with constant F across periods 7 to 10 and constant M; (5) constant estimates per period across years for all parameters; (6) constant annual estimates (no seasonal effect); and (7) period F* and F estimates with constant M. The constant F for periods 7 to 10 was chosen to

[2] Present address Virginia Institute of Marine Science, Gloucester Pt. VA

account for small sample sizes in the upper right corner of the matrix. Results of the chi-square test indicated that predicted values were not statistically different than those expected, with Pr>0.05 for models 1, 4 and 7. Based on the QAIC value, model 1 provided the best combination of parsimony and fit (Table 3). However, the parameter estimates were not robust to the starting values in the solution algorithm as the F estimates in the final 3 periods converged to different solutions depending on initial values. The reduced model, model 4, provided a more robust solution and was selected as the most appropriate model configuration. A comparison of observed and expected tag recaptures (Figure 7) indicated that recaptures can be adequately predicted using this model. The residuals show a pattern of consistent under-estimation of tag recaptures from the spring 2003 release (Figure 8), although the magnitude of the residuals is very small. The residuals from the three fall releases show no trend.

Comparison of mixing and non-mixing estimates of fishing mortality suggest that black sea bass were more vulnerable to exploitation during the initial release period. In each of the three release cohorts where both a non-mixed and mixed F could be estimated, the non-mixing F was higher (Table 4). The difference was particularly obvious in the spring 2004 release where the non-mixing F for the initial period (F^*_3) was 0.18 whereas subsequent F_3 estimates were 0.10. Fall releases (F_2 and F_4) differed between mixing and non-mixing estimates by 15 and 20%, respectively.

Average seasonal mortality estimates were derived from the model partial Fs. During the October to December/January to April period, fishing mortality averaged 0.16 per month, compared to the partial F from May through September period when fishing mortality averaged 0.22. The annualized fishing mortality standardized to calendar year, increased from 0.32 in 2003 to 0.41 in 2005 but then declined in 2007 to 0.37 (Table 5). Natural mortality, estimated as constant across years and seasons, was 1.08 (Table 4).

The tagging results indicate that fishing mortality has been relatively stable since 2002. Profile likelihoods and the associated 95% confidence intervals for the suite of seasonal F, F* and M estimates are presented in Figures 9 and 10. The distinctiveness of the minimum likelihood decreases for the parameters furthest from the initial release period resulting in a greater uncertainty in the estimates at the end of the recovery time series.

The tag recaptures in the model are influenced by both tag retention and reporting rates. The reporting rate adjustments assume that all high reward tags recaptured are recovered. However, in situations where fish are being quickly discarded, tagged fish may not be recovered and may die soon after discarding. To examine the sensitivity of the natural mortality estimate to under-reporting, we incrementally decreased high reward reporting rates. Overall reporting rate decreased linearly with decreased high reward reporting and the estimate of natural mortality decrease was curvilinear (Figure 11). When the high reward reporting was equal to 28.2%, the model estimate of natural mortality was 0.2.

Discussion

Recent developments in mark-recapture models have advanced their use for evaluating the exploitation of marine fishes. In particular, the parameterization of the Brownie bird banding models into instantaneous rates makes tagging model results similar to traditional catch at age stock assessment models. The lack of an analytical stock assessment was the impetus for developing a tag recapture program for black sea bass. Consequently, the results from the tagging models may help in determining status of black sea bass in the Mid-Atlantic. The most recent estimate of the fishing mortality that produces the maximum yield per recruit (i.e. F_{max})

was calculated to be F=0.33 (NEFSC 2007). The tagging results imply that fishing mortality exceeds this level, although the distribution of the 95% confidence interval shows that there is some probability that F is actually below F_{max}.

Seasonal patterns in fishing mortality reflect differences in the black sea bass fisheries. During the inshore period, sea bass are exposed to a coastwide recreational fishery and a directed pot fishery, whereas the offshore fishery is generally a non-directed trawl fishery targeting species such as summer flounder or *Loligo* squid (Shepherd and Terceiro 1994). The locations of optimal inshore black sea bass habitat, such as artificial reefs, are generally well known to fishermen and are routinely targeted. Among several tag release locations on artificial reefs, the recovery rate was as high as 25 to 35%. Movement of black sea bass is highly seasonal and did not occur until several weeks after tagging. Consequently, the exploitation of tagged fish was greater before they mixed during migration but the non-mixing model was able to adjust for this pre-migration period.

The parameterization of the Brownie model into instantaneous rates allowed potential estimation of natural mortality. Fishing mortality is determined from tag recoveries while the estimation of natural mortality is based on unaccounted tags (Hoenig et al. 1998b). Consequently, the parameter M is true natural mortality but is influenced by biases resulting from tag attrition over time, overestimated reporting rates, changes in selectivity with size, permanent emigration from the study area, increased predation on tagged fish, etc. and any other process which could result in unaccounted for tag losses. Any of these processes could result in an over-estimation of natural mortality in the model.

In fisheries stock assessments, natural mortality is often based on the lifespan of the species (Hewitt and Hoenig 2005) and assuming a life expectancy of 15 years for black sea bass (Musick and Mercer 1977), M has been set at 0.2 in recent stock assessments (NEFSC 2007). The tag based estimate of 1.08 is significantly higher and contradictory to M predicted from maximum age. A biased estimate of M in the tagging model could be the result of model misspecification or biased tag data. However, model misspecification does not appear to be a problem as reflected in the residuals and profile likelihoods. Among tag return biases necessary to overestimate M, it would be difficult to create a scenario resulting in an M equal to 0.2. Initial tag loss (type 1), modeled as 15%, differs from long term attrition of tags (type 2) (Beverton and Holt 1957). Tag attrition can be parameterized similar to M but to reduce M to 0.2 based on misspecification of retention, tag attrition would have to approach 0.88. There is no direct evidence to suggest a loss of this magnitude. Holding studies demonstrated that tags could be retained for at least one year. An immunological response to tags resulting in encapsulation and expulsion has been documented in some species (Vogelbein and Overstreet 1987) but while this may have been possible in sea bass, there would have to be comparable chronic tag loss rates among all release cohorts. Reduction in tag legibility could also create tag attrition problems in the returns (Henderson-Arzapalo et al. 1999). However, there were few reports among fishermen returning tags that legibility was an issue.

Over estimation of reporting rates resulting from violation of the 100% reporting assumption of high reward tags could bias natural mortality estimates. A reporting rate of 30% on high reward tags would have been needed to produce an M of 0.2. This would be highly unlikely and would also imply an unrealistically high exploitation rate. Another possible bias could result from release of tagged fish independent of local abundance followed by non-mixing, but an area based model produced comparable results for M and the use of a non-mixing model

should account for initial distribution problems. A potential bias resulting from a dome-shaped selectivity pattern was also discounted after examining the recovery rate by size.

Since tag recovery biases alone do not adequately explain the high natural mortality estimated in the tag models, the possibility exists that M on black sea bass is actually greater than expected. Sea bass are structure oriented, protogynous hermaphrodites with a transition from female to male generally between ages 3 to 5, which was approximately the size of fish tagged and released. During spawning, large dominant males undergo physiological changes and begin aggressively defending territory. The importance of secondary male *C. striata* to spawning success is not documented but in congeneric species the importance of secondary males has ranged from irrelevant to critical contributors to the gene pool (Petersen 1991). If these male *C. striata* only provide a pool of potential dominant males, there would be little evolutionary advantage for the population to maintain a large number of secondary males to compete with smaller females and the large males. The consequence could be a higher natural mortality from such things as senescence, increased aggression by dominant males or higher predation rates if the secondary males are forced into marginal habitats. If life expectancy of tagged fish was only three or four years beyond the age at release, the natural mortality of these fish could be significantly greater than 0.2. This does not imply that a high M was constant across all ages, but rather increases in the post transitional ages.

The tagging program for black sea bass in the Middle Atlantic was designed to simultaneously distribute tagged fish throughout the stock, test for tag induced mortality and tag loss, estimate annual reporting rates, and document recapture information. The release-recapture matrix was examined with an analytical tagging model that incorporated temporal variations in exploitation, and by association, spatial changes in exploitation. The results imply that this stock of black sea bass may be experiencing exploitation above the level currently considered optimal. The tagging results also suggest that our understanding of natural mortality developed from gonochoristic species may not be appropriate for this protogynous hermaphrodite. Biases in parameter estimation due to tag loss, etc. may explain in part the high value for natural mortality, but the magnitude of the value suggests that natural mortality is greater than would be predicted from maximum observed age.

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Table 1. Regular tags release and recapture totals by season for black sea bass ≥ 26 cm marked and released in the Middle Atlantic, 2002-2004.

Release Period	Total # Released	Recaptures Oct 2002-Apr 2003	May 2003-Sept 2003	Oct 2003-Apr 2004	May 2004-Sept 2004	Oct 2004-Apr 2005
Fall 2002	3,391	202	108	40	26	11
Spring 2003	2,314		176	58	55	13
Fall 2003	2,863			253	136	32
Spring 2004	0				-	-
Fall 2004	3,742					223
Total	12,310	202	284	351	217	279

Release Period	May 2005-Sept 2005	Oct 2005-April 2006	May 2006-Sept 2006	Oct 2006-April 2007	May 2007-Sept 2007	never seen again
Fall 2002	14	3	1	0	0	2,986
Spring 2003	15	5	5	0	0	1,987
Fall 2003	20	9	7	1	1	2,404
Spring 2004	-	-	-	-	-	-
Fall 2004	164	49	39	9	8	3,250
Total	213	66	52	10	9	10,627

Table 2. Regular and high reward tag release and recapture totals used in calculation of reporting rates. Totals limited to released sea bass ≥ 29.5 cm and recaptures in the first and second seasons.

			Recaptures			
Total # Released	Oct 2002 - April 2003	May 2003 - Sept 2003	Oct 2003 - April 2004	May 2004 - Sept 2004	Oct 2004 - April 2005	May 2005 - Sept 2005
High Reward tags						
251	21	13				
57		10	2			
208			26	19		
0				-		
146					20	12
Regular tags						
2688	172	76				
1942		173	53			
1941			200	104		
0				-		
2079					163	106
Reporting rate						
Fall 2002	76%	53%				
Spring 2003		51%	78%			
Fall 2003			82%	59%		
Spring 2004				-		
Fall 2004					57%	62%
Average	76%	52%	80%	59%	57%	62%

Table 3. Summary of black sea bass tagging models evaluated.

model	likelihood	QAIC	# parameters	df	T	Pr	c hat
1	-7078.85	8893.50	23	10	14.67	0.145	1.60
2	-7125.06	3526.84	6	27	145.12	<0.001	4.05
3	-7144.74	2908.94	3	30	147.59	<0.001	4.92
4	**-7086.00**	**10142.09**	**11**	**22**	**29.14**	**0.120**	**1.40**
5	-7094.88	8212.20	6	27	46.48	0.011	1.73
6	-7098.60	5211.32	13	20	95.95	<0.001	2.74
7	-7080.46	14122.22	14	19	17.22	0.575	1.00

Table 4. Seasonal estimates of fishing mortality for non-mixing (F*) and following mixing (F). Natural mortality (M) held constant for time series.

F_{1*}	0.13
F_{2*}	0.24
F_{3*}	0.18
F_{5*}	0.17
F_2	0.20
F_3	0.10
F_4	0.27
F_5	0.15
F_6	0.25
F_7	0.19
F_8	0.19
F_9	0.19
F_{10}	0.19
M_{1-10}	0.54

Table 5. Annualized estimates of instantaneous fishing and natural mortality for black sea bass.

	F	M
2002	*	1.1
2003	0.32	1.08
2004	0.39	1.08
2005	0.41	1.08
2006	0.38	1.08
2007	0.37	1.08

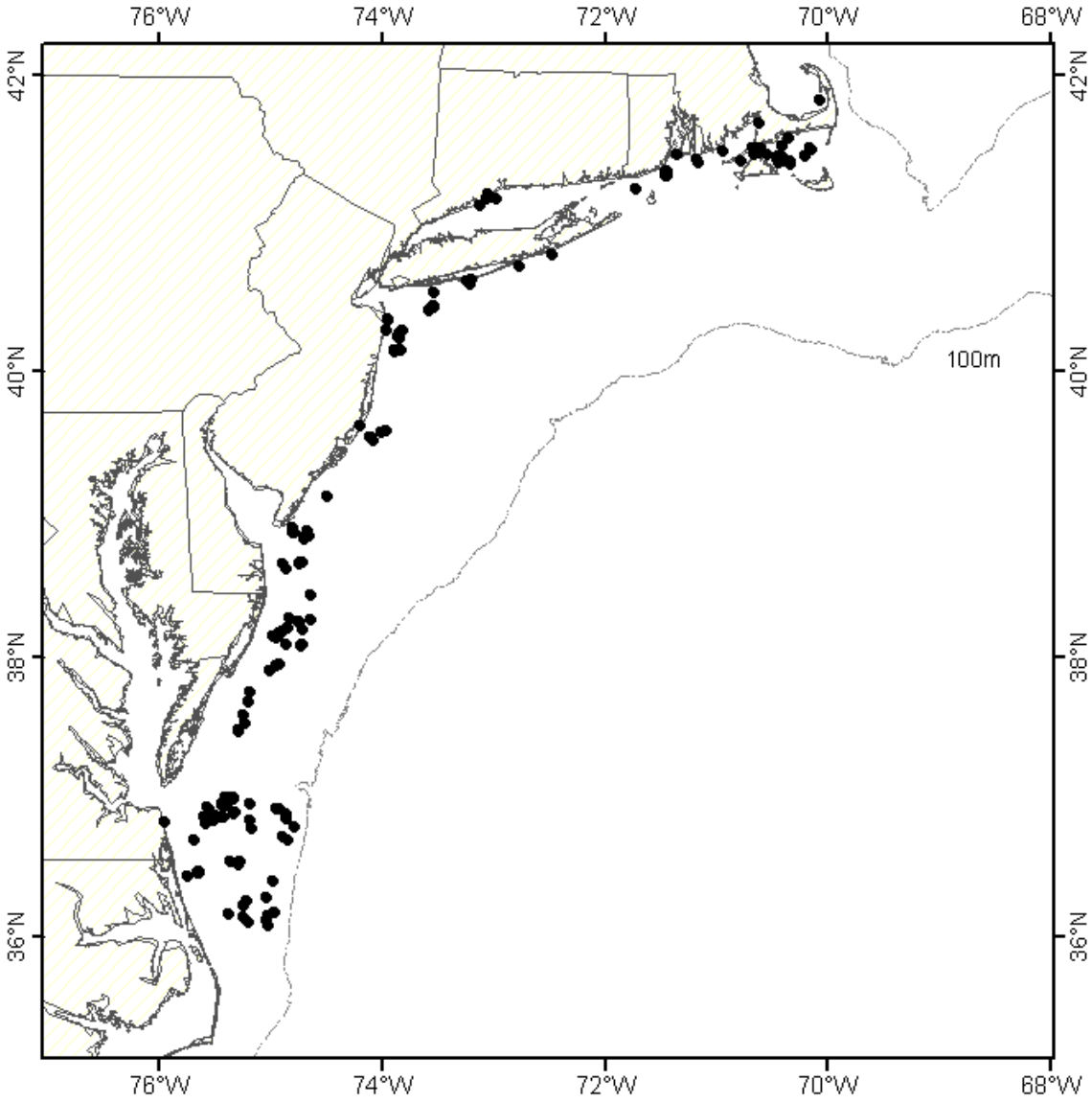

Figure 1. Distribution of black sea bass tag releases, 2002-2004.

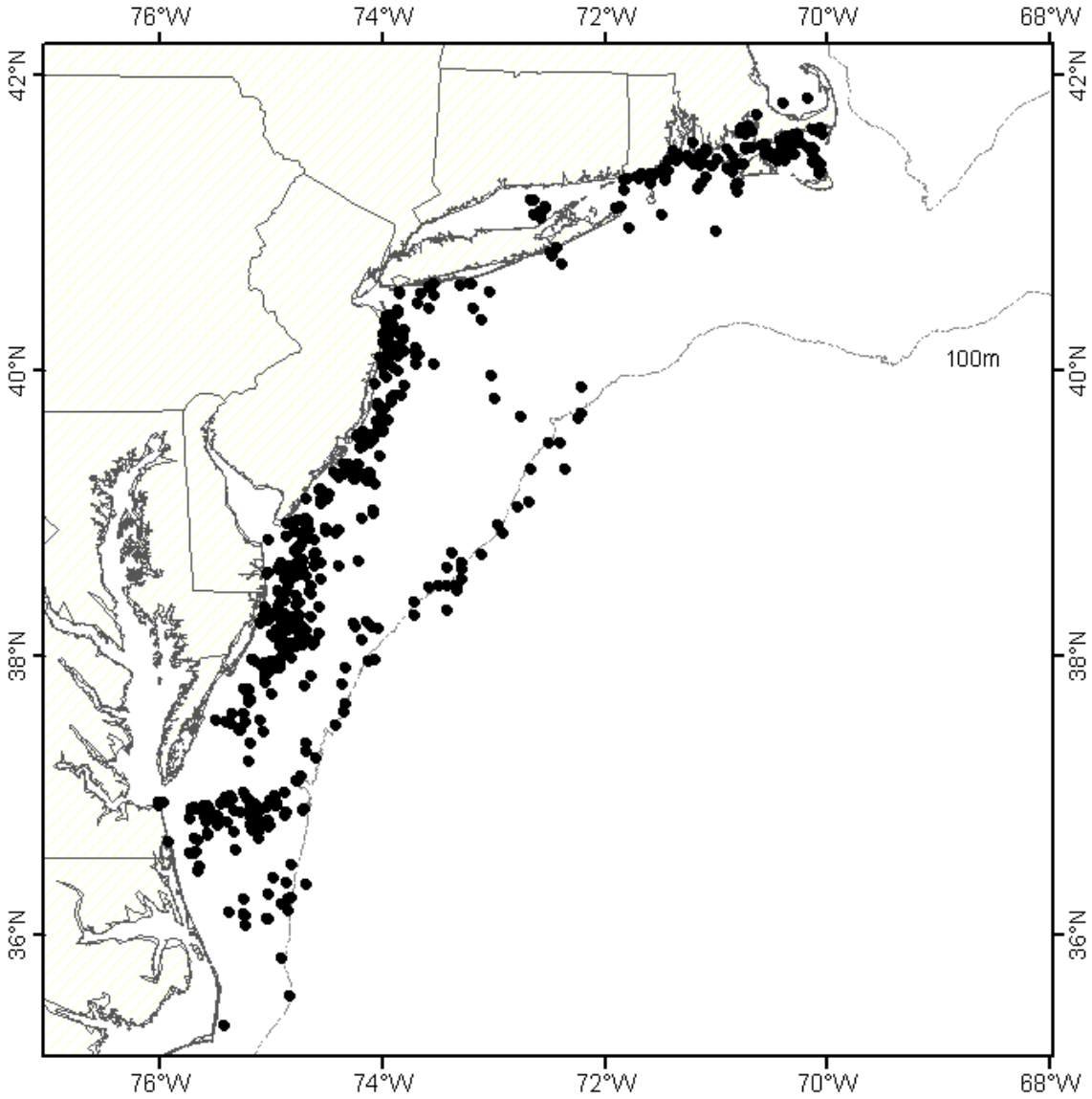

Figure 2. Black sea bass tag recapture locations, 2002-2007.

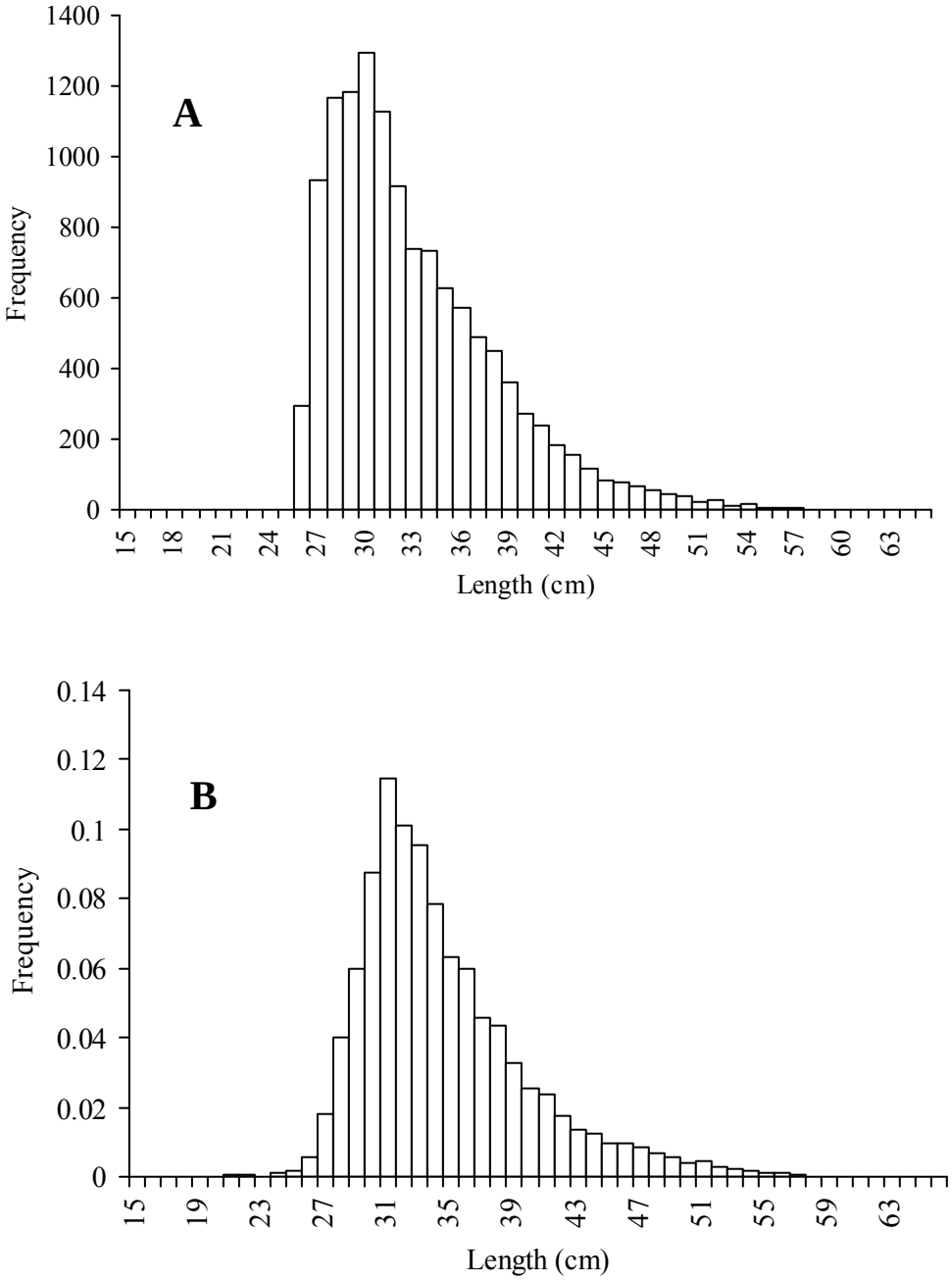

Figure 3. A: Length frequency distribution of marked and released black sea bass (2002-2004) and B: length frequency distribution from recreational and commercial fisheries (2002-2004).

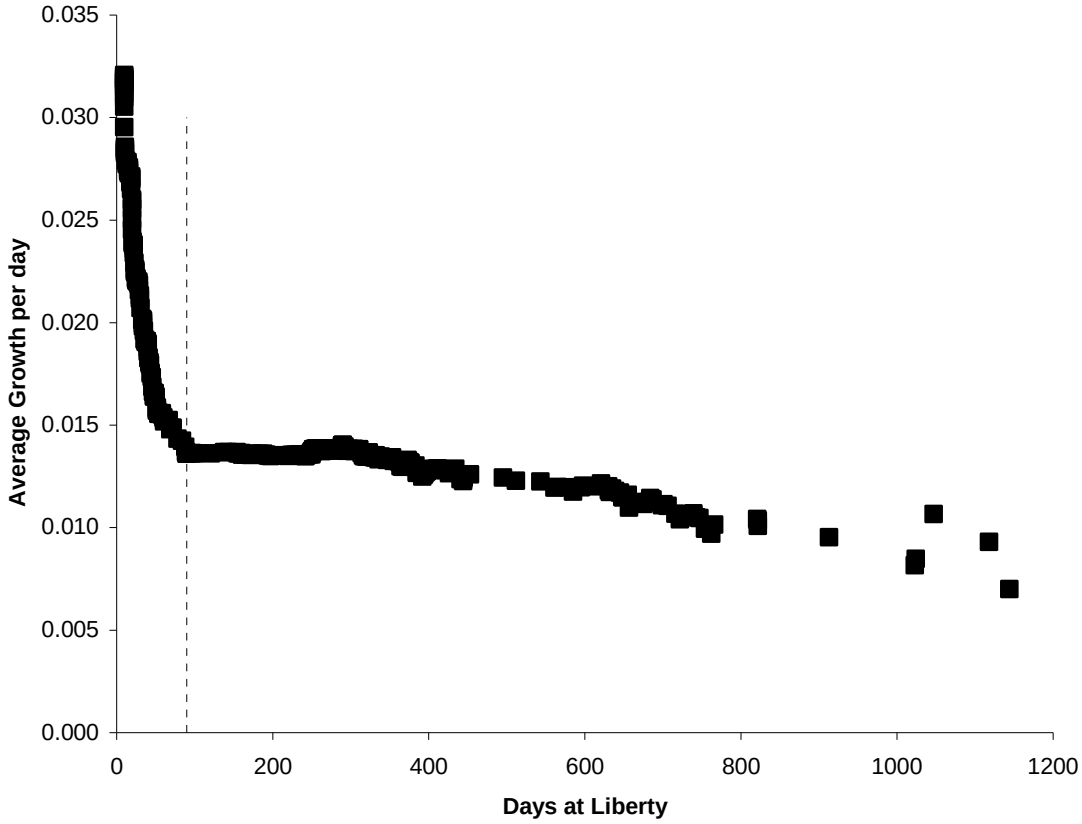

Figure 4. Consecutive moving average growth per day by the days at liberty. The 90 day point indicated by vertical line.

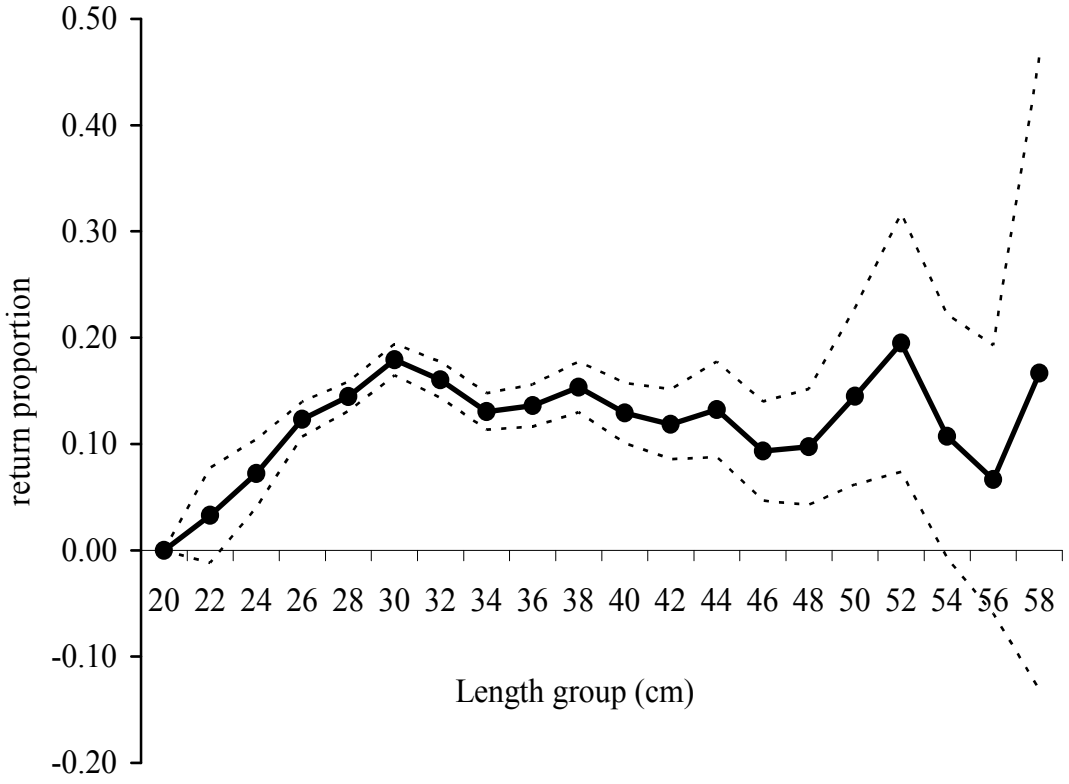

Figure 5. Selectivity by 2 cm length group represented by return proportion among all recoveries.

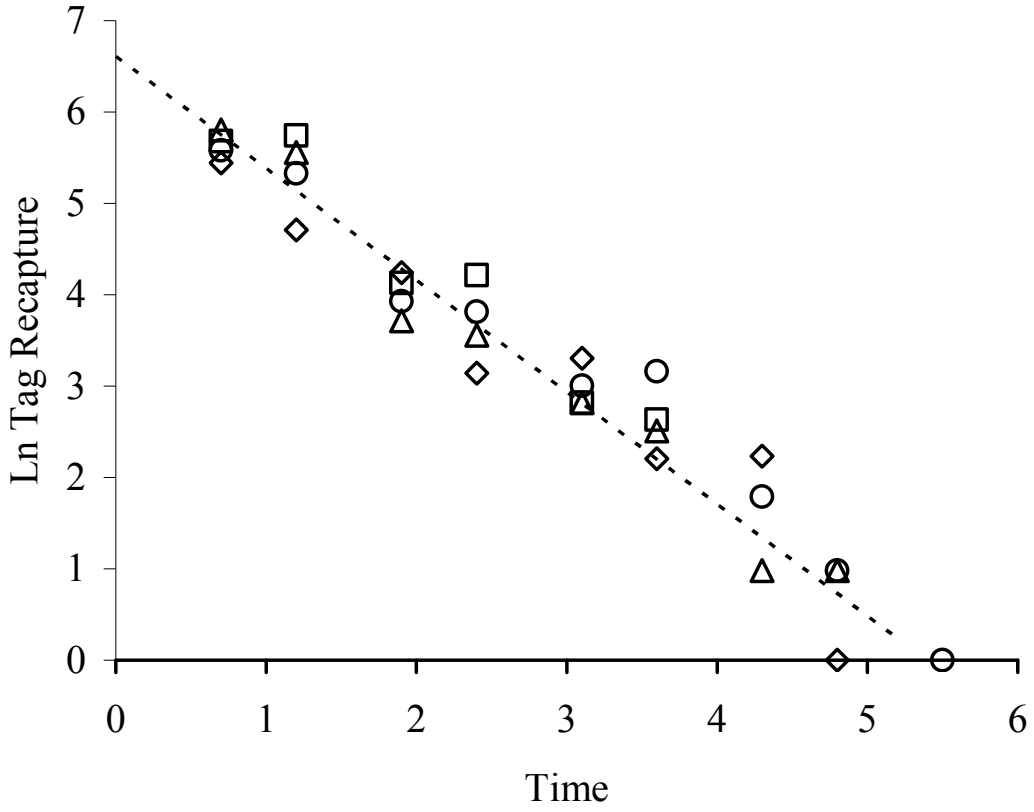

Figure 6. Catch curve equivalent of tag recaptures among all release cohorts. Different symbols represent release cohorts.

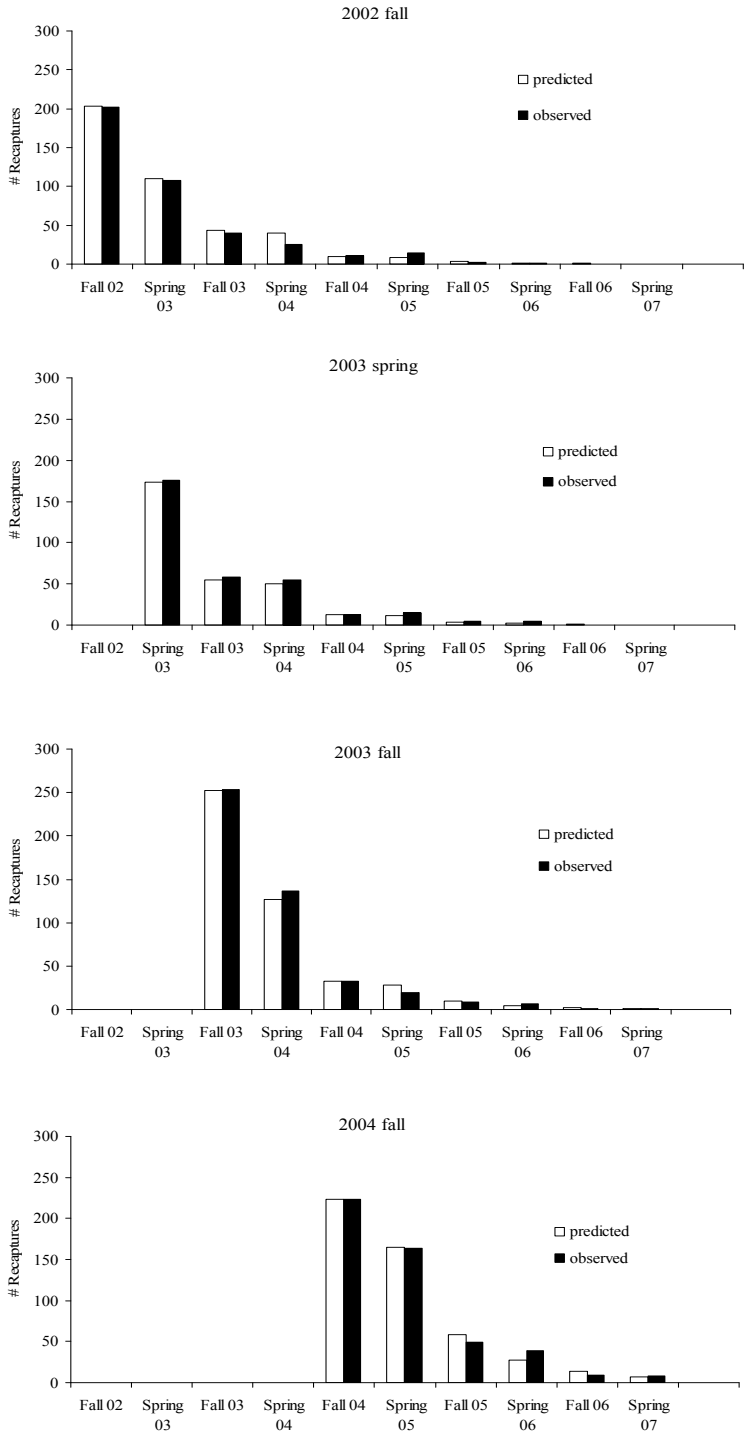

Figure 7. Comparison of observed and predicted tag recaptures by release cohort and season of recapture (model 4).

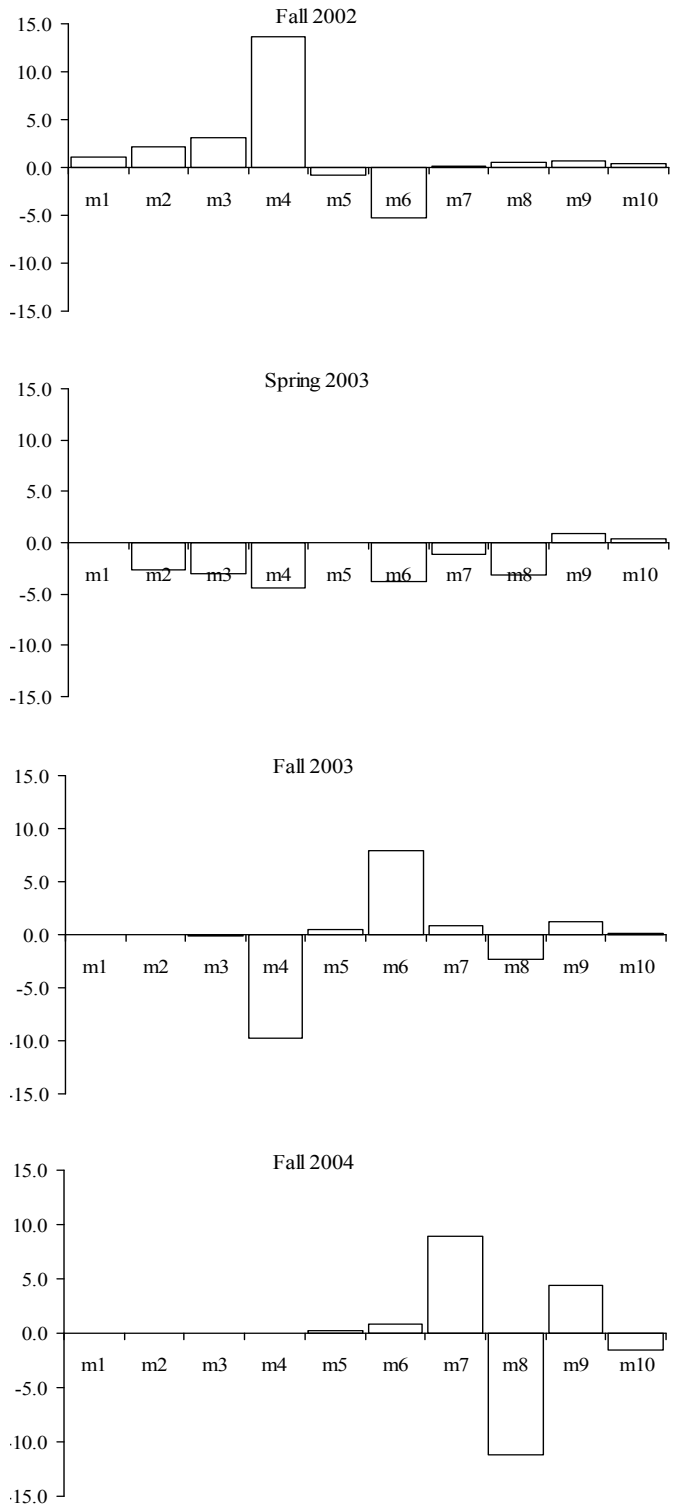

Figure 8. Residual difference between observed and predicted black sea bass tag recaptures, by release cohort and season (model 4).

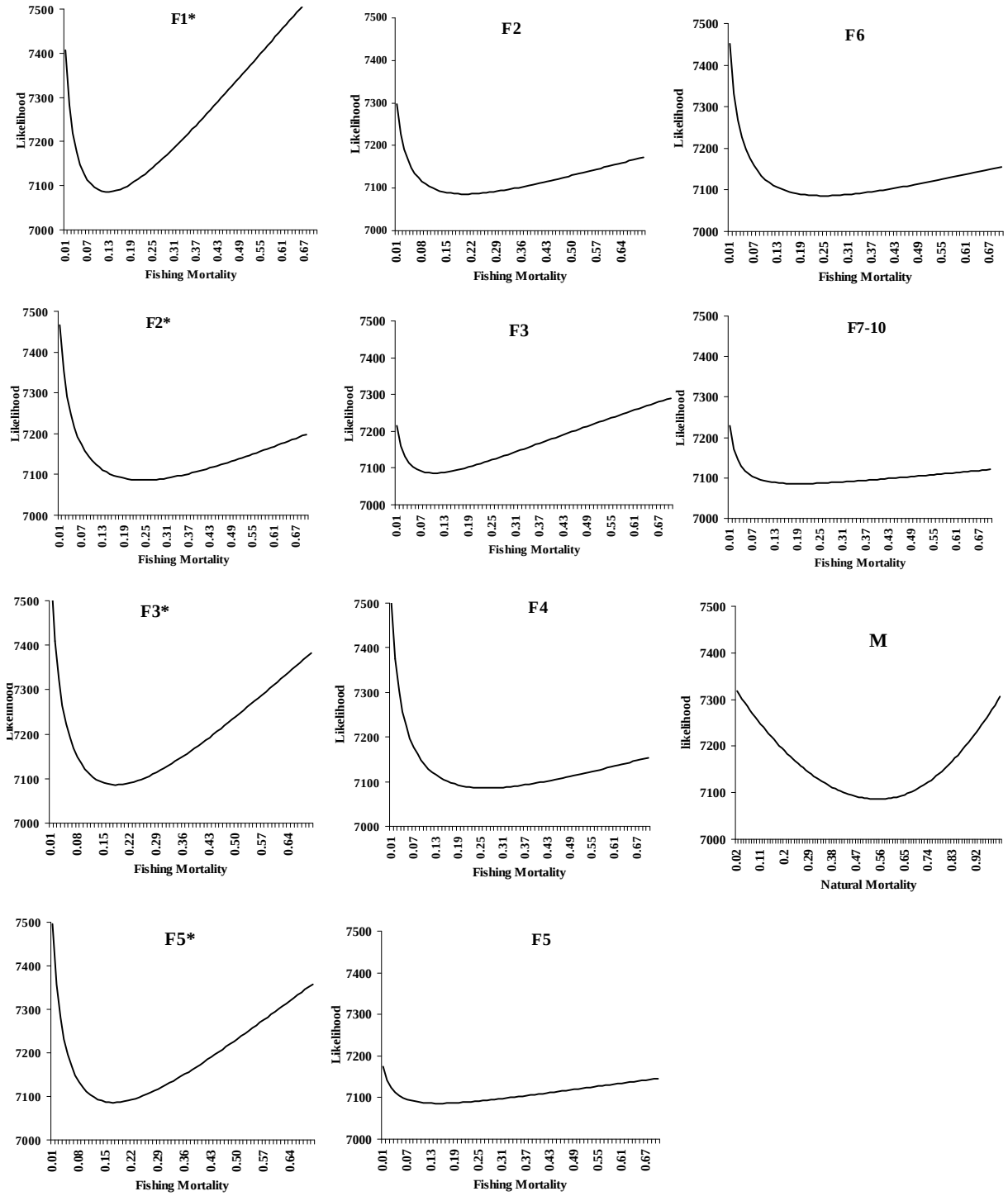

Figure 9. Profile likelihoods of parameter estimates in black sea bass tag model.

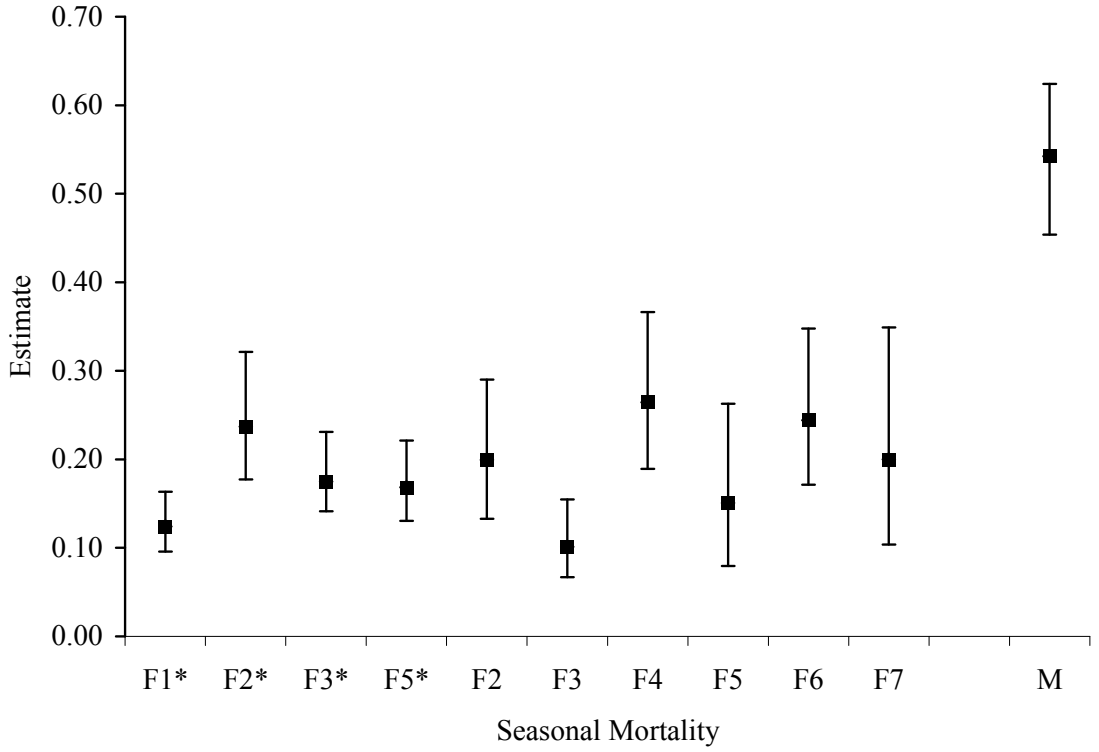

Figure 10. Estimates of fishing mortality for the non-mixed and mixed periods (F* and F) by fishing season and natural mortality (M) (model 4). Values shown with ± 95% confidence intervals derived from profile likelihoods.

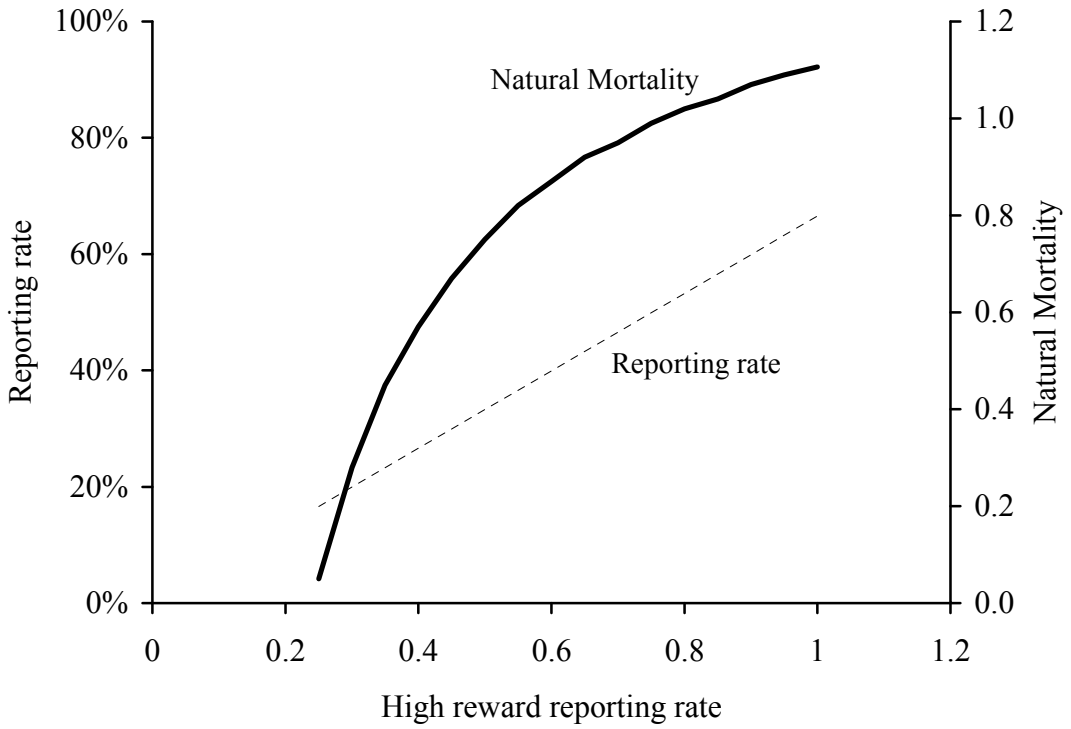

Figure 11. Effect of changes in high reward reporting rate assumption on overall reporting rate and natural mortality estimate.

Black sea bass; Appendix 2

SCALE Model

Introduction

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At LEngth (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions. The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of the average mean lengths at age is essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time.

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model can not account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average

fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^{*}_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^{*}_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1-e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov=s catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len} F_y PR_{len} \left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \ PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\text{Vrec})^2$ is than used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to

the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L}_{\mathrm{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\mathrm{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y}_{\mathrm{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch_lf} = -N_{eff}\sum_{y}\left(\sum_{inlen}^{L_\infty}\left(\left(C_{y,len}+1\right)\ln\left(1+\sum_{a} C_{pred,y,a,len}\right) - \ln\left(C_{y,len}+1\right)\right)\right)$$

$$\mathrm{L}_{\mathrm{vrec}} = \sum_{y=2}^{Nyears}\left(Vrec_y\right)^2 = \sum_{y=2}^{Nyears}\left(R_1 - R_y\right)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{rec_i,inage_i,y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y,inage_i,len} * q_{rec\,i}\right)\right)^2\right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{adult_i,inlen+_i,y}\right) - \left(\sum_{a}\sum_{inlen_i}^{L_\infty}\ln\left(N_{pred,y,a,len} * q_{adult\,i}\right)\right)\right)^2\right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf}\left[-N_{eff}\sum_{y}\left(\sum_{inlen_i}^{L_\infty}\left(\left(I_{lf_i,y,len}+1\right)\ln\left(1+\sum_{a} N_{pred,y,a,len}\right) - \ln\left(I_{lf_i,y,len}+1\right)\right)\right)\right]$$

In equation L_{catch_lf} calculations of the sum of length is made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length is used in the calculation.

$$Obj\ \ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Northeast Fisheries Science Center Reference Document 09-02b

The Northeast Data Poor Stocks Working Group Report

December 8-12, 2008 Meeting

Part B. Weakfish

by Northeast Data Poor Stocks Working Group

NOAA's National Marine Fisheries Service, 166 Water St., Woods Hole MA 02543-1026

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

January 2009

Northeast Fisheries Science Center Reference Documents

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January 22, 2009

WEAKFISH

This report contains five Working Papers. They were provided to the Peer Review Panel of the Northeast Data Poor Stocks Working Group at the December 8-12, 2008 meeting in Woods Hole, MA. The Peer Review Panel was asked to provide guidance/suggest methodologies for scientists to use in future weakfish assessments. The Report of the Peer Review Panel is available at: http://www.nefsc.noaa.gov/nefsc/saw, under the heading "Northeast Data Poor Stocks Working Group, 2008."

Working Paper 1	**Weakfish Stock Assessment Methodology**
Working Paper 2	**Weakfish Biomass Dynamic Models and External Factor Hypothesis**
Working Paper 3	**Weakfish Predation Models Summary**
Working Paper 4	**Weakfish Stock Assessment**
Working Paper 5	**Questions regarding the Weakfish Stock Assessment for the Data Poor Stocks Working Group Review Panel**

This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

Working Paper 1

Weakfish Methodology

By

Jeffrey Brust
for
Weakfish Stock Assessment Sub-Committee

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

This information was distributed solely for the purpose of pre-dissemination peer reivew at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

WEAKFISH WP#1. (11/24/08)

MEMORANDUM

TO: Data Poor Working Group Review Panel Members

FROM: Jeff Brust, for Weakfish Stock Assessment Subcommittee

RE: Update to Weakfish Stock Assessment Methodology

Among the materials provided for your review of the weakfish stock assessment is the most recent peer reviewed assessment (ASMFC 2006), which includes the assessment (in two parts), the peer review report, and supplemental information requested by the ASMFC Weakfish Management Board. For the ongoing assessment, we are using very similar methodologies as those outlined in the 2006 peer reviewed assessment. However, there are some changes and updates ASMFC staff and the Stock Assessment Subcommittee felt would benefit from your review.

The attached report is a preliminary draft of portions of the stock assessment report, including management and assessment history, description of primary fisheries, and description of available fishery dependent and fishery independent data sources. Information contained in the current report is consistent with the text of the 2006 assessment, but the current report provides additional detail on certain aspects, such as the survey indices.

You will note certain sections of this draft are highlighted in yellow. This draft was developed prior to the Weakfish Data Workshop in July 2008. Highlighted text indicates sections that need to be updated based on discussions and decisions made during the July workshop. As these edits will not be done prior to the Data Poor Workshop, I would like to provide you with a list of some of the more substantial changes to input data that were decided on at the July workshop.

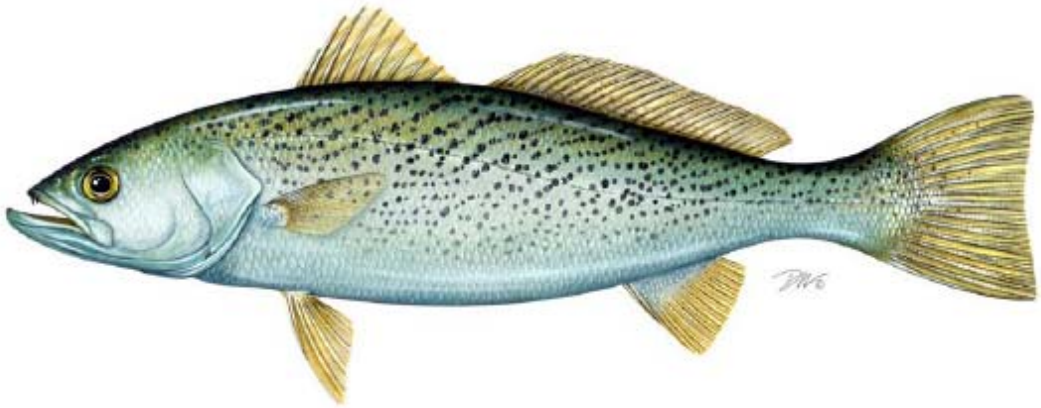
- Recreational weakfish catch (A, B1, B2) from Florida were "corrected" for sand seatrout and sand seatrout/weakfish hybrids
- The recreational discard mortality rate was decreased from 20% to 10%
- Recreational discard length frequency were assigned based on recent headboat discard data (previously, discards assumed the same size as harvest)
- Commercial discard rates have been updated with recent data
- New Jersey trawl index now based on delta log-normal for August cruise only (previously arithmetic mean for August and October cruises)
- Recreational index now based on all private boat trips in Mid-Atlantic (previously used only trips that caught a suite of species commonly occurring with weakfish)

Most of these changes could be made retroactive to 2000 (the most recent year age-length keys are available).

In addition to these changes to input data, I have requested the principle modelers for other candidate models to provide updates to changes in their methodology. These updates will hopefully be sufficient to allow you to adequately review the assessment as a work in progress. I look forward to discussing the

assessment and any recommendations you may have at the December Data Poor Working Group in Woods Hole.

WEAKFISH STOCK ASSESSMENT REPORT



A Report of the ASMFC Weakfish Technical Committee

Presented to the 49th Stock Assessment Workshop
Stock Assessment Review Committee
Woods Hole, MA

June 2009

NOTE: ZZ Section prefix will be replaced with letter assigned to assessment by J. Weinberg.

ZZ1.0 CONTRIBUTORS

ASMFC Weakfish Technical Committee and Stock Assessment Subcommitte:

Greg Skomal, Massachusetts Division of Marine Fisheries
Brian Murphy, Rhode Island Division of Fish and Wildlife
Dr. Vic Crecco, Connecticut Bureau of Marine Fisheries
Christina Grahn, New York Department of Environmental Conservation
Jeffrey Brust, New Jersey Division of Fish and Wildlife, *Stock Assessment Subcommittee Chair*
Russ Allen, New Jersey Division of Fish and Wildlife, *Technical Committee Chair*
Dr. Des Kahn, Delaware Division of Fish and Wildlife
Jim Uphoff, Maryland Department of Natural Resources
Ellen Cosby, Potomac River Fishery Commission
Joe Cimino, Virginia Marine Resources Commission
Dr. James Kirkley, Virginia Institute of Marine Science
Lee Paramore, North Carolina Division of Marine Fisheries
Dr. Charlie Wenner, South Carolina Department of Natural Resources
Erin Levesque, South Carolina Department of Natural Resources
Joseph Munyandorero, Florida Fish and Wildlife Conservation Commission
Dr. Doug Vaughan, Southeast Fishery Science Center
Dr. Wilson Laney, US Fish and Wildlife Service
Patrick Campfield, Atlantic States Marine Fisheries Commission

and

Nichola Meserve, Atlantic States Marine Fisheries Commission, *Species Coordinator*

ZZ2.0 TERMS OF REFERENCE FOR WEAKFISH

1. Evaluate biases, precision, uncertainty, and sampling methodology of the commercial and recreational catch including landings and discards.

2. Evaluate precision, geographical coverage, representation of stock structure, and relative accuracy of the fisheries independent and dependent indices of abundance.

3. Evaluate the catch at age modeling methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Review the severity of retrospective bias. (This TOR will change following the stock assessment workshop in September.)

4. Evaluate the aggregated biomass modeling and index methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Determine whether these techniques, including predator-prey extensions, could substitute for age-based modeling for management advice. (This TOR will change following the stock assessment workshop in September.)

5. Review evidence for constant or recent systematic changes in natural mortality.

6. Estimate and determine the accuracy and precision of biological reference points.

7. Review stock projections and impacts on the stock under different assumptions of fishing and natural mortality.

8. Make research recommendations for improving data collection and assessment.

ZZ3.0 EXECUTIVE SUMMARY

ZZ3.1 Major findings for TOR 1 - Evaluate biases, precision, uncertainty, and sampling methodology of the commercial and recreational catch including landings and discards.

ZZ3.2 Major findings for TOR 2 – Evaluate precision, geographical coverage, representation of stock structure, and relative accuracy of the fisheries independent and dependent indices of abundance.

ZZ3.3 Major findings for TOR 3 - Evaluate the catch at age modeling methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Review the severity of retrospective bias. (This TOR will change following the stock assessment workshop in September.)

ZZ3.4 Major findings for TOR 4 - Evaluate the aggregated biomass modeling and index methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Determine whether these techniques, including predator-prey extensions, could substitute for age-based modeling for management advice. (This TOR will change following the stock assessment workshop in September.)

ZZ3.5 Major findings for TOR 5 - Review evidence for constant or recent systematic changes in natural mortality.

ZZ3.6 Major findings for TOR 6 - Estimate and determine the accuracy and precision of biological reference points.

ZZ3.7 Major findings for TOR 7 - Review stock projections and impacts on the stock under different assumptions of fishing and natural mortality.

ZZ3.8 Major findings for TOR 8 - Make research recommendations for improving data collection and assessment.

ZZ4.0 INTRODUCTION

This is the first update to the weakfish stock assessment since 2006 when the assessment was peer reviewed through the Atlantic States Marine Fisheries Commission (ASMFC) External Peer Review process. The 2006 assessment updated the stock through the 2003 fishing season. The current assessment includes harvest data and survey indices through 2007.

ZZ4.1 Management Unit Definition

Weakfish stocks on the U.S. Atlantic coast are managed through the ASMFC Interstate Fishery Management Plan (FMP) for Weakfish. Under this FMP, weakfish are managed as a single unit stock throughout their coastal range. Historically, all states from Massachusetts through Florida had a declared interest in the species. Currently, however, Massachusetts, Connecticut, South Carolina, Georgia, and Florida maintain *de minimus* status.

ZZ4.2 Management History

The first fishery management plan for weakfish was implemented by ASMFC in 1985 to address stock declines, bycatch concerns, the lack of sufficient data for management, and interstate user conflicts. The management measures under the FMP were voluntary and provided no benefit to the stock.

Amendment I, adopted in 1991, established a target fishing mortality rate of $F_{20\%} = 0.34$. This would be achieved by a 52% reduction in directed harvest, as well as reductions in bycatch mortality in the penaeid shrimp fisheries. Although adoption of turtle excluder devices (TEDs) in the shrimp fishery led to bycatch reductions, none of the states with directed fisheries adopted regulations consistent with the Amendment. Consequently, Amendment I was not successful at attaining the target fishing mortality rate.

Continued concern regarding the status of the weakfish stock (as a result of ASMFC fishery management regulations not being mandatory) was a major impetus for the development and passage of the Atlantic Coastal Fisheries Cooperative Management Act, which made compliance with ASMFC fishery management plans mandatory for member states. As an interim measure, the ASMFC approved Amendment II to the Weakfish FMP for implementation in April 1995. The provisions of Amendment 2 were mandatory and included harvest control strategies such as a 12” minimum size, maintaining current minimum mesh sizes, and bycatch reduction requirements. Fishing mortality would be reduced in a stepwise fashion, with a 25% reduction in harvest occurring in 1995 and the remainder occurring in 1996. The effects of Amendment II were positive, although below average fishery catch rates, a lack of older age fish, and below average spawning stock biomass indicated further improvements were necessary.

In response, Amendment III was developed to reduce fishing mortality to $F = 0.50$ by the year 2000, restore an expanded age structure, and restore fish to their full geographical range. Commercial fisheries were regulated by a combination of season and area closures, mesh regulations to minimize harvest of fish less than 12”, and stricter requirements for bycatch reduction devices (BRDs). The minimum recreational requirements were a 12” minimum size limit and four fish possession limit. States were allowed to implement alternate size and bag

limit regulations if they were conservationally equivalent to the minimum requirements. Bag limits were not required for minimum sizes of 16" or greater.

In 2000, a peer review of a stock assessment with data through 1998 indicated that weakfish biomass was high and fishing mortality rate was below the target of $F = 0.50$. Despite being ahead of schedule, it was recommended that low fishing mortality rates be continued to maintain an appropriate spawning biomass and promote expansion of stock size and age composition. Also as a result of the assessment, the Weakfish Technical Committee recognized several inconsistencies between management practices and stock dynamics. These could only be addressed through the development of a new Plan amendment. In the meantime, however, Addendum I to Amendment III was passed to maintain current regulations until approval of the new amendment.

Weakfish stocks on the U.S. Atlantic coast are currently managed under Amendment IV to the FMP. Although Amendment III was successful in reducing fishing mortality and increasing biomass, reference points established in Amendment III were too high to ensure sufficient spawning stock biomass. In addition, the reference period used to develop recreational management measures represented an overexploited stock (insufficient abundance of older, larger individuals). In response to these concerns, Amendment IV, passed in November 2002, established new fishing mortality and spawning stock biomass reference points, and adjusted the reference period to a period of greater stock health (1981 to 1985). Amendment IV establishes new reference points for fishing mortality target of $F_{target} = F_{30\%} = 0.31$, a fishing mortality threshold of $F_{threshold} = F_{20\%} = 0.5$, and a spawning stock biomass threshold of $SSB_{threshold} = SSB_{20\%} = 31.8$ million pounds. A fishing mortality rate greater than $F = 0.5$ constitutes overfishing, and the stock is considered overfished if SSB is less than 31.8 million pounds. If it is determined that the weakfish stock is overfished, Amendment IV requires ASMFC to implement measures to rebuild the population within 6 years (1½ generations).

Several addenda have been passed to improve management capabilities under Amendment IV. Addendum I was passed in December 2005 to modify biological sampling targets. Addendum III (May 2007) modified bycatch reduction requirements to maintain consistency with the South Atlantic Fishery Management Council. Of greater significance was passage of Addendum II in February 2007. A stock assessment conducted in 2006 showed a significant turn of events from previous assessment results (see full discussion in Section ZZ4.3, **Assessment History**). Model results indicated that weakfish stocks were at historic low levels, despite relatively low fishing mortality rates. A series of supplementary analyses indicated that the primary force behind the stock decline was interactions with other species, such as competition and predation. Projection analyses indicated that even with a full moratorium on harvest, stock rebuilding would occur slowly at best without a significant decrease in other sources of mortality. To minimize overall mortality without unduly penalizing fishermen, and to prevent expansion of the fishery in the event the stock begins to rebuild, Addendum II requires that all states 1) maintain current minimum sizes, 2) implement a recreational six fish bag limit, and 3) impose a 150 pound commercial bycatch trip limit. Addendum II also establishes triggers to re-evaluate these criteria. Commercial measures will be reconsidered when coastwide commercial harvest reaches 80% of the 2000-2004 average harvest. Commercial and recreational measures will be re-

evaluated when combined harvest for any state in one year exceeds 125% of their previous five year average.

ZZ4.3 Assessment History

Early stock assessment analyses for weakfish were conducted using a variety of virtual population models, such as the Murphy VPA (ASMFC 1991) and CAGEAN. The first peer reviewed assessment analyzed data through 1996 using Extended Survivor Analysis (XSA). The peer review was conducted in 1997 by the Stock Assessment Review Committee (SARC) at the 26th Northeast Regional Stock Assessment Workshop (SAW). The Review Committee had concerns with the XSA model runs and requested updated runs as well as exploratory CAGEAN and ADAPT model runs. These were conducted, but there was insufficient time to fully review the results. As such, the review committee did not endorse the point estimates of *F* and SSB. Regardless, all models used indicated that SSB was increasing rapidly and fishing mortality rates were decreasing rapidly. SSB had increased an average of 22.5% per year since 1991, while *F* had decreased an average of 21.4% per year since 1990 (NEFSC 1998). The SARC concluded that continuation of low fishing mortality rates and good recruitment would allow for age expansion to a point comparable to that observed in the early 1980s.

The subsequent assessment, including data through 1998, was peer reviewed at the 30th SAW/SARC in 1999 (NEFSC 2000). The stock was assessed using the ADAPT VPA as recommended by the 26th SARC. Ages in recent years had begun to be taken from otoliths, which required a conversion of scale-based ages from earlier years to otolith-based ages. The approved VPA run included only indices from the core abundance area (New York to North Carolina). The model indicated that fishing mortality rates had declined to 0.21 in 1998, well below both $F_{MAX} = 0.27$ and $F_{MSY} = 0.6$. In addition, SSB had increased to about 39,000 metric tons, approximately 55% of an unfished stock. The SARC did observe a noticeable retrospective pattern, which overestimated stock size and underestimated fishing mortality in the last few years. Regardless, the Review Committee concluded that results of the ADAPT VPA could be used to calculate biological reference points, and that figures illustrating the expanded size and age composition of weakfish would be useful for developing management advice.

A stock assessment update was conducted in 2002 (with data through 2000) using the SARC approved methodology (ADAPT VPA with tuning indices from the core area; Kahn 2002). The assessment showed that estimates of fishing mortality decreased further to $F = 0.12$, while SSB increased to over 50,000 mt. Although this assessment was not peer reviewed, the Weakfish Technical Committee (TC) expressed concern about a strong retrospective pattern that resulted in high levels of uncertainty in recent year estimates. The committee recognized poor biological sampling of commercial catches, commercial discards, and recreational discards as a likely source of much of this error, especially when coupled with the assumption of error-free catch at age estimates used by ADAPT. Estimates of *F* and SSB were "corrected" by multiplying each parameter by the average amount each parameter changed in recent years with the addition of more data. Even so, the corrected estimate of $F = 0.23$ was substantially below $F_{Target} = 0.31$, and corrected SSB = 35,000 mt was more than double $SSB_{Threshold} = 14{,}428$ mt.

In 2003, the Weakfish Stock Assessment Subcommittee (WSAS) began preparation for a 2004 peer review through the 40th SAW. Model results using the SARC approved methodology still

exhibited a strong retrospective pattern, and results from both ADAPT VPA and biomass dynamic models indicated the stock was at very high levels (carrying capacity in the case of the biomass dynamic model; see Uphoff 2005) with very low fishing mortality. The Technical Committee was concerned that these results were not consistent with low catch rates being observed by commercial and recreational fishermen targeting weakfish.

For these reasons, the WSAS deemed the ADAPT VPA methodology as insufficient to characterize the weakfish resource and proceeded to investigate alternative assessment methods. Although the revised weakfish assessment was incomplete at the time of the SAW, the SARC agreed to review the work and provide guidance on issues that were impeding the progress of the assessment (such as the inconsistency between survey indices and fishery-dependent indices of abundance and catch at age).

The Review Committee agreed with the WSAS that the results of the work in progress, although using the same approach as the SARC-approved assessment in 1999, were not suitable for management. The Review Committee indicated that they felt the problem was conflicting data, and expressed skepticism about the reliability of some survey indices, especially the Northeast Fishery Science Center Fall Survey. Recommendations from the SARC proved to be useful, and some were incorporated into the stock assessment. The assessment was also expanded to include some alternative approaches previously explored by the WSAS in the 2002 update process. (ASMFC 2006, Part A)

The stock assessment was completed in February 2006 and submitted to ASMFC for evaluation through the ASMFC External Peer Review process. The Peer Review Panel consisted of four fisheries biologists with expertise in population dynamics and stock assessment methods. The Panel did not endorse the statements regarding weakfish stock status and identified several issues that required additional work or attention by the Weakfish Technical Committee before they would support its use for management purposes (ASMFC 2006, Part B). In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards.

The Weakfish Management Board directed the Technical Committee to address the issues identified by the Review Panel. Specifically, the Management Board tasked the Technical Committee with further investigating stock structure and discards; determining agreements and disagreements among the assessment report, the peer review panel report, and the 40th SARC report; and providing an account of the implementation of recommendations from the 40th SARC.

In August 2006, the Technical Committee provided a response to these tasks (ASMFC 2006, Part C). Based on these responses, the Technical Committee's analyses, and significant evidence, the Management Board accepted the following five points for management use:

1. The stock is declining;
2. Total mortality is increasing;
3. There is little evidence of overfishing occurring;
4. Something other than fishing mortality is causing the stock decline, and;

5. There is a strong chance that regulating the fishery will not, in itself, reverse the stock decline.

ZZ4.4 Life History (Lee Paramore)

ZZ4.4.1 Reproduction

ZZ4.4.2 Age and Growth

ZZ4.4.3 Natural mortality

ZZ4.4.4 Stock Definitions

The weakfish range extends along the Atlantic coast from Massachusetts to southern Florida, although strays are occasionally found as far as Nova Scotia, Canada and into the eastern Gulf of Mexico. Primary abundance occurs between New York and North Carolina. Within their range there is evidence of multiple stocks. Munyandorero (2006; see ASMFC 2006, Part C) provides a concise but thorough overview of available information on weakfish stock structure. The following is an excerpt.

> Investigations of weakfish population structure along the US Atlantic coast have been undertaken through tagging, meristic, morphological, life history, genetic and otolith chemistry studies (Table 1). The conclusions reached are conflicting. While Crawford et al (1988), Graves et al. (1992) and Cordes and Graves (2003) did not detect genetic differentiation within the weakfish population, Chapman et al. (unpublished report) found that weakfish are made up of a series of overlapping stocks, without complete panmixia. Non-genetic studies found evidence of existence of multiple weakfish sub-populations (e.g., Nesbit 1954; Shepherd & Grimes 1983, 1984; Scoles 1990) or important spatial structure of the weakfish population (Thorrold et al. 1998, 2001). Mark-recapture, meristic, morphological and life-history studies (e.g., review by Crawford et al. 1988) indicated that weakfish could be partitioned into sub-stocks…

Crawford et al (1988) recommend that weakfish be managed as separate northern and southern stocks, while Graves et al (1992) recommend management of a single unit stock. The Weakfish Technical Committee reviewed the available information and reached the following conclusions.

- Evidence of stock structure exists
- Data is inadequate to define stock structure, and there is enough potential mixing that pinpointing the location of a north/south split is not possible at this time
- If a north to mid-Atlantic subpopulation is in serious decline, this does not warrant a north-south split based on conservation concerns (ASMFC 2006, Part C).

Based on those recommendations, the ASMFC Weakfish FMP continues to manage Atlantic coast weakfish as a single unit stock throughout their coastal range.

ZZ4.5 Habitat description

Weakfish are found in shallow marine and estuarine waters along the Atlantic coast. They can be found in salinities as low as 6 ppt (Dahlberg 1972) and temperatures ranging from 17° to 26.5^{o} C (Merriner 1976).

Like many other North Atlantic species, weakfish exhibit a north-inshore/south-offshore migration pattern, although in the southern part of their range they are considered resident. Shepherd and Grimes (1983) observed that migrations occur in conjunction with movements of the 16-24° isotherms. Warming of coastal waters during springtime triggers a northward and inshore migration of adults from their wintering grounds in the Mid-Atlantic. The spring migration brings fish to nearshore coastal waters, coastal bays, and estuaries where spawning occurs.

Weakfish spawn in estuarine and nearshore habitats throughout their range. Principal spawning areas are from North Carolina to Montauk, NY, although extensive spawning and presence of juveniles has been observed in the bays and inlets of Georgia and South Carolina. Larval and juvenile weakfish generally inhabit estuarine rivers, bays, and sounds, but have been taken in freshwater (Thomas 1971) and as far as 70 km offshore (Berrien et al 1978). Mercer (1983) found that juveniles are most prevalent in shallow bays and navigation channels and are commonly associated with sand or sand/grass bottoms.

Weakfish form aggregations and move southward and offshore as temperatures decline in the fall. Important wintering grounds for the stock are located on the continental shelf from Chesapeake Bay to Cape Lookout, North Carolina.

ZZ4.6 Fishery description

ZZ4.6.1 Overview of fisheries

ZZ4.6.1.1 Commercial Fishery

Records of commercial weakfish landings are available back to 1950 through the National Marine Fisheries Service (NMFS) website. From 1950 through the 1960s commercial landings ranged from about 2,000 to 4,000 metric tons (MT) per year (Figure ZZ4.6-1). Beginning in 1970, reported landings began a dramatic increase to a record high of more than 16,000 MT in 1980. From 1982 to 1988, landings fluctuated between approximately 8,000 and 10,000 MT. Except for a brief recovery in the mid- to late-1990s, landings have declined continuously from 1989 to the present. Estimated harvest in 2007 is the lowest on record at approximately 388 MT.

Throughout this period, three states - New Jersey, Virginia, and North Carolina - have consistently accounted for 70 to 90% of the coastwide total harvest (Table ZZ4.6-1; Figure ZZ4.6-2). North Carolina has predominated with nearly 37% of the coastwide harvest over the last ten years, while Virginia and New Jersey have averaged 25.6% and 17.0% respectively. During this same time period, New York has accounted for nearly 10% of coastwide harvest.

From the mid 1950s to the early 1980s landings from the trawl fishery generally accounted for 50 to 70% of total landings (Figure ZZ4.6-3). Beginning in the early 1980s, harvest from

trawlers began a gradual decline, and recently have accounted for approximately 20% of total harvest. Conversely, between 1979 and 1987, landings from gill nets increased from around 10% of annual harvest to 45% of annual harvest, and have remained relatively stable since that time. Over the entire time period, pound nets and haul seines have each averaged between 10 and 20% of total harvest annually, despite exhibiting generally negative trends over time.

Discarding of weakfish by commercial fishermen is known to occur, and discard mortality is assumed to be 100%. De Silva (2004) provided the first quantitative analysis of weakfish discards. Most discarding occurs in conjunction with two gears (trawls and gillnets) and a limited number of target species. Prior to 1996, discards are assumed to have occurred for non-regulatory reasons because few regulations were in place to limit the fishery. Since 1996, both regulatory and non-regulatory discarding has occurred. Regardless, population removals as a result of commercial discarding appear to be minor relative to harvest, even in recent years as harvest has decreased. (ADD SPECIFICS FROM RECENT YEARS AFTER UPDATE JANAKA'S WORK)

ZZ4.6.1.2 Recreational Fishery

Recreational harvest statistics for the weakfish fishery are available on the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) website for the period 1981 to 2007. From 1981 to 1988, the number of weakfish caught and the number harvested fluctuated without trend between 2 million and around 11 million fish; however, during this same time period, harvested weight generally declined from around 16 million pounds to 6 million pounds (Figure ZZ4.6-4). During this time period, nearly 90% of all fish caught were retained.

From 1989 to 1993, catch (numbers) and harvest (numbers and weight) remained relatively stable. Catch fluctuated between 1.6 and 2.2 million fish, while harvest ranged between 0.95 and 1.8 million fish and 1.1 to 2.2 million pounds. The harvest ratio during this period decreased from around 90% to less than 50%. CORRECT MRFSS ESTIMATES FOR FL SEATROUT

In 1994, weakfish catches increased and averaged around 6 million fish until 2000. Harvest numbers increased to a lesser extent and fluctuated between approximately 1.5 and 2.5 million fish. Harvest weight also increased to a relative peak of 4 million pounds during this period. By 2003, all statistics had declined to at or near time series minima and have remained relatively stable. In 2007, total catch was 2.01 million fish, with a harvest of 0.58 million fish and 0.69 million pounds. Since 1994, harvest ratios have fluctuated between approximately 20 and 40% of all fish caught.

The recreational fishery has been dominated in the last fifteen years or so by New Jersey, accounting for 40 to 50% of total harvest (Table ZZ4.6-2). Since 1995, several states have each had periods of substantial landings, with Delaware contributing 20-30% of total harvest for 1995-1998, Maryland accounting for approximately 25% from 1999 to 2001, and North Carolina averaging 22.5% from 2003 to 2007. From 1995 to 2004, Virginia consistently harvested between 10 and 20% of coastwide harvest, but has decreased in recent years.

From 1981 to 1990, recreational harvest decreased from around 35% of total (commercial and recreational) harvest to approximately 15% (Figure ZZ4.6-6). Since 1990, harvest from the

recreational fishery has gradually increased, reaching a peak of approximately 58.5% in 2005 but dropping back to around 45% in 2006 and 2007.

Recreational discard mortality is assumed to be 20% of all discarded fish. Change to 10%, provide justification, references From 1981 to 1989, the proportion of landings to catch averaged 89%. Even with high landings, discard mortality was lowest of the time series, with all but one year having fewer than 200,000 fish. Between 1989 and 1995, harvest to catch ratio dropped drastically to the second lowest value (27%), and the number of dead discards increased to more than 800,000 in 1995. Harvest to catch ratio rebounded slightly to 41% in 1997 and 1998, but has since dropped back and has varied between 20 and 40% since 1999. Despite relatively stable discard rates since 1995, the number of dead discards has varied greatly due to large interannual fluctuation in catch. Discard mortality reached a peak of more than one million fish in 1996, with nearly equal values in 2000, but have since decrease along with catch. For the last five years, discard mortality has ranged between 250,000 and 500,000 fish.

ZZ4.7 Current status

Throughout the 1980s and early 1990s, weakfish stocks experienced unsustainably high fishing mortality rates, which led to a decline in abundance into the 1990s. Amendments II and III were successful at reducing fishing mortality, and an increase in biomass was evident in the late 1990s. The most recent assessment indicates that fishing mortality has remained low under Amendment IV, yet weakfish biomass has dropped back to near historic low levels by 2003. Available evidence indicates that interspecific interactions are the primary cause for the biomass declines (ASMFC 2006, Part A). A peer review of the stock assessment did not endorse the statements regarding weakfish stock status and identified several issues that required additional work or attention by the Weakfish Technical Committee before they would support its use for management purposes (ASMFC 2006, part B). In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards. In August 2006, the Technical Committee responded to the peer review panel's concerns (ASMFC 2006, Part C). Based on these responses, the Technical Committee's analyses, and significant evidence, the Weakfish Management Board accepted the following five points for management use:

1. The stock is declining;
2. Total mortality is increasing;
3. There is little evidence of overfishing occurring;
4. Something other than fishing mortality is causing the stock decline, and;
5. There is a strong chance that regulating the fishery will not, in itself, reverse the stock decline.

ZZ5.0 EVALUATE BIASES, PRECISION, UNCERTAINTY, AND SAMPLING METHODOLOGY OF THE COMMERCIAL AND RECREATIONAL CATCH INCLUDING LANDINGS AND DISCARDS. (TOR #1)

ZZ5.1 Commercial

ZZ5.1.1 Landings

Commercial landings data were taken from two sources. Where available, state-specific harvest records collected through a mandatory reporting system were considered the most reliable source for landings. Unfortunately, not all states require mandatory reporting of weakfish harvest. In such cases, landings estimates were obtained from the NMFS commercial landings database, available through the NMFS Office of Science and Technology, Fisheries Statistics Division website (*http://www.st.nmfs.gov/st1/*). Although estimates are available from NMFS, it is not mandatory to report weakfish harvest to NMFS. Discrepancies between NMFS reported harvest and state reported harvest under mandatory reporting suggest that NMFS harvest estimates for weakfish are a potential source of uncertainty. In an attempt to quantify the uncertainty between the two reporting systems, state reported landings from Delaware and Virginia were compared to federally reported landings in these two states for the period 2004 to 2006. Combined across all gears, NMFS reported landings for a given year differed from state landings by less than 10% in all instances except Virginia in 2006, when the difference exceeded 23% (Figure ZZ5.1-1). However, when evaluated at the gear level, more than one-third of all year/state/gear combinations differed by more than 20%, and in three cases exceeded 100% (Figure ZZ5.1-2). Generally speaking, then, annual estimates of weakfish harvest reported by state and federal agencies are relatively consistent when combined across all gears, but the allocation of landings by gear exhibit moderate to severe uncertainty.

ZZ5.1.1.1 Biological samples

Commercial biological samples include lengths, weights, and ages from state-specific port sampling programs. Commercial samples were combined with similar data from recreational and fishery independent sources to develop length-weight relationships and age-length keys (ALK) for use in the estimation of commercial catch at age.

Lengths

Commercial length data were used for two primary purposes: the development of length-weight equations and characterizing the distribution of commercial catches by length and age. Because a combination of both total length and fork length data were available, lengths were standardized to fork length measurements. A conversion factor was developed using data pooled across all sources for 2004 to 2006. Total length was converted to fork length using the equation

$$FL = (TL + 5.8106) / 1.0437$$

Length-weight equations were developed as in the 2006 assessment (ASMFC 2006, Part A). Length and weight data from all sources were pooled, and relationships were developed by region/year/season. Sample sizes and parameter estimates are presented in Table ZZ5.1-1.

Characterization of fishery catch at size was conducted using the same methods as the 2006 assessment (ASMFC 2006, Part A). Length frequencies were stratified by region/year/season/state/gear and applied to catch at the same level of stratification. Length-weight estimates were used in conjunction with length frequency distributions to convert estimates of harvested weight to a weighted estimate of harvested numbers at size (Quinn and Deriso 1999). Landings not identified to specific gear were pooled at the region/year/season level and classified as "other". In addition, cells with minimal landings (< 1% of region/year/season total) generally had insufficient sample size (see below) to characterize that fishery. These cells were pooled with landings from the "other" gear category and characterized using all available samples for that region/year/season.

Sample size and ratio of sample size per metric ton of landings were used to evaluate adequacy of sampling intensity. It was determined that a minimum sample of 30 lengths per stratum (region/year/season/state/gear) was required to adequately characterize a fishery. Strata with fewer than 30 samples were characterized using data substituted from a representative stratum with sufficient sample size. The minimum of 30 samples is much lower than sample sizes suggested in recent literature (Miranda 2007; Vokoun et al 2001). Insufficient sampling would tend to introduce uncertainty into the catch at size estimates; however, these studies recommend sample sizes necessary to meet an objective (characterizing entire population) much different than the current analysis (characterizing harvest of specific gear). Miranda (2007) notes that distributions with a smaller size range require a smaller sample size. Considering minimum size limits and gear selectivity, the sample size required to characterize a fishery is likely lower than those in published literature. Vaughan (2000) reports that a generally accepted level of sampling during SAW/SARC reviews is 100 fish per 200 MT of landings. A minimum sample size of 30 fish per stratum typically results in thousands of fish per 200 metric tons of landings for strata with direct or substituted samples.

Not all states collect sufficient commercial length frequency data to characterize their fisheries. For strata with insufficient length samples, data were substituted from the next most appropriate stratum. In most cases, substituted data came from the same region/year/season, but was substituted from another state and/or gear (TABLE of CAA substitutions). Care was taken to minimize differences in gear selectivity, and when necessary substituted data were truncated to account for differences in minimum size between the two states. Regardless, the Technical Committee recognizes that substituted data are not always representative of the stratum to which they are applied, resulting in uncertainty in the length frequency distribution of the catch. Of greatest concern are the geographic differences in fish size, coupled with the general lack of samples north of Delaware. In the northern part of their range, weakfish generally attain much larger sizes than in central and southern regions. As such, minimum sizes and average size of harvested fish are much larger in the northern portions of the range. When commercial samples from these states are insufficient and data are substituted from more southern states, the effect is an underestimation of the proportion of large fish in the harvest. In 2006, New Jersey began collecting commercial biological data. These data will serve to better characterize landings from this key state, and likely be more representative of catches in this region, decreasing uncertainty in catch at size estimates. Potential effects of these substitutions are explored in greater detail in Brust (2007, in prep). SUMMARIZE THEM HERE.

In summary, uncertainty in length data can be introduced both by sample size and substitution of data from alternate strata. Although sample sizes are generally less than recommended to characterize the length distribution of a population, they are much higher than levels commonly accepted as necessary to characterize a fishery. A minimum sample of 30 fish per stratum was considered an appropriate compromise between uncertainty due to low sample size from the stratum in question and uncertainty of samples from a substituted stratum.

For the southern region, characterization of the fisheries was done slightly differently. Commercial sampling in North Carolina includes collection of both lengths and weights, so it was possible to develop an average fish weight by gear and season for each fishery. The average weight was applied to the harvest weight to estimate number harvested. The number harvested was then partitioned to catch at size using the length frequency distribution of the samples. Florida, the only other southern region state with landings, collects no biological samples. Biological sample data from North Carolina were used as proxy information for Florida landings.

Ages

The principle use of age data is in the development of age-length keys. Sample sizes of ages by year, season, and source are provided in Table ZZ5.1-2. Prior to 1990, ages were based on scale samples. During the 1990s, otoliths became the principle method for aging weakfish. For the 1998 stock assessment, scale-based ages in previous years were converted to otolith-based ages using a scale-otolith conversion matrix (similar to an age-length key) based on direct comparison of approximately 2,300 samples (Daniel and Vaughan 1997; NEFSC 1998). Uncertainty in either aging method, as well as in the scale-otolith conversion matrix would be propagated through the catch-at-age matrix.

Age-length data from all available sources (commercial, recreational, fishery independent) were pooled by region/year/season to develop stratum specific age-length keys (four keys per year) as described by Vaughan (2000). Length intervals with missing information in the keys were filled by either averaging age distribution for lengths above and below, substitution from another stratum, or interpolating age distribution across several length bins. Results of the catch at size analyses were combined across states and gears within a region to develop estimates of harvest numbers at size by region/year/season.

ZZ5.1.2 Discards

Commercial discards were estimated using the ratio estimation method described in de Silva (2004). Data from the NMFS Observer Database were queried to identify a suite of target species and gears most commonly associated with weakfish discards. The suite of target species was then subset using principle component analysis to minimize duplicate counting. Where available, trip or haul level estimates of discarded weakfish weight and target species harvest weight were used to develop annual ratios of gear/species-specific discard ratios. Ratios for the southern region (NC – FL) were considered insignificant, and the remainder of the analysis was conducted only for the northern region. Gear-species discard ratios were applied to harvest estimates by year/species/gear to estimate total weakfish discard weight by year/species/gear. Weakfish discard length frequency data by gear (all species combined) were used to convert discard weight to discard at size. Annual estimates by gear were partitioned into seasonal

estimates by using the proportion of annual landings by season and gear from the NMFS landings database. Gear-season discards at size were summed across gears and converted to seasonal discards at age by applying the appropriate seasonal ALK.

NEED TO UPDATE THIS PARAGRAPH For the current assessment, weakfish discard to target species harvest ratios were not calculated for 2004 to 2006. Instead, the average gear-species ratio for 2001-2003 were applied to each year. Also, discard length frequencies from gillnet trips were extremely low for 2004-2006 (Table of N). As a substitute, combined gillnet length frequencies from 2002-2006 were applied to all years from 2004 to 2006. As with the 2006 assessment, all discards were assumed to be discarded dead and were added to the overall catch at age matrix.

ZZ5.2 Recreational

ZZ5.2.1 Landings

Recreational landings data were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) database, which is available through the NMFS Office of Science and Technology, Fisheries Statistics Division website (*http://www.st.nmfs.gov/st1/*). MRFSS provides estimates for three subcategories of catch, including observed harvest (Type A), unobserved harvest (*e.g.* filleted before observation, discarded dead; Type B1) and discarded alive (Type B2). Estimates of harvest were developed for each region/year/season combination as a sum of observed and unobserved harvest (Type A + B1).

Precision in recreational catch and harvest estimates are calculated as a percent standard error (PSE). Lower values indicate better precision, and PSE values less than 20 are generally considered "acceptable" (NEFSC 1998). However, a recent review of the survey identified several potential biases and inadequacies of the sampling and estimation methodologies (NRC 2006; see http://www.nap.edu/catalog.php?record_id=11616). These include the inability to interview anglers at private access sites; the increasing use of household cell phones which are unavailable to the telephone sampling frame; reliance on unverified assumptions; and differences in statistical properties of data collected through different survey methods. The effects of these biases on estimates of recreational catch, harvest, and discards can not easily be quantified, leading to uncertainty in MRFSS recreational estimates. This uncertainty applies to all catch types over the entire time series, which has been collected using the same general methodology throughout.

ZZ5.2.1.1 Biological samples

Biological samples collected by MRFSS include lengths and weights of a subsample of Type A fish. No ages are collected from the recreational fishery. Recreational length-weight data were combined with similar data from commercial and fishery independent sources to develop length-weight relationships (see section ZZ5.1, Commercial). Length data were also used to partition harvest into harvest at size. Because of small sample sizes (Table ZZ5.1-2), length observations were pooled by region/year/season to expand harvest estimates at the same level of stratification. Unlike commercial data, estimates of recreational harvest in numbers are directly available from

the MRFSS website. Catch at size was estimated as the proportion measured at size by stratum multiplied by the estimated harvest (A+B1 fish) for that stratum.

The number of length samples collected by MRFSS is very low, but is still above the generally accepted level of 100 lengths per 200 mt of landings. Regardless, limited length samples may introduce error into the characterization of the fishery landings.

ZZ5.2.1.2 Catch at Age

Catch at age estimates for the recreational sector were calculated using similar methods as the commercial CAA (Section 5.1.2.1), except that estimates of harvest numbers were directly available from MRFSS, and estimating catch at size did not require stratifying to the state and gear level. Total harvest number by region/year/season was partitioned into numbers at size using appropriate length frequency distributions. These were converted to recreational catch at age by applying the appropriate ALK. Annual recreational harvest at age was found by summing across regions.

ZZ5.2.2 Discards

Estimates of the number of recreational weakfish discards (Type B2 fish) were obtained from the MRFSS database. As in previous assessments, discard mortality is assumed to equal 20% of all discards. Since discarded fish are not observed by creel samplers, no biological data are available. In the absence of direct information, length frequencies of discards are assumed to be the same as observed (Type A) fish, and discard mortality at size is characterized using these data. The lack of direct observations of length frequencies of discarded fish contributes uncertainty into estimates of harvest.

ZZ5.3 Catch Matrix Development

The catch-at-age matrix for 2004-2007 was developed using the same general procedure used in previous assessments. Catch at size from the four major sources of removals (commercial harvest, commercial discards, recreational harvest, recreational discards) were combined by region/year/season. ALKs for the corresponding stratum were applied to pooled catch at size to estimate catch at age. Results were pooled across regions and seasons to estimate total annual removals at age.

As described in each of the pertinent sections, there are several potential sources of uncertainty in the overall catch at age estimates. These include inaccurate harvest/discard estimates as a result of under/over reporting or inappropriate survey methods; insufficient sample size to characterize the length frequency distribution of a fishery; errors in aging techniques or the scale-otolith age conversion; substitution of data from alternate cells in the catch at size characterization and age-length keys; and others. Attempts have been made to quantify some of these error sources; however, the extent of uncertainty associated with each of these sources, and their cumulative effect, remains largely unknown. A persistent cumulative trend in either direction would result in inaccurate catch at age estimates and may influence assessment results.

NEED EFFORT DATA FOR COMM AND RECR FISHERIES

ZZ6.0 EVALUATE PRECISION, GEOGRAPHICAL COVERAGE, REPRESENTATION OF STOCK STRUCTURE, AND RELATIVE ACCURACY OF THE FISHERIES INDEPENDENT AND DEPENDENT INDICES OF ABUNDANCE.

ZZ6.1 NEFSC Bottom Trawl Survey

The National Marine Fisheries Service (NMFS) Northeast Fishery Science Center (NEFSC) conducts seasonal trawl surveys between Nova Scotia and Cape Hatteras. Stratified random sampling is conducted using a #36 Yankee otter trawl equipped with roller gear and a 1.25 cm mesh codend liner. The survey covers a large portion of the geographic range of weakfish, including their "core" distribution area (NEFSC 1996) of New Jersey to North Carolina. Despite the extended latitudinal range, the survey is not capable of sampling in shallow waters, and few sites are conducted in waters less than 9 m. In addition, the survey does not sample the South Atlantic portion of the range.

Weakfish are infrequent in the winter, spring, and summer surveys, but are commonly intercepted in the fall during their offshore migration. Because weakfish are rarely caught in this survey north of New Jersey the 26th SAW/SARC recommended developing an index of weakfish abundance using only strata from the south end of Long Island to Cape Hatteras during the fall survey. USE NJ to NC index Indices at age are developed by applying annual length frequency data from the survey to the annual mean catch per tow and then applying appropriate age-length keys. (What ALKs are used? Are they survey specific YES, when available!) During 1982 – 1990, the keys were coastwide. Since 1991, the keys used were developed from the Mid-Atlantic region. Because this survey occurs in the fall, true ages are increased by one year to develop an index of abundance on January 1 of the year following the survey (*e.g.* fall 1997 age 0 fish are treated as January 1, 1998 age 1 fish).

The annual mean catch per tow appears nearly cyclical, with relative peaks in abundance generally every 4 to 6 years (FIGURE). From 1981 through the mid 1990s, mean catch per tow cycled without trend, generally ranging between 40 and 120 fish per tow. Beginning in the mid 1990s, abundance gradually increased to a time series maximum of approximately 500 fish per tow in 2004. During 2005 – 2007, abundance decreased to about 200 fish per tow, but increased in 2008 to over 300 fish per tow. Standard error (SE) shows a similar pattern as CPUE, with an overall cyclical pattern and a gradual increase beginning in the mid 1990s. During the early portion of the time series, SE varied between approximately 10 and 50, increasing to a peak of 90 in 2004. Coefficient of variation (CV; SE as a ratio of the mean) has varied without trend between approximately 0.1 and 0.4 since 1990.

The survey index is dominated by age 1 fish (age 0 fish progressed to age 1), although fish have been observed out to age 6. Age distribution was greatest in the early 1980s, but was truncated to predominantly ages 1-3 by the early 1990s. Age distribution expanded somewhat during the late 1990s as the stock began rebuilding as a result of management measures, but has since declined to primarily ages 1-4.

The Technical Committee has expressed concerns that the NEFSC fall survey is not a good indicator of weakfish abundance. The timing of the survey, along with the highly contagious

distribution of weakfish, leads to high variability between years and between tows within a year. The Technical Committee is also concerned about the survey's ability to capture larger/older fish. The New Jersey trawl survey, which occurs in the months before and after the NEFSC survey in nearly identical strata (see below), catches a substantially larger proportion of large fish than the NEFSC fall survey(Figure). Finally, catch curve analysis shows in several instances year class abundance increasing over time (TABLE 3 of ASMFC 2006, Part 1). For these reasons, the TC has concluded that the NEFSC fall survey not be utilized as an "aged" or biomass index. What about utility as a YOY index, or as a composite index. What is size range of survey and size range of age 1 and/or age 2 fish?

TC Recommendation?? Not for aged index, not for biomass index, possibly for YOY (needs more evaluation). Problem with dropping is lose coastwide index and lose early part of time series (only survey that goes back to 1981). Being used to help estimate avg weight of discarded fish in recr fishery.

ZZ6.2 New Jersey Ocean Trawl Program

New Jersey has conducted a stratified random trawl survey in nearshore ocean waters (0 to 90 feet) from Ambrose Channel (entrance to New York Harbor) to Cape Henlopen Channel (entrance to Delaware Bay) since 1988. The survey originated as bi-monthly cruises, but since 1991 has consisted of five cruises per year (January, April, June, August, and October). Strata are nearly identical to those used by NEFSC in this region (New Jersey's northern- and southern-most strata are truncated at New Jersey state boundaries). The gear used is a two-seam trawl with a 25 m headrope and 0.25" bar mesh codend liner. Due to funding constraints, several different vessels have been used to conduct the survey.

The geographic range of the survey is limited to nearshore ocean waters of the species distribution within the northern and southern borders of New Jersey. The survey occurs within the region sampled by the NEFSC trawl survey. The use of a smaller vessel, however, allows the New Jersey survey to provide better coverage in shallow waters.

The majority of weakfish are observed during the June, August and October cruises, although catches in June are inconsistent. An index of weakfish abundance is therefore developed using the August and October cruises. Since 1991, length frequencies have been aged using pooled (fishery dependent and fishery independent) late season ALKs from the northern region. Because the survey occurs in the fall, indices at age are progressed forward one age to indicate abundance on January 1 of the following year.

From 1989 to 1994, abundance was relatively stable between 20 and 40 fish per tow. Since 1995, abundance has varied much more widely and exhibits a similar cyclical nature as the NEFSC survey. The time series minimum of 5.72 fish per tow occurred in 1999, while the maximum of over 200 fish per tow occurred in 2005. SE has followed a similar trend as the mean over the time series, and CV has varied without obvious trend, ranging from approximately 0.2 to 0.5. (FIGURE)

From 1989 to 1995, the catch consisted primarily of ages 1-3, with ages 4-6 making up generally less than 10% of the total. Throughout the 1990s, age structure expanded, and in 1998 and 1999,

fish ages 4 and older accounted for more than 30% of the total CPUE. Since the turn of the century, age structure has again contracted, with older ages falling to less than 10% of the total since 2006. Regardless, the proportion of age 4 fish in the catch is generally higher now than it was during the early portion of the time series.

The Technical Committee has expressed concern that this survey suffers from some of the same shortcomings of the NEFSC fall survey. In particular, tow-level and annual mean catches show great variability, and catch curve analysis resulted in negative estimates of mortality for some year classes. Other concerns? The Technical Committee has therefore determined that the New Jersey trawl survey should not be used as an aged-index of weakfish abundance.

TC Recommendation?? Keep as is, but also investigate pos tows index; Uphoff's other indices are biomass based

ZZ6.3 Delaware DFW Delaware Bay Trawl Survey

The Delaware Division of Fish and Wildlife has conducted a trawl survey within the Delaware Bay intermittently since 1966 (1966-1971, 1979-1984, and 1990 – present). The survey collects monthly samples (March through December) at nine fixed stations throughout the Delaware portion of the Bay. The net used has a 30.5 foot headrope and 2" stretch mesh codend. For the current assessment, only the 1981-1984 and 1990-present time series are evaluated. Weakfish abundance is calculated as an average number of age 1+ fish per nautical mile for June to October cruises, and the index is treated as a mid-year abundance. Since 1991, length frequencies have been aged using survey specific age-length keys.

The geographic range of this survey is limited to the Delaware Bay, a very small portion of the weakfish stock range; however, the Bay is known to be a major spawning ground for weakfish on the Atlantic coast (REFERENCE). As the survey occurs monthly for a large portion of the year, fish from a wide size and age distribution are available to the survey, from young of year to large older spawners.

Weakfish abundance was moderate in the early 1980s and early 1990s (approximately 15-30 fish/nm). Beginning in 1992, abundance increased sharply to a time series high of over 233 fish in 1996. Abundance decreased by more than half in 1997, and has exhibited a generally declining trend since that time. CV of the composite index showed relatively high variability from 1991 to 1995, ranging from 0.2 to 0.6. Interannual variability in CV stabilized in 1995 and generally ranged from 0.19 to 0.26 until 2001. Since 2001, CV has shown a slight increase, estimated at 0.33 in 2006. (FIGURE)

Age structure advanced from primarily age 1 and 2 fish in the early 1990s to include ages 7 and 8 in 1998-2000. Abundance of age 4+ fish accounted for 30 to 35% of the total index in 1997 and 1998 as the large 1993 year class moved through and benefits of previous regulatory actions were realized. Abundance of older ages has since declined to levels observed in the early 1990s, with 4+ fish accounting for less than 1% of the total.

The Delaware 30-foot trawl survey occurs in one of the major weakfish spawning areas and has been shown to capture a wide size and age range of weakfish throughout the year. Trends in

abundance correspond well with anecdotal and observed information from commercial and recreational fisheries. The Technical Committee has determined that the Delaware 30-foot trawl survey provides a reliable index of weakfish abundance. However, due to lack of older fish over most of the time series, abundance at age indices are restricted to ages 1 through 4.

TC Recommendation?? Keep it, ages 1 through 6+

ZZ6.4 SEAMAP Fall Survey

The Southeast Area Monitoring and Assessment Program (SEAMAP) has conducted three seasonal trawl surveys since 1989 between Cape Hatteras, NC and Cape Canaveral, FL. A stratified random design is employed to sample inner (4.6 to 9.1 m) and outer (9.1 to 18.2 m) depth strata using twin 75-foot highrise mongoose trawls towed behind a double rigged St. Augustine shrimp trawler. The geographic range of the survey encompasses nearshore ocean waters south of Cape Hatteras, and SEAMAP is the only fishery independent survey conducted in the southern portion of the weakfish range. Unfortunately, catches of weakfish south of North Carolina are extremely small and of little value as an index of abundance. An index of abundance is therefore generated using only strata off North Carolina during fall cruises. Survey length frequencies are aged with annual late-season keys from 1989-1990, and annual late-season South Atlantic keys since 1991. The keys were developed from pooled commercial and research samples. Survey specific ages where available, otherwise use south late key (primarily NC data). Fall aged fish are progressed one age to estimate January 1 abundance in the following year.

Until 2002, the survey index varied without trend, ranging from approximately 5 to 30 fish per tow, with the exceptions of 1993 with an index of less than 1 fish per tow, and 1994 and 1995 with indices of approximately 44 and 52 fish per tow. From 2003 to 2005, the index increased to between 35 and 60 fish per tow, before jumping drastically to nearly 500 fish per tow in 2006. In 2007, the index dropped back down to 45 fish per tow. (FIGURE)

Survey variability and precision? (updated in trawl surveys.xls)

Age structure is truncated in the survey catch-at-age matrix, and the survey is driven primarily by age 1 and age 2 fish. Barring the 2006 index value, strongest recruitment (age 1) events occurred in 1995 and 2003. The 2006 index is anomalously high, with an age 3 index greater than the age 1 index in most years. Age 4+ fish generally constitute less than 1% of the total catch, with a maximum of 11.2% in 1998 and 7.7% in 1999 as the strong 1994 year class moved through.

TC recommendation? Need catch curve analysis (Des, send data), pres/abs, geo mean (Jim, send him the data), review and present all strata/states, discuss concerns (sand seatrout etc an justify which data we use based on concerns and analyses ; possible vessel problems in 2007 may have delayed survey or stopped sampling. If add in other non-core surveys, can still justify keeping southern SEAMAP stations out because of sand seatrout concerns

ZZ6.5 Massachusetts DMF Trawl Survey

The Massachusetts Division of Marine Fisheries conducts a stratified random trawl survey in six depth zones (0-30, 31-60, 61-90, 91-120, 121-180 and >180 feet) and five geographic regions within the state. Sampling has been conducted twice per year (May and September) since 1978. Survey gear consists of a two-seam whiting trawl with a 39 foot headrope and a 0.5" stretch mesh codend liner. Weakfish, primarily young of year, are most commonly observed during the fall survey in the three regions south of Cape Cod. Mean catch per tow is used as an index of young of year abundance in the survey year.

The MA DMF trawl survey area encompasses nearshore ocean and estuarine areas within Massachusetts state boundaries. Like the New Jersey trawl survey, the survey area overlaps a portion of the NEFSC trawl survey area, but a smaller vessel allows more comprehensive sampling of shallow waters. Although large numbers of weakfish have been observed in Cape Cod Bay and Massachusetts Bay (Collette and Klein-MacPhee 2002), these waters are generally considered the northern extent of the weakfish range.

Mean annual catch per tow is consistently under 2 fish, with only three exceptions since 1981. Abundance generally declined from 1981 to 1984. In 1985, abundance increased more than 100-fold to the time series high of more than 15 fish per tow. Recruitment was again relatively high in 1986 (2.7 fish per tow), before dropping back to near zero levels for 1987 to 1994. Since 1994, abundance has shown a general upward trend, while at the same time exhibiting greater interannual variability. The second highest index value of 2.9 fish per tow occurred in 2006, before dropping back to just 0.2 fish per tow in 2007. (FIGURE)

Standard error is high and exhibits a similar trend as mean abundance. The CV is generally greater than 60%, and exceeds 90% in eight years. Because of the low catch rates and high variability, the TC has determined that this index provides little information on the abundance of weakfish. This is consistent with the NEFSC (2000) recommendation to use only indices from the core area.

TC Recommendation?? CV too high, get rid of it

ZZ6.6 Rhode Island Trawl Survey

NEED DISCUSSION ON RI SURVEY

precision, geographical coverage, stock structure, and relative accuracy??

Keep it for now, but need precision estimates. RI currently converting to Access so it may be a few weeks. Brian will work on this.

ZZ6.7 Connecticut DEP Long Island Sound Trawl Survey

Since 1984, the Connecticut DEP has conducted spring and fall trawl surveys in the Connecticut portion of Long Island Sound between the New York/Connecticut border in the west and New London, CT in the east. Survey effort consists of three spring cruises conducted during April, May and June, and three fall cruises in September and October. Stratified random sampling is employed based on four depth zones and three bottom types. Survey gear consists of a 14 x 9.1

m high-rise otter trawl with 0.196" codend mesh. The survey catches mostly YOY and age 1 weakfish as defined by examination of length frequencies. Indices of abundance for age 0 and age 1+ are developed as geometric mean catch per tow.

Sampling is limited to Long Island Sound. The Sound encompasses a very small portion of the weakfish range, but may serve as a primary spawning/nursery habitat in this region. Not a lot of spawning, but maybe eggs/juvs from other spawning areas come in

From 1984 to 1998, the YOY index varied without trend, and generally ranged from approximately 3 to 10 fish per tow, with relatively strong year classes (10-15 fish per tow) occurring in five years. In 1999, recruitment increased sharply and has remained above 30 fish per tow in all years except 2005 and 2006. Time series highs of more than 63 fish per tow occurred in 2000 and 2007, while minimum catches of approximately 1 fish or less occurred in 1984, 1986, and 2006. Coefficient of variation of the YOY index has exhibited a generally negative trend over the time series. (FIGURE)

The fall and spring age 1+ indices have never exceeded 1 fish per tow and 0.5 fish per tow, respectively. Except for the first few years of the time series, the two 1+ indices exhibit similar trends, and show strong positive correlation ($r = 0.55$). From 1984 to 1989, the fall index declines in abundance while the spring index remains stable or increases slightly. Both indices increase from 1989 to 1991, decrease through 1994, increase to time series highs in 1997 (fall) and 1999 (spring), and have generally declined since then. The CV for the fall index generally ranges from 0.2 to 0.6 and appears to have been on an increasing trend since 1997.

Low correlation was observed between the fall age 1+ index and the fall age 0 index lagged forward one year ($r = 0.06$; correlation table). Correlation was slightly better ($r = 0.2$) for the spring 1+ and fall age 0 lagged forward. One possible explanation is that weakfish in this area recruit to the spawning population at older ages; however, correlations between the 1+ indices and the age 0 index lagged forward two and three years were weaker, and in three of four cases, negative. This suggests that the Long Island Sound survey is inadequate for sampling either age 0 or age 1+ fish.

TC recommendation? Because this survey is conducted outside the apparent core area, NEFSC (2000) recommended that this survey not be used as an index of abundance. But large catches and good precision, so keep it.

ZZ6.8 NYDEC Peconic Bay Juvenile Trawl Survey

The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey in the Peconic Bay estuary of Long Island since1985. Weakfish was the primary target species when the survey was initiated, and Peconic Bay was selected for the survey area because of its importance as a weakfish spawning ground. Random sampling occurs weekly between May and October using a semi-balloon shrimp trawl with a 16 foot headrope and 0.5" stretch mesh codend liner. The survey samples mainly young of year weakfish, and a YOY index has historically been calculated as an arithmetic mean catch per tow over all sampling months. In 2005 and 2006, technical difficulties constrained sampling to May – July (2005) and July – October (2006), so a revised index using only July and August has been calculated. The two

indices show a similar increasing trend and are well correlated (r = 0.96). The July/August index provides higher estimates of abundance and appears to be more variable between years, although standard deviation as a ratio of the mean is lower for the July/August index than for all months combined. WHICH TO USE? – use July/August, need CIs but need more data to do it (now in log scale, need to calculate CIs?

The July/August index ranges from less than one fish per tow to more than 30/tow. Despite large interannual variations, there appears to be a gradual increase in recruitment over the time series. Strong year classes occurred in 1991, 1996, and 2005 (time series high). Standard error of the catch has increased over the time series as well; however, CV has decreased greatly from 1987 to 1996, and has remained below 1.5% since then. (FIGURE)

TC recommendation? Because this survey is conducted outside the apparent core area, NEFSC (2000) recommended that this survey not be used as an index of abundance. But good precision, so keep it.

ZZ6.9 Delaware DFW Delaware Bay Juvenile Trawl Survey

In addition to their 30-foot trawl survey, the Delaware DFW conducts a fixed station survey in Delaware Bay targeting juvenile finfish. Sampling is conducted monthly from April through October using a semi-balloon otter trawl. The net has a 17' headrope and a 0.5" stretch mesh codend liner. Weakfish are a significant component of the catch, with the greatest majority of these weakfish (more than 99% in some years) being young of the year. A YOY index is calculated as the geometric mean number per tow during the June to October cruises.

As with the Delaware 30-foot index, the survey is restricted to Delaware Bay. Although this encompasses only a small portion of the geographic range of weakfish, the Bay is known to provide significant spawning and nursery habitat for the species.

Throughout this timeseries, recruitment indices have generally fallen between 5 and 15 fish per tow, with only 2 values below and three values above this range. Weak recruitment occurred in 1983 and 1988, with less than 5 fish per tow, while the two strongest recruitment events of 20.1 and 16.8 fish per tow occurred in 1991 and 2005, respectively. Average recruitment over the timeseries has been approximately 10.8 fish per tow. The index indicates three general stanzas in recruitment since 1981. From 1981 to 1990, recruitment was generally below the long term average. In 1991, recruitment increased to the timeseries high beginning a decade of above-average recruitment. In 2001, recruitment dropped below average and has remained there for five of the last seven years. (FIGURE)

Precision??

TC recommendation? Keep it

ZZ6.10 Maryland DNR Chesapeake Bay and Coastal Bays Juvenile Trawl Surveys

The Maryland Department of Natural Resources conducts two juvenile trawl surveys: one in the Chesapeake Bay from 1980 to the present, and one in the coastal bays from 1972 to the present. Both surveys sample fixed stations using a 16 foot semi-balloon otter trawl with a 0.5" stretch

mesh codend liner. The coastal bays project samples monthly from April through October, while the Chesapeake survey runs monthly from May through October. Due to non-standardized survey methods during the early portions of both surveys, only data from 1989 onward are used to calculate YOY abundance indices. Indices are calculated as geometric mean catch per tow.

Both surveys are confined to Maryland state waters which constitute only a small portion of the weakfish range. Regardless, both survey areas are sheltered estuarine environments and may provide suitable spawning and nursery habitat for the species.

The Chesapeake index shows a steadily increasing trend from a timeseries low of 0.4 fish per tow in 1989 to the timeseries high of 8.1 fish per tow in 2001. Since 2001, the index has exhibited a steady decline to less than 2 fish per tow in 2007. The coastal bays index appears stable between 0.9 and 1.9 fish per tow for 1989 to 1994. In 1995, recruitment increases dramatically to 4.4 fish per tow, decreasing gradually back to 2.6 in 2001. During this period (1989 to 2001), interannual variability has been minor with few exceptions. Beginning in 2001, interannual variability increases dramatically. The weakest recruitment of the timeseries occurred in 2002, followed in 2003 by the timeseries high of 5.6 fish per tow. (FIGURE)

precision?? Get from Jim or Harry,

TC Recommendation?? Keep both but maybe down weight coastal bay index (if we weight the indices)

ZZ6.11 Virginia Institute of Marine Science Chesapeake Bay Trawl Survey

The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay since 1955. Over time there have been several changes to sampling strategy and survey area. Currently, sampling is conducted using a 30 foot semi-balloon otter trawl with a 6.35 mm codend liner. Sampling is performed monthly throughout the year using stratified random sampling in the mainstem bay and fixed stations in tributaries. Young of year are identified through examination of length frequencies (monthly ranges), and an index of recruitment is computed using August-October tows from three major tributaries.

The geographic region covered by the survey includes the Virginia portion of the Chesapeake Bay and lower portions of its three main tributaries (James, York, and Rappahannock Rivers). Although sampling does occur in the main stem, catches of weakfish are generally minimal in the Bay, so the index is limited to the three tributaries. Few large weakfish are present year round, but the estuaries provide suitable nursery grounds for juveniles.

Recruitment varies widely over the timeseries, ranging from less than 5 fish per tow to more than 35 fish per tow. Interannual variability is often large, particularly in the early portion of the timeseries, with the maximum and minimum indices occurring in consecutive years. From 1986 to 1990, the survey shows a rapid increase from 4.7 to 30.0 fish per tow, followed by a sharp drop back to 7.0 fish per tow by 1994. Recruitment rebounded slightly through 1999, but has exhibited a generally declining trend ever since. (FIGURE)

No estimates of survey variability are available for the current index. (Data were not provided, and the program has recently lost some key staff.) Geer (1994), however, indicates that between 1981 and 1993 several changes in gear, vessel, and station type occurred, the most recent between the 1990 and 1991 surveys. It is possible that some of the interannual variability observed in the index is due to these methodological changes.

TC recommendation - need more info – are data standardized re survey changes, is it geo mean, use river only or bay and river, use only stdized portion of time series

ZZ6.12 North Carolina DMF Pamlico Sound Juvenile Trawl Survey

The North Carolina Division of Marine Fisheries conducts a juvenile trawl survey in Pamlico Sound. Sampling is conducted in June and September using a stratified random design. Survey gear consists of twin 30-foot mongoose trawl nets with 0.75" codend mesh. Data from these surveys are used to develop a 1+ index (June) and a YOY index (September), both based on length frequency analysis.

Between 1987 and 1999, the YOU index ranged from approximately 10 to 100 fish per tow, and was characterized by large interannual fluctuations. Strong year classes were present in 1988 and 1999, with weakest recruitment occurring in 1987 and 1993. From 1999 to 2002, recruitment dropped rapidly from 99.9 to 22 fish per tow. Since 2002, the index indicates a modest rebound to 56.8 fish per tow in 2007 and exhibits much less interannual variability.

For the early portion of the time series, the 1+ index shows little correlation with the YOY index. Around the mid 1990s, correlation between the indices improves until the last two years. The time series high occurred in 2000 (consistent with the strong 1999 year class), with the second highest value occurring in 2006. Low values were observed in 1989 to 1992, 2003, and 2007.

precision, geographical coverage

TC Recommendation?? – get geo mean from Lee, rewrite discussion

ZZ6.13 Pamlico Sound Independent Gillnet Study (PSIGNS)

This is the first weakfish stock assessment to evaluate the PSIGNS survey. Sampling in Pamlico Sound was initiated in May of 2001 and has sampled continuously since that time. The major objective of the PSIGNS is to provide independent relative abundance indices for key estuarine species.

Sampling uses a stratified random design based on area and water depth. Twice per month a deep-water and shallow-water sample are collected from each of 8 areas using a gillnet consisting of eight 30 yard segments of 3, 3½, 4, 4½, 5, 5½, 6, 6½ inch stretched mesh gill net. Nets are typically deployed within an hour of sunset and retrieved the next morning, for approximate soak times of 12 h. This sampling design results in a total of approximately 32 gill net samples (16 deep and 16 shallow samples) being collected per month across both the Rivers and Sound. Catch rates of target species were calculated annually and expressed as an overall CPUE along with corresponding length class distributions. The overall CPUE provides a relative

index of abundance showing availability of each species to the study, while the length distribution and age CPUE estimates show the size structure of each species for a given year. The overall CPUE was defined as the number of a species of fish captured per sample and was further expressed as the number of a species of fish at length per sample, with a sample being one array of nets fished for 12 hours. Due to disproportionate sizes of each stratum and region, the final CPUE estimate was weighted. For weakfish the CPUE at age was calculated for 6-month periods (Jan-Jun and Jul-Dec) in the same manner as was done for the CAA workup in the last assessment.

ADD NEAMAP and ChesMMAP – not for index, but use bio data

ZZ6.14 MRFSS

Historically, a fishery dependent index of weakfish abundance was developed using recreational catch per "directed trip" (trips where weakfish was identified as a target species; *cf.* NEFSC 1998, 2000). During the review of the 2000 assessment, the SARC expressed concern regarding fishery dependent indices. Potential sources of bias in fishery dependent indices include non-random distribution of effort, and hyperstability of the index (as abundance - and therefore catch – declines, so does the number of trips; Hilborn and Walters 1992).

In 2006, a revised recreational index was developed that the Technical Committee feels largely circumvents the concerns expressed by the 30th SAW. Estimates of catch used are all fish (A+B1+B2) captured by the recreational private/rental boat mode in state waters of the mid-Atlantic region (New York to Virginia). As described in Crecco (2005), the private/rental mode is highly mobile and capable of catching weakfish over a large range of sizes. Catches were constrained to the mid-Atlantic region because private/rental boat catches from this region have accounted for greater than 60% of annual catch. Two estimates of effort were used to convert catch to CPUE. The first, as described in Crecco (2005) uses all private/rental boat trips in state waters of the mid-Atlantic region. The second, detailed by Brust (2004) estimates effort as the number of private/rental boat trips in mid-Atlantic state waters that captured any of a suite of species typically associated with catches of weakfish. The two indices are highly correlated (FIGURE). Although the 2006 assessment used the index based on the suite of associated species, the current assessment uses the index based on all mid-Atlantic private/rental boat trips. This index is preferable because of its ease of calculation without loss of information, and because it provides consistency between assessment methodologies (*i.e.* VPA vs. relative F). (FIGURE)

The methods described above include both harvested and discarded fish. Based on assumptions regarding availability to the fishery (gear and area) at size, this method is considered to provide a composite index of ages 2+. A second index was developed using similar methods, but including only harvested fish. Recreational length frequency data from the northern region, early/late season were used to expand the number harvested to harvest at size. The northern early/late age-length key was then used to partition harvest into ages. This method provides indices at age for 3 through 6+.

Both indices are developed using data from mid-Atlantic state waters. This region encompasses the primary distribution of weakfish within its range. Although all sizes and ages of weakfish

are present in this region, younger fish are not considered to be captured or harvested by the fishery, so the indices are only representative of mature fish.

DISCUSS INDICES (Need to develop - 06 assess used assoc spp trips; want to change to all trips)

Estimates of precision are available for the different components of the indices (catch, harvest, and effort); however, there are no direct estimates of survey precision. Discussions on uncertainty in catch and effort estimates are presented in section ZZ5.2.

TC Recommendation??

Jim's work – favors aggregate biomass assessment; looking at alternative methods to analyze indices; trying to ID criteria for good vs bad index; did work on biomass indices, not numerical indices; criteria are precision, accuracy (hard to determine), consistency (low interannual variability) and coherence with other surveys – could use these for indices presented above; NEFSC can't be salvaged; NJ index not weighted by stratum size; 3 possible "usable" NJ biomass indices – "best" is positive tows * mn wt / tow; can use NJ pos tows index as tuning index, can even use aged

Lee's work – include as aged index; Lee to work on write up

Yan – standardized CPUEs – recommends using stdized surveys; right now not all indices are stdized (she hasn't received all data), also none of them have been aged; right now, keep our data, but if in future (even during this assessment) find Yan's data is better, we can reconsider

Joseph – natural mortality – review different non-age based and several age-specific M methods; all have drawbacks; many sensitive to reference value; choice of method is subjective, but leaning towards lorenzen cuz population specific;

ASMFC 2006. 2006 Weakfish Stock Assessment: Weakfish Stock Assessment Report, Terms of Reference and Advisory Report, and Technical Committee Supplemental Material. December 2006. 315 pp.

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Table ZZ4.6-1. Commercial landings and (percent of annual total) by state and year. Landings are in metric tons.

	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Total
1981	18.1	109.8	12.4	615.9	1,701.1	477.0	153.5	1,121.2	7,662.9	0.0	0.2	86.3	11,958.4
	(0.15)	(0.92)	(0.1)	(5.15)	(14.23)	(3.99)	(1.28)	(9.38)	(64.08)	(0)	(0)	(0.72)	
1982	10.4	80.2	11.6	570.2	940.5	587.2	113.0	974.9	5,466.9	0.2	0.3	79.9	8,835.3
	(0.12)	(0.91)	(0.13)	(6.45)	(10.64)	(6.65)	(1.28)	(11.03)	(61.88)	(0)	(0)	(0.9)	
1983	3.1	74.3	19.4	385.6	985.5	409.1	176.9	1,176.1	4,642.0	0.0	1.2	53.4	7,926.6
	(0.04)	(0.94)	(0.24)	(4.86)	(12.43)	(5.16)	(2.23)	(14.84)	(58.56)	(0)	(0.02)	(0.67)	
1984	2.2	76.0	14.2	219.8	1,248.1	354.9	147.4	956.6	5,892.6	0.0	0.4	57.1	8,969.3
	(0.02)	(0.85)	(0.16)	(2.45)	(13.92)	(3.96)	(1.64)	(10.67)	(65.7)	(0)	(0)	(0.64)	
1985	1.4	74.0	12.8	175.2	1,374.4	449.4	143.4	944.5	4,454.9	0.0	0.0	60.0	7,690.0
	(0.02)	(0.96)	(0.17)	(2.28)	(17.87)	(5.84)	(1.86)	(12.28)	(57.93)	(0)	(0)	(0.78)	
1986	2.6	57.9	6.2	163.2	1,455.4	328.2	152.7	904.5	6,490.7	0.0	0.0	49.3	9,610.7
	(0.03)	(0.6)	(0.06)	(1.7)	(15.14)	(3.41)	(1.59)	(9.41)	(67.54)	(0)	(0)	(0.51)	
1987	0.8	35.7	13.4	149.3	949.9	262.1	166.4	890.3	5,220.2	0.0	0.1	55.8	7,744.0
	(0.01)	(0.46)	(0.17)	(1.93)	(12.27)	(3.38)	(2.15)	(11.5)	(67.41)	(0)	(0)	(0.72)	
1988	1.7	8.8	1.1	56.5	1,058.2	240.7	377.7	668.2	6,845.6	0.0	0.0	52.2	9,310.7
	(0.02)	(0.09)	(0.01)	(0.61)	(11.37)	(2.59)	(4.06)	(7.18)	(73.52)	(0)	(0)	(0.56)	
1989	0.9	4.4	1.0	46.9	661.6	240.5	337.4	465.0	4,588.5	0.1	0.0	78.1	6,424.4
	(0.01)	(0.07)	(0.02)	(0.73)	(10.3)	(3.74)	(5.25)	(7.24)	(71.42)	(0)	(0)	(1.22)	
1990	0.8	11.2	0.6	9.0	439.2	278.1	300.4	547.7	2,631.8	0.0	0.0	62.2	4,281.0
	(0.02)	(0.26)	(0.01)	(0.21)	(10.26)	(6.5)	(7.02)	(12.79)	(61.48)	(0)	(0)	(1.45)	
1991	0.9	11.3	9.7	50.6	532.6	225.6	148.9	480.7	2,408.0	0.0	0.0	74.8	3,943.1
	(0.02)	(0.29)	(0.25)	(1.28)	(13.51)	(5.72)	(3.78)	(12.19)	(61.07)	(0)	(0)	(1.9)	
1992	1.4	13.7	1.6	76.2	426.7	164.4	174.8	249.5	2,205.6	0.0	0.0	67.1	3,381.0
	(0.04)	(0.41)	(0.05)	(2.25)	(12.62)	(4.86)	(5.17)	(7.38)	(65.24)	(0)	(0)	(1.98)	
1993	0.5	4.5	0.7	40.1	378.5	88.3	82.5	493.5	1,954.7	0.0	0.0	65.5	3,108.8
	(0.02)	(0.14)	(0.02)	(1.29)	(12.18)	(2.84)	(2.65)	(15.87)	(62.88)	(0)	(0)	(2.11)	
1994	0.0	8.2	5.0	45.1	315.4	118.8	63.9	587.1	1,583.0	0.0	0.0	81.5	2,808.0
	(0)	(0.29)	(0.18)	(1.61)	(11.23)	(4.23)	(2.28)	(20.91)	(56.37)	(0)	(0)	(2.9)	
1995	0.2	23.9	2.9	78.2	393.4	127.6	31.5	673.6	1,865.8	0.0	0.0	22.8	3,219.9
	(0.01)	(0.74)	(0.09)	(2.43)	(12.22)	(3.96)	(0.98)	(20.92)	(57.95)	(0)	(0)	(0.71)	
1996	0.0	19.7	3.1	165.7	372.9	0.0	60.2	719.9	1,804.3	0.0	0.0	2.0	3,147.8
	(0)	(0.63)	(0.1)	(5.26)	(11.85)	(0)	(1.91)	(22.87)	(57.32)	(0)	(0)	(0.06)	
1997	0.0	14.1	5.0	152.7	470.1	253.5	87.4	706.7	1,615.3	0.0	0.0	5.3	3,310.1
	(0)	(0.43)	(0.15)	(4.61)	(14.2)	(7.66)	(2.64)	(21.35)	(48.8)	(0)	(0)	(0.16)	
1998	0.2	35.0	6.6	225.2	818.6	250.7	110.9	845.5	1,521.4	0.0	0.0	6.8	3,820.9
	(0.01)	(0.92)	(0.17)	(5.89)	(21.42)	(6.56)	(2.9)	(22.13)	(39.82)	(0)	(0)	(0.18)	
1999	1.2	57.3	10.1	222.2	585.7	199.7	101.4	759.3	1,187.3	0.0	0.0	7.9	3,132.1
	(0.04)	(1.83)	(0.32)	(7.09)	(18.7)	(6.38)	(3.24)	(24.24)	(37.91)	(0)	(0)	(0.25)	

Table 1 (continued). Commercial landings and (percent of annual total) by state and year. Landings are in metric tons.

	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Total
2000	0.2	85.9	3.6	160.0	486.0	149.1	94.5	618.2	847.8	0.0	0.0	4.3	2,449.6
	(0.01)	(3.51)	(0.15)	(6.53)	(19.84)	(6.09)	(3.86)	(25.24)	(34.61)	(0)	(0)	(0.18)	
2001	0.1	49.7	3.1	262.5	379.9	85.1	84.3	508.9	889.2	0.0	0.0	4.9	2,267.7
	(0)	(2.19)	(0.14)	(11.58)	(16.75)	(3.75)	(3.72)	(22.44)	(39.21)	(0)	(0)	(0.22)	
2002	0.4	55.7	4.6	233.1	391.5	78.4	50.5	518.9	829.3	0.0	0.0	2.6	2,165.0
	(0.02)	(2.57)	(0.21)	(10.77)	(18.08)	(3.62)	(2.33)	(23.97)	(38.3)	(0)	(0)	(0.12)	
2003	0.2	28.7	1.4	65.5	154.3	41.5	21.5	208.4	385.0	0.0	0.0	1.2	907.7
	(0.02)	(3.16)	(0.15)	(7.22)	(17)	(4.57)	(2.37)	(22.96)	(42.41)	(0)	(0)	(0.13)	
2004	0.0	17.4	2.8	80.9	92.8	23.3	0.0	161.9	310.9	0.0	0.0	1.2	691.2
	(0)	(2.52)	(0.41)	(11.7)	(13.43)	(3.37)	(0)	(23.42)	(44.98)	(0)	(0)	(0.17)	
2005	0.0	18.9	2.8	49.8	29.2	32.1	16.2	176.9	191.2	0.0	0.0	3.3	520.4
	(0)	(3.63)	(0.54)	(9.57)	(5.61)	(6.17)	(3.11)	(33.99)	(36.74)	(0)	(0)	(0.63)	
2006	3.9	20.2	3.2	69.3	93.7	15.6	23.2	85.2	164.6	0.0	0.0	2.7	481.6
	(0.81)	(4.19)	(0.66)	(14.39)	(19.46)	(3.24)	(4.82)	(17.69)	(34.18)	(0)	(0)	(0.56)	
2007	0.2	9.3	0.9	39.3	74.6	11.1	12.6	156.7	79.6	0.0	0.0	3.5	387.9
	(0.04)	(2.41)	(0.22)	(10.13)	(19.23)	(2.87)	(3.26)	(40.39)	(20.53)	(0)	(0)	(0.91)	

Table ZZ4.6-2. Recreational harvest and (percent of annual total) by state and year. Harvest values are numbers of fish.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Total
1981	5,946	18,371	18,707	275,120	1,028,787	122,744	177,761	7,484,780	204,230	2,580	2,433		9,344,461
	(0.06)	(0.2)	(0.2)	(2.94)	(11.01)	(1.31)	(1.9)	(80.1)	(2.19)	(0.03)	(0.03)	(0)	
1982		18,614	11,769	88,234	104,066	217,821	440,146	715,892	200,045	17,342		40,161	1,854,090
	(0)	(1)	(0.63)	(4.76)	(5.61)	(11.75)	(23.74)	(38.61)	(10.79)	(0.94)	(0)	(2.17)	
1983	2,732	74,608	6,363	36,934	2,857,093	1,009,899	595,286	354,846	387,871	6,807	17,209	293,303	5,642,951
	(0.05)	(1.32)	(0.11)	(0.65)	(50.63)	(17.9)	(10.55)	(6.29)	(6.87)	(0.12)	(0.3)	(5.2)	
1984	2,237	0	1,561	20,133	1,026,043	593,107	104,057	782,848	489,468	7,836		493,521	3,520,811
	(0.06)	(0)	(0.04)	(0.57)	(29.14)	(16.85)	(2.96)	(22.23)	(13.9)	(0.22)	(0)	(14.02)	
1985		17,092	2,874	89,538	812,839	365,693	305,799	505,223	217,671	61,788	4,811	36,340	2,419,668
	(0)	(0.71)	(0.12)	(3.7)	(33.59)	(15.11)	(12.64)	(20.88)	(9)	(2.55)	(0.2)	(1.5)	
1986		4,595	7,315	34,582	2,500,622	914,489	1,947,394	2,418,046	611,363	78,315	18,130	129,270	8,664,121
	(0)	(0.05)	(0.08)	(0.4)	(28.86)	(10.55)	(22.48)	(27.91)	(7.06)	(0.9)	(0.21)	(1.49)	
1987			777	7,447	1,666,619	638,342	824,883	1,015,413	624,160	18,841	10,802	64,248	4,871,532
	(0)	(0)	(0.02)	(0.15)	(34.21)	(13.1)	(16.93)	(20.84)	(12.81)	(0.39)	(0.22)	(1.32)	
1988			0	13,215	642,032	974,712	1,163,766	2,297,053	438,148	1,834	0	95,509	5,626,269
	(0)	(0)	(0)	(0.23)	(11.41)	(17.32)	(20.68)	(40.83)	(7.79)	(0.03)	(0)	(1.7)	
1989				6,436	303,289	254,170	226,505	357,864	190,193	6,810	8,245	141,880	1,495,392
	(0)	(0)	(0)	(0.43)	(20.28)	(17)	(15.15)	(23.93)	(12.72)	(0.46)	(0.55)	(9.49)	
1990		407		3,057	216,385	179,837	370,528	286,458	91,300	8,027	2,273	73,983	1,232,255
	(0)	(0.03)	(0)	(0.25)	(17.56)	(14.59)	(30.07)	(23.25)	(7.41)	(0.65)	(0.18)	(6)	
1991			18,695	28,072	545,665	366,464	221,242	351,947	140,826	19,616	4,954	115,210	1,812,691
	(0)	(0)	(1.03)	(1.55)	(30.1)	(20.22)	(12.21)	(19.42)	(7.77)	(1.08)	(0.27)	(6.36)	
1992		9,624	434	5,282	311,659	100,561	137,260	265,645	35,490	23,501	1,751	68,943	960,150
	(0)	(1)	(0.05)	(0.55)	(32.46)	(10.47)	(14.3)	(27.67)	(3.7)	(2.45)	(0.18)	(7.18)	
1993			2,460	12,610	203,915	235,312	238,768	108,392	106,737	7,360	14,752	148,968	1,079,274
	(0)	(0)	(0.23)	(1.17)	(18.89)	(21.8)	(22.12)	(10.04)	(9.89)	(0.68)	(1.37)	(13.8)	
1994			0	1,872	591,571	300,211	332,846	169,740	177,965	46,858	718	204,714	1,826,495
	(0)	(0)	(0)	(0.1)	(32.39)	(16.44)	(18.22)	(9.29)	(9.74)	(2.57)	(0.04)	(11.21)	
1995		1,568		22,310	671,850	406,730	88,695	226,682	62,475	29,897	22,437	55,435	1,588,079
	(0)	(0.1)	(0)	(1.4)	(42.31)	(25.61)	(5.59)	(14.27)	(3.93)	(1.88)	(1.41)	(3.49)	
1996		0		16,320	1,104,251	633,920	183,408	193,861	90,704	5,695	5,413	35,757	2,269,329
	(0)	(0)	(0)	(0.72)	(48.66)	(27.93)	(8.08)	(8.54)	(4)	(0.25)	(0.24)	(1.58)	
1997		1,415	517	112,986	1,028,334	647,529	162,900	557,809	184,954	2,039	44,202	72,970	2,815,655
	(0)	(0.05)	(0.02)	(4.01)	(36.52)	(23)	(5.79)	(19.81)	(6.57)	(0.07)	(1.57)	(2.59)	
1998	618	0	2,183	21,392	920,558	455,603	290,051	463,525	191,181	15,838	718	24,678	2,386,345
	(0.03)	(0)	(0.09)	(0.9)	(38.58)	(19.09)	(12.15)	(19.42)	(8.01)	(0.66)	(0.03)	(1.03)	
1999		2,296	1,606	18,347	583,883	224,307	340,096	229,209	127,163	3,941	1,679	119,027	1,651,554
	(0)	(0.14)	(0.1)	(1.11)	(35.35)	(13.58)	(20.59)	(13.88)	(7.7)	(0.24)	(0.1)	(7.21)	

Table ZZ4.6-2 (continued). Recreational harvest and (percent of annual total) by state and year. Harvest values are numbers of fish.

	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Total
2000		712	7,342	42,406	760,279	311,553	475,348	286,752	71,247	5,585	4,181	123,797	2,089,202
	(0)	(0.03)	(0.35)	(2.03)	(36.39)	(14.91)	(22.75)	(13.73)	(3.41)	(0.27)	(0.2)	(5.93)	
2001		2,301	715	28,126	736,069	72,451	302,719	175,872	158,605		3,316	46,409	1,526,583
	(0)	(0.15)	(0.05)	(1.84)	(48.22)	(4.75)	(19.83)	(11.52)	(10.39)	(0)	(0.22)	(3.04)	
2002		1,420	1,796	24,962	492,876	121,884	100,467	178,110	90,170	90,245	852	69,106	1,171,888
	(0)	(0.12)	(0.15)	(2.13)	(42.06)	(10.4)	(8.57)	(15.2)	(7.69)	(7.7)	(0.07)	(5.9)	
2003	109	298	443	9,234	151,101	20,124	41,048	86,112	153,753	4,162	1,573	29,614	497,571
	(0.02)	(0.06)	(0.09)	(1.86)	(30.37)	(4.04)	(8.25)	(17.31)	(30.9)	(0.84)	(0.32)	(5.95)	
2004		0	0	7,596	183,649	6,967	29,645	103,181	237,395	153,589	9,815	46,020	777,857
	(0)	(0)	(0)	(0.98)	(23.61)	(0.9)	(3.81)	(13.26)	(30.52)	(19.75)	(1.26)	(5.92)	
2005		1,009		359	1,053,005	19,031	22,164	30,346	163,265	129,575	5,764	79,021	1,503,539
	(0)	(0.07)	(0)	(0.02)	(70.04)	(1.27)	(1.47)	(2.02)	(10.86)	(8.62)	(0.38)	(5.26)	
2006		3,297		9,123	417,527	11,158	470	58,814	153,696	7,123	3,501	80,427	745,136
	(0)	(0.44)	(0)	(1.22)	(56.03)	(1.5)	(0.06)	(7.89)	(20.63)	(0.96)	(0.47)	(10.79)	
2007		0		7,120	209,310	4,182	10,316	44,493	114,332	71,230	4,712	118,743	584,438
	(0)	(0)	(0)	(1.22)	(35.81)	(0.72)	(1.77)	(7.61)	(19.56)	(12.19)	(0.81)	(20.32)	

Table ZZ5.1-1. Sample size and parameter estimates for weakfish length-weight equations.

Region	Year	Season	N	a	b
North	2004	Early	1487	1.85E-08	3.023663
North	2004	Late	2997	3.2E-08	2.927907
North	2005	Early	878	4.25E-08	2.884075
North	2005	Late	2724	4.2E-08	2.892038
North	2006	Early	1135	2.95E-08	2.956832
North	2006	Late	2028	1.13E-07	2.735412
South	2004	Early	322	5.34E-08	2.867107
South	2004	Late	280	6.78E-08	2.820563
South	2005	Early	295	2.5E-08	2.979039
South	2005	Late	289	2.11E-08	3.009672
South	2006	Early	367	1.68E-08	3.045197
South	2006	Late	278	5.7E-08	2.843432

Table ZZ5.1-2. Biological sampling intensity by state and season for recent years (need to update 2007).

			Commercial				Recreational		
Year	**Season**	**State**	**Ages**	**Lengths**	**Landings (MT)**	**Lengths / MT**	**Lengths**	**Landings (MT)**	**Lengths / MT**
2001	Early	MA	0	0	0.0	0.0	0	0.0	0.0
		RI	178**	178**	10.8	16.5	0	0.0	0.0
		CT	34	0	0.3	0.0	0	0.0	0.0
		NY	0	0	39.9	0.0	9	39.0	0.2
		NJ	0	0	108.0	0.0	43	114.8	0.4
		DE	300	370	75.0	4.9	69	50.7	1.4
		MD	0	8	27.3	0.3	5	15.6	0.3
		VA	152	758	249.9	3.0	82	107.6	0.8
		NC	328	9,747	723.3	13.5	19	2.4	7.8
		SC				0.0	0	0.0	0.0
		GA			0.0	0.0	1	0.1	8.3
		FL		0	2.4	0.0	6	10.4	0.6
		SEAMAP	99						
		Total	**992**	**11,306**	**1,236.9**	**9.1**	**234**	**340.8**	**0.7**
2001	Late	MA	0	0	0.1	0.0	0	0.0	0.0
		RI	178**	178**	38.9	4.6	0	0.0	0.0
		CT	69	0	2.7	0.0	1	2.2	0.5
		NY	0	372**	222.9	1.7	3	29.7	0.1
		NJ	0	0	271.8	0.0	362	452.7	0.8
		DE	861	0	2.7	0.0	59	27.8	2.1
		MD	193	261	68.2	3.8	294	241.9	1.2
		VA	420	1,806	280.6	6.4	106	61.7	1.7
		NC	220	3,199	158.8	20.1	161	69.4	2.3
		SC				0.0	0	0.0	0.0
		GA				0.0	2	1.2	1.6
		FL		0	2.5	0.0	17	7.6	2.2
		SEAMAP	151						
		NEFSC	617						
		Total	**2,699**	**6,003**	**1,049.2**	**5.7**	**1005**	**894.2**	**1.1**
2002	Early	MA	0	0	0.2	0.0	0	0.0	0.0
		RI	50	50	30.4	1.6	0	0.0	0.0
		CT	22	0	2.6	0.0	0	0.0	0.0
		NY	0	0	45.0	0.0	4	9.5	0.4
		NJ	0	0	92.4	0.0	101	229.0	0.4
		DE	561	1,179	54.9	21.5	201	81.1	2.5
		MD	20	21	11.0	1.9	12	10.8	1.1
		VA	328	2,399	325.8	7.4	110	39.9	2.8
		NC	231	9,121	691.8	13.2	47	7.9	5.9
		SC	0			0.0	0	0.2	0.0
		GA	0			0.0	0	0.0	0.0
		FL	0	0	1.6	0.0	17	21.2	0.8
		SEAMAP	122*			0.0			0.0
		CHESMAP	141			0.0			0.0
		Total	**1,478**	**12,770**	**1,255.7**	**10.2**	**492**	**399.5**	**1.2**

Table ZZ5.1-2 (continued). Biological sampling intensity by state and season for recent years.

			Commercial				Recreational		
Year	**Season**	**State**	**Ages**	**Lengths**	**Landings (MT)**	**Lengths / MT**	**Lengths**	**Landings (MT)**	**Lengths / MT**
2002	Late	MA	0	0	0.2	0.0	0	0.0	0.0
		RI	0	0	25.2	0.0	2	1.7	1.2
		CT	42	0	2.0	0.0	1	5.1	0.2
		NY	0	0	188.1	0.0	8	17.1	0.5
		NJ	0	0	299.0	0.0	164	321.7	0.5
		DE	760	0	23.5	0.0	58	29.2	2.0
		MD	44	216	44.8	4.8	58	68.2	0.9
		VA	318	4,170	211.2	19.7	141	94.1	1.5
		NC	281	3,642	130.8	27.8	59	29.6	2.0
		SC				0.0	7	22.6	0.3
		GA				0.0	1	0.3	3.2
		FL		0	1.1	0.0	21	5.7	3.7
		SEAMAP	153			0.0			0.0
		CHESMAP	550			0.0			0.0
		NEFSC	692			0.0			0.0
		Total	**2,838**	**8,028**	**925.9**	**8.7**	**520**	**595.2**	**0.9**
2003	Early	MA	0	0	0.2	0.0	0	0.0	0.0
		RI	0	0	8.4	0.0	0	0.0	0.0
		CT	4	0	4.6	0.0	0	0.0	0.0
		NY	0	0	30.6	0.0	1	11.6	0.1
		NJ	36	104	70.4	1.5	22	58.2	0.4
		DE	580	944	38.4	24.6	14	4.8	2.9
		MD	0	7	3.2	2.2	0	0.0	0.0
		VA	350	1,900	100.5	18.9	41	49.8	0.8
		NC	269	5,227	267.9	19.5	42	15.6	2.7
		SC				0.0	0	0.0	0.0
		GA				0.0	0	0.0	0.0
		FL		0	1.0	0.0	9	4.5	2.0
		SEAMAP	219*			0.0			0.0
		CHESMAP	78			0.0			0.0
		Total	**1,500**	**8,182**	**525.2**	**15.6**	**129**	**144.5**	**0.9**
2003	Late	MA	0	0	0.0	0.0	1	0.4	2.5
		RI	211	343	20.3	16.9	1	1.1	0.9
		CT	22	0	0.3	0.0	1	1.6	0.6
		NY	0	0	34.7	0.0	4	5.3	0.8
		NJ	29	0	83.6	0.0	38	93.2	0.4
		DE	372	0	3.1	0.0	23	21.5	1.1
		MD	202	276	11.1	24.9	17	11.2	1.5
		VA	323	2,226	108.1	20.6	49	47.9	1.0
		NC	220	3,523	114.1	30.9	89	57.6	1.5
		SC				0.0	2	2.0	1.0
		GA				0.0	3	0.6	5.0
		FL		0	0.2	0.0	13	5.6	2.3
		SEAMAP	0			0.0			0.0
		CHESMAP	595*			0.0			0.0
		NEFSC	0			0.0			0.0
		Total	**1,975**	**6,368**	**375.5**	**17.0**	**241**	**247.8**	**1.0**

Table ZZ5.1-2 (continued). Biological sampling intensity by state and season for recent years.

			Commercial				Recreational		
Year	**Season**	**State**	**Ages**	**Lengths**	**Landings (MT)**	**Lengths / MT**	**Lengths**	**Landings (MT)**	**Lengths / MT**
2004	Early	MA		0	0.0	0.0		0.0	0.0
		RI		0	5.5	0.0		0.0	0.0
		CT		0	0.3	0.0		0.0	0.0
		NY		0	20.8	0.0	1	0.7	1.4
		NJ		0	35.4	0.0	6	48.6	0.1
		DE	46	182	13.7	13.3		0.0	0.0
		MD	12	13	1.2	10.8		0.0	0.0
		VA	353	1,408	47.3	29.8	126	19.2	6.6
		NC	300			0.0	31	36.5	0.8
		SC				0.0	11	1.7	6.5
		GA				0.0	0	0.8	0.0
		FL				0.0	15	9.4	1.6
		SEAMAP	246			0.0			0.0
		CHESMAP	263			0.0			0.0
		Total		**1,603**	**124.3**	**12.9**	**190**	**116.9**	**1.6**
2004	Late	MA		0	0.0	0.0		0.0	0.0
		RI	4	0	11.9	0.0		0.0	0.0
		CT		0	2.5	0.0		0.0	0.0
		NY		0	47.4	0.0	4	8.0	0.5
		NJ		0	57.6	0.0	61	94.4	0.6
		DE	552	0	9.6	0.0	13	3.1	4.2
		MD	136	403	21.8	18.5	44	19.8	2.2
		VA	55	1,848	101.7	18.2	45	27.4	1.6
		NC	289			0.0	142	87.7	1.6
		SC				0.0	38	52.0	0.7
		GA				0.0	15	4.3	3.5
		FL				0.0	14	7.2	1.9
		SEAMAP	316			0.0			0.0
		CHESMAP	811			0.0			0.0
		NEFSC	476			0.0			0.0
		Total		**2,251**	**252.5**	**8.9**	**376**	**303.9**	**1.2**
2005	Early	MA		0	0.0	0.0		0.0	0.0
		RI	1	21	5.2	4.1	1	3.8	0.3
		CT		0	1.1	0.0		0.0	0.0
		NY		0	9.8	0.0		0.0	0.0
		NJ		0	22.7	0.0	2	8.3	0.2
		DE	43	572	21.8	26.3	12	9.6	1.3
		MD	18	18	0.8	23.4		0.0	0.0
		VA	217	1,000	55.4	18.0	294	5.0	58.8
		NC	284			0.0	37	13.2	2.8
		SC				0.0	0	0.1	0.0
		GA				0.0	25	3.0	8.3
		FL				0.0	13	36.8	0.4
		SEAMAP	185			0.0			0.0
		CHESMAP	99			0.0			0.0
		Total		**1,611**	**116.7**	**13.8**	**384**	**79.8**	**4.8**

Table ZZ5.1-2 (continued). Biological sampling intensity by state and season for recent years.

			Commercial				Recreational		
Year	**Season**	**State**	**Ages**	**Lengths**	**Landings (MT)**	**Lengths / MT**	**Lengths**	**Landings (MT)**	**Lengths / MT**
2005	Late	MA		0	1.3	0.0		0.0	0.0
		RI	59	59	13.7	4.3		0.0	0.0
		CT		0	1.6	0.0		0.0	0.0
		NY		0	31.3	0.0	6	0.3	20.0
		NJ		0	71.9	0.0	131	513.3	0.3
		DE	618	0	10.4	0.0	29	8.3	3.5
		MD	260	455	13.3	34.1	30	4.0	7.5
		VA	244	3,046	109.5	27.8	51	4.3	11.9
		NC	277			0.0	117	58.4	2.0
		SC				0.0	31	42.6	0.7
		GA				0.0	4	0.5	8.0
		FL				0.0	25	8.5	2.9
		SEAMAP	285			0.0			0.0
		CHESMAP	1005			0.0			0.0
		NEFSC	594			0.0			0.0
		Total		**3,560**	**253.1**	**14.1**	**424**	**640.2**	**0.7**
2006	Early	MA		0	0.6	0.0		0.0	0.0
		RI	5	0	5.6	0.0		0.0	0.0
		CT		0	2.7	0.0		0.0	0.0
		NY		0	17.6	0.0	1	4.6	0.2
		NJ	43	350	19.3	18.1	17	55.7	0.3
		DE	79	117	10.5	11.2	5	3.5	1.4
		MD		3	0.3	9.1		0.0	0.0
		VA	360	1,738	45.2	38.5	51	22.5	2.3
		NC	396			0.0	95	27.4	3.5
		SC				0.0	3	0.6	5.0
		GA				0.0	0	0.9	0.0
		FL				0.0	37	22.7	1.6
		SEAMAP	120			0.0			0.0
		CHESMAP	167			0.0			0.0
		Total		**2,208**	**101.7**	**21.7**	**209**	**137.9**	**1.5**
2006	Late	MA		0	3.3	0.0		0.0	0.0
		RI	38	38	15.0	2.5	3	17.5	0.2
		CT		0	0.5	0.0		0.0	0.0
		NY		0	51.7	0.0	4	1.7	2.4
		NJ	256	379	74.6	5.1	69	203.6	0.3
		DE	481	0	5.2	0.0	11	5.2	2.1
		MD	180	494	14.4	34.3	0	0.3	0.0
		VA	253	3,540	66.1	53.6	8	1.0	8.0
		NC	341			0.0	149	35.8	4.2
		SC				0.0	75	3.0	25.0
		GA				0.0	1	0.5	2.0
		FL				0.0	13	10.6	1.2
		SEAMAP	197			0.0			0.0
		CHESMAP	550			0.0			0.0
		NEFSC	995			0.0			0.0
		NEAMAP	494						
		Total		**4,451**	**230.7**	**19.3**	**333**	**279.2**	**1.2**

Table ZZ5.1-2 (continued). Biological sampling intensity by state and season for recent years.

			Commercial				Recreational		
Year	**Season**	**State**	**Ages**	**Lengths**	**Landings (MT)**	**Lengths / MT**	**Lengths**	**Landings (MT)**	**Lengths / MT**
2007	Early	MA			0.2	0.0		0.0	0.0
		RI			4.1	0.0		0.0	0.0
		CT			0.6	0.0		0.0	0.0
		NY			14.2	0.0		0.0	0.0
		NJ			53.6	0.0	8	23.5	0.3
		DE			9.9	0.0	2	0.6	3.3
		MD			1.9	0.0		0.0	0.0
		VA		997	94.1	10.6	4	6.6	0.6
		NC				0.0	14	3.9	3.6
		SC				0.0	25	2.3	10.9
		GA				0.0	4	1.3	3.1
		FL				0.0	11	8.8	1.3
		SEAMAP				0.0			0.0
		CHESMAP				0.0			0.0
		Total		**997**	**178.6**	**5.6**	**68**	**47.0**	**1.4**
2007	Late	MA			0.0	0.0		0.0	0.0
		RI			5.3	0.0		0.0	0.0
		CT			0.3	0.0		0.0	0.0
		NY			25.1	0.0	0	3.7	0.0
		NJ			20.2	0.0	30	111.2	0.3
		DE			1.2	0.0	6	1.4	4.3
		MD			6.2	0.0	7	8.8	0.8
		VA		1,831	56.8	32.2	5	15.2	0.3
		NC				0.0	65	53.0	1.2
		SC				0.0	150	18.6	8.1
		GA				0.0	5	0.4	12.5
		FL				0.0	27	51.3	0.5
		SEAMAP				0.0			0.0
		CHESMAP				0.0			0.0
		NEFSC				0.0			0.0
		Total		**1,831**	**115.1**	**15.9**	**295**	**263.6**	**1.1**

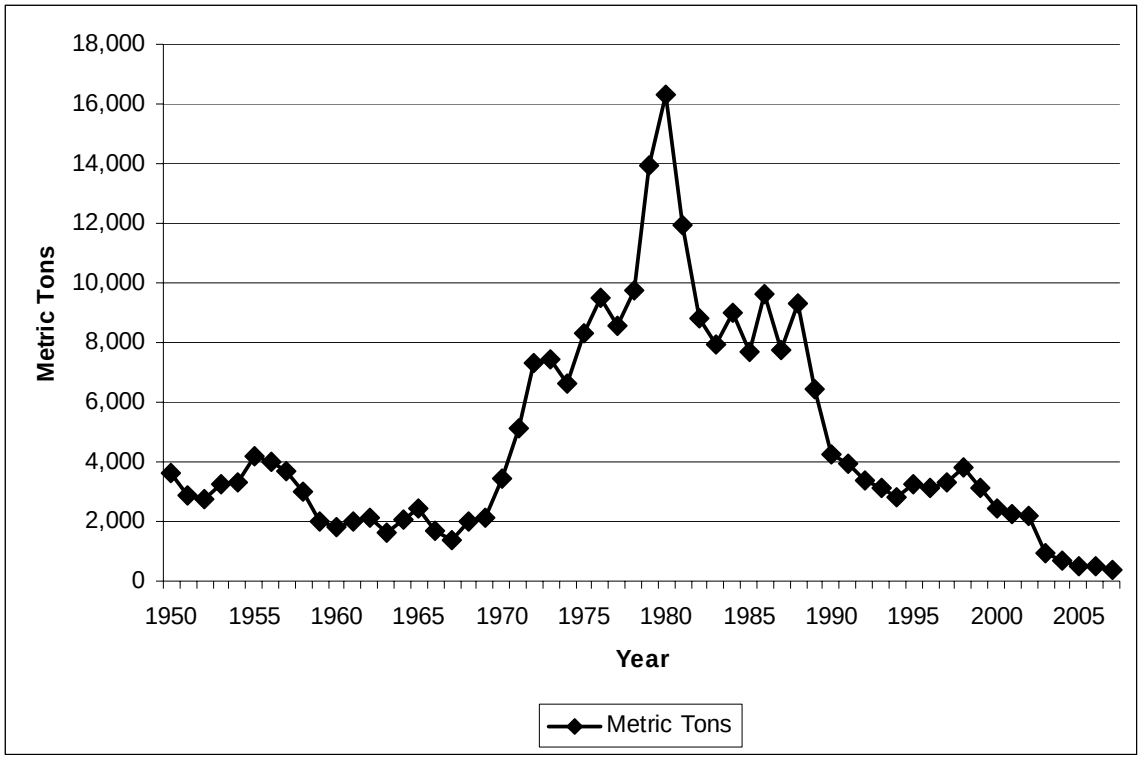


Figure ZZ4.6-1. Commercial harvest of weakfish on the Atlantic coast.

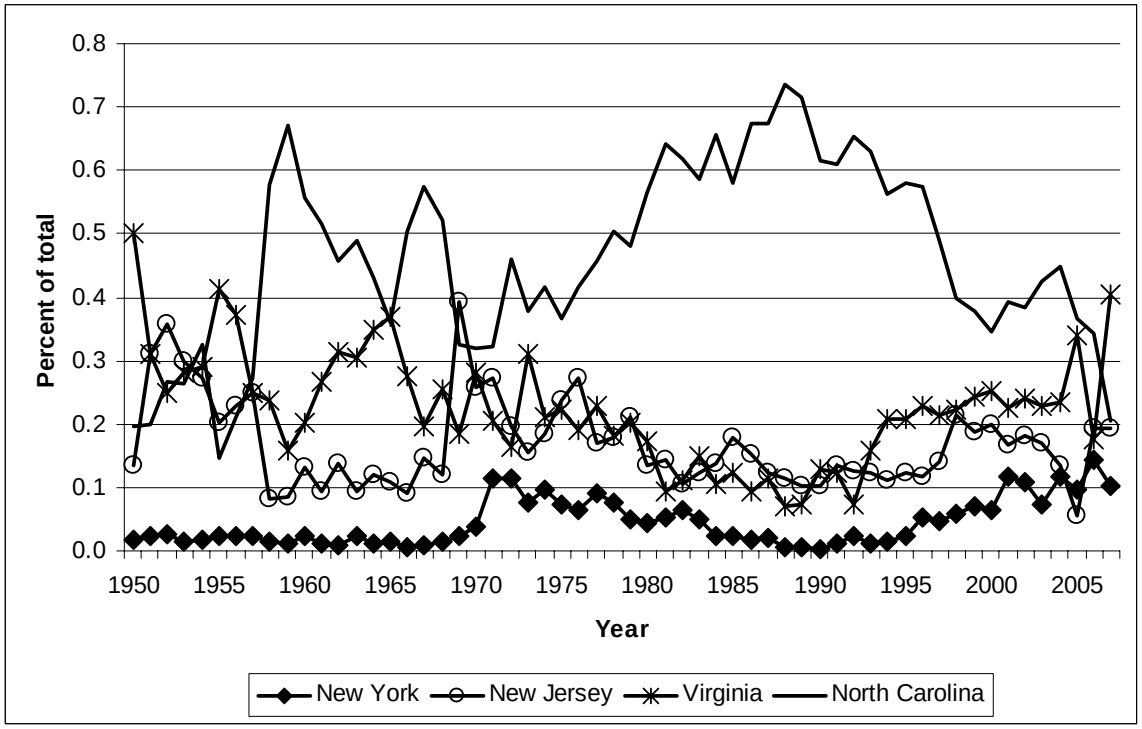


Figure ZZ4.6-2. Proportion of annual commercial weakfish harvest by dominant states.

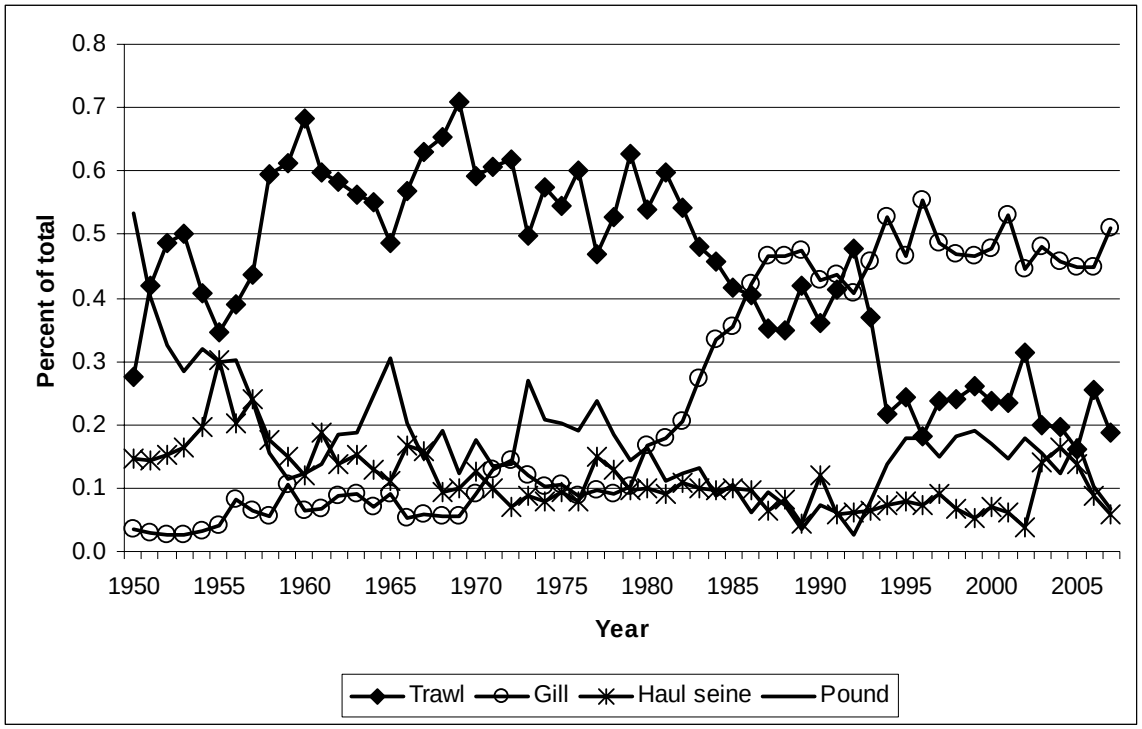


Figure ZZ4.6-3. Proportion of annual commercial weakfish harvest by dominant gears.

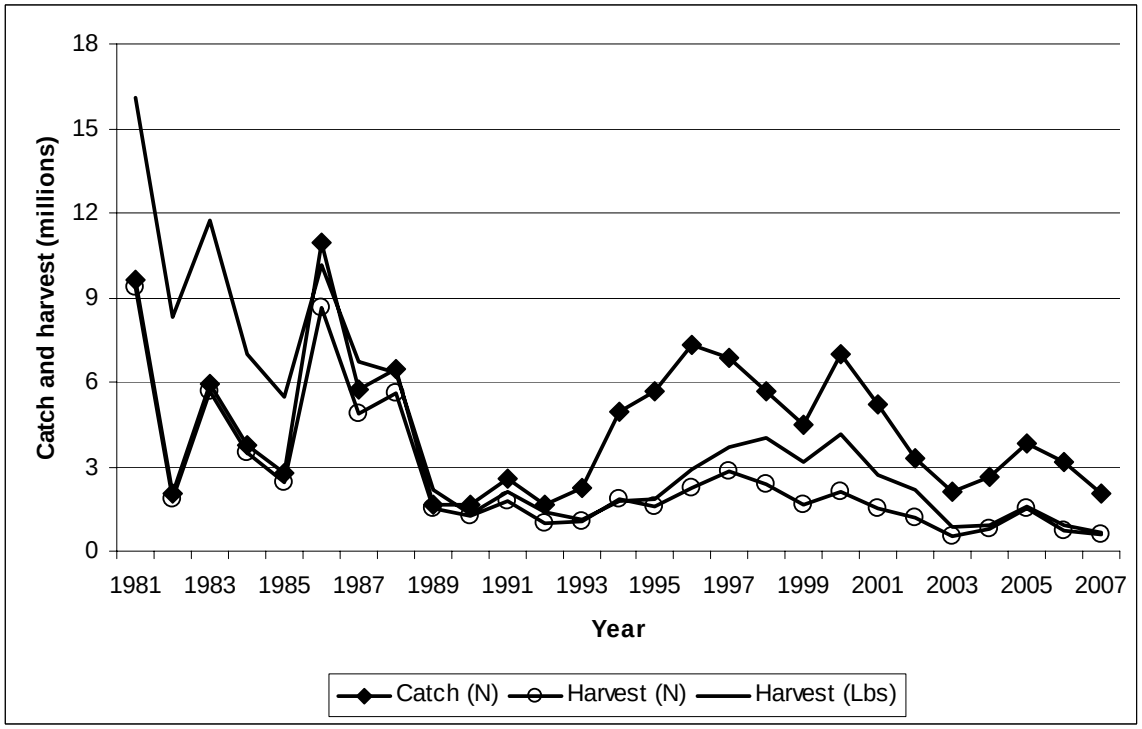


Figure ZZ4.6-4. Recreation catch (numbers) and harvest (numbers and pounds) of weakfish on the Atlantic coast.

Figure 4.6-5. Proportion of annual recreational weakfish harvest by dominant states. (Should this be a table instead?)

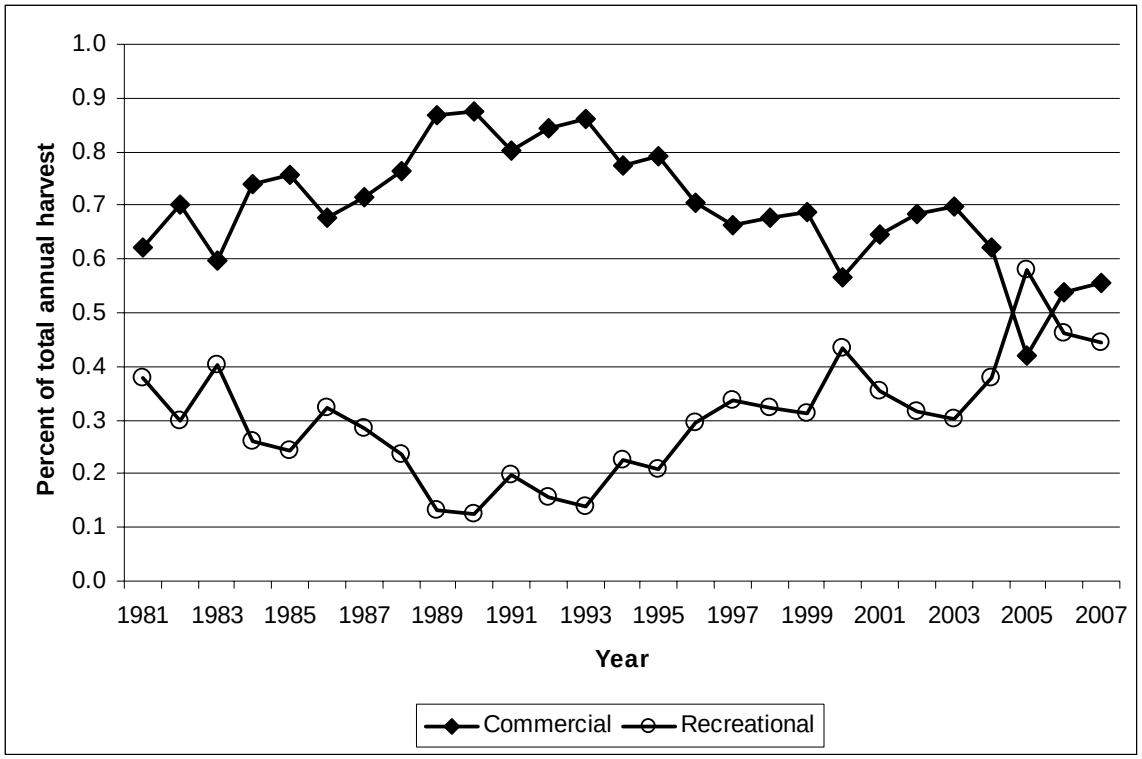
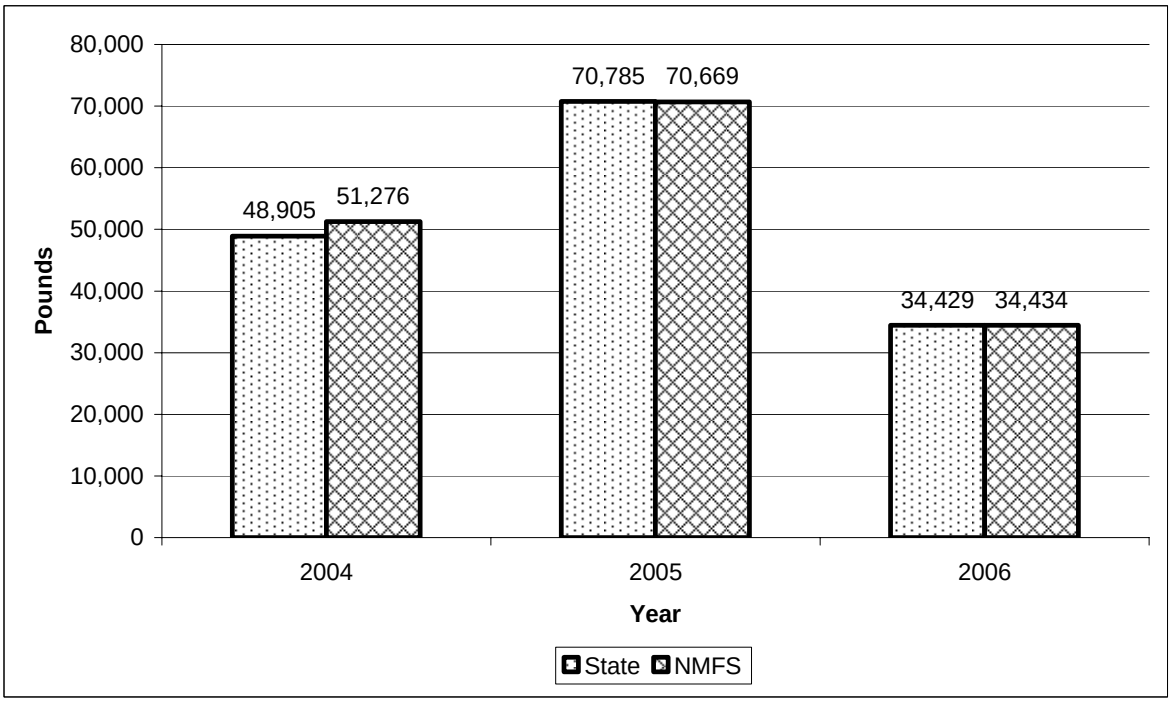


Figure 4.6-6. Proportion of total annual weakfish landings (excluding discards) by the commercial and recreational sectors.

Figure 5.1-1. Comparison of state and federally reported landings on an annual basis for A) Delaware and B) Virginia.

A)



B)

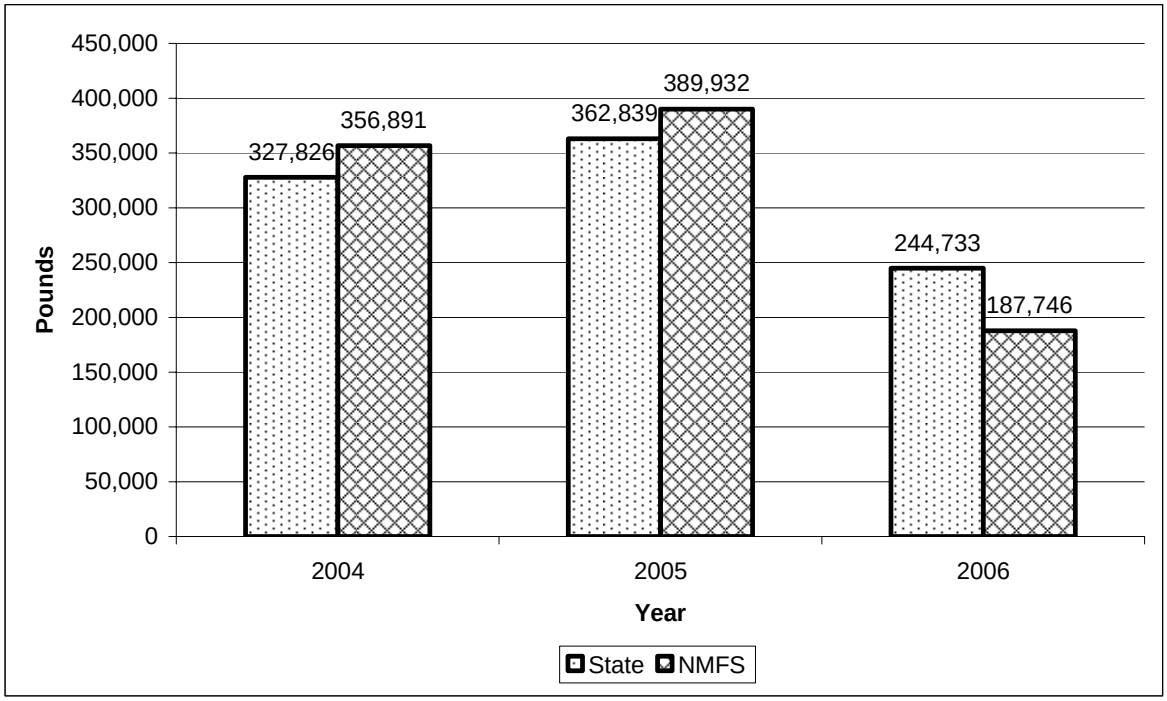
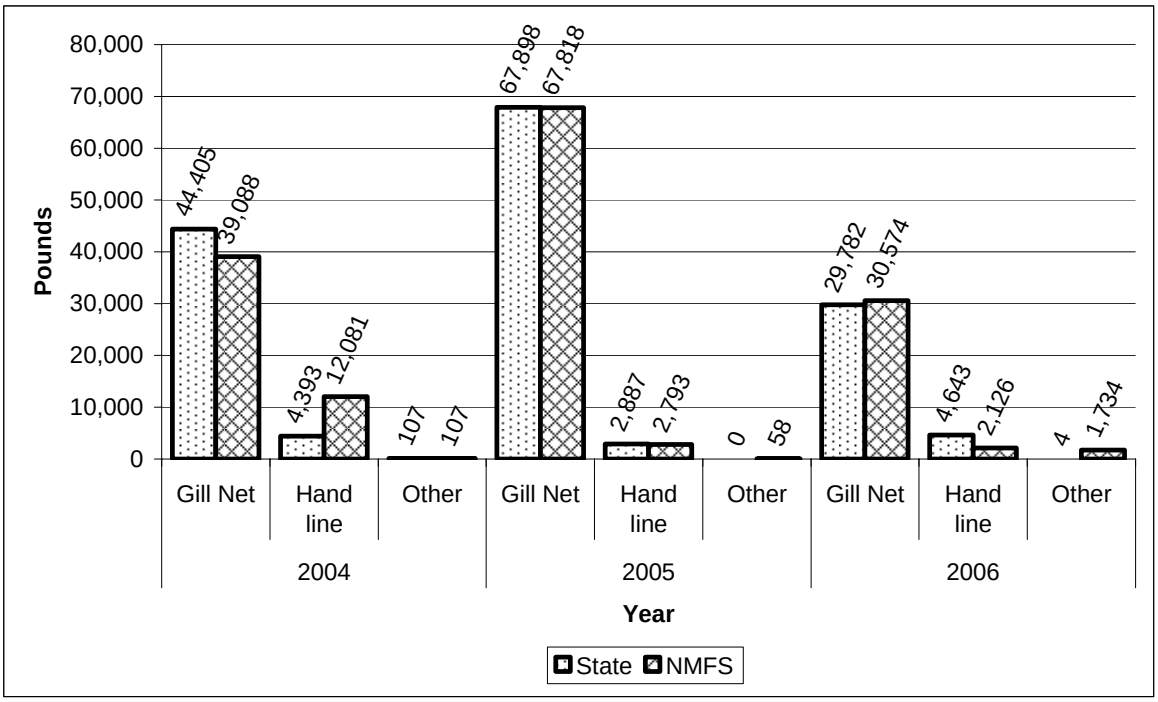
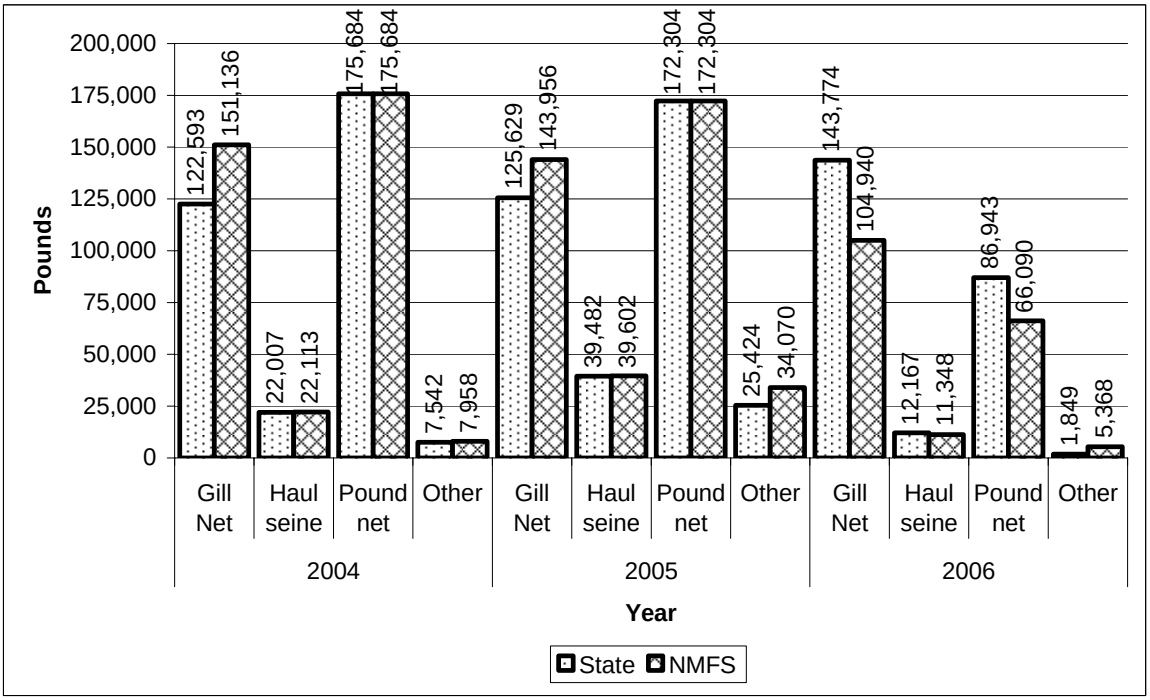


Figure 5.1-2. Comparison of state and federally reported data by gear for A) Delaware and B) Virginia.

A)



B)



Working Paper 2

Weakfish
Biomass Dynamic Models Summary

By
Jim Uphoff

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

FOR PEER REVIEW ONLY

WEAKFISH WP#2 (11/24/08)

Biomass dynamic models and external factor hypothesis testing

Jim Uphoff

November 13, 2008

Note that a four index logistic biomass dynamic model (fishing only) was developed and rejected by the TC as implausible (stock at carrying capacity and very low F). This summary describes model development after that effort.

Indices
Last time
One index.
MRFSS weight per trip 1981-2003.
Released fish and harvest mean weights based on harvest mean weight.

This time
Three indices
1. MRFSS weight per trip 1981-2006.
    Released fish assigned headboat release weight (constant at 0.15 kg).
    Harvested fish use harvest mean wt.
2. Two survey indices; mean wt confined to exploitable sizes (25 cm+)
2. Delaware trawl survey kg per trawl 1990-2006.
3. NJ August positive tows * mean wt 1989-2006.
4. Indices standardized as Z transformation+2 for time period in common (1990-2006).
5. Indices compatible: positively correlate with each other, landings, converged portion of best previous VPA.

Harvest from NMFS and MRFSS

Discards
Recreational (number discard estimate*mortality* mean wt).
Last time – 20% release mortality and mean wt = harvest wt.
This time – 10% release mortality and mean wt = head boat estimate (constant 0.15 kg).

Commercial
Last time – Annual discard ratio estimates.
This time – All year discard ratio estimates.

External Factors
Based on previous analyses of environmental and predator/competitor candidates by Crecco or Uphoff.
Candidate external factors considered: striped bass, spiny dogfish, Atlantic croaker, bluefish, summer flounder, forage fish, sea temperature, NAO.
Selection of final candidates considered spatial-temporal overlap, diet information, statistical analysis, modeling.

Previous Final External
Striped bass age 2+ biomass from VPA (1981 = 1982-1984 mean).

Current Final External
Striped bass age 2+ biomass from ASMFC SCAM (1981 = 1982-1984 mean).
Menhaden age 1+ biomass from ASMFC forward projection.

Hypotheses
Tested with 3 to 5 parameter models.

Last time 3 hypotheses
1. Logistic production fc.
2. Fishing only (1 of 3).
3. Fishing + striped bass Type 3 predator-prey fc (2 of 3).
3. Fishing + striped bass depensatory fc; bass*scalar (miss-labeled as Type 1 fc; 3 of 3).

This time 12 hypotheses
1. Logistic and Gompertz production fc's with 6 variations each (2 fc*6 external = 12).
2. Fishing only (1 of 6 external).
3. Fishing + Type 1-3 predator-prey fc (2-4 of 6 external).
4. Fishing + striped bass depensatory fc; bass*scalar (5 of 6 external).
5. Fishing + depensatory as menhaden:bass fc (6 of 6 external); formalizes hypothesis developed in previous biomass dynamic predator-prey.

Last time goodness of fit
SSQ, r-square, residuals, biology.

This time goodness of fit
AICc added to above.

Last time relative F vs model F
Harvest related losses / MRFSS index rescaled to Converged VPA (Crecco's rescaled relative F).

This time relative F vs model F
(Harvest related losses * model index scalar) / mean Z+2 index.
Crecco's rescaled relative F can be added once finalized.

Implemented in spreadsheet with Evolver genetic algorithm (Palisade Corporation) both assessments.

Minimize lognormal error in predicted and observed indices.

Output
F, predation/competition losses, nonequilibrium M, biomass, surplus production, production, equilibrium and non-equilibrium reference points.

Projections can be made.

Working Paper 3

Weakfish
Predation Models Summary

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

-For Peer Review Only- **WEAKFISH WP#3**

(11/24/08)

Weakfish Predation Models Summary

Additional analyses for the weakfish stock assessment include several new and updated approaches. Time series (1981-2007) of weakfish age aggregated (ages 1+) *F* and stock biomass (mt) estimates were derived in the new assessment based on blended relative abundance indices from the MRFSS mid-Atlantic private boat fishery, the August NJ trawl survey, and the DE trawl survey.

1) New Analysis - Ricker stock recruitment (S-R) modeling that included the coast-wide blended recruitment index for the 1981 to 2007 year-classes against spawning stock size (mt) that consisted of the age aggregated (ages 1+) biomass (mt) estimates from the index-based analysis. This nonlinear model was run alone and in combination with a blended index of predation (Tpred) consisting of the time series of coast-wide striped bass and spiny dogfish abundance. When the Ricker model was run without predation effects, the statistical fit to the S-R data was strong (high coeifficient of determination and low standard errors about the parameter estimates), but a significant serial correlation in the residuals was noted, indicating serious process error. When the Ricker model was fitted to S-R data in the presence of Tpred, the fit was strong, the precision of the parameter estimates was higher, and most importantly, the residual pattern became random over time, suggesting that enhanced predation of age 0 weakfish (emergence of a demographic bottleneck) by striped bass and spiny dogfish is an important process in the current weakfish stock-recruitment relationship.

2) New Analysis - Comprehensive screening of potential candidate predators (striped bass, spiny dogfish, bluefish and Summer flounder), environmental factors (mean summer (July-September) sea surface water temperature and deviations in the winter North Atlantic Oscillation index) and fishing-related effects (discards (mt) and discard-related F) against several response variables (weakfish surplus production, index of weakfish biomass and juvenile weakfish mortality) using a Pearson correlation matrix and stepwise multiple regression methods in SAS. Results revealed that only striped bass and spiny dogfish abundance was significantly ($P < 0.001$) linked to the recent (post 1998) rise in weakfish juvenile mortality and corresponding decline in weakfish biomass and surplus production.

3) Updated Steele-Henderson (S-H) model runs for Atlantic coast weakfish with and without predatory (Tpred) effects from 1981 to 2007. Another run with the S-H model includes the potential effects of declining menhaden abundance, as a secondary prey effect, on the recent rise in predatory mortality of striped bass on weakfish.

4) Updated (through 2007) equilibrium and non-equilibrium overfishing (Fmsy, Bmsy) estimates and their 95% confidence limits for weakfish based on results from the updated Steele-Henderson model. Results reveal that Atlantic coast weakfish is severely depleted by enhanced predatory mortality but is not overfished.

Working Paper 4

Weakfish
Stock Assessment Report

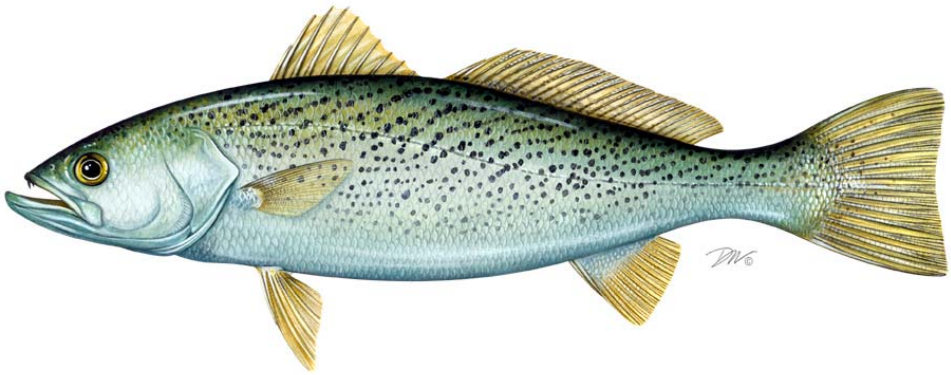
Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

Atlantic States Marine Fisheries Commission

2006 Weakfish Stock Assessment

Weakfish Stock Assessment Report
Terms of Reference and Advisory Report
Technical Committee Supplemental Material



December 2006

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

ACKNOWLEDGEMENTS

The Atlantic States Marine Fisheries Commission (ASMFC) thanks all of the individuals who contributed to the development of the weakfish stock assessment and the peer review of the assessment. The Commission extends its appreciation to the Weakfish Stock Assessment Peer Review Panel for its efforts in evaluating the stock assessment and developing the Terms of Reference and Advisory Report: Dr. Brian Rothschild, Panel Chair, University of Massachusetts - Dartmouth; Dr. Steven Cadrin, NOAA/UMass Cooperative Marine Education and Research Program; Dr. Steven Martell, University of British Columbia; and Dr. Ransom Myers, Dalhousie University.

The Commission also thanks the ASMFC Weakfish Technical Committee (TC) and Weakfish Stock Assessment Subcommittee (SAS) for developing the consensus stock assessment report, especially Dr. Desmond Kahn (Chair, Weakfish Stock Assessment Subcommittee; Delaware Department of Natural Resources), Dr. Vic Crecco (Connecticut Department of Environmental Protection) and Jim Uphoff (Chair, Weakfish Technical Committee; Maryland Department of Natural Resources) for their presentations of the stock assessment to the Peer Review Panel. Additional members of the Weakfish Stock Assessment Subcommittee include Jeffrey Brust (New Jersey Department of Environmental Protection), Brian Murphy (Rhode Island Department of Environmental Management), Robert O'Reilly (Virginia Marine Resources Commission), Lee Paramore (North Carolina Division of Marine Fisheries), and Douglas Vaughan (National Marine Fisheries Service – Beaufort). Additional gratitude is due to the TC and SAS members that continued work on the assessment after the peer review to complete the follow-up tasks assigned by the Weakfish Management Board.

Appreciation is given to the Commission staff dedicated to the performance of the Weakfish Stock Assessment Peer Review and the finalization of this report, specifically – Brad Spear, Joe Grist, and Patrick Kilduff.

This is a report of the Atlantic States Marine Fisheries Commission pursuant to U.S. Department of Commerce, National Oceanic and Atmospheric Administration Award No. NA05NMF4741025.

PREFACE

This document contains the following reports:

Section A – Stock Assessment
Weakfish Stock Assessment Report for Peer Review (Part 1)
(ASMFC Weakfish Stock Assessment Subcommittee, February 2006)

Weakfish Stock Assessment Report for Peer Review (Part 2) – An Ecological Assessment of Weakfish: Examination of Fishing and Trophic Effects on the Recent Stock Decline
(ASMFC Weakfish Stock Assessment Subcommittee, February 2006)

Section B – Peer Review
Terms of Reference and Advisory Report to the Weakfish Stock Assessment and Peer Review
(ASMFC Weakfish Stock Assessment Peer Review Panel, April 2006)

Section C – Supplemental Material Requested by the Weakfish Management Board
Implementation of 40th SARC Recommendations
(ASMFC Weakfish Technical Committee, June 2006)

Summary of Weakfish Technical Committee (TC) agreements and disagreements with the 2006 peer review and the record of implementing recommendations of the 40th SARC
(ASMFC Weakfish Technical Committee, July 2006)

Executive Summary: How Much Additional Discarding and Under-Reporting are Necessary to Cause the Decline in Weakfish?
(Uphoff, J., June 2006)

Executive Summary: Estimating at-sea discards of weakfish using NEFSC observer database
(ASMFC Weakfish Technical Committee, July 2006)

The weakfish population structure along the Atlantic coast: a literature review
(Munyandorero, J., July 2006)

Overview of the Weakfish Resource
(Uphoff, J., August 2006)

What's Next with Weakfish? Fishery Status & Board Requests (presentation)
(ASMFC Weakfish Technical Committee, August 2006)

EXECUTIVE SUMMARY

The first peer review of a weakfish stock assessment was conducted in 1996 by the Stock Assessment Review Committee (SARC) at the 26th Northeast Regional Stock Assessment Workshop (SAW). The Review Committee did not approve the assessment and recommended that future assessments be conducted using ADAPT VPA. (Assessments up to that time had employed CAGEAN and Extended Survivor VPA, among other catch-at-age models.) The subsequent assessment, including data through 1998, was peer reviewed at the 30th SAW/SARC, which concluded that results of the ADAPT VPA could be used to calculate biological reference points and that figures illustrating the expanded size and age composition of weakfish would be useful for developing management advice. However, the Review Committee did find a noticeable retrospective bias in the ADAPT results which overestimated stock size and underestimated fishing mortality in the last few years.

A stock assessment update was conducted in 2002 (with data through 2000) using the SARC-approved methodology. Although this assessment was not peer reviewed, the Weakfish Technical Committee (TC) expressed concern about a strong retrospective bias that may have resulted from some shortcomings in the assessment data and model.

In 2003, the Weakfish Stock Assessment Subcommittee (SAS) began preparation for a 2004 peer review through the 40th SAW. Model results using the previously approved SARC methodology still exhibited a strong retrospective pattern, and results from both ADAPT VPA and a biomass dynamic model portrayed the stock as at very high levels, carrying capacity in the case of the biomass dynamic model, with very low fishing mortality. In light of the fishery landings having dropped to record low levels, the model results were not deemed credible.

For these reasons, the SAS deemed the ADAPT VPA methodology as insufficient to characterize the weakfish resource and proceeded to investigate alternative assessment methods. Although the revised weakfish assessment was incomplete at the time of the peer review, the SARC agreed to review the work and provide guidance on issues that were impeding the progress of the assessment, such as the inconsistency between survey indices, some of which portrayed an increase in abundance, and fishery-dependent indices of abundance and catch-at-age, which had declined significantly.

The Review Committee agreed with the SAS that the results of the work in progress, although using the same approach as the SARC-approved assessment in 1999, were not suitable for management at present. The Review Committee indicated that they felt the problem was conflicting data, and expressed skepticism about the reliability of some survey indices, especially the Northeast Science Center Fall Survey. Recommendations from the SARC proved to be useful, and some were incorporated into the stock assessment. The assessment was also expanded to include some alternative approaches previously explored by the SAS in the 2002 update process.

The stock assessment was completed in February 2006 (See Section A). The assessment was submitted to the Commission and was evaluated through the Commission's external peer review process on March 20-22, 2006 in Providence, RI. The Peer Review Panel consisted of four

fisheries biologists with expertise in population dynamics and stock assessment methods. The stock assessment was reviewed relative to the following Terms of Reference:

1. Characterize commercial and recreational catch including landings and discards.
2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.
3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.
4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.
5. Review the estimated biological reference points, as appropriate.
6. Review stock projections.
    - Review the projection of impacts on the stock of recent estimated rise in fishing mortality.
    - Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.
7. Make research recommendations for improving data collection and assessment.

The Panel reviewed the 2006 Weakfish Stock Assessment and did not endorse the recommendations within the assessment report regarding stock status of weakfish along the Atlantic coast (see Section B). The Panel identified several issues that required additional work or attention by the Weakfish TC before they would support its use for management purposes. In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards.

The Weakfish Management Board directed the Weakfish TC to address the issues identified by the Review Panel. Specifically, the Board tasked the TC with furthering investigating stock structure and discards; determining agreements and disagreements among the assessment report, the peer review panel report, and the 40th SARC report; and providing an account of the implementation of recommendations from the 40th SARC.

Final Results

In August 2006, the Weakfish TC provided a response to the Board tasks (see Section C). Based on these responses, the TC's analyses, and significant evidence, **the Board accepted the following five points for management use**:

1) the stock is declining,
2) total mortality is increasing,
3) there is not much evidence of overfishing,
4) something other than fishing mortality is causing the decline in the stock, and
5) there is a strong chance that regulating the fishery will not, in itself, reverse stock decline.

WEAKFISH STOCK ASSESSMENT REPORT FOR PEER REVIEW (PART 1)

February 2006

BY

THE ASMFC WEAKFISH STOCK ASSESSMENT SUBCOMMITTEE

Desmond M. Kahn, Chair
Jim Uphoff, Vice-Chair
Victor Crecco
Douglas Vaughan
Brian Murphy
Jeffrey Brust
Robert O'Reilly
Lee Paramore

Note: an external peer review panel did not endorse the recommendations within this assessment report. For more information see the Peer Review Report (Section B), and the Weakfish Technical Committee's responses to that report (Section C).

ACKNOWLEDGEMENTS

Brad Spear of ASMFC has been helpful in many ways. We appreciate the substantial work done by Harry Rickabaugh of Maryland DNR and Patrick Kilduff of the ASMFC staff in developing the catch at age and weight at age estimates. We thank Robin Cook, Peter Shelton, Norman Hall, John Casey and Terry Smith of the 40th SARC for their helpful comments and analysis. Alan Seaver of the North East Fisheries Science Center has been very helpful on ADAPT software issues.

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EXECUTIVE SUMMARY

This assessment covers the period of 1982 through 2003 for catch-at-age analysis and biomass dynamic modeling and 1982-2004 or, conditionally, 2005, for some other approaches. The last peer-reviewed assessment covered 1982-1998 (NEFSC 2000). In 2002, an update was conducted which covered 1982 – 2000.

Recreational landings have been in decline since 2000, while commercial landings have been in decline since 1998. From 2000 through 2003, commercial landings were the lowest in the period. The 2003 recreational landings were the lowest in the period; the previous low point was in 1993. These declines suggest that abundance has declined. One or two of the research trawl surveys, however, contradict the picture that abundance has declined to very low levels, but those surveys show evidence of large year-to-year effects in weakfish availability, which reduces their value as indicators of trends in relative abundance. All variants of the recreational CPUE indices have been declining since about 1998.

Cohort catch curves of the catch-at-age matrix indicated that mortality had been relatively high for cohorts from the 1980s, declined to low levels for year classes born in the early 1990s, but then increased to very high mortalities for year-classes produced from the mid-late 1990s. Since Z was about 1.4 for recent year classes, subtraction of an assumed constant M = 0.25 indicated that F has increased greatly for these cohorts to levels of 1.15 or so. This pattern in Z of a decline in the early 1990 year classes followed by an increase was significantly correlated with the pattern found in cohort catch curve estimates of the Delaware trawl survey indices of relative abundance.

As in past assessments using ADAPT, retrospective bias was present in all ADAPT runs, meaning estimates of variables such as F and stock size were unstable for recent years, changing as additional years of data are added or subtracted. These biases occurred in opposite directions when either survey indices or recreational CPUE indices were employed. Model configurations using recreational CPUE indices of relative abundance as tuning indices, however, showed more recent stability than runs without these indices. Depending on the tuning indices selected, stable estimates of F and biomass are available from 1982 through about 1997 to 2000. Assuming M = 0.25, estimated fully-recruited F dropped sharply in 1995. For run #14 using trawl indices for tuning, F dropped to 0.26 in 1995, then rose to 0.40 in 1996 and about 0.36 in 1997 and 1998. After that, retrospective bias makes estimates unstable. The estimates of F decline to 0.03 in 2003, however. For run #20 using the recreational CPUE indices, fully recruited F dropped to 0.32 in 1995, then increased to 1.06 in 2000, the last year with relatively stable estimates. For this run, in contrast to the run with trawl survey indices, estimated F climbs to 1.6 – 1.5 in 2002-2003. Estimated SSB from ADAPT climbed above the SSB threshold estimated in the currency of the 2002 assessment update of 14,400 metric tons in 1994 with the trawl survey indices (run #14) and increased to 31,628 metric tons in 1997, higher than any previous year. Later year's estimates are unstable, but climb to 125,843 mt by 2003. For the run tuned to the recreational CPUE indices (run #20), SSB approached the threshold from below in 1994 and 1996, but did not exceed it until 1996. SSB climbed to a peak in 1997 of 18,752 mt, then declined to 6,260 mt in 2000. Estimates for late years are unstable, but declines by 2003 to 2,573 mt, lowest by far in

the time series. The lack of stable recent estimates from ADAPT considerably reduces its value for management.

When trawl survey exploitable biomass per tow was used as an index of stock biomass, a biomass dynamic model indicated that the stock reached very high levels of 37,000 – 39,000 mt by 1997 and remained there through 2003, near carrying capacity. Estimated biomass-weighted F from this model was very low in recent years (0.11 – 0.17 between 1994-2000), then dropped rapidly to 0.03 by 2003.

Reviewers from the 40th SARC reviewed the assessment as work in progress prior to development of the ADAPT runs with the recreational CPUE indices. They concluded that the models tuned to the trawl surveys revealed problems with the survey data and recommended extensive analysis of this data. Following their recommendation, we subjected each index to cohort catch curve analysis and found that two of the surveys produced negative Z estimates for recent cohorts.

We were forced to investigate alternative approaches due to the instability of recent years' estimates of F and SSB from ADAPT, and the unrealistic estimates from the biomass dynamic model and ADAPT tuned to survey indices. These models estimated recent extremely high biomass and very low F, despite severe declines in fishery catches. As a result, we estimated trends in fishing mortality as relative F, calculated as annual catch divided by an index of relative abundance averaged over two years. The index was a version of recreational catch per trip in weight (including discards), which had the advantage of great geographical coverage in contrast to most of the survey indices. One valuable attribute of relative F analysis is that it does not make assumptions about the amount or constancy of natural mortality. The general trends in relative F were confirmed when trawl survey exploitable biomass indices were used in place of the recreational CPUE index.

Biomass-weighted relative F estimates from 1982-2004 closely followed the trend in ages 1-5 biomass-weighted F from the converged portion of the ADAPT VPA models. We then converted these relative F estimates to absolute values of F by scaling them to the VPA F estimates for 1987-1991. Biomass weighted fishing mortality (FWt) estimates (ages 1+) on weakfish rose steadily from about 0.41 in 1982 to peak levels in 1988 (FWt = 1.08). The FWt estimates remained relatively high (FWt range: 0.60 to 0.81) from 1989 to1992 (Table 2), then declined steadily to below the 0.40 level in most years from 1993 to 2005. The 2004 and 2005 FWt estimates were around 0.25.

With time series of F and catch, we estimated stock biomass as catch/F. Biomass was high initially (34,010 mt in 1982), remained relatively high in the mid-1980s, then declined sharply in 1989 and remained below 10,000 mt through 1993. Stock biomass than began to rebuild, reached a secondary peak in 1998 (28,858 mt) and declined steadily to levels similar to those of the early 1990s, with the lowest level of the time series in 2004 (5,739 mt). We then developed a time series of surplus production estimates which indicated some recent years with negative production.

An external Gompertz production model provided a good fit ($R^2 = 0.68$) to the biomass data with statistically significant ($P < 0.05$) r and K parameter estimates. The resulting overfishing thresholds (Fmsy, Bmsy) for weakfish of 0.32 and 25,259 mt, respectively, were similar in magnitude to previous estimates. However, this production model consistently over predicted weakfish biomass from 1998 to 2005 by 10 to 50%. A full Steele-Henderson (S-H) production model including striped bass as a major predator was fitted by nonlinear least squares regression and also by iterative re-weighted least squares regression. Both S-H models provided very good fits ($R^2 = 0.88, 0.94$) to the biomass and predation data with statistically significant ($P < 0.05$) r, K, c and A parameter estimates. Overall, the S-H model was not only a better fit to weakfish biomass than the basic Gompertz model, but it also estimated the r and K parameters with much higher precision, particularly from iterative re-weighting.

The resulting weakfish overfishing thresholds (Fmsy, Bmsy) from the nonlinear least squares S-H model for weakfish were 0.59 and 21,179 mt, respectively. The overfishing thresholds (Fmsy,Bmsy) based on the iterative re-weighted S-H model were 0.55 and 23,400 mt, respectively and had higher precision than the nonlinear least squares fit. Moreover, unlike the severe residual pattern evident from 1998 to 2004 in the Gompertz model fit, there is little if any systematic residual pattern from the S-H model fitted by iterative re-weighting. The biomass-weighted F estimates after 1995 were all well below the overfishing definition (Fmsy = 0.55) from the S-H model. Weakfish biomass has been well below Bmsy = 23,400 mt since 2000 despite low and stable fishing mortality rates from 1995 to 2005.

Total mortality (Z) on Atlantic coast weakfish has risen steadily since about 1998, whereas fishing mortality (F) rates based on relative F were relatively low and stable during this period. Since total mortality (Z) each year was the sum of fishing and natural mortality, the recent rise in Z and ensuing failure in weakfish surplus production were more likely due to a recent increase in natural mortality. Most of the statistical evidence given herein supports the predation hypothesis as the most reasonable explanation for the recent rise in M and failure in weakfish productivity. Although results from regression and production models alone do not demonstrate causality, recent empirical evidence is consistent with a predation hypothesis involving striped bass. In addition, the apparent emergence of a weakfish recruitment bottleneck between ages 0 and 1 makes stock rebuilding via the implementation of additional management measures a difficult task.

We developed projections of weakfish stock biomass under a range of F levels, using an external production modeling approach that did not require an assumption of ecological stability. Z was considered to be the negative counterpart of the intrinsic rate parameter (r') and the Schaefer biomass dynamic model was reparameterized with the intrinsic rate of increase parameterized as (r' – Z) to project biomass into the future under current F levels, a 50% reduction and a complete moratorium. Results indicated that stock decline would continue even with a moratorium. However, continued current levels of F were projected to drive the stock to extinction within 10 years, while a 50% reduction would merely extend the time to extinction. A moratorium would eliminate extinction, but only a decline in M would allow stock rebuilding.

Part 2 of this assessment contains analyses that further examine the role of finfish predation and inter-specific competition on the recent rise in weakfish natural mortality. Several hypotheses

are offered to better interpret the intricate trophic pathways between weakfish and several candidate finfish species of importance in the mid-Atlantic region, including Atlantic menhaden, spot and bay anchovy, Atlantic croaker and striped bass. Our findings demonstrate that the potential impacts of predation and interspecific competition on weakfish and other exploited finfish stocks should be integrated into fisheries models and rigorously tested as a potential alternative explanation to the overfishing hypothesis.

TERMS OF REFERENCE

1. Characterize commercial and recreational catch including landings and discards.

2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.

3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.

4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.

5. Review the estimated biological reference points, as appropriate.

6. Review stock projections.
    - Review the projection of impacts on the stock of recent estimated rise in fishing mortality.
    - Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.

7. Make research recommendations for improving data collection and assessment.

INTRODUCTION

The management unit for weakfish is the Atlantic Coast. The fisheries for weakfish were largely unregulated until the 1990s, although some states had their own regulations. Weakfish are subjected to estuarine and near-shore fisheries from a variety of gears as they moved into and out of their estuarine spawning grounds. The largest landings, however, have historically occurred in the North Carolina fisheries targeting the overwintering aggregations off the Carolina coast. The Atlantic States Marine Fisheries Commission developed a Fishery Management Plan in 1985, which was first amended in 1992, but these plans were not mandatory. In 1993, Delaware and New Jersey instituted some management measures prior to most other states, but coastwide management measures were not implemented until 1995 when Amendment 2 to the Weakfish Fishery Management Plan was implemented under a mandatory basis governed by the Atlantic Coastal Cooperative Fisheries Management Act. Amendment 4 was passed in 2002 and made some relatively minor changes to regulations.

Commercial management measures include a minimum size of 12" (certain gears in certain states excepted), minimum mesh sizes to achieve the minimum size limits and effort restrictions designed to achieve a 32% reduction in fishing mortality from a baseline time-period (1990-1992) representing an unregulated fishery. All states but North Carolina have seasonal closures. North Carolina has an area closure (waters south of Cape Hatteras) instead. The plan also mandated bycatch reduction devices for the South Atlantic shrimp fishery, which required testing to demonstrate a 40% reduction in bycatch by number or a 50% reduction in bycatch mortality.

For the recreational sector, Amendment 3 included a varied set of recreational minimum size and creel limit combinations designed to provide incentives for conservation, based on equivalency in the currency of spawning stock biomass. For example, current regulations allow a 6 fish creel limit if a state has a 12" minimum size, an 8 fish creel limit if the minimum size is 13" (33 cm), a 10 fish creel limit if the minimum size is 14" (35.6 cm), etc. Northerly areas of the range tend to have larger fish, on average. Whether these larger fish are simply the product of northern habitat, or are larger, older fish from southerly areas that migrate north in the summer is not clear. Minimum sizes in New York and southern New England are 16" (40.64 cm) for both recreational and commercial fisheries, while states to the south have 13" minimums for recreational and 12" minimums for commercial, although some states have varied their recreational regulations within the suite of options offered in the FMP.

Weakfish have historically waxed and waned, according to landings records. For example, Bigelow and Schroeder (1953) report that during the latter part of the eighteenth century they were "…well known in Massachusetts Bay. But they vanished so completely sometime prior to 1800 that when a stray specimen was taken at Provincetown in June 1838, it was sent to Boston for identification. In the second half of the 1800s, they again became abundant off southern Massachusetts by 1870. Around 1900, a significant fishery developed in the southern Gulf of Maine with landings of 45 mt, in which 2 kg weakfish were abundant. Bigelow and Schroeder stated that "This marked the commencement of a period of local abundance, which was entirely unexpected (for nothing like it had been experienced since the settlement of the country), and which (with its equally sudden eclipse) is perhaps the most interesting event in the history of the local fisheries…during the summer of 1903 that the traps at North Truro alone reported 280,000 pounds (116 mt)." In 1906, when landings had begun to decline, "…the Cape Cod Bay traps (excluding Barnstable, Chatham, Yarmouth and Dennis) reported almost half a million pounds for that year (208 mt). By 1910 only 907 pounds were reported from the Gulf of Maine. Weakfish were completely absent in most years since that time in landings reports from the Gulf through the period covered by their 1953 report. They discuss a hypothesis that "weakfish are plentiful when bluefish are scarce…"

Joseph (1972) reported that as of 1967, "…weakfish stocks have been at record lows for the past few years." All the states north of Cape Hatteras collectively landed only 416 metric tons in 1967, whereas the "all-time high catch" was 14,969 mt in 1945. In the 1970s and early 1980s, large catches and large weakfish were common. Catch-per-unit effort estimates from Virginia data showed a large peak in 1936, not in 1945. This analysis indicated that weakfish had been continuously declining from 1945 to 1967. Joseph also cites Perlmutter et al. (1956) who stated that prior to 1910 the bulk of the weakfish catch was obtained north of Chesapeake Bay and were predominantly fish aged 3 and older, but by the 1920s, Virginia was taking more than half the

total catch. Virginia, however, as today, "has always depended on smaller and younger fish. This means that in 1945 the number of weakfish captured may have been as much as twice the number caught in 1908 when the landings were approximately the same by weight." Joseph then raises the possibility that this shift to higher numbers of younger fish could have led to recruitment overfishing. He also reported that the abundance of weakfish larvae in ichthyoplankton tows in lower Chesapeake Bay in 1959-1963 was less than one per tow, whereas Pearson (1941) had collected 25-67 larvae per tow in 1929-1930. Joseph advanced a hypothesis that the decline in weakfish stocks was caused by the3 advent of widespread use of DDT beginning in 1945. It was used for mosquito control in salt marshes as well as for agriculture.

Several Mid-Atlantic states had thousands of weakfish per year entered in their recreational tournaments, where the minimum sizes were as high as 4.4 kg. In 1981, coastwide landings were 19,000 metric tons (Table 2). From 1982 through 1988, landings fluctuated from 10,000 to 14,000 tons. Landings declined beginning in 1989, reaching a nadir of 3600 tons in 1993 and 1994. Landings then climbed to a second peak during1982-1988, declined rapidly in the early 1990s, rebuilt slightly through 1998, and finally declined to an all-time low by 2003.

Previous assessments

The stock assessment of weakfish was last updated in 2002 (Kahn 2002b) with data through 2000. That report focused on results from tuned virtual population analysis using ADAPT. The Weakfish Stock Assessment Subcommittee had also in hand several alternative approaches that we were exploring, including a relative exploitation analysis (Crecco 2002), biomass dynamic model (Uphoff 2002a) and Integrated Catch at Age model (separable VPA: De Silva 2002). The ASMFC Weakfish Management Board, however, requested that we update the ADAPT model, since that had been used for the 1999 stock assessment, which had been approved by the Stock Assessment Review Committee meeting at the Northeast Fisheries Science Center in late 1999 (NEFSC 2000).

The 2002 assessment update had a serious problem with severe retrospective bias in the ADAPT results. This problem was uncovered by retrospective analysis, where the model was run with the most recent year of data removed; this was done repeatedly going back for several years. The estimates of fully-recruited fishing mortality and spawning stock biomass for a given year were then compared over the runs to see if they changed as additional years of data were included. While it has often been stated that the most recent year's estimates from VPA are the least certain, the retrospective analysis of the 2002 model showed that the uncertainty extended back for several years. A distinct pattern was apparent; as additional years of data were added, the estimate of F for a given recent year increased substantially. Conversely, estimated SSB declined by 50%. For example, when 1996 was the terminal year (all data after 1996 deleted), the estimate of fully recruited $F_{1996} = 0.17$. After the addition of four years of data through 2000, the estimate of F_{1996} rose to 0.32, an 88% increase. The estimate of $SSB_{1996} = 40{,}379$ metric tons (mt) when 1996 was the terminal year. When data through 2000 was included, the estimate of SSB_{1996} declined to 27,134 mt, which was a 33% decline. This bias extended back 7 years to the 1993 estimates. The estimated $SSB_{1993} = 12{,}164$ mt when 1996 was the terminal year. When data through 2000 was included, this estimate declined by 27% to 8,884 mt.

The assessment approved by the SARC had a similar retrospective bias which was discussed in the report (NEFSC 2000). Essentially the retrospective bias means that estimates of management parameters for recent years are unstable and hence unreliable. As part of the 2002 assessment process, Uphoff (2002b) presented a bias correction approach for the retrospective pattern, but such corrections are dependent on the assumption that the bias pattern in estimates of several years back will continue into the new terminal year estimates. Previous assessments had used untuned VPA, Cagean and Extended Survivors VPA. The 26th SARC reviewed an earlier assessment in 1998 but did not approve the catch at age modeling effort in that assessment. The 26th SARC recommended that ADAPT be used for the catch-at-age analysis.

Review of work in progress by the 40th SARC

The 40th SARC meeting in November 2004 reviewed the current assessment as a work in progress, after we made it clear that we did not have a completed assessment in November 2004. One of the SARC reviewers commented on development of the catch-at-age matrix after discussing the need to estimate catch at age from different states with different minimum sizes and from the recreational data obtained from NMFS that, "Because of the nature of this fishery, this is a complex undertaking." (Shelton 2004). The SARC agreed that "the current status of the assessment was insufficient as a basis for providing advice."(Cook undated). The SARC found there were conflicting signals from the research trawl surveys which tended to indicate higher abundance versus the catch or catch-based indices, which indicated declining abundance. The SARC recommended analysis of the various surveys and exclusion of any that are not internally consistent or that portray unrealistic variation or strong year-to-year variation. The SARC also recommended that the assessment proceed by stating various hypotheses about stock status with implied management action, then evaluating which evidence and analyses support the various hypotheses. This approach of exploring alternative hypotheses dealing with conflicting data is also recommended by Hilborn and Walters (1992, pp. 491, 536) and Schnute and Hilborn (1993).

A decision table for weakfish management lays out 3 basic hypotheses: stock increase, stock stability and stock decline (Table 1A). The table lays out potential likely stock responses for each hypothesis to three general management approaches: restricting harvest, status quo and liberalizing harvest. In general, in the case of stock decline, restriction would pose the best chance of reducing or stemming the decline. In the case of stock stability, status quo seemed reasonable, and in the case of stock increase, liberalization would be reasonable, although not required. In contrast, liberalization or status quo may increase the chance of further stock decline, if that hypothesis is correct. We attempt to summarize the evidence supporting each hypothesis in Table 1B.

LIFE HISTORY

Weakfish are an important sciaenid species of the Atlantic coast with its primary range from North Carolina in the upper southeast through southern New England. It is also encountered south to Florida. Weakfish are primarily estuarine and inshore oceanic inhabitants who migrate seasonally. In the autumn, they migrate south to North Carolina or Virginia coastal waters, where they overwinter. In spring they move northward and inshore into estuarine spawning grounds including Pamlico Sound in North Carolina, Chesapeake and Delaware Bays and smaller coastal

estuaries up through Gardiners Bay on eastern Long Island, New York and as far north as Long Island Sound and Narragansett Bay in Rhode Island. The ASMFC Fisheries Management Plan considers weakfish to be a unit stock, based on genetic analysis (Graves et al. 1992). Recent work however, using geochemical composition of otoliths, found weakfish homed to their natal estuaries (Thorrold et al. 2001). This was the first published example of an estuarine spawner exhibiting homing behavior. Earlier tagging work performed in the 1930s also indicated that weakfish returned to their natal estuary (Nesbit 1954). These findings are not consistent with the unit stock hypotheses, and it should be pointed out that the genetic analysis cannot detect separate stocks if there is even a very minimal amount of mixing among stocks.

Surveys along the Atlantic coast indicate that estuaries provide feeding areas and spawning grounds for adult weakfish and are equally as important as nursery areas for juveniles. Adult weakfish are often found near the periphery of eelgrass beds, perhaps because weakfish feed on shrimp, other crustaceans, and small fish that are found near these grass beds. Spawning occurs in late May through the summer in the latitude of Delaware Bay and occurs inside the Bay. Spatial and temporal variation in juvenile weakfish diet has been observed in studies conducted in the Delaware Bay and Chesapeake Bay (Hartman and Brandt 1995, Grecay and Targett 1996, Latour et al. *in review*). In Delaware Bay, Grecay and Targett (1996) found mysid shrimp to dominate the diet of juvenile weakfish collected in 1986, while the bay anchovy dominated the diet of juvenile weakfish collected in the Chesapeake Bay in the early 1990s. Latour et al. (*in review*) examined the diet of weakfish from the Chesapeake Bay from 2002 to 2004 and found that mysid shrimp were an important component of the diet not only in juvenile weakfish but also for adults in contrast to earlier diet studies of Chesapeake Bay weakfish (Hartman and Brandt 1995). Part 2 of this report examines changes in reported weakfish diet in detail.

Older weakfish typically have been shown to become increasingly piscivorous with age, with Atlantic menhaden or other clupeids comprising a significant portion of the diet of older weakfish (Merriner 1975, Hartman and Brandt 1995). Recently, Latour et al. (*in review*) found mysids and bay anchovy to comprise a significant portion of the diet of all age weakfish in Chesapeake Bay, with Atlantic menhaden comprising only a small portion of the diet of age-5+ weakfish. Differences in the two studies were attributed to different sampling methods or temporal changes in the abundance of prey items between the time periods of the two studies. The low prevalence of other sciaenids, spot and croaker, in light of high commercial landings of those species was also noted (Latour et al. *in review*).

Maximum age recorded using otoliths was 17 years. The ASMFC Weakfish Technical Committee considers Tmax to be 12 years. World record weight is 7.75 kg. Growth rate has slowed since 1990, to the point that mean lengths at age of adults are several inches shorter than they were about 1990 (Lowerre-Barbieri et al. 1995, Kahn 2002a). Weakfish weight at age plummeted in the 1990s by nearly half for 3-5 year-old weakfish. Ninety per cent of weakfish are mature at age one. Weakfish are indeterminate batch spawners (Lowerre-Barbieri et al. 1996). The 26th SARC recommended that M = 0.25 be used in modeling constant natural mortality.

FISHERY DESCRIPTION

Landings from 1950-2003 peaked in 1981 (Figure 1A). During the period from 1982-2004, landings were highest at the beginning, totaling about 12,500 metric tons in 1982. Landings declined in 1989 through 1993. An increase began in 1995, the year Amendment 2 was approved. Landings then peaked at above 5,000 metric tons in 1998. A decline began in 1999, which continued through 2004, which was a record low level of less than a thousand metric tons (Figure 1). Landings of weakfish by the commercial and recreational sectors have followed similar trends of strong declines in recent years (Table 2; Figures 1, 1A, and 2). This fact is strong evidence that the stock is declining. If recreational landings, for example, had declined at a much higher rate than commercial landings, we could suppose that recreational fishers had reduced efforts directed at weakfish, or that weakfish had changed behavior to make them less available to recreational anglers, specifically. Since landings by both sectors have declined in parallel, changes in directed effort or availability are much less likely reasons.

In the winter, overwintering aggregations off North Carolina are harvested by gill nets and fly net trawlers, and these landings are large enough that they cause North Carolina to exceed other states' commercial landings (Table 2). Other major states are Virginia and New Jersey. When weakfish move north and inshore into estuaries from Pamlico Sound, North Carolina through Narraganset Bay, Rhode Island, they are harvested by a variety of estuarine gears, including gill nets, pound nets and floating traps, seines and hand lines. When weakfish move south on the fall migration along the coast, the aggregations are targeted with trawls and gill nets. In 1999, for instance, gill nets caught the largest share of the commercial landings, 48%, while trawl landings were second at 27%, followed by pound nets at 20% and haul seine at 5% (Vaughan 2000).

Patterns in recreational total catch and harvest changed after imposition of minimum sizes and creel limits in 1995 (Figure 2a). After this time, total catch (A + B1 + B2 of the MRFSS) became significantly larger than harvest. This suggests that the regulations had a significant impact on recreational harvest, causing a large increase in live releases (discards).

There have been significant changes in reporting requirements for commercial landings in two major states, Virginia and North Carolina, during the period covered by this assessment, as well as a federal change. In 1993, Virginia implemented a commercial fishermen mandatory reporting system, whereby each harvester reports daily activity (harvest, effort) on a monthly basis. The previous system in Virginia had been a voluntary buyer-reporting system. North Carolina in 1994 mandated trip-level reporting by licensed dealers for all commercial landings. This program requires dealers to complete a trip ticket for each transaction with a fisherman. These reports must be submitted on a monthly basis to the North Carolina Division of Marine Fisheries (NCDMF). Previously, the state had a voluntary reporting system from 1978-1993 obtained through a NMFS/NCDMF cooperative statistics program. In addition, NMFS in 2004 implemented a mandatory electronic reporting system for all federally-permitted seafood buyers. The combined effect of these improvements in these reporting systems is a probable increase in accuracy in landings estimates.

North Carolina landings from four estuarine gears show declines over the period 1994-2003 (Figure 3a). Catch-per-unit effort indices of abundance from these gears suggest that the landings decline is from a decline in abundance, not a decline in effort (Figure 3b). Virginia estuarine pound net CPUE exhibits a similar decline. In contrast to the estuarine gears, CPUE of two

oceanic gears employed on the overwintering aggregations off North Carolina do not show a declining trend, although CPUE declined in the most recent years (Figure 3c). Because these gears target aggregations, such fisheries can maintain CPUE in the face of stock declines if fishers can locate remaining aggregations, particularly mobile gears such as fly net trawlers. Therefore, lack of a declining trend in these latter two indices should not be taken as indicative of stable abundance. In contrast, estuarine fisheries would usually be targeting weakfish in less aggregated distributions.

INDICES OF RELATIVE ABUNDANCE

Recreational catch per unit effort indices

Indices of relative abundance from recreational catch-per-unit effort were reinstated in this assessment. While tables of similar indices appeared in the last peer-reviewed assessment report (NEFSC 2000), the indices had not been used in the final run because the SARC advised that fishery dependent indices were less desirable than fishery independent indices. Problems have come to light with many of the available fishery independent indices during the course of this assessment (see below). An advantage of the recreational indices is that they have very broad geographic coverage, whereas most of the fishery independent indices are limited to the waters of one state. By using only part of the recreational fishery for the indices, the exact correspondence to the catch at age matrix is reduced.

We have developed a measure of effort that seems improved over previous estimates. Previously, the effort was termed directed effort, defined as trips that either caught weakfish or for which anglers stated n interviews that they were targeting weakfish. This approach has the danger of exhibiting hyperstability (Hilborn and Walters 1992), because as weakfish catches decline, the number of trips defined as directed will also decline. The resulting index tends to remain relatively high because the divisor (number of directed trips) falls off rapidly. Consequently, the index may not decline at the rate that abundance declines. Our new indices are based on either total catch or harvested catch per trip, where the trips are those that caught one of a suite of species that are significantly correlated with weakfish in anglers catches. If weakfish abundance declines, anglers will continue to fish for the co-occurring species. Consequently, the number of trips will not decline due to a decline in weakfish catches, and the indices are unlikely to exhibit hyperstability.

The indices are based on catches and trips in the private-rental boat mode in state waters in the Mid-Atlantic region. This component, while comprising a majority of the catch in the Mid-Atlantic region, which is the dominant region for recreational catch, is still only a portion of the total recreational catch. One index is the total catch per trip, including discards. Such discards are not aged, so this index is considered an age-aggregated index over ages 2 – 6+. We have also developed harvest-at-age indices which consist of the total recreational harvest (A + B1) of the private-rental boat mode in Mid-Atlantic state waters, divided by the total number of trips that caught one of the suite of co-occurring species. The total harvest was divided into harvest at age by multiplying it times the proportion at age of the total Atlantic coast recreational harvest per year.

Recreational indices of abundance show relatively high but erratic levels in the 1980s, a decline into the early 1990s, then some recovery into the mid-late 1990s, particularly by the total catch per trip. Following the imposition of recreational minimum size limits and bag limits in the early-mid 1990s, the total catch per trip began to increase and diverged from the total harvest per trip, presumably due to a change in selectivity caused by the new regulations. Selectivity of the harvest per trip age-structured indices presumably changed in the early-mid 1990s. After the increase of indices through about 1997, they leveled off and began to decline in 1997 to 2000, depending on the index (Figure 3e). Indices declined to very low levels by 2003. Figure 3d portrays harvested weight per trip. Fig 3e portrays the tuning indices used in ADAPT. Total harvest at age was lagged forward when used in ADAPT to tune abundance the following January 1. Total catch per trip, including discards was not lagged. A third set of recreational tuning indices was developed by Crecco (2005) and used to estimate relative abundance for relative F calculation (Figure 3f). These indices are from MRFSS data on private boas trips in the Mid-Atlantic, either total weight caught including discards (discard mean weight assumed equal to harvested mean weight) per trip, using total trips, or total number caught, including discards per trip.

Research trawl surveys of relative abundance

After the 30th SARC recommended that the weakfish assessment use only data from the core area of abundance (NEFSC 2000), defined as New York through North Carolina, the SAS pared down the number of age-structured surveys employed to four: the NMFS North East Fishery Science Center (NEFSC) fall inshore survey which has run continuously since 1975, the New Jersey Division of Fish, Game and Wildlife ocean trawl survey (NJ) conducted from 1989 through the present, the Delaware Division of Fish and Wildlife's 30 ft. trawl survey of Delaware Bay (DE) conducted intermittently from 1966 but used here from 1982-1984 and 1991-2003, and the South East Monitoring and Assessment Program (SEAMAP) conducted from 1989 through the present (Table 3). We also use six indices of age 0 abundance which we lag and tune to age 1 abundance that are conducted by the New York Department of Environmental Conservation in Peconic Bay, the Delaware Division of Fish and Wildlife's juvenile trawl survey in Delaware Bay, one conducted by the Maryland Department of Natural Resources in Chesapeake Bay and one conducted in the Maryland Coastal bays, one conducted by the Virginia Institute of Marine Sciences in the Chesapeake Bay and one conducted by the North Carolina Division of Marine Fisheries in Pamlico Sound. We also use a survey of 1 year old abundance conducted by the North Carolina Division of Marine Fisheries in Pamlico Sound that we lag and use to tune abundance estimates of age 2 (Table 4). Shelton in his report from the 40th SARC in 2004, stated that "a very important point in the context of the 2004 weakfish assessment" was made in Crecco's (2002) relative exploitation analysis using data through 2000, that "tuning indices that display high frequency fluctuations in relative abundance (large year effects) are likely prone to excessive measurement error, poor reliability and low information content about stock variability". Because of these concerns, we developed an objective screening and evaluation analysis for the four trawl surveys, namely catch curve estimation of year class total mortality. The criteria for inclusion was that a survey did not display negative Z, that is, that a survey not indicate that year classes grow in abundance throughout their life. In fact, year classes can only decline in number throughout their life.

Here we focus on the four age-structured surveys, as these have the major influence on abundance and F estimates for both the ADAPT model and the biomass dynamic model based on survey indices of relative abundance (Uphoff 2005a). The only survey that was conducted continuously from 1981-2003 is the NEFSC fall inshore survey. While this survey covers the region from Cape Cod to Cape Hatteras, the NEFSC has recently revised the weakfish index, using only tows inshore from New Jersey through Cape Hatteras. The mean total catch per tow and exploitable biomass per tow (Uphoff 2005a) from 1981-2003 peaked in 2003 (Figure 4). This peak in 2003 also appears in the indices for ages 1-3 (Figure 5). Due to lack of precision in fitting indices of older ages, the SAS uses only ages 1-4 of this survey. As part of the assessment, we used catch curve analysis to estimate the instantaneous total mortality for each year class appearing in each survey. The NEFSC survey Z estimates showed biologically impossible results, namely that total mortality was negative, indicating a year class gained members during its lifetime. Therefore, while we used this survey during our initiql ADAPT run to be comparable to the 2002 ADAPT run, we excluded it from further runs as biased and biologically implausible. The probable cause of this bias is large effects of year-to-year changes in availability of weakfish to the survey. This survey comes down the coast once in the fall. If it coincides with the fall migration of weakfish, catches are likely to be large, and vice versa. The migratory nature of weakfish produces serious difficulties for a coastal survey that is run once a year, such as the NEFSC survey.

The New Jersey coastal trawl survey index has exhibited saw-toothed fluctuations in recent years with no trend (Figure 6). The indices by age indicate that the relatively high 2004 value is primarily due to age 1, but age 3 and age 4 are relatively high also. When the survey indices were analyzed as year class catch curves, the survey had a recent year class, 2000, that showed negative Z, like the NEFSC survey. The 2000 year class had only 2 ages in the survey, ages 1 and 2, but they also show a positive slope. This survey then, in recent years, also exhibits estimates that are biologically impossible. On that basis, we eliminated the New Jersey survey from the second set of ADAPT runs.

Moving down the coast, the Delaware survey shows a different pattern than the NEFSC and the New Jersey surveys. The total catch per tow and the index of exploitable biomass peaked in 1996 and have generally declined since then, with some fluctuation (Figure 8). The indices by age have been high recently in age 1, followed by age 2 (Figure 9). Older ages have declined, however. In fact, age truncation is occurring in the indices: Age 6 declined to 0 in 2002 and 2003, while age 5 declined to 0 in 2003. This truncation is the reverse of the build-up of the age structure that occurred in the early 1990s. In 1991, the oldest age present was age 3. Older ages appeared gradually until Age 8 appeared in 1999. By 2001, though, the age structure began to truncate. Total mortality estimates by catch curve analysis found no year classes displaying negative Z in this survey (Table 3).The year class mortality estimates show a decline to a nadir for the 1993 year class, which was present from 1994-2000. Total instantaneous mortality then increased to levels of 1.5 or higher for the 1996-1999 year classes, declining slightly for the 2000 year class.

The final age-structured survey is the SEAMAP survey, from which we use tows along the North Carolina coast only. This survey's mean catch per tow increased to high levels in the 2003 and 2004 indices (lagged 2002 and 2003 fall indices). The age-structured indices for ages 1 and 2 are

the source of the increase in the last 2 years, with ages 3 and 4 showing very low and relatively flat values (Figure 9a). Ages 5 and 6 from this survey have been eliminated due to low precision, as for the NEFSC survey. Catch curve estimates of total instantaneous mortality from the SEAMAP survey found no instances of negative Z (Table 3). Since only 4 ages were available, little information about trends and precise estimates of Z can be obtained from this survey. Since all estimates of Z were positive, however, this index was judged to be biologically plausible to some extent and was included in the second cut of ADAPT runs.

DEVELOPMENT OF CATCH-AT-AGE AND WEIGHT AT AGE MATRICES

Prior to the 1990s, most ageing of weakfish was based on scales. Otoliths were used increasingly in the 1990s. They were judged to be clearer to read. The Technical Committee conducted comparative studies using otoliths and scales from the same fish and determined that different age patterns of age structure were obtained with the otoliths versus scales. The committee decided to convert older scale-based ages to otolith equivalents, using a procedure akin to age-length keys. So for a given scale age, certain proportions were assigned to several otolith ages, based on scale-otolith data. For some years now, only otolith ages have been accepted.

The catch-at-age matrix for 2001-2003 was developed using the same general procedure outlined in Kahn (2002b). Four age-length keys were developed for each year, following the procedure used by Vaughan (2000), a north early (first six months), north late (second six months), south early and south late. All age-length data available from commercial samples or research surveys was pooled into these keys. Sample sizes are presented in Table 4. The overall number of samples per metric ton landed is higher for commercial than for recreational landings. The distribution of samples among regions, however, shows that the northern areas of the range have been deficient in sampling. Few commercial samples have been conducted north of Delaware. In recent years, Rhode Island has obtained length and some age samples from its floating trap fishery; these samples indicated a striking difference from the size structure of the more southerly landings (Figure 3d). In New York and southern New England, the minimum size for recreational or commercial harvest is 16” (40.6 cm), while New Jersey and south have minimum sizes of 13” (33 cm) for some New Jersey gears some of the year, or 12” (30.5 cm) for commercial catches in New Jersey’s other gears and all states south of New Jersey (Virginia and North Carolina have some estuarine gears with no minimum size for landings). No state south of New York has a 16” minimum size for recreational harvest, because many fish are caught below this size limit. The Rhode Island commercial length frequencies and the higher minimum sizes in the north indicate that northern areas tend to produce larger fish, whether due to migration of larger southern fish north or for some other reason. Consequently, substitution of southern length frequency distributions for northern commercial harvest may bias the estimated catch at age towards younger fish. While we truncated the lfds at the 16 inch minimum size for years 2000-2003, this procedure was not followed for previous years.

Recreational catch at age was developed as in Vaughan (2000), where for each year, early and late catches were divided into geographic regions, a north and south region. Therefore four length frequency distributions were obtained from the Marine Recreational Fishery Statistical Survey (MRFSS) for each year: north early, north late, south early and south late. The corresponding age-length keys were applied to each of the length frequency distributions to

convert length frequencies into proportions at age. These proportions at age were multiplied by the estimated total recreational losses. These losses were estimated as the MRFSS estimated total number harvested (A + B1) plus 20% of the estimated discard numbers (B2 portion of the MRFSS estimates). The Weakfish Technical Committee has in the past estimated recreational discards to undergo a mortality rate of 20%. Recent discussions have concluded that the committee may change this mortality rate estimate to 10% based on recent experimental results, but we have not implemented this change yet. Although discarded weakfish may tend to be smaller than harvested weakfish since 1995 due to imposition of minimum size limits, we currently have no data with which to estimate lengths of discarded weakfish. Consequently, we assume the discards have the same length distribution as harvested weakfish.

Commercial catch at age was developed by half year, state and gear due to different regulations among states and different size selectivity among gears. Gears employed fall into five main categories: trawl, gill net, pound net, haul seine and long haul seine and hook and line (handlines). Gears were sometimes combined or substituted, depending on availability or lack of sample data for a particular gear. For the north region, length data from Virginia, Delaware and Rhode Island were developed into gear-specific length frequency distributions for gill net, haul seine and pound net/floating trap gear. Maryland contributed trawl length samples for late 2003 and some pound net lengths. Virginia pound net data was used for trawl length frequency distributions in many states, due to severe lack of sample data from trawl landings. Some trawl length frequency distributions were obtained from the NMFS At-Sea Observer database. MRFSS recreational length frequency distributions were used to estimate commercial hook and line catch lengths. For New Jersey and New York catches, Virginia, Delaware and Rhode Island length frequencies by gear were used, but we truncated them to account for 16 inch minimum size limits in New York and the 13 inch minimum size for portions of the New Jersey landings. Catch at age matrices were developed for each gear in each state (where applicable) for each half of the three years 2001-2003.

To allocate landings among lengths, lengths were converted to weight using a length-weight equation for each half-year, developed from length-weight data supplied by the states (H. Rickabaugh, MD DNR personal communication). The frequencies at length then became the frequencies for each mean weight. Frequencies at weight were then converted to proportions at each length-weight combination. The total landings in pounds for a gear-state-season were multiplied by these proportions to give the landings in pounds at each length-weight combination. Landings at each length were then divided by the mean weight at that length to convert from pounds into numbers of fish at length, giving catch at length in numbers. The catch at length was then converted into the catch at age by means of an age-length key.

For the first time, the catch at age matrix included estimates of commercial discards (de Silva 2004). The Subcommittee learned that data on weakfish discards was included in some of the NMFS at sea observer data, which began in 1994. These data were developed into several different matrices of estimated discards using different methods and assumptions. The primary gear that produced weakfish discards was trawl gear. Smaller numbers of discards were produced by gill net. Small sample sizes and spotty coverage in many years made estimation tenuous in many cases. After due consideration, the committee chose a method that scales up the ratio of discards to harvest of a reduced core suite of target species. That is, the ratio of at sea

observations of the number of discarded weakfish to pounds of harvested target species by gear (trawl and gill net) was scaled up to total discard estimates based on total landings of the target species. For example, if 50 weakfish were discarded per 1000 pounds of bluefish landed by trawl gear, we would get the total coastwide landings of bluefish by trawl gear, divide those landings by 1000, and multiply the quotient by 50 to estimate the total number of weakfish discards due to bluefish harvest with trawl gear for that year. For trawl gear, the most common target species were summer flounder, Atlantic longfin squid, horseshoe crabs, butterfish, bluefish and weakfish. For gillnet catches, the most common target species harvested with weakfish discards were weakfish, bluefish, Atlantic croaker, butterfish, spot, Atlantic menhaden and spiny dogfish. For a full explanation of the procedures used and problems encountered, see de Silva (2004). The primary reason for discarding weakfish in most years was regulations; the second most common reason was market conditions. For 1998-2000, however, market conditions were the most common reason for discarding weakfish.

We also explored an alternative to the ratio approach, which was a regression approach; however, it produced poorer estimates than the ratio method. We also explored an alternative to scaling up observed discards by total target species landings. This alternative is estimating discards per trip and scaling up to total discards by the total number of trips. Unfortunately, commercial trip data was not available for much of the range of weakfish.

One pitfall with our approach is the possibility of overcounting discards. For example, if weakfish discards occurred on a trip that harvested croaker and bluefish, we did not want to scale up these discards by both the bluefish landings and the croaker landings, for that would be double counting. We used a reduced suite of target species to avoid overcounting of discards. A principal components analysis determined species associations among the target species. That is, the analysis determined which groups of species were often harvested together (on the same trip). Then we could scale up the observed discards per unit harvest for one species from each group to avoid overcounting discards. We thus selected a reduced suite of core species by selecting only one target species from each association. For trawl gear, four target species groups were identified: 1) Atlantic long-fin squid, 2) butterfish, 3) weakfish, Atlantic croaker and bluefish and 4) summer flounder. For gill net, four groups were also identified: 1) Atlantic menhaden and weakfish 2) Atlantic croaker and butterfish 3) spiny dogfish and 4) bluefish and spot.

Since the observer database does not cover years prior to 1994, estimated discards were hindcast, assuming that regulatory discards only occurred after imposition of regulations in the early 1990s. That is, the proportion of discards that occurred in the database for market reasons was assumed to be occurring back to 1982. Thus estimated discards were lower prior to 1994. Completed commercial discards at age are most commonly ages 0, 1 and 2 (Table 4, from Table 47 of de Silva (2004)). Since the VPA does not analyze catches of age 0, the addition of commercial discards to the catch at age tends to primarily increase the catch of ages 1 and 2. Figure 10 shows the catch at age estimate for 2002 with and without commercial discards as an example.

The total catch at age matrix including recreational and commercial landings and discards is in Table 5. Because commercial discard data was only available through 2002, we averaged the commercial discard estimates for 2001 and 2002 and used these for 2003.

For our update of the input data from 2001-2003, the estimates of the catch weights at age were developed using the process suggested by Quinn and Deriso (1999, p. 305) for unbiased estimates, employing the age-length keys and an average weight-at-age that is weighted by the frequencies at length within ages. This involved constructing spreadsheets for every component of the catch that we had developed catch at age matrices for, namely semi-annually for each significant gear in each of the nine states with commercial landings, plus 4 recreational catch at age matrices per year. For the 3 years we updated, the total number of spreadsheets developed exceeded two hundred. The report of the 30th SARC (NEFSC 2000) listed the following suggestion as a research recommendation: "Obtain mean weights at age corresponding to the catch-weighted mean weight from the catch at age estimation process." Previously, catch weights at age had been estimated with a von Bertalanffy model using all available age-length data, assuming catch occurred in the middle of the year. The problem with the old procedure is that it failed to take selectivity of the gear into account. It appears that we have fulfilled this SARC recommendation.

Catch weights at age for recent years showed a geographical trend, especially for younger ages. Mean weights at age tended to be larger in northern states (Figures 11-13). This could be due to higher minimum sizes in more northerly states, in part. The stock weights at age, or January 1 biomass weight at age, in contrast to the catch mean weight at age, is intended to depict the mean weight at age of the total stock, without fishery selectivity effects. The trend in these mean weights has been higher levels in the 1980s, when estimates are based on scale ages, and low points about 1995-1998, with recent increases (Figure 14).

On a related note, the 30th SARC report also made a research recommendation to "Investigate source of the relatively large sum of products correction factor." It is unclear exactly what this refers to, but it may have referred to the product of the estimated catch at age and the estimated mean catch weight at age. The sum over ages of this product should match the total landings. There does not appear to be a large discrepancy currently except for two years in the 1980s (Figure 15).

CATCH-AT-AGE ANALYSIS

Cohort catch curves

The most basic analysis of the catch at age matrix consisted of catch curves by year class or cohort catch curves. The cohort approach avoids violations of the assumption of constant recruitment that occur when catch curve analysis is performed across the catches at age of one year (Ricker 1975). The standard methodology was followed, where the log of the catch at each age was plotted, and analysis included all ages to the right of the modal age (Table 6; B. Murphy, RI DMF personal communication). Figure 16 plots the resulting estimates of total instantaneous mortality, Z, and estimates of F based on the assumption that M = 0.25, which the Weakfish Technical Committee has assumed in the past. Since the Z and F estimates are for the lifespan of

a cohort, they are not values that apply to only one year, as in a VPA. Rather, they estimate mortality over the range of years analyzed, as stated in Table 6. The general pattern is that year classes of the 1980s had relatively high Z estimates, fluctuating around 0.8. A nadir was reached with the year classes of the early 1990s, where Z for the 1992 year class was 0.3. This year class would have reached age 3 when Amendment 2 took effect in April 1995. However, Z climbed abruptly for the 1994 year class and reached a plateau for the remaining cohorts, fluctuating without trend from 1.3 to 1.5. The general trend of Z estimates here is supported by a significant correlation with year class Z estimates from an independent source, the catch curve analysis of the Delaware trawl survey (Figure 17). If we assume M = 0.25, F would be 1.05 to 1.25. However, these F levels are not supported by other analyses. The fishery regulations were relatively stable during this whole period. This suggests that the increase in Z indicated here could have been due to an increase in M, rather than an increase in F in the late 1990s and early 2000s.

Gulland's cohort analysis

The catch at age matrix was subjected to a Gulland cohort analysis (Haddon 2001), which is essentially an untuned virtual population analysis. This can be seen as an analysis of the catch data. Because the analysis proceeds from the most recent years and moves backwards, the most recent years' estimates are least reliable, since it assumes that the ages in the most recent year have no survivors. Therefore, the last three to four years' estimates should not be considered reliable. Starting four or five years back, prior to 2000, however, the estimates have more validity. As opposed to catch curves, cohort analysis gives estimates of F at age and year, assuming M = 0.25 (Table 7), and estimates of stock size (Table 8, Figure 18).

We consider 1999 to be the most recent year of reliable estimates. Figure 18 indicates that stock size was relatively high in the early and mid-1980s, peaking in 1986 at about 120 million fish. The stock then declined to about 50 million from 1989 – 1992. The stock began to increase in 1993, reached a recent peak in 1994-1996 at about 75 million, then declined to about 30 million in 1999. If we assume M was constant at 0.25, fully-recruited F estimates (ages 4 and 5) are erratic in the 1980s, fluctuating greatly between 1.0 and 2.5. From 1989 through 1993, F estimates are more stable, ranging between about 1.50 and 1.80. The estimate of F declines in 1994 and 1995, to about 0.75 in 1993 and fluctuated between 0.75 and 1.00 without trend until 1999. The pattern of average Z for ages 1-5 is also plotted in Figure 18. This estimate fluctuates erratically from 1982-1988, then stabilizes from 1989 – 1993 at about 1.25. Estimated Z declines in 1994 and 1995, and then fluctuates around 0.75 through 1999. This decline from 1995-1999 seems consistent with a reduction in F due to implementation of Amendment 2, in April 1995. The increased Z estimates for the 1995-1998 year classes seen in the two catch curve analyses (Delaware survey and catch at age matrix) are not detectable here, but no reliable estimates of Z are available after 1999 from the cohort analysis, which covers much of the relevant period for the later year classes in the catch curve analysis.

The estimates of fully-recruited F for the period since Amendment 3 was passed are considerably higher than some other estimates, fluctuating between 0.75 and 1.00. Most of the shifts in F and Z seem consistent with changes in fishery management. During the period of the unrestrained fishery in the 1980s and early 1990s, F and Z estimates were high. Some states, primarily New

Jersey and Delaware, imposed restrictions beginning in the early 1990s. Amendment 2, passed in July 1994, went into full force in April 1995.

ADAPT results

ADAPT was employed to analyze the catch at age data, in conjunction with survey and fishery dependent indices of relative abundance to tune terminal year estimates (actually, ADAPT estimates abundance in the terminal year + 1 and F in the terminal year). The first ADAPT run presented here, run 24, is an update of the model configuration recommended by the 30th SARC and implemented in the 2002 update (Kahn 2002b). Run 24 differs from the earlier models in that it includes estimated commercial discards in the catch-at-age matrix, but it uses the same set of tuning indices: all four age-structured surveys discussed above, plus age 1 indices from New York, Delaware, Maryland (2 such surveys), Virginia (VIMS survey) and North Carolina (Table 12), plus an age 2 survey from North Carolina. The run results (Table 9A) showed strong retrospective bias, similar to those of earlier years, and as such, is not considered reliable for recent years. The retrospective pattern is that F is underestimated (Figure 19, Table 9B) and spawning stock biomass is overestimated (Figure 20, Table 9B). When only data through 1998 is entered the fully-recruited F estimate for the terminal year, 1998, was 0.14. Once five additional years of data were input through 2003, the 1998 F estimate rose by 207% to 0.43. Conversely, the 1998 SSB estimate declined by more than half from 59,102 MT with 1998 data to 22,599 MT with 2003 data. With this amount of bias, the results of the VPA do not appear to be reliable after the early 1990s. The estimated F in 1991 increases by only 2.5% with the addition of 5 years of data, while estimated SSB for 1991 declined by 3%. Basically, in this run, the survey tuning indices indicate the stock is relatively high, so the estimated stock size in the terminal year +1, 2004, is estimated as a high number, 206 million (Table 9A). The stock size is then back-calculated to the terminal year, 2003, assuming M = 0.25 and adding in the catch. Since the catch was low and estimated losses due to natural mortality are moderate, the estimated stock size in 2003 is not much bigger than that of 2004. That result indicates total mortality was low, so when Z was estimated, it is relatively low. The assumed constant value of M = 0.25 was subtracted from that low Z and F is then estimated as extremely low, only .012 for age 4 in 2003, for instance. The combination of a high estimate of stock size in 2004 due to the survey indices, the low catch in 2003, and the assumption that M = 0.25 produce high terminal year estimates of stock size and F.

The 40th SARC panel that reviewed this assessment as work in progress agreed that the combination of high survey indices and low catches produced inflated estimates of N and low estimates of F. The reviewers indicated that the conflict between the high trawl indices and the low catch produced the retrospective bias observed. They were critical of some survey indices, particularly the NEFSC indices. They recommended critical review and removal of surveys that did not give biologically plausible results. Following their review, we conducted the catch curve analysis of the surveys described above and eliminated the NEFSC and NJ surveys on the grounds that they showed negative mortality, or “spontaneous generation” (growth of a year class in numbers during its life, as opposed to constant decline in numbers). The next run, run 14, used only the two remaining age-structured surveys, the Delaware and SEAMAP (Figures 21, 22, Table 9A). This model run showed a more severe retrospective pattern than run 24, however, with the terminal year F estimate with data through 1998 (F_{1998} = 0.08), increasing by 450% with

the addition of five years of data to 0.44 (Table 9B). The estimated SSB for 1998 declined by 77% from the run with 1998 as the terminal year to the run with 2003 as the terminal year. Again, this indicates that F is probably greatly underestimated for recent years in run 14 and SSB is probably greatly overestimated.

Our next change was to include fishery-dependent indices of abundance as tuning indices. The Weakfish SAS had used recreational catch at age per unit effort as tuning indices in VPA prior to the 30th SARC. That committee recommended against using any fishery-dependent indices "because the SARC believed sufficient fishery-independent surveys were available" (NMFS 2000). However, we added recreational CPUE indices because the surveys did not give the model tuning information for estimation of terminal year abundance consistent with the fishery experience of drastically declining catches, except for some aspects of the Delaware survey. The 40th SARC agreed with this decision. These recreational CPUE indices are declining over the last several years.

Run 18 used the Delaware and SEAMAP age-structured indices and the age 1 and 2 tuning indices included in runs 24 and 13, plus recreational fishery harvest per trip for ages 3-6 (Table 9A). Since harvest changed due to minimum size and bag limits over the time series, we also added the unaged total recreational catch per trip (including discards – B2 component of MRFSS) as an aggregated index tuned to ages 2-6. The retrospective pattern in F and SSB of run 18 is similar to the previous two runs (Figures 23A, B), except that the final estimate of SSB for 1998 was approximately 2/3 of the final 1998 estimate of the two previous runs (Table 9B). Conversely, the final F estimate for 1998 was 50% higher than the estimates from the previous two runs. Not until we look back at the 1992 estimates have the estimates of F and SSB closely converged among these three runs, although they become roughly similar by 1995.

The DEDFW survey has a distinctive residual pattern in Run 18, however (Figure 24A). This survey had negative residuals in the early 1980s for younger ages, consistent with statements in reports from that period that recruitment was low. The survey resumption in 1990 began with negative residuals, followed by consistently positive residuals in the mid-1990s followed by negative residuals in recent years. The SEAMAP survey residuals are fairly random, but positive in 2003 and 2004 (Figure 24B). Recruitment indices residual patterns are consistent with a change in fishery selectivity around 1995 when mandatory compliance was instituted under Amendment 2. Residuals were largely negative prior to 1995 and then became positive, with several again becoming negative by 2002 (Figure 24C). The opposite pattern occurs with the recreational CPUE residuals (Figure 24D). In this case, residuals of the age-structured harvest per trip indices switched from positive to negative in 1995. This is consistent with a regulation-driven change in recreational selectivity, as minimum sizes and creel limits caused an increase in discarding, changing the catchability of the recreational fishery and consequently of these indices. Large negative residuals occurred for theses indices for ages 4 and 5 in 2004. The exception to the general pattern is the total catch index pooled over ages (Figure 24D). That index has a fairly random pattern, as would be expected since total catch (including discards) should not be affected by creel and size limits.

Run 18 has considerably higher F estimates and lower SSB estimates than runs 13 and 24, such that the SSB estimates for 1999-2001 are below the biomass threshold in Amendment 4 of

14,421 MT. However, the estimated SSB for 2002 and 2003 increased to 23,567 MT by 2003 (Figure 23B, 2003 data). Again, however, this estimate is biased high and presumably will decrease substantially with additional data. The estimated F for 1996-2000 is much higher in run 18 than in runs 13 and 24. In the former, the F estimates range from 0.50 in 1996 up to 0.75 in 2000. In the latter two runs, these estimates range from about 0.3 up to 0.44. The estimated F for 1995 is almost always lower than that of 1996-2000. For run 18, $F_{1995} = 0.31$, while for run 14, $F_{1995} = 0.28$. That year saw the mandatory implementation of Amendment 2.

Run 20 is the final ADAPT run presented here. It used only the recreational CPUE indices for tuning of aged 2-6 as described for run 18 (Table 9A). This completed a combination of runs with all survey indices (run 24), a reduced group of trawl survey indices screened for biological plausibility (Run 14), a run with these two surveys plus the recreational CPUE indices (run 18) and the recreational CPUE indices alone (run 20. No index tuned the estimate of age 1. Run 20 also shows a strong retrospective bias, but in the opposite direction from the other runs (Figures 25, 26, Table 9B). This pattern is reversed for estimates when data through 2002 only is entered. Here F is overestimated in recent years and SSB is underestimated. When 1998 is the terminal year, $F_{1998} = 2.05$, but with data through 2003, it declined to 0.70, for a 66% decline. The estimate of SSB when 1998 is the terminal year was only 5,468 mt, but it increased to 12,674 with the addition of data through 2003. Again, by about 1993, the estimates have converged to rough similarity with those previous runs. Distinct patterns appear in the residuals for this run (Figure 26B). For the age-structured harvest-per-trip indices, initially residuals were positive. They became mostly negative in the early 1990s and remained so until 2002, when ages 3 and 4 became positive, followed in 2003 by ages 5 and 6. Large negative residuals did not appear in this run, with none exceeding an absolute value of 2.0. The residuals for the total catch including discards (ages 2:6) were negative from 1989-1997 and positive from 1998-2003. Some of these residual patterns are clearly related to the change in selectivity in the middle 1990s, but this relationship is not as clear-cut as in Run 18.

The reason that the choice of tuning indices affects the estimates back approximately 10 years to 1993 has to do with the way ADAPT calculates the F on the oldest true age. Because ages 6 and older are pooled into the so-called "plus group", age 5 is termed the oldest true age in these analyses. VPA calculations move backwards through each cohort or year class, from more recent years when each cohort was older towards years farther back when each cohort was younger. In the case of the oldest true age, however, it is not correct to back calculate from a plus group, here age 6, to the oldest true age, here age 5. That is because the plus group contains members of more than one cohort, and to back calculate from plus group to oldest true age would inflate the age 5 numbers. Consequently, ADAPT uses the F estimate from the other fully-recruited ages as the F estimate for the oldest true age. In this case, we have only one other fully recruited age, age 4. Because we have only two fully recruited ages, either option in ADAPT to calculate this F on the oldest true, the average method and the Heincke method, arrive at the same number. So the F calculated for the cohort that is age 4 in a given year is used as the estimate of age 5 F, which age belongs to the previous cohort. This F estimate is used to calculate the abundance of age 5 with the catch data and catch equation (Anonymous 2003), $N = ZC/FA$, where A is total annual mortality as a percentage. Here Z is estimated assuming $M = 0.25$, so $F + 0.25 = Z$. Now that the abundance of the oldest true age in that year has been determined, the program back calculates the abundance of the same cohort in the previous year as age 4. The F estimated for age 4 is used

for the oldest true age of the previous cohort. Consequently, the effect of the tuned estimate of N in year T + 1 and F in year T propagates backward through a whole series of cohorts, in this case for about a total of 10 years.

The net result of the ADAPT models is that we have stable estimates from 1982 through about 1992 or 1993. More recent years have unstable estimates of fishing mortality and SSB which change dramatically as additional data is added. In previous assessments, this pattern was noted and discussed, but perhaps not emphasized as it should have been. For management purposes, we consider ADAPT results unreliable for parameters and trends after 1993. The estimates of F from 1982 through 1991 have proved useful, however. Crecco (2005) used them to scale relative F estimates to absolute F estimates. A cautionary note here is that the fact that the 1982-1993 estimates are stable does not necessarily mean they are accurate. Simulation work by Sinclair et al. (1991) found that the stable, converged estimates of VPA were not always accurate estimates. Since they created simulated data, they knew the correct estimates. In our case, we do not have that luxury. The combination of scanty data in the 1980s, even compared with more recent years, and the conversion of scale ages to otolith ages indicates considerable uncertainty in the estimated catch at age matrix during that decade.

In terms of the three biological hypotheses presented above, which are supported by the catch at age analyses presented above? Unfortunately, the ADAPT models are unhelpful in discerning recent stock trends. The catch curves by year class indicate that total mortality declined greatly for cohorts originating in the early 1990s, but then climbed up to high levels of about 1.4 since the 1995 year class (Figure 16). This estimate is a 75% increase over the Z estimates from the early 1980s. These estimates are averaged, essentially, over all ages in a year class, so they tend to be quite lower than the fully-recruited F estimates from VPA for the 1980s. The total mortality of 1.4 indicates that either fishing or natural sources of mortality have greatly increased in the later 1990s and early 2000s. This level of Z could produce stock decline and could be considered to support that hypothesis.. These estimates are supported by the independent Z estimation from the catch curves developed from the Delaware survey indices, and that considerably strengthens the case for a recent large increase in total mortality (Figure 17). The cohort analysis assumes that instantaneous natural mortality is constant at 0.25. Given that assumption however, the estimated stock size through 1999 declines steeply from the 1994-1996 plateau (Figure 18). Although that is not very recent, it is consistent with a stock decline at least over the period 1997-1999. The estimated decline occurred despite the fact that the estimate of F declined significantly after 1994. The stock decline depicted, then, does not seem to be caused by an increase in F.

SIZE AND AGE STRUCTURE ANALYSIS

Amendment 4 requires that descriptors of age or size structure be reported to the Management Board as part of each stock assessment. Proportional stock density (PSD) is a standardized method for analyzing length-frequency data that quantifies size structure into categories of sizes of interest to recreational anglers (Uphoff 2005b). The Quality+ PSD (PSD Q+) equaled the proportion of weakfish greater than or equal to 210 mm (8.3 inches) that were 340 mm (13.4 inches) or larger in DE, NJ, and NEFSC trawl surveys. Sample sizes in the DE and NJ surveys

were large enough for precise estimates of PSD Q+, but sample sizes in the NEFSC survey were not and these data were excluded from analysis.

The PSD Q+ size quality indices for NJ (1989-2003) and DE (1966-1971, 1979-1984, and 1990-2003) indicated that size quality of weakfish in recent years was quite poor (Figure 27). A recovery in size quality after Amendment 3 (1996) faltered after 1998. Weakfish PSD Q+ has the potential to be a good bit higher than the peak observed in 1998. Values in the early 1980s were twice as high as this peak.

The DE PSD Q+ index was significantly and positively associated with recreational fishing quality (trophy citations) over a broad (DE, MD, VA) area, commercial and recreational yield along the Atlantic Coast, recreational harvest per trip in the mid-Atlantic (VA-NY), and the proportion of recreational harvest outside of 3 miles. Proportion of recreational harvest in bays and sounds was negatively associated with DE PSD Q+. These associations indicated that this size quality index was a highly relevant measure of population and fishery status that should meet the needs of the Weakfish Management Board. This analysis of size structure of the weakfish stock seems to be consistent with a stock in decline.

Our analysis of age structure assumes that the percentages at age from ADAPT output are not affected by retrospective bias. This assumption seems reasonable based on retrospective analysis of the 2002 ADAPT output (Kahn 2002). The mean bias for age 1, age 2, and age 3 weakfish in that final run was 0.88 for age 1, 0.83 for age 2, and 0.85 for age 3. Results of the current Run 20, the run preferred by the Technical Committee, show there has been a steep decline in the percentage of older weakfish since 1999 in all three runs (Figure 27a). Older weakfish comprised 5-8% of the estimated population during 1999 and this percentage fell to about 1% by 2003. Clearly, age structure is contracting rather than expanding toward "that necessary for restoration of the fishery".

BIOMASS DYNAMIC MODELING

Biomass dynamic models (also known as surplus production models) are the simplest analytical methods that provide a full stock assessment (Haddon 2001). They are relatively simple to apply because they pool the overall effects of growth, mortality, and recruitment into a single production function. Their data needs are small - minimum data needed are an index of relative abundance and landings (both in weight). The stock is considered as undifferentiated biomass and age, size, and sex structure are ignored (Haddon 2001). Hilborn and Walters (1992) stated that if both methods are applied and give different answers, then assessment scientists should try to understand why the answers are different and analyze their management implications. This biomass dynamic model has been developed to supplement and corroborate the age-structured techniques employed elsewhere in the assessment.

Trawl survey indices of relative abundance were formulated as kg per tow (Figure 28; Uphoff 2005a). These indices were also employed to estimate relative F, where harvest in MT was divided by the average of the indices for that year plus the following year. The index is then harvest as a proportion of average biomass for a year and is more similar to F than to exploitation. These estimates indicate that F reached a peak in 1987, then declined gradually to a

low level in the mid 1990s (Figure 9c). A small rise in relative F occurred in some of the estimates in 1997-1998, then levels were very low through 2003.

The time-series fitting method was used to estimate production model parameters (Hilborn and Walters 1992; Haddon 2001). We used a spreadsheet version of the discrete form of the biomass dynamic model based on the logistic function:

$$U_t = U_{t-1} + rU_{t-1} (1-(U_{t-1} / sK)) - sC_{t-1} + \varepsilon;$$

where U_t was the index of abundance in year t; U_{t-1} = index of abundance the previous year, r = intrinsic rate of population increase; s = scalar for the abundance index; K = maximum population biomass; C_{t-1} = harvest (commercial and recreational) in the previous year; and ε is measurement error (Hilborn and Walters 1992). A genetic algorithm super solver (Evolver, Palisade Corporation) was used to estimate parameters that minimized observation error ε (observed $\log_e U_t$ - predicted $\log_e U_t)^2$ (Prager 1994). The spreadsheet version of the model combined with the genetic algorithm provided a great deal of flexibility for trying different model variations.

Biomass of the exploitable stock in year (EB_t) was estimated as predicted U_t / s (Hilborn and Walters 1992). Instantaneous annual fishing mortality rate in year t was estimated as

$$F_t = C_t / [(EB_t + EB_{t-1}) / 2] \text{ (Ricker 1975);}$$

F_t in 2003 was approximated as C_t / EB_t (Haddon 2001). Relative biomass was calculated for sensitivity analyses as EB_t / B_{msy} in some cases or EB_t / K in others; relative F was estimated equivalently.

Residuals were examined for normality and serial trends. Bootstrapping (Efron and Gong 1983) and jackknifing ("inflated" jackknife; Efron and Tibshirani 1993) sample reuse techniques were used to describe variability of parameters in the preferred run.

Several deterministic approaches were used to investigate sensitivity of preferred model parameters (r, K, s, and U_0) and estimates of F and EB. Discard estimates (recreational and commercial; de Silva 2004) were included in one run. Deterministic runs were made to test sensitivity of the preferred trawl survey based model to z-transformation (untransformed indices were modeled), aggregation of indices (mean z+1), addition or omission of discards, and omission of each z-transformed survey index time-series. An extended z+1 transformed trawl survey time-series (1975-2003) was created and compared to the base time-series. Delaware survey data were also split into long (1981-2003) and short (1990-2003) time-series, reflecting survey vessel changes (Michels and Greco 2003) and one DE model was developed with scalars for 1981-1989 and 1990-2003. Production model parameters r and K, and relative F (F/r) and relative biomass (EB/K) time-series were calculated for each model. Time-series sensitivity was explored by sequentially removing time-blocks of up to five years from the end of the time-series and up to seven years from the beginning.

All three time-series of z-transformed + 1 biomass indices generally agreed that EB was low during 1985-1993, and likely rising during 1994-1996 (Figure 28); EB indices were mixed from low to high during 1981-1984. Trawl survey EB z+1 indices indicated the stock slowly declined through the early 1990s and then underwent rapid growth in the mid-1990s. In any given year after 1996, trawl indices would lie between lows observed during 1981-1991 and values more

than four-times that level (Figure 28). Trawl based indices were positively correlated with each other. Correlations of EBNJ with EBFSC (Pearson correlation coefficient or $\rho = 0.69$) and EBDE with EBNJ ($\rho = 0.78$) were strongest and both were significant at $P < 0.005$. EBDE and EBFSC were not as strongly correlated ($\rho = 0.45$, $P = 0.054$).

The fit of the preferred run was modest ($r^2 = 0.42$; Figure 28). The overall mean of residuals was near zero (-0.09); residuals were positively skewed with a negative tail. EBFSC (N = 23) contributed 46% to total SSQ; EBNJ (N = 15), 31%; and EBDE (N = 18), 23%. A sequential trend was not apparent in the residuals as a whole. Residuals of EBFSC tended to be slightly positive overall (mean = 0.06) while residuals of EBNJ and EBDE tended to be negative (means = -0.23 and –0.17, respectively).

The intrinsic rate parameter (r) equaled 1.32 and K was estimated at about 41,000 mt; EB index in 1981 was estimated as 0.98 and the scalar was $4.932 \bullet 10^{-5}$. Precision of all bootstrapped (N = 200) parameters was excellent and estimates were not noticeably different between bootstrapped and jackknifed estimates.

Estimates of EB fell from 20,000 mt to 5,000 mt during 1981-1990, steadily climbed to 37,000 mt by 1997 and then leveled off between 37,000 and 39,000 mt (Figure 29). When changes in biomass were slight (1981-1990 and after 1996), bootstrapped estimates were very precise. Modest variation in estimates was observed when growth in biomass was rapid (1990-1996). Estimates of biomass have been very close to K since 1997 (Figure 29).

Estimates of F were near or exceeding the level that would have collapsed the stock ($F_{collapse} = r = 1.32$) during 1981-1991 (Figure 29). A rapid drop in estimated F followed and F was 0.17 by 1994. Estimates of F fell between 0.11 and 0.17 during 1994-2000 and F was all but extinguished by 2003 (F = 0.03; Figure 29). Trends in precision of F were the same as those for biomass; there was virtually no variation when changes were gradual, with some variation evident when transition was rapid.

The addition of discard estimates did little to change estimates in the directed harvest model (Figure 29). Parameter r rose slightly to 1.35, K fell to 39,910 mt, s increased slightly to $5.848 \bullet 10^{-5}$, and U_{1981} increased to 1.45. Estimates of EB were slightly lower and F estimates were slightly higher when discards were included (Figure 29).

Twelve additional trawl survey based biomass dynamic models were developed for the 1981-2003 time-series, as was one extended time-series (1975-2003) model (Table 9C). Generally, the z+1 transformation resulted in stable parameter estimates in their eight scenarios; r ranged between 1.10-1.44 and K fell between 36,000 and 47,000 mt. Removal of each time-series of z+1 transformed surveys did not affect parameter estimates appreciably. Extending the three z+1 index time-series to 1975 resulted in a large drop in r (to 0.33), while K remained within the range of the estimates made with the shorter z+1 time-series. Biomass dynamic models using untransformed indices individually produced lower and more variable estimates of r (0.33-1.12) and higher estimates of K (some very much higher). DE survey models were very sensitive to length of time-series and whether a single scalar was used or scalars were developed for about each half of the time-series. Estimates of r for the DE treatments ranged between 0.33 and 1.08

and K estimates fell between 82,000 and 1.54• 10^8 mt. NEFSC or NJ survey models featured r's of 0.83 and 1.12, respectively, while K was estimated as 54,000 and 57,000 mt. A biomass dynamic model using all three untransformed indices (necessitating an additional two scalars and two initial year survey parameters) estimated r as 1.80 and K as 42,000 mt (Table 9C).

Relative biomass (EB/K) estimates from these different trawl survey model formulations were in general agreement and indicated that biomass has been high and stable since 1996. Biomass estimates approached K in the most recent years. Relative biomass was generally lowest in the 1980s and increased rapidly during the early to mid-1990s. Timing and trajectories of this increase in biomass were more variable in the different models.

All trawl survey model formulations of relative F (F/r) indicated that F has been very low for the past decade. Relative F was high through 1989 and fell rapidly by 1993. The scale of the 1975-2003 scenario was generally over twice as high as all 1981-2003 scenarios, but the trajectory was similar over the years in common. Relative F was high (F at approximately r) and rising through1980 in this extended time-series; it then followed the previously described trajectory for the 1981-2003 models.

When up to five years of recent data were removed from the preferred model, parameters, F, and EB did not detectably change. Removal of up to seven years from the beginning of the time-series had a profound effect on estimates of K and s, and induced some variation in r and U_0. As up to seven years were sequentially removed from the beginning, K steadily dropped from about 41,000 mt to 22,000 mt; the scalar steadily rose. K and s were significantly correlated ($r = -0.85$, $P = 0.015$). Sequential removal of years from the beginning of the time-series generally caused estimated EB to fall and F to rise in the more recent years of the time-series, while preserving the general trend observed (low EB to high EB and high F to low F) when all years were retained.

Biomass dynamic models of trawl survey indices portrayed an Atlantic Coast weakfish stock that is now at very high biomass and subject to little F. These results seem contradictory to landings that have continuously declined since 1998 and are now the lowest in the time-series, unless the stock is now comprised of individuals too small to be of interest to recreational and commercial fisheries (a stunted population) or fishers have become disinterested in weakfish.
These results are supportive of results obtained in the previous assessment (1981-2000) with biomass dynamic models, ADAPT VPA and ICA VPA (Kahn 2002b; de Silva 2002; Uphoff 2002a, 2002b). All survey based biomass dynamic models in this analysis indicated that biomass was low in the 1980s and then experienced a rapid recovery in the early to mid-1990s; estimated F was excessive in the 1980s, dropped precipitously in the early 1990s, and stabilized at a minimally low level afterwards. Biomass may now be near carrying capacity. Significant reductions in F and biomass recovery would have occurred prior to what were considered significant management measures in Amendment 3 to the Weakfish FMP (Lockhart et al. 1996).

Biomass dynamic models of trawl survey indices portrayed an Atlantic Coast weakfish stock that is now at very high biomass and subject to little F (Figure 29). These results are supportive of results obtained in the previous assessment (Kahn 2002b). All survey-based biomass dynamic models in this analysis indicated that biomass was low in the 1980s and then experienced a rapid recovery in the early to mid-1990s; estimated F was excessive in the 1980s, dropped

precipitously in the early 1990s, and stabilized at a low level afterwards. Results of these models indicate that biomass may now be near carrying capacity. According to model results, significant reductions in F and biomass recovery occurred prior to what were considered significant management measures. These results seem contradictory to landings that have continuously declined since 1998 and are now the lowest in the time-series, unless the stock is now comprised of individuals too small to be of interest to recreational and commercial fisheries (a stunted population) or fishers have become disinterested in weakfish.

RELATIVE AND SCALED-UP ABSOLUTE F, STOCK BIOMASS, SURPLUS PRODUCTION AND SURPLUS PRODUCTION MODELS.

Biomass-based Relative Abundance Indices

A time series (1982-2004) of weakfish relative biomass indices were derived as a ratio between annual recreational weakfish catches (MRFSS: A + B1 +B2) in weight and total fishing effort data from the private boat sector based on the MRFSS annual surveys:

$$RelWt = MidWt / Effortt , \qquad (1)$$

Where RelWt denotes a biomass-based relative abundance index, MidWt is the recreational catches in weight from the private/rental boat mode of the MRFSS for the Mid-Atlantic region (New York through Virginia) in year t and Effort is the annual total trips of the private/rental boat mode in the Mid-Atlantic region in year t.

The resulting age aggregated (ages 1+) indices (Table 10) were confined to the private boat recreational catch and effort data from the Mid Atlantic subregion (New York to Virginia). This approach seemed justified because private boat catches from this subregion have, in most years, comprised a large (> 60%) percentage of the coast-wide recreational catches. Also, the private boat catch and effort estimates from the Mid Atlantic subregion have been measured with relatively high precision (relative CV < 0.13). Moreover, the private boat fishery is highly mobile and, unlike most trawl surveys, capable of catching larger (> 60 cm.) weakfish throughout their range. Since the MRFSS has monitored weight (kg) data from only the harvest (A, B1), the catch in weight of released weakfish (B2) was derived indirectly by assuming that the average weight (kg) of released fish (B2) was the same as the average weight of harvested fish. Although released weakfish caught in the recreational fishery are likely to weigh less than harvested fish, particularly after the imposition of minimum size limits in 1994, there is no known time series (1982-2004) of weight measurements on released fish with which to verify our assumption. Also, if recreational harvest (A, B1) in weight was used instead of total catch in weight (A, B1, B2) in the numerator of equation (1), the resulting indices after 1993 would be underestimated. Beginning in 1994, minimum size limits and daily creel limits were imposed coast-wide on the weakfish recreational fishery, thereby reducing weakfish recreational harvest from 1994 to 2005. Note that our indirect approach of estimating the B2 catch in weight in this context has also been used to estimate the B2 discards in weight for the current ADAPT VPA.

The abundance indices via equation (1) were based on total private boat fishing effort from the Mid Atlantic subregion rather than from directed fishing effort on weakfish (Table 10). In a

previous analysis (Crecco 2005d), the time series (1982-2004) of directed fishing effort from the Mid Atlantic private boat fishery was used to estimate weakfish abundance indices. Since the direct and total fishing effort time series was highly correlated (Pearson $r = 0.96$, $P < 0.0001$), the trend in abundance indices derived from total and directed effort was nearly identical and therefore the use of directed fishing effort would not have altered this analysis.

While this index is fishery dependent, problems of autocorrelation between it and coast-wide landings should be relatively minor for three reasons. First, commercial landings and discards have comprised, in most years, at least 65% of the total weakfish harvest. Thus, the Mid Atlantic private boat indices from 1982-2004 utilizes only about 20-30% of the total annual harvest in the index including the commercial harvest, thereby minimizing autocorrelation to the coast-wide landings. Second, the indices were based on the Mid Atlantic private boat catches (A, B1 B2) that include released fish instead of the harvest (type A and B1). This should further minimize the degree of autocorrelation with the total coast-wide harvest. Finally, the weakfish indices were based on the ratio of private boat recreational catch to fishing effort. This extra step of dividing catch by effort should reduce the probability of autocorrelation since the time series of coastwide harvest was inversely related (Pearson $r = -0.51$, $P < 0.006$) with private boat fishing effort from the Mid Atlantic region.

Fishing Mortality, Stock Biomass and Surplus Production

Relative fishing mortality estimates were also derived from 1982 to 2004. Relative F was estimated as a ratio of annual landings (commercial and recreational plus discards in mt) of ages 1+ weakfish in year t to the average of relative abundance indices in years t and t+1:

$$RelFWt = HARVt / [(RelWt + RelWt+1)/2] , \qquad (2)$$

where RelFWt is the biomass-based relative F for year t, HARVt is the total harvest in metric tons including estimated weight of discards for year t, RelWt is the relative abundance index for year t and RelWt +1 is the index for year t+1 (Table 10). Since the index is not yet available for 2006, an estimate of relative F for 2005 cannot be derived via equation (2). Instead, an approximate estimate for 2005 was derived as a ratio of the preliminary 2005 landings to the 2005 index. Note that the 2005 weakfish recreational landings and discards (mt) are available from the MRFSS, but the 2005 commercial landings and discards are not yet available. A preliminary 2005 coast-wide harvest estimate (commercial and recreational plus discards) was derived by dividing the 2005 recreational coast-wide harvest and discards by the 0.45, which was the ratio of 2004 recreational harvest to the 2004 total harvest.

The next step in this analysis was to transform relative F estimates into units of absolute biomass-weighted fishing mortality of ages 1+ weakfish. This transformation was made by multiplying the relative F estimates values from 1982 to 2005 by a scalar consisting of the ratio of the average biomass weighted F (ages 1+) from run 20 of ADAPT VPA for 1987-1991 to the average the relative F estimate from 1987-1991 (Crecco 2005b). The VPA F estimates were confined here to the 1987 - 1991 period because the 1987-1991 F estimates from the VPA were fully converged and therefore robust to retrospective bias noted from more recent (1999-2003) F estimates (Table 10).

Average stock biomass (mt) of ages 1+ weakfish was estimated from 1982 to 2004 as a ratio of coastwide harvest to the scaled biomass weighted F:

$$Biot = HARVt / FWt,. \quad (3)$$

where Biot is the stock biomass for year t, HARVt is the harvest in year t in metric tons, including discards, and FWt is the biomass-weighted F for year t (Table 11).

A time series (1982-2004) of weakfish surplus production estimates from 1982-2004 was derived by subtracting weakfish stock biomass in year t from stock biomass in year t+1 followed by the addition of annual total landings (mt) in year t:

$$SURPt = Biot1 - Biot + HARVt , \quad (4)$$

where SURPt is surplus production in year t, Biot+1 is the stock biomass in year t + 1, Biot is stock biomass in year t and HARVt is harvest in year t (mt) including discards (Table 11). Surplus production estimates have been used to monitor trends in per capita stock productivity for exploited finfish populations (Jacobson et al 2002).

Biomass weighted fishing mortality estimates on weakfish rose steadily from about 0.41 in 1982 to peak levels in 1988 (FW1988 = 1.08) (Table 10). The F estimates remained relatively high (FWt range: 0.60 to 0.81) from 1989 to1992, then fell steadily to below the 0.40 level in most years from 1993 to 2005. The 2004 and 2005 FWt estimates were around 0.25.

Weakfish biomass levels remained relatively high between 15,000 and 34,000 mt from 1982 to 1988 then fell consistently below 10,000 mt from 1989 to 1993 (Table 11). Biomass rose abruptly to above 20,000 mt from 1994 to 1999, then weakfish biomass fell steadily thereafter to the lowest level in the time series in 2004 (5,700 mt). The preliminary 2005 biomass level of 7,300 mt is about 28% higher than the 2004 estimate, but the 2005 level is the third lowest in the time series (Table 11).

The time series of weakfish surplus production from 1982 to 2004 generally followed the trend in stock biomass (Table 11). Weakfish surplus production remained relatively high from 1982 to 1986 and again in 1993 and 1994, but levels fell greatly after 1997 and remained low thereafter despite relatively low and stable fishing mortality (Table 10). Weakfish surplus production estimates were negative in 2000 and 2002, indicating the absence of sustainable harvest in those years. Surplus production estimates were positive in 2003 and 2004, but were below the estimates prior to 1999 (Table 11).

Biomass Weighted Natural Mortality (MWt)

Most of the current evidence (Uphoff 2005b; Crecco 2005c) suggests that the recent decline in weakfish surplus production is likely due to a recent rise in weakfish natural mortality (M) linked to enhanced predation and perhaps inter-specific competition. It would be useful to estimate a time series of age aggregated (ages 1+) natural mortality (M) rates and relate the M time series

statistically (stepwise regression model) to the candidate finfishes and abiotic factors. Statistical support for the Predation Hypothesis would be evident if the time series of one or more of the candidate finfish predators were positively correlated ($P < 0.05$) to the trend in weakfish natural mortality. Standard output from the ADAPT VPA includes biomass weighted fishing mortality (Fvpa) rates of ages 1+ weakfish from 1982 to 2003. Recall that the natural mortality rate (Mvpa) in all VPA runs was assumed to be constant at 0.25 across all ages and years. As a result, biomass weighted total mortality (ZWt) rates from 1982 to 2003 were easily derived by adding 0.25 to each of the aggregated age 1+ F values from the VPA run #20 that included MRFSS recreational cpue as the sole tuning index. The Weakfish Stock Assessment Subcommittee chose run #20 as the preferred VPA model run. The degree of retrospective bias in recent F and weakfish stock size estimates from run #20 was much less extensive than the bias for other model runs that were tuned by either trawl survey indices alone, or a combination of trawl survey and MRFSS indices. Note that scaled biomass (ages 1+) weighted fishing mortality (FWt) have been estimated independently from the VPA via equation 2 (Table 10). As a result, a time series of biomass weighted natural mortality rates (MWt) of ages 1+ weakfish were calculated from 1982 to 2003 by subtracting the biomass weighted FWt estimates (Table 10, Figure 34) from total mortality estimate (ZWt) estimates based on the VPA run #20.

Although natural mortality of age 1+ weakfish was assumed to be constant in previous Yield-per-Recruit and VPA model runs, the trend in annual biomass weighted natural mortality (MWt) from 1982 to 2003 does not support this assumption (Figure 34). Annual (MWt) estimates for ages 1+ weakfish were highly variable with systematic trends occurring from 1982 to 2003 (Table 10). Weakfish MWt levels from 1982 to 1986 remained relatively high, ranging from 0.44 to 0.82. Weakfish MWt levels fluctuated greatly between 1987 and 1995 from a high of 0.64 in 1988 to a low of 0.01 in 1989 (Figure 34). After 1995, however, weakfish natural mortality (MWt) rose steadily from 0.31 in 1996 to a high of 1.09 in 2002. Not only was annual weakfish MWt levels not constant from 1982 to 2003, but the long-term (1982-2003) average MWt level derived here (mean MWt = 0.47, SE = 0.06) was significantly higher (t-statistic = 3.67, $P < 0.01$) than the assumed constant M = 0.25.

Age 0 Mortality

One major problem in quantifying predation or other trophic responses on weakfish is pinpointing the period in the life history where the highest predation risk takes place. A temporal shift in predation mortality can occur across many weakfish ages (ages 0+) or may be confined mainly to a single age group (i. e. age 0 mortality). Since age 0 weakfish rarely exceed 18 cm TL, this early stage is particularly susceptible to a heightened risk of mortality from a vast array of potential finfish predators. Several recent predation studies (Beck 1997; Wahle 2003) have shown that size dependent mortality during the juvenile stage may lead to a demographic bottleneck which can inhibit the flow of recruitment to older ages. If this bottleneck is severe and persists over time, prey abundance will eventually cascade downward, resulting in a stock collapse emanating from the youngest to the oldest ages (i. e. bottom-up effect). To examine whether or not a demographic bottleneck may occur for age 0 weakfish, a time series of relative weakfish juvenile mortality (Z0) estimates was derived for the 1982 to 2003 year-classes. The Z0 estimates were expressed by a log ratio between coast-wide age 1 abundance (N1t+1) in year t+1 to the mean coast-wide juvenile abundance index (N0t) in year t:

$$Z0 = - \log (N1t+1 / N0t) . \qquad (5)$$

Weakfish juvenile abundance (N0) has been monitored along the Atlantic coast from Rhode Island to North Carolina including the South Atlantic (SEAMAP) from 1982-2004. Nine juvenile surveys (Table 12) were used to construct an average coast-wide index (N0) from 1982 to 2004 (see Section for more details). The abundance indices were expressed as the geometric mean catch per tow or geometric mean catch per seine haul, resulting in indices of vastly different magnitude. As a result, before the indices from the nine surveys were combined into a coast-wide average index (N0), the relative abundance values for each survey had to be standardized to equivalent abundance units. Equivalent units were established in a three-step process. First, the long-term (1982-2004) geometric mean abundance index was derived annually for the recruitment time series of each of the nine surveys. Second, a scalar for each data set was derived as a ratio of the long-term average index to the long-term average New Jersey index. Each annual index from each data set was then multiplied times the respective scalar, thereby transforming the magnitude of the eight indices to units of the New Jersey indices (Table 13). Finally, the coast-wide geometric mean index (N0) was derived as the grand mean across the scaled indices from 1982-2004 (Table 13).

A brief description of each of the nine juvenile trawl surveys is given below. The Rhode Island Division of Fish and Wildlife has conducted a juvenile finfish trawl survey in Narragansett Bay from 1982 to 2004. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Connecticut DEP trawl survey has employed a stratified random design based on 120 tows per year. Tows have been conducted biweekly with a 42 ft otter trawl throughout Long Island Sound from April to June and from September to October. The survey data on weakfish are available from 1984 to 2004. Juvenile and age 1 weakfish (geometric mean catch/tow) have been primarily sampled by this trawl survey. The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey from 1985 to 2004 using a 16 ft. trawl targeting juvenile estuarine finfish in the Peconic Bay of Eastern Long Island. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. New Jersey has conducted an ocean trawl program from 1989 to 2004 using a stratified random design. Relative abundance (geometric mean catch/tow) of juvenile and ages 1+ weakfish have been monitored annually from August and October based on 78 tows/year. The Delaware Division of Fish and Wildlife conducts a juvenile trawl survey in Delaware Bay with a 16 ft. trawl from 1982 to 2004. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Maryland Department of Natural Resources has conducted a juvenile trawl survey in Chesapeake Bay from 1980 to 2004 using a 16 ft. otter trawl. A time series of juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay from 1987 to 2004. A time series of juvenile weakfish abundance (geometric mean catch/tow) was derived annually using August-October tows from three river tributaries. The North Carolina Division of Marine Fisheries has conducted a juvenile trawl survey in Pamlico Sound from 1987 to 2004. A time series of juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Southeast Area Monitoring and Assessment Program (SEAMAP) has conducted trawl surveys of juvenile and adult (ages 1+) weakfish since 1989 which sample from

Cape Hatteras to Cape Canaveral. A time series (1989-2004) of juvenile abundance has been expressed as the geometric mean catch/tow.

A time series (1982-2004) of weakfish age 1 abundance estimates (N1 in millions of fish) used in the numerator of equation (5) was taken directly from run #20 from the VPA (Table 13). The N1 estimates from run #20 were derived independently of the relative juvenile abundance estimates (Table 12) since none of the juvenile indices were used to tune run # 20. Note that the juvenile abundance indices in the denominator of equation (5) are expressed in relative units. Thus, the juvenile total mortality rates (Z0) are relative mortality estimates in contrast to the ages 1+ natural mortality estimates (MWt) from the previous section that are absolute mortality estimates based on total abundance data from run #20 of the VPA. Also, note that the current VPA generated age 1 abundance estimates (t+1) for the 1981 to 2002 year-classes during the years 1982 to 2003. Since there is currently no 2004 age 1 index that represents the 2003 year-class, age 1 abundance for the 2003 year-class was assumed to be the same as the age 1 abundance estimate for the 2002 year-class (Table 13). Given the steady decline in age 1 abundance (N1) from the VPA from 1997 to 2002, this assumption seemed reasonable. The age 1 abundance (N1) values from the VPA were occasionally larger than the magnitude of the coast-wide juvenile index (Table 13) resulting in some negative values of mortality (Z0) via equation (5). In order to generate mortality rates (Z0) as positive integers, all age 1 abundance data (N1) were scaled down by dividing the N1 values by an arbitrary value of 9.0.

Weakfish juvenile indices varied greatly across the nine surveys for the 1982 to 2004 year-classes (Table 12). In the Rhode Island survey, juvenile indices remained relatively high from 1982 to about 1999, then juvenile year-class strength after 1999 dropped quickly to low levels. Juvenile indices from other state survey, however, exhibited a general rise in year-class recruitment after 1995 (Table 12). When the nine juvenile data sets were standardized and combined into a mean coast-wide index (N0) (Table 13), the coast-wide weakfish juvenile recruitment showed a fairly persistent rise after 1994 (Figure 32). The persistent rise in juvenile recruitment after 1998 coincided with a pronounced drop in weakfish ages 1+ biomass (Table 11), indicating the presence of compensatory survival from the larval to juvenile stage. Abundance of age 1 weakfish (N1J) based on run #20 of the VPA varied without trend from 1982 to about 1995, then age 1 abundance fell steadily from 1996 to 2003 (Figure 33) in sharp contrast to the general rise in juvenile recruitment after 1995. The resulting weakfish juvenile mortality (Z0) estimates increased in magnitude for the 1995 to 2003 year-classes (Figure 33). These findings strongly suggest that recent natural mortality on juvenile weakfish increased systematically since 1995 consistent with the recent emergence of a trophic bottleneck that may have interfered with the flow of recruitment from age 0 to ages 1+.

PREDATION HYPOTHESIS

Coastwide weakfish biomass (mt) has fallen steadily by 65% since 1999 to levels well below the estimated Bmsy threshold. Total mortality (Z) estimates from both the VPA (run #20) and cohort catch curves have risen sharply since 1996 but biomass weighted F estimates (ages 1+) during this period have remained low and steady (Crecco 2005a). Moreover, annual changes in average annual F (lagged or unlagged) from 1982 to 2004 exhibited no statistical relationship (Pearson $r = 0.22$, $P < 0.31$) to changes in weakfish surplus production (Crecco 2005b),

suggesting that the recent failure in weakfish productivity is not related to fishing effects. As a result, the sudden and unexpected drop in weakfish productivity since 1998 is thought to be due to a systematic rise in weakfish natural mortality (M). This increase in M is likely due to one or a combination of biotic and abiotic factors including a rise in finfish predation, enhanced interspecific competition for food and perhaps a major temporal shift in key environmental variables that could play a role in affecting weakfish recruitment.

Statistical and empirical evidence gathered thus far supports a Predation Hypothesis involving striped bass (*Morone saxatilus*) as a primary predatory finfish on weakfish (Uphoff 2005a, 2005b; Crecco 2005a, 2005c). Striped bass abundance along the Atlantic coast has recently risen to record high levels after 1998 (ASMFC 2005) coincident with the recent failure in weakfish productivity. Although statistical and empirical evidence linking striped bass to the recent failure in weakfish productivity is persuasive, there is yet no direct evidence that ties the recent increase in weakfish M directly to striped bass predation. Also, the weakfish age(s) at which the risk of predation is highest has yet to be established. Since predation is generally regarded as a major force structuring marine fish communities (Bax 1991), it would be useful in this context to present an analytical model that merges the population dynamics of weakfish with the foraging characteristics of striped bass. In addition, to provide a more thorough examination of the Predation Hypotheses, other candidate finfish predators on weakfish such as bluefish, summer flounder and spiny dogfish need to be considered as well as potential competitors of weakfish. Finally, systematic changes in finfish productivity may respond to high frequency climatic changes over broad geographical areas (Scheffer et al. 2001). Thus, a more complete examination of temporal shifts in climatic variables, such as water temperature and long-term deviations in the North Atlantic Oscillation Index, need to be considered as an alternative to the Predation hypothesis.

In this section, we used the age-aggregated Steele and Henderson (1984) (S-H) production model to further examine the joint effects of fishing and predation on Atlantic coast weakfish. The S-H model has extensive theoretical appeal since it incorporates the compensatory stock dynamics of the prey (weakfish) with fishing effects plus a sigmoid foraging response by the predatory finfish that may lead to critical depensation at low prey abundance (Spencer and Collie 1997). Since the S-H model can also accommodate climatic variables (Spencer 1997), this modeling approach represents a modest but straightforward attempt at ecosystem modeling. In this section, the S-H model was used to re-estimate overfishing thresholds (Fmsy, Bmsy) for weakfish in the presence of finfish predation. In addition, more robust and precise estimates of the overfishing thresholds (Fmsy, Bmsy) from the S-H model were attempted through iterative reweighted least squares regression. Model validation and an analysis of process error were also undertaken by an examination of residual patterns. As first indicated by Uphoff (2005c), the predation exponents estimated directly from S-H model can be used to derive weakfish natural mortality rates (Mp) associated with striped bass predation. In this section, a time series (1982-2004) of Mp values was compared to the magnitude and trend in age aggregated annual MWt estimates (ages 1+) derived independently from run # 20 of the VPA (i. e. M = Z-F) combined with biomass weighted fishing mortality rates. A direct causal link between the rise in weakfish natural mortality and striped bass predation would be established, if the 1982-2004 predator-related Mp estimates derived empirically from the S-H model closely track the weakfish ages 1+ M estimates. Finally a stepwise multiple linear regression model was used to identify additional

explanatory variables that may be linked to changes in weakfish surplus production, weakfish natural mortality (MWt) and weakfish juvenile total mortality from 1982 to 2004. These explanatory variables included other finfish predators (i.e. summer flounder, bluefish and spiny dogfish), a potential finfish competitor of weakfish (Atlantic croaker) and selected climatic variables (mean annual water temperatures (C) and annual deviations in the North Atlantic Oscillation index).

Statistical Analysis

A stepwise multiple regression model (SAS 2002) was used to identify several key biotic and abiotic factors that may be linked statistically ($P < 0.05$) to changes in weakfish surplus production (SURPt), weakfish natural mortality (MWt) and weakfish juvenile mortality (Z0) from 1982 to 2004. The stepwise analysis was conducted separately using surplus production (SURPt), age aggregated (ages 1+) natural mortality (MWt) and age 0 mortality (Z0) as dependent variables in the three stepwise models. Explanatory variables in the three model runs included biomass weighted fishing mortality (FWt), as well as stock abundance of several candidate finfish predators on weakfish such as striped bass, bluefish, summer flounder and spiny dogfish (Table 14). Striped bass is regarded as a voracious predator from the Mid and North Atlantic on menhaden, gizzard shad and herring (Hartman 1993). Larger (> 60 cm) striped bass, however, have been reported to undergo an ontogenic shift in prey preference from herring and small menhaden to spot and weakfish in Chesapeake Bay (Hartman and Brandt 1995; Walter and Austin 2003). Bluefish (*Pomatomous saltatrix*) also prey upon a variety of finfishes including weakfish throughout the Atlantic coast (Bowman et al. 2000). Larger (> 50 cm) summer flounder (*Paralichthys dentatus*) (Bowmann et al 2000) also prey on a variety of finfishes including smaller (< 20 cm) weakfish from mostly the North and Mid Atlantic. By contrast, spiny dogfish (*Squalus acanthias*) are found coast-wide and are regarded as a primary finfish predator of river herring, capelin, and sand lance (Bowmann et al 2000), although Rountree (1999) reported that spiny dogfish also prey upon smaller weakfish.

A time series of Atlantic croaker (*Micropoganias undulatus*) abundance was also included as a potential competitor of weakfish (Table 14). The ecological role of Atlantic croaker as a potential competitor or predator on weakfish is poorly understood but croaker trophic status is thought to be somewhat below that of weakfish (Miller et al 2004). Thus croaker may compete with or prey upon small weakfish particularly in Mid Atlantic waters during spring when both species overlap. Potential weakfish predators and competitors are thought to undermine weakfish surplus production by enhancing weakfish natural mortality or by constricting the flow of age 0 recruitment (i. e. trophic bottleneck). As a result, one or more the candidate finfishes in the model would be identified as a potential stressor on weakfish surplus production if the respective regression slope(s) associated with each finfish in the stepwise regression was negative and statistically significant ($P < 0.05$). Conversely, in the analyses with weakfish ages 1+ natural mortality (MWt) and juvenile mortality (Z0) as dependent variables, support for the Hypothesis would be given if the slope(s) for one or more of the candidate finfishes were positive and statistically significant ($P < 0.05$). Fishing mortality estimates (FWt) were also included as an explanatory variable to further test the overfishing hypothesis. If, for example, fishing mortality (FWt) was positively correlated ($P < 0.05$) to the recent rise in age aggregated (ages 1+) natural

mortality (MWt), this might imply that discard losses due to fishing have been severely underestimated in the catch-at-age matrix used in the VPA model.

In this analysis, annual abundance of four out of five candidate finfish (striped bass, summer flounder, bluefish, and spiny dogfish) was taken from the most current assessment of that species (Table 14). Coast-wide biomass (mt) of spiny dogfish was expressed annually as thousands of metric tons by the area swept approach based on the NEFSC spring trawl survey (Matt Gates, ASMFC spiny dogfish Technical Committee pers. comm.). Coast-wide striped bass, summer flounder (fluke), and bluefish stock abundance estimates from 1982 to 2004 were taken from the most recent ADAPT VPA runs (ASMFC web site, 2005). Fluke abundance from 1982 to 2004 was expressed as spawning stock biomass in mt based on the 2005 VPA. Bluefish abundance was expressed each year as millions of pounds of ages 1+ fish based on the ASAP model. In the case of the Atlantic croaker, stock size estimates from the VPA are only available from 1982 to 2002. For this reason, the 1982-2004 total recreational catch of croaker (A, B1, B2) from the MRFSS was used as a coast-wide index in the stepwise regression (Table 14). Croaker abundance each year was represented by the total catches (A, B1 and B2) from the Mid Atlantic subregion. Use of croaker recreational catches as a stock index seemed justified, given that the 1982-2002 recreational catches were highly correlated (Pearson $r = 0.80$, $P < 0.0001$) to the 1982-2002 VPA abundance estimates. Striped bass abundance was expressed as millions of ages 8+ fish from the 2005 VPA. The striped bass VPA tended to overestimate recent (2002-2004) F levels and therefore underestimate recent (2002-2004) stock sizes. As a result, a second time series of ages 7+ stripers (millions of fish) was also used in the stepwise model based on the ratio of ages 7+ landings to tagged-based F estimate of ages 7+ stripers (Kahn 2005b). Given that recent (2002-2004) tag-based F estimates were 20% to 40% lower than the corresponding F estimates from the VPA, the tag-based abundance estimates exhibited a more pronounced rise from 2002 to 2004 (Table 14).

Changes in large-scale climatic conditions could have also influenced the recent decline of weakfish surplus production by interrupting the formation of dominant year-classes. A time series of average annual surface water temperature (Temp, C) and deviations in the winter North Atlantic Oscillation (NAO) index (Table 14) were also included in the stepwise model as potential environmental forcing variables on weakfish surplus production. Since all female weakfish reach sexual maturity by age 2 (Wilk 1979), the Temp and NAO variables were lagged t-1 and t-2 years to coincide with weakfish recruitment to the adult stock. A time series (1980-2002) of average annual water temperatures was taken from a continuous temperature recorder located at the Millstone Nuclear Power Station, Waterford CT. Annual deviations in the NAO indices from 1980 to 2002 were taken from a recent American lobster manuscript (Fogarty and Gendron 2004).

The time series of weakfish surplus production (SURPt) from 1982 to 2004 (Table 11) was regressed in a stepwise model against the nine explanatory variables (Table 14). The stepwise model selected striped bass abundance based on the VPA (Strip) as the most significant ($P < 0.001$) explanatory variable that was inversely related to weakfish surplus production (Table 15). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. The correlation matrix (Table 16) indicated that weakfish surplus production was also inversely related ($P < 0.05$) to striped bass abundance based on tagging (Strip2) and to Atlantic croaker

(Croak). The time series of tag-based striper abundance (Strip2) and croaker abundance (Croak) from 1982 to 2004 closely followed (co-linear) the trend in VPA-based striper abundance (Strip) (Table 14). Thus, due to the presence of substantial co-linearity, the stepwise model was unable to select either Strip2 or Croak as a second or third significant variable. None of the other six explanatory variables including fishing mortality (FWt) were negatively and significantly related ($P < 0.05$) to weakfish surplus production (Table 16). Statistical evidence given here strongly suggests that the recent failure in weakfish productivity was linked to predation and inter-specific competition with striped bass and perhaps Atlantic croaker.

The time series of biomass weighted natural mortality estimates (MWt) on ages 1+ weakfish from 1982 to 2004 (Table 10, Figure 34) were used as a response variable in a second stepwise model against the nine explanatory variables (Table 14). The stepwise model selected fluke (summer flounder) as the most significant ($P < 0.001$) explanatory variable (Pearson $r = 0.79$, $P < 0.0001$) that was closely tied to the trend in weakfish ages 1+ natural mortality (Table 15). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. The correlation matrix (Table 16) revealed that weakfish natural mortality (MWt) was also positively related ($P < 0.05$) to both striped bass abundance estimates (Strip, Strip2). Since the time series of striped bass abundance from 1982 to 2004 closely tracked (co-linear) the trend in fluke abundance (Table 14), the stepwise model was unable to select either Strip or Strip2 as a second significant ($P < 0.05$) variable. None of the other six explanatory variables were positively and significantly related ($P < 0.05$) to weakfish ages 1+ natural mortality (Table 16). Statistical evidence given here strongly suggests that the recent rise in weakfish ages 1+ natural mortality (MWt) was linked to enhanced predation from fluke and striped bass.

The time series of juvenile weakfish mortality rates (Z0) from 1982 to 2004 (Table 13, Figure 33) were used as a response variable in a third stepwise model against the nine explanatory variables (Table 14). The stepwise model selected striped bass abundance from the VPA as the most significant ($P < 0.001$) explanatory variable that was closely tied (Pearson $r = 0.91$, $P < 0.0001$) to the rise in weakfish juvenile mortality (Z0) (Table 15, Figure 35). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. However, striped bass abundance based on tagging (Strip) (Pearson $r = 0.81$, $P < 0.0001$) and Atlantic croaker abundance (Pearson $r = 0.85$, $P < 0.0001$) were both closely tied to the pronounced rise in weakfish juvenile mortality (Table 16). The correlation matrix (Table 16) also revealed that weakfish juvenile mortality (Z0) was, to a lesser extent, positively related ($P < 0.05$) to fluke (Pearson $r = 0.46$, $P < 0.03$). Since the time series of Atlantic croaker abundance from 1982 to 2004 closely tracked (co-linear) the trend in striped bass (Table 14), the stepwise model was unable to select croaker as a second significant ($P < 0.05$) variable. None of the other five explanatory variables were positively and significantly related ($P < 0.05$) to weakfish ages 1+ natural mortality (Table 16). Statistical evidence given here strongly suggests that the recent failure in weakfish productivity was due primarily to the emergence of a age 0 recruitment bottleneck linked to enhanced predation with striped bass and perhaps Atlantic croaker and fluke.

Steele-Henderson (S-H) Model

The age aggregated Steele-Henderson (S-H) production model (Steel and Henderson 1984) was used to re-estimate the overfishing thresholds (Fmsy, Bmsy) for weakfish with and without the

presence of a significant ($P < 0.05$) predator-prey response. The S-H model assumes the existence of compensatory density-dependent mortality for finfish populations, a position widely held by most fish population ecologists (Wahle 2003). All of the population dynamics processes (somatic growth, natural mortality and recruitment) in the S-H model are subsumed in the intrinsic rate of population increase (r) and to a lesser extent in the carrying capacity (K) parameters. Like all production models, successful fitting (precise and robust parameter estimates) from the S-H model requires a high degree of contrast in the time series (1982-2004) of weakfish biomass. Previous production modeling (Uphoff 2005a; Crecco 2005a) has thus far indicated that precise estimates (r, K) were obtained based on the 1982-2004 time series of weakfish landings and biomass estimates. The S-H model was originally expressed as a logistic production model with an added sigmoid function that reflected the foraging response by the predator. Previous weakfish production modeling indicated that the gompertz asymmetrical model was a better fit to the weakfish biomass data than the logistics model (Crecco 2005a, 2005b). As a result, the surplus production portion of the S-H model was converted from the logistics to the Gompertz form:

Biot+1= Biot+log(K)*r*Biot*(1-(log(Biot)/log(K)))- catcht-[(c*Predt*(Biot)**2)/(A**2+(Biot)**2)] (6)

where: Biot+1 = weakfish biomass (mt) in year t+1;
Biot = weakfish biomass (mt) in year t;
Predt = abundance of the predator in year t;
K = estimated carrying capacity of weakfish (mt);
r = intrinsic rate of population increase;
c = per capita consumption rate of the predator;
A = weakfish biomass (mt) where predator satiation takes place.

In the Gompertz model, Fmsy is expressed solely by the intrinsic rate estimate (r), whereas Bmsy is expressed as K/2.72, where 2.72 = exp 1 (Quinn and Deriso 1999). All parameter estimates (r, K, c and A) from the S-H model (equation 6) were derived from the NLIN procedure (Marquardt algorithm) contained in the Statistical Analysis System (SAS 2002). The S-H model was fitted to weakfish biomass (Biot, Biot+1) (Table 11) and one or more of the candidate finfish predators (Predt) (Table 14) by nonlinear least squares regression methods. Note that the choice of one or more of the candidate finfish predators (Predt) (Table 14) was conditional upon results from the stepwise regression analysis.

Given the potential for moderate to severe measurement errors in the input data, the S-H models was also fitted as a nonlinear robust regression using the iterative reweighted least squares method outlined by Holland and Welsch (1978). The algorithm and rationale for this approach is described in the current SAS (2002). This re-weighting scheme allowed the down weighting of data from certain years in the model where model residuals (regardless of direction) exceeded a previously defined threshold level. As indicated by Holland and Welsch (1978), the choice of a threshold is subjective and always represents a trade-off between minimizing the variances around the parameters (r, K, c and A) and at the same time generating globally converged parameter estimates. As suggested by Holland and Welsch (1978), a range of threshold estimates were used initially and the final threshold value was selected that satisfied the trade-off between global convergence of all parameter estimates and parameter estimates with maximum precision (minimum variance). The two step re-weighting approach always produced converged estimates (global estimates) that were within 10% of the parameter estimates (r, K, c and A)

derived by the ordinary least squares approach. However, the standard errors about the estimates based on iterative re-weighting were always 30 to 45% lower, resulting in much narrower confidence limits about the overfishing definitions (Fmsy, Bmsy) and the predation parameters (c, A).

As indicated by Steele and Henderson (1984), the S-H model (equation 6) is a conventional discrete time surplus production model:

Biot+1= Biot+log(K)*r*Biot*(1-(log(Biot)/log(K)))- catcht , (7)

that is merged with a type 3 predator functional response of the type:

[(c*Predt*(Biot)**2)/(A**2+(Biot)**2)] (8)

In previous weakfish surplus production modeling (Uphoff 2005a), the discrete logistics model in the absence of predation effects (equation 7) was shown to seriously over predict recent (1998-2003) weakfish biomass, leading to a clear trend in recent residuals. This clear residual pattern indicated that the conventional production model (equation 7) was highly uncertain especially for short-term predictions. Model uncertainty is usually caused by the failure to include one or more informative parameters, or by choosing the wrong form of the model. Note that a model with low levels of uncertainty will produce no systematic residual pattern over time. To further examine for potential model uncertainty, the discrete component (equation 7) of the S-H model (i. e. without predation effects) was fitted to the 1982-2004 weakfish biomass estimates (Biot, Biot+1) (Table 11). If a systematic pattern should emerge in the residuals based on the recent (1998-2004) observed and predicted weakfish biomass (Biot+1) estimates, then severe process errors would again be manifested in the model. Statistical support for the Predation Hypothesis would be evident, if the addition of the predator component (equation 8) to the S-H model (equation 6) not only improved the model fit, but also greatly reduced model uncertainty that had previously plagued the discrete production model (equation 7).

In an earlier weakfish report, Uphoff (2005c) noted that if the predation parameter estimates (c, A) from the S-H model are sufficiently precise, then a time series of weakfish biomass estimates (Dt) consumed annually by the predator (Predt) can be derived in the form:

Dt = [(c*Predt*(Biot)**2) / (A**2 + (Biot)**2] . (9)

Once Dt estimates were obtained via equation (9), the instantaneous natural mortality rate (biomass weighted) ascribed to predation (Mp) can be derived:

Mp = Dt / [(Biot + Biot+1) /2]. (10)

Further empirical support for the Predation Hypthesis would be given if the biomass weighted natural mortality due to predation (Mp) on weakfish from 1982 to 2004 closely followed the trend in age 1+ weakfish natural mortality (MWt) estimates based on run #20 from the VPA.

The Gompertz surplus production model (equation 7) was fitted by nonlinear least squares regression to weakfish stock biomass in year t and t+1. This model did provide a good fit (r**2 = 0.68) to the biomass data with statistically significant (P < 0.05) r and K parameter estimates (Table 17). The resulting overfishing thresholds (Fmsy, Bmsy) for weakfish of 0.32 and 25,259 mt, respectively, were similar in magnitude to previous estimates (Table 17). However, this production model consistently over predicted weakfish biomass from 1998 to 2005 by 10 to 50% (Table 18), indicating that the Gompertz model was plagued by substantial model uncertainty. Although fitting the model (equation 7) by iterative reweighting least squares substantially improved the fit (r**2 = 0.82) and enhanced precision around the parameter estimates (r, K) and overfishing definitions (Fmsy, Bmsy) (Table 17), a severe residual pattern nevertheless persisted from 1998 to 2005 (Table 19). Severe model uncertainty, as indicated by a systematic trend in the residuals, usually indicates the absence of an informative parameter(s) to the model.

The full S-H production model (equation 6) was fitted by nonlinear least squares regression and iterative re-weighting to weakfish stock biomass in year t and t+1 (Biot, Biot1) and striped bass (Strip) as the potential predator (Tables 11 and 14). Both S-H model provided very good fits (r**2 = 0.88, 0.94) to the biomass and predation data with statistically significant (P < 0.05) r, K, c and A parameter estimates (Table 20). Overall, the S-H models was not only a better fit to weakfish biomass than the basic Gompertz model, but the r and K parameters, particularly from iterative re-weighting, were estimated with much higher precision. The resulting weakfish overfishing thresholds (Fmsy, Bmsy) from the nonlinear least squares S-H models for weakfish was 0.59 and 21,179 mt, respectively (Table 20). The overfishing thresholds (Fmsy,Bmsy) based on the iterative re-weighted S-H model was 0.55 and 23,400 mt, respectively (Table 11). The S-H model fitted by iterative re-weighting exhibited clear improvements in precision about the parameters (r, K, c and A) over the traditional least squares S-H model. Moreover, unlike the severe residual pattern evident from 1998 to 2004 based on the traditional gompertz models (Tables 18 and 19), there is little if any systematic residual pattern from the S-H model fitted by iterative re-weighting (Table 21). This indicated little if any uncertainty for the S-H model fitted by iterative re-weighting least squares. Finally, the time series (1982-2003) of predation-based natural mortality (Mp) from striped bass was derived via equations (9) and (10) (Table 22). The predatory mortality rates (Mp) rose in magnitude after 1997 coincident with a steady drop in weakfish biomass. This inverse relationship between Mp and weakfish biomass is consistent with the presence of depensatory density-dependent predation mortality which, if persistent over time, could be highly destabilizing to future weakfish population growth. Finally, the time series (1982-2004) of predatory natural mortality (Mp) was significantly correlated (Pearson r = 0.61, P <0.003) to the age 1+ natural mortality (MWt) values estimated independently (Table 22, Figure 36). These findings strongly suggest that the recent rise in weakfish ages 1+ natural mortality (MWt) coupled with the failure in weakfish productivity (SURPt) are tied directly to the increase in striped bass predation mortality (Mp).

Most of the statistical evidence given herein supports the Predation Hypothesis as the most reasonable explanation for the recent failure in weakfish productivity. Although results from the stepwise model identified striped bass, Atlantic croaker and fluke as primary weakfish predators (Table 15), striped bass was selected first over the other two in two (SURPT, Z0) out of three model runs. In the case of the stepwise model with ages 1+ natural mortality (MWt) as the response variable, striped bass was chosen second only to fluke as a major predator of adult

weakfish (Tables 15 and 16). Annual changes in fluke abundance from 1982 to 2004 were closely coupled to annual changes in weakfish ages 1+ MWt (Tables 10 and 14). Nevertheless, it is doubtful that this statistical relationship suggests a plausible causal mechanism. The mouth gape of even large (> 75 cm) fluke is relatively small (Olla et al. 1972) as compared to the mouth gape of other inshore apex predators such as striped bass and bluefish. The relatively small mouth size of fluke is primarily adapted to the consumption of invertebrates and small (< 25 cm) finfish prey. Therefore, larger fluke could conceivably prey heavily on age 1 weakfish (length range: 18-25 cm). However, it would be highly unlikely that even the largest fluke could prey effectively enough on ages 2+ weakfish to have caused the close positive fit (Pearson $r = 0.79$, $P < 0.0001$) given here between weakfish ages 1+ natural mortality and fluke abundance (Table 16). Therefore, we regard the promising statistical relationship given here between weakfish ages 1+ MWt and fluke abundance as a statistical artifact.

The close statistical coupling between the recent rise in weakfish juvenile mortality (Z0) and the parallel rise in striped bass and croaker abundance from 1982 to 2004 (Figure 35) implies that the recent emergence of a recruitment bottleneck at age 0 was due to predation. If this bottleneck persists over time, the flow of weakfish age 0 recruitment to older ages may become severely constricted, causing the weakfish stock to cascade downward from the bottom up. The contribution of croaker as a competitor or predator responsible for the weakfish recruitment bottleneck is difficult to establish at this time. Dietary studies of croaker are few in number (Miller et al 2004), but current research indicates that croaker, due to their relatively small size, eat mostly invertebrates (Overstreet and Heard 1978). The diet of croaker does overlap that of smaller (< 40 cm) weakfish, and like weakfish, larger (> 33 cm) croaker apparently undergo an ontogenic shift in diet from invertebrates to mainly fish (Miller et al 2004). Nevertheless, there is currently no empirical evidence that large croaker prey on weakfish of any size. On the other hand, since the diet of juvenile weakfish and croaker overlap, the strong statistical relationship given here between weakfish age 0 mortality and croaker abundance might indicate a rise in inter-specific competition for food between croaker and weakfish. If the outcome of recent inter-specific competition has favored croaker as indicated by the recent rise in croaker abundance (Table 14), somatic growth rates of age 0+ weakfish may have recently fallen, rendering juvenile and ages 1+ weakfish more susceptible to predation. This potential interaction between weakfish growth and predation mortality is directly supported by growth studies by Uphoff (2005b), who reported a steady decline in the coast-wide percentage of 13 in. + weakfish from 45.0% during the mid -1980's to about 1.0% in 2003. Although the strong statistical relationship between weakfish age 0 mortality and croaker abundance cannot be ruled out at this time, there is no empirical evidence thus far that Atlantic croaker are a major predator of juvenile weakfish.

The preponderance of statistical evidence given here supports the Predation Hypothesis involving striped bass as the primary predator of weakfish. Statistical evidence in support of the Predation Hypothesis consists of a strong inverse correlation (Pearson $r = -0.66$, $P < 0.0004$) between weakfish surplus production and striped bass abundance from 1982 to 2004 (Table 16). The strong correlation (Pearson $r = 0.91$, $P < 0.0001$) between weakfish juvenile mortality (Z0) and striped bass abundance (Figure 35) also suggests that the emergence of a weakfish recruitment bottleneck at age 0 was largely due to striped bass. Finally, striped bass mortality rates (Mp) on ages 1+ weakfish derived empirically from the S-H model from 1982 to 2003 were

closely correlated (Pearson r = 0.61, P < 0.002) to ages 1+ natural mortality (MWt) rates derived independently from run #20 of the VPA.

Although results from regression and production models alone do not demonstrate causality, recent empirical evidence is consistent with the Predation Hypothesis involving striped bass. Striped bass are known to consume finfish prey up to 60% of their own body length (Manooch 1973). Unlike large fluke and Atlantic croaker that prey mainly on small (< 22 cm) fish, large (> 76 cm) striped bass can easily prey on larger (> 40 cm) weakfish. In addition, the recent drop in weakfish productivity after 1997 was shown to have a spatial component that matched the distribution of striped bass. Weakfish landings and surplus production fell rapidly after 1998 from the Mid and North Atlantic subregions, but surplus production from the South Atlantic subregion had remained steady (Crecco 2005c). It so happens that anadromous striped bass are very abundant along the Mid and North Atlantic coast throughout the year, but are seldom encountered in any numbers south of Cape Lookout, NC. The predator assemblage south of Cape Lookout, NC is largely composed of Gulf Stream predators such as king mackerel and cobia etc. This well -defined spatial match between prey (weakfish) and predator (striped bass) clearly supports the validity of the Predation Hypothesis. Further empirical support of the hypothesis includes recent food habit studies of striped bass (Walter and Austin 2003; Ruderghausen et al 2005), indicating that weakfish and other sciaenids (spot) were primary food items of larger (> 60 cm) striped bass in Chesapeake Bay and Albemarle Sound. Moreover, a recent rise in striped bass abundance has been linked empirically to the steady decline of blueback herring in the Connecticut River and Albemarle Sound (Savoy and Crecco 2004; Rudershausen et al 2005), as well as with the menhaden decline from Chesapeake Bay (Uphoff 2003; Walter and Austin 2003). These findings suggest that the recent rise in striped bass production to record levels from 1997 to 2004 is largely responsible for the recent decline in weakfish productivity and sustainable yield.

The strong inverse relationship between striped bass mortality (Mp) rates (Figure 36, Table 22) and weakfish biomass since 1997 (Figure 37, Table 11) is consistent with the presence of depensatory density-dependent mortality. This phenomenon plus the apparent emergence of a weakfish recruitment bottleneck between ages 0 and 1 (Figures 32 and 33) makes stock rebuilding via the implementation of fisheries management measures an exceedingly difficult task. As indicated by Spencer and Collie 1997), fish stocks that are subject to moderate to severe depensatory predatory mortality, often undergo a sudden and persistent drop in surplus production over time even when fishing mortality rates have remained low for several years. Note that the biomass weighted fishing mortality (FWt) on ages 1+ weakfish have been below the Steele-Henderson Fmsy of 0.55 (Table 20) since about 1993 (Figure 36). Under depensatory predation, the weakfish stock is also expected to remain low and unresponsive to favorable climatic events and to further fishery management restrictions. Note that weakfish stock biomass has fallen steadily since 1999 to a 2005 stock biomass level of 7400 mt which is about 60% below the new Bmsy level of 23,400 mt (Table 20, Figure 37). The phenomenon of depensatory mortality, if driven largely by striped bass predation, could lead to a persistent and perhaps irreversible failure in weakfish productivity unless striped bass productivity in the next few years reverts back to pre 1998 levels.

The pessimistic outlook regarding the future of the Atlantic coast weakfish due to depensatory predation may be tempered somewhat by our findings of compensatory density-dependent survival during or before the juvenile stage. Compensatory mortality was manifested here by the recent and persistent rise in the coast-wide juvenile recruitment (N0) after 1995 (Figures 32) despite the pronounced drop in weakfish biomass after 1998 (Figure 37, Table 11). It is notoriously difficult to sort out the ramifications on future weakfish stock growth when both depensatory and compensatory mechanisms are operating simultaneously. However, the added stock resiliency due to compensatory processes at the juvenile stage may persist over several more years. If so, it may in fact overcome or at least balance out the adverse effects of depensatory predation, allowing the weakfish stock to achieve equilibrium at the current low levels for the foreseeable future.

The most restrictive management measures, such as a coast-wide moratorium to weakfish harvest, would reduce the 2004 F of 0.25 and landings to zero. A coast-wide moratorium would also reduce the high total mortality (Z) levels on ages 1+ weakfish by about 30% based on the 2004 ratio of fishing (F) to total mortality (F / Z). In a sense, the F/Z ratio is a relative measure of leverage that fishery managers can exert in order to enhance the chances of rebuilding depleted stocks. From 1982 to 1995, the F/Z ratios for weakfish were, in most years, well above 0.75, indicating the presence of relatively high leverage and thus a high probability that management measures if implemented then would have lead to stock rebuilding. As natural mortality (M) on ages 1+ weakfish increased after 1999 (Table 22), however, the F/Z ratios fell quickly below 0.35, thereby greatly reducing the likelihood that management measures imposed after 2005 would eventually lead to a weakfish stock recovery. This relationship between the probability of stock rebuilding via management action and the F/Z ratio was recently addressed by (Uphoff 2005d) by forecasting weakfish stock abundance over the next 20 years from the logistic production model. If M was allowed to remain at the 2003 level, he reported little if any future weakfish stock rebuilding following a 50% reduction in fishing mortality (F) if the current weakfish fishing mortality rates (F) on weakfish comprised less than 40% of total mortality (Z). The problem of weakfish stock rebuilding is made even worse by the emergence of a recruitment bottleneck at age 0 (Figure 33). Even a coast-wide moratorium to weakfish harvest would have little if any impact on the recently emergent recruitment bottleneck, where age 0 weakfish are not susceptible to direct harvest.

Like virtually all finfish stock assessments conducted along the Atlantic coast, natural mortality (M) of age 1+ weakfish was assumed to be constant (M = 0.25) in previous Yield-per-Recruit and VPA model runs. We found that the trend in annual biomass weighted natural mortality (MWt) from 1982 to 2003 did not support the constant M assumption (Table 10, Figure 34). Annual (MWt) estimates for ages 1+ weakfish rose steadily from 0.31 in 1996 to a high of 1.09 in 2002 (Figure 34). The management consequences of assuming a constant M when M actually rises systematically over time can be serious (Mertz and Myers 1997). As noted in this weakfish assessment, by holding M constant, the resulting ages 1+ fishing mortality rates (F) on weakfish would have risen steadily to around 0.85 in 2003 based on the VPA run #20. If the constant M assumption and ensuing VPA results were accepted without qualification, we would have concluded falsely that the recent failure in weakfish productivity was due to overfishing. In future assessments here and elsewhere, the assumption of constant M for ages 1+ fish needs to be critically examined. In addition, the impacts of trophic and environmental effects on exploited

finfish stocks should be integrated into fisheries models and rigorously tested as a potential alternative hypothesis to the overfishing hypothesis.

STOCK PROJECTIONS

The weakfish assessment has evolved into aggregated biomass modeling after the failure of ADAPT VPA to provide accurate estimates of recent stock parameters (Crecco 2005a; Kahn et al. 2005). Crecco (2005) used external surplus production modeling (Jacobson et al. 2002) to estimate overfishing thresholds for weakfish. Surplus production models can be used as a basis for projections (Prager 1994), but the underlying assumptions of ecological stability (Spencer and Collie 1997) and dependence of changes in biomass on F in the model would render their utility doubtful in a situation where M is changing and likely the dominant factor driving biomass dynamics.

The current weakfish assessment provides the pieces for an external production modeling approach that does not require an assumption of ecological stability. Estimates of full time-series (1981-2003) of F and biomass (B) were provided in Crecco (2005) and Z was estimated with minimal or no retrospective bias through 2000 (Kahn et al. 2005). Therefore, biomass-based estimates of Z (F + M) were available through 2000. If Z is considered the negative counterpart of the intrinsic rate parameter (r′; Jordan and Coakley 2004), the Schaefer biomass dynamic model can be parameterized as

$$1)\ B_t = B_{t-1} + (r'-Z) \bullet B_{t-1} \bullet (1-(B_{t-1} / K)).$$

This estimate of r′ may not be equivalent to the standard estimate of r derived by production modeling because M can vary within the estimate of Z. In the discrete time-step form, an initial estimate of biomass, (B_{1981}), r′ and K are estimated. The latter two parameters are critical for projecting biomass under assumed levels and trajectories of annual F and M. This model was used to project biomass into the future under assumed levels of F_t and M_t.

Methods

Development of projections was a two-step process. First, r′, K, and B_{1981} were estimated using the 1981-2000 estimates of B_t from Crecco (2005) and Z from Kahn et al. (2005; VPA with MRFSS tuning only). Estimates of B_t and Z_t were ultimately based on MRFSS private boat catch per effort as a biomass index and catch estimates that included discards (Crecco 2005a; Kahn et al. 2005). Equation 1 was fit in an Excel spreadsheet using Solver to minimize $\sum$ (ln observed B_t – ln predicted B_t). This was considered the base model for projections. Instantaneous annual fishing mortality rate in year t was estimated from predicted biomass as

$$(2)\ F_t = H_{t-1} / [(B_t + B_{t-1}) / 2] \text{ (Ricker 1975);}$$

where B is estimated from the equation 1 and H is harvest (including estimated discards).

The second step completed the estimates of Z_t through 2003. Crecco's (2005) estimates of B_t for 2001-2003 were assumed to be accurate. Goalseek in Excel was used to estimate Z_t necessary to produce B_t given the parameters estimated by equation 1. With estimates of Z_t complete, M_t could be estimated as $Z_t – F_t$ through 2002. Since F_t in equation 2 was harvest based, F_{2003} could not be estimated without projecting biomass forward and F_{2002} represented the

last estimate in the time-series. An estimate of F_{2003} was available from Crecco (2005), so M could be estimated for 2003 in this case.

Bootstrapping (N = 250) indicated precision of r′, K, B_{1981}, B_t, and F_t of the base model for 1981-2003 data. To investigate model sensitivity, estimates of r and K from previous production models were used as a starting point (r = 1.17 and K =49,500 mt; r = 0.58 and K = 57,700 mt; and r = 0.90 and K =64,028 mt; predator-prey, Schaefer, and Gompertz, respectively; Uphoff 2005a; Crecco 2005a), held K constant, and estimated only r′ and B_{1981}.

Projections of biomass through 2025 used base model r′, K, B_{2003} and mean estimates of F_t and M_t for 2001-2002 as a starting point. It was assumed that cuts in F would not occur until 2006, so biomass trajectory during 2004-2005 was based on a continuation of average conditions. Cuts were instituted in 2006 and maintained until 2025. Biomass trajectory was estimated for Z minus F • 0 (no action), F • 0.25, F • 0.5, F • 0.75, F • 1.0 (complete moratorium with no discard loss), F • 1.5, and F • 2.0. The latter two cuts implied instant reductions in M as well as F.

The Technical Committee (TC) requested simulations that depicted a gradual decline in M to a baseline of M = 0.25. This level of M equaled the constant estimate of M used in previous SARC reviewed weakfish stock assessments (NEFSC 1998; 2000) and in the ADAPT VPA in the current assessment (Kahn et al. 2005). Use of a baseline M other than 0.25 in projections may have required rerunning VPA and rescaled relative F analyses (V. Crecco, CT DEP, personal communication).

The model was modified to portray declines in M over time to a base level of M = 0.25. Scenarios were run of cuts in F (0, 25%, 50%, 75%, and 100%) with constant declines in M_t to this baseline level. A decrease in M after 2006 until $M_t = 0.25$ was simulated as

$$(3)\ M_{t+1} = M_t \bullet ß.$$

Once $M_t \bullet ß = 0.25$ was reached, M_t was held constant at 0.25.

To gain insight on how rapidly M could decrease, the trajectory of the increase in M during 1996-2001 (M increased from 0.29 to 1.13) was reversed to mimic a rate of maximum decline (ß). The estimate of M in 2002, 0.77, was not included because it was lower than the maximum estimated M in 2001 (1.13). Solver in Excel was used to estimate the initial M and ß in equation 1 that minimized the sum of squared differences between the observed and estimated M. The model was further constrained so that M in the final year was 0.25. This model predicted the change in M well ($r^2 = 0.99$) and estimated ß as 0.76. This estimate of ß was rounded to 0.8. Values of ß less than 0.8 tended to produce very similar results in previous projection exercises to ß = 0.8 (Uphoff 2005a; 2005b).

Results and Discussion

The external production model fit the 1981-2000 biomass estimates well ($r^2 = 0.84$, $P < 0.001$; Figure 39). There was some serial patterning of residuals, with three to four year periods of over- or underestimation (Figure 39). Model parameters were estimated as r′ = 0.90, K = 86,409 mt, and B_{1981} = 40,692 mt. Bootstrapping indicated these estimates were extremely precise, with a maximum difference of no more than 0.02% among these parameters. This precision carried

over to estimates of biomass and other parameters derived from biomass (F_t and M_t). Base model estimates of Z_t were 1.49 during 2001, 1.22 during 2002, and 1.45 during 2003.

Estimated F_t was high during 1981-1991, typically 0.6 or greater (Figure 40). Fishing mortality fell to about 0.2 by 1999 and then began a steady rise to 0.4 by 2002. Estimates of M_t were higher than F_t during 1982-1984 and then plunged to near zero by 1987. M_t varied from 0.2-0.5 during 1988-1998 and then increased to 0.8-1.1 during 2000-2002 (Figure 40).

Estimates or r′ were insensitive to values of K used in the external production models (Table 23). Even though estimates of K varied between 49,500 and 86,400 mt, estimates of r′ fell between 0.893 and 0.903 (Table 23). Estimates of r′ increased linearly as K increased. High precision in estimating r′ was important because the early phases of recovery would be dependent on it. Estimates of B_{1981} varied somewhat among the model conditions and all were less than estimated in Crecco (2005; Figure 41). Biomass estimated by external production models with varying assumptions about K converged with each other by 1985 and were very similar through 2000. These estimates diverged somewhat from those in Crecco (2005; Figure 41). This pattern of agreement was exhibited with estimates of F_t (Figure 42) and M_t (Figure 43) as well. The increase in M since the late 1980s exhibited here corresponded with trends in M_t from the Schaefer biomass dynamic model with a striped bass predation term (Uphoff 2005a).

Projections of biomass started in 2003 at 6,843 mt, $F_{current} = 0.41$, and $M_{current} = 0.95$. Modeled stock biomass dropped to about 2,000 mt before management actions were implemented in 2006 (Figure 44); this represented about 7% of mean 1998-2000 biomass that served as a target for recovery. Recovery was indicated once the mean 1998-2000 biomass (29,875 mt) was reached. The TC chose this value because it had been attained in the recent past; harvests and other attributes such as size quality were considered to be nearly recovered at that time. A value equal to 30% of K was considered as a target as well as a proxy for Amendment 4's 30% maximum spawning potential (30% MSP). This target was rejected because of substantial uncertainty of estimates of K among methods tried (Table 23) and the potential for it to change unexpectedly and drastically under the regime shift concept (Spencer and Collie 1995). Estimation of 30% MSP required equilibrium assumptions (constant growth and M) that could no longer be supported.

Weakfish biomass fell continuously in all cases when only $F_{current}$ was cut and $M_{current}$ was unchanged (Figure 44). In the two scenarios where current F was maintained or cut by 25%, weakfish became "extinct" (exploitable biomass = 0) after 2020 and 2025, respectively. Only the scenario of a completely effective moratorium, where discard mortality did not occur, kept biomass from falling to less than 100 mt by 2025. Under a completely effective moratorium, biomass was projected to fall to 875 mt in 2025 (Figure 44). Stemming the decline in weakfish biomass by managing the fishery alone seems unlikely based on these simulations unless the amount of Z attributed to F has been seriously underestimated (for instance, F is 0.8 instead of 0.4).

Biomass increased only when some depreciation of $M_{current}$ was part of the reduction in $Z_{current}$ (Figure 45; Table 23). Biomass slowly increased when $Z_{current}$ was reduced by $1.5 \bullet F_{current}$

starting in 2006. Recovery did not occur until 2025 with the 1.5 • $F_{current}$ cut (Figure 45). A cut in $Z_{current}$ equal to 2.0 • $F_{current}$ resulted in recovery by 2015 (Figure 45).

Without cuts in $F_{current}$, a decline to a baseline M of 0.25 when ß = 0.8 did not allow biomass to approach the level of recovery through the modeled horizon (2006-2025; Figure 46). If $F_{current}$ was cut by 25%, biomass recovered by 2024. When a 50% cut in $F_{current}$ was instituted, recovery occurred by 2021 and recovery to target biomass occurred in 2018 when $F_{current}$ was cut by 75% (Figure 46).

In light of the recent declines in landings, questions have been raised regarding the effectiveness of Amendment 3 of the FMP, imposed in 1995. The Amendment, bolstered by the federal Atlantic Coast Cooperative Fisheries Management Act, which made ASMFC management plans mandatory along the coast, included creel limits, minimum sizes, minimum commercial mesh sizes and restrictions on commercial effort. Following this, landings and relative abundance began to increase. A striking divergence appeared between the MRFSS estimates of total catch including discards (B2 component) and the estimated recreational harvest (A + B1 component) (Figure 2A). The former began rising well above estimates of the latter. This was the apparent conservation effect of minimum size limits and creel limits on the fishery. Previously, the two estimates had been almost identical. Estimates of scaled-up relative F have been relatively low and stable since 1995. ADAPT estimates of SSB showed increases in 1996 and 1997 before beginning the recent decline in 1998, according to Run 20. Abundance of the plus group began to increase after 1995 through 1999. Although this improvement in stock status did not persist, the technical committee strongly supports a continuation of at least the current fisheries conservation measures, because they had an apparent positive effect during the middle 1990s.

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TABLES

Table 1A. Decision Table for Weakfish Management. Table entries are possible or probable results of the given management action, given a correct biological hypothesis.

	MANAGEMENT ACTION		
BIOLOGICAL HYPOTHESIS	**Restrict**	**Status Quo**	**Liberalize**
Stock Increasing	Probably lower yield; possible further stock growth	higher yield	much higher yield
Stock Stable	Reduced yield; stock growth	stable yield	higher yield at first, but stock could decline
Stock Declining	Even lower yield ; reduction in total mortality and possible reduction in stock decline; including possible stabilization or even increase	low and declining yield, continued stock decline(?)	Possible temporary increase in yield, then greater stock decline (?)

TABLE 1B. Evidence in support of the three hypotheses of stock status and trends in Table 1A.

1. Analyses and data supporting increasing stock hypothesis:

- NMFS and NJ survey Total CPT
- results from ADAPT with trawl surveys as tuning indices (severe retrospective bias invalidates these results, though)
- ADAPT tuned to trawl surveys plus recreational catch per unit effort indices (again severe retrospective bias largely invalidate this)

2. Analyses and data supporting stable stock hypothesis:

- Biomass dynamics model with trawl survey tuning indices: stable and high

3. Analyses and data supporting declining stock hypothesis:

- decline in New Jersey age-structured trawl survey exploitable biomass catch per tow
- decline in Delaware age-structured trawl survey exploitable biomass catch per tow
- age structure truncation in Delaware trawl survey catch
- decline in recreational catch
- decline in commercial catch
- decline in recreational harvest per trip
- decline in recreational total catch per trip
- biomass dynamic models tuned to recreational fishery cpue indices
- results of ADAPT tuned to only recreational catch per unit effort as indices (again severe retrospective bias invalidates this result, however)
- decline in untuned cohort analysis through 1999
- length frequency analysis of Delaware and New Jersey survey catches (proportional stock densities) shows a decline in size structure
- stock size estimated by N = catch/F from scaled up F estimates.
-decline in surplus production through 2002

Table 2. Atlantic coast harvest of weakfish from 1981 through 2003, by sector and total.

	RECREATIONAL HARVEST			COMMERCIAL LANDINGS		TOTAL LANDINGS	
TOTAL YEAR	TOTAL CATCH, INCLUDING DISCARDS (A+B1+B2)	HARVEST IN NUMBERS (A + B1)	HARVEST IN POUNDS	POUNDS	COMMERCIAL PROPORTION OF HARVEST IN POUNDS	POUNDS	METRIC TONS
1981	9,629,309	9,344,461	16,105,028	26,363,607	0.62	42,468,635	19,260.15
1982	2,044,670	1,854,090	8,285,326	19,478,274	0.70	27,763,600	12,591.2
1983	5,916,269	5,642,950	11,730,619	17,475,003	0.60	29,205,622	13,245.18
1984	3,769,040	3,520,811	7,013,781	19,773,587	0.74	26,787,368	12,148.47
1985	2,775,824	2,419,670	5,489,026	16,953,357	0.76	22,442,383	10,177.95
1986	10,973,586	8,664,122	10,141,786	21,187,973	0.68	31,329,759	14,208.51
1987	5,719,807	4,871,532	6,749,890	17,072,159	0.72	23,822,049	10,803.65
1988	6,446,383	5,626,268	6,331,649	20,526,402	0.76	26,858,051	12,180.52
1989	1,674,568	1,495,391	2,177,237	14,163,008	0.87	16,340,245	7,410.54
1990	1,671,808	1,232,253	1,347,260	9,438,260	0.88	10,785,520	4,891.39
1991	2,601,480	1,812,691	2,130,563	8,692,760	0.80	10,823,323	4,908.54
1992	1,667,809	960,151	1,398,980	7,453,788	0.84	8,852,768	4,014.86
1993	2,218,559	1,079,275	1,102,340	6,853,579	0.86	7,955,919	3,608.13
1994	4,928,951	1,826,495	1,795,517	6,190,520	0.78	7,986,037	3,621.79
1995	5,696,423	1,588,079	1,855,548	7,098,831	0.79	8,954,379	4,060.94
1996	7,306,298	2,269,330	2,925,392	6,940,578	0.70	9,865,970	4,474.36
1997	6,832,363	2,815,654	3,692,716	7,297,859	0.66	10,990,575	4,984.39
1998	5,697,395	2,386,345	4,044,974	8,424,725	0.68	12,469,699	5,655.19
1999	4,477,989	1651554	3,143,427	6,903,940	0.69	10,047,367	4,556.63
2000	6,727,052	2,089,202	4,154,794	5,372,672	0.56	9,527,466	4,320.85
2001	5,233,868	1526583	2,722,630	4,988,718	0.65	7,711,348	3,497.21
2002	3,289,765	1,171,889	2,192,607	4,767,232	0.68	6,959,839	3,156.39
203	2,098,056	497,571	864,962	1,970,291	0.69	2,835,253	1,285.83
2004	2,602,057			1,178,582			
2005							

Table 2A. Age and length sample intensity by half-year and state used for the catch-at-age calculations since the 30th SAW.NMFS (2000), which reviewed the weakfish assessment from 1982-1998. Age samples for the SEAMAP fall and NEFSC fall inshore surveys were produced by Dr. Charles Wenner, South Carolina Department of Natural Resources.

YEAR	SEASON	STATE	AGED	MEASURED FROM COMM LANDINGS	COMM LANDINGS MT	COMM LENGTHS / MT	MEASURED FROM REC LANDINGS, MRFSS	RECREATIONAL LANDINGS, MT	REC LENGTHS / MT
1999	EARLY	MA	0	0	0.2	0.0	0	0.00	0
		RI	0	0	18.3	0.0	2	0.78	2.55
		CT	0	0	2.7	0.0	1	0.94	1.06
		NY	0	0	39.3	0.0	10	17.74	0.56
		NJ	0	0	115.3	0.0	48	188.49	0.25
		DE	335	4256	163.8	26.0	96	88.28	1.09
		MD	1	43	28.5	1.5	20	28.26	0.71
		VA	159	1182	345.6	3.4	56	93.43	0.60
		NC	309	9995	991.4	10.1	135	33.55	4.02
		SC	0	0	0.3	0.0	1	0.27	3.73
		GA	102	0	0.3	0.0	0	0.00	0
		FL	0	43	4.5	9.6	7	17.01	0.41
	SEAMAP	SURVEY	229						
		TOTAL	**1,135**	**15,519**	**1,710**	**9.1**	**376**	**468.8**	**0.80**
1999	LATE	MA	0	0	1	0.0	0	0.00	0.00
		RI	0	0	38.9	0.0	2	1.88	1.06
		CT	0	0	7.5	0.0	2	1.95	1.03
		NY	0	0	182.8	0.0	15	10.86	1.38
		NJ	0	0	470.4	0.0	152	434.84	0.35
		DE	0	70	36.3	1.9	134	131.34	1.02
		MD	226	556	72.7	7.6	242	218.71	1.11
		VA	374	2128	414.2	5.1	61	87.82	0.69
		NC	348	5752	186.5	30.8	123	39.61	3.11
		SC	0	0	0		3	1.72	1.74
		GA	129	0	0		2	0.73	2.73
		FL	10	13	3.5	3.7	81	27.65	2.93
	SEAMAP	SURVEY	255						
	NEFSC	SURVEY	373						
		TOTAL	**1,715**	**8,519**	**1,414**	**6.0**	**817**	**957**	**0.85**
2000	EARLY	MA	0	0	0.0		0	0.00	0.00
		RI	0	46	17.1	2.7	1	0.87	1.15
		CT	0	0	1.0	0.0	3	2.92	1.03
		NY	0	0	57.8	0.0	7	59.53	0.12
		NJ	0	0	173.5	0.0	45	299.31	0.15
		DE	481	1995	106.8	18.7	54	177.02	0.31
		MD	113	113	22.4	5.0	22	31.05	0.71
		VA	165	1219	258.8	0.0	117	142.25	0.82
		NC	424	11816	608.7	4.8	51	18.80	2.71
		SC	0	0	0.0		0	0.00	0.00
		GA	0	0	0.0		1	0.20	5.13
		FL	25	25	1.9	4.8	47	24.12	1.95
	SEAMAP	SURVEY							
		TOTAL	**1,208.0**	**15,214.0**	**1,248.0**	**12.2**	**348.0**	**756.1**	**0.46**
2000	LATE	MA	0	0	0.0		0	0.00	0.00
		RI	0	132	58.6	2.3	0	0.00	0.00
		CT	0	0	2.2	0.0	12	13.00	0.92
		NY	0	0	76.3	0.0	2	15.10	0.13
		NJ	0	0	312.4	0.0	132	569.83	0.23
		DE	965	224	21.1	10.6	20	111.17	0.18
		MD	99	99	60.7	1.6	221	284.95	0.78
		VA	390	1885	365.7	5.2	77	82.83	0.93
		NC	192	6426	232.4	27.7	71	21.08	3.37
		SC					9	2.86	3.14
		GA					3	1.40	2.15
		FL		0	2.1	0.0	29	26.33	1.10
	SEAMAP	SURVEY							
	NEFSC	SURVEY							
		TOTAL		**8,766.0**	**1,131.5**	**7.7**	**576.0**	**1,128.6**	**0.5**

Table 2A, continued

YEAR	SEASON	STATE	AGED	MEASURED FROM COMM LANDINGS	COMM LANDINGS MT	COMM LENGTHS / MT	MEASURED FROM REC LANDINGS, MRFSS	RECREATIONAL LANDINGS, MT	REC LENGTHS / MT
2001	EARLY	MA	0	0	0.0	0.0	0	0.00	0.00
		RI	178**	178**	10.8	16.5	0	0.00	0.00
		CT	34	0	0.3	0.0	0	0.00	0.00
		NY	0	0	39.9	0.0	9	39.04	0.23
		NJ	0	0	108.0	0.0	43	114.82	0.37
		DE	300	370	75.0	4.9	69	50.69	1.36
		MD	0	8	27.3	0.3	5	15.61	0.32
		VA	152	758	249.9	3.0	82	107.63	0.76
		NC	328	9,747	723.3	13.5	19	2.44	7.78
		SC					0	0.00	0.00
		GA			0.0		1	0.12	8.06
		FL		0	2.4	0.0	6	10.42	0.58
	SEAMAP	SURVEY	99	na	na		na		
		TOTAL	**992**	**11,306**	**1,237**	**9.1**	**234**	**341**	**0.7**
2001	LATE	MA	0	0	0.1	0.0	0	0.00	0.00
		RI	178**	178**	38.9	4.6	0	0.00	0.00
		CT	69	0	2.7	0.0	1	2.22	0.45
		NY	0	372***	222.9	1.7	3	29.72	0.10
		NJ	0	0	271.8	0.0	362	452.70	0.80
		DE	861	0	2.7	0.0	59	27.77	2.12
		MD	193	261	68.2	2.8	294	241.87	1.22
		VA	420	1806	280.6	6.4	106	61.66	1.72
		NC	220	3199	158.8	21.6	161	69.42	2.32
		SC					0	0.00	0.00
		GA					2	1.22	1.64
		FL		0	2.5	0.0	17	7.63	2.23
	SEAMAP	SURVEY	151	na	na		na		
	NEFSC	SURVEY	617	na	na		na		
		TOTAL	**2,699**	**6,003**	**1,049.3**	**5.7**	**1,005**	**894**	**1.1**
2002	EARLY	MA	0	0	0.2	0.0	0	0.00	0.00
		RI	50	50	30.4	1.6	0	0.00	0.00
		CT	22	0	2.6	0.0	0	0.00	0.00
		NY	0	0	45.0	0.0	4	9.48	0.42
		NJ	0	0	92.4	0.0	101	228.98	0.44
		DE	561	1,179	54.9	21.5	201	81.06	2.48
		MD	20	21	11.0	1.9	12	10.80	1.11
		VA	328	2,399	325.8	7.4	110	39.92	2.76
		NC	231	9,121	691.8	13.2	47	7.92	5.93
		SC					0	0.18	0.00
		GA					0	0.00	0.00
		FL		0	1.6	0.0	17	21.17	0.80
	SEAMAP	SURVEY	122*	na	na		na		
	CHESMAP	SURVEY	141	na	na		na		
		TOTAL	**1,478**	**12,770**	**1,255.74**	**10.2**	**492**	**400**	**1.2**
2002	LATE	MA	0	0	0.2	0.0	0	0.00	0.00
		RI	0	0	25.2	0.0	2	1.72	1.16
		CT	42	0	2.0	0.0	1	5.12	0.20
		NY	0	0	188.1	0.0	8	17.11	0.47
		NJ	0	0	299.0	0.0	164	321.67	0.51
		DE	760	0	23.5	0.0	58	29.23	1.98
		MD	44	216	44.8	4.8	58	68.16	0.85
		VA	318	4170	211.2	19.7	141	94.08	1.50
		NC	281	3642	130.8	27.8	59	29.61	1.99
		SC					7	22.56	0.31
		GA					1	0.31	3.22
		FL		0	1.1	0.0	21	5.66	3.71
	SEAMAP	SURVEY	153	na	na		na		
	CHESMAP	SURVEY	550	na	na		na		
	NEFSC	SURVEY	692	na	na		na		
		TOTAL	**2,838**	**8,028**	**925.9**	**8.7**	**520**	**595**	**0.9**

Table 2A, continued

YEAR	SEASON	STATE	AGED	MEASURED FROM COMM LANDINGS	COMM LANDINGS MT	COMM LENGTHS / MT	MEASURED FROM REC LANDINGS, MRFSS	RECREATIONAL LANDINGS, MT	REC LENGTHS / MT
2003	EARLY	MA	0	0	0.2	0.0	0	0.00	0.00
		RI	0	0	8.4	0.0	0	0.00	0.00
		CT	4	0	4.6	0.0	0	0.00	0.00
		NY	0	0	30.6	0.0	1	11.55	0.09
		NJ	36	104	70.4	1.5	22	58.20	0.38
		DE	580	944	38.4	24.6	14	4.77	2.94
		MD	0	7	3.2	2.2	0	0.00	0.00
		VA	350	1900	100.5	18.9	41	49.83	0.82
		NC	269	5227	267.9	19.5	42	15.64	2.68
		SC					0	0.00	0.00
		GA					0	0.00	0.00
		FL		0	1.0	0.0	9	4.50	2.00
	SEAMAP	SURVEY	219*	na	na		na		
	CHESMAP	SURVEY	78	na	na		na		
		TOTAL	**1500**	**8,182**	**525.2**	**15.6**	**129**	**144**	**0.9**
2003	LATE	MA	0	0	0.0	0.0	1	0.40	2.53
		RI	211	343	20.3	16.9	1	1.08	0.93
		CT	22	0	0.3	0.0	1	1.60	0.62
		NY	0	0	34.7	0.0	4	5.28	0.76
		NJ	29	0	83.6	0.0	38	93.16	0.41
		DE	372	0	3.1	0.0	23	21.48	1.07
		MD	202	276	11.1	24.8	17	11.20	1.52
		VA	323	2226	108.1	20.6	49	47.93	1.02
		NC	220	3523	114.1	30.9	89	57.60	1.55
		SC					2	1.95	1.02
		GA					3	0.60	4.98
		FL		0	0.2	0.0	13	5.56	2.34
	SEAMAP	SURVEY	0	na	na		na		
	CHESMAP	SURVEY	595*	na	na		na		
	NEFSC	SURVEY	0						
		TOTAL	**1975**	**6368**	**375.5**	**17.0**	**241**	**247.9**	**1.0**

* MANY AGED WERE AGE 0

**EARLY AND LATE SEASONS POOLED

***NMFS AT-SEA OBSERVER DATA FROM NY-BASED TRAWLS

Table 3. Results of catch curve analysis of the four age-structured research trawl surveys. Each year class represented in each survey was subjected to catch curve analysis. For each survey, the table presents the number of ages represented for each year class, the statistical probability that the linear regression is due to chance alone and the resulting estimate of Z. Entries in bold are year classes present in the terminal year of the survey when they function as tuning indices in the estimation of stock size in the terminal year plus one. Estimates of Z that are negative are highlighted. Negative Z indicates a cohort gained animals instead of lost them as time proceeded, because the catch curve has a positive slope. These results are biologically nonsensical, and are grounds for disqualifying a survey if those year classes are present in the terminal year.

	NEFSC			NEW JERSEY			DELAWARE			SEAMAP		
YEAR CLASS	NUMBER OF AGES	*P*	Z	NUMBER OF AGES	*P*	Z	NUMBER OF AGES	*P*	Z	NUMBER OF AGES	*P*	Z
1981	4	*ns*	0.81									
1982	4	*ns*	0.57									
1983	4	0.02	0.94									
1984	4	0.083	1.83									
1985	4	0.13	1.5									
1986	4	*ns*	0.54									
1987	4	*ns*	0.43									
1988	4	0.055	1.37	6	0.003	1.09						
1989	4	0.016	1.59	6	0.019	1.76						
1990	4	0.023	1.7	6	0.009	1.06	6	0.003	1.12	4	0.104	2.01
1991	4	0.067	0.9	6	0.096	0.37	6	0.027	0.70	4	*ns*	0.42
1992	4	*ns*	0.57	6	*ns*	0.29	6	0.009	0.78	4	*ns*	0.72
1993	4	*ns*	-0.12	6	0.047	0.77	6	0.02	0.56	4	0.024	2.14
1994	4	0.076	1.18	6	0.0035	0.74	6	0.0004	0.88	4	0.12	1.48
1995	4	0.013	1.43	6	0.0005	0.95	6	0.0045	1.23	4	*ns*	0.35
1996	4	0.102	0.82	6	0.037	0.75	6	0.013	1.51	4	0.11	1.79
1997	4	*ns*	-0.06	6	0.075	0.66	**6**	**0.18**	**1.49**	4	*ns*	1.23
1998	4	0.053	0.6	**6**	*ns*	**0.51**	**5**	**0.062**	**1.90**	4	0.10	2.18
1999	4	0.13	0.63	**5**	**0.053**	**0.60**	**4**	**0.11**	**1.68**	4	*ns*	1.13
2000	**4**	***ns***	**0.38**	**4**	**0.079**	**-1.80**	**3**	***ns***	**1.19**	**4**	**0.04**	**1.34**
2001	**3**	**0.08**	**-0.52**	**3**	***ns***	**0.10**	**2**	**--**	**Pos. Z**	**3**	***ns***	**0.91**
2002	**2**	**--**	**Neg. Z**	**2**	**--**	**Pos. Z**				**2**	**--**	**Pos Z**

Table 4. Commercial discard at age matrix for Mid-Atlantic based on a reduced suite of target species by year for all gears combined using the NMFS web site non-seasonal landings. This is table 47 in de Silva (2004).

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total
1973	496,272	1,798,471	432,026	10,992	1,353	328	63	2,739,505
1974	358,872	1,276,077	537,044	97,007	29,789	6,756	1,310	2,306,855
1975	327,205	1,675,847	477,224	128,566	34,446	7,857	1,529	2,652,674
1976	398,670	1,794,891	838,439	139,509	41,493	9,461	1,845	3,224,308
1977	118,146	857,487	815,590	138,242	21,875	6,298	52	1,957,690
1978	530,594	1,726,687	1,030,398	115,699	2,054	404	65	3,405,901
1979	1,405,045	2,936,122	1,205,998	179,724	75,242	17,090	3,314	5,822,535
1980	432,452	2,474,408	1,490,736	204,834	52,510	15,268	278	4,670,486
1981	1,119,410	2,150,565	1,139,045	242,816	4,434	899	117	4,657,286
1982	1,231,231	2,020,770	1,173,279	54,421	4,153	1,405	270	4,485,529
1983	338,196	1,573,161	769,150	120,319	4,590	1,090	204	2,806,710
1984	1,431,711	2,911,017	844,951	83,804	5,562	1,335	303	5,278,683
1985	664,091	1,363,018	572,220	112,636	5,630	1,315	260	2,719,170
1986	339,109	1,578,321	778,022	127,113	7,668	1,799	328	2,832,360
1987	226,608	1,279,953	809,783	93,259	6,879	1,685	356	2,418,523
1988	66,507	1,209,939	698,020	89,845	34,294	8,202	1,505	2,108,312
1989	434,524	1,459,189	508,949	27,032	4,681	1,125	233	2,435,733
1990	107,696	615,116	353,646	81,365	4,603	957	168	1,163,551
1991	112,805	692,218	365,542	64,104	18,979	4,420	914	1,258,982
1992	280,006	873,586	364,007	35,170	3,343	815	159	1,557,086
1993	126,917	1,205,400	586,812	53,935	5,533	1,179	207	1,979,983
1994	219,550	378,474	934,132	355,722	127,660	2,953	945	2,019,436
1995	810,598	576,647	421,332	125,037	42,341	1,329	455	1,977,739
1996	1,026,321	643,909	403,408	608,121	138,314	28,882	1,418	2,850,373
1997	81,776	488,903	550,869	229,738	318,110	35,324	8,578	1,713,298
1998	262,115	300,532	296,292	309,302	79,709	70,208	26,904	1,345,062
1999	2,347,445	416,099	104,082	123,654	183,637	15,922	15,080	3,205,919
2000	766	224,967	453,005	276,424	84,084	27,765	3,605	1,070,616
2001	1,872,576	342,137	432,406	201,192	86,170	17,497	10,359	2,962,337
2002	1,739,612	747,214	153,041	75,843	16,362	5,765	1,809	2,739,646

Table 5. The catch-at-age matrix through 2003, including commercial and recreational harvest and discards.

	1	2	3	4	5	6+
1982	9,914	12,967	5,473	2,778	722	639
1983	8,004	12,869	5,823	2,780	568	424
1984	10,444	14,737	6,521	3,045	485	255
1985	14,153	11,262	3,246	1,171	213	55
1986	18,611	15,778	4,942	1,824	264	52
1987	16,256	14,343	4,347	1,485	145	11
1988	8,162	16,141	10,545	6,092	1,051	71
1989	3,705	5,305	4,334	2,922	626	85
1990	9,510	4,890	2,094	1,205	591	89
1991	9,796	5,826	2,750	1,374	463	57
1992	5,179	6,046	2,211	1,255	528	65
1993	4,975	6,357	2,180	1,139	401	48
1994	3,544	3,810	3,357	1,490	202	39
1995	4,047	3,517	3,504	1,617	197	54
1996	2,126	2,456	4,682	3,094	1,363	99
1997	1,459	2,104	2,792	5,355	1,505	406
1998	1,136	2,005	3,844	1,983	2,897	897
1999	1,221	1,252	2,200	3,241	718	1,138
2000	1,159	1,499	1,939	1,838	1,851	466
2001	549	2,279	1,255	819	431	370
2002	1,142	700	2,451	808	391	217
2003	857	1,066	742	554	104	130

Table 6. Catch curve analysis results for the catch at age matrix, analysed by year class. Number of ages indicates the number of ages used in the regression, *P* indicates the statistical significance of the regression, R^2 indicates the proportion of variance explained and F value is the F statistic of the regression. Note that Fishing mortality = Z - M, where M = 0.25. 1993 data was not amenable to catch curve analysis, because the modal age was too old.

Year Class	# Ages	Z	Fishing Mortality	P	R^2	F value
1982	3	1.55	1.30	0.22	0.77	7.59
1983	3	0.77	0.52	0.20	0.82	9.82
1984	3	0.97	0.72	0.42	0.25	1.65
1985	4	1.08	0.83	0.04	0.90	26.87
1986	4	1.19	0.94	0.002	0.99	389.89
1987	4	0.73	0.48	0.001	0.97	98.79
1988	3	0.96	0.71	0.068	0.98	87.57
1989	4	1.07	0.82	0.020	0.94	48.57
1990	4	1.06	0.81	0.042	0.88	22.20
1991	3	0.45	0.20	0.219	0.77	7.78
1992	4	0.29	0.04	0.115	0.68	7.25
1993	-	-				
1994	8	0.96	0.71	0.0003	0.89	57.61
1995	5	1.40	1.15	0.002	0.96	90.48
1996	4	1.31	1.06	0.006	0.98	159.89
1997	3	1.51	1.26	0.174	0.85	12.77
1998	3	1.26	1.01	0.220	0.77	7.69

Table 7. Estimates of F, instantaneous fishing mortality by age and year from Gulland's cohort analysis
performed on the catch at age matrix.

	AGE						
YEAR	1	2	3	4	5	6+	FULLY-RECRUITED F (average of ages 4 and 5)
1982	0.29	0.70	0.81	1.24	0.88	---	1.06
1983	0.25	0.79	0.86	1.60	1.04	---	1.32
1984	0.31	1.07	1.47	2.24	2.08	---	2.16
1985	0.29	0.70	0.79	1.47	1.45	---	1.46
1986	0.36	0.66	0.84	1.95	2.95	---	2.45
1987	0.42	0.55	0.40	0.71	0.98	---	0.85
1988	0.44	1.05	1.16	2.00	2.39	---	2.20
1989	0.23	0.62	1.02	1.50	1.89	---	1.70
1990	0.51	0.56	0.58	1.01	2.22	---	1.61
1991	0.50	0.75	0.78	1.05	1.90	---	1.48
1992	0.21	0.71	0.78	1.17	2.27	---	1.72
1993	0.19	0.46	0.65	1.46	2.20	---	1.83
1994	0.10	0.23	0.51	1.53	1.39	---	1.46
1995	0.23	0.14	0.36	0.52	0.96	---	0.74
1996	0.09	0.22	0.29	0.66	1.32	---	0.99
1997	0.12	0.13	0.45	0.69	0.87	---	0.78
1998	0.13	0.24	0.40	0.71	1.14	---	0.92
1999	0.17	0.21	0.49	0.75	0.66	---	0.71
2000	0.13	0.34	0.62	1.12	1.63	---	1.37
2001	0.14	0.42	0.56	0.62	0.97	---	0.79
2002	0.50	0.28	1.25	0.97	0.74	---	0.85
2003	---	---	---	---	---	---	

Table 8. Stock size by year and age estimated by Gulland's Cohort Analysis of the catch at age matrix. Newton's method was used for the final estimates (Haddon 2001).

	AGE						
YEAR	1	2	3	4	5	6+	TOTAL 1 - 6+
1982	44,849	28,833	10,985	4,309	1,369	665	91010.2
1983	40,777	26,254	11,204	3,816	971	442	83464.2
1984	43,793	24,748	9,300	3,690	602	266	82399.5
1985	62,727	24,972	6,582	1,669	305	59	96314.5
1986	69,393	36,470	9,676	2,315	299	56	118208.5
1987	53,490	37,783	14,701	3,260	257	12	109504.1
1988	25,546	27,472	16,944	7,655	1,250	75	78942.4
1989	20,487	12,777	7,488	4,129	803	90	45773.4
1990	26,468	12,709	5,341	2,096	719	94	47426.6
1991	28,034	12,330	5,643	2,338	593	61	49000.6
1992	30,535	13,299	4,553	2,013	638	69	51105.9
1993	32,680	19,241	5,112	1,631	489	51	59204.4
1994	43,206	21,090	9,443	2,088	296	42	76164.6
1995	22,418	30,535	13,087	4,431	354	58	70881.7
1996	27,043	13,914	20,695	7,130	2,043	105	70929.0
1997	14,991	19,193	8,684	12,021	2,866	423	58178.8
1998	10,849	10,394	13,100	4,328	4,715	931	44318.1
1999	8,910	7,452	6,339	6,846	1,650	1,180	32377.8
2000	10,829	5,868	4,706	3,020	2,522	661	27607.6
2001	4,789	7,416	3,260	1,980	771	386	18602.2
2002	3,257	3,248	3,787	1,447	830	228	12796.5
2003	878	1,542	1,917	845	429	307	5918.0

Table 9A. Summary of selected 1982-2003 ADAPT VPA runs for wekfish.

		24	14	18	20	32
Indices		All Trawl Surveys	DE, SEAMAP surveys YOY Surveys	DE, SEAMAP surveys Rec. Harvest/Trip at age Total Rec Catch/trip	Rec. Harvest/Trip at age Total Rec Catch/trip	Rec. Harvest/Trip at age Total Rec Catch/trip
M		constant 0.25	constant 0.25	constant 0.25	constant 0.25	constant 0.25 1982-1995 increasing 1995 - 2001 constant 2001-2003 M = 0.6
Number of indices used		27	17	19	5	5
MSR		1.29	1.192	1.445	0.687	0.87
2004 N; CV						
	1	68,477; 0.39	57,287; 0.0019	37922; 0.47	not estimated	not estimated
	2	50,912; 0.32	49,403; 0.0022	31,019; 0.40	not estimated	not estimated
	3	33,654; 0.29	35,203; 0.0031	16,599; 0.38	2227.8; 0.72	2629; 0.80
	4	11,775; 0.27	18,728; 0.0058	5,671; 0.39	258.3; 0.80	320; 0.86
	5	39,909; 0.18	60,381; 0.0018	8,741; 0.29	164.6; 0.76	127; 0.86
6+		1,592; 1.18	3,163; 0	80; 0.12	64.1 0.85	73; 0.96
2003 F						
	1	0.1	0.02	0.02	0.19	0.17
	2	0.03	0.03	0.05	0.35	0.26
	3	0.05	0.03	0.1	1.24	0.96
	4	0.01	0.01	0.05	1.36	1.38
	5	0.06	0.04	0.12	1.59	1.41
6+		0.06	0.04	0.12	1.59	1.41
2003 F_{4-5}		0.03	0.03	0.09	1.48	1.39
zero indices treated as		0.01	0.01	missing	missing	missing
Method for full F year T		Average Method	Average Method	Average Method	Average Method	Average Method

Table 9B. Retrospective bias in four ADAPT runs: 24, 13, 18 and 20. Output estimates of F and SSB when only data through 1998 is input, and when data through 2003 is input and resulting per cent change in estimates.

RUN NUMBER:	**24**	**14**	**18**	**20**
F_{1998} with 1998 data	0.10	0.10	0.30	2.05
SSB_{1998} with 2003 data	59,102	85,561	36,482	5,468
F_{1998} with 2003 data	0.43	0.36	0.64	0.70
SSB_{1998} with 2003 data	22,599	27,551	14,156	12,674
% change in F_{1998}	+207	+260	+113	-66
% CHANGE IN SSB_{1998}	-62	-68	-61	+132

Table 9C. Comparison of biomass dynamic model sensitivity analyses: estimates of intrinsic rate (r) and unfished stock biomass (K, mt of 25 cm+ weakfish). Model is a general description of indices and treatments; Indices is the number of indices included in the sensitivity run, q's is the number of scalars estimated; and Discards indicates whether discard estimates were included with landings. NE = Northeast Fisheries Science Center Survey. All surveys use trawls. Regression coefficients were not calculated for every model.

Model	Years	Indices	q's	Discards	r^2	N	(SSQ/N)^0.5	r	K
NE, DE, NJ Z transformed	1981-2003	3	1	No	0.41	56	0.66	1.32	41912
NE, DE, NJ Z transformed	1981-2003	3	1	Yes		56	0.49	1.35	39910
Mean of NE, DE, NJ Z indices	1981-2003	1	1	No	0.58	23	0.44	1.10	47260
Mean of NE, DE, NJ Z indices	1981-2003	1	1	Yes		23	0.23	1.44	41950
Multiple q's, NE, DE, NJ	1981-2003	3	3	No	0.56	56	0.77	1.80	41912
NEFSC	1981-2003	1	1	No	0.41	23	0.78	0.83	53581
NJ	1989-2003	1	1	No	0.26	15	0.61	1.12	56889
DE	1990-2003	1	1	No	0.48	14	0.52	0.85	1.54E+08
DE	1981-1984, 1990-2003	1	1	No	0.33	18	0.51	0.33	251708
DE, 2 q's for years	1981-1984, 1990-2003	1	2	No	0.49	18	0.46	1.08	82043
DE&NJ Z indices	1981-2003	2	1	No	0.48	38	0.56	1.37	40850
NE&NJ Z indices	1981-2003	2	1	No		41	0.54	1.34	35926
NE&DE Z indices	1981-2003	2	2	No		33	0.65	1.35	36141
NE, DE, NJ Z transformed	1975-2003	3	1	No	0.33	64	0.36	0.33	38313

TABLE 10. TOTAL HARV+DISCARDS (HARVDIS, mt), MID-ATLANTIC PRIVATE BOAT FISHING EFFORT (TRIPS * 1000),MID-ATLANTIC PRIVATE BOAT REC CATCH (MIDHARV2,MT), PRIVATE BOAT CPUE (RelWt)
AND RelWt+1 IN T+1, AVERAGE AVRelWt IN YEARS T AND T+1, RELATIVE F AND SCALED FWt AND BIOMASS WEIGHTED M (MWt), 1982-2005

YEAR	HARVDIS	teffort	midharv2	RelWt	relwt1	avrelwt	RelFwt	FWt	MWt
1982	13823	6028	2805.90	0.46548	0.50041	0.48294	28622.46	0.40644	0.57
1983	14426	8472	4239.46	0.50041	0.31305	0.40673	35468.49	0.50365	0.67
1984	13338	7881	2467.12	0.31305	0.27831	0.29568	45110.00	0.64056	0.82
1985	11181	6994	1946.49	0.27831	0.41802	0.34816	32114.40	0.45602	0.49
1986	15590	10003	4181.41	0.41802	0.35225	0.38513	40479.53	0.57481	0.44
1987	11691	8554	3013.15	0.35225	0.30444	0.32835	35605.73	0.50560	0.23
1988	13090	8862	2697.96	0.30444	0.12821	0.21633	60510.07	0.85924	0.64
1989	8136	6756	866.21	0.12821	0.08615	0.10718	75909.95	1.07792	0.01
1990	5440	7881	678.91	0.08615	0.10483	0.09549	56970.88	0.80899	0.06
1991	5610	8713	913.38	0.10483	0.13552	0.12017	46682.86	0.66290	0.34
1992	4793	6904	935.60	0.13552	0.08764	0.11158	42955.58	0.60997	0.39
1993	4448	8750	766.89	0.08764	0.18681	0.13723	32413.81	0.46028	0.33
1994	5395	9087	1697.51	0.18681	0.28561	0.23621	22840.19	0.32433	0.25
1995	5977	8581	2450.79	0.28561	0.37890	0.33226	17989.19	0.25545	0.22
1996	6879	8844	3351.02	0.37890	0.34514	0.36202	19001.69	0.26982	0.31
1997	7206	9725	3356.46	0.34514	0.44201	0.39357	18309.24	0.25999	0.37
1998	7809	8630	3814.51	0.44201	0.37756	0.40978	19056.48	0.27060	0.47
1999	6219	7935	2995.92	0.37756	0.41587	0.39671	15676.32	0.22260	0.56
2000	6126	11324	4709.30	0.41587	0.23894	0.32741	18710.67	0.26569	0.81
2001	5369	11982	2863.04	0.23894	0.23951	0.23923	22443.23	0.31869	0.61
2002	4434	9551	2287.53	0.23951	0.11906	0.17929	24731.48	0.35119	1.09
2003	2660	11286	1343.76	0.11906	0.05831	0.08869	29993.56	0.42591	0.76
2004	1483	11146	649.89	0.05831	0.10468	0.08150	18197.39	0.25840	.
2005	1937	11866	1242.18	0.10468	.	.	18503.36	0.26275	.

TABLE 11. WEAKFISH AVERAGE BIOMASS (BIOt, MT) IN YEAR T, BIOMASS IN T+1 (BIOt+1, MT) TOTAL WEAKFISH HARVEST (HARVDIS) AND WEAKFISH SURPLUS PRODUCTION (SURPt),1982-2005 NOTE THAT SURPt ESTIMATE IN 2005 NOT POSSIBLE WITHOUT A 2006 BIOMASS ESTIMATE

YEAR	BIOt	BIOt1	HARVDIS	SURPt
1982	34010.03	28642.76	13823	8455.73
1983	28642.76	20822.34	14426	6605.58
1984	20822.34	24518.42	13338	17034.08
1985	24518.42	27122.04	11181	13784.62
1986	27122.04	23122.96	15590	11590.92
1987	23122.96	15234.34	11691	3802.38
1988	15234.34	7547.86	13090	5403.52
1989	7547.86	6724.46	8136	7312.60
1990	6724.46	8462.86	5440	7178.39
1991	8462.86	7857.77	5610	5004.91
1992	7857.77	9663.76	4793	6598.99
1993	9663.76	16634.26	4448	11418.49
1994	16634.26	23398.25	5395	12158.99
1995	23398.25	25494.39	5977	8073.15
1996	25494.39	27716.32	6879	9100.93
1997	27716.32	28857.87	7206	8347.55
1998	28857.87	27937.54	7809	6888.67
1999	27937.54	23056.82	6219	1338.28
2000	23056.82	16846.89	6126	-83.93
2001	16846.89	12625.75	5369	1147.86
2002	12625.75	6245.47	4434	-1946.28
2003	6245.47	5739.10	2660	2153.63
2004	5739.10	7372.09	1483	3115.99
2005	7372.09	.	1937	.

TABLE 12. OBSERVED WEAKFISH JUVENILE INDICES FROM RHODE ISLAND TO THE SOUTH ATLANTIC

YCL	RI	CT	NY	NJ	DE	MD	VIMS	NC	SEA
1982	9.80	.	.	.	6.0	0.24	6.0	.	.
1983	7.00	.	.	.	11.5	0.22	10.9	.	.
1984	5.70	1.00	.	.	4.5	1.30	10.9	.	.
1985	2.20	6.19	.	.	6.7	0.13	6.1	.	.
1986	6.20	13.16	1.5	.	9.3	1.70	37.0	.	.
1987	1.80	0.63	0.3	.	12.8	0.44	4.6	.	.
1988	3.20	3.49	0.3	.	5.8	0.40	17.8	12.1	.
1989	10.10	8.69	0.1	25.7	4.7	0.20	21.8	102.0	.
1990	2.80	5.56	0.6	43.4	11.1	0.20	21.3	14.2	.
1991	16.50	11.95	0.3	14.7	8.7	0.80	30.0	50.2	2.1
1992	24.00	3.05	4.4	27.1	20.1	0.50	15.3	37.0	0.9
1993	5.60	4.08	1.2	6.0	14.7	2.30	15.9	43.7	0.2
1994	5.70	11.19	0.4	23.9	14.8	1.10	15.4	8.7	15.3
1995	15.60	5.22	1.7	37.1	11.5	1.50	7.0	68.1	43.8
1996	2.20	15.23	0.9	77.5	13.5	6.10	11.0	38.2	3.6
1997	38.60	12.38	4.7	46.3	12.1	5.10	7.4	72.4	20.3
1998	25.80	5.02	2.7	21.8	15.4	7.30	14.8	32.8	0.7
1999	4.20	30.93	0.5	3.0	11.4	16.00	9.9	70.4	4.5
2000	0.01	63.31	2.2	25.3	13.5	2.10	16.3	100.0	24.5
2001	0.01	40.09	3.9	0.1	14.1	6.50	11.1	63.0	9.0
2002	0.30	41.35	3.2	21.7	7.6	7.50	11.5	30.3	5.6
2003	0.20	49.41	2.6	39.3	6.0	3.90	8.6	22.0	44.3
2004	3.10	58.98	1.4	72.7	10.9	1.80	5.4	23.9	22.2

TABLE 13. JUVENILE INDICES SCALED IN MAGNITUDE TO THE NEW JERSEY INDICES WITH THE COASTWIDE MEAN JUVENILE INDEX (N0), THE AGE 1 INDEX (NIJ) AND THE JUVENILE MORTALITY (Z0) RATE

YCL	RI1	CT1	NY1	NJ	DE1	MD1	VIMS1	NC1	SEA1	N0	N1J	Z0
1982	36.260	.	.	.	16.80	2.496	13.20	.	.	17.19	4.55556	1.32798
1983	25.900	.	.	.	32.20	2.288	23.98	.	.	21.09	4.90000	1.45956
1984	21.090	1.600	.	.	12.60	13.520	23.98	.	.	14.56	7.04444	0.72604
1985	8.140	9.904	.	.	18.76	1.352	13.42	.	.	10.32	7.87778	0.27004
1986	22.940	21.056	26.70	.	26.04	17.680	81.40	.	.	32.64	6.04444	1.68640
1987	6.660	1.008	5.34	.	35.84	4.576	10.12	.	.	10.59	2.92222	1.28757
1988	11.840	5.584	5.34	.	16.24	4.160	39.16	7.865	.	12.88	2.31111	1.71795
1989	37.370	13.904	1.78	25.7	13.16	2.080	47.96	66.300	.	23.14	2.96667	2.05412
1990	10.360	8.896	10.68	43.4	31.08	2.080	46.86	9.230	.	18.07	3.26667	1.71048
1991	61.050	19.120	5.34	14.7	24.36	8.320	66.00	32.630	4.41	26.21	3.92222	1.89948
1992	88.800	4.880	78.32	27.1	56.28	5.200	33.66	24.050	1.89	35.58	3.97778	2.19106
1993	20.720	6.528	21.36	6.0	41.16	23.920	34.98	28.405	0.42	20.39	5.31111	1.34524
1994	21.090	17.904	7.12	23.9	41.44	11.440	33.88	5.655	32.13	21.62	2.50000	2.15733
1995	57.720	8.352	30.26	37.1	32.20	15.600	15.40	44.265	91.98	36.99	3.18889	2.45098
1996	8.140	24.368	16.02	77.5	37.80	63.440	24.20	24.830	7.56	31.54	1.68889	2.92719
1997	142.820	19.808	83.66	46.3	33.88	53.040	16.28	47.060	42.63	53.94	1.11111	3.88251
1998	95.460	8.032	48.06	21.8	43.12	75.920	32.56	21.320	1.47	38.64	0.90000	3.75965
1999	15.540	49.488	8.90	3.0	31.92	166.400	21.78	45.760	9.45	39.14	1.18889	3.49413
2000	0.037	101.296	39.16	25.3	37.80	21.840	35.86	65.000	51.45	41.97	0.38889	4.68142
2001	0.037	64.144	69.42	0.1	39.48	67.600	24.42	40.950	18.90	36.12	0.71111	3.92777
2002	1.110	66.160	56.96	21.7	21.28	78.000	25.30	19.695	11.76	33.55	0.56667	4.08102
2003	0.740	79.056	46.28	39.3	16.80	40.560	18.92	14.300	93.03	38.78	0.56667	4.22589
2004	11.470	94.368	24.92	72.7	30.52	18.720	11.88	15.535	46.62	36.30	.	.

TABLE 14. TIME SERIES OF ATL. CROAKER, TAG-BASED STRIPED BASS, VPA-BASED STRIPED BASS SUMMER FLOUNDER, SPINY DOGFISH AND BLUEFISH ABUNDANCE. AVERAGE ANNAUL WATER TEMPERATURE (LAGGED T-2)
AND DEVIATIONS IN THE NORTH ATL OSCILLATION INDEX (LAGGED T-2), 1982-2004.

YEAR	croak	STRIP	strip2	FLUKE2	SHK2	BLUE2	TEMP	NAO
1982	361	1395	218	17.5	695	229.1	11.1	31
1983	4143	1619	253	17.5	250	212.5	11.0	112
1984	2597	1734	271	18.8	265	182.2	11.1	44
1985	3698	1498	234	16.1	1057	162.9	12.0	187
1986	4903	1734	271	15.0	278	170.3	12.0	87
1987	4828	1210	357	13.9	550	154.9	12.0	-34
1988	4854	2849	348	14.4	708	119.6	11.9	27
1989	3400	3827	501	8.1	464	103.7	11.8	-41
1990	6434	2075	997	5.2	939	91.8	11.1	39
1991	15348	1844	1278	7.5	547	83.7	11.3	277
1992	9401	1994	1840	6.0	736	71.2	12.1	216
1993	13542	2486	2022	7.3	566	72.0	12.6	56
1994	17127	4027	2373	9.2	515	67.0	11.5	179
1995	11599	3486	2832	12.0	461	67.7	11.7	146
1996	10973	5201	3129	15.6	769	65.6	11.6	165
1997	17522	4893	3606	15.9	516	64.7	12.5	216
1998	16569	3877	4120	15.7	355	70.7	10.6	-206
1999	15952	4256	4072	17.8	480	73.0	10.9	-11
2000	22407	8280	4592	16.5	355	80.3	12.1	39
2001	21186	9907	5960	19.4	305	87.7	12.9	93
2002	20772	13066	6621	25.5	472	88.2	12.2	153
2003	18773	13672	6056	29.4	469	92.2	12.5	49
2004	17600	17099	6712	36.7	225	104.1	12.7	112
2005	.	.	.	.	.	.	.	.

Table 15. Three stepwise regression models with weakfish surplus production (SURPt), biomass weighted (ages 1+) natural mortality (MWt) and juvenile mortality (Z0) used as dependent variables. The independent variables included abundance of striped bass, bluefish, croaker, fluke and spiny dogfish as well as mean annual water temperature, deviations in the North Atlantic Oscillation Index and fishing mortality (FWt). Given below are the independent variables that were selected by the stepwise model. The slope (b) of the regression its standard error (SEb), Pearson correlation coefficient (r) and the probability (P) level for model fit are included.

	Dependent Variables											
Significant Variable	**SURPt**				**MWt**				**Z0**			
	b	**SEb**	**r**	**P**	**b**	**SEb**	**r**	**P**	**b**	**SEb**	**r**	**P**
Strip	**-0.83**	**0.21**	**-0.66**	**<0.001**								
Fluke					**0.03**	**0.006**	**0.79**	**<0.0001**				
Strip2									**0.0005**	**0.00005**	**0.91**	**<0.0001**

Table 16. Pearson correlation (r) matrix relating the three weakfish dependent variables (SURPT, MWt, Z0) with each of the nine potential explanatory variables. The P value indicates the level of statistical significance.

	Dependent Variable					
Explanatory Variable	**SURPt**		**MWt**		**Z0**	
	r	**P**	**r**	**P**	**r**	**P**
Strip	**-0.62**	**0.001***	**0.55**	**0.009***	**0.84**	**0.0001***
Strip2	**-0.66**	**0.001***	**0.44**	**0.04***	**0.91**	**0.0001***
Fluke	**-0.37**	**0.07**	**0.79**	**0.0001***	**0.46**	**0.03***
Croaker	**-0.60**	**0.003***	**0.30**	**0.17**	**0.85**	**0.0001***
Bluefish	**0.33**	**0.13**	**0.24**	**0.29**	**-0.61**	**0.002****
Spiny Dog	**0.23**	**0.29**	**-0.36**	**0.10**	**-0.36**	**0.10**
Temperature	**-0.26**	**0.23**	**0.12**	**0.61**	**0.27**	**0.23**
NAO	**0.13**	**0.56**	**-0.002**	**0.99**	**-0.10**	**0.65**
FWt	**0.22**	**0.31**	**-0.32**	**0.14**	**-0.20**	**0.33**

- *** indicates a statistically significant (P < 0.05) relationship with dependent variable.**
- **** indicates a statistically significant (P < 0.05) relationship with dependent variable but in the wrong direction.**

Table 17. Parameter estimates (r, K) and weakfish overfishing thresholds (Fmsy, Fcoll, Bmsy) derived from the basic (see equation 7) Gompertz production model (no predation effects) fitted by nonlinear least squares and by iterative reweighting least squares, 1982-2004. The standard error (SE) is given for each parameter estimate, as well as the coefficient of determination (r2).**

	Least Squares		*Iterative Reweighting*	
Parameters	**Mean**	**SE**	**Mean**	**SE**
r	**0.32**	**0.11**	**0.36**	**0.07**
K	**68,704 mt**	**25,618 mt**	**62,072 mt**	**11,989 mt**
r2**	**0.68**		**0.82**	
	Overfishing Thresholds			
Fmsy	**0.32**	**0.11**	**0.36**	**0.07**
Fcoll	**0.87**	**0.30**	**0.98**	**0.19**
Bmsy	**25,259 mt**	**9,412 mt**	**22,821 mt**	**4,417 mt**

TABLE 18. OBSERVED AND PREDICTED WEAKFISH BIOMASS AND RESIDUALS FROM GOMPERTZ PRODUCTION MODEL WITH NO ITERATIVE REWEIGHTING

YEAR	BIOL	pred22	RESID22
1982	28643	27664.87	978.13
1983	20822	21879.39	-1057.39
1984	24518	14896.08	9621.92
1985	27122	20953.48	6168.52
1986	23123	19198.01	3924.99
1987	15234	18990.86	-3756.86
1988	7548	8887.38	-1339.38
1989	6724	4223.48	2500.52
1990	8463	5785.83	2677.17
1991	7858	7979.14	-121.14
1992	9664	7986.35	1677.65
1993	16634	10713.85	5920.15
1994	23398	18196.42	5201.58
1995	25494	24993.03	500.97
1996	27716	26258.62	1457.38
1997	28858	28177.34	680.66
1998	27397	28709.05	-1312.05
1999	23057	28847.07	-5790.07
2000	16847	24486.57	-7639.57
2001	12626	18465.05	-5839.05
2002	6245	14438.58	-8193.58
2003	5739	7894.16	-2155.16
2004	7372	8350.52	-978.52
2005	7372	10182.53	-2810.53

TABLE 19. OBSERVED AND PREDICTED WEAKFISH BIOMASS,RESIDUALS (RBI) AND WEIGHTING COEFFICENTS FROM GOMPERTZ PRODUCTION MODEL WITH ITERATIVE REWEIGHTING

YEAR	BIOL	pred11	RBI	_WEIGHT_
1982	28643	27779.62	863.38	0.98168
1983	20822	22102.22	-1280.22	0.95994
1984	24518	15228.40	9289.60	0.00000
1985	27122	21242.02	5879.98	0.32851
1986	23123	19446.97	3676.03	0.69417
1987	15234	19297.73	-4063.73	0.63381
1988	7548	9252.63	-1704.63	0.92954
1989	6724	4540.42	2183.58	0.88574
1990	8463	6088.12	2374.88	0.86559
1991	7858	8309.66	-451.66	0.99497
1992	9664	8308.20	1355.80	0.95513
1993	16634	11058.38	5575.62	0.37971
1994	23398	18557.72	4840.28	0.50518
1995	25494	25296.45	197.55	0.99904
1996	27716	26533.12	1182.88	0.96575
1997	28858	28416.35	441.65	0.99519
1998	27397	28928.01	-1531.01	0.94296
1999	23057	29091.47	-6034.47	0.30298
2000	16847	24794.26	-7947.26	0.04851
2001	12626	18825.48	-6199.48	0.27616
2002	6245	14802.12	-8557.12	0.00922
2003	5739	8186.74	-2447.74	0.85753
2004	7372	8631.84	-1259.84	0.96119
2005	7372	10496.55	-3124.55	0.77347

Table 20. Parameter estimates (r, K, c, A) and weakfish overfishing thresholds (Fmsy, Fcoll, Bmsy) derived from the Steele-Henderson Production Model (see equation 6) with striped bass predation effects fitted by nonlinear least squares and by iterative reweighting least squares, 1982-2004. The standard error (SE) is given for each parameter estimate, as well as the coefficient of determination (r2).**

	Least Squares		*Iterative Reweighting*	
Parameters	**Mean**	**SE**	**Mean**	**SE**
r	**0.59**	**0.16**	**0.55**	**0.09**
K	**57,607 mt**	**13,620 mt**	**63,649 mt**	**11,683 mt**
c	**1.52**	**0.53**	**1.71**	**0.41**
A	**10,364 mt**	**3,966 mt**	**11,541 mt**	**3,406 mt**
r2**		**0.88**		**0.94**
	Overfishing Thresholds			
Fmsy	**0.59**	**0.16**	**0.55**	**0.09**
Fcoll	**1.60**	**0.43**	**1.50**	**0.25**
Bmsy	**21,179 mt**	**5,001 mt**	**23,400 mt**	**4,305 mt**

TABLE 21.OBSERVED AND PREDICTED WEAKFISH BIOMASS,RESIDUALS (RBI) AND REWEIGHTING COEFFICIENTS FROM STEELE-HENDERSON MODEL WITH STRIPED BASS AND ITERATIVE REWEIGHTING

YEAR	BIOL	pred11	rbi	_WEIGHT_
1982	28643	29747.52	-1104.52	0.95083
1983	20822	24388.75	-3566.75	0.54815
1984	24518	17986.22	6531.78	0.01672
1985	27122	24078.38	3043.62	0.65763
1986	23123	21720.70	1402.30	0.92135
1987	15234	22626.86	-7392.86	0.00000
1988	7548	11005.06	-3457.06	0.57168
1989	6724	6284.94	439.06	0.99215
1990	8463	8680.47	-217.47	0.99807
1991	7858	11122.99	-3264.99	0.61222
1992	9664	11007.51	-1343.51	0.92768
1993	16634	13462.74	3171.26	0.63164
1994	23398	18843.16	4554.84	0.33247
1995	25494	25479.17	14.83	0.99999
1996	27716	24037.78	3678.22	0.52402
1997	28858	26027.77	2830.23	0.69978
1998	27397	27863.24	-466.24	0.99115
1999	23057	27675.86	-4618.86	0.31879
2000	16847	18461.01	-1614.01	0.89650
2001	12626	12240.82	385.18	0.99395
2002	6245	7231.76	-986.76	0.96065
2003	5739	6248.72	-509.72	0.98942
2004	7372	6039.48	1332.52	0.92884
2005	7372	.	.	.

TABLE 22. WEAKFISH FISHING MORTALITY (FWt), PREDATOR NATURAL MORTALITY (MP) FROM EXPONENTS OF THE S-H MODEL AND NATURAL MORTALITY (MWt), 1982-2004

YEAR	FWT	MP	MWT
1982	0.410	0.06828	0.57
1983	0.500	0.09630	0.67
1984	0.640	0.10006	0.82
1985	0.460	0.08121	0.49
1986	0.570	0.09993	0.44
1987	0.510	0.08637	0.23
1988	0.860	0.27173	0.64
1989	1.080	0.27474	0.01
1990	0.810	0.11842	0.06
1991	0.660	0.13512	0.34
1992	0.610	0.12328	0.39
1993	0.460	0.13325	0.33
1994	0.320	0.23224	0.25
1995	0.260	0.19613	0.22
1996	0.270	0.27743	0.31
1997	0.260	0.25208	0.37
1998	0.270	0.20320	0.47
1999	0.220	0.24501	0.56
2000	0.270	0.56747	0.81
2001	0.320	0.78241	0.61
2002	0.350	1.29008	1.09
2003	0.430	0.88369	0.76
2004	0.260	0.88427	.
2005	0.263	.	.

Table 23. Model conditions used for projections and to test for sensitivity. Starting model = Base 3 Parameter is the base model run where r?, K, and B_{1981} were estimated simultaneously; Schaefer, Gompertz and Predator-prey used previous surplus production models as a starting point and held K constant (fixed). Recent F and Z are the two year averages for 2001-2002, with the exception of the 3 Parameter model with F fixed at values estimated in Crecco (2005); this run used the average for 2001-2003.

Starting model	Base 3 Parameter	Crecco (2005)	Schaefer[1]	Gompertz[1]	Predator-prey[2]
F	Estimated	Fixed[1]	Estimated	Estimated	Estimated
K	Estimated	Estimated	Fixed	Fixed	Fixed
Estimated K (mt)	86,409	86,409	57,700[1]	64,028[1]	49,500[2]
Estimated r?	0.903	0.903	0.896	0.897	0.893
Recent F	0.41	0.35	0.41	0.41	0.41
Recent Z	1.36	1.39	1.43	1.38	1.42
Recent F/Z	0.30	0.25	0.28	0.29	0.29
Z - (F*0.5)	1.15	1.21	1.23	1.18	1.22
Z - (F*1.0)	0.95	1.04	1.02	0.98	1.02
Z - (F*1.5)	0.75	0.86	0.82	0.77	0.81
Z - (F*2.0)	0.54	0.69	0.62	0.57	0.61

1 = Crecco (2005).
2= Uphoff (2005).

FIGURES

Figure 1.
Total Weakfish Landings 1981-2004

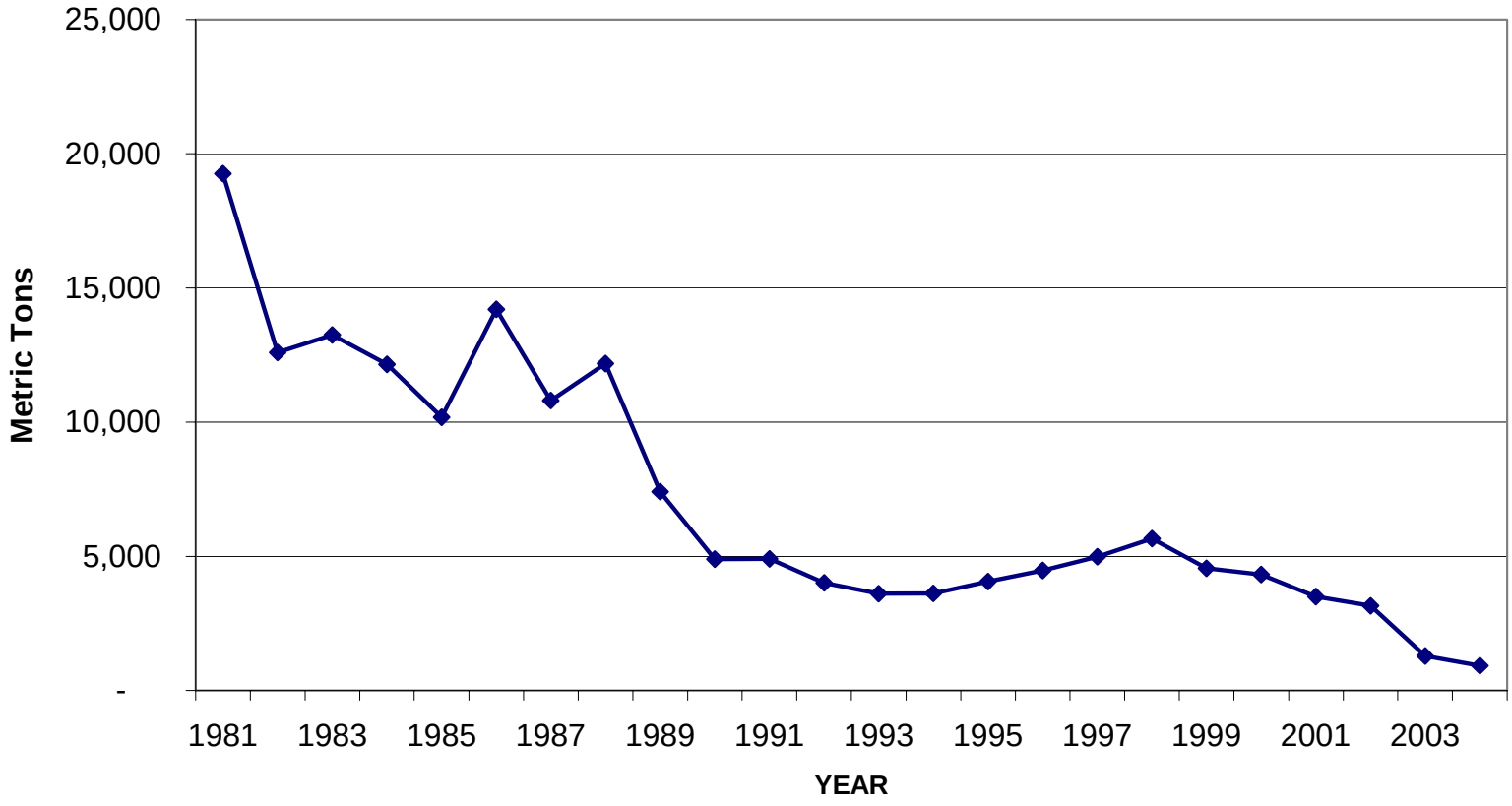


Figure 1A. Atlantic coast 1950-2003 commercial and 1981-2003 recreational landings of weakfsh.

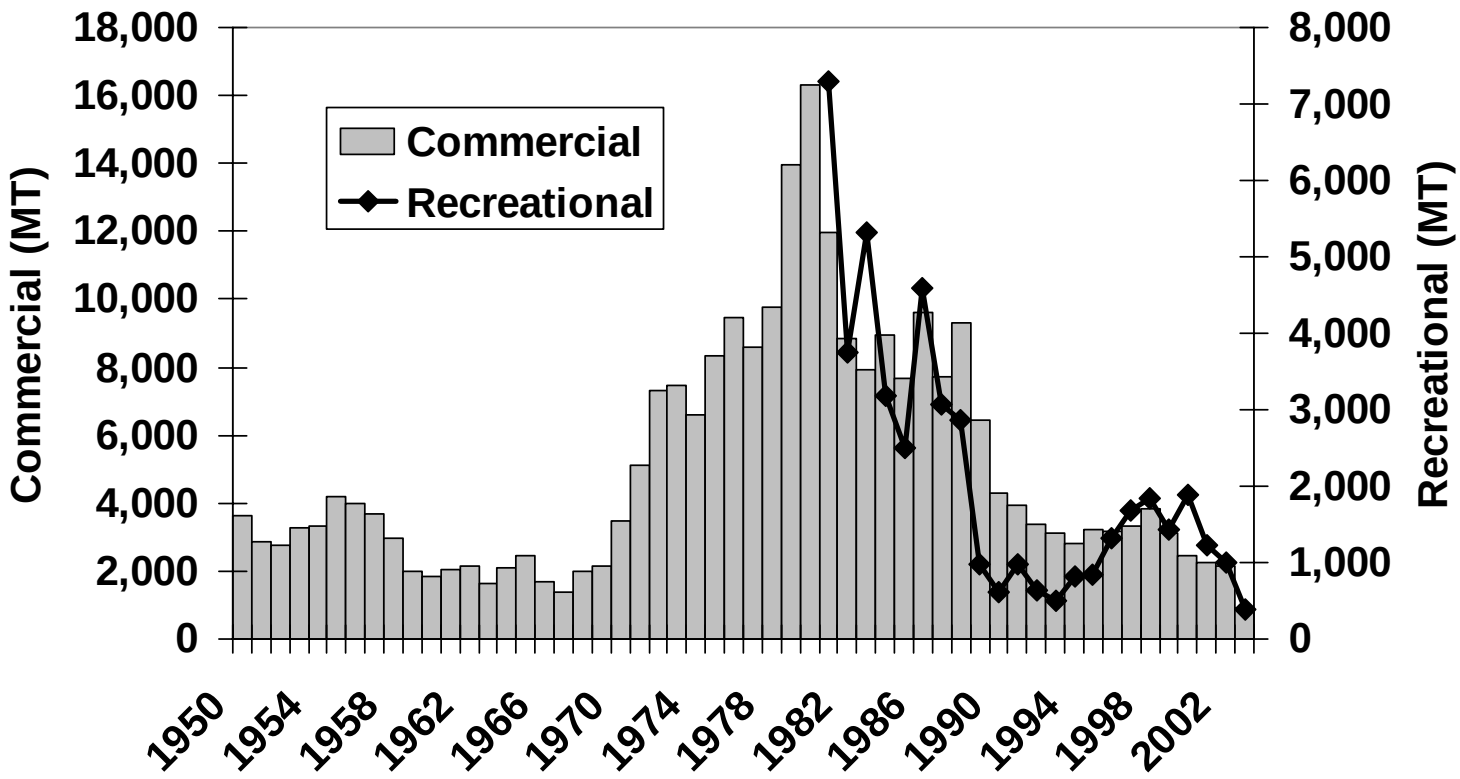


Figure 2. WEAKFISH LANDINGS BY SECTOR, 1981-2004

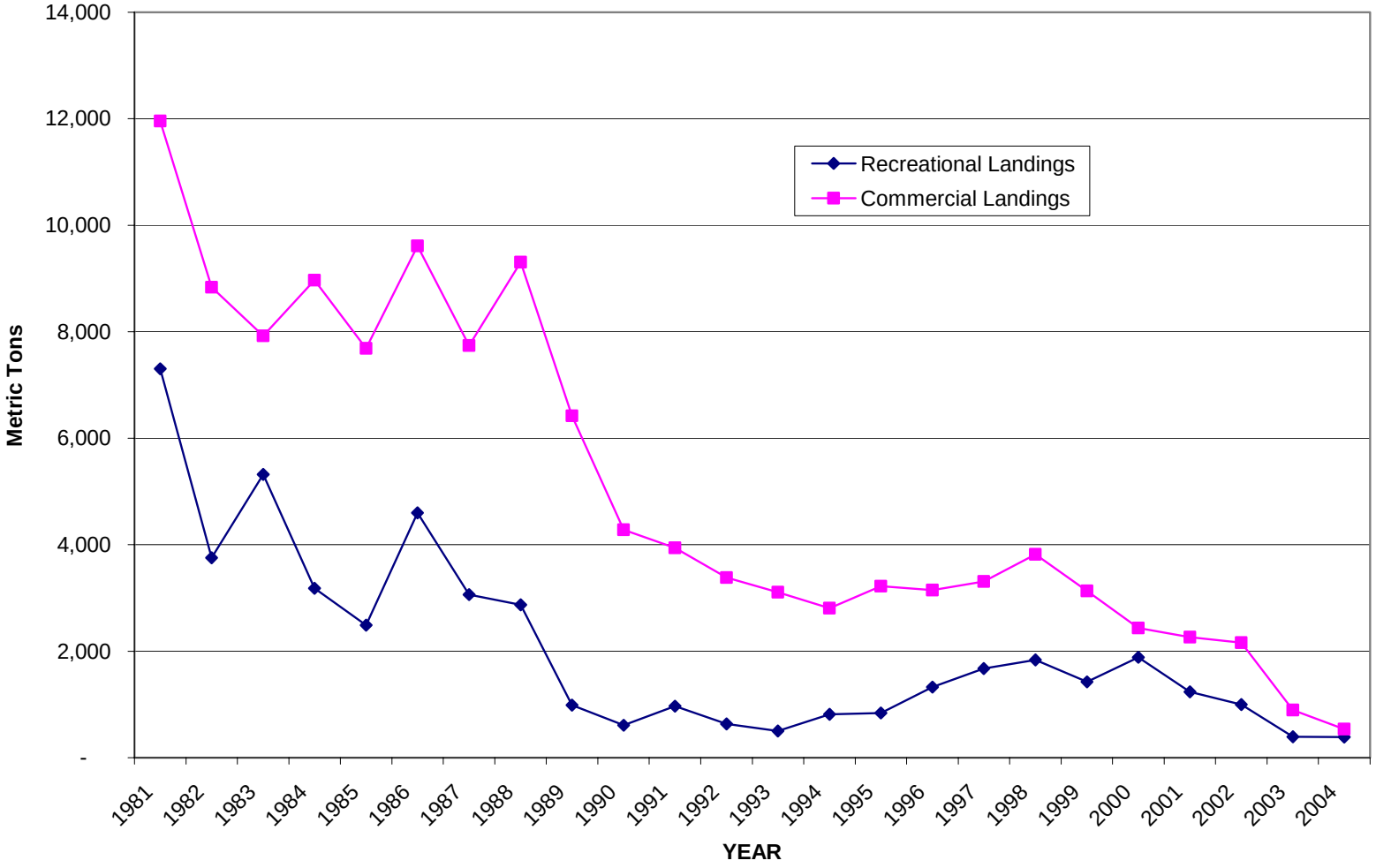


Figure 2a. Coastwide Weakfish Recreational Catch and Harvest Through 2004

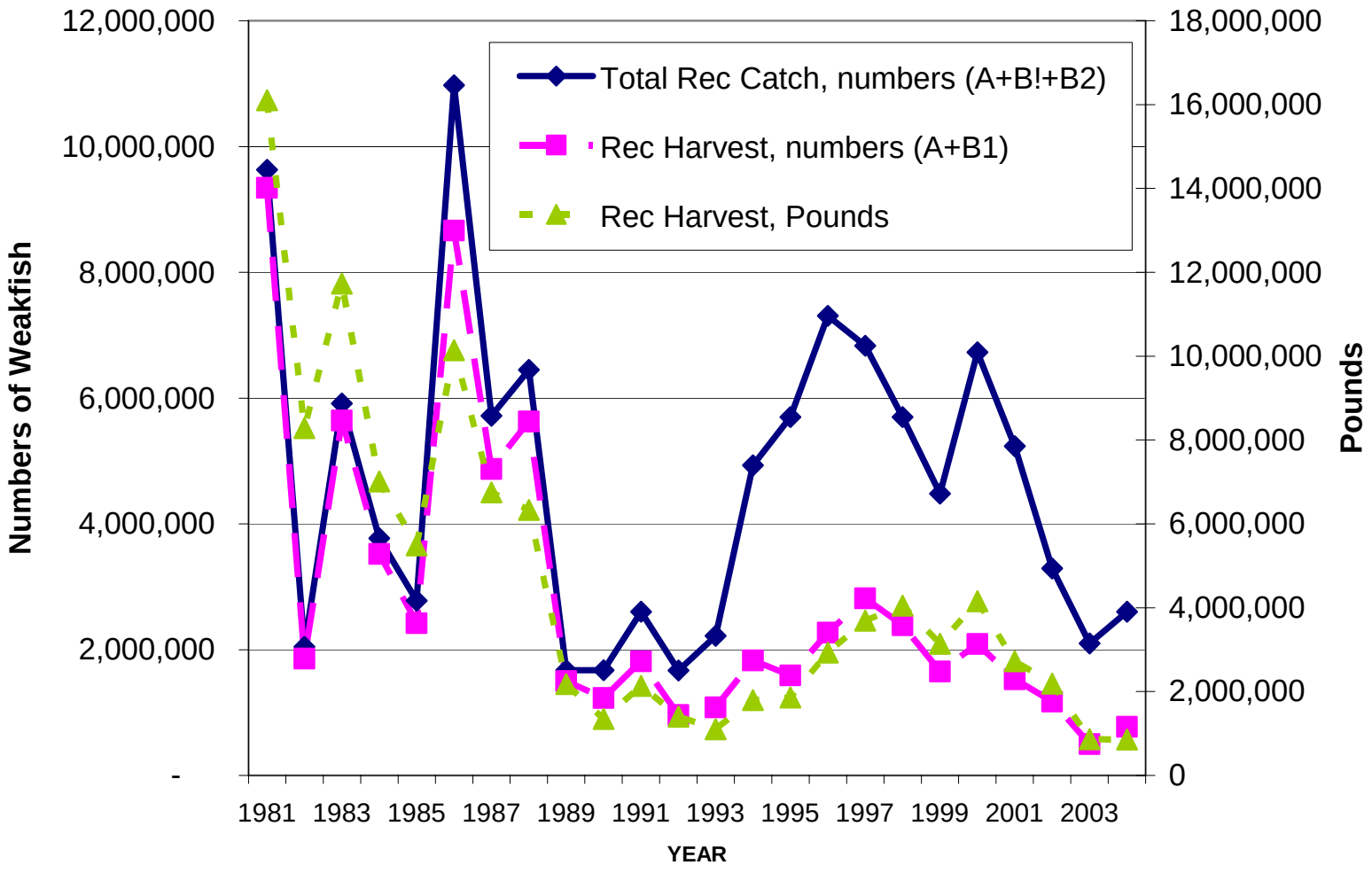
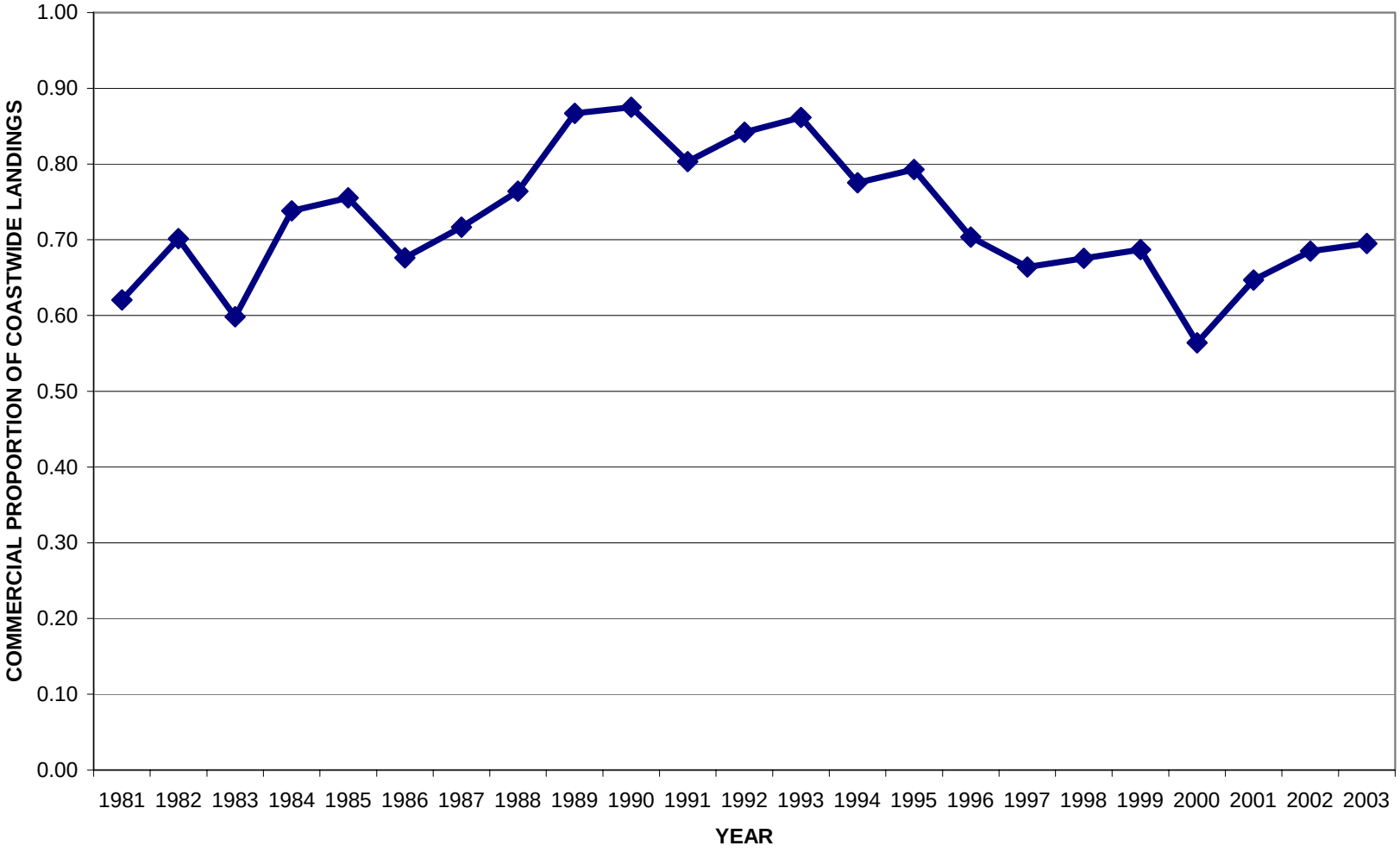


Figure 3. Commercial proportion of Coastwide Landings



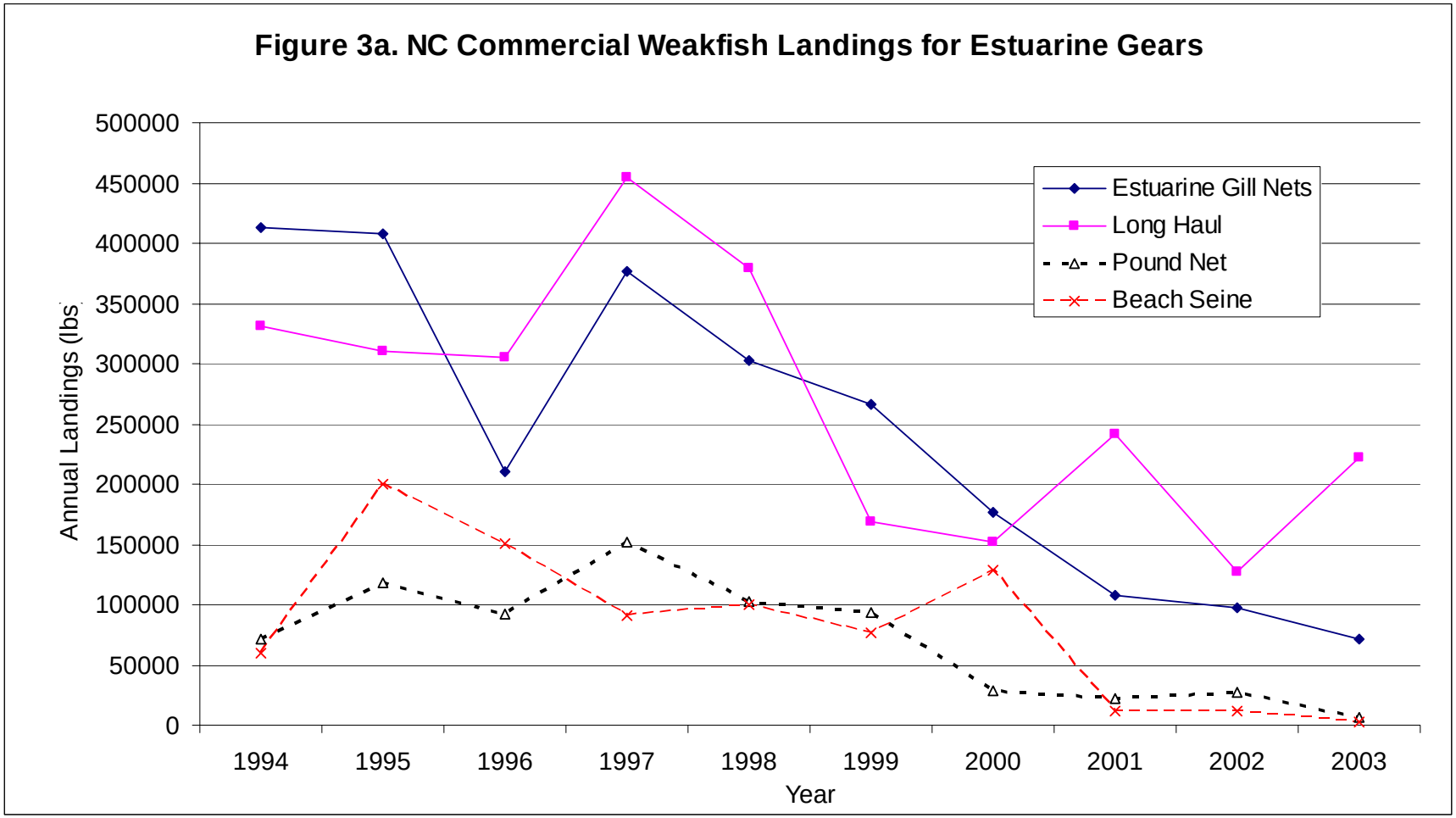


Figure 3a. NC Commercial Weakfish Landings for Estuarine Gears
Annual Landings (lbs)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year
Estuarine Gill Nets
Long Haul
Pound Net
Beach Seine

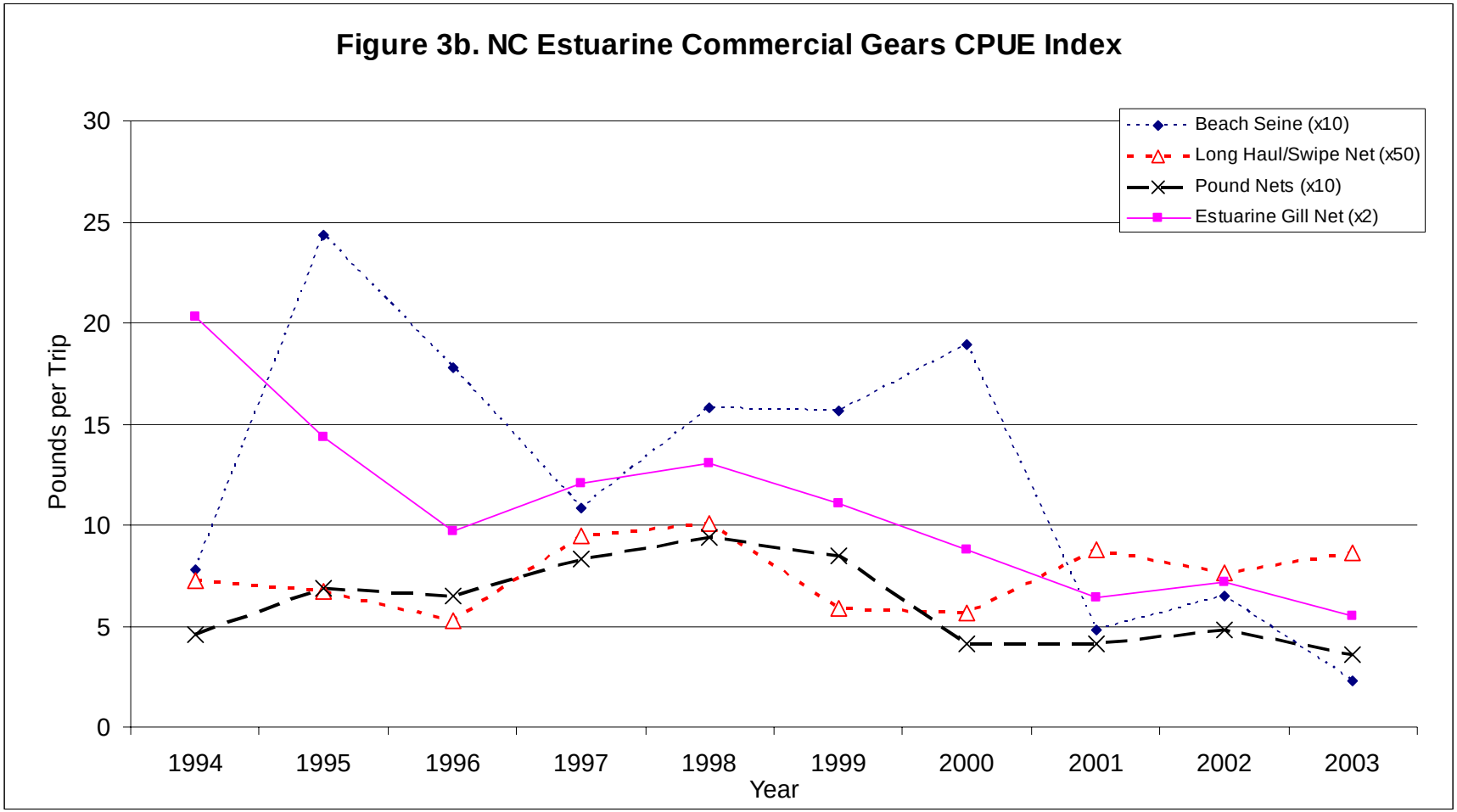


Figure 3b. NC Estuarine Commercial Gears CPUE Index
Beach Seine (x10)
Long Haul/Swipe Net (x50)
Pound Nets (x10)
Estuarine Gill Net (x2)
Pounds per Trip
30
25
20
15
10
5
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year

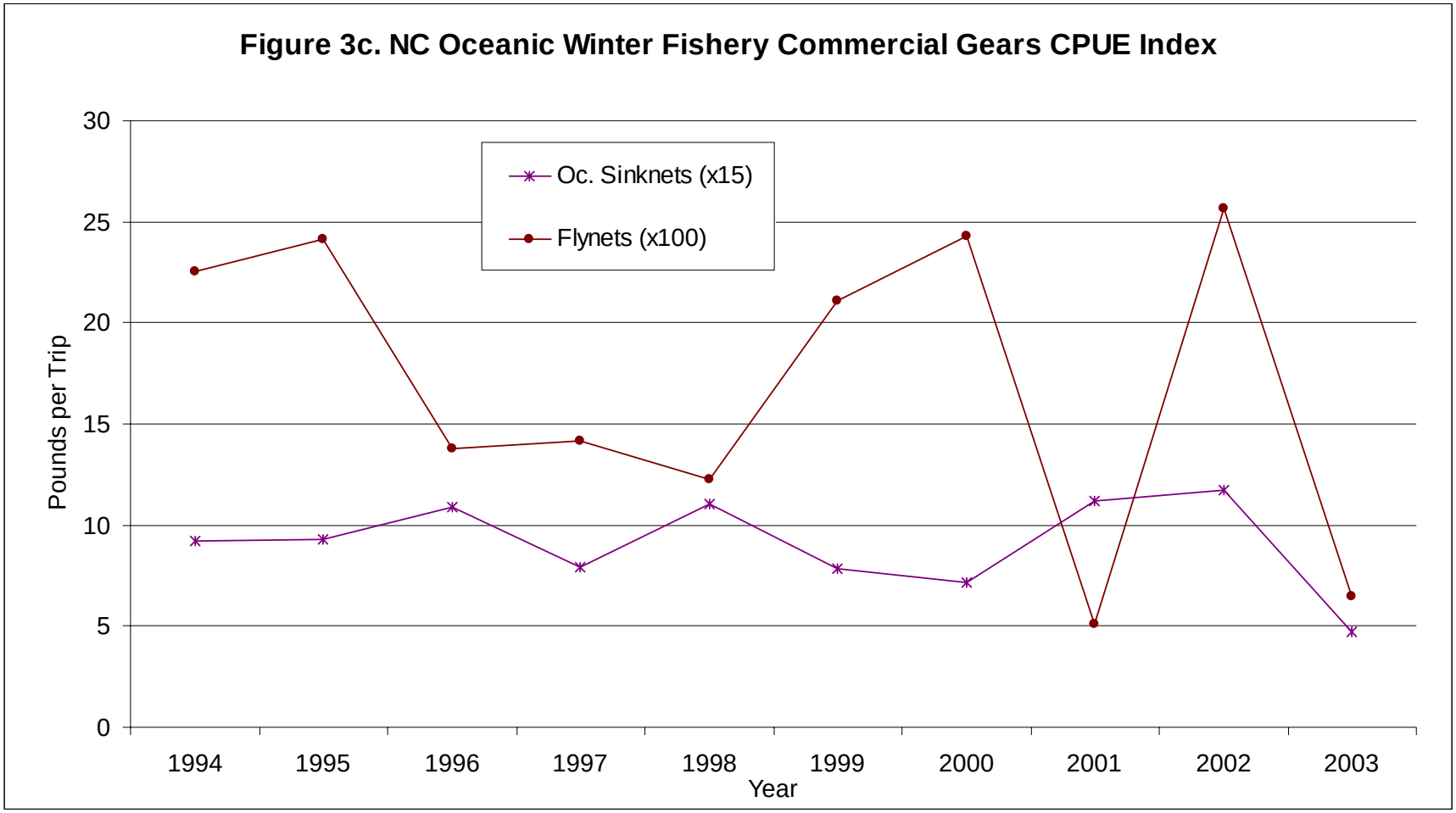


Figure 3c. NC Oceanic Winter Fishery Commercial Gears CPUE Index
Oc. Sinknets (x15)
Flynets (x100)
Pounds per Trip
30
25
20
15
10
5
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year

Figure 3d. Recreational fishery Catch-per-trip Indices of Relative Abundance

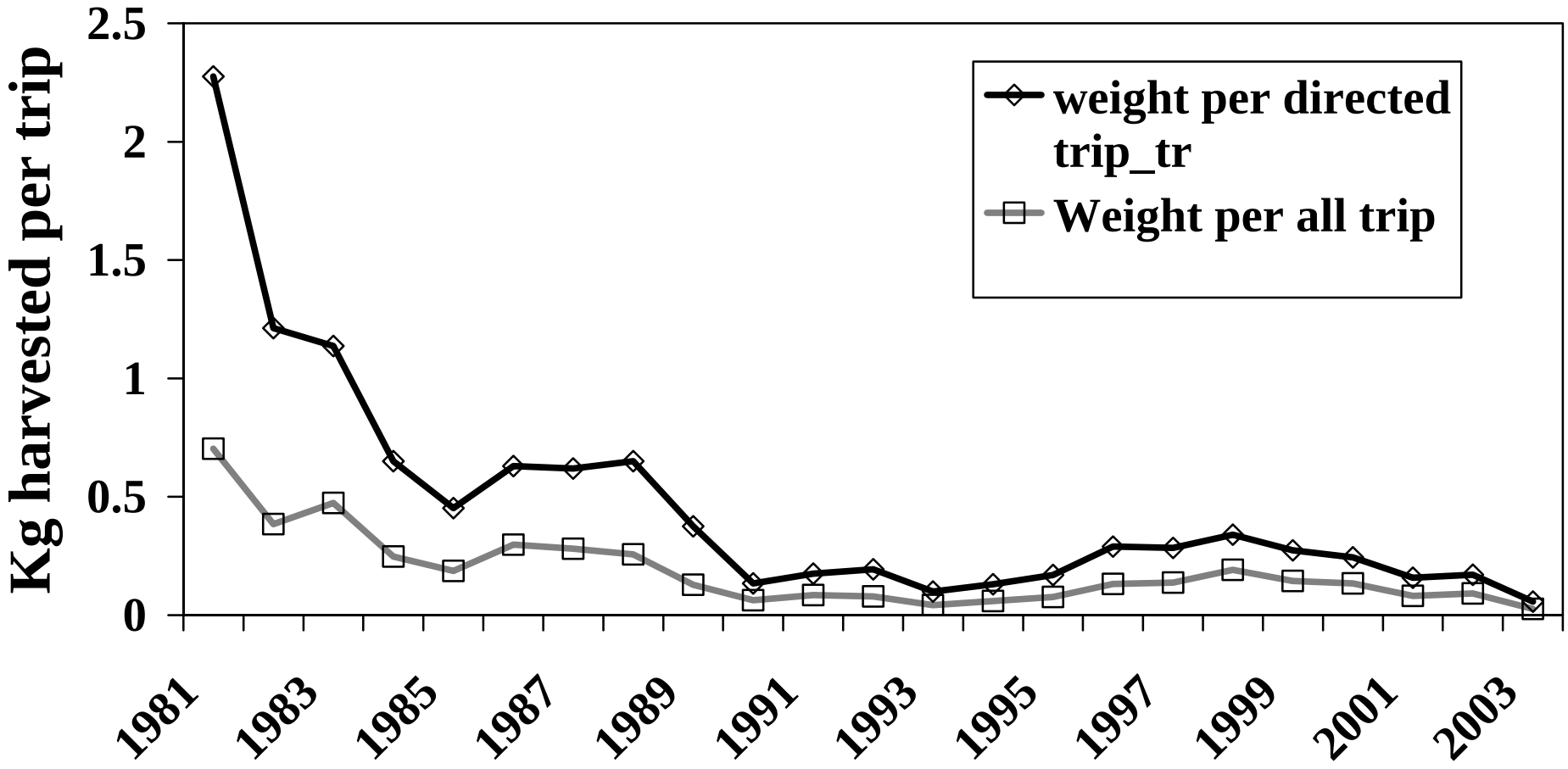


Figure 3e. Recreational harvest per trip age-structured tuning indices and total catch per trip aggregated for ages 2-6

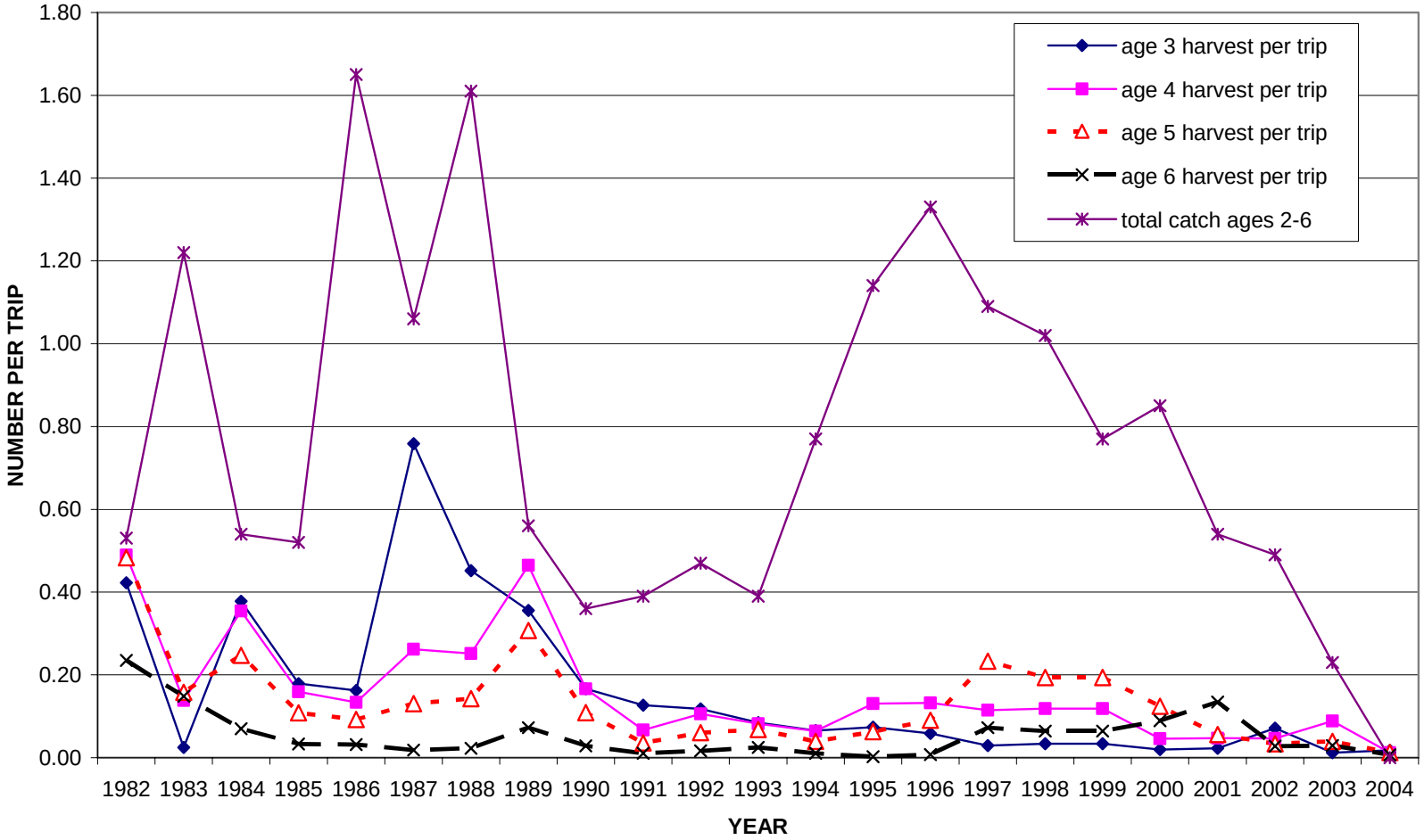


Figure 3f. Relative Abundance from Mid-Atlantic Private Boat Total Catch and Total Trips

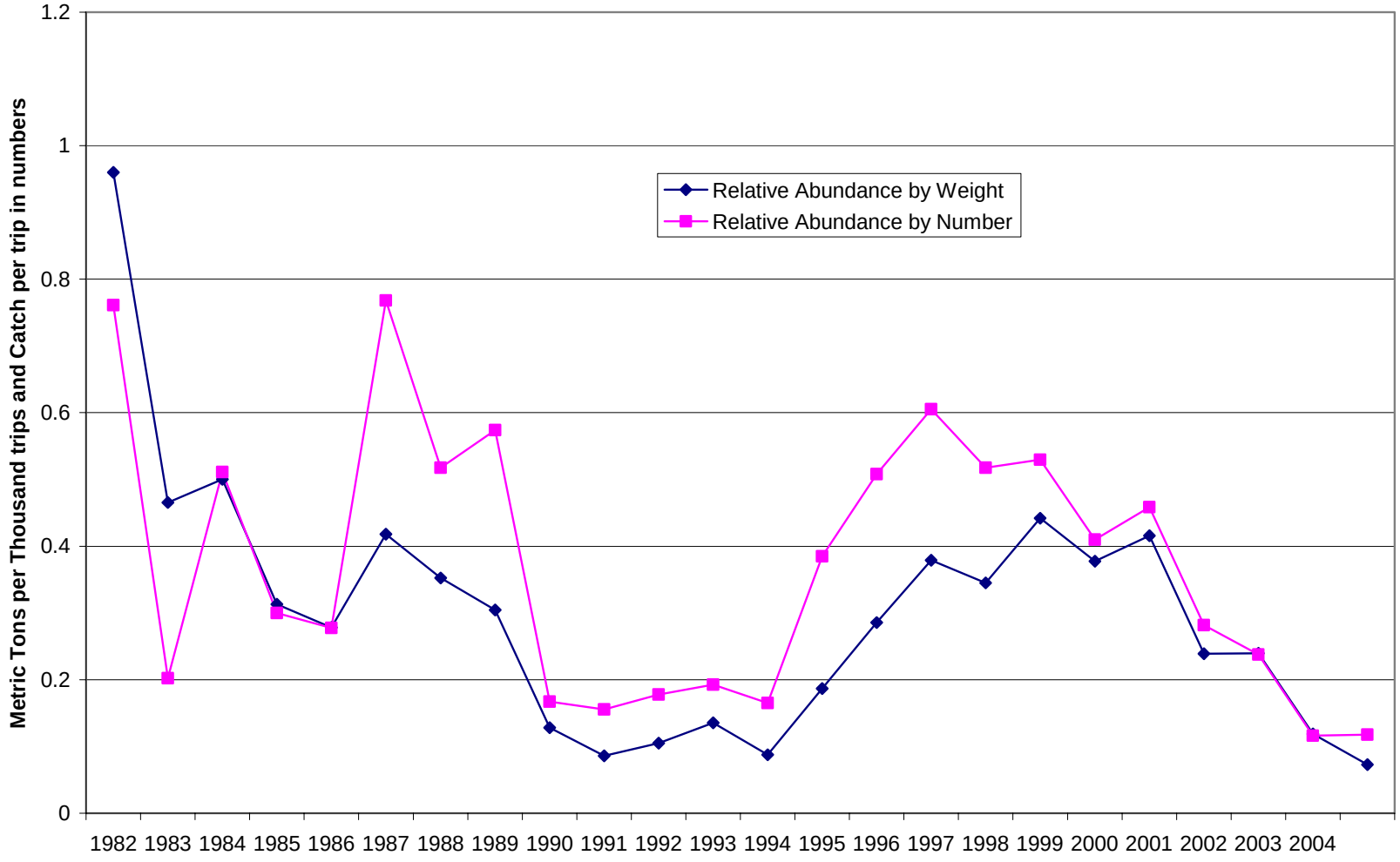


FIGURE 4. NEFSC FALL INSHORE SURVEY TOTAL CATCH PER TOW

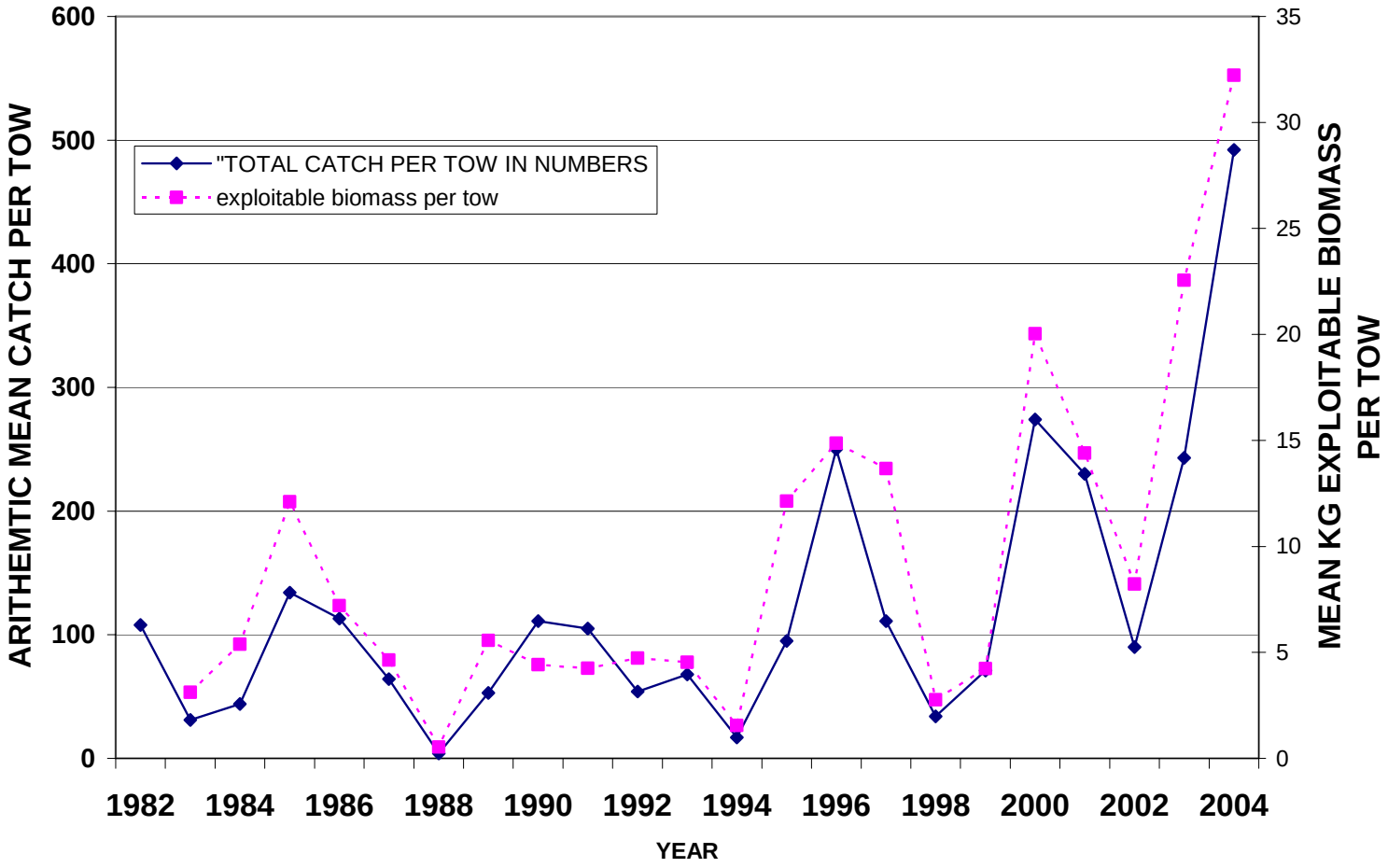


FIGURE 5. NEFSC SURVEY INDICES BY AGE

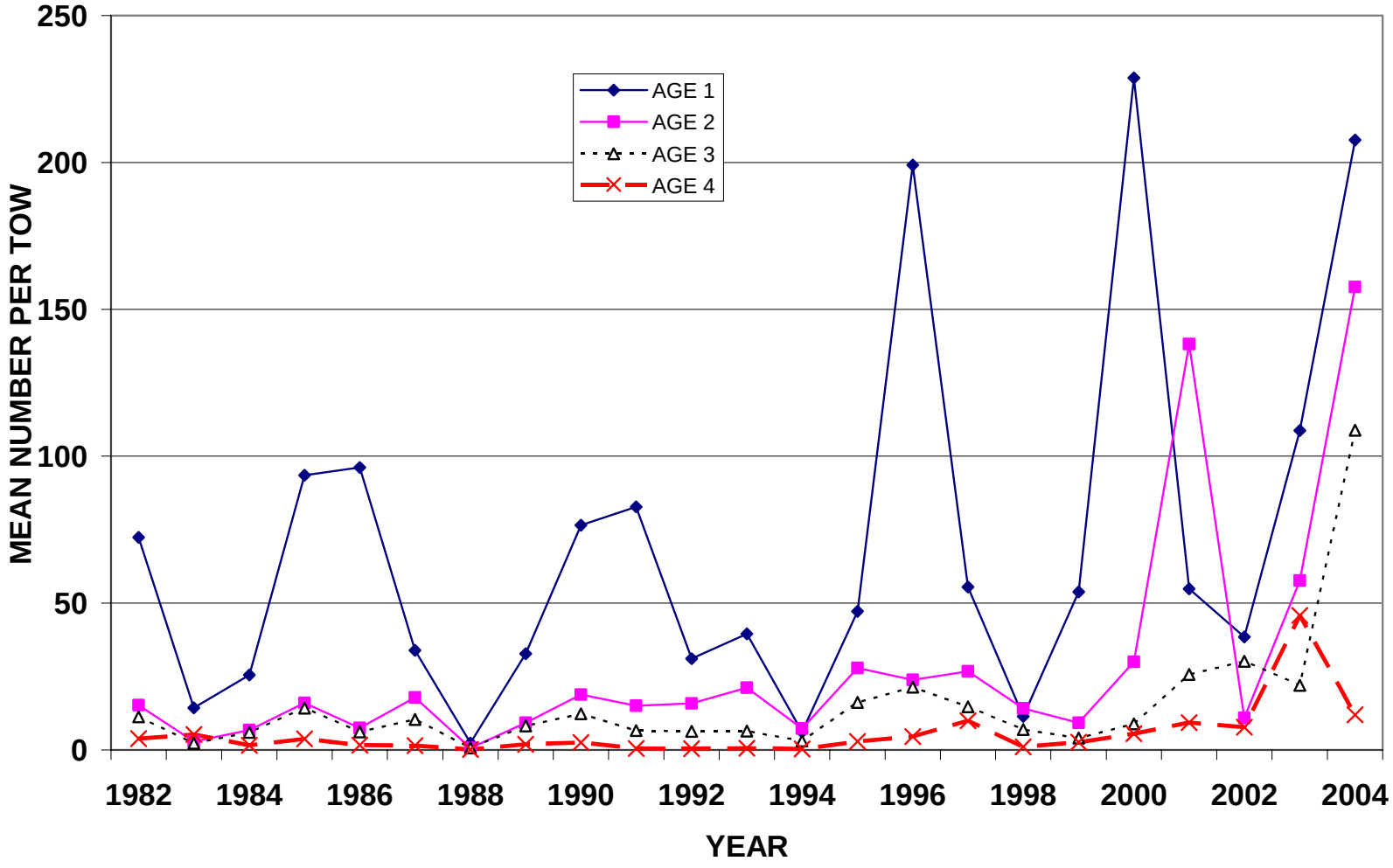


Figure 6. NJ Survey Total Catch Per Tow

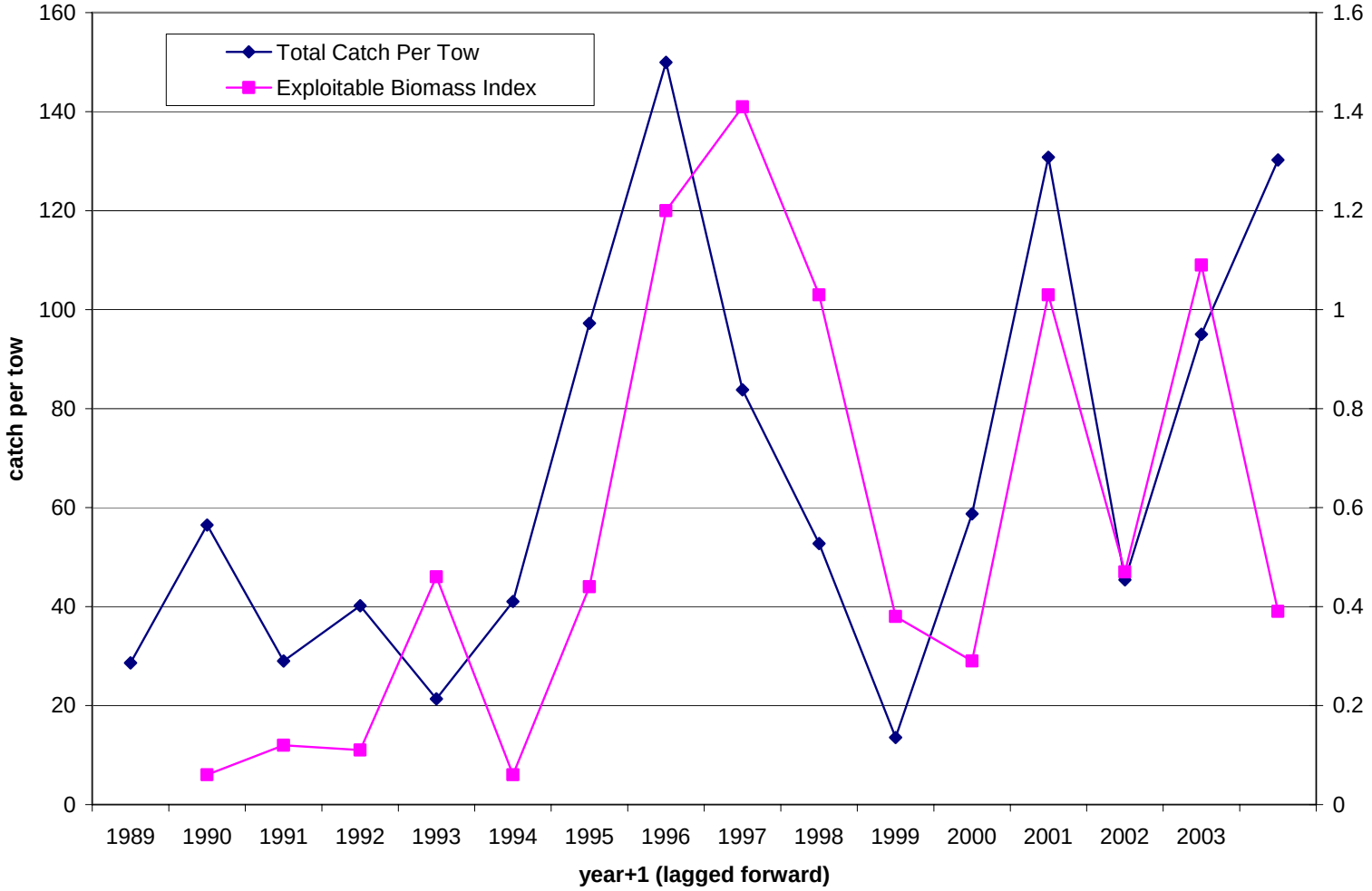


FIGURE 7. NJ INDICES BY AGE

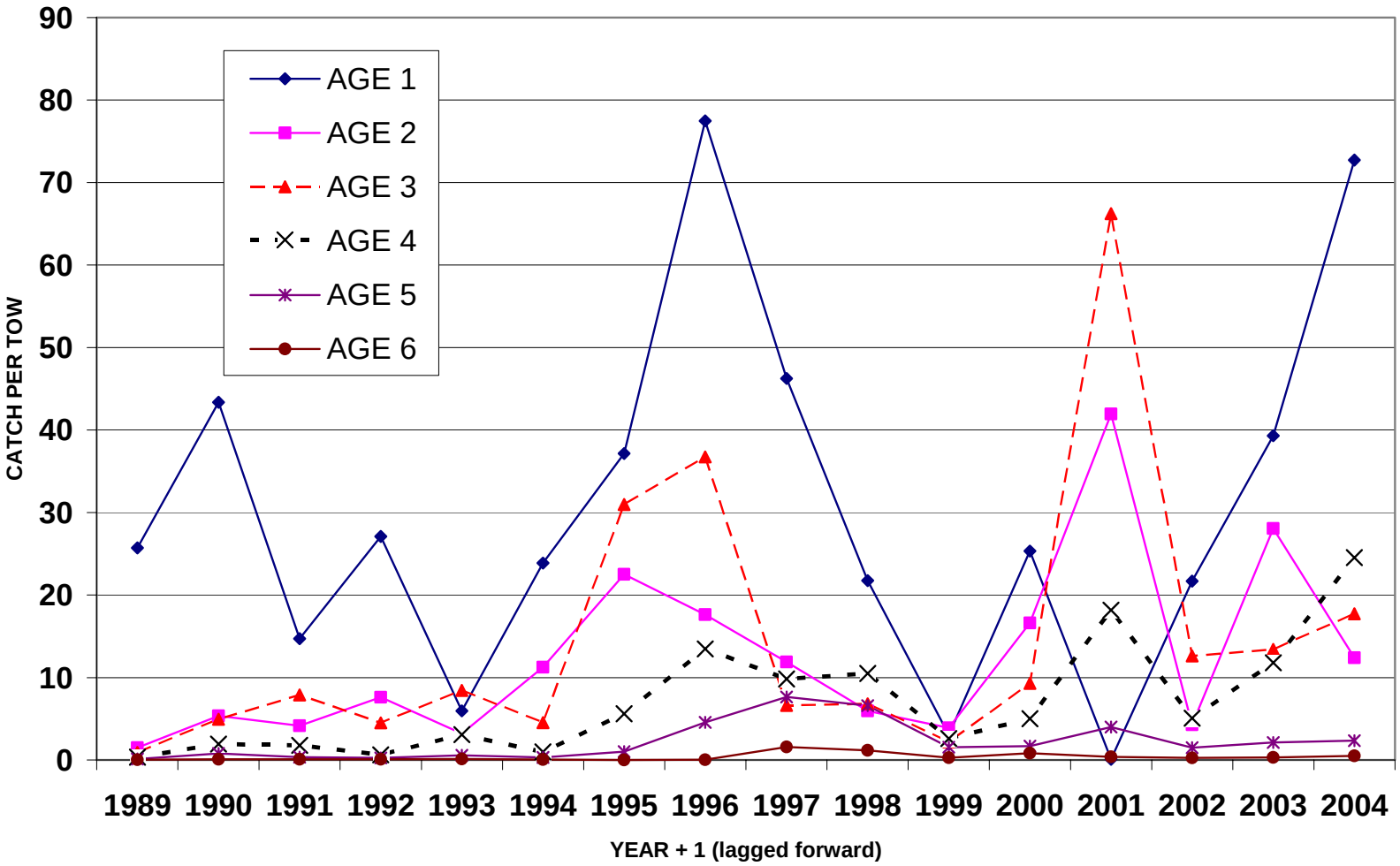


FIGURE 8.DELAWARE SURVEY TOTAL CATCH PER TOW

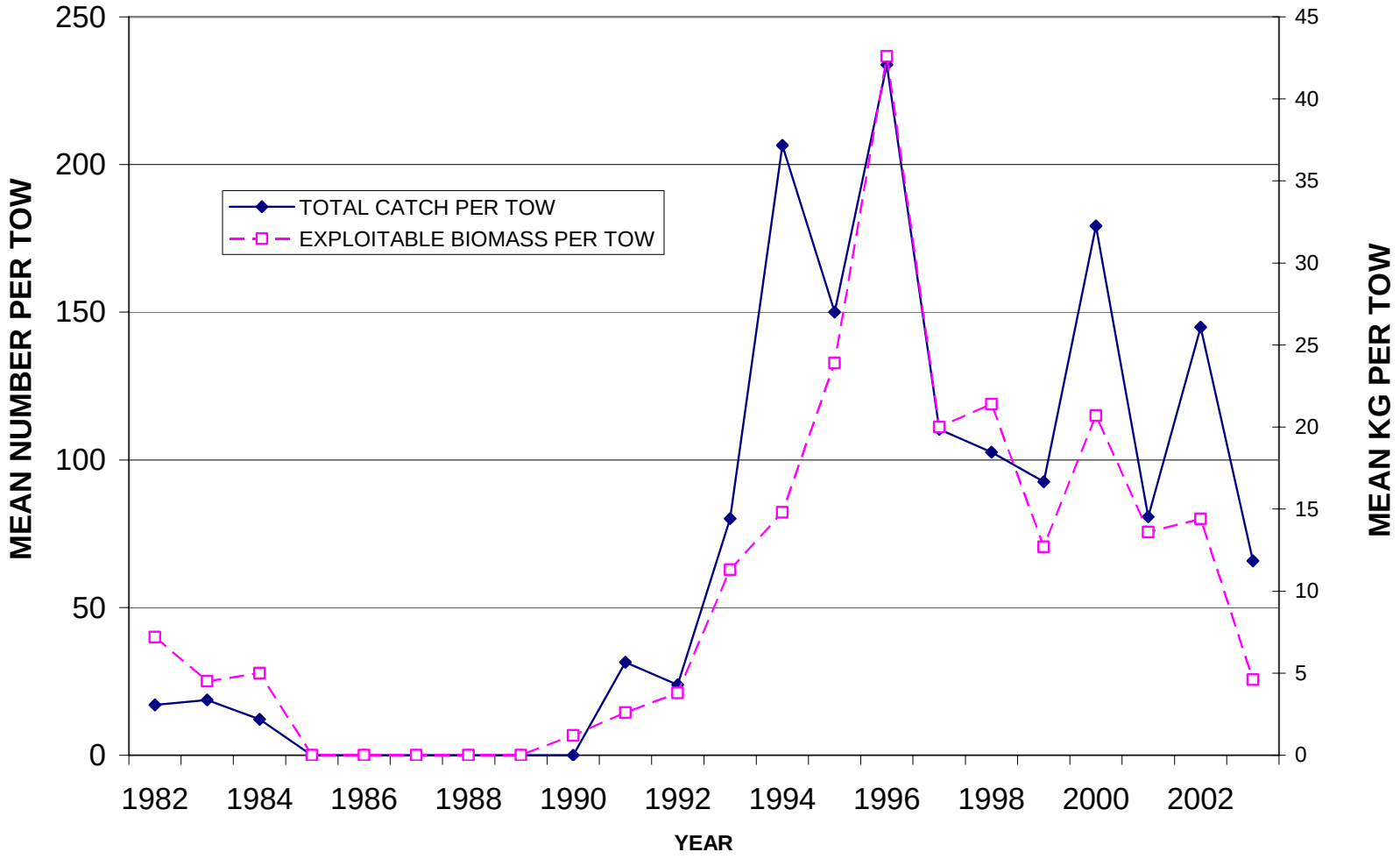


FIGURE 9. DE SURVEY INDICES BY AGE

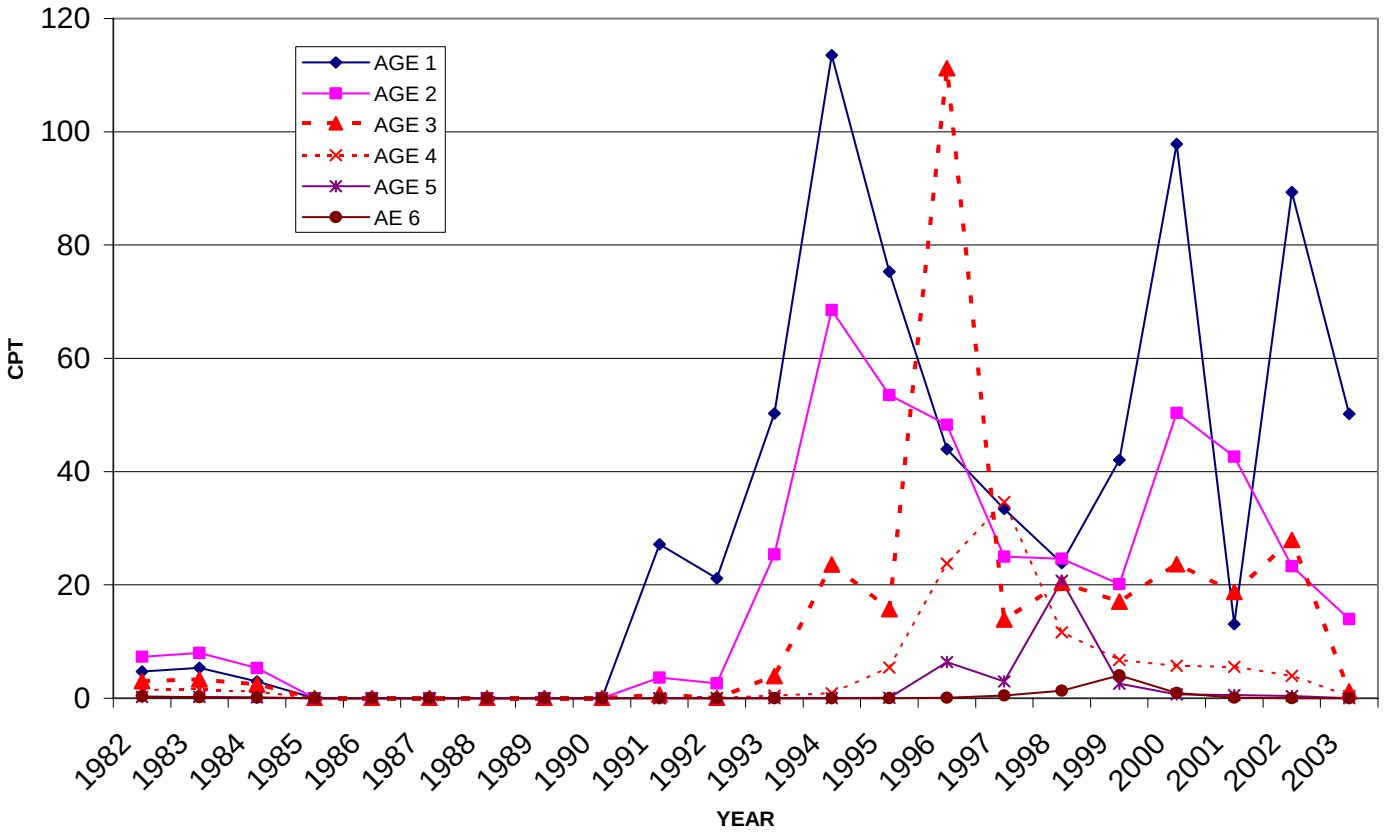


Figure 9a. SEAMAP INDICES BY AGE

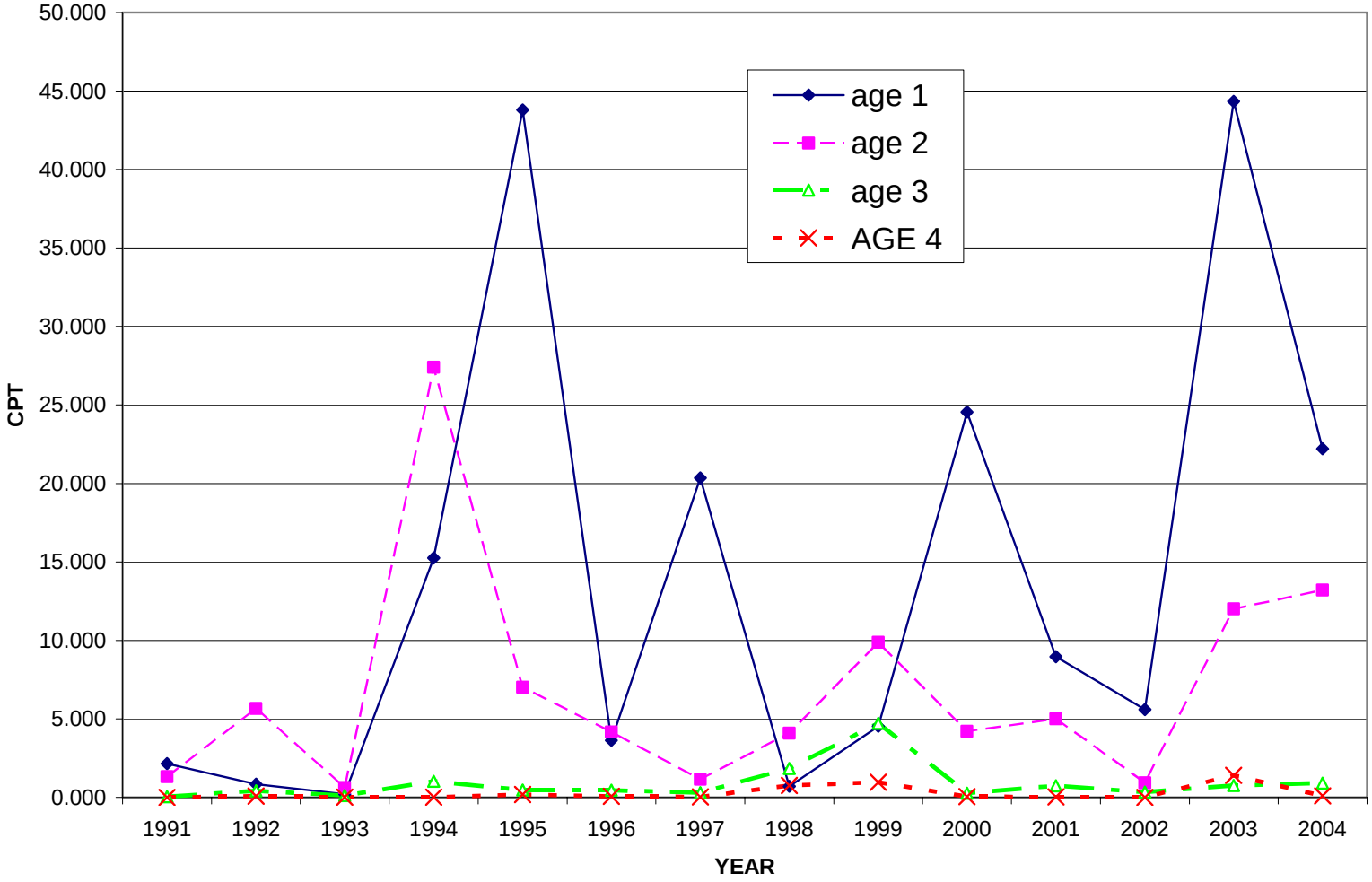


Figure 9b. Relative F based on Recreational Total Catch in Weight and in Number

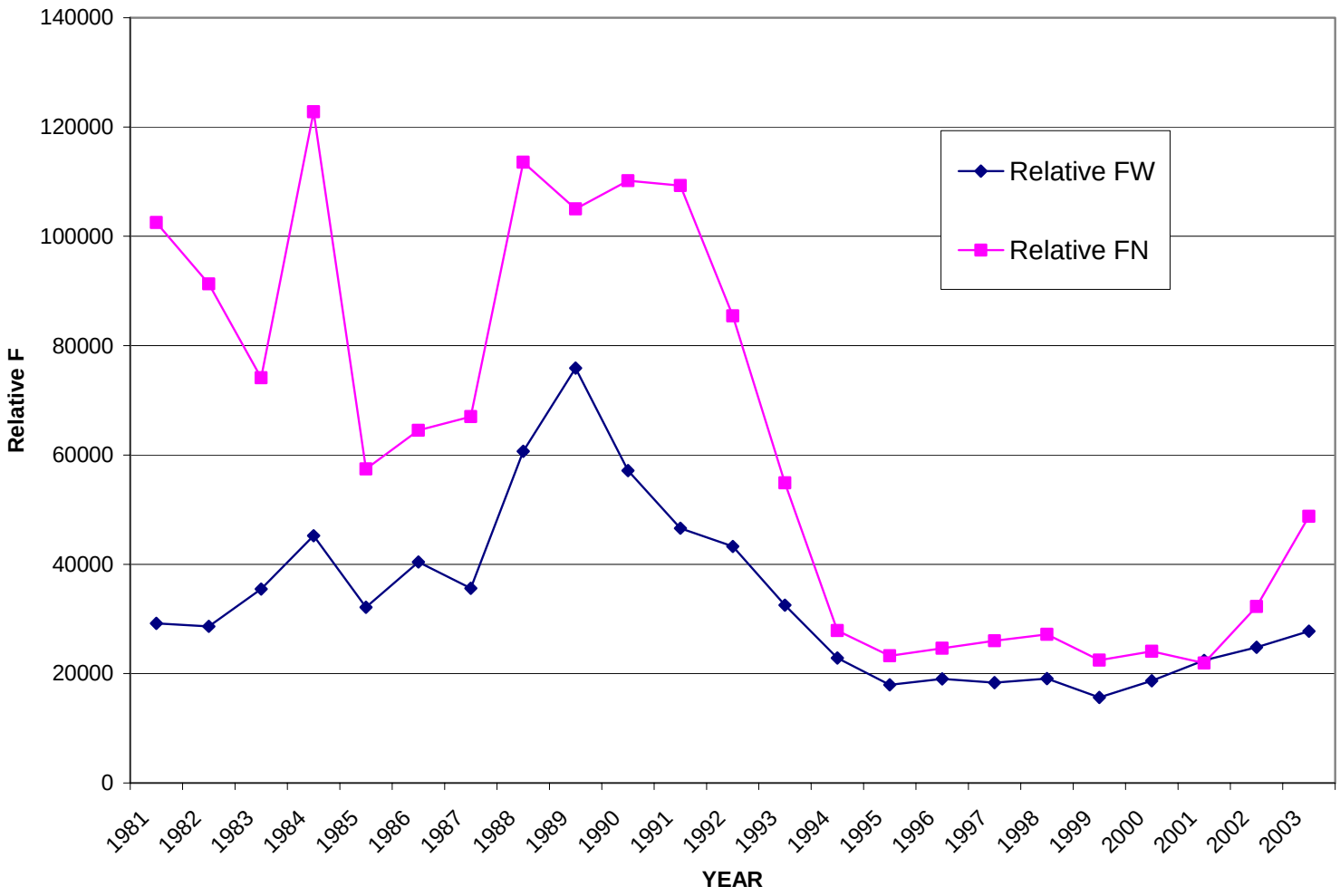


Figure 9c. Relative F derived from Z + 1 transformed trawl survey exploitable biomass indices, divided by 10,000 to rescale.

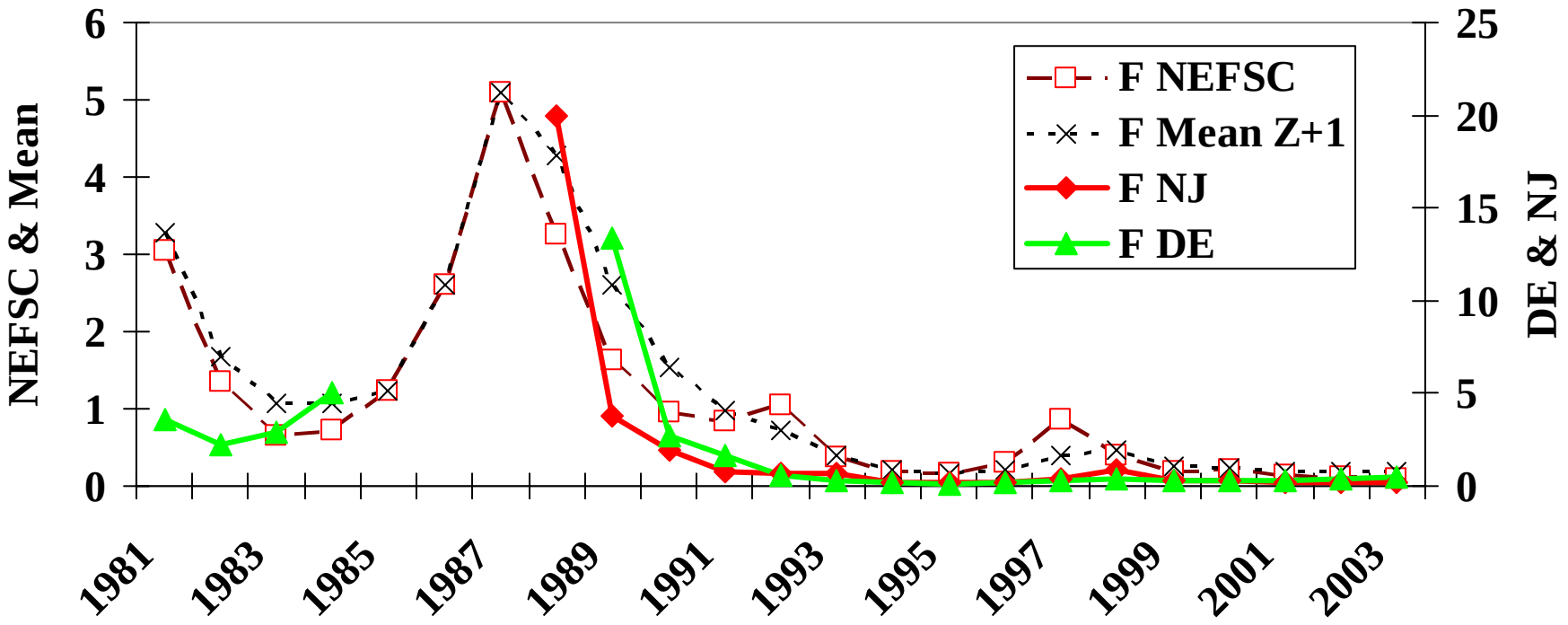


Figure 10.EFFECT OF INCLUDING CORE SPECIES COMMERCIAL DISCARDS ON 2002 CAA

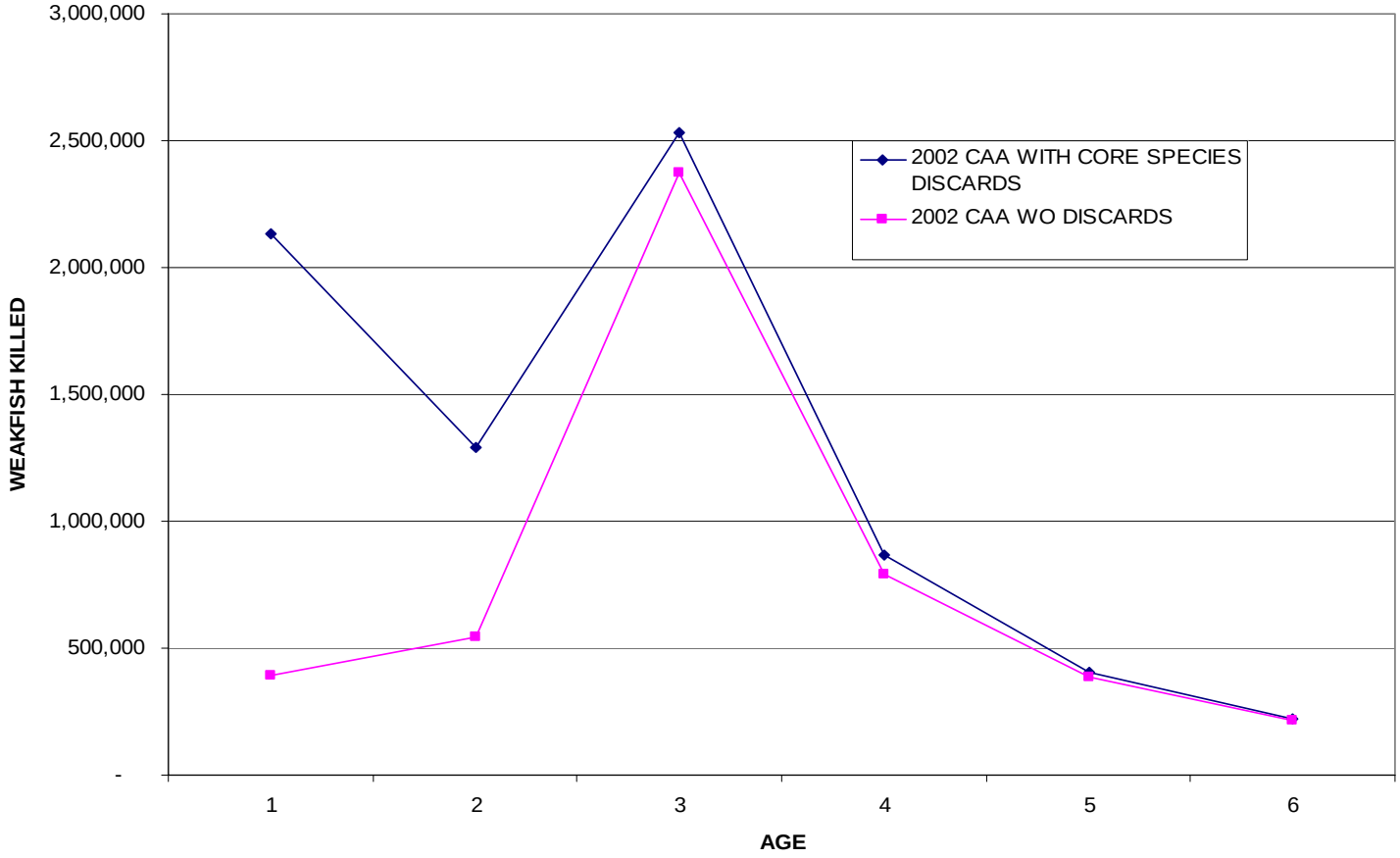


Figure 11. Mean Weight at Age of the Commercial Harvest by State, 2001

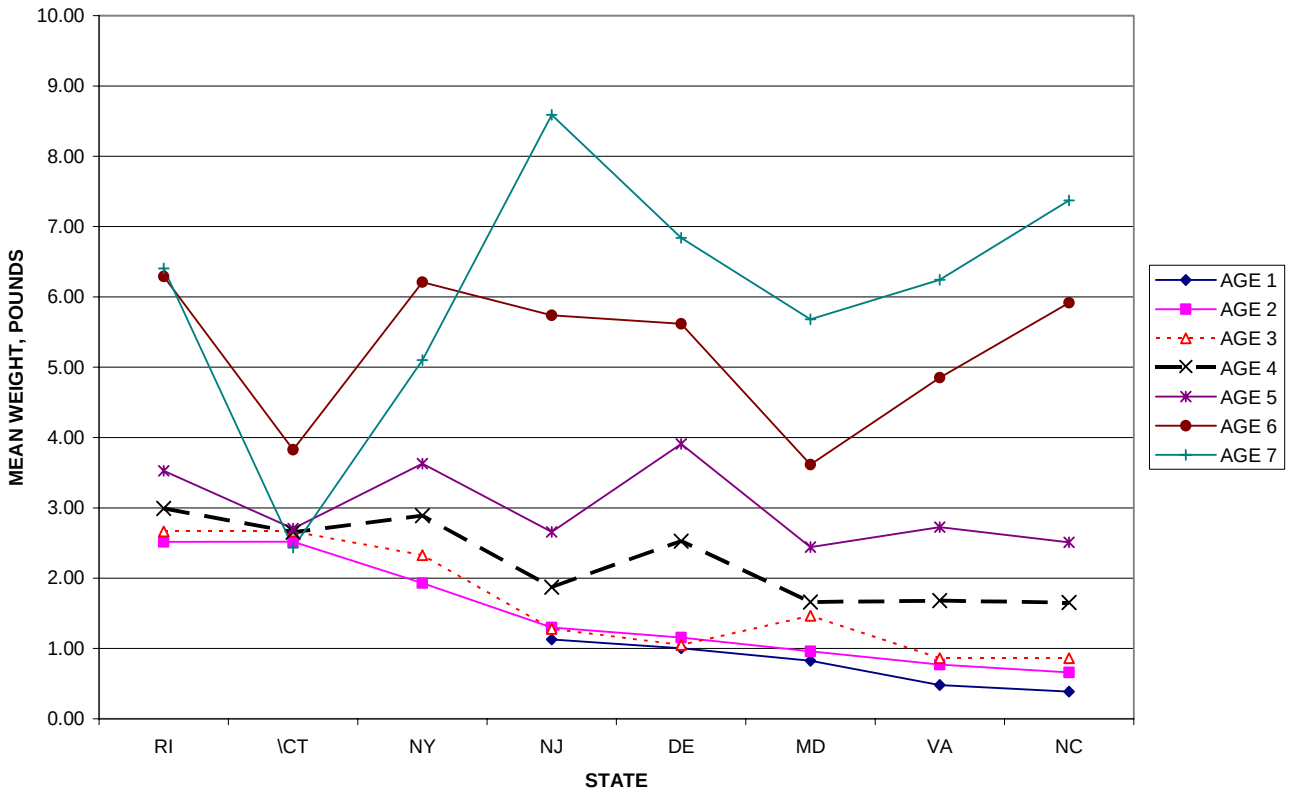


Figure 12. Mean Weight at Age of the Commercial Harvest by State, 2002

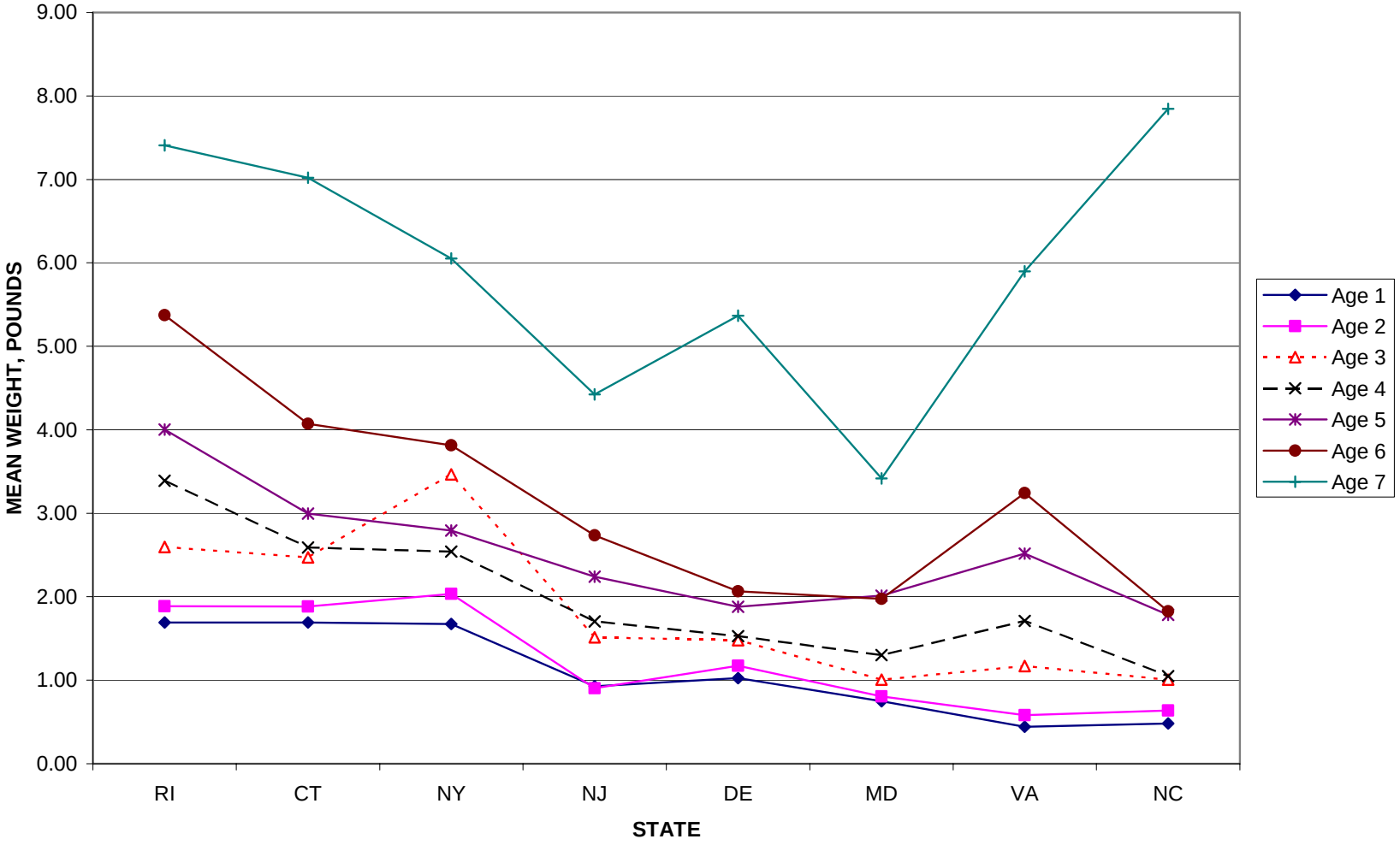


Figure 13. Mean Weight at age of the commercial harvest by state, 2003

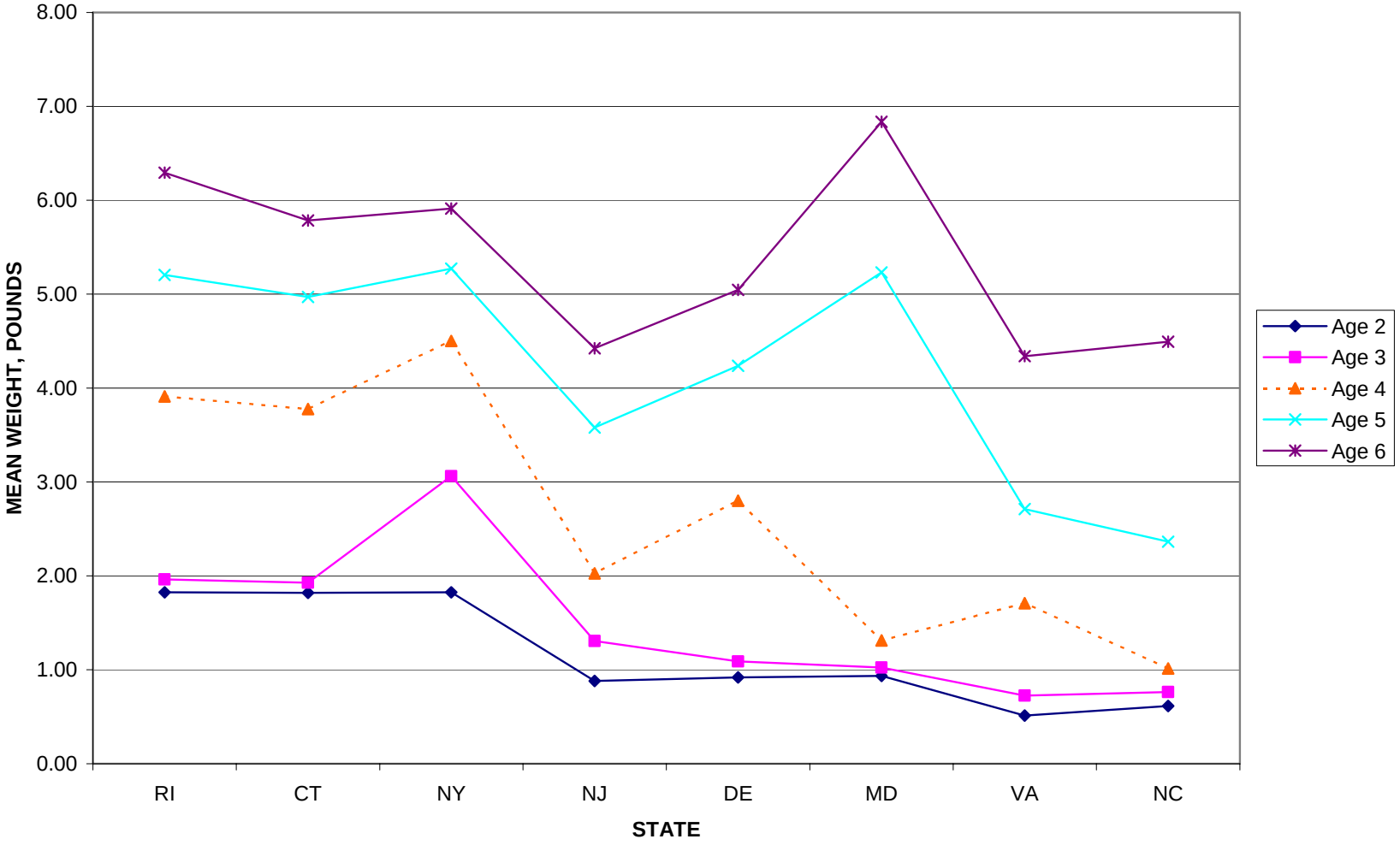


Figure 14. January 1 Stock Mean Weight at Age

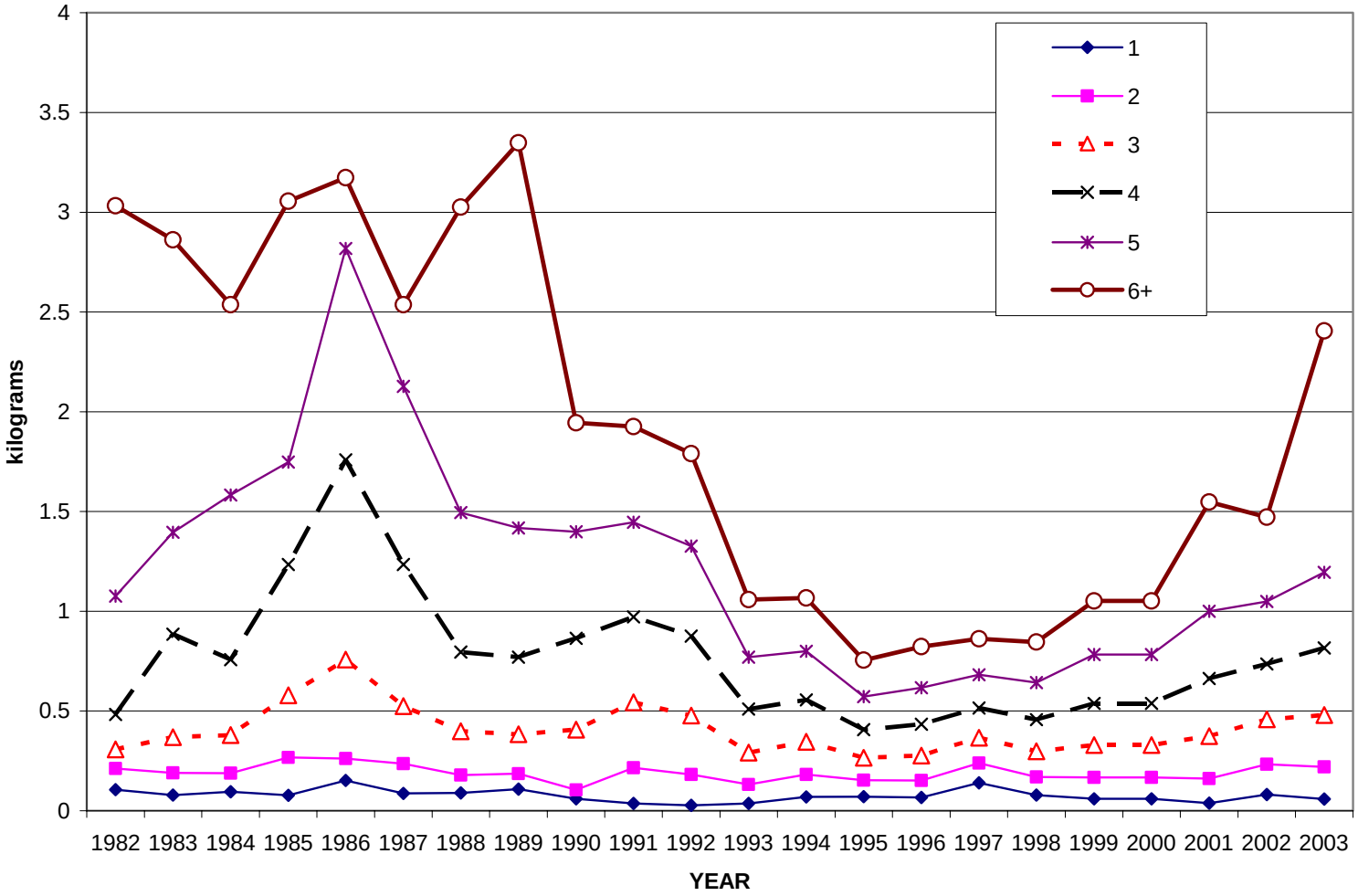


Figure 15 Landings versus Sum of cross-products (mean catch weight-at-age * catch-at a-age)

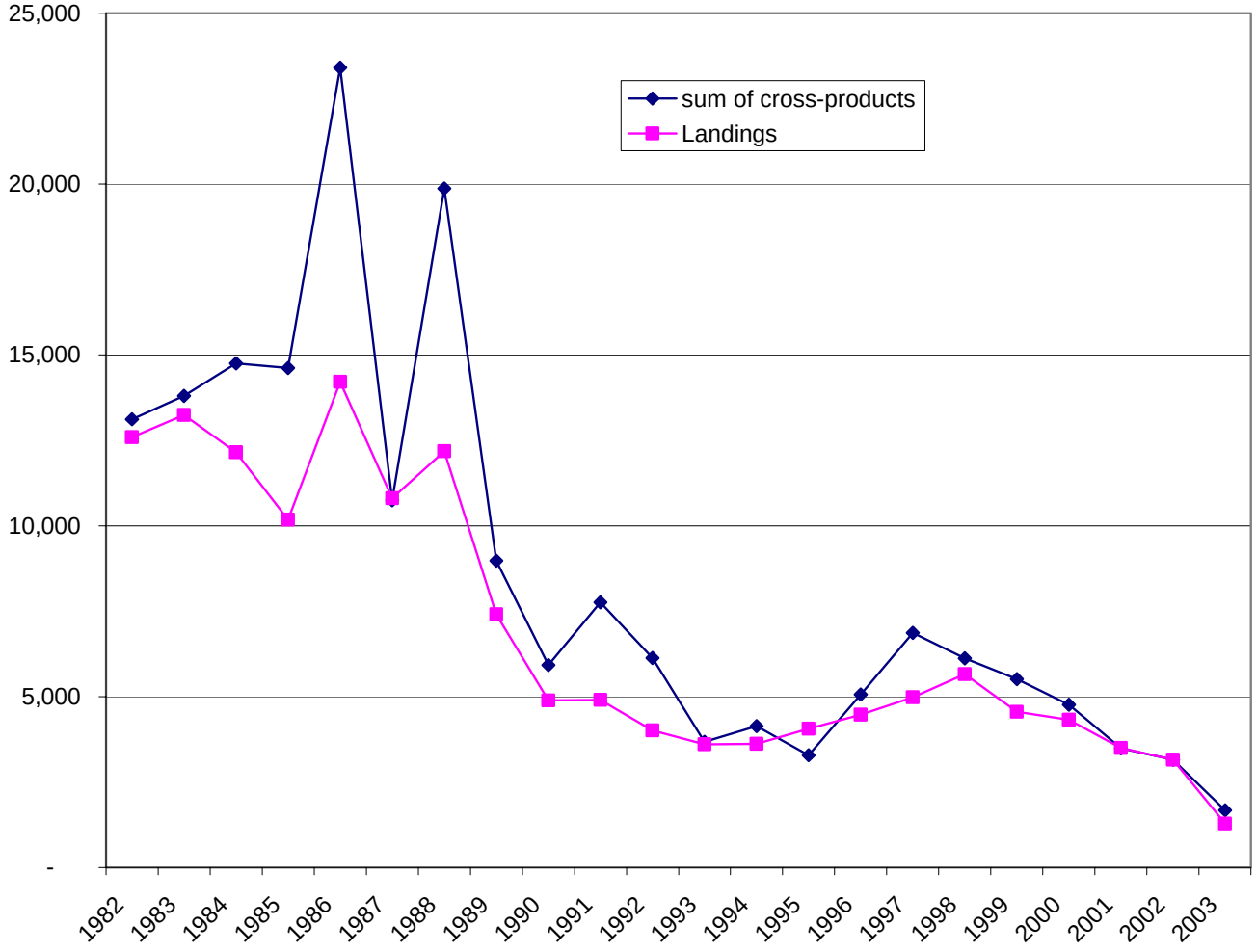


Figure 16. Weakfish Mortality Estimated From Catch Curve Analysis of the Catch at Age Matrix

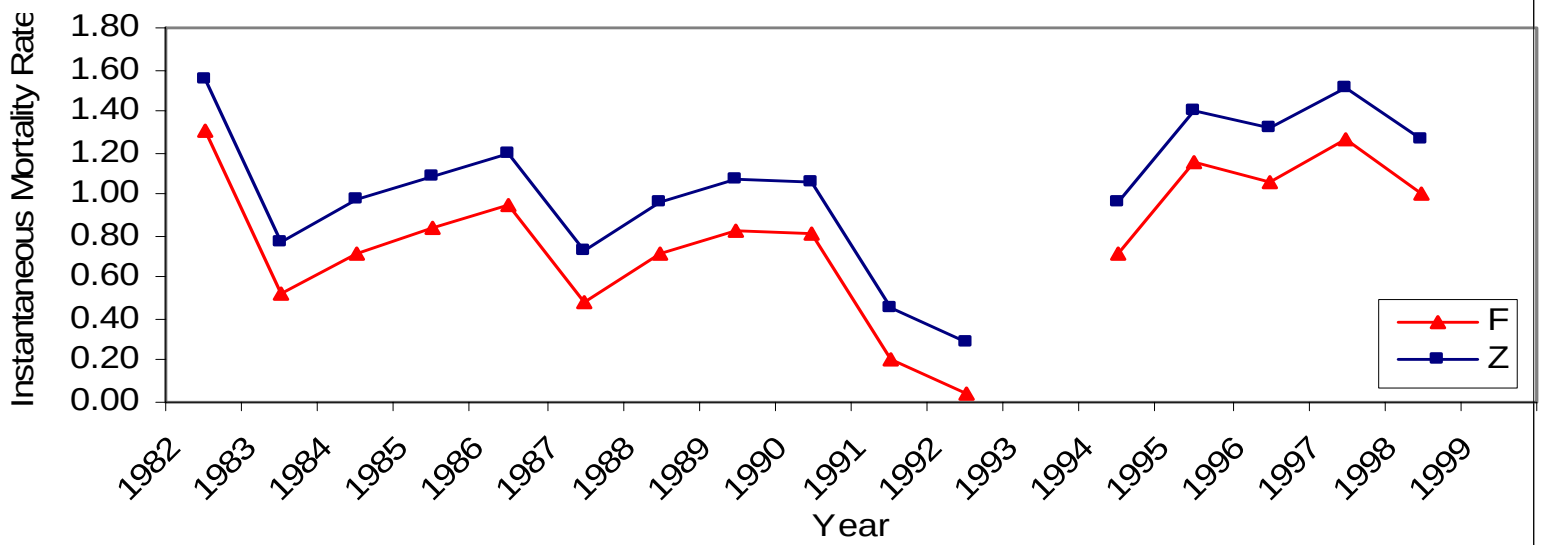


FIGURE 17. CORRELATION BETWEEN YEAR CLASS Z ESTIMATES FROM CATCH CURVE ANALYSIS OF THE CATCH AT AGE MATRIX AND THE DELAWARE SURVEYFOR THE 1990 - 1998 YEAR CLASSES (1993 YEAR CLASS EXCLUDED)

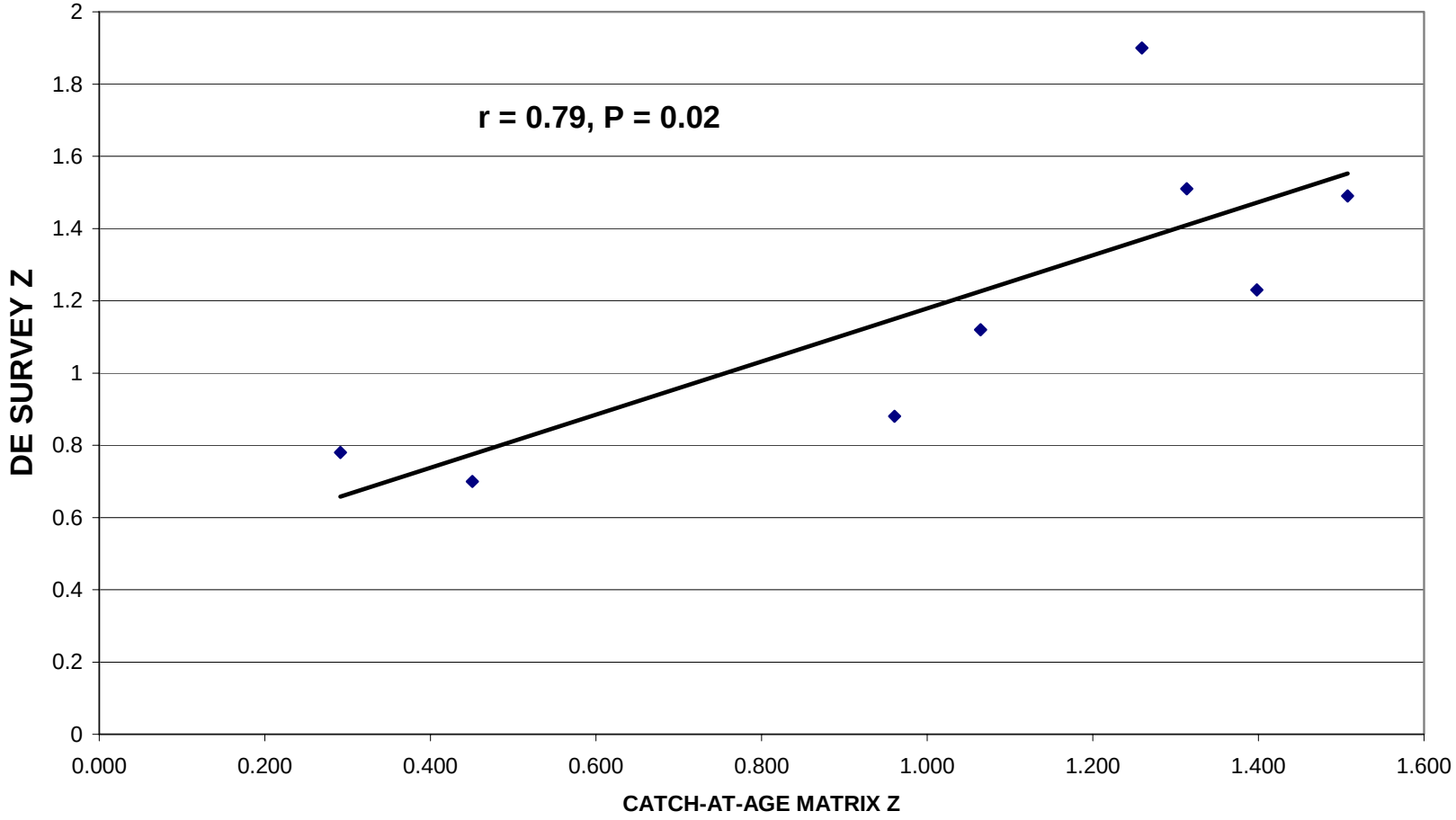
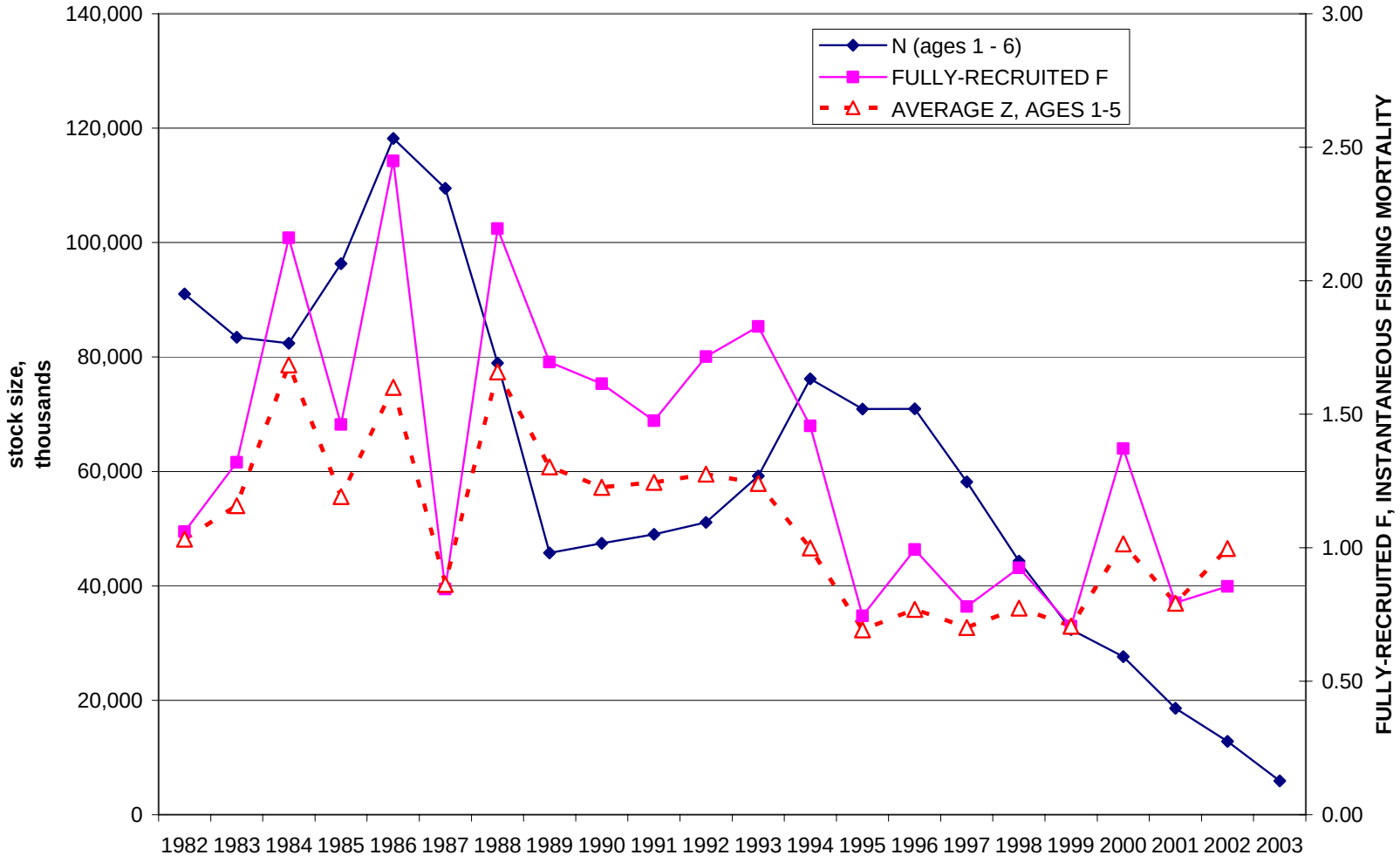


Figure 18. Gulland's Cohort analysis for weakfish



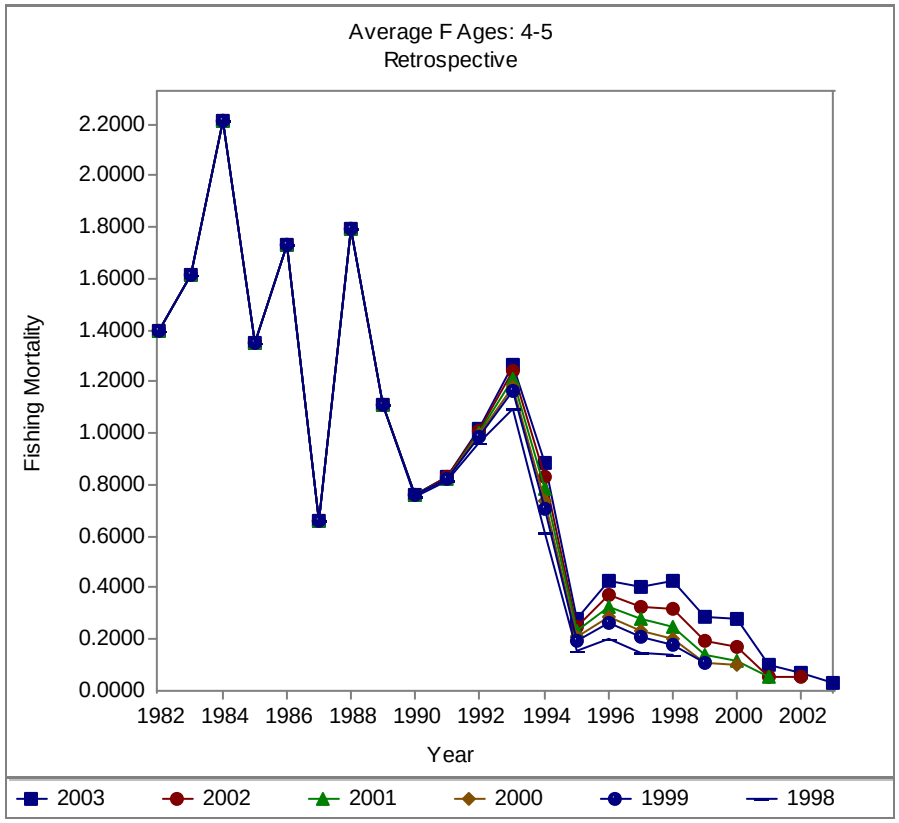


Figure 19. ADAPT run 24 retrospective pattern in fully-recruited F estimates.
The 1998 line shows estimated F when only data available through 1998 is used.
The 2003 line shows estimates when all data through 2003 is used.

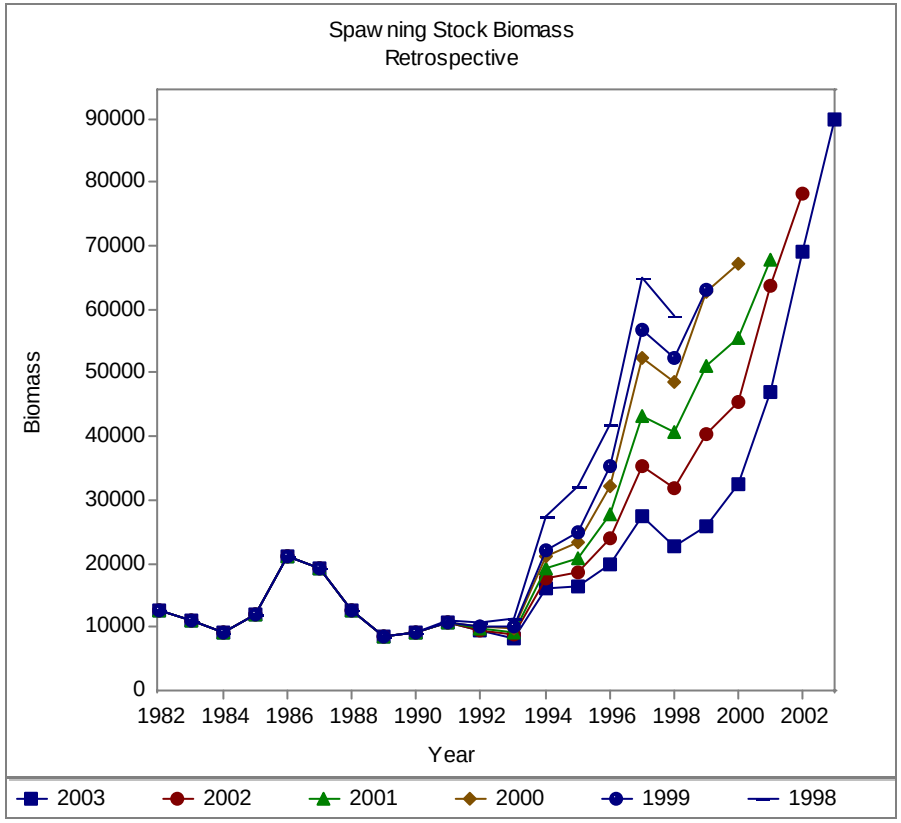


Figure 20. ADAPT run 24 retrospective pattern in estimated spawning stock biomass. Each line shows estimates when the label is the final year of data in the analysis.

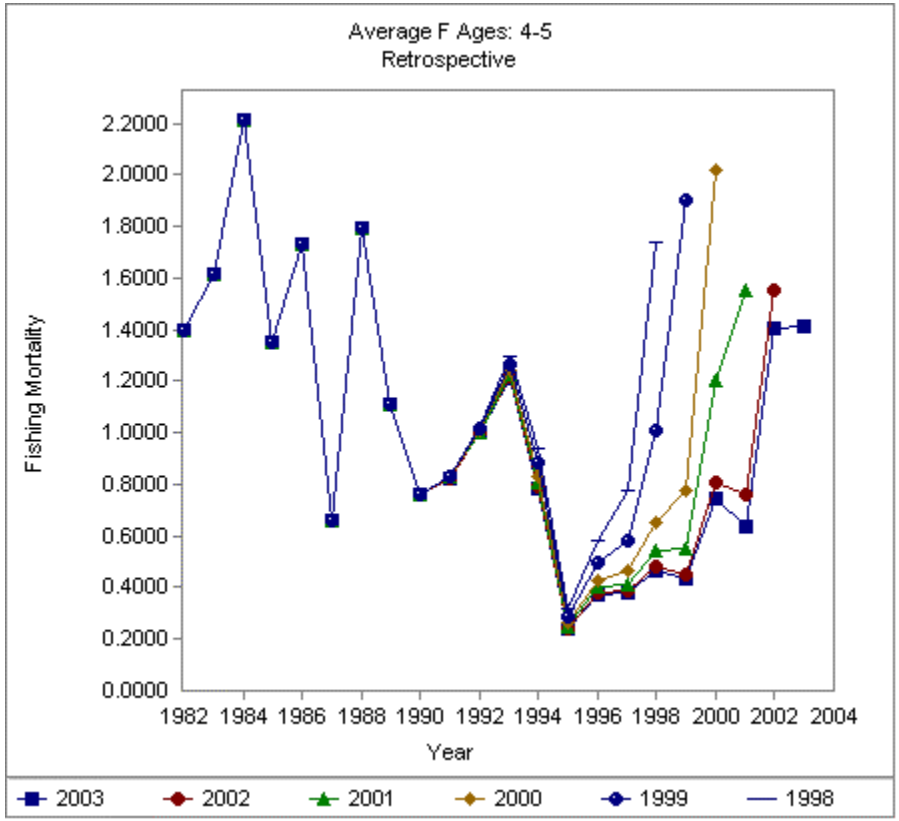


Figure 21. Run 14 retrospective pattern in fully-recruited fishing mortality.

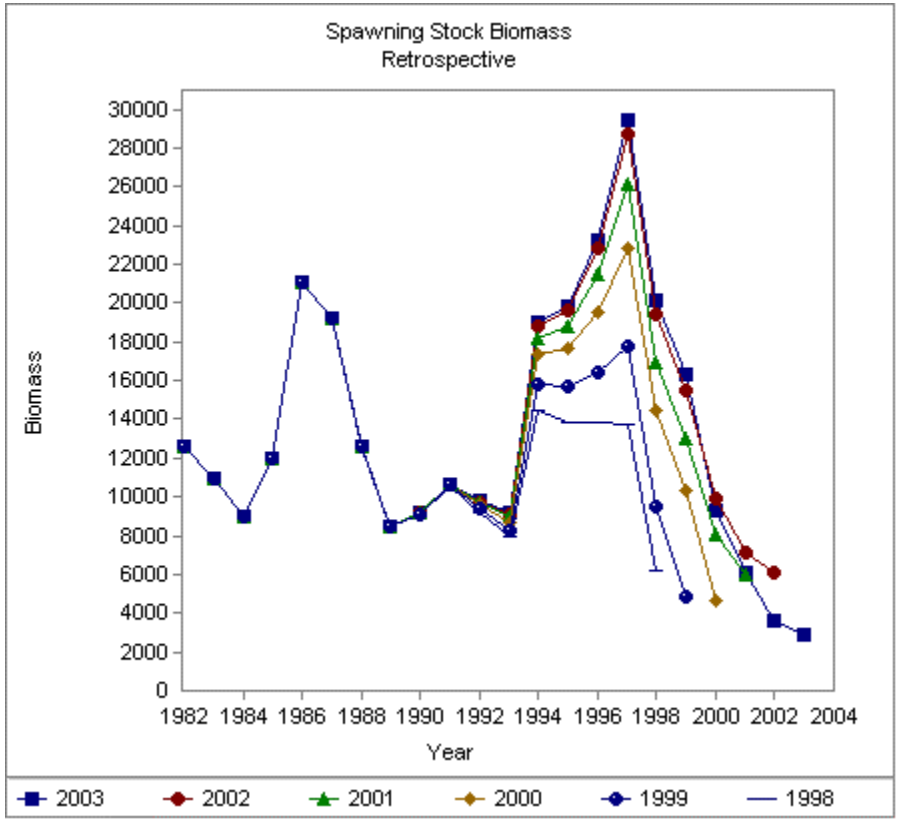


Figure 22. Run 14 retrospective pattern in spawning stock biomass estimates.

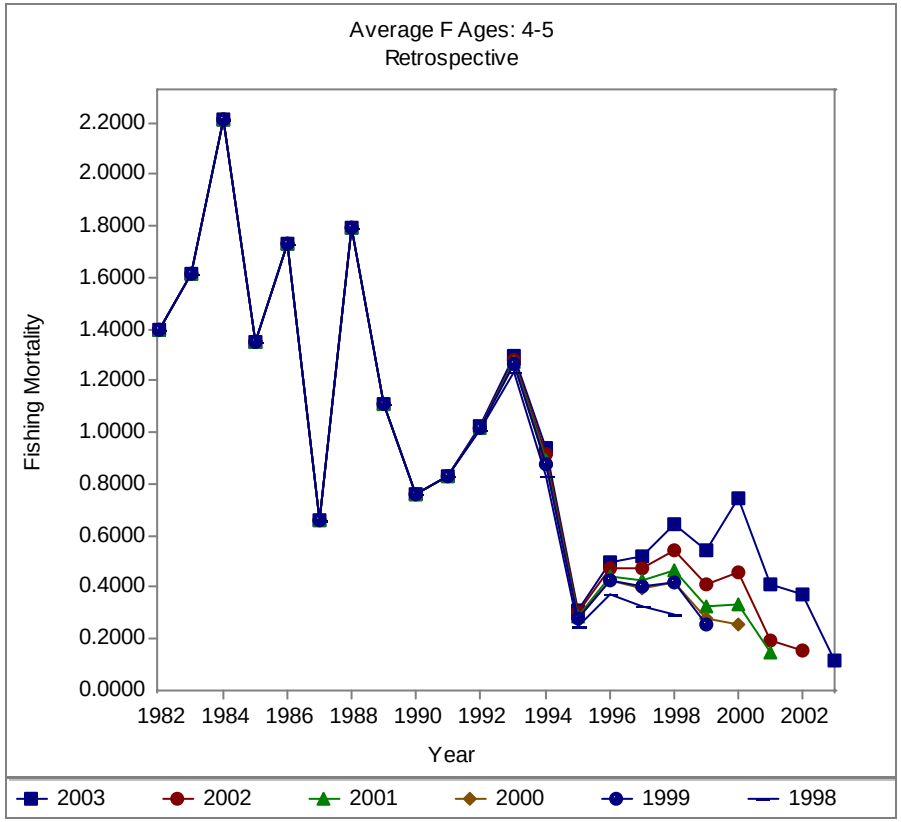
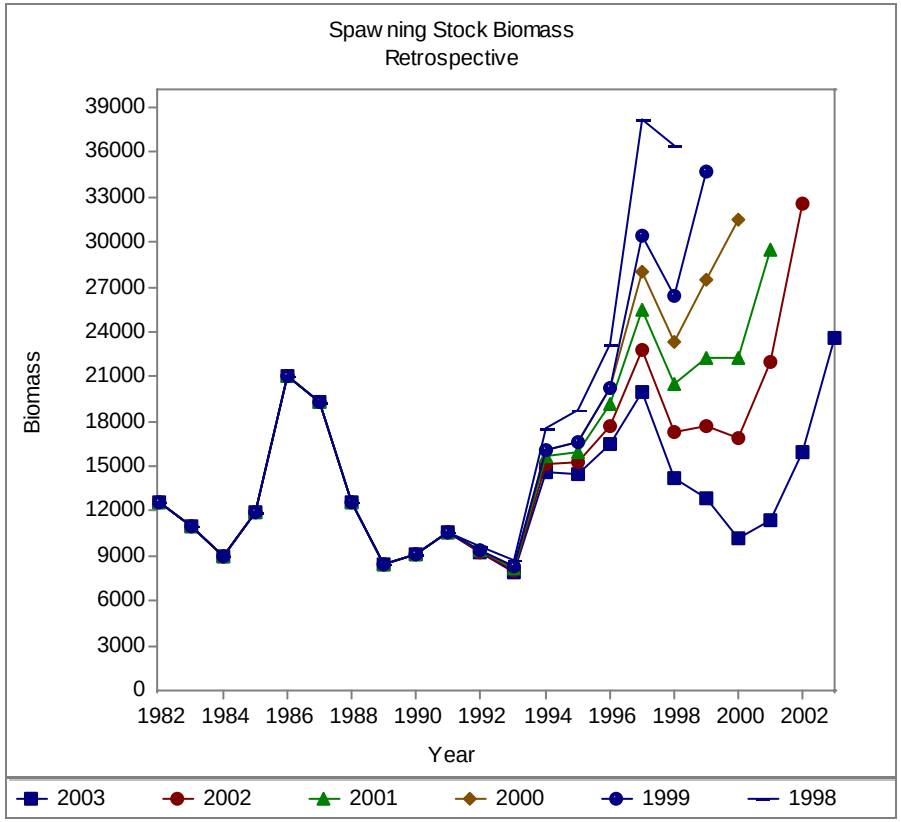


Figure 23A. Run 18 retrospective pattern for fully-recruited F.



Run 23B. Run 18 retrospective pattern in spawning stock biomass.

Figure 24A. DEDFW Survey residuals from Run 18

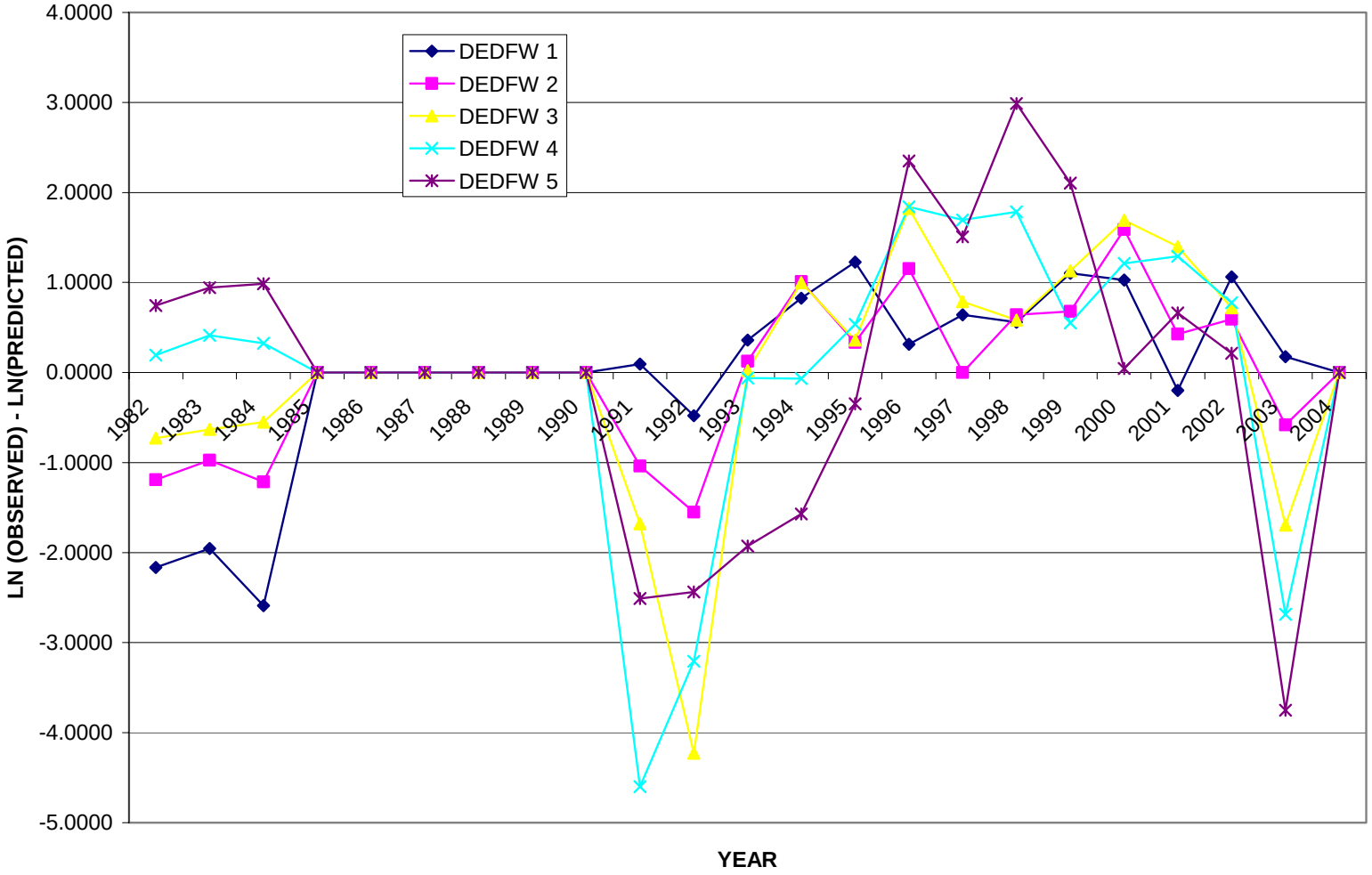


Figure 24B. SEAMAP Residuals from Run 18

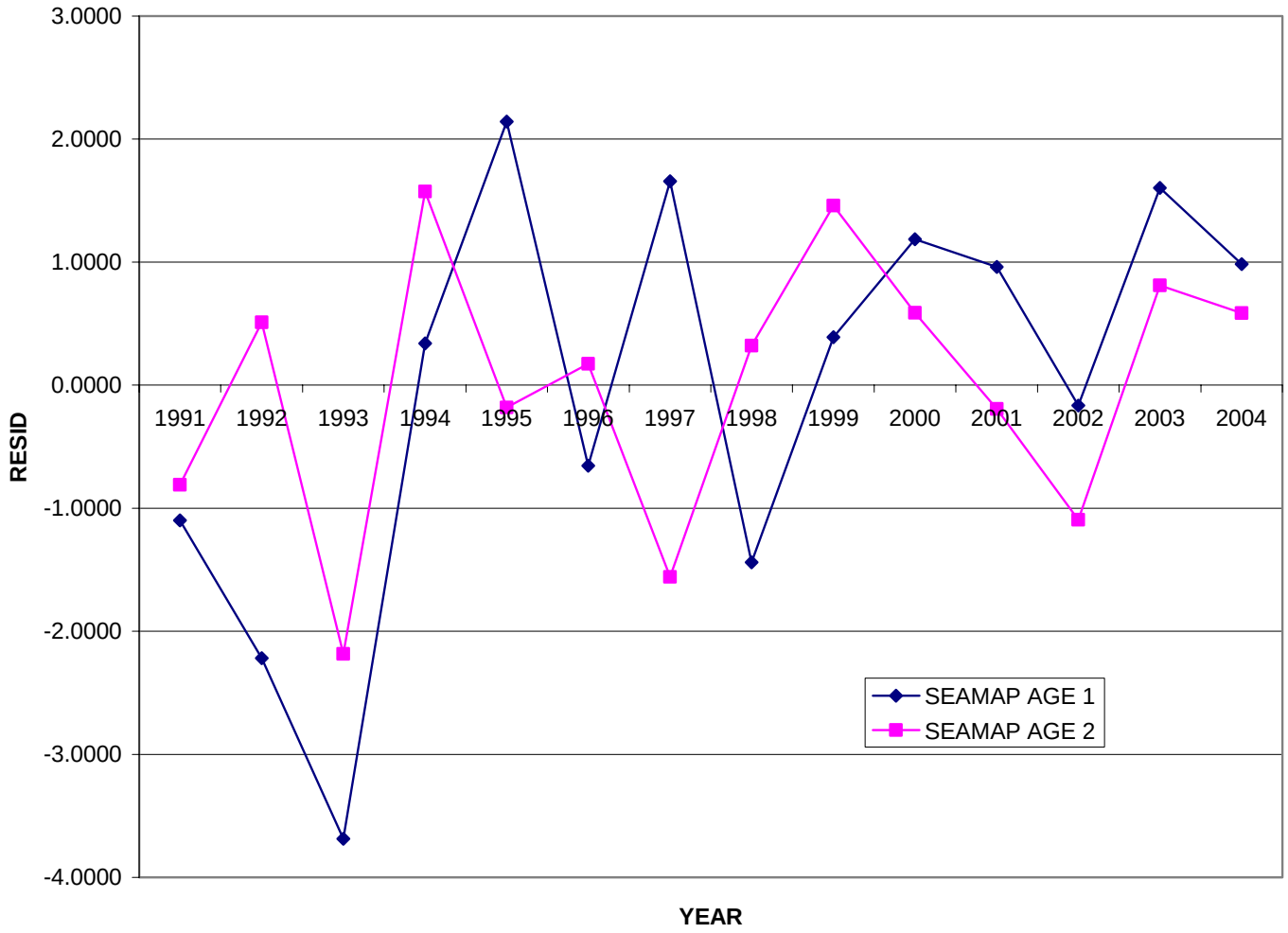


Figure 24C. Residuals from recruitment indices, Run 18

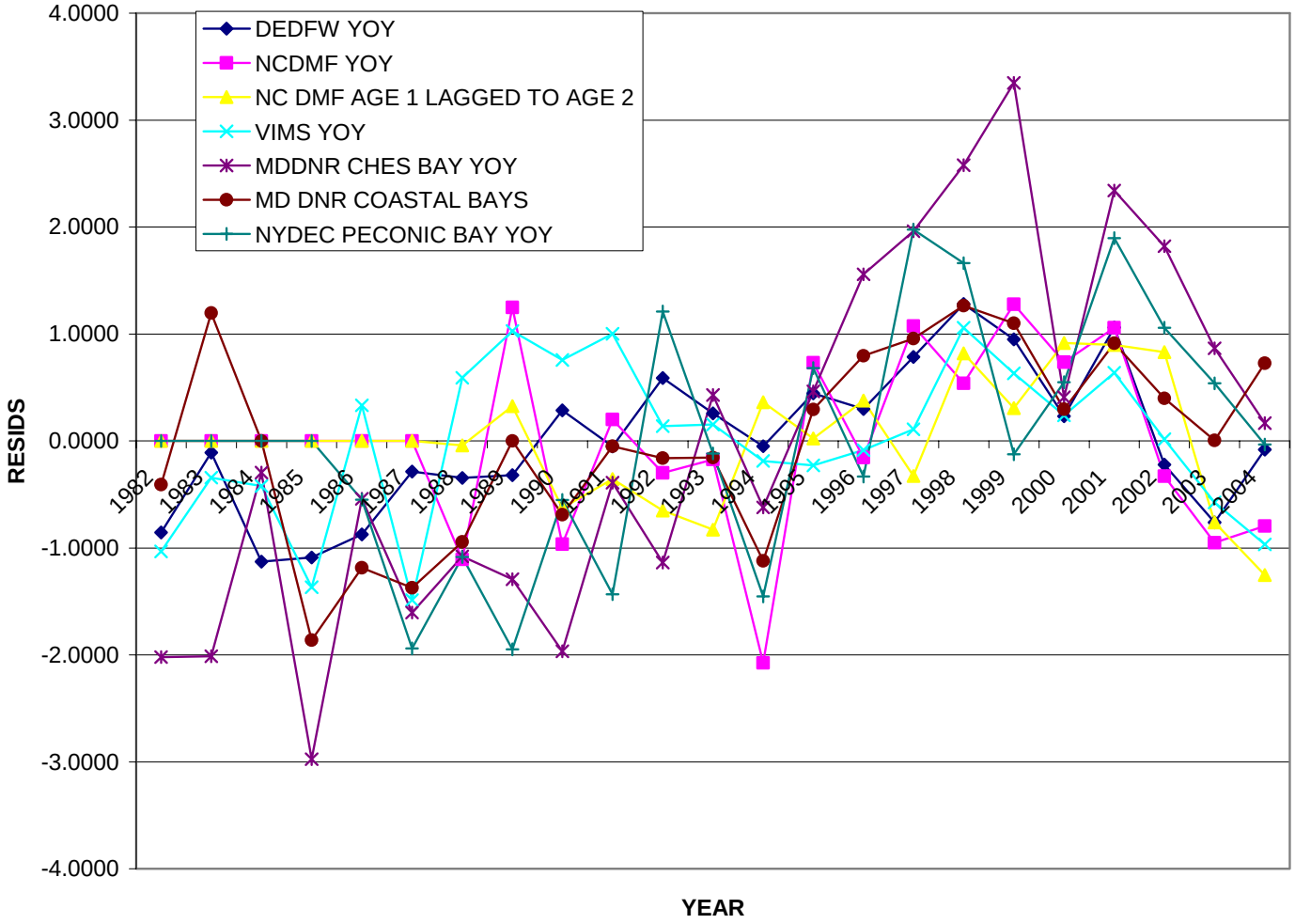


Figure 24D. Recreational CPUE residuals from Run 18

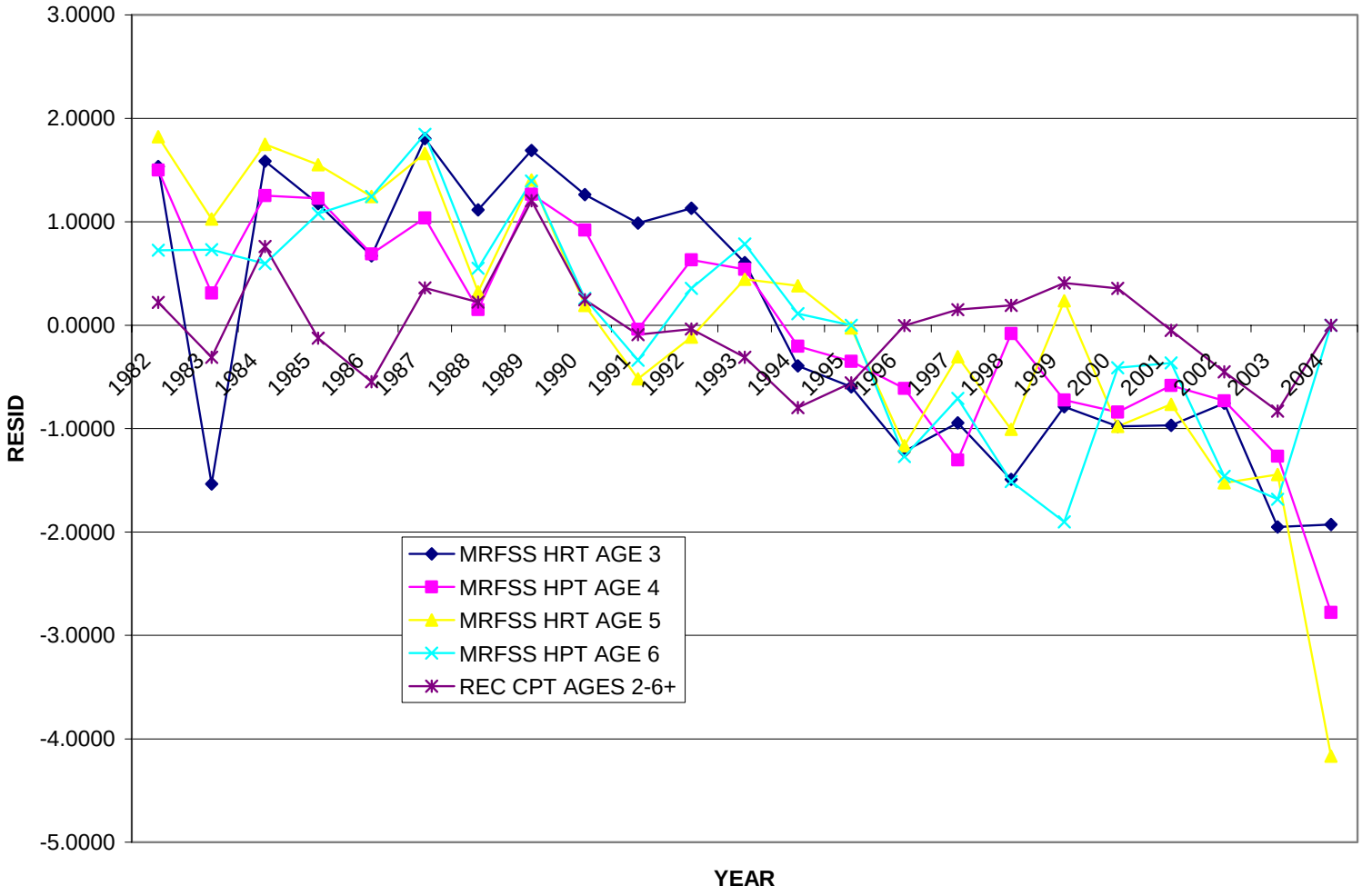


Figure 25. Run 20 Retrospective Pattern in F

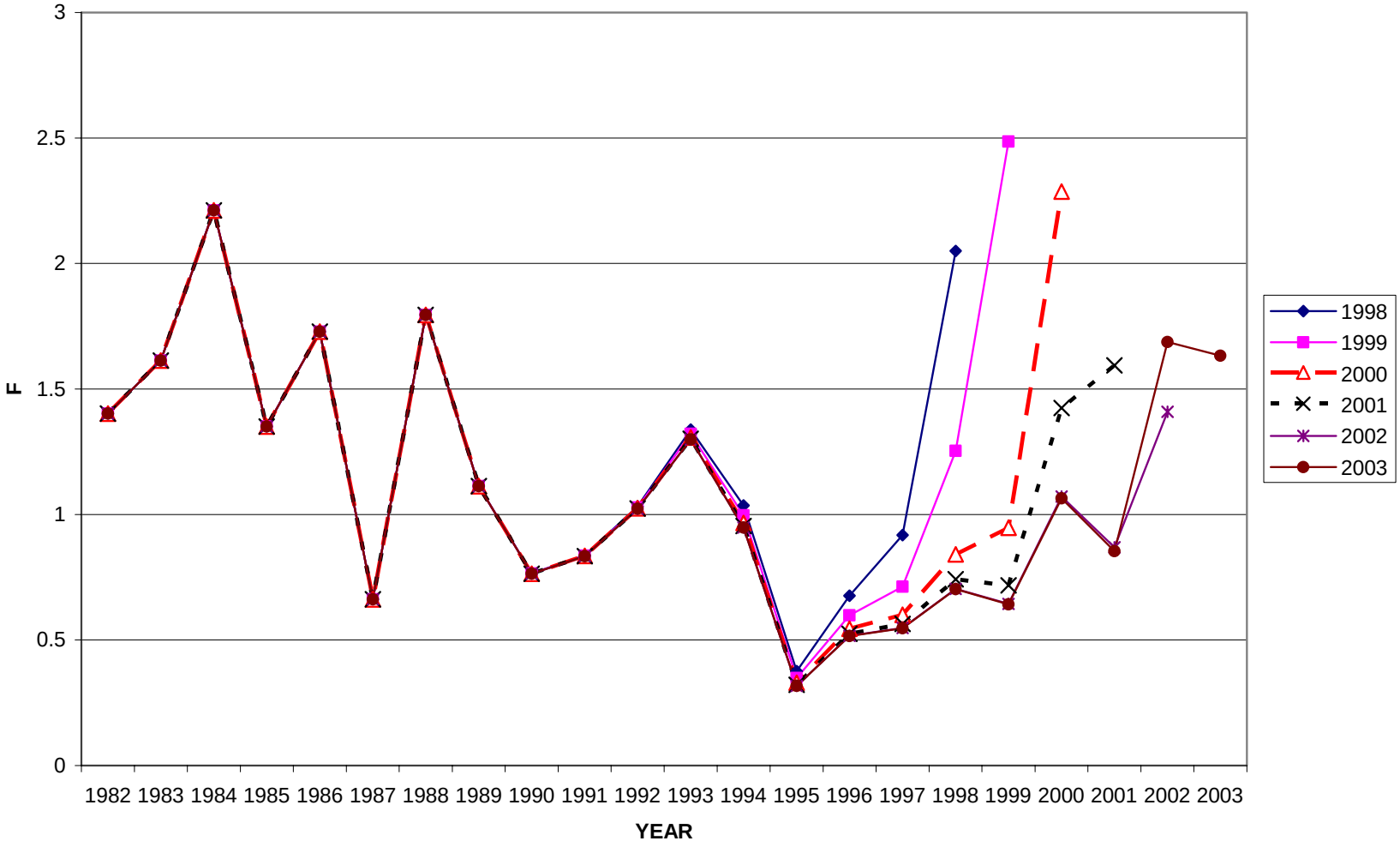


Figure 26. Run 20 Retrospective Pattern in SSB

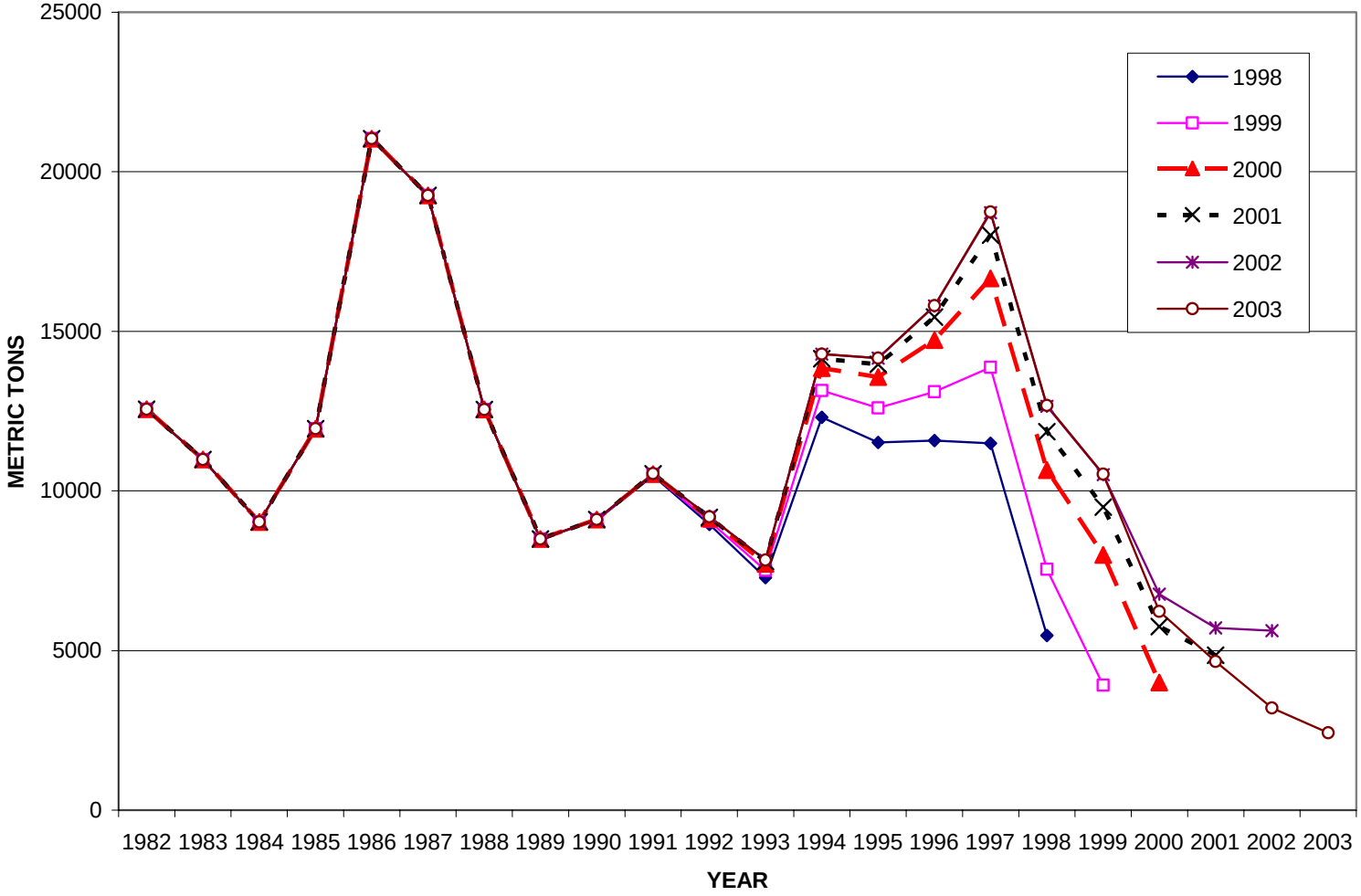


Figure 26B. Run 20 residuals from recreational CPUE indices

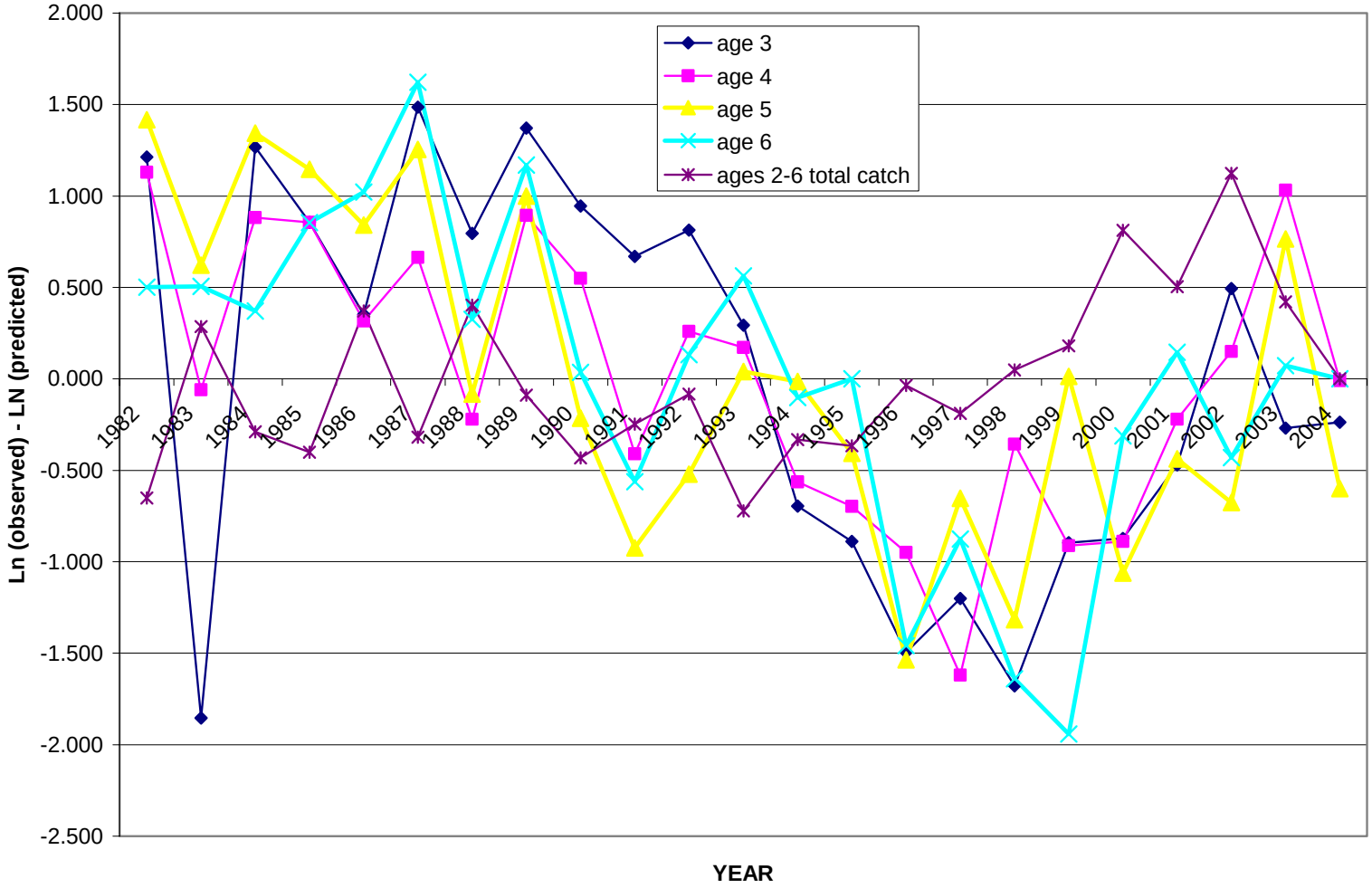


Figure 27. Delaware and New Jersey trawl survey Quality+ PSD

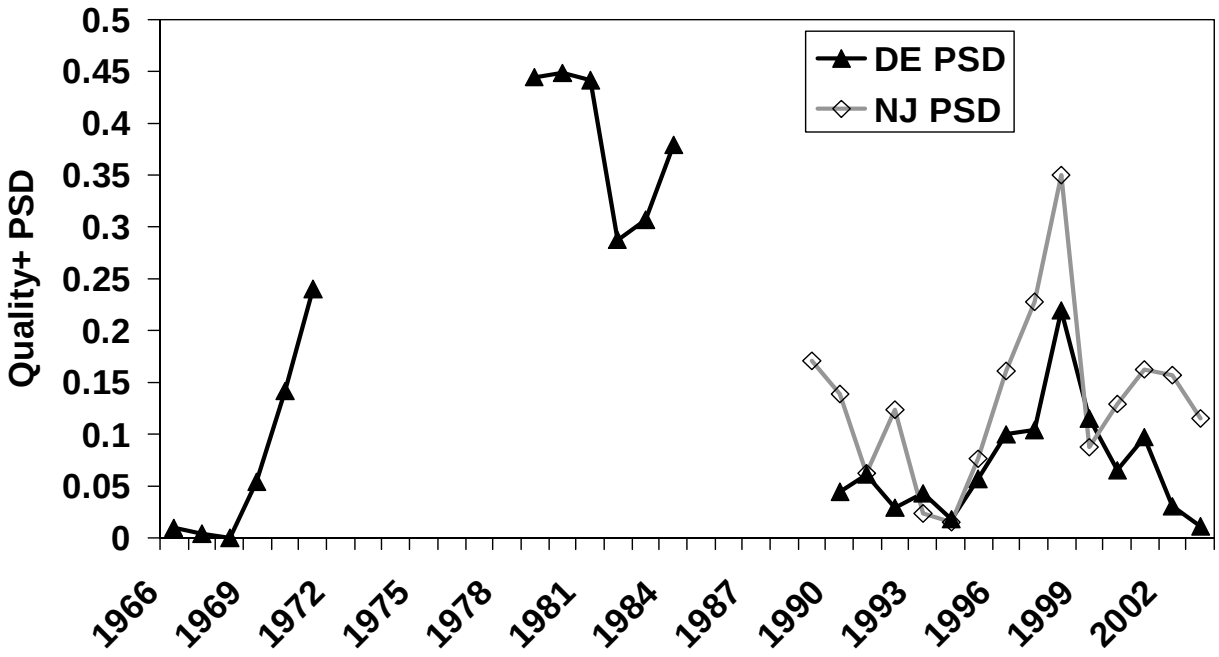


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Figure 27a. Percent of population estimate that was ages 6 and older in three ADAPT VPA runs.

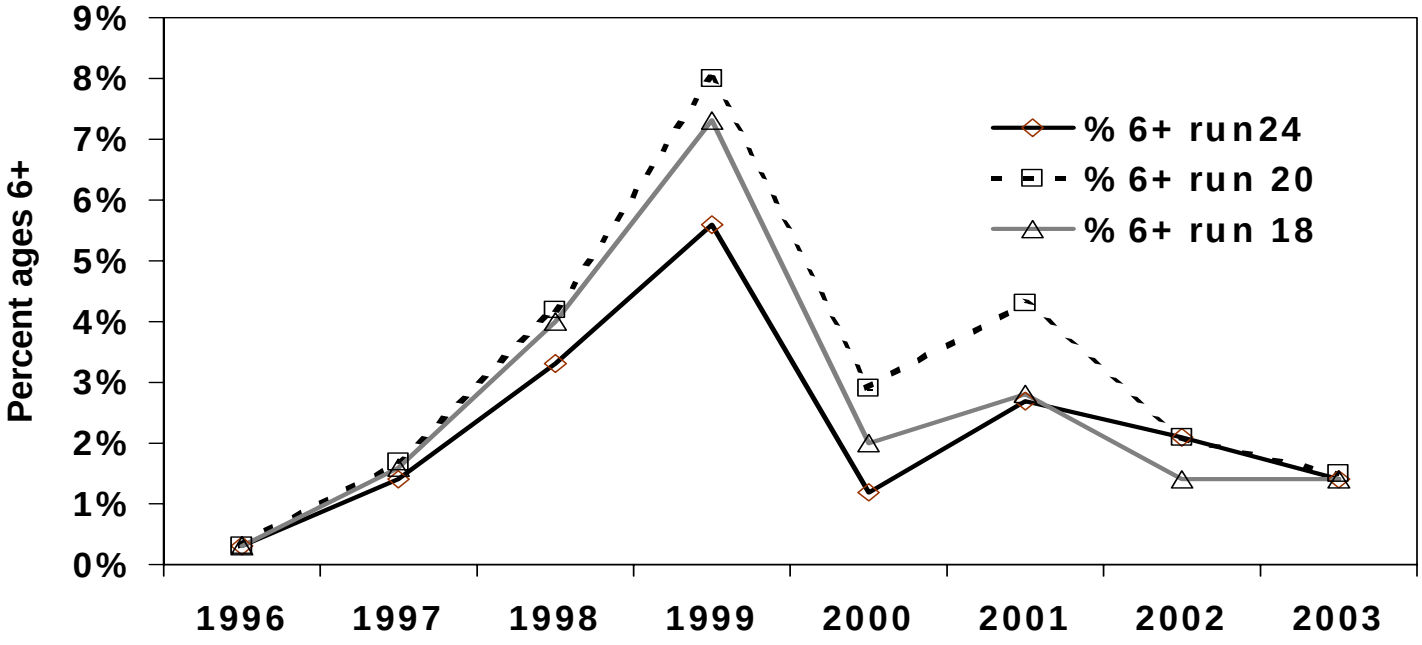


Figure 28. Trawl survey biomass indices (kg/tow of 25 cm + weakfish)

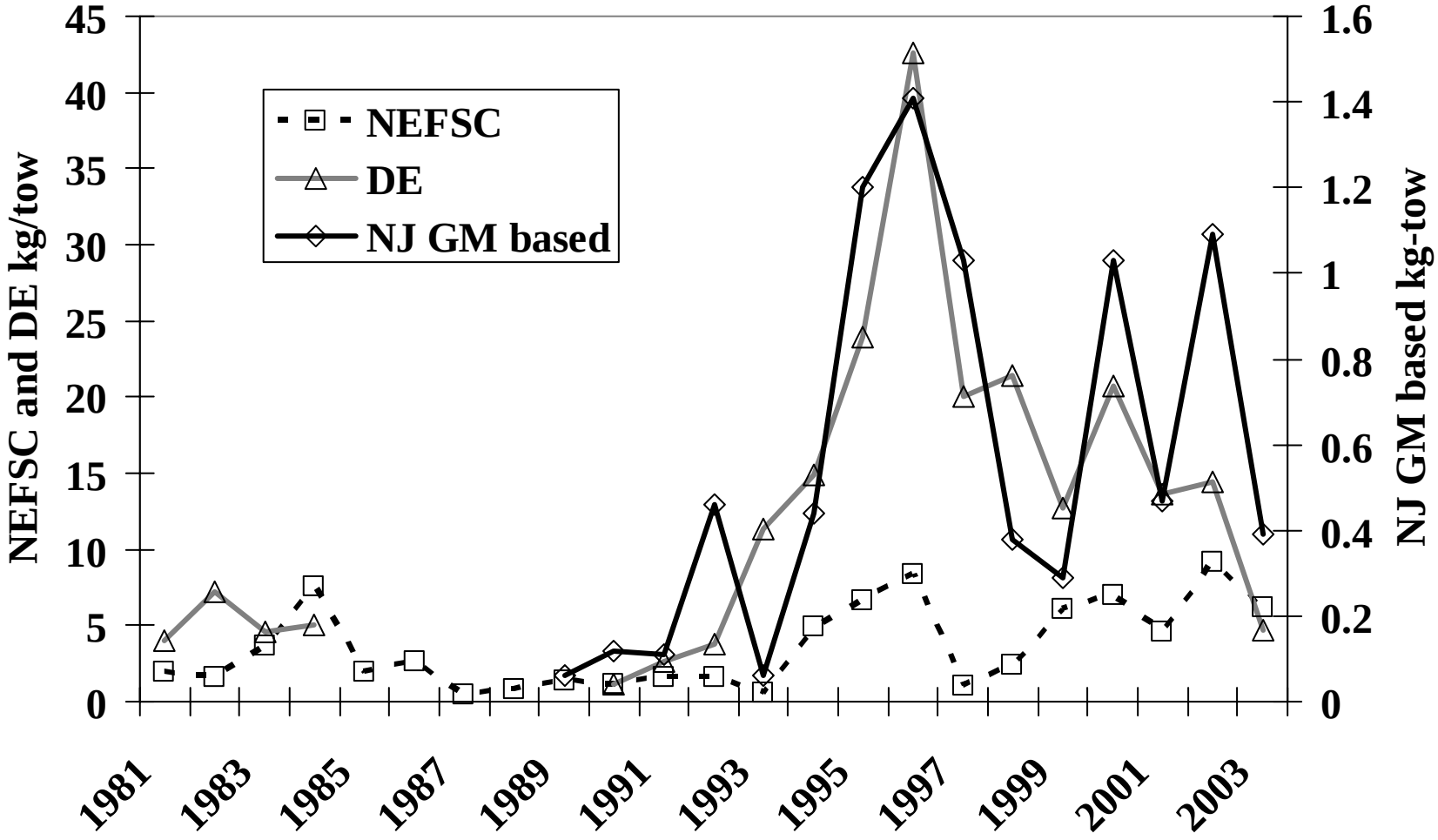


Figure 29. Model results based on trawl survey indices: F and biomass estimates with and without discards

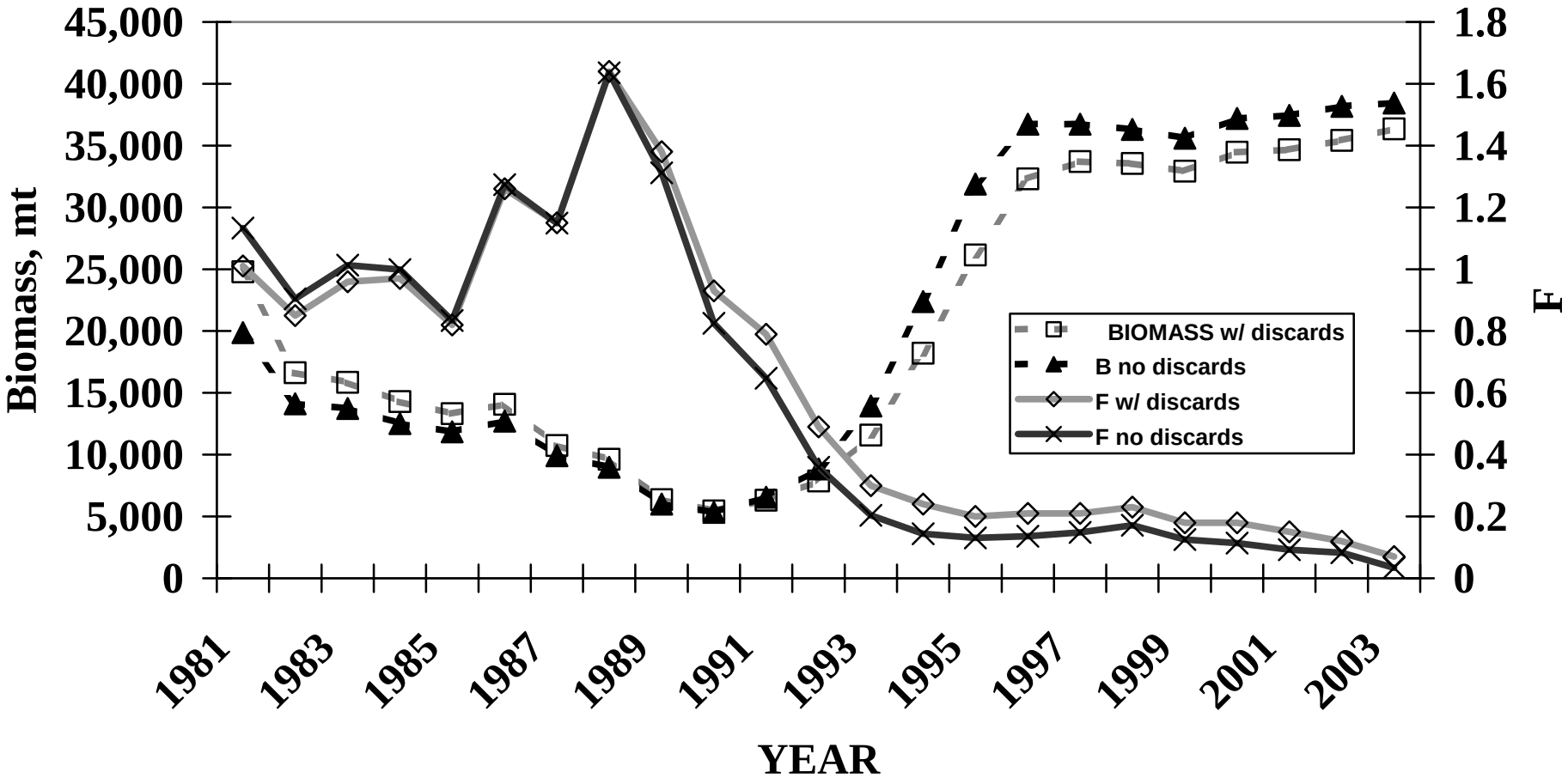


Figure 32. Standardized age 0 weakfish indices. Nj (grand mean) indicates general trend.

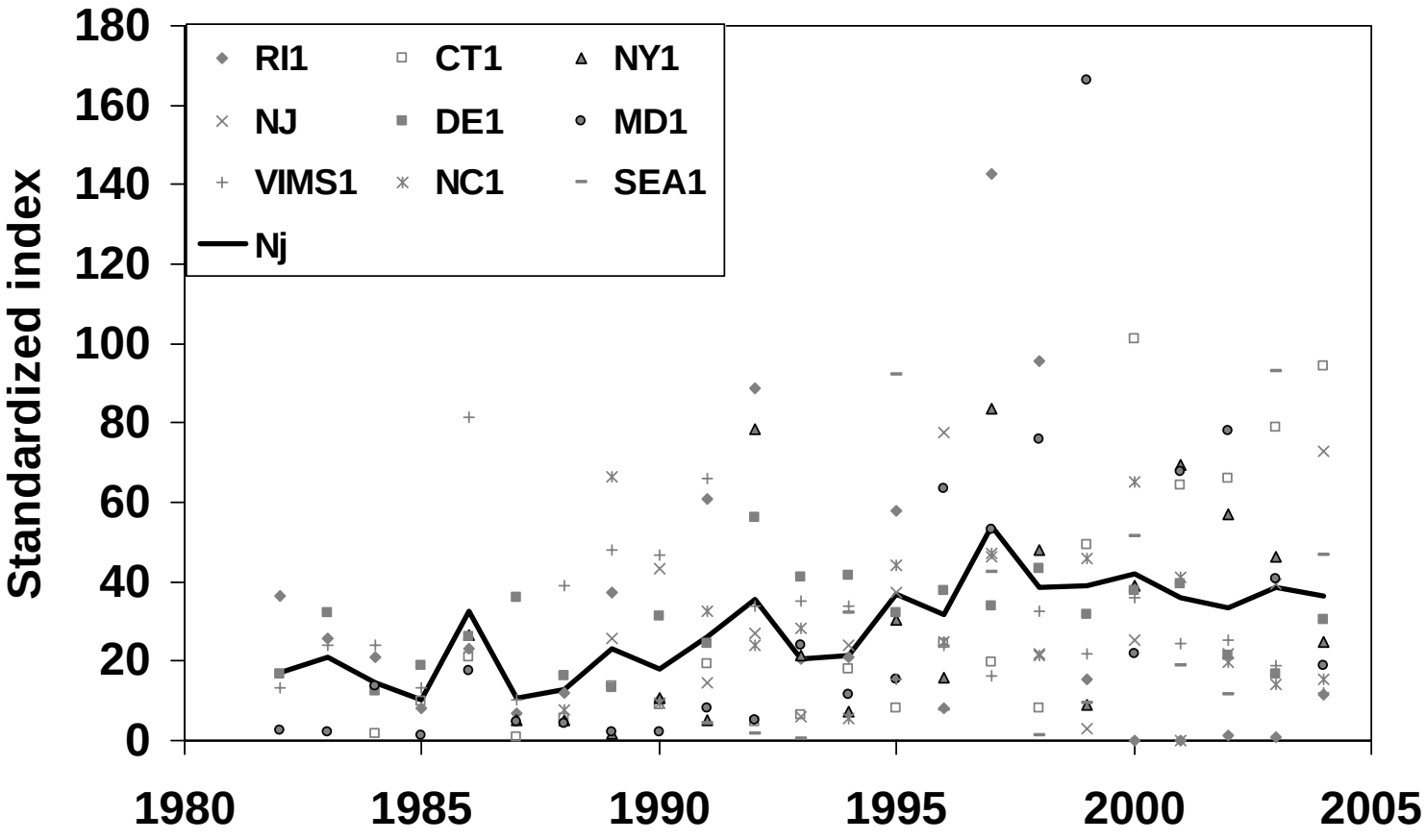


Figure 33. Trends in age 0 (Nj), age 1 (Ny), and age 0-1 total mortality (RZj) indices.

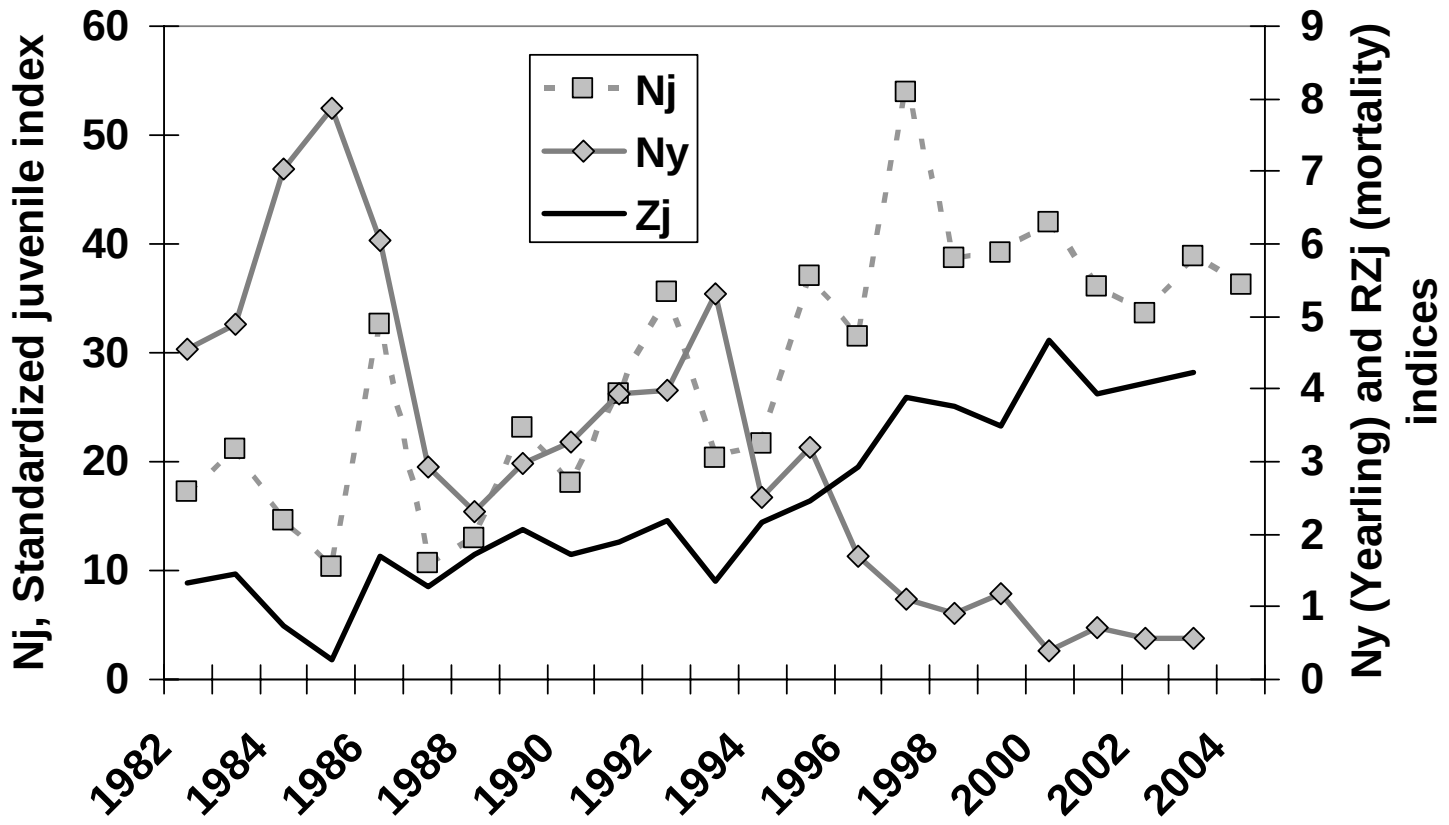


Figure 34. Trends in $M_{Wt.}$

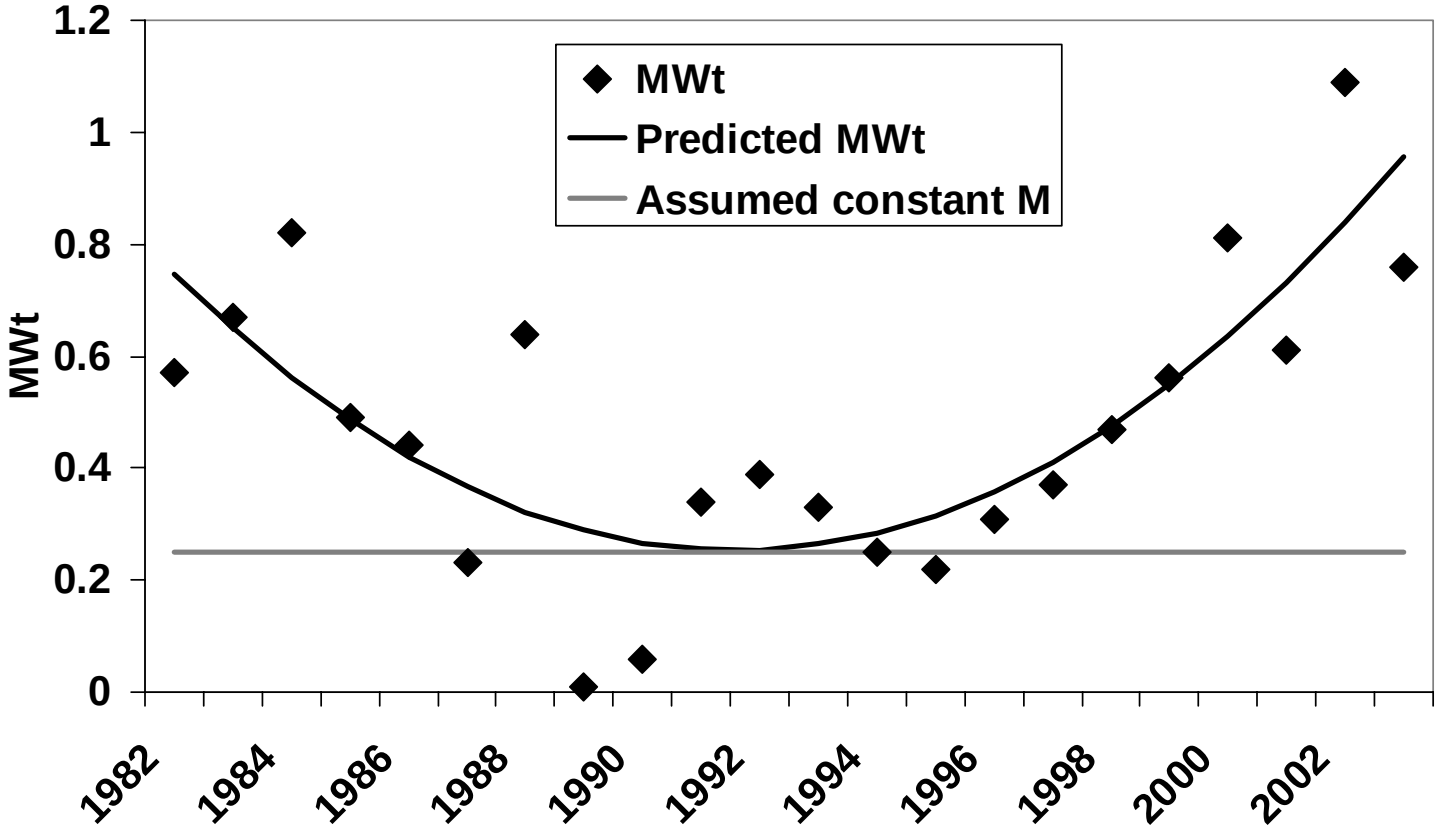


Figure 35. Juvenile weakfish mortality index (units arbitrary) and VPA-based estimates of biomass of ages 8+ striped bass.

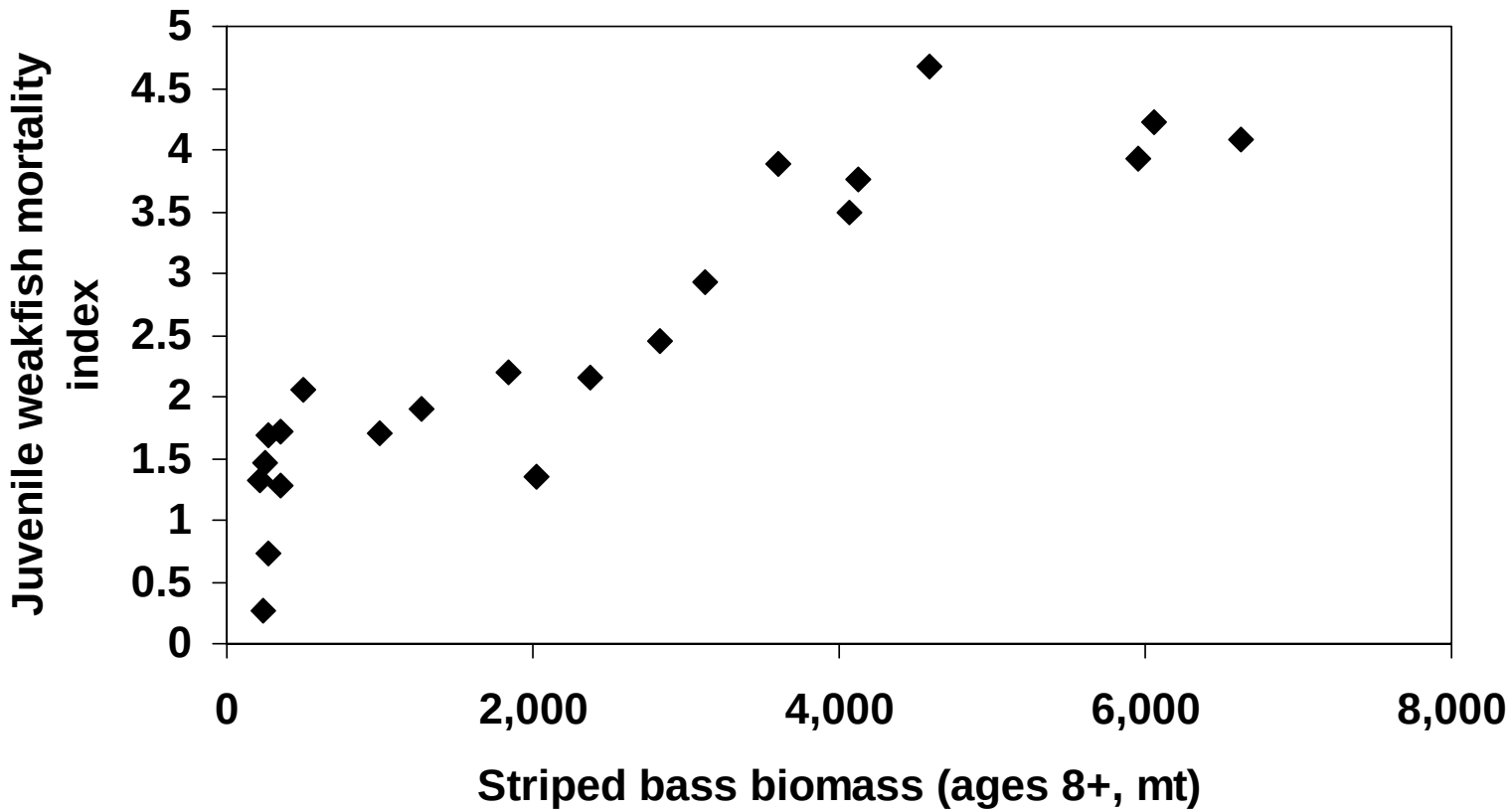


Figure 36. Gompertz striped bass-weakfish predator-prey model estimates of F, F_{msy}, M_p, and M_{vpa}. Model with iterative reweighting was used.

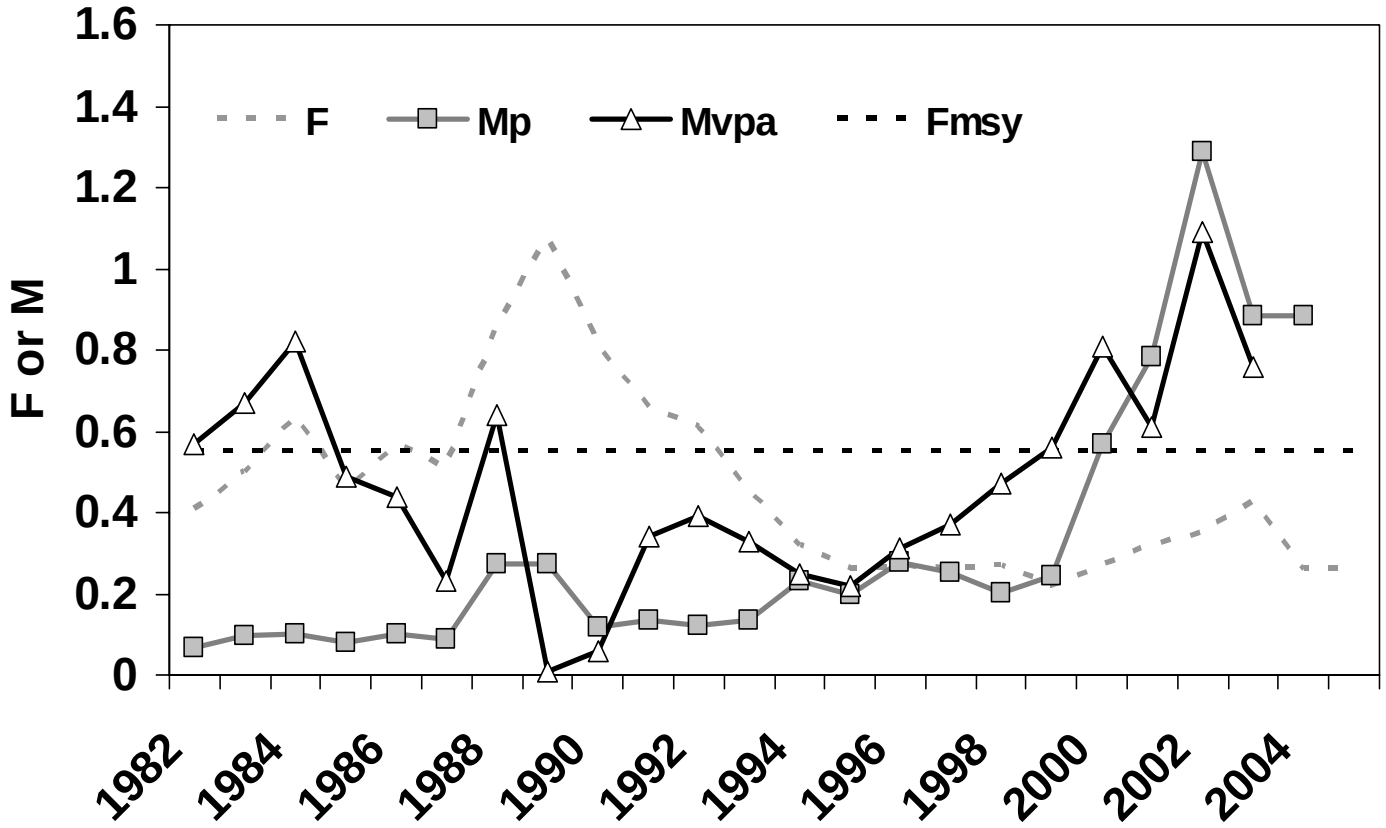


Figure 37. Gompertz surplus production model estimate of weakfish biomass with and without striped bass predation terms. IR indicates iterative reweighting was used in the fitting process.

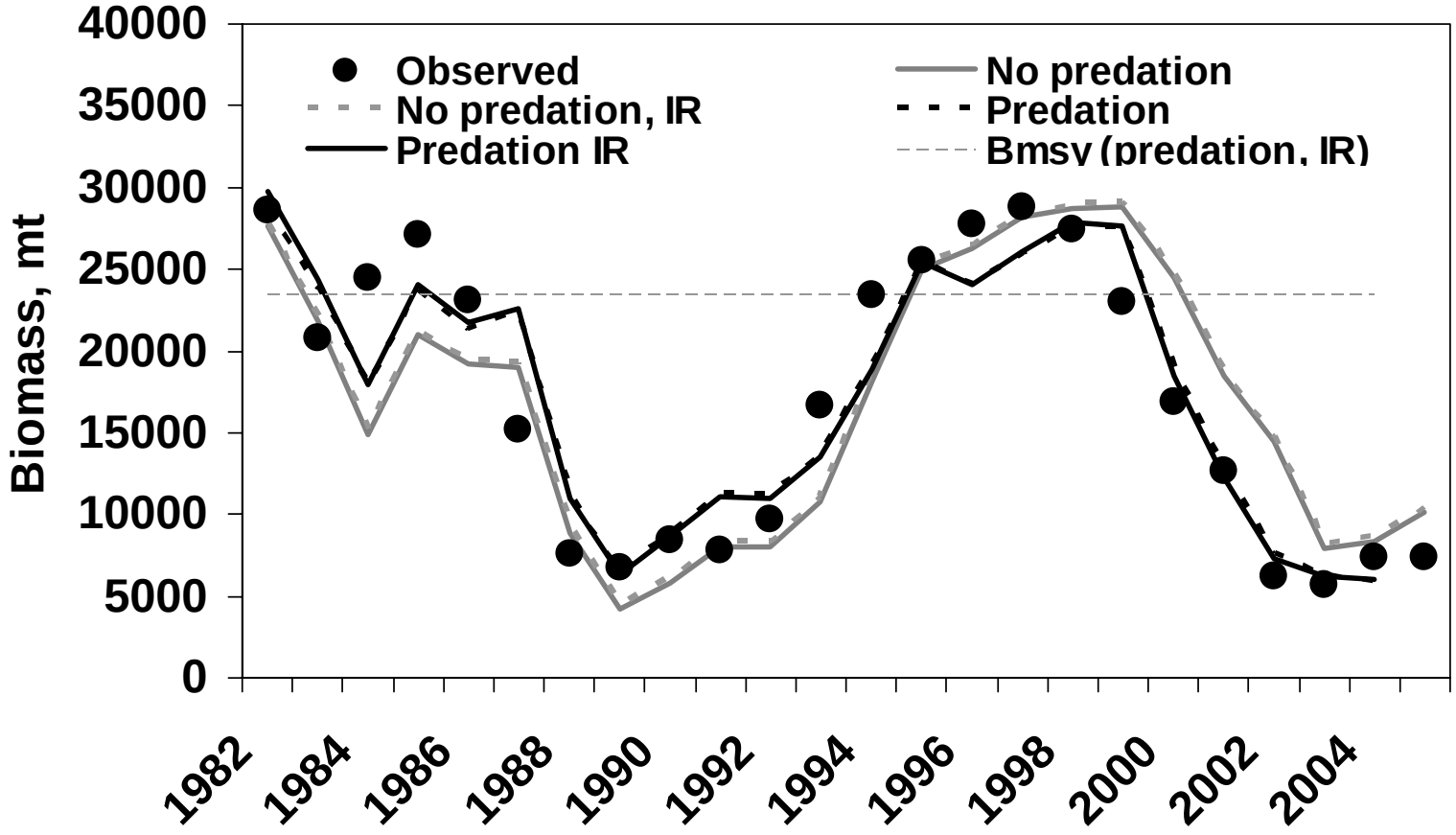


Figure 38. Observed (average biomass; Crecco 2005) and biomass predicted by external production model with varying M and F.

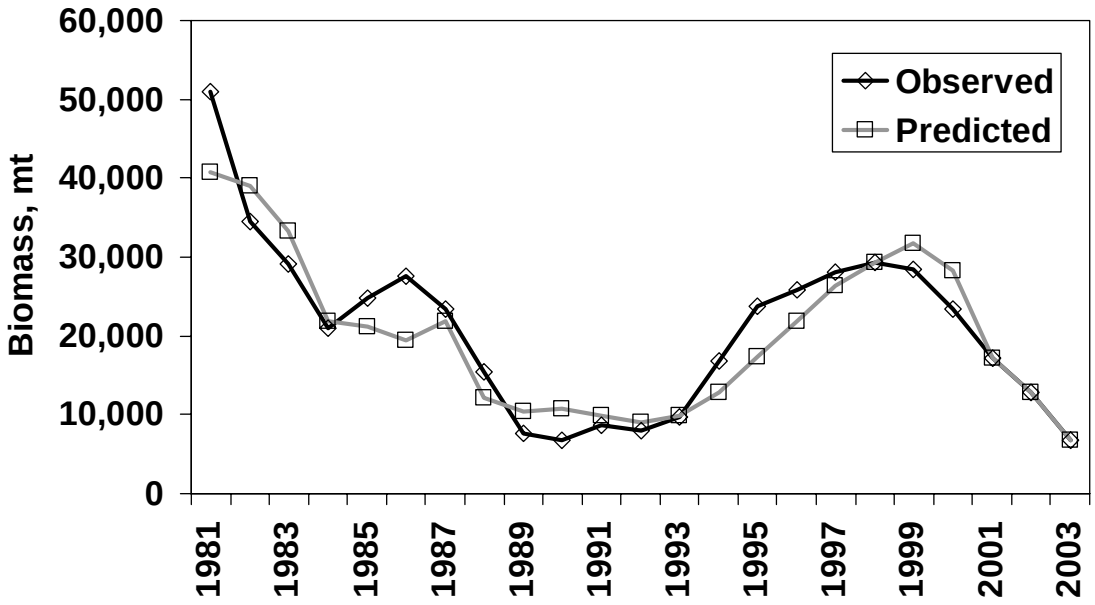


Figure 39. Trends in estimated F and M from external production model without an ecological stability assumption.

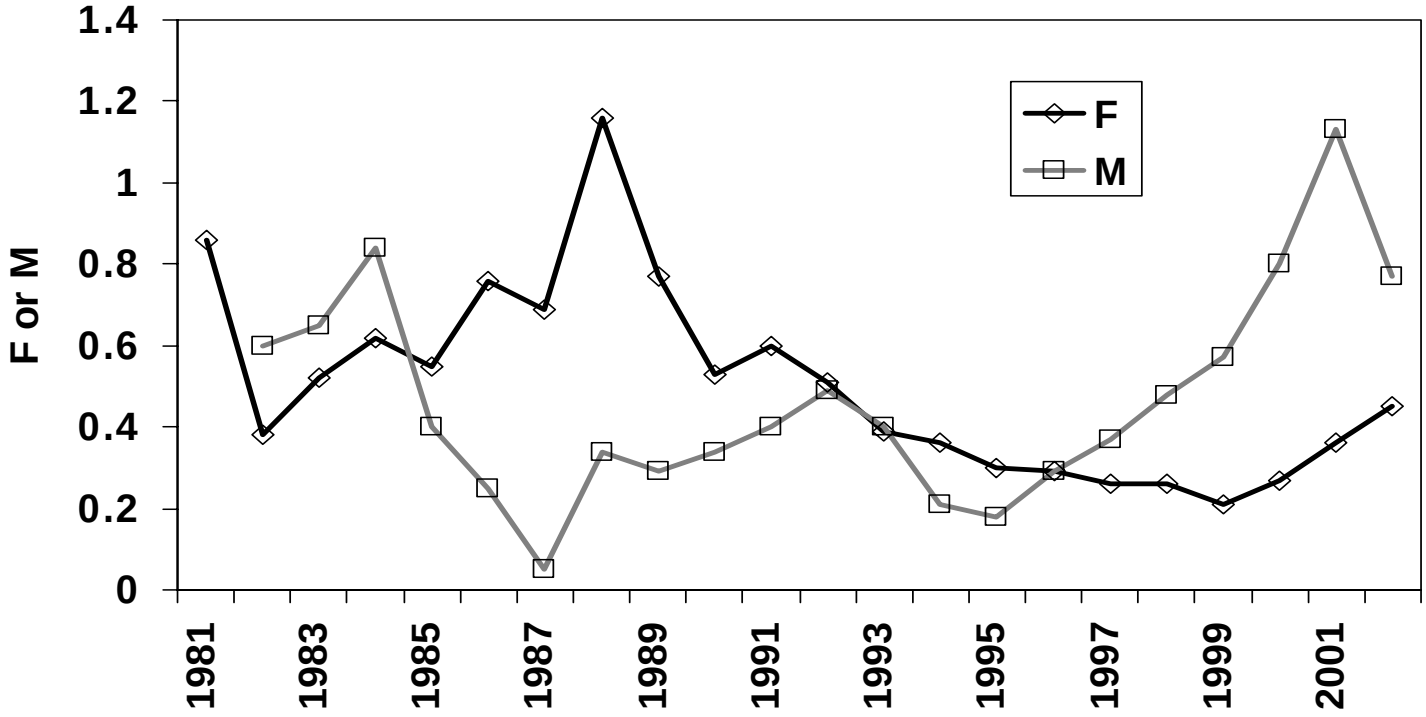


Figure 40. Estimated weakfish biomass during 1981-2003 based on different assumptions. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). See Table 1 for model details. The 3 parameter model is the base model.

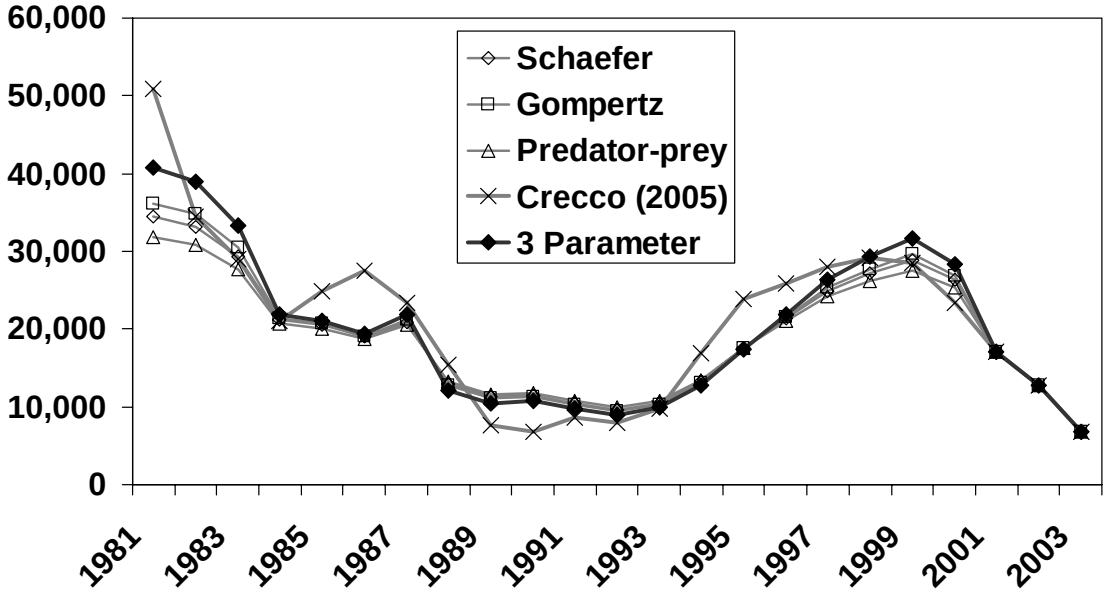


Figure 41. Estimates of F under different model conditions. See Table 1 for model details. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). The 3 parameter model is the base model.

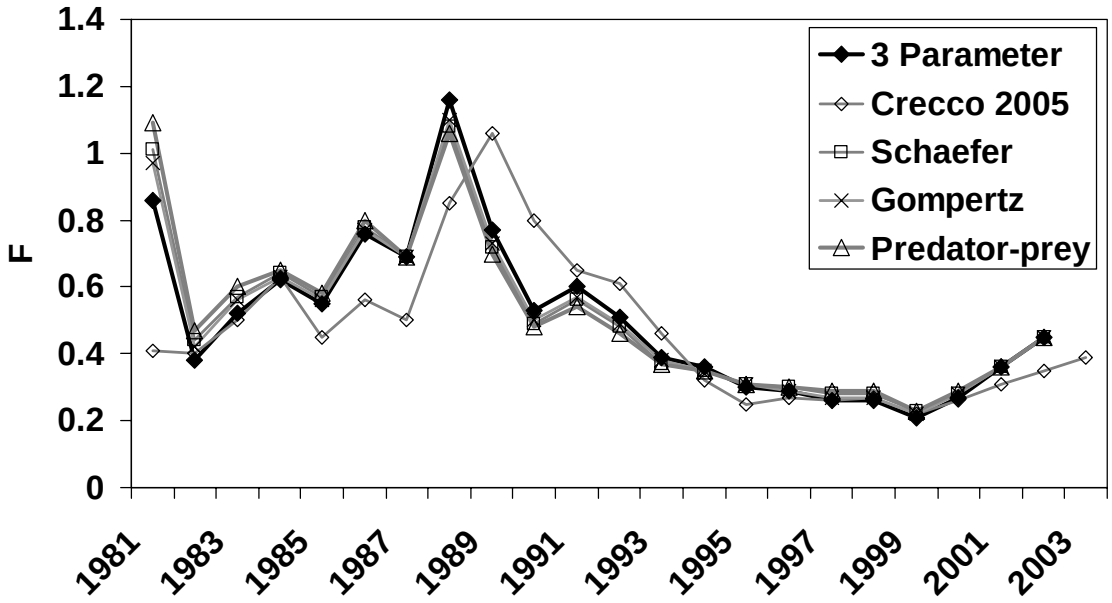


Figure 42. Estimates of M under different model conditions. See Table 1 for model details. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). The 3 parameter model is the base model.

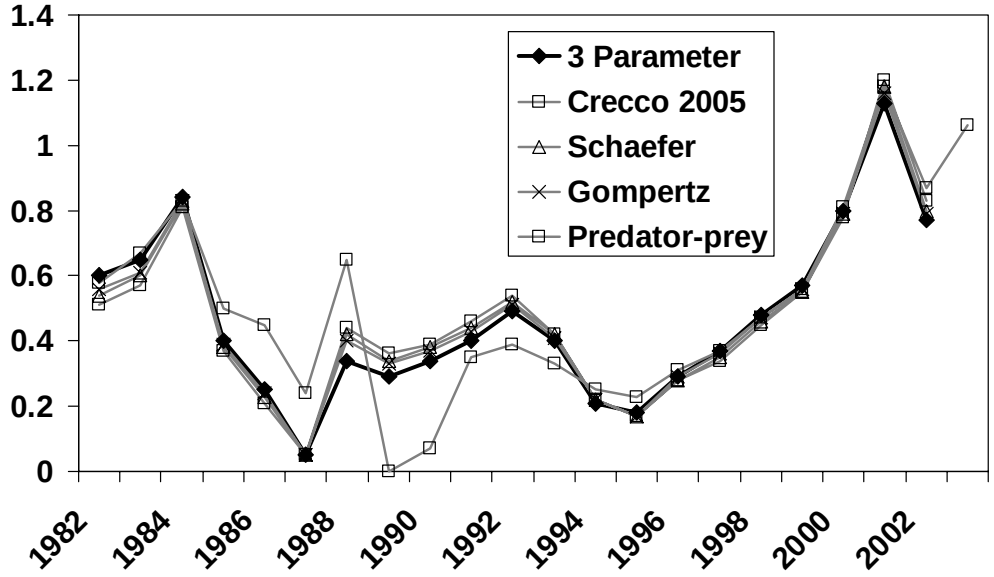


Figure 43. Projected weakfish biomass without a reduction in F (F = current), with F cut by 25%, 50%, and 75%, and a complete moratorium (discard mortality = 0) when M is kept at its current level.

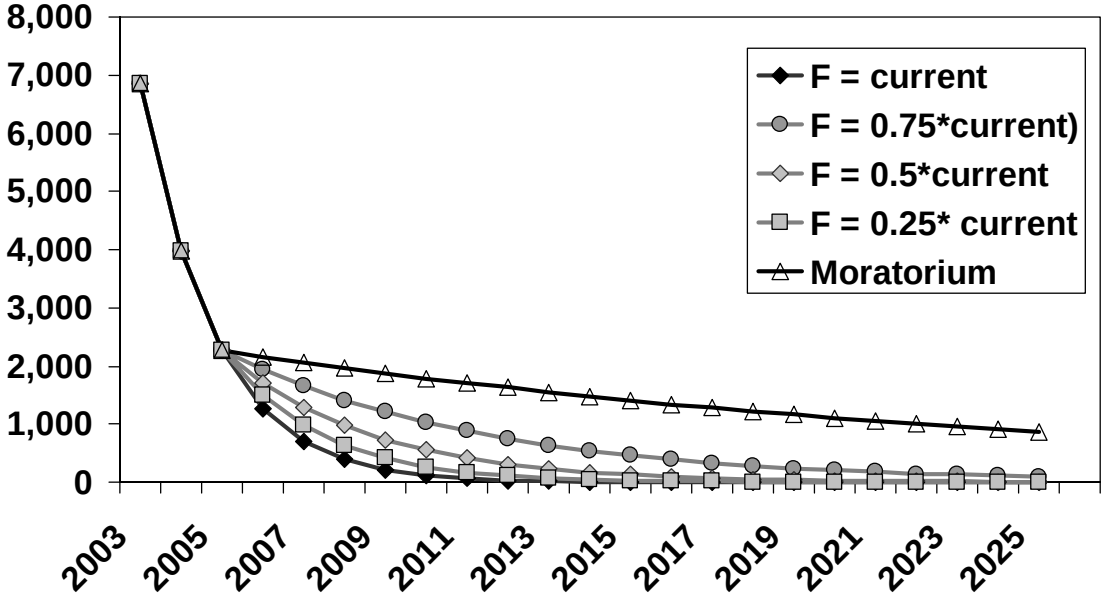


Figure 44. Projected weakfish biomass with reduction in Z equivalent to 1.5 * F or 2.0* F after 2005. See Table 1 for model details. Recovery is indicated at mean 1998-2000 biomass (29,785 mt).

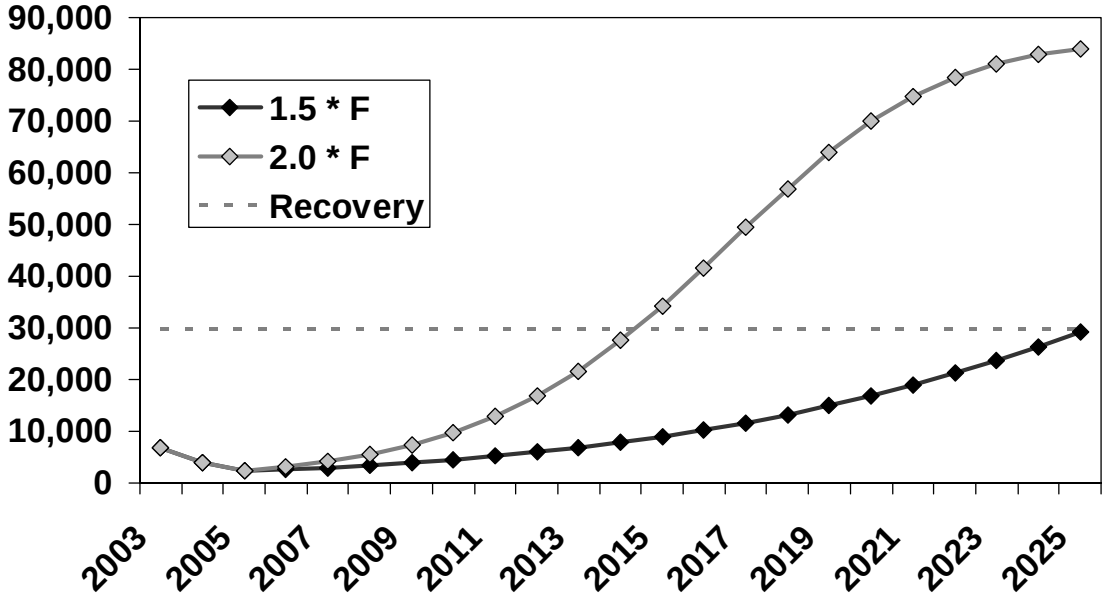


Figure 45. Projected biomass with no reduction in current F or cuts of 25%, 50%, or 75% when M depreciates from 0.95 in 2006 by a constant coefficient (0.8) to a base level (Mb = 0.25). Recovery is indicated at mean 1998-2000 biomass (29,785 mt).

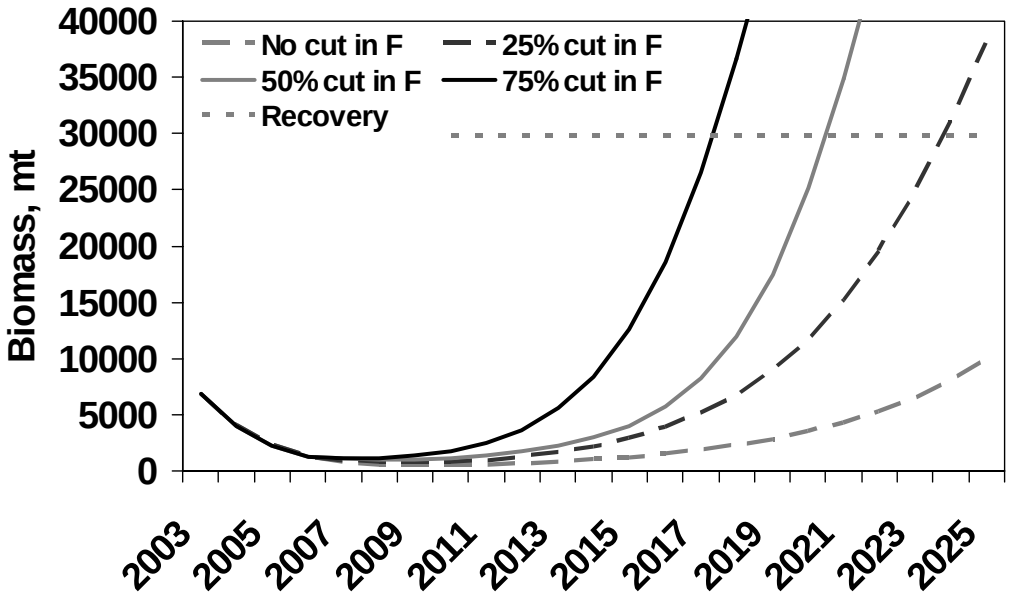
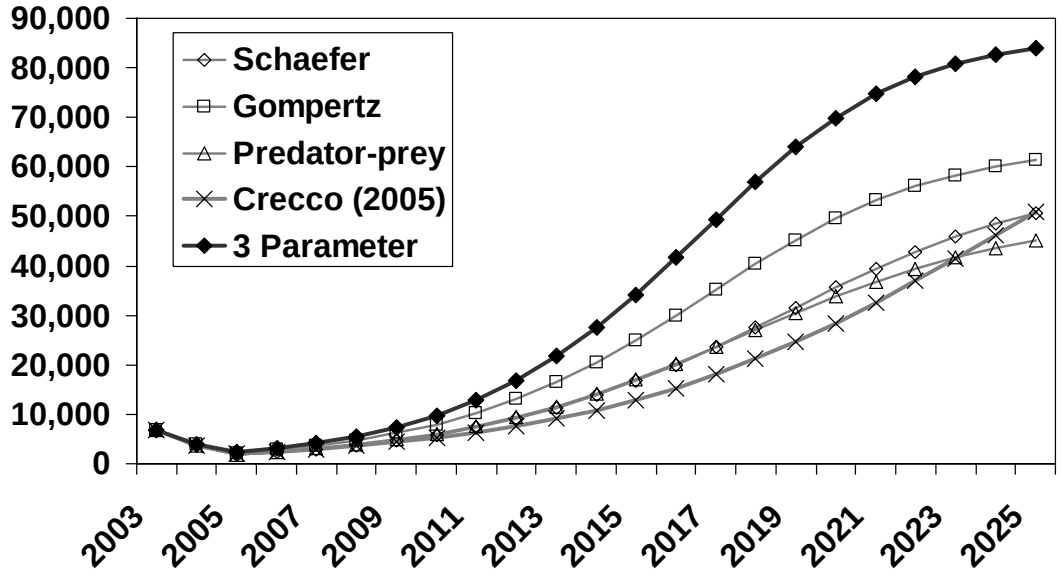


Figure 46. Projected weakfish biomass with reduction in Z equivalent to 2.0 * F. See Table 1 for model details. Recovery occurs in 2016 for the Schaefer, 2014 for Gompertz, 2015 for predator-prey, 2020 for Crecco (2005), and 2014 for the base model.



WEAKFISH STOCK ASSESSMENT REPORT FOR PEER REVIEW (PART 2)

An Ecological Assessment of Weakfish: Examination of Fishing and Trophic Effects on the Recent Stock Decline

February 2006

By

Jim Uphoff
Maryland Department of Natural Resources
Fisheries Service
301 Marine Academy Drive
Stevensville, MD 21666
juphoff@dnr.state.md.us

Note: an external peer review panel did not endorse the recommendations within this assessment report. For more information see the Peer Review Report (Section B), and the Weakfish Technical Committee's responses to that report (Section C).

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INTRODUCTION

Weakfish fisheries were subject to increasingly restrictive management during the early and mid-1990s (ASMFC 2002). After imposition of Amendment 3 in 1996, weakfish were thought to be on the path to recovery. Recent recreational and commercial landings of weakfish along the Atlantic Coast approached all-time lows as population estimates derived from age structured (de Silva 2002; Kahn 2002a) or biomass dynamic models (Uphoff 2005a) reached all-time highs. This increasing dichotomy between weakfish stock assessment results and fishery performance has lead the Weakfish Technical Committee to re-examine the basic survey data used and to consider external factors that lie outside of the purview of traditional assessments. One of the recommendations of the 40th Stock Assessment Review Committee (or SARC) examination of our preliminary assessment was for the Weakfish Stock Assessment Subcommittee (WSAS) to formulate multiple hypotheses about stock status and evaluate them with empirical data, an approach advocated by Sainsbury (1998) as part of a new paradigm for stock assessment in the 21st century.

A great preponderance of evidence indicates that weakfish abundance and surplus production have declined to low levels (Crecco 2005a or b; Weakfish Stock Assessment Report Part 1 or Part 1). The most reliable estimates of trends or values of F during 1981-2003 have indicated it has been modest since at least 1995 (Part 1). This has lead to the formulation of a hypothesis that the most likely cause of declining weakfish fortune is increased natural mortality (Part 1).

We specifically addressed the hypothesis that M has been changing for weakfish and that it is the primary driver behind the recent crash. At this stage, an increase in M in recent years is a default postulate reflecting the difficulty in finding evidence of increasing F other than by adhering dogmatically to the notion that M is constant for weakfish at 0.25. We investigated hypotheses that weakfish biomass dynamics, growth, and survival were negatively affected by striped bass competition and predation exacerbated by depleted forage (hereafter, predation hypothesis). In particular, this is an alternative, nonfishing mortality hypothesis explaining an aborted weakfish recovery. We conducted an analysis on a portion of the food web (weakfish, its primary fish competitor, and three forage fish species) along the mid-Atlantic region (New York-North Carolina) that constitutes the "core area" for weakfish stock assessment (Northeast Fisheries Science Center 2000). We also addressed the potential for other candidate predator-competitors to contribute to the recent decline of weakfish.

We undertook statistical explorations of the inter-relationship of weakfish, striped bass (weakfish's primary competitor and potential predator), four other potential predator-competitors (summer flounder, bluefish, spiny dogfish, and Atlantic croaker), two main forage species for piscivores along the mid-Atlantic (bay anchovy and Atlantic menhaden) and a forage species of demonstrated importance within Chesapeake Bay but possibly more limited importance elsewhere (spot; Mercer 1985; Taylor 1987; Hartman and Brandt 1995; Hartman 2003; Walter et al. 2003). Weakfish have been specifically identified as a minor food item in some, but not all, striped bass diet studies in the mid-Atlantic region (Manooch 1973; Austin and Walter 1998). In the mid-Atlantic region, bay anchovy represent the prey most consumed by these species as they initiate piscivory, but both predators switch predominately to similar, larger prey (clupeids, primarily Atlantic menhaden) within a year (Mercer 1985; Taylor 1987; Hartman and Brandt

1995). Juvenile menhaden and spot are most relevant to younger, smaller weakfish making the transition through piscivory because piscivorous fishes are size selective and gape limited, and typically select prey that are 20-30% of their length (Stein et al. 1988; Juanes 1994). Stakeholders, Weakfish Management Board members, and other biologists have suggested that Atlantic croaker, summer flounder, bluefish, and spiny dogfish may be potential predator-competitor candidates for explaining the decline in weakfish. Each of these species inhabits mid- and north Atlantic waters where concerns about the depletion of weakfish are greatest.

Weakfish and striped bass make an early switch to a fish diet (age 0 for weakfish and age 1 for striped bass; Mercer 1985; Hartman and Brandt 1995; Hartman 2003; Walter et al. 2003). This early switch to a fish diet indicates that both species are specialized piscivores (Persson and Bronmark 2002). Early switching requires high growth rate, which implies high densities of proper forage and safe foraging opportunities. If unfavorable conditions prevail, growth is reduced, and vulnerability to competitors and predators is increased. Population densities of specialists are generally a result of their success in a feeding stage where they experience intense competition (Persson and Bronmark 2002). Species undergoing ontogenetic diet shifts face a risk of delayed transitions among feeding stages if food resources are limited and competition is intense. Such ontogenetic bottlenecks are common in piscivorous fishes because competition may retard growth and prevent size advantage necessary to feed on the larger prey in the next stage. Individuals not reaching size advantage over prey may become stunted at size where consumption balances metabolic requirements (Bax 1998; Persson and Bronmark 2002).

Empirical models can be used to detect potentially important patterns of fish predation and may provide insight into processes that may be responsible for patterns described in the analysis (Whipple et al. 2000). We explored whether shifts in weakfish landings growth, natural mortality, and distribution (or their proxies) coincided with forage abundance and striped bass biomass using correlation and regression analyses, inferring competition for forage if test results were logical and statistically significant. This approach provided a bridge between the common assumption that predation and competition imposes a constant rate of mortality allowing the stock to be assessed in isolation from its environment (single species assessment; Bax 1998; Sainsbury 1998) and the more complex process-based multispecies models (Whipple et al. 2000).

Abundances of many exploited fish stocks vary widely and these variations may not be explained with single species population models (Spencer 1997). There is increasing evidence that concurrent changes multiple stocks occur at longer time-scales (Steele 1996). Often environmental factors are sought as underlying causes for changes in status, but sustained periods of high and low abundance are often exhibited by fish populations that are much more dramatic than shifts in climate or other environmental factors (Steele and Henderson 1984). These shifts can be regarded as jumps between alternative equilibrium states of ecological systems (Steele and Henderson 1984). The term “regime shift” has been used to suggest these changes are causally connected and can be linked to other changes in an ecosystem (Steele 1996). There is an assumption that environmental factors are the underlying mechanism with fishing as a contributing element (Steele 1996). Continuous changes in intrinsic population growth rate, carrying capacity, F, or rate of predation can lead to “flips” into periods of high or low abundance (Spencer and Collie 1995). A classical logistic population growth formula

combined with an S-shaped predation function reproduces these fluctuations when subjected to simulated directional environmental fluctuations or changes in fishing pressure (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1997a).

We applied the predator-prey model of Steele and Henderson (1984) to examine relative effects of fishing and striped bass predation and competition on recent (1981-2003) weakfish dynamics. We interpreted the "effect" of striped bass to potentially include collateral damage to weakfish such as starvation and cannibalism due to competition, as well as direct consumption by striped bass.

When applied generally, this predator-prey model has reproduced the types of rapid shifts in abundance exhibited by marine populations and it was useful in exploring the role of dogfish predation on Georges Bank haddock recovery and management (Spencer and Collie 1995; 1997b). This predator-prey model is essentially a Schaefer biomass dynamic model with a sigmoidal type III predation function added to estimate additional predation losses (Collie and Spencer 1993). In this analysis, it provided estimates of M and F that quantified the extent that striped bass, other candidate predator-competitors species, and fishing mortality could be influencing weakfish.

METHODS

Data Sources for Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings as Stock Size Indicators

Commercial landings (1950-2003) of striped bass and weakfish were obtained from the National Marine Fisheries Service's website (www.st.nmfs.gov/st1/). These data (Figure 1) represented the longest time-series readily available for both species that could be used to look for changes on decadal time-scales.

We used weakfish recreational catch rates (private/rental harvest and releases per trip in mid-Atlantic state waters based on all trips) as an indicator of stock biomass (Crecco 2006). Recreational catch per effort indices (WRI) were available for 1981-2003. Weakfish 25 cm FL and larger weakfish have constituted the bulk of weakfish measured by the MRFSS. Brust (2004) determine a MRFSS directed trip index of weakfish catch (harvest and releases) per trip when effort was limited to weakfish plus a suite of five species (summer flounder, Atlantic croaker, spot, bluefish, and black sea bass) considered to be commonly associated with weakfish. This index was very closely correlated (Pearson $r = 0.96$, $P < 0.0001$) with the more general WRI (Crecco 2005b), so it was not considered further in analyses.

Delaware and New Jersey trawl survey exploitable biomass indices (Z-transformed with one added for plots; Uphoff 2005a; Part 1) were used as additional indicators of weakfish stock biomass. Larger sizes of weakfish present in WRI were present in these surveys (Uphoff 2004). A third trawl survey, the Northeast Fisheries Science Center fall survey was not considered because exploitable-sized weakfish were not well represented (Uphoff 2004) and because of concerns about high inter-annual variability expressed by reviewers at the 40th SARC.

We examined whether catchability (q) of WRI, DE, and NJ indices was proportional to stock biomass. Each annual biomass index was divided by converged VPA biomass estimates (1982-1993 were considered converged) to estimate q. These estimates of q were plotted against converged biomass. Correlation analysis was used to describe associations of WRI, and DE and NJ trawl indices.

Weakfish weight at age data consisted of estimates for 1982-2003 from the VPA catch-at-age matrix. Trends in ages 1-5 were examined; older ages aggregated into an age 6+ group were not used because of possible bias from different age compositions. Scale ages had been converted to otolith ages for the early half of the matrix (NEFSC 1998).

We used the quality+ proportional stock density index (DE PSD Q+) derived from the Delaware trawl survey to summarize long-term 1966-2003 length-frequency data (Uphoff 2004; Part 1). The Delaware trawl survey time-series was not continuous (1966-1971, 1979-1984, and 1990-2003). The Delaware Quality+ PSD (DE PSD Q+) equaled the proportion of weakfish greater than or equal to 210 mm that were 340 mm or larger. The DE PSD Q+ index was significantly and positively associated with recreational fishing quality (trophy citations) over a broad area (DE, MD, and VA), commercial and recreational yield along the Atlantic Coast, WRI, and the proportion of recreational harvest outside of 3 miles (Uphoff 2004; Part 1).

The annual sum of ADAPT VPA biomass estimates for 2 year-old and older striped bass were used as competitor biomass during 1982-2003 (A. Sharov, MDDNR, personal communication; Uphoff 2003). The average of age 2+ striped bass biomass estimates for 1982-1986 was used as an estimate for 1981 (6,236 mt). Atlantic menhaden dominated diets of striped bass age 2 and greater in the early 1990s in upper Chesapeake Bay (Hartman and Brandt 1995) and were one of the dominant food items along the Atlantic coast (Walter et al. 2003; Nelson et al. 2003). Striped bass of this size would also be important predators of spot (Hartman and Brandt 1995) and would be capable of consuming weakfish.

Striped bass egg-presence absence in Chesapeake Bay spawning rivers (proportion of plankton tows with striped bass eggs; hereafter the large bass biomass index or LBI) was used as a long-term index of biomass (1955-2003; Uphoff 1997). Egg presence-absence scaled relative biomass between 0 and 1. This index tracks biomass of mature spawning females, generally bass 6 years-old or older, but was assumed to be a general indicator of stock biomass.

Indices of Atlantic menhaden, spot, and bay anchovy relative abundance were obtained from agencies in NC, VA, MD, DE, and NJ. Survey locations, gears, time-series duration, estimator of central tendency reported, data source, and which of the three forage species was surveyed were summarized in Table 1. In one case (Atlantic menhaden in Ablemarle Sound), two estimators of central tendency were used. All forage indices were z-transformed to place them on the same scale and split into two regions (NC-MD or DE and NJ) for graphic presentation.

Age 0 abundance estimates of Atlantic menhaden along the Atlantic Coast were available for 1955-2002 (ASMFC 2004a). A long-term juvenile menhaden time-series (1959-2003 proportion of seine hauls in Maryland's portion of Chesapeake Bay; Table 1; Uphoff 2003) was substituted for age 0 abundance estimates in some analyses. The menhaden juvenile index and juvenile abundance estimates are significantly related ($r^2 = 0.67$, $P < 0.001$), but the MD index indicated substantially higher relative abundance of juveniles in the 1970s and 1980s than the abundance estimates. Coastal abundance estimates of our other forage species did not exist, so we could not determine whether they might be applied broadly as we did with the MD juvenile menhaden index.

Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings as Stock Size Indicators

Statistical analyses featured either weakfish commercial landings (1950-2003), DE PSD Q+ (1966-2003, discontinuous time-series), DE and NJ trawl survey indices, or WRI (1981-2003) as dependent variables. Estimates of absolute stock size based on single species stock assessment models were not used for statistical analysis because assumptions of constant natural mortality (VPA) and ecological stability (biomass dynamic models) were necessary to derive these estimates (Mertz and Meyers 1997; Spencer and Collie 1997b). Scatter plots of all bivariate analyses were examined for linear or nonlinear associations or relationships. Ecological systems are highly nonlinear and it was likely that the dynamics of interest might not be reasonably approximated as linear functions (Sainsbury 1998). Functional responses of predators are often nonlinear and time lags in the response of predators to prey and vice versa would be likely (Bax 1998). Natural log transformations were used to induce linearity in some cases.

Correlation analysis was used to empirically explore associations. Level of significance was adjusted for multiple comparisons by dividing $P = 0.10$ by the number of comparisons made for each species. Regressions and correlations were considered significant at $P \leq 0.10$. Residuals were examined for normality and serial trends.

Weakfish landings were plotted against striped bass landings, with each decade (starting in 1950) illustrated by a different symbol; landings from 2000-2003 were included with the 1990s. This differentiation of decades allowed examination of whether the 1970s and 1980s had a different or shifted relationship than the remaining decades. This plot allowed for development of an analytical strategy for examining the hypotheses that (1) striped bass and weakfish landings were negatively related and (2) a shift over decadal time scales was present in the landings data.

We used categorical regression to evaluate these hypotheses. The different decadal groups were coded as 0 (low period; 1960-1969 and 1990-2003) and 1 (high period; 1970-1989) and used with landings as independent variables in a multiple regression (Neter and Wasserman 1974). This test assumed that the slopes of the weakfish and striped bass landings were equal, but intercepts (decades) were different (Neter and Wasserman 1974).

Stepwise multiple regression analysis was used to test the relationship of ln-transformed weakfish landings to ln-transformed menhaden abundance or the Maryland juvenile menhaden

index and LBI. Partial correlation coefficients were calculated to judge the contribution of each variable to model fit (Ott 1997).

We used correlation analysis to explore associations of DE PSD Q+ and available forage fish (Atlantic menhaden, spot, and bay anchovy) relative abundance indices along the mid-Atlantic. The long-term association (1966-2003) of weakfish size quality and striped bass biomass was examined by correlating weakfish DE PSD Q+ and LBI. The short-term (1982-2003) association of weakfish DE PSD Q+ and age 2+ striped bass biomass was also explored with correlation analysis. We developed a multiple regression model of DE PSD Q+ against LBI and Atlantic Coast age 0 menhaden abundance to test the hypothesis that both this predator/competitor and important forage species influenced the size dynamics of weakfish during 1966-2002. In general, forage species were expected to have positive associations or relationships with weakfish DE PSD Q+ and striped bass were expected to have been negatively associated or related.

Weakfish abundance along the Atlantic Coast during 1981-2003, indexed by WRI or the standardized (z-transformation) DE and NJ trawl surveys, were plotted against age 2+ striped bass biomass. Statistical descriptions of these data were not attempted after viewing the complex relationships exhibited in the plots.

Time Varying Natural Mortality from VPA

Standard output from the ADAPT VPA includes biomass weighted fishing mortality rates of ages 1+ weakfish (F_{vpa}) from 1982 to 2003 (Part 1; Crecco 2006; 2005a). As a result, biomass weighted total mortality (Z_{vpa}) rates from 1982 to 2003 were easily derived by adding 0.25 to each of the aggregated F_{vpa} values from VPA run 20 (MRFSS recreational CPUE as the sole tuning index). The WSAS chose run 20 as the preferred VPA model run. The degree of retrospective bias in recent F_{vpa} and weakfish stock size estimates from run 20 was much less extensive that the bias for other model runs that were tuned by either trawl survey indices alone, or a combination of trawl survey and MRFSS indices (D. Kahn, DEDFW, personal communication). Note that rescaled F analysis (Crecco 2005a) estimated biomass weighted F of the same ages encompassed in Z_{vpa}, but independently from the VPA (Crecco 2006). As a result, a time-series of biomass weighted natural mortality rates (M_{vpa}) of ages 1+ weakfish were calculated for each year t from 1982 to 2003 by

$$(5)\quad M_{vpat} = Z_{vpat} - F_{RFAt};$$

where F_{RFAt} is the rescaled F estimate and Z_{vpat} total mortality estimate based on VPA run 20.

Striped Bass-Weakfish Predator-Prey Modeling

WRI during 1981-2003 was used as an index of relative abundance for analyses with the Steele and Henderson (1984) model (Table 2). Landings during 1981-2003 included both directed harvest and discards by the recreational and commercial fisheries (Crecco 2005; Part 1). Biomass estimates for 2 year-old and older striped bass were used as predator-competitor biomass during 1981-2003 (Table 2).

We used a spreadsheet version of a Schaefer (logistic) biomass dynamic model formulated by Haddon (2001) and added the type III predation function to it (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1995). The predator-prey model used the following discrete time-step equation:

$$(6)\ B_t = B_{t-1} + rB_{t-1}\ (1-(B_{t-1} / K)) - H_{t-1} - [(cP_{t-1}(B_{t-1})^2)/(A^2+(B_{t-1})^2)] + \varepsilon;$$

where B_t was weakfish biomass in year t; B_{t-1} = biomass the previous year, r = intrinsic rate of population increase; K = maximum population biomass; H_{t-1} = harvest (commercial and recreational, including discard estimates) in the previous year; maximum c is per capita consumption by predator (striped bass) biomass (P_{t-1}); A is weakfish biomass where predator satiation begins; and ε is measurement error (Hilborn and Walters 1992: Collie and Spencer 1993; Spencer and Collie 1995). The Haddon (2001) spreadsheet version of the logistic model was easy to adapt to this predator-prey formulation because it estimated weakfish biomass as a first step and then estimated catchability (q) as B_t/WRI_t (Haddon 2001). Estimating weakfish biomass first allowed striped bass biomass to be used directly and parameter A to be estimated directly rather than converting them to weakfish index equivalents. The mean of the estimates of q_t (q_{mean}) was used to predict WRI_t as $B_t * q_{mean}$. Biomass was estimated directly for 1981 (B_{1981}) and then the model estimated subsequent years (Haddon 2001).

Standard Schaefer model equilibrium biological reference points (BRPs), F_{msy} (r/2) and B_{msy} (K/2) were estimated (Haddon 2001). In providing guidance on precautionary approach BRPs to the National Marine Fisheries Service, Restrepo et al. (1998) recommended F_{msy} and B_{msy} as limit reference points. F_{msy} constituted the threshold over which overfishing was occurring and B_{msy} determined the stock size below which the stock would be considered overfished (Restrepo et al. 1998). BRPs adopted for weakfish management under Amendment 4 (ASMFC 2002) were $F_{30\%}$ as a target F (0.31), $F_{20\%}$ (0.5) as a limit BRP, and 20% SSB of unfished stock size (14,400 mt) as a threshold. These reference points were dependent on an age-structured stock assessment and could not be used in comparisons with production model-based BRPs, therefore F_{msy} and B_{msy} were substituted.

An observation error model was used that assumed all residual errors were in the index observations and the equation used to describe the time-series was deterministic and without error (Haddon 2001). A genetic algorithm super solver (Evolver, Palisade Corporation) was used to estimate predator-prey model parameters that minimized observation error (observed ln WRI_t - predicted ln $WRI_t)^2$ (Haddon 2001). The spreadsheet version of the model combined with the genetic algorithm provided a great deal of flexibility for trying different model variations. Residuals were examined to see if they were normally distributed with a mean of zero and to see if serial trends were present.

Instantaneous annual fishing mortality rate in year t was estimated as:

$$(7)\ F_t = H_{t-1} / [(B_t + B_{t-1}) / 2] \text{ (Ricker 1975).}$$

An equivalent instantaneous natural mortality rate associated with striped bass predation and competition was estimated. The type III predator-prey term in equation 1:

$$(8)\ \ [(cP_{t-1}(B_{t-1})^2)/(A^2+(B_{t-1})^2)]\ ,$$

estimated loss of weakfish biomass, D_t, that was equivalent to catch H_t. Instantaneous annual natural mortality associated with striped bass was estimated as:

$$(9)\ \ M_{bt} = D_{t-1} / [(B_t + B_{t-1}) / 2].$$

Total instantaneous annual mortality of weakfish (Z_{bt}) due to due to fishing and striped bass predation equaled $F_t + M_{bt}$. This estimate did not account for other sources of natural mortality not associated with food web effects represented by striped bass.

Consumption of weakfish biomass per unit of striped bass biomass was estimated as

$$(10)\ \ D_t / P_t.$$

The functional response of striped bass to weakfish was displayed visually by plotting D_t / P_t against B_t.

Surplus production estimated from the logistic predator-prey analysis (SP_t) was estimated with two equations. The first estimate was from the standard equation.

$$(11)\ \ B_t - B_{t-1} + H_{t-1}$$ (Prager 1994; Jacobson et al. 2002).

The second estimate of SPt explicitly accounted for losses due to striped bass predation and competition:

$$(12)\ \ B_t - B_{t-1} - D_{t-1} + H_{t-1}.$$

Surplus production estimated by both equations was plotted against F and M_b to explore the possible linkage of these two sources of mortality to changes in surplus production.

Estimates of F or Z from the predator-prey model were compared to F_{Rfa} (F from rescaled relative F analysis; Crecco 2005a; 2006), estimates of F from a Schaefer biomass dynamic model without a predator-prey term (based on WRI), or Z_{vpat}. Biomass estimates were compared among predator-prey, Schaefer (described below), and rescaled relative F models. Weakfish exploitable biomass estimated by the predator prey model was plotted with age 2+ striped bass biomass and combined weakfish and striped bass biomass.

Bootstrapping (Efron and Gong 1983) was used to describe variability of parameters estimated in the spreadsheet version of the logistic predator-prey model. The bootstrapping technique recommended by Prager (1994) that preserved the original order of the time-series was used. For each set of bootstrap trials, a synthetic data set was constructed by combining a random sample of the original residuals with the ordered predictions from the original fit; the model was then rerun with each set of synthetic observations (Efron and Gong 1983; Prager 1994; Haddon

2001). Percentile confidence intervals of model parameters (r, K, B_{1981}, c, and A) and the time-series of biomass, F, and M_b were estimated.

Several approaches were used to investigate sensitivity of predator-prey model parameters (r, K, B_{1981}, c, and A) and estimates of F, M_b, and biomass. All sensitivity analyses were deterministic; bootstrapping was not used. We were particularly attuned to changes that created a decline in biomass at the end of the time-series such as that exhibited in the rescaled relative F analysis (Crecco 2005). Results (SSQ, r^2, residuals, estimates of parameters r and K, and F and biomass time-series) from the S-H striped bass-weakfish model were contrasted with a Schaefer biomass dynamic model using the WRI. Sensitivity of model parameters to the beginning or ending of the time-series was tested by removing up to three years of data and running the model. An additional sensitivity run used a fixed value for B_{1981} , 49,000 mt, predicted from a regression of DE PSD Q+ and average biomass estimated from rescaled F analysis.

Alternative Weakfish Predator-Competitors

Three approaches were used to evaluate the potential of Atlantic croaker, bluefish, summer flounder, and spiny dogfish to influence weakfish biomass dynamics. First, long-term trends in Atlantic Coast commercial landings were analyzed for trends to determine if negative associations with weakfish landing were suggested any of the candidate species. We assumed that landings would be largely reflective of stock biomass in this long-term analysis. Second, biomass estimates from single species assessments, generally within 1981-2003, were obtained and used as predator biomass (P_{t-1} in equation 6) in a species-specific predator-weakfish model used above to explore weakfish-striped bass biomass dynamics (see *Predator-Prey Modeling*). Analytical results were contrasted with those found for striped bass. Finally, literature on candidate species' diets was reviewed to see if predation on weakfish and competition for bay anchovy, Atlantic menhaden, and spot were possible.

Commercial landings (1950-2003) of the four candidates were obtained from the National Marine Fisheries Service's website (www.st.nmfs.gov/st1/; Figure 1). Some bias was likely introduced by increasingly restrictive management after the early 1980s for most of these species (Atlantic croaker would possibly be a lightly regulated exception). After inspection of trends, landings of dogfish were dropped from the analysis. Dogfish landings (not separated by species) were generally low throughout the time-series, but were punctuated by several year periods of high landings. These rapid changes did not appear in character with an animal with modest reproductive characteristics (slow growth, delayed maturity, long gestation, and small number of pups produced; NEFSC 2003). Correlation analysis was used to determine associations ($P \leq 0.10$) among candidate species' landings and weakfish landings. A significant, negative correlation with weakfish would suggest that a candidate species was a predator-competitor.

Biomass time-series from single species assessments were obtained for Atlantic croaker (ASMFC 2005), bluefish (NEFSC 2005a), summer flounder (NEFSC 2005b), and spiny dogfish (NEFSC 2003). Species, time-series and estimation technique were as follows: age 1+ Atlantic croaker SSB, 1981-2002, age structured surplus production model; age 1+ bluefish biomass, 1982-2003, VPA; age 1+ summer flounder biomass, 1982-2003, VPA; and total biomass of spiny dogfish, 1981-2003, expanded area swept by survey trawl (Lowess smoothed). Atlantic

croaker SSB was considered a reasonable proxy for biomass since 90% were considered mature at age 1 and all were mature afterward (ASMFC 2005).

We applied the logistic predator-prey model to examine relative effects of fishing and potential predation and competition from each of our four candidate species on recent (1981-2003) weakfish dynamics. The application of this model for weakfish and striped bass was described in detail above. Deterministic runs were made; bootstrapping and sensitivity analyses were not explored. Model fit (r^2 of observed and predicted indices), its ability to produce a decline in weakfish biomass after the late 1990s, and how closely its levels of weakfish biomass were to those estimated by Crecco (2005) were used to evaluate each candidate predator-competitor. Weakfish biomass estimates of Crecco (2005a) were termed "observed" quantities in these comparisons.

A "scorecard" was kept for each candidate species. Ten criteria were considered - four based on statistical or model results, and six on surveyed diet literature (Table 3). Each variable could be scored between 0 and 1. Maximum score summed to ten. Eight variables were dichotomous, while two were continuous. All six literature variables on diet presence were dichotomous: presence of weakfish, bay anchovy, Atlantic menhaden, spot, clupeids, and sciaenid. In order for a score of one to have been considered in the clupeid and sciaenid categories, diet summaries had to either consider these general categories only or species other than weakfish, menhaden or spot had to be identified. The regression coefficient between the biomass estimates made for 1981-2003 by rescaled F analysis and predator-prey analysis was one of the continuous scores and the biomass closeness ratio of mean 1981-2003 biomass made by rescaled F and predator-prey analyses was the other. This latter ratio was expressed to keep it less than one (either rescaled F biomass to predator-prey biomass or vice-versa) depending on species-specific bias (Table 3).

RESULTS

Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings

Recreational catch per trip (WRI) was intermittently high during 1981-1988, fell to a low level through 1993, rose to a peak similar to previous highs by 1996 and then fell steadily to its nadir in 2003 (Figure 2). Delaware biomass indices were consistently low during 1981-1984. Both the NJ and DE biomass indices indicated a substantial rise during 1990-1996 and both fell afterwards, although the decline in DE was more substantial and consistent than NJ. All three indices had declined by 2003, but the magnitude of decline was inconsistent. WRI had approached its lowest level ever, DE was quite low but not at its lowest, and NJ was somewhat low but had been fluctuating annually between low and high for five years (Figure 2).

Estimated q of the WRI varied over the time-series (CV = 36%), but was generally stable across the estimates of converged VPA biomass (Figure 3). The highest estimate was about three-times greater than the lowest. The two highest estimates of WRI q occurred earliest in the time-series (1981 and 1982) at a mid-level of biomass (≈ 20,000 mt). Scatter plots of DE and NJ biomass indices suggested inverse relationships of q and biomass at worst and random 10-fold fluctuations at best. Highest estimates of q in both state surveys occurred at the lowest biomass (Figure 3). Coefficients of variation of these two surveys' catchability estimates during 1982-

1993 were near 100%. We considered these trawl surveys qualitative indicators of changes in biomass.

Correlation of WRI and DE biomass index was not significant when 1981-1984 were included. All three sets of indices were positively correlated with each other during 1989-2003 (WRI and DE, Pearson $r = 0.90$; WRI and NJ, Pearson $r = 0.71$; DE and NJ, Pearson $r = 0.79$; $P \leq 0.003$ in all cases).

Mean weight-at-age was higher prior to 1993 and the difference between mean weights-at-age during 1981-1992 and 1993-2003 increased with age (Figure 4). Median average weight-at-age during 1982-1992 was 7% larger than during 1993-2003 for age 1, 22% larger for age 2, 34% for age 3, 80% for age 4, and 85% for age 5.

The DE PSD Q+ index indicated that size quality of weakfish in recent years was quite poor (Figure 5). A recovery in size quality in the 1990s faltered after 1998; the percentage of quality sized and larger weakfish fell from about 20% in 1998 to 1% in 2003. Weakfish DE PSD Q+ has the potential to be a good bit higher than the peak observed in 1998. Values in the early 1980s were twice as high (45%) as the peak observed in 1998 (Figure 5).

Biomass estimates of age 2+ striped bass were low (5,500-7,700 mt) during 1982-1986 (Figure 6). Biomass rose steadily from 12,000 mt to 83,000 mt during 1987-1998 and then rose slowly to 104,000 mt by 2003. *LBI* was near 0.80-0.90 during 1966-1978 with a hiatus near 0.65 during 1971-1974. After 1978, *LBI* steadily fell and reached a low of about 0.35 during 1983-1984. *LBI* rose rapidly after 1985 and reached 0.80 in 1992; *LBI* has fluctuated near 0.80 during 1993-2003. Age 2+ biomass was positively and significantly correlated with *LBI* (Pearson $r = 0.71$, $P < 0.0002$). Striped bass recovery indicated by *LBI* was much more rapid than VPA estimates of age 2+ biomass, but the relative scale of recovery was similar (Figure 6).

Striped bass biomass was negatively associated with weakfish size quality. Weakfish DE PSD Q+ was significantly and negatively correlated with ln-transformed striped bass age 2+ biomass during 1982-2003 (Pearson $r = -0.74$, $P = 0.0007$) and with *LBI* during 1966-2003 (Pearson $r = -0.67$, $P = 0.0002$).

Indices of relative abundance of Atlantic menhaden in MD, VA, and NC exhibited similar trends (Figure 7). Abundance was low during 1966-1970 and after the early 1990s. Abundance was slightly to well above the time-series average during 1974-1986. Relative abundance was slightly below average during 1987-1991 and then decreased to previous lows observed during 1966-1970 (Figure 7). Relative abundance of menhaden in Delaware Bay surveys (DE and NJ) was steady and low prior to 1993 and has fluctuated from slightly below average to well above the time-series average in the past decade (Figure 8). Coastal abundance estimates of age 0 Atlantic menhaden ranged from 128 to 850 $\bullet 10^9$ (Figure 9). Age 0 abundance estimates were frequently in the lowest quartile ($< 280 \bullet 10^9$) during 1966-1972 and after 1994 and frequently in the upper quartile ($> 569 \bullet 10^9$) during 1975-1991. These age 0 population estimates exhibited a pattern similar to that observed in Chesapeake Bay and Ablemarle Sound surveys, but dissimilar to Delaware Bay.

Trends in spot relative abundance in MD and VA were similar to those of Atlantic menhaden; abundance was low during 1966-1971 and after 1991, and high in the interim (Figure 10). Relative abundance in MD and VA appeared to have been suppressed since the mid-1990s, while Pamlico Sound exhibited similar fluctuations as those observed in the early half of its time-series (Figure 10). Indices in Delaware Bay (DE and NJ) exhibited large fluctuations of high to low during the 1980s and early 1990s (Figure 11). These fluctuations began to dampen in the mid-1990s and indices have been below the time-series average since 1998 (Figure 11).

Bay anchovy indices in MD and VA fluctuated about their time-series means during 1966-1986 (Figure 12). An index was not available for NC. After 1994, MD Chesapeake Bay and MD coastal bay indices became asymptotic at a below average level, and VA indices were typically, but not always, below average (Figure 12). Bay anchovy indices in DE and NJ fluctuated above and below their means throughout their time-series (Figure 13).

Significant ($P < 0.10$) positive associations of DE PSD Q+ and forage relative abundance occurred consistently (but not among all surveys) in MD and VA for all three species (Table 4). Significant positive correlations (Pearson $r = 0.60$-0.79) with DE PSD Q+ were exhibited for Atlantic menhaden in MD, VA, and NC indices (3 of 4 comparisons) and coastwide abundance estimates. Spot were significantly and positively associated (Pearson $r = 0.54$-0.73) with PSD Q+ in DE Bay (1 of 3 surveys), and both Chesapeake Bay seine surveys. The VA Chesapeake Bay trawl survey index was positively, but not significantly correlated. Bay anchovy were significantly associated with PSD Q+ in MD ocean bay trawl and VA Chesapeake Bay seine surveys (Pearson $r = 0.61$ and 0.63, respectively). Two other Chesapeake Bay surveys of bay anchovy were not significantly correlated with PSD Q+, nor were surveys from other geographic locations (Table 4).

The multiple regression model of weakfish DE PSD Q+ versus *LBI* and age 0 menhaden abundance during 1966-2003 was significant ($r^2 = 0.61$, $P < 0.0001$). Partial regression coefficients indicated age 0 menhaden abundance ($P < 0.0001$) explained 50% of variation in weakfish PSD Q+ and striped bass biomass accounted for 11% ($P = 0.02$). The model picked up the general trend (rise and fall) of the DE PSD Q+ time-series, but did not always match the details (Figure 14).

The scatter plot of WRI and age 2+ striped biomass (Figure 15) exhibited at least four stanzas that were sequential with both striped bass biomass and time. During 1982-1988, striped bass biomass was below 20,000 mt and WRI was high on average, but also highly variable. During 1989-1993, striped bass biomass rose from 20,000 to 40,000 mt while WRI was steady and low. Both striped bass biomass and WRI rose steadily and then held steady during 1994-2000; striped bass biomass reached about 85,000 mt while WRI returned to high levels exhibited during the early 1980s. In the final stanza (2001-2003), striped bass biomass continued to increase past 100,000 mt, but WRI steadily decreased and reached its nadir (Figure 15).

The relationship of weakfish exploitable biomass, indicated by DE and NJ trawl survey indices and striped bass age 2+ biomass (Figure 16) was similar to that exhibited by WRI. The earliest data, DE trawl survey during 1982-1984 indicated much lower relative biomass than WRI. Trends in remaining data (1989-2003) were very similar to WRI. Exploitable biomass indices

increased from about 0.1 to 3.0-4.0 concurrently with striped bass increasing from 20,000 to 70,000 mt. As striped bass biomass continued to rise to 100,000 mt in 2003, weakfish biomass indices fell to 0.5-1.0. A consistent indication of decline was not evident until 2003 (Figure 16).

Examination of long-term commercial landings of weakfish and striped bass (1950-2003) suggested that periods of high weakfish landings corresponded to low periods of striped bass landings and vice-versa. Decadal differences were evident when weakfish landings were plotted against striped bass landings (Figure 17). Weakfish landings were shifted upwards during 1970-1989 at the same amount of striped bass landings as during remaining years. A negative relationship of striped bass and weakfish landings that reflected two periods of underlying weakfish productivity was described by the multiple regression of weakfish landings against period and striped bass landings (Figure 17). This regression was significant at $P < 0.001$ and explained 76% of variation in weakfish landings. The relationship was described by the equation $W = -0.47*B + 5720*C + 4115$; where W = weakfish landings; B = striped bass landings, and C = decadal category (low = 0 = 1950-1969 and 1990-2003; high = 1 = 1970-1980). The net visual effect of this regression was to depict predicted weakfish landings as abrupt decadal blocks, with slight declines in the low periods and a slight increase during the high period (Figure 18). All coefficients and the intercept were significantly different from zero. Residuals appeared normally distributed with a mean near zero (mean = $3 \bullet 10^{-13}$). When categories were ignored, relationship of striped bass to weakfish commercial landings was negative and significant, but weak ($r^2 = 0.12$); a pronounced serial trend corresponding to the high and low periods was evident in the residuals.

Multiple regression analysis suggested a negative, nonlinear relationship between weakfish landings striped bass biomass (indexed by LBI) and a positive, nonlinear relationship with $\log_e$-transformed juvenile Atlantic menhaden abundance (MJ) during 1955-2002. There was an overall significant negative correlation between LBI and $\log_e$ MJ (Pearson $r = -0.49$, $P < 0.0004$), but this correlation was not "close" enough to warrant elimination of either variable in the multiple regression (Ricker 1975). The model was significant ($R^2 = 0.52$, $P < 0.0001$) and was described by the equation:

$$\log_e W = -1.75*LBI + 0.53 * \log_e MJ - 4.41;$$

where W = weakfish landings, LBI = striped bass egg presence-absence index, and MJ = menhaden juvenile abundance. Partial r^2 indicated that $\log_e$ MJ explained 41% of variation ($P < 0.0001$) and LBI explained 11% ($P < 0.0023$). The model moderately overestimated weakfish landings during 1955-1960 and usually underestimated them (sometimes badly) during 1972-1982 (Figure 19). Landings were well predicted after 1985. Residuals were nearly always negative during 1955-1970, always positive during 1971-1982, and then alternated with 3-4 year periods of negative and then positive residuals. The mean of the residuals was very close to zero.

Stepwise regression of the Maryland juvenile menhaden index (MI) and LBI indicated both terms were significant ($R^2 = 0.76$, $P < 0.0001$; Figure 19); MI accounted for the vast majority of the fit (partial $r^2 = 0.73$, $P < 0.0001$) while striped bass accounted for a minor, but significant, fraction (partial $r^2 = 0.03$, $P < 0.04$). As above, there was an overall significant negative correlation between LBI and MI (Pearson $r = -0.52$, $P < 0.0002$), but this correlation was not

"close" enough to warrant elimination of either variable in the multiple regression (Ricker 1975). Residuals appeared normally distributed with a mean near 0; a serial trend was not evident. This regression model reasonably reproduced the time blocks of weakfish landings featured in the categorical regression expressed above; both predictions were significantly correlated (Pearson r = 0.81, $P < 0.001$).

Time Varying Natural Mortality from VPA

Although natural mortality of age 1+ weakfish was assumed to be constant in previous assessments (NEFSC 1998; 2000), the trend in annual biomass weighted natural mortality (M_{vpa}) from 1982 to 2003 does not support this assumption (Figure 20). M_{vpa} estimates, though variable, changed systematically. A quadratic function (inverse parabola) fit the time trend of M_{vpa} (all terms significant at $P < 0.00013$; $R^2 = 0.63$, $P < 0.0001$; Figure 20) and depicted M_{vpa} falling from 0.75 in 1982 to near 0.25 during 1990-1993, then rising to 0.95 by 2003. The 1982-2003 average M_{vpa} (mean $M_{vpa} = 0.47$, SE = 0.06) was significantly higher (t-statistic = 3.67, $P <0.01$) than the assumed constant M of 0.25 (Crecco 2006).

Predator-Prey Modeling

The Steele and Henderson (1984) predator-prey model fit the data well and explained 78% of the variation in the weakfish index (Figure 21). The model generally overestimated the index somewhat during 1989-1994 and underestimated it during 1996-2000 (Figure 21). Residuals had a mean of –0.052 and were skewed towards negative values. Model parameters were estimated as r = 1.17, K = 49,080 mt, c = 0.076, and A = 1,959 mt. Maximum sustained yield reference points were $F_{msy} = 0.58$ and $B_{msy} = 24{,}540$ mt.

The initial biomass estimate (1981) equaled 65,274 mt and exceeded the estimate of K (Figure 22). B_{msy} was never exceeded after 1981. Biomass was about 19,000 mt in 1982 and fell to 7,900 mt by 1990; biomass rose to 16,000 mt in 1997 and then began to decline again, reaching 8,000 mt in 2003 and 5,700 mt in 2004 (Figure 22). Biomass estimates in 2003 and 2004 represented 40% and 32%, respectively, of B_{msy} (or 20% and 16% of unfished biomass) under this set of ecosystem conditions.

Instantaneous annual fishing mortality rates rose from 0.5 to 1.3 during 1981-1988, fell to 0.4 by 1993, and then remained steady below F_{msy} at about 0.4-0.5 during the following decade (Figure 22). Instantaneous annual natural mortality rates associated with striped bass were very low during 1981-1986 ($M_b < 0.04$) Estimates of M_b rose steadily after 1986, equaled F by 1999-2000 ($M_b \approx 0.5$), exceeded F by 50% by 2002 ($M_b \approx 0.7$), and easily doubled F by 2003 ($M_b \approx 1.1$; Figure 22). Changes in biomass in the of the time-series largely reflected F until the late 1990s, when a decline largely reflected M_b. The large drop in biomass between 1981 and 1982 was not explained by either F or M_b.

Surplus production estimates (SP_t), calculated with or without accounting for striped bass competition, were near 12,000 mt during 1982-1986 (Figure 23). Estimates from both equations then began to fall through 1990. When striped bass losses were not included in estimation, SP_t

rose after 1990, peaked at about 7,400 mt in 1995, and then underwent a steady decline to about 400 mt by 2003. When striped bass associated losses were included in the estimation of SP_t it declined slowly to 3,500 mt in 1992, remained steady there for three years, rapidly declined to near zero by 1998, and became increasingly negative afterwards (Figure 23).

Plots of SP_t (estimated by either equation) against F (Figure 24) or M_b (Figure 25) indicated a strong logical and negative influence of M_b, but not F; 1981 was omitted from the plots and appeared to represent an outlier. The plot of F versus SP_t estimated by either equation indicated an illogical, positive association.

A low number of bootstrap trials were performed (N=50) after determining that precision of all estimated parameters was extremely high. Coefficients of variation (CV) of r, K, s, B_{1981}, c, and A were all below 1%. CV's of annual biomass, F, and M_b were below 1% for 1981-2000 and would rise to 4-5% at the end of the time-series (biomass estimates were made through 2004; F and M_b were estimated through 2003).

A Schaefer production model could not reproduce the recent decline in WRI without addition of a striped bass predation term (Figure 26). Sum of squares fell from 3.49 (Schaefer) to 2.62 (Steele and Henderson) with the addition of striped bass as a predator-competitor, primarily due to improved fit at the end of the time-series (2003 squared residual = 1.33 in the Schaefer model and 0.10 in the Steele and Henderson model). Improvement in overall fit was modest ($r^2 = 0.72$ without and 0.78 with predation term). Mean of the Schaefer model residuals was -0.075. Schaefer model residuals exhibited much of the same serial pattern described above for the Steele and Henderson model, but became sharply negative at the end of the time-series. Intrinsic rate of increase was estimated to have been much lower, 0.47, in the Schaefer model and K was considerably higher, 71,000 mt.

The time-series modeled had great bearing on the nature of the predator-prey relationship (c and A), but little influence on production parameters (r and K; Table 5) and equilibrium MSY reference points derived from them. Parameters r and K varied by no more than ±10% from the original fit (1981-2003) with the seven treatments. Predator-prey parameter c varied only 10% from the original estimate when years were removed from the end of the time-series, but changes were substantial (105-267%) when years were removed from the beginning. Parameter A was extremely sensitive to the time-series used. The original series produced the lowest estimate and other years' estimates were 370-1300% greater (Table 5).

Only models fit to the 1981-2003 or 1982-2003 time-series could reproduce the recent decline of the observed WRI out of the seven sensitivity treatments (up to three years removed from beginning or end of time-series and 1981 fixed at 49,000 mt; Figure 27). The remaining treatments indicated that biomass leveled-off or was rising slightly at the end of the time-series (Figure 27). The 2003 estimate of WRI influenced trajectory the most at the end of the time-series. Only the 1981-2003 and 1982-2003 time-series will be described further because of the inability of the other treatments to create a decline at the end of the time-series.

If the time-series began in 1981, modeled striped bass functional response was highly depensatory in the Steele-Henderson model; weakfish per bass was nearly constant (≈ 0.71-0.76)

across the entire range of estimated biomass (6,700-66,000 mt; Figure 28). The asymptotic value of weakfish biomass where striped bass demand for weakfish was satiated (A=1,959 mt) was greatly exceeded throughout the time-series. If 1982 was used to initiate the time-series, weakfish consumption per striped bass was much more density-dependent (changing nearly linearly from about 0.04 to 0.11 as weakfish biomass rose from 7,900 to 19,000 mt (Figure 28). Weakfish biomass at satiation (A=11,387) was reached within the time-series.

Trends in estimates of F were generally comparable among the predator-prey, rescaled relative F, and the Schaefer biomass dynamic models except during the more recent years (Figure 29). Fishing mortality was highest and generally increasing during the 1980s; F fell substantially during the early 1990s, and remained steady and low during the remainder of the 1990s. Trajectories of F after 1999 diverged among models; F remained steady in the predator-prey model, increased with the rescaled F analysis (but remained modest), and fell to a very low level with the Schaefer biomass dynamic model. Estimates of F from both time-series (1981-2003 and 1982-2003) used with the predator prey model were similar. Recent estimates of F from the Schaefer model exhibited the same pathology (trending in recent years to near zero; Figure 29) as estimates made with biomass dynamic models based on trawl survey indices (Uphoff 2005a).

Trends of estimates of M_b were similar (increasing) through 2001 for Steele and Henderson models applied to the two time-series (Figure 30). Estimates of M_b were below 0.05 through 1985 and then steadily increased to approximately 0.70 by 2001. Estimates diverged after 2001, M_b based on the 1982-2003 time-series stabilized at about 0.7 while those based on 1981-2003 continued to increase to 1.1 by 2003 (Figure 30).

Trends in Z were similar between predator-prey models and the 1982-2003 ADAPT VPA (Figure 31); estimates of 1982-2003 Z_b based on the 1981-2003 and 1982-2003 time-series were significantly correlated with Z_{vpa} (Pearson r = 0.57, P < 0.005 and Pearson r = 0.53, P < 0.012, respectively). Total mortality rates estimated by the predator-prey model using the 1981-2003 time-series were high during 1982-1992 (Z_b = 0.8-1.5), dropped significantly by 1995 (Z_{bt} = 0.5-0.7), began a steady climb and returned to previous high levels by 2000, and continued to increase through 2003. Estimates of Z_b based on the 1982-2003 time-series were similar to those from the other two approaches over most of the time-series, but were much lower in 2003. The 1982-2003 predator-prey model estimates of Z_b plateaued at about 1.1-1.3 during 1998-2002 and then fell to just below 1.0 in 2003; these levels of Z_b were only sustained previously during 1986-1989. Estimates of Z_{vpa} have been between 0.9 and 1.4 since 2001; this sustained level was not evident in the ADAPT time-series since 1981-1992 (Figure 31).

Excluding 1981, weakfish biomass estimated by the predator-prey models did not exceed 20,000 mt (Figure 32). Biomass estimated from rescaled F analysis peaked at about 30,000 mt, while the Schaefer model estimates were as high as 60,000 mt. Predator-prey and rescaled F estimates of biomass were very similar in trend (declines and increases were concurrent) and magnitude of low biomass, but differed in magnitude of how high biomass could have been (Figure 32).

Striped bass-weakfish model estimates of weakfish biomass began to recover after 1990 and rose from 7,000 mt to 18,000 mt by 1997 (regardless of predator-prey model time-series). Increases in striped bass biomass beyond 70,000-80,000 mt were offset by decreases in weakfish biomass.

After 1997, weakfish biomass decline to about 8,000 mt. When weakfish biomass was added to striped bass biomass, an asymptotic combined biomass level of 100,000 -110,000 mt was suggested. This may represent the combined carrying capacity for these two species under the limited forage conditions in existence since the mid-1990s.

Alternative Predator-Competitors

Only striped bass commercial landings were significantly and negatively correlated (Pearson r = -0.35, P = 0.0095) with weakfish landings during 1950-2003 (Table 6). Bluefish and summer flounder landings during 1950-2003 had highly significant positive correlations (Pearson r = 0.73 and P < 0.0001 in both cases) with weakfish landings. Atlantic croaker harvests were marginally correlated with those of weakfish (Pearson r = 0.24, P = 0.08).

Trends in candidate species biomass during 1981-2003 varied (Figure 33). Striped bass exhibited a steady increase throughout, starting at about 5,000 mt and ending at about 100,000 mt. Summer flounder exhibited a general saddle shape trend – declining from 30,000 mt to 11,000 mt during 1981-1989, steadying at this low level until1994, and then steadily increased to 50,000 mt. Bluefish declined steadily from 150,000 mt until reaching 50,000 mt in the late 1990s; the stock stabilized for several years, and then increased to 90,000 mt over the last two years. Spiny dogfish steadily increased from 300,000 mt in the early 1980s to 560,000 mt by the early 1990s. Then they steadily decreased to about 400,000 mt (Figure 33).

Atlantic croaker biomass in the predator-prey model resulted in weakfish biomass estimates of about the same magnitude as that observed (biomass closeness ratio = 0.93), but did not produce a decline in recent years (Table 6, Figure 34). The croaker biomass time-series ended in 2002. Absence of an Atlantic croaker biomass estimate for 2003 is of concern because it was a crucial data point for producing a decline in biomass in predator-prey modeling of striped bass and weakfish. Estimates of r and K (1.00 and 53,823 mt, respectively) were similar to those for the striped bass-weakfish model. Parameter A (weakfish biomass where satiation occurs) estimated for the Atlantic croaker-weakfish model was greater than carrying capacity, casting doubt on the applicability of this model or at least the type III functional response to these data.

With bluefish as a predator, the Steele and Henderson model indicated that weakfish biomass was fluctuating about a mean level (Figure 35). Estimated biomass was about 10-times the observed level (closeness ratio = 0.08). There was little support for bluefish as an influential predator-competitor competitor based on the logistic Steele and Henderson model ($r^2 = 0.01$; Table 6).

Summer flounder biomass produced a similar trend in estimated biomass ($r^2 = 0.62$), but the estimates were 20% to 150% higher than the observed values (biomass closeness ratio = 0.56; Table 6, Figure 36). A recent decline in weakfish biomass was produced with summer flounder biomass as a predator. The intrinsic rate was about half that of the striped bass-weakfish model, while K was about 6-times higher (Table 6). Per capita consumption estimates (c = 1.2 mt tons consumed per mt of flounder) indicated flounder would need to consume over 15-times the amount weakfish as estimated for striped bass to produce a similar trend in biomass (Table 6).

Using spiny dogfish biomass estimates in the predator-prey model resulted in weakfish biomass estimates similar to those observed (closeness ratio = 0.89), but did not result in a good fit (r^2 = 0.29) or a decline in recent years (Table 6; Figure 37). Parameters r and K were similar to those in the striped bass-weakfish model; A was in excess of K, indicating this model was not entirely appropriate for examining the dogfish-weakfish relationship (Table 6).

Striped bass-weakfish landings analysis and predator-prey model results have already been described extensively and will not be described further here. Comparison of striped bass landings regression and predator-prey model results with other candidate species is presented in Table 6. Striped bass consumed weakfish directly and all five of the forage categories were well represented in diet studies reviewed (Table 7).

The ecological role of Atlantic croaker as a potential competitor or predator on weakfish is poorly understood but croaker trophic status is below that of weakfish (Hartmann et al. 1995; Miller et al. 2004). Diet information for Atlantic croaker were limited and confined to recent years in Chesapeake Bay (Miller et al. 2004). Weakfish were not listed as a diet item for Atlantic croaker. The only diet item on the scorecard that was consumed by Atlantic croaker was bay anchovy (Table 7).

Bluefish diets were summarized for both Chesapeake Bay (Hartman and Brandt 1995) and the North Atlantic and Mid-Atlantic coasts (Buckel et al. 1999a; 1999b). Weakfish were present at a low level in bluefish diets along the North and Mid-Atlantic (Buckel et al. 1999a; Table 7). Bay anchovy, Atlantic menhaden, spot, and clupeids were important items in at least one of the three studies (Table 8). Sciaenids other than spot and weakfish were present, but were a minor component of bluefish diets.

Summer flounder diets for the North and Mid-Atlantic were summarized in Bowman et al. (2000), Link and Almeida (2000), and Link et al. (2002a). Weakfish were present at a low level in summer flounder diets in the inshore region North of Cape Hatteras (Bowman et al. 2000; Table 8). Bay anchovy was the only candidate forage species specifically identified, while anchovies in general comprised less than 5% of summer flounder diets. Neither Atlantic menhaden nor spot were specifically mentioned, but clupeids generally comprised less than 10% of diet by weight. Sciaenids were a minor component of summer flounder diets (Table 8).

Rountree (1999), Link and Almeida (2000), and Link et al. (2002b) described spiny dogfish diets along the North and Mid-Atlantic region. Rountree (1999) reported that spiny dogfish prey on weakfish (Table 8). Only general categories containing our candidate species were identified: anchovies, clupeids, and sciaenids (Table 8). Clupeids were a major component of diet by weight, ranking second among all groups summarized in these two studies. Anchovies and sciaenids were minor components.

The weakfish predation-competition scorecard indicated that striped bass was by far the most likely predator-competitor candidate (9.5 out of 10 possible), followed by summer flounder (6.2), bluefish (6.1; 6.0 points due to diet studies), spiny dogfish (5.2), and Atlantic croaker (2.65; Table 8).

Summer flounder was the only candidate species beside striped bass to both have weakfish in its diet and reproduce the recent fall of weakfish biomass in predator-prey modeling. Based on these factors, summer flounder biomass was combined with striped bass in a predator-prey model run (hereafter, bass - flounder model).

The striped bass – flounder model fit the three predator-prey model criteria better than both species alone. The trend in biomass estimated from rescaled F analysis was faithfully reproduced (Figure 38). Fit of predicted biomass to observed improved ($r^2 = 0.83$). The ratio of predicted to observed biomass was close to 1 (0.95) and the decline in recent biomass was reproduced in the model (Figure 38). Model production parameters r and K (1.22 and 53,302 mt) and predator-prey functional response parameters (c = 0.096 and A = 2,976 mt) were much closer to those of striped bass than summer flounder (see Table 7). The shading of these parameters towards striped bass far exceeded the weighting expected based on biomass alone; average summer flounder biomass during 1982-2003 was 59% of striped bass biomass.

DISCUSSION

At this time, weakfish have changed from a harvestable commodity to a supporting role as forage for the striped bass recovery (and perhaps other species recoveries). Weakfish in the Mid-Atlantic region are currently in a period of low productivity that has low forage abundance underlying it. Since the early to mid-1990s, regional (NC-NJ) indices of three important forage species (Atlantic menhaden, spot, and bay anchovy) have dropped to low levels. Under these conditions, their population dynamics are dominated by striped bass, perhaps with a negative contribution by summer flounder. Changes in weakfish size, abundance, and biomass dynamics were consistent with trends in forage relative abundance, striped bass and summer flounder biomass, and M over a broad geographic area and time-span. These changes supported the hypothesis that the aborted weakfish recovery largely reflected increased natural mortality due to striped bass competition and predation precipitated by depleted forage.

Equilibrium MSY limit reference points, consistent with the precautionary approach and estimated from the S-H model (Steele and Henderson striped bass-weakfish predator-prey model), indicated that F had been below the F_{msy} limit for nearly a decade, but biomass had fallen well below the B_{msy} limit in the last several years. Biomass was below B_{msy} for most of the time-series, regardless of S-H model employed and F was below F_{msy} since the early 1990s. Under equilibrium conditions, this should not be possible; fishing mortality rates in this range should have been associated with stock expansion or stability. S-H models indicated these equilibrium-based biological reference points have limited utility in this situation where M is rising rapidly. Biological reference points can be sensitive with species subject to predation and cannibalism and may represent moving targets (Collie and Gislason 2001). In the case of the striped bass-weakfish model, by 2003 rising M_b ate away at the amount of F that represented a level of "safe" fishing; $r - M_b$ fell from 0.66 in 2001 to 0.08 in 2003. Even though F fell from 0.50 during 2000-2002 to 0.39 in 2003, the amount of residual productivity ($r - M_b - F$) went from positive to negative (0.16 to -0.31) during 2000-2003.

Natural mortality of age 1+ weakfish was originally assumed to be constant across ages and years (M = 0.25; NEFSC 1998; 2000). We found that the trend in annual natural mortality

estimates during1982-2003 did not support the constant M assumption. Striped bass-weakfish predator-prey models corroborated the rise in M over the past decade. In future assessments here and elsewhere, the assumption of constant M for ages 1+ fish needs to be critically examined. The weakfish ADAPT VPA assumes constant natural mortality (Part 1). Misspecification of M in a VPA creates particularly large biases for lightly fished stocks and, when combined with changes in F, leads to a time-varying bias (Mertz and Meyers 1997).

For medium-term advice, it may suffice to consider one-way interactions and categorize each species as predator or prey (Collie and Gislason 2001). This simplification, which we employed in our S-H models, is convenient because it allows predators to be added to a single species assessment (Collie and Gislason 2001). However, Walters and Martell (2004) warned that this approach does not recognize how trophic ontogeny may cause more complex dynamics.

Biomass dynamic models implicitly assume that underlying ecological conditions remain unchanged (variations in stock size reflect random variation and fishing; Spencer and Collie 1997). Without an additional predator-competitor term, a Schaefer model based on WRI indicated that biomass was continuing to increase and F was falling to a very low level. This same unrealistic trend was produced by trawl index-based biomass dynamic models (Uphoff 2005a). After modeling under an ecological stability assumption, we were left with concluding that recreational and commercial fishers were no longer interested in harvesting a high population of weakfish or that the population was so high that they stunted at smaller sizes than are of interest (Uphoff 2005a). Decreasing forage and increasing competition among predators make it appear unlikely that ecological conditions were stable over the time span modeled.

Term c (per capita consumption by striped bass) in the predator-prey model represented combined effects of direct striped bass predation, but it could be that cannibalism and starvation induced by intense competition with striped bass were being described as well. Predators' responses to prey can be divided into a functional response (number of prey consumed per unit area per unit time by an individual) and a numerical response (numbers change with prey density; Yodzis 1994; Bax 1998). Numerical response to prey density may have a direct development component (growth, birth, and death), but interaction with other predators may also influence this response (Bax 1998). Individual predators may interfere with one another in a number of ways that might affect population growth (Yodzis 1994). Among these interactions, the ones most relevant to weakfish and striped bass would be (1) they may hinder one another's feeding activities, leading to starvation; (2) they may eat one another (including cannibalism); (3) they may indulge in territorial behavior; and/or (4) they may emigrate (Yodzis 1994).

Striped bass did not appear tightly linked to weakfish as prey and loss of weakfish at high recent striped bass population size represented collateral damage. Versions of the 1981-2003 or 1982-2003 logistic predator-prey models, where c was a constant multiplied by striped bass biomass to estimate bass-related weakfish losses ($D_t = c \bullet P_t$) instead of a type III function, produced similar estimates of r and c, but more variable estimates of K, as logistic models employing a sigmoid predator-prey function. Variations in c were particularly important; both trials with linear predator-prey functions produced estimates of c (0.073 and 0.069 for 1981 and 1982 as initial years, respectively) that were similar to the 1981-2003 sigmoid function model estimate (c = 0.076). In the case of the 1982-2003 time-series logistic model, a constant c improved fit over

the sigmoid version (linear model SSQ = 2.49, sigmoid SSQ = 2.71). Only the sigmoid model of the 1982-2003 time-series supported the concept of striped bass predation dependent on the biomass of weakfish. The three other versions of the logistic predator-prey model indicated striped bass related mortality was depensatory. Trends in biomass, F , and M_b from constant c were quite similar to those presented for sigmoid functions.

In this analysis, there was a good chance that striped bass represented predators that were not tightly linked to weakfish, a secondary prey. Depensatory mortality may exist when a fish population is faced with a predator that spends much of its time feeding on one prey species, but also has secondary prey (Hilborn and Walters 1992). Predator abundance may be independent of the secondary prey and if the predators are efficient at finding and capturing secondary prey, then the number eaten will be more or less constant. As primary prey abundance declines, the mortality rate caused by the predators on the secondary prey increases (Hilborn and Walters 1992). As indicated by Spencer and Collie (1997), fish stocks that are subject to moderate to severe depensatory predatory mortality often undergo a sudden and persistent drop in surplus production over time, even when fishing mortality rates have remained low for several years.

There is little experience to judge the suitability of parameter A (weakfish biomass where predator satiation begins) in the type III predation function. The ratio of A/K in the 1981-2003 logistic weakfish - striped bass model (0.04) was comparable to estimates generated by Spencer and Collie (1995; 1997) for Georges Bank haddock and spiny dogfish (0.05 – 0.07). Dogfish were considered a depensatory predator of haddock (Spencer and Collie 1995; 1997b). The ratio of A/K in the 1982-2003weakfish logistic predator-prey model (with Type III function) was considerably higher (0.23) and would indicate a more density-dependent relationship.

The "effect" of these different predator-prey relationships estimated from the two time-series (1981-2003 or 1982-2003) may be best illustrated by exploratory projections. In these projections, striped bass biomass was held constant at its 2003 level through 2022. A constant exploitation rate of 0.1 was set after 2004 (a rate higher than this crashes the 1981-2003 based model). With c = 0.76 and A = 1,956 mt (estimates from1981-2003), the population stabilized by 2010 at very low biomass (555 mt). With c = 0.155 and A = 11,387 mt (estimates from 1982-2003 time-series), the population increases to about 23,300 mt by 2022.

Unlike harvest, we are unlikely to ever have a natural mortality "body count" to unequivocally estimate M. Results from regression and production models demonstrate striped bass-weakfish linkage and they are consistent with studies of striped bass predation in the mid-Atlantic. Weakfish have been specifically identified as a food item in some, but not all, striped bass diet studies in the mid-Atlantic region. They have appeared in studies conducted in lower Chesapeake Bay (Austin and Walter 1998) and Ablemarle Sound (Manooch 1973). They were infrequent diet items, comprising about 1-8% of diets by number and 2-3% on a weight or volume basis (Manooch 1973; Austin and Walter 1998). Weakfish were present in striped bass larger 400 mm in lower Chesapeake Bay in fall and winter (Austin and Walter 1998), while they were present in striped bass larger than 300 mm in Ablemarle Sound during "cooler" months (Manooch 1973). During winter 2004-2005, weakfish comprised 5% of striped bass diets by weight along North Carolina's coast (A. Overton, East Carolina University, personal communication).

Significant ($P < 0.10$) positive associations of weakfish size quality (1966-2003 DE PSD Q+ index) and forage abundance occurred consistently (but not among all surveys) in MD and VA for all three species and sporadically in NJ and NC. Regressions of striped bass biomass and juvenile menhaden abundance against DE PSD Q+ indicated a significant positive influence of forage and negative influence of striped bass on weakfish size quality. The DE PSD Q+ index represented the longest time-series of fishery-independent data on weakfish population dynamics. Length-frequency data, indexed by DE PSD Q+, contains much of the information contained in age-frequency data and even cursory examination of a length-frequency can give useful insights into population dynamics of a stock (Powell 1979; Hoenig et al. 1987). A population's length-frequency distribution results from its recent history of recruitment and mortality, integrated with growth (Barry and Tegner 1989). Two major parameters affecting DE PSD Q+, growth and mortality, have likely been influenced directly by competition for limited forage and predation.

The DE PSD Q+ index could have been influenced by trends in recruitment; size quality could have diminished because of recent recruitment of strong year-classes. Recruitment indices for weakfish in Crecco (2006) have exhibited wide regional variation, but the overall trend of the grand mean has been an increase during the 1990s and stabilization at a high level afterward (Figure 39). However, juvenile mortality has risen (Crecco 2006), while landings and other relative abundance or biomass indices have declined to well below average during 2002-2004. If the DE PSD Q+ index was to decline due to strong recruitment alone, then these abundance indicators and landings should be increasing.

The PSD Q+ index was chosen over growth equations because a long-time series of otolith-based growth estimates was not available and of because uncertainties in growth estimation. Otoliths were not primary aging media until the early to mid-1990s (NEFSC 1998). Fitting von Bertalannfy growth curves to these data has not been straightforward. Kahn (2002b) estimated von Bertalannfy curves by assigning constant asymptotic maximum length (L_∞) of 765 mm because of implausible estimates of this parameter; this same step was necessary to update 2001-2003 growth equations. Estimates of remaining von Bertalannfy parameters could have been confounded because they are interrelated (Jensen 1997). If assignment of constant L_∞ represents a real phenomenon, a 17% loss in maximum size (from 919 mm) has occurred since the otolith-based estimate made by Lowerre-Barbieri et al. (1995) for the early 1990s.

Kahn (2002b) described a decreasing trend in weakfish Brody growth coefficients in von Bertalannfy growth equations estimated for weakfish during 1990-1999. The Brody growth coefficient dropped by over half after 1990-1992 (Kahn 2002b). Kahn (2002b) also noted lower mean weights-at-age estimated for 2000 than those estimated for 1989-1992 by Lowerre-Barbieri et al. (1995). Weakfish weight-at-age has exhibited large drops since 1992 and the magnitude of the decline increased with increasing age. These changes corresponded to decreased forage relative abundance and increased striped bass biomass.

Significant decreases in weight-at-age of weakfish implied a corresponding rise in natural mortality. Natural mortality rates of fishes increase as a nonlinear function of decreasing body mass under equilibrium conditions when mortality is primarily derived by predation (Peterson and Wroblewski 1984; Boudreau and Dickie 1989).

Median weights-at-age of weakfish of 3 year-old weakfish during 1993-2003 were 75% of those during 1981-1992, while those of ages 4 and 5 during 1993-2003 were 55%. These changes in weight suggest that starvation-related mortality was possible for weakfish and indicated that older weakfish would be most likely to be subjected to starvation. Mortality due to starvation is a size-dependent process (Persson and Bronmark 2002). In a simulation of ontogenetic predator-prey dynamics of pikeperch, Persson and Bronmark (2002) assumed starvation occurred if individual weight dropped below 70% of weight predicted by a length-weight equation. In experiments with fasting juvenile rainbow trout, mean wet weight of starved fish that died were 77% of weight at the beginning of the experiment (Simpkins et al. 2003). A weight-based prediction of starvation is likely to be pretty coarse and may not correspond to the point where protein is broken down to meet metabolic demands (J. Jacobs, NOAA, personal communication).

Declines in weakfish mean weight exhibited in the weight-at-age matrix reflected a bottleneck of appropriate sized prey (juvenile menhaden and spot). If weakfish have stunted at these diminished weights because of low forage availability, this stunted size should reflect the size of forage needed. In experiments, Hartman (2000) found that peak profitability for striped bass occurred at a ratio of prey weight to predator weight of 0.12. When this ratio is applied to weakfish median weight-at-age estimates for 2-5 year-olds since 1993, it indicates that prey weighing an average of 29-109 grams (prey size increasing with weakfish age) would have been most profitable. These weights corresponded to menhaden (growth parameters in ASMFC 2004a) or spot (Fishbase parameters; www.fishbase.org) less than one year-old.

Atlantic menhaden is a buffer species that absorbs predatory pressure from other species when they are sufficiently abundant (ASMFC 2004b). Striped bass actively select for Atlantic menhaden, but will feed on other species when menhaden are not sufficiently abundant (Overton 2003; ASMFC 2004b; Ruderhausen et al. 2005) and they appear capable of limiting their prey populations along the Atlantic coast (Hartman 2003). As menhaden have become less abundant, striped bass searching is likely to lead to increasing encounters with vulnerable-sized weakfish (Walters and Martel 2004) reflected in the close correspondence of weakfish mortality and striped bass biomass.

Attack success of striped bass on Atlantic menhaden has likely been falling (Uphoff 2003). As the ratios of biomass of age 2+ striped bass to: biomass of age 0-2 menhaden (or biomass of bass big enough to eat menhaden: biomass of menhaden small enough to be eaten; based on ASMFC assessments; Uphoff 2003) along the Atlantic Coast fell to asymptotic lows in the mid-1990s, natural mortality of weakfish rose (as indicated by M_{vpa}, $M_{b,}$ and the estimated trend of juvenile mortality; Crecco 2006; Figure 40). Potential attack success of striped bass on menhaden would be indexed by this ratio because a predator's functional response (number of prey consumed per unit area, per unit time by an individual predator) is both a function of attack success and prey handling time (Yodzis 1994). Handling time varies little for a given predator (Yodzis 1994). Predator feeding efficiency will be inversely related to prey density as consumption rate declines and search effort increases (Ney 1990).

Hartman and Brandt (1995) found striped bass in Chesapeake Bay increased their use of the pelagic food web (primarily menhaden) as they aged, while weakfish increased use of benthic

resources (spot). Stable isotope analysis of striped bass scales collected during 1982-1997 from Chesapeake Bay indicated striped bass increased their use of the benthic food web as menhaden abundance decreased (Pruell et al. 2003). This shift would place them in more direct competition with weakfish and increase the chance striped bass would be occupying the same habitat as weakfish while feeding.

The percent of weakfish and striped bass diets represented by menhaden in Chesapeake Bay dropped substantially between the early 1990s and 2000s (Hartman and Brandt 1995; Overton 2003; Bonzek et al. 2004). The menhaden fishery, centered in Chesapeake Bay, harvests larger menhaden than those consumed by most weakfish or smaller striped bass (ASMFC 2004b), but direct competition with large striped bass is possible. Generalizations of functional response suggested that the fishery would outcompete striped bass at low menhaden densities (Uphoff 2003). A prey-size cascade could have been precipitated by competition between large striped bass and the fishery. Large striped bass are now relying more on small pelagic prey (bay anchovy and juvenile clupeids) needed by small striped bass and weakfish, while diets of these smaller piscivores have shifted to benthic invertebrates (see below; Griffin and Margraf 2003; Overton 2003). Slowing of weakfish growth due to a diet bottleneck, in turn, leaves them more vulnerable to striped bass predation, as do increased searching times for juvenile weakfish attempting the transition to piscivory. Increased searching time for small weakfish to obtain anchovy increases their exposure to larger striped bass that are now competing for the same resource. There is a horrific linkage between getting food and being food (Walters and Martell 2004).

Spot harvests in the mid-Atlantic are considerably less than those of the menhaden fishery, but their impact in relation to the population is unknown because a stock assessment is lacking. Bycatch in shrimp fisheries would kill spot at a size needed by weakfish and striped bass; however, shrimp fisheries do not operate in the geographic range (NJ-VA) where depletion of spot was suggested by correlation analysis. Pamlico Sound (NC) spot indices did not suggest depletion where substantial shrimp bycatch might have been expected. Striped bass generally do not range into Pamlico Sound (Boreman and Lewis 1987).

Weakfish biomass estimated for 1981 with the S-H model exceeded the estimate of K by nearly 30%, was over three-times the next highest biomass, and generally appeared as an outlier in most time-series and bivariate plots with other parameters. However, it could also have indicated rapid initiation of a regime shift in weakfish production. This year (1981) was the last year of an extraordinary three-year period of high landings, maximum DE PSD Q+, and trophy catches (Uphoff 2005a). A speculative Schaefer biomass dynamic model of an extended time-series (1975-2003; Uphoff 2005a) indicated that by 1981 weakfish biomass was in rapid decline from a period of very high biomass. This extended time-series analysis was similar in trend over years in common to the Schaefer biomass dynamic model included in comparisons with the predator-prey model. Estimates of stock biomass trends were in general agreement among models featured in this analysis until the late 1990s, when the Schaefer biomass dynamic model estimates began to diverge from S-H model estimates.

A negative relationship of Atlantic Coast striped bass and weakfish landings that reflected one high (1970s - 1980s) and two low periods (1950s -1960s, and 1990s -current) of underlying

weakfish productivity was indicated by categorical and multiple regression analyses of 1950-2003 weakfish and striped bass commercial landings, LBI, and indicators of Atlantic menhaden juvenile abundance. Earlier landings appear to confirm the negative relationship between these species' landings and rapid changes in weakfish status. Commercial records for these two species were intermittent from 1887-1950, but were reasonably frequent by the late 1920s (Joseph 1972; Boreman and Austin 1985). Catches of weakfish were generally high during the late 1920s through the mid-1940s while striped bass landings were low, but rising. Weakfish landings collapsed within four years in the late 1940s, while striped bass landings continued a sustained increase that lasted into the early 1970s (Joseph 1972; Boreman and Austin 1985). Correlations with landings of other four other candidate predator-competitors did not suggest a significant negative interaction.

Generally, autocorrelated variability that mimics long-term environmental patterns has been the forcing function that underlies regime shifts in simulations of populations with the S-H model (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1995; Spencer and Collie 1997a). Movement from high to low equilibrium states can be induced by increased fishing and depensatory mortality (Collie and Spencer 1993). Additional stress, usually attributed to fishing, reduces the level of environmental perturbation necessary to flip a system into a low equilibrium state (Collie and Spencer 1993) and causes flips to occur with higher frequency (Steele 1996). In the recent case of weakfish, it is likely depensatory mortality associated with striped bass under low forage conditions is the force leading to low productivity. The regime shift concept implies that different regimes have inherent stability, so that significant forcing is required to flip the system into alternative states (Steele 1996). The simple models for regime shifts have only two states, but nature may more complex and returning to a desired state may not be guaranteed by reduced fishing on weakfish, increased fishing on striped bass, or betting on beneficial environmental change (Steele 1996).

It is not possible to look at all predation processes in a fishery ecosystem (Bax 1998; Sainsbury 1998) and we have concentrated on a limited representation of the food web. Atlantic menhaden, spot, and bay anchovy represented 65-99% of total prey consumed by striped bass and weakfish during their estuarine residency in Chesapeake Bay during the early 1990s (Hartman and Brandt 1995). Atlantic menhaden and bay anchovy accounted for nearly 65% of weakfish diets by weight in Delaware Bay during 1985 (Taylor 1987). Clupieod fishes (herrings and anchovies) have dominated the diets of striped bass above age 1 (Walter et al. 2003). Summer and fall diets of striped bass were dominated by these three forage species in Chesapeake, Delaware, and North Carolina regions (Walter et al. 2003). Young-of-year weakfish feed on mysid shrimp and bay anchovy, while older weakfish feed on clupeid species that are abundant in a given area (Mercer 1985; Hartman and Brandt 1995). Striped bass evolved as a schooling species to take advantage of the great energy resource of clupeids along the Atlantic Coast (Stevens 1979). Diet studies strongly suggest that these two piscivores compete strongly for the same forage resources and changes in population characteristics such as growth, mortality, and abundance could be linked under conditions of scarce forage.

Weakfish diet studies have been infrequently conducted in the recent past. Age-specific weakfish diets (ages 0-2) were described by Hartman and Brandt (1995) during 1990-1992 in mid-Chesapeake Bay, while Virginia Institute of Marine Science's Chesapeake Bay Multispecies

Monitoring and Assessment Program (ChesMMAP) characterized age-specific diets of weakfish (ages 0-5) in the entire Bay during 2002-2003 (Bonzek et al. 2004). These latter data were presented at the 2004 American Fisheries Society Meeting and were provided for this analysis (R. Latour, VIMS, personal communication). We have limited the following discussion to Atlantic menhaden, spot, bay anchovy, and invertebrates. Diets in Hartman and Brandt (1995) preceded decreases in forage relative abundance and weakfish weight-at-age, while those described in Bonzek et al. (2004) represent recent conditions of depleted forage and reduced weight-at-age.

Weakfish diet studies in Chesapeake Bay have indicated major changes in the past decade. Atlantic menhaden, spot, bay anchovy, and invertebrates comprised over 75% of diets, by weight, during 1990-1992 and 2002-2003 (Figure 41). Bay anchovy and Atlantic menhaden have become much less frequent in weakfish diets between the early 1990s and early 2000s, spot have disappeared, and invertebrates have comprised a greater part of the diet.
Weakfish in Chesapeake Bay during both periods made a rapid transition to piscivory - bay anchovy dominated their diets as young-of year. However, transition from bay anchovy to dominance of spot and Atlantic menhaden at age 2 that occurred during the early 1990s was not evident in recent years. Older weakfish (ages 2+) are subsisting on the same invertebrate and bay anchovy diet as ages 0-1, with a much smaller supplement of menhaden (Figure 41). Striped bass diets in Chesapeake Bay have undergone similar changes as those described for weakfish; small striped bass are now relying more on invertebrate prey and large striped bass on small pelagic prey such as bay anchovy and age 0 clupeids, and benthic invertebrates (Griffin and Margraf 2003; Overton 2003). This suggests that larger prey (juvenile menhaden and spot) were insufficiently available for both species to complete the transition to piscivory.

Weakfish are cannibalistic; weakfish juveniles were specifically mentioned in diet studies reviewed by Mercer (1985) and comprised about 20% of weakfish diet by weight in Delaware Bay during 1985 (Taylor 1987). Weakfish were not specifically mentioned in Chesapeake Bay diets during 1990-1992 (Hartman and Brandt 1995), but other weakfish comprised 10% of age 2 and 6% of ages 3-5 diets in Chesapeake Bay during 2002-2003 (R. Latour, VIMS, personal communication). Increased cannibalism could be a consequence of weakfish's inability to compete with striped bass for other forage fish.

Discussions between the Weakfish Stock Assessment Subcommittee (WSAS) and the 40th SARC panel spawned the multiple hypothesis approach adopted by the WSAS to deal with conflicting signals in the data and analyses in this assessment. This approach led the WSAS to formulate and test, and reformulate and retest alternative hypotheses about M to explain patterns in the underlying data. This assessment strategy indicated the likelihood that the dynamics of striped bass predation and competition, and regime change took over in the 1990s once overharvesting had been controlled. Models used in this investigation were of intermediate complexity because of the basic limitations of the observational data. Simplified procedures allowed for the testing of overfishing and ecological hypotheses; overfishing was not supported as the sole cause of the recent decline.

Because of the large numbers of inputs into complex age-structured models, other parameters that may be indicative of other underlying dynamics (growth, productivity, recruitment, natural

mortality, spatial dynamics, fishing efficiency, and fishing selectivity) are held constant or ignored. This assessment strategy must become less favored in light of realization that the dynamics of predation, competition, environmental regime shifts, and habitat alteration or deterioration may take over once overharvesting has been controlled (Link 2002). Simply presuming that ceasing exploitation on an overfished stock will result in recovery ignores the uncertainty imposed by ecological systems (Link 2002). Stationarity of ecological conditions or constancy of M cannot be an acceptable default assumption (Sainsbury 1998).

We do not advocate abandoning more complex age-structured models, but are advocating testing the overfishing hypothesis with less time-consuming methods before plunging into their application. If these less intensive methods (trend analyses, relative F, year-class catch curves, and surplus production models, for example) lend some support to F as a major contributor to the dynamics in question, then proceed with more intensive analysis. If the hypothesis that fishing is a major contributor to a decline is not well supported, time should be spent pursuing alternate explanations.

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TABLES

Table 1. Descriptions of surveys used as estimates of forage relative abundance in the mid-Atlantic region. MH = Atlantic menhaden, S = spot, and BA = bay anchovy.

Location	Gear	Time-series	Estimator	Source	Species
NC, Ablemarle Sound	Seine	1972-2002	Geometric mean	L. Paramore, NC DMF	MH
NC, Ablemarle Sound	Seine	1972-2002	Delta log-normal	ASMFC 2004a	MH
NC, Pamlico Sound	16 ft trawl	1988-2002	Arithmetic mean	L. Paramore, NC DMF	S
VA, Chesapeake Bay	Seine	1967-1973, 1980-2003	Geometric mean	www.fisheries.vims.edu	MH, S, BA
MD, Chesapeake Bay	Seine	1959-2003	Presence-absence	E. Durell, MD DNR	MH S, BA
MD, Coastal Bays	16 ft trawl	1972-2003	Geometric mean	Casey and Doctor (2004)	S, BA
DE, Delaware Bay	30 ft trawl	1966-1972, 1980-1984, 1990-2002	Arithmetic mean	Michels and Grecco (2003)	MH, S
DE, Delaware Bay	16 ft trawl	1980-2002	Arithmetic mean	Michels and Grecco (2003)	S, BA
NJ, Delaware Bay	Seine	1980-2003	Arithmetic mean	J. Brust, NJ DEP	MH, S, BA

Table 2. Weakfish landings (mt commercial and recreational, including discards), weakfish biomass indices (WRI, kg catch per trip), and striped bass biomass (mt) estimates used as inputs for the logistic predator-prey model.

Year	Weakfish Harvest	WRI	Striped Bass
1981	20814	0.96	6236
1982	13823	0.46	5495
1983	14426	0.5	4656
1984	13338	0.31	6532
1985	11181	0.28	6794
1986	15590	0.42	7701
1987	11691	0.35	11741
1988	13090	0.3	14739
1989	8136	0.13	20402
1990	5440	0.09	24857
1991	5610	0.1	28655
1992	4793	0.14	35771
1993	4448	0.09	41806
1994	5395	0.19	49611
1995	5977	0.29	60005
1996	6879	0.38	70322
1997	7206	0.34	78778
1998	7809	0.44	83480
1999	6219	0.38	84275
2000	6126	0.42	85650
2001	5369	0.24	95746
2002	4434	0.24	89280
2003	2660	0.12	104282

Table 3. Variables and scoring criteria for the candidate species "scorecard". RF = rescaled F analysis (Crecco 2005) and PP = predator-prey model.

Variable	**Scoring criterion**
1950-2003 landings correlation	1 if significant and negative, 0 otherwise.
Biomass correlation	1981-2003 RF and PP estimates r^2 = score
Recent decline	1 if decline and 0 otherwise
Biomass closeness	Mean RF: mean PP or mean PP:mean RF, whichever < 1
Weakfish in diet	Absent or present, 0 or 1
Bay anchovy in diet	Absent or present, 0 or 1
Atlantic menhaden in diet	Absent or present, 0 or 1
Spot in diet	Absent or present, 0 or 1
Clupieds in diet	Absent or present, 0 or 1
Scianeids in diet	Absent or present, 0 or 1

Table 4. Correlations of relative abundance of major weakfish forage species in Mid-Atlantic region surveys and the DE Trawl Survey Quality+ PSD. Pearson correlation coefficient = r. Grey highlights indicate significant at P < 0.1 after adjustment for multiple comparisons. Ablemarle Sound correlations depict two estimators of central tendency applied to the same data.

State	Survey	Menhaden (r, P)	Spot (r, P)	Bay Anchovy (r, P)
NJ	DE Bay Seine	-0.35, 0.137	0.68, 0.0015	0.22, 0.368
NJ	Ocean trawl CPUE, number			-0.43, 0.129
NJ	Ocean trawl CPUE, weight			-0.36, 0.209
DE	16 foot DE Bay Trawl		0.13, 0.601	-0.27, 0.277
DE	30 foot DE Bay Trawl	-0.43, 0.040	-0.09, 0.669	
MD	Coast Bays 16 ft trawl		0.49, 0.03	0.61, 0.0063
MD	Chesapeake 100 ft seine	0.79, <0.0001	0.73, <0.0001	-0.163, 0.427
VA	Chesapeake 100 ft seine	0.60, 0.004	0.54, 0.009	0.63, 0.0016
VA	30 foot trawl, Chesapeake		0.39, 0.088	-0.52, 0.025
NC	Ablemarle Sound Seine GM	0.33, 0.159		
NC	Ablemarle Sound Seine Delta log-normal	0.64, 0.003		
NC	Pamlico Sound Trawls		-0.22, 0.439	
Coastwide	Abundance estimate	0.71, <0.0001		

Table 5. Sensitivity of logistic Steele-Henderson predator-prey (striped bass-weakfish) model parameters to different time-series. Original treatment is the 1981-2003 time-series. Parameter r is the intrinsic rate of increase, K = carrying capacity (mt), B_0 = initial biomass of time-series, c = per capita consumption of weakfish by striped bass, A is weakfish biomass where satiation of striped bass occurs, and mean q is average catchability.

Treatment	r	K	Bo	c	A	Mean q
Original	1.17	49080	65275	0.076	1959	0.000020
end 2002	1.14	49080	65262	0.084	9242	0.000020
end 2001	1.11	49081	65146	0.082	12500	0.000019
end 2000	1.08	49080	65298	0.076	20335	0.000018
start 1982	1.26	49139	16744	0.155	11387	0.000020
start 1983	1.23	48738	16738	0.164	14824	0.000020
start 1984	1.22	43989	16744	0.155	15705	0.000020
1981 fixed	1.16	44719	49000	0.279	27293	0.000020

Table 6. Estimates of logistic predator-prey model parameters r, K , and c (per capita effect of weakfish by striped bass) under sigmoidal and linear (constant) striped bass predation functions. SSQ is the sum of squared deviations of observed and predicted WRI indices.

Time-series	Predator function	r	K (mt)	c	SSQ
1981-2003	Sigmoid	1.17	49,080	0.076	2.62
1982-2003	Sigmoid	1.26	49,139	0.155	2.71
1981-2003	Linear	1.09	55,136	0.073	2.89
1982-2003	Linear	1.25	37,883	0.069	2.49

Table 7. Summary of results of analyses of candidate predator-competitors and weakfish. Model refers to a logistic Steele and Henderson (1984) predator-prey model . "Recent decline?" indicates that the predator-prey model with weakfish produced a decline in weakfish biomass in the most recent years. Biomass ratio is the ratio of predicted to observed (or vice-versa, depending on which is < 1) 1981-2003 mean biomass estimates. Parameter r = intrinsic rate of population increase; K = maximum population biomass (mt); maximum c is per capita consumption by candidate predator; A is weakfish biomass (mt)where predator satiation begins.

	Atlantic croaker	**Bluefish**	**Summer flounder**	**Spiny dogfish**	**Striped bass**
Landings Pearson correlation	r = 0.24 P = 0.08	r = 0.73 P < 0.0001	r = 0.73 P < 0.0001	NA	r = -0.34 P = 0.01
Predator-prey model r^2	0.72	0.01	0.62	0.29	0.78
Recent decline?	No	No	Yes	No	Yes
Biomass ratio	0.93	0.08	0.56	0.89	0.73
r (intrinsic rate)	1.00	2.92	0.62	1.22	1.17
K (mt)	53,823	296,109	293,653	56,672	49,080
c	0.398	1.198	1.190	0.214	0.076
A (mt)	88,414	90,377	43,843	92,115	1,959

Table 8. Scorecard for candidate species interaction with weakfish. Scoring criteria are explained in Table 3. Potential maximum score = 10 and indicates how strong a candidate a species would be for negative interactions with weakfish.

	Score				
Variable	**Atlantic croaker**	**Bluefish**	**Summer flounder**	**Spiny dogfish**	**Striped bass**
Landings correlation	0	0	0	0	1
Biomass correlation	0.72	0.01	0.62	0.29	0.78
Recent decline	0	0	1	0	1
Biomass closeness	0.93	0.08	0.56	0.89	0.73
Weakfish in diet	0	1	1	1	1
Anchovy in diet	1	1	1	1	1
Menhaden in diet	0	1	0	0	1
Spot in diet	0	1	0	0	1
Clupieds in diet	0	1	1	1	1
Scianeids in diet	0	1	1	1	1
Score (sum)	2.65	6.09	6.18	5.18	9.51

FIGURES

Figure 1. Atlantic Coast commercial landings of weakfish, striped bass, Atlantic croaker, summer flounder, and bluefish.

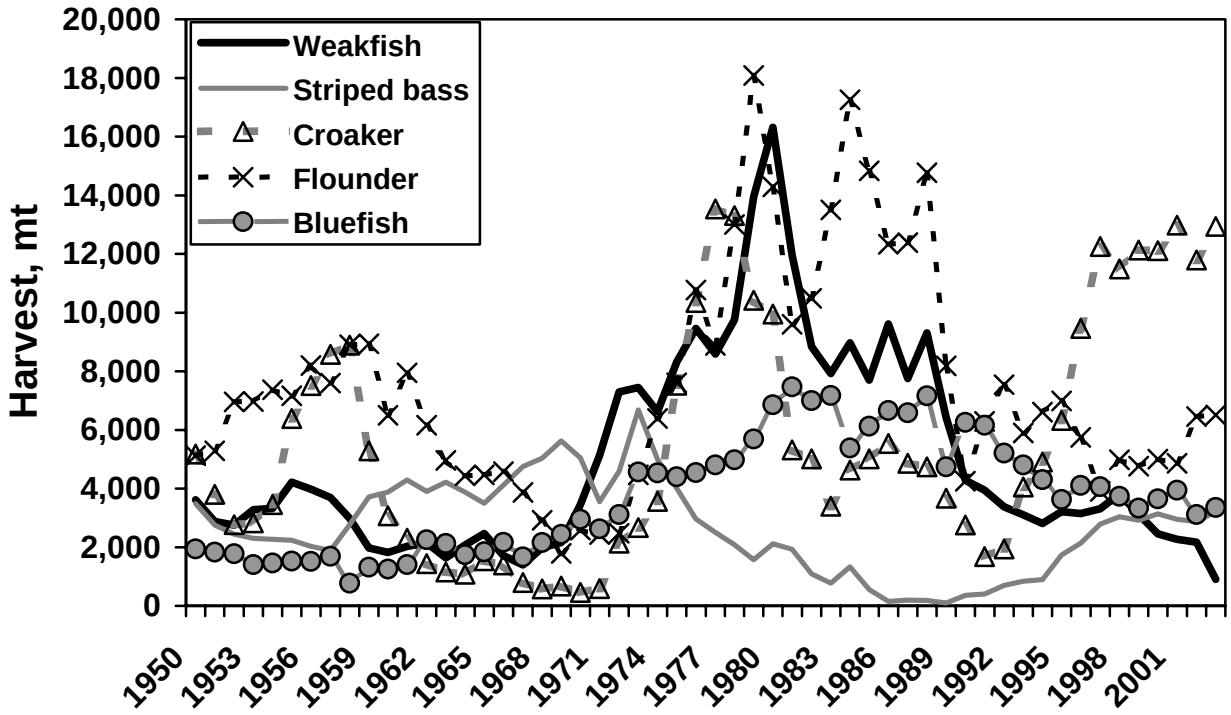


Figure 2. Relative abundance or biomass indices for weakfish. WRI is an MRFSS catch per trip index and equals MRFSS estimates of private/rental catch per trip in mid-Atlantic state waters (harvest and releases). Delaware and New Jersey trawl survey exploitable biomass indices estimated relative biomass of 25 cm and larger weakfish and are z-transformed values plus one.

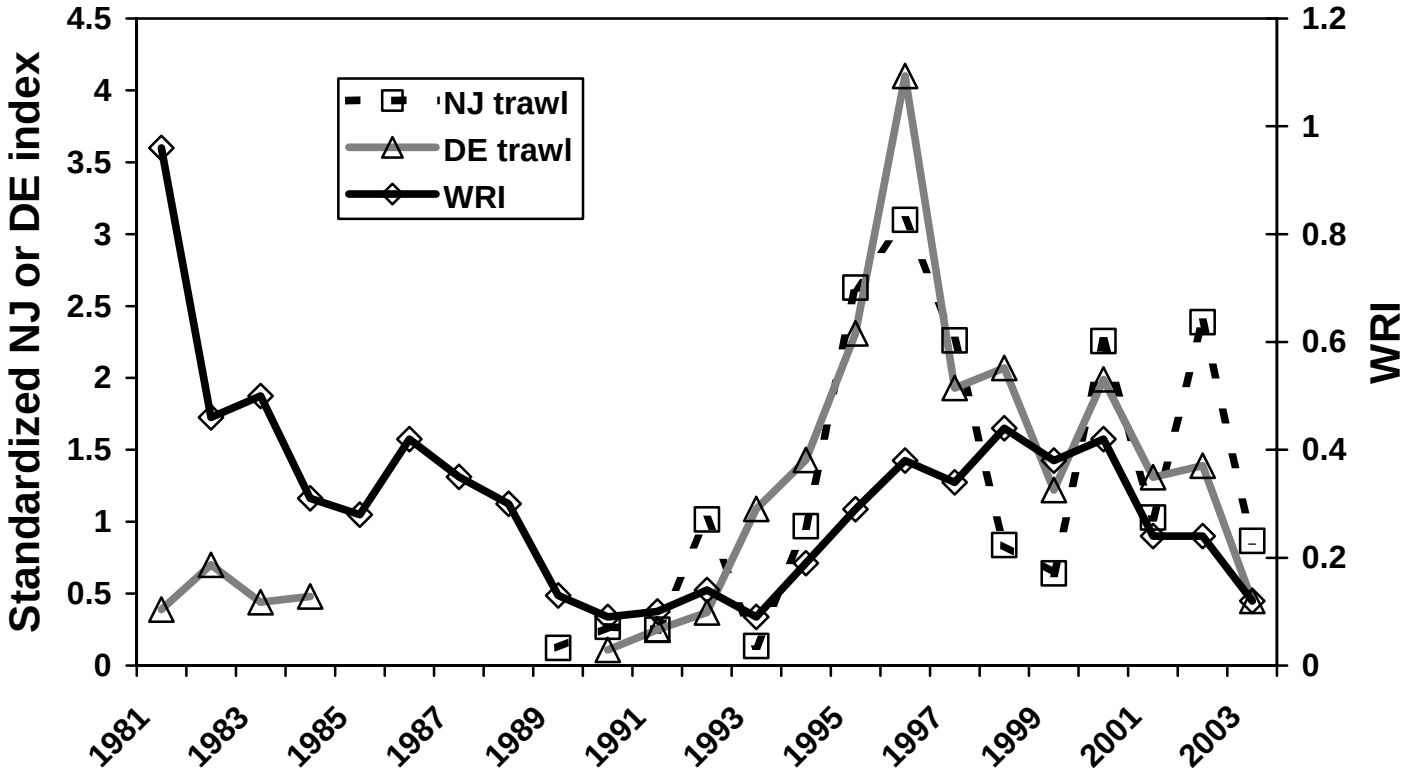


Figure 3. Estimated WRI and New Jersey and Delaware trawl survey catchability versus converged VPA biomass. Delaware estimates have been divided by 10 to place them on the figure.

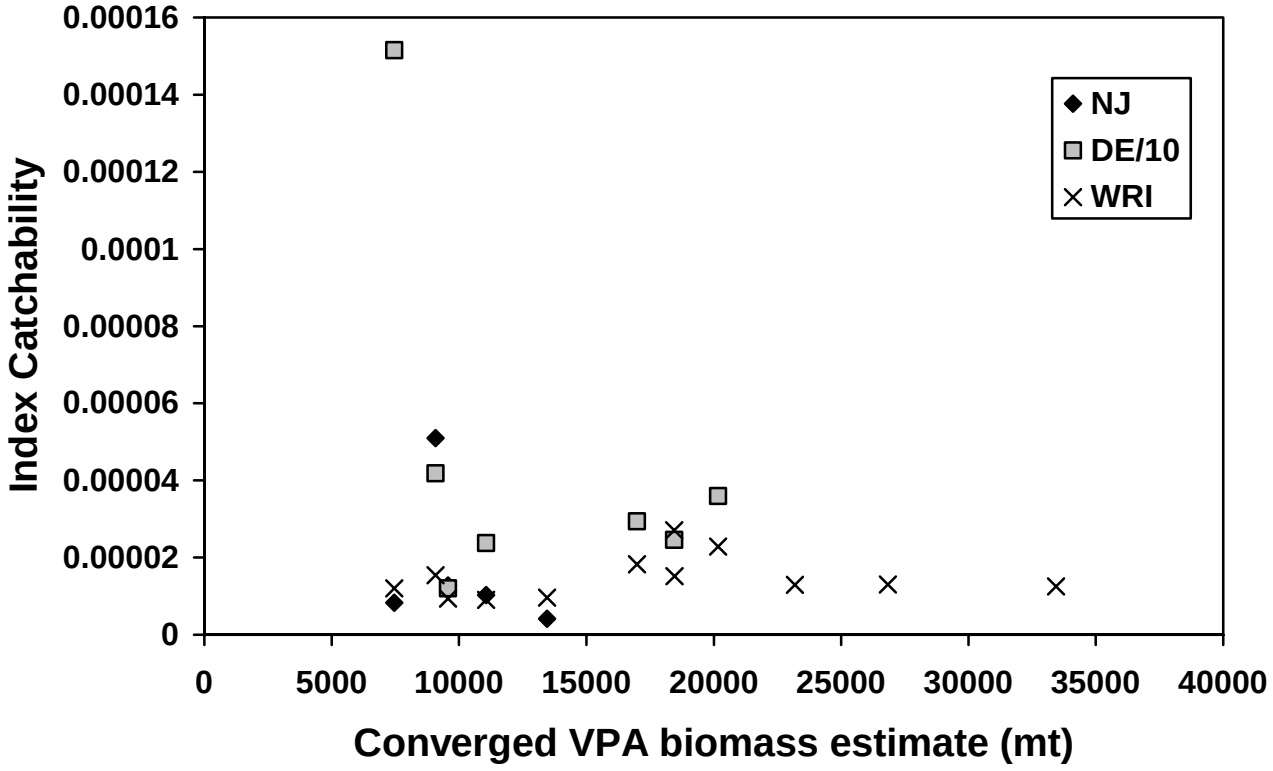


Figure 4. Mean weight at age of 1-5 year-old weakfish in the VPA catch-at-age matrix.

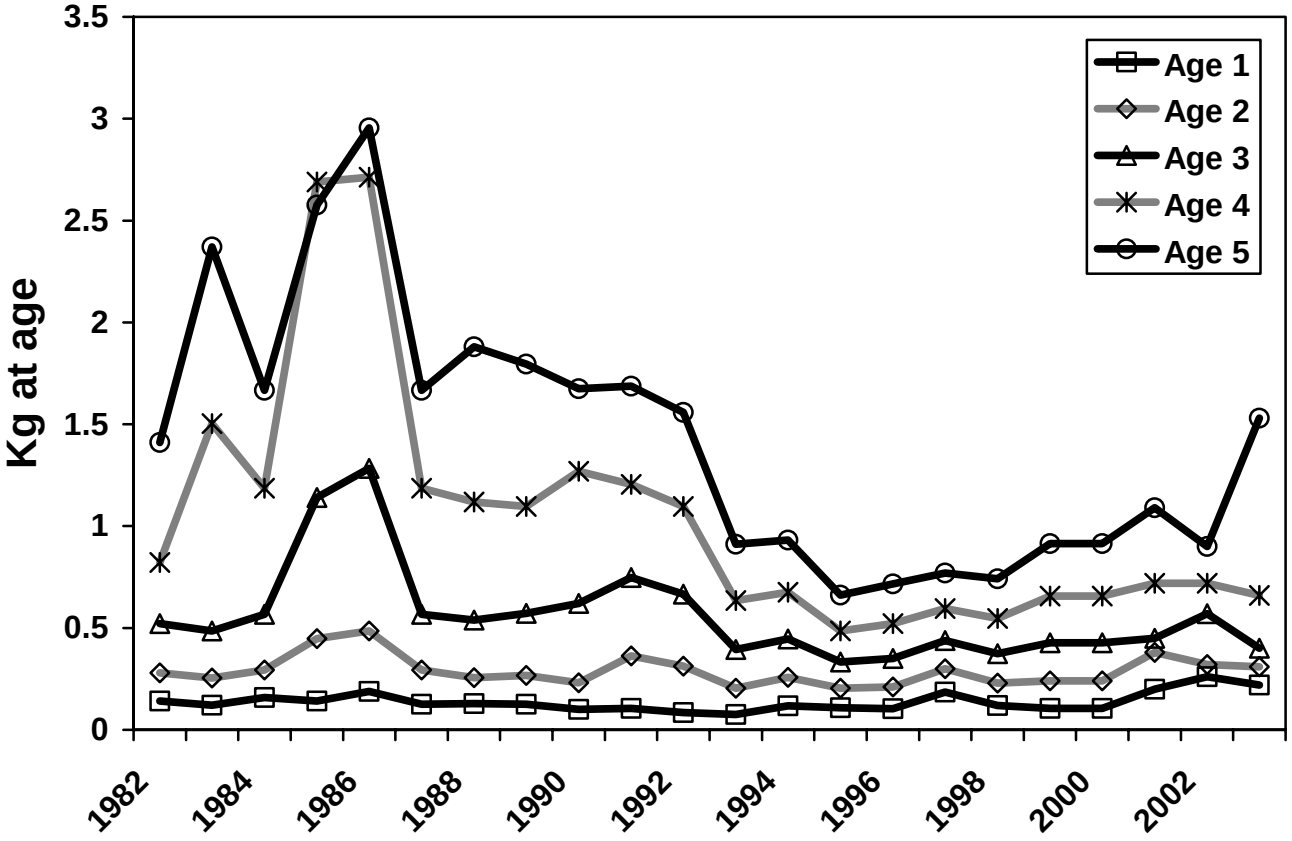


Figure 5. Delaware trawl survey Quality Proportional Stock Density (PSD Quality +). This index equals number of 340 mm+ weakfish divided by number that are 210 mm+ and indicates the proportion of weakfish of interest to anglers.

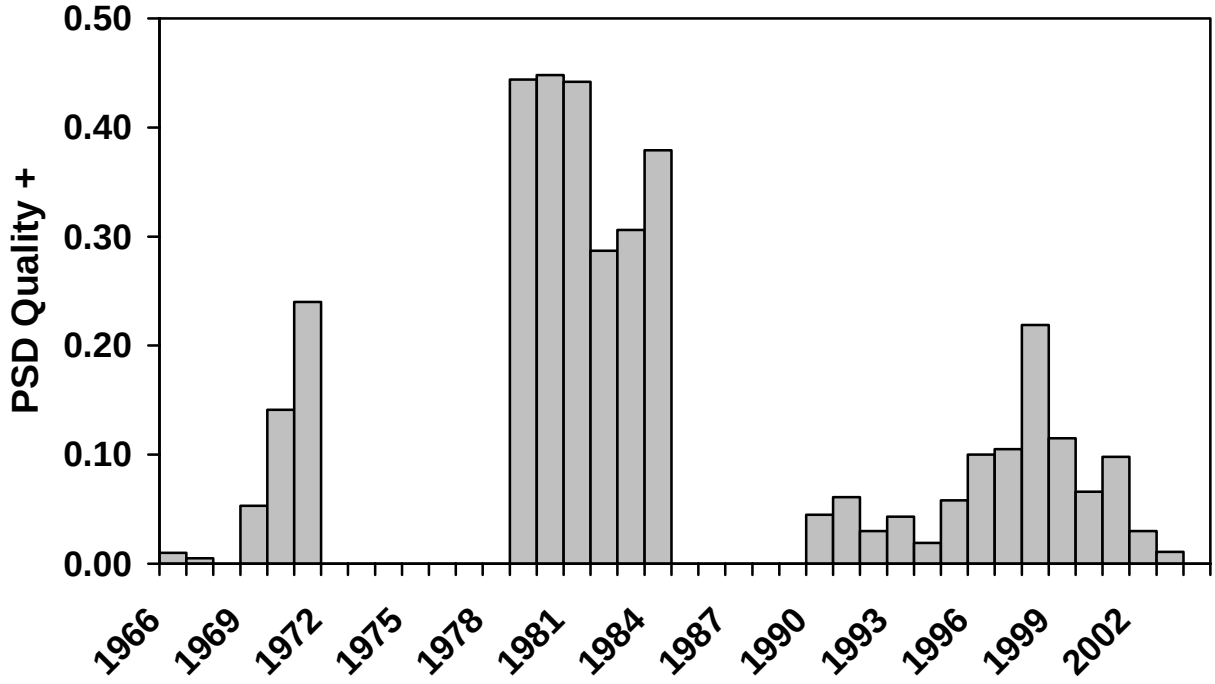


Figure 6. Striped bass biomass indicators along the Atlantic Coast.
Age 2+ biomass was estimated by ADAPT VPA (A. Sharov, MDDNR, personal communication). Egg presence-absence is the proportion of plankton tows with eggs in Chesapeake Bay spawning rivers and is a long-term indicator of mature female biomass (Uphoff 1997).

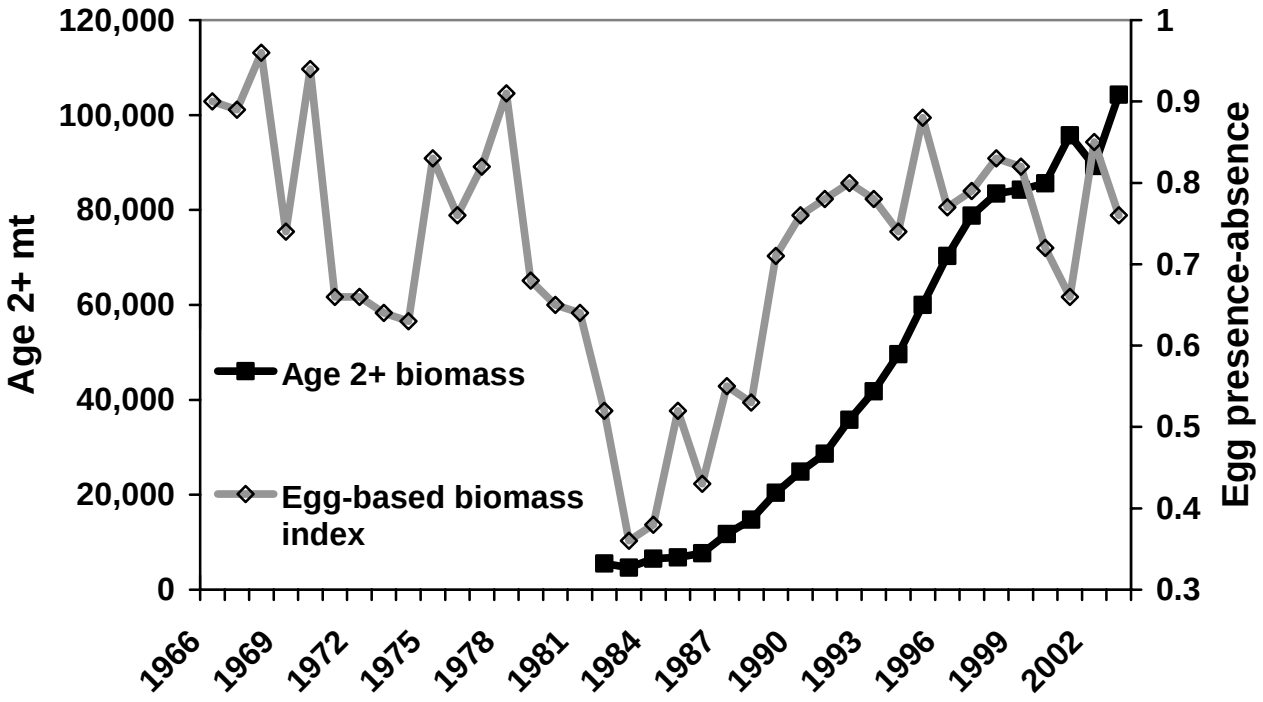


Figure 7. Z-transformed indices of relative abundance of age 0 menhaden in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices for NC are based on the same survey, but different estimators of central tendency; GM = geometric mean and DLN is delta log-normal. A value of zero indicates average abundance for the available time-series.

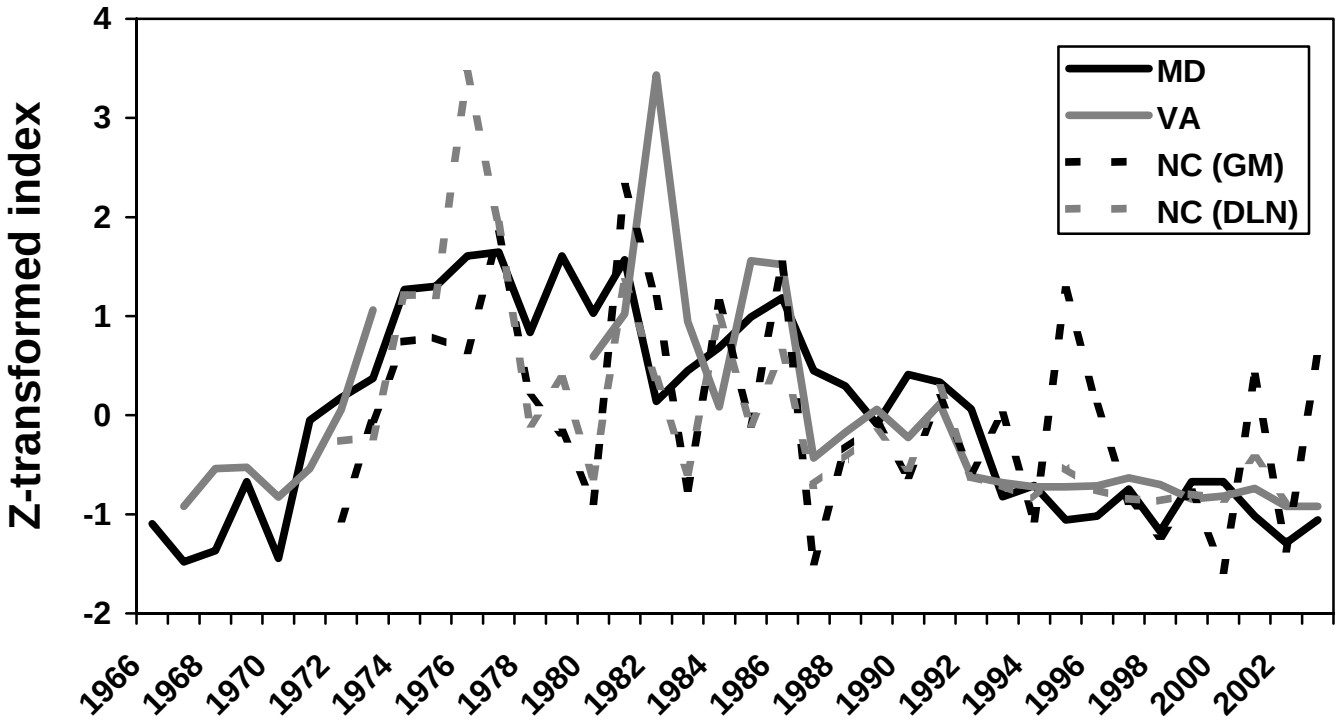


Figure 8. Z-transformed indices of relative abundance of age 0 menhaden in Delaware Bay. Methodologies and locations are summarized in Table 1. A value of zero indicates average abundance for the available time-series.

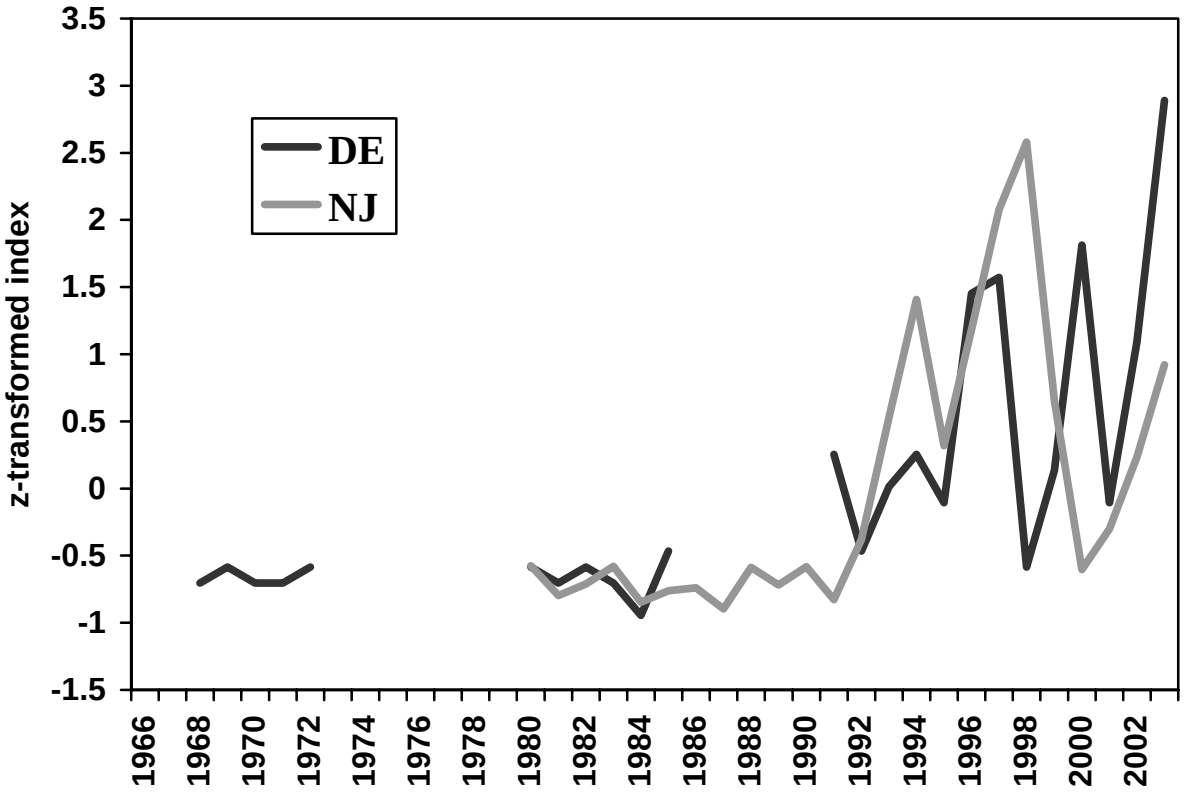


Figure 9. Estimated abundance of age 0 Atlantic menhaden along the Atlantic Coast (ASMFC 2004).

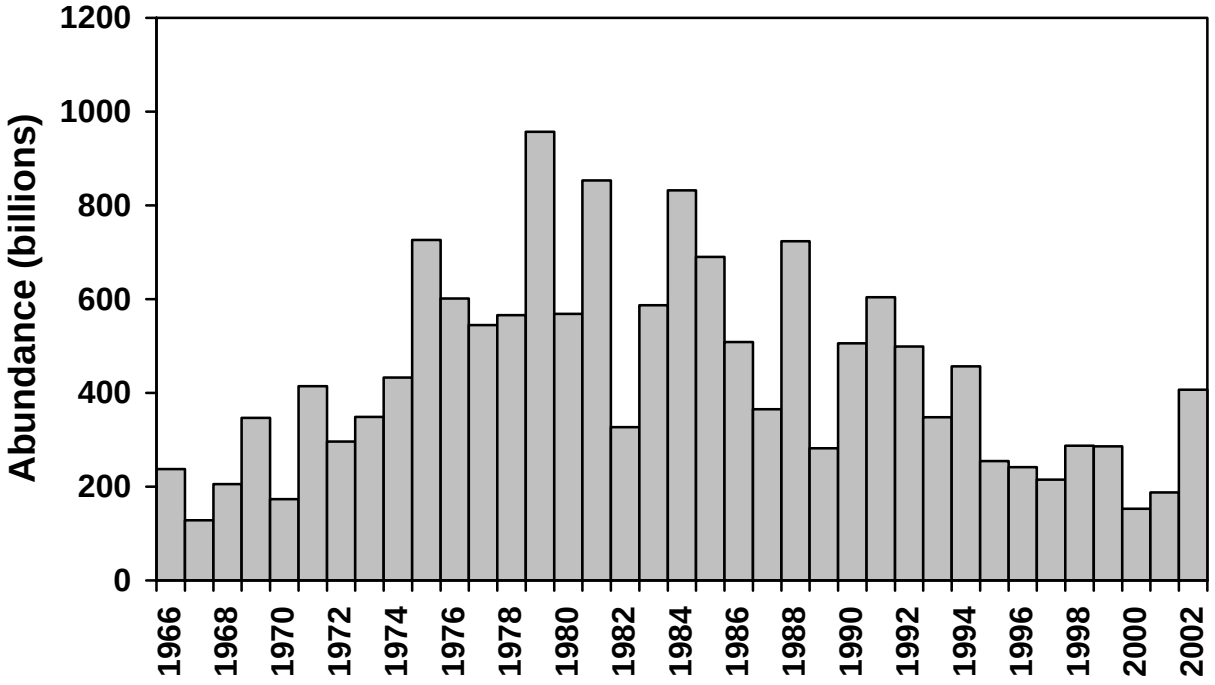


Figure 10. Z-transformed indices of relative abundance of spot in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

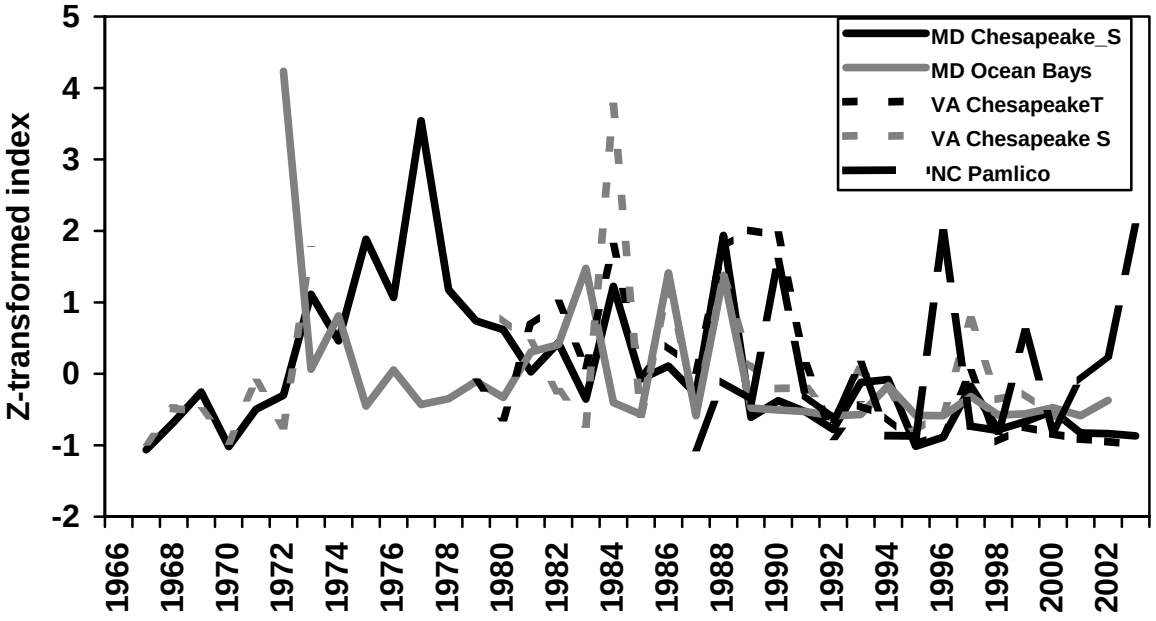


Figure 11. Z-transformed indices of relative abundance of spot in Delaware and New Jersey. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

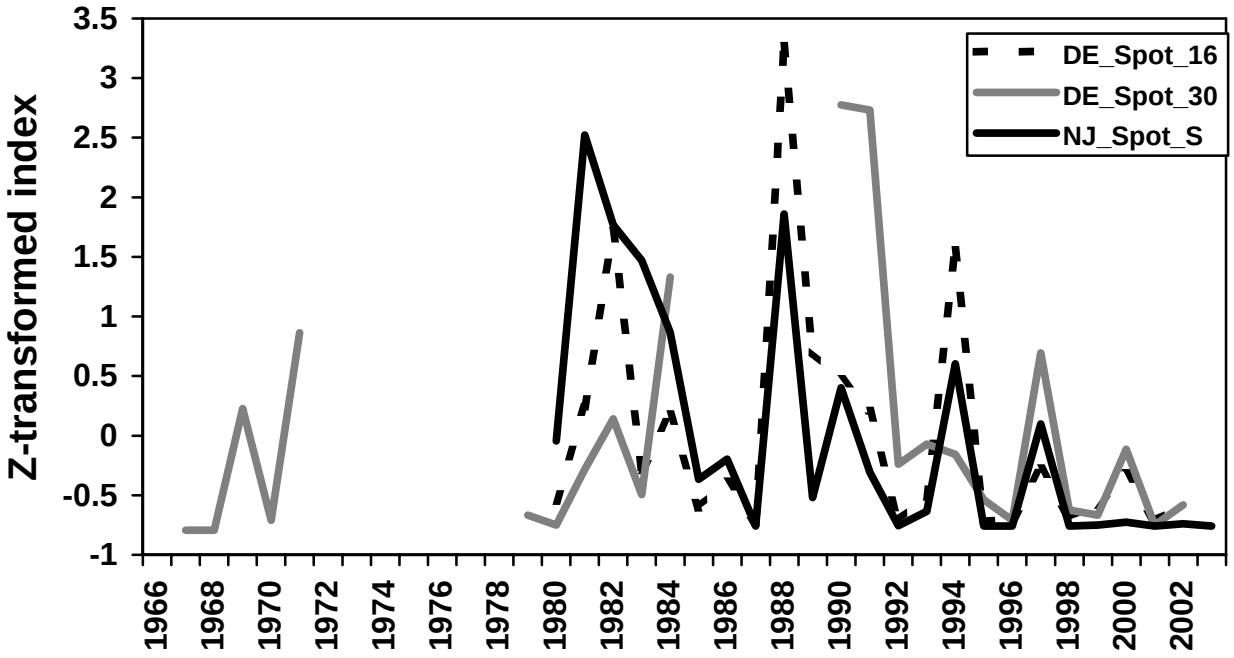


Figure 12. Z-transformed indices of relative abundance of bay anchovy in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

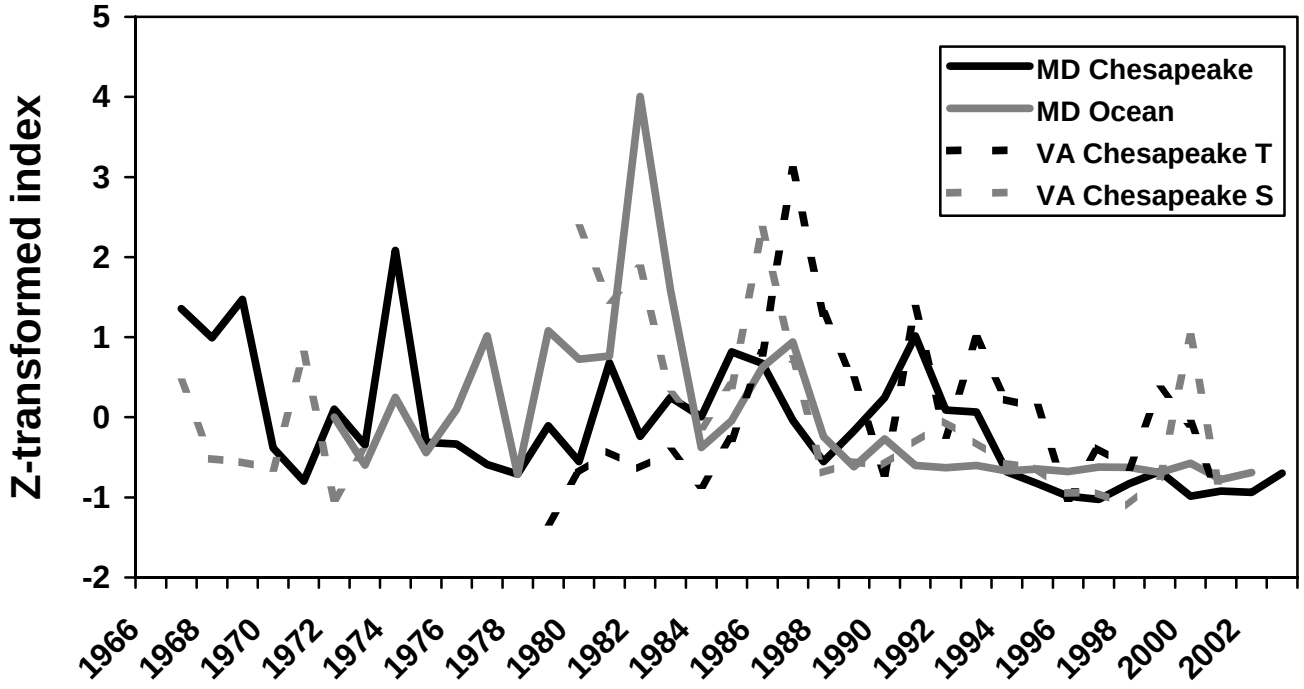


Figure 13. Z-transformed indices of relative abundance of bay anchovy in Delaware and New Jersey. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

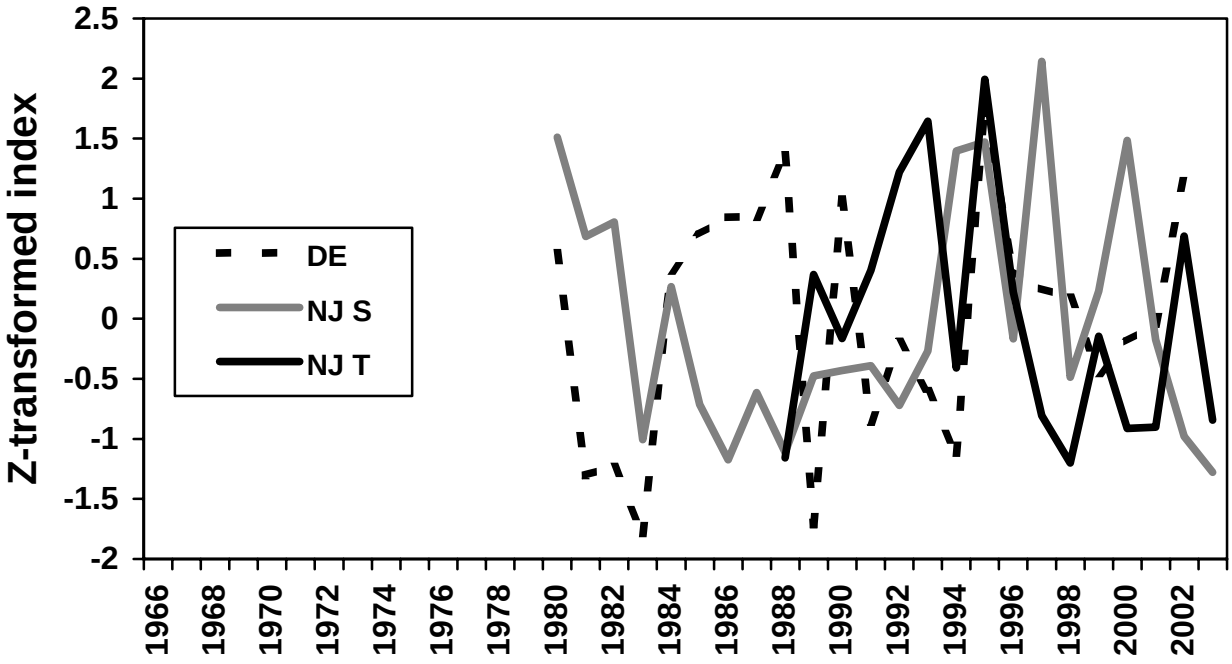


Figure 14. Predicted and observed PSD Q+ weakfish size quality index from multiple regression of age 0 menhaden abundance and a striped bass biomass index.

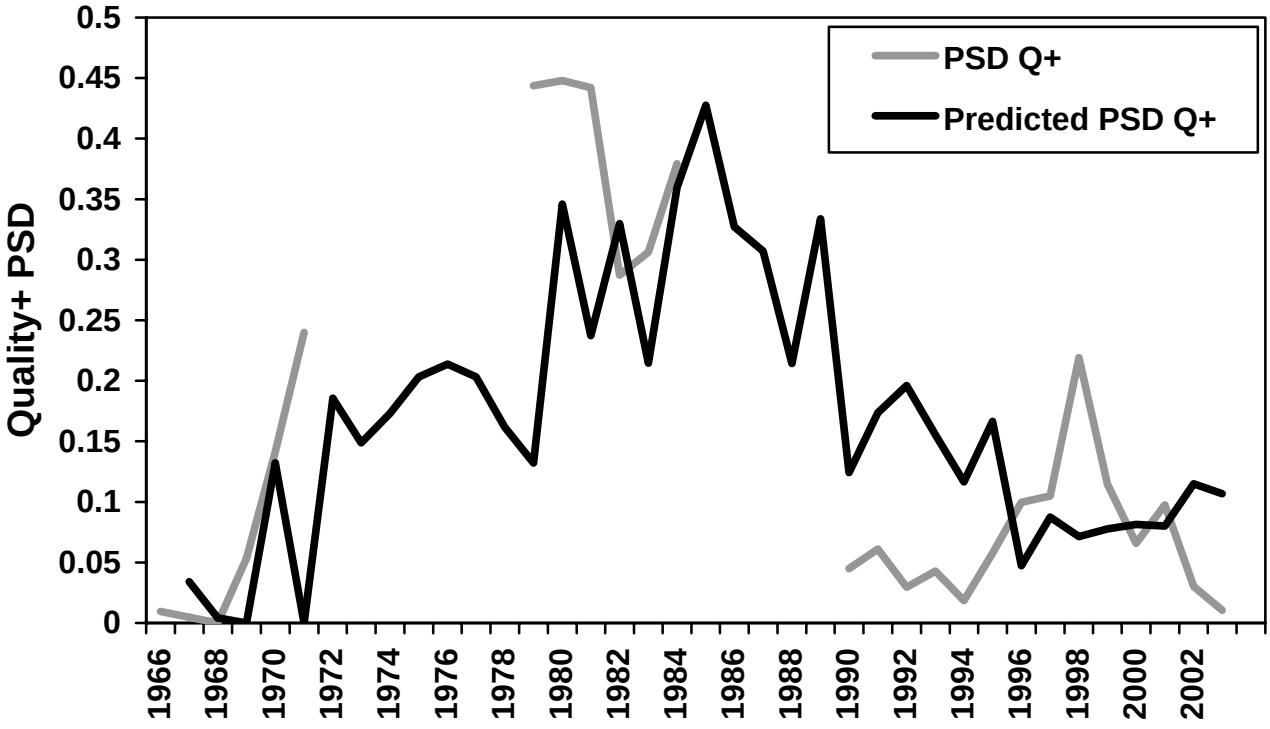


Figure 15. Weakfish catch per trip (includes number harvested and released) index (WRI) versus age 2+ striped bass biomass. Different stanzas are represented by different symbols.

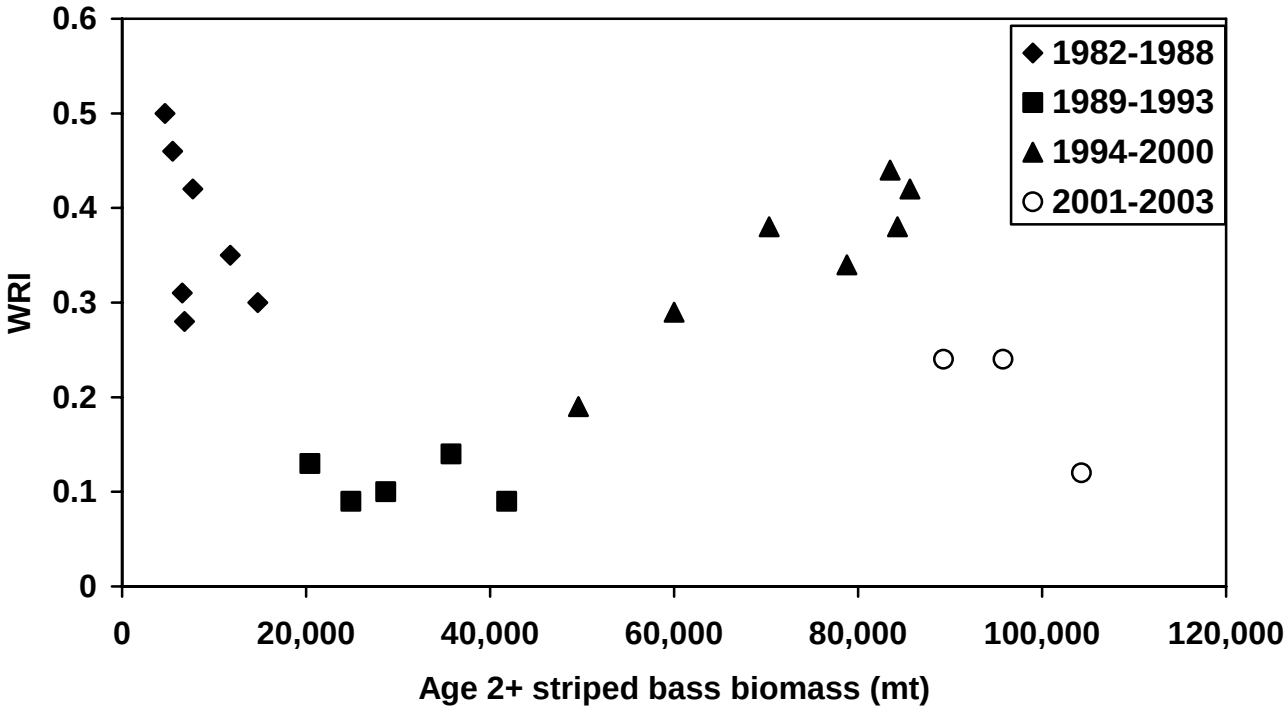


Figure 16. Weakfish biomass indices for DE and NJ trawl surveys versus age 2+ striped bass biomass. Indices are Z-transformed + 1 values. Stanzas in Figure 15 (WRI and striped bass) are maintained and represented by different symbols. Solid symbols represent DE and unfilled symbols indicate NJ.

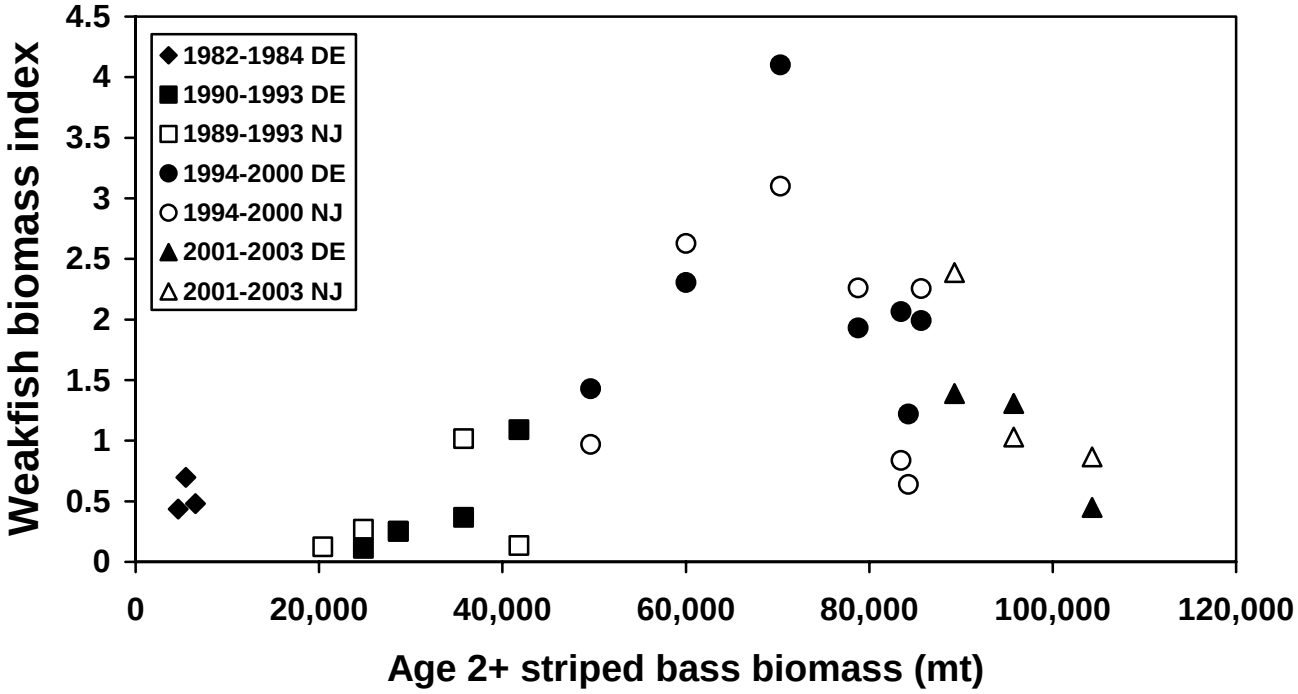


Figure 17. Atlantic Coast commercial landings of weakfish plotted against striped bass landings during 1950-2003. Decades are identified by different symbols; 1990s included 2000-2003. Predicted landings estimated by categorical regression are indicated by solid lines.

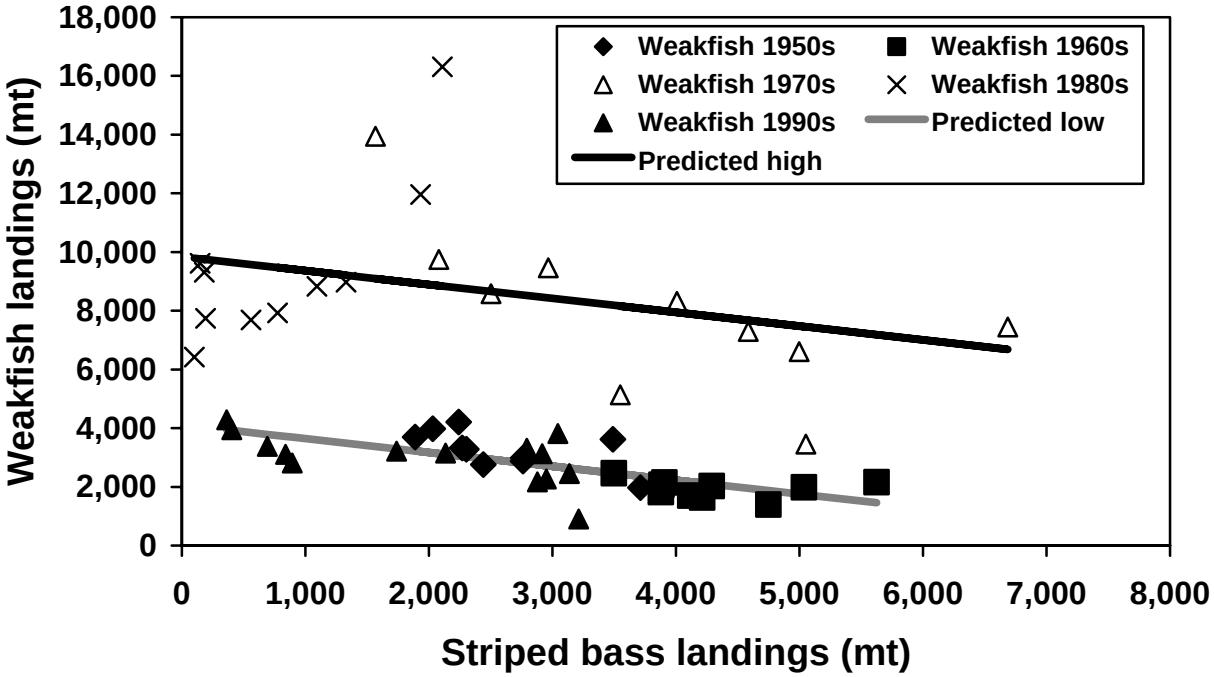


Figure 18. Observed and predicted weakfish landings from categorical regression of bass egg index and time period category.

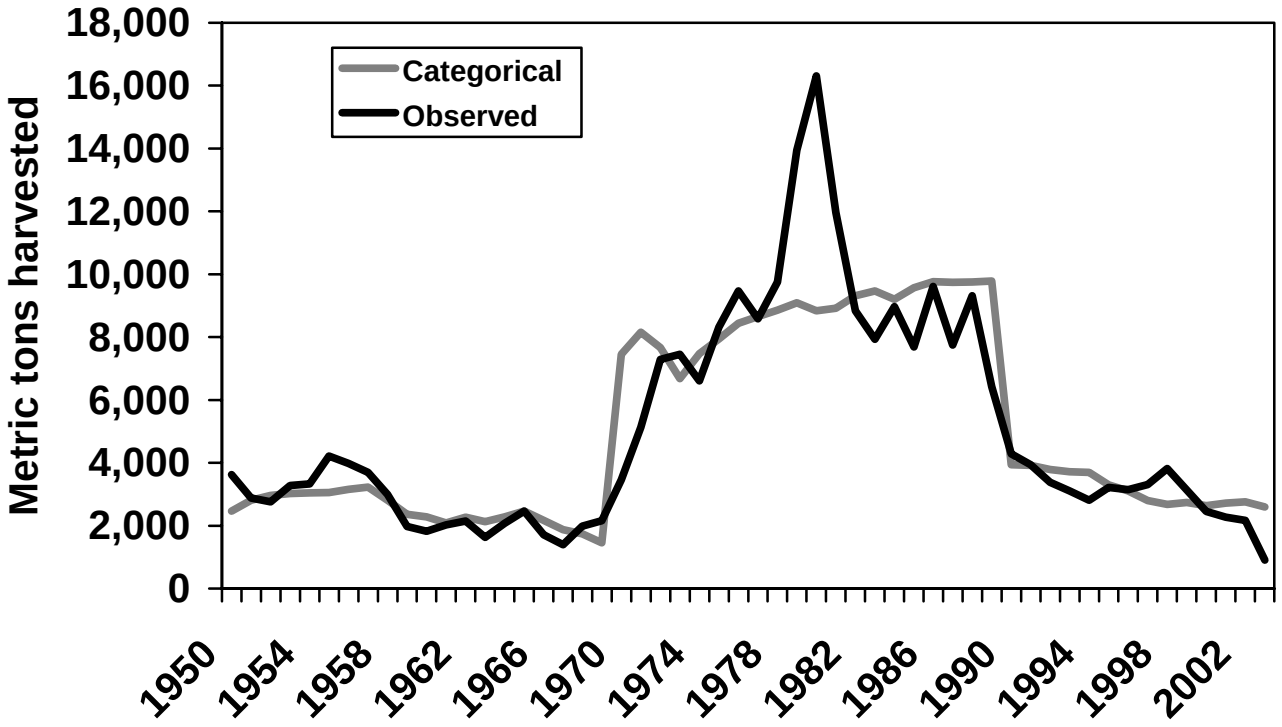


Figure 19. Observed and predicted weakfish landings from multiple regressions of bass egg index and menhaden abundance estimates or menhaden juvenile index.

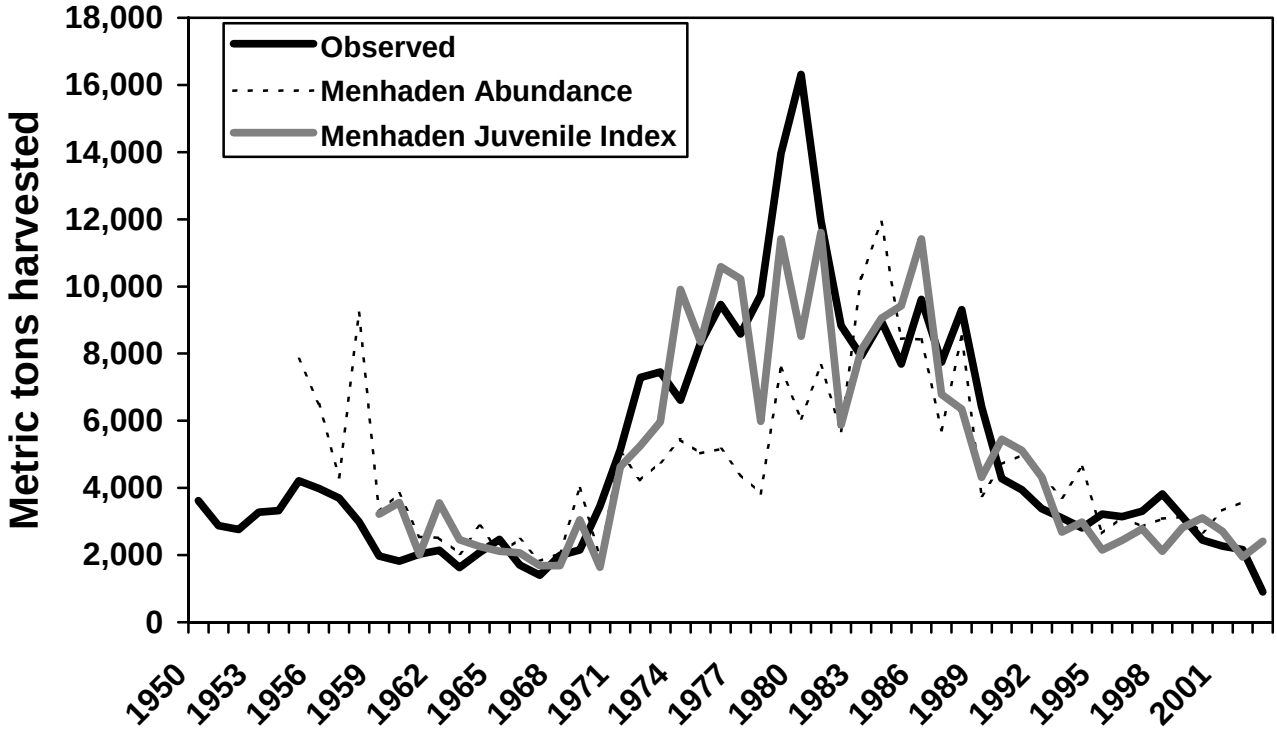


Figure 20. Trends in M_{vpa}.

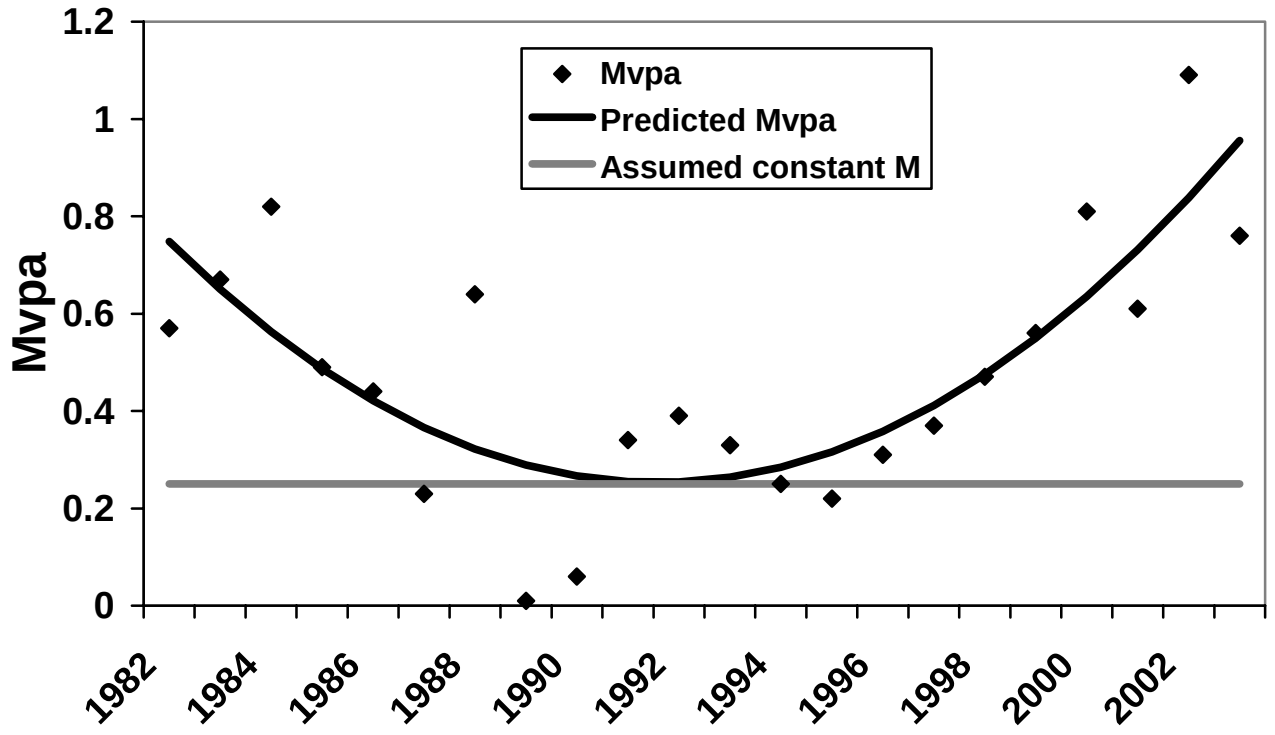


Figure 21. Observed and weakfish biomass indices estimated by logistic striped bass-weakfish predator-prey model.

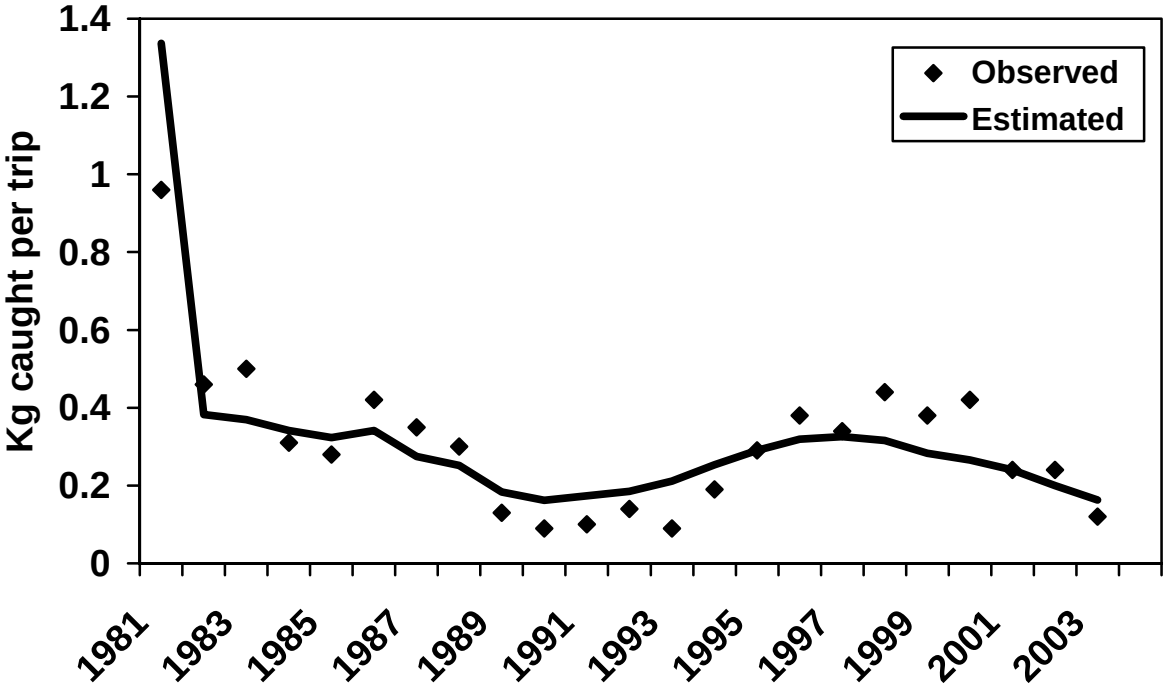


Figure 22. Annual instantaneous mortality rates due to fishing (F), striped bass competition and predation (Mb), F+Mb (Z), and biomass estimated from the logistic predator-prey model.

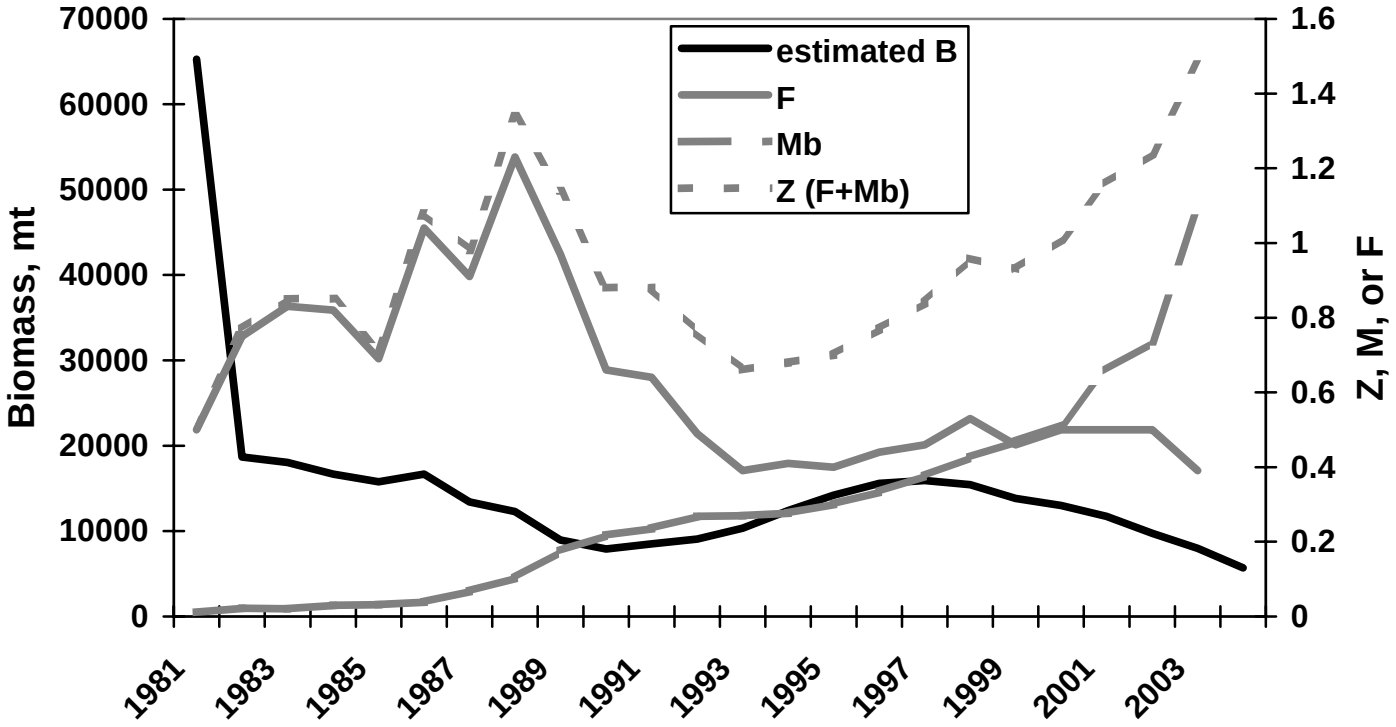


Figure 23. Surplus production estimated from the logistic predator-prey model with and without (traditional) accounting for striped bass predation and competition.

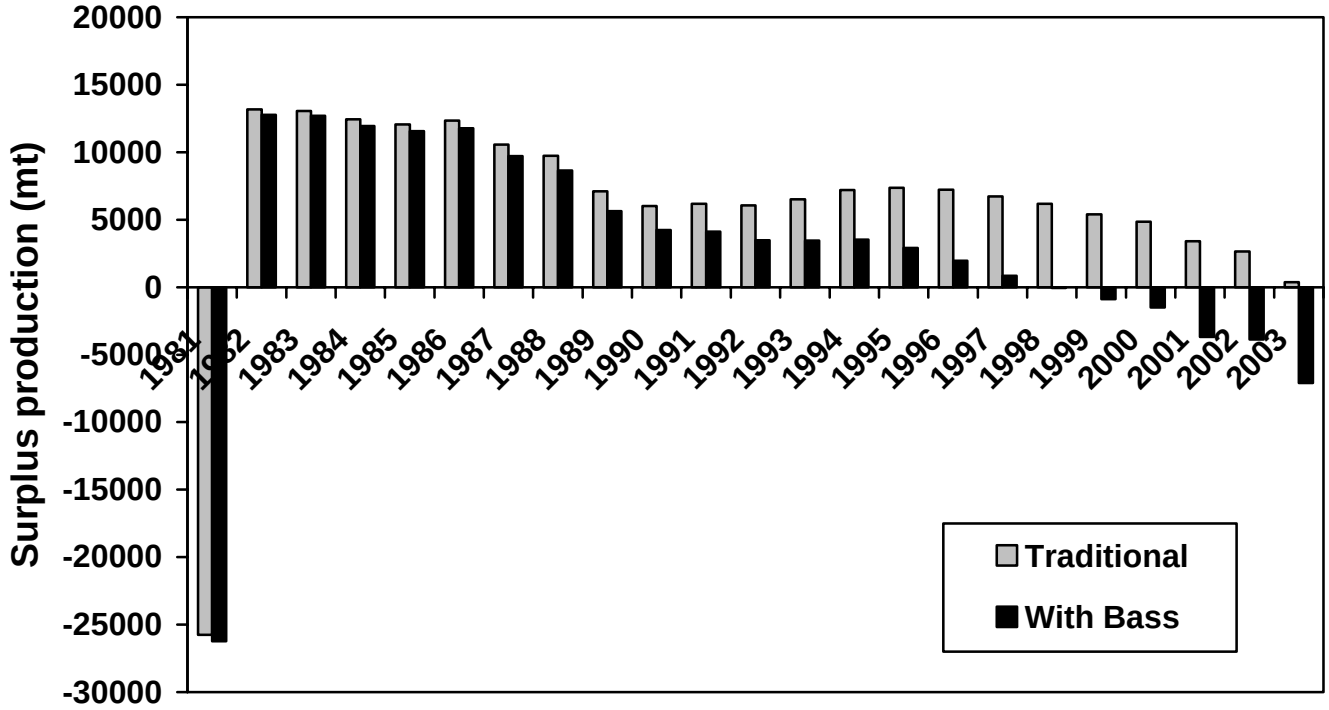


Figure 24. Surplus production calculated with and without (traditional) striped bass associated losses plotted against estimates of F during 1982-2003 from the logistic predator-prey model. Points from 1981 were treated as outliers and omitted from this plot.

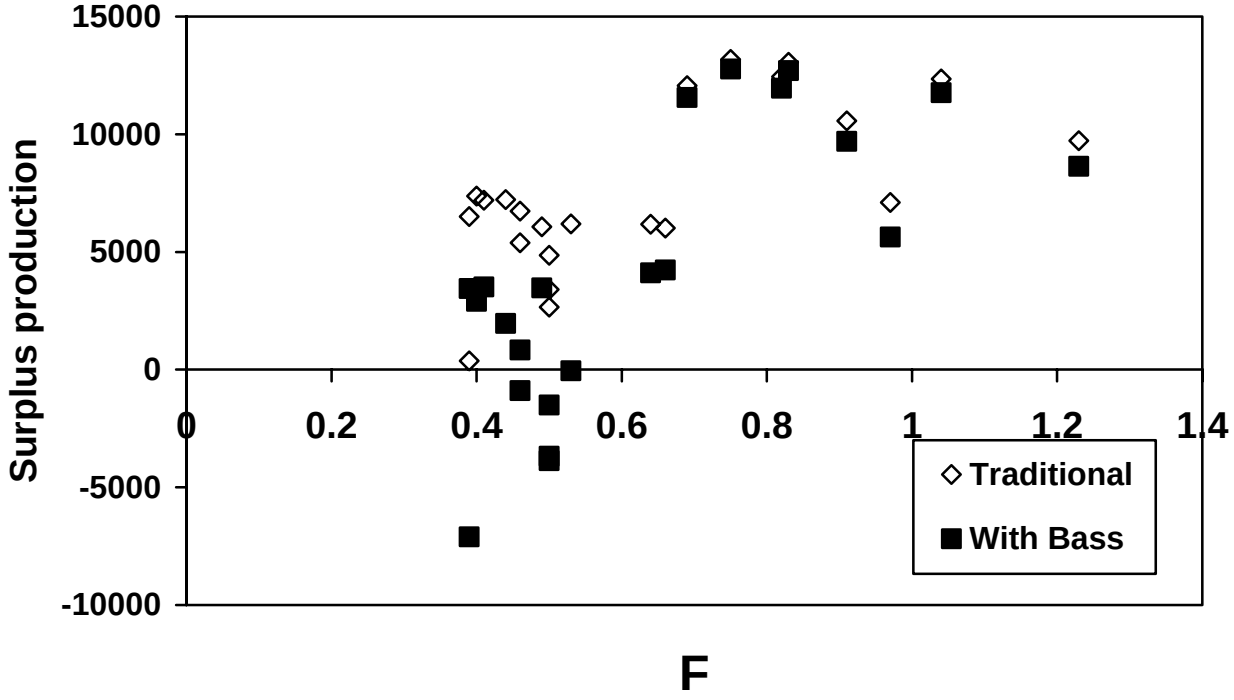


Figure 25. Surplus production calculated with and without (traditional) striped bass associated losses plotted against estimates of Mb during 1982-2003 from the logistic predator-prey model. Points from 1981 were treated as outliers and omitted from this plot.

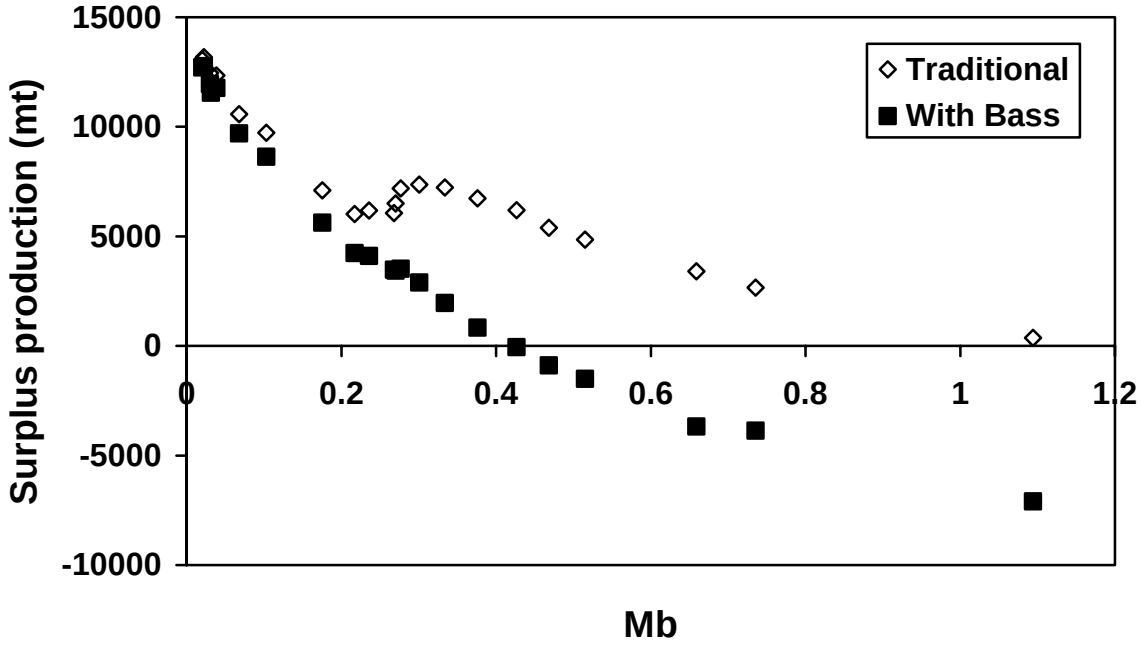


Figure 26. Fit of Schaefer and logistic Steele and Henderson (predator-prey) models to the WRI time-series

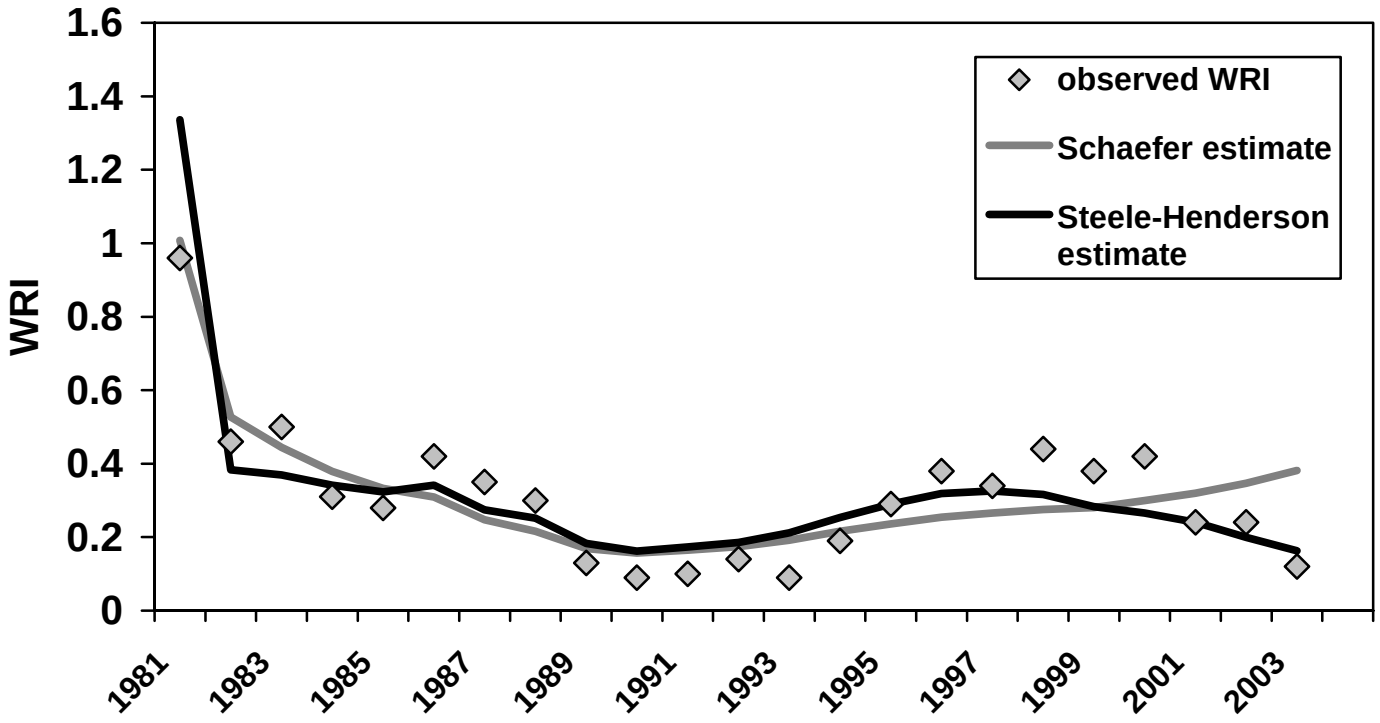


Figure 27. Observed and predicted indices from sensitivity analysis of time-series of the logistic predator-prey model. Original data – 1981-2003. 1-3 years removed from beginning (start) and end; 1981 fixed indicates a value was set to initiate time-series.

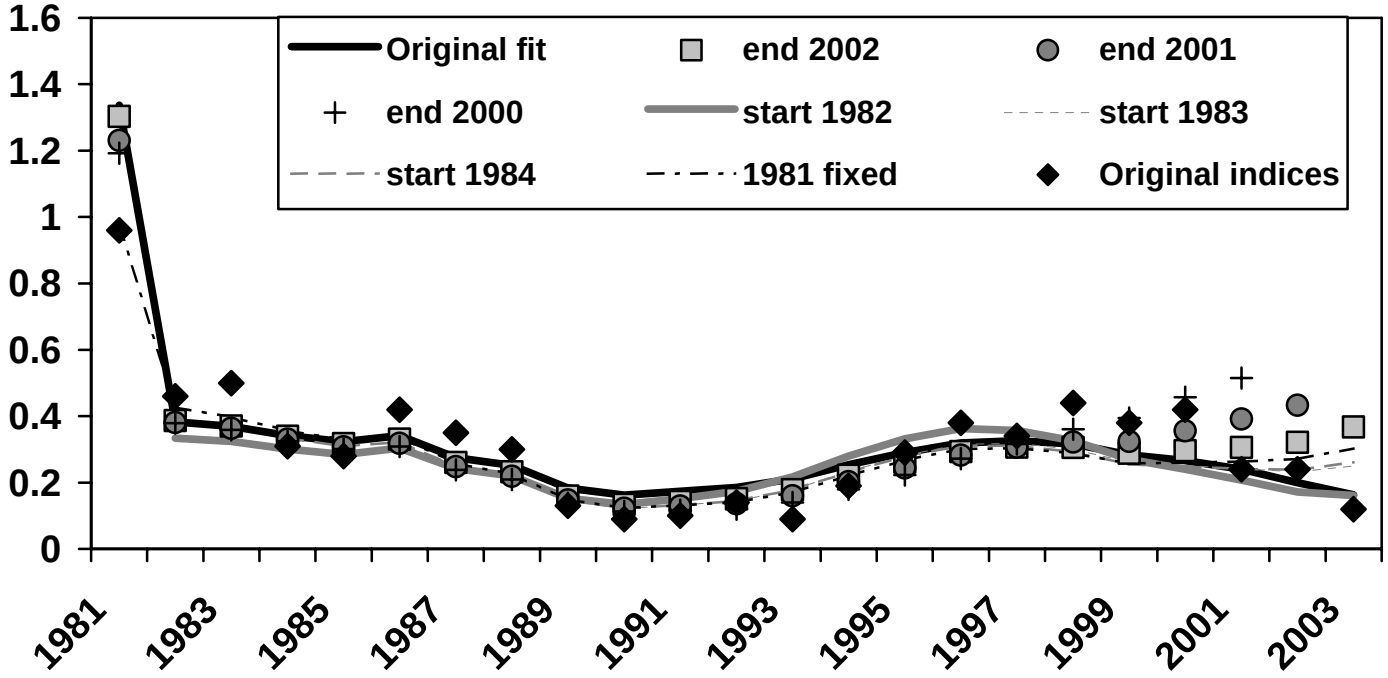


Figure 28. Logistic predator-prey model predicted weakfish biomass consumed per unit of striped bass biomass plotted against weakfish biomass (striped bass functional response) for two time-series. Intersections of predator-prey parameters c and A are indicated for each time-series by open symbols.

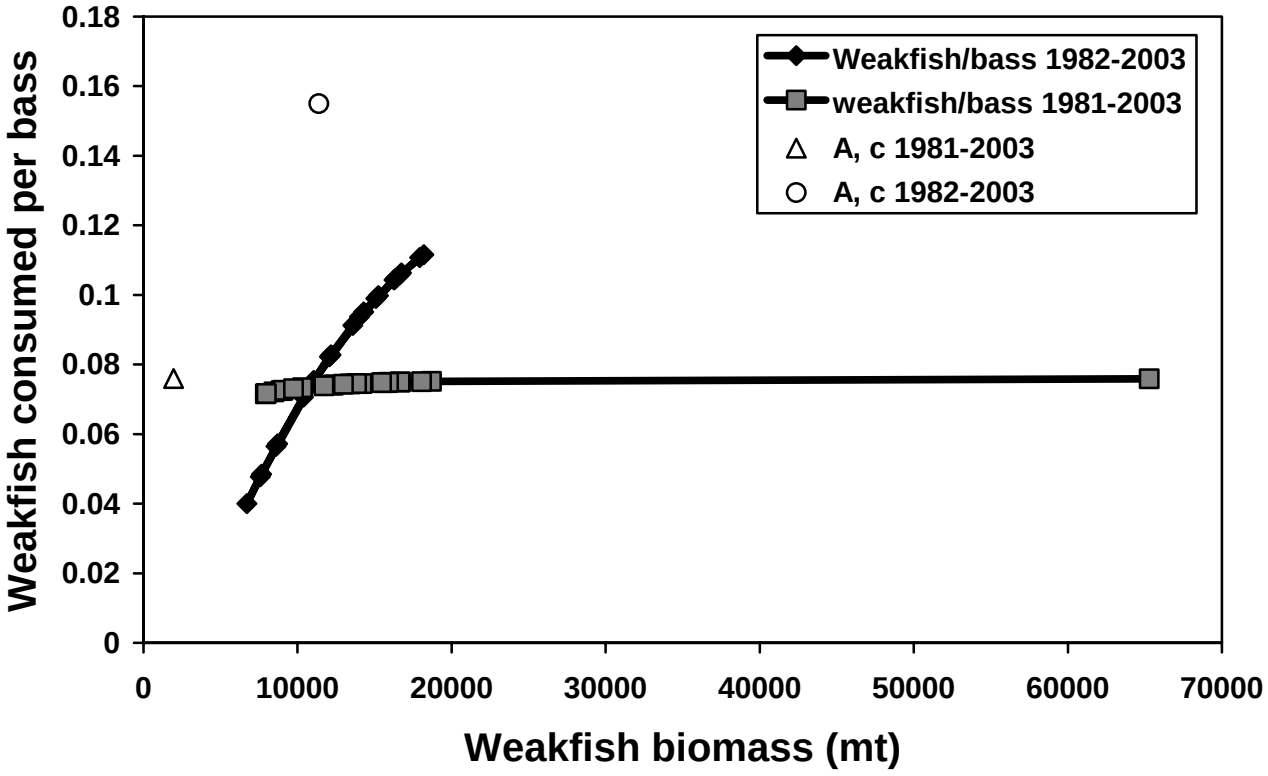


Figure 29. F estimated from rescaled VPA, Schaefer, and logistic Steele and Henderson predator-prey models with the WRI as their basis.

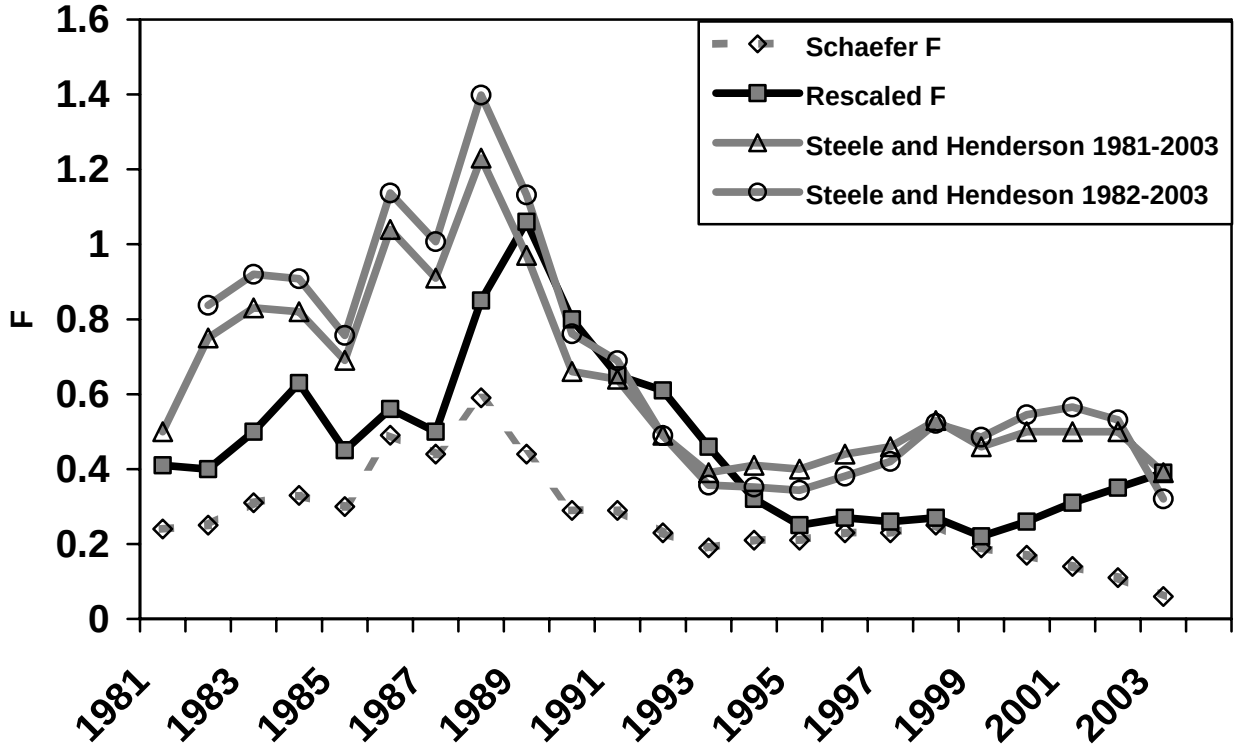


Figure 30. Estimates of Mb from the logistic weakfish-bass predator-prey model applied to two time-series.

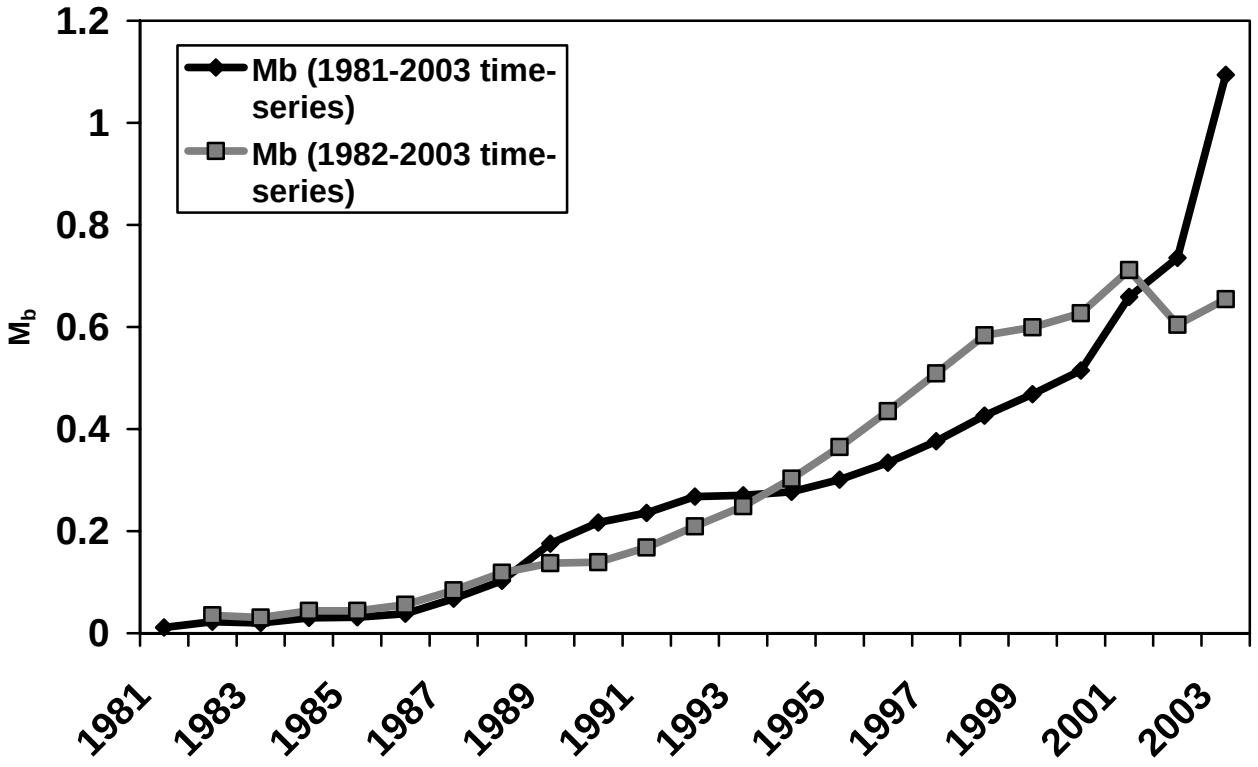


Figure 31. Estimates of Z from ADAPT and from logistic striped bass-weakfish predator-prey models (Steele and Henderson model). Predator-prey model does not include M from sources other than striped bass.

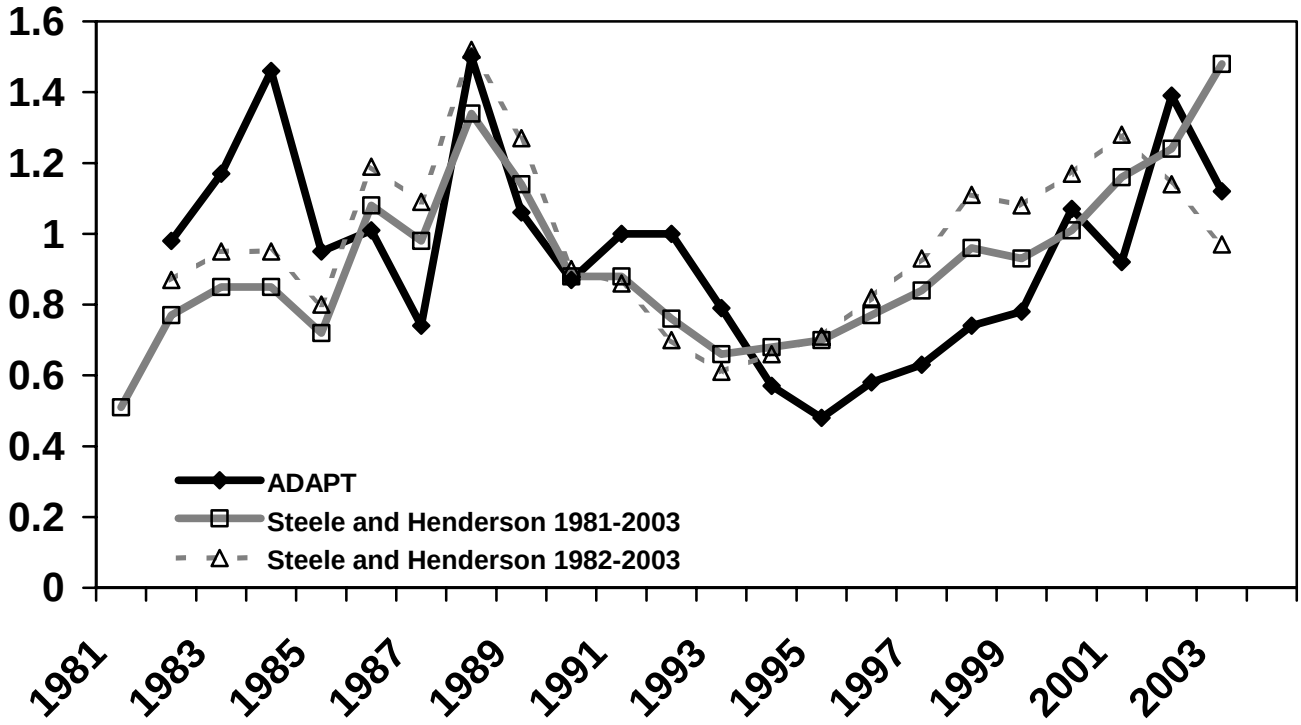


Figure 32. Logistic predator-prey model biomass estimates based on WRI. Figure omits 1981 estimates.

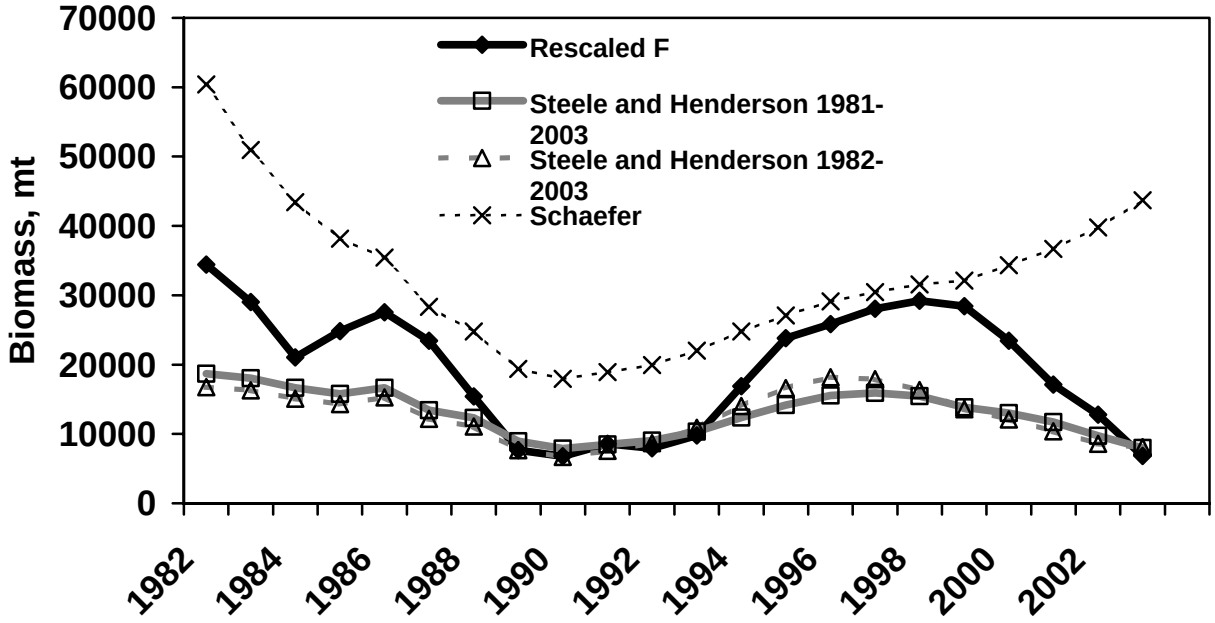


Figure 33. Trends in biomass of weakfish and other candidate alternative predator-competitors for the logistic predator-prey model.

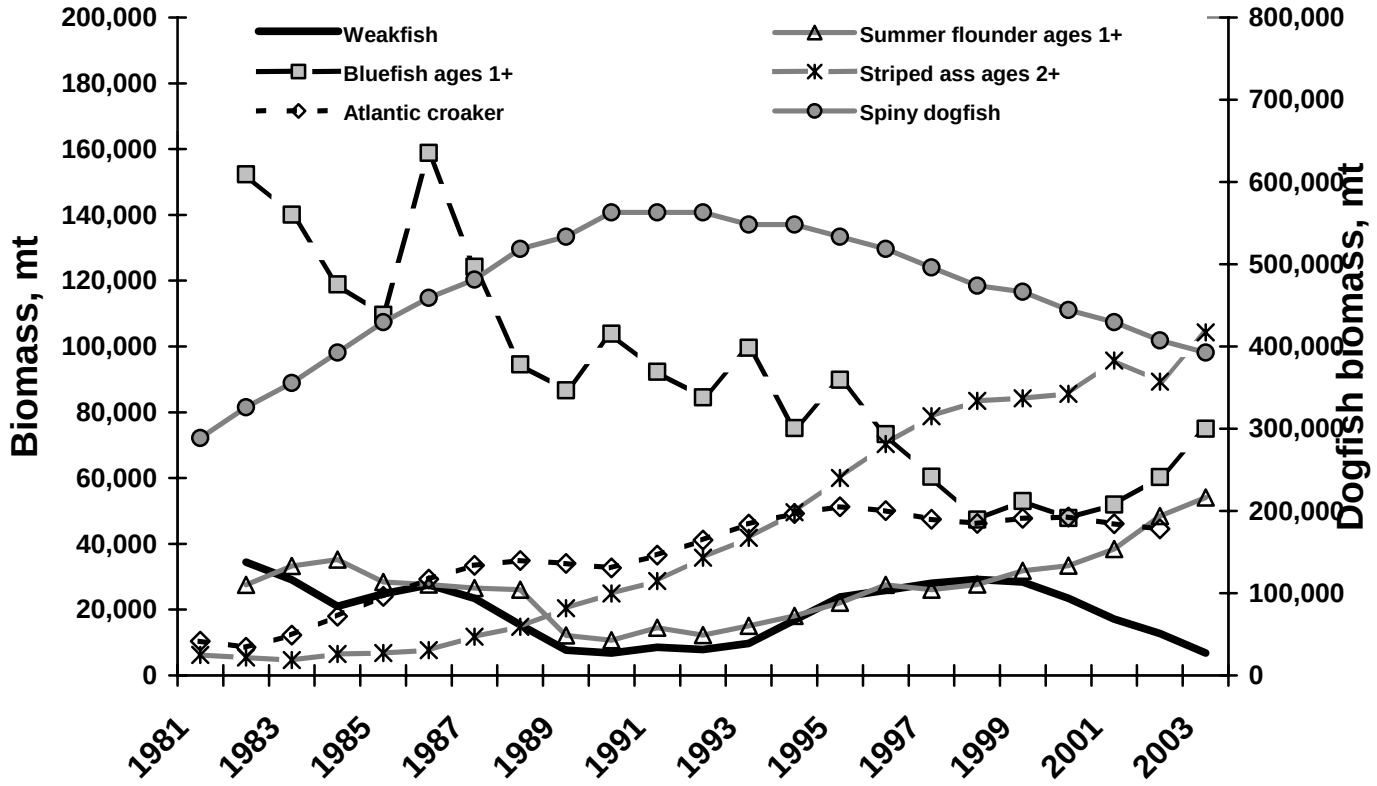


Figure 34. Weakfish biomass predicted from an Atlantic croaker- weakfish logistic predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

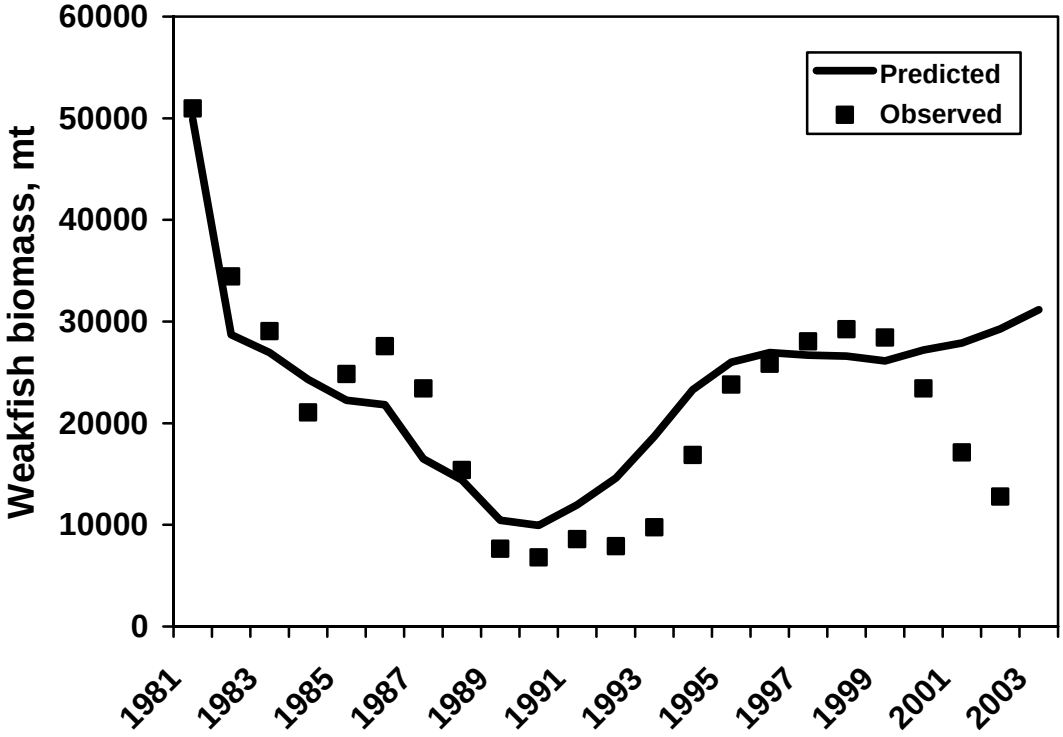


Figure 35. Weakfish biomass predicted from a logistic bluefish - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

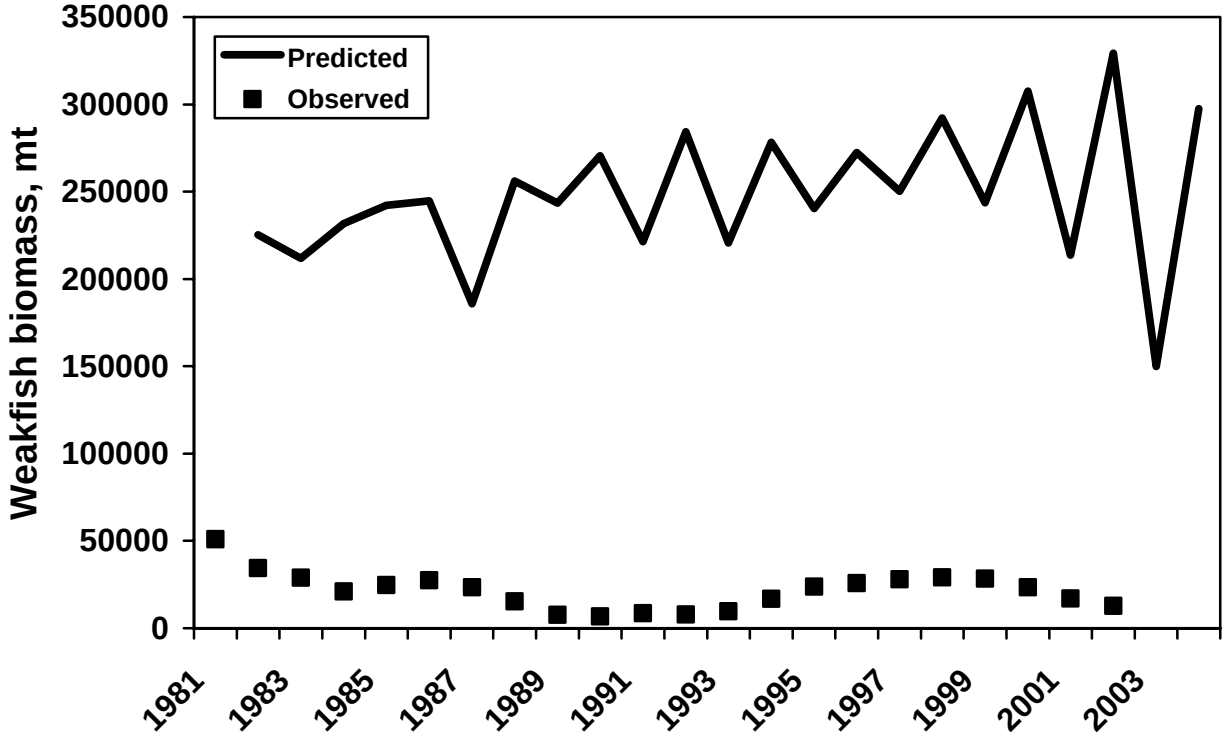


Figure 36. Weakfish biomass predicted from a logistic summer flounder - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

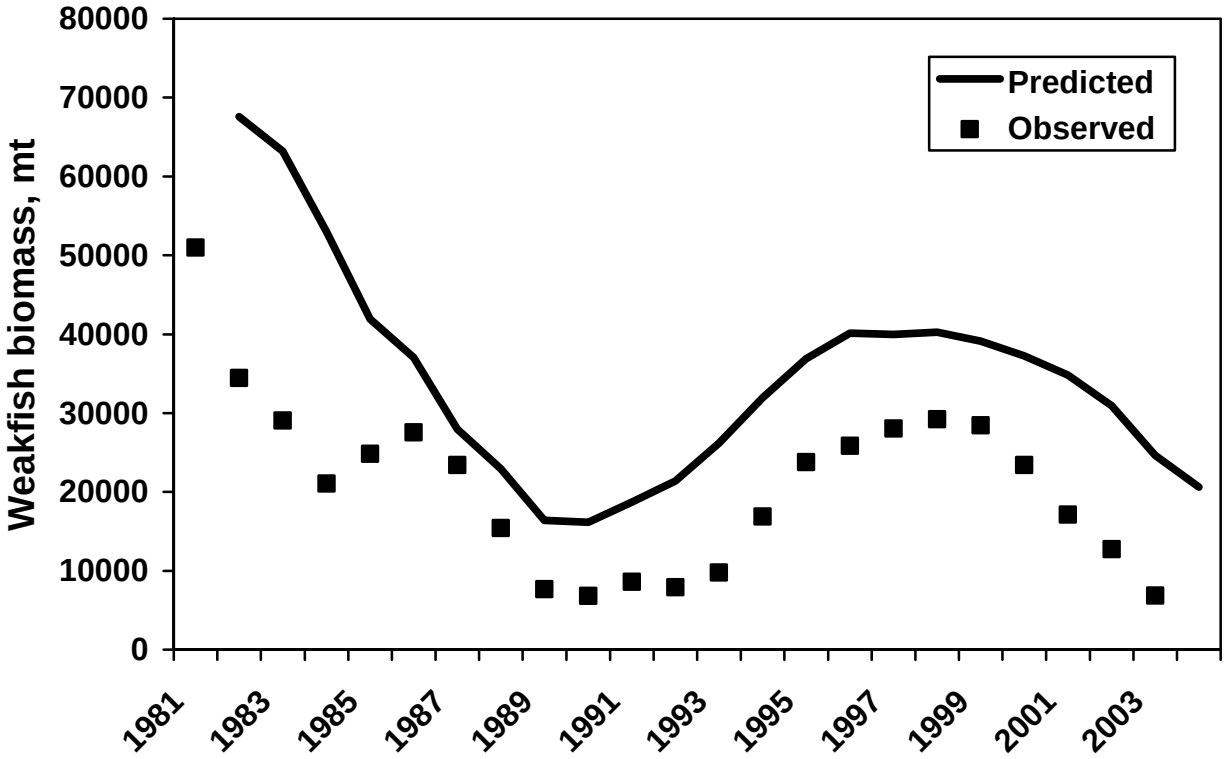


Figure 37. Weakfish biomass predicted from a logistic spiny dogfish - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

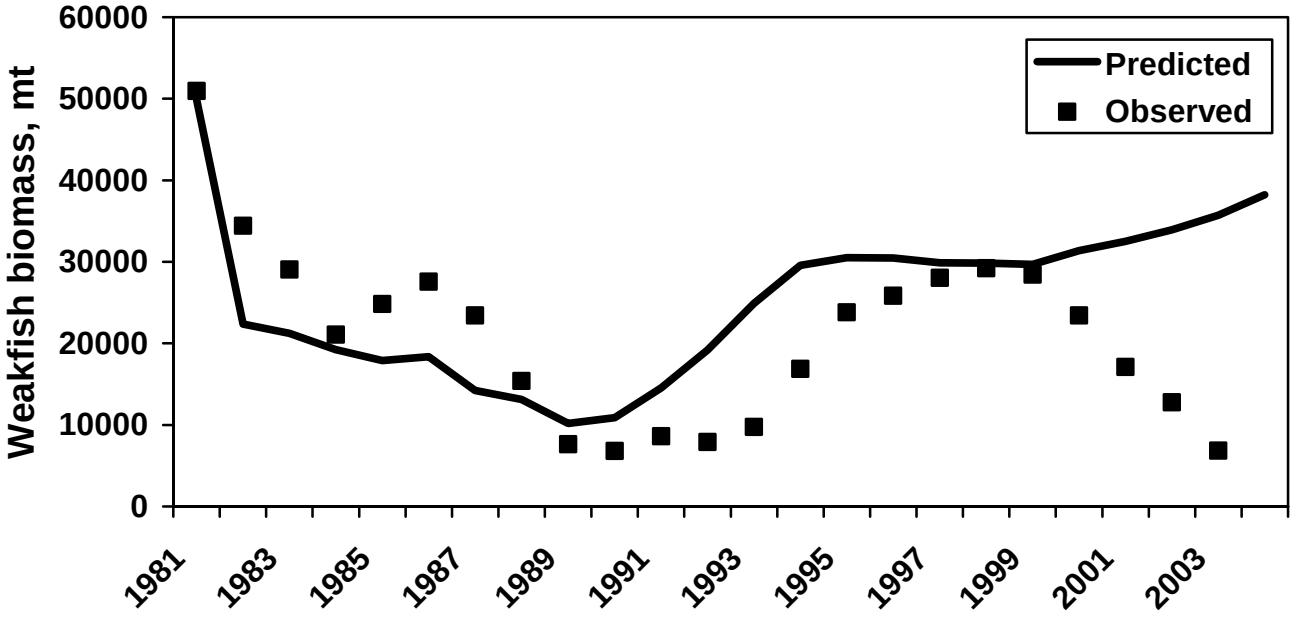


Figure 38. Weakfish biomass predicted from striped bass and summer flounder - weakfish logistic predator -prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

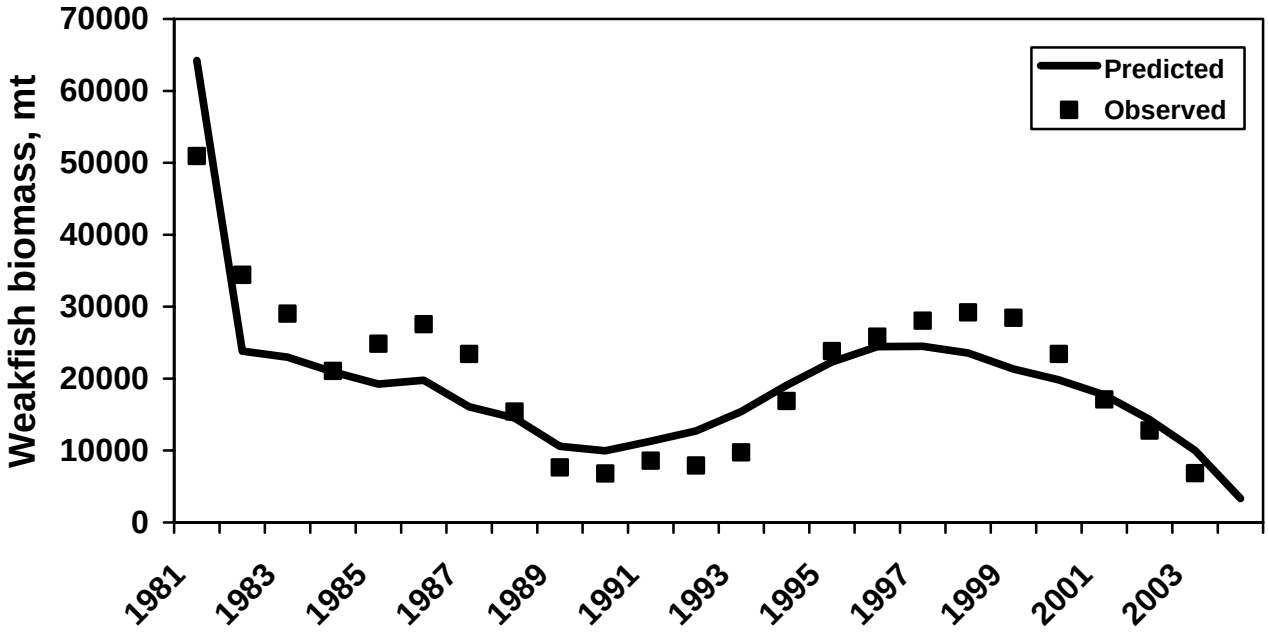


Figure 39. Standardized age 0 weakfish indices from Crecco (2006). Nj (grand mean) indicates general trend.

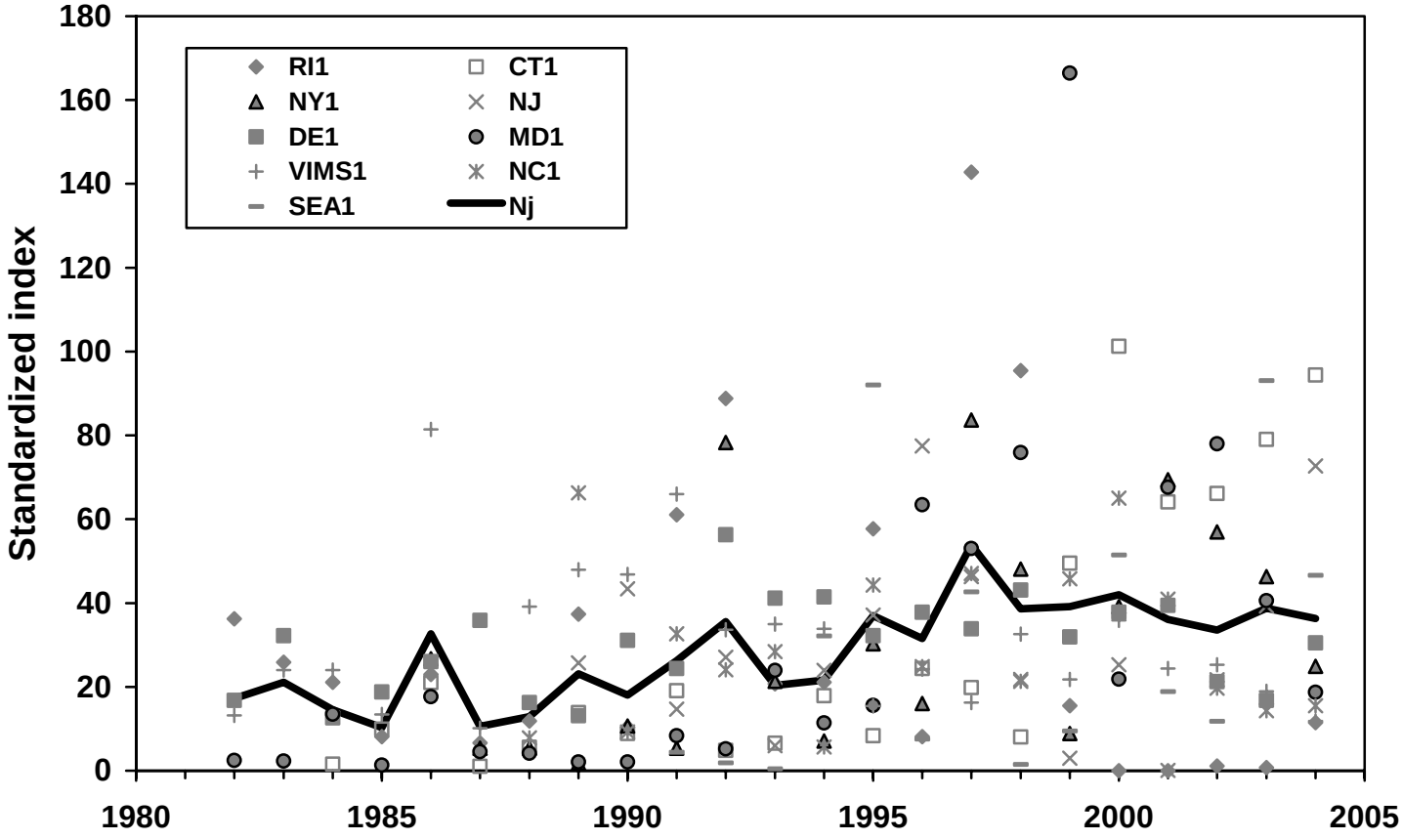


Figure 40. Decreased menhaden : bass ratio corresponded to increased weakfish M attributed to bass competition and predation. Note: rapid rise in M estimates as the ratio becomes asymptotically low in the mid-1990s. Age 0 weakfish mortality index (RZj; Crecco 2006) has been divided by 4 to scale it to the plot.

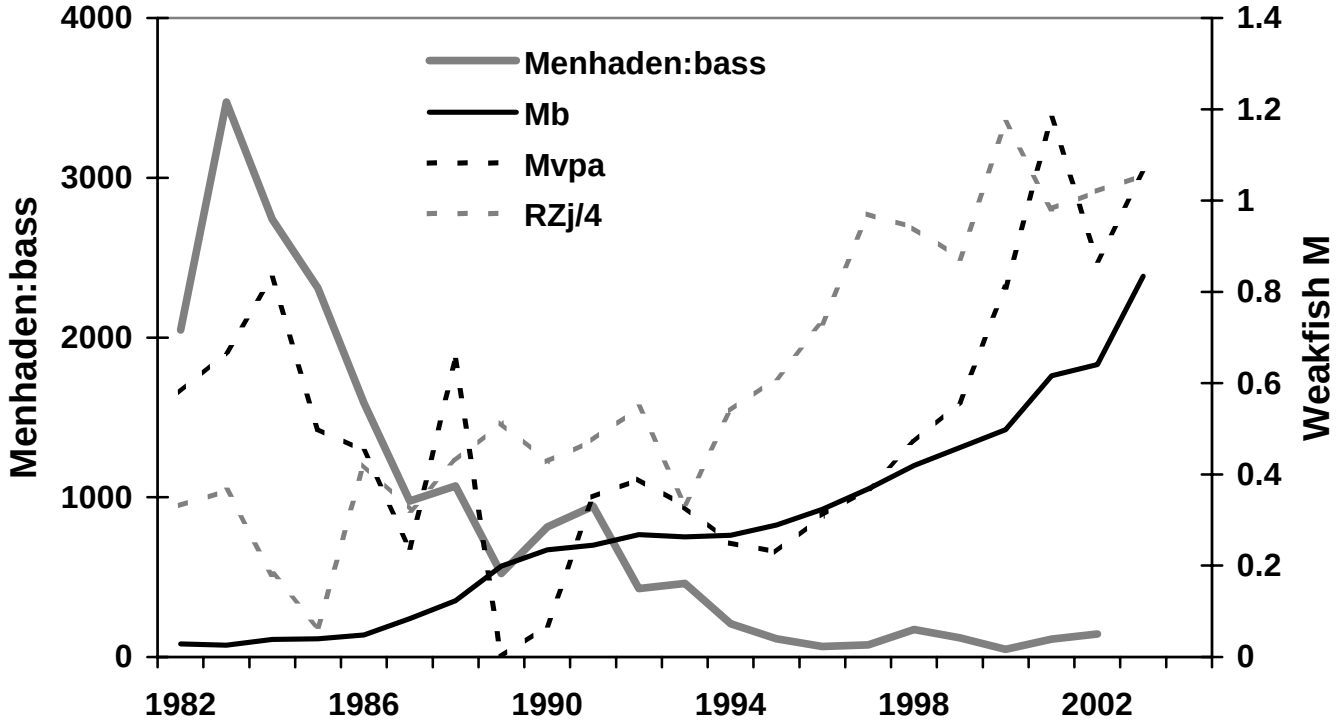
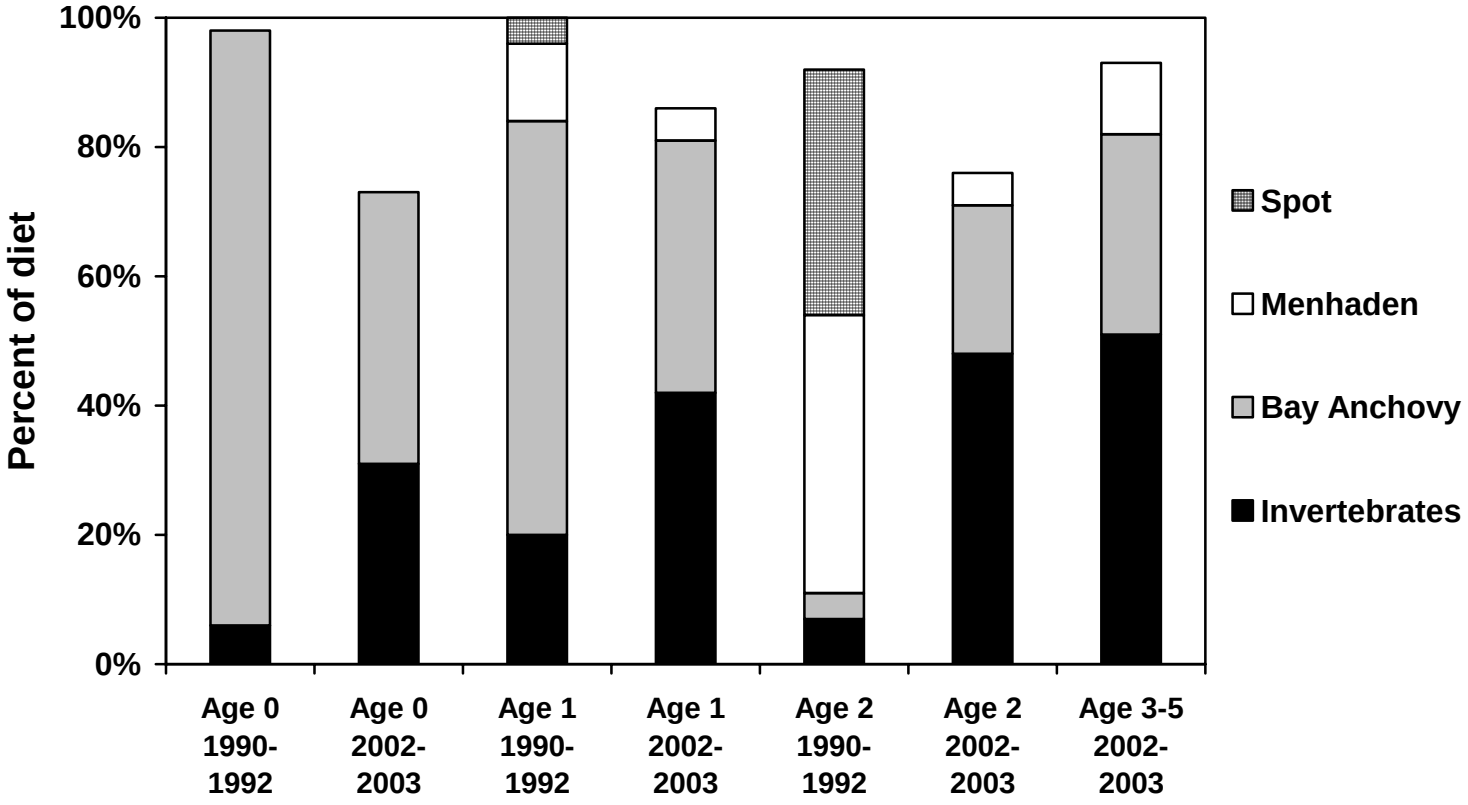
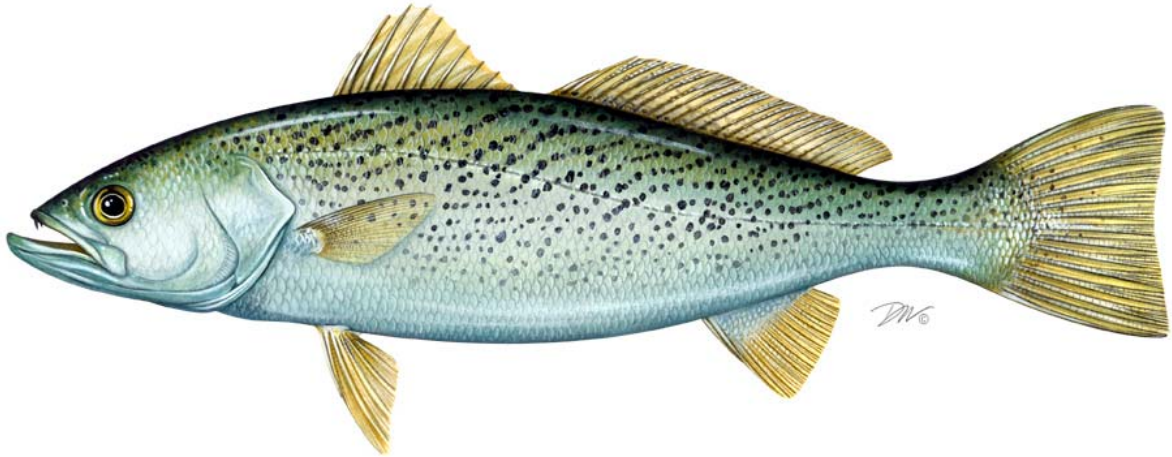


Figure 41. Comparison of age-specific weakfish diets (by weight) in Chesapeake during 1990-1992 and 2002-2003. Data for 1990-1992 were from Hartman and Brandt (1995) and data for 2002-2003 were provided by R. Latour (VIMS).



Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report to the Weakfish Stock Assessment Peer Review



April 2006

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

Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report to Weakfish Stock Assessment Peer Review

Conducted on
March 20-22, 2006
Providence, RI

Dr. Brian J. Rothschild, Panel Chair, University of Massachusetts – Dartmouth
Dr. Steven X. Cadrin, NOAA/UMass Cooperative Marine Education and Research Program
Dr. Steven J. D. Martell, University of British Columbia
Dr. Ransom A. Myers, Dalhousie University

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Preface

Summary of the Commission Peer Review Process

The Benchmark Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes evaluation of input data, model development, model assumptions, scientific advice, and review of broad scientific issues, where appropriate.

The Commission's Benchmark Stock Assessment Peer Review Process outlines options for conducting an external peer review of Commission managed species. These options are:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).

2. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).

3. The Transboundary Resources Assessment Committee (TRAC) reviews stock assessments for the shared resources across the USA-Canada boundary and it is conducted jointly through the National Marine Fisheries Service and the Canada Department of Fisheries and Oceans (DFO).

4. An external Commission stock assessment review panel conducted by 3-4 stock assessment biologists (state, federal, university). The Commission review panel will include scientists from outside the range of the species to improve objectivity.

5. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

The ASMFC Weakfish Stock Assessment Peer Review Panel (Option 4 from above) met on March 20-22, 2006 in Providence, Rhode Island to review the Weakfish Stock Assessment.

Purpose of the Terms of Reference and Advisory Report

The Terms of Reference and Advisory Report provides summary information concerning the weakfish stock assessment and results of the External Peer Review to evaluate the accuracy of the data and assessment methods for this species. Specific details of the assessment are documented in a supplemental report entitled Weakfish Stock Assessment Report for Peer Review. A copy of the supplemental report can be obtained via the Commission's website at www.asmfc.org under the Weakfish page or by contacting the Commission at (202) 289-6400.

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TERMS OF REFERENCE FOR THE WEAKFISH PEER REVIEW

The ASMFC Weakfish Stock Assessment Peer Review Panel (Panel) does not endorse the recommendations of the ASMFC Weakfish Technical Committee (TC) regarding stock status of weakfish along the Atlantic coast. The TC based its conclusions on a biomass dynamics model that included striped bass predation. The Panel feels that the biomass dynamic model relies too heavily on recreational catch per unit effort (CPUE) data that excludes a portion of the geographic range of weakfish and that the model excludes information on relative stock size from research surveys. The Panel felt that there was insufficient attention to the fact that juvenile survey abundance indices were generally increasing over the time series and too much reliance on the assumption that recent trends in landings directly reflect abundance. The TC did not fully consider the substantial portion of catch being discarded (e.g., commercial and recreational discards increased since 1994 and in 2003 reported discards were greater than total landings). Evidence for predation of exploitable size weakfish by striped bass is weak. Furthermore, if geographic stock structure were considered in analysis of these data, conclusions about stock status may be different than those provided by the TC.

1. Characterize commercial and recreational catch including landings and discards.

There is evidence of stock structure. Nesbitt (1954) indicated at least three stocks from tagging and Thorrold et al. (2001) indicated high fidelity of weakfish to their natal estuary, and there is substantial regional heterogeneity in population dynamics of stock structure. The fact that geographic stock structure has not been included in the analysis may explain the observed annual variation in growth and mortality. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.

Despite the evidence for stock structure, weakfish along the coast have been assumed to be single stock. All assessments to date have been based on this assumption. In fact, data have been pooled as if there had been a single stock and consequently the appropriate statistical weights among stocks have not been determined.

Commercial landings since 1950 appear to be estimated with moderate precision and landings since 1994 appear to be well estimated; however, given that weakfish are often taken as bycatch and have relatively low value, the overall estimates may be less accurate than the TC believes. The TC felt that the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS) recreational landings since 1981 are well estimated, but the Panel was concerned that there was substantial uncertainty in the MRFSS estimates. The accuracy of these data may be heterogeneous over regions and time. The panel noted some inconsistencies in the various catch tables, where the total estimated landings from all fisheries are not equal in the various tables that presented total landings.

The discard patterns are not what we would expect given the change in regulations in the mid-1990s. Discards rates varied in recent years (proportion of total commercial catch that was discarded: 1999 – 51%, 2000 – 17%, 2001 – 55%, 2002 – 61%). The high discards rates are a concern for conservation and management of weakfish, as most estimates of discard rates are generally underreported given the change in fishermen behavior when observers are onboard vessels. Commercial discards are estimated with moderate precision to1994, but there are no direct data in earlier years. Recreational discards are estimated with moderate precision since 1981. Discard mortality is uncertain (assumed variable by commercial gears and assumed 20% for the recreational fishery).

Dedicated age-length keys are unavailable for most potions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994). Overlap among ages for small fish is worrisome because this probably adds considerable bias in the catch-age information that used in the ADAPT virtual population analysis (VPA; NOAA Fisheries Toolbox Version, 2004. VPA/ADAPT, Version 2.1.9. [Internet address: http://nft.nefsc.noaa.gov]). Geographic patterns in growth may confound estimation of catch-at-age. Age-structure is poorly estimated particularly for recreational and commercial discarded portions of the catch.

There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass). Abrupt changes in mean weight-at-age data may result from errors in the calculation of the catch-at-age. The changes in mean weight are coincident with a conversion from scale ages to otolith ages. The Panel was not afforded the opportunity to review a statistical analysis of the scale-otolith conversions. In addition, there was no information from fishery independent surveys on changes in growth in the stock assessment report.

There are substantial deficiencies in biological samples (i.e. age and length) in some regions (Table 2A in the stock assessment report). Particularly notable is the absence of sampling in New York or New Jersey; thus, it is impossible to make precise evaluation of this stock without information from this region. It seems likely that larger and older fish migrate further north seasonally and may be less represented in the sampling, given the lack of data from these regions. Estimates of total mortality from sample catch-at-age assume that older fish are fully represented in the samples. Some age-length samples are collected with the intention of obtaining estimates of growth; therefore, they are not representative of age-frequency of the catch (e.g., North Carolina).

In conclusion, deficiencies in stock identification and sampling make this stock assessment very difficult to validate. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based ages); therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.

2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.

Fishery Independent Surveys

There is a lot of information in the fishery independent surveys, but the information is noisy and difficult to interpret. However, there are consistent long-term trends in the young of year indices among almost all of the surveys. Including all of the survey information into a VPA calibration, in the form assumed by ADAPT, implicitly assumes equal weighting of all surveys regardless of geographic coverage, representativeness, or statistical properties. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent. In general, a comprehensive review of the use of state and federal survey fishery independent surveys would benefit ASMFC stock assessments.

The TC evaluated the following four fishery independent surveys: the NMFS fall inshore trawl survey, the New Jersey ocean trawl survey, the Delaware trawl survey, and the SEAMAP trawl survey). Other surveys were included in a graphical analysis of the young of year trends.

Both the TC and the Panel felt the NMFS Northeast Fisheries Science Center's fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative

abundance, and tracked some cohorts well. Concerns with the survey as an indicator of abundance include the interannual variability of the timing of the survey relative to weakfish migration, the fact that the survey only catches young weakfish, catch curve analysis from the survey yields negative estimates of total mortality rates (Z), and confounding temperature effects. The survey has a dedicated age-length key and fish were initially aged by scales before changing to otoliths.

Trends of relative weakfish abundance for the New Jersey ocean trawl survey were consistent with perception of weakfish stock development up to mid-1990s, but were then inconsistent with fishery catch rates. The survey is limited to sampling the coastal ocean of New Jersey. The survey is conducted five times per year in January, April, June, August, and October, but only survey tows from August and October were used to develop the weakfish index and there was a skewed distribution of catches. Age data are available for some years, but in others age data were 'borrowed' from adjacent surveys.

Although the Delaware Bay trawl survey sampling area is limited geographically, it is located near the center of weakfish population abundance. The survey is conducted monthly with dedicated age samples, and abundance-at-age patterns are generally consistent (e.g., all Z estimates are positive).

The SEAMAP survey is the southern most survey examined by the Weakfish TC. The survey is conducted in spring, summer, and fall from Cape Hatteras, North Carolina to Cape Canaveral, Florida, but only data from the fall survey from North Carolina were utilized. The abundance-at-age patterns are generally consistent, as evident by positive Z estimates from cohort catch curve analysis, but the index is noisy. Some age data are available from the SEAMAP survey; however, for years when no ages were available, age data were 'borrowed' from adjacent surveys.

Fishery dependent indices

Commercial catch per unit effort indices (from North Carolina) were presented to the Panel. Catch per unit effort for both the North Carolina estuarine commercial gears and the North Carolina ocean winter fishery were affected by regulations in 1994 and only cover a small portion of the geographic range of weakfish.

The TC utilized a recreational CPUE based on the NMFS MRFSS using mid-Atlantic private boat CPUE (all trips or trips targeting black sea bass, bluefish, Atlantic croaker, summer flounder, weakfish, and spot). This index includes kept and released catch and, compared to the commercial indices, is less affected by regulations. This fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore). For the recreational fishery, there are no dedicated age data and no lengths are available for the released portion; therefore, 'borrowed' age-length keys were applied from commercial and survey data, which could have caused a false consistency with the catch-at-age.

Each fishery dependent index has nuances with catchability (i.e., technological changes), which were not discussed. The mid-Atlantic private boat fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.

The Panel concluded that fishery independent survey data requires a more comprehensive analysis to get a coast wide perception of relative stock size and that fishery dependent indices may not be a reliable indicator of stock size.

3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.

The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).

The TC makes the case for increasing Z based on the ADAPT (Run #20 – the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20. The Panel found the results from the ADAPT and subsequent analyses dependent upon these results are suspect.

Inferences on changes in M were based on nominal fishing effort (in units of private boat day in the mid-Atlantic, f = catch divided by CPUE) scaled to ADAPT estimates of fishing mortality rate from Run #20 over 1987 to 1991 where M was assumed to be 0.25. This short time period may reflect atypical catchability based on migration of weakfish (mid-Atlantic private boat catch was as low as 10% of total catch during this time period, but was much higher in other periods). Changes in M were calculated to be the residual between estimates of fishing mortality rates (F) and Z where the F came from the VPA estimates.

The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.

A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate. Alternatively, if competition with other piscivores were the precise hypothesis, then a competition term in the biomass dynamics model would be appropriate. The Steele-Henderson model applied by the TC would be appropriate for predation of exploitable size weakfish by striped bass. The Panel felt that the evidence for predation of exploitable size weakfish by striped bass is weak. Even if the hypothesis is well founded and the population process equation is appropriate, then accurate data on relative stock size and independent information on total mortality are needed.

If M has increased over time, then the corresponding estimate of F_{msy} would be greater than the estimate of F_{msy} that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true F_{msy}. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than F_{msy}. Therefore, assuming constant M is more risk averse than assuming an increase in M. This is why investigating variability in M is very important.

4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.

The Panel applauds the effort to examine alternative explanations to the data (e.g., change in M) and appreciates creative solutions to these problems; however, the data are not adequate to test the hypothesis of increasing natural mortality of weakfish. Because this issue is so important along the Atlantic coast, it is worthwhile investigating historical data (i.e., data prior to 1981). The Panel encourages continued exploration of trophic dynamic models, as being conducted for other fishery resources with reduced productivity (e.g., the reduced productivity of cod throughout the north Atlantic). Members of the Panel recommended conducting tagging studies to directly measure changes in natural mortality rates.

The Panel was reluctant to recommend the use of any age-based analysis, given the questions about the reliability of the catch-at-age data. Refer to the discussion under Term of Reference 1 and 2 regarding poorly sampled catch-at-age and noisy survey indices.

There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years. These differences in recruitment are correlated with substantial decreases in weight-at-age, which suggests that there is some limitation of weakfish carrying capacity. However, since no estimates of weight-at-age were provided for the survey data, this hypothesis was difficult to evaluate.

Estimated landings decreased since the early 1990s, but estimated discards increased since 1994. All indices of stock size indicate a positive response to the regulations during the early and mid 1990s. Since 1994, abundance indices are equivocal; some show an increase (NEFSC Fall; Connecticut and SEAMAP young-of-year surveys), some show no trend (New Jersey), and others a decrease (mid-Atlantic recreational CPUE) (see Figures 1 and 2).

The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes. Despite the uncertainty of recent indices of stock size, it appears that current regulations should be continued or strengthened to decrease discarded catch until a stronger indication of population response (decline or recovery) is seen. The Panel recommends that the ASMFC engage in a comprehensive monitoring program, including the estuarine and ocean environment that would help address short falls in stock assessments of weakfish and other species.

5. Review the estimated biological reference points, as appropriate.

For the reasons stated in Term of Reference 3, reference points from multispecies biomass dynamics model are not well estimated. Neither stock and recruitment analyses nor growth studies were presented to the Panel. In lieu of an accepted analytical assessment, conventional reference points are irrelevant and fisheries management needs to rely on historical measures of relative abundance (e.g., a period of high stock abundance from research surveys). Management needs to be adaptive to see if there is a response in the stock.

6. Review stock projections.

- **Review the projection of impacts on the stock of recent estimated rise in fishing mortality.**
- **Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.**

The only projections presented to the Panel were based on the hypothesis of increased natural mortality. For the reasons stated in Term of Reference 3, these projections are not a reliable basis for management. In lieu of an alternate analytical model, projections were not available.

7. Make research recommendations for improving data collection and assessment.

The Panel makes the following research recommendations to improve weakfish data collection and stock assessment efforts:

Catch

- Sample age-composition of commercial catch throughout the range of the fishery.
- Continued observer coverage to estimate discards.
- Partition catch and catch samples by stock.
- Make a substantial investment in monitoring and assessment.
- Develop statistically efficient measurement of catch.
- Develop estimates of discard rates in the commercial fishery.
- Collect information on fishing effort (e.g., number of fishing vessels, number of units, and bycatch by gear).

Aging

- As recommended in SARC 40, further research should be conducted on growth (i.e. validation of scale to otolith conversion).
- Improve regional growth estimates, including studies of density dependent growth.
- Conduct a detailed analysis of the development of the age-length key.

Stock size indices

- Evaluate selectivity of gears (to improve estimates of Z).
- Conduct tagging studies to directly measure changes in natural mortality rates.
- Conduct a detailed analysis of the young of year surveys and the interrelationship among YOY surveys, and the design of a future comprehensive YOY survey.
- Focus on the development of very high resolution catch per unit of effort time series from among the various regions.
- Evaluate the effect of interannual variation on distribution and catchability.
- Conduct a comprehensive review of the use of state and federal survey fishery independent surveys for use in all ASMFC stock assessments.
- Development of analytic methods is needed to determine the status of the resources, which absolutely requires the development of more reliable data sets. Discounting a survey does not imply that it is not necessarily informative about the sub-stock in that region.
- Conduct a comprehensive monitoring program, including the estuarine and ocean environment. Such a program would address short falls in stock assessments of this and other ASMFC managed species.
- Conduct a comprehensive examination of the assemblages of species in a historical construct.

Growth

- A detailed analysis of factors affecting somatic growth should be carried out using data from research surveys if at all possible.

Advisory Report

Status of Stocks

The catch has decreased since the early 1990s. All indices of stock size indicate a positive response to the regulations enacted in Amendment 3 to the Weakfish Fishery Management Plan. Since 1994, survey indices are equivocal; some show an increase (NEFSC Fall, YOY – Connecticut, New Jersey, SEAMAP), some no trend (New Jersey), and others a decrease (Mid-Atlantic recreational CPUE).

Trends in mortality are uncertain. Despite the uncertainty of recent indices of stock size, it appears that current regulations should be continued or strengthened to decrease discarded catch until a stronger indication of population response (either a decline or a recovery) is seen.

Stock Identification and Distribution

Weakfish are part of the Family Sciaenidae or "drums." Weakfish are found along the Atlantic coast with its primary range from North Carolina through southern New England and have been reported as far south as Florida and as far north as the Gulf of Maine. Weakfish are primarily estuarine and inshore oceanic inhabitants that migrate seasonally. In the autumn, they migrate south to North Carolina or Virginia coastal waters, where they overwinter. In spring weakfish move northward and inshore into estuarine spawning grounds including Pamlico Sound in North Carolina, Chesapeake and Delaware Bays and smaller coastal estuaries up through Gardiners Bay on eastern Long Island, New York and as far north as Long Island Sound and Narragansett Bay in Rhode Island.

The ASMFC Fisheries Management Plan considers weakfish to be a unit stock, based on genetic analysis (Graves et al. 1992). Recent work however, using geochemical composition of otoliths, found weakfish homed to their natal estuaries (Thorrold et al. 2001). Earlier tagging work performed in the 1930s also indicated that weakfish returned to their natal estuary (Nesbit 1954).

Management Unit

The weakfish management unit spans the East Coast of the United States from Massachusetts through Florida.

Fishery Description and Landings

Landings from 1950-2003 peaked in 1981. During the period from 1982-2004, landings were highest at the beginning, totaling about 12,500 mt in 1982. Landings declined in 1989 through 1993. An increase in landings began in 1995. Landings then peaked at above 5,000 mt in 1998. Weakfish landings began to decline again in 1999, which continued through 2004 to record low level. Trends of strong declines in recent years are seen in landings of weakfish by both the commercial and recreational sectors.

In the winter, overwintering aggregations off North Carolina are harvested by gill nets and fly net trawlers. Virginia and New Jersey also comprise an important component of commercial landings. During their annual migration, weakfish are harvested by a variety of estuarine gears, including gill nets, pound nets and floating traps, seines and hand lines. In the fall migration along the coast, weakfish aggregations are targeted with trawls and gill nets. In 1999, for instance, gill nets caught the largest share of the commercial landings, 48%, while trawl landings were second at 27%, followed by pound nets at 20% and haul seine at 5%.

Patterns in recreational total catch and harvest changed after imposition of minimum sizes and creel limits in 1995. After this time, total catch (A + B1 + B2 of the MRFSS) became significantly larger than harvest. This suggests that the regulations had a significant impact on recreational harvest, causing a large increase in live releases (discards).

In 1993, Virginia implemented a commercial fishermen mandatory reporting system, whereby each harvester reports daily activity (harvest, effort) on a monthly basis. This program replaced a voluntary buyer-reporting system. In 1994, North Carolina mandated trip-level reporting by licensed dealers for all commercial landings that requires dealers to complete a trip ticket for each transaction with a fisherman. These reports must be submitted monthly to the North Carolina Division of Marine Fisheries (NCDMF). Previously, the state had a voluntary reporting system from 1978-1993 obtained through a NMFS/NCDMF cooperative statistics program. In addition, NMFS implemented a mandatory electronic reporting system in 2004 for all federally permitted seafood buyers.

There are no explicit commercial discard estimates after 2002 and no information on the operation of the fishery. Only total catch and landings were provided in the Stock Assessment Report. The Panel had to calculate discards from total catch and landings. This information is crucial to understand the dynamics of fisheries impacts on the stock. In addition, the Panel found it important to consider how the "scrap" fishery affects commercial discard rates or biases the results of a production based model that assumes fixed selectivity.

The high discards rates pose an additional concern for conservation and management or weakfish, as most estimates of discard rates are generally underreported given the change in fishermen behavior when observers are onboard vessels.

Data and Assessment

In lieu of an accepted analytical stock assessment, status determination and advice are based on a descriptive summary of catch and survey data.

Biological Reference Points / Fishing mortality

For the reasons stated in Term of Reference 3, reference points from multispecies biomass dynamics model are not well estimated. Neither stock and recruitment analyses nor growth studies were presented to the Panel. In lieu of an analytical assessment, conventional reference points are irrelevant and fisheries management needs to rely on historical measures of relative abundance (e.g., a period of high stock abundance from research surveys). Management needs to be adaptive to see if there is a response in the stock.

Recruitment / Spawning Stock Biomass

There is some optimism for weakfish stock status. Despite uncertainty in stock productivity, recruitment has not declined in any portion of the range. In fact, evidence suggests that there has been a recent increase in recruitment over the last 15 years.

Sources of Information

Graves, J. E., J. R. McDowell and M. L. Jones. 1992. A genetic analysis of weakfish *Cynoscion regalis* stock structure along the mid-Atlantic Coast. Fishery Bulletin 90:469-475.

Nesbit, R. A. 1954. Weakfish migration in relation to conservation. Special Scientific Report - Fisheries No. 115. Fish and Wildlife Service, U. S. Dept. of the Interior.

Thorrold, S. R., C. Latkoczy, P. K. Swart and C. M. Jones. 2001. Natal homing in a marine fish Metapopulation. Science 291: 297-299.

Figures

Figure 1. Relative abundance indices for age-0 weakfish from various fisheries independent surveys. The overall mean shows an increasing trend, but some show declining trends in recent years (e.g., VIMS) and others show increasing trends.

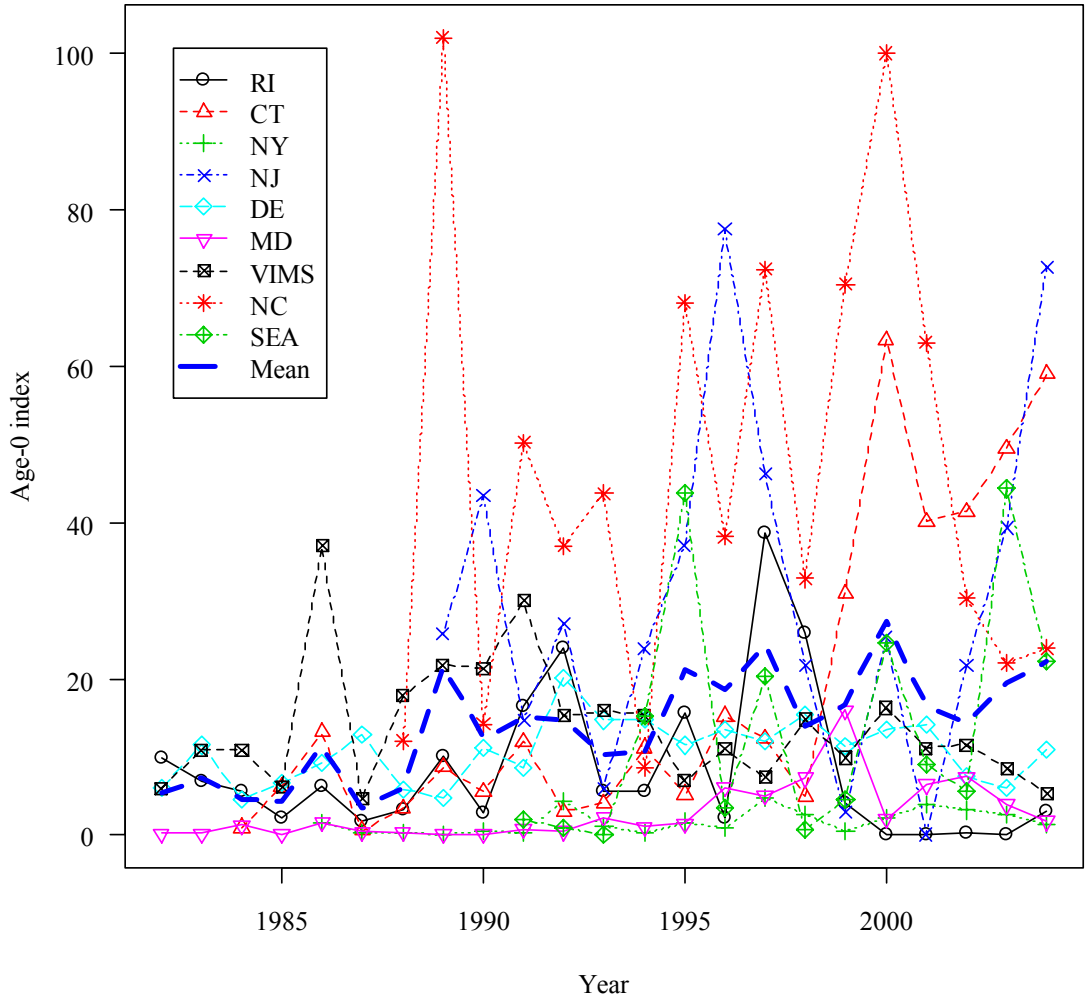
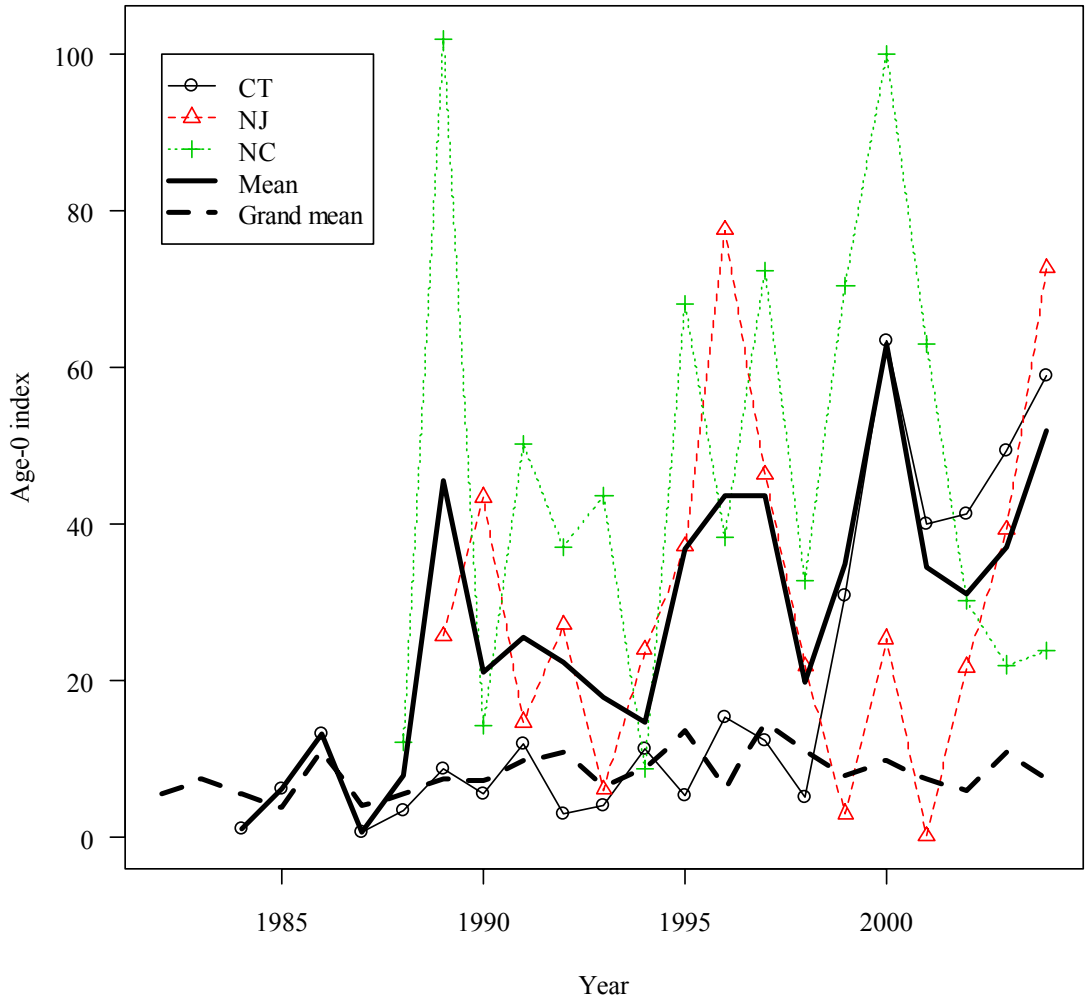


Figure 2. Age-0 abundance indices from the Connecticut (CT), New Jersey (NJ), and North Carolina (NC) fisheries independent surveys. The dark solid line is the mean trend of the CT, NJ, and NC surveys, and the dashed line is the trend of all other surveys shown in Figure 1. These trends suggest an increase in age-0 recruits to the fishery, but are inconsistent with the trends in the recreational CPUE index that was used for tuning the ADAPT VPA.



Supplemental Material Requested by the Weakfish Management Board from the Weakfish Technical Committee following Peer Review

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Implementation of 40th SARC Recommendations

Weakfish Technical Committee
June 2006

Implemented Items: January 2005 – February 2006.
Commercial and recreational data should be examined with regard to its precision and accuracy, both in terms of absolute estimates of catches and its age composition.
Aggregate catches:

1. Commercial catches are a census, so precision cannot be estimated. As with any species' landings, we assume they are accurate.
2. Recreational catch precision is estimated by MRFSS (PSE) and is acceptable. NRC (2006) review indicates serious shortcoming in estimates (any species) that may make accuracy doubtful.
3. Discard estimates and their precision were estimated by De Silva (2004). Precision is sometimes poor. Accuracy cannot be addressed.

Age composition of catches:
It is unclear how precision and accuracy of age structure could be addressed. Sampling of age composition from areas not well covered in the past (NY and NJ) could address a major TC concern about accuracy of CAA if an age-structured assessment is pursued.

Evaluate information content of input data regarding year-class strength.

1. Year-class catch curves of survey data were conducted and indicated only the DE large trawl survey provided suitable consistency (Kahn et al. 2006).
2. Bubble plot of CAA indicates year-classes can be followed over time (D. Kahn DEDFW, personal communication; presented to 2006 peer-review and Board).
3. Gulland-type cohort analysis of CAA provided estimates of N and F (Kahn et al. 2006).

Validate ageing.
Ageing of weakfish by otoliths has been validated in the primary literature (Lowerre-Barbieri et al. 1994). Further work for the TC was summarized by Wenner (1999).

Develop age aggregated indices where CAA inconsistencies are problematic.

1. Age aggregated biomass indices for trawl surveys were developed (Uphoff 2005; summarized in Kahn et al. 2006), evaluated, and accepted by TC.
2. Size structure indices were developed (Proportional Stock Density indices or PSD's (Uphoff 2004; summarized in Kahn et al. 2006), evaluated, and accepted by TC.
3. Age aggregated MRFSS-based recreational index was developed (Crecco 2005a; 2005b; Brust 2005), evaluated, and accepted by TC.

Research into divergence of trawl survey indices and MRFSS index.

1. Aggregated biomass indices evaluated (Uphoff 2006).
2. Correlation analysis indicates that MRFSS, DE, and NJ are significantly correlated. NEFSC significantly correlated with NJ and marginally with DE. MRFSS and NEFSC not correlated. MRFSS index was not "odd man out" (Uphoff 2006).
3. Inclusion of NEFSC with NJ and DE leads to most optimistic status.
4. Substitution of MRFSS for NEFSC indicates declining status.
5. PSD (length-frequency) analysis indicates proportion exploitable in NEFSC too small to estimate reliably (Uphoff 2004). NJ and DE sample sizes provide reliable, precise estimates, and are well correlated. MRFSS CPUE well correlated with PSD.
6. Assessment of index catchability (NEFSC, NJ, DE, MRFSS) and converged VPA biomass indicated MRFSS catchability was most consistent (Uphoff 2006). Survey catchability was much more variable and inverse relationships with biomass were suggested (Uphoff 2006).

Review ecological and other explanations for possible decline of weakfish.

1. Food web dysfunction was explored by Crecco (2005a; 2005c), Kahn et al. (2006), and Uphoff (2006).
2. Selected climatic variables (mean annual water temperatures (C) and annual deviations in the North Atlantic Oscillation index) were tested (Kahn et al. 2006).

Items Not Implemented

1. *Evaluate basic data for suitability of CAA approach.* The 30th SARC considered data adequate for CAA analysis, but they were not aware of the details on how the fisheries were sampled (i.e., NJ and NY missing samples). A detailed re-analysis of basic data was not started due to time constraints. The 2006 review casts doubt on applying an age-structured approach.
2. *Survey catch rates at age should be evaluated in space and time for consistent year-class signals.* Detailed spatial analysis has not been conducted on an age-structured or aggregated basis. TC may not have spatial analysis (GIS) expertise.
3. *Compare survey distributions to observed changes in pattern of landings to try and explain inconsistencies in trends in different series.*

References

Brust, J. C. 2005. Development of a recreational CPUE index for weakfish using proxy data to estimate target effort. New Jersey Department of Natural Resources.

Crecco, V. 2005a. Fishing mortality (F), stock biomass, and overfishing thresholds for Atlantic Coast Weakfish from 1981-2003. Connecticut Marine Fisheries Division, Old Lyme. Connecticut Marine Fisheries Division, Old Lyme.

Crecco, V. 2005b. Biomass weighted fishing mortality (F), stock biomass and overfishing thresholds for Atlantic Coast weakfish from 1981 to 2004 using directed recreational fishing effort. Connecticut Marine Fisheries Division, Old Lyme.

Crecco, V. 2005c. Biomass weighted fishing mortality (F), stock biomass, and overfishing thresholds between the South Atlantic (NC to FL) weakfish and Mid-North Atlantic weakfish from 1981-2004. Connecticut Marine Fisheries Division, Old Lyme.

de Silva, J. A. 2004. Estimating At-Sea discards of weakfish using NEFSC Observer database. A report to the Weakfish Technical Committee of the Atlantic States Marine Fisheries Commission. Florida Fish and Wildlife Commission, Florida Marine Research Institute, St. Petersburg.

Kahn, D. M., J. Uphoff, V. Crecco, D. Vaughan, B. Murphy, J. Brust, R. O'Reilly, and L. Paramore. 2006. Weakfish stock assessment report for peer review (Part 1). Delaware Division of Fish and Wildlife, Little Creek.

Lowerre-Barbieri, S. K., M. E. Chittenden, and C. M. Jones. 1994. A comparison of a validated otolith method to age weakfish, *Cynoscion regalis*, with the traditional scale method.

Uphoff, J. H., Jr. 2004. Indicators of weakfish size quality: proportional and relative stock density indices for weakfish. A report to the Atlantic States Marine Fisheries Commission's Weakfish Technical Committee. Maryland Department of Natural Resources, Stevensville.

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Uphoff, J. H., Jr. 2006. Weakfish stock assessment report for peer review (Part 2). An ecological assessment of weakfish: examination of fishing and trophic effects on the recent stock decline. Maryland Department of Natural Resources, Stevensville.

Wenner, C. A. 1999. A summarization of the results of age determination of weakfish, *Cynoscion regalis*, by means of the examination of otoliths. A report to the Atlantic States Marine Fisheries Commission's Weakfish Technical Committee. Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston.

Summary of Weakfish Technical Committee (TC) agreements and disagreements with the 2006 peer-review and the record of implementing recommendations of the 40th SARC

July 2006

Overall, the TC agreed with major statements in the review 9 times and disagreed 14; there were 2 agreements and 12 disagreements on main issues (top 4). Eight issues were identified by the 40th SARC and all but 2 were implemented by the TC. "TC Mean Rank" is the average rank of importance each TC member assigned to general issues in the peer-review (1 = most important & 9 = least). Columns labeled "Statements TC agrees" or "Statements TC disagrees" indicate the number of major statements in the peer-review relating to the general issue that the TC agreed or disagreed with; agreements or disagreements were unanimous among TC members. Number of disagreements does not constitute importance. Letters in "Agree statement & details" or "Disagree statement & details" columns refer to specific statements by the peer-review panel that can be found in Section 1 (pages 2-4 of this report). These letters also reference where details of TC agreements or disagreements can be located (Section 2, pages 5-18). "SARC 40 concern" indicates an issue present in 40th SARC panelist documents. NEFSC is the Northeast Fisheries Science Center index and MRFSS is the recreational catch index. CAA = catch at age.

TC Mean Rank	2006 Peer Review General Issue	Statements TC agrees	Statements TC disagrees	Agree statement & details	Disagree statement & details	SARC 40 concern	SARC 40 Implemented
1.4	Indices (NEFSC and JI's useful, MRFSS not)	1	5	P	K, L, M, N, V	Yes	Yes
3.2	Uncertain direction of Z, F, M, biomass		1		W		
4.1	Food web / ecological explanations	1	5	O	Q, R, S, T, U	Yes	Yes
4.4	Landings not accurate (recreational, commercial, & discards)		1		D	Yes	Yes
5.6	CAA matrix problem - missing samples	3	1	C, E, H	F	Yes	No
5.9	Evidence of stock structure	2		A, B			
5.9	Growth - survey estimates not provided	1		J			
5.9	Growth - no validation		1		G	Yes	Yes
6.4	Spatial analysis could help	1		I		Yes	No
	Sum for 2006 peer review	**9**	**14**				
	SARC 40 Issue not in Peer-Review						
	CAA - evaluate indices					Yes	Yes
	Research divergence of trawl and MRFSS indices					Yes	Yes

Section 1: Specific Issues or Statements in the 2006 Peer Review Summarized in Table 1 Agree details or Disagree details columns. List is in order of appearance in the peer review document.

A. There is evidence of stock structure.

B. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.

C. Dedicated age-length keys are unavailable for most portions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994).

D. … given that weakfish are often taken as bycatch and have relatively low value, overall accuracy of landings may be less than TC believes.

E. Missing CAA samples (northern region), overlap of lengths-at-age, and geographic patterns in growth may confound estimation of CAA.

*F. There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass).*

G. No validation of annuli in otolith based ages, in scale based ages, or in relationship of otolith to scale based ages.

H. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based; therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.

I. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent.

J. No information from fishery independent surveys on changes in growth was presented.

K. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so.

L. Both the TC and Panel felt the NEFSC fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative abundance, and tracked some cohorts well.

M. Each fishery dependent index [in this case, the MRFSS aggregated biomass index] has nuances with catchability (i.e., technological changes) which were not discussed. The mid-Atlantic fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.

N. This [private boat] fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore).

O. The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).

P. The TC makes the case for increasing Z based on the ADAPT Run #20 (the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20.

Q. The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M.

R. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.

S. A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model.

T. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate.

U. If M has increased over time, then the corresponding estimate of F_{msy} would be greater than the estimate of F_{msy} that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true F_{msy}. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than F_{msy}. Therefore, assuming constant M is more risk averse than assuming an increase in M.

V. There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years.

W. The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes.

Section 2: Details of Agreements and Disagreements with the April 2006 Peer Review Panel Outlined in Table 1

Format of Section 2

This section provides detailed responses to the Peer review panel comments (in italics) that are represented by letters in Table 1 and listed in order of appearance (and lettered) in Section 1. The TC agreement or disagreement is in bold. An additional response from the TC is in normal type. Part 1 or Part 2 in the text refers to sections of the weakfish assessment. References can be found in the report on the TC response to the 40th SARC.

What was the TC trying to do?

1. **Answer the question "Is the stock declining?"**
2. **If so, what are the likely underlying causes for the decline?**

Some important aspects of the assessment were not addressed by the Panel. Development of aggregated biomass indices, estimates of relative F (catch / index), proportional stock densities (PSD, a length structure index), biomass dynamic modeling without predation, and the concept of rescaling relative F to absolute F units were not commented on.

Peer Review Section 1. Characterize commercial and recreational catch including landings and discards.

A. There is evidence of stock structure.

TC Agrees

It has been discussed regularly in the past decade. The TC provided stock structure information to the panel and has summarized it for the Board for this meeting (August 2006). Tagging, meristics, and otolith microchemistry support regional dynamics, but suggest moderate exchange among regions. Genetic analyses indicate largely homogeneous populations. The TC notes that difficulty in defining stocks and implementing stock-specific assessments in a mixed stock fishery would be major obstacles.

<u>Other ASMFC assessments (striped bass, Atlantic menhaden, and red drum) have known or potential stock structure, but are assessed as single stocks.</u>

B. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.

TC Agrees

- TC agrees that evidence of stock structure exists.
- But there is inadequate data and enough potential mixing that pinpointing where to split is questionable.

C. Dedicated age-length keys are unavailable for most portions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994).

TC Agrees

The TC notes that this is not a feature restricted to the weakfish assessment alone. In particular, all ASMFC age-structured assessments (striped bass, summer flounder, bluefish) that feature recreational catches rely on borrowed age-length distributions.

D. … given that weakfish are often taken as bycatch and have relatively low value, overall accuracy of landings may be less than TC believes.

TC Disagrees

The TC did not express an opinion on the accuracy of landings. The assessment used landings as they are used in other assessments.

4. Weakfish are valuable and most major harvesting states have or had directed fisheries.
5. Directed landings and legal bycatch are recorded.
6. Prior to imposition of Amendments 2-4, regulation was minimal and there was little regulatory reason for discarding.
7. Weakfish recreational catches (survey methodology) follow commercial catches (census methodology) closely (correlation r = 0.86).
8. Discard estimates and their precision were estimated by De Silva (2004). Precision is sometimes poor. Accuracy cannot be addressed.
9. Including and excluding discards had little effect on assessment trends and estimates.
10. Amount of commercial discards needed to account for decline is much larger than current estimates (3-13 X's in 2003) based on modeling. Evidence does not point toward any Atlantic coast fishery capable of generating 3,000-13,000 mt of additional unreported weakfish discards. The results of these bycatch scenarios taken at face value suggest that weakfish regulations created this massive boost in discards.

E. Missing CAA samples (northern region), overlap of lengths-at-age, and geographic patterns in growth may confound estimation of CAA.

TC Agrees

*F. There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass).*

TC Disagrees

Part 1, Figure 15 indicates good agreement during 1981-2003, except for two years in the late 1980s.

G. No validation of annuli in otolith based ages, in scale based ages, or in relationship of otolith to scale based ages.

TC Disagrees

Ageing of weakfish by otoliths has been validated in the primary literature (Lowerre-Barbieri et al. 1994). Further work for the TC was summarized by Wenner (1999). Conversion of scale to otolith ages was covered in the 30th SARC.

H. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based); therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.

TC Agrees

This applies primarily to VPA. Index driven and biomass dynamic model assessments using aggregated landings provided similar trends; the latter were presented to the Panel, but not mentioned in their review.

I. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent.

TC Agrees

Detailed spatial analysis has not been conducted on an age-structured or aggregated basis. TC may not have spatial analysis (GIS) expertise.

J. No information from fishery independent surveys on changes in growth was presented.

TC Agrees

Growth estimates could be made for some years and surveys with extended age structure and otolith collections (DE and NJ). Bias could result if large weakfish avoid trawls or if growth variation reflects stock structure.

Peer Review Section 2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.

K. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so.

TC Disagrees

This was not one of our beliefs. This was the configuration of the SARC 30 approved model. We ran multiple index configurations of VPA, untuned VPA, and biomass dynamic models (Part 1, pages 27-28 & a 15 min presentation to the panel), to try and understand survey contributions.

L. Both the TC and Panel felt the NEFSC fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative abundance, and tracked some cohorts well.

TC Disagrees

While the TC would agree that the NEFSC survey has good geographic coverage and adequate precision, we have found it to be unsuitable as an index of exploitable weakfish abundance or biomass for the following reasons:

1. Cohort catch curves of NEFSC survey indicate spontaneous generation (year-class increases in abundance) in some cases.
2. Too few weakfish of sizes of interest to fishery were present in this survey after minimum size was raised in mid-1990s (fishery selectivity changed and NEFSC no longer sampled relevant sizes). PSD (length-frequency) analysis indicated proportion 13 inches+ in NEFSC was too small to estimate reliably (Uphoff 2004). NJ and DE sample sizes provide reliable, precise PSD estimates, and are well correlated.
3. Use of NEFSC index leads to conclusion of high stock status, contradicts other indices and landings.
4. NEFSC index significantly correlated with NJ and marginally with DE. MRFSS and NEFSC not correlated (r = 0.03; J. Uphoff, recent analysis).

M. Each fishery dependent index [in this case, the MRFSS aggregated biomass index] has nuances with catchability (i.e., technological changes) which were not discussed. The mid-Atlantic fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.

N. This [private boat] fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore).

TC Disagrees with M and N.

This is a strong statement that can't be supported without an independent estimate of abundance and movement.

During the Weakfish TC meeting in Providence, V. Crecco was asked to comment on the contention by the Weakfish Peer Review Committee that the private boat recreational catches have comprised an ever increasing proportion of the total coast-wide weakfish harvest from 1989 to 2005. Based on these findings, the Review Committee concluded that the Mid Atlantic private boat CPUE was an uninformative index of coast-wide weakfish abundance.

V. Crecco examined the inputs (total recreational catch and effort) in the Mid Atlantic private boat indices from 1989 to 2005 based on the MRFSS database. There appears to be major confusion among the Reviewers regarding their definition of "landings" and "catches" in their assertion about the private boat index. The Reviewers used column 2 (total coast-wide landings and discard losses) and column 4 (Mid Atlantic private boat catches mt) in Part 1, Table 10, page 70 to generate ratios of private boat catches to total coast-wide landings from 1989 to 2005. Unfortunately for the Reviewers, the data in col 4 in Table 10 are recreational total catches including weakfish released alive (A, B1 and B2) in the Mid Atlantic private boat fishery. These recreational catch data are not directly comparable with the coast-wide landings (commercial and recreational harvest) plus discard <u>losses</u> (20% of recreational releases and all commercial gill net and trawl releases) in column 2. As a result, the apparent rise in the percentage of private boat catches to total landings from 1989 to 2005 is baseless because the units of catch and harvest are incompatible. If you compare the Mid Atlantic private boat harvest (A and B1) to the total coast-wide harvest, the percentage composition of the private boat harvest varies without trend from 1989 to 2005 with a long-term mean of 18%. The imposition of coast-wide minimum size limits and creel limits in 1994 on the recreational fisheries generated a sharp rise in the magnitude of B2 catches (releases) in the Mid Atlantic private boat fishery from 1994 to 2005. Therefore, the argument put forth by the Reviewers regarding the reliability of the Mid Atlantic private boat index is an artifact of a faulty comparison of apples (coast-wide landings) and oranges (private boat catches).

The 40th SARC recommended development of a recreational CPUE index. The TC developed the MRFSS index as a substitute for the NEFSC survey. Substitution of MRFSS for NEFSC indicates a decline to low status instead of an increase to high status indicated by the NEFSC survey. These conflicting trends clearly required a choice between these indices.

Correlation analysis indicates that MRFSS, DE, and NJ biomass indices are significantly correlated. MRFSS and DE indices are significantly correlated with total landings (J Uphoff, recent analysis). MRFSS CPUE well correlated with DE PSD (long-term indicator of status).

Analyses were conducted with multiple indices and this was indicated to the panel. They were available for review upon request. They were not included because of space limitations and information overload.

MRFSS index coverage is broad (NY-VA) and constitutes the core area where weakfish are likely to be a sought gamefish rather than an angler's afterthought. The MRFSS Index includes offshore catches. Minor sportfisheries exist to the north and south of the index region. Northern region (north of New York) MRFSS catch estimates average 0.3% of total catch and southern region (NC-FL) averages 14%. Recreational catches in south have increased, but most have been in NC. Commercial catches in NC have fallen. If weakfish distribution were shifting, wouldn't both sectors in NC reflect an increase? Omitting south catches (NC-FL recreational and portion of NC commercial) from the coastal Steele Henderson model (hence, a mid- to north Atlantic assessment) produces results with minimal differences.

Assessment of index catchability (NEFSC, NJ, DE, MRFSS) and converged VPA biomass during 1982-1993 indicated MRFSS catchability was most consistent (Part 2, page 12). Survey catchabilities were much more variable and inverse relationships with biomass were suggested. NEFSC survey had the worst attributes in catchability. If converged VPA is considered a reasonable estimate of biomass, than MRFSS index q varied up to 3x's during this period, while NEFSC survey q's varied up to 28x's. Trawl survey q must be quite variable too, given the sawtooth pattern exhibited in NJ and NEFSC indices.

Changes in catchability over the recent decade were not described in Parts 1 or 2, however. Evidence for MRFSS index q to change is supported by estimating relative q (MRFSS index divided by DE or NJ index during 1989-2003 (biomass units for all; this was estimated for the panel at the review). MRFSS catchability rose from and fell to baseline during 1997-2000. Using NJ and DE survey biomass indices as tuning could ameliorate this.

Peer Review Section 3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.

O. The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).

TC Agrees

Selectivity and catchability can be confounded with M in age structured assessments.

The Z's have increased in recent years. These phenomena (selectivity and q) would have had to only increased greatly in recent years after imposition of substantial conservation measures (minimum mesh sizes, increased length limits, seasons, NC area closures).

We did not have samples from NJ and NY during early and late in the time-series (when stock was relatively high), so this bias should be the same both periods of the assessment (extended age and size structure were present). Age-structured and age-aggregated assessments detected much higher F's during the early period than recent years.

The mixed nature of the commercial fishery off NC in winter and its migration down the coast through MD and VA in fall does provide an opportunity to sample these "missing" fish.

P. The TC makes the case for increasing Z based on the ADAPT Run #20 (the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20.

TC Agrees

In ADAPT runs other than #20 (tuned to trawl surveys), F decreases to an unrealistically low level and the stock biomass increases 3x's beyond anything estimated previously and shows no sign of decreasing. It implies decreased catches because fishers are disinterested or weakfish have become more devious. Run 20 retrospective bias was low compared to trawl survey tuned runs. The 40th SARC did not consider runs with trawl surveys credible.

The 40th SARC panel encouraged development of an MRFSS index.

At least three other ASMFC assessments feature MRFSS indices: Atlantic croaker, striped bass and bluefish.

Q. The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M.

TC Disagrees

Part 2, page 17: SSQ, r^2, bootstrapping, and Figure 26 (observed and predicted points for models with and without predation term). Biomass dynamic models without predation based on surveys were presented in Part 1, pages 25-29. Also part of slide presentation. Part 1, pages 35, 41-42, Tables 15-21, included parameter SE, SSQ, R^2, and residual patterns.

R. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.

TC Disagrees

The panel was presented with this summary of the reach of statistical analyses and Steele and Henderson model:

- **High-low weakfish biomass domains evident long-term (statistical).**
- **Menhaden has large influence over long-term domains (statistical).**
- **Now in low domain – cutting F may not allow for recovery because bass M high (Steele and Henderson).**
- **Bass-weakfish model (Steele and Henderson) applies to low domain.**

The Steele and Henderson (S-H) model was not developed to fully explain the triangular food web (menhaden, bass, weakfish) presented. It was used to explore depensatory mortality caused by striped bass during the most recent two decades of declining and low forage abundance. The combination of statistical analyses and S-H model explored this food web hypothesis. This combined approach was explicit in the Part 2 introduction of the scope of the analyses. The model is appropriate for the exploration, but it will not supply a full explanation. It does account for 78% of variation in the MRFSS index since 1981.

This is something we may not have explicitly talked about with the Panel, but the MRFSS catch index is composed of some weakfish that are small. MRFSS harvest length-frequencies contain some weakfish as small as 5 inches and 8-10 inch fish are not uncommon. The catch (releases) will be comprised of an even larger fraction of small weakfish vulnerable to predation. The MRFSS index, based on catch, is not as

vulnerable to selection changes as a harvest-based index or a survey index, such as the NEFSC fall survey, where a very large fraction of fish present in the survey went from legal to sublegal after regulations were imposed.

Recent diet analyses of large striped bass collected off Cape Hatteras (2005) and Virginia Beach (2006) in fall and winter by Dr Anthony Overton (East Carolina University) indicate a fairly steady prey-predator length ratio (0.1-0.3) for striped bass, before it tapers of to 0.45. In other words, a 900-1100 mm striped bass can readily eat weakfish that would be legal-sized. Smaller weakfish (8 inches) would be fairly vulnerable to striped bass as small as 500 mm. Weakfish comprised 5% of diets by weight in this study, the highest percentage I know of. The Steele and Henderson model in Part 2 indicates that a decline in weakfish would be induced by striped bass even though weakfish are only a minor part of the diet (1-2% of total when compared to bioenergetics estimates of bass total consumption). This is consistent with the importance of weakfish in bass diet studies; Part 2 page 23.

Consumption of weakfish by striped bass associated with the model (0.09-0.10 kg weakfish per kg striped bass) is very modest compared to total consumption of fish by bioenergetics (4-7 kg of fish per kg of striped bass) and is consistent with mid-Atlantic diet studies.

The Panel's interpretation that the model can only be applied to exploitable weakfish eaten by striped bass is not correct. A production model subsumes recruitment, growth, and natural mortality into a single function. The effects of predation may not be evenly applied across the three sub-functions and the model is just going to calculate a general loss associated with a predator trend. See Part 2, page 22.

Analysis of predation on small weakfish (relative Z) was presented in Part 1, pages 32-34. The rise in relative Z was consistent with M associated with bass in the predator-prey model.

S. A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model.

TC Disagrees

<u>We operated from very specific hypotheses and used methods suited to modest data sets.</u> The approach suggested by the Panel would likely lead to an overparameterized model. We developed the hypothesis that M has been changing for weakfish and that it is the primary driver behind the recent crash as a specific alternative, nonfishing mortality hypothesis explaining an aborted weakfish recovery. We investigated specific hypotheses that weakfish biomass dynamics, growth, and survival were negatively affected by striped

bass and exacerbated by depleted forage. We postulated and eliminated other candidate predator/competitors and environmental factors (water temperature and North Atlantic Oscillation index) to see how easily "spurious" hypotheses could be confirmed. See the Introduction of Part 2 and Part 1, page 35 for further specifics.

T. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate.

TC Disagrees

Stock-recruitment analysis requires a good underlying assessment. Errors in the estimation of SSB can produce a "relationship" that may not exist. If you start with a single species assessment under an assumption of constant M when M isn't constant, you will end up with a misleading relationship. Stock-recruitment relationships are seldom well estimated or can appear to be when they are, in fact, seriously biased.

U. If M has increased over time, then the corresponding estimate of F_{msy} would be greater than the estimate of F_{msy} that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true F_{msy}. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than F_{msy}. Therefore, assuming constant M is more risk averse than assuming an increase in M.

TC Disagrees

Constant M was a very risk prone assumption in most model configurations. Most VPA runs (except run 20 with MRFSS tuning) and standard Schaefer models without predation did not indicate that F was at anything that would have caused concern.

Only VPA run 20 under constant M=0.25, rescaled F analysis based on run 20 that allowed for estimation of varying M, or biomass dynamic models with a bass predation component indicated otherwise. VPA run 20 under constant M=0.25would indicate that large cuts in F were necessary and would lead to recovery. Rescaled F analysis and bass predation models indicated that M was much higher than F and recovery was unlikely by cutting F without a drop in M.

Equilibrium MSY limit reference points estimated from the S-H model (Steele and Henderson striped bass-weakfish predator-prey model; Part 2, page 21), indicated that F had been below the equilibrium F_{msy} limit for nearly a decade, but biomass had fallen well below the B_{msy} limit in the last several years. By 2003, rising M_b (bass-related natural mortality) ate away at the amount of F that represented a level of "safe" fishing; residual production after bass predation ($r - M_b$) fell from 0.66 in 2001 to 0.08 in 2003. Even though F fell from 0.50

during 2000-2002 to 0.39 in 2003, the amount of residual productivity after bass predation and fishing ($r - M_b - F$) went from positive to negative (0.16 to -0.31) during 2000-2003. By 2003, completely cutting F to compensate for high M_b would result in slow biomass growth at best.

Peer Review Section 4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.

V. There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years.

TC Disagrees

This is true for the grand mean of multiple surveys. However, in the last 3 years (2000-2003) in the north (RI-DE) and south (MD-NC) there is some evidence of regional declines and a more chaotic picture than indicated by the grand mean. In the north, 2 state indices have declined to below average, 1 is steady at below average relative abundance, and 2 have increased (1 to above average and 1 to average). In the south, 3 have declined below average, and 1 has increased to above average. Age 0 sized weakfish relative abundance in SEAMAP and NEFSC is above average.

W. The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes.

TC Disagrees

The TC unanimously still supports the five points of agreement reached in February 2005 regarding weakfish stock status. The five points were

- **stock is in decline;**
- **total mortality is increasing;**
- **not much evidence of overfishing;**
- **something other than F is going on; and**
- **strong circumstantial evidence of increasing M.**

Stock assessment can provide support for decision making by describing possible alternative states of nature and their consequences to management (See Part 1,Tables 1A and 1B, pages 54-55) . This is what the TC sought to do with the divergent signals it obtained after extensive analysis. There are uncertainties and different interpretations associated with the quality of fisheries data, analysis, and interpretation, as evidenced between the amount of disagreement between the TC and Panel. There clearly are risks associated with

paring away too much information as the Panel has done – there is simply nothing left as a basis for making decisions.

In a decision analysis context, it can be very important to carry a hypothesis through the assessment and examine its management implications even if it has a low probability of being correct. A hypothesis that is rejected as being improbable based on usual scientific criteria should remain in a decision analysis if it has particularly important management implications. The implications of increasing M have been demonstrated by the TC. Simply presuming that ceasing exploitation on an overfished stock has to result in recovery ignores the uncertainty imposed by ecological systems. Weakfish may or may not recover with more regulation in a world where food webs exist.

The Panel's alternative to a decline because of rising M is massive discarding arising from Amendments 2-4. In this case, weakfish regulations created a huge discarding problem (manifold greater than landings) that cannot be solved by only regulating the weakfish fishery. This hypothetical problem, which cannot be confirmed with our current discard data and methodology, likely requires keeping major mobile finfish fleets of the mid-Atlantic from fishing for any species inshore. It is interesting to note that the Panel did not indicate or suggest that directed overfishing was occurring.

Finally, there is a body of models in this assessment, based on accepted conventions, that indicates things are going swimmingly and nothing further needs to be done. They are not necessarily reflective of indices, landings, or fishers' experience over much of the mid-Atlantic. These models require application of pretzel logic to be acceptable - no one really wants to catch weakfish anymore.

Executive Summary: How Much Additional Discarding and Under-Reporting is Needed to Cause the Decline in Weakfish?

Jim Uphoff

June 20, 2006

The Weakfish Peer Review panel suggested that a steep rise in unreported commercial discards of weakfish after 1995 could have created the recent weakfish stock collapse in lieu of our hypothesis of a rise in natural mortality. As a response, I fit a biomass dynamic model to three biomass indices, harvest, estimated discards, and an additional loss term (L_F) mimicking various commercial bycatch scenarios (constant function of harvest plus discards, two increasing functions of time, or an inverse function of biomass). Additional losses were imposed after 1995 to reflect regulatory discards. Results were contrasted with those of a striped bass–weakfish predator-prey model and a biomass dynamic model without L_F. Additional losses from simulated bycatch scenarios or striped bass predation improved fit over the unaltered model (Figure 1). Median L_F estimates during 1996-2003 (6,100-6,800 mt) were greater than median bycatch (1,700 mt) and harvest (4,400 mt). By 2003, L_F estimates were 3-13 times discards used in the assessment depending on how trends in L_F were simulated (Figure 2). There is no evidence available thus far that points toward any Atlantic coast fishery capable of generating 3,000-13,000 mt of additional unreported weakfish discards. The results of these bycatch scenarios taken at face value suggest that weakfish regulations created this massive boost in discards. Thus, implementation of further conservation measures short of a coast-wide moratorium on all Atlantic coast fisheries will not minimize this discard problem.

Rising natural mortality provided a reasonable alternative to enormous undetected discards. Estimated losses of weakfish to modeled striped bass predation fell just below upper range of commercial bycatch scenarios. Striped bass biomass has increased approximately 20-fold since 1981 and modeling indicated little change in weakfish consumed per unit area per unit time (depensatory mortality). This situation is analogous to a fishery able to apply more effort while maintaining catch efficiency. Consumption of weakfish by striped bass associated with the model (0.09-0.10 kg weakfish per kg striped bass) is very modest compared to total consumption of fish by bioenergetics (4-7 kg of fish per kg of striped bass) and is consistent with mid-Atlantic diet studies.

Figure 1. Fit of biomass dynamic model using original harvest + discards with and without additional loss functions. WRI = MRFSS private boat catch per trip index; NJ and DE are trawl survey indices. Loss functions depict striped bass predation, losses as an inverse function of weakfish biomass, quadratic or linear functions of time, and as a constant function of the sum of harvest and estimated discards.

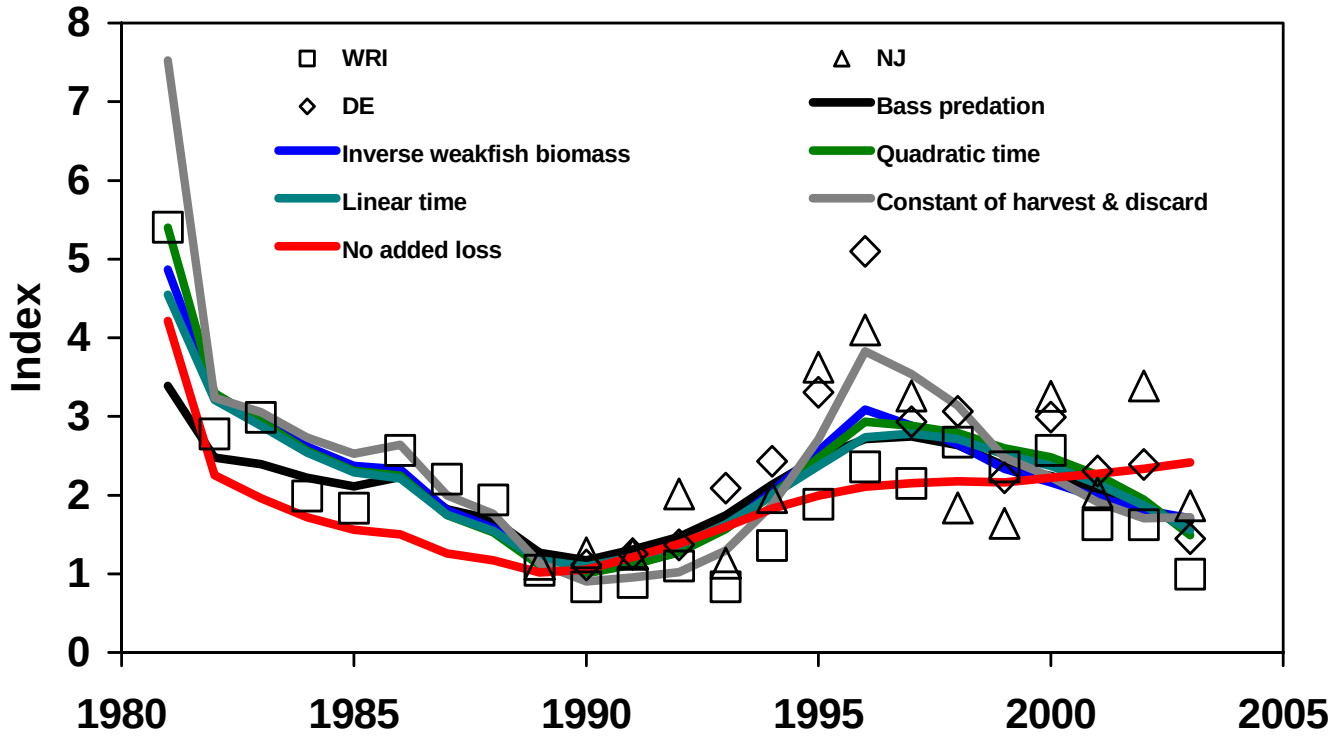
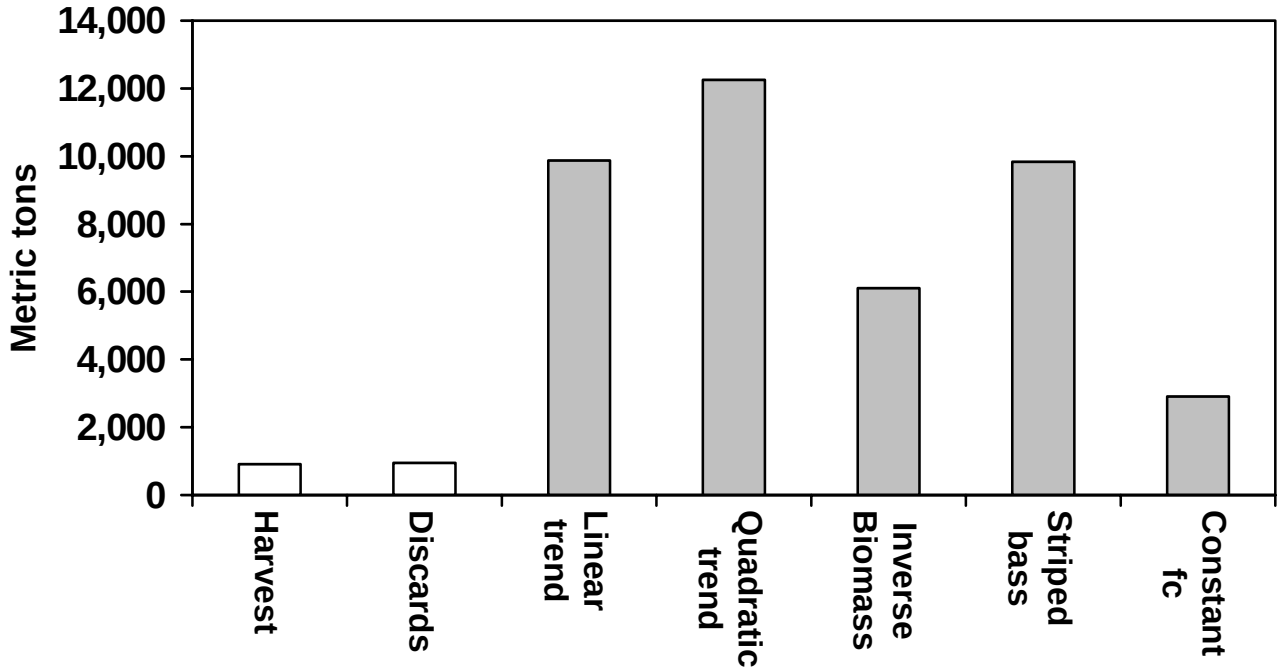


Figure 2. Metric tons of additional losses in 2003 from different loss scenarios contrasted with commercial harvest and discard estimates



Executive Summary: Estimating At-Sea discards of weakfish using NEFSC Observer database

Weakfish Technical Committee

July 2006

This is a brief summary of *Estimating At-Sea discards of weakfish using NEFSC Observer database*, a report prepared by Janaka de Silva (FL) in 2004 for the Weakfish Technical Committee. This report provided the technical basis for discard estimates used in the recent stock assessment.

Estimates of commercial discards were developed from 1994-2003 NMFS at sea observer data. The database contained information on weakfish discards, target species catches, estimates of landings of species kept on the haul, and length data of both discards and fish kept. We only evaluated hauls that were completely sampled for discards. During 1994-2003, discard data were primarily available for gillnets (287 trips and 615 hauls; 89% landed in Virginia, North Carolina or New Jersey) and otter trawls (196 trips and 519 hauls; 41% landed in Maryland and 49% in New Jersey, New York, or Rhode Island.). The annual number of gillnet trips where weakfish discards were observed ranged from 5 to 68. The numbers of otter trawl trips where weakfish discards were observed ranged from 4 to 45.

We developed estimates of weakfish discards using annual (1994-2003) discard ratios (weakfish : target species) and NMFS commercial landings of a suite of target species. The ratio of at sea observations of weight or number of discarded weakfish to pounds of harvested target species by gear (trawl and gill net) was scaled up to total discard estimates based on total landings of the target species. Discards were subdivided into regulatory and market discards. Identification of target species was only based on complete trips and hauls where weakfish discards were observed. Target species were weakfish, longfin squid, Atlantic croaker, butterfish, summer flounder, Atlantic menhaden, spiny dogfish, spot, and bluefish. We assumed that gear-specific relationships among the target species in the data set reflected the entire fishery.

Slightly more than half of ratio estimates were significantly different from zero. Ratio estimators work best when there is evidence of a positive linear relationship between the response and explanatory variable. Total discard estimates presented in this report included estimates from target species where there was not evidence of a strong linear relationship between weakfish discards and the target species we examined.

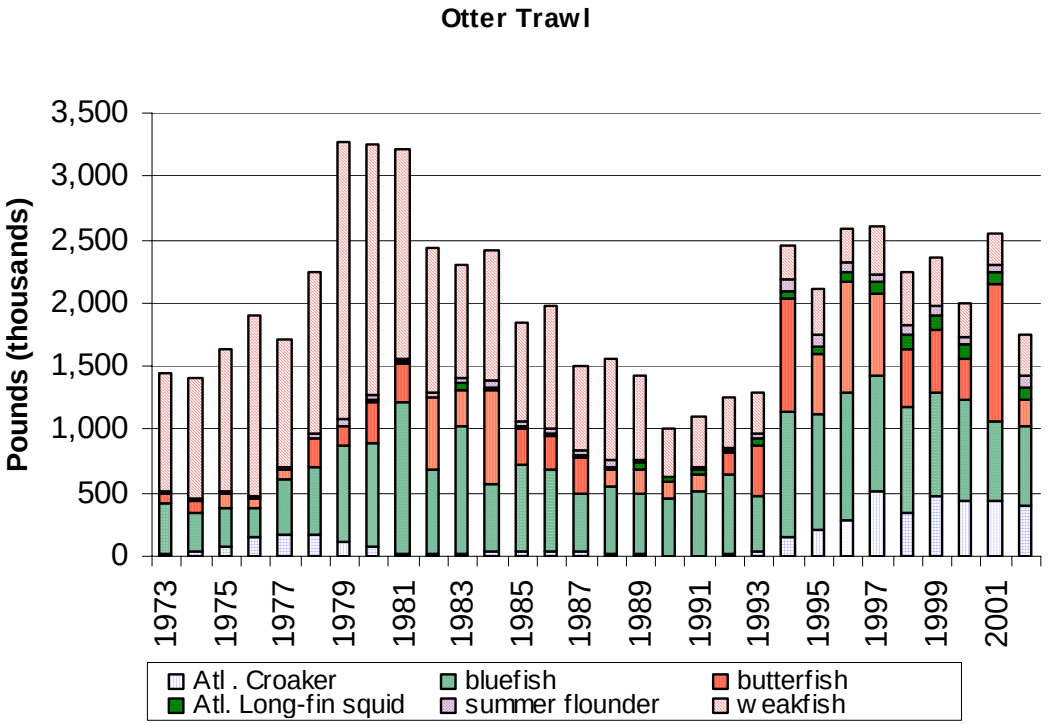
During 1973-1992, coast-wide commercial fishing regulations on weakfish were not in place. Market-related discard ratios were used to estimate weakfish discards during 1973-1992. In 1993, New Jersey and Delaware enacted weakfish regulations that may have lead to non-market discarding and the total discard ratio was used for these states. For all other states, discard estimates for 1993 were based on the non-regulatory discard ratios. During 1994-2002, total discard ratios were used to estimate weakfish discards for all states. Commercial discard data was not available for 2003 when these estimates were formulated for the assessment and we averaged the commercial discard estimates for 2001 and 2002.

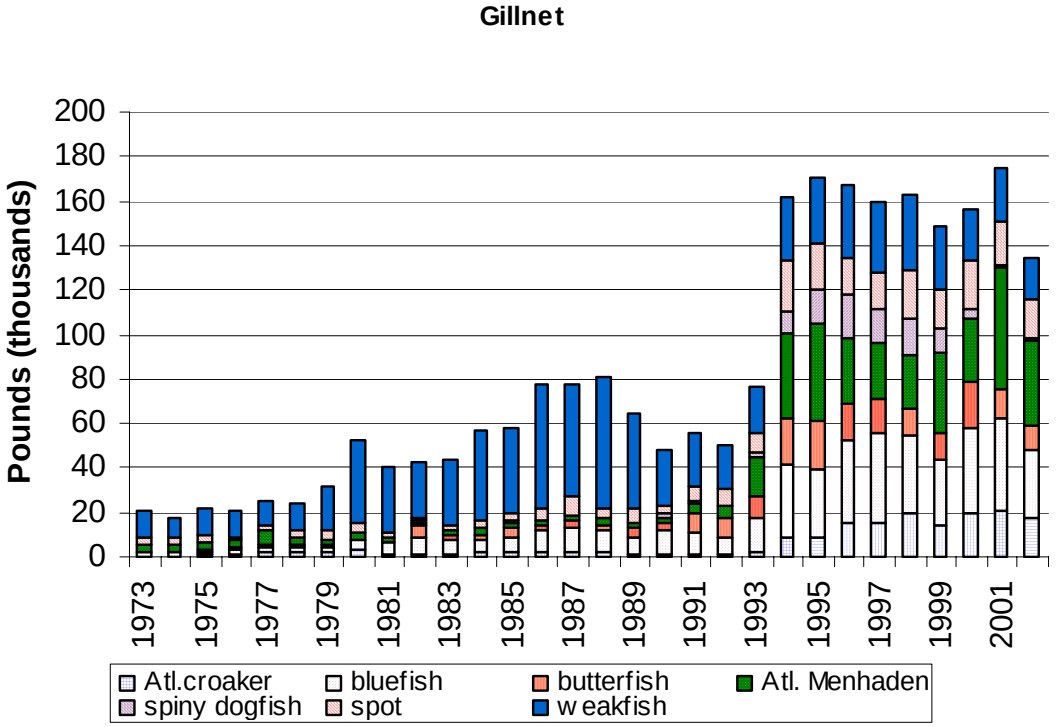
We considered all estimated commercial discards to have died in the stock assessment. Weakfish discards for the mid-Atlantic were predominantly associated with otter trawls (Figure 1). Trends in otter trawl weakfish discards for the mid-Atlantic show a cyclical trend, with peaks around the late 1970's (~ 3 million pounds) declining to a low of around 1 million pounds in 1990, and stabilizing around 2.5 million pounds in recent years. Trawl fisheries for Atlantic croaker, summer flounder, bluefish, butterfish, and weakfish account for most discards once regulations were imposed (since mid-1990s). For mid-Atlantic gillnets, discards rose from 50,000-80,000 pounds prior to 1994 to 150,000-160,000 pounds during 1994-2001. Estimated discards fell to around 120,000 pounds in 2002. Gill net discards are now mostly from the Atlantic croaker, Atlantic menhaden, spot, butterfish, and weakfish fisheries; discards from the spiny dogfish fishery no longer appear in our estimates (Figure 1).

We also developed discard estimators using a regression approach, but found the models to be of poor quality. While effort (trip) based estimators could be developed, the corresponding effort information on the target species in the fishery are only available for some states and in certain years.

Most commercial fisheries were eliminated from the South Atlantic by the mid-1990s. Weakfish discard estimates for the South Atlantic were low and of poor quality because they were based on estimates from the mid-Atlantic. They were not included in the assessment.

Figure 1. Estimated weight of weakfish discarded by mid-Atlantic otter trawl and gill net fisheries





The weakfish population structure along the Atlantic Coast: a literature review

A report to the Atlantic States Marine Fisheries Commission's Weakfish Technical Committee

By

Joseph Munyandorero
Florida Fish and Wildlife Conservation Commission
Florida Fish and Wildlife Research Institute
100 8th Avenue SE
St. Petersburg, FL. 33701
Phone: (727)896-8626 ext 4122
Joseph.Munyandorero@MyFwc.com
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Weakfish population structure

This note summarizes available information on weakfish population structure, part of which (especially the tagging outputs, meristic, morphological and life history characters of weakfish inhabiting the Mid-Atlantic) was reviewed by Mercer (1985, 1989). Weakfish, *Cynoscion regalis*, occur along the Atlantic coast of the United States of America from eastern Florida to Massachusetts, but are most abundant between New York and North Carolina (Mercer 1989). Weakfish stock assessments and related fishery management plans have been configured and implemented on the basis of a single, panmictic weakfish population (e.g., Mercer 1985, Anon. 2002).

Investigations of weakfish population structure along the US Atlantic coast have been undertaken through tagging, meristic, morphological, life history, genetic and otolith chemistry studies (Table 1). The conclusions reached are conflicting. While Crawford et al (1988), Graves et al. (1992) and Cordes & Graves (2003) did not detect genetic differentiation within the weakfish population, Chapman et al. (unpublished report) found that weakfish are made up of a series of overlapping stocks, without complete panmixia. Non-genetic studies found evidence of existence of multiple weakfish sub-populations (e.g., Nesbit 1954; Shepherd & Grimes 1983, 1984; Scoles 1990) or important spatial structure of the weakfish population (Thorrold et al. 1998, 2001). Mark-recapture, meristic, morphological and life-history studies (e.g., review by Crawford et al. 1988) indicated that weakfish could be partitioned into sub-stocks, and assessed and managed on a regional basis.

Whether studies did or did not detect discrete weakfish populations, it is worth mentioning views expressed and observations made by authors which may have assessment and management implications:

- Although the weakfish population is genetically homogeneous throughout its area of distribution, it exhibits variations in the population parameters (i.e. growth, mortality and fecundity), upon which the ability of a population to sustain a harvest is largely dependent (…);

therefore, as a practical matter, it is probably best to manage weakfish as discrete northern and southern units, even though these units are not reproductively isolated (Crawford et al. 1988).

- The genetic homogeneity found within the weakfish population contrasts with the geographical (and likely eco-phenotypic) variations of morphological and life history characters reported in other studies (…). There is clearly some interdependence among areas as also supported by tagging data (…). To obtain a meaningful estimate of the magnitude of the interdependence between these areas would require an extensive, time-consuming and expensive tagging study. Until such information is available, it would be best to manage the weakfish resource as a single interdependent stock (Graves et al. 1992).
- Weakfish tagging data indicate that low levels of exchange occur between geographically distant populations of weakfish (e.g., Schwartz et al. 1979; Music & Pafford 1984; Bain et al. 1998).
- Our data show much more spatial structure than is currently assumed by fisheries managers, and it may be useful to consider weakfish population dynamics from a metapopulation perspective. However, these results do not contradict the genetic findings, because there are sufficient exchanges even among those estuaries with the highest levels of natal homing, to prevent genetic divergence (Thorrold et al. 2001).
- The results suggest that a cline of morphometric characters or substantial mixing among the morphological types occur intermediate in the range for weakfish. Moreover, weakfish samples collected from the winter fishery off NC suggest that 79.1% belong to the Long Island (med) reference sample and 20.9% to the Pamlico Sound reference sample. This finding suggests that a significant proportion of weakfish that overwinter off NC are similar in morphology to those found in Long Island Sound in spring… It appears likely that a majority of these fish are found in Delaware Bay and north in spring, and Chesapeake Bay and north in fall (Scoles 1990).
- Overall, there are two groups of weakfish (north and south) along the Atlantic coast. Still, due to the coastal nature and migratory behavior of the species, these groups are not genetically isolated. However, there is sufficient evidence that gene flow (and subsequent recruitment) is so limited that the southern aggregations make minimal contributions to northern populations (Chapman et al, unpublished report).

Conclusion

Two main contrasting findings emerged from the literature on weakfish population structure along the Atlantic Coast. On the one hand, most genetic studies indicate that the weakfish population is genetically homogeneous. On the other, this population appears to be a mosaic of reproductively interdependent regional (even natal estuaries) sub-populations, as evidenced by meristic, morphological and life-history traits and, more importantly, by one genetic investigation and otolith chemistry studies.

On the basis of this information, pragmatism may dictate whether assessment and management strategies have to deal with a single unit-stock or separate unit-stocks (i.e., isolated, panmictic sub-populations, characterized by uniform growth, mortality, fecundity parameters, etc.). Gulland (1988) considered definition of a unit-stock an essentially operational matter, being tied to the models used, the questions asked, and information available. Stock structure is not considered in the striped bass assessment, even though stock structure is well defined.

It is worth keeping in mind that subdividing a stock (initially treated as a whole) into sub-stocks may meet homogeneity requirements, but it presents potential for not meeting the condition of isolation. One may expect that multi-stock assessment models will be complex and data-consuming, without any warranty of improvement in comparison with single- stock assessment models. In fact, the complications here potentially stem from (i) weakfish migration patterns (e.g., Mercer 1985, 1989), resulting in unknown mixing rates between various fishing locations, and (ii) the sequential nature of the exploitation along the weakfish migratory route.

Technical Committee Position

On June 20, 2006, the Weakfish Technical Committee (TC) reviewed this information on stock structure. Full agreement was reached on the following:

- Evidence of stock structure exists.
- Data is inadequate to define stock structure and there is enough potential mixing that pinpointing north/south (N/S) split is not possible at this time.
- If a north to mid-Atlantic subpopulation is in serious decline, this does not warrant a N/S split based on conservation concerns.
- The Board needs to clarify its reasoning for a N/S split.
- Does the Board want research recommendations on this from the TC?

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Overview of the Weakfish Resource

By Jim Uphoff, ASMFC Weakfish Technical Committee Chair

Weakfish fisheries were subject to increasingly restrictive management during the early and mid-1990s and were thought to be on the path to recovery. Between 1999 and 2003, recreational and commercial landings of weakfish along the Atlantic coast plummeted to all-time lows while population estimates from traditional single species assessments reached all-time highs. This dichotomy of assessment results and fishery performance lead the Weakfish Technical Committee to consider less traditional assessment techniques.

A preponderance of evidence from these alternative approaches indicated that a large rise in natural mortality that started in the mid-1990s largely caused weakfish biomass and size structure to decline greatly by 2003. These declines could not be attributed to a slight rise in fishing mortality. When concerns about weakfish first arose during the late 1980s and early 1990s, estimates of fishing mortality were high. Conservative management measures were imposed beginning in the early 1990s and fishing mortality rates fell to modest levels after 1994. Biomass and size structure rebuilt for a time, but underwent a rapid decline after the late 1990s.

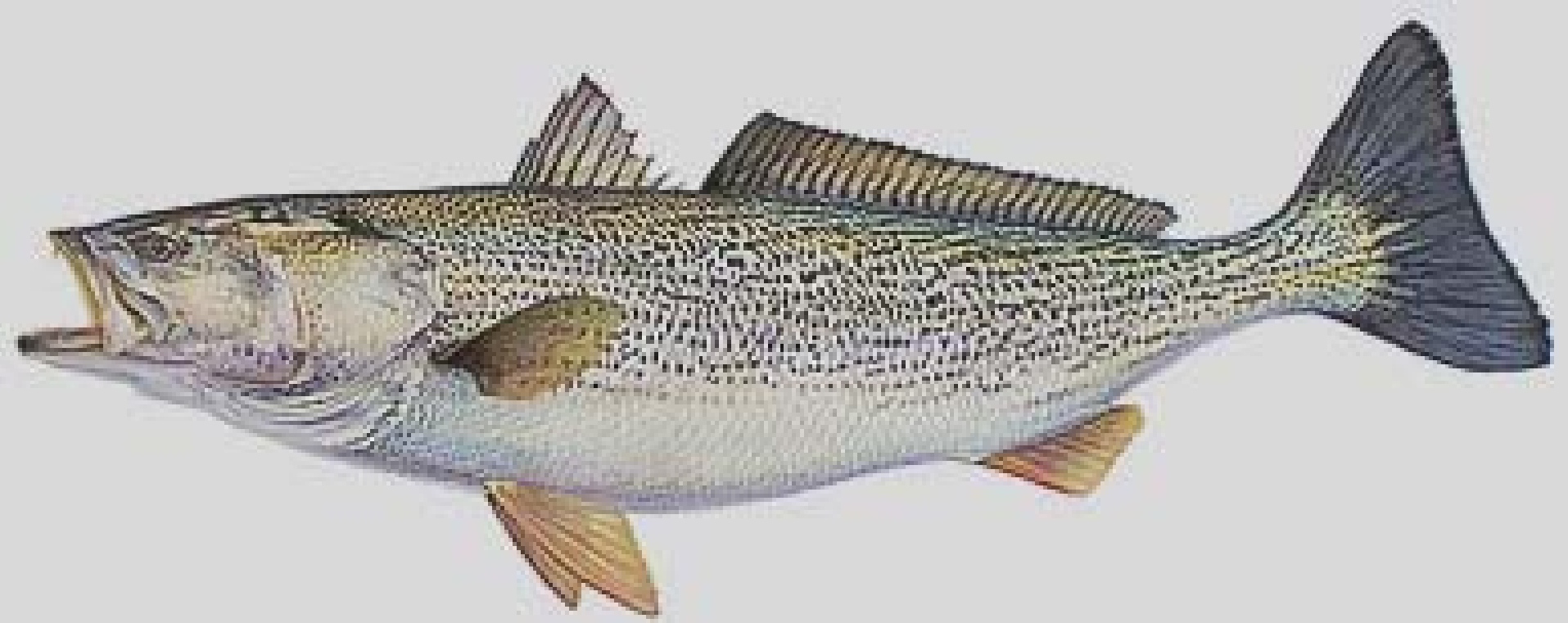
High and rising natural mortality does not provide managers much leverage for recovery by managing the weakfish fishery alone. However, projections indicated that cuts in fishing mortality will be needed for timely recovery if natural mortality declines.

In the past, we have presumed that ceasing exploitation on an overfished stock has to result in recovery. This presumption has ignored uncertainty imposed by ecological systems. The rapid decline in recent weakfish biomass and landings was reminiscent of rapid transitions between extended periods of high or low commercial landings dating back to the late 1920s. In theory, these rapid changes could reflect an underlying environmental driver whose effect has been accelerated by high fishing or predation rates.

The Technical Committee developed and tested specific hypotheses to evaluate candidate predator/competitors (striped bass, summer flounder, bluefish, spiny dogfish and Atlantic croaker), forage species (Atlantic menhaden, bay anchovy, and spot), climatic factors (water temperature and North Atlantic Oscillation index), high discard losses, and overfishing. Insufficient forage, especially Atlantic menhaden, and increased predation by striped bass have emerged from these analyses as leading candidates behind rising natural mortality. Contributions by remaining candidates or others may exist, but have not been detected or tested.

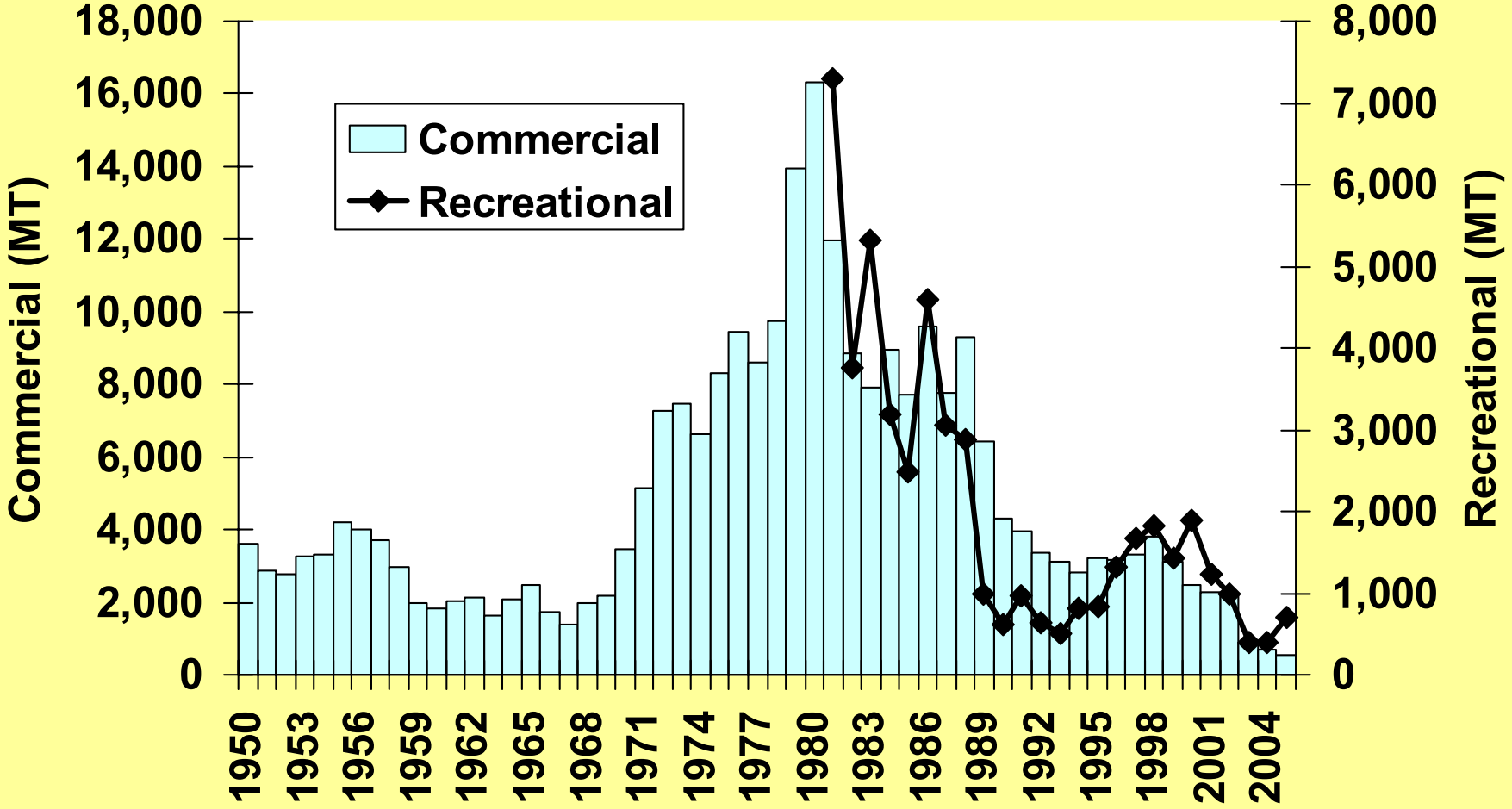
The following presentation was provided to the Commission's Weakfish Management Board at its August 2006 meeting. It was prepared to address questions raised by the Management Board and External Peer Review Panel regarding fishery status and possible next steps in the management program.

What's Next with Weakfish?

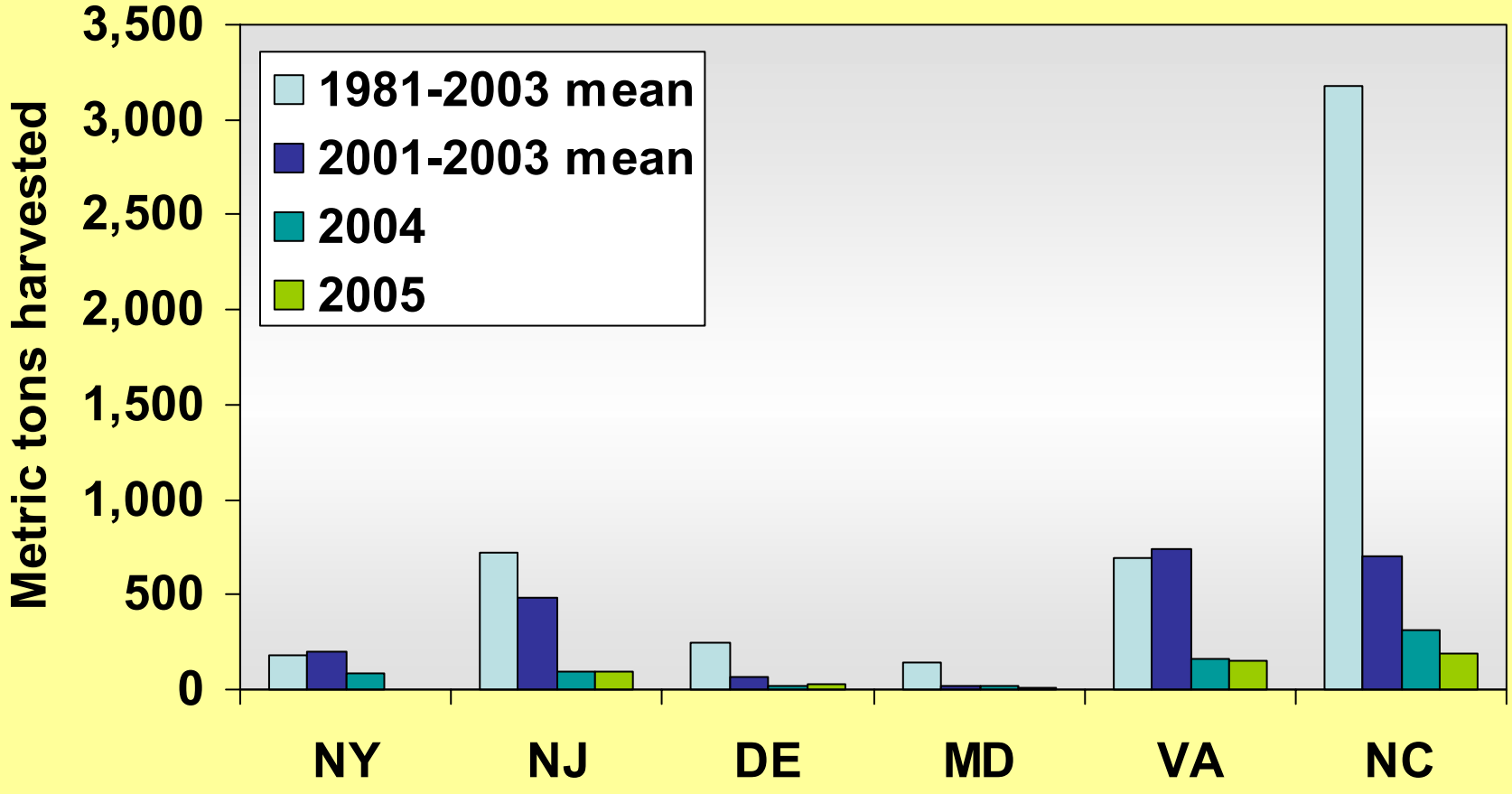


A Report of the Weakfish Technical Committee
- Fishery Status & Board Requests
August, 2006

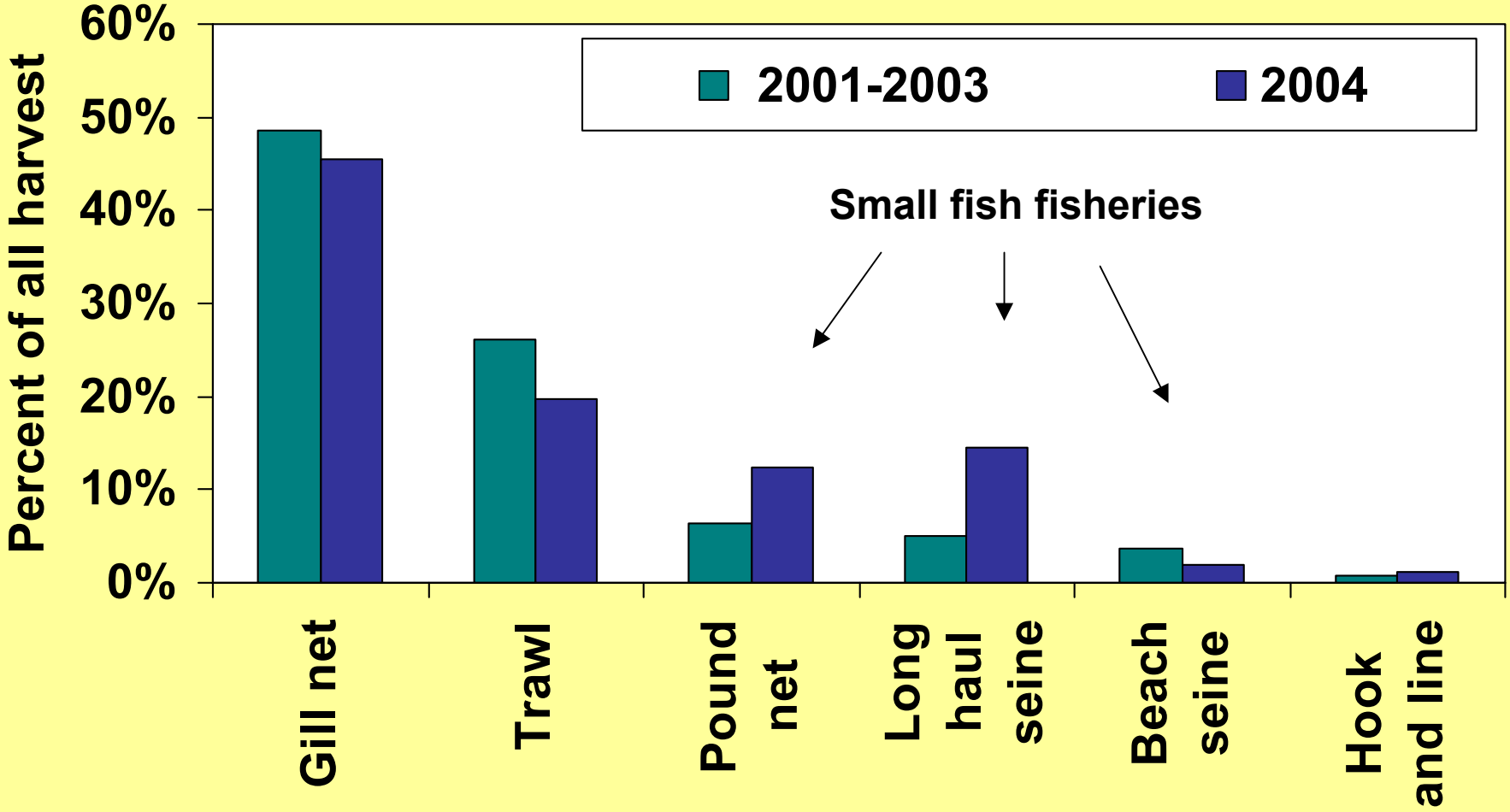
Atlantic coast harvest of weakfish, 1950-2005



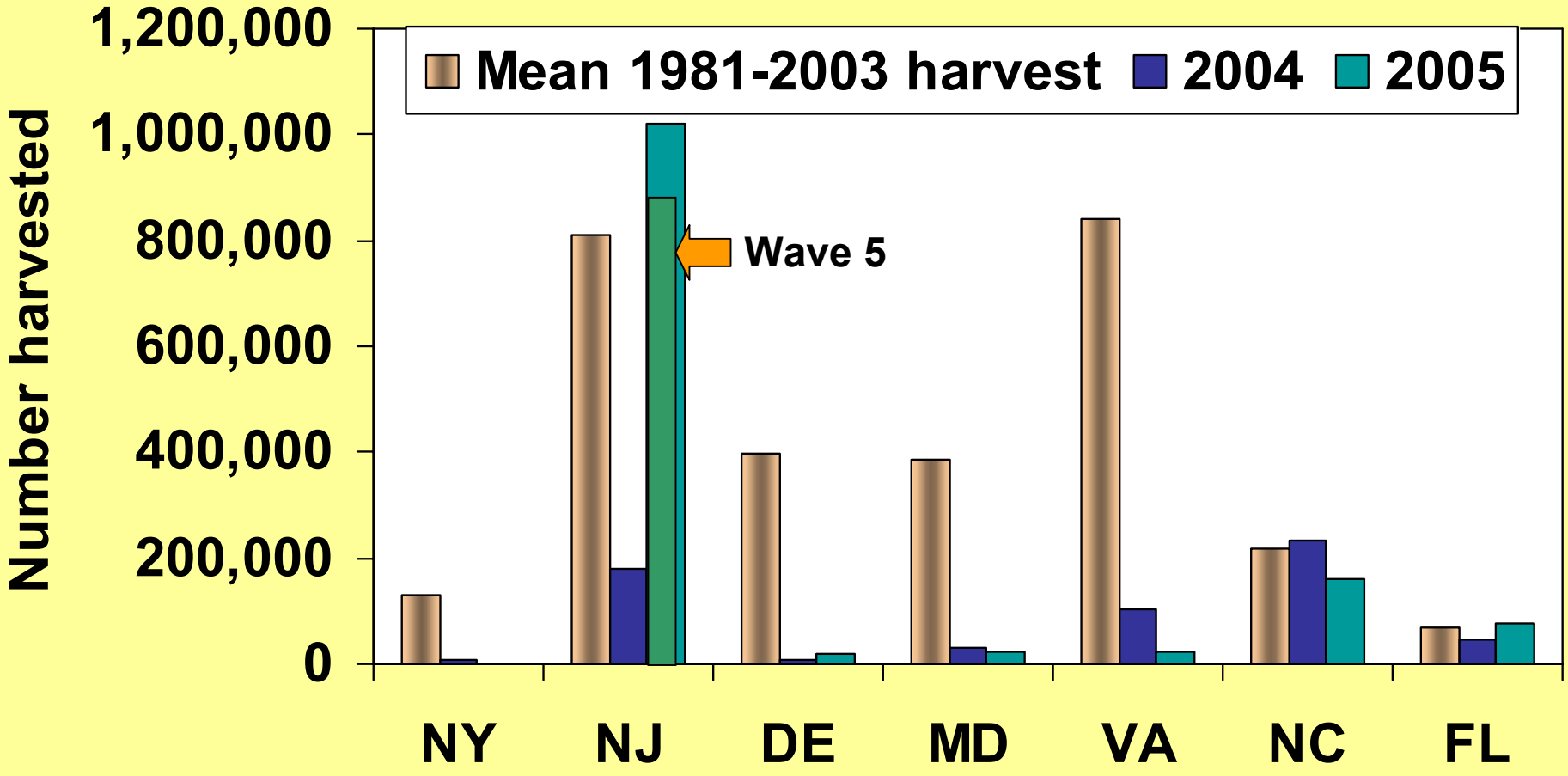
Average commercial harvest by state during 1981-2003 and 2001-2003 vs 2004 and 2005 (incomplete)



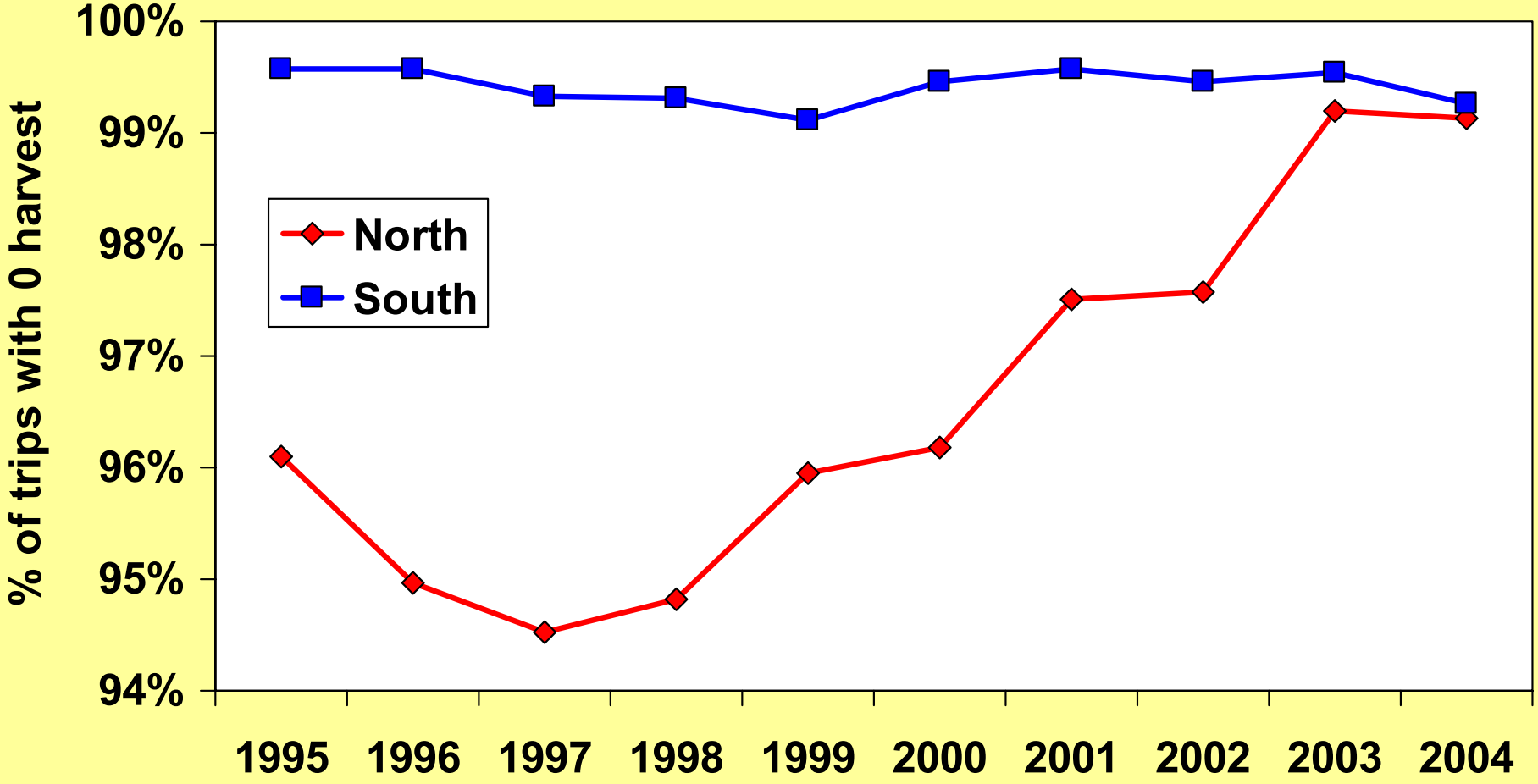
Distribution of mean 2001-2003 commercial catch and 2004 by gear



Average 1981-2003 and 2004, 2005 recreational harvest, in numbers, by state



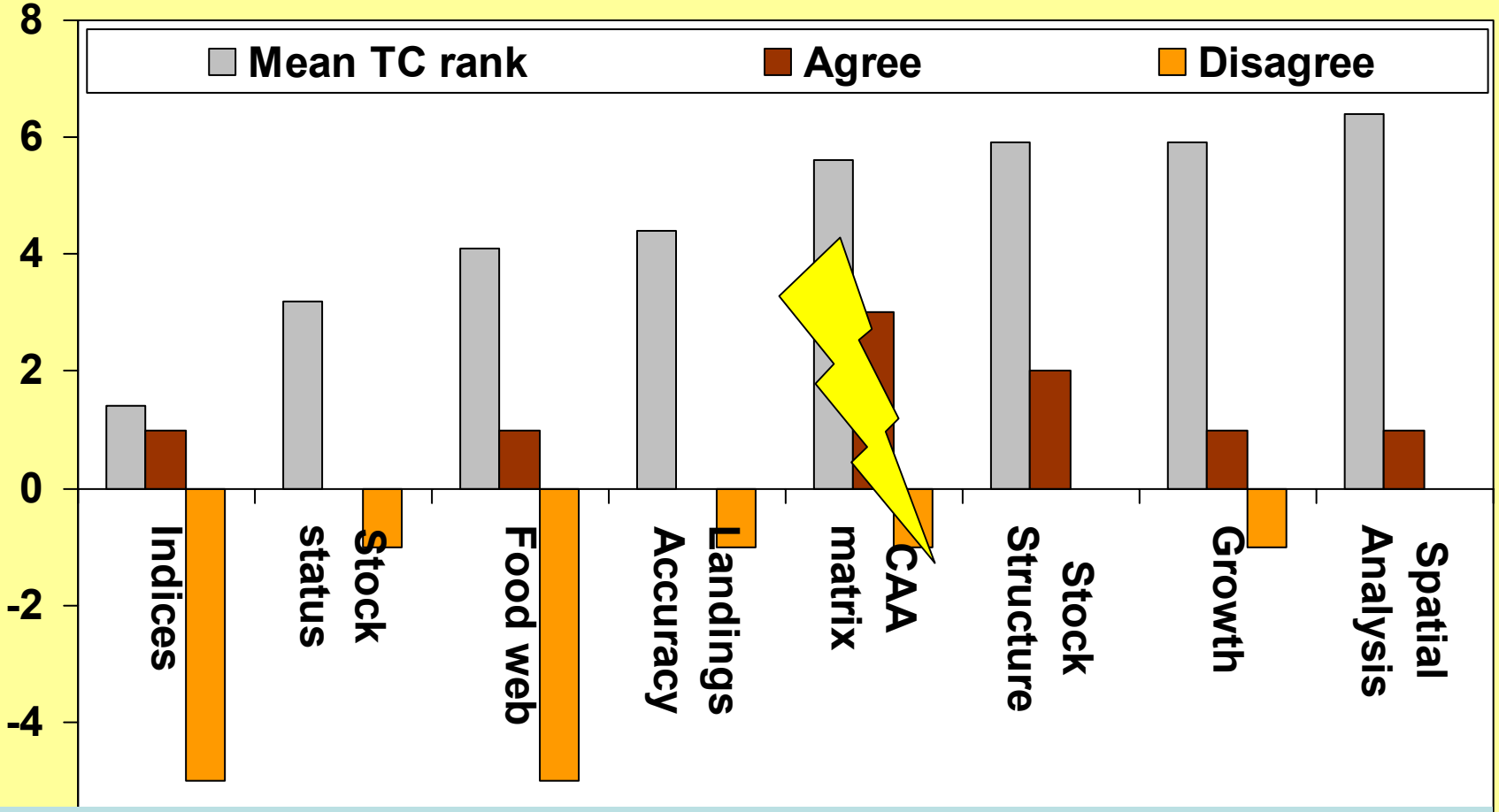
Percent of all recreational trips in the north (NY-VA) & south (NC-FL) that did not harvest weakfish



40th SARC Recommendations

- The TC did not disagree with recommendations
- 6 of 8 recommendations were implemented in the year between reviews
- 2 not implemented required much more time (CAA review) or additional capability (spatial analysis may need GIS to examine anything but gross patterns).

TC agreements and disagreements with 2006 peer-review statements. Lowest mean rank = most important. Agree or disagree displays number of specific statements.



Agreements or disagreements usually unanimous

Indices – main issue is NEFSC trawl survey vs MRFSS index

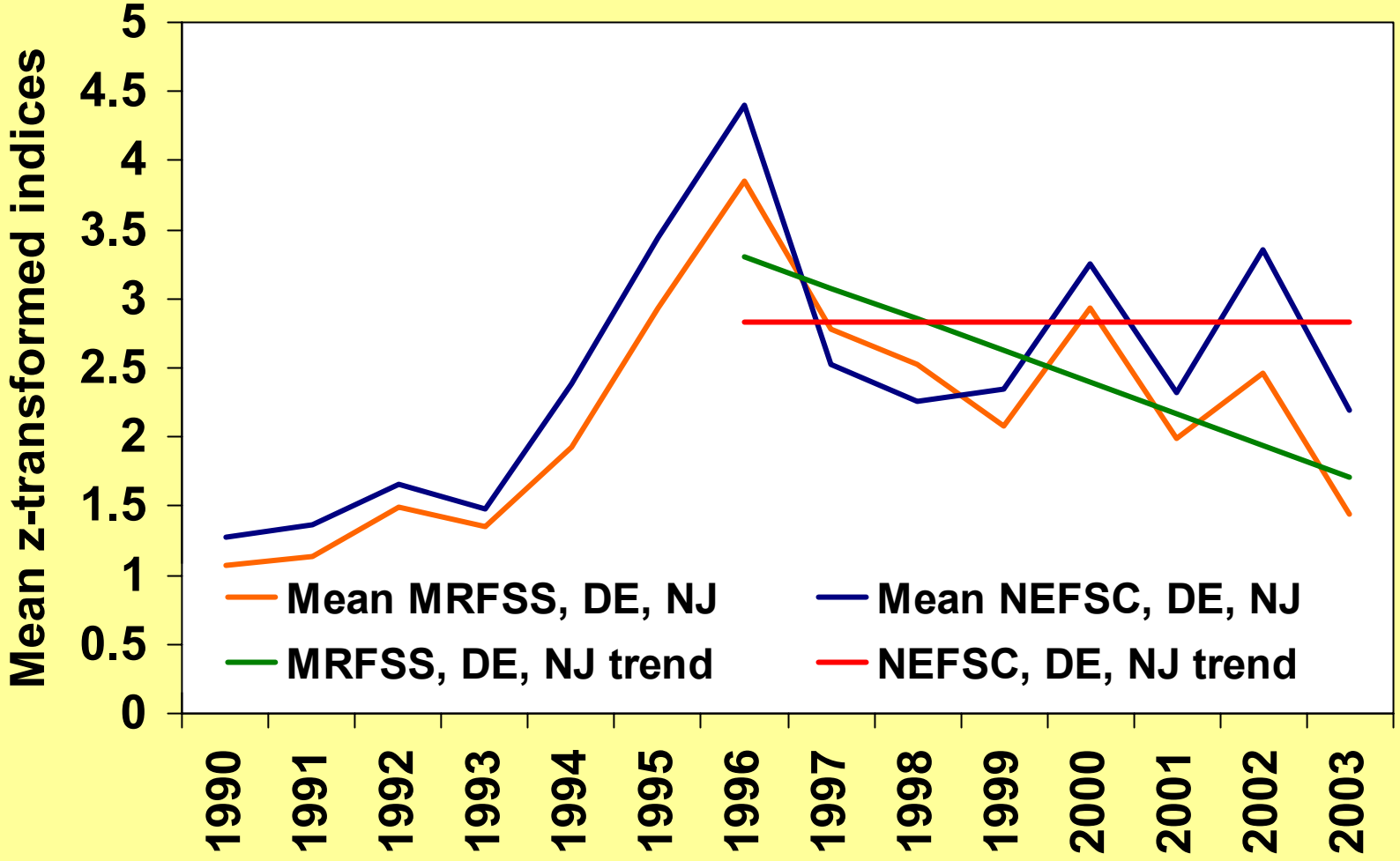
- TC chose MRFSS catch index
- MRFSS index suggested at 40th SARC
- Panel rejected MRFSS – catchability
- TC rejected NEFSC – catchability, spontaneous generation, poor size representation
- Striped bass, bluefish, croaker assessments have MRFSS indices

Indices – No correlation of MRFSS vs NEFSC
Disagreement requires choice

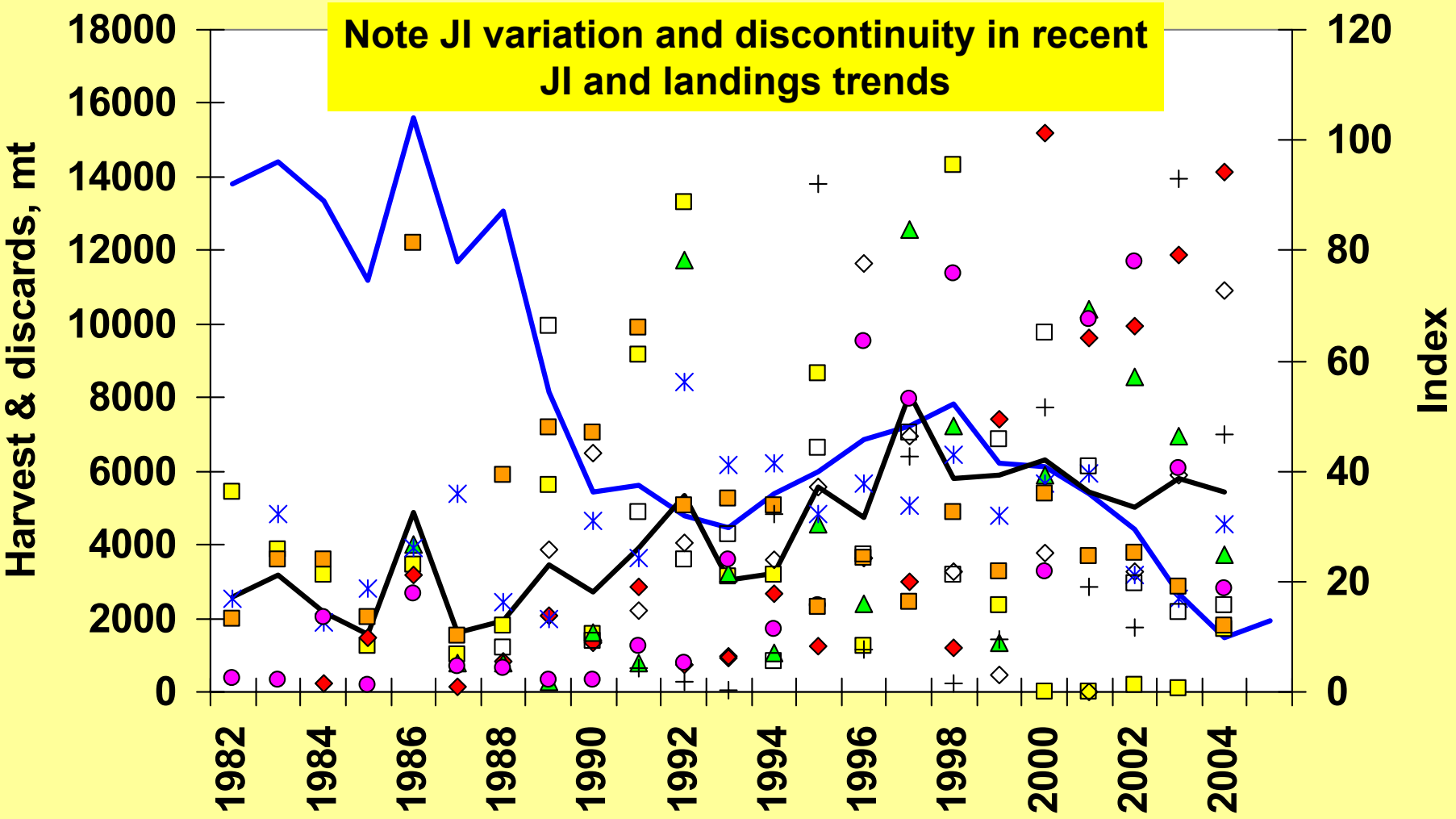
Green = P <0.05, Yellow= P < 0.10, Red = NS

Index	NJ	DE	NEFSC
MRFSS	0.59	0.75	-0.05
NJ		0.78	0.66
DE			0.52

Consequences – very different view of recent trend depending on whether MRFSS or NEFSC is averaged with DE & NJ surveys (all standardized)



Increasing trend in JI a cause for optimism? Standardized age 0 weakfish indices versus harvest + discards (blue line). JI grand mean (black line) indicates general JI trend; symbols = different surveys.

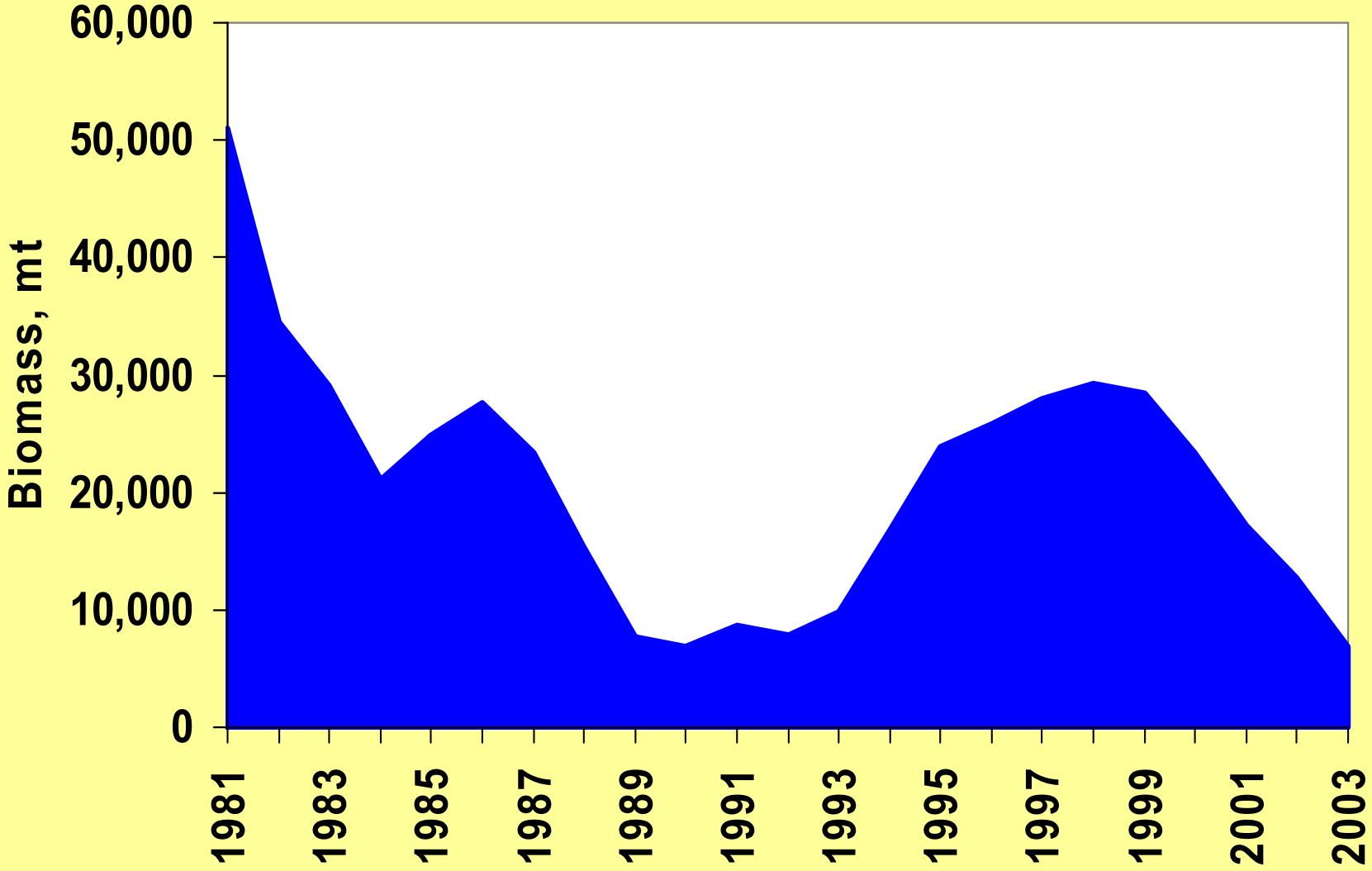


Stock Status: Review didn't offer view

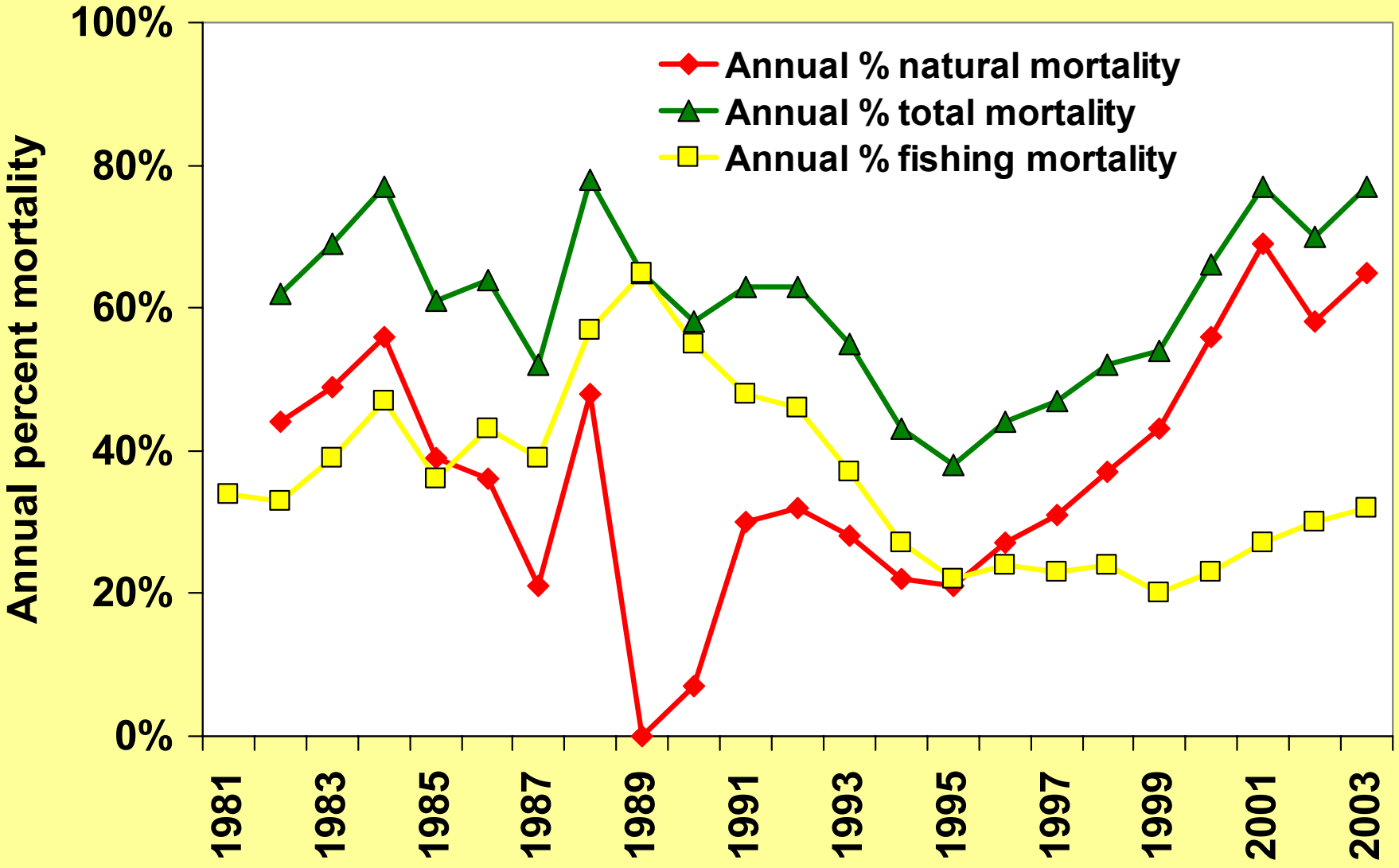
TC position:

- Stock declining
- Total mortality increasing
- Not much evidence of overfishing
- Something other than F is going on (increasing M)
- Strong chance regulating fishery won't help.

Estimated weakfish biomass during 1981-2003.



Annual total, fishing and natural mortality. These rates have been translated into annual percentages, so fishing and natural mortality are not additive.



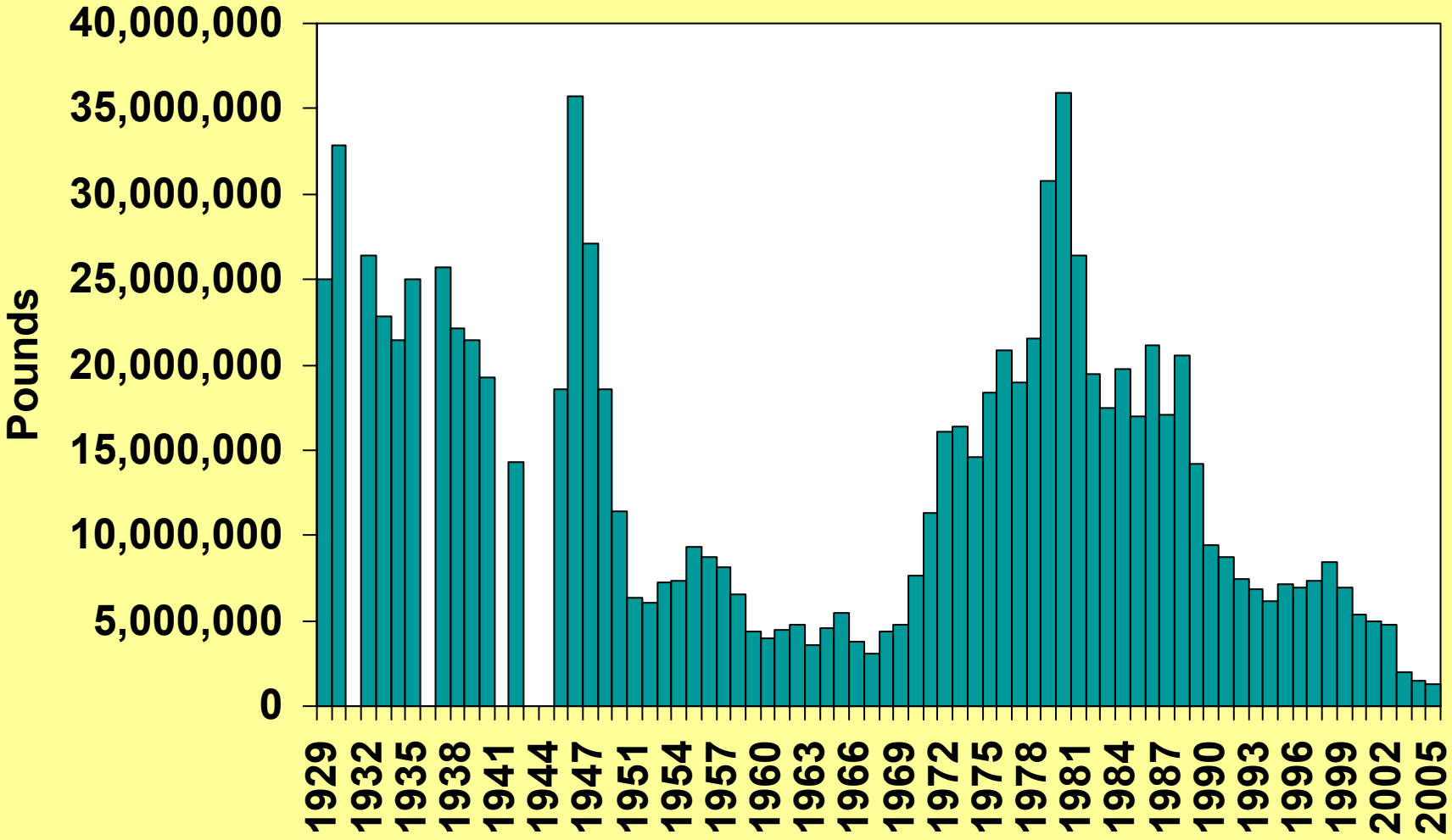
Major Reason for Decline?

- Neither TC, 40th SARC, nor peer-review implicated directed F as lead cause
- TC considers food-web dysfunction as most plausible contributor to high M
- Panel suggested undetected commercial discards lead to high F
- Food-web or discards indicate little direct leverage on stock and do not present a clear-cut solution

Food-Web Conclusions

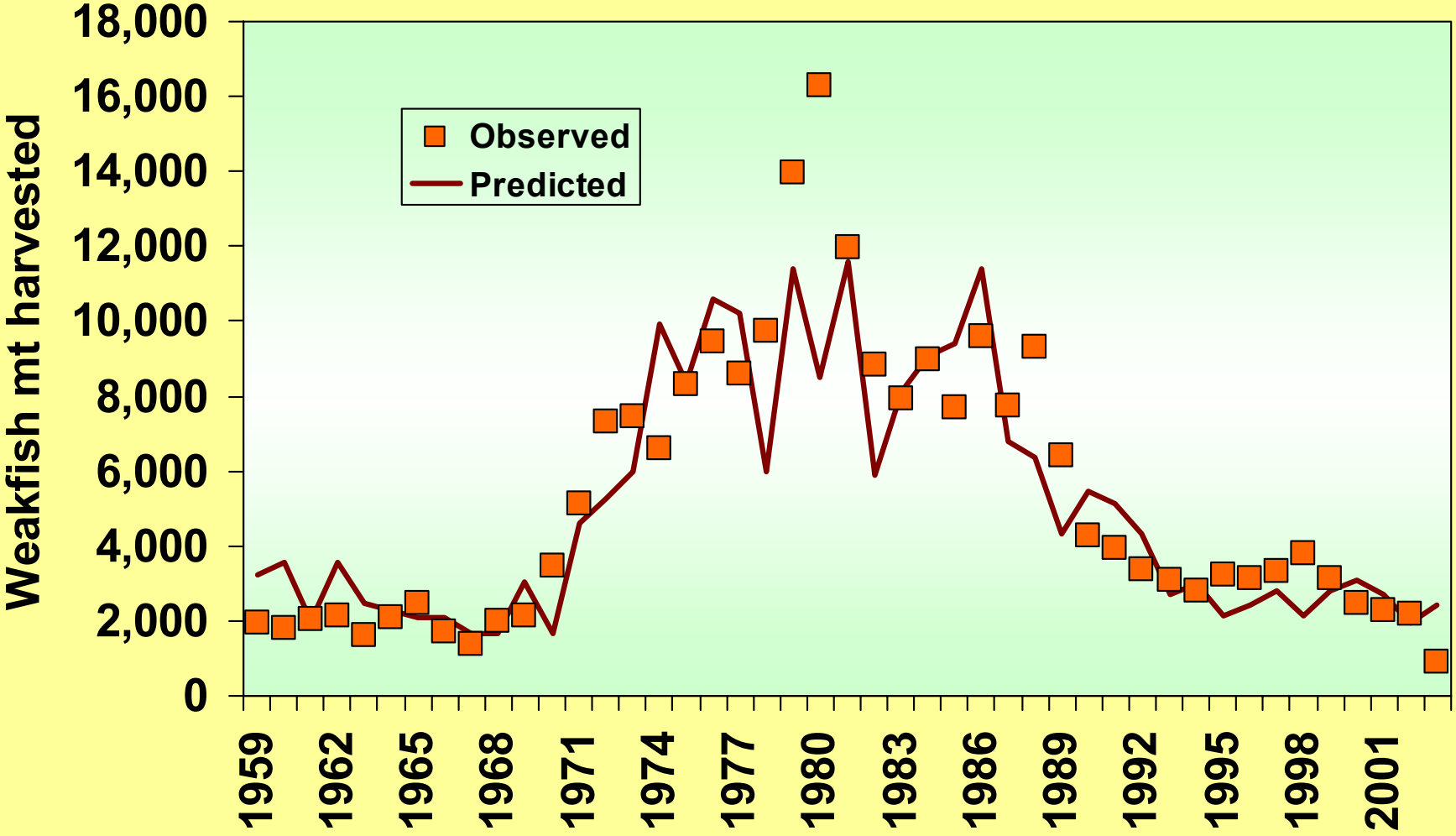
- Diet bottleneck plausible
- High-low weakfish biomass domains evident in long-term landings.
- Now in low domain – cutting F may not allow for recovery because M high.
- Menhaden has large influence over long-term domains.
- Adding bass to single-species model necessary to fit recent decline.
- Bass-weakfish model applies to low domain.

High-low domains appear in 1929-2005 commercial landings

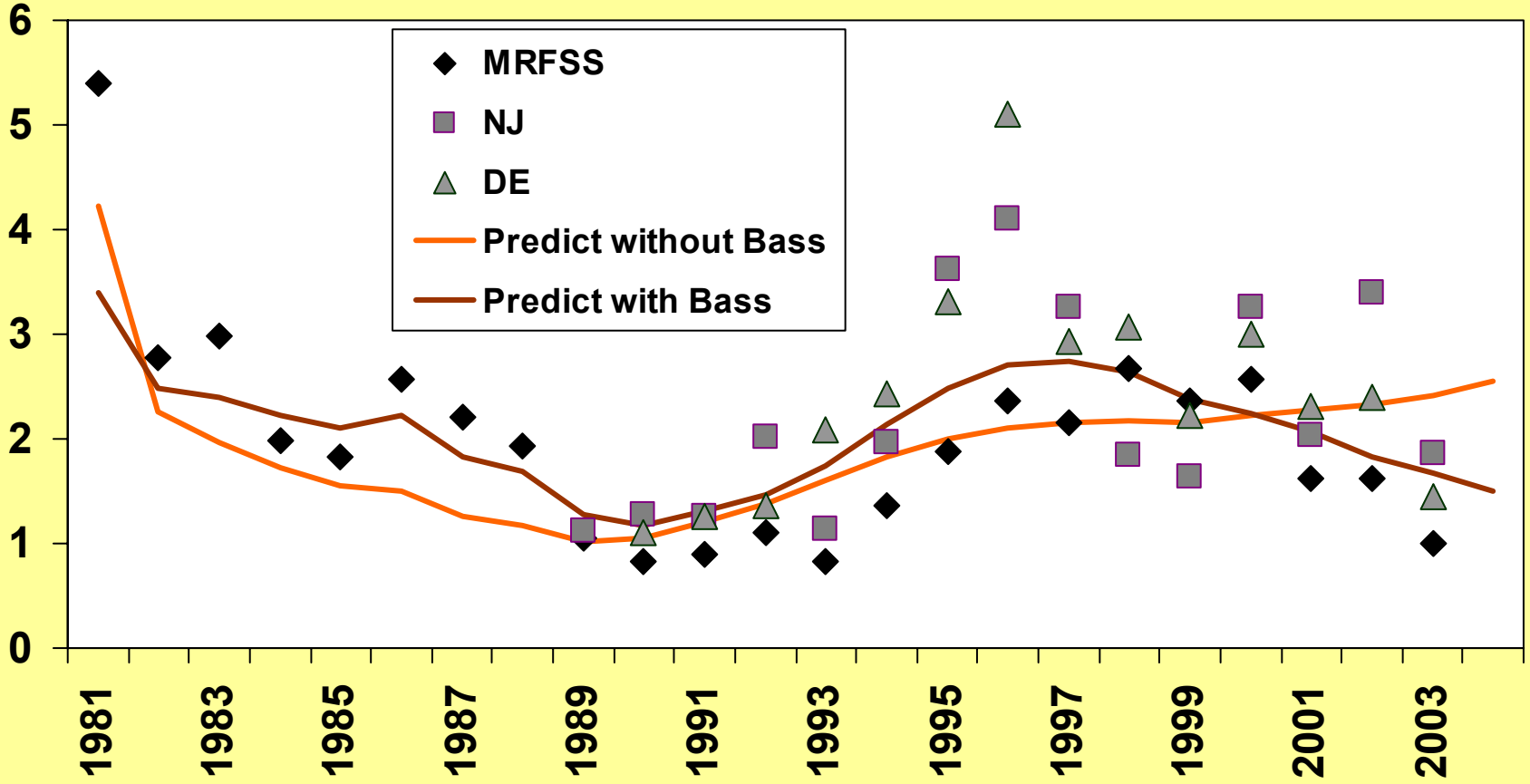


Food-web. Fit to weakfish commercial landings from multiple regression of large bass index and menhaden juvenile index (both terms significant).

Menhaden partial r^2 = +0.73; bass partial r^2 = -0.03.

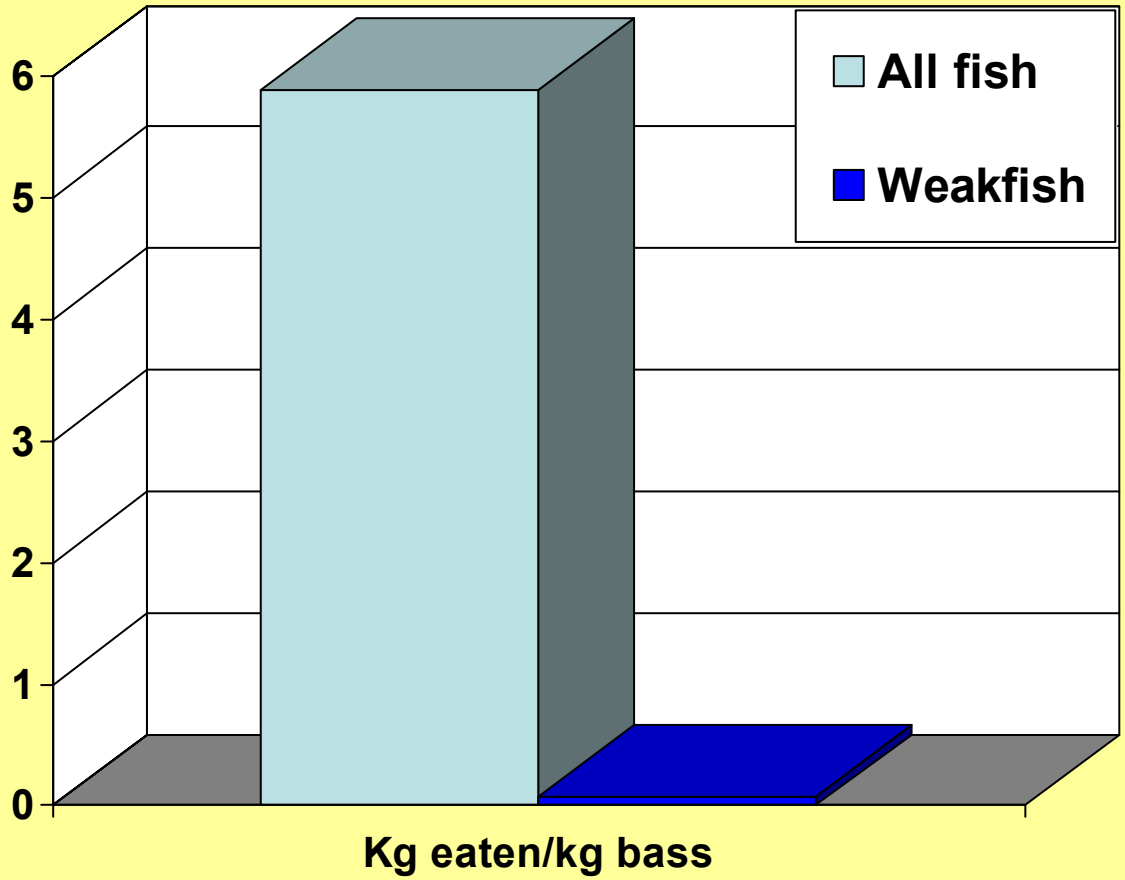


Food-web. If bass losses aren't included, you don't get a declining trend in recent years. DE and NJ surveys included with MRFSS.



Food Web –weakfish only need to be a very minor constituent of bass diet.

Comparison of bass bioenergetics total fish consumption and bass-weakfish model consumption



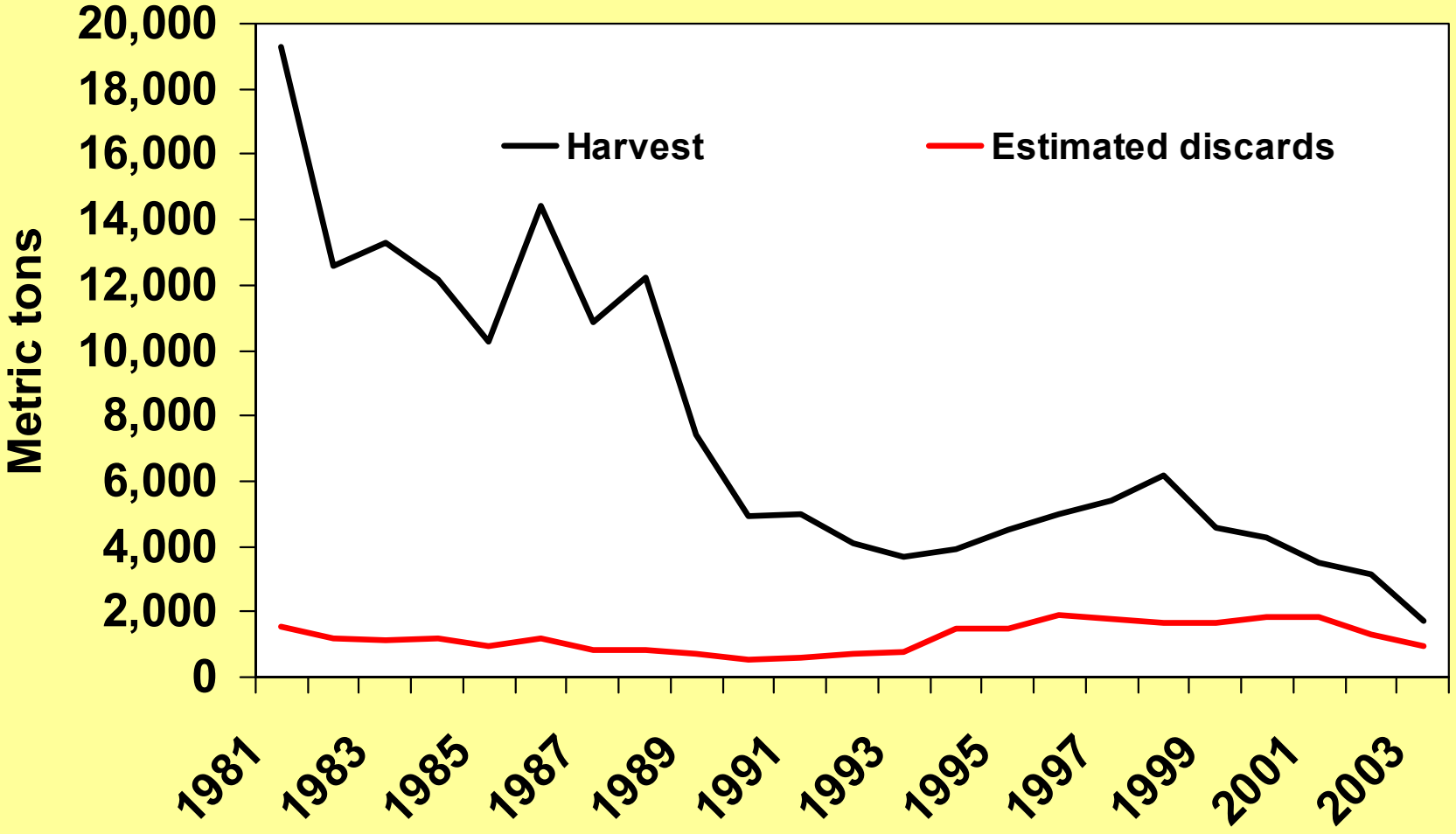
Landings Inaccurate?

- We use the same commercial and recreational landings as other ASMFC assessments
- Commercial discards estimated by technique used for Atlantic croaker (passed peer-review)
- Recreational ages have to be “borrowed” in any assessment

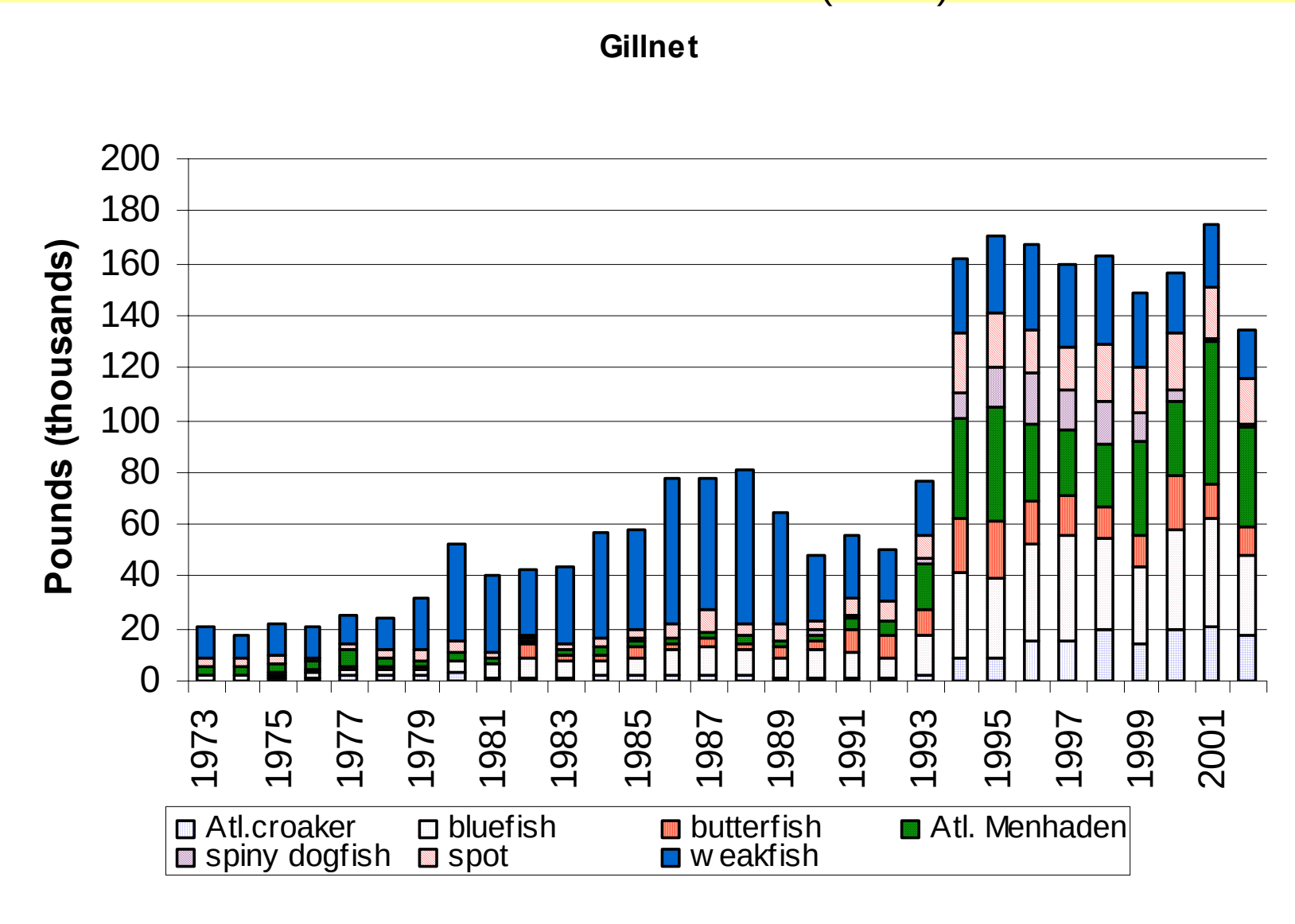
Commercial Discards

- De Silva (2004) thoroughly estimated gill net and trawl discards during 1994-2003 from ratios of harvest to discards in observer samples
- Precision poor to adequate (95% CI overlaps 0 about 50% of estimates)
- Estimates prior to 1994 estimated from 1994-2002 market discard ratios
- Estimates after 1994 based on market & regulatory discards
- Loss estimates on high side – all commercial assumed dead (+ 20% recreational)

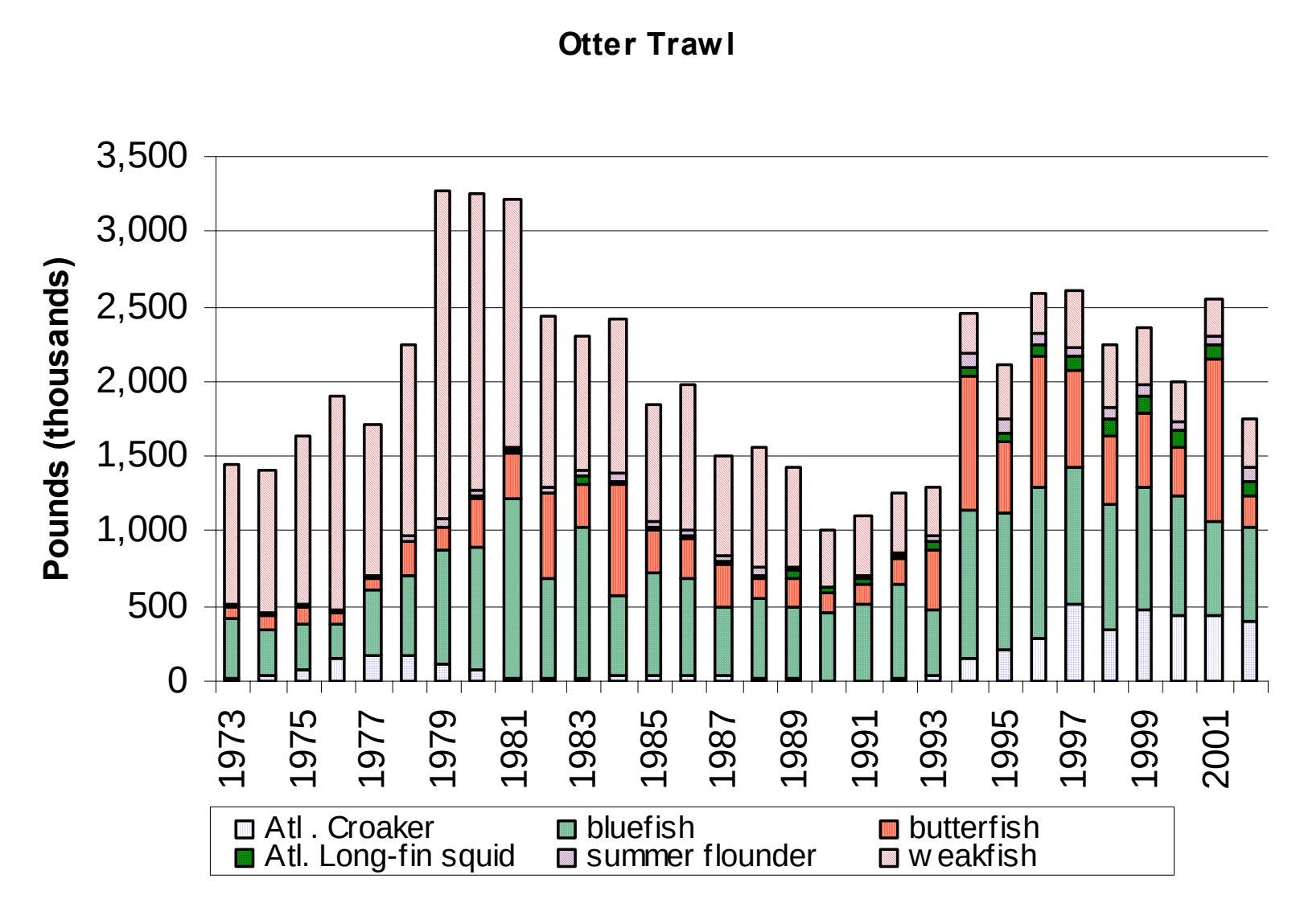
Reported harvest and estimated discards (recreational and commercial combined)



Weakfish discards from gillnets in the mid-Atlantic by target species. Note discard estimates prior to 1994 were based on non-regulatory discard ratios and include regulatory discards after 1993. From de Silva (2004)



Weakfish discards from otter trawl in the mid-Atlantic by target species. Note discard estimates prior to 1994 were based on non-regulatory discard ratios and include regulatory discards after 1993. From de Silva (2004)

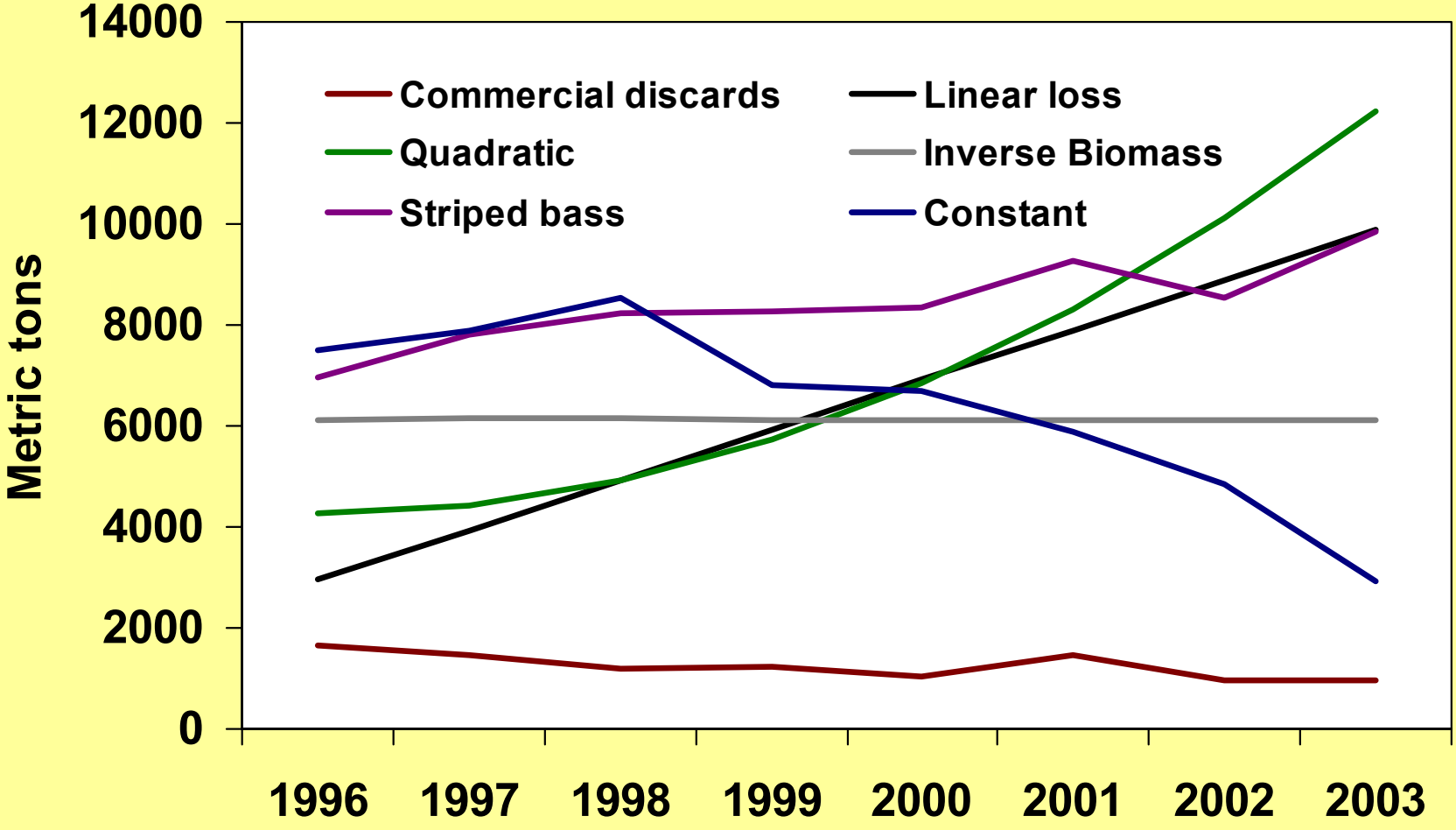


How much commercial “ghost” discard loss do you need to produce a decline?

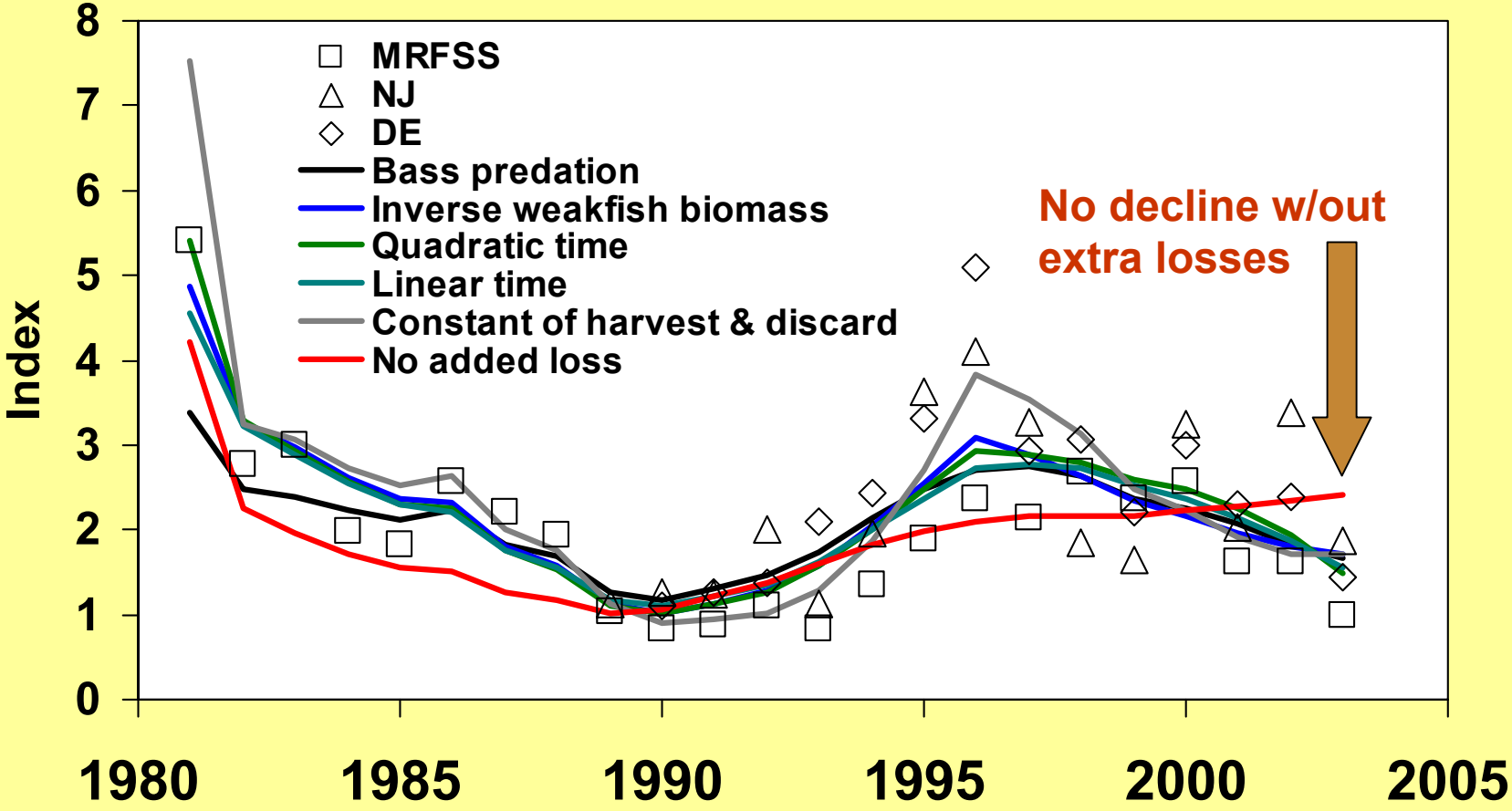
- Peer-review postulated unmeasured commercial (“ghost”) discards as explanation for decline.
- Biomass dynamic model with generic additional losses (time trends, fc of current losses, inverse biomass) tested hypothesis.
- Contrast with no extra loss and striped bass predation
- Used MRFSS, NJ & DE biomass indices.
- “Ghost” losses modeled to start after Amendment 2 (begin in 1996).
- Produce range of possible estimates.
- Search for fisheries capable of producing them.

“Ghost” losses needed to create decline compared to estimated commercial discards.

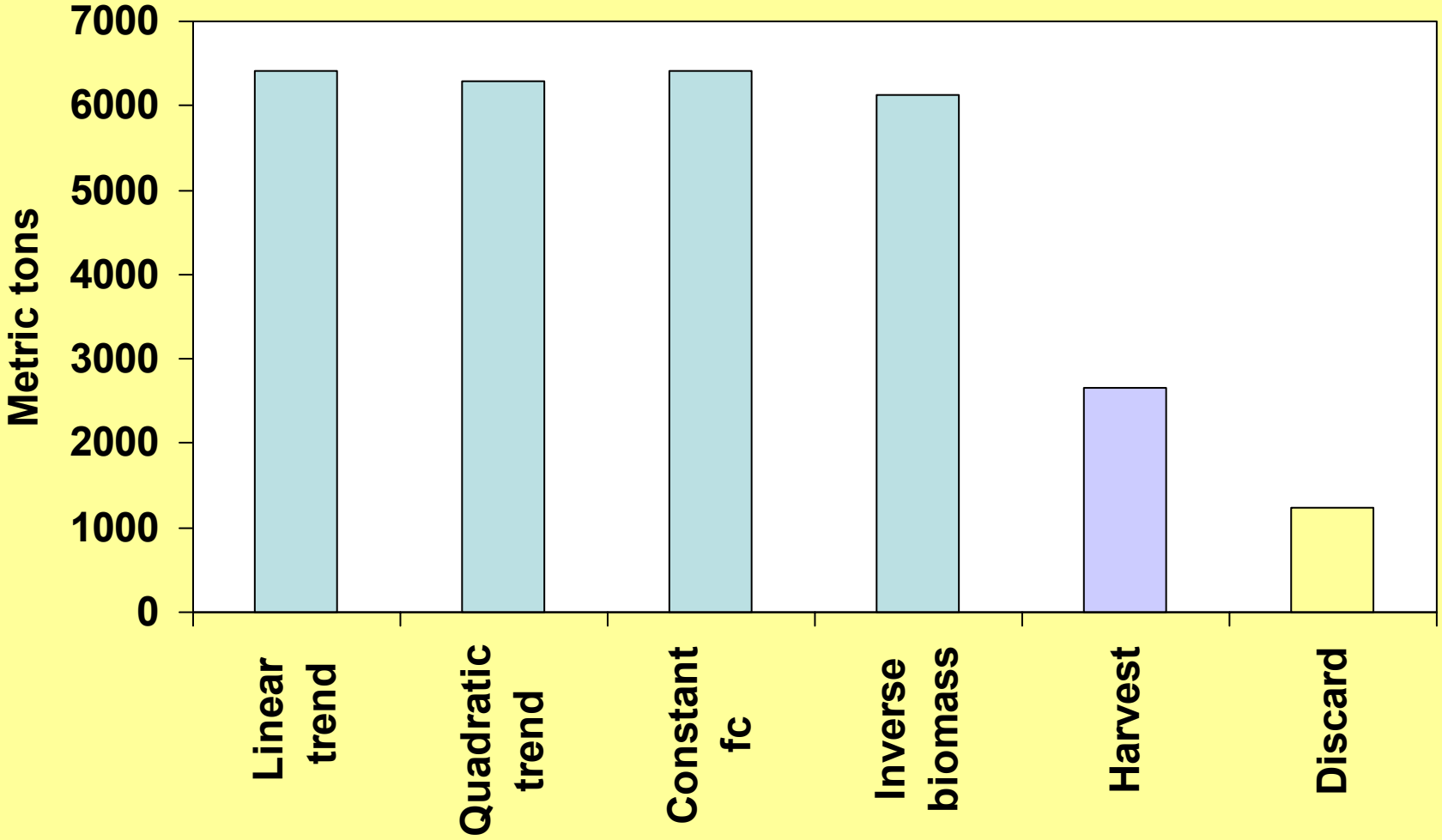
All fit about the same ($R^2 \approx 0.6$).



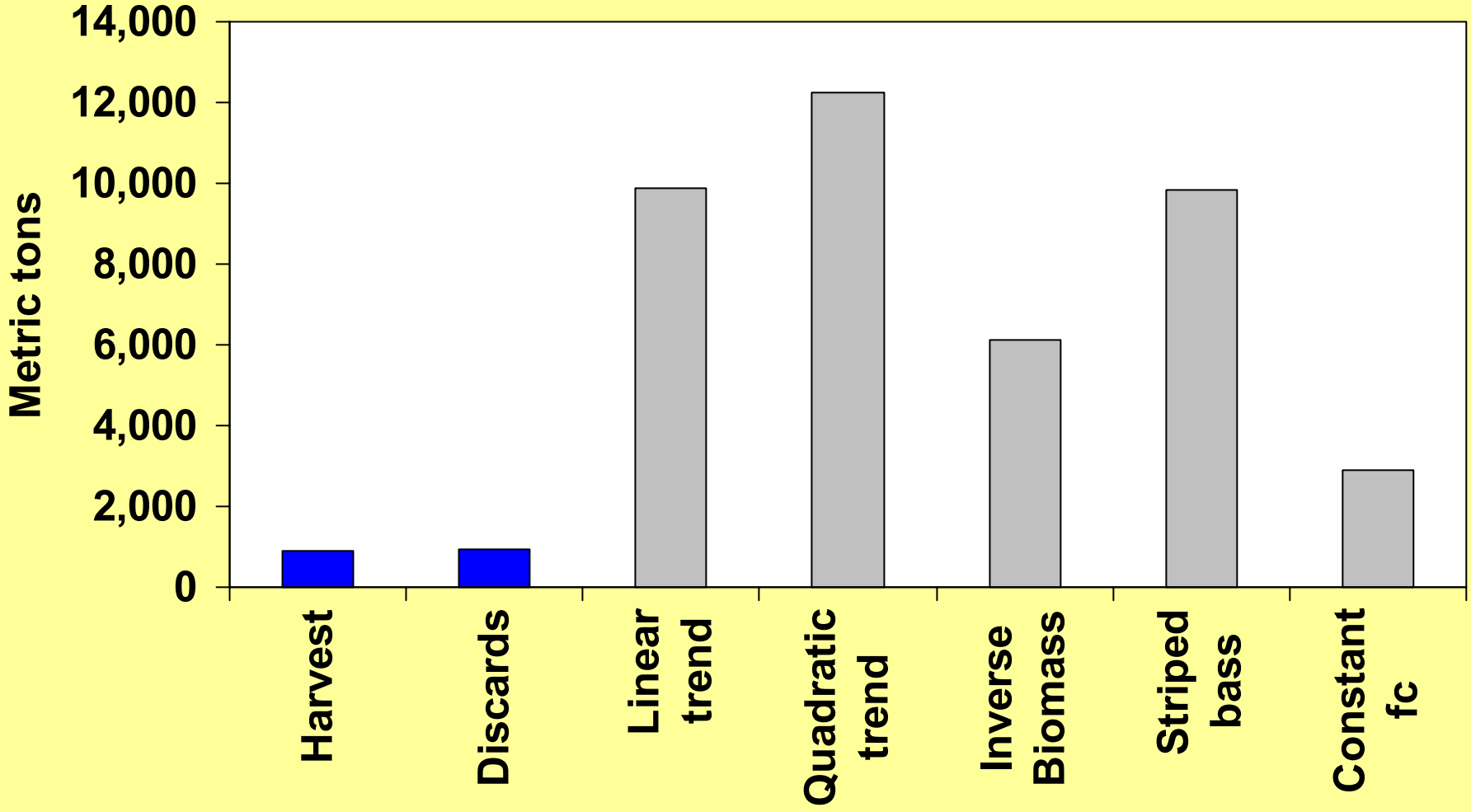
Fit of biomass dynamic model using original harvest + discards with and without additional loss functions. MRFSS = private boat catch per trip index; NJ and DE are trawl survey indices.



Averages of 1996-2003 commercial "ghost" losses from models, observed commercial harvest, and estimated commercial discard losses



Metric tons of additional losses in 2003 from different loss scenarios contrasted with commercial harvest and discard estimates



Discard models - conclusions

- Discard losses needed to create decline manifold higher than estimated discards
- Little $ incentive for harder fishing that would lead to this magnitude of discards
- TC could not offer candidate fisheries
- Other species should be showing same symptoms

Ghost Discard Management Conundrum

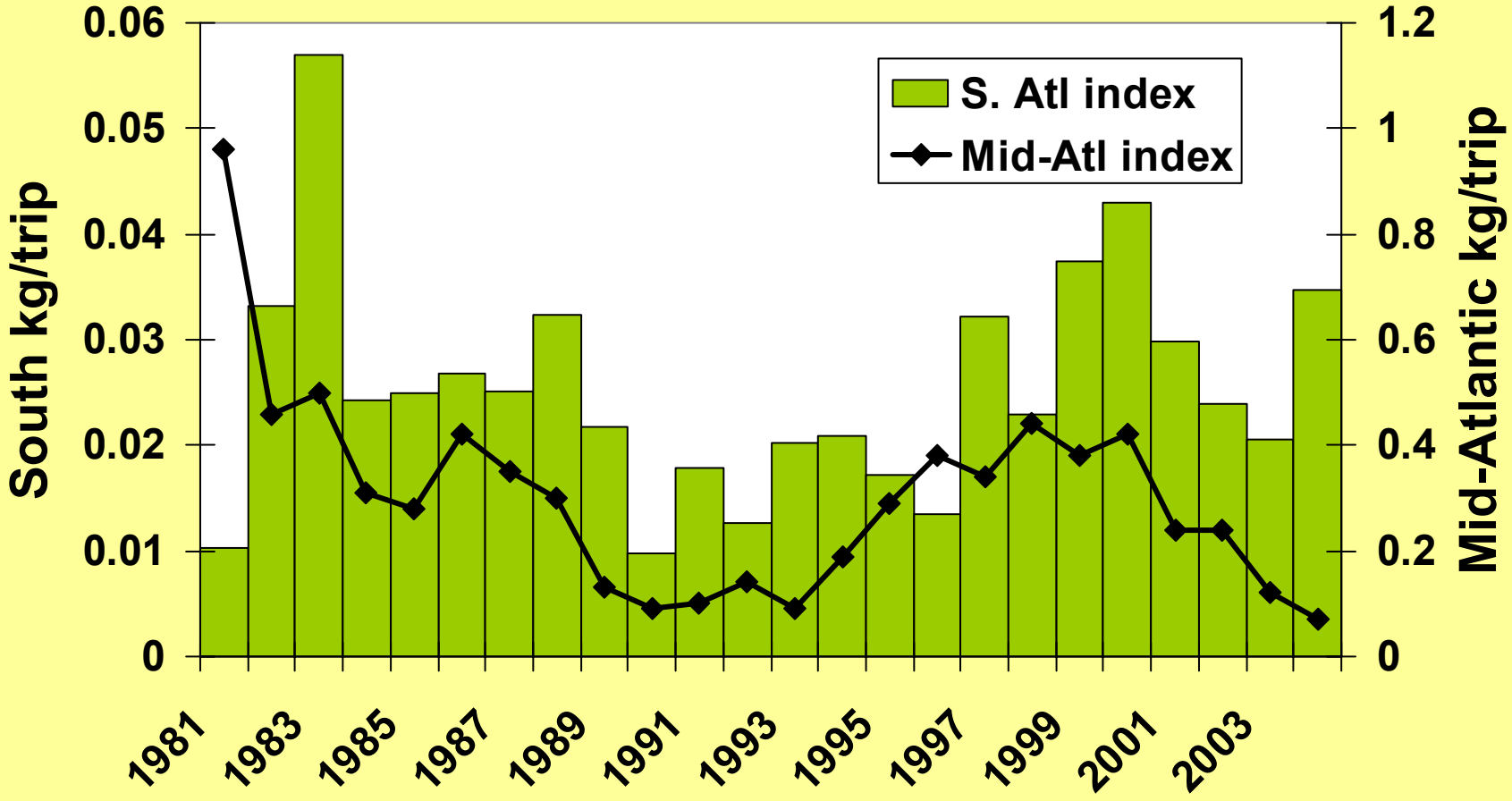
- If “ghost” commercial discards are responsible for decline, then they likely resulted from increased regulation starting with Amendment 2.
- How will more regulation, short of stopping fishing on all species, stem a decline created by regulation?

Stock Structure

- Is there enough evidence to recommend that the Board consider a split?
- If so, what difference would be suggested?
- Where should the split occur?

South versus mid-Atlantic relative biomass indices suggest different trends

(MRFSS; mean weight harvested * catch per private boat trip; includes releases)



Genetic analyses indicate homogeneous stock

Tagging, otolith microchemistry, meristics, and morphology indicate stock structure

This information was reviewed by the Technical Committee in June 2005 and 2006

The Technical Committee declined recommending a north / south split on both occasions.

June 2006 TC Meeting

- Evidence of stock structure exists.
- Data inadequate to define structure
- Enough potential mixing, can't pinpoint N/S split.
- If north to mid-Atlantic stock is in serious decline, this does not warrant split based on conservation concerns.
- Board needs to clarify reasoning for split.
- Does the Board want stock structure research recommendations from the TC?

Working Paper 5

Weakfish
Questions for Review Panel

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.

WEAKFISH WP#5 (11/24/08)

--FOR PEER REVIEW ONLY--

Questions regarding the Weakfish Stock Assessment, for the Data Poor Working Group Review (12/08)

Abundance indices
- Does strong correlation of recreational indices using various effort estimates justify use of simpler method?
- Please provide input on criteria for selecting and eliminating "final" tuning indices.

Analytical methods
- Should terminal year estimates be presented for management if catch at age modeling is known to produce a retrospective pattern? At what level of retrospective change would terminal year estimate be considered unreliable?
- Discuss merits and drawbacks of using re-scaled relative F and other methods to estimate F, biomass, and abundance in recent years (*i.e.* to eliminate retrospective pattern).

Non-equilibrium
- Analyses explored discrepancies between surveys, landings, and anecdotal info indicated factors other than F might be driving the population. Provide insight on analyses that allow judgment of the likelihood that equilibrium or non-equilibrium assumptions are being met?
- Is there sufficient evidence to support the conclusion of increasing natural mortality? Please provide suggestions for methods to evaluate the assumption of constant M.
- Please provide input on incorporating ecosystem (*e.g.* predation) losses into an age-structured model.

General
- Suggestions to strengthen assessment (research, analyses, methods).

Research Communications Branch
Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
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