

*39th Northeast Regional Stock Assessment Workshop (39th SAW)*

# **Assessment Report**

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

**July 2004**

## Northeast Fisheries Science Center Reference Documents

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# 39<sup>TH</sup> SAW ASSESSMENT REPORT

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# SAW ASSESSMENT REPORT

## INTRODUCTION

The Northeast Stock Assessment Workshop (SAW) process has three parts: preparation of the stock assessments by SAW Working Groups or by ASMFC Technical Committees/ Assessment Subcommittees; peer review of the assessments by a panel of outside experts who judge the adequacy of the work as a basis for providing scientific advice to managers; and a presentation of results and reports to the Region's managers

As of this SAW cycle, the 39<sup>th</sup>, the process has been revised in two fundamental ways. First, the SARC is now a smaller panel (3 panelists and a chair in this case) with all panelists provided by the University of Miami's Independent System for Peer Review (CIE). Second, the SARC is no longer asked to produce management advice. Instead, existing Council and Commission protocols (e.g. Plan Development Teams, Monitoring Committees, Technical Committees) are used to formulate relevant management advice given that an assessment has been accepted by the SARC.

Likewise, the structure of the 39<sup>th</sup> *SAW Assessment Report* differs slightly from previous reports. A comprehensive SAW Report is prepared after the SARC peer review and includes: an *Assessment Summary Report* - a brief summary of assessment results in a format useful to managers; this *Assessment Report* - a detailed account of the assessments for each

stock; and SARC panelist reports – one for each panelist and a separate report from the SARC chair summarizing the individual panelist reports.

The 39<sup>th</sup> Stock Assessment Review Committee was convened in Woods Hole, at the Northeast Fishery Science Center, June 7-10, 2004, to review assessments of black sea bass, sea scallops and bluefish. The basis for review were detailed assessment reports (and summary reports) produced by the SAW Coastal Pelagic Working Group for black sea bass, the SAW Invertebrate Working Group for sea scallops and the ASMFC Bluefish Technical Committee for bluefish. A panelist list, meeting agenda, list of working group meetings and list of attendees are provided in Tables 1 – 4, respectively.

In overview, the SARC accepted the assessments for black sea bass and scallops and rejected the assessment for bluefish. Thus, this report provides results of only the black sea bass and scallop assessments. The individual SARC panelist reports and the SARC Chair's report do, however, provide discussion on the bluefish assessment as well as the rationale for rejection and suggestions for new approaches which may prove productive in the future.

Table 1. 39<sup>th</sup> Stock Assessment Review Committee panel.

**The 39<sup>th</sup> NORTHEAST REGIONAL  
STOCK ASSESSMENT REVIEW COMMITTEE  
(39<sup>th</sup> SARC)**

**June 7-10, 2004  
Northeast Fisheries Science Center  
Woods Hole, Massachusetts**

**SARC Chairman**

**Andrew Payne  
Centre for Environment, Fisheries and Aquaculture Science, Lowestoft,  
England (CIE)**

**SARC Panelists**

**Mike Armstrong  
Centre for Environment, Fisheries and Aquaculture Science, Lowestoft,  
England (CIE)**

**Din Chen  
International Pacific Halibut Commission, University of Washington, Seattle  
(CIE)**

**Paul Medley  
Consultant, Alne, England (CIE)**

Table 2. Agenda, 39<sup>th</sup> Stock Assessment Review Committee meeting.

**39<sup>TH</sup> NORTHEAST REGIONAL STOCK ASSESSMENT WORKSHOP (SAW 39)  
STOCK ASSESSMENT REVIEW COMMITTEE (SARC) MEETING**

**Stephen H. Clark Conference Room  
Northeast Fisheries Science Center  
Woods Hole, Massachusetts  
June 7-10, 2004**

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**AGENDA**

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<b>TOPIC</b>	<b>PRESENTER</b>	<b>SARC LEADER</b>	<b>RAPPORTEUR</b>
MONDAY, 7 June (1:00 - 5:00 PM).....			
Opening			
<b>Welcome</b>	<b>John Boreman</b> , Center Director		
<b>Introduction</b>	<b>Terry Smith</b> , SAW Chairman		
<b>Agenda</b>	<b>Andy Payne</b> , SARC Chairman		
<b>Conduct of meeting</b>			
<b>Black Sea Bass (B)</b>	<b>Gary Shepherd</b>	<b>Din Chen</b>	<b>Laurel Col</b>
<b>SARC Discussion</b>	<b>Andy Payne</b>		
TUESDAY, 8 June (8:30 - 5:00 PM).....			
<b>Sea Scallop (A)</b>	<b>Dvora Hart</b>	<b>Paul Medley</b>	<b>Larry Jacobson</b>
<b>SARC Discussion</b>	<b>Andy Payne</b>		
WEDNESDAY, 9 June (8:30 - 5:00 PM) .....			
<b>Bluefish (C)</b>	<b>Jessica Coakley</b>	<b>Mike Armstrong</b>	<b>Laura Lee</b>
<b>SARC Discussion</b>	<b>Andy Payne</b>		
THURSDAY, 10 June (8:30 - 5:00 PM) .....			
<b>SARC Report writing (closed)</b>			



Table 3. 39<sup>th</sup> Stock Assessment Workshop, list of working group meetings.

<u>ASSESSMENT GROUP</u>	<u>CHAIR</u>	<u>SPECIES</u>	<u>MEETING DATE/PLACE</u>
SAW INVERTEBRATE WORKING GROUP	LARRY JACOBSON	SEA SCALLOP	APRIL 5-7, 2004 MAY 4-6, 2004 WOODS HOLE
Bill DuPaul, VIMS		Trevor Kenchington, FSF	
Dave Rudders, VIMS		Fred Serchuk, NEFSC	
Russel Brown, NEFSC		John Walter, VIMS	
Ron Smolowitz, FSF		Brad Harris, SMAST	
Paul Rago, NEFSC		Grant Law, Rutgers	
Deborah Hart, NEFSC		John Quinlan, Rutgers	
Richard Taylor		Jake Nogueira, SMAST	
Kevin Stokesbury, SMAST		Tu Trong, SMAST	
Stephen Smith, DFO		Mike Marino, SMAST	
Andrew Applegate, NEFMC		Joachim Gröger, SMAST	
Toni Chute, NEFSC		Hanamunt Singh, WHOI	
Victor Nordahl, NEFSC		Amit Huppert, WHOI	
SAW PELAGIC WORKING GROUP	WILLIAM OVERHOLTZ/GARY SHEPHERD	BLACK SEA BASS	APRIL 27-28, 2004 WOODS HOLE
Liz Brooks, SEFSC		Chris Legault, NEFSC	
Steve Cadrin, NEFSC		Chris Moore, MAFMC	
Jessica Coakley, DE FW		Josh Moser, NEFSC	
Steve Doctor, MD DNR		Roy Pemberton, VIMS	
Mary Fabrizio, NEFSC		Paul Rago, NEFSC	
Blanch Jackson, NEFSC		David Simpson, CT DEP	
Kohl Kanwit, ME DNR		David Smith, USGS	
Toni Kerns, ASMFC		Mark Terceiro, NEFSC	
Rob Latour, VIMS		Azure Westwood, NEFSC	

<u>ASSESSMENT GROUP</u>	<u>CHAIR</u>	<u>SPECIES</u>	<u>MEETING DATE/PLACE</u>
ASMFC BLUEFISH STOCK ASSESSMENT SUBCOMMITTEE			
	JESSICA COAKLEY	BLUEFISH	DECEMBER 9, 2003 FEBRUARY 25-27, 2004 APRIL 4-7, 2004
Jim Armstrong, MAFMC		Patrick Kilduff, ASMFC	
Herb Austin, VIMS		Wilson Laney, USFWS	
Tom Baum, NJ		Rob Latour	
Beth Burns		Laura Lee, RI/ASMFC	
Paul Caruso, MA		Rich McBride, FL	
Jessica Coakley, DE		Chris Moore, MAFMC	
Mark Collins, SC		Herb Moore	
Andy Cooper, UNH		Brandon Muffley	
Eric Durell, MD		Brian Muffley	
Kurt Gottschall, CT		Brian Murphy, RI	
Doug Grout, NH		Rob O'Reilly, VA	
Mandy Hewitt		Gary Shepherd, NEFSC	
Bruce Joule, ME		Alice Webber, NY	
Toni Kerns, ASMFC		Erick Williams	

Table 4. 39<sup>th</sup> Stock Assessment Review Committee, list of attendees

Larry Alade, NEFSC	William Kramer, NEFSC
Frank Almeida, NEFSC	Laura Lee, ASMFC/RIDFW
Andy Applegate, NEFMC	Paul Medley, Panelist
Mike Armstrong, CEFAS, Panelist	Chris Moore, MAFMC
John Boreman, Director, NEFSC	Joshua Moser, NEFSC
Paul Caruso, MADMF	Victor Nordahl, NEFSC
Din Chen, IPHC, Panelist	Bill Overholtz, NEFSC
Toni Chute, NEFSC	Andy Payne, CEFAS, SARC Chairman
Jessica Coakley, DE, Bluefish	Paul Rago, NEFSC
Laura Col, NEFSC	Gary Shepherd, NEFSC, Black sea bass
Bill DuPaul, VIMS	Ron Smolowitz, Industry
James Fletcher, Industry	Terry Smith, NEFSC, SAW Chairman
Dvora Hart, NEFSC, Scallops	Mark Terceiro, NEFSC
Larry Jacobson, NEFSC, Scallops	James Weinberg, NEFSC
Trevor Kenchington, Industry	Shari Wiley, NEFSC
Toni Kerns, ASMFC	Abdul-Aziz Yakubu, Howard Univ.
Patrick Kilduff, ASMFC	

**A. Assessment of the Northern Stock of Black Sea Bass**

Consensus Assessment Report

SARC 39

**SAW Coastal/Pelagic Working Group**

National Marine Fisheries Service  
Northeast Fisheries Science Center  
Woods Hole Laboratory  
Woods Hole, MA

May 4, 2004

A meeting of the Coastal/Pelagic working group was held April 27-29<sup>th</sup> in Woods Hole, MA. The objective was to produce a stock assessment for the northern stock of black sea bass for consideration at the 39<sup>th</sup> SARC. Participants in the meeting were:

Dr. Liz Brooks - NMFS, Miami Laboratory, Miami, FL  
Dr. Steve Cadrin - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Jessica Coakley - DE Fish and Wildlife, Dover, DE  
Steve Doctor - MD Dept. Natural Resources, Stevensville, MD  
Dr. Mary Fabrizio - NMFS, J.J. Howard Laboratory, Sandy Hook NJ  
Blanche Jackson – NMFS, Woods Hole Laboratory, Woods Hole, MA  
Kohl Kanwit - ME Dept. Natural Resources, W Boothbay HBR, ME  
Toni Kerns – Atlantic States Marine Fisheries Commission, Washington, DC  
Dr. Rob Latour - Virginia Institute of Marine Science, Gloucester Pt. VA  
Dr. Chris Legault - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Dr. Chris Moore -Mid-Atlantic Fishery Management Council, Dover DE  
Josh Moser - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Roy Pemberton - Virginia Institute of Marine Science, Gloucester Pt. VA  
Dr. Paul Rago - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Gary Shepherd - NMFS, Woods Hole Laboratory, Woods Hole, MA  
David Simpson - CT Dept. Environmental Protection, Old Saybrook, CT  
Dr. David Smith - USGS, Leetown Laboratory, Leetown, WV  
Dr. Mark Terceiro - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Dr. William Overholtz - NMFS, Woods Hole Laboratory, Woods Hole, MA  
Azure Westwood - NMFS, Woods Hole Laboratory, Woods Hole, MA

Terms of reference were:

- 1) Characterize the commercial and recreational catch data (including length distributions).
- 2) Update NEFSC survey indices and evaluate appropriate state survey indices.
- 3) Summarize tagging program results.
- 4) Develop tag-based estimate(s) of exploitation.
- 5) Evaluate use of index-based methods for estimating relative Fs.
- 6) Evaluate biological reference points.

## INTRODUCTION

Black sea bass (*Centropristis striatus*) range from the Gulf of Maine to southern Florida, with the majority of landings from Massachusetts to North Carolina. The population is partitioned into two stocks north and south of Cape Hatteras, NC (Musick and Mercer 1977, Shepherd 1991). The northern stock of black sea bass is jointly managed by the Atlantic States Marine Fisheries Commission (ASMFC) and the Mid-Atlantic Fishery Management Council (MAFMC) under Amendment 9 to the Summer Flounder, Scup, and Black Sea Bass Fishery Management Plan (FMP). The most recent stock assessment, completed in June 1998, indicated that black sea bass were over-exploited and at a low biomass level (NEFSC 1998). The status of the stock was determined using a time series of relative abundance indices from the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) spring offshore bottom-trawl survey, beginning in 1968. Amendment 12 to the Summer Flounder, Scup and Black Sea Bass FMP established a biomass threshold based on the maximum value of a three-year moving average of the NEFSC spring offshore survey mean biomass-per-tow. The overfishing definition in the FMP is based on  $F_{max}$  as a proxy for  $F_{msy}$ . Since there is not a currently accepted value of fishing mortality for black sea bass, the status of the stock relative to the overfishing definition cannot be established. However, a relative measure of exploitation (total landings / exploitable biomass index) can be used to evaluate stock status.

The conclusion of the 27<sup>th</sup> SARC was that black sea bass were overfished and overfishing was likely occurring. It was recommended that regulatory measures should continue with the objective of increasing total biomass and spawning stock biomass as well as expanding the age distribution within the population. The rebuilding schedule developed in the FMP calls for a reduction in the target exploitation rate for 2001-2002 to 37% with a further reduction in 2003 to the exploitation rate associated with  $F_{max}$  (25.6% for  $F_{max} = 0.33$ ).

## FISHERIES

Commercial sea bass landings have varied without trend since 1981, ranging from a low of 2.0 million pounds in 1994 to a high of 4.3 million pounds in 1984 (Table 1, Figure 1). The 2003 quota restricted landings of 3.1 million pounds was average for 1981-2000 but slightly lower than 2002 landings of 3.5 million pounds. Recent landings are all substantially below the peak landings of 21.8 million pounds estimated for 1952 (NEFSC 1998).

Commercial black sea bass landings in 2002-2003 were primarily from sea bass pots (42%), otter trawl (40%) and hook and line (12%). Massachusetts, New Jersey, Virginia and Maryland account for the majority (69%) of landings. Minimum size is 11" (28 cm) and landings are restricted by quota. The pot and hook fisheries begin in coastal waters in May and continue until late October in MA to December in southern areas (Shepherd and Terceiro 1994). Otter trawl landings are generally offshore during the winter months in the summer flounder, scup and squid fisheries (Shepherd and Terceiro 1994).

Biological samples collected by NMFS were used to expand length frequencies of commercial landings. Samples from 2002 and 2003 landings were partitioned by quarter, market

category (small, medium, large and jumbo) and gear type (pots, trawls, hand lines and float traps). Large accounted for 33% and 31% of landings in 2002 and 2003, respectively although mediums (28% and 29%) and jumbos (23% and 27%) were a significant part of landings in both years. Expansion of lengths were made from 17 samples in 2002 and 25 in 2003. Length to weight conversions were based on length-weight equations in Wigley et al (2002).

Ln Wt (kg) = ln a + b ln Len (cm)	ln a	b
spring	-11.2205	3.0225
autumn	-11.5992	3.122

Expanded length distributions are shown in Figures 2 and 3. Total estimated landings were 5.7 million fish in 2002 and 4.9 million in 2003. Commercial discards were not estimated.

Recreational fisheries account for roughly half of black sea bass landings. The recreational fishery takes place in coastal areas from May until November and is subject to a 12" (30 cm) minimum size, a 25 fish bag limit and a 2 week closed season. Landings ranged from a low of 1.2 million pounds in 1998 to a high of 12.4 million pounds in 1986 (Table 1, Figure 1). MRFSS estimates of black sea bass recreational landings (A + B1) in 2002 were 2,024 mt (3.38 million fish) and 1,933 mt (3.33 million fish) in 2003. The average for 1981-2001 was 1,772 mt. In 2000-2002, an average of 55% of the recreational landings were from the state of New Jersey. The next highest percentages per state were 9.7% from Delaware and 8.7% from Maryland. Length distributions from the recreational landings are shown in figures 4 and 5. Recreational discards (B2) amounted to 11.7 million and 9.1 million fish in 2002 and 2003, respectively. The previous assessment assumed a 25% discard mortality rate which would result in losses of 2.9 million and 1.8 million sea bass. A published estimate (Bugley and Shepherd 1991) of 5% results in 585,000 and 455,000 sea bass lost due to discarding.

## FISHERY INDEPENDENT SURVEY INDICES

### NEFSC

The highest abundance index (Log re-transformed mean number per tow) occurred in 1974 and was followed by a period of decline until the mid-1980s (Table 2, Figure 6). A slight rise in abundance was evident in the late 1980s but was followed by a decade of fluctuations around low levels of abundance. Since 1999 there has been a noticeable increase and the index in 2002 (2.175 / tow) was the highest in the time series and three times greater than the series average (0.7 / tow). The preliminary point estimate of the 2004 index (0.86 / tow) remains slightly above average. The NEFSC winter survey, begun in 1992, followed a similar pattern with a large index for 2002 (8.2/tow) followed by a higher index in 2003 (10.4 / tow) (Table 3, Figure 7). The preliminary 2004 index dropped to 2.0 /tow, below the time series average of 3.2 / tow. The autumn survey has also had relatively large indices in recent years (Table 4) but has not been considered reliable as an index of adult abundance due to potential catchability issues during sea bass residency in coastal waters.

Total biomass indices from the spring and winter trawl surveys indicate a significant increase over the past six years. Spring survey log re-transformed mean weight per tow peaked in 2003 at 0.85 kg/tow, well above the long term average of 0.25 kg/tow (Table 5, Figure 8). The preliminary 2004 index declined to 0.39 kg/tow. The winter survey also peaked in 2003 at 1.83 kg/tow, three times greater than the time series average of 0.63 kg/tow (Table 6, Figure 9). The 2004 index decreased to 0.67 kg/tow. A 3-point moving average of an exploitable biomass index provides the basis for biomass determination in the current FMP. During development of the FMP, exploitable biomass from survey results was defined as fish greater or equal to 22 cm. The working group decided to maintain this definition for evaluation of trends over the time series. Exploitable biomass increased substantially beginning in 1998 and reached a peak in 2002 of 0.799 kg/tow that exceeded the 1974 threshold value of 0.509 kg/tow (Table 7, Figure 10). The index has declined in successive years since 2002, reaching 0.320 kg / tow in 2004 (preliminary estimate). The 3-point moving average of the non-transformed biomass indices, as used in the FMP, peaked in 2003 at 1.403 kg/tow compared to the 1978 standard of 0.976 kg/tow (Table 7). The preliminary 2004 index declined to 0.937 kg / tow. Relative exploitation rate (total landings/biomass index) reached its lowest point in 2002 and 2003 (Table 7).

The difference in the pattern between total biomass indices and exploitable biomass appears to be due to the influence of a strong 2002 year class (Table 8, Figure 11). A black sea bass juvenile index has been defined in previous assessments as the log re-transformed stratified mean #/tow for fish  $\leq 14$  cm. The recruitment index has shown several recent strong year classes with 4 of the past 6 years above the time series average. The 2000 (0.661) and 2002 (0.554) recruitment indices were well above average (0.144) for the period 1968-2003. The 2003 index (0.154) suggests an average year class while the preliminary 2004 juvenile index was below the long term mean.

#### *Massachusetts Division of Marine Fisheries*

The Massachusetts spring bottom trawl survey, initiated in 1978, showed a recent increase in sea bass abundance with a peak index of 4.0/tow in 2000 (Table 9, Figure 12). However the indices have declined since and were below the time series average (1.21/tow) in 2003 (0.83/tow). The comparable biomass indices also peaked in 2000 at 1.93 kg/tow and have declined in 2003 to 0.72 kg/tow. The time series of number per tow and weight per tow were not strongly correlated with the NMFS, Connecticut or New Jersey surveys. The MA juvenile sea bass index from the autumn survey indicates strong cohorts in 2000 and 2003.

#### *Connecticut Long Island Sound Trawl survey*

The time series of geometric mean number per tow from the CT trawl survey begins in 1984 (Table 9, Figure 12). The survey shows a similar trend as the NMFS surveys with a sharp increase in abundance over the past several years, beginning in 1998. The index peaked in 2002 at 0.67/tow and decreased in 2003 to 0.21/tow, which remains above the series average of 0.14/tow.

#### *New Jersey Coastal Ocean Survey*

The New Jersey trawl survey is conducted during January, April, June, August, and October. The survey data from April was used as the index of abundance because it had the

closet relationship with all other survey indices of abundance. Mean number per tow peaked in 2002 (2.7/tow) and remained above average (0.73/tow) in 2003 (1.66/tow). Biomass indices were similar, peaking in 2002 and remaining above average in 2003. Indices of juvenile abundance ( $\leq 14$  cm) varied considerably among bi-monthly surveys (Table 10, Figure 11). However, the 2002 year class was dominant in both June and August surveys.

The state survey indices were well correlated with the NEFSC spring and winter surveys (Table 11), however the NEFSC fall survey did not match either state or federal surveys well. MA indices also were not highly correlated with either NMFS or NJ but were closest to CT with an  $r$  value of 0.52.

#### *Maryland Coastal Bays Survey*

Maryland Department of Natural Resources has conducted trawl surveys at twenty fixed stations in Maryland coastal bays since 1972. Sampling is done from April to October using a 16 ft. otter trawl and captures primarily juvenile fish. A time series of geometric mean numbers per tow is provided in Table 10.

### **TAGGING PROGRAM**

A tagging program for black sea bass was suggested in the research recommendations of the 27<sup>th</sup> SARC as a method to determine exploitation rate and examine migration patterns. The project was initiated in 2002 with funding from NOAA's MARFIN program. Estimation of survival, and subsequently exploitation rates, for fish populations using mark-recapture data depends on several assumptions. Among those assumptions are that distribution of tagged fish is equivalent to untagged fish, survival of tagged fish is not influenced by the tags, tag shedding during the recovery period is minimal, fish survive the tagging procedure, the tag recoveries are reported accurately, the rate of tag reporting is known and the tags recoveries represent dead fish. Most of these assumptions can be tested through experimentation and appropriate adjustments made in the estimation of survival rates.

#### *Tag mortality and retention*

Three experiments were conducted to determine tag retention and tag induced mortality. In the Woods Hole aquarium, 9 fish (29 to 38 cm) were collected in August 2002 by hook and line and placed in a 250 gallon aquarium tank. After a day of acclimation, the fish were tagged with Floy internal anchor tags with a 3 1/2" tube and a 1/4" x 3/4" anchor tab. A small incision was made with a hook scalpel through the lower left abdominal wall and the tag inserted. Four fish survived until May with no tag losses. The remaining five fish retained the tags but died from diseases related to captivity 4 - 8 months after tagging.

A second experiment was conducted in the NEFSC J.J. Howard Laboratory in Sandy Hook, NJ under the direction of Dr. Mary Fabrizio. Thirty-one sea bass were tagged with internal anchor tags and held for 10 - 12 months. Sizes ranged from 22.5 to 36 cm TL. Within the first week, the tag loss rate was 3.2% (1 loss from 31 fish). Over the remainder of the experiment, the loss rate was 6.9% (2 losses from the remaining 29 fish (1 jumper at day 9 not



included)). Overall, 3 tags were lost among 31 fish for a loss rate of 9.7% and no deaths were attributed to the tagging.

A third experiment was conducted by Brian Murphy of the Rhode Island Division of Fish and Wildlife. The duration of the study was 27 days and involved 30 tagged fish ranging in size from 26 to 41 cm. Tag loss was 13.3% with no tag induced mortalities. Among all three experiments, tag loss was 10.1% (7 of 70) and tag induced mortality was 0% (Figure 13).

### *Tag Releases*

Locations and sample size of tag releases were chosen to disperse the tags throughout the range of the fishery, proportional to annual landings. In addition, the design was to release all the tags coastwide within a two week period, beginning in September 2002. Releases were repeated in May 2003 and September 2003. Appropriate sample size for tag release was estimated by examining the variance of a population estimate from a Petersen model. Using catch estimates from 2000 ( $N_c$ ) a series of tag release values ( $M$ ), and recovered tags ( $M_c$ ) under three recovery rate assumptions (10, 20 and 30%), population size ( $N$ ) was calculated as:

$$N = M (N_c / M_c)$$

Variance was estimated as (Sullivan et al. 1993, Seber 1970):

$$V(N) = ((M+1) (N_c+1)(M-M_c)(N_c-M_c)) / ((M_c+1)^2 (M_c+2))$$

Under all three recovery rates, approximately 3,000 fish or greater produced relatively little reduction in variance (Figure 14). Therefore, the total number of releases per period was targeted as a minimum of 3,000. The number of high reward tags targeted for release was 10%, and were regularly distributed among regular tags. For budgetary reasons the number of high reward tags in spring releases were reduced because of an anticipated high recapture rate.

Tags were released in September 2002 during 3 trips on sea bass pot boats in Nantucket Sound, MA, 1 trip in Cape Cod Bay, MA, 3 pot trips in Narragansett Bay, RI, 2 trips with recreational hook and line gear in Long Island, NY, 1 trip using lobster pot gear in LI, NY, 1 trip with sea bass pot gear in south/central NJ, 1 trip with recreational hook and line gear from Cape May, NJ, 1 trip with recreational hook and line gear in Ocean City, MD and 2 trips with commercial hook and line gear off Norfolk, VA. In May 2003, tags were released in MA, NJ, DE, MD, and VA all with commercial and recreational hook and line gear, and in September 2003, tags were released in MA, RI, CT, NY, NJ, MD and VA from hook and line and pot gear. A group of tags ( $n= 249$ ) were also released in mid-April 2003 off VA. Tag release locations are summarized in figure 15.

Fish brought onboard a vessel for tagging were examined for evidence of external injuries and measured (total length to nearest ½ cm). A small incision was made in the lower abdominal wall and an anchor tag was inserted into the incision. In cases where there was an inflated air bladder, the bladder was punctured as the tag was inserted. If the bladder remained

inflated, the fish was vented with a syringe needle while being held in a holding tank. Fish were returned to the water as soon as possible, generally in less than 1 minute. If there was some question about the condition, the fish was returned to a tank until it showed signs of recovery, usually within several minutes. If the fish did not recover, the tag was removed and the fish discarded. Occasionally (perhaps 2-3 per trip) a released fish would be unable to return to the bottom. In that event, attempts were made to recover the fish and remove the tag. If unsuccessful, the tag number was noted and excluded from the results. Equipment was sterilized with Betadine during each tagging cruise as time allowed. At each station, depth, surface water temperature, location (lat/lon or loran C) and tagger were recorded. Depths ranged from 6 m to 36.5 m. Locations were also categorized as places well known to the general fishing public or those known only to the captain. Regular tags (orange) were imprinted with tag # and a telephone number on both sides of the tag. Special high reward tags (red) also specified \$100 reward. In total, 8,909 regular tags and 659 high reward tags were released (Table 12). Tagged fish ranged in length from 19 to 61 cm; 3% of tagged fish were below 26 cm. Length frequencies of tagged fish are shown in figure 16 by geographic region and regions combined for each release season. The tagged fish appeared to be comparable to the fishery length frequencies for each release period (Figure 17).

### *Dispersal*

An assumption in tagging models is that tagged fish are homogeneously dispersed among non-tagged fish. The rate of movement of tagged fish among NEFSC statistical areas served as one measure of dispersal rate. For each release season, tagged fish were caught in an adjacent statistical area within 1 to 2 weeks of tagging, suggesting that dispersal was occurring in a relatively short time (Table 13a-13c).

Date and location information from release and recapture data allowed the calculation of linear distance and angle of movement (Sullivan et al. 1993) (Appendix I). Tag release locations were initially grouped into 4 regions: MA-RI, NY-northern NJ, southern NJ- DE, MD-VA. Vectors were created with the mean linear angle and mean distance of all tags released in a given region among five groups of days at liberty: 1-60 days, 61-120 days, 121-225 days, 226-365 days and >365 days. The results suggest that fish dispersed from the original tagging location and were likely to mix in the offshore areas during the winter. The general trend was for fish in the northern end of the range to move south-southwest along the 50 fathom line during winter. Sea bass in the NJ-DE area tended to move east-southeast to the shelf edge during winter. Black sea bass further south had a general tendency of seasonal movement towards the east. The extent of seasonal movement was significantly reduced from New Jersey south, particularly in the Virginia area. Most fish in all areas returned the following spring to the area of release although site fidelity was not 100%.

Based on the distribution of tag recaptures relative to release area, the study area was subdivided into 3 regions: Massachusetts to New York, New Jersey to Delaware, and Maryland to North Carolina (Figure 15). These regions were used for subsequent analyses of reporting and recapture rates. Analysis of recapture matrices by region for fall 2002 and spring 2003 releases indicate 4% - 5% movement among regions within a year at large (4.6% and 4.1%, respectively).

### *Recaptures*

Tags recovered by fishermen, dealers or others were reported to NEFSC via telephone. We asked for information on tag number, date and location of recapture, size of fish, type of fishery (recreational, party/charter, commercial) and gear, port and condition of tagged area on the fish. Tags were not required to be returned unless they were high reward tags or a questionable tag number.

Among the fall 2002 releases were a series in Rhode Island using a local pot fisherman. The fish were tagged and released along the same transect as the pots were set. Within the next several weeks, that same fisherman recaptured and reported over 70 tagged bass. It was evident that the tagged fish did not disperse properly but returned to the pots for shelter (these were unbaited pots typical in New England). Therefore in subsequent analyses we eliminated fish tagged and recaptured by that fisherman within the first two weeks at large.

A total of 1,154 regular tags and 107 high reward tags had been reported as of April 30, 2004 (Figure 18).

The black sea bass commercial and recreational fisheries have different minimum size limits; commercial is 11" (28 cm) and recreational is 12" (30 cm). Estimation of reporting rates and exploitation rates required a definition of the size at which sea bass are to fully vulnerable to exploitation. The working group decision was to use the 28 cm limit because of comparability between size of released fish and fisheries data, the inherent measurement error in the fisheries, the contribution of discards to total catch (unknown sizes and amounts) and the potential growth of fish from 28 to 30 cm during the course of the year.

### *Reporting Rates*

Recapture rates of the high reward tags, relative to regular tags, was used to calculate tag reporting rates. The underlying assumption was that \$100 rewards would elicit 100% compliance from fishermen. Incremental rewards have been used in both bird banding and fish tagging studies and \$100 is generally accepted as a reasonable tag value that would provide full compliance (see Working Group comments).

Reporting rates were calculated as:

$$R_s = (R / M) / (R_h / M_h)$$

where:

$R_s$  = reporting rate for tag recoveries

$R$  = number of regular tags reported

$M$  = number of regular tags released

$R_h$  = number of high reward tags reported

$M_h$  = number of high reward tags released

The Working Group recommended comparison of reporting rate between cells using a log-linear model for categorical data. Stratification into season of release and a smaller geographic cell than region (as previously defined) reduced the sample sizes such that many cells had no reported high reward tags and consequently no reporting rate. Data from fall 2002 and spring 2003 releases were combined to increase sample sizes (fall 2003 releases were not included since time at large was not long enough to include in subsequent exploitation estimates). Tag fate was categorized as either fish killed by the recreational fishery, the commercial fishery or not killed. The working group decided that legal size fish which were caught and re-released, with the tag removed, would constitute a killed fish. The reasoning was that under a quota or bag limited fishery with fish readily available, fishermen would likely replace a tagged fish with a non-tagged fish. Therefore to account for the substituted fish and the fact that the released fish was effectively removed from the population of tagged fish, released fish with tags removed (10.6% of recaptures) were included as kills. Additional restrictions on the data set were: fish greater or equal to 28 cm, fish caught in the same region of release (to avoid migration effects in the recapture rates), same season of release, fish at large greater than 7 days and removal of the first two weeks of recoveries by the RI fisherman as previously noted. Restricted input data are provided in table 14. Expected frequencies of tag type (regular or high reward tags), region (north, middle or south) and tag fate (recreational killed, commercial killed or not removed) were compared in a full log-linear model using SAS CATMOD (2004) (Appendix II). The main effects were significant ( $Pr > 0.01$ ), as well as a significant region\*fate interaction term ( $PR > 0.001$ ) (the 3-way interaction could not be estimated). A simplified model was run using only the significant terms with similar results. The significant interaction term is likely the result of different recapture rates between the recreational fishery in the middle region and the commercial fishery in the north. Based on the significance of the main effects in the model, expected recapture rates were calculated using separate reporting rates by region and fishery.

Results of the reporting rate calculations by region and fishery are presented in table 15. There were no reported high reward tags in the NJ-DE commercial fishery, so reporting rate had to be estimated from other fisheries or regions. Reporting rates varied from 49% to 100%. Overall, the recreational fishery had a 68.9% reporting rate and the commercial fishery was 57.1%. Anecdotal reports from commercial fishermen suggest that the assumption of 100% reporting for high reward tags may be incorrect. To evaluate the implications of an incorrect assumption, reporting rates were also calculated assuming only 80% reporting rate of the \$100 tags from commercial fishermen (cells with 0 reported were increased to 1 reported). The change resulted in an overall commercial reporting rate decrease to 44.4 % (Table 16).

### *Exploitation Rate Estimation*

The northern stock of black sea bass is managed as a single unit stock from Massachusetts to Cape Hatteras, NC. Therefore, estimates of exploitation and fishing mortality were provided as a single stock-wide value.

Exploitation rates were calculated using a modification of the Petersen estimate. The number of fish recaptured (R) was adjusted for the reporting rate from the area/fishery cell. The number of tags released was reduced by a tag loss rate of 10%. Therefore, exploitation rate estimate was calculated as:

$$\mu = \sum (R_{rf} / \gamma_{rf}) / \sum (M_{rf} - (M_{rf} * \theta))$$

where:

- $\mu$  = exploitation rate
- $R_{rf}$  = tags recaptured by region and fishery
- $\gamma_{rf}$  = tag reporting rate by region and fishery
- $M_{rf}$  = tags released by region and fishery
- $\theta$  = percent of tag loss

Fishing mortality was calculated from the exploitation rate by iteration of F values that would produce the equivalent  $\mu$ , assuming a natural mortality of 0.2.

The recommendation of the working group was to estimate exploitation rates by region and fishery and weight the final estimate by annual landings or survey abundance indices within each cell. The purpose was to reduce the affect of heterogeneity of tag release and recoveries due to unequal sample sizes. However, there was a difficulty in producing region specific estimates with R/M models when inter-region mixing occurs, due to the confounding of recovery rate, migration and local abundance (Dorazio 1993). For example, suppose an equal number of fish are marked in area A and B. The recaptures in area A would be the sum of fish originating in A plus those originating in B but migrating to A. However, there would be no information available to determine what percent of the unseen marked population also moved into A. Therefore, any exploitation estimate would have an unknown number of marked fish available for recapture. If the assumption can be made that recaptures in different regions is limited (4-5% in this study), local F can be calculated and an overall weighted F produced. Weighting by proportion of tags released in each cell (region, fishery) approximates the estimate based on the sum of all releases. Choice of the weighting factor then presents a problem. Weighting by catch assumes that catch reflects abundance when in fact it also represents exploitation rate which is the objective in solving R/M. Consequently it becomes a circular argument. Survey indices which overlap the inshore fishery are unreliable due to the problems with using trawl gear in sea bass habitat. In each of the options, the effects of migration, abundance and exploitation rate are confounded. With a simple r/m model, it is not possible to find a unique solution for exploitation rate among regions without independent estimates of the other factors. However, a series of weighting schemes and F estimates were produced to examine the sensitivity of different assumptions. The recommended approach remained use of recapture rates, adjusted for regional/fishery specific reporting rates, divided by the total number of tags released.

Estimates were made separately for fall 2002 and spring 2003 releases (using the same reporting rates). Input data were limited to fish  $\geq 28$  cm that were caught and killed (including caught, tag removed and released) after 7 days following tagging but within 365 days at large

(Tables 17 and 18). High reward tags were included in the estimate assuming 100% reporting. A second estimate was made assuming 80% reporting of commercial high reward tags (Tables 19 and 20).

The overall exploitation rate for October 2002-September 2003 recoveries from September 2002 releases was estimated at 0.148 or  $F = 0.18$ ; May 2003 releases recovered from June 2003-May 2004 had an exploitation rate of 0.197 or  $F = 0.24$  (Tables 17 and 18). Alternative exploitation rate estimates, assuming 80% commercial reporting of high reward tags were 0.170 ( $F=0.21$ ) in fall 2002 and 0.207 ( $F=0.258$ ) in spring 2003 (Tables 19 and 20).

Sensitivity of fishing mortality estimates to alternative weighting schemes are provided in table 21. Options included region/fishery specific and region specific estimate assuming no inter-region movement, weighting schemes assuming equal proportions among regions, and proportions skewed to one region (50%, 25%, 25%).

### *Other Tagging Models*

An alternative model was evaluated for calculation of fishing mortality (Rago and Goodyear 1985) Fishing mortality was estimated as the value that produced the expected number of tag recaptures equivalent to the observed number using the equation:

$$E_{(i,j)} = N_{(i)} * S_t * (1 - (\exp(-(F+M))^{(t_j - t_i)})) * (F/(F+M))$$

where:

- $E_{(i,j)}$  = expected number of tags returns at time  $t_j$  from releases at  $t_i$
- $N_{(i)}$  = number of marked fish released at time  $t_i$  modified for tag loss and reporting rate.
- $S_t$  = fraction of marked fish that survive tagging (100%)
- $F$  = instantaneous rate of fishing mortality
- $M$  = instantaneous rate of natural mortality (0.2)
- $t_j$  = time period of recapture
- $t_i$  = time period of release

Solving for  $F$  such that  $E_{(i,j)} = R_{(ij)} * \gamma$

where:

- $R_{(ij)}$  = observed tag recaptures
- $\gamma$  = overall reporting rate of 63.6% (combined regions, fisheries for fall 2002-spring 2003 releases).

Estimates were also made assuming a 10% lower reporting rate.

The estimate of  $F$  for the period October 2002 – September 2003 was 0.15, and for June 2003 – May 2004 equaled 0.27 (Table 22). Alternative estimates using an 80% commercial

reporting of high reward tags (overall = 56.4%) produced estimates of 0.18 and 0.31 for the fall and spring, respectively. Assuming an overall reporting rate 10% lower (57.2%) produced estimates of 0.17 and 0.30 for fall 2002 and spring 2003 releases.

## **REPLACEMENT F**

Spring survey biomass indices and landings data were further examined using the program AIM (An Index Method from NOAA Fisheries Toolbox, version 1.4). The model uses a statistical fitting procedure to examine the relationship between indices and landings to calculate a relative F and estimate a replacement ratio necessary to maintain the population. Two models runs were used; one with the longer time series of data involving only commercial landings (1968-2003) and a second with a shorter time series which included recreational landings. The NEFSC spring survey log re-transformed biomass indices provided the relative abundance information.

The analysis using total landings since 1981 produced a significant relationship in the simple regression between relative F and replacement ratio (Table 23). The bootstrap mean relative F value for a ln replacement ratio of 0 was equal to 17.319 with an 80% interval between 14.92 and 21.12 (Figure 19). The relative F in 2003 was 3.91, with a replacement ratio of 2.18. A comparable analysis using the longer time series with only commercial landings produced similar results (Table 24). The relative F value with ln replacement ratio of 0 was equal to 7164.47, with an 80% bootstrap interval of 6472.82 to 7860.93 (Figure 19). The 2003 relative F from this data set was 1638.50 with a replacement ratio of 2.186. In both cases relative F in 2003 suggest the biomass should continue to increase at the current levels of removal (Figures 20 and 21).

## **BIOLOGICAL REFERENCE POINTS**

The present BRP for black sea bass is  $F_{max}$  as a proxy for  $F_{msy}$ .  $F_{max}$  as currently defined is equal to 0.33 based on Thompson-Bell yield per recruit model (Table 25, Figure 22). The working group did not recommend any changes to the estimate. The group also concluded that the use of F from the tagging results as a fully recruited F for comparison to  $F_{max}$  was acceptable.

Biomass reference points have been based on exploitable biomass indices from the NEFSC spring survey. No alternative biomass estimates are available and no recommendations were made to change the current biomass threshold reference point.

## **SUMMARY**

Results of the assessment for the northern stock of black sea bass show a level of exploitation at or below the management target and biomass levels comparable to the 1970s. Exploitation rate estimates from fall 2002 releases ranged from 0.14 to 0.17; spring 2003 releases were 0.20 to 0.24. Associated fishing mortality estimates ranged from 0.17 to 0.21 in October 2002 – September 2003 while June 2003 to May 2004 preliminary estimates were 0.24 to 0.30.

Relative exploitation values based on the NEFSC spring survey were the lowest in the time series. Relative F estimates from the AIM model indicate low values and well below the F needed to maintain replacement. Relative biomass indices from state and federal surveys show a stock biomass that increased substantially since 1998, reached highest values between 2000 and 2002 and have begun to decline in 2003. Juvenile recruitment over the past five years, based on survey indices, has included possibly two strong cohorts.

Tag reporting rates varied by geographic region and type of fishery. Coastwide the recreational reporting rate was higher at 69% compared to the commercial rate of 57%. Regional differences occurred in reporting rates and tended to be highest in the MD-NC region (90-100%) but may have been influenced by low sample sizes and the assumption of 100% reporting of high reward tags. A relaxation of that assumption to 80% commercial reporting decreased the southern reporting rate from 90 to 68%.

The conclusion of the working group was that the stock appeared to be below the target exploitation rate and target F. Although biomass has been high over the past several years, recent decreases in biomass indices suggests that caution should be exercised in setting quotas. The current tagging models provided an acceptable measure of exploitation but there remains an unknown degree of uncertainty in the estimates.

## **WORKING GROUP COMMENTS**

The comments could be divided into several general topics:

1. Tag retention: The group felt that further studies should be conducted to examine tag retention. Some issues to consider would be effect of vessel movement while tagging compared to tagging under laboratory conditions, effect of handling fish in the laboratory after tagging; pectoral fin erosion by tags over long term; and possible temperature effects (i.e. temperature contrast in water column when fish are caught or released and differences in tagging mortality rate between areas due to temperature differences). Also include a control group to examine possible affects of gear used to collect fish. The use of double tagging to estimate tag loss should be considered in future releases.
2. Experimental design: the group stressed the importance of continuing releases in the same geographic areas as the past releases. Shifts in locations can create difficulty in comparisons between release cohorts. Effort should continue to be made to distribute tag releases in proportion to expected population abundance.
3. Tag reporting: Tag reporting may be increased with additional outreach efforts and perhaps a 1-800 phone number for reporting tags. Consideration should be given to include sociologists in the project to identify the reasons behind non-reporting. Further efforts should be made to compare reporting rates among specific groups by area, gear types etc.



4. Modeling: The group strongly endorsed the continuation of the tagging program through at least another round of releases. The difficulties involved with use of the simple Peterson estimates may be overcome with more sophisticated models. However, implementation of models such as MARK or SURVIV, require development of recapture matrices involving several release-recapture periods. Although it was suggested that such models should be explored using the current data, the modeling efforts will be strengthened with additional data.
5. General comments: Beyond the sea bass program, the group discussed the future of tagging programs within the states and the NEFSC. It was agreed that a proper experimental design was critical prior to any release of tags. The number of tags released should be estimated based on expected reporting rate and exploitation rate. Tag releases should be made over several years in a consistent fashion and should be done each time over a short release time period (several weeks not months). Degree of tag loss should be examined, tag induced mortality and efforts made to quantify reporting rates. Prior to release, the proper infrastructure should be in place to data collection, outreach to increase likelihood of reporting and funding to pay rewards returned over several years. Although it was noted that compared to many techniques, tagging projects were relatively inexpensive, efforts should be made to coordinate tagging among species to reduce costs (i.e. tag scup and fluke while tagging sea bass).

## **RESEARCH RECOMMENDATIONS**

1. Continue tagging project over another season at the minimum.
2. Conduct double tagging experiment to estimate tag loss over time.
3. Develop non-parametric bootstrap method to estimate variance in R/M model.
4. Develop survival estimates using tagging models such as MARK.
5. Develop age information for possible re-examination of age based analytical models.
6. Evaluate use of a short time series of tag based mortality estimates for conversion of relative index based estimates to absolute values.
7. Increase outreach efforts, possibly with the assistance of sociologists.

## LITERATURE CITED

- Bugley, K. and G. Shepherd. 1991. Effect of catch-and-release angling on the survival of black sea bass. *North American Journal of Fisheries Management*. 11:468-471.
- Dorazio, R.M. 1993. The difficulties of interpreting region-specific rates of tag recovery. Report for the Striped Bass Stock Assessment Subcommittee, Atlantic States Marine Fisheries Commission. July 19, 1993.
- Musick, J.A. and L.P. Mercer. 1977. Seasonal distribution of black sea bass, *Centropristis striata*, in the Mid-Atlantic Bight with comments on the ecology and fishery of the species. *Transactions of the American Fisheries Society* 106: 12-25.
- Northeast Fisheries Science Center. 1998. Report of the 27th Northeast Regional Stock Assessment Workshop (27th SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessments, NEFSC Ref. Doc. 98-15.
- Rago, P. J. and C.P. Goodyear. 1985. Estimation of mortality rates and population size from tagging studies in Everglades National Park, 1984-1985. Unpubl. Report December 20, 1985.
- Seber, G.A.F. 1970. The effects of trap response on tag-recapture estimates. *Biometrika* 26:13-22.
- Shepherd, G.R. 1991. Meristic and morphometric variation in black sea bass north of Cape Hatteras, North Carolina. *North American Journal of Fisheries Management*. 11:139-148.
- Shepherd, G.R. and M. Terceiro. 1994. The summer flounder, scup and black sea bass fishery of the Middle Atlantic Bight and Southern New England waters. NOAA Tech. Report NMFS 122, 13 pp.
- Sullivan, P.J., T.O. Geernaert, G. St-Pierre, and S.M. Kaimmer. 1993. Mark-recapture methods for the Pacific halibut assessment: a feasibility study conducted off the central coast of Oregon. *International Pacific Halibut Commission Sci. Rpt.* 76. 41 pp.
- Thompson, W.H. and F.H. Bell. 1934. Biological statistics of the Pacific halibut fishery. 2. Effect of changes in intensity upon total yield and yield per unit of gear. *Rep. Int. Fish. (Pacific halibut) Comm.* 8: 49p.
- Wigley, S.E., H.M. McBride, and N.J. McHugh. 2003. Length-weight relationship for 74 fish species collected during NEFSC research vessel bottom trawl surveys, 1992-99. NOAA Tech. Mem. NMFS-NE-171. 26 pp.

## BLACK SEA BASS TABLES

Table 1. Landings of the northern stock of black sea bass, 1968-2003.

Year	commercial landings 000s lbs	commercial landings (mt)	recreational landings (mt)	total landings (mt)
1963				
1964				
1965				
1966				
1967				
1968	2,648	1201		
1969	2,643	1199		
1970	2,425	1100		
1971	1,354	614		
1972	1,676	760		
1973	2,560	1161		
1974	2,357	1069		
1975	4,156	1885		
1976	3,726	1690		
1977	5,344	2424		
1978	4,663	2115		
1979	4,134	1875		
1980	2,760	1252		
1981	2,489	1129	559	1688
1982	2,595	1177	4483	5660
1983	3,336	1513	1850	3363
1984	4,332	1965	656	2621
1985	3,419	1551	951	2502
1986	4,191	1901	5621	7522
1987	4,167	1890	873	2763
1988	4,142	1879	1301	3180
1989	2,919	1324	1492	2816
1990	3,501	1588	1252	2840
1991	2,804	1272	1899	3171
1992	3,007	1364	1227	2591
1993	3,113	1412	2196	3608
1994	1,975	896	1337	2233
1995	2,039	925	2815	3740
1996	3,245	1472	1811	3283
1997	2,615	1186	1936	3122
1998	2,564	1163	522	1685
1999	2,974	1349	755	2104
2000	2,714	1231	1798	3029
2001	2,934	1331	1630	2961
2002	3,532	1602	2024	3626
2003	3,077	1396	1933	3329

Table 2. NEFSC spring offshore survey In re-transformed stratified mean number per tow.

Year	MEAN	95% CI	
		LOW	HIGH
1968	0.159	0.109	0.212
1969	0.113	0.084	0.142
1970	0.111	0.073	0.150
1971	0.135	0.084	0.188
1972	0.555	0.393	0.735
1973	0.377	0.242	0.526
1974	1.277	0.851	1.803
1975	0.648	0.506	0.803
1976	1.587	1.286	1.929
1977	1.014	0.817	1.233
1978	0.854	0.650	1.082
1979	0.483	0.369	0.607
1980	1.328	0.981	1.735
1981	0.465	0.373	0.562
1982	0.120	0.085	0.156
1983	0.387	0.261	0.526
1984	0.219	0.149	0.292
1985	0.388	0.277	0.508
1986	1.136	0.811	1.519
1987	0.680	0.525	0.849
1988	0.982	0.731	1.269
1989	0.428	0.329	0.533
1990	0.553	0.372	0.757
1991	0.838	0.598	1.114
1992	0.962	0.735	1.218
1993	0.290	0.210	0.375
1994	0.198	0.131	0.269
1995	0.521	0.409	0.642
1996	0.306	0.228	0.389
1997	0.704	0.524	0.904
1998	0.210	0.154	0.268
1999	0.801	0.541	1.103
2000	1.066	0.788	1.388
2001	1.126	0.866	1.423
2002	2.175	1.769	2.641
2003	2.136	1.598	2.787
2004	0.864	0.700	1.043

Table 3. NEFSC winter survey In re-transformed stratified mean number per tow.

Year	MEAN	95% CI	
		LOW	HIGH
1992	2.452	2.015	2.952
1993	1.365	1.091	1.676
1994	0.761	0.554	0.996
1995	1.537	1.203	1.921
1996	3.319	2.640	4.126
1997	0.700	0.564	0.847
1998	0.771	0.637	0.915
1999	1.176	0.947	1.431
2000	4.481	3.523	5.641
2001	3.829	3.196	4.558
2002	8.188	6.718	9.937
2003	10.400	7.752	13.850
2004	2.023	1.704	2.379

Table 4. NEFSC fall survey In re-transformed stratified mean number per tow.

Year	MEAN	95% CI	
		LOW	HIGH
1972	0.454	0.330	0.590
1973	2.069	1.554	2.689
1974	1.871	1.423	2.402
1975	3.952	2.786	5.477
1976	4.547	3.021	6.653
1977	3.824	2.960	4.877
1978	0.521	0.330	0.739
1979	0.675	0.520	0.845
1980	1.844	1.270	2.562
1981	1.004	0.598	1.514
1982	1.230	0.924	1.585
1983	1.778	1.379	2.244
1984	0.905	0.598	1.270
1985	1.882	1.468	2.366
1986	3.685	2.572	5.146
1987	1.357	0.932	1.875
1988	3.695	2.834	4.749
1989	1.553	1.079	2.135
1990	2.069	1.483	2.792
1991	2.292	1.692	3.026
1992	1.880	1.277	2.643
1993	0.740	0.577	0.921
1994	1.642	1.251	2.101
1995	3.457	2.391	4.858
1996	0.838	0.586	1.130
1997	1.927	1.489	2.443
1998	3.299	2.324	4.559
1999	2.609	1.615	3.979
2000	6.102	4.278	8.557
2001	2.050	1.573	2.616
2002	3.138	2.306	4.178
2003	2.741	2.085	3.536

Table 5. NEFSC spring offshore survey In re-transformed stratified mean weight (kg) per tow.

Year	95% CI		
	MEAN	LOW	HIGH
1968	0.054	0.035	0.074
1969	0.058	0.040	0.075
1970	0.073	0.048	0.100
1971	0.051	0.020	0.083
1972	0.156	0.098	0.216
1973	0.203	0.112	0.303
1974	0.621	0.378	0.907
1975	0.315	0.247	0.386
1976	0.591	0.439	0.760
1977	0.379	0.277	0.490
1978	0.336	0.251	0.426
1979	0.290	0.215	0.369
1980	0.277	0.187	0.374
1981	0.232	0.174	0.294
1982	0.041	0.026	0.056
1983	0.125	0.067	0.186
1984	0.108	0.064	0.154
1985	0.147	0.098	0.197
1986	0.355	0.225	0.499
1987	0.254	0.178	0.335
1988	0.328	0.238	0.424
1989	0.146	0.093	0.202
1990	0.131	0.079	0.186
1991	0.077	0.034	0.121
1992	0.306	0.220	0.399
1993	0.094	0.059	0.130
1994	0.080	0.043	0.118
1995	0.153	0.103	0.206
1996	0.105	0.073	0.137
1997	0.250	0.168	0.339
1998	0.091	0.057	0.126
1999	0.292	0.164	0.434
2000	0.161	0.104	0.222
2001	0.383	0.275	0.502
2002	0.723	0.582	0.875
2003	0.852	0.601	1.141
2004	0.390	0.300	0.485



Table 6. NEFSC winter survey In re-transformed stratified mean weight (kg) per tow.

Year	MEAN	95% CI	
		LOW	HIGH
1992	0.464	0.374	0.560
1993	0.506	0.390	0.632
1994	0.170	0.112	0.231
1995	0.365	0.262	0.477
1996	0.501	0.380	0.633
1997	0.198	0.142	0.257
1998	0.195	0.166	0.224
1999	0.266	0.212	0.323
2000	0.478	0.366	0.599
2001	0.949	0.747	1.175
2002	1.573	1.293	1.888
2003	1.832	1.360	2.398
2004	0.671	0.551	0.801

Table 7. NEFSC Spring offshore survey indices of exploitable biomass ( $\geq 22$  cm) and relative exploitation rate.

Year	3 pt avg		ln re-transformed 3 pt avg		Rel Expl. index/1000	3 pt avg mov. Avg.
	Mean kg/tow	mov. Avg.	Mean kg/tow	mov. Avg.		
1968	0.152		0.040			
1969	0.217	0.145	0.024	0.042		
1970	0.066	0.115	0.062	0.041		
1971	0.063	0.095	0.036	0.069		
1972	0.155	0.163	0.108	0.092		
1973	0.272	0.464	0.131	0.249		
1974	0.964	0.694	0.509	0.292		
1975	0.846	0.814	0.237	0.367		
1976	0.631	0.866	0.355	0.247		
1977	1.120	0.827	0.149	0.232		
1978	0.730	<b>0.976</b>	0.193	0.149		
1979	1.078	0.700	0.104	0.144		
1980	0.292	0.560	0.134	0.134		
1981	0.311	0.210	0.164	0.106	10.32	
1982	0.027	0.161	0.019	0.088	294.25	115.39
1983	0.145	0.098	0.081	0.066	41.60	120.94
1984	0.122	0.144	0.097	0.098	26.98	30.05
1985	0.164	0.281	0.116	0.142	21.56	27.97
1986	0.559	0.367	0.213	0.177	35.36	23.50
1987	0.380	0.448	0.204	0.205	13.56	21.63
1988	0.407	0.308	0.199	0.162	15.97	20.95
1989	0.138	0.230	0.085	0.123	33.31	27.62
1990	0.144	0.113	0.085	0.072	33.58	44.25
1991	0.057	0.188	0.048	0.114	65.84	37.30
1992	0.362	0.187	0.208	0.099	12.47	55.73
1993	0.141	0.196	0.041	0.102	88.89	46.47
1994	0.086	0.125	0.059	0.069	38.04	53.96
1995	0.148	0.126	0.107	0.086	34.95	36.34
1996	0.143	0.197	0.091	0.111	36.04	31.35
1997	0.300	0.185	0.135	0.093	23.06	30.53
1998	0.111	0.278	0.052	0.136	32.50	21.68
1999	0.424	0.230	0.222	0.137	9.49	21.37
2000	0.156	0.350	0.137	0.198	22.11	14.73
2001	0.470	0.582	0.235	0.390	12.59	13.08
2002	1.121	1.247	0.799	0.509	4.54	7.96
2003	2.151	1.403	0.493	0.537	6.75	
2004	0.937		0.320			

Table 8. NEFSC black sea bass juvenile indices  
( $\leq 14$  cm) from spring survey.

Year	In re-transformed stratified mean #/tow
1968	0.085
1969	0.000
1970	0.000
1971	0.000
1972	0.143
1973	0.000
1974	0.000
1975	0.061
1976	0.557
1977	0.163
1978	0.148
1979	0.017
1980	0.482
1981	0.045
1982	0.003
1983	0.009
1984	0.007
1985	0.085
1986	0.149
1987	0.030
1988	0.232
1989	0.070
1990	0.171
1991	0.499
1992	0.164
1993	0.007
1994	0.011
1995	0.162
1996	0.063
1997	0.024
1998	0.000
1999	0.347
2000	0.661
2001	0.078
2002	0.554
2003	0.154
2004	0.080

Table 9. Black sea bass mean number per tow from state spring surveys.

	MA #/tow	CT #/tow	NJ #/tow
1968			
1969			
1970			
1971			
1972			
1973			
1974			
1975			
1976			
1977			
1978	1.958		
1979	0.988		
1980	0.997		
1981	2.233		
1982	2.158		
1983	4.529		
1984	1.597	0.164	
1985	1.208	0.274	
1986	1.583	0.123	
1987	0.705	0.053	
1988	0.420	0.045	
1989	0.547	0.079	0.166
1990	0.698	0.103	0.044
1991	0.381	0.072	0.327
1992	0.087	0.026	0.392
1993	0.112	0.072	0.123
1994	0.219	0.121	0.202
1995	0.465	0.066	1.673
1996	0.154	0.107	0.295
1997	0.452	0.095	0.763
1998	0.224	0.042	0.317
1999	1.255	0.077	1.094
2000	4.003	0.219	0.246
2001	1.752	0.253	0.912
2002	1.880	0.673	2.699
2003	0.830	0.213	1.657

Table 10. Juvenile black sea bass indices, mean number per tow. NJ indices are log<sub>e</sub> transformed, MD indices are geometric mean

	MA	NJ	MD
<b>1972</b>			8.34
<b>1973</b>			1.40
<b>1974</b>			1.94
<b>1975</b>			1.48
<b>1976</b>			1.28
<b>1977</b>			0.78
<b>1978</b>	79.3		0.75
<b>1979</b>	73.2		0.07
<b>1980</b>	93.1		1.08
<b>1981</b>	62.9		0.78
<b>1982</b>	397.2		0.53
<b>1983</b>	185.7		0.00
<b>1984</b>	201.3		0.99
<b>1985</b>	198.5		1.70
<b>1986</b>	80.4		4.94
<b>1987</b>	35.3		1.35
<b>1988</b>	60.4	0.536	1.41
<b>1989</b>	6.5	0.380	0.16
<b>1990</b>	4.3	0.043	1.24
<b>1991</b>	9.5	0.851	1.12
<b>1992</b>	10.8	0.872	0.92
<b>1993</b>	1.1	0.449	0.18
<b>1994</b>	45	0.178	0.84
<b>1995</b>	32.6	0.512	1.71
<b>1996</b>	23.6	1.032	0.06
<b>1997</b>	5.3	5.136	0.93
<b>1998</b>	9.9	2.880	0.33
<b>1999</b>	22.1	0.577	1.74
<b>2000</b>	195.5	0.974	1.95
<b>2001</b>	87.9	0.628	1.12
<b>2002</b>	118.9	0.815	1.95
<b>2003</b>	178.2	0.516	0.82

Table 11. Correlation among spring surveys.

	NMFS spring	MA	CT	NJ	NMFS winter	NMFS fall
NMFS -spr	1.00					
MA	0.10	1.00				
CT	0.62	0.52	1.00			
NJ	0.76	0.23	0.73	1.00		
NMFS -winter	0.90	0.39	0.69	0.63	1.00	
NMFS -fall	0.45	0.25	0.19	0.26	0.25	1.00

Table 12. Summary of black sea bass releases by state, season, tag type.

<b>Fall 2002</b>	<b>MA</b>	<b>RI</b>	<b>CT</b>	<b>NY</b>	<b>NJ</b>	<b>DE</b>	<b>MD</b>	<b>VA</b>
regular	1168	234		206	517		1014	332
\$	93	24		20	33		98	44
<b>Spring 2003</b>								
regular	131				445	283	557	955
\$	7				25	16	35	
<b>Fall 2003</b>								
regular	369	535	24	216	686		550	652
\$	30	30	2	18	55		46	83

Table 13a. Tagged black sea bass dispersal among statistical areas for Fall 2002 releases.

Release Area	Recapture Area						
	538	539	612	613	614	621	631
<b>week 1</b>							
538	2						
539		33					
612			1				
613				9			
614					1		
621						1	
631							1

Release Area	Recapture Area									
	514	537	538	539	612	613	614	621	625	631
<b>week 2</b>										
514	2									
537										
538		1	4							
539				32						
612					4	1				
613						3				
614							1			
621								3		
625										2
631										

Release Area	Recapture Area									
	514	537	538	539	612	613	614	621	625	631
<b>week 3</b>										
514										
537										
538		1	13							
539				14						
612					4					
613										
614										
621								1		
625										4
631										

Release Area	Recapture Area							
	514	537	538	539	612	613	614	621
<b>week 4</b>								
514	7							
537								
538		3	14					
539								
612					4			
613						2		
614								
621							1	2

Table 13b. Tagged black sea bass dispersal among statistical areas for spring 2003 releases.

Release area	Recapture area							
	week 1	538	612	614	621	625	631	635
538		3						
612			5	1				
614								
621					14			
625						1		
631							4	1
635								

week 2	538	612	614	615	621	631
538	2					
612		4		1		
614						
615						
621			1		17	
631						6

week 3	538	612	621	626	631
538	1				
612		15			
621			12		
626				2	
631					1

week 4	538	612	613	621	631
538	1				
612		5	1		
613					
621				15	1
631					2



Table 13c. Tagged black sea bass dispersal among statistical areas for fall 2003 releases.

		Recapture area									
week 1		538	539	612	613	614	621	625	631		
Release Area	538	2	1								
	539		11								
	612			8		1					
	613				5						
	614					2					
	615					4					
	621						11				
	625							2	5		
	631										
week 2		538	539	611	612	613	614	615	621	625	631
538	1										
539		3									
611			1								
612				2							
613					5						
614						42	4				
615							1				
621								13			
625									5		
631											11
week 3		539	612	613	614	615	621	631			
539	6										
612		1									
613			3								
614				4							
615				1							
621						3					
631								8			
week 4		539	611	612	613	614	615	621	631		
539	1										
611		1									
612			2								
613				2							
614					14	1					
615					2						
621							2				
631									6		

Table 14. Black sea bass tag recapture rates by region, fishery and combined for fall 2002 and spring 2003 releases. Assumed reporting rate for \$100 tags of 100%.

**Regular Tags**

Area	Number Released	Recreational Recaptures	Commercial Recaptures	total
MA-NY	1652	43	131	174
NJ-DE	1050	179	8	187
MD-VA	2623	53	45	98
<b>total</b>	<b>5325</b>	<b>275</b>	<b>184</b>	<b>459</b>

**Recapture rate**

Rec.		Com.		Area only	Fishery only		Overall
Rec.	Com.	Rec.	Com.		Rec.	Com.	
2.6%	7.9%			MA-NY	3.3%		
17.0%	0.8%			NJ-DE	3.5%	5.2%	3.5%
2.0%	1.7%			MD-VA	1.8%		8.6%

**High Reward Tags**

Area	Number Released	Recreational Recaptures	Commercial Recaptures	total
MA-NY	132	7	18	25
NJ-DE	57	17	0	17
MD-VA	158	2	3	5
<b>total</b>	<b>347</b>	<b>26</b>	<b>21</b>	<b>47</b>

**Recapture rate**

Rec.		Com.		Area only	Fishery only		Overall
Rec.	Com.	Rec.	Com.		Rec.	Com.	
5.3%	13.6%			MA-NY	7.2%		
29.8%	0.0%			NJ-DE	4.9%	7.5%	6.1%
1.3%	1.9%			MD-VA	1.4%		13.5%

Table 15 . Black sea bass tag reporting rates by region, fishery and combined for fall 2002 and spring 2003 releases. Assuming 100% reporting of high reward tags.

Area	Fishery		Area	Area	Fishery		Overall
	Rec.	Com.			Rec.	Com.	
MA-NY	49.1%	58.2%	MA-NY	45.4%	68.9%	57.1%	63.6%
NJ-DE	57.2%	0.0%	NJ-DE	71.7%			
MD-VA	100.0%	90.4%	MD-VA	127.7%			

Table 16. Black sea bass tag reporting rates by region, fishery and combined for fall 2002 and spring 2003 releases with the assumption of 80% reporting of high reward tags in the commercial fishery.

Area	Fishery		Area	Area	Fishery		Overall
	Rec.	Com.			Rec.	Com.	
MA-NY	49.1%	47.6%	MA-NY	39.1%	68.9%	44.4%	56.4%
NJ-DE	57.2%	43.4%	NJ-DE	67.7%			
MD-VA	100.0%	67.8%	MD-VA	106.4%			

Table 17. Black sea bass Fall 2002 tag release/recaptures for fish  $\geq 28$  cm, at large  $> 7$  and  $\leq 365$  days and without RI recaptures within 2 weeks of releases. Killed fish only, assuming 100% high reward reporting and 10% tag loss rate.

region	Releases		fishery	Regular Tag		expected High		sum
	Regular Tags	High Reward Tags		Recaptures	Reporting Rates	Recaptures	Reward Recaptures	
MA-NY	1524	125	Com	120	58.2%	206	15	221
			Rec	33	49.1%	67	7	74
NJ-DE	416	24	Com	7	57.2%	12	0	12
			Rec	47	57.2%	82	6	88
MD-VA	1192	130	Com	28	90.4%	31	4	35
			Rec	22	100.0%	22	2	24
sum	3132	279				421	34	455

tag loss adj.		Overall	
R	M	u	F
Regular	2819	14.8%	0.177
\$	251		
Overall	3070		

\* region 2 com reporting rate set = rec

Table 18 . Black sea bass Spring 2003 tag release/recaptures for fish  $\geq 28$  cm, at large  $> 7$  and  $\leq 365$  days and without RI recaptures within 2 weeks of releases. Killed fish only, assuming 100% high reward reporting and 10% tag loss rate.

region	Releases		fishery	Regular	Reporting	expected	High	sum
	Regular Tags	High Reward Tags		Tag Recaptures	Rates	regular Recaptures	Reward Recaptures	
MA-NY	128	7	Com	10	58.2%	17	0	17
			Rec	8	49.1%	16	0	16
NJ-DE	634	33	Com	3	<b>57.2%</b>	5	0	5
			Rec	130	57.2%	227	10	237
MD-VA	1431	28	Com	20	90.4%	22	0	22
			Rec	97	100.0%	97	2	99
sum	2193	68		268		385	12	397

tag loss adj.	
R	M
Regular	385
\$	12
Overall	397

Overall	
u	F
19.5%	<b>0.241</b>

Table 19. Black sea bass Fall 2002 tag release/recaptures for fish  $\geq 28$  cm, at large  $> 7$  and  $\leq 365$  days and without RI recaptures within 2 weeks of releases. Killed fish only, assuming 80% high reward reporting and 10% tag loss rate.

Releases			fishery					
region	Regular Tags	High Reward Tags	Regular Tag Recaptures	Reporting Rates	expected regular Recaptures	High Reward Recaptures	sum	
MA-NY	1524	125	Com	120	47.6%	252	19	271
			Rec	33	49.1%	67	7	74
NJ-DE	416	24	Com	7	43.4%	16	1	17
			Rec	47	57.2%	82	6	88
MD-VA	1192	130	Com	28	67.8%	41	5	46
			Rec	22	100.0%	22	2	24
sum	3132	279				481	40	521

tag loss adj.		Overall	
	R	M	F
Regular	481	2819	
\$	40	251	
Overall	521	3070	

Overall	F
17.0%	0.207

Table 20. Black sea bass Spring 2003 tag release/recaptures for fish  $\geq 28$  cm, at large  $> 7$  and  $\leq 365$  days and without RI recaptures within 2 weeks of releases. Killed fish only, assuming 80% high reward reporting and 10% tag loss rate.

region	Releases		fishery	Regular	Reporting	expected	High	sum
	Regular Tags	High Reward Tags		Tag Recaptures	Rates	regular Recaptures	Reward Recaptures	
MA-NY	128	7	Com	10	47.6%	21	2	23
			Rec	8	49.1%	16	2	18
NJ-DE	634	33	Com	3	43.4%	7	2	9
			Rec	130	57.2%	227	12	239
MD-VA	1431	28	Com	20	67.8%	30	2	32
			Rec	97	100.0%	97	2	99
sum	2193	68		268		398	22	421

tag loss adj.	
R	M
Regular	398
\$	22
Overall	420

Overall	
u	F
20.6%	0.258

\* region 2 com reporting rate set = region 1

Table 21. Sensitivity analyses of alternative weighting schemes in the calculation of from R/M model. M per region assumed independent and 100% reporting of high reward

Region	Fishery	Fall 2002	Spring 2003
		F	F
MA-NY	Com	0.179	0.170
	Rec	0.056	0.160
NJ-DE	Com	0.035	0.010
	Rec	0.280	0.568
MD-VA	Com	0.032	0.019
	Rec	0.022	0.086
Weighted by proportion M per		<b>0.176</b>	<b>0.258</b>
overall			
<u>Alternative weighting</u>			
by % marked per <u>regio</u>		0.183	0.258
Hypothetica	33:33:33	0.168	0.348
Regiona	25:50:25	0.189	0.405
Proportion of	50:25:25	0.175	0.352
	25:25:50	0.138	0.287

Table 22 . Alternative estimation method for black sea bass tag release/recaptures.  
 Limited to fish at large >7 days, <=365 days; excludes RI recaptures <=14 days;  
 Released fish >= 28 cm, releases adjusted for 10% tag loss; includes regular and high reward tags;  
 high reward tags assume 100% reporting; regular tags adjusted for overall reporting rate.

expected recaptures:  $E(i,j) = N(i) * St * (1 - (\exp(-(F+M))^{(tj - ti)})) * (F/(F+M))$   
 solve F such that  $E(i,j) = R(i,j)$   
 time = Sept. 2002 to Sept. 2003

**Fall 2002**

10/01/2002 - 9/30/2003

Ni	3411		
St	1		
F	<b>0.152</b>	E(i,j)	R(i,j)
M	0.2	438.0	438
tj	1		
ti	0	\$ rcaps=	34
Rs	0.636	rcaps=	257

**if commercial high reward reporting rate 80%**

Ni	3411		
St	1		
F	<b>0.174</b>	E(i,j)	R(i,j)
M	0.2	496.0	495.7
tj	1		
ti	0	red rcaps=	40
Rs	0.564	or rcaps=	257

**if overall reporting rate 10% lower**

Ni	3411		
St	1		
F	<b>0.169</b>	E(i,j)	R(i,j)
M	0.2	483.0	483
tj	1		
ti	0	red rcaps=	34
Rs	0.572	or rcaps=	257

**Spring 2003**

6/1/2003 - 5/1/2004

Ni	2261		
St	1		
F	<b>0.236</b>	E(i,j)	R(i,j)
M	0.2	433.0	433
tj	1		
ti	0	\$ rcaps=	12
Rs	0.636	rcaps=	268

Ni	2261		
St	1		
F	<b>0.276</b>	E(i,j)	R(i,j)
M	0.2	497.0	497.2
tj	1		
ti	0	red rcaps=	22
Rs	0.564	or rcaps=	268

Ni	2261		
St	1		
F	<b>0.266</b>	E(i,j)	R(i,j)
M	0.2	481.0	481
tj	1		
ti	0	red rcaps=	12
Rs	0.572	or rcaps=	268

- Ni # tags released
- St tag induced mortality
- F fishing mortality
- M natural mortality
- tj end of time period
- ti beginning of time period
- Rs reporting rate



**Table 23 . AIM results using shortened catch time series.**

First Year: 1981  
 Last Year: 2003  
 Number of Years: 23

Number of Years for Smoothing Abundance Indices: 4  
 Number of Years for Smoothing Relative F: 1  
 Number of Realizations for Randomization Test: 1000  
 Number of Bootstrap Iterations: 1000  
 Number of Lags for Auto & Cross-correlation: 7

Relative F Smoothing Method is Lagged

	Catch	SPR WT
1981	1.6900E+00	2.3200E-01
1982	5.6600E+00	4.1000E-02
1983	3.3600E+00	1.2500E-01
1984	2.6200E+00	1.0800E-01
1985	2.5000E+00	1.4700E-01
1986	7.5200E+00	3.5500E-01
1987	2.7600E+00	2.5400E-01
1988	3.1800E+00	3.2800E-01
1989	2.8200E+00	1.4600E-01
1990	2.8400E+00	1.3100E-01
1991	3.1700E+00	7.7000E-02
1992	2.5900E+00	3.0600E-01
1993	3.6100E+00	9.4000E-02
1994	2.2300E+00	8.0000E-02
1995	3.7400E+00	1.5300E-01
1996	3.2800E+00	1.0500E-01
1997	3.1200E+00	2.5000E-01
1998	1.6900E+00	9.1000E-02
1999	2.1000E+00	2.9200E-01
2000	3.0300E+00	1.6100E-01
2001	2.9600E+00	3.8300E-01
2002	3.6300E+00	7.2300E-01
2003	3.3300E+00	8.5200E-01

Base Case Results

	Replacement Ratio	Relative F
1981	N/A	7.2844828
1982	N/A	138.0487805
1983	N/A	26.8800000
1984	N/A	24.2592593
1985	1.1620553	17.0068027
1986	3.3729216	21.1830986
1987	1.3823129	10.8661417
1988	1.5185185	9.6951220
1989	0.5387454	19.3150685
1990	0.4838412	21.6793893
1991	0.3585565	41.1688312
1992	1.7947214	8.4640523
1993	0.5696970	38.4042553
1994	0.5263158	27.8750000
1995	1.0987433	24.4444444
1996	0.6635071	31.2380952
1997	2.3148148	12.4800000
1998	0.6190476	18.5714286

1999	1.9499165	7.1917808
2000	0.8726287	18.8198758
2001	1.9294710	7.7284595
2002	3.1197411	5.0207469
2003	2.1860167	3.9084507

Simple Regression Results

$$\text{LN(Replacement Ratio)} = A + B * \text{LN(Relative F)}$$

SPR WT Coefficient	A	B
Estimated Value	2.2254E+00	-7.7808E-01
Std Error Coeff	4.4470E-01	1.5970E-01
t Statistic	5.0042E+00	-4.8720E+00
p-Value (2 Sided)	1.0862E-04	1.4335E-04
Variance Inflation Factor	1.8103E+01	1.0000E+00

Relative F (for ln(Replacement Ratio = 0) = 1.746357E+01

Analysis of Variance

Degrees of Freedom for Regression	1.0000E+00
Degrees of Freedom for Error	1.7000E+01
Total Degrees of Freedom	1.8000E+01
Sum of Squares for Regression	4.9267E+00
Sum of Squares for Error	3.5285E+00
Total Sum of Squares	8.4552E+00
Regression Mean Square	4.9267E+00
Error Mean Square	2.0756E-01
F-Statistic	2.3737E+01
p-Value	1.4335E-04
R Squared (percent)	5.8268E+01
Adjusted R Squared (percent)	5.5814E+01
Estimated Standard deviation of model error	4.5559E-01
Mean of response (dependent) variable	1.1947E-01
Coefficient of Variation (percent)	3.8134E+02

Least Absolute Value Regression Results

$$\text{LN(Replacement Ratio)} = A + B * \text{LN(Relative F)}$$

SPR WT Coefficient	A	B
Estimated Value	2.3217E+00	-8.3749E-01
Sum of Absolute Value of Error	= 5.4203E+00	
Relative F (for ln(Replacement Ratio = 0)	= 1.599398E+01	

Table 24. AIM results when using commercial catch series only.

First Year: 1968  
 Last Year: 2003  
 Number of Years: 36

Number of Years for Smoothing Abundance Indices: 4  
 Number of Years for Smoothing Relative F: 1  
 Number of Realizations for Randomization Test: 1000  
 Number of Bootstrap Iterations: 1000  
 Random Number Generation Seed: 123456  
 Number of Lags for Auto & Cross-correlation: 7

Relative F Smoothing Method is Lagged

	Catch	SPR WT
1968	1.2010E+03	5.4000E-02
1969	1.1990E+03	5.8000E-02
1970	1.1000E+03	7.3000E-02
1971	6.1400E+02	5.1000E-02
1972	7.6000E+02	1.5600E-01
1973	1.1610E+03	2.0300E-01
1974	1.0690E+03	6.2100E-01
1975	1.8850E+03	3.1500E-01
1976	1.6900E+03	5.9100E-01
1977	2.4240E+03	3.7900E-01
1978	2.1150E+03	3.3600E-01
1979	1.8750E+03	2.9000E-01
1980	1.2520E+03	2.7700E-01
1981	1.1290E+03	2.3200E-01
1982	1.1770E+03	4.1000E-02
1983	1.5130E+03	1.2500E-01
1984	1.9650E+03	1.0800E-01
1985	1.5510E+03	1.4700E-01
1986	1.9010E+03	3.5500E-01
1987	1.8900E+03	2.5400E-01
1988	1.8790E+03	3.2800E-01
1989	1.3240E+03	1.4600E-01
1990	1.5880E+03	1.3100E-01
1991	1.2720E+03	7.7000E-02
1992	1.3640E+03	3.0600E-01
1993	1.4120E+03	9.4000E-02
1994	8.9600E+02	8.0000E-02
1995	9.2500E+02	1.5300E-01
1996	1.4720E+03	1.0500E-01
1997	1.1860E+03	2.5000E-01
1998	1.1630E+03	9.1000E-02
1999	1.3490E+03	2.9200E-01
2000	1.2310E+03	1.6100E-01
2001	1.3310E+03	3.8300E-01
2002	1.6020E+03	7.2300E-01
2003	1.3960E+03	8.5200E-01

Base Case Results

	Replacement Ratio	Relative F
1968	N/A	22240.7407407
1969	N/A	20672.4137931
1970	N/A	15068.4931507
1971	N/A	12039.2156863
1972	2.6440678	4871.7948718
1973	2.4023669	5719.2118227
1974	5.1428571	1721.4170692
1975	1.2221145	5984.1269841
1976	1.8254826	2859.5600677
1977	0.8763006	6395.7783641
1978	0.7051417	6294.6428571
1979	0.7156076	6465.5172414
1980	0.6942356	4519.8555957
1981	0.7238690	4866.3793103
1982	0.1444934	28707.3170732
1983	0.5952381	12104.0000000
1984	0.6400000	18194.4444444
1985	1.1620553	10551.0204082
1986	3.3729216	5354.9295775
1987	1.3823129	7440.9448819
1988	1.5185185	5728.6585366
1989	0.5387454	9068.4931507
1990	0.4838412	12122.1374046
1991	0.3585565	16519.4805195
1992	1.7947214	4457.5163399
1993	0.5696970	15021.2765957
1994	0.5263158	11200.0000000
1995	1.0987433	6045.7516340
1996	0.6635071	14019.0476190
1997	2.3148148	4744.0000000
1998	0.6190476	12780.2197802
1999	1.9499165	4619.8630137
2000	0.8726287	7645.9627329
2001	1.9294710	3475.1958225
2002	3.1197411	2215.7676349
2003	2.1860167	1638.4976526

Simple Regression Results

$$\text{LN(Replacement Ratio)} = A + B * \text{LN(Relative F)}$$

Coefficient	A	B
Estimated Value	8.4237E+00	-9.4919E-01
Std Error Coeff	1.0122E+00	1.1465E-01
t Statistic	8.3222E+00	-8.2788E+00
p-Value (2 Sided)	2.7384E-09	3.0586E-09
Variance Inflation Factor	1.7870E+02	1.0000E+00

$$\text{Relative F (for ln(Replacement Ratio) = 0)} = 7.148225E+03$$

Analysis of Variance

Degrees of Freedom for Regression	1.0000E+00
Degrees of Freedom for Error	3.0000E+01
Total Degrees of Freedom	3.1000E+01
Sum of Squares for Regression	1.2575E+01
Sum of Squares for Error	5.5041E+00
Total Sum of Squares	1.8079E+01
Regression Mean Square	1.2575E+01
Error Mean Square	1.8347E-01
F-Statistic	6.8539E+01
p-Value	3.0586E-09
R Squared (percent)	6.9555E+01
Adjusted R Squared (percent)	6.8540E+01
Estimated Standard deviation of model error	4.2833E-01
Mean of response (dependent) variable	6.7345E-02
Coefficient of Variation (percent)	6.3603E+02

Least Absolute Value Regression Results

$\text{LN}(\text{Replacement Ratio}) = A + B * \text{LN}(\text{Relative F})$

Coefficient	A	B
Estimated Value	8.6533E+00	-9.7562E-01

Sum of Absolute Value of Error = 1.0706E+01

Relative F (for  $\ln(\text{Replacement Ratio}) = 0$ ) = 7.112004

Table 25. Yield per recruit of black sea bass, assuming M=0.2.

Proportion Fishing Mortality Before Spawning = 0.53  
 Proportion Natural Mortality Before Spawning = 0.30

Age	Selectivity F	Selectivity M	Stock Weight	Catch Weight	Maturity
1	0.0000	1.00	0.0590	0.0640	0.10
2	0.1020	1.00	0.1620	0.1770	0.65
3	0.6780	1.00	0.3700	0.3210	0.90
4	0.9550	1.00	0.6540	0.5240	1.00
5	1.0000	1.00	0.8030	0.7980	1.00
6	1.0000	1.00	1.1960	1.2540	1.00
7	1.0000	1.00	1.0310	1.1320	1.00
8	1.0000	1.00	1.6560	1.4370	1.00
9	1.0000	1.00	1.8360	1.9310	1.00
10	1.0000	1.00	1.9970	1.9970	1.00
11	1.0000	1.00	2.1630	2.1630	1.00
12	1.0000	1.00	2.3800	2.3800	1.00
13	1.0000	1.00	2.5750	2.5750	1.00
14	1.0000	1.00	2.7470	2.7470	1.00
15	1.0000	1.00	2.8980	2.8980	1.00

Reference Point	F	YPR	SSBR	Mean Age	Mean Gen T	Exp Spawn
F Zero	0.000	0.000	3.828	4.731	8.297	3.265
F-01	0.187	0.261	1.628	3.405	6.339	1.937
F-Max	<b>0.329</b>	0.280	1.048	2.915	5.340	1.502
F at 20 %MSP	0.465	0.274	0.766	2.638	4.706	1.255

## **BLACK SEA BASS FIGURES**

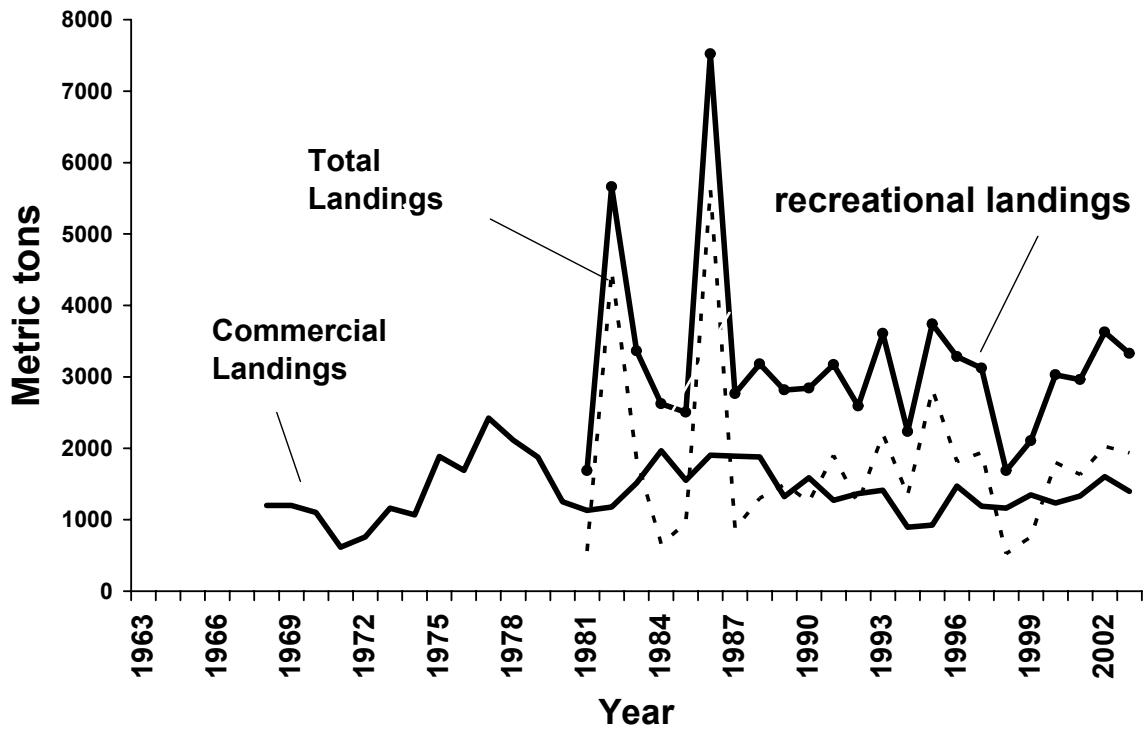


Figure 1. Landings of the northern stock of black sea bass in mt.

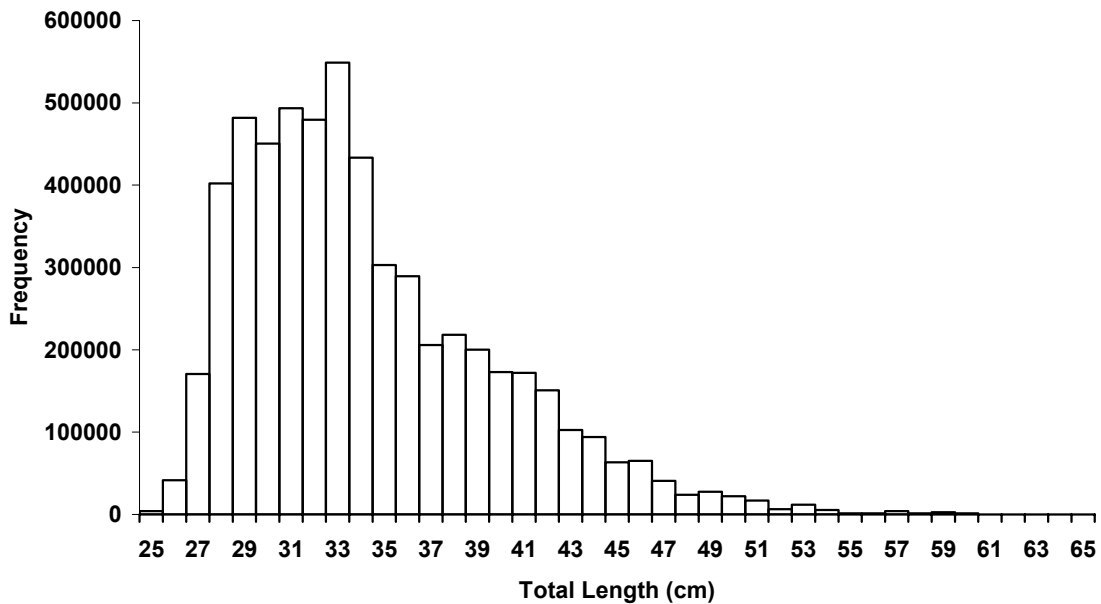


Figure 2 . 2002 commercial black sea bass landings length distribution.



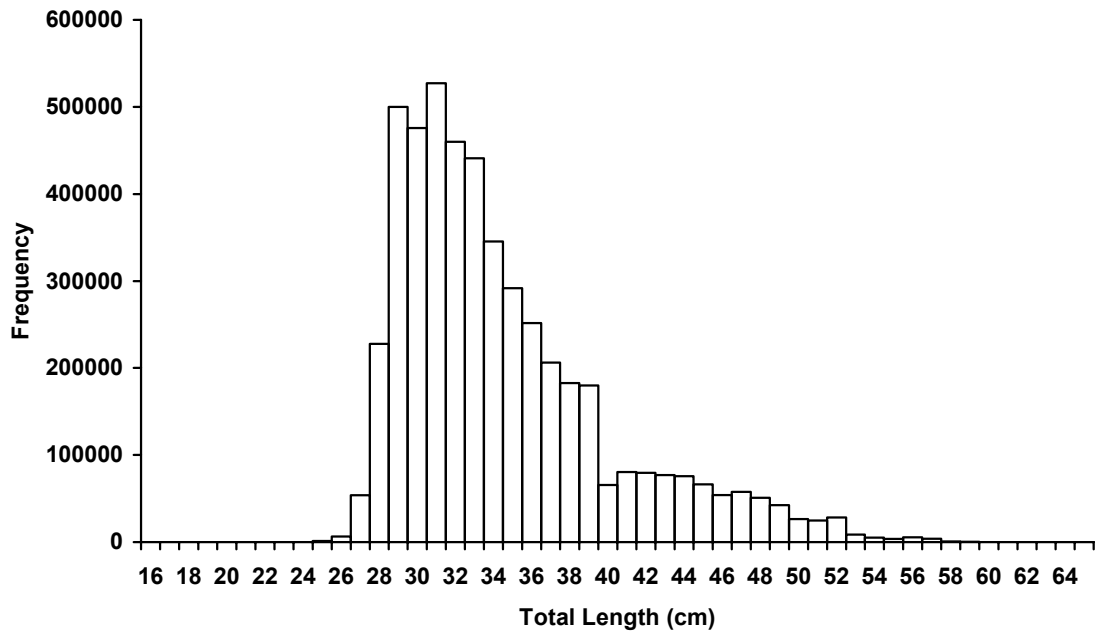


Figure 3. 2003 commercial black sea bass landings length distribution.

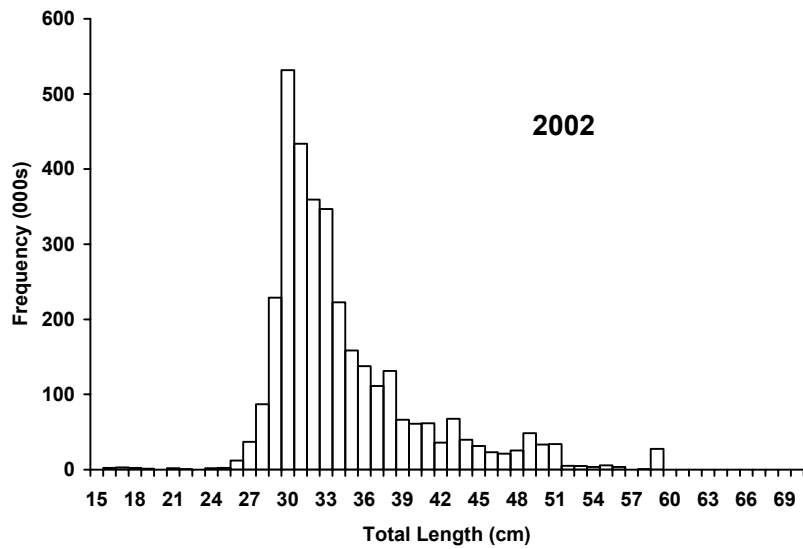


Figure 4. 2002 length frequency of black sea bass recreational landings.

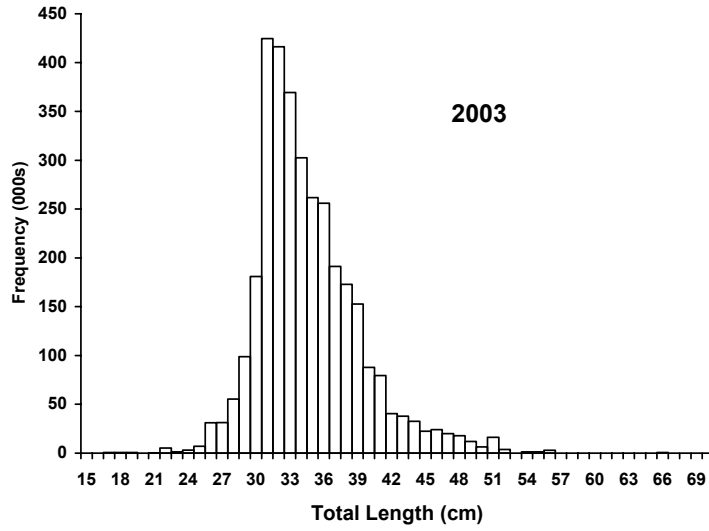


Figure 5. 2003 length frequency of black sea bass recreational landings.

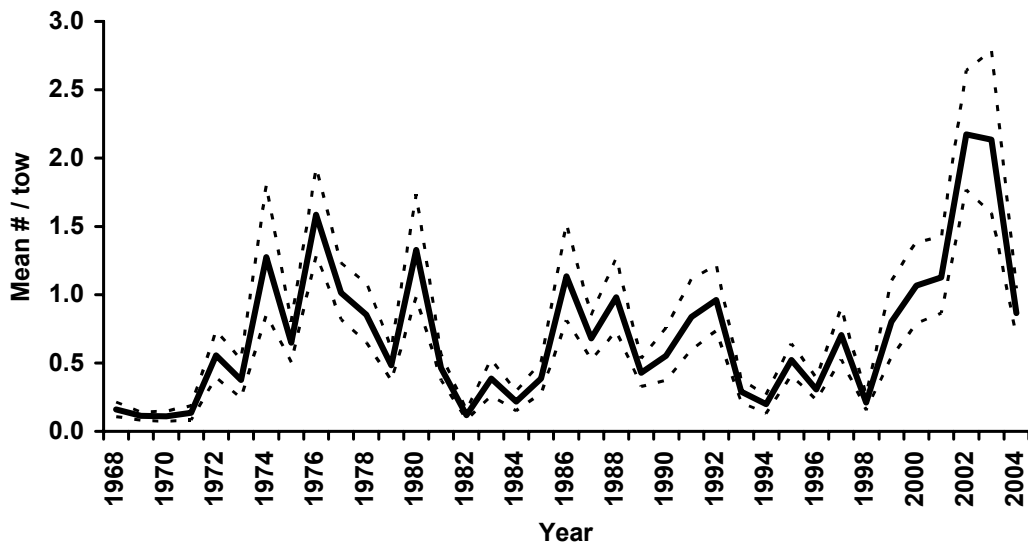


Figure 6. NEFSC spring offshore ln re-transformed mean number per tow of black sea bass,  $\pm$  95% confidence intervals.

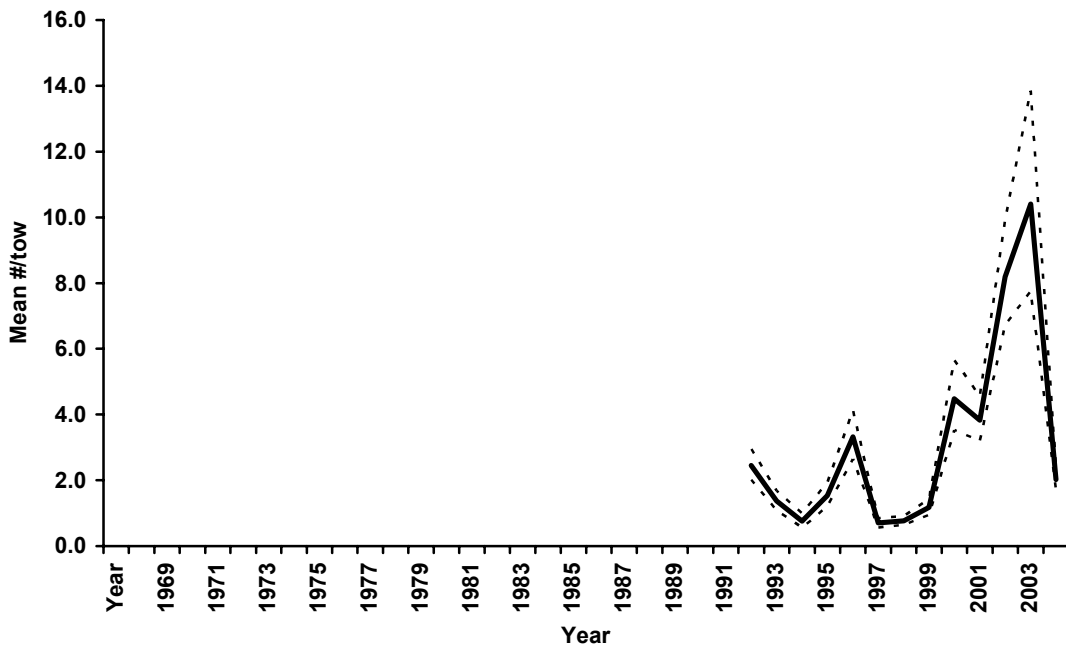


Figure 7. NEFSC winter survey ln re-transformed mean number per tow of black sea bass,  $\pm$  95% confidence intervals.

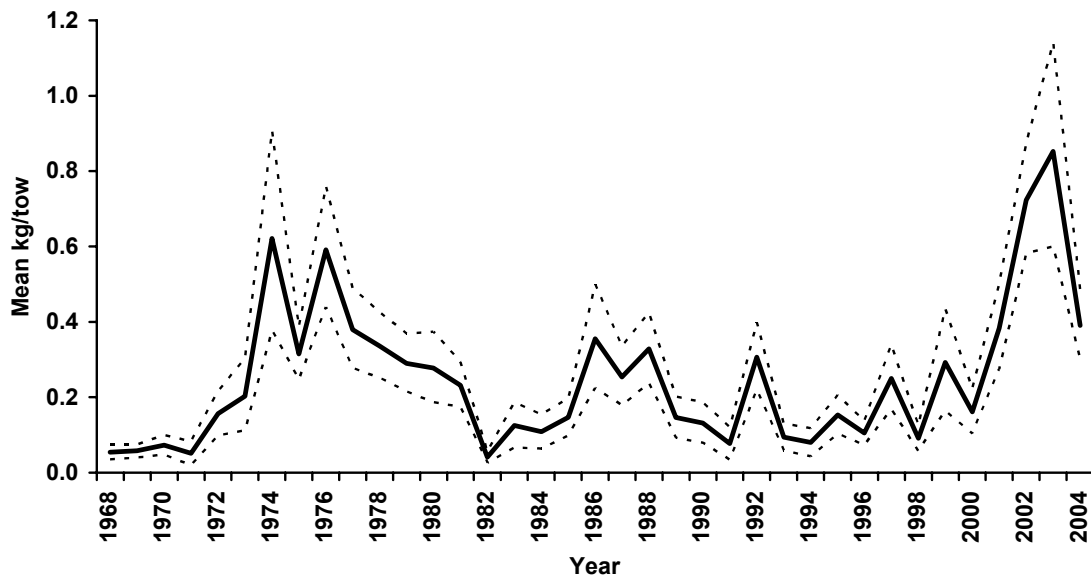


Figure 8. NEFSC spring offshore ln re-transformed mean weight (kg) per tow of black sea bass,  $\pm$  95% confidence intervals.

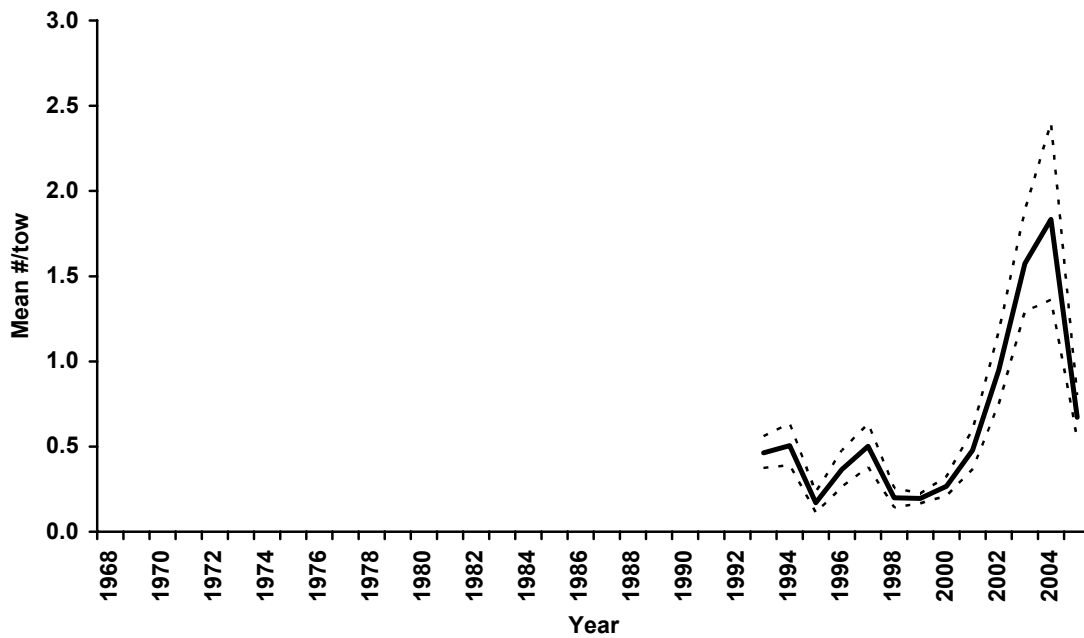


Figure 9. NEFSC winter survey ln re-transformed mean weight (kg) per tow of black sea bass,  $\pm$  95% confidence intervals.

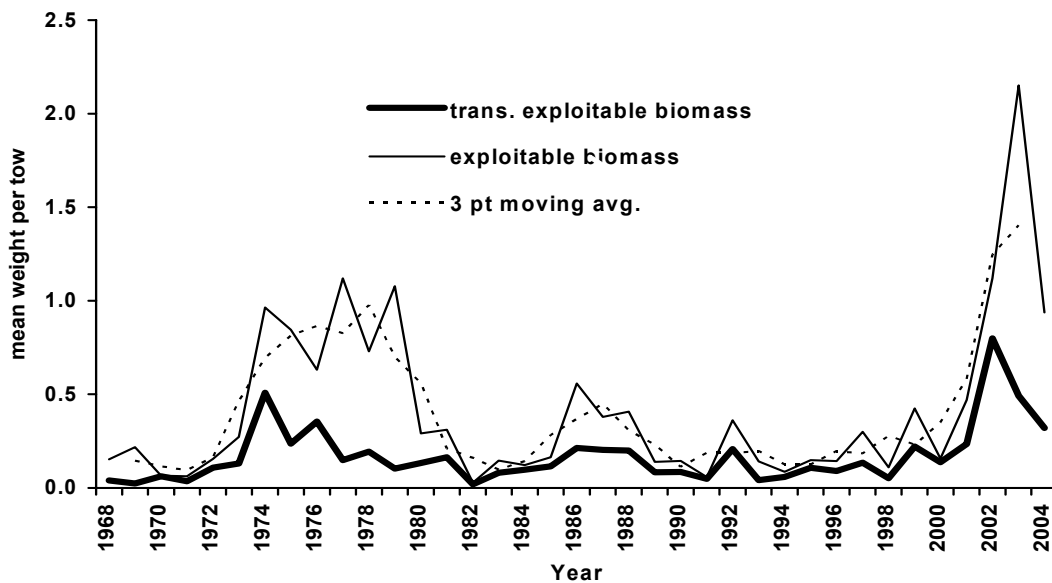
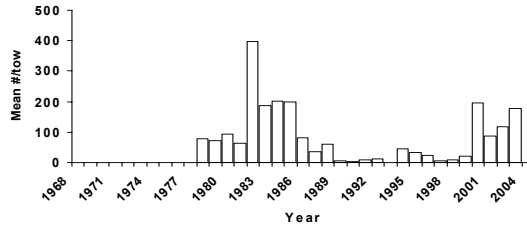
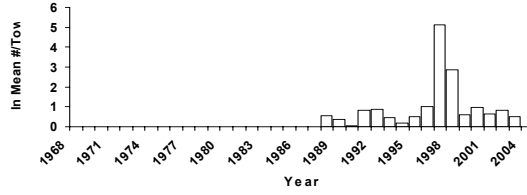


Figure 10. NEFSC spring offshore survey black sea bass index of exploitable biomass, ( $\geq 22$  cm), 3 point moving average and ln re-transformed exploitable biomass.

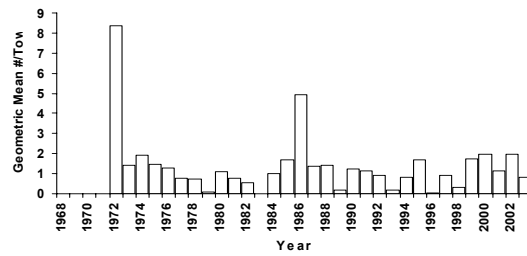
MA DMF - Fall Juvenile Indices



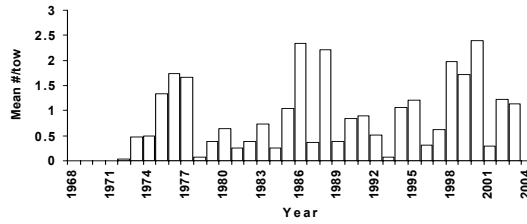
NJ DEP October juvenile index



MD DNR coastal juvenile index



NMFS Fall survey juvenile indices



NMFS Spring Juvenile Index

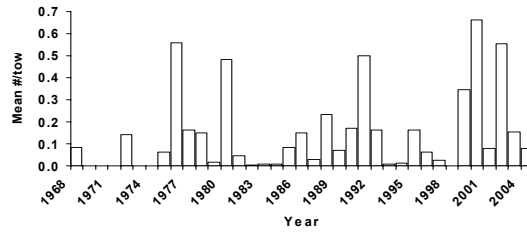


Figure 11. Juvenile abundance indices from state and federal surveys.

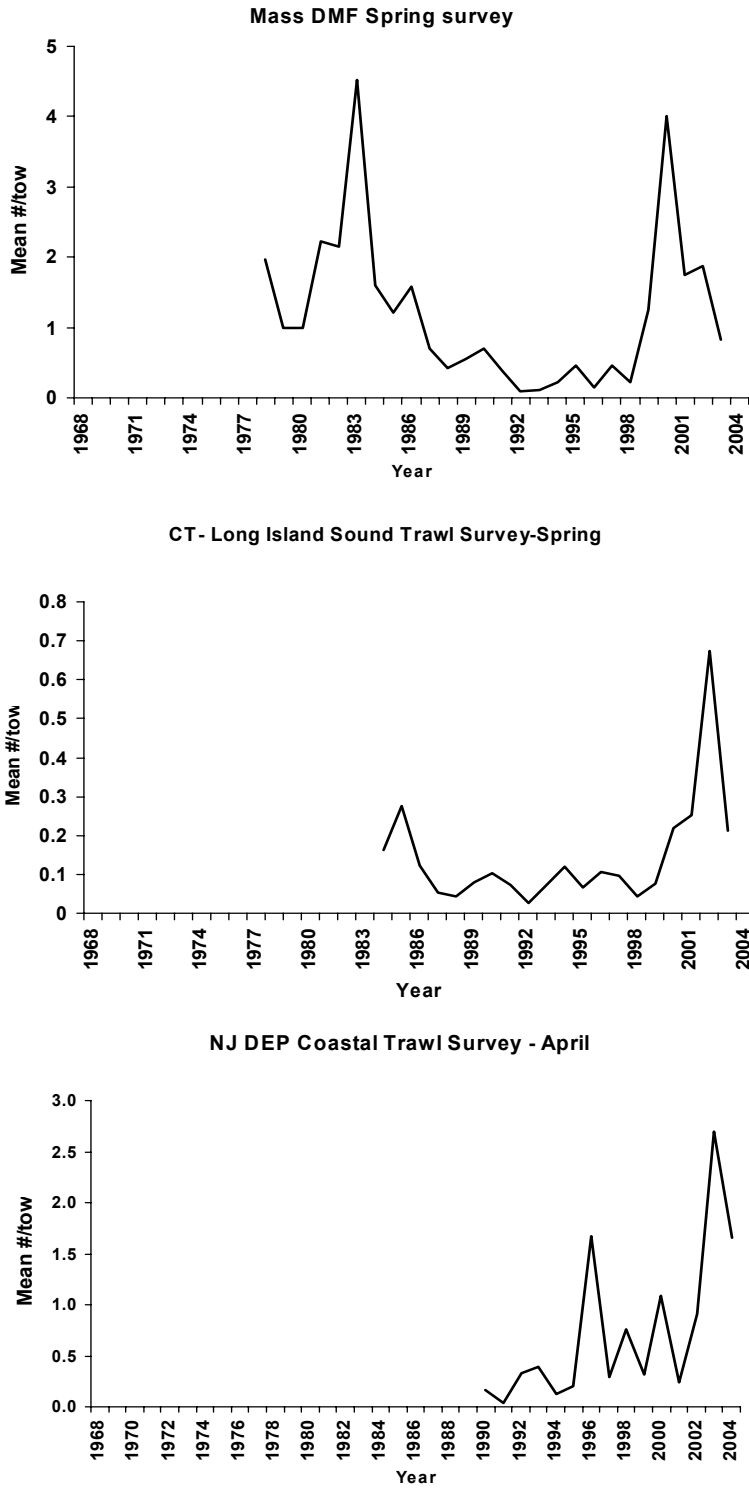


Figure 12. Abundance indices (mean #/tow) from state spring surveys.

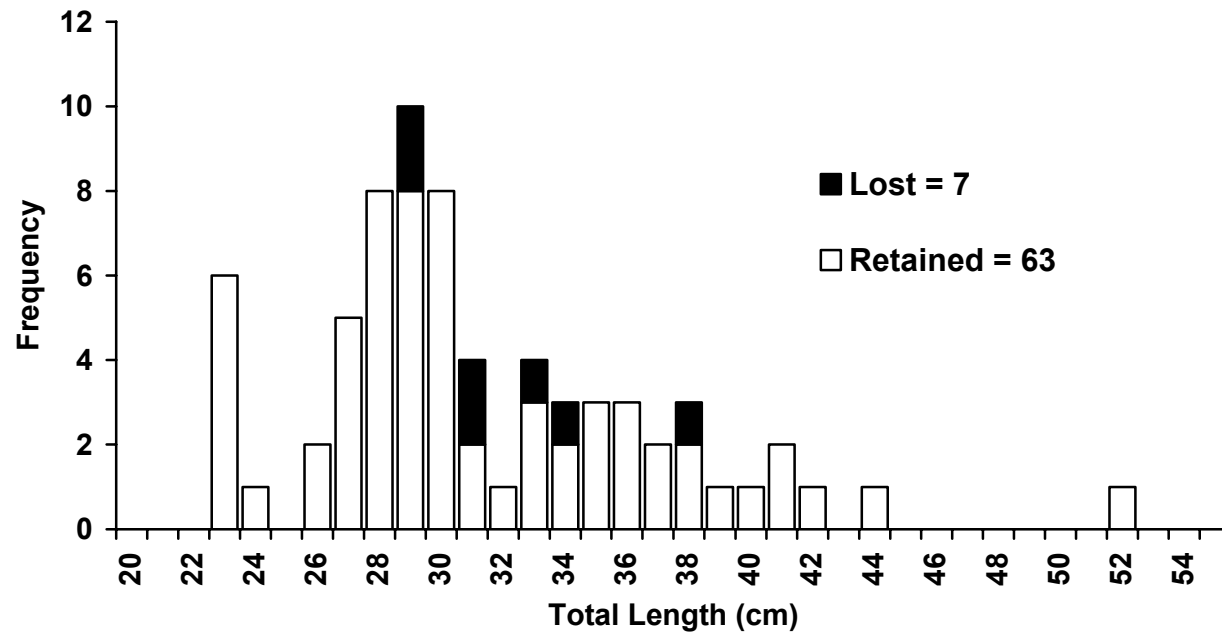


Figure 13. Sum of length distribution of black sea bass used in tag retention experiments. Fate of tags as indicated.

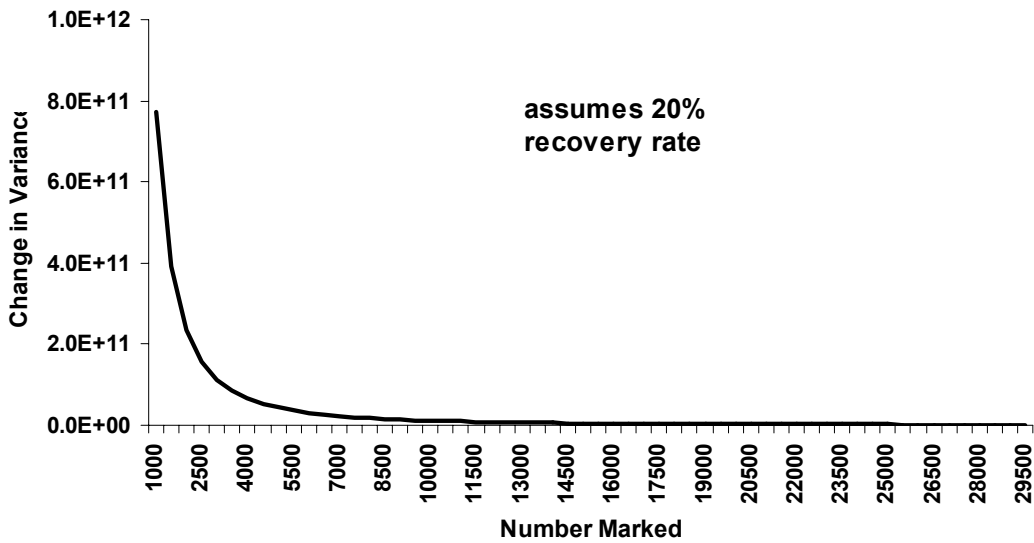
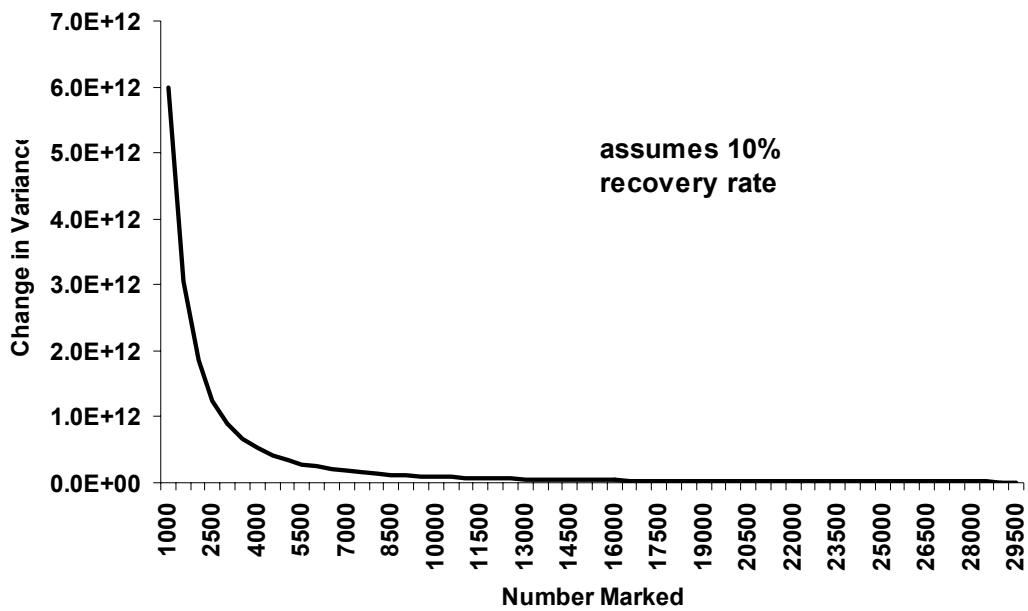


Figure 14. Effect on variance of N with changes in sample size under 2 recovery rate assumptions.



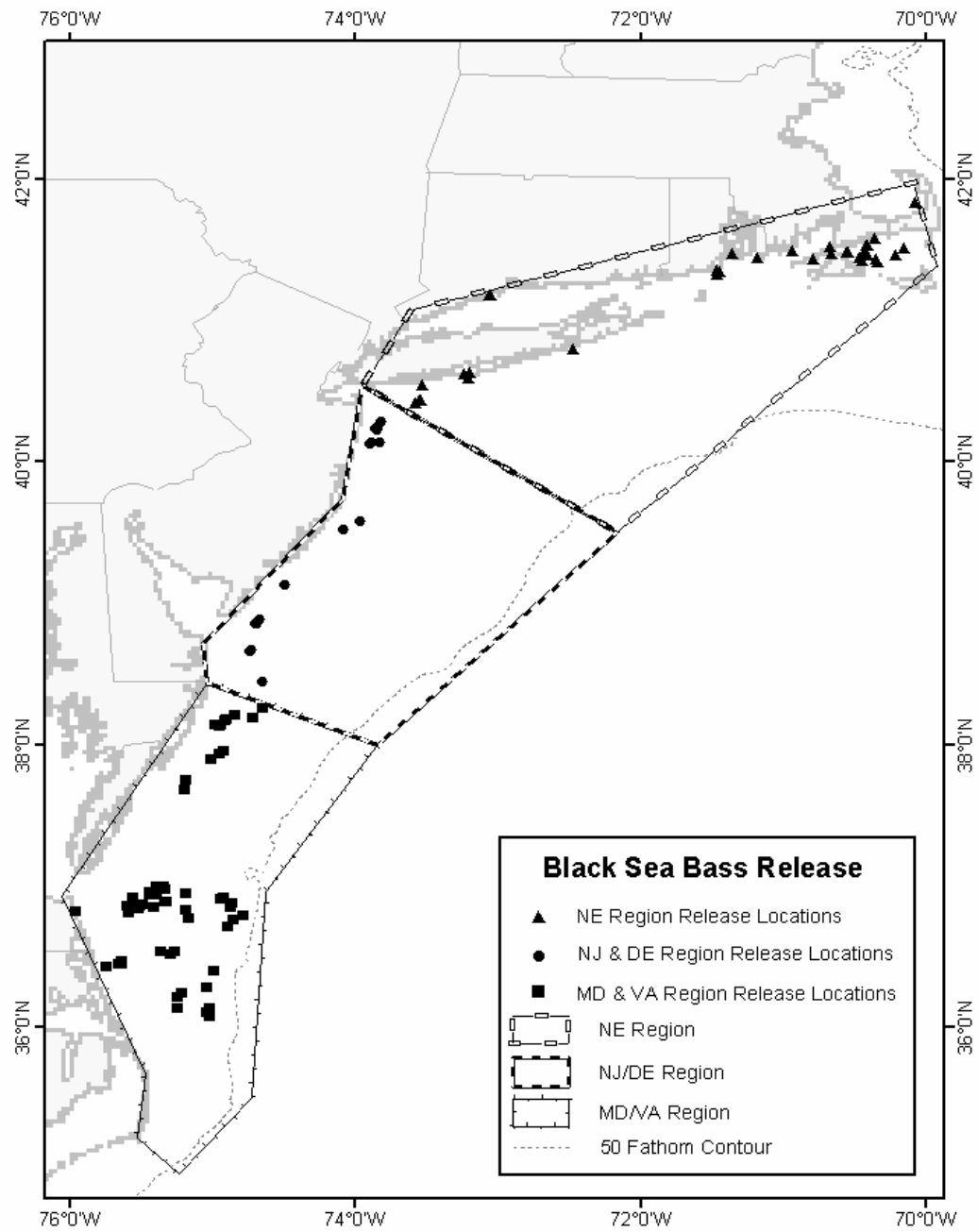


Figure 15. Geographic distribution of black sea bass tag releases. Three regions indicated.

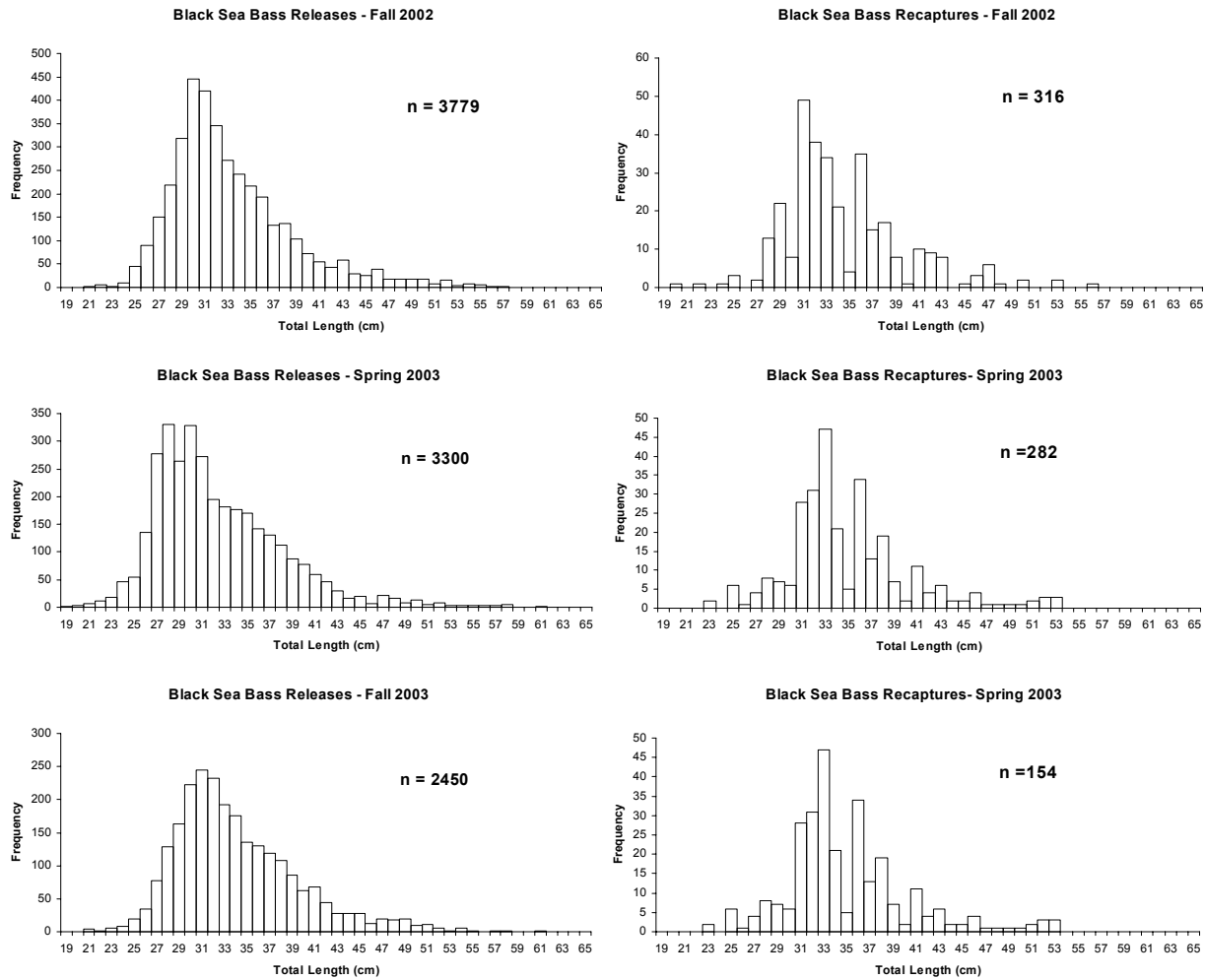


Figure 16. Length distributions of tagged and released black sea bass and subsequent recapture sizes.

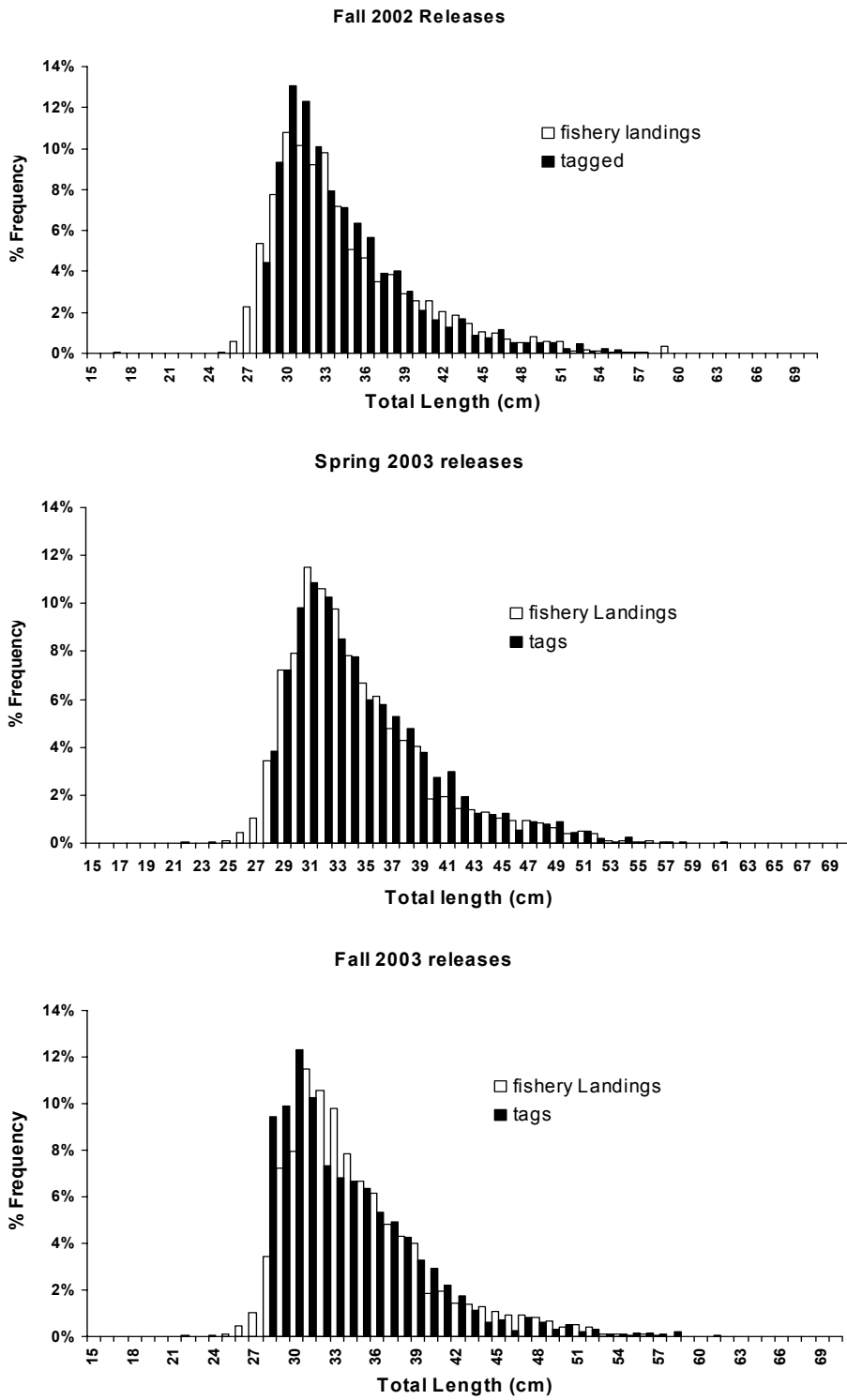


Figure17. Comparison between length distributions of tagged black sea bass and fishery landings.

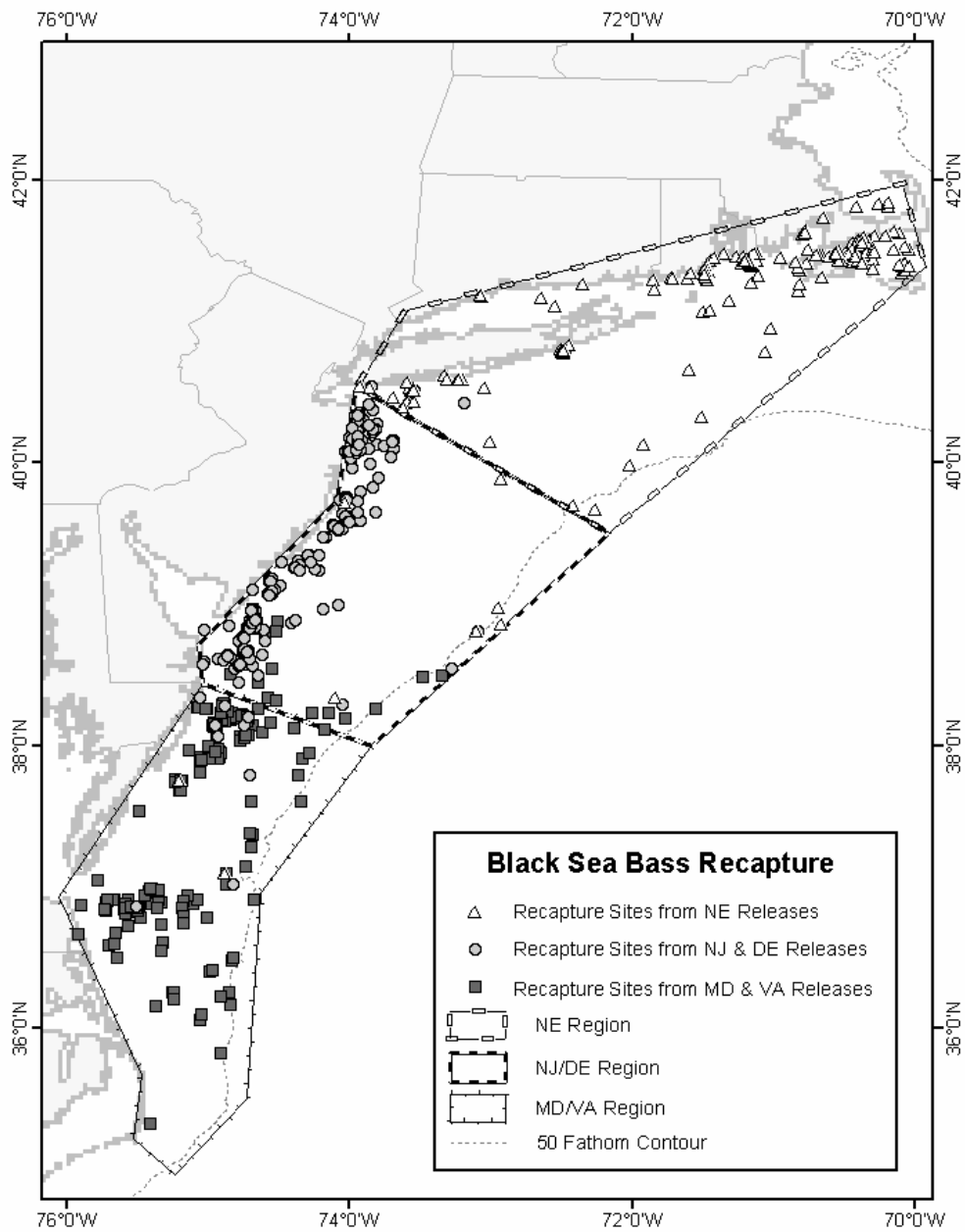


Figure18. Geographic distributions of recaptured black sea bass for all releases combined.

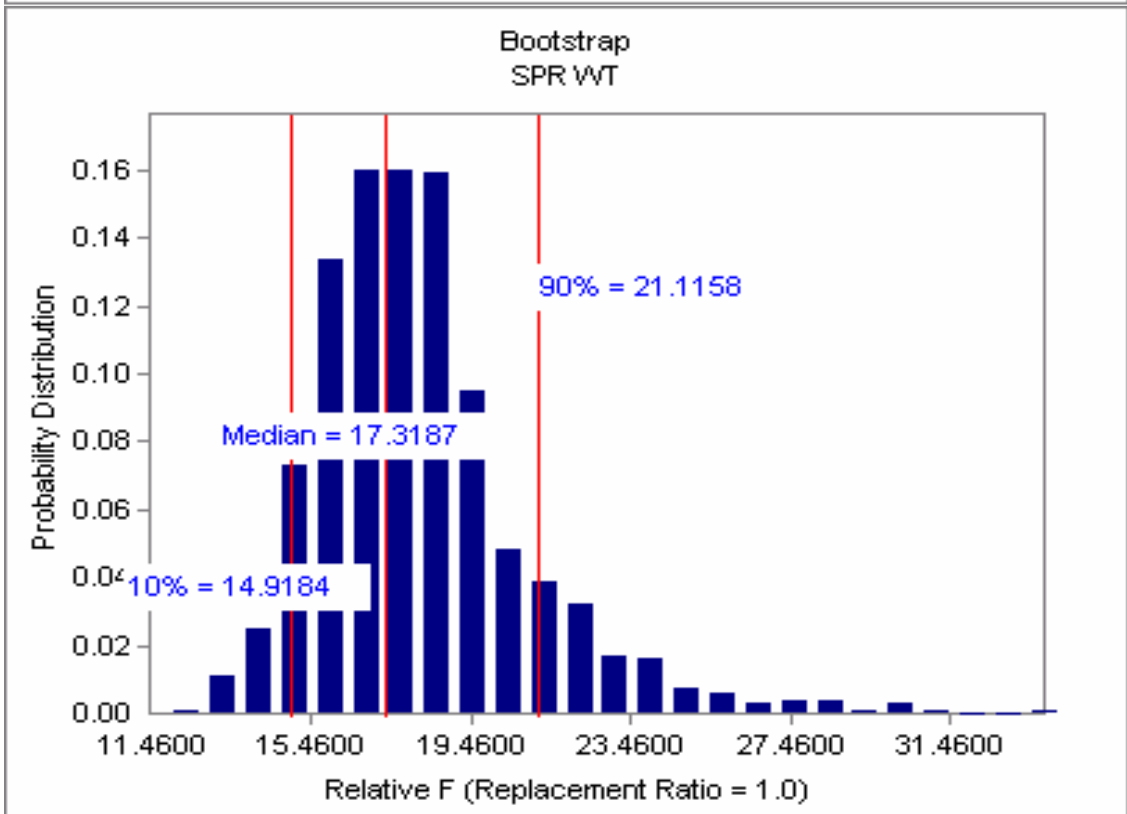
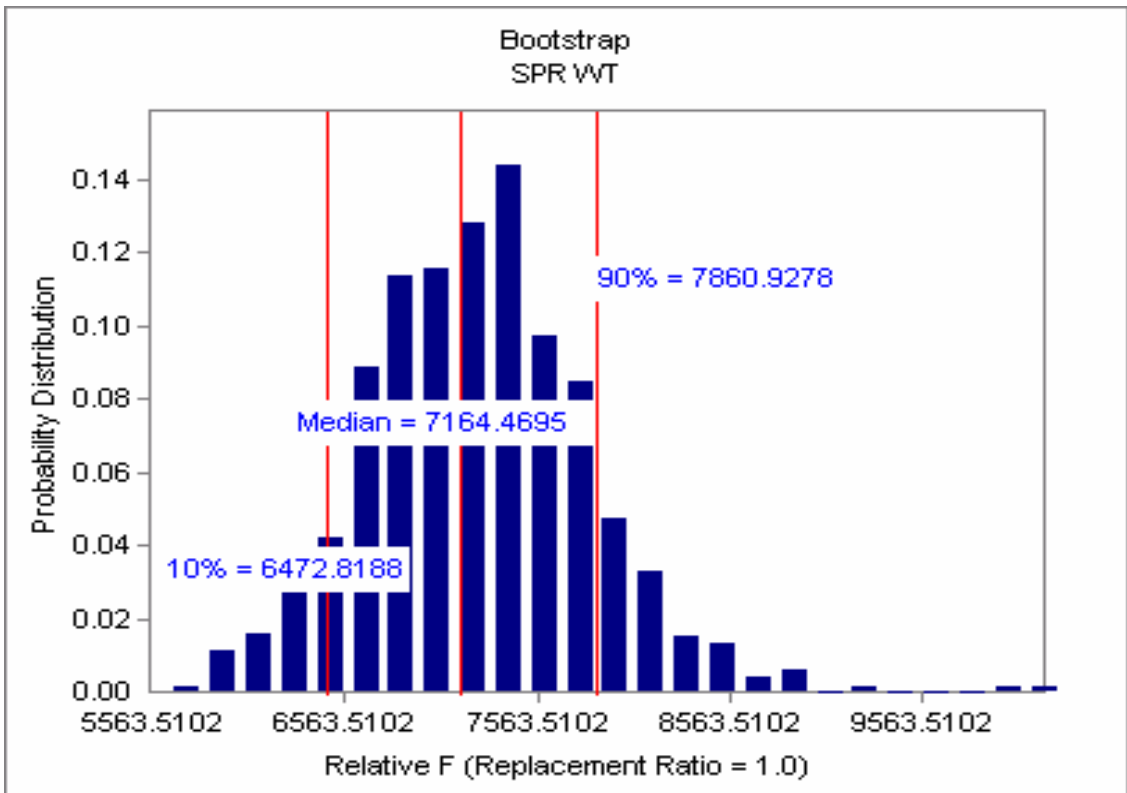


Figure19. Bootstrap distributions of relative Fs using AIM model. Top graph for commercial landings series, bottom for shorter total landings.

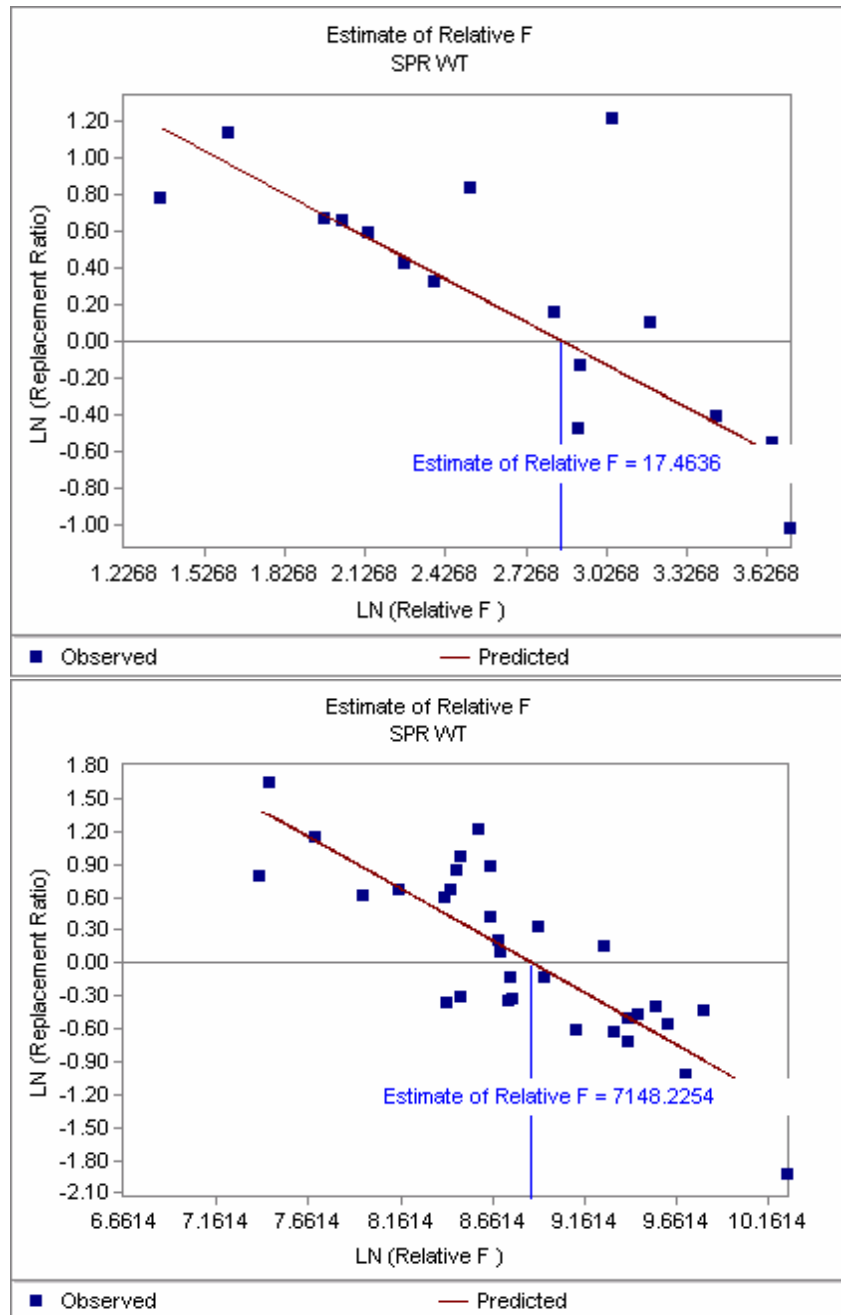


Figure 20. Relationship between relative F and associated replacement ratio. Top graph uses total landings series and bottom commercial landings only.

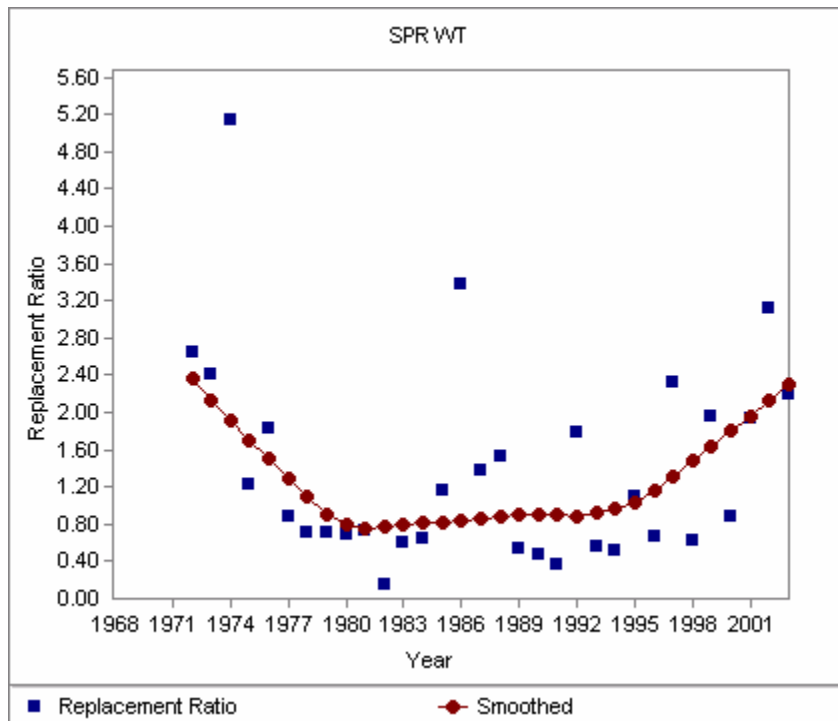
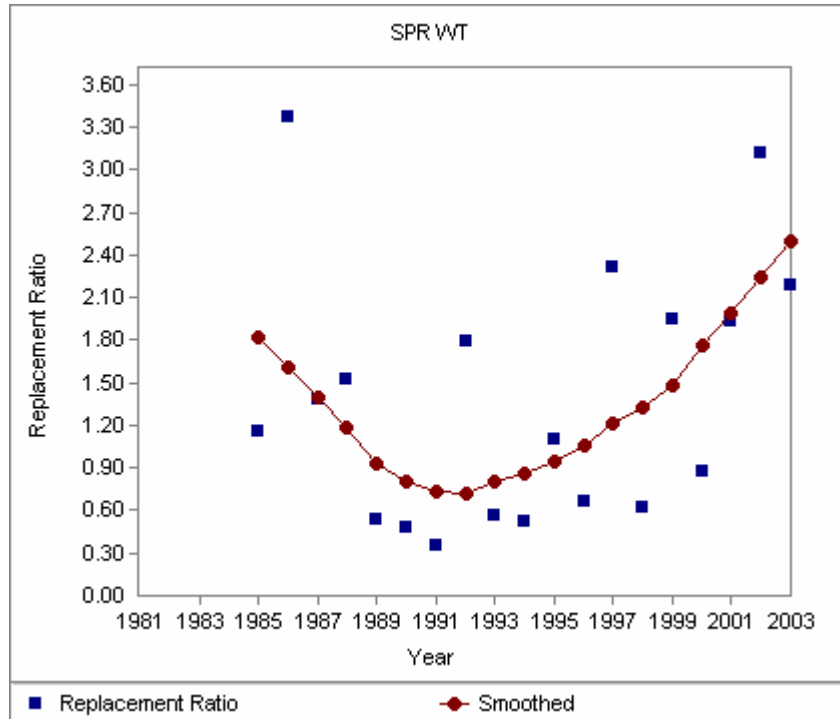


Figure 21. Time series of replacement ratios from AIM model and Lowess smoothed average. Top figure for total landings and bottom for commercial landings series.

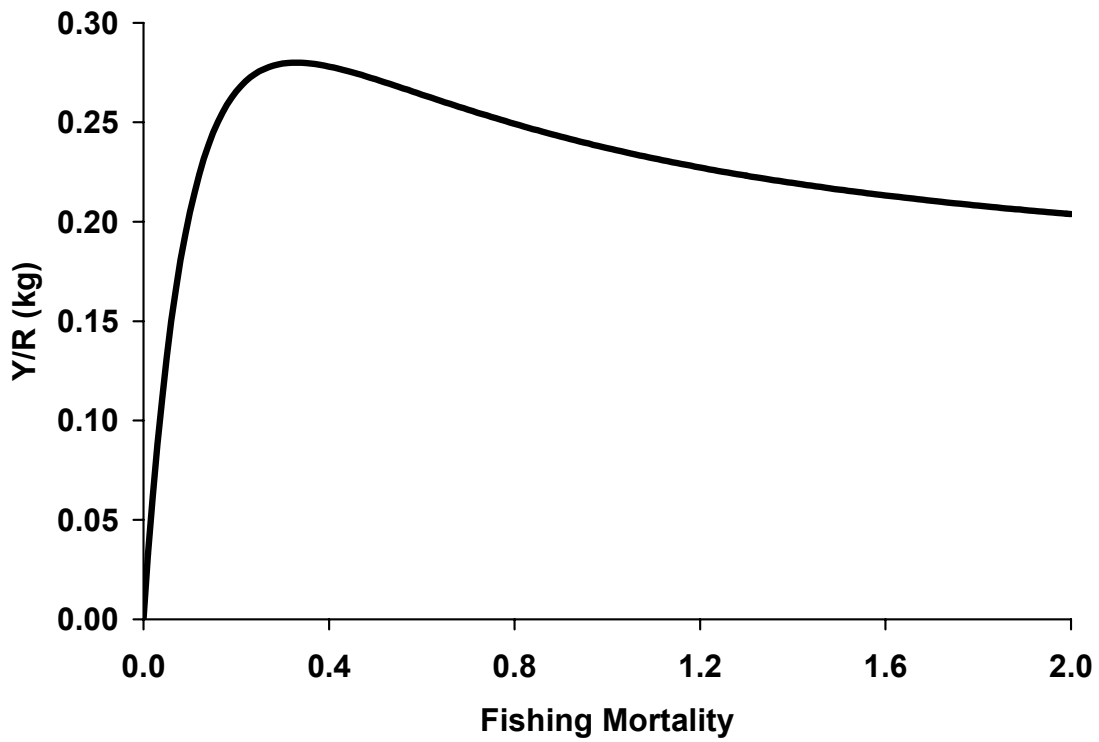
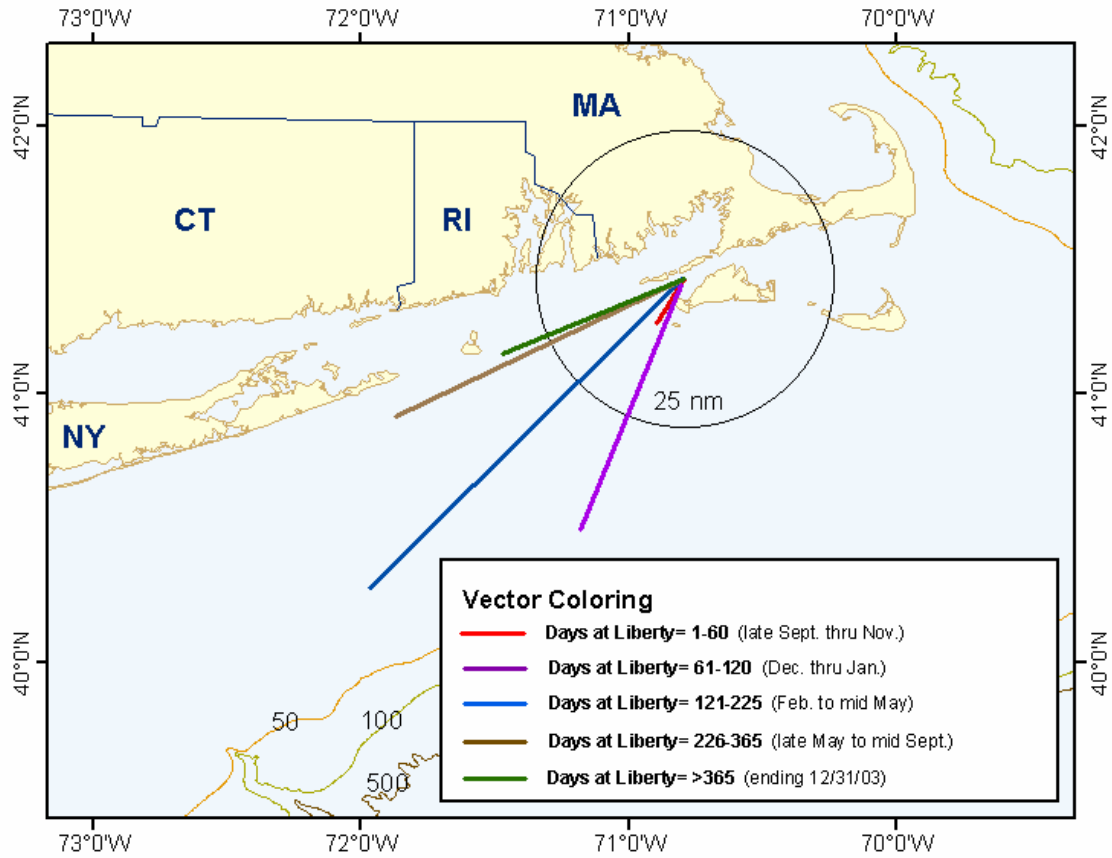


Figure 22. Yield per recruit (kg) for black sea bass. Age at full recruitment equals 5 (96% at age 4).  $F_{max} = 0.33$ .



## Appendix I. Black Sea Bass Region Vector Summary

**Figure A1.**  
New England Region (MA, RI, CT releases):



Total releases: 2511

Total recaptures: 289

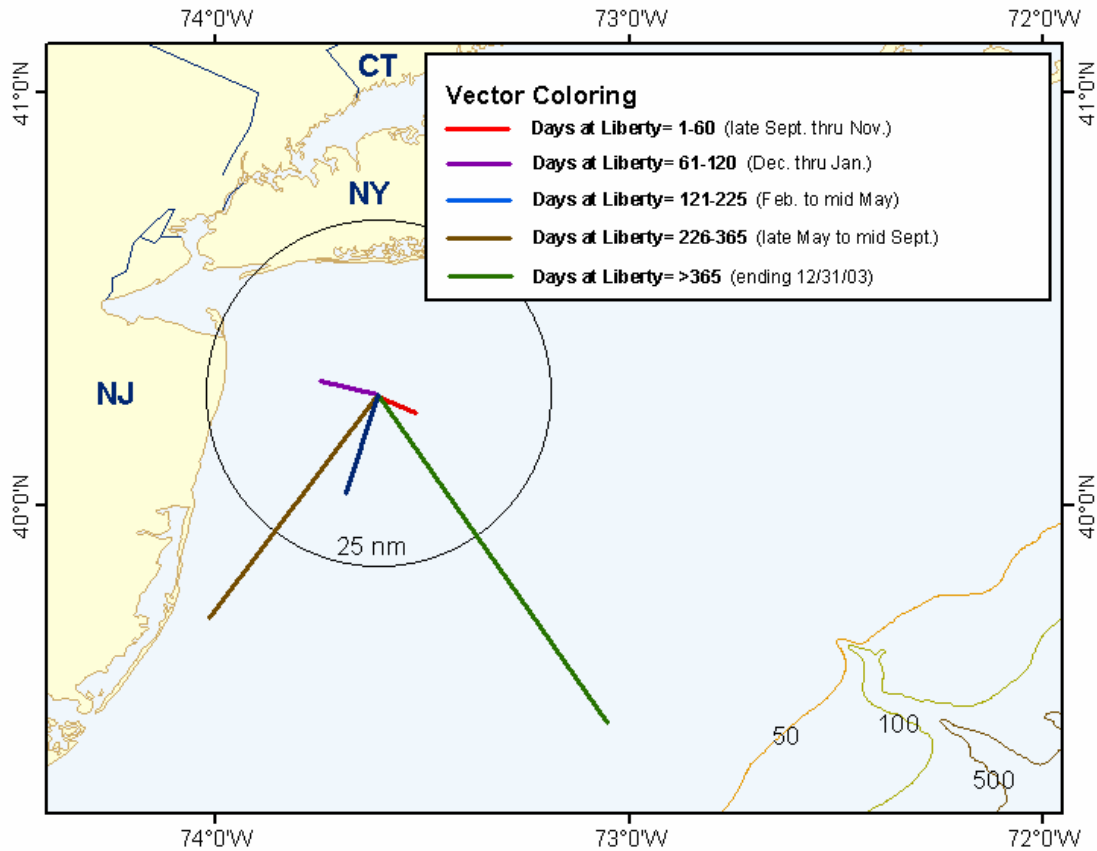
Recapture rate: 11.5%

Distance Traveled      Max: 234 nm              Mean: 19.6 nm

Days at Liberty              Max: 402              Mean: 73

Dist./Day              Max: 9.9 nm/day      Mean: 0.7 nm/day

**Figure A2.**  
**Long Island-N. NJ Region:**



Total releases: 953

Total recaptures: 125

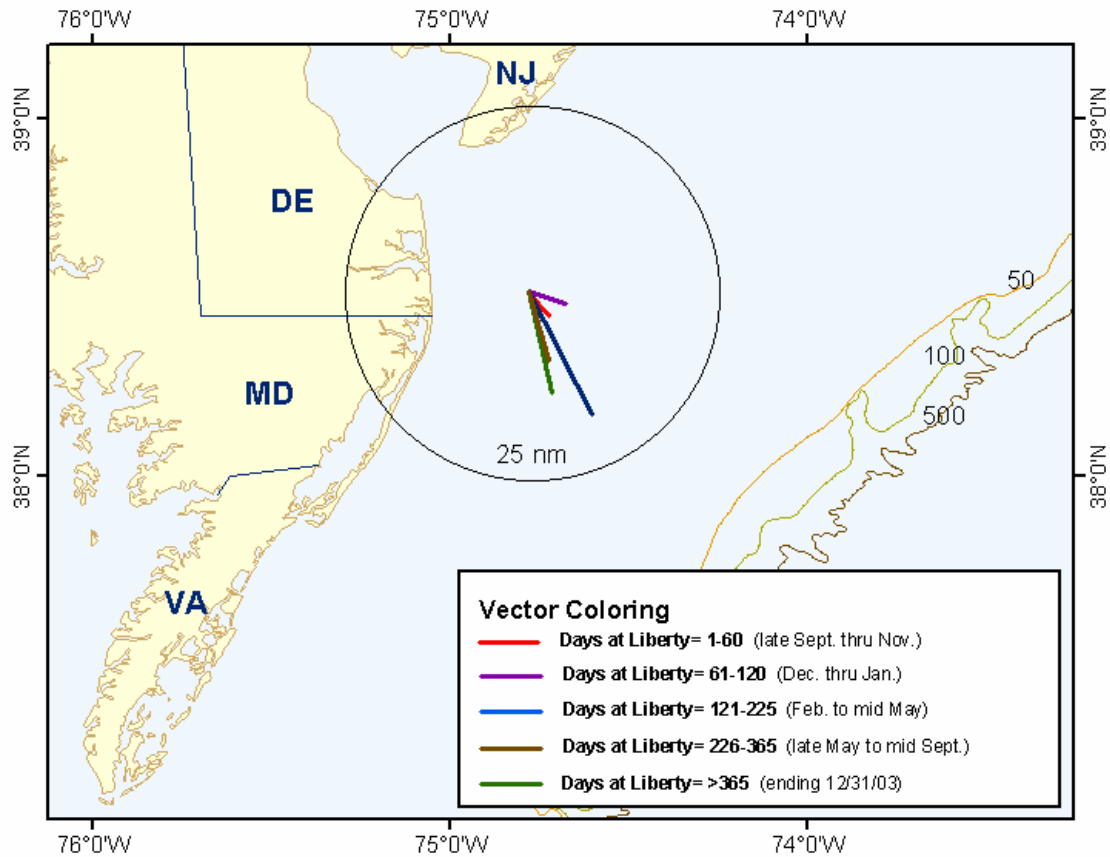
Recapture rate: 13.1%

Distance Traveled      Max: 171 nm      Mean: 8.3 nm

Days at Liberty      Max: 421      Mean: 44

Dist./Day      Max: 7.8 nm/day      Mean: 0.4 nm/day

**Figure A3.**  
**Cape May-Delmarva Peninsula Region:**



Total releases: 2812

Total recaptures: 339

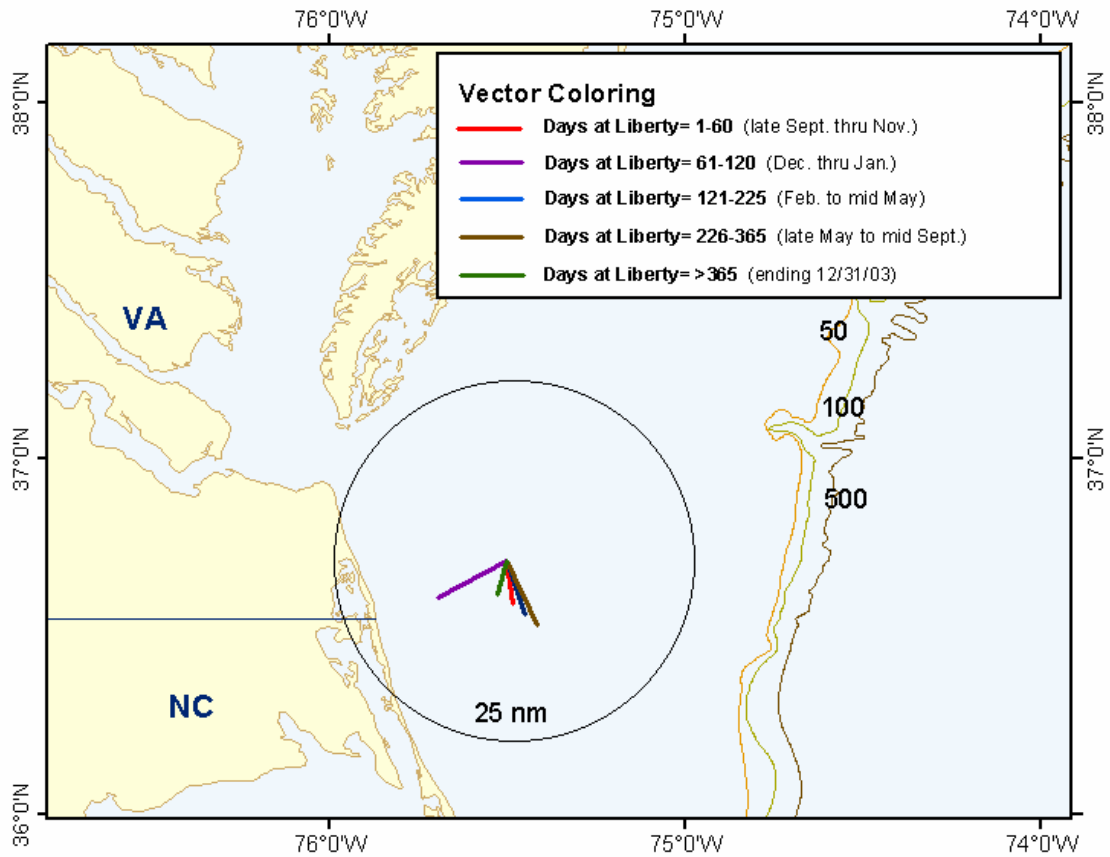
Recapture rate: 12.1%

Distance Traveled    Max: 182 nm            Mean: 8.9 nm

Days at Liberty        Max: 470                Mean: 117

Dist./Day                Max: 10.1 nm/day      Mean: 0.2 nm/day

**Figure A4.**  
**Virginia Beach Region:**



Total releases: 819

Total recaptures: 103

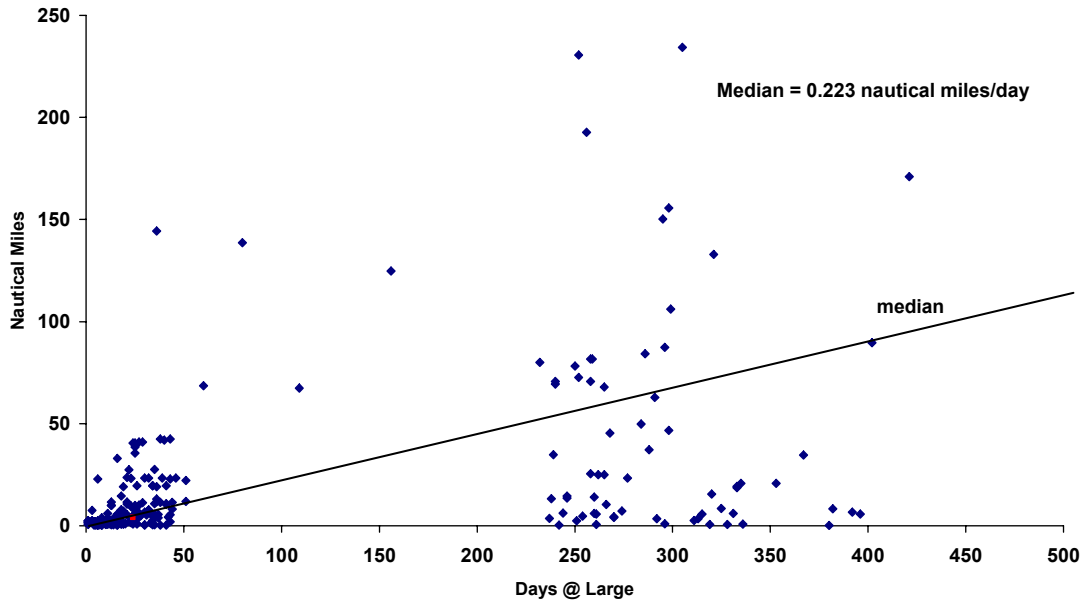
Recapture rate: 12.6%

Distance Traveled      Max: 62 nm              Mean: 7.1 nm

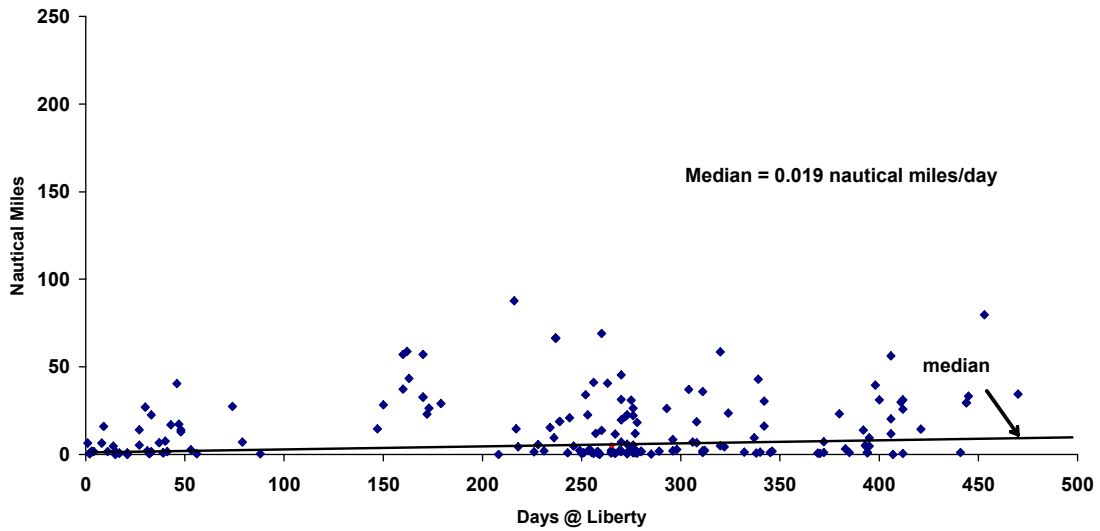
Days at Liberty              Max: 406              Mean: 89

Dist./Day                      Max: 1.8 nm/day      Mean: 0.2 nm/day

Fall 2002 MA-NY releases



Fall 2002 NJ-VA releases



**Appendix II. Log-linear model results of black sea bass reporting rates using SAS CATMOD.**

Response	type*region*fate	Response Levels	17
Weight Variable	count	Populations	1
Data Set	NEWFATE	Total Frequency	5672
Frequency Missing	0	Observations	30

Type 1= regular tags  
 2= High reward tags

Sample      Sample Size

Region 1= MA - NY  
 2= NJ - DE  
 3= MD - NC

-----  
 1                      5672

Fate 1= not removed  
 2= Recreational killed  
 3= Commercial killed

Response Profiles

Response	type	region	fate
-----			
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	3	1
16	2	3	2
17	2	3	3

\_Response\_ Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0
2	1	1	0	1	0	0	1	0	1	0	1	0	0	0	1	0	0
3	1	1	0	1	0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	0	0
4	1	0	1	0	1	1	0	1	0	0	0	1	0	0	0	1	0
5	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	1
6	1	0	1	0	1	-1	-1	-1	-1	0	0	-1	-1	0	0	-1	-1
7	1	-1	-1	-1	-1	1	0	1	0	-1	0	-1	0	-1	0	-1	0
8	1	-1	-1	-1	-1	0	1	0	1	0	-1	0	-1	0	-1	0	-1
9	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1
10	-1	1	0	-1	0	1	0	-1	0	1	0	0	0	-1	0	0	0
11	-1	1	0	-1	0	0	1	0	-1	0	1	0	0	0	-1	0	0
12	-1	1	0	-1	0	-1	-1	1	1	-1	-1	0	0	1	1	0	0
13	-1	0	1	0	-1	1	0	-1	0	0	0	1	0	0	0	-1	0
14	-1	0	1	0	-1	0	1	0	-1	0	0	0	1	0	0	0	-1
15	-1	-1	-1	1	1	1	0	-1	0	-1	0	-1	0	1	0	1	0
16	-1	-1	-1	1	1	0	1	0	-1	0	-1	0	-1	0	1	0	1
17	-1	-1	-1	1	1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1

The CATMOD Procedure

Maximum Likelihood Analysis

Iteration	Sub Iteration	-2 Log Likelihood	Convergence Criterion	Parameter Estimates						
				1	2	3	4	5	6	7
0	0	32139.972	1.0000	0	0	0	0	0	0	0
1	0	28815.127	0.1034	1.0383	0.1561	-0.8102	-0.2790	0.0859	1.9389	-0.6516
2	3	20076.527	0.3033	1.3433	0.5228	-1.0404	-0.4736	1.0372	3.0646	-0.9324
3	1	17004.075	0.1530	1.2685	0.4945	-0.5834	-0.1467	0.0624	2.6155	-0.9882
4	0	16836.472	0.009857	1.2551	0.4798	-0.3948	-0.2055	0.0595	2.5373	-1.0366
5	0	16831.238	0.000311	1.2677	0.4950	-0.4155	-0.2055	0.0496	2.5308	-1.0236
6	0	16831.235	1.9593E-7	1.2680	0.4953	-0.4159	-0.2055	0.0493	2.5306	-1.0232
7	0	16831.235	3.009E-13	1.2680	0.4953	-0.4159	-0.2055	0.0493	2.5306	-1.0232

Maximum Likelihood Analysis

Iteration	Parameter Estimates									
	8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0	0
1	1.3170	-0.9698	-0.3634	-0.2051	-0.3951	0.9111	0.0397	0.2330	-1.1135	0
2	-0.2602	-0.3856	-0.7323	-1.1457	-0.1741	2.3430	-0.2280	-0.0979	-0.3736	0
3	0.0339	-0.0404	-0.3696	-0.8414	-0.3318	1.6768	0.1070	-0.1112	0.0871	0
4	0.1272	-0.1088	-0.4156	-0.6869	-0.1882	1.5067	0.1077	-0.1987	0.0679	0
5	0.1264	-0.1048	-0.3951	-0.7218	-0.1868	1.5375	0.0964	-0.1791	0.0510	0
6	0.1266	-0.1049	-0.3946	-0.7227	-0.1864	1.5381	0.0961	-0.1785	0.0503	0
7	0.1266	-0.1049	-0.3946	-0.7227	-0.1864	1.5381	0.0961	-0.1785	0.0503	0

Maximum likelihood computations converged.

Maximum Likelihood Analysis of Variance

Source	DF	Chi-Square	Pr > ChiSq
type	1	213.55	<.0001
region	2	13.86	0.0010
type*region	2	3.17	0.2054
fate	2	681.20	<.0001
type*fate	2	2.70	0.2588
region*fate	4	178.46	<.0001
type*region*fate	3*	1.22	0.7480
Likelihood Ratio	0	.	.

NOTE: Effects marked with '\*' contain one or more redundant or restricted parameters.

Analysis of Maximum Likelihood Estimates

Effect	Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
type	1	1.2680	0.0868	213.55	<.0001
region	2	0.4953	0.1344	13.59	0.0002



Analysis of Maximum Likelihood Estimates

Effect	Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
region	3	-0.4159	0.2433	2.92	0.0874
type*region	4	-0.2055	0.1262	2.65	0.1035
	5	0.0493	0.2229	0.05	0.8250
fate	6	2.5306	0.1096	533.07	<.0001
	7	-1.0232	0.2069	24.45	<.0001
type*fate	8	0.1266	0.0903	1.97	0.1609
	9	-0.1049	0.2051	0.26	0.6091
region*fate	10	-0.3946	0.1383	8.14	0.0043
	11	-0.7227	0.2166	11.14	0.0008
	12	-0.1864	0.2488	0.56	0.4539
	13	1.5381	0.1405	119.82	<.0001
type*region*fate	14	0.0961	0.1306	0.54	0.4622
	15	-0.1785	0.2051	0.76	0.3842
	16	0.0503	0.2293	0.05	0.8265
	17	.	.	.	.

Maximum Likelihood Predicted Values for Response Functions

Sample	Function Number	-----Observed-----		-----Predicted-----		Residual
		Function	Standard Error	Function	Standard Error	
1	1	6.63922203	0.707569	6.63922203	0.707569	0
	2	2.2512918	0.743392	2.2512918	0.743392	0
	3	3.95124372	0.713874	3.95124372	0.713874	0
	4	6.14525802	0.707864	6.14525802	0.707864	0
	5	4.03424064	0.713337	4.03424064	0.713337	0
	6	0.69314718	0.866025	0.69314718	0.866025	0
	7	7.1592919	0.707382	7.1592919	0.707382	0
	8	2.30258509	0.74162	2.30258509	0.74162	0
	9	2.74084002	0.72956	2.74084002	0.72956	0
	10	4.06902675	0.713125	4.06902675	0.713125	0
	11	0.69314718	0.866025	0.69314718	0.866025	0
	12	1.70474809	0.768706	1.70474809	0.768706	0
	13	3.15700042	0.721995	3.15700042	0.721995	0
	14	1.60943791	0.774597	1.60943791	0.774597	0
	15	4.35027794	0.711654	4.35027794	0.711654	0
	16	-0.6931472	1.224745	-0.6931472	1.224745	0

Maximum Likelihood Predicted Values for Frequencies

Sample	type	region	fate	Function Number	-----Observed-----		-----Predicted-----		Residual
					Frequency	Standard Error	Frequency	Standard Error	
1	1	1	1	F1	1529	33.41897	1529	33.41898	6.3665E-10
	1	1	2	F2	19	4.351592	19	4.351593	0
	1	1	3	F3	104	10.10411	104	10.10411	0
	1	2	1	F4	933	27.92004	933	27.92004	3.8904E-10
	1	2	2	F5	113	10.52372	113	10.52373	0
	1	2	3	F6	4	1.999295	4	1.999294	0
	1	3	1	F7	2572	37.49283	2572	37.49283	1.07775E-9
	1	3	2	F8	20	4.464244	20	4.464245	0
	1	3	3	F9	31	5.552528	31	5.552529	0
	2	1	1	F10	117	10.70451	117	10.70451	0
	2	1	2	F11	4	1.999295	4	1.999294	0
	2	1	3	F12	11	3.313407	11	3.313408	0
	2	2	1	F13	47	6.827191	47	6.827192	0
	2	2	2	F14	10	3.159489	10	3.159489	0
	2	3	1	F15	155	12.27861	155	12.27858	-2.3067E-9
	2	3	2	F16	1	0.999912	1	0.999912	0
	2	3	3	F17	2	1.413964	2	1.413964	0

**Reduced Model**

Sample	Sample Size
1	5672

Response Profiles

Response	type	region	fate
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	3	1
16	2	3	2
17	2	3	3

\_Response\_ Matrix

	1	2	3	4	5	6	7	8	9
1	1	1	0	1	0	1	0	0	0
2	1	1	0	0	1	0	1	0	0
3	1	1	0	-1	-1	-1	-1	0	0
4	1	0	1	1	0	0	0	1	0
5	1	0	1	0	1	0	0	0	1
6	1	0	1	-1	-1	0	0	-1	-1
7	1	-1	-1	1	0	-1	0	-1	0
8	1	-1	-1	0	1	0	-1	0	-1
9	1	-1	-1	-1	-1	1	1	1	1
10	-1	1	0	1	0	1	0	0	0
11	-1	1	0	0	1	0	1	0	0
12	-1	1	0	-1	-1	-1	-1	0	0
13	-1	0	1	1	0	0	0	1	0
14	-1	0	1	0	1	0	0	0	1
15	-1	-1	-1	1	0	-1	0	-1	0
16	-1	-1	-1	0	1	0	-1	0	-1
17	-1	-1	-1	-1	-1	1	1	1	1

Maximum Likelihood Analysis

Iteration	Sub Iteration	-2 Log Likelihood	Convergence Criterion
0	0	32139.972	1.0000
1	0	19481.248	0.3939
2	0	17709.493	0.0909
3	0	16865.254	0.0477
4	0	16844.48	0.001232
5	0	16844.447	1.9744E-6
6	0	16844.447	6.5E-12

Maximum Likelihood Analysis

Iteration	Parameter Estimates								
	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0
1	0.9317	0.0496	-0.5972	1.8324	-0.7582	-0.2569	-0.0985	-0.6082	0.6981
2	1.2471	0.1873	-0.1005	2.7003	-1.1659	-0.3565	-0.6109	0.1685	0.9777
3	1.3539	0.2969	-0.3181	2.6611	-1.1362	-0.3696	-0.8444	-0.0942	1.4985
4	1.3649	0.3298	-0.3811	2.6374	-1.1017	-0.3262	-0.8576	-0.1290	1.5281
5	1.3650	0.3302	-0.3822	2.6362	-1.1012	-0.3256	-0.8588	-0.1317	1.5303
6	1.3650	0.3302	-0.3822	2.6362	-1.1012	-0.3256	-0.8588	-0.1318	1.5304

Maximum likelihood computations converged.

Maximum Likelihood Analysis of Variance

Source	DF	Chi-Square	Pr > ChiSq
type	1	2427.99	<.0001
region	2	16.48	0.0003
fate	2	1761.35	<.0001
region*fate	4	296.29	<.0001
Likelihood Ratio	7	13.21	0.0671

Analysis of Maximum Likelihood Estimates

Effect	Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
type	1	1.3650	0.0277	2427.99	<.0001
region	2	0.3302	0.0823	16.10	<.0001
	3	-0.3822	0.1201	10.13	0.0015
fate	4	2.6362	0.0699	1420.76	<.0001
	5	-1.1012	0.0922	142.79	<.0001
region*fate	6	-0.3256	0.0832	15.34	<.0001
	7	-0.8588	0.1236	48.27	<.0001
	8	-0.1318	0.1208	1.19	0.2756
	9	1.5304	0.1378	123.30	<.0001

Maximum Likelihood Predicted Values for Response Functions

Sample	Function Number	-----Observed-----		-----Predicted-----		Residual
		Function	Standard Error	Function	Standard Error	
1	1	6.63922203	0.707569	6.63968757	0.184338	-0.0004655
	2	2.2512918	0.743392	2.36907841	0.277221	-0.1177866
	3	3.95124372	0.713874	3.97851632	0.205106	-0.0272726
	4	6.14525802	0.707864	6.12113676	0.185454	0.02412126
	5	4.03424064	0.713337	4.04576855	0.203723	-0.0115279
	6	0.69314718	0.866025	0.68305362	0.531986	0.01009356
	7	7.1592919	0.707382	7.14454158	0.183683	0.01475033
	8	2.30258509	0.74162	2.27810663	0.284591	0.02447846
	9	2.74084002	0.72956	2.73009175	0.055406	0.01074827
	10	4.06902675	0.713125	3.90959582	0.175814	0.15943093
	11	0.69314718	0.866025	-0.3610133	0.271628	1.05416053
	12	1.70474809	0.768706	1.24842457	0.197481	0.45632353
	13	3.15700042	0.721995	3.39104501	0.176985	-0.2340446
	14	1.60943791	0.774597	1.31567679	0.196044	0.29376112
	15	4.35027794	0.711654	4.41444982	0.175128	-0.0641719
	16	-0.6931472	1.224745	-0.4519851	0.279146	-0.2411621

Maximum Likelihood Predicted Values for Frequencies

Sample	type	region	fate	Function Number	-----Observed-----		-----Predicted-----		Residual
					Frequency	Standard Error	Frequency	Standard Error	
1	1	1	1	F1	1529	33.41897	1545.23042	32.51361	-16.230416
	1	1	2	F2	19	4.351592	21.5919195	4.493692	-2.5919195
	1	1	3	F3	104	10.10411	107.959598	9.971438	-3.9595977
	1	2	1	F4	933	27.92004	920.003529	26.91074	12.9964714
	1	2	2	F5	113	10.52372	115.469831	10.30551	-2.4698306
	1	2	3	F6	4	1.999295	4	1.999298	0
	1	3	1	F7	2572	37.49283	2560.05064	36.37653	11.9493649
	1	3	2	F8	20	4.464244	19.7143613	4.294582	0.28563867
	1	3	3	F9	31	5.552528	30.9797107	5.378199	0.02028934
	2	1	1	F10	117	10.70451	100.769584	5.643677	16.2304164
	2	1	2	F11	4	1.999295	1.40808045	0.302024	2.59191955
	2	1	3	F12	11	3.313407	7.04040226	0.74591	3.95959774
	2	2	1	F13	47	6.827191	59.9964714	3.574457	-12.996471
	2	2	2	F14	10	3.159489	7.53016937	0.77744	2.46983063
	2	3	1	F15	155	12.27861	166.949365	8.984007	-11.949365
	2	3	2	F16	1	0.999912	1.28563867	0.287904	-0.2856387
	2	3	3	F17	2	1.413964	2.02028934	0.36607	-0.0202893



**B. Stock Assessment for Atlantic Sea Scallops**  
*(Placopecten magellanicus)*

Consensus Assessment Report

SARC 39

**SAW Invertebrate Subcommittee<sup>1,2</sup>**

National Marine Fisheries Service  
Northeast Fisheries Science Center  
Woods Hole Laboratory  
Woods Hole, MA

May 25, 2004

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<sup>1</sup>Deborah Hart (National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole) led the stock assessment team.

<sup>2</sup> Contributing members of the Invertebrate Subcommittee as follows: Affiliated with the Northeast Fisheries Science Center: Russell Brown, Antoine Chute, Larry Jacobson, Victor Nordahl, Paul Rago and Fred Serchuk; affiliated with the New England Fisheries Management Council: Andrew Applegate; affiliated with the Virginia Institute of Marine Science, College of William and Mary: Bill DuPaul, Dave Rudders and John Walter; affiliated with Rutgers University: Joachim Groger, Grant Law and John Quinlan; affiliated with the School of Marine Science and Technology, University of Massachusetts: Brad Harris, Mike Marino, Jake Nogueira, Kevin Stokesbury and Tu Trong; affiliated with the Woods Hole Oceanographic Institution: Amit Huppert and Hanamunt Singh; affiliated with the Fisheries Survival Fund: Trevor Kenchington and Ron Smolowitz; affiliated with the Department of Fisheries and Oceans, Canada: Stephen Smith; no affiliation listed: Richard Taylor.



## 1.0 STOCK SUMMARY

This stock assessment is summarized a separate *Assessment Summary* document . This document includes the stock assessment and five appendices that contain important information.

## 2.0 TERMS OF REFERENCE

(A) Update status of the Georges Bank, Mid-Atlantic and Gulf of Maine sea scallop resources through 2003 using all applicable information, including fishery dependent information and fishery independent surveys (e.g. NEFSC trawl survey, SMAST video survey and others as appropriate). Provide estimates of fishing mortality and stock size. Characterize uncertainty in estimates.

(B) Evaluate stock status relative to current reference points.

(C) Provide short-term projections of stock biomass and catches consistent with target fishing mortality rates

(D) Update estimates of biological reference points (e.g. B-MSY, F-MSY) using revised biological and fisheries data, as appropriate.

(E) Evaluate information provided by various current survey approaches and suggest possible ways to integrate their results.

(F) Continue the development of stock assessment modeling approaches that integrate all appropriate sources of fishery dependent and fishery independent data.

## 3.0 INTRODUCTION AND LIFE HISTORY

The Atlantic sea scallop, *Placopecten magellanicus*, is a bivalve mollusk that occurs on the eastern North American continental shelf. Major aggregations in U.S. waters occur in the Mid-Atlantic from Virginia to Long Island, on Georges Bank, in the Great South Channel, and in the Gulf of Maine. U. S. landings during 2003 exceeded 25,000 MT (meats), a new record, and 2003 U.S. ex-vessel sea scallop revenues were over \$226 million making the sea scallop fishery the second most valuable in the northeastern United States. Unusually strong recruitment in the Mid-Atlantic Bight area in recent years has been one contributor to the landings; recruitment in the Mid-Atlantic area during the last six years (1998-2003) was over an order of magnitude higher than the six-year period at the start of the survey time series (1979-1984). Increased yield-per-recruit due to effort reduction measures has also contributed to the high landings. The mean meat weight of a landed scallop is now over 20g, compared to under 14g a decade ago.

Area closures have had a strong influence on sea scallop population dynamics. Roughly one-half of the productive scallop grounds on Georges Bank and Nantucket Shoals have been closed for most of the time since December 1994. Scallop abundance and biomass has built up in

these closed areas; currently over 80% of the sea scallop biomass in the U.S. portion of Georges Bank is in areas closed to fishing. Portions of Georges Bank closed areas were temporarily opened for limited scallop fishing during 1999-2001, and a regular rotation of openings is planned to begin during the summer of 2004. While there are no indefinite closures in the Mid-Atlantic, two areas were closed for three years starting in 1998 in order to allow small scallops in these areas to grow to more optimal sizes before they are harvested. A new rotational closure is planned to go into effect in the Mid-Atlantic starting in 2004.

### *Life History and Distribution*

Sea scallops are found in the Northwest Atlantic Ocean from North Carolina to Newfoundland along the continental shelf, typically on sand and gravel bottoms. In Georges Bank and the Mid-Atlantic, most are harvested at depths between 30 and 100 m, while the bulk of the landings from the Gulf of Maine are from near-shore relatively shallow waters (< 40 m). Sea scallops filter-feed on phytoplankton, microzooplankton, and detritus particles. Sexes are separate with external fertilization, and larvae are planktonic for 4-7 weeks before settling to the bottom. Scallops recruit to the NEFSC survey at about 2 years old (40-70 mm), and to the commercial fishery currently around 4 years old (90-105 mm), though historically most three year olds (70-90 mm) were vulnerable to the commercial fishery.

According to Amendment 10 of the Atlantic Sea Scallop Fishery Management Plan, all scallops in the US EEZ belong to a single stock. However, the U.S. sea scallop stock can be divided into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine regional components based on survey data, fishery patterns, and other information (NEFSC 2001). Biologically, the stock is likely composed of smaller regional meta-populations with some movement of larvae from Georges Bank into Southern New England and from Southern New England to the Mid-Atlantic. The main regional components are Georges Bank (including the Great South Channel and Nantucket Shoals) and the Mid-Atlantic Region. NEFSC shellfish survey strata are helpful in defining regional components of the sea scallop stock for assessment work (Fig. B3-1). However, relatively small, but imprecisely known, amounts of sea scallop biomass occur in areas outside regularly surveyed NEFSC shellfish strata. Landings from other regions have been relatively small (Table B3-1). Abundance and fishing mortality estimates for Georges Bank and the Mid-Atlantic are estimated separately in this assessment and then combined to characterize the condition of the stock as a whole.

### *Age and growth*

Sea scallops grow rapidly during the first few years of life with a 50-80% increase in shell height and quadrupling in meat weight between the ages of 3 and 5 years old (Fig. B3-2). The largest observed sea scallop had a shell height (SH) of about 23 cm (shell height is the longest distance between the umbo and outer margin of a scallop shell; length measurements of scallops throughout this assessment are shell heights), but animals larger than 17 cm are rare in commercial and survey catches.

Sea scallop growth is traditionally modeled using the von Bertalanffy growth equation. Growth parameters for an average scallop used in this stock assessment (see table below) were estimated using shell heights and age data from presumably annual rings patterns in shell samples (Serchuk et al. 1979). Merrill et al. (1966) reported problems with identification of annual rings on the external surface of the valve and proposed ring counts in the resilium (hinge ligament) to age scallops. Age determinations by ring counts conflicted with results from oxygen isotope studies by Krantz (1983) and Krantz et al. (1984). In contrast, Tan et al. (1988) found that isotope studies and ring counts gave consistent ages. All of the isotope studies were based on only a few samples, however.

Analysis of growth in closed areas indicated the possibility that growth in the Georges Bank closed areas might be greater than that predicted by the Serchuk et al. with the growth parameter  $K$  in closed areas perhaps higher by about 20% (NEFSC 2001). Increased growth might be due to the closure (e.g., if disturbances caused by fishing gear reduced the growth rate of the scallops), or to a Lee's effect with fast growers fished harder and therefore underrepresented in shell samples. Temporal changes in the growth rate, differences were due to ageing techniques and \ statistical errors are also possible. Additionally, because growth depends on depth (Posgay 1979, Schick et al. 1988, Smith et al. 2001), it is possible that the apparently faster growth reflects the depth distribution of certain dominant year classes. In the Mid-Atlantic, analysis of the growth in closed areas suggests that growth is somewhat slower than predicted by the Serchuk et al. equation (NEFSC 2001).

Von Bertalanffy growth parameters (Serchuk et al. 1979).

Stock Area	$K$ ( $y^{-1}$ )	$L_{\infty}$ (mm)
Georges Bank	0.3374	152.46
Mid-Atlantic	0.2997	151.84

### *Maturity and fecundity*

Sexual maturity commences at age 2 but scallops younger than 4 years may contribute little to total egg production (MacDonald and Thompson 1985; NEFSC 1993). Spawning generally occurs in late summer or early autumn. DuPaul et al. (1989) found evidence of spring, as well as autumn, spawning in the Mid-Atlantic Bight area. Almeida et al. (1994) and Dibacco et al. (1995) found evidence of limited winter-early spring spawning on Georges Bank.

### *Shell height/meat weight relationships*

Shell height-meat weight relationships are important because survey data are in numbers of scallops by shell height while landings data are in meat weights. Shell height/meat weight relationships are described by the equation  $\ln(W) = \alpha + \beta \ln(L)$ , where  $W$  is meat weight in grams and  $L$  is shell height in mm. Survey samples collected in 1997-1998 (NEFSC 1999) suggested that mean meat weights were smaller than the estimates in Serchuk and Rak (1983) that were

used in previous assessments. NEFSC (2001) combined the Serchuk and Rak (1983) with those of NEFSC (1999) to obtain new “blended” estimates (see table below).

Shell height-meat weight relationships vary seasonally and interannually and are affected by depth, temperature, location and other factors. According to Serchuk and Smolowitz (1989), meat weights are generally lowest during September-December after spawning, highest in the spring (March-May), and intermediate during the summer (June-August) when NEFSC sea scallop surveys are usually conducted and shell height-meat samples were collected. No adjustments were made to shell height-meat weight parameters in this assessment for any of these factors. Rather, the assessment assumes that shell height-meat weight parameters from survey samples taken over the entire stock area during the summer approximate average values for the stock as whole during the entire year during all years.

	$\alpha$	$\beta$
Georges Bank		
NEFSC (1999)	11.4403	3.0734
Serchuk & Rak (1983)	11.7656	3.1693
NEFSC (2001)	11.6038	3.1221
Mid-Atlantic Bight		
NEFSC (1999)	12.3405	3.2754
Serchuk & Rak (1983)	12.1628	3.2539
NEFSC (2001)	12.2484	3.2641

### Recruitment

McGarvey et al. (1993) reported a stock-recruit relationship for sea scallops on Georges Bank, but that relationship was driven mostly by a single year class (1978), and thus remains questionable. From 1982-1994, no relationship was observed between spawning stock biomass and recruits two or three years later, possibly because of the low contrast in spawning biomass. Since 1994, there has been a large increase in spawning-stock biomass in Georges Bank, primarily due to area closures. A log-log plot of egg production (including the Canadian portion of Georges Bank) vs. recruits (U.S. portion only, 40-72 mm)/egg production gives insight as to the possibility of a stock-recruitment relationship in sea scallops (Fig B3-3a). A regression line fit to the data with a slope of zero would indicate that recruitment is directly proportional to egg production, whereas a slope of  $-1$  would indicate no relationship between recruitment and egg production. Slopes between 0 and  $-1$  suggest partial compensation, while a slope less than  $-1$  implies over-compensation. Linear regression results for sea scallops on Georges Bank stock had a slope of  $-0.85$  ( $R^2 = 0.3$ ), indicating a slight tendency for increased recruitment at higher spawning biomasses. However, the slope was imprecisely estimated and could not be distinguished statistically from a slope of  $-1$ . Therefore, there is little evidence at this time for a relationship between egg production and recruitment on Georges Bank.

A similar linear regression analysis for the Mid-Atlantic gives a slope of  $-0.3$  (Fig B3-3b), suggesting a relationship between egg production and recruitment and that recent increases

in spawning stock biomass may have induced increases in recruitment. However, the high egg production has all been in the most recent years (especially the last four years available). Besides a stock-recruitment relationship, such a pattern could be caused by autocorrelated environmental factors, where good environmental conditions for recruitment over a period of years induce high spawning biomass.

Besides traditional stock-recruitment relationships, fishing activity might directly affect recruitment success. A number of unproven hypotheses exist. The large area closures on Georges Bank give an excellent opportunity to explore for such effects, as they can be considered a classic controlled (BACI) manipulation. There are several hypotheses about possible mechanisms that might differentially affect recruitment in closed and open areas. High densities of adult scallops might increase the mortality rate of newly settled juvenile spat due to space limitation, competition for food, or cannibalism. It has been suggested that scallop dredging may increase settlement success by clearing the bottom of benthic fauna. These factors would tend to reduce recruitment in closed areas only. In contrast, if small (pre-recruit) scallops suffer incidental fishing mortality, or if adult scallops or other benthic fauna enhance the survival of settling spat by providing good substrate, then observed recruitment might differentially increase in closed areas compared to open areas.

Larval scallops are probably capable of travel over long distances prior to settlement. Therefore, an increase in larval production within closed areas, due to increases in spawning biomass and/or fertilization success (due to the higher densities within closed areas), could result in improved recruitment within both open and closed areas, whereas the localized effects discussed above would differentially affect the open and closed areas.

To test whether closures have any effect on recruitment, numbers of scallops 40-72 mm in the Georges Bank closed areas (Closed Area I, Nantucket Lightship, and the northern part of Closed Area II) were compared to those in the open areas, both before and after the area closures at the end of 1994. Data from the transitional 1995 year and from the southern portion of Closed Area II were excluded; the latter because it was heavily fished in 1999 and 2000 but closed for the rest of the period. A two-way ANOVA was performed on the log-transformed data, with the independent variables being "period" (i.e., either 1982-1994, or 1996-2003) and "region" (i.e., either currently open areas, or the closed areas). A stock-recruitment relationship caused by an increase in larvae released in the closed areas would be indicated by a "period" effect. Any of the proposed differential effects on post-larval survival between open and closed areas would appear as an interaction term between period and region. Mean recruitment in the open and closed areas was similar, indicating no "region" effect ( $p = 0.95$ ). While recruitment post-closure was higher, the difference was not significant ( $p = 0.37$ ), so that it is inconclusive whether or not the closures have increased recruitment. Because there were similar increases in recruitment in the open and closed areas, there was no evidence of an interaction effect ( $p = 0.99$ ). Thus, the data do not give support to the hypotheses that recruitment would differentially increase or decrease in areas closed to fishing.

### *Natural mortality estimates from survey “clapper” data*

The rate of natural mortality is usually assumed to be  $M = 0.1 \text{ y}^{-1}$  for scallops with shell heights  $> 40 \text{ mm}$  (NEFSC 1999) based on Merrill and Posgay (1964) who estimated  $M$  based on ratios of clappers to live scallops in survey data. Clappers are shells from dead scallops that are still intact (i.e., both halves still connected by the hinge ligament). The basis of the estimate (Dickie 1955) is an assumed balance between the rate at which new clappers are produced ( $M/L$ , where  $L$  is the number of live scallops) and the rate at which clappers separate ( $S/C$ , where  $S$  is the rate at which shell ligaments degrade, and  $C$  is the number of clappers). At equilibrium, the rates of production and loss must be equal, so that  $M/L = S/C$  and:

$$M=C/(L/S).$$

Merrill and Posgay estimated  $S=1.58 \text{ y}^{-1}$  from the amount of fouling on the interior of clappers. The observed ratio  $C/L$  was about 0.066 and  $M$  was estimated to be about  $0.1 \text{ y}^{-1}$ . MacDonald and Thompson (1986) found a similar overall natural mortality rate.

Time-series of estimated trends in natural mortality, based on clapper ratios and Merrill and Posgay’s method, for the Mid-Atlantic and Georges Bank are shown in Figure B3-4. Clapper ratios for both areas tend to be lower than in Merrill and Posgay. It is unclear whether this is because mortality has been lower than in previous time, or whether there were differences in the clapper separation rate or catchability between the recent years and during Merrill and Posgay’s study, or because of the change from an unlined to a lined dredge. There have been recent increases in clapper ratios on Georges Bank. These may represent episodic mortality events, but also could be related to the increases in size/age in the Georges Bank stock. Larger size classes tend to have higher clapper ratios, but it is unclear whether this is due to increased separation time of larger clappers or to increased natural mortality as scallops age, or a combination of both (NEFSC 2001).

## **4.0 - FISHERIES**

The U.S. sea scallop fishery is conducted mainly by about 300 vessels with limited access permits. However, there has been an increase in recent years in landings from vessels with open access general category permits; these are primarily smaller vessels that fish near-shore beds. Principal ports are New Bedford MA, Cape May NJ, and Norfolk VA. Scallop dredges (mostly the offshore New Bedford style) are the principal gear type in all regions (Table B3-1). However, some scallop vessels use otter trawls in the Mid-Atlantic.

Sea scallop fisheries in U.S. EEZ are managed under the Atlantic Sea Scallop Fishery Management Plan (FMP) initially implemented on May 15, 1982. Until 1994, the primary management control was a minimum average meat weight requirement for landings. Fig. B4-1 gives a timeline of all management measures implemented since 1982.



FMP Amendment #4 (NEFMC 1993), implemented in 1994, changed the management strategy from meat count regulation to effort control for the entire U.S. EEZ. Effort controls included incrementally increasing restrictions on days-at-sea (DAS), minimum ring size, and crew limits (Fig. B4-1). In order to comply with the Sustainable Fisheries Act of 1996, Amendment #7 was implemented during 1998, with more stringent days-at-sea limitations and a mortality schedule intended to rebuild the stocks within ten years. Subsequent analyses considering effects of closed areas indicated that the stocks would rebuild with less severe effort reductions than called for in Amendment 7, and the Amendment 7 days-at-sea schedule was modified by Frameworks 12-15. Frameworks 11-13 permitted temporary access to the Georges Bank closed areas in 1999-2001, and Frameworks 14-16 provided for the controlled reopening of the Mid-Atlantic rotational closures.

A new set of regulations, Amendment #10, is expected to be implemented during 2004. This amendment formalizes an area management system, with provisions and criteria for new rotational closures, and separate days-at-sea allocations for reopened closed areas and general open areas. A new rotational closure for the area offshore of Delaware Bay will go into effect when Amendment 10 is implemented. Amendment 10 will allow each vessel with a full-time scallop permit 42 days-at-sea in open areas and four trips with trip limits of 18,000 lbs. in the Hudson Canyon South area that had been closed during 1998-2001. Pending approval of Framework 16, restricted access is anticipated in portions of two of the Georges Bank closed areas during 2004. Limited-access scallop vessels are restricted to a 7-man crew, which tends to limit the processing power of scallop vessels because regulations require most scallops to be shucked at sea. New gear regulations are scheduled to go into effect in September, 2004, which will require a 4" minimum ring size (an increase from 3.5") to improve selectivity, and a minimum 10" twine top (previously 8" in open areas and 10" in reopened closed areas) to reduce flounder bycatch.

#### *Landings and effort history*

Major changes in collection of commercial fishing data for northeast U.S. fisheries occurred in June 1994. Prior to 1994, commercial fishing data were collected based on interviews and the dealer "weigh-out" database. This was changed in 1994 to a new mandatory reporting system comprised of dealer reports (DR) and vessel trip reports (VTR). DR data contain total landings, and, since 1998, landings by market category. VTR data contain information about area fished, fishing effort, and retained catches of sea scallops. Ability to link DR and VTR reports in data processing is reduced by incomplete data reports and other problems, although there have been significant improvements since 1994 (Wigley et al. 1998). These problems make it difficult to precisely estimate catches and fishing effort, and to prorate catches and fishing effort among areas and gear types. The regulatory and reporting changes cause some uncertainty in comparing trends in fishing effort and catch rates before and after 1994.

Commercial landings data in this assessment were based on port interviews and the weigh-out database prior to April 1994, and on the DR and VTR databases after April 1994.

Proration of total commercial sea scallop landings into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine regions generally followed procedures in Wigley et al. (1998).

Sea scallop landings in the U.S. increased substantially after the mid-1940's (Fig. B4-2), with peaks occurring around 1960, 1978, 1990, and in the most recent period (2001-2003). Maximum U.S. landings were 25,107 MT meats in 2003.

U.S. Georges Bank landings peaked during the early 1960's, and around 1980 and 1990 (Table B3-1 and Figure B4-3). Landings in the U.S. portion of Georges Bank declined precipitously during 1993 and remained low through 1998, before rebounding in 1999, due in part to the reopening of Closed Area II. Landings in Georges Bank during 1999-2003 have been fairly steady, averaging almost 5000 MT annually. Until recently, the Mid-Atlantic area had been less productive than Georges Bank, with landings between 1962-1982 averaging less than 1800 MT/year. Since the mid-eighties, an upward trend in both recruitment and landings is evident in the area. Landings during each of the last four years (2000-03) set new records for the region. Landings were over 19,000 MT in 2003.

Gulf of Maine landings peaked at 1614 MT in 1980, and in general made up a small percentage of total landings. Gulf of Maine sea scallop landings during 2003 (254 MT) were less than 1% of the total.

LPUE data (Fig. B4-4) showed a general downward trend during 1979 to the mid-1990s, but increased considerably in the last five years. As already pointed out, trends in LPUE are complicated by changes in collection of fishing effort data in 1994.

#### *Discards and Fishery Selectivity*

The NEFSC sea sampling program collects information about lengths and weight of landed and discarded sea scallops from sampled tows (Fig B4-5). Ratios of discard to total catch (by weight) indicate a general increasing trend in scallop discard rates with peaks in 1994, 2000, and 2003. Except for 2003, the number of observed trips was limited, so that the ratio in a given year may be imprecise. The estimated cull size (defined as the greatest shell height for which 50% or more of scallops caught are discarded) has increased in recent years (Fig B4-5), which in large part explains the recent increase in discarding. Small scallops may be discarded because they provide relatively little meat weight for the time spent shucking.

### **5.0 – SURVEYS AND SELECTIVITY**

NEFSC sea scallop surveys were carried out in 1975 and then annually after 1977 to measure abundance, size composition, and recruitment of sea scallops in the Georges Bank (including the Canadian portion during some years), Mid-Atlantic and occasionally other regions. A 2.44 m (8') lined survey dredge has been used consistently since 1979. The northern edge of Georges Bank was not surveyed until 1982, so survey data for this area are incomplete for this area during 1979-1981. Thus, survey data used in this assessment are for 1982-2003 for Georges Bank and 1979-2003 in the Mid-Atlantic.

The *R/V Albatross IV* was used for all NEFSC scallop surveys except during 1990-1993, when the *R/V Oregon* was used instead. Surveys by the *R/V Albatross IV* during 1989 and 1999 were incomplete on Georges Bank. In 1989, the *R/V Oregon* and *R/V Chapman* were used to sample the South Channel and a section of the Southeast Part. Serchuk and Wigley (1989) found no significant differences in catch rates for the *R/V Albatross IV*, *R/V Oregon* and *R/V Chapman* based on a complete randomized block gear experiment (3 vessels x 13 stations=39 tows) in stratum 34. Therefore, as in previous assessments (e.g., NEFSC 2001), survey indices for the period 1990-93 based on data from the *R/V Oregon* were used without adjustment. The Northern Edge and Peak Area of Georges Bank was not surveyed by any vessel in 1989. Abundances in this area in 1989 were estimated by averaging 1988 and 1990 survey data. The 1989 Georges Bank survey data should be used cautiously because of these potential problems.

The *F/V Tradition* was used to complete the 1999 survey on Georges Bank. The *F/V Tradition* towed the standard NMFS scallop survey dredge as well as a New Bedford commercial scallop dredge side by side. For the purposes of the computing survey trends, only data from the (port) NMFS survey dredge was used. There were 21 comparison stations occupied by both the *F/V Tradition* and the *R/V Albatross IV* and NEFSC (2001) found no statistically significant differences in catch rates between the two vessels after corrections were made for differences in dredge width (NEFSC 2001).

Calculation of mean numbers of scallops per tow, mean meat weight per tow and variances in this assessment were standard calculations for stratified random surveys (Serchuk and Wigley 1989; Wigley and Serchuk 1996; Richards 1996; Lai and Hendrickson 1997, Smith 1997) with some extensions described below.

No valid tows were performed during some years for certain strata. In these cases, the survey data from the same stratum from the two adjacent years (when available) were "borrowed" and averaged to fill in the gap in the time series (NEFSC 2001).

#### *Stratum areas and post-stratification*

The stratum areas calculated using GIS (Arcview and Arcinfo) and used by NEFSC (2001) were used also for this assessment. Relatively high abundance of sea scallops in closed areas makes it desirable in some cases to post-stratify survey data by splitting NEFSC shellfish strata that cross open/closed area boundaries. In addition, after post-stratification, it is desirable to group strata into regions corresponding to open and closed areas. Finally, in cases where the closed or open portion of an NEFSC survey stratum was very small, it is necessary to combine the small portion with an adjacent stratum to form a new stratum (NEFSC 1999).

Rules for splitting strata along open/closed boundaries, assigning small portions to adjacent strata, and grouping strata into regions were the same as in NEFSC (1999, 2001; see Table B5-4 in NEFSC 2001) with a few refinements. Closed Area II region in NEFSC (1999) was broken into two new regions in NEFSC (2001) by assigning the closed portions of survey strata 6621, 6610 and 6590 in Closed Area II to the new "Closed Area II (South)" region. All

other portions of Closed Area II were assigned to the new “Closed Area II (North)” region (Fig B3-1). This allows the assessment to take into account the disparate population dynamics of the northern and southern areas of Closed Area II. The southern part of Closed Area II was heavily fished in 1999-2000. A very large (1998) year class was subsequently observed there during the 2000-2003 NMFS scallop surveys. By contrast, the northern portion of Closed Area II has not been fished since December, 1994.

A new scheme for post-stratifying scallop survey catches in the Nantucket Lightship Closed Area is introduced in this assessment. The new stratum, consists of the northeast corner because recruitment and biomass is considerably greater than elsewhere in the Nantucket Lightship area. Extra tows that have been added to the northeast corner of the Nantucket Lightship Area in surveys during recent years which can be used in connection with the new stratification scheme to potential increase the accuracy of abundance estimates.

*Survey and commercial dredge selectivity*

Beginning in 1979, NEFSC sea scallop surveys used a 2.44-m (8-ft) wide dredge equipped with 5.1-cm (2-in) rings and a 3.8-cm (1.5 in) plastic mesh liner. According to Serchuk and Smolowitz (1980), the liner reduces catchability of scallops greater than 75 mm in shell height (Fig B5-1). Based on data from Serchuk and Smolowitz’s (1980) experiment with lined and unlined, survey dredges NEFSC (1995; 1997) estimated that the selectivity curve for an unlined survey dredge was:

$$w'_h = \frac{1}{1 + \exp(3.7992 - 0.0768h)}$$

where  $h$  is shell height in mm. The estimated selectivity curve for a survey dredge with a liner was:

$$w_h = \frac{0.7148 e^{0.9180(0.7148)(x-106.3091)} + e^{0.9180(x-106.3091)}}{e^{0.9180(0.7148)(x-106.3091)} + e^{0.9180(x-106.3091)}} \quad (1)$$

where  $x = 160 - h$  (Fig. B5-2).

Original survey catch data for scallops  $> 40$  mm in each tow ( $c_{h,t}$  for the number of scallops shell height  $h$  in tow  $t$ ) were adjusted for use throughout this assessment by applying the size-specific selectivity of the lined dredge ( $w_h$ ). With this adjustment, survey shell height distributions approximate the shell height distribution of the population of scallops sampled by the tow ( $p_{h,t}$ ):

$$p_{h,t} = c_{h,t} / w_h$$

Population shell height estimates and distributions for each tow were partitioned into prerecruit (not vulnerable to commercial dredges) and fully recruited (completely vulnerable to

commercial dredges) classes by applying a commercial dredge selectivity function developed by consensus (NEFSC 1995):

$$s_h = \begin{cases} 0 & \text{if } h \leq h_{\min} \\ \frac{h - h_{\min}}{h_{\text{full}} - h_{\min}} & \text{if } h_{\min} < h < h_{\text{full}} \\ 1 & \text{if } h \geq h_{\text{full}} \end{cases}$$

where  $h_{\min} = 65$  mm and  $h_{\text{full}} = 88$  mm (Fig. B5-3).

#### *Re-estimation of gear selectivity parameters*

In recent years the method of Millar's (1992) SELECT method has become standard approach for estimation of gear selectivity patterns. SELECT uses a conditional likelihood approach that distinguishes between the relative fishing intensity of a type of gear ( $p$ ) and the parameters ( $a$  and  $b$  in the standard logistic curve) that define the size-specific relative probability of capture. SELECT was used in this assessment to verify previous analyses and estimates of selectivity parameters. Excel spreadsheet software for this analysis was from Tokai (1997), obtained from <http://www.stat.auckland.ac.nz/~millar/selectware/> and used for sea scallops after testing based on several data sets.

For a simple comparison of two gear types, the general approach of Millar (1992) is to fit a function to the ratio of catches in gear 1 to the total catch in gear 1 and 2. Using this approach the ratio can be modeled as a multinomial likelihood function. Millar's important contribution to selectivity was to recognize not only proper statistical properties of the conditioned ratio, but also to incorporate the difference in relative fishing intensity ( $p$ ).

$$\phi(L) = \frac{p r(L)}{(1-p) + p r(L)}$$

The function  $r(L)$  represents a general function for the selectivity curve. When a two-parameter logistic curve is employed the modeled proportion becomes

$$\phi(L) = \frac{p r(L)}{(1-p) + p r(L)} = \frac{p \frac{e^{a+bL}}{1 + e^{a+bL}}}{(1-p) + p \frac{e^{a+bL}}{1 + e^{a+bL}}} = \frac{p e^{a+bL}}{(1-p) + e^{a+bL}}$$

The proportion of the catch in each length category can now be modeled as a function of three parameters ( $p, a, b$ ) and asymptotic variances can be obtained from the Fisher information matrix. Model fit can be evaluated using residual plots and the total deviance statistic. Likelihood ratio tests can be used to compare alternative parameterizations.

Results for the Serchuk and Smolowitz's (1980) experiment suggest that the model in which the split fraction  $p$  is estimated fits significantly better than the model with  $p$  fixed at 0.5 (Table B5-1). Examination of the deviance residuals and other comparisons confirms the appropriateness of the SELECT model (Fig B5-1). Results show that unlined survey dredge was more efficient than the lined dredge. A factor that converts catches by the unlined dredge into predicted catches for the lined dredge is  $p/(1-p) = 0.582/(1-0.582) = 1.392$ , which is nearly identical to the rescaling parameter used in SARC 23 where survey catches of scallops greater than 60 mm in lined dredges were divided by 0.7147 (or multiplied by  $1/0.7147 = 1.399$ ) to obtain equivalent catches for unlined dredges. Thus the application of SELECT model supports the adjustment factor that has been applied traditionally to standardize the research vessel dredge survey.

Model fit to data from the F/V Tradition was poor when the fishing intensity parameter  $p$  was not estimated (Table B5-1). A likelihood ratio test suggested that improvement in fit was statistically significant when  $p$  estimated. For the comparison of raw catches, the estimate  $p=0.751$  is close to the value expected based on dredge relative widths of the 8' survey and 15' commercial dredges  $0.652=15/(8+15)$ . If the commercial dredge and research dredge were equally efficient, then the estimate for  $p$  should tend to equal the expected value 0.652. The ratio of these proportions can be used to estimate efficiency of the research dredge relative to the commercial dredge. For this experiment, the ratio was  $0.652/0.751 = 0.868$  indicating that the lined dredge is less efficient than the unlined F/V dredge.

As noted in SARC 32, the correction factor for size-based selectivity of lined survey dredges results in good agreement with expectations based on commercial and survey length composition data from side-by-side tows collected during the F/V Tradition experiment. To further evaluate this point, the raw data from the research dredge were adjusted by Eq. 1 and the SELECT model was re-run. The results (Table B5-1) indicate  $p=0.683$ , which is nearly equivalent to the split predicted on the basis of dredge widths alone (i.e., 0.652). Thus, comparison of research and commercial dredge catches suggest nearly equal efficiency when the research dredge catches are adjusted (Eq.1) for dredge width and selectivity due to the liner in survey gear.

Four inch rings will be required as part of the Amendment 10 regulations starting in September, 2004. A number of side-by-side experiments comparing catches by dredges with 4" rings to catches by tows with 3.5" rings were conducted by the Virginia Institute of Marine Science. Estimated survey dredge catches were approximated by back-calculation from the 3.5" ring data using the above survey dredge selectivity curve. Because of difficulty fitting this data using the SELECT model, it was fit using a weighted (inversely by catch in the 4" ring dredge) least squares model. The estimated logistic selectivity parameters were  $a = 9.69$  and  $b = 0.102$  (Fig B5-3). The selectivity curve for 4" rings is shifted to the right and tends to increase more gradually with full selectivity not reached until over 120 mm. This is due to an increase in the efficiency of 4" rings compared to 3.5" rings at large sizes. Bourne (1964) found a similar phenomenon when comparing 4" rings to 3" rings.

Scallop density estimates from recent video surveys (Stokesbury 2002; Stokesbury et al. 2004) were used in this assessment to estimate region-specific survey dredge efficiencies by comparing them to the 2003 NFMS survey (NEFSC 2001; Appendix 3). Results from a joint SMAST/NMFS calibration experiment (Appendix 1) showed that video length-frequencies measurements had substantially more measurement error than those from dredge surveys. However, results from the preliminary CASA model for sea scallops (appendices 4-5) indicate that video size-frequencies can provide useful information provided that measurement error is accommodated in the model.

#### *Use of rock chains in NEFSC scallop surveys*

Tows on hard-bottom areas (especially in the Great South Channel) tend to catch large rocks, which may cause safety problems and reduce the catchability of scallops. NEFSC proposes to use rock excluders (“rock chains”) on the survey dredge in strata 49-52 in the Great South Channel to reduce these potential problems (Appendix 2).

#### *Estimating survey tow distances and area swept*

To estimate the distance of survey tows, an inclinometer sensor has been attached the gooseneck of survey dredges during recent years. The inclinometer records the angle of the gooseneck during the tow. Because of difficulty in interpreting the inclinometer signal in previous assessments (NEFSC 2001), a video camera was attached to a survey dredge. Results from five experimental tows with the video camera during the 2003 scallop survey were used to determine how inclinometer data can be used in surveys to estimate tow distance.

Typical inclinometer traces for tows during 2003 are shown in Figure B5-4. The inclinometer trace at the start of each tow followed essentially the same pattern: a steep decline of the frame to a flat position when it initially settles to the bottom, a sharp upward jerk as the wire tightens, a momentary lowering of the frame as the wire slackens, another sharp jerk upward and then a steady settling of the frame to between 0 and 25 degrees from the bottom as the tow got under way and the gear and ship began to move forward together as one.

Based on the inclinometer data, survey tows were judged to have begun when the frame began to flatten out (become more in parallel with the bottom) beginning at the second upward surge. The vast majority of tows followed this pattern at the outset, but some tows surged only once, or hit the bottom at the right angle and speed and began the tow without significant back-and-forth pulling at the beginning. The start of fishing time for a one-surge tow was when the frame began to settle down from the sharp upward swing. For a no-surge tow, fishing time began after the first steep change in angle representing the gear moving off the ship through the water column and coming in contact with the bottom. The disjointed movements of the ship and the gear at the beginning of the tow were not considered fishing time.

The end of the most tows was indicated by a sudden upward jerk of the frame followed by a few minutes of the gear moving through the water column at a 45 to 55 degree angle, then increasing rapidly as it lifted onto the ship. Some tows showed just a smooth and steady increase

in the angle of the frame as it traveled to the surface. The sudden change in the angle of the frame as the winch started pulling it toward the surface was almost always quite evident, and marked the end of fishing time.

The duration of each tow during the 2003 survey was calculated by plotting the inclinometer angle on the y-axis and time on the x-axis, so it was possible to see exactly when in time each inclinometer change took place. The start and end of the tow were noted using the criteria described above, it was determined at what time these occurred, then the start time was subtracted from the end time to calculate the total time the gear was fishing. To calculate the distance towed, the time towed (in minutes) was multiplied by the average speed-over-ground (SOG) for the tow (in knots), then divided by 60 to get the distance in nautical miles.

Besides using the inclinometer, survey tow distance can be estimated by two other methods. First, the tow time (“towdur”) can be estimated by recording when the lead fisherman believes the tow started and stopped. Area swept can then be calculated by multiplying this towdur by SOG as above. Area swept can also be estimated multiplying towdur by the nominal speed of 3.8 knots.

Mean tow distance estimated using inclinometer data was 1.003 nm (see below) and slightly larger estimates by the other two methods. Linear regression indicated a slight, but statistically significant ( $p < 0.001$ ), decrease in towpath length with depth. The estimated regression line was:

$$\text{Distance} = 1.0407 - 0.00058 \text{ Depth}$$

where the distance is in nautical miles and depth is in meters. For example, the towpath at 40m depth would be about 1.018 nm compared to 0.983 nm at 100m depth.

	<b>N Tows</b>	<b>Mean</b>	<b>Median</b>	<b>Std.Dev.</b>	<b>SEM</b>
Inclinometer tow distance	434	1.0029	1.0007	0.0530	0.0025
Tow dist from towdur and SOG	434	0.9970	0.9936	0.0516	0.0025
Towdur * 3.8 knots	432	0.9734	0.9720	0.0350	0.0017

Appendix 3 summarizes information about scallop dredge efficiency, based on depletion experiments and comparison of video and dredge surveys, with the goal of estimating absolute scallop abundance.

*Survey abundance and biomass trends, 1979-2003*

Biomass and abundance estimates from 1979-2003 for the Mid-Atlantic Bight and 1982-2003 for Georges Bank are presented in Table B5-2 and Figures B5-5 and B5-6. Only random tows were used except in the post-stratified portion of the Nantucket Lightship Area (the “Asia rip”, see above). Variances for strata with zero means were not considered. Confidence intervals were obtained by bootstrapping (Smith 1997, see Appendix 3).



In the Mid-Atlantic Bight, abundance and biomass appear to be increasing rapidly and are currently at record levels. In Georges Bank, biomass and abundance increased in 1995-2000 after implementation of closures and effort reduction measures. Biomass has been consistently high and at near-record levels since 2000, while abundance has declined from its record level in 2000.

The biomass and abundance indices for closed areas in Georges Bank and the Mid-Atlantic Bight showed notable increases after closure. The increase in biomass was more rapid after the Mid-Atlantic closures that were specifically closed to protect high densities of small scallops. These areas were also chosen because they had histories of strong recruitment. Several additional strong year classes settled in the Hudson Canyon South area after the area was closed that contributed to the increases in abundance and biomass. In contrast, the areas that were closed in Georges Bank were not related to scallop recruitment.

Biomass and abundance in the open areas of both regions have increased since 1999. The increases in the open areas have been greater in the Mid-Atlantic, where the biomass is continuing to increase, largely due to good recruitment the last several years. In contrast, recruitment on Georges Bank has been below average in 2002-2003. Biomass in open area declined during 2002-2003. Increases in the open areas in both stock areas were due to a combination of effort reduction and good recruitment. Effort reduction measures have had some effect despite the fact that area closures tend to displace effort into the open areas.

Survey data maps showing the spatial distribution of sea scallop biomass during 1994 (just before the Georges Bank closed areas were implemented) and the during the most recent 2003 survey (Fig. B5-7). Biomass has increased considerably since 1994 in Georges Bank closed areas (shown in gray) and in the Great South Channel. Mid-Atlantic biomass has also increased substantially since 1994, especially in the Hudson Canyon South area (in gray) that was closed for three years between 1998 and 2001 and in the Delmarva area to the south of the closed area.

## **6.0 - BIOMASS, POPULATION SIZE, AND FISHING MORTALITY**

Unless otherwise noted, the natural mortality rate assumed for sea scallop in this assessment is  $M=0.1 \text{ y}^{-1}$  (Merrill and Posgay 1964, and see above). Besides fishing mortality resulting in landings, fishing activity may induce discard mortality and incidental (non-catch or indirect) fishing mortality.

### *Discard mortality*

Discard mortality may have been important for sea scallops in some years (see below) and may be important in some calculations. Small sea scallops (currently less than about 90 mm shell height) may be discarded rather than shucked. Discarded sea scallop may suffer mortality on deck due to crushing, high temperatures, or desiccation. There may also be mortality after

they are thrown back into the water from physiological stress and shock, or from increased predation due to shock and inability to swim or due to shell damage.

Murawski and Serchuk (1989) estimated that about 90% of tagged scallops were still living several days after being tagged and placed back in the water. Total discard mortality (including mortality on deck) is uncertain but has been estimated as 20% (W. DuPaul, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, VA, pers. comm.). Though there is considerable uncertainty due to the limited data, an estimate of about 10% (on deck) + 10% (after release) = 20% total mortality of discarded sea scallops seems reasonable.

### *Incidental fishing mortality*

Scallop dredges likely kill and injure some scallops that are contacted but not caught, primarily due to damage (e.g., crushing) caused to the shells by the dredge. Caddy (1973) estimated that 15-20% of the scallops remaining in the track of a dredge were killed. Murawski and Serchuk (1989) estimated that less than 5% of the scallops remaining in the track of a dredge suffered non-landed mortality. Caddy's study was done in a relatively hard bottom area in Canada, while the Murawski and Serchuk work was done in sandy bottom off the coast of New Jersey. It is possible that the difference in indirect mortality estimated in these two studies was due to different bottom types (Murawski and Serchuk 1989).

In order to use the above estimates to relate landed and non-landed fishing mortality, it is necessary to know the efficiency  $e$  of the dredge (the probability that a fully recruited scallop in the path of a dredge are captured). Denote by  $c$  the fraction of scallops that suffer mortality among those which were in the path of the dredge but not caught. The best available information indicates that  $c = 0.15-0.2$  (Caddy 1973), and  $c < 0.05$  (Murawski and Serchuk 1989). The ratio  $R$  of scallops in the path of the dredge that were caught, to those killed but not caught is:

$$R = e/[c(1-e)]$$

If scallops suffer direct (i.e., landed) fishing mortality at rate  $F_L$ , then the rate of indirect (non-landed) fishing mortality will be (Hart 2003):

$$F_I = F_L / R = F_L c (1-e)/e.$$

If, for example, the dredge efficiency  $e$  is 50%, then  $F_I = F_L c$ . Assuming  $c = 0.15$  to  $0.2$  (Caddy 1973) gives  $F_I = 0.15 F_L$  to  $0.2 F_L$ . With  $c < 0.05$  (Murawski and Serchuk 1989),  $F_I < 0.05 F_L$ .

## *Non-model based fishing mortality and biomass estimates*

Non-model based fishing mortality and biomass estimators based on catch and survey data include catch-biomass, survey-based, equilibrium length-based, and rescaled catch-biomass based approaches. Most were used in the previous assessment (NEFSC 2001).

### Catch-biomass method

If survey dredge efficiency  $e$  is known, then biomass can be estimated directly from mean meat weights per survey tow:

$$B_y^* = \frac{b_y A}{a e}$$

where  $b_y$  is mean meat weight per tow from the survey in year  $y$ ,  $B_y^*$  is stock biomass,  $a$  is the area ( $\text{nm}^2$ ) swept by a standard tow, and  $A$  is the size ( $\text{nm}^2$ ) of the stock area or region. In this assessment,  $a$  was assumed to be the area swept by an 8 ft NEFSC survey dredge during a 1 nm tow (see above). The NEFSC scallop survey takes place in the summer which, about mid-year. Therefore  $B_y^*$  is approximately equal to mean biomass during the calendar year.

Annual catch-biomass fishing mortality rates  ${}^cF_y$  were estimated:

$${}^cF_y = \frac{C_y}{B_y^*}$$

where  $C_y$  is the meat weight of scallops killed by fishing during the calendar year (Ricker 1975). Because  $C_y$  represents only reported landings, this estimate will be biased low if there were non-reported landings, or if there was non-yield fishing mortality. Additionally, these estimates are biomass-weighted, which tend to be biased low compared to numbers-weighted estimates when there is spatial heterogeneity in fishing mortality (Hart 2001). Because of these factors, and uncertainty in the estimates of dredge efficiency, NEFSC (1999 and 2001) used the catch-biomass estimates as an index (the catch-biomass index, or CBI) of relative trends in fishing mortality. The CBI was estimated here assuming 40% dredge efficiency on Georges Bank and 60% in the Mid-Atlantic.

### Survey-based (two-bin) method

The survey-based approach divides the survey data for each year into two shell height size bins. The first bin approximates the size range of new recruits to the fishery. The second bin includes sea scallops of all larger sizes.

The first bin for Georges Bank consisted of scallops of 80-100 mm shell height and the second bin consisted of all scallops larger than 100 mm. An 80 mm sea scallop was almost fully

recruited to the fishery (except during the most recent period) and will grow to 100 mm in one year, according to von Bertalanffy growth curves for scallops in the Georges Bank stock area. For the Mid-Atlantic region, where growth has been estimated to be slightly slower, the first bin consisted of 80-98.5 mm scallops and the second bin consisted of scallops larger than 98.5 mm. Using these data, survey-based fishing mortalities were calculated:

$${}^s F_t = -\ln\left(\frac{P_{t+1}}{R_t + P_t}\right) - M,$$

where  $R_t$  was the mean population number of scallops per standard survey tow in the first bin (new recruits) during survey year  $t$  and  $P_t$  was the mean population number of scallops per standard survey tow in the second bin. Survey years are the annual period between NEFSC sea scallop surveys (summer to summer).

#### Rescaled catch-biomass method

Rescaled catch-biomass estimates are the most accurate for fishing mortality available in this assessment and are intended for use in determining stock status. Following NEFSC (2001), rescaled survey-based estimates were computed:

$${}^R F_y = {}^c F_y \left( \frac{{}^s \bar{F}_t}{{}^c \bar{F}_y} \right)$$

where average catch-biomass  ${}^c \bar{F}_y$  and survey-based  ${}^s \bar{F}_t$  fishing mortality rates were for a time period containing year  $y$ . This estimator is based on the idea that the catch-biomass estimate tracks the trend in fishing mortality accurately, while the appropriate overall scale is given by mean survey fishing mortality rates. It gives a smoother trend than the survey fishing mortalities, but does not require assumptions about dredge efficiency and non-yield mortality, and is scaled to be numbers-based. For this assessment, the data for 1979-2003 in the Mid-Atlantic and 1982-2003 in Georges Bank was used to estimate the scaling factor.

Following NEFSC (2001), coefficients of variation (CVs) for rescaled fishing mortality estimates were computed using CVs for the rescaling factor (the mean of the survey-based estimates) and CVs for the catch-biomass estimates. The mean survey-based fishing mortality is:

$$F_{MEAN} = \frac{-1}{n} \sum_{t=0}^{n-1} \ln \frac{P_{t+1}}{R_t + P_t} = \frac{1}{n} [\ln(P_0 + R_0) - \ln P_n + \sum_{t=1}^{n-1} (\ln(R_t + P_t) - \ln(P_t))]$$

The terms inside the right-hand sum covary, with the correlation between  $R_t + P_t$  and  $P_t$  being about  $\rho=0.6$ . Because  $\text{Var}(\ln(X)) = \text{Var}(X)/E(X)^2$ , the variance of  $F_{MEAN}$  is:

$$\frac{1}{n^2} \left[ \frac{\sigma_{P_0+R_0}^2}{(P_0 + R_0)^2} + \frac{\sigma_{P_n}^2}{P_n^2} + \sum_{t=1}^{n-1} \left( \frac{\sigma_{R_t+P_t}^2}{(R_t + P_t)^2} + \frac{\sigma_{P_t}^2}{P_t^2} - \text{Cov}(R_t + P_t, P_t) \right) \right]$$

where the covariance term was calculated assuming a correlation coefficient of 0.6. Standard errors for the catch-biomass index were computed assuming an estimated CV of 0.1 for the landings together with the CVs from the surveys.

### *Beverton-Holt length-based estimates*

The Beverton-Holt (1956) equilibrium length-based fishing mortality estimator may provide independent information about fishing mortality rates and is given by:

$${}^{BH}F_t = K \frac{L_\infty - l_{m,t}}{l_{m,t} - l_c} - M$$

where  $l_{m,t}$  is the mean shell height beyond  $l_c$ , taken here to be 90 mm. Because this estimator was derived under an equilibrium assumption, it may not be accurate when, as is typical, the fishery is not in equilibrium. However, it still can give useful information if it is understood how it is affected by non-equilibrium conditions.

Large year classes will cause the Beverton-Holt estimator to be biased high when they first pass the length  $l_c$  and will bias it low as the year class ages. Also, this estimator tends to be a lagging indicator of fishing mortality, because the mean size will be a function of not only the present fishing mortality, but that of past years. To partially compensate for these properties, the Beverton-Holt indices were computed as three-year forward moving averages of the original estimators.

### *Whole-stock estimates*

Because of differences in e.g., growth rates, between Georges Bank and the Mid-Atlantic, fishing mortalities were calculated separately in the two areas. The overall status determination however requires a whole-stock estimates of fishing mortality. For this purpose, the Georges Bank and Mid-Atlantic estimates were combined using a number-weighted average, using swept area calculations. Because evidence indicates that dredge efficiency on Georges Bank is lower than in the Mid-Atlantic, the swept-area abundances in the Mid-Atlantic were multiplied by 0.67, roughly corresponding to the estimated ratio of dredge efficiencies between the two areas. Results were only slightly sensitive to the exact value of this dredge efficiency-weighting factor.

### *Results*

All methods give qualitatively similar results (Table B6-1 and Fig B6-1). In Georges Bank, fishing mortality peaked in 1991 and declined drastically after 1993, at first due to a shift

in effort as fishers found better fishing opportunities in the Mid-Atlantic, and then because of the build-up of scallops in the groundfish closed areas. In the Mid-Atlantic, fishing mortality was generally high from 1983-1996, and then declined from 1996-1999, likely due primarily to effort reduction measures, the rotational closures, and to the reopening of portions of the groundfish closed areas in 1999, which drew effort out of the Mid-Atlantic. Fishing mortality has averaged about  $0.5 \text{ y}^{-1}$  since 1999. Whole-stock fishing mortality rates peaked in 1991 and declined substantially between 1993 and 1998. Fishing mortalities since 1999 have been between 0.22 and  $0.3 \text{ y}^{-1}$ , with the 2003 estimate at the upper end of the range.

#### *Model-based fishing mortality estimates*

A length-based, forward projecting assessment model (CASA) was developed for sea scallops in this assessment. Though not used as the primary assessment tool for this assessment, it is presented for review in Appendices 4 and 5 so that it can be employed in future assessments.

## **7.0 - BIOLOGICAL REFERENCE POINTS**

Because of the lack of well-defined stock-recruitment relationships for sea scallops, the per-recruit reference points  $F_{\text{MAX}}$  and  $B_{\text{MAX}}$  are used by managers as proxies for  $F_{\text{MSY}}$  and  $B_{\text{MSY}}$ .  $F_{\text{MAX}}$  is defined as the fishing mortality rate (in units  $\text{y}^{-1}$ ) for fully recruited scallops that generates maximum yield-per-recruit.  $B_{\text{MAX}}$  for sea scallops is defined in survey units (meat weight in  $\text{g tow}^{-1}$ ) and computed as the product of  $\text{BPR}_{\text{MAX}}$  (biomass per recruit at  $F = F_{\text{MAX}}$ , from yield-per-recruit analysis) and median numbers of recruits per tow based on NEFSC sea scallop survey data. Biological reference points, fishing mortality rates and biomass estimates used in status determination here are for the entire U.S. scallop stock, whereas region-specific estimates for Georges Bank and the Mid-Atlantic Bight were used previously (NEFSC 2001).

The per-recruit reference points  $F_{\text{MAX}}$  and  $B_{\text{MAX}}$  are reasonable proxies for  $F_{\text{MSY}}$  and  $B_{\text{MSY}}$  provided that recruitment is independent of stock size or has reached its asymptotic value at  $B_{\text{MAX}}$ , and if fishing mortality as well as other parameters do not vary over space. However, there are special considerations for sessile organisms such as sea scallops where fishing mortality is not uniform and particularly when closed areas are present. In such a case, mean yield-per-recruit, averaged over all recruits, may be different than yield-per-recruit obtained by a conventional per-recruit calculation performed on a recruit that suffers the mean fishing mortality risk (Hart 2001). This condition is exaggerated, as in the case of the scallop fishery, with use of rotational or long-term closures. Recent research indicates that the fishing mortality that achieves maximum or optimal yield may be less than that indicated by a conventional yield-per-recruit analysis (Hart 2001, 2003).

#### *Length-based yield-per-recruit model*

A new model for length-based yield-per-recruit analysis (LBYPR, implemented in Fortran-90) was developed for the previous sea scallop assessment (NEFSC 2001; Hart 2003).

LBYPR gives similar results to age-based yield-per-recruit models for sea scallops (e.g., Applegate et al. 1998; NEFSC 1999) but is more flexible because it does not require any assumptions about age (e.g., the results do not depend on the value for  $t_0$  in the von Bertalanffy growth equation) and it allows selectivity patterns to be modeled naturally and directly as functions of length. In contrast, conventional age-based approaches require assumptions about fishery selectivity at age, and mean weights at age (NEFSC 1999). In the scallop fishery, selectivity actually depends on shell height rather than age. Sea scallops grow quickly and there is likely a wide range of sizes at each age. These factors complicate estimation of mean selectivity and meat weight at age. LBYPR avoids these uncertainties by carrying out calculations based on length, rather than age.

In LBYPR, recruits start at a user specified starting shell height  $h_0$ . Starting shell height is converted to an assumed starting age based on an inverted von Bertalanffy growth model; the results are independent of this assumed starting age. Age is increased in each time step as the model runs, and shell heights are calculated based on age and the von Bertalanffy growth model. Shell heights are converted to meat weights with shell height-meat weight relationships. Parameters important in the LBYPR model (including the assumed rate of natural mortality, von Bertalanffy growth parameters, shell height-meat weight relationships, and fishery selectivity) were set at current best estimates (see above), unless otherwise specified. The main changes in these parameters since NEFSC (2001) are an increase in the cull size from 75 to 90 mm, and new estimations of commercial dredge selectivity for dredges with 3.5" and with 4" rings.

Size-dependent fishing mortality rates for sea scallops in LBYPR were  $F(h) = F_0L(h)$ , where  $F_0$  is the fully recruited fishing mortality rate,  $h$  is shell height, and  $L(h)$  is the selectivity of a commercial scallop dredge.  $L(h)$  can be chosen on the basis of estimated gear selectivity (see above), or from fishery selectivity (including targeting). Scallops caught in commercial dredges are discarded if their shell height is less than a specified cull size  $h_d$  (if  $h_{min} < h < h_d$ ). The mortality rate for discarded scallops is  $d$ . All individuals caught in the model with shell heights greater than  $h_d$  are assumed to be landed, and are included in total yield.  $F_c(h)$  is the size-specific rate at which scallops are landed (i.e. caught and retained). Natural mortality  $M(h)$  may depend on shell height.

Let  $F_0$  be the fishing mortality on a full recruit due to landings. Incidental fishing mortality is modeled as  $iF_0$  (i.e., proportional to fully recruited fishing mortality  $F_0$ , and independent of size).  $Z(h)$  is the total mortality rate, computed as the sum of natural mortality  $M(h)$ , discard mortality  $dF_c(h)$  ( $h < h_d$ ), and incidental mortality due to fishing  $iF_0$ , and landings  $F_c(h)$  with ( $h > h_d$ ).

The fraction of the initial number of recruits remaining  $t$  years after the beginning of the simulation is:

$$R(t) = \exp\left(-\int_{a_0}^t Z(\tau)d\tau\right).$$

Total expected yield ( $Y$ ) and biomass ( $B$ ) over the lifetime of each recruit are:

$$Y = \int_{a_0}^{a_f} R(t)F_c(h(t))w(h(t))dt$$

$$B = \int_{a_0}^{a_f} R(t)w(h(t))dt$$

where  $a_f$  is the end time of the simulation, usually  $30 + a_0$ . For convenience,  $a_0$  was chosen so that the scallops start the simulation at 40 mm shell height. The integrals were computed numerically with a time step of 0.01 years.

Managers currently use an estimate for  $F_{MAX}$  of 0.24. Baseline runs indicate that revised estimates of  $F_{MAX}$  are close to 0.24 for 4" rings but are slightly below this figure with 3.5" rings (Table B7-1).

Sensitivity runs indicate that LBYPR results were relative to robust to assumptions about scallop biology and the fishery (Table B7-1). Runs were conducted using the new 3.5" ring logistic selectivity curve, the previous SARC-23 piecewise linear selectivity curve, and the estimated 4" ring selectivity curve. There was little difference in the results between the two 3.5" selectivity patterns, but the 4" rings increased YPR by 4-8% and  $F_{MAX}$  by 4-15% over the 3.5" ring runs. Note that the increases with 4" rings are greater when incidental mortality was assumed low. Parameters for faster growth in the Georges Bank stock (as suggested in NEFSC 2001) modestly increase  $F_{MAX}$ ,  $Y_{MAX}$ , and  $B_{MAX}$ , while slower growth in the Mid-Atlantic analogously slightly lowers these quantities. Incidental fishing mortality lowers  $F_{MAX}$ , due to the assumption that incidental fishing mortality affects pre-recruit and partially recruited scallops. Note, however, that targeting of beds composed mostly of larger scallops (which is occurring in some areas) could alleviate the effects of incidental mortality to some extent.

Natural mortality may be age- or size-dependent (MacDonald and Thompson 1986; NEFSC 2001). To explore this possibility, simulations were performed with  $M=0.05 \text{ y}^{-1}$  for shell heights less than 120 mm, and  $0.1 \text{ y}^{-1}$  for larger sizes. In another run,  $M$  was taken to be  $0.1 \text{ y}^{-1}$  for shell heights less than 120 mm, and  $0.2 \text{ y}^{-1}$  for larger shell heights. The latter gave  $F_{MAX}>0.3 \text{ y}^{-1}$  and in some cases greater than  $0.4 \text{ y}^{-1}$ . In addition to the runs described above, LBYPR analyses were carried out with no incidental fishing mortality and with 0 or 100% discard mortality, or at a cull size characteristic of previous years ( $h_d = 75\text{mm}$ ). Reference points were also estimated under rotational management (Hart 2003), where areas were closed for 3 years, and then subject to ramped mortality (1.6, 2.0, and 2.4 of the time-averaged  $F$  over the 6 year period), corresponding to the recommended policy in Amendment 10 (NEFMC 2003).

## 8.0 - STATUS DETERMINATION



According to the Amendment 10 overfishing definition (NEFMC 2003), sea scallops are overfished when the survey biomass index for the whole stock falls below  $1/2 B_{MAX}$ . Overfishing occurs if fishing mortality exceeds the  $F_{MSY}$  proxy  $F_{MAX}$ .

As described above, managers use  $F_{MAX}$  from yield-per-recruit analysis and  $B_{MAX}$  as proxies for  $F_{MSY}$  and  $B_{MSY}$ .  $F_{MAX}$  is the fishing mortality rate (in units  $y^{-1}$ ) for fully recruited scallops that generates maximum yield-per-recruit (see recent  $F$  and  $F_{MAX}$  estimates above). The target biomass level is  $B_{MAX}$ .  $B_{MAX}$  and data for status determinations are cast in units of survey data, i.e. meat weight per tow. Specifically, the biomass reference point  $B_{MAX}$  is defined as:

$$B_{MAX} = \text{Median recruitment} \times BPR_{MAX}$$

where  $BPR_{MAX}$  is biomass-per-recruit at  $F_{MAX}$ , based on a yield-per-recruit analysis.

The current management reference point  $F_{MAX} = 0.24 y^{-1}$  in Amendment 10 (NEFMC 2003) is from an age-based Thompson-Bell yield-per-recruit analysis (Applegate et al. 1998).  $B_{MAX} = 5.6 \text{ kg/tow}$  in Amendment 10 was estimated using median recruitment from 1982-2002 survey data for the entire resource as.

On the basis of the 2003 NMFS scallop survey results, scallop biomass is about 7.6 kg/tow, well above  $B_{MAX} = 5.6 \text{ kg/tow}$ , so that sea scallops are not overfished. The rescaled fishing mortality estimate for the combined resource is 0.30 and above the overfishing threshold of  $F_{MAX} = 0.24$ , so that overfishing is occurring.

## 9.0 – RESEARCH RECOMMENDATIONS

1. More comparison tows between standard survey dredges and those equipped with rock chains are necessary to more precisely estimate the correction factor(s) needed to convert between survey tows with and without rock chains.
2. Explore potential for surveying hard bottom areas not currently covered using survey dredges equipped with rock chains.
3. Explore the use of VMS and landings data to characterize condition of the resource on grounds not covered by the survey.
4. Further work is required to better characterize the selectivity of the commercial dredges with 4" rings relative to the standard NEFSC survey dredge.
5. Because assumptions about growth are important in almost any stock assessment model, better estimation of scallop growth, including variability in growth, is important in improving the precision of sea scallop stock assessments.

6. Work presented during the assessment indicates substantial variability in shell height-meat weight relationships due to depth, season, year and possibly area. Additional work on this subject may be useful, especially with respect to area-based management.
7. Based on recent work on scallops in the US and Canada, there is a potential for tracking year-to-year variability in natural mortality based on clapper data. Use of clapper data in stock assessment models to estimate natural mortality should be investigated.
8. The statistical properties of the new “CASA” model should be fully evaluated prior to the next meeting. The properties of concern include performance in the face of process errors (e.g. variability in  $M$  and growth), measurement errors in data, and characterization of uncertainty. In addition, use of smaller time steps, length groups might be helpful. It may prove possible to apply the model or similar models to smaller geographic areas.
9. There appears to be considerable scope for reducing variability in scallop survey data by changing the allocation of tows to survey strata.
10. Comparison of SMAST video survey with the NEFSC survey has proved valuable in estimating efficiency of survey and commercial dredges and in improving abundance estimates. The benefits of future video surveys could be enhanced by increasing coordination in carrying out the video and NEFSC surveys on the same grounds, so that the NEFSC scallop strata are fully covered by the video survey. More intense video surveys in small areas, such as was done in 1999-2002, can help reduce the variances of the efficiency estimates.
11. This assessment demonstrates the potential for fully incorporating results of cooperative surveys in stock assessment models for scallops. Areas where additional information could be obtained by cooperative research include abundance in areas not normally surveyed by NEFSC, gear properties, and temporal and spatial variation in shell height/meat weight relationships, mortality, recruitment and growth.

## 11.0 – LITERATURE CITED

- Almeida, F., T. Sheehan, and R. Smolowitz. 1994. Atlantic sea scallop, *Placopecten magellanicus*, maturation on Georges Bank during 1993. NEFSC Ref. Doc. 94-13.
- Applegate, A., S. Cadrin, J. Hoenig, C. Moore, S. Murawski, and E. Pikitch. 1998. Evaluation of existing overfishing definitions and recommendations for new overfishing definitions to comply with the Sustainable Fisheries Act. Final Report, June 17, 1998. New England Fisheries Management Council, Saugus, MA.
- Beverton, R.J.H. and S.J. Holt. 1956. A review of methods for estimating mortality rates in fish populations, with special reference to sources of bias in catch sampling. Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 140:67-83.
- Bland, J. M. and D. G. Altman. 1986. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet i:307-310.
- Bland, J.M. and D.G. Altman. 1995. Comparing methods of measurement: why plotting difference against standard method is misleading. Lancet 346:1085-1087.
- Bourne, N. 1964. A comparison of catches by 3- and 4- inch rings on offshore scallop drags. *J. Fish. Res. Bd. Can.* 22(2):313-333.
- Butler, J.L., L.D. Jacobson, J.T. Barnes, and H.G. Moser. 2003. Biology and population dynamics of cowcod (*Sebastes levis*) in the southern California Bight. *Fish. Bull.* 101: 260-280.
- Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. *J. Fish. Res. Bd. Can.* 30:173-180.
- Dibacco, C., G. Robert, and J. Grant. 1995. Reproductive cycle of the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), on northeastern Georges Bank. *J. Shellfish Res.* 14:59-69.
- Dickie, L.M. 1955. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby Area of the Bay of Fundy. *J. Fish. Res. Bd. Can.* 12:797-857.
- D’Orazio, M. 2003. Estimating the variance of the sample mean in two-dimensional systematic sampling. *J. Agric. Biol. and Environ. Statistics.* 8:280-295.
- DuPaul, W.D., J.E. Kirkley and A.C. Schmitzer. 1989. Evidence of a semiannual reproductive cycle for the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), in the Mid-Atlantic region. *J. Shellfish Res.* 8:173-178.
- Fournier, D., and Archibald, CP. 1982. General theory for analyzing catch at age data. *Can. J. Fish. Aquat. Sci.* 39: 1195-1207.

- Gedamke, T. , W. D. DuPaul, and J. M. Hoenig. 2004. A spatially explicit open-ocean DeLury analysis to estimate commercial scallop dredge efficiency. N. Amer. J. Fish. Management (in press).
- Gunderson, D.R. 1993. Surveys of Fisheries resources. Wiley. New York. 248 p.
- Hart, D.R. 2001. Individual-based yield-per-recruit analysis, with an application to the Atlantic sea scallop, *Placopecten magellanicus*. Can. J. Fish. Aquat. Sci. 58:2351-2358.
- Hart, D.R. 2003. Yield- and biomass-per-recruit analysis for rotational fisheries, with an application to the Atlantic sea scallop (*Placopecten magellanicus*). Fish. Bull. 101:44-57.
- Hillborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall. New York. 570 p.
- Jacobson, L.D., Cadrin, S.X., and J.R. Weinberg. 2002. Tools for estimating surplus production and  $F_{MSY}$  in any stock assessment model. N. Am. J. Fish. Mgmt. 22: 326-338.
- Keyfitz, N. 1968. Introduction to the mathematics of population. Addison-Wesley. Reading, Massachusetts. 450 p.
- Krantz , D.E. 1983. Environmental and growth information from stable isotope records in the sea scallop, *Placopecten Magellanicus*. MS Thesis. Univ. S. Carolina.
- Krantz, D.E., D.S. Jones, and D.F. Williams. 1984. Growth rates of the sea scallop, *Placopecten magellanicus*, determined from the  $^{18}\text{O}/^{16}\text{O}$  record in shell calcite. Biol. Bull. 167:186-199.
- Lai, H.L., and L. Hendrickson. 1997. Current resource conditions in USA Georges Bank and Mid-Atlantic sea scallop populations: Results of the 1997 NMFS sea scallop research vessel survey. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 97-09: 73p
- MacDonald, B.A. and R.J. Thompson. 1985. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. I. Reproductive output and total production. Mar. Ecol. Prog. Ser., 25:295-303.
- MacDonald, B.A. and R.J. Thompson. 1986. Production, dynamics and energy partitioning in two populations of the giant scallop *Placopecten magellanicus* (Gmelin). J. Exp. Mar. Biol. Ecol. 101:285-299.
- McGarvey, R., F. M. Serchuk, and I.A. McLaren. 1993. Spatial and parent-age analysis of stock-recruitment in the Georges Bank sea scallop (*Placopecten magellanicus*) population. Can. J. Fish. Aquat. Sci. 50:564-574.

- Merrill, A.S., and J.A. Posgay. 1964. Estimating the natural mortality rate of sea scallop. Res. Bull. Int. Comm. N.W. Atlantic Fish. 1:88-106.
- Merrill, A.S., J.A. Posgay and F. Nichy. 1966. Annual marks on shell and ligament of sea scallop (*Placopecten magellanicus*). Fish. Bull. 65:299-311.
- Method, R. D. 2000. Technical description of the stock synthesis assessment program. NOAA Tech. Memo. NMFS-NWFSC-43: 1-46.
- Millar, R.B. 1992. Estimating the size-selectivity of fishing gear by conditioning on the total catch. J. Amer. Stat. Assoc. 87:962-968.
- Murawski, S.A and F.M. Serchuk. 1989. Environmental effects of offshore dredge fisheries for bivalves. ICES C.M. 1989/K:27
- NEFMC. 1993. Amendment #4 and supplemental environmental impact statement to the sea scallop fishery management plan. New England Fisheries Management Council, Saugus, MA.
- NEFMC. 2003. Final Amendment 10 to the Atlantic sea scallop fishery management plan with a supplemental environmental impact statement, regulatory impact review, and regulatory flexibility analysis. New England Fisheries Management Council, Newburyport, MA.
- NEFSC 1993. Status of fishery resources off the northeastern United States for 1993. NOAA Tech. Memo. NMFS-F/NEC-101.
- NEFSC. 1995. [Report of the] 20th Northeast Regional Stock Assessment Workshop (20th SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessment. NEFSC Ref. Doc. 95-18, Woods Hole, MA.
- NEFSC. 1997. [Report of the] 23rd Northeast Regional Stock Assessment Workshop (23rd SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessment. NEFSC Ref. Doc. 97-05, Woods Hole, MA.
- NEFSC 1999. [Report of the] 29th Northeast Regional Stock Assessment Workshop (29th SAW). Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 99-14, Woods Hole, MA
- NEFSC. 2001. [Report of the] 32nd Northeast Regional Stock Assessment Workshop (32nd SAW). Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 01-05, Woods Hole, MA.
- Overholtz, W.J., Jacobson, L., Melvin, G.D., Cieri, M., Power, M., and Clark, K. 2004. Stock assessment of the Gulf of Maine-Georges Bank herring complex, 1959-2002. Northeast Fish. Sci. Ctr. Ref. Doc. 04-06.

- Pennington, M., Burmeister, L-M., and Hjellvik, V. 2002. Assessing the precision of frequency distributions estimated from trawl-survey samples. *Fish. Bull.* 100: 74-80.
- Posgay, J.A. 1979. Depth as a factor affecting the growth rate of the sea scallop. *Int. Coun. Explor. Sea C.M.* 1979/K:27. 5 p.
- Press, W.H., Flannery, B.P., S.A. Teukolsky, and W.T. Vetterling. 1990. *Numerical recipes.* Cambridge Univ. Press, NY.
- Rudders, D. B., W. D. Dupaul, and J. E. Kirkley. 2000. A comparison of size selectivity and relative efficiency of sea scallop, *Placopecten magellanicus* (Gmelin, 1791), trawls and dredges. *J. Shellfish Res.* 19:757-764.
- Richards, R.A. 1996. Current resource conditions in USA Georges Bank and Mid-Atlantic sea scallop populations: Results of the 1996 NMFS sea scallop research vessel survey. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 96-12: 75p.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fisheries Res. Brd. Canada.* Ottawa. Bull. #191. 382 pp.
- Serchuk, F.M., Wood, P.W., Posgay, J.A. and Brown, B.E. 1979. Assessment and status of sea scallop (*Placopecten magellanicus*) populations of the northeast coast of the United States. *Proc. Natl. Shellfish. Assoc.* 69:161-191.
- Serchuk, F.M. and R.J. Smolowitz. 1980. Size selection of sea scallops by an offshore scallop survey dredge. *ICES C.M.* 1980/K:24.
- Serchuk, F.M. and Smolowitz, R.J. 1989. Seasonality in sea scallop somatic growth and reproductive cycles. *J. Shellfish Res.* 8:435.
- Serchuk, F. M., and R.S. Rak. 1983. Biological characteristics of offshore Gulf of Maine scallop populations: size distributions, shell height-meat weight relationships and relative fecundity patterns. NMFS, Woods Hole Lab. Ref. Doc. No. 83-07. 42p.
- Serchuk, F.M., and S.E. Wigley. 1989. Current resource conditions in USA Georges Bank and Mid-Atlantic sea scallop populations: Results of the 1989 NMFS sea scallop research vessel survey. NEFSC SAW - 9, Working Paper No. 9, 52p.
- Schick, D.F., S.E. Shumway and M.A. Hunter. 1988. A comparison of growth rate between shallow water and deep water populations of scallops, *Placopecten magellanicus* (Gmelin, 1791), in the Gulf of Maine. *Am. Malacol. Bull.* 6:1-8.
- Smith, S.J. 1988. Evaluating the efficiency of the delta-distribution mean estimator. *Biometrics* 44:485-493.

- Smith S. J. 1997. Bootstrap confidence limits for groundfish trawl survey estimates of mean abundance. *Can. J. Fish. Aquat. Sci.* 54:616-630.
- Smith, S.J., E.L. Kenchington, M.J. Lundy, G. Robert and D. Roddick. 2001. Spatially specific growth rates for sea scallops (*Placopecten magellanicus*). Pp. 211-231 in: Spatial processes and management of marine populations. Lowell Wakefield Fish. Symp. Ser. 17.
- Stokesbury K.D.E. 2002. Estimation of sea scallop abundance in closed areas of Georges Bank USA Trans. Am. Fish. Soc. 131:1081-1092.
- Stokesbury, K.D.E, B.P. Harris, M.C. Marino II and J.I. Nogueira. 2004. Estimation of sea scallop abundance using a video survey in off-shore U.S. waters. *J. Shellfish Res.* 23: 33-40.
- Sullivan, P.J., Lai, H.L., and Gallucci, V.F. 1990. A catch-at-length analysis that incorporates a stochastic model of growth. *Can. J. Fish. Aquat. Sci.* 47: 184-198.
- Tan, F.C., D. Cai, and D.L. Roddick. 1988. Oxygen isotope studies on sea scallops, *Placopecten magellanicus*, from Browns Bank, Nova Scotia. *Can. J. Fish. Aquat. Sci.* 45:1378-1386.
- Thompson, S.K. 2002. Sampling. 2<sup>nd</sup> Edition. J. Wiley Inc. New York.
- Tokai, T. 1997. Maximum likelihood parameter estimates of mesh selectivity logistic model through SOLVER on MS-Excel. *Bull. Jpn. Fish. Ocean.* 62:235-247.
- Wigley, S.E., and F.M. Serchuk. 1996. Current resource conditions in Georges Bank and Mid-Atlantic sea scallop populations: Results of the 1994 NEFSC sea scallop research vessel survey. NEFSC Ref. Doc. 96-03.
- Wigley, S.E., M. Terceiro, A. DeLong, and K. Sosebee. 1998. Proration of 1994-96 USA commercial landings of Atlantic cod, haddock, and yellowtail flounder to unit stock areas. NEFSC Ref. Doc. 98-02.

Year	Gulf of Maine			Georges Bank			S. New England			Mid-Atlantic Bight			Uncl.	Total						
	trawl	other	sum	dredge	trawl	other	sum	dredge	trawl	other	sum	dredge	trawl	other	sum	trawl	other	sum		
1964	0	208	208		0	6,241	6,241		52	3	55		0	137	137		52	6,590	6,642	
1965	0	117	117		3	1,478	1,481		2	24	26		0	3,974	3,974		5	5,592	5,598	
1966	0	102	102		0	883	884		0	8	8		0	4,061	4,061		1	5,055	5,056	
1967	0	80	80		4	1,217	1,221		0	8	8		0	1,873	1,873		4	3,178	3,182	
1968	0	113	113		0	993	994		0	56	56		0	2,437	2,437		0	3,599	3,599	
1969	1	122	123		8	1,316	1,324		0	18	19		5	846	851		14	2,302	2,317	
1970	0	132	132		5	1,410	1,415		0	6	6		14	459	473		19	2,006	2,026	
1971	4	358	362		18	1,311	1,329		0	7	7		0	274	274		22	1,949	1,971	
1972	1	524	525		5	816	821		0	2	2		5	653	658		11	1,995	2,006	
1973	0	460	460		15	1,065	1,080		0	3	3		4	245	249		19	1,773	1,792	
1974	0	223	223		15	911	926		0	4	5		0	937	938		16	2,076	2,091	
1975	6	741	746		13	844	857		8	42	50		52	1,506	1,558		80	3,132	3,212	
1976	3	364	366		38	1,723	1,761		4	3	7		317	2,972	3,288		361	5,061	5,422	
1977	4	254	258		27	4,709	4,736		1	10	11		27	2,564	2,591		58	7,536	7,595	
1978	1	0	243	5,532	37	0	5,569	25	2	0	27	4,175	21	0	4,196		9,974	61	0	10,035
1979	5	1	407	6,253	25	7	6,285	61	5	0	66	2,857	29	1	2,888		9,572	64	9	9,645
1980	122	3	1,614	5,382	34	2	5,419	130	3	0	133	1,966	9	0	1,975	< 0.01	8,968	169	4	9,142
1981	73	7	1,305	7,787	56	0	7,843	68	1	0	69	726	5	0	731		9,806	135	7	9,948
1982	28	5	664	6,204	119	0	6,322	126	0	0	126	1,602	6	2	1,610		8,562	153	7	8,723
1983	72	7	895	4,247	32	4	4,284	243	1	0	243	3,081	18	10	3,109		8,386	124	21	8,530
1984	18	10	678	3,011	29	3	3,043	161	3	0	164	3,647	26	2	3,675		7,470	76	14	7,560
1985	3	10	421	2,860	34	0	2,894	77	4	0	82	3,227	47	1	3,276		6,572	88	11	6,672
1986	2	6	316	4,428	10	0	4,438	76	2	0	78	3,257	101	0	3,359		8,068	115	7	8,190
1987	0	9	382	4,821	30	0	4,851	67	1	0	68	7,488	315	1	7,803		12,749	346	10	13,104
1988	7	13	526	6,036	18	0	6,054	65	4	0	68	5,774	402	2	6,178		12,381	430	16	12,826
1989	0	44	644	5,637	25	0	5,661	127	11	0	138	7,549	422	2	7,973		13,913	458	45	14,416
1990	0	28	574	9,972	10	0	9,982	110	6	0	116	5,954	476	4	6,435		16,581	493	32	17,107
1991	3	75	605	9,235	77	0	9,311	55	16	0	71	6,195	808	9	7,011		16,012	903	84	16,999
1992	2	45	722	8,230	7	0	8,238	119	5	0	124	4,386	563	5	4,955		13,411	577	50	14,039
1993	2	32	797	3,637	18	0	3,655	65	1	0	66	2,382	392	3	2,778		6,848	413	36	7,296
1994	3	3	525	1,133	3	1	1,137	0	1	0	1	5,176	688	9	5,872		6,827	693	13	7,534
1995	4	238	665	967	15	0	982	35	1	0	36	5,408	744	166	6,318		6,799	762	404	7,965
1996	20	121	773	2,040	6	0	2,045	74	0	0	74	4,335	656	9	4,999		7,006	682	130	7,818
1997	21	98	699	2,317	10	0	2,326	69	0	0	69	2,442	357	111	2,910		5,339	387	209	5,936
1998	10	1	455	1,990	27	0	2,016	95	6	0	102	2,359	574	15	2,948	44	4,792	610	17	5,565
1999	3	0	280	5,151	4	0	5,155	46	5	3	54	3,646	958	50	4,653	4	9,074	965	50	10,146
2000	8	1	191	5,412	25	0	5,437	84	2	0	86	7,707	1,142	10	8,860	49	13,301	1,175	11	14,623
2001	18	29	430	4,941	11	0	4,952	27	1	2	31	14,161	1,570	38	15,768		19,485	1,599	67	21,180
2002	7	2	542	5,653	40	0	5,694	41	3	0	43	16,016	1,591	5	17,612		22,202	1,639	7	23,891
2003	7	1	254	4,908	14	0	4,922	84	2	0	85	18,189	1,470	1	19,660	187	23,343	1,491	1	25,107
Mean	11	35	547	4,674	26	0	4,700	84	3	0	88	6,090	606	21	6,716		11,324	645	56	12,056
Min	0	0	191	967	3	0	982	0	0	0	1	1,602	6	0	1,610		4,792	76	1	5,565
Max	72	238	895	9,972	119	4	9,982	243	16	3	243	18,189	1,591	166	19,660		23,343	1,639	404	25,107



Table B5-1. Gear selectivity parameter estimates for the Serchuk and Smolowitz (1980) and *F/V Tradition* experiments.

(a) Serchuk and Smolowitz (1980) experiment.

Parameter	p=0.5 (fixed)		p estimated	
	Value	Std Err.	Value	Std Err.
a	-4.8032	0.3688	-4.4453	0.2691
b	0.1019	0.0091	0.0811	0.0066
p	0.5000	---	0.5815	0.0085
L50	47.1461	0.9742	54.804	1.4483
IQR	21.5670	1.9202	27.089	2.1878
Ho	model Deviance	136.68	28.61	
	degrees of freedom	24	23	
	significance	9.4495E-18	0.19358978	
Ho	p=0.5 deviance	---	108.07	
	degrees of freedom	---	1	
	significance	---	2.5945E-25	

(b) *F/V Tradition* experiment

Parameter	Raw Data				Adjusted R/V Data	
	p=0.5 (fixed)		p estimated		p estimated	
	Value	Std Err.	Value	Std Err.	Value	Std Err.
a	-21.46947	0.8356	-15.3815	0.2550	-15.2401	0.2520
b	0.317893	0.0128	0.1958	0.0035	0.1943	0.0034
p	0.5	0.0012	0.7509	0.0012	0.6829	0.0013
L50	67.5367	0.2170	78.5699	0.1648	78.4511	0.1507
IQR	6.911827	0.2791	11.2236	0.1994	11.3106	0.1985
Ho	model Deviance	47682.5	6552.2		8292.5	
	degrees of freedom	31	30		30	
	significance	0	0		0	
Ho	p=0.5 deviance	---	41130.26			
	degrees of freedom	---	1			
	significance	---	0			

Table B5-2. Stratified mean sea scallop survey data for Georges Bank, Mid-Atlantic Bight and combined (40+ mm shell height). Calculations include corrections for survey dredge selectivity (NEFSC 1997). Population values were split into recruited and not recruited portions using the piecewise linear commercial dredge selectivity function (NEFSC 1992).

Year	Num/Tow	CV	Num/Tow		Biomass g/Tow	CV	Biomass Not	Fully	Mean Meat Weight (G)
			Num/tow Not Recruited	Fully Recruited			Recruited g/Tow	Recruited g/Tow	
<b>Georges Bank</b>									
1982	133	37%	100	33	869	18%	304	565	6.6
1983	61	21%	24	37	720	16%	97	623	11.9
1984	39	11%	15	23	544	9%	55	490	14.0
1985	65	14%	31	34	706	13%	126	579	10.8
1986	116	13%	79	37	917	9%	269	648	7.9
1987	126	15%	67	58	1,082	13%	245	837	8.6
1988	104	15%	56	48	904	12%	216	688	8.7
1989	111	36%	56	55	943	33%	248	695	8.5
1990	207	22%	129	78	1,340	20%	475	865	6.5
1991	251	30%	200	51	1,246	14%	551	695	5.0
1992	264	38%	185	79	1,638	29%	787	851	6.2
1993	70	28%	47	23	531	17%	204	327	7.6
1994	45	16%	20	25	457	13%	69	388	10.2
1995	120	18%	92	28	747	13%	285	462	6.2
1996	139	16%	70	69	1,332	14%	256	1,076	9.6
1997	100	13%	28	72	1,612	14%	98	1,514	16.1
1998	317	31%	145	172	4,000	37%	508	3,492	12.6
1999	246	17%	67	179	4,306	25%	158	4,148	17.5
2000	888	30%	542	346	8,131	21%	2,243	5,888	9.2
2001	473	13%	147	327	7,010	14%	616	6,394	14.8
2002	397	13%	33	364	8,051	13%	174	7,877	20.3
2003	311	12%	61	250	7,529	14%	231	7,299	24.2
<b>Mid-Atlantic Bight</b>									
1979	43	9%	11	32	728	10%	46	681	16.9
1980	51	12%	27	24	615	7%	62	553	12.1
1981	40	17%	18	22	488	11%	64	423	12.3
1982	40	11%	16	24	508	8%	64	444	12.8
1983	38	9%	20	19	472	8%	65	407	12.3
1984	39	10%	15	24	454	9%	49	406	11.8
1985	93	13%	58	35	734	9%	207	528	7.9
1986	152	8%	89	64	1,186	7%	323	863	7.8
1987	152	8%	94	58	1,039	6%	276	763	6.9
1988	179	10%	78	101	1,683	8%	302	1,381	9.4
1989	216	9%	129	87	1,525	7%	462	1,063	7.1
1990	264	22%	173	91	1,672	17%	702	970	6.3
1991	103	10%	48	55	963	10%	196	767	9.4
1992	53	10%	24	28	543	7%	82	461	10.3
1993	164	11%	138	26	753	8%	391	362	4.6
1994	162	10%	95	67	1,043	8%	326	717	6.4
1995	218	13%	125	94	1,547	11%	567	980	7.1
1996	77	8%	23	53	773	7%	116	657	10.1
1997	54	12%	28	26	533	6%	66	467	9.8
1998	195	17%	145	50	1,101	15%	474	627	5.7
1999	309	21%	173	136	2,281	18%	640	1,641	7.4
2000	389	14%	131	257	4,005	13%	572	3,434	10.3
2001	398	12%	141	257	4,519	13%	523	3,995	11.3
2002	404	11%	112	292	5,122	12%	399	4,723	12.7
2003	864	15%	495	370	7,603	9%	1,297	6,306	8.8

**Combined**

1982	83	28%	55	28	676	11%	176	500	8.1
1983	49	13%	22	27	587	10%	80	507	12.1
1984	39	8%	15	24	496	6%	51	445	12.8
1985	80	9%	46	35	721	8%	169	552	9.1
1986	135	7%	84	51	1,061	6%	298	763	7.8
1987	140	8%	82	58	1,059	7%	262	798	7.6
1988	144	8%	68	77	1,320	6%	262	1,058	9.2
1989	167	13%	95	72	1,254	12%	363	892	7.5
1990	237	16%	153	85	1,517	13%	596	921	6.4
1991	172	21%	119	53	1,095	9%	361	734	6.4
1992	151	31%	99	52	1,053	21%	410	643	7.0
1993	120	11%	96	24	650	8%	304	346	5.4
1994	108	9%	60	48	770	7%	206	564	7.2
1995	173	10%	110	63	1,175	9%	436	739	6.9
1996	106	11%	45	61	1,033	9%	181	852	10.3
1997	76	9%	28	48	1,035	10%	81	954	14.9
1998	251	20%	145	107	2,451	29%	490	1,961	10.5
1999	268	14%	124	144	1,978	16%	416	1,562	11.1
2000	621	21%	323	299	5,926	14%	1,350	4,576	10.0
2001	433	9%	144	290	5,678	10%	566	5,112	13.3
2002	401	8%	75	326	6,485	9%	294	6,192	16.2
2003	607	12%	293	314	7,569	8%	801	6,768	12.5

**Table B6-1. Fishing mortality estimates.**

<b>Georges Bank</b>														
	<b>80-100</b>	<b>100+</b>	<b>SurveyF</b>	<b>CV</b>	<b>Landings</b>	<b>MinEBms</b>	<b>Ebms</b>	<b>CV</b>	<b>CBI</b>	<b>CV</b>	<b>RescaledF</b>	<b>CV</b>	<b>BH-F</b>	<b>MovAvg</b>
1982	14.77	11.40			6448	3124	7811	0.12	0.83	0.15	1.44	0.16	0.50	0.53
1983	22.18	12.03	0.68		4527	3443	8608	0.10	0.53	0.14	0.92	0.15	0.70	0.57
1984	10.52	11.25	1.01		3207	2707	6767	0.10	0.47	0.14	0.82	0.14	0.38	0.49
1985	17.13	12.48	0.46		2976	3204	8011	0.14	0.37	0.17	0.65	0.18	0.61	0.68
1986	15.21	14.85	0.59		4516	3585	8964	0.09	0.50	0.13	0.88	0.14	0.48	0.78
1987	35.75	14.82	0.61		4919	4631	11578	0.13	0.42	0.16	0.74	0.17	0.95	1.04
1988	27.79	12.84	1.27		6123	3806	9515	0.10	0.64	0.14	1.12	0.14	0.89	1.32
1989	35.57	10.20	1.28		5799	3842	9605	0.32	0.60	0.34	1.05	0.34	1.29	1.33
1990	53.88	8.84	1.54		10098	4785	11962	0.22	0.84	0.24	1.47	0.24	1.78	1.27
1991	26.89	12.04	1.55		9382	3844	9611	0.09	0.98	0.14	1.70	0.14	0.92	0.88
1992	32.37	11.29	1.14		8362	4708	11770	0.17	0.71	0.19	1.24	0.20	1.10	0.87
1993	8.72	7.15	1.71		3721	1806	4514	0.10	0.82	0.14	1.43	0.14	0.63	0.68
1994	16.4	7.2	0.69		1138	2145	5363	0.12	0.21	0.16	0.37	0.16	0.87	0.72
1995	10.9	12.1	0.57		1018	2554	6385	0.12	0.16	0.15	0.28	0.16	0.54	0.54
1996	37.86	23.50	-0.12		2120	5950	14874	0.14	0.14	0.17	0.25	0.18	0.74	0.48
1997	24.94	44.45	0.22		2395	8370	20926	0.14	0.11	0.17	0.20	0.18	0.36	0.33
1998	66.74	91.99	-0.38		2118	19308	48271	0.39	0.04	0.40	0.08	0.40	0.34	0.33
1999	59.25	84.69	0.53		5209	22937	57342	0.31	0.09	0.32	0.16	0.33	0.28	0.35
2000	133.52	135.59	-0.04		4569	32560	81401	0.20	0.06	0.23	0.10	0.23	0.36	0.38
2001	151.48	154.86	0.45		4955	35358	88396	0.15	0.06	0.18	0.10	0.19	0.41	0.28
2002	145.32	215.07	0.25		5249	43561	108903	0.13	0.05	0.17	0.08	0.17	0.35	
2003	33.77	207.89	0.45		5048	40360	100901	0.13	0.05	0.17	0.09	0.17	0.08	
<i>Mean8203</i>	<i>44.59</i>	<i>50.75</i>	<i>0.69</i>	<i>0.04</i>	<i>4723</i>		<i>29158</i>		<i>0.40</i>		<i>0.69</i>		<i>0.66</i>	

### Mid-Atlantic Fishing Mortality Estimates

	80-98.5	98.5+	SurveyF	CV	Landings	MinEBms	EBms	CV	CBI	CV	RescaledF	CV	BH-F	MovAvg
1979	10.9	19.1			2888	4326	7210	0.10	0.67	0.14	0.64	0.15	0.38	0.39
1980	7.0	16.2	0.52		1975	3512	5854	0.07	0.56	0.12	0.54	0.12	0.33	0.45
1981	9.0	10.1	0.73		731	2686	4476	0.10	0.27	0.14	0.26	0.14	0.47	0.46
1982	11.3	10.6	0.49		1610	2819	4698	0.08	0.57	0.13	0.55	0.13	0.55	0.55
1983	6.4	10.8	0.61		3109	2582	4304	0.08	1.20	0.13	1.16	0.13	0.36	0.61
1984	14.8	8.2	0.64		3675	2577	4295	0.09	1.43	0.13	1.37	0.13	0.73	0.85
1985	16.9	11.8	0.57		3276	3351	5584	0.07	0.98	0.12	0.94	0.12	0.75	0.99
1986	40.0	15.9	0.49		3359	5480	9133	0.07	0.61	0.12	0.59	0.12	1.06	1.10
1987	40.1	13.6	1.31		7803	4842	8071	0.06	1.61	0.12	1.55	0.12	1.16	1.16
1988	66.4	24.8	0.67		6178	8768	14613	0.07	0.70	0.12	0.68	0.12	1.10	1.24
1989	53.5	16.2	1.63		7973	6748	11247	0.07	1.18	0.12	1.13	0.12	1.22	1.21
1990	49.7	11.7	1.69		6435	6161	10268	0.10	1.04	0.14	1.00	0.14	1.41	1.05
1991	33.5	14.8	1.32		7011	4872	8120	0.11	1.44	0.15	1.38	0.15	1.01	0.85
1992	15.3	10.9	1.39		4955	2928	4880	0.07	1.69	0.12	1.62	0.12	0.73	1.13
1993	12.9	7.5	1.14		2794	2300	3833	0.07	1.22	0.12	1.17	0.12	0.83	1.38
1994	44.5	7.6	0.89		5872	4552	7587	0.08	1.29	0.13	1.24	0.13	1.84	1.58
1995	50.0	13.2	1.27		6318	6224	10373	0.09	1.02	0.13	0.97	0.13	1.48	1.17
1996	39.5	10.1	1.73		4999	4168	6947	0.06	1.20	0.12	1.15	0.12	1.43	1.04
1997	12.6	13.2	1.23		2910	2967	4944	0.06	0.98	0.11	0.94	0.11	0.61	1.00
1998	28.9	11.0	0.75		2948	3980	6633	0.14	0.74	0.17	0.71	0.17	1.10	1.16
1999	87.7	26.9	0.30		4653	10418	17363	0.15	0.45	0.18	0.43	0.18	1.30	1.05
2000	169.9	69.9	0.39		9691	21800	36334	0.13	0.44	0.16	0.43	0.16	1.09	0.86
2001	129.5	114.1	0.64		15812	25365	42274	0.14	0.62	0.17	0.60	0.17	0.76	0.69
2002	147.2	137.2	0.47		17233	29985	49976	0.12	0.57	0.16	0.55	0.16	0.72	
2003	158.8	188.2	0.31		19822	40033	66721	0.09	0.50	0.14	0.48	0.14	0.60	
<i>Mean7903</i>	<i>50.3</i>	<i>31.7</i>	<i>0.88</i>	<i>0.02</i>	<i>6161</i>		<i>14229</i>		<i>0.92</i>		<i>0.88</i>		<i>0.92</i>	

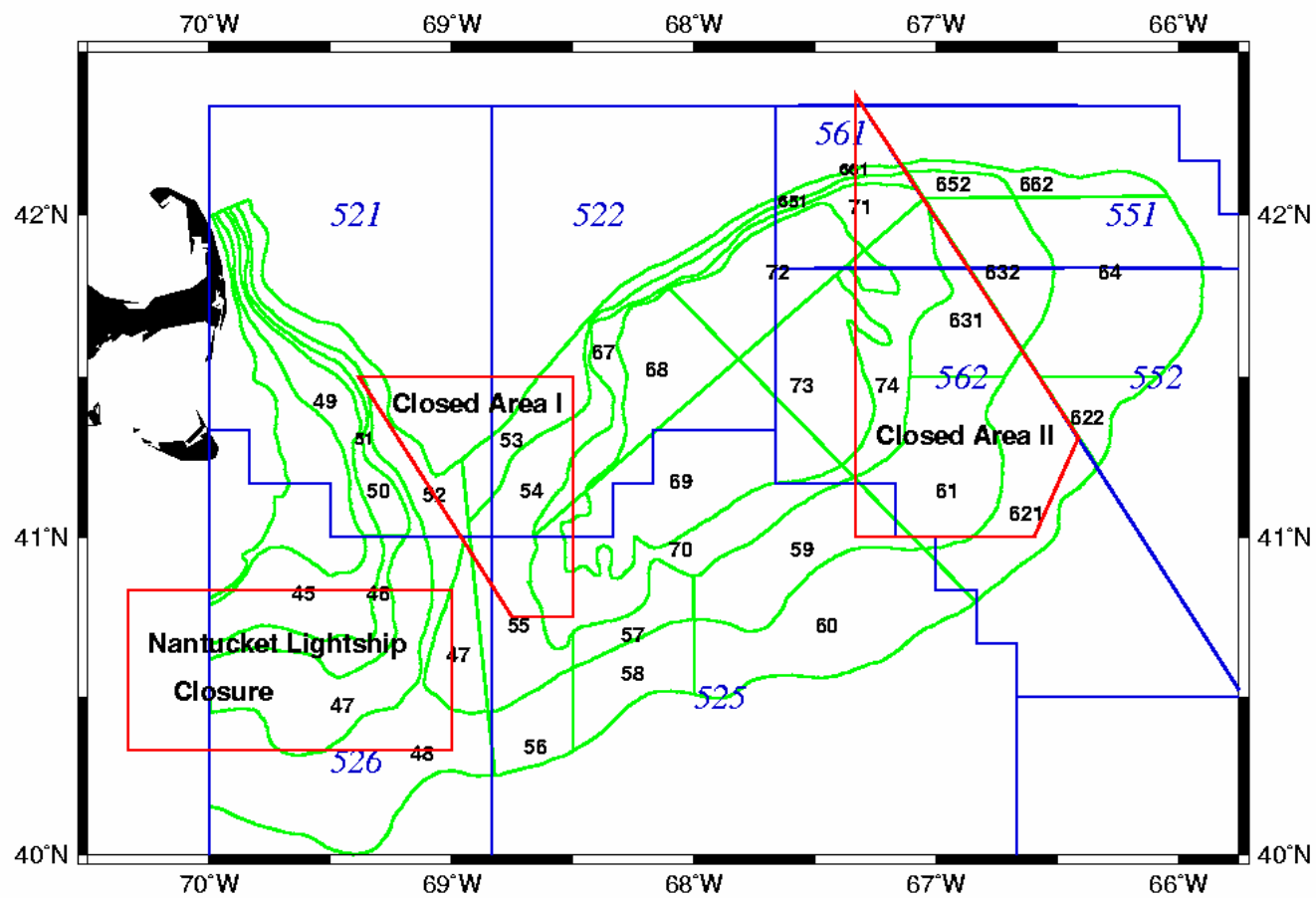
**Combined Fishing Mortality Estimates (Number weighted)**

	<b>SurveyF</b>	<b>Landings</b>	<b>Ebms</b>	<b>CBI</b>	<b>RescaledF</b>	<b>CV</b>	<b>BH-F</b>	<b>MovAvg</b>
1982		8058	12509	0.64	1.10	0.08	0.52	0.56
1983	0.66	7636	12912	0.59	0.99	0.07	0.60	0.61
1984	0.83	6882	11062	0.62	1.09	0.07	0.55	0.69
1985	0.51	6252	13595	0.46	0.78	0.08	0.67	0.85
1986	0.53	7875	18096	0.44	0.70	0.07	0.83	0.97
1987	0.94	12722	19648	0.65	1.13	0.08	1.05	1.11
1988	0.89	12301	24127	0.51	0.84	0.07	1.02	1.29
1989	1.48	13772	20851	0.66	1.10	0.14	1.25	1.27
1990	1.61	16533	22230	0.74	1.25	0.11	1.61	1.19
1991	1.44	16393	17731	0.92	1.55	0.07	0.96	0.90
1992	1.20	13317	16650	0.80	1.32	0.09	1.02	1.10
1993	1.43	6515	8347	0.78	1.30	0.07	0.73	1.17
1994	0.83	7010	12950	0.54	0.97	0.08	1.55	1.26
1995	1.09	7336	16758	0.44	0.80	0.08	1.25	0.88
1996	0.55	7119	21820	0.33	0.58	0.08	0.99	0.62
1997	0.43	5305	25870	0.21	0.35	0.08	0.41	0.52
1998	-0.20	5066	54904	0.09	0.18	0.17	0.46	0.60
1999	0.43	9862	74705	0.13	0.27	0.14	0.70	0.62
2000	0.12	14260	117735	0.12	0.22	0.11	0.64	0.56
2001	0.52	20767	130670	0.16	0.28	0.09	0.54	0.47
2002	0.34	22482	158878	0.14	0.26	0.09	0.49	
2003	0.38	24870	167622	0.15	0.30	0.08	0.36	
<i>Mean8203</i>	<i>0.76</i>		<i>44530</i>		<i>0.79</i>		<i>0.83</i>	

Table B7-1 Length-based yield-per-recruit analysis results

Stock	$L_{inf}$	$K$	$a$	$b$	$M$	$h_d$	$d$	$i$	rings	$F_{max}$	$Y_{max}$	$B_{max}$	Comments
<b>GB</b>	<b>152.46</b>	<b>0.3374</b>	<b>-11.6038</b>	<b>3.1221</b>	<b>0.1</b>	<b>90</b>	<b>0.2</b>	<b>0.225</b>	<b>3.5-log</b>	<b>0.189</b>	<b>13.58</b>	<b>95.54</b>	<b>Standard 3.5" ring run</b>
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0.2	0	3.5-log	0.215	17.59	90.02	No incidental mortality
GB	152.46	0.4	-11.6038	3.1221	0.1	90	0.2	0.225	3.5-log	0.202	15.11	98.44	Fast growth
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.225	3.5-log	0.178	13.24	94.69	Cull size prior to 1999
GB	152.46	0.3374	-11.6038	3.1221	0.05/0.1	90	0.2	0.225	3.5-log	0.184	16.15	116.08	M increases at 120 mm
GB	152.46	0.3374	-11.6038	3.1221	0.1/0.2	90	0.2	0.225	3.5-log	0.282	10.97	55.40	M increases at 120 mm
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0	0.225	3.5-log	0.202	14.08	93.41	No discard mortality
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	1	0.225	3.5-log	0.147	11.99	107.53	100% discard mortality
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0.2	0.225	3.5-pl	0.196	13.82	94.42	SARC-23 selectivity curve
<b>GB</b>	<b>152.46</b>	<b>0.3374</b>	<b>-11.6038</b>	<b>3.1221</b>	<b>0.1</b>	<b>90</b>	<b>0.2</b>	<b>0.225</b>	<b>4</b>	<b>0.214</b>	<b>14.14</b>	<b>95.90</b>	<b>Standard 4" ring run</b>
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0.2	0	4	0.275	19.15	85.30	No incidental mortality
GB	152.46	0.4	-11.6038	3.1221	0.1	90	0.2	0.225	4	0.227	15.73	98.40	Fast growth
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.225	4	0.208	14.05	96.53	Cull size typical prior to 1999
GB	152.46	0.3374	-11.6038	3.1221	0.05/0.1	90	0.2	0.225	4	0.208	16.86	115.85	M increases at 120 mm
GB	152.46	0.3374	-11.6038	3.1221	0.1/0.2	90	0.2	0.225	4	0.325	11.45	57.14	M increases at 120 mm
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0	0.225	4	0.214	14.23	96.49	No discard mortality
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	1	0.225	4	0.202	13.79	98.57	100% discard mortality
GB	152.46	0.3374	-11.6038	3.1221	0.1	90	0.2	0.225	4	0.227	14.29	93.78	Rotation - 3 closed then ramped fc
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.225	fishery	0.184	13.45	93.38	Fishery Selectivity 79-99
GB	152.46	0.3374	-11.6038	3.1221	0.1	85	0.2	0.225	fishery	0.214	14.27	94.03	Fishery Selectivity 00-03
<b>MA</b>	<b>151.84</b>	<b>0.2997</b>	<b>-12.2484</b>	<b>3.2641</b>	<b>0.1</b>	<b>90</b>	<b>0.2</b>	<b>0.04</b>	<b>3.5-log</b>	<b>0.198</b>	<b>15.99</b>	<b>92.91</b>	<b>Standard 3.5" ring run</b>
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	0.2	0	3.5-log	0.200	16.85	93.07	No incidental mortality
MA	151.84	0.23	-12.2484	3.2641	0.1	90	0.2	0.04	3.5-log	0.182	13.20	86.31	Slow growth
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0.04	3.5-log	0.177	15.30	93.60	Cull size prior to 1999
MA	151.84	0.2997	-12.2484	3.2641	0.05/0.1	90	0.2	0.04	3.5-log	0.192	19.44	114.40	M increases at 120 mm
MA	151.84	0.2997	-12.2484	3.2641	0.1/0.2	90	0.2	0.04	3.5-log	0.302	13.19	54.07	M increases at 120 mm
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	0	0.04	3.5-log	0.224	16.84	87.28	No discard mortality
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	1	0.04	3.5-log	0.140	13.57	108.78	100% discard mortality
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	0.2	0.04	3.5-pl	0.208	16.40	90.87	SARC-23 selectivity curve
<b>MA</b>	<b>151.84</b>	<b>0.2997</b>	<b>-12.2484</b>	<b>3.2641</b>	<b>0.1</b>	<b>90</b>	<b>0.2</b>	<b>0.04</b>	<b>4</b>	<b>0.244</b>	<b>17.29</b>	<b>90.44</b>	<b>Standard 4" ring run</b>
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	0.2	0	4	0.265	18.43	86.58	No incidental mortality
MA	151.84	0.23	-12.2484	3.2641	0.1	90	0.2	0.04	4	0.234	14.36	83.89	Slow growth
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0.04	4	0.234	17.05	91.24	Cull size typical prior to 1999
MA	151.84	0.2997	-12.2484	3.2641	0.05/0.1	90	0.2	0.04	4	0.239	21.07	110.43	M increases at 120 mm
MA	151.84	0.2997	-12.2484	3.2641	0.1/0.2	90	0.2	0.04	4	0.406	14.59	53.06	M increases at 120 mm
MA	151.84	0.2997	-12.2484	3.2641	0.1	90	0.2	0.04	4	0.265	17.48	87.74	Rotation - 3 closed then ramped fc
MA	151.84	0.2997	-12.2484	3.2641	0.1	N/A	N/A	0.04	fishery	0.198	16.11	91.25	Fishery Selectivity 79-98
MA	151.84	0.2997	-12.2484	3.2641	0.1	N/A	N/A	0.04	fishery	0.260	17.67	88.77	Fishery Selectivity 01-03

Figure B3-1. NEFSC Scallop Survey Maps with Closed Areas  
(a) Georges Bank





(b) Mid-Atlantic Bight

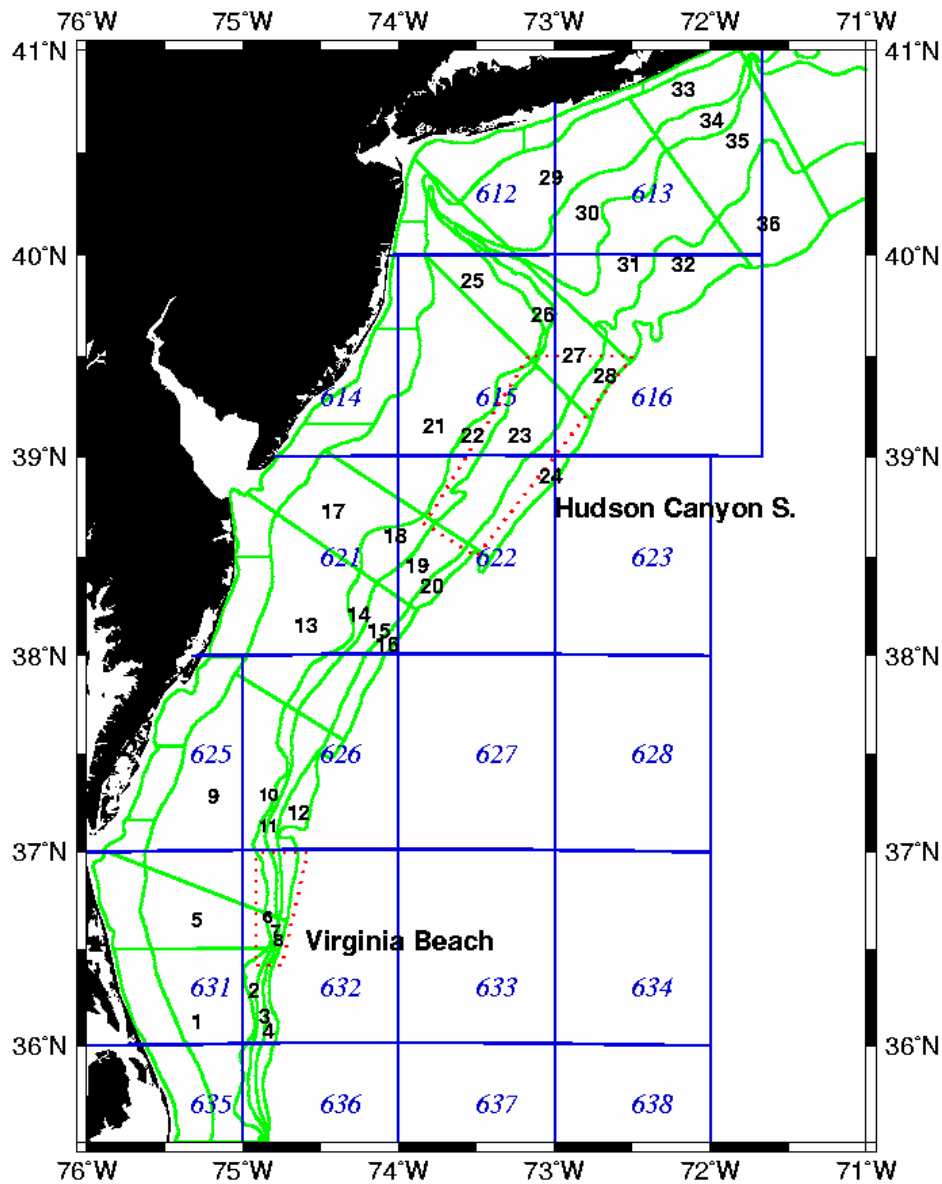


Figure B3-2. Growth in shell height and meat weights of a scallop that started at 40 mm shell height, using the standard growth and shell height/meat weight parameters for Georges Bank.

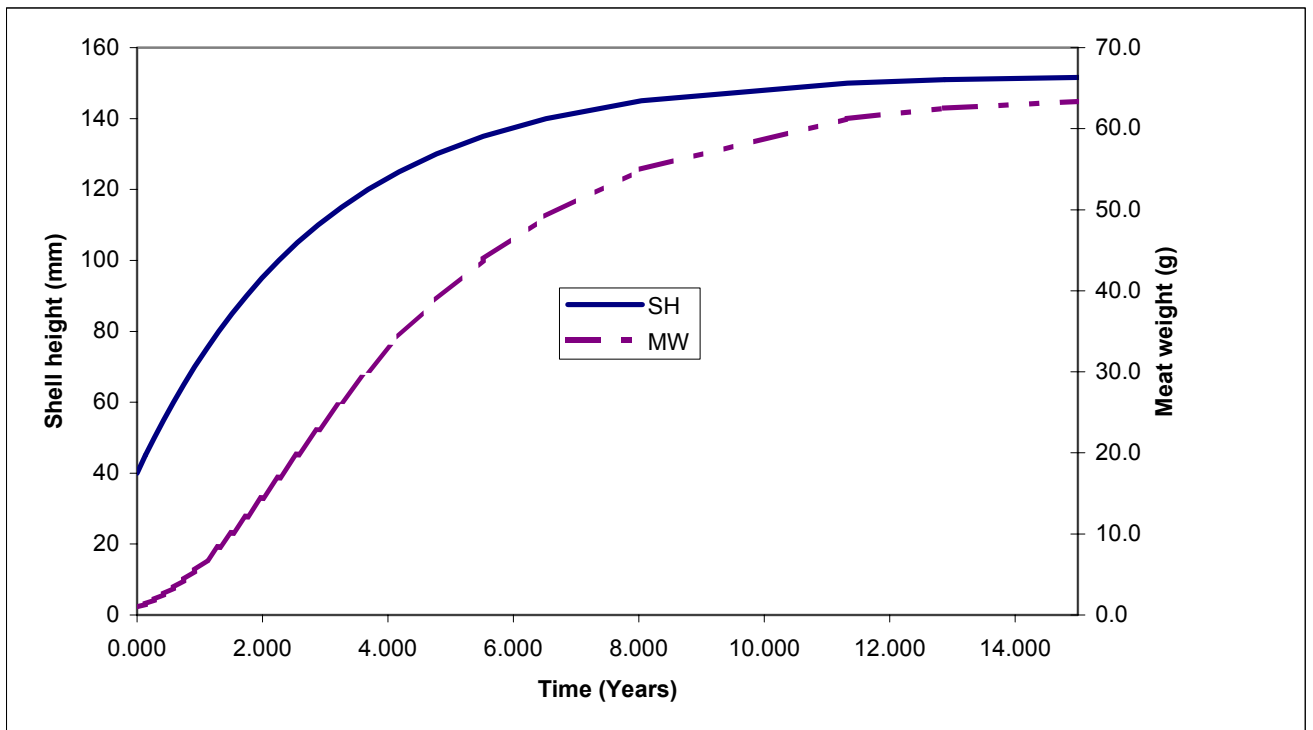
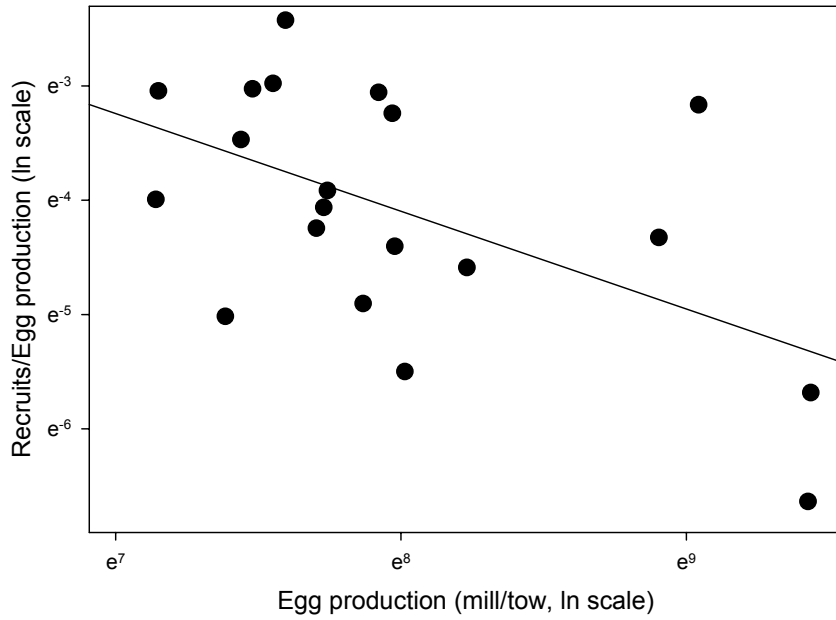


Figure B3-3. Stock-recruitment relationships.  
(a) Georges Bank



(b) Mid-Atlantic Bight

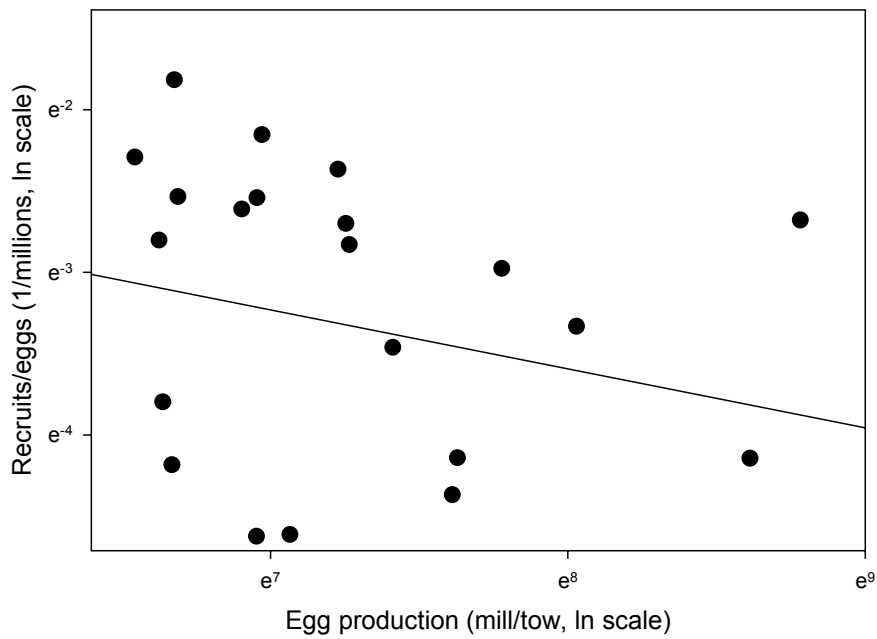


Figure B3-4. Natural mortality as estimated by clapper ratios, assuming the clapper separation rate given by Merrill and Posgay (1964).

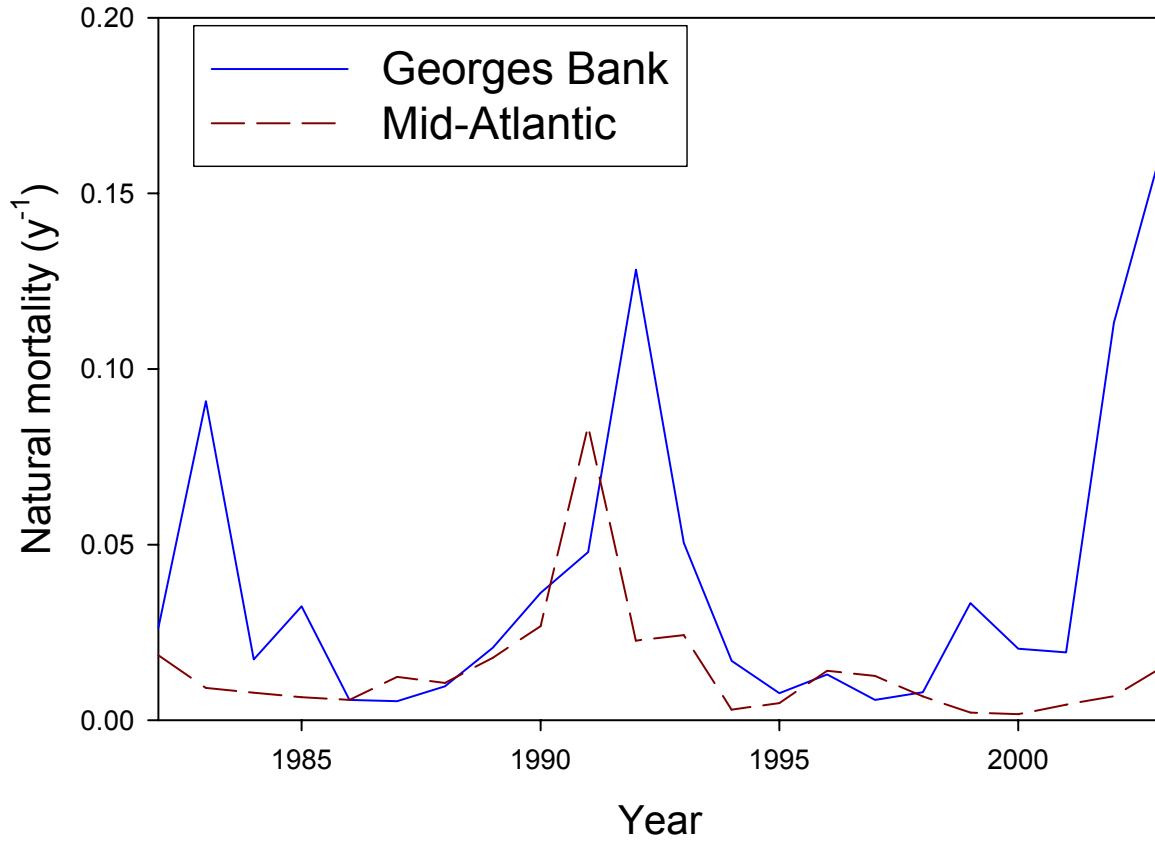


Figure B4-1. Sea scallop management timeline since 1982. “MPP” denotes meats per pound.

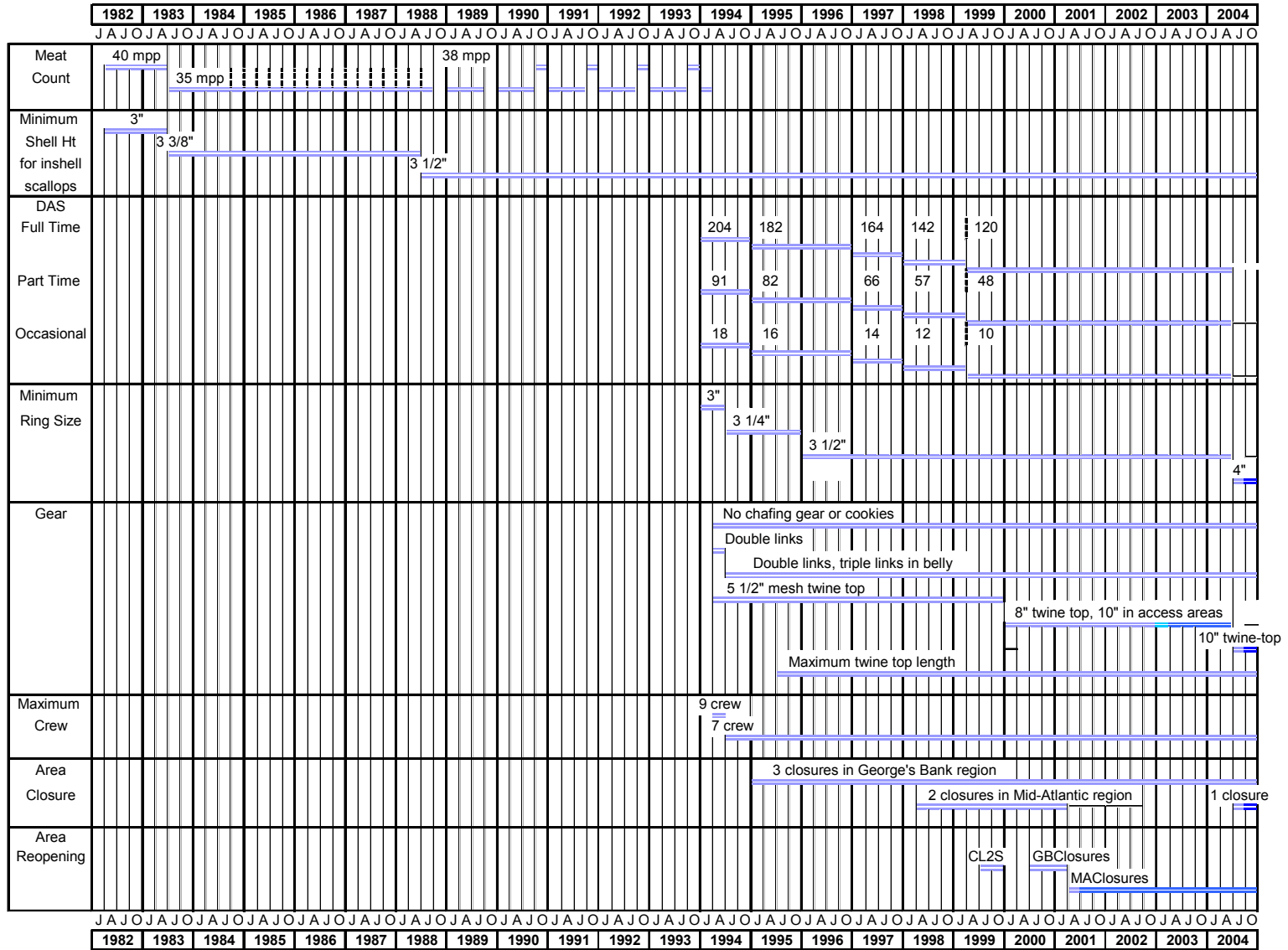


Figure B4-2. Long-term scallop landings (MT meats) in NAFO areas 5 and 6 (U.S. and Canada Georges Bank)

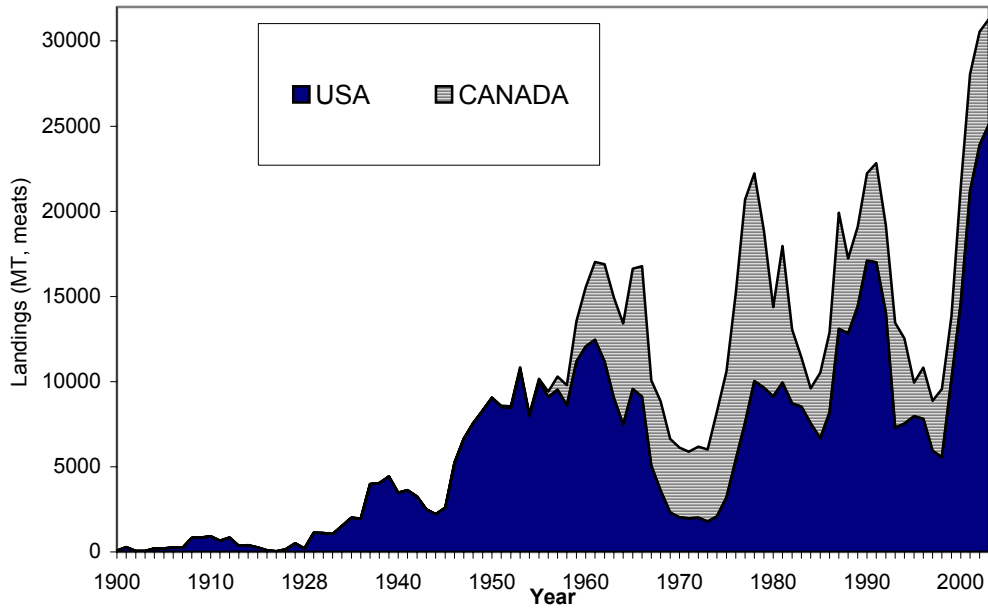


Figure B4-3. U.S. landings by region, 1964-2003.

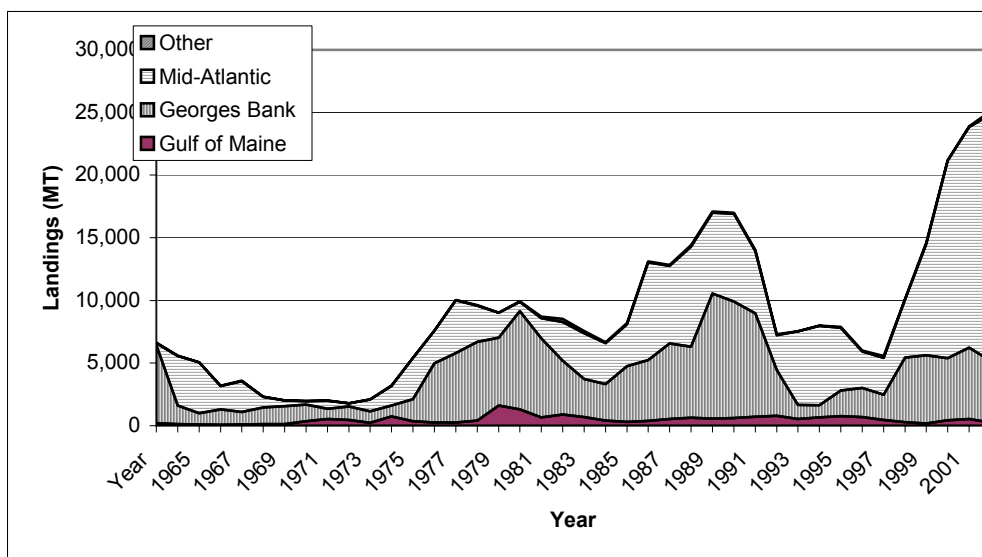


Figure B4-4. Landings-per-unit effort (lbs meats per day absent) for Georges Bank and the Mid-Atlantic Bight.

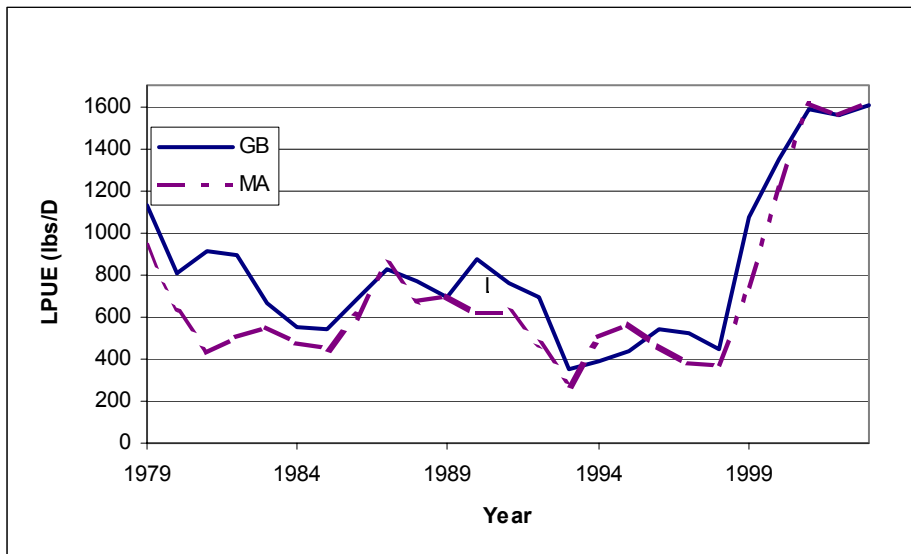


Figure B4-5. Cull sizes (the point of 50% retention) and discarded to kept ratios (by weight) for observed scallop trips (excluding closed area access trips).

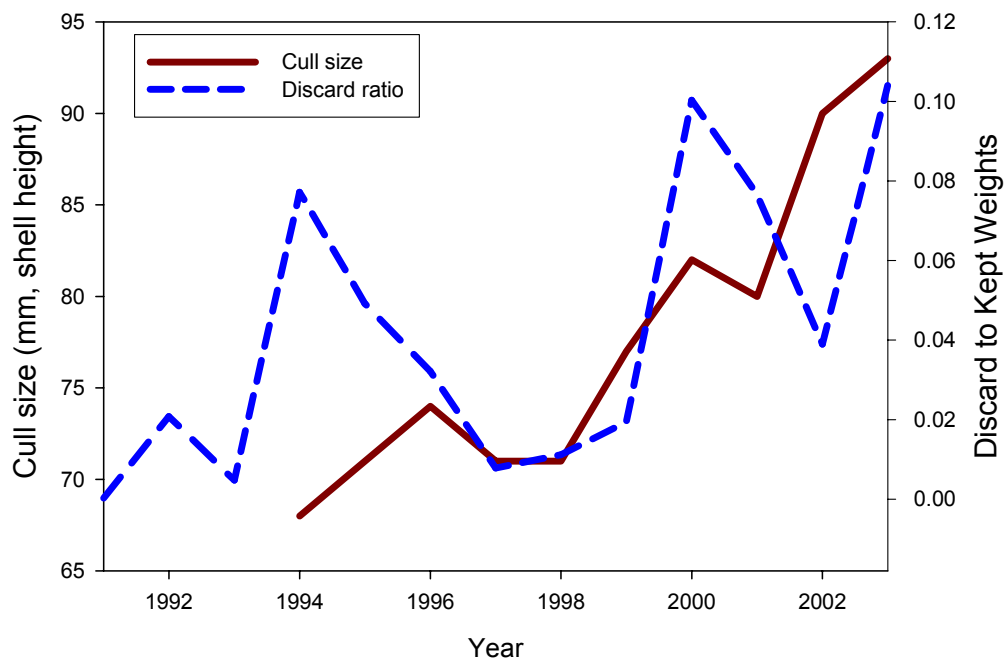


Fig. B5-1. Comparison of observed and predicted shell height frequencies for lined and unlined dredges with 2.0 inch rings from the Serchuck and Smolowitz (1980) experiments. Input data shown in top panel; model comparisons in bottom panel.

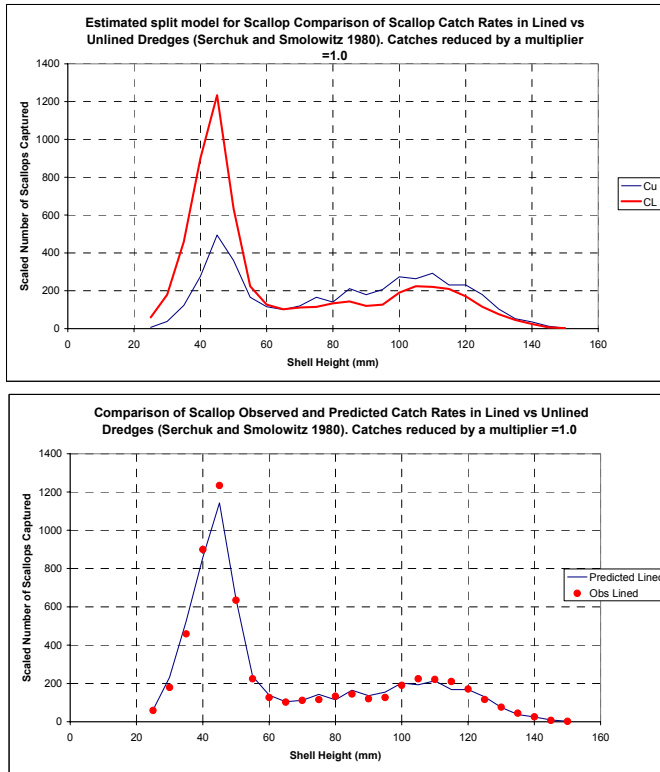


Figure B5-2. Estimated selectivity of the lined survey dredge.

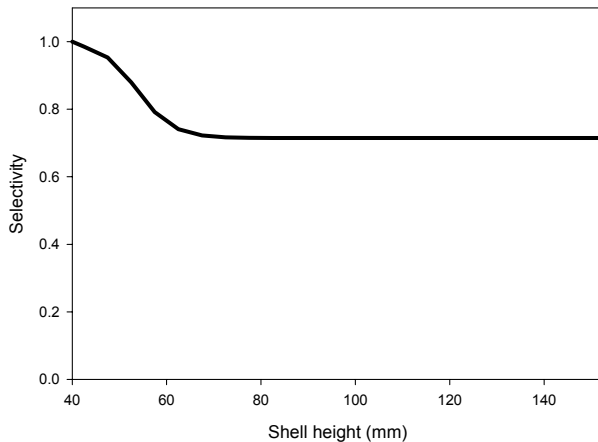




Figure B5-3. Estimated selectivity of commercial scallop dredges with 3.5” and 4” rings. The solid line is the 3.5” ring dredge selectivity from SARC-23, the dashed-dotted line is the estimated selectivity from the F/V Tradition experiment, and the long dashed line is the estimated 4” ring selectivity.

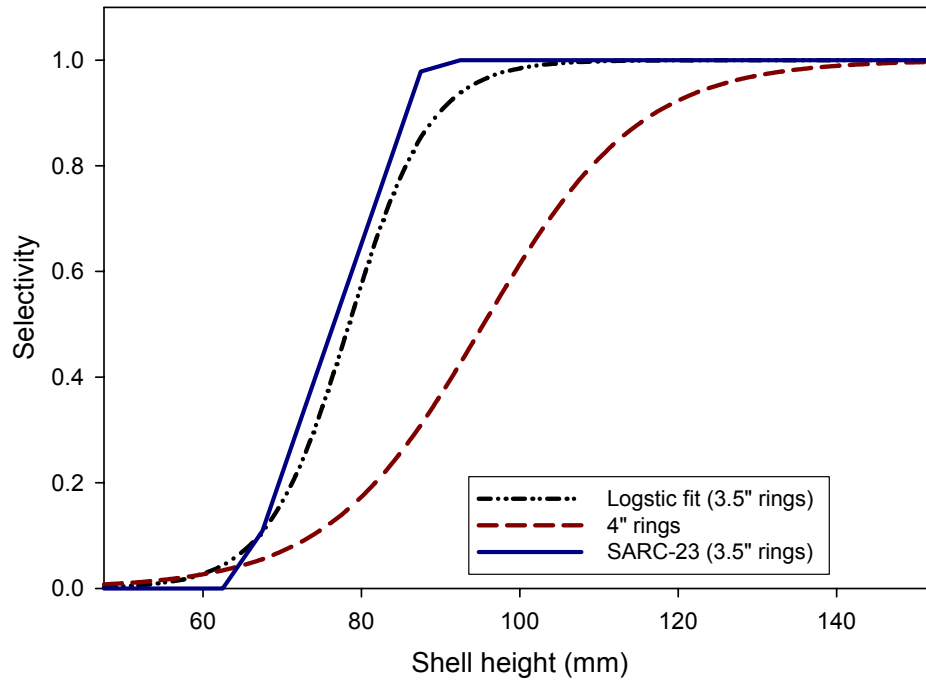


Figure B5-4. Typical inclinometer traces from 15 minute tows in the 2003 NMFS scallop survey.

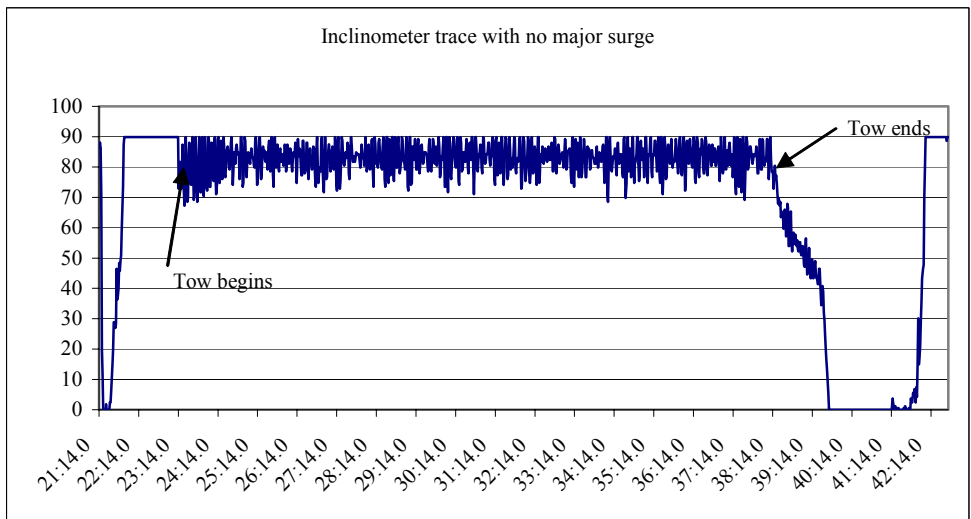
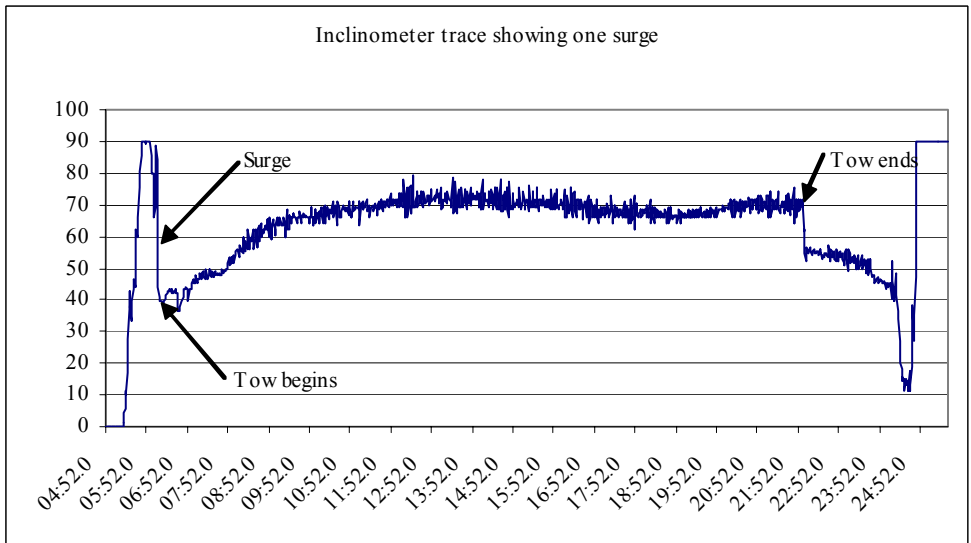
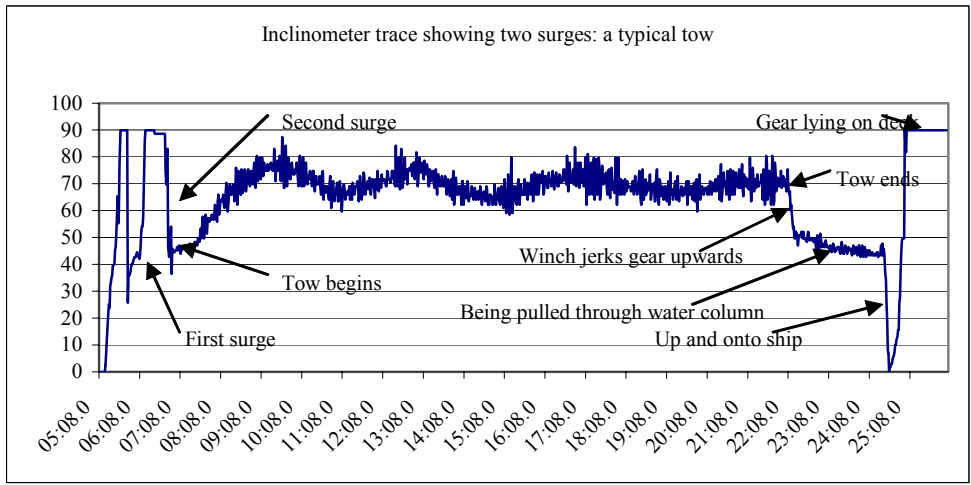
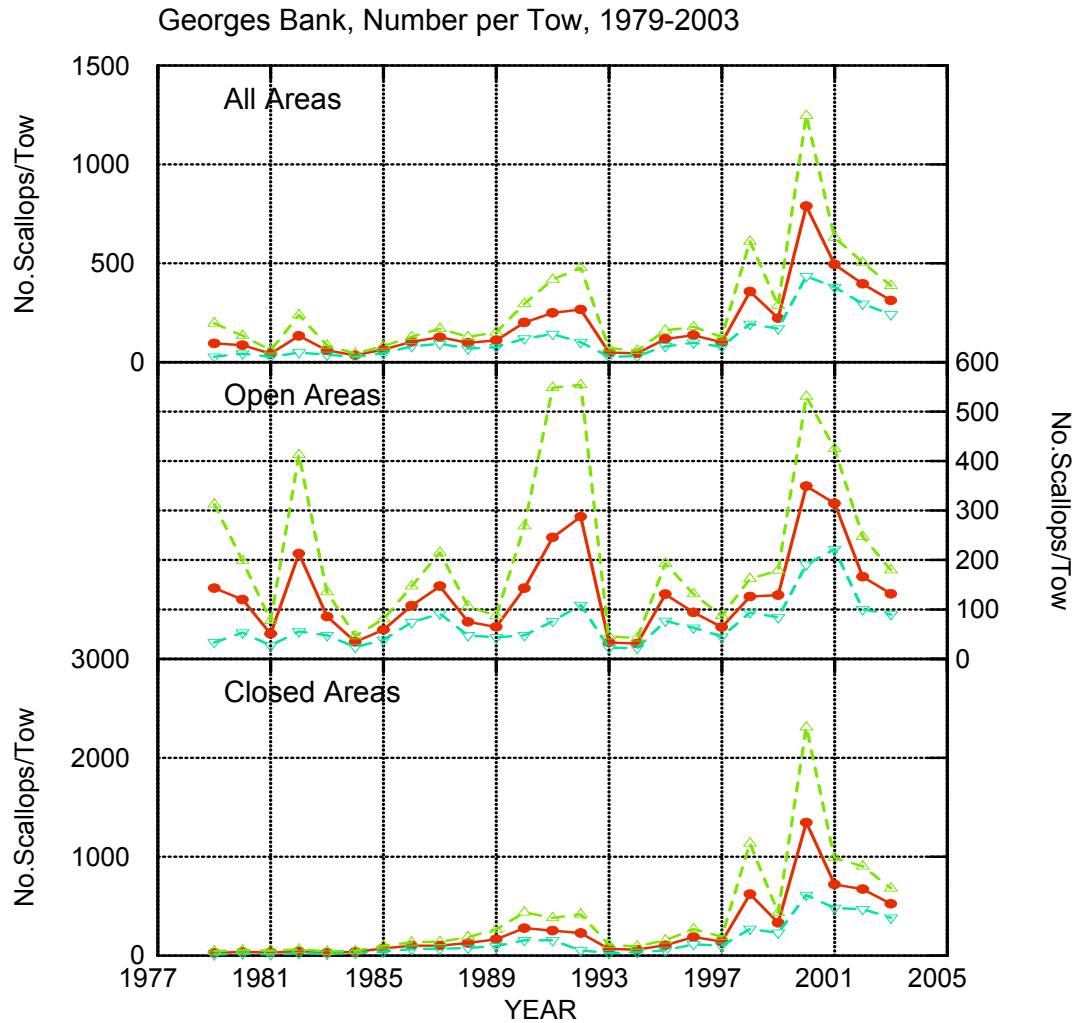


Figure B5-5. Stratified mean sea scallop abundance (>40 mm) in Georges Bank and the Mid-Atlantic, overall, and open and closed, with bootstrapped confidence intervals. Note the changes in scales for the graphs.

(a)



(b)

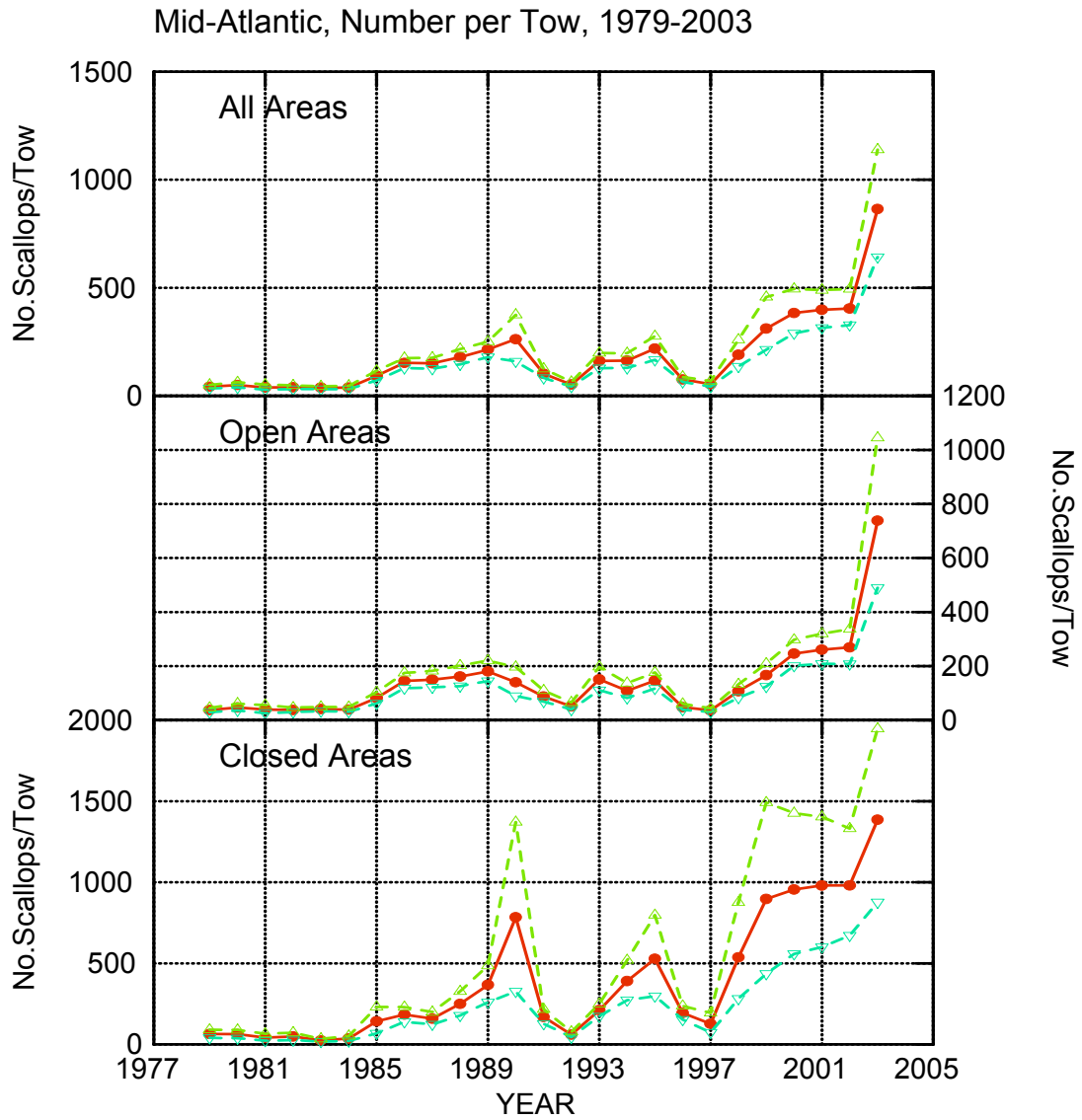
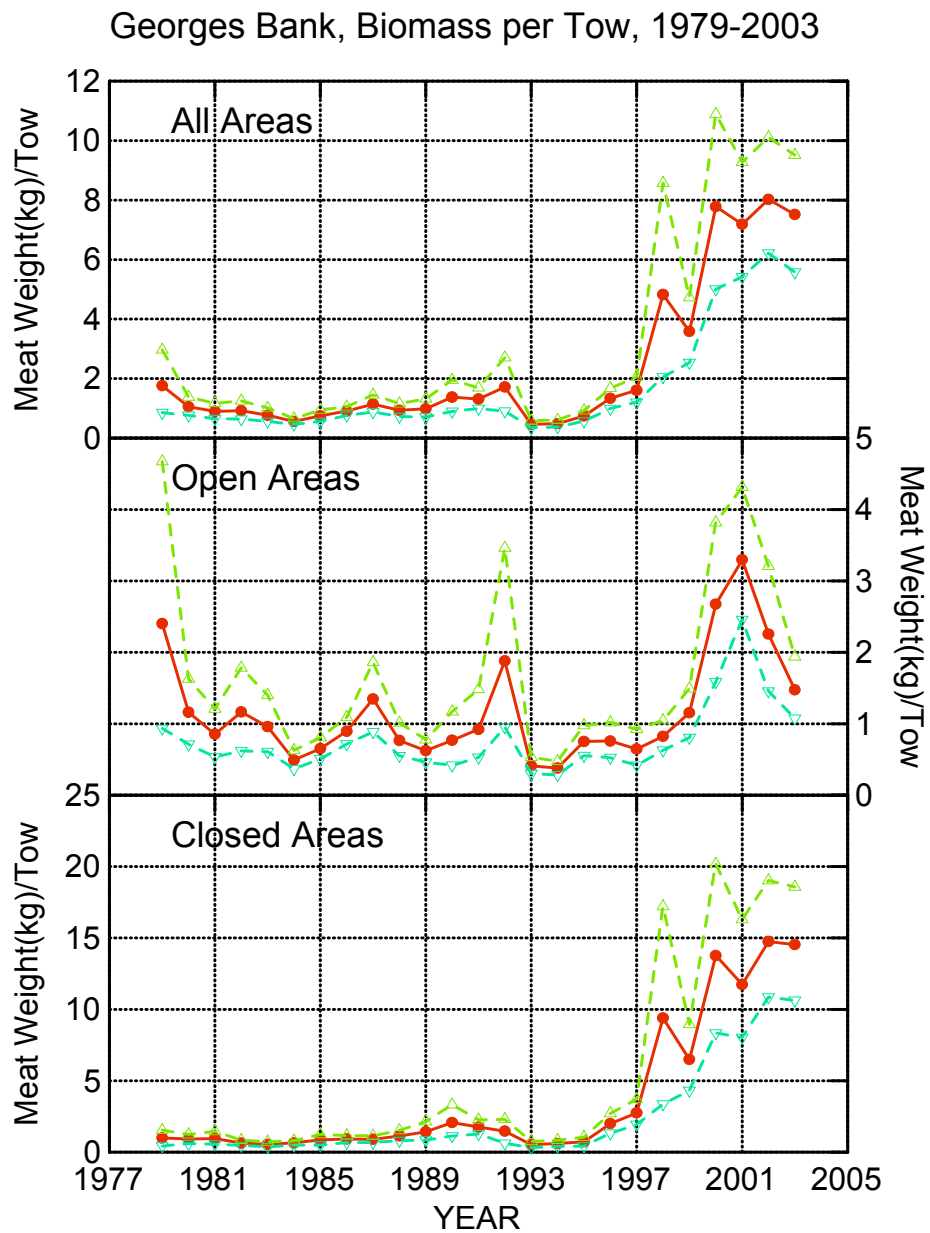


Figure B5-6. Stratified mean sea scallop biomass in Georges Bank and the Mid-Atlantic, overall, and open and closed, with bootstrapped confidence intervals. Note the changes in scales for the graphs.

(a)



(b)

Mid-Atlantic, Biomass per Tow, 1979-2003

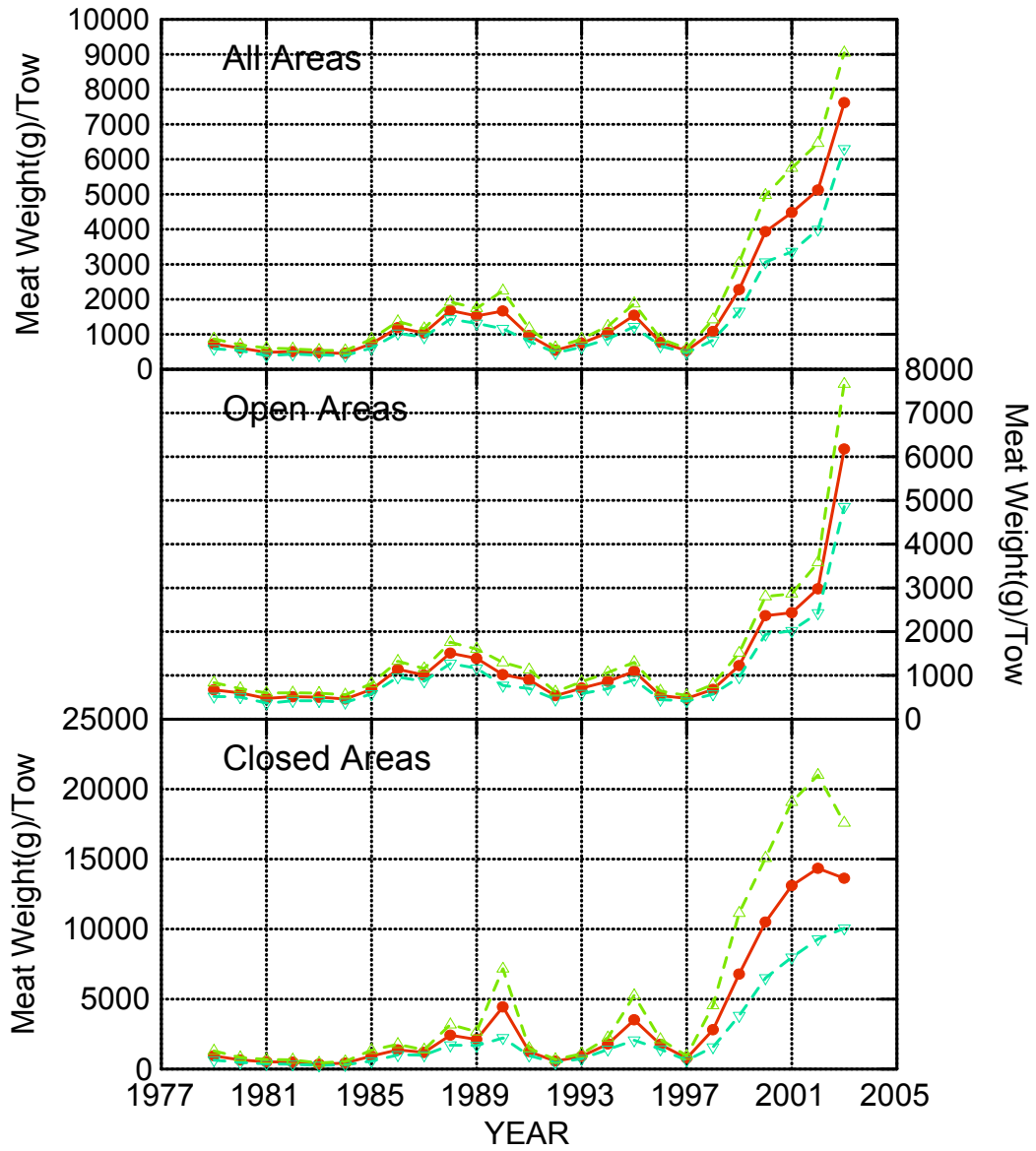
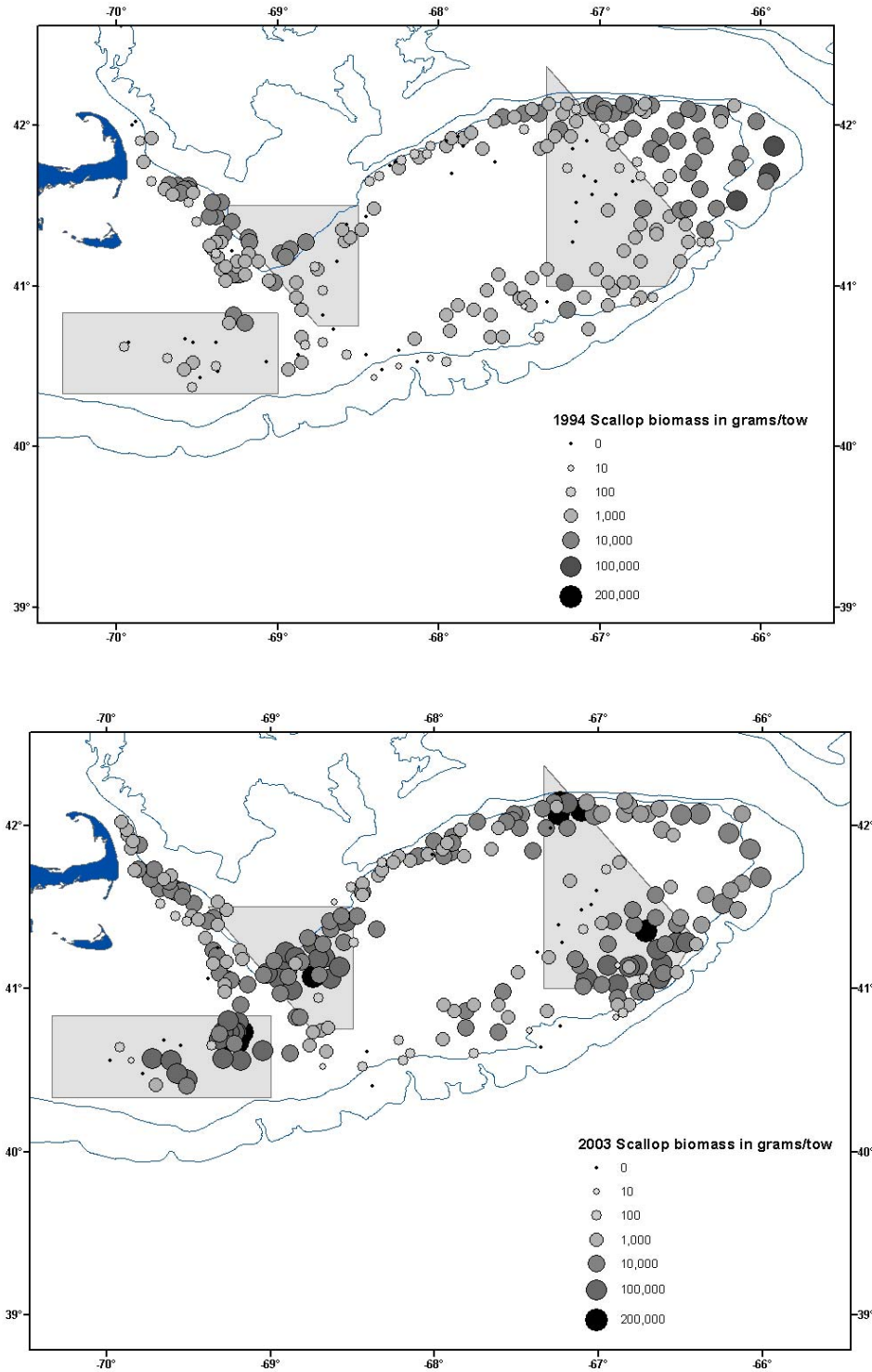


Figure B5-7. Comparison of biomass distributions on Georges Bank and the Mid-Atlantic in 1994 and 2003.

(a) Georges Bank



(b) Mid-Atlantic.

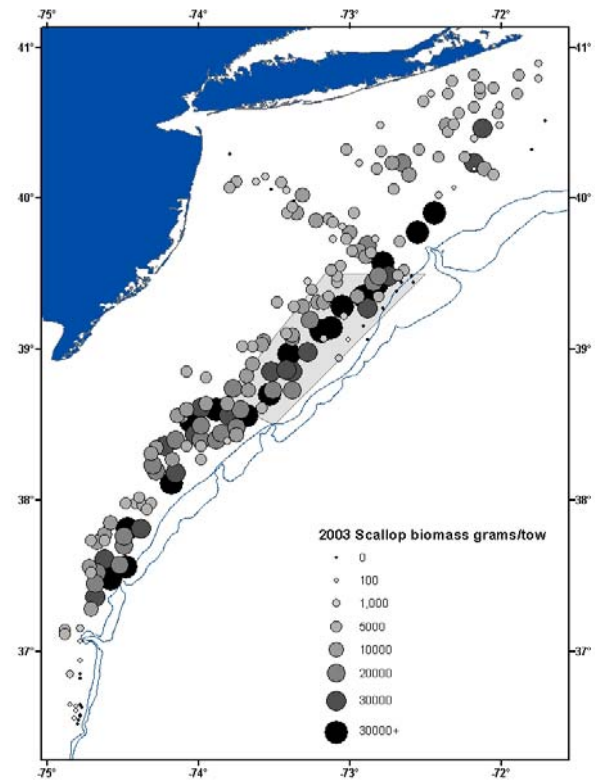
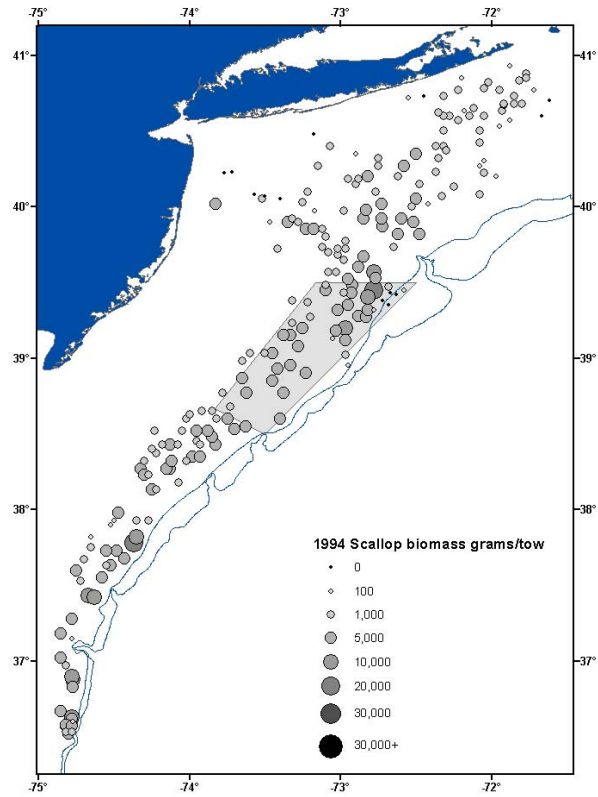
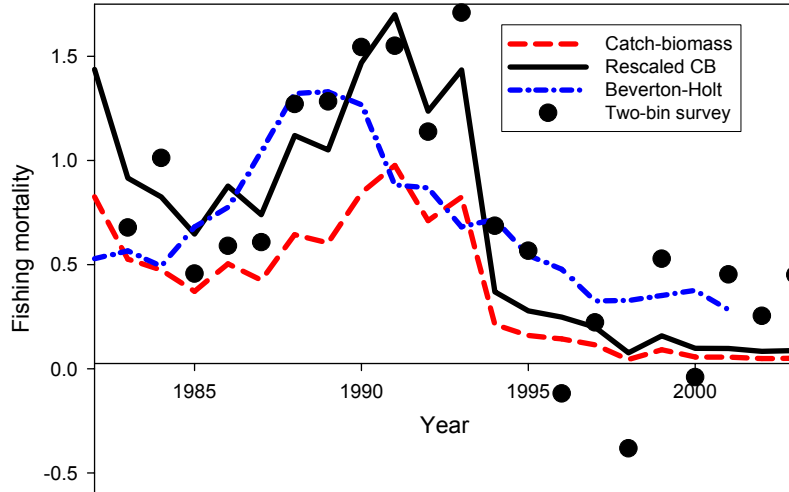


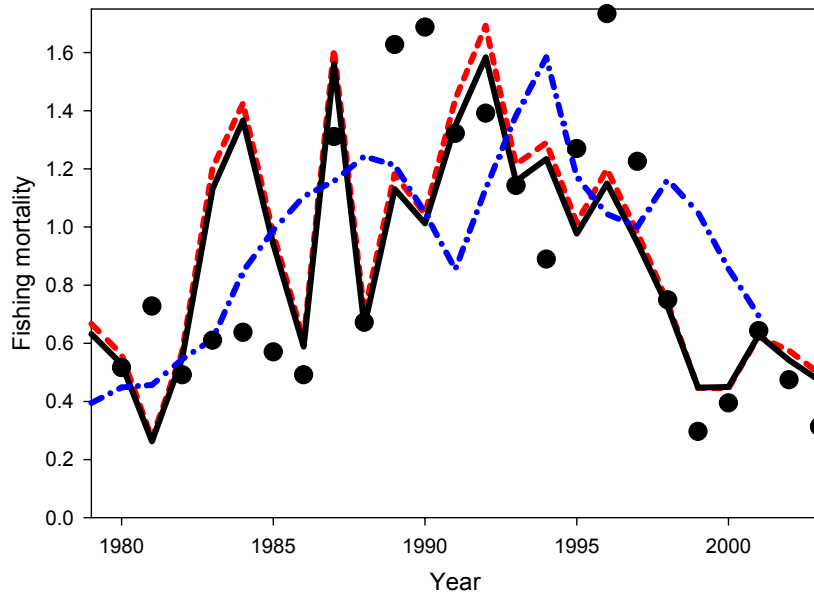


Figure B6-1. Estimates of fishing mortality (Two-bin survey, catch-biomass, rescaled catch-biomass, and Beverton-Holt) for Georges Bank, Mid-Atlantic, and combined.

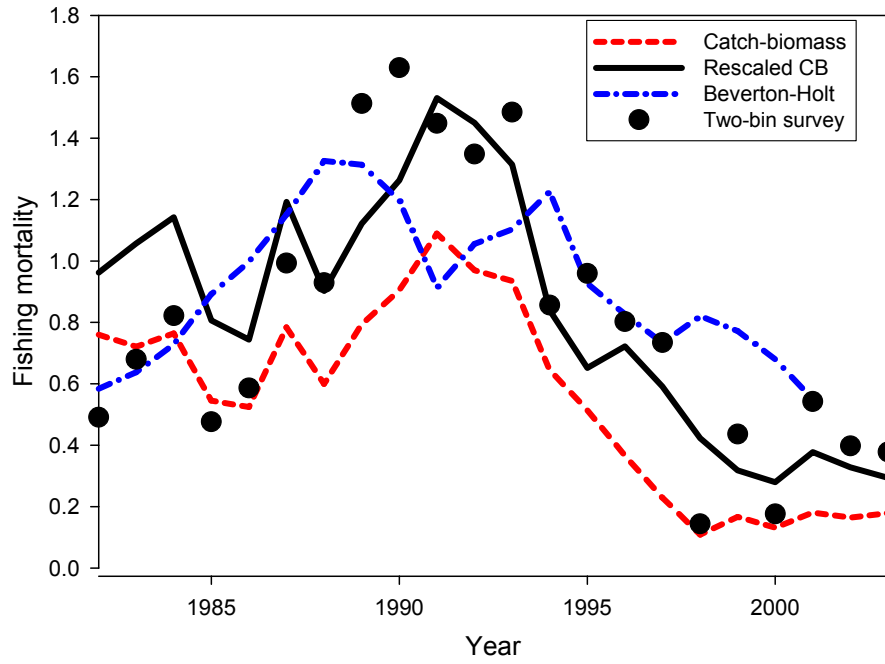
(a) Georges Bank



(b) Mid-Atlantic



(c) Overall



## **APPENDIX 1. MEASUREMENT ERRORS IN SHELL HEIGHT MEASUREMENTS FROM VIDEO AND DREDGE SURVEYS**

The School of Marine Science and Technology (SMAST) at the University of Massachusetts, Dartmouth and the Northeast Fisheries Science Center (NEFSC) carried out collaborative experiments during February 2004 to characterize potential measurement errors in sea scallop shell height data collected during video and dredge surveys. Measurement errors are present to varying degrees in all types of survey data and it is important to know if they are large enough to affect stock assessment results and fisheries management advice. Data sets with measurement errors may provide information not elsewhere available and it is usually possible to accommodate measurement errors, once they are quantified, using modern stock assessment modeling techniques. For example, SMAST video data are valuable because they likely sample scallops over a broad range of lengths (80+ mm) with high and constant efficiency. The NEFSC survey dredge, for example, has lower efficiency for large scallops that must be accommodated when using dredge survey data. Even large measurement errors may be tolerated if large quantities of data can be collected inexpensively. In any case, decisions about how to interpret and use data are easier to make once the nature of any measurement errors is determined.

Shell height data are an important element in stock assessment work for sea scallops because shell heights are converted to meat weights that are used to calculate stock biomass. Meat weight increases as a cubic function of shell height so that doubling the shell height of a sea scallop would, for example, increase its meat weight by about 8-fold. Thus, relatively small errors in shell height data might result in significant under- or over estimation of stock biomass. Moreover, maximum shell height and shell height composition data are used to estimate growth and mortality parameters used in estimating stock status and in calculating biological reference points used by managers.

The SMAST/NMFS study was designed to measure two types of measurement errors: 1) errors that systematically bias shell height data so that measurements are consistently lower or higher than actual shell height, and 2) random measurement errors that increase the variability of shell height measurements making them higher or lower than the actual shell height without affecting the mean. Both types of errors are potentially important. The former tend to bias stock biomass estimates. Effects of the latter are more complex. Random errors obscure information about growth and recruitment strength in shell height composition data, by shifting scallops from modal shell height groups to adjacent shell height groups (i.e. by “smoothing” the length composition). Large random measurement errors may artificially increase the apparent abundance of very large or small scallops. The rapidly increasing nature of shell height-meat weight relationships in scallops means that a 10% increase in shell height generates a change in meat weight that is larger than the decrease in meat weight from a 10% decrease in shell height. Consequently, biomass estimates will be biased with symmetrical (equal positive and negative) random errors in shell heights data.

The purpose of the collaborative SMAST/NEFSC experiments was to estimate measurement errors in shell height data collected routinely in video surveys and using measurement boards which have been used since the late 1970's to collect shell height from scallops taken during NEFSC dredge surveys. For experiments, video and measuring board shell height measurements were compared with accurate shell height measurements made using scientific calipers. Caliper measurements are least affected by measurement errors and were used as a presumably accurate "standard" in data analysis. SMAST and NEFSC staff carried out all of the experimental work at the SMAST facility in New Bedford, analyzed the data, and prepared this report collaboratively.

### *Materials and Methods*

Shell height of a sea scallop is the longest distance between the umbo and the shell margin. The NEFSC scallop survey (Serchuk and Wigley, 1986) uses a measuring board to record shell heights to the nearest 5 mm interval. For example, a scallop with shell height = 54.7 mm falls into the 50.0-54.9 mm shell height group and, in the absence of any measurement errors, would be recorded as 52.5 mm in the NEFSC scallop survey. Measurement boards used in experiments were standard equipment actually used on scallop surveys. During surveys, a number of technicians measure scallops using different measurement boards (each scallop is measured once). All scallops are measured unless the tow is unusually large, in which case all scallops in a large random subsample are measured. These procedures reduce errors in characterizing shell height composition for survey catches due to subsampling. Errors may depend on the height of the technician to the extent that the technician's eye will be higher above the board.

Scallops are placed on measuring boards with the umbo resting on the bottom of the board and ventral valve (bottom shell) down (towards the board). Technicians sit with the board in the middle of their field of view and a tally device is used to record the number of scallops in each 5 mm interval. Measurement errors may occur because the ventral valve of scallop shells is rounded and the technician looks down at the shell margin (which lies above the board) towards the measurement marks. The shell may roll somewhat against the board. The technician may record a shell height observation using the wrong shell size group.

SMAST conducted video surveys during 1999-2003 using methods described by Stokesbury et al. (2002) and Stokesbury et al. (2004). Briefly, a video camera mounted at the top of a steel pyramid-shape frame gives a 2.8 m<sup>2</sup> image of the sea floor (in calculations, the assumed area is increased to 3.235 m<sup>2</sup> to compensate for "edge" effects). Video survey stations are arrayed in a systematic pattern along the coast and four images are collected at each station. After the first image is collected, for example, the pyramid is raised so that the sea floor can no longer be viewed, the vessel is allowed to drift for approximately 50 m, and then the pyramid is lowered again to collect the second image. After the pyramid touches bottom, the field of view is allowed to clear before a video image is captured for analysis.

Images of the sea floor are recorded on a high resolution S-VHS tape. The time, depth, number of scallops observed, and latitude and longitude from differential GPS are recorded for each image. Video survey gear includes an additional smaller camera mounted lower and on the side of the pyramid that is useful for identifying and counting small specimens. Experimental results for the small camera are not presented here because the large camera is used to obtain data most immediately useful for stock assessment work.

VHS video survey images (Appendix Figure 1-1) are replayed in the laboratory where a digitized image with each scallop uniquely identified is created using Image Pro Plus<sup>®</sup> software. A technician placed the computer cursor on the umbo and the outer margin of each shell so that Image Pro calculated and the distance between the two points. Shell height data from video measurements are recorded to the nearest mm.

Measurement errors in video shell height measurements may arise from a variety of factors. The maximum resolution of the video system is 3 mm due to pixel size so that, for example, a 100 mm scallop measured properly might be recorded as being 99 or 102 mm. There may be errors in cursor placement during the measurement process. Irregularities on the bottom and the angle of the scallop with respect to the camera may contribute to measurement errors.

Scallop shell height data from video images are affected by the distance between the scallop and the center of the sampling frame because specimens further from the middle are also further from the camera. Other factors, such as lens curvature and resolution of video equipment, also appear important. Correction factors to adjust for distance from the middle of the sampling frame have been developed but are currently uncertain. Moreover, it is theoretically possible to make adjustments for bias but it is probably not possible to use correction factors to remove random errors from shell height data (a more promising approach is to include measurement errors in models fit to the data). For example Stokesbury et al. (2002) used a “step” correction factor and Stokesbury et al. (2004) used the “curve” correction factor:

$$c = sh \sqrt{\frac{(x)^2 + (y)^2}{(y)^2}}$$

where:

c = corrected shell height (mm)

sh = original shell height (mm)

y = vertical camera height from the base of the sampling pyramid

x = distance from the center of the quadrant (mm).

Results for video data with and without the curve correction factor are presented in this report.

Damaged shell margins due to the survey dredge; previous encounters with commercial gear, and benthic predators may all cause measurement errors in shell height data from measurement boards, video gear and calipers. However, these factors had little

effect on experimental data where the goal was to measure the shell heights (including broken edges) by various methods using the same scallops or scallop shells.

Measuring board and video shell heights for the same scallop or group of scallops collected by different technicians were treated as independent observations in this analysis because the data from both surveys used in stock assessment modeling are single measurements from one technician. It should be possible to use the experimental data to quantify the component of variance in shell height data due to differences among technicians in both surveys. Some results of this analysis are relevant but the topic is outside the scope of this report.

#### Experiment I (live scallops)

Live scallops ( $n=393$ , caliper shell heights 56-141 mm) were collected by fishing vessels during early February, taken to the laboratory and then divided in a haphazard fashion into ten groups with 24-61 individuals per group. Each group was held until needed in laboratory tanks filled with seawater inside mesh bags labeled 1-10 for identification. Scallops from one group at a time were placed haphazardly on sand and gravel spread under the video equipment in a large tank filled with seawater (sand and gravel were used to mimic some types of natural irregularities in the sea floor). Shell height data were collected from the video images using standard video survey procedures with four shell height measurements made independently for each specimen by four different persons. In addition to video measurements, all of the scallops in each group were individually measured once with calipers by one technician and once independently by each of three technicians using different measuring boards.

Mean shell height and shell height composition information for each type of measurement, as well as scatter plots and linear regression were used to characterize bias and random errors. It was not possible to evaluate measurement errors for individual scallops in Experiment 1 because individual scallops in the experiment were not uniquely identified. It was possible to estimate bias as, for example, the mean shell height for board measurements minus the mean shell height for caliper measurements.

#### Experiment 2 (numbered scallops shells)

In the second experiment, the dorsal valve (top shell) of 172 individual scallop shells (caliper shell heights 39-192 mm) was marked with unique labels so that video, measurement board, and caliper shell heights could be compared for each individual shell. Labels were inside (under) the valve to prevent identification by technicians while measurements were taken. For video measurements, the shells were placed haphazardly on sand and gravel at the bottom of a tank filled with seawater. Two technicians (rather than four as in Experiment 1) were available for collecting measuring board shell height data during the second experiment.

## Results

### Experiment 1 (live scallops)

Shell height measurements by measuring boards all had a slight negative bias (-0.4 to -0.9 mm, Appendix Table 1-1). Video measurements without the curve correction factor had a usually negative bias (-1.4 to 0.5 mm) while video measurements with the correction factor showed relatively high positive bias (3.3 to 5.4 mm).

Shell heights from measuring boards were relatively precise (Appendix Figure 1-2). Combining individual board and caliper measurements for all groups, the standard error of residuals around the regression line  $\ln(SH_{board}) = \alpha \ln(SH_{video})$  was 0.017 ( $\alpha=0.998$ ,  $R^2=0.99$ ). Assuming a multiplicative model with constant CV, these results indicate that the CV for measurement errors in board shell height data is about 1.7%. This technique was not applied to video data because it was not possible to link individual video and caliper shell height measurements for live scallops.

### Experiment 2 (numbered scallops shells)

Measurement errors for individually identified scallop shells in Experiment 2 were characterized by computing the mean and standard deviation of shell height differences for each shell (e.g. video shell height minus caliper shell height), and with Bland-Altman plots (Bland and Altman 1986; Bland and Altman 1995). Bland-Altman plots are designed to avoid spurious conclusions in comparing data with measurement errors to a relatively precise standard.

As in Experiment 1, results for uniquely labeled shells showed a small negative bias for measuring boards (Appendix Table 1-2). Video measurements without the curve correction had a substantial negative bias (-5.8 to -4.0 mm). Video measurements with the curve correction factors had an intermediate positive bias (0.4 to 2.4 mm). Bland-Altman plots confirm these patterns and suggest that the standard deviation of random measurement errors probably increases with shell size (Appendix Figure 1-3). Increasing standard deviations indicate that random measurement errors for one technician may be multiplicative with a constant CV that is independent of shell size (rather than a constant standard deviation). Differences in results for live scallops in Experiment 1 and scallop shells in Experiment 2 were due to a much wider and more even range of lengths for shells in Experiment 2.

The CV for random measurement errors in each set of shell height data was estimated by applying normal measurement errors to caliper data and choosing the CV value that gave the best fit to the observed data (e.g. for video measurements by one technician, Appendix Figure 1-4). Assuming random errors had constant CV's and using curve corrected data, CVs for random measurement errors ranged 0.023 to 0.025 (average 0.024) for measuring boards and 0.053 to 0.084 (average 0.072) for video measurements by different technicians.

## Discussion

Shell height data from video (without curve corrections) and measurement boards involve measurement errors that cause a negligible negative bias. Random measurement errors were smaller in shell height data from measuring boards. Based on live scallops, the CV for random errors with measurement boards averaged 0.024. For a 100 mm sea scallop, the 95% probability interval for measurement errors with measurement boards would be  $-4.8$  to  $4.8$  mm. The proportion of shell height measurements assigned to an incorrect 5 mm shell height group with measurement boards would be roughly  $2 * P(z < -2.5/2.4) = 30\%$  where  $P(z)$  is the cumulative probability for  $z$  from a standard normal distribution. Very few random measurement errors (about  $2 * P(z < -7/1.7) = 0.18\%$ ) would be large enough to place a shell in shell height groups beyond those just above and below the true shell height group.

CVs for random measurement errors in video shell height data averaged 7.2 mm. For a 100 mm scallop, the 95% probability interval for random measurement errors is wider ( $-14.4$  to  $14.4$  mm for a shell height of 100 mm). Roughly 73% of shells would be assigned to the wrong 5 mm shell height group using video shell height measurements. A relatively large proportion (30%) would be assigned to shell height groups beyond the first groups above and below the true shell height group.

The SMAST/NEFSC experiments could be used to help characterize the relationship between lengths of scallops and scallop shells on the bottom of the tank and lengths in experimental video survey data. However, sampling by dredges was not included in experiments. Therefore, potential differences between the shell height distributions of scallops on the bottom of the ocean and scallops in dredge survey catches due to size specific selectivity patterns were not addressed. Similarly, measurement errors from the video may be smaller under controlled conditions in a tank than in the field.

It would be useful to conduct additional experiments with a large number of individually marked live scallops with higher proportions at small and large sizes. An even distribution of shell heights for live scallops is important because bias with and without curve correction factors differed between Experiment 1 and Experiment 2 because of differences in size composition of live scallops and shells. Data used here were sufficient to characterize measurement errors in broad terms but at least one additional experiment (preferably with individually marked live scallops) is required if more precise estimates of measurement error are required. In future experiments, it might be worthwhile to evaluate differences in shell height measurement errors due to different individuals collecting measuring board and video data.



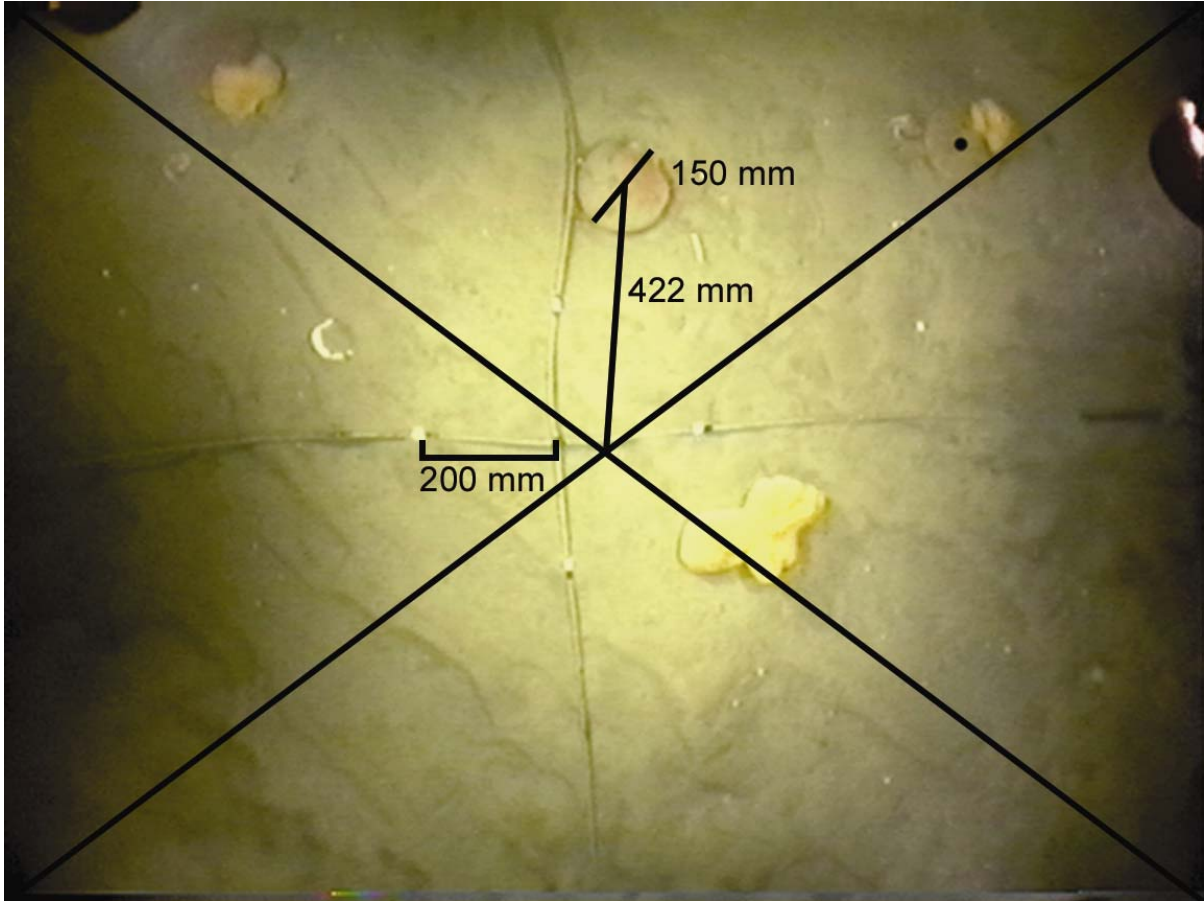
Appendix Table 1-1. Mean shell heights (mm) and bias estimates (in mm relative to caliper measurements, e.g. the mean for measuring board one minus the mean of caliper measurements) for live scallops in experiment 1. Means for all groups combined are the simple average of the means for each group.

Group	Board 1	Board 2	Board 3	Video Data Without Correction Factor				Video Data With Correction Factor				Calipers	N
				Technician 1	Technician 2	Technician 3	Technician 4	Technician 1	Technician 2	Technician 3	Technician 4		
1	102.9	103.5	102.5	101.7	100.9	102.3	102.6	106.5	105.6	107.3	107.4	103.7	45
2	98.3	98.5	97.9	95.6	98.2	97.7	96.9	101.1	104.1	103.5	102.5	98.8	36
3	97.0	97.3	96.4	95.2	96.7	96.4	93.4	100.2	102.2	101.6	98.7	97.8	54
4	103.3	103.5	103.1	104.6	105.2	105.2	104.3	108.1	109.0	109.0	107.8	103.1	26
5	95.7	95.7	95.0	95.2	96.0	96.1	93.4	99.6	100.4	100.5	97.6	96.2	44
6	100.1	100.1	99.7	102.6	103.2	103.7	100.2	106.3	107.6	107.6	103.8	100.6	25
7	97.3	97.9	96.9	95.9	96.7	99.7	93.8	101.5	102.3	105.3	98.7	98.8	25
8	101.3	101.6	101.1	104.5	101.2	103.8	101.2	110.2	106.8	109.4	106.7	101.9	28
9	102.8	103.6	104.2	105.2	103.6	104.6	103.5	109.9	108.3	109.3	108.0	103.9	50
10	97.9	97.8	97.6	99.2	97.4	98.6	100.1	104.2	102.4	103.6	105.3	98.5	60
Averages	99.7	99.9	99.4	100.0	99.9	100.8	99.0	104.8	104.9	105.7	103.6	100.3	393
Bias	-0.7	-0.4	-0.9	-0.4	-0.4	0.5	-1.4	4.4	4.5	5.4	3.3		

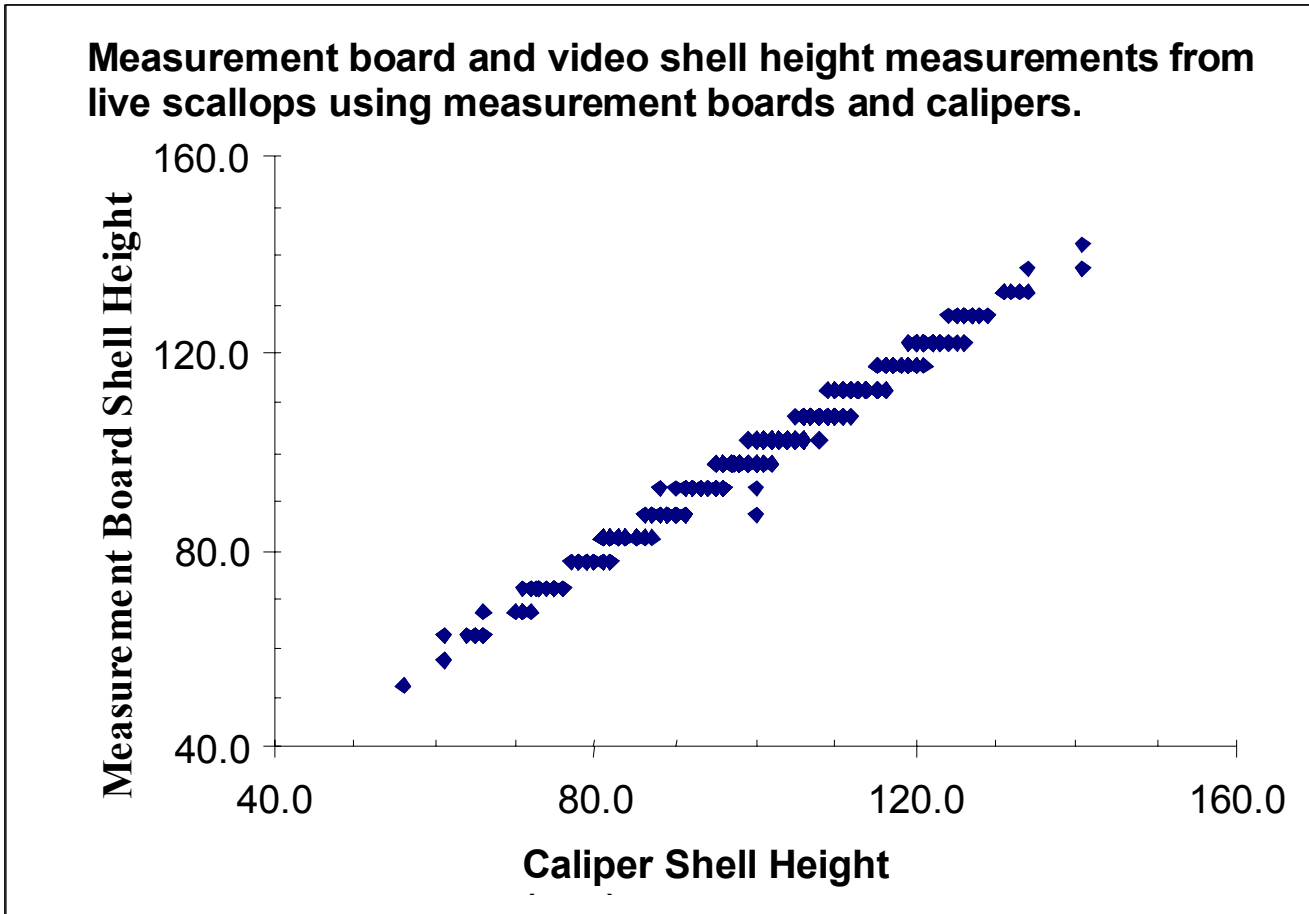
Appendix Table 1-2. Means and standard deviations (mm) for differences (e.g. measuring board – caliper) in shell height measurements from individually labeled scallop shells. Differences between measurements by different technicians (1-4 for video data; 1-2 for measuring boards) and caliper shell heights. Results are shown for video shell heights with and without a correction factor.

<b>Technique, technician and correction</b>	<b>Mean Difference (mm)</b>	<b>SD (mm)</b>
Video 1 no curve correction	-4.0	5.7
Video 1 with curve correction	2.3	5.8
Video 2 no curve correction	-4.3	7.0
Video 2 with correction	2.0	7.2
Video 3 no curve correction	-4.0	5.5
Video 3 with correction	2.4	5.7
Video 4 no curve correction	-5.8	6.0
Video 4 with correction	0.4	5.9
Measuring board 1	-0.9	1.7
Measuring board 2	-0.4	1.6

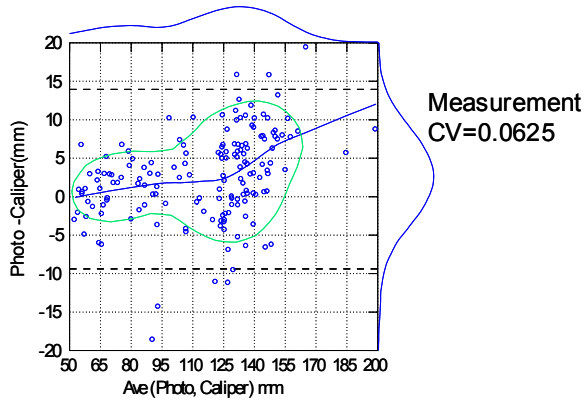
Appendix Figure 1-1. Digitized SMAST video survey image.



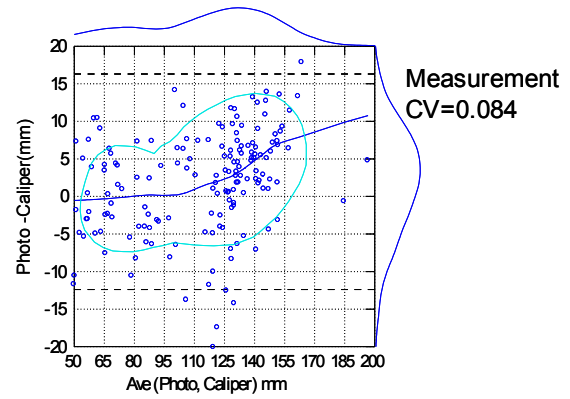
Appendix Figure 1-2.



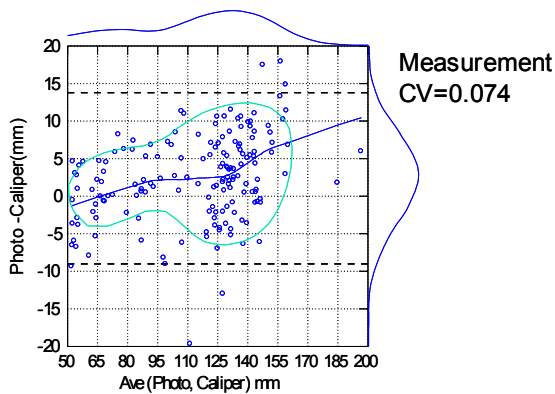
Bland-Altman Plot: Caliper vs Curve Video: Observer M1



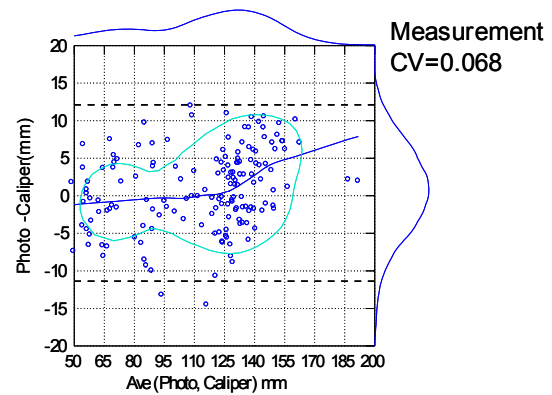
Bland-Altman Plot: Caliper vs Curve Video: Observer M2



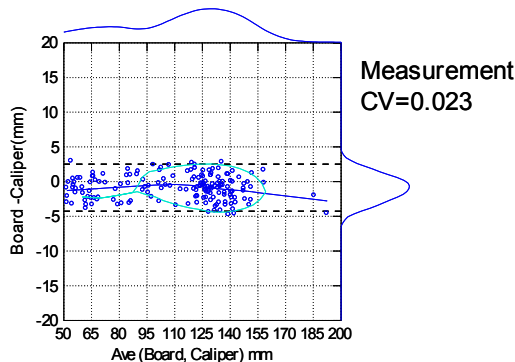
Bland-Altman Plot: Caliper vs Curve Video: Observer M3



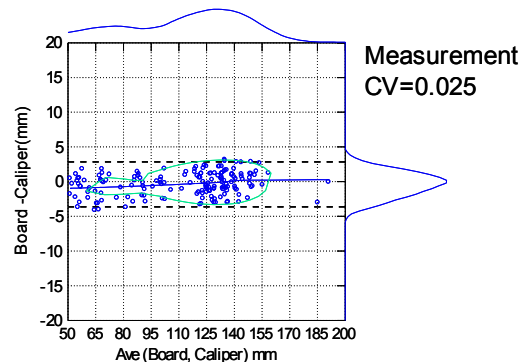
Bland-Altman Plot: Caliper vs Curve Video: Observer M4



Bland-Altman Plot: Caliper vs Board: Observer M5

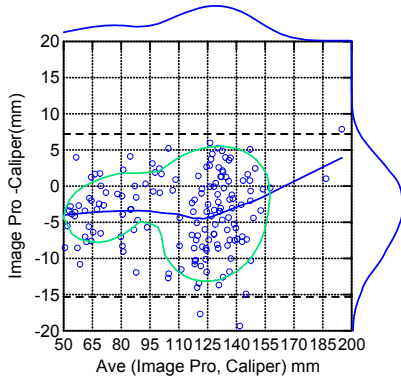


Bland-Altman Plot: Caliper vs Board: Observer M6

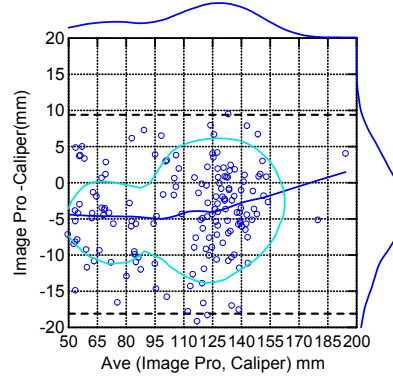


Appendix Figure 1-3. Bland-Altman plots for video and measuring board shell height (mm) measurements by different technicians using caliper measurements as an accurate standard. There were four technicians for video data and two technicians for measuring board data. Video data include curve corrections that worsen bias but have little effect on variance. The y-axis in each plot represents the difference between the measurement and standard. The x-axis gives the mean of the measurement and standard. The dashed bounds represent +/- two standard deviations of the differences. A lowess smooth (tension=0.5) line in each plot shows trends in bias related to shell size. The marginal distributions of the x and y-axes are shown probability distributions estimated using nonparametric kernel smoothers. The area enclosed by the smooth curves is a nonparametric kernel estimate for a 70% confidence region on the bivariate distribution of the data. CV's for random measurement errors were estimated by adding measurement error (assuming a constant CV) to the caliper data to achieve best fit to the measurements.

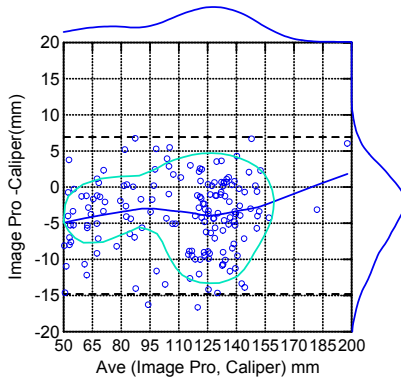
Bland-Altman Plot: Caliper vs Image Pro: Observer M1



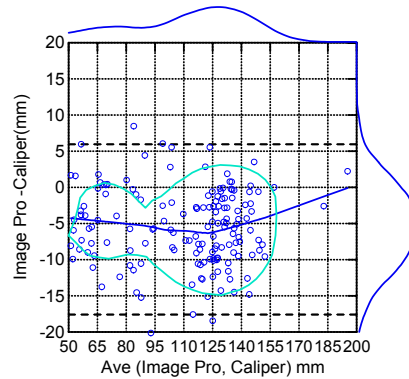
Bland-Altman Plot: Caliper vs Image Pro: Observer M2



Bland-Altman Plot: Caliper vs Image Pro: Observer M3



Bland-Altman Plot: Caliper vs Image Pro: Observer M4



Appendix Figure 1-4. Bland-Altman plots for video shell height (mm) measurements (with no correction factor) by different technicians using caliper measurements as an accurate standard. Axes, etc. as in Appendix Figure 1-3.

## APPENDIX 2. NEFSC PROPOSAL FOR ROCK CHAINS IN SCALLOP SURVEYS

Rock chains limit the size of rocks entering the NEFSC scallop survey gear and may increase safety for staff processing catches during the survey. NEFSC is considering using rock chains on all tows in certain rocky strata to improve safety, reduce damage to gear, and to save time. Results from a paired-tow experiment comparing the performance of the NMFS survey scallop dredge with and without rock chains on soft and rocky bottom types were reviewed to determine: 1) the strength of the statistical evidence for an effect of rock chains on sea scallop catch rates, particularly in rocky strata; 2) adequacy of potential correction factors for adjusting historical catch rates in rocky strata to equivalent catches with rock chains; and 3) tentative plans to continue collecting rock chain data.

Each station was assigned to a habitat type (either hard/rocky or soft/sandy) before the experiment based on historical survey data. Possible differences between catch rates for scallops for gear with and without rock chains were tested using a paired t-test with log-transformed catches. Data used in the test were the differences between log-transformed catches with and without rock chains at each station. For the hard bottom analysis, one of the tows by the gear with rock chains caught no scallops so the constant 1.0 was added to the catches from all tows before being the data were log transformed. The data were tested for normality to justify using the paired t-test. For all three sampling sites (pooled, hard, and soft) the log transformed values and the log-transformed values with the constant added were not significantly different from normal (Appendix Table 2-1).

Results for rocky habitats were most important because of plans to use rock chains in rocky areas. The paired t-test for rocky habitat with the constant added was significant ( $p$  value = 0.009) with a mean difference of 0.444 in the log scale and a standard deviation of 1.02. The 95% confidence interval was 0.770 to 0.119. Transformation of the mean to the original scale gave  $\exp(0.444)=1.56$  which suggests that rock chain catches average 56% larger than non-rock chain catches at the same site. This simple calculation ignores bias induced by exponentiation of lognormal random variables. Using an approximate bias correction, the conversion factor is  $1.56 * \exp[(1.02)^2/2] = 2.62$  (Appendix Table 2-2.).

The practice of adding a constant before log transformation may effect results and there is little guidance concerning what the value of the constant should be. The data for rocky habitats were reanalyzed without the constant after removing the station where one tow had no catch. The paired t-test was still significant ( $p=0.005$ ). The mean log scale difference was 0.506 with a standard deviation of 1.06. Back transforming and applying the bias correction factor gives  $1.66 * \exp[(1.058)^2/2] = 2.90$  (Appendix Table 2-2).

The simple bias correction factor used above is approximate and meant for large sample sizes. An “exact” correction factor (Smith 1988) gave similar results (2.84).

The mean catch in the standard dredge is 256.7 (var= 189,438.4) and 337.2 (var = 280,968.2) in the rock chain dredge. An alternative non-parametric test (Wilcoxon's rank sum test) on arithmetic catches (no log transformation or constant) and omitting the station with a zero tow was conducted for rocky habitat because of uncertainty about the normality of the data and potential effects of adding a constant (Appendix Figure 2-1). The nonparametric test was significant ( $p=0.029$ ) suggesting a difference in catch between the two dredge types

The Invertebrate Subcommittee commended NEFSC survey staff on their work but noted the variability in potential correction factors and recommended that collection of more data from paired samples on hard bottom sites. Calculation and use of calibration constants with appropriate bias corrections can be deferred until the sample size for the experiment is increased and reviewed.

Preliminary results suggested that the performance of gear without rock chains might become increasingly impeded as more large rocks enter the gear (Appendix Figure 2-2). As the number of large rocks in the standard dredge increases, the log difference between the dredges increase. The effects of this problem on the above analyses should be investigated.



**Appendix Table 2-1.**

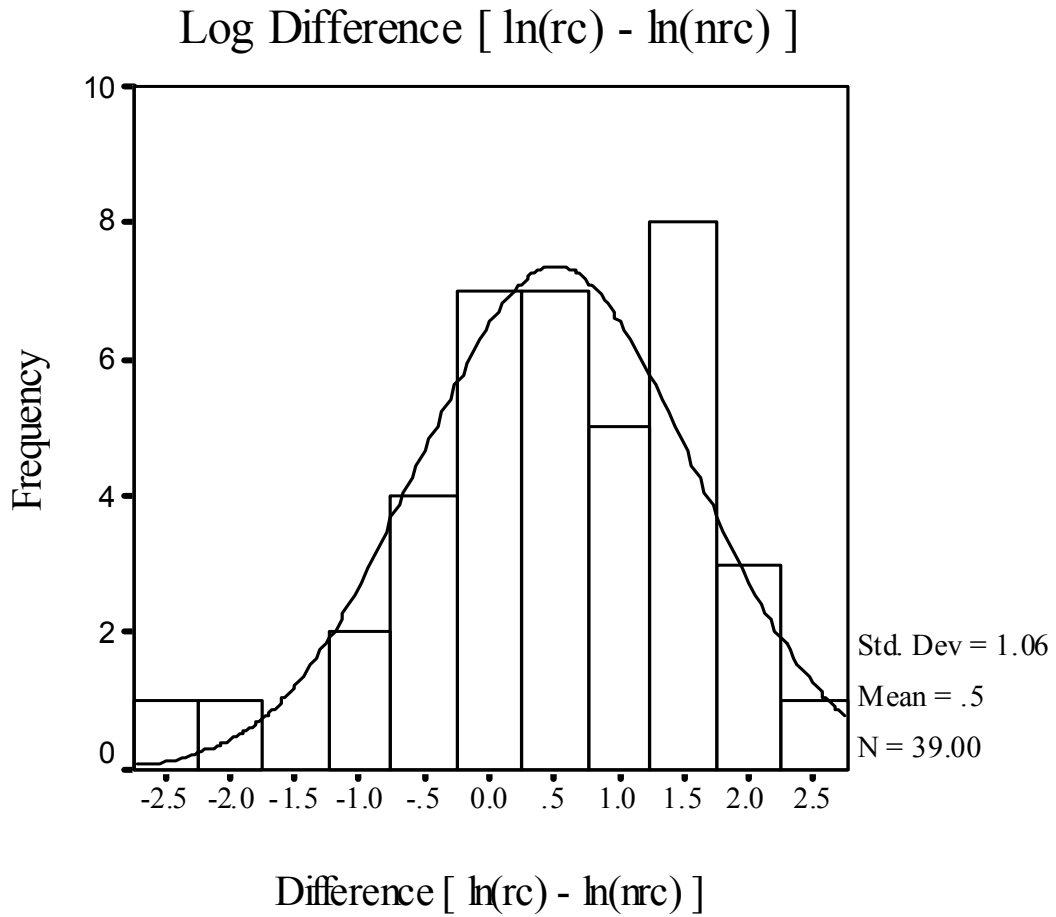
Test of Normality (Kolmogorov-Smirnov Test <sup>a</sup> )				
Habitat	Trans.	Sig.	Df	Statistic
Pooled	ln(x+1)	0.20*	68	0.07
	ln(x)	0.20*	61	0.07
Hard	ln(x+1)	0.20*	40	0.10
	ln(x)	0.20*	39	0.09
Soft	ln(x+1)	0.06	28	0.16
	ln(x)	0.20*	22	0.12
*. This is the lower bound of the true sign.				
a. Lilliefors Significance Correction				

**Appendix Table 2-2.**

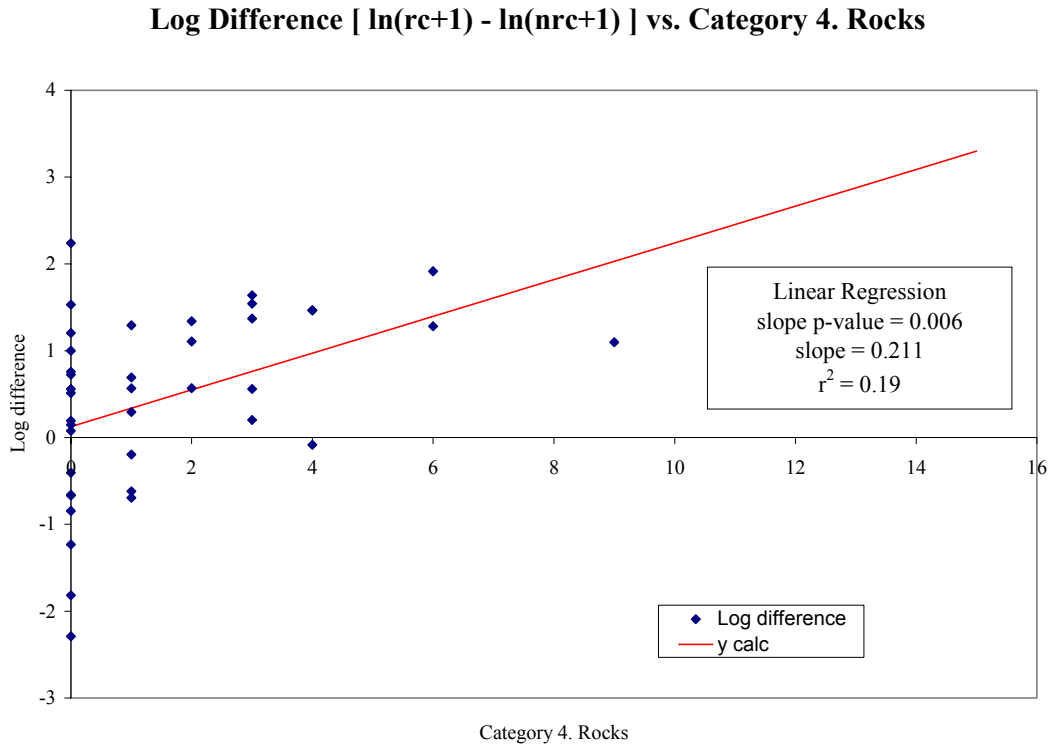
Paired T-test, sample pairs = 40, ln(x+1)		
		Exp.
Mean	0.44	1.56
S.D.	1.02	
C.I. Lower	0.12	1.13
C.I. Upper	0.77	2.16
Bias Correction $\exp(S.D.^2/2)$		1.68
Calibration Factor (bias * exp(Mean))		2.62

Paired T-test, sample pairs = 39, ln(x)		
Approximate		
		Exp.
Mean	0.51	1.66
S.D.	1.06	
C.I. Lower	0.16	1.18
C.I. Upper	0.85	2.34
Bias Correction $\exp(S.D.^2/2)$		1.75
Calibration Factor (bias * exp(Mean))		2.90

Appendix Figure 2-1. Distribution of differences between log survey catches with and without rock chains.



Appendix Figure 2-2. Difference in log survey catches with and without rock chains as a quantity of large (Category 4) rocks in the tow without rock chains.



### APPENDIX 3. EFFICIENCY ESTIMATES FOR THE NEFSC SURVEY DREDGE

The ratio densities from the NEFSC scallop dredge and SMAST video surveys were used to estimate absolute NEFSC scallop dredge efficiency assuming that the detection probability of scallops in the video survey was 100%. This ratio can be examined at levels of spatial resolution ranging from tow level estimates ( $10^{-3}$  km<sup>2</sup>) to population level ( $10^4$  km<sup>2</sup>). Fine scale spatial comparisons were not possible because of insufficient data. Analysis at wide spatial scales may mask important regional variations in dredge efficiency associated with bottom type and depth. For this analysis, dredge efficiency was examined on the scale of subareas of about  $10^2$  to  $10^3$  km<sup>2</sup>. Data from video and dredge surveys were post-stratified into subareas occupied by both surveys. Bootstrap methods were used to estimate precision of efficiency estimates for each subarea.

To identify subareas with maximum overlap between video and dredge surveys, waters along the coast were subdivided into 8 discrete subareas (Appendix Table 3-1). Within each subarea, NMFS shellfish strata boundaries were used to partition the video observations into corresponding sets. Strata with greater than 80% video coverage were included in subareas and calculations. Scallops less than 80 mm shell height were excluded from the analysis because the probability of detection in the video survey is lower and the selectivity of the NEFSC survey dredge differs for scallops smaller than 80 mm.

On average, the distance between video stations was 3 nm so that the area of each quadrant is 9 nm<sup>2</sup>. The sum of video quadrants within a NMFS stratum was used to measure the effective stratum size for the post-stratified video survey. For example, NMFS stratum 11 is 213.5 nm<sup>2</sup> (Appendix Table 3-2). Ten dredge samples were taken in this stratum and 24 video stations were visited. The estimated stratum size for the video survey in this case was  $24 * 9 = 216$  nm<sup>2</sup>.

Each survey type was then analyzed as a stratified random design. For the dredge survey this simply meant estimation of density for a smaller number of original strata. For the video survey this process implies that the video estimates can be considered (approximately) as a random sample within an arbitrary new boundary (D'Orazio 2003; Thompson 2002, p. 135; Gunderson 1995; Hilborn and Walters 1992).

Bootstrap estimation methods (Smith 1997) and SPlus software provided by Stephen J. Smith (Department of Fisheries and Oceans, Bedford Institute of Oceanography, Halifax Nova Scotia) were used to estimate the sampling distributions of scallop densities and dredge efficiency for each subarea. A total of 2500 bootstrap densities were computed for each survey and subarea combination and used to compute sampling distributions for density and efficiency estimates. Sampling distributions for efficiency estimates were approximated by dividing each bootstrap density value for the dredge survey by a corresponding bootstrap density value for the video survey. Results were summarized by percentiles (Appendix Table 3-3).

Efficiency estimates compared favorably with estimates by Gedamke et al. (in press) and previous stock assessments (NEFSC 2001). Survey dredge efficiency estimates (medians of bootstrap sampling distributions) were generally higher in the Mid-Atlantic region with estimates of 38% in the Delmarva region, 63% in the New York Bight, and 51% in the Hudson Canyon closed area. On Georges Bank, dredge efficiency in Closed Areas I and II were 55% and 40%, respectively. The low efficiency found in the Nantucket Lightship estimate may be due to insufficient overlap in the western portion of the Nantucket Lightship Area, and the exclusion of non-random tows in the high-density northeast portion of the area. Pooled estimates of dredge efficiency for the entire Mid-Atlantic and Georges Bank areas were 46% and 33%. Note, however, that the lack of overlap in certain areas (e.g., the New York Bight, Nantucket Lightship Closed Area, and the Southeast Part) may cause the combined estimates to be biased, because some areas were covered more completely than others. The combined estimate for Closed Area I and II on Georges Bank was 45%.

*Importance of considering efficiency in comparing survey results*

Analysis of the SMAST video (Stokesbury et al., 2004) and NEFSC scallop survey (minimum swept-area) results for 2003 demonstrated shortcomings in direct comparison of simple abundance and biomass estimates. Comparisons may be misleading without accommodation for differences in survey gear efficiency, area surveyed, size composition and, for biomass estimates, length-weight relationships. Of these, survey gear efficiency is the most important factor for computations of biomass. In this analysis, sensitivity estimates (number per square meter) from two surveys are a proxy for differences in gear efficiency because, other things equal, surveys with the same gear efficiency should give the same density estimates. Results for simple biomass calculations are summarized here because naïve comparison of biomass estimates is most problematic.

Estimates of total scallop biomass (in meat weight) from a survey can be expressed as a function of the average density, the survey domain (or total area), the size frequency of individuals, and the relationship between shell height and meat-weight. For a survey distributed over  $L$  strata with scallops in  $J$  shell-height intervals, the simple biomass estimate  $B_{TOT}$  is

$$B_{TOT} = \sum_{h=1}^L d_h A_h \sum_{j=1}^J f_{j,h} MW_{j,h}$$

where:

$d_h$  = average density within stratum  $h$  (affected by gear efficiency)

$A_h$  = area of stratum  $h$

$f_{j,h}$  = proportion of individuals of size  $j$  within stratum  $h$

$MW_{j,h}$  = average meat weight of individuals of shell height  $j$  in stratum  $h$ .

This general equation can be expanded further by substituting the relationship between shell height and meat weight as

$$MW_{j,h} = \alpha_h SH_j^{\beta_h}$$

where  $\alpha_h$  and  $\beta_h$  represent stratum-specific parameters for the shell height-meat weight relationship. The general equation can now be written as

$$B_{TOT} = \sum_{h=1}^L d_h A_h \sum_{j=1}^J f_{j,h} \alpha_h SH_j^{\beta_h}$$

The terms inside the second summation represent the average weight of scallops within a stratum. Differences in average weight can arise from differences in the size frequency distribution as well as from the shell height-meat weight relationship. This distinction is important because of measurement errors in shell height measurements from video surveys and differences in procedures for estimating shell height-meat weight relationships.

Following Keyfitz (1968, p. 189), the “decomposition of observed changes” method was used to measure discrepancies that arise in naïve comparisons that do not account for the factors listed above. To measure the effect of differences in shell height-meat weight relationships, for example, one can calculate the percent change in either SMAST video (Stokesbury et al. 2004) or NEFSC scallop survey (minimum swept area) estimates when shell height-meat weight parameters are used from the other survey. Effects due to differences in more than one factor can be evaluated in an analogous manner.

Results show that the estimate of survey gear efficiency is the most important factor when estimating biomass from the 2003 NEFSC survey. If dredge efficiency were assumed to be 100%, the biomass implied by the SMAST video (Stokesbury et al. 2004) survey changed by -53% when the minimum swept area density from the NEFSC scallop survey was substituted, and the minimum swept area biomass from the NEFSC scallop survey increased by +115% when density from the video survey was substituted. This indicates that dredge efficiency is less than 100% in the dredge survey, consistent with other dredge efficiency studies (e.g., NEFSC 2001; Gedamke et al. in press) and results in this stock assessment. Substituting shell height composition decreased SMAST estimated biomass by 12% and increased NEFSC estimated biomass by 17%. Substituting shell height/meat weight parameters increased the SMAST estimate by 8% and decreased the NMFS estimate by 7%.

Appendix Table 3-1 Summary of sampling effort by stratum and group for dredge and video surveys for 2003 used to estimate efficiency of the NEFSC survey dredge.

SMAST video survey data:									
Count of Photo Station	Subarea								Grand Total
NMFS Strata	1	2	3	4	5	6	7	8	
10	12								12
11	24								24
14	19								19
15	42								42
18	24								24
19	27								27
22	16		19						35
23			79						79
24			28						28
27			15						15
30		70							70
31		91							91
34		24							24
46								16	16
47				26				56	82
49				27					27
50				18					18
51				11					11
52				28	10				38
53					22				22
54				8	25				33
55				25	15				40
61						64			64
71							7		7
621						39			39
651							10		10
661						3	10		13
Grand Total	164	185	141	143	72	106	27	72	910

NEFSC dredge survey data:									
Count of Station	Group								Grand Total
2-3 digit stratum	1	2	3	4	5	6	7	8	
10	6								6
11	10								10
14	10								10
15	12								12
18	9								9
19	10								10
22	4		6						10
23			20						20
24			5						5
27			8						8
30		9							9
31		16							16
34		6							6
46								5	5
47				3				10	13
49				9					9
50				14					14
51				10					10
52				10	4				14
53					11				11
54				4	9				13
55				7	3				10
61						16			16
71							4		4
621						13			13
651							10		10
661						3	9		12
Grand Total	61	31	39	57	27	32	23	15	285

Appendix Table 3-2. Summary of subarea definitions and stratum sizes for comparisons of SMAST video survey and NMFS dredge survey efficiency estimates.

Subarea	Region	Open or Closed Area?	NMFS Strata	Photo Survey Sample Information		Dredge Survey Sample Information	
				Area Sampled (nm <sup>2</sup> )	Number of Potential Stations	Area Sampled (nm <sup>2</sup> )	Number of Potential Stations
1	MAB	OPEN	10	108	28,625,623	124.1247421	99,234
1	MAB	OPEN	11	216	57,251,247	213.46	170,653
1	MAB	OPEN	14	171	45,323,904	206.16	164,818
1	MAB	OPEN	15	378	100,189,682	387.77	310,014
1	MAB	OPEN	18	216	57,251,247	236.59	189,148
1	MAB	OPEN	19	243	64,407,652	242.59	193,944
1	MAB	OPEN	22	144	38,167,498	139.00	111,124
2	MAB	OPEN	30	630	166,982,803	668.68	534,592
2	MAB	OPEN	31	819	217,077,643	933.55	746,352
2	MAB	OPEN	34	216	57,251,247	208.02	166,305
3	MAB	HCCA	22	171	45,323,904	175.61	140,395
3	MAB	HCCA	23	711	188,452,020	749.31	599,053
3	MAB	HCCA	24	252	66,793,121	270.45	216,217
3	MAB	HCCA	27	135	35,782,029	137.34	109,800
4	GBK	OPEN	47	234	62,022,184	250.60	200,346
4	GBK	OPEN	49	243	64,407,652	223.02	178,297
4	GBK	OPEN	50	162	42,938,435	156.41	125,049
4	GBK	OPEN	51	99	26,240,155	113.73	90,924
4	GBK	OPEN	52	252	66,793,121	238.79	190,903
4	GBK	OPEN	54	72	19,083,749	73.26	58,567
4	GBK	OPEN	55	225	59,636,715	252.26	201,677
5	GBK	Closed Area I	52	90	23,854,686	108.72	86,921
5	GBK	Closed Area I	53	198	52,480,309	204.76	163,697
5	GBK	Closed Area I	54	225	59,636,715	222.58	177,947
5	GBK	Closed Area I	55	135	35,782,029	137.10	109,607
6	GBK	Closed Area II	61	576	152,669,991	632.53	505,691
6	GBK	Closed Area II	621	351	93,033,276	361.29	288,840
6	GBK	Closed Area II	661	27	7,156,406	12.35	9,872
7	GBK	OPEN	71	63	16,698,280	73.13	58,462
7	GBK	OPEN	651	90	23,854,686	88.00	70,353
7	GBK	OPEN	661	90	23,854,686	104.82	83,803
8	GBK	Nantucket Lightship Closed Area	46	144	38,167,498	136.19	108,884
8	GBK	Nantucket Lightship Closed Area	47	504	133,586,242	544.39	435,226
8a	GBK	NLSA--Access Area in 2000	46 & 47			147.09	117,595



Appendix Table 3-3. Summary of video and dredge survey density and efficiency estimates for scallops greater than 80 mm shell height in the dredge survey.

Subarea	Region	Sub Area	Open or Closed Area?	Density (#/m <sup>2</sup> ) or ratio	Percentile						
					5%	10%	25%	50%	75%	90%	95%
1	MAB	DMV	OPEN	Video	0.243	0.254	0.271	0.291	0.312	0.332	0.345
				Dredge	0.087	0.092	0.101	0.110	0.121	0.130	0.135
				Ratio	0.281	0.304	0.339	0.380	0.423	0.468	0.493
2	MAB	NYB	OPEN	Video	0.044	0.047	0.054	0.075	0.093	0.112	0.129
				Dredge	0.023	0.027	0.035	0.046	0.058	0.071	0.076
				Ratio	0.252	0.318	0.438	0.625	0.882	1.143	1.336
3	MAB	HCCA	CLOSED	Video	0.206	0.216	0.234	0.253	0.273	0.291	0.302
				Dredge	0.091	0.098	0.112	0.128	0.145	0.159	0.167
				Ratio	0.346	0.377	0.438	0.507	0.586	0.661	0.709
4	GBK	Sch	OPEN	Video	0.038	0.042	0.047	0.054	0.062	0.070	0.075
				Dredge	0.011	0.011	0.013	0.015	0.017	0.018	0.019
				Ratio	0.169	0.187	0.224	0.269	0.323	0.379	0.416
5	GBK	CA1	CLOSED	Video	0.091	0.105	0.128	0.157	0.186	0.214	0.234
				Dredge	0.053	0.060	0.072	0.085	0.101	0.116	0.124
				Ratio	0.295	0.340	0.428	0.549	0.705	0.903	1.078
6	GBK	CA2	CLOSED	Video	0.199	0.218	0.246	0.283	0.326	0.366	0.394
				Dredge	0.064	0.074	0.092	0.115	0.141	0.164	0.178
				Ratio	0.211	0.245	0.312	0.403	0.512	0.638	0.711
7	GBK	NEP	OPEN	Video	0.026	0.030	0.042	0.055	0.066	0.079	0.086
				Dredge	0.007	0.008	0.010	0.012	0.014	0.016	0.017
				Ratio	0.121	0.139	0.179	0.241	0.315	0.412	0.496
8	GBK	NLSA??	CLOSED	Video	0.181	0.201	0.234	0.272	0.316	0.356	0.381
				Dredge	0.020	0.024	0.031	0.040	0.049	0.057	0.062
				Ratio	0.067	0.082	0.111	0.147	0.186	0.234	0.265
9	MAB	All	ALL	Video	0.174	0.179	0.188	0.199	0.210	0.221	0.229
				Dredge	0.075	0.079	0.084	0.091	0.098	0.105	0.109
				Ratio	0.363	0.384	0.417	0.456	0.502	0.549	0.576
10	GBK	All	BOTH	Video	0.138	0.145	0.155	0.169	0.183	0.196	0.204
				Dredge	0.042	0.045	0.050	0.056	0.063	0.069	0.073
				Ratio	0.236	0.255	0.291	0.332	0.378	0.428	0.462
11	GBK	All Open		Video	0.040	0.043	0.048	0.055	0.062	0.068	0.072
				Dredge	0.010	0.011	0.012	0.014	0.016	0.017	0.018
				Ratio	0.174	0.188	0.217	0.258	0.305	0.353	0.386
12	GBK	All Closed	CLOSED	Video	0.196	0.207	0.225	0.248	0.270	0.292	0.304
				Dredge	0.059	0.063	0.071	0.081	0.090	0.099	0.105
				Ratio	0.225	0.244	0.278	0.329	0.380	0.429	0.466
12a	GBK	Closed Areas 1 and 2	Closed	Video	0.176	0.187	0.208	0.233	0.259	0.285	0.299
				Dredge	0.072	0.078	0.090	0.104	0.119	0.134	0.144
				Ratio	0.283	0.315	0.374	0.450	0.535	0.626	0.674

## APPENDIX 4. PRELIMINARY CASA MODELS FOR SEA SCALLOPS

CASA model results are for use by reviewers in evaluating CASA as a primary analytical tool for the next sea scallop stock assessment. At meetings during 2004, the Invertebrate Subcommittee opted to use methods from NEFSC (2001) to evaluate the official status of sea scallops for the 2004 stock assessment; results described in this appendix are therefore not intended by the Subcommittee for use by managers. The Subcommittee also decided, however, that the CASA modeling approach had considerable merit, provided information not otherwise available, and that it could be used as a primary stock assessment method in the next stock assessment if reviews and subsequent testing proved favorable.

To facilitate review work, this appendix describes CASA models and example results for sea scallops in the Mid-Atlantic Bight (MAB) and Georges Bank (GBK) regions.<sup>3</sup> In the interests of space, results for MAB sea scallops are emphasized. More data were available for MAB and the fishery in GBK is a bit more complicated (due to extensive closed areas during recent years where fishing is periodically allowed), but results were basically similar. See Appendix 5 for a general and technical description of the model.

### *Model structure*

Length bins in the models for both regions were 20-155 mm in 5 mm increments. The 155 mm bin includes the best available estimates of  $L$  for both stocks (NEFSC 2001). Von Bertalanffy  $K$  values and length-weight parameters were fixed at the best available estimates for both regions (NEFSC 2001). The natural mortality rate  $M$  was assumed to be  $0.1 \text{ y}^{-1}$ . Based on examination of survey length composition data, scallops were assumed to recruit into the first 13 size bins (20-84.9 mm, see below) with probabilities for each bin from region-specific beta distributions (beta distribution parameters estimated in the model).

Growth probabilities were from gamma distributions with parameters estimated in the models for each region using length increment data from shells collected during the 2001 NEFSC scallop survey from the GBK and MAB regions. Minimum and maximum growth increments were specified based on a visual examination of the data (Appendix Table 4-1). In retrospect, higher values of maximum growth increments should have been used and minimum and maximum values should have been specified more carefully. Growth matrices estimated in the model for both areas were similar and seemed reasonable (Appendix Table 4-2). Length based selectivity in the NEFSC scallop survey was assumed fixed at the best available estimates, although selectivity parameters for the NEFSC scallop survey were estimated in some sensitivity analysis runs. Selectivity parameters for the commercial fishery and for other surveys in the MAB region were estimated in the models.

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<sup>3</sup> See Appendix 5 for a technical description of the CASA model.

## *Mid-Atlantic Bight*

Model runs for MAB sea scallops during 1979-2004 used a very wide range of data (Appendix Table 4-3). The last year in the analysis was 2004 because data from the NEFSC winter bottom trawl survey during 2004 was available and because information about scallop abundance and length composition during early 2004 should improve estimates for 2003. However, estimates for 2004 were based little information and are not presented. Landings in 2004 were assumed equal in calculations to the mean during 2001-2003.

Based on information about recent developments in the fishery and availability of fishery length composition data, the CASA model was configured to estimate ascending logistic selectivity curves for the MAB fishery during three periods: 1979-1998, 1999-2000 and 2001-2004. The latter two fishery periods correspond to years with closed areas in the MAB region when well-recognized changes in the fishery occurred. The fishery period 1979-1998 covered many changes in the fishery but too little fishery length composition data were available to estimate additional selectivity patterns.

Data from the sea scallop survey were supplemented by winter, spring and fall trawl survey data in the MAB. The winter survey uses a flounder trawl that is similar to those used by commercial scallop trawl vessels, while the spring and fall surveys use gear that is not optimal for catching scallops. Because the trawl surveys are mainly intended to survey finfish, they need to be employed cautiously in scallop assessments.

Double-logistic selectivity curves were estimated for MAB sea scallops in bottom trawl surveys. Double logistic selectivity curves are potentially dome shaped (highest selectivity at intermediate sizes) to accommodate the possibility that bottom trawls are less efficient for small and large scallops (Rudders et al., 2000). Double logistic curves tend to collapse towards ordinary logistic curves when there is no support for a domed selectivity pattern in the fishery length composition data.

### Results

Trial runs with a preliminary version of the model for MAB sea scallops showed no evidence of retrospective bias in biomass or fishing mortality estimates (Appendix Figure 4-1). The Working Group's final "basecase" run converged readily with a full rank Hessian matrix (Appendix Table 4-4). CV's for fishing mortality and abundance were plausible and of reasonable magnitude indicating good model performance. Subjectively, and in comparison to experience with other stocks, the data for MAB sea scallop seemed consistent and relatively easy to model.

Fit to survey index information was good although residuals plots for the NEFSC winter bottom trawl survey showed a temporal pattern that may be related to the overall abundance level (Appendix Figures 4-2 to 4-5). Survey selectivity patterns seemed reasonable with domed patterns for bottom trawl surveys and relatively high selectivity for small scallops in the winter bottom trawl survey (which uses ground gear designed to

catch flatfish that is probably relatively efficient for small scallops). Selectivity patterns were similar for the fall and spring bottom trawl surveys, which used the same gear in most years (Appendix Figure 4-6).

The NEFSC survey dredge efficiency estimate from the model fit was similar to the distribution of bootstrap estimates from an external analysis of SMAST video survey data and NEFSC survey data for scallops 80+ mm on the same grounds (Appendix Figure 4-6). Sensitivity analysis (not shown) indicated that the external efficiency estimates had almost no effect on abundance or fishing mortality estimates for MAB. Fit to LPUE and catch data was generally good, although predicted catches were substantially higher than catch data during 1989-1991 and 1995 (Appendix Figures 4-7 to 4-8) as the model tried to explain conflicting evidence in the catch and most of the survey abundance trends.

Fit to fishery and survey length composition data for MAB sea scallops was generally good (Appendix Figure 4-9). The estimated CV for errors in assigning lengths to scallops in the SMAST video survey was 7.6%. With 100 mm scallops, for example, a CV of 7.6% implies a 95% probability interval for assigned lengths of roughly 85-115 mm, or six length bins in the CASA model. The CASA model estimate for the measurement error CV was similar to estimates from a calibration experiment carried out by SMAST and NEFSC using survey video equipment in a tank with scallops and scallop shells of known size (Appendix 1).

In terms of population dynamics (Appendix Figure 4-10), CASA model runs showed widely recognized recent increases in abundance during recent years. Recruitment in 2003 was estimated imprecisely (CV 56%) but was apparently at record levels. Fishing mortality and exploitation levels were similar to rescaled- $F$  estimates used for status determination in this assessment and were correlated with trends in fishing effort data (Appendix Figure 4-10). Based on model estimates, catch biomass generally equaled or exceeded surplus production until 1997 (Appendix Figure 4-11).

Model estimates show recent increases in mean weight (Appendix Figure 4-11) and stock abundance with more scallops at larger sizes and increases in numbers at all sizes (Appendix Figure 4-12). Estimates reflect changes in fishery length composition towards larger scallops during recent years (Appendix Figure 4-13). Estimated length composition of new recruits was reasonable in comparison to average length compositions from the NEFSC survey during 1979-2003 (Appendix Figure 4-14).

The very high fishing mortality estimate for MAB sea scallops during 1995 was likely exaggerated due to conflicting information in the fishery and survey data during those years. Sensitivity analysis (not shown) showed that reducing the assumed CV for catch measurement errors reduced  $F$  and the residual for catch data in 1995, while reducing goodness of fit to LPUE and most of the survey time series.

### Likelihood profile analysis

A preliminary model for MAB was fit while fixing the model's estimate of efficiency for the NEFSC scallop survey dredge to a wide range of feasible values. The lower boundary of the range for efficiency ( $e=0.2$ ) implies that the survey dredge captures 20% of the scallops in its path. The upper boundary implies that the dredge captures 100% of the scallops in its path. In comparison, the basecase run for MAB sea scallops estimated an efficiency of 0.59. Estimated fishing mortality increases and estimated abundance decreases at higher values of assumed efficiency.

Profile analysis results showed that the commercial fishery data (catch weight and LPUE) fit best at relatively high values ( $e=0.7-0.8$ ) for survey dredge efficiency. With the exception of trends in the winter bottom trawl survey, survey data fit best at relatively low values ( $e=0.2-0.5$ ) for survey dredge efficiency. Trend and length composition data from the scallop survey fit best at efficiency levels ( $e=0.5-0.6$ ) near the basecase estimate of  $e=0.59$ . In considering profile analysis results for MAB sea scallops, it may be important to remember that selectivity parameters for the scallop survey were fixed at estimates obtained outside the model, while selectivity parameters for other surveys and the commercial fishery were estimated without constraint. Data from the scallop survey would likely fit well over a broader range of efficiency values if the corresponding selectivity parameters had been estimated in the model.

### Sensitivity analyses

A preliminary model for MAB was used to perform a limited number of sensitivity analyses. The model was not able to estimate plausible values for the natural mortality rate  $M$  or von Bertalanffy growth parameter  $K$ . Scenarios in which NEFSC scallop survey selectivity parameters were estimated seemed to provide plausible results with implied efficiencies ranging 0.46-0.48. Preliminary runs that excluded bottom trawl survey trend and length composition data also seemed to provide plausible results.

### *Georges Bank*

The CASA model for sea scallops in the Georges Bank was similar to the model for sea scallops in the Mid-Atlantic Bight except that trawl survey data were not used due to problems with the catchability of scallops in trawls in MAB, and that the time series starts in 1982 rather than 1979. Data used for GBK included commercial catch and length composition, LPUE and NEFSC scallop survey trend and length composition data. The condition of the fishery in Georges Bank differs from MAB, due to higher peak fishing mortality rates and the dynamics of the closed areas established in late-1994, and fished substantially afterward only during 1999-2000.

Four fishery periods were used in modeling GBK sea scallops to accommodate implementation of closed areas and periodic fishing in closed areas. An ascending logistic selectivity pattern was assumed for the commercial fishery during the first period (1979-1995) prior to the closed areas. A double-logistic selectivity curve (potentially

domed) was assumed during the second period (1996-1998) when large scallops were accumulating in closed areas where they were protected from the fishery. The domed selectivity pattern mimics the action of the fishery operating in open areas and taking primarily intermediate-size scallops. A second double logistic selectivity curve was estimated for the third period (1999-2000) when substantial fishing occurred in closed areas. Finally, a third double logistic selectivity curve was estimated for the fourth period when closed areas again protected large scallops.

## Results

Goodness of fit and residual patterns for GBK sea scallops was generally similar to results for MAB. The estimated efficiency of the NEFSC scallop survey dredge was lower for GBK ( $e=0.42$ ) than for MAB, presumably due to rocky ground on Georges Bank.

Abundance and mortality estimates were similar to rescaled-F estimates used for status determination in this assessment, and were correlated with trends in fishing effort data (Appendix Figure 4-15). Fishery selectivity estimates were plausible with ascending logistic selectivity patterns during 1979-1995 when all scallops were available to the fishery, and 1999-2000 when portions of the groundfish closed areas were reopened (Appendix Figure 4-16). In contrast, the CASA model estimated domed shaped fishery selectivity patterns for periods (1996-1998 and 2001-2003) when large scallops in the closed areas were protected. Selectivity curves for later years show a shift in the fishery towards larger scallops. The double logistic selectivity curve estimated for 1999-2000 collapsed to an ascending logistic pattern because fishery length composition data for this period include substantial proportions of large scallops.

### *Simulation analysis*

The CASA model for sea scallops was fit to one simulated data set with no measurement errors as a preliminary test of model performance, and as a means of verifying validity of the computer code used to make calculations in CASA. The simulated data were generated in a separate program that is commonly used to simulate effects of different management options.

Population dynamics in the simulator were like those for MAB sea scallops. The simulation model and CASA were alike in general terms, except that shorter time steps were used in the simulator and growth was handled in a simpler, more deterministic fashion. A single fishery period with an ascending logistic fishery selectivity pattern was assumed in both models. Selectivity of the NEFSC scallop survey was fixed at the same values in both models. Despite differences in model structure, CASA was able to reproduce the conditions assumed in generating the simulated data (Appendix Figure 4-17). The simulation results suggest that the CASA model was working properly, though more simulations are necessary to determine the effects of catch and survey errors and misspecified growth on model performance.

	Bin_22.5	Bin_27.5	Bin_32.5	Bin_37.5	Bin_42.5	Bin_47.5	Bin_52.5	Bin_57.5	Bin_62.5	Bin_67.5	Bin_72.5	Bin_77.5	Bin_82.5	Bin_87.5	Bin_92.5	Bin_97.5	Bin_102.5	Bin_107.5	Bin_112.5	Bin_117.5	Bin_122.5	Bin_127.5	Bin_132.5	Bin_137.5	Bin_142.5	Bin_147.5	Bin_152.5		
Bin_22.5																													
Bin_27.5																													
Bin_32.5																													
Bin_37.5																													
Bin_42.5																													
Bin_47.5	4																												
Bin_52.5	1	9	6	3																									
Bin_57.5		7	40	35	5																								
Bin_62.5		6	47	149	86	5																							
Bin_67.5		1	37	214	175	17	8	1																					
Bin_72.5			8	105	190	54	11	24	8																				
Bin_77.5			2	23	91	70	22	31	61	16	3																		
Bin_82.5				1	16	49	36	27	105	94	22	4																	
Bin_87.5					2	9	14	14	69	157	84	40	8																
Bin_92.5						3	7	7	28	98	127	77	65	13															
Bin_97.5					2				5	24	62	80	118	71	8	1													
Bin_102.5									4	27	36	52	132	102	19														
Bin_107.5										2	6	13	46	129	117	24	1												
Bin_112.5												2	4	35	76	106	51	2											
Bin_117.5													1	5	12	82	112	50	3										
Bin_122.5															1	9	39	92	72	8									
Bin_127.5																	2	21	58	77	3								
Bin_132.5																		1	10	36	8	6							
Bin_137.5																			1	28	70	6	9						
Bin_142.5																				4	50	2	9	9					
Bin_147.5																					10	4	41	4	9	32			
Bin_152.5																									2	2	6	21	5
N increments	5	23	140	530	567	204	94	104	276	393	327	243	258	267	279	227	223	208	166	144	125	106	89	54	43	27	5		
Effective N	2	6	35	100	100	51	24	26	69	98	82	61	65	67	70	57	56	52	42	36	31	27	17	14	11	7	3		

Appendix Table 4-1. Growth increment data used in the CASA model for sea scallops in the GBK and MAB regions. Columns give the initial length bin and rows give the length bin one year later. Cells below the black area are feasible for each starting length (i.e. growth  $\geq$  zero). "N increments" is the number of observations in each row. "Effective N" is the effective number of observations assumed in fitting the CASA model. The effective number of observations was meant to approximate the number of scallops observed in each starting bin. Assuming that the number of increments observed per scallops was about five, the effective number of observations was the number of increments divided by five.

	Bin_22.5	Bin_27.5	Bin_32.5	Bin_37.5	Bin_42.5	Bin_47.5	Bin_52.5	Bin_57.5	Bin_62.5	Bin_67.5	Bin_72.5	Bin_77.5	Bin_82.5	Bin_87.5	Bin_92.5	Bin_97.5	Bin_102.5	Bin_107.5	Bin_112.5	Bin_117.5	Bin_122.5	Bin_127.5	Bin_132.5	Bin_137.5	Bin_142.5	Bin_147.5	Bin_152.5		
Bin_22.5	0																												
Bin_27.5	0	0																											
Bin_32.5	0	0	0																										
Bin_37.5	0	0	0	0																									
Bin_42.5	0	0	0	0	0																								
Bin_47.5	0.145808	0	0	0	0	0																							
Bin_52.5	0.308495	0.811802	0.077018	0.017455	0	0	0																						
Bin_57.5	0.307618	0.077811	0.2438	0.124626	0.033278	0	0	0																					
Bin_62.5	0.174422	0.065755	0.329143	0.30291	0.168435	0.055223	0	0	0																				
Bin_67.5	0.063656	0.033306	0.239973	0.338605	0.322072	0.213942	0.086245	0.016956	0	0																			
Bin_72.5	0	0.011327	0.110066	0.216404	0.30368	0.328912	0.256713	0.134985	0.032124	0	0																		
Bin_77.5	0	0	0	0	0.172534	0.265945	0.323551	0.313741	0.180385	0.0536	0.005506	0																	
Bin_82.5	0	0	0	0	0	0.135978	0.227631	0.329827	0.330584	0.227786	0.092409	0.011805	0																
Bin_87.5	0	0	0	0	0	0	0.10586	0.204491	0.294328	0.335248	0.300955	0.134347	0.0207	0															
Bin_92.5	0	0	0	0	0	0	0	0	0.162578	0.256148	0.361453	0.332145	0.184466	0.036588															
Bin_97.5	0	0	0	0	0	0	0	0	0	0.127217	0.239677	0.330029	0.352102	0.239675	0.062301	0													
Bin_102.5	0	0	0	0	0	0	0	0	0	0	0.191674	0.292756	0.358172	0.295578	0.100748	0.001895													
Bin_107.5	0	0	0	0	0	0	0	0	0	0	0	0	0.149976	0.251414	0.349617	0.346718	0.16037	0.00485											
Bin_112.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.114152	0.208442	0.327029	0.402636	0.229942	0.011394										
Bin_117.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.084062	0.166069	0.30384	0.419868	0.314504	0.024867									
Bin_122.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.059436	0.131258	0.252972	0.415712	0.410472	0.051932								
Bin_127.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.092369	0.198091	0.386589	0.518678	0.10021							
Bin_132.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.060299	0.142735	0.336688	0.599827	0.187147							
Bin_137.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.035338	0.092703	0.251757	0.641391	0.341102						
Bin_142.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.048206	0.153561	0.593833	0.604383						
Bin_147.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.017901	0.061764	0.387159	0.944204					
Bin_152.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003301	0.008458	0.055796	1				
N increments	0.999999	1	1	1	0.999999	1	1	1	0.999999	0.999999	1	1	1	1.000001	1	1	0.999999	1.000001	0.999999	1.000001	1	1	1	1	1	1	1	1	
Effective N	2	6	35	100	100	51	24	26	69	98	82	61	65	67	70	57	56	52	42	36	31	27	17	14	11	7	3		

Appendix Table 4-2. Growth probabilities estimated in the CASA model for sea scallops in the MAB region (estimates for GBK were similar). Columns give the initial length bin and rows give the length bin one year later. Cells below the black area are feasible for each starting length (i.e. growth  $\geq$  zero). Formatting as in Appendix Table 4-1.



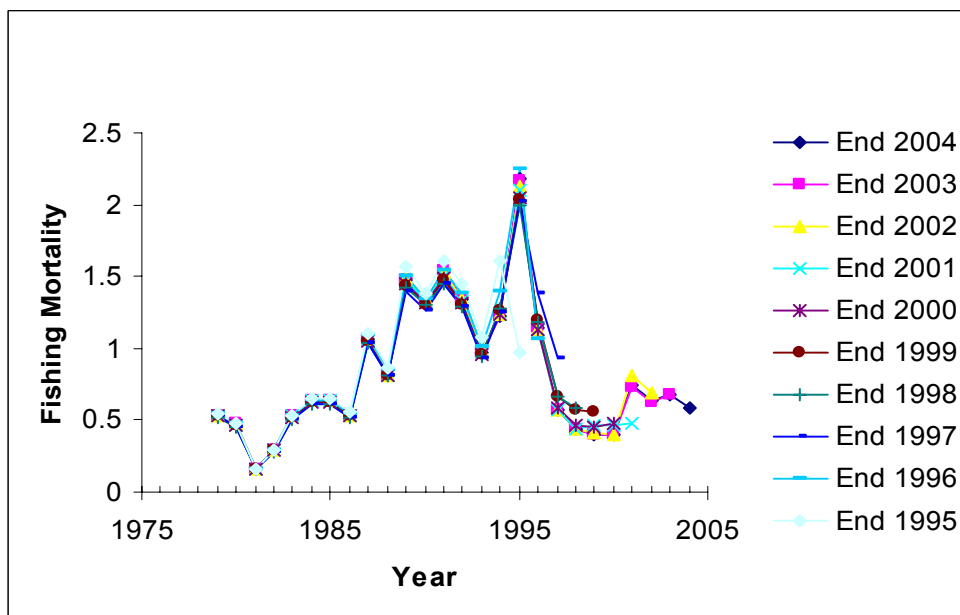
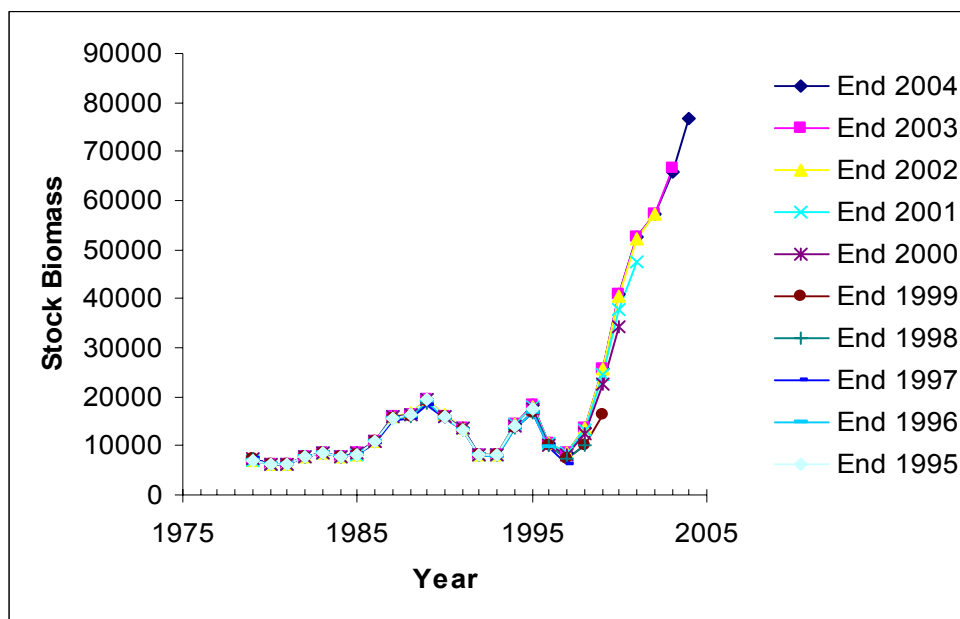
Appendix Table 4-3. Data for MAB sea scallops used in CASA model.

Data Type	Years in Model	Distribution for Measurement Errors	Comments
Commercial landed weight	1979-2004 (mean 2001-03 used for 2004)	Normal, CV=10%	MT, not adjusted for discard or incidental mortality
Landings per unit effort	1980-2003	Normal, CV=25%	MT landed / days absent for large (Type 4) scallop dredge vessels based on port interview and dealer data (1993 and earlier) or VTR logbooks and dealer data (1994 and later). Data for 1979 omitted.
Length increments			Increment observations from sea scallop shells collected during 2002 sea scallop survey. There were 1,565 increment measurements from MAB and 3,551 measurements from GBK. After preliminary examination data for MAB and GBK were pooled for use in both areas.
NEFSC survey dredge efficiency	NA	Beta over 0,1	Beta prior with the same mean and CV as distribution of bootstrap estimates from SMAST and NEFSC scallop survey densities for sea scallops 80+ mm on same grounds.
<i>Survey abundance data</i>			
NEFSC scallop survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Survey selectivity assumed known.
NEFSC winter bottom trawl survey abundance index	1992-2004	Log normal, variances from survey CVs	N/tow for sea scallops 20+ mm. Logistic survey selectivity estimated.
NEFSC fall bottom trawl survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Logistic survey selectivity estimated.
NEFSC spring bottom trawl survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Logistic survey selectivity estimated.
SMAST Video Survey	2003	NA	Densities for sea scallops 80+ compared to densities in NEFSC scallop survey on same grounds to estimate efficiency of NEFSC scallop survey dredge.
<i>Length composition</i>			
Commercial length composition	1979-1984; 1995-2003	Multinomial, effective sample size = 10% N tows sampled	Data for 1979-1984 from port samples; data for 1995-2003 from observer data.
NEFSC scallop survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins
NEFSC winter bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 20+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
NEFSC fall bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
NEFSC spring bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
SMAST video survey	2003	Multinomial, effective sample size = 34	Sea scallops 20+ mm in 5 mm bins. Original numbers at length not adjusted for bias. CV for measurement errors estimated in model.

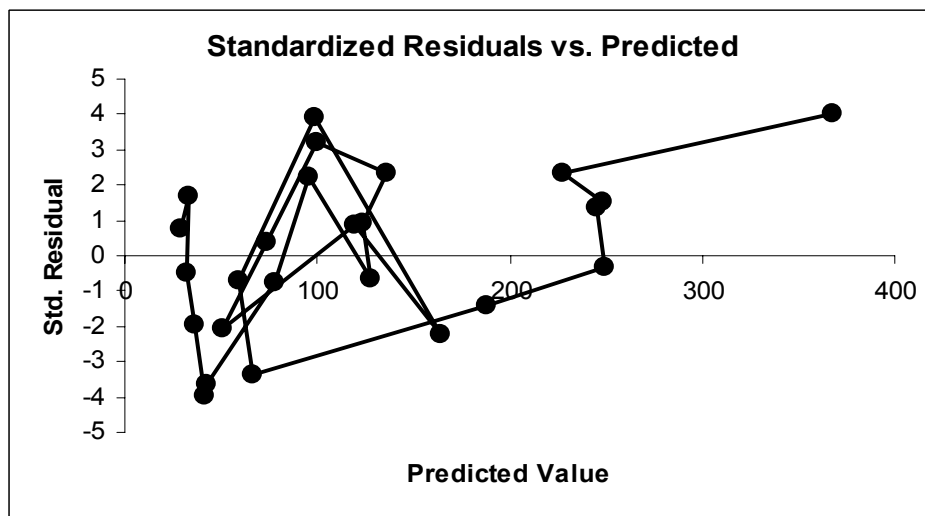
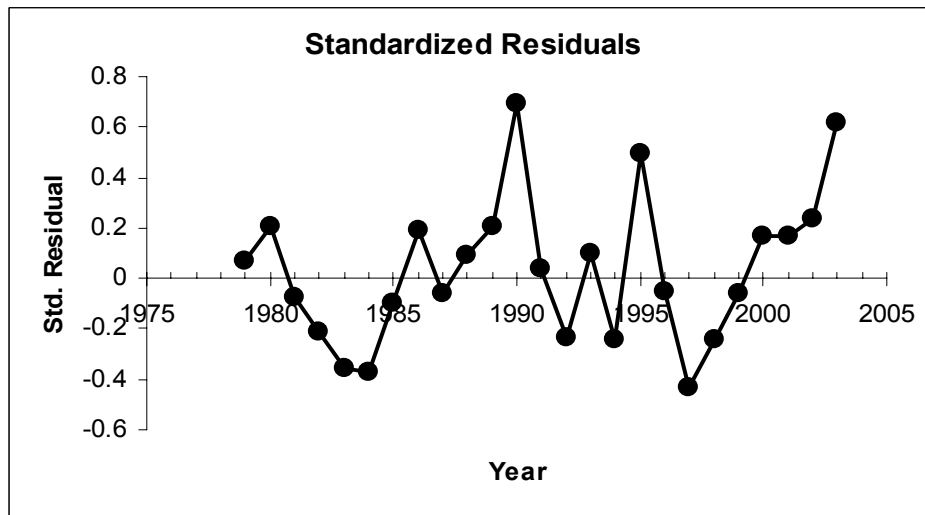
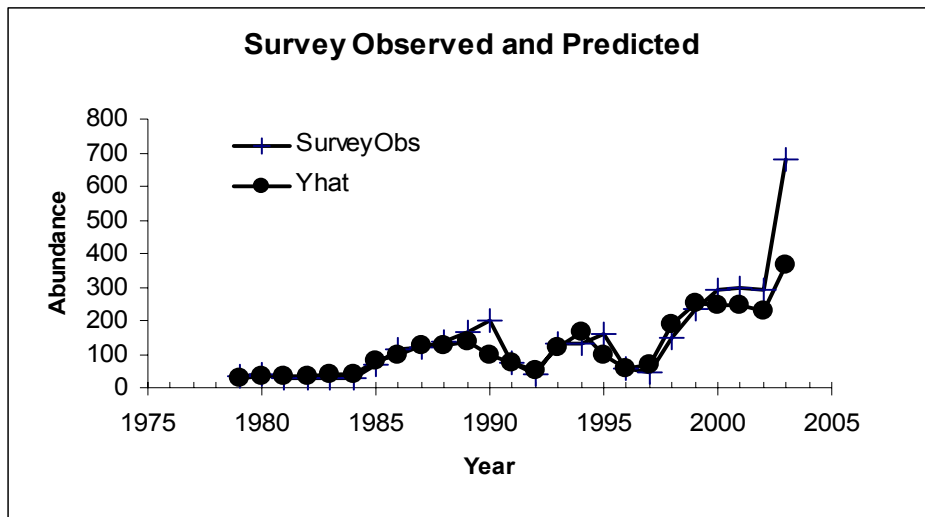
Appendix Table 4-4. Estimates, standard errors and CVs for parameters estimated in the CASA model for sea scallops in the Mid-Atlantic Bight region.

No.	Description	Estimate	SE	CV	No.	Description	Estimate	SE	CV
1	Log initial abundance	19.913	0.041	0.00	44	Log F dev 1989	0.762	0.150	0.20
2	Log beta distribution par new recruits	1.089	0.138	0.13	45	Log F dev 1990	0.643	0.143	0.22
3	Log beta distribution par new recruits	1.074	0.110	0.10	46	Log F dev 1991	0.798	0.103	0.13
4	Log mean recruitment	20.116	0.040	0.00	47	Log F dev 1992	0.655	0.097	0.15
5	Log Q scallop survey	-0.533	0.036	0.07	48	Log F dev 1993	0.319	0.130	0.41
6	Log Q winter BTS	-3.212	0.111	0.03	49	Log F dev 1994	0.539	0.137	0.25
7	Log Q fall BTS	-2.264	0.084	0.04	50	Log F dev 1995	1.148	0.103	0.09
8	Log Q spring BTS	-2.750	0.089	0.03	51	Log F dev 1996	0.503	0.098	0.19
9	Log intercept slx SMAST video survey	2.210	2.022	0.92	52	Log F dev 1997	-0.203	0.108	0.53
10	Log slope slx SMAST video survey	-1.186	1.844	1.55	53	Log F dev 1998	-0.479	0.108	0.23
11	Log slope slx winter BTS (ascending)	1.968	0.193	0.10	54	Log F dev 1999	-0.555	0.206	0.37
12	Log intercept slx winter BTS (ascending)	-2.540	0.136	0.05	55	Log F dev 2000	-0.559	0.189	0.34
13	Log slope slx winter BTS (descending)	-4.000	0.061	0.02	56	Log F dev 2001	0.037	0.187	5.05
14	Log intercept slx winter BTS (descending)	-3.045	0.273	0.09	57	Log F dev 2002	-0.125	0.183	1.46
15	Log slope slx fall BTS (ascending)	2.127	0.058	0.03	58	Log F dev 2003	-0.061	0.190	3.12
16	Log intercept slx fall BTS (ascending)	-2.285	0.102	0.04	59	Log F dev 2004	-0.229	0.211	0.92
17	Log slope slx fall BTS (descending)	2.879	0.191	0.07	60	Log recruitment dev 1980	-1.049	0.083	0.08
18	Log intercept slx fall BTS (descending)	-1.793	0.168	0.09	61	Log recruitment dev 1981	-1.482	0.113	0.08
19	Log slope slx spring BTS (ascending)	2.587	0.614	0.24	62	Log recruitment dev 1982	-1.370	0.122	0.09
20	Log intercept slx spring BTS (ascending)	-2.393	0.085	0.04	63	Log recruitment dev 1983	-1.030	0.099	0.10
21	Log slope slx spring BTS (descending)	2.703	0.093	0.03	64	Log recruitment dev 1984	-1.007	0.122	0.12
22	Log intercept slx spring BTS (descending)	-1.746	0.081	0.05	65	Log recruitment dev 1985	0.224	0.092	0.41
23	Log mean F	-0.363	0.047	0.13	66	Log recruitment dev 1986	0.085	0.101	1.19
24	Log intercept growth CV	-1.922	0.012	0.01	67	Log recruitment dev 1987	0.536	0.085	0.16
25	Slope growth CV	0.010	0.000	0.04	68	Log recruitment dev 1988	0.205	0.113	0.55
26	Log Q for LPUE	-2.443	0.167	0.07	69	Log recruitment dev 1989	0.670	0.090	0.13
27	Log shape parameter for LPUE	-0.401	0.241	0.60	70	Log recruitment dev 1990	-0.061	0.115	1.90
28	Log intercept fishery slx period 1	2.543	0.072	0.03	71	Log recruitment dev 1991	-1.008	0.146	0.15
29	Log slope fishery slx period 1	-1.846	0.079	0.04	72	Log recruitment dev 1992	-0.915	0.119	0.13
30	Log intercept fishery slx period 2	2.629	0.290	0.11	73	Log recruitment dev 1993	0.874	0.074	0.08
31	Log slope fishery slx period 2	-1.821	0.338	0.19	74	Log recruitment dev 1994	0.812	0.089	0.11
32	Log intercept fishery slx period 3	2.747	0.205	0.07	75	Log recruitment dev 1995	-0.317	0.120	0.38
33	Log slope fishery slx period 3	-1.871	0.236	0.13	76	Log recruitment dev 1996	-2.047	0.236	0.12
34	Log F dev 1979	-0.265	0.085	0.32	77	Log recruitment dev 1997	-0.136	0.093	0.69
35	Log F dev 1980	-0.388	0.103	0.26	78	Log recruitment dev 1998	1.272	0.075	0.06
36	Log F dev 1981	-1.474	0.112	0.08	79	Log recruitment dev 1999	1.125	0.088	0.08
37	Log F dev 1982	-0.863	0.110	0.13	80	Log recruitment dev 2000	0.671	0.113	0.17
38	Log F dev 1983	-0.271	0.093	0.34	81	Log recruitment dev 2001	0.728	0.110	0.15
39	Log F dev 1984	-0.101	0.084	0.84	82	Log recruitment dev 2002	0.387	0.146	0.38
40	Log F dev 1985	-0.106	0.093	0.88	83	Log recruitment dev 2003	1.999	0.112	0.06
41	Log F dev 1986	-0.277	0.099	0.36	84	Log recruitment dev 2004	0.833	0.531	0.64
42	Log F dev 1987	0.414	0.099	0.24	85	Logit length error SMAST video	-2.499	1.223	0.49
43	Log F dev 1988	0.138	0.134	0.97					

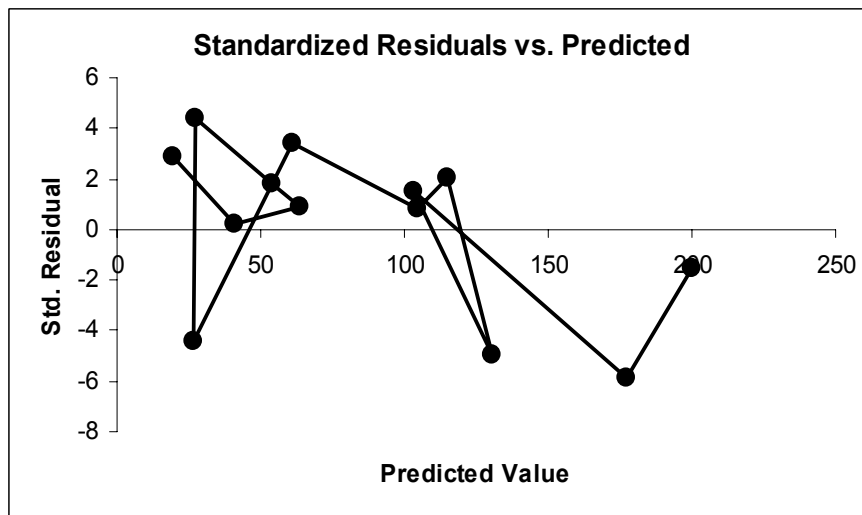
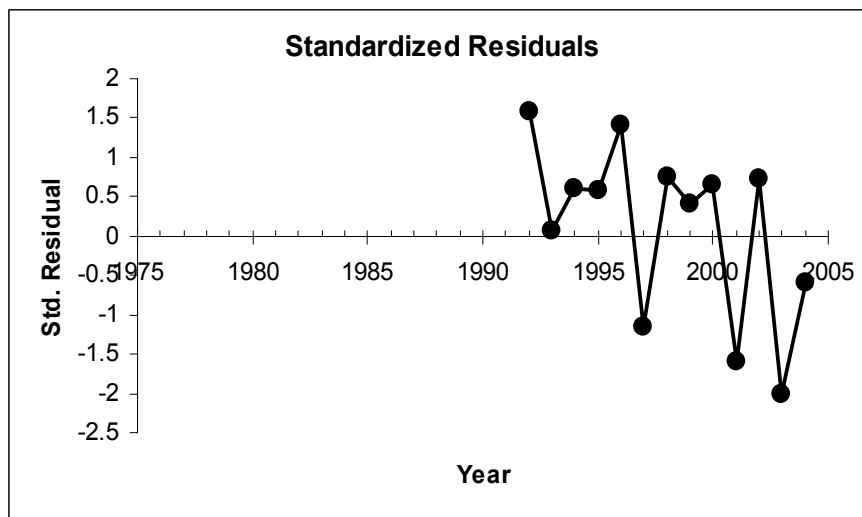
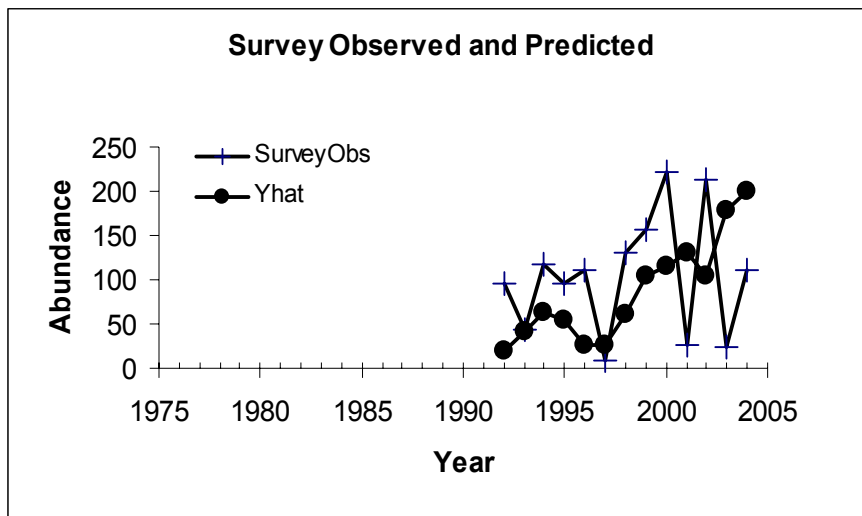




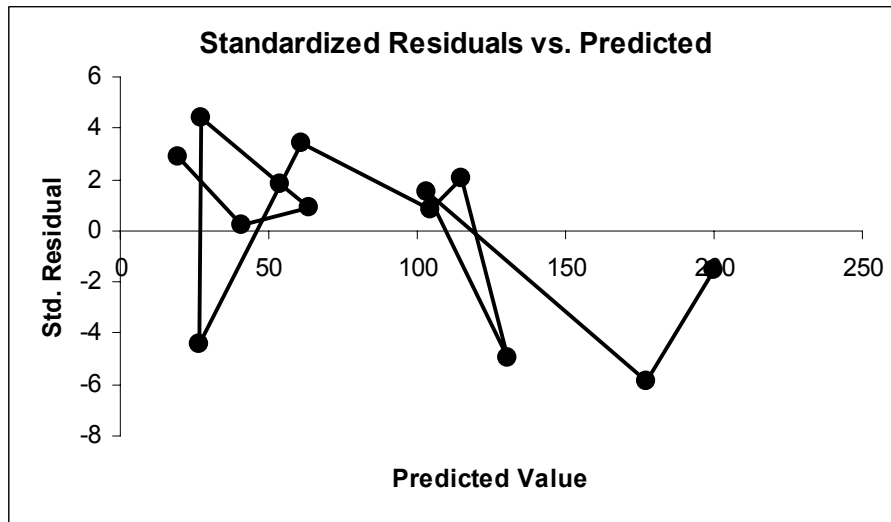
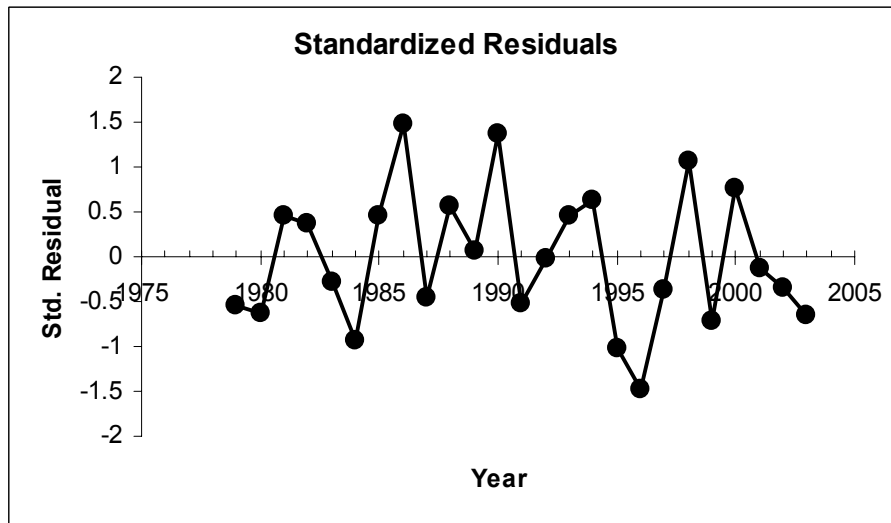
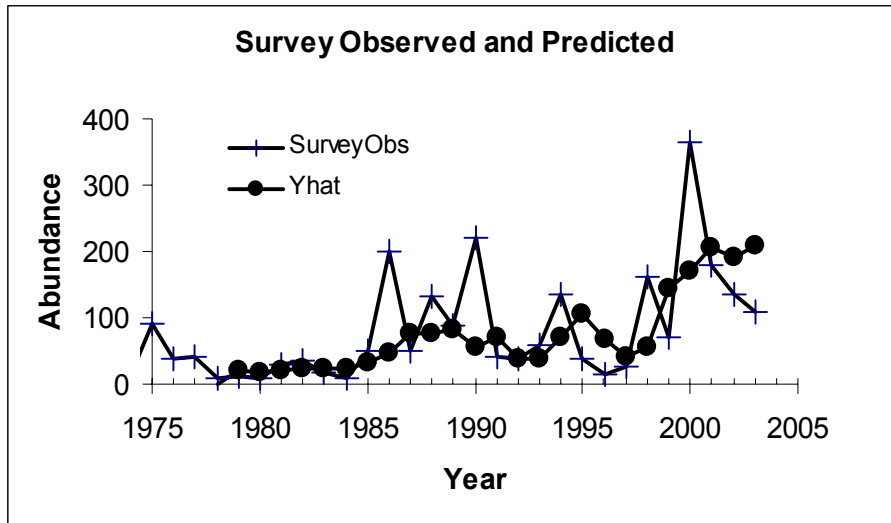
Appendix Figure 4-1. Retrospective analysis for biomass (top) and fishing mortality (bottom) estimates from a preliminary version of the CASA model for MAB sea scallops.



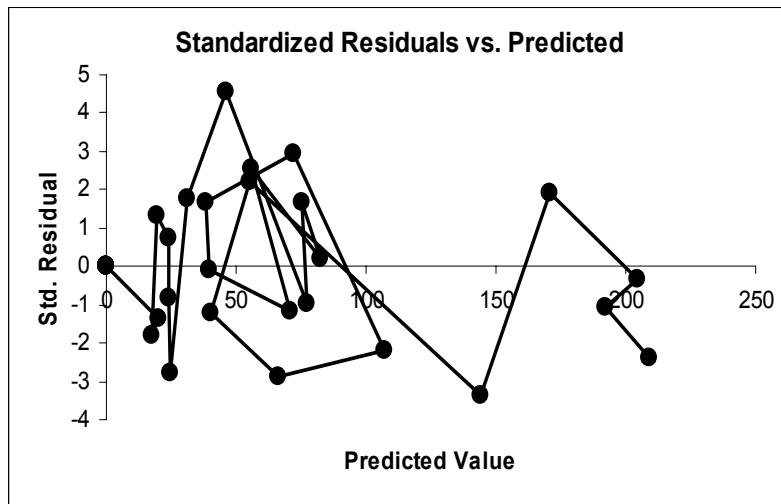
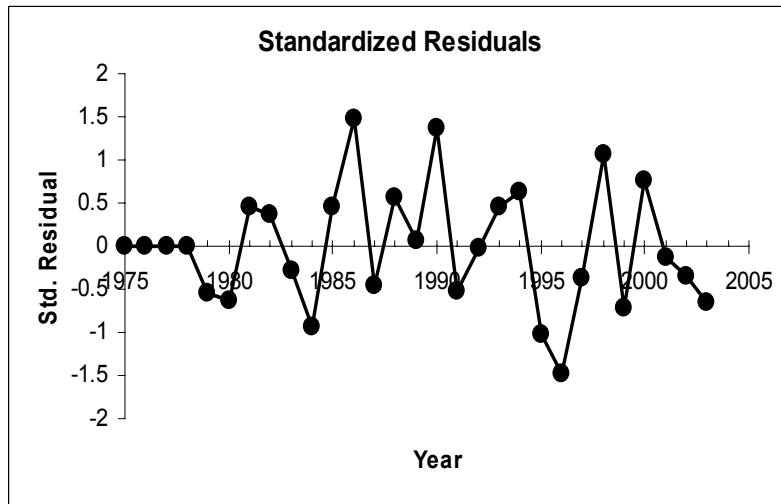
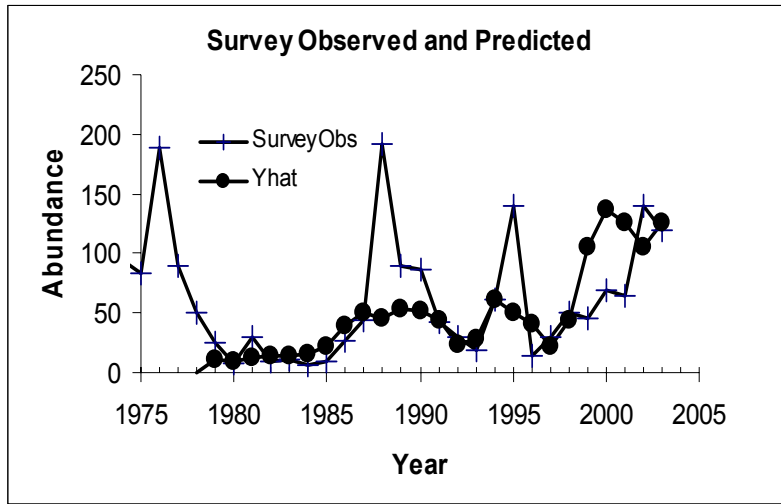
Appendix Figure 4-2. CASA model fit to NEFSC scallop survey data for MAB sea scallops.



Appendix Figure 4-3. CASA model fit to NEFSC winter bottom trawl survey data for MAB sea scallops.

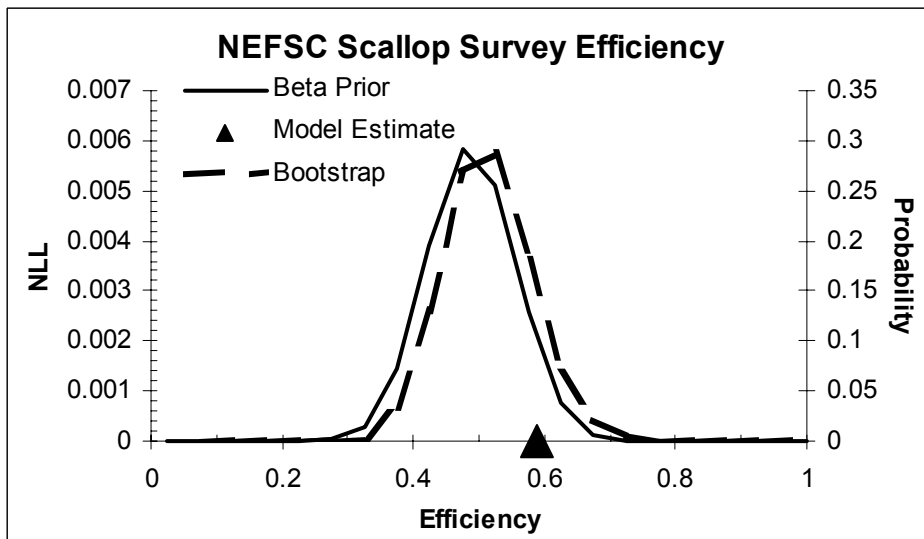
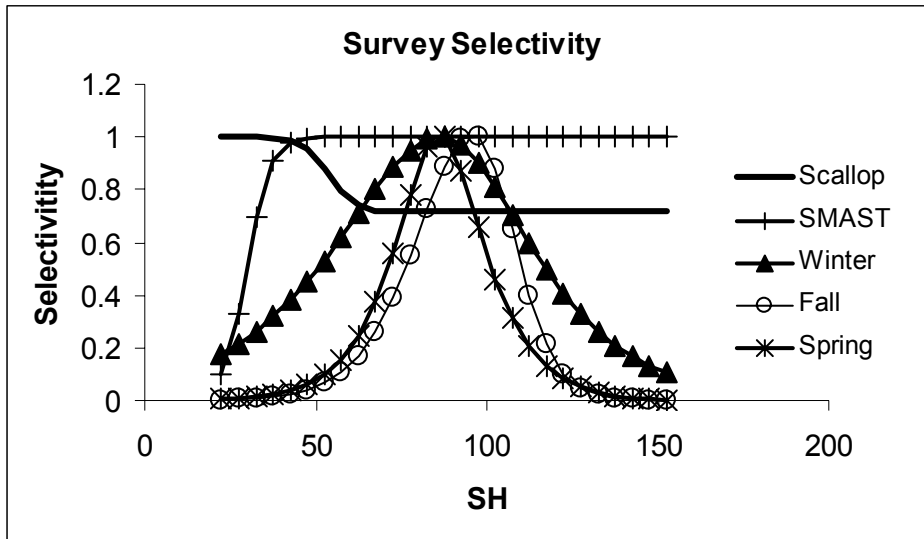


Appendix Figure 4-4. CASA model fit to NEFSC fall bottom trawl survey data for MAB sea scallops.

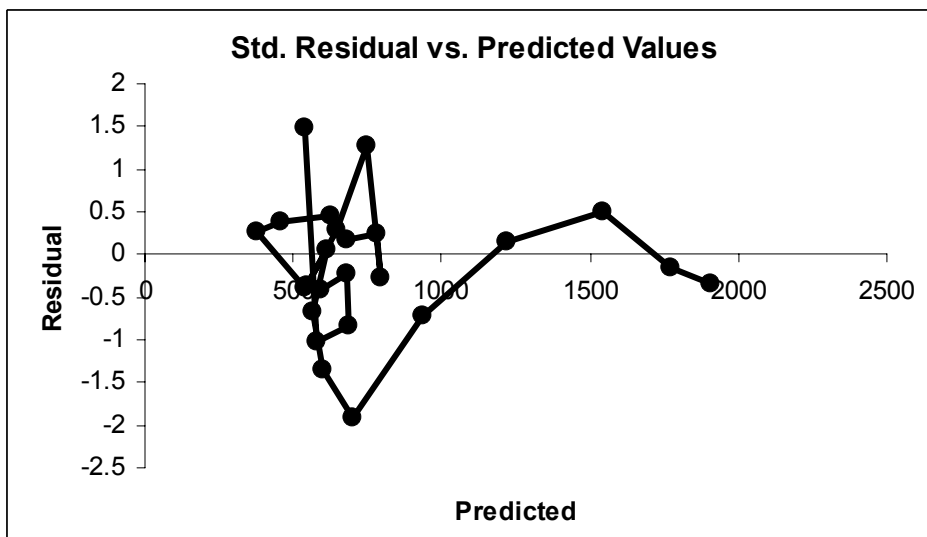
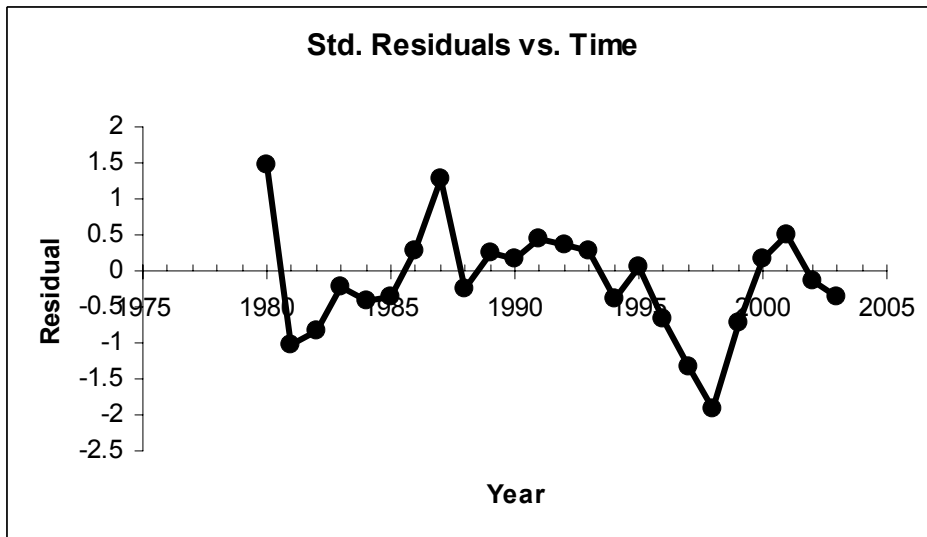
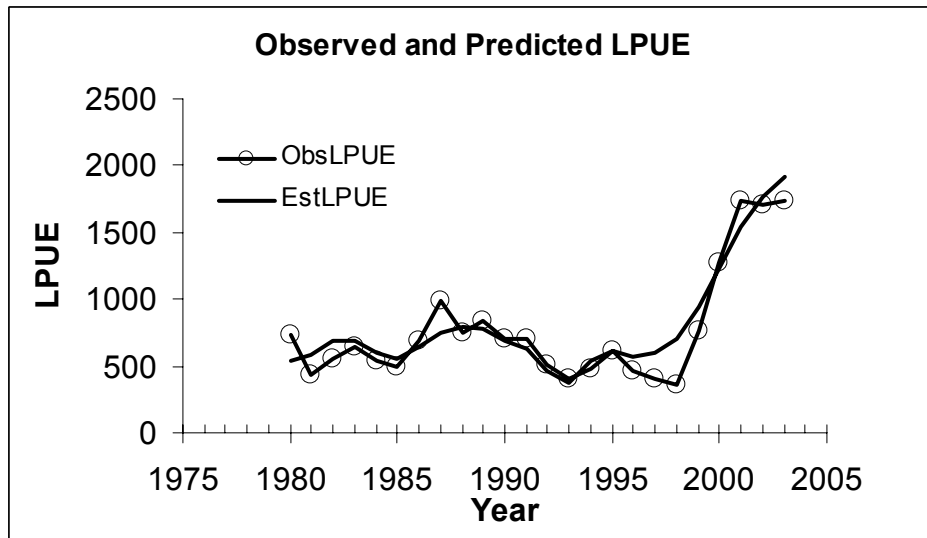


Appendix Figure 4-5. CASA model fit to NEFSC spring bottom trawl survey data for MAB sea scallops.

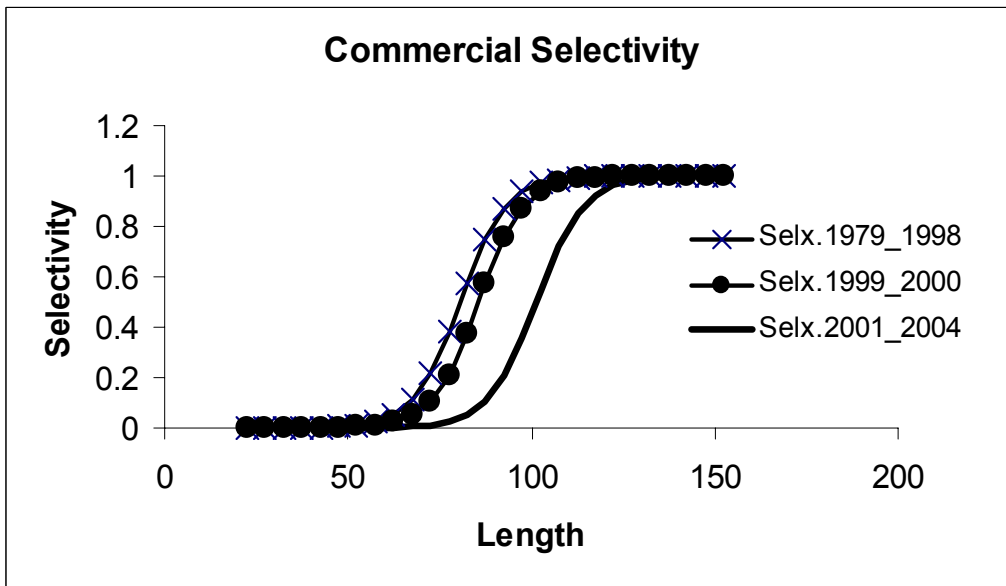
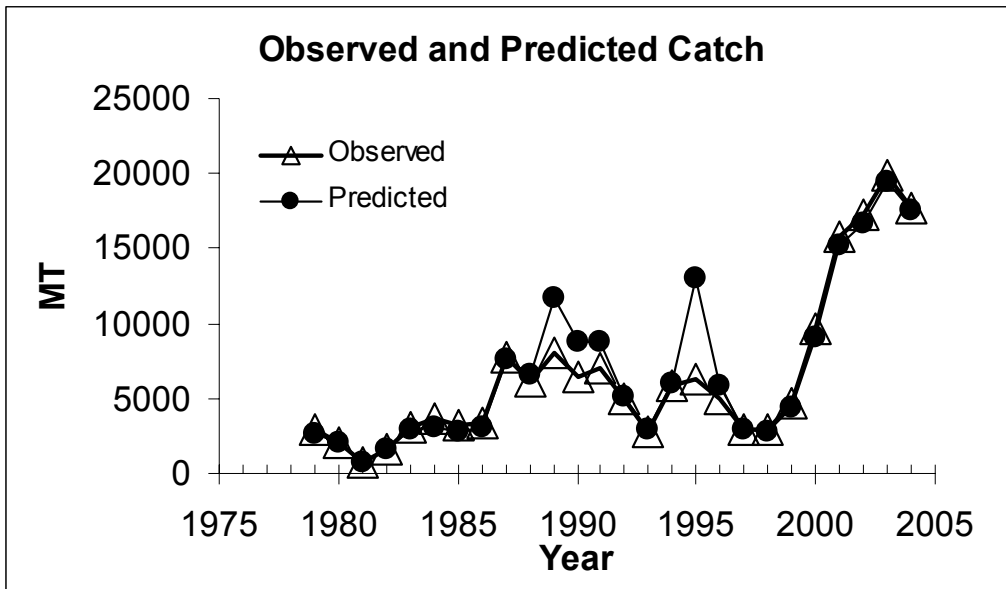




Appendix Figure 4-6. Survey selectivity patterns and NEFSC survey efficiency estimates for sea scallops in the MAB region.

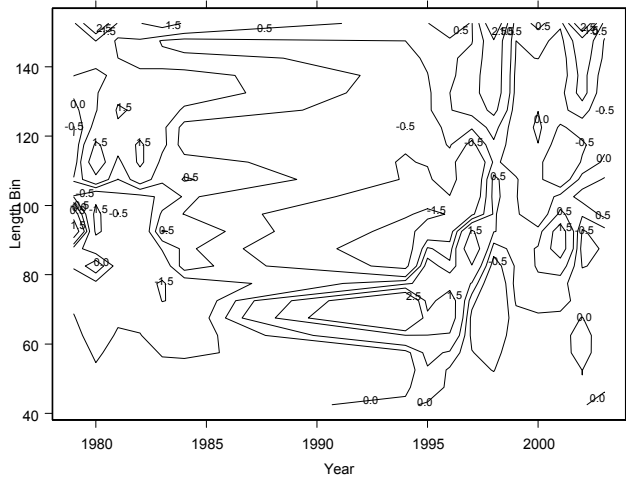


Appendix Figure 4-7. CASA model fit to LPUE data for MAB sea scallops.

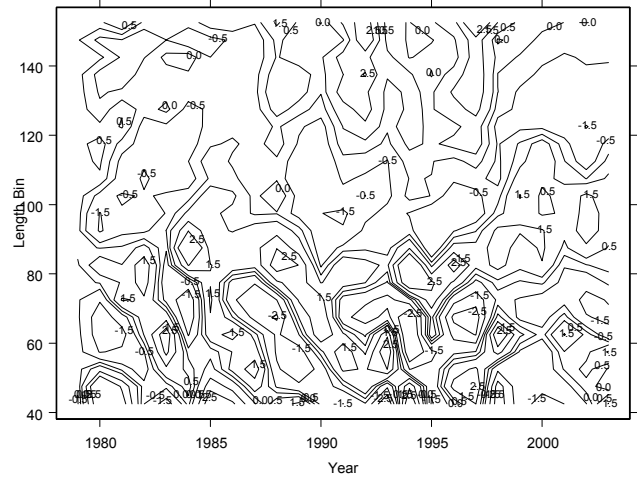


Appendix Figure 4-8. CASA model fit to landings data and estimated fishery selectivity patterns for MAB sea scallops.

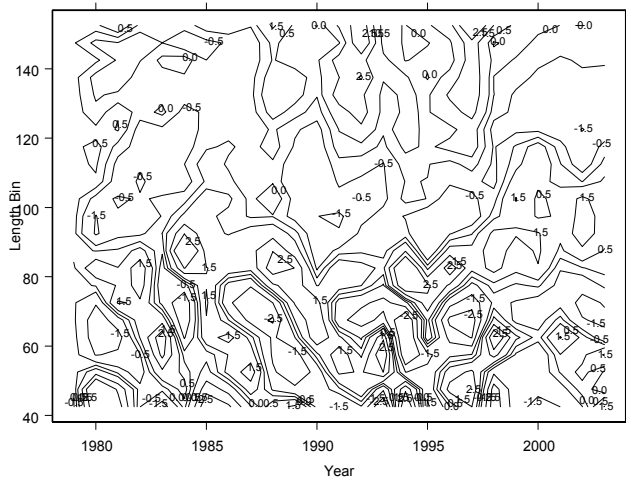
Standardized residuals MAB fishery length composition



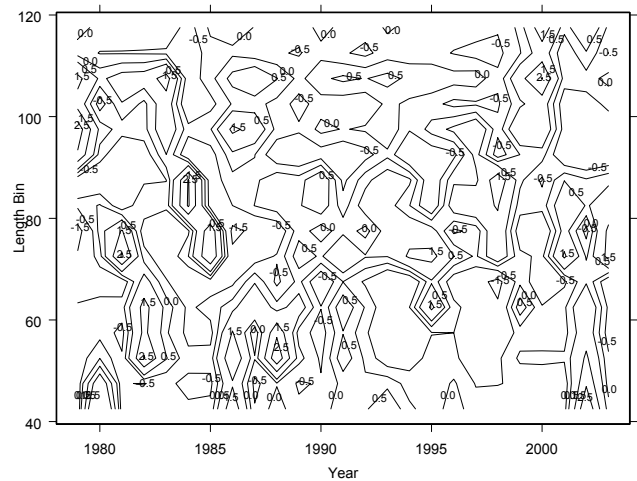
Standardized residuals scallop survey length composition



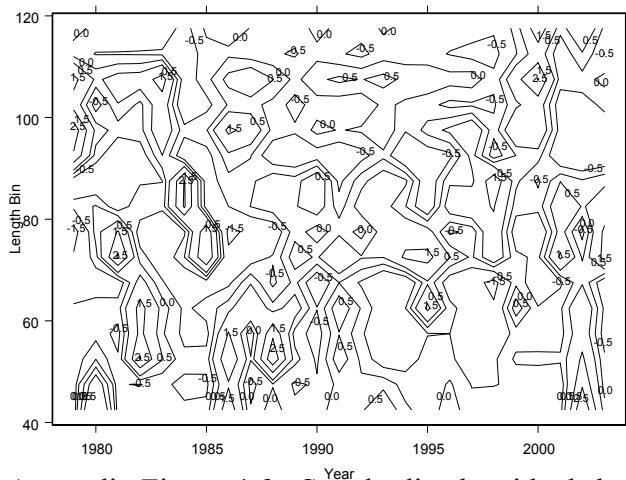
Standardized residuals winter BTS length composition



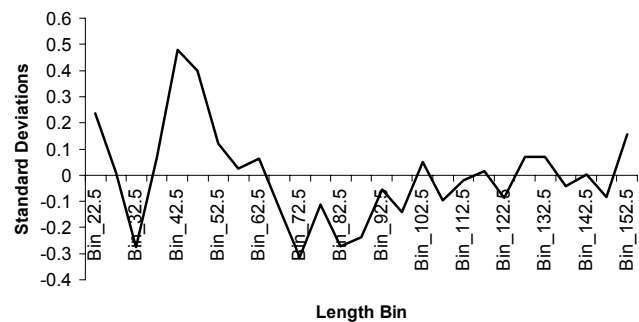
Standardized residuals fall BTS length composition



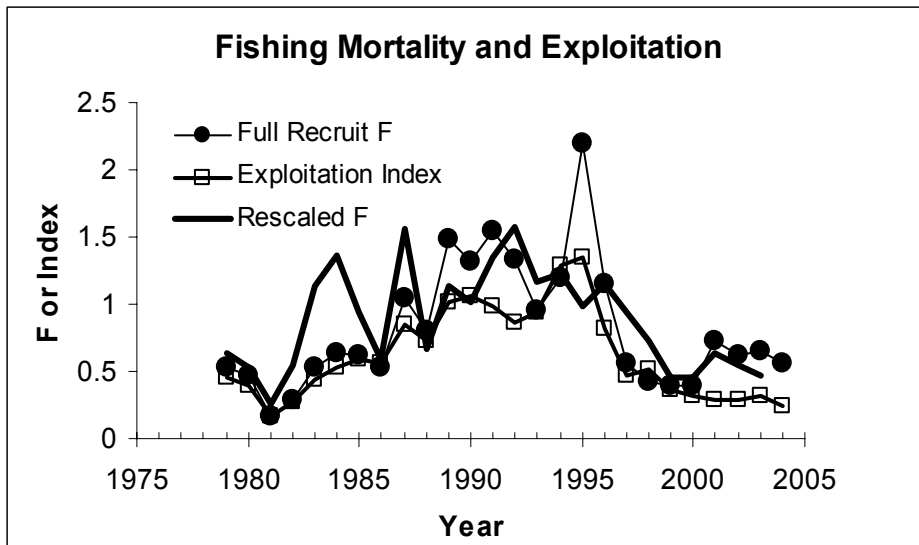
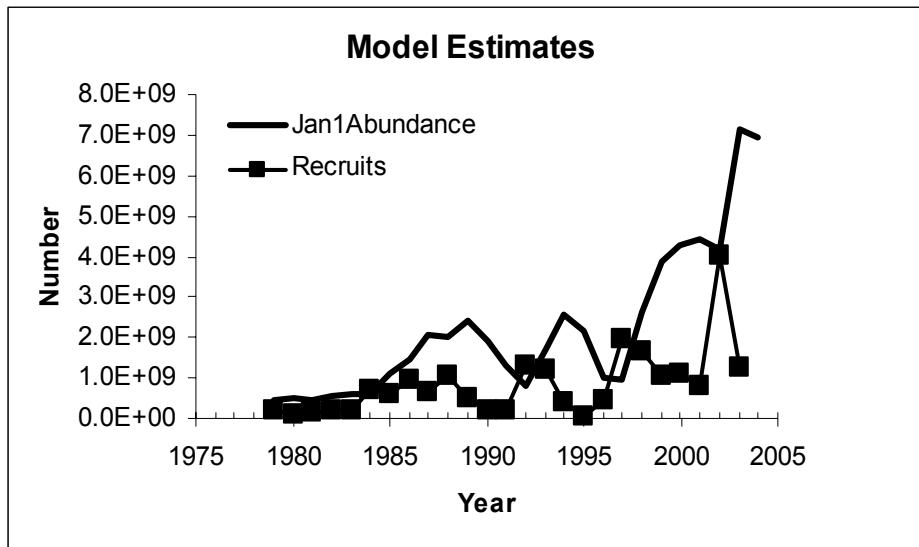
Standardized residuals spring BTS length composition



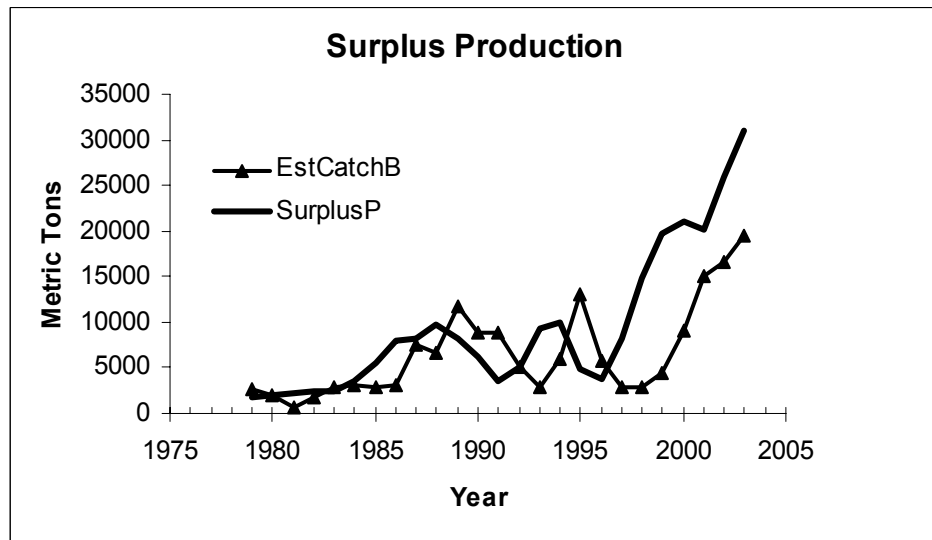
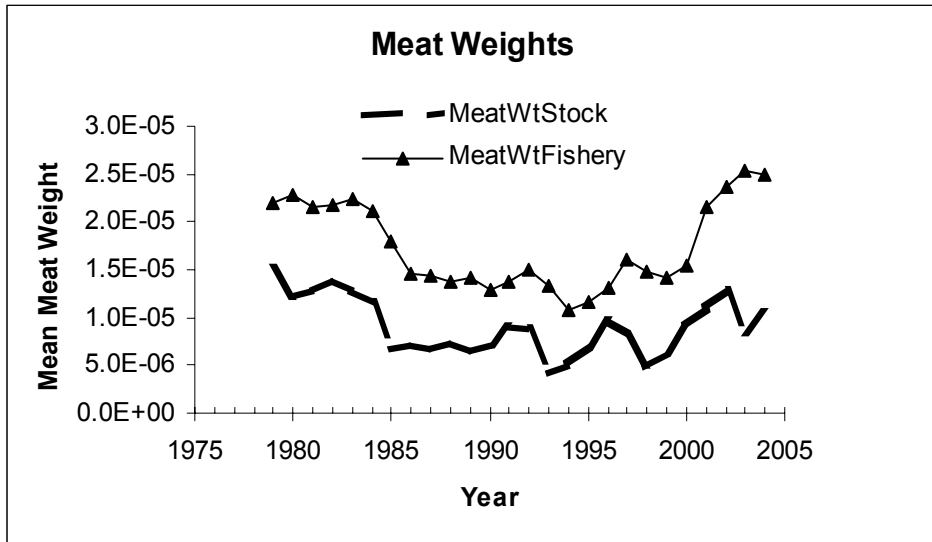
Standardized Residuals 2003 SMAST video survey length composition



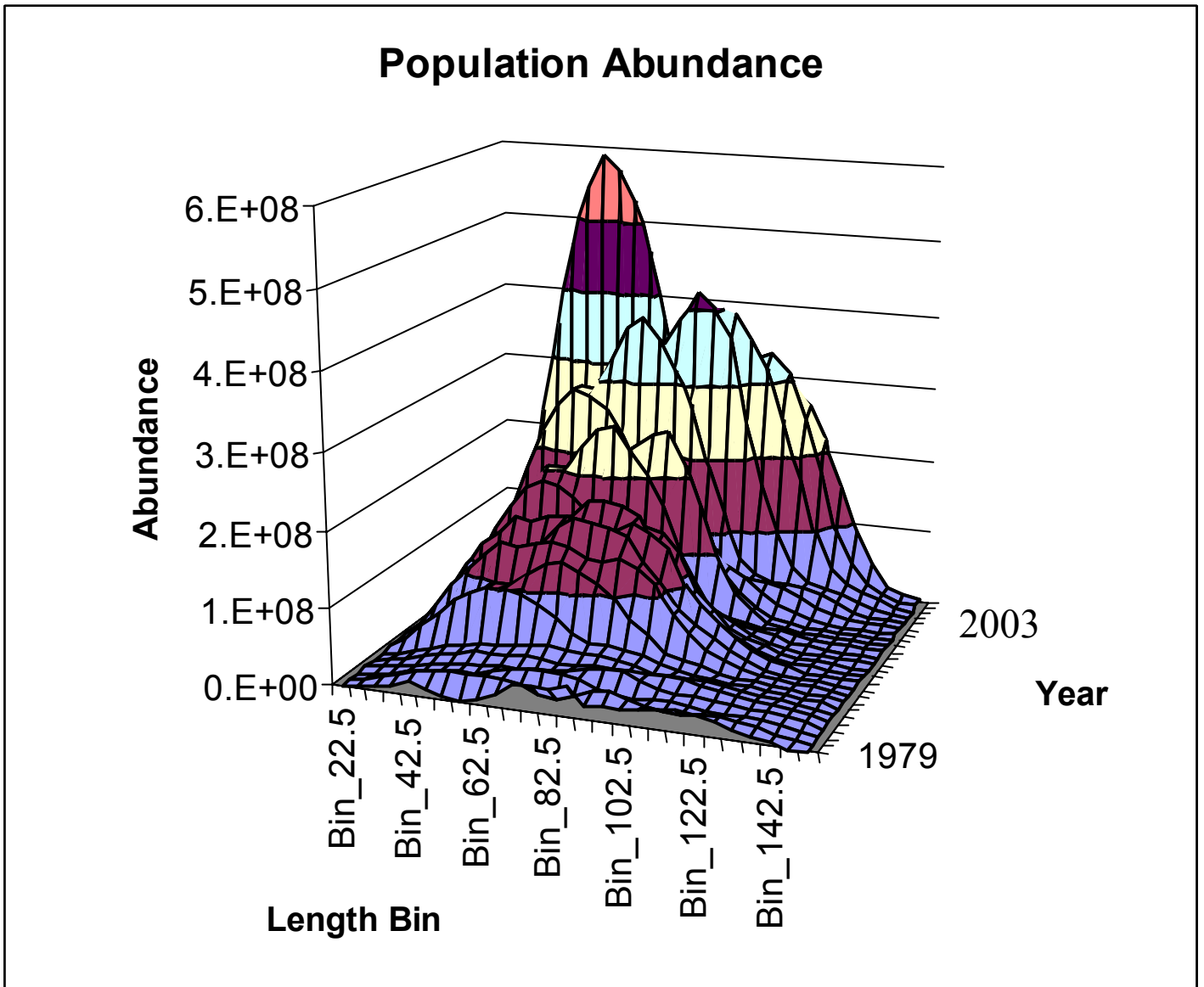
Appendix Figure 4-9. Standardized residuals by year and length bin for MAB sea scallop length composition data. Fishery length composition data were for 1979-1984 and 1994-2003. The apparent residual pattern for fishery data during 1985-1993 is an artifact due to no data.



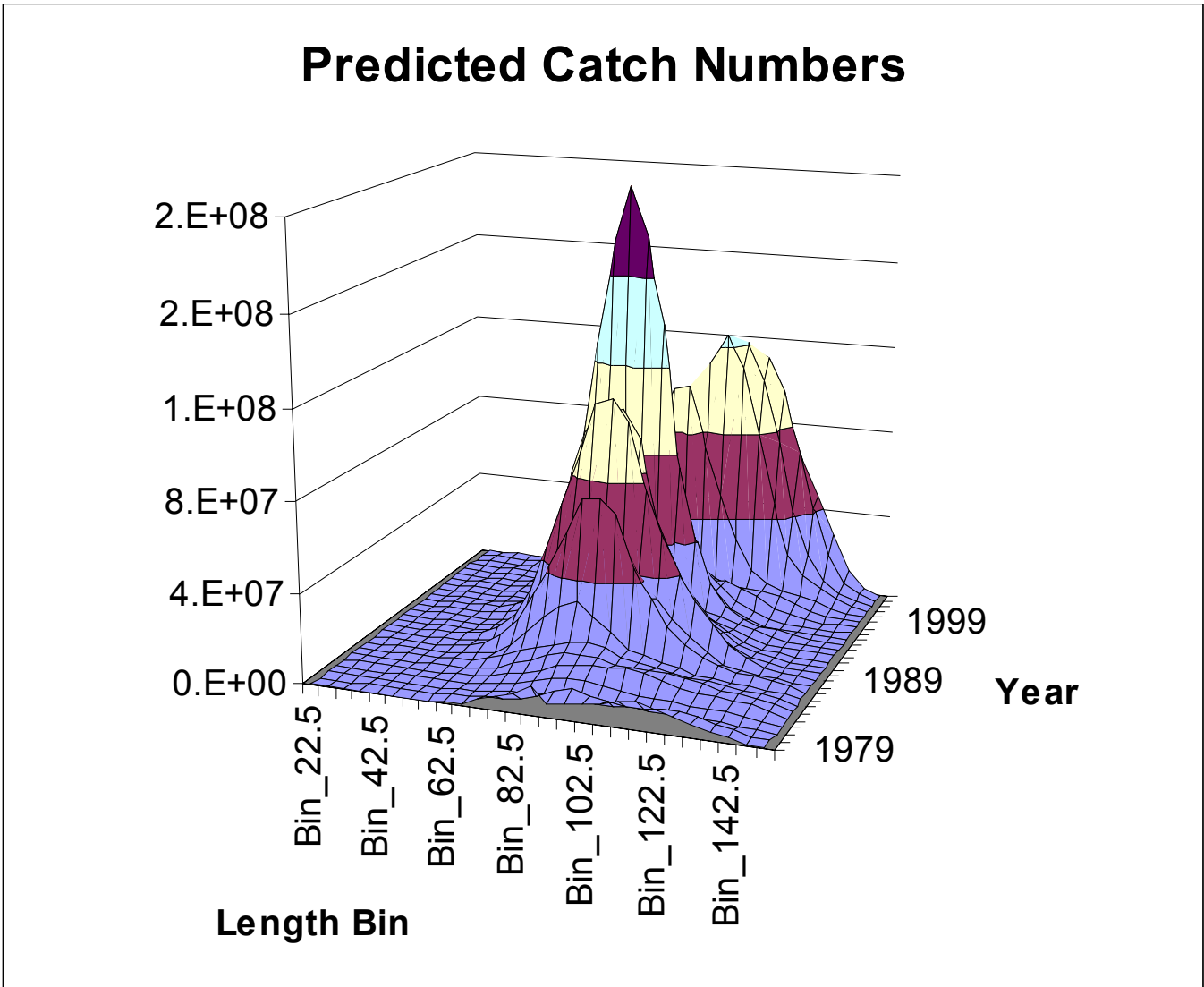
Appendix Figure 4-10. CASA model estimates of abundance, recruitment and fishing mortality for MAB sea scallops. In the lower panel, “Full Recruit F” is for length groups fully selected by the fishery and reflects changes in fishery selectivity, “Exploitation Index” is total catch number divided by abundance of scallops 90+ mm, and “Rescaled F” is for fishing mortality estimates by the method used for status determination.



Appendix Figure 4-11. CASA model estimates of mean meat weights in the stock and fishery (top) and surplus production compared to catch of MAB sea scallops.

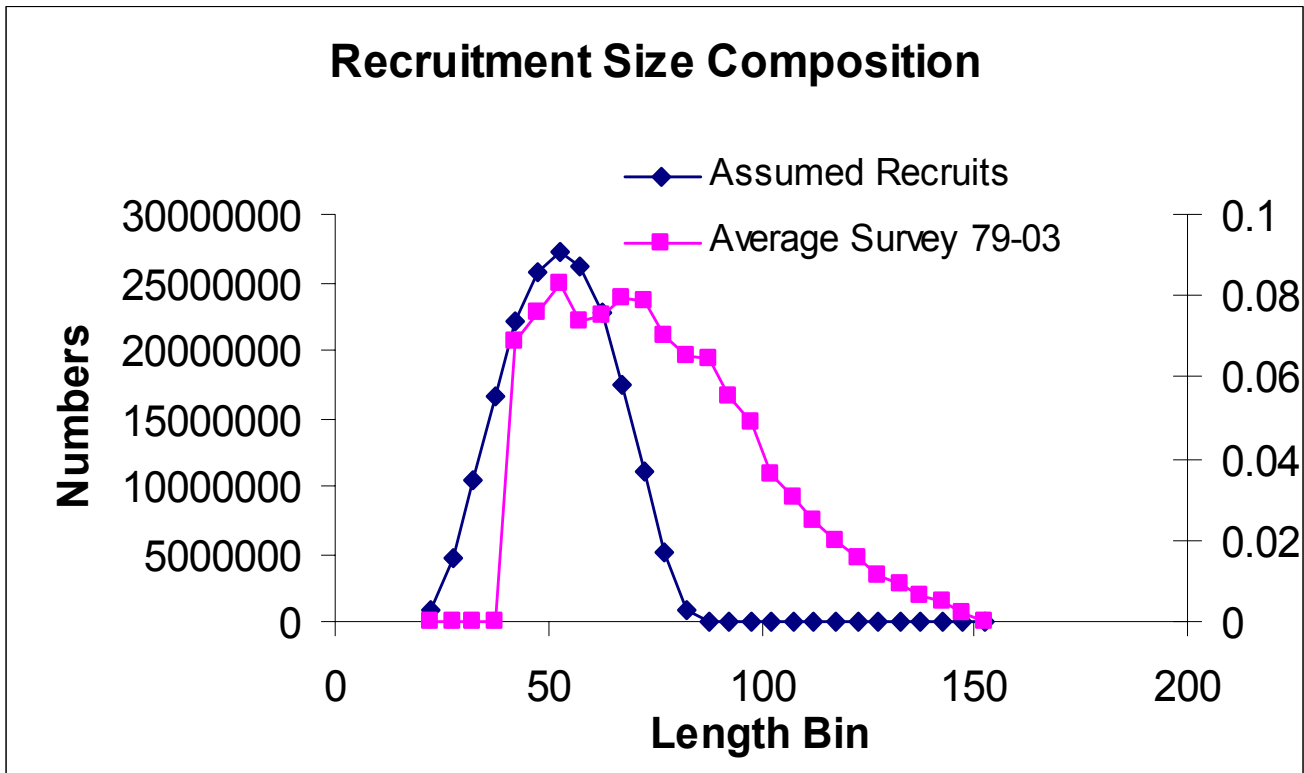


Appendix Figure 4-12. CASA model estimates of abundance at length by year for MAB sea scallops.

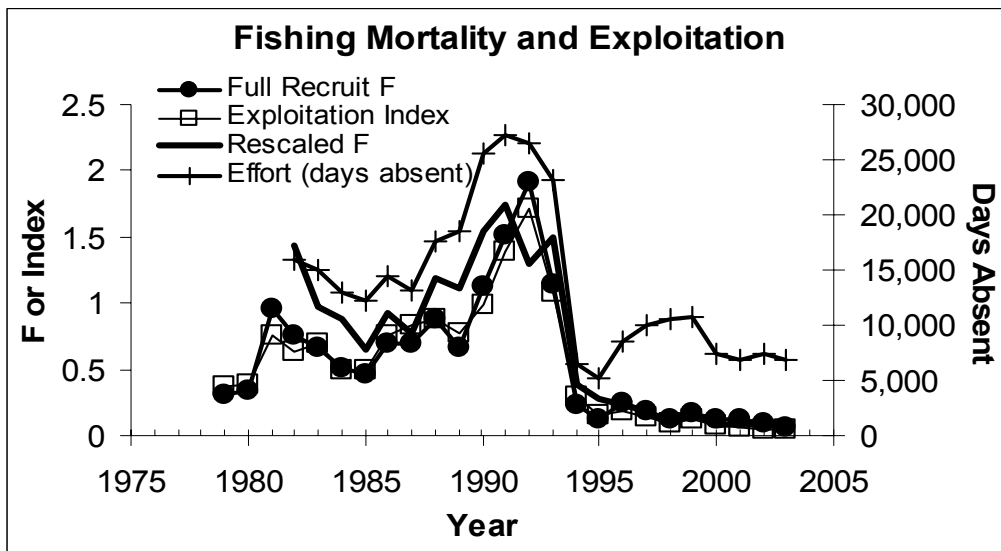
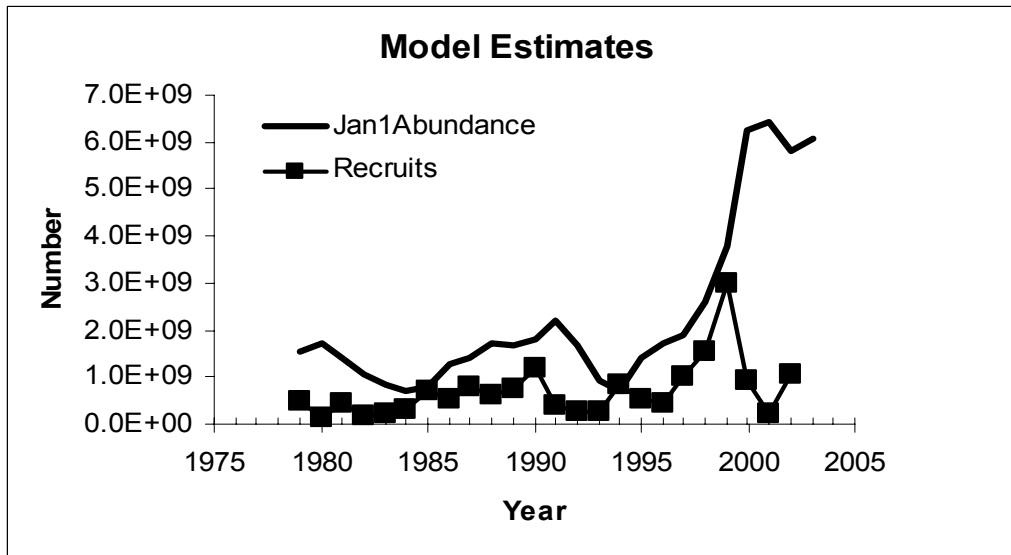


Appendix Figure 4-13. CASA model estimates of catch at length by year for MAB sea scallops.

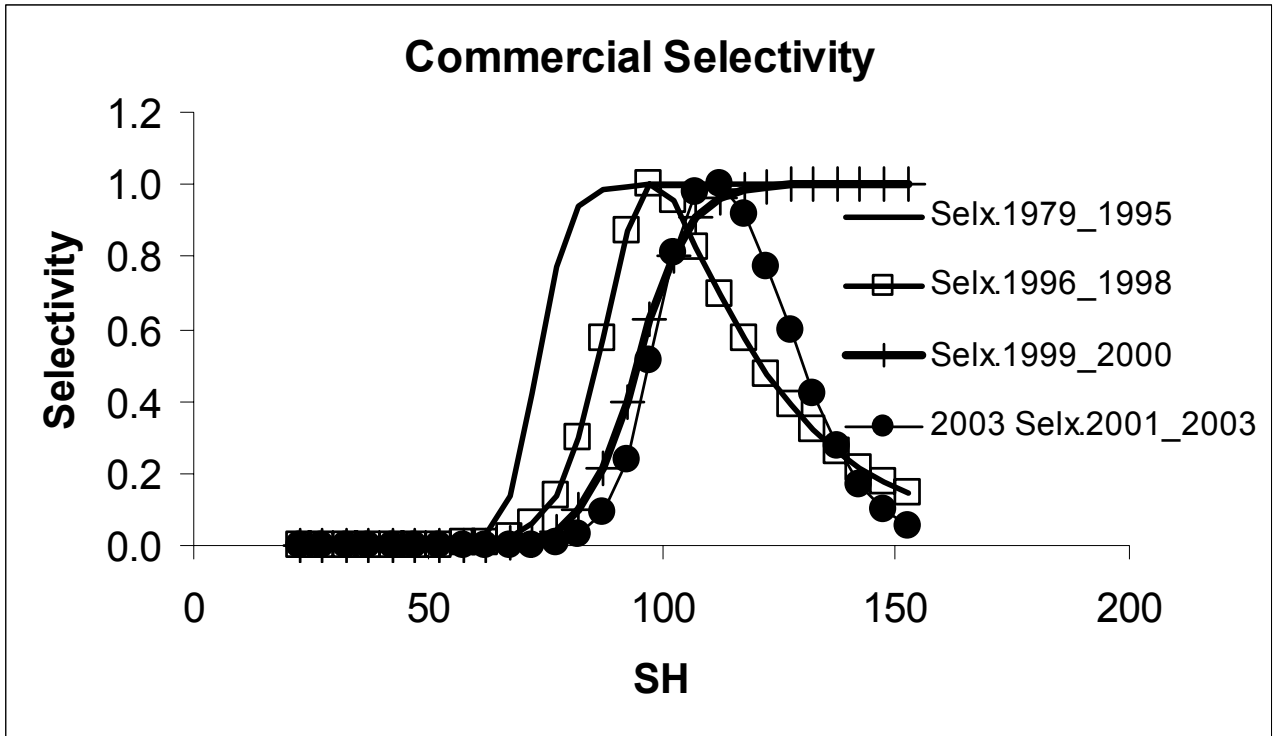




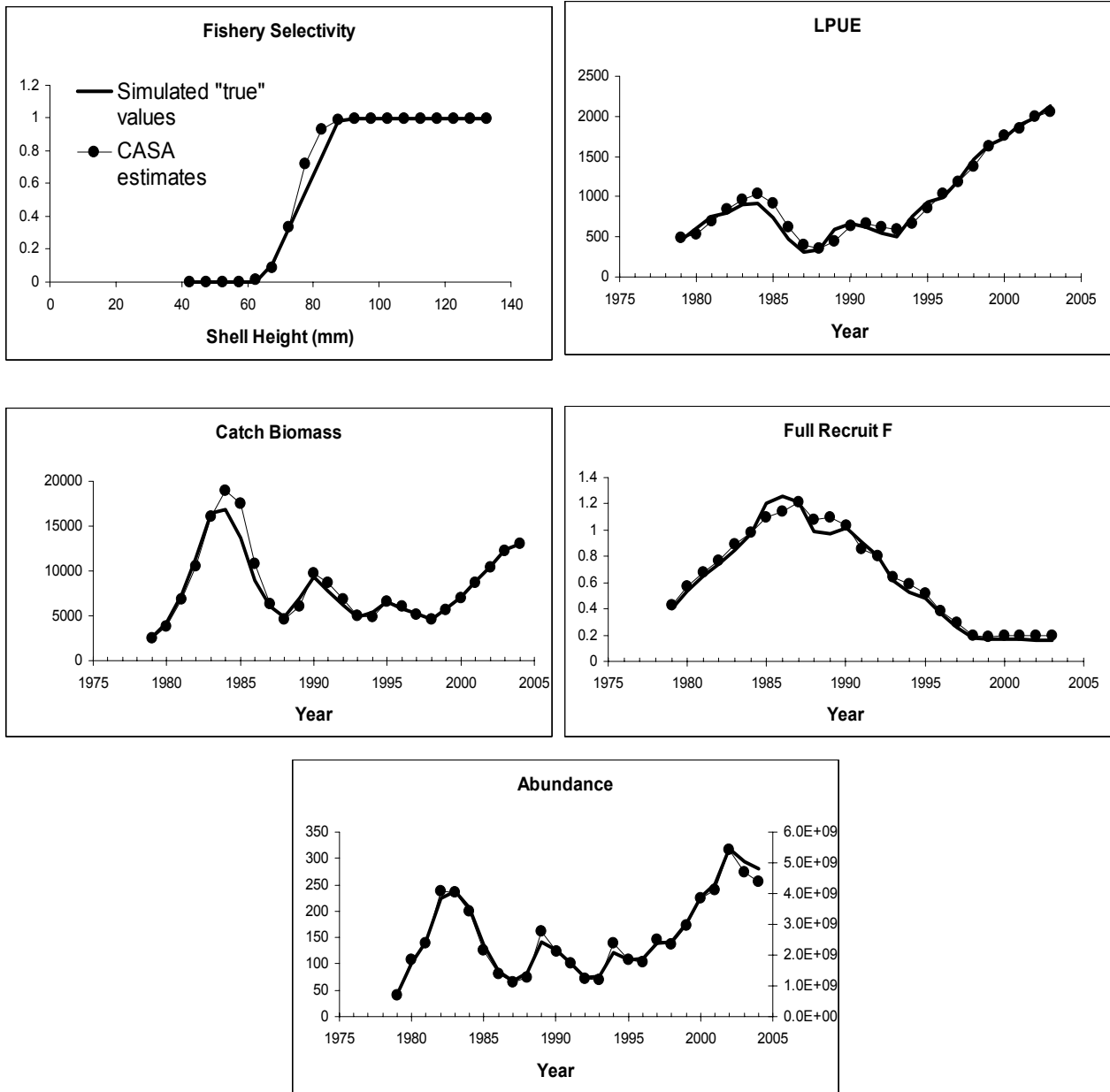
Appendix Figure 4-14. Assumed length composition of new recruits in the CASA model compared to average NEFSC scallop survey length composition data for 1979-2003. The steep ascending limb for the average survey length composition during 1979-2003 is an artifact due to using survey data for scallops larger than 40 mm.



Appendix Figure 4-15. CASA model estimates of abundance, recruitment and fishing mortality for GBK sea scallops. In the lower panel, “Full Recruit F” is for length groups fully selected by the fishery and reflects changes in fishery selectivity, “Exploitation Index” is total catch number divided by abundance of scallops 90+ mm, and “Rescaled F” is for fishing mortality estimates by the method used for status determination. Fishing effort is days absent from port.



Appendix Figure 4-16. Fishery selectivity patterns estimated in the CASA model for GBK sea scallops.



Appendix Figure 4-17. Results of simulation tests.



## APPENDIX 5. THE CASA LENGTH STRUCTURED STOCK ASSESSMENT MODEL

The stock assessment model described here is based on Sullivan et al.'s (1990) CASA model.<sup>4</sup> CASA is entirely length-based with population dynamic calculations in terms of the number of individuals in each length group during each year. Age is largely irrelevant in model calculations. Unlike many other length-based stock assessment approaches, CASA is a dynamic, non-equilibrium model based on a forward simulation approach. CASA incorporates a very wide range of data with parameter estimation based, in the broadest sense, on maximum likelihood. CASA can incorporate prior information about parameters such as survey catchability in a quasi-Bayesian fashion. The implementation described here was programmed in AD-Model Builder (Otter Research Ltd.).<sup>5</sup>

### *Population dynamics*

Time steps in the model are the same as the time periods used to tabulate catch and other data. In principle, the accuracy of calculations improves as time steps in the model become shorter, but data considerations often limit time steps to years. In this description, time steps are referred to as “years” without loss of generality. If time steps are years, then instantaneous rates have units  $y^{-1}$ . The number of years in the model  $n_y$  is flexible and can be changed easily (e.g. for retrospective analyses), usually by making a single change to the input data file.

The definition of length groups (or length “bins”) is a key element in the CASA model and length-structured stock assessment modeling in general. Length bins are identified by their lower bound. With 10 mm length bins, for example, the 20 mm size bin includes individual 20-29.9 mm. Calculations requiring information about length (e.g. length-weight) use the mid-length  $\ell_j$  of each bin.

In the current implementation, the user must specify the size of length bins ( $L_{bin}$ ) in the data and model, the minimum size ( $L_{min}$ ) at the lower bound of the first length bin in the data and model, and the maximum asymptotic length ( $L$ ). Based on these specifications, the model determines the number ( $n_L$ ) of length bins to include in modeling. The last bin is a “plus-group” containing individuals  $L$  and larger. The number of length groups in catch at length and other data should be  $\geq n_L$ . Based on user specifications, the program takes care adjusting the original data to the length groups used in the model.

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<sup>4</sup> Original programming in AD-Model Builder by G. Scott Boomer and Patrick J. Sullivan (Cornell University), who bear no responsibility for errors in the current implementation.

<sup>5</sup> AD-Model Builder can be used to calculate variances for any estimated or calculated quantity in a stock assessment model, based on the Hessian matrix with “exact” derivatives and the delta method. Experience with other models (e.g. Overholtz et al., 2004) suggests that variances estimates from AD-Model Builder, which consider the variance of all model parameters, are similar to variances calculated by the common method of bootstrapping survey abundance data.

## Growth

Although age is not considered, Von Bertalanffy growth models are implicit in several of the configurations of the CASA model. The growth parameter  $L_\infty$  is not estimable because it is used in defining length bins prior to the parameter estimation phase.<sup>6</sup> The von Bertalanffy growth parameter  $t_0$  is not estimable because it is irrelevant in length-based models that predict growth during a year based on the von Bertalanffy growth parameter  $K$ ,  $L_\infty$  and size at the beginning of the year.

At the beginning of the year, scallops in each size group grow (or not) based on growth terms  $P(b,a)$  that measure the probability that a surviving individual that starts in bin  $a$  will grow to bin  $b$  by the beginning of the next year (columns index initial size and rows index subsequent size). Growth probabilities do not include any adjustments for mortality. In the CASA model, growth occurs immediately at the beginning of each year and the model assumes that no growth occurs during the year.

Growth probabilities depend on growth increments because:

$$L_2 = L_1 + \iota$$

where  $L_1$  is the starting length,  $L_2$  is length after one year of growth and  $\iota$  is the growth increment. Following Sullivan et al. (1990), and for simplicity, growth probabilities are calculated assuming that all individuals start at the middle of their original length bin  $\ell_a$ , and then grow to sizes that cover the whole range of each possible subsequent size bin. Thus:

$$P(b,a) = \int_{j=\ell_b - L_{bin}/2}^{\ell_b + L_{bin}/2} P(j | \ell_a) \partial j = \aleph(\ell_b + L_{bin}/2 | \ell_a) - \aleph(\ell_b - L_{bin}/2 | \ell_a)$$

where  $P(j | \ell_a)$  is the probability of increment  $j$  for an individual originally in bin  $a$  (at mid-length  $\ell_a$ ).  $\aleph(a | \ell_a)$  is the initial size-specific cumulative distribution function for growth increments. In CASA, cumulative distributions for growth increments are computed by numerical integration based on Simpson's rule (Press et al., 1990) and a user-specified number of steps per bin. The user can change the number of steps to balance the accuracy of the calculation against time required for growth calculations.

Growth probabilities  $P(b,a)$  are calculated in CASA by one of four options. Option 1 is similar to Sullivan et al.'s (1990) approach in that growth probabilities are calculated by numerical integration assuming that increments follow gamma distributions. The gamma distributions for growth increments are starting size-specific

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<sup>6</sup> "Estimable" means a potentially estimable parameter that is specified as a variable that may be estimated in the CASA computer program. In practice, estimability depends on the available data and other factors. It may be necessary to fix certain parameters at assumed fix values or to use constraints of prior distributions for parameters that are difficult to estimate, particularly if data are limited.

and are specified in terms of mean increments and CV's. Mean increments  $\bar{i}_a$  are from the von Bertalanffy growth curve:

$$\bar{i}_a = (L_\infty - \ell_a)(1 - e^{-K})$$

where  $K=e^\chi$  is the von Bertalanffy growth coefficient and  $\chi$  is an estimable parameter.<sup>7</sup> Under Option 1, CVs are a log-linear function of length:

$$CV_L = e^{\kappa + \lambda L}$$

where  $\kappa$  and  $\gamma$  are estimable parameters. Sullivan et al. 1990 assumed constant CV's for growth. This implementation of the CASA model includes the special case of constant CV's when  $\lambda=0$ .

Option 2 constructs a transition matrix directly from size-specific annual growth data (i.e. data records consisting of starting length, length after one year and number of observations). Under Option 2:

$$P(b, a) = \frac{n(b|a)}{\sum_{j=a}^{n_L} n(j|a)}$$

where  $n(b|a)$  is the number of individuals that started at size  $a$  and grew to size  $b$  after one year.

Under option 3, mean increments are from the von Bertalanffy growth curve as in option 1, but with length-specific CVs (and other model parameters) estimated in the model based on growth increments and other data (see below for goodness of fit calculations). Under option 3, the von Bertalanffy growth parameter  $K$ , which describes mean growth, and parameters for variance in growth ( $\kappa$  and  $\gamma$ ) are estimable. Option 4 uses a constant, user-specified transition matrix provided as data to the model.

Growth calculations based on assumed gamma distributions (Sullivan et al. 1990) might be unrealistic for some species because the gamma distribution predicts growth increments of zero to infinity. Therefore, with options 1-3, the user may specify minimum and maximum growth increments for each size. Probabilities from truncated gamma distributions for growth increments between the minimum and maximum values are normalized to sum to one before use in population dynamics calculations. Size bins outside those specified are ignored in all model calculations.

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<sup>7</sup> Most intrinsically positive or intrinsically negative parameters are estimated in log scale to ensure estimates do not change sign, and to enhance statistical properties of estimates.



### Abundance, recruitment and mortality

Population abundance in each length bin during the first year of the model is:

$$N_{1,L} = N_1 \pi_{1,L}$$

where  $L$  is the size bin, and  $\pi_{1,L}$  is the initial population length composition expressed as proportions so that  $\sum_{L=1}^{n_L} \pi_L = 1$ .  $N_1 = e^\eta$  is total abundance at the beginning of the first modeled year and  $\eta$  is an estimable parameter. It is not necessary to estimate recruitment in the first year because recruitment is implicit in the product of  $N_1$  and  $\pi_L$ . The current implementation of CASA takes the initial population length composition as data supplied by the user.

Abundance at length in years after the first is calculated:

$$\vec{N}_{y+1} = P(\vec{N}_y \otimes \vec{S}_y) + \vec{R}_{y+1}$$

where  $\vec{N}_y$  is a vector (length  $n_L$ ) of abundance in each length bin during year  $y$ ,  $P$  is the matrix ( $n_L \times n_L$ ) of growth probabilities  $P(b,a)$ ,  $\vec{S}_y$  is a vector of length-specific survival fractions for year  $y$ ,  $\otimes$  is for the element-wise product, and  $\vec{R}_y$  is a vector holding length-specific abundance of new recruits at the beginning of year  $y$ .

Survival fractions are:

$$S_{y,L} = e^{-Z_{y,L}} = e^{-(M+F_{y,L})}$$

where  $Z_{y,L}$  is the total instantaneous mortality rate. The natural mortality rate  $M=e^{\varpi}$  ( $\varpi$  estimable) is the same for all length groups in all years. Length-specific fishing mortality rates are  $F_{y,L} = F_y s_{y,L}$  where  $s_{y,L}$  is the size-specific selectivity for the fishery in year  $y$  (scaled to a maximum of one at fully recruited size groups), and  $F_y$  is the fishing mortality rate on fully selected individuals.<sup>8</sup> Fully recruited fishing mortality rates are  $F_y = e^{\phi + \delta_y}$  where  $\phi$  is an estimable parameter for the log of the geometric mean of fishing mortality in all years, and  $\delta_y$  is an estimable “dev” parameter.<sup>9</sup>

Given abundance in each length group, natural mortality, and fishing mortality,

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<sup>8</sup> In this context, “selectivity” describes the combined effects of all factors that affect length composition of catch or landings. These factors include gear selectivity, spatial overlap of the fishery and population, size-specific targeting, size-specific discard, etc.

<sup>9</sup> Dev parameters are a special data type for estimable parameters in AD-Model Builder. Each set of dev parameters (e.g. for all recruitments in the model) is constrained to sum to zero. Because of the constraint, the sums  $\phi + \delta_y$  involving  $n_y + 1$  terms amount to only  $n_y$  parameters.

predicted fishery catch-at-length in numbers is:

$$C_{y,L} = \frac{F_{y,L} (1 - e^{-Z_{y,L}}) N_{L,y}}{Z_{y,L}}$$

Total catch number during each year is  $C_y = \sum_{j=1}^{n_L} C_{y,L}$ . Note that, because the catches are in effect assumed to be taken at the beginning of the year, model catches (by weight) will tend to be biased low, especially during years when mostly smaller scallops were taken.

Recruitment (the sum of new recruits in all length bins) at the beginning of each year after the first is calculated based on estimable parameters that measure annual deviations  $\gamma_y$  from the log-scale geometric mean  $\rho$ :

$$Ry = e^{\rho + \gamma_y}$$

Proportions of recruits in each length group are calculated based on a standard beta distribution  $B(w,r)$  over the first  $n_r$  length bins. Proportions of new recruits in each size group are the same from year to year. Beta distribution coefficients must be larger than zero and are calculated  $w=e^\omega$  and  $r=e^\rho$ , where  $\omega$  and  $\rho$  are estimable parameters.

#### *Population summary variables*

Total abundance at the beginning of the year is the sum of abundance at length  $N_{y,L}$  at the beginning of the year. Average annual abundance is:

$$\bar{N}_{y,L} = N_{y,L} \frac{1 - e^{-Z_{y,L}}}{Z_{y,L}}$$

The current implementation of the NC model assumes that weight-at-length is the same for the stock and fishery and a single set of length-weight conversion parameters is used in all calculations. For example, total stock biomass is:

$$B_y = \sum_{L=1}^{n_L} N_{y,L} w_L$$

where  $w_L$  is weight at length computed at the midpoint of each length bin using the length-weight relationship specified by the user. Total catch weight is:

$$W_y = \sum_{L=1}^{n_L} C_{y,L} w_L$$

$F_y$  estimates for two years are comparable if fishery selectivity in the model was the same in both years. A simpler exploitation index is calculated for use when fishery selectivity changes over time:

$$U_y = \frac{C_y}{\sum_{j=x}^{n_L} N_{y,L}}$$

where  $x$  is a user-specified length bin (usually at or below the first bin that is fully selected during all fishery selectivity periods).  $U_y$  exploitation indices from different years with different selectivity patterns may be relatively comparable if  $w$  is chosen carefully.

Surplus production during each year of the model can be computed approximately from biomass and catch estimates (Jacobson et al., 2002):

$$P_t = B_{t+1} - B_t + \delta C_t$$

where  $\delta$  is a correction factor that adjusts catch weight to population weight at the beginning of the next year by accounting for mortality and growth. The adjustment factor depends strongly on the rates for growth and natural mortality and only weakly on the natural mortality rate. In the absence of a direct estimate, useful calculations can be carried out assuming  $\delta=1$ .

#### *Fishery and survey selectivity*

The current implementation of CASA includes six options for calculating fishery and survey selectivity patterns. Fishery selectivity may differ among “fishery periods” defined by the user. Selectivity patterns that depend on length are calculated using lengths at the mid-point of each bin ( $\ell$ ). After initial calculations (described below), selectivity curves are rescaled to a maximum value of one.

Option 1 is a flat with  $s_L=1$  for all length bins. Option 2 is an ascending logistic curve:

$$s_{y,\ell} = \frac{1}{1 + e^{A_y - B_y \ell}}$$

Option 3 is an ascending logistic curve with a minimum asymptotic minimum size for small size bins on the left.

$$s_{y,\ell} = \left( \frac{1}{1 + e^{A_y - B_y \ell}} \right) (1 - D_y) + D_y$$

Option 4 is a descending logistic curve:

$$s_{y,\ell} = 1 - \frac{1}{1 + e^{A_Y - B_Y \ell}}$$

Option 5 is a descending logistic curve with a minimum asymptotic minimum size for large size bins on the right:

$$s_{y,\ell} = \left(1 - \frac{1}{1 + e^{A_Y - B_Y \ell}}\right)(1 - D_y) + D_y$$

Option 6 is a double logistic curve used to represent “domed-shape” selectivity patterns with highest selectivity on intermediate size groups:

$$s_{y,\ell} = \left(\frac{1}{1 + e^{A_Y - B_Y \ell}}\right) \left(1 - \frac{1}{1 + e^{D_Y - G_Y \ell}}\right)$$

The coefficients for selectivity curves  $A_Y$ ,  $B_Y$ ,  $D_Y$  and  $G_Y$  carry subscripts for time because they may vary between fishery selectivity periods defined by the user. All options are parameterized so that the coefficients  $A_Y$ ,  $B_Y$ ,  $D_Y$  and  $G_Y$  are positive. Under options 3 and 5,  $D_y$  is a proportion that must lie between 0 and 1.

Depending on the option, estimable selectivity parameters may include  $\alpha$ ,  $\beta$ ,  $\delta$  and  $\gamma$ . For options 2, 4 and 6,  $A_Y = e^{\alpha_Y}$ ,  $B_Y = e^{\beta_Y}$ ,  $D_Y = e^{\delta_Y}$  and  $G_Y = e^{\gamma_Y}$ . Options 3 and 5 use the same conventions for  $A_Y$  and  $B_Y$ , however, the coefficient  $D_Y$  is a proportion estimated as a logit-transformed parameter (i.e.  $\delta_Y = \ln[D_Y/(1-D_Y)]$ ) so that:

$$D_Y = \frac{e^{\delta_Y}}{1 + e^{\delta_Y}}$$

The user can choose, independently of all other parameters, to either estimate each fishery selectivity parameter or to keep it at its initial value. Under Option 2, for example, the user can estimate the intercept  $\alpha_Y$ , while keep the slope  $\beta_Y$  at its initial value.

### *Tuning and goodness of fit*

There are two steps in calculating the negative log likelihood (NLL) used to measure how well the model fits each type of data. The first step is to calculate the predicted values for data. The second step is to calculate the NLL of the data given the predicted value. The overall goodness of fit measure for the model is the weighted sum of NLL values for each type of data and each constraint:

$$\Lambda = \sum \lambda_j L_j$$

where  $\lambda_j$  is a weighting factor for data set  $j$  (usually  $\lambda_j=1$ , see below), and  $L_j$  is the NLL for the data set. The NLL for a particular data is itself is usually a weighted sum:

$$L_j = \sum_{i=1}^{n_j} \psi_{j,i} L_{j,i}$$

where  $n_j$  is the number of observations,  $\psi_{j,i}$  is an observation-specific weight (usually  $\psi_{j,i} = 1$ , see below), and  $L_{j,i}$  is the NLL for a single observation.

Maximum likelihood approaches reduce the need to specify *ad-hoc* weighting factors ( $\lambda$  and  $\phi$ ) for data sets or single observations, because weights can often be taken from the data (e.g. using CVs routinely calculated for bottom trawl survey abundance indices) or estimated internally along with other parameters. In addition, robust maximum likelihood approaches (see below) may be preferable to simply down-weighting an observation or data set. However, despite subjectivity and theoretical arguments against use of *ad-hoc* weights, it is often useful in practical work to manipulate weighting factors, if only for sensitivity analysis or to turn an observation off entirely. Observation specific weighting factors are available for most types of data in the CASA model.

### *Missing data*

Availability of data is an important consideration in deciding how to structure a stock assessment model. The possibility of obtaining reliable estimates will depend on the availability of sufficient data. However, NLL calculations and the general structure of the CASA model are such that missing data can usually be accommodated automatically. With the exception of catch data (which must be supplied for each year, even if catch was zero), the model calculates that NLL for each datum that is available. No NLL calculations are made for data that are not available and missing data do not generally hinder model calculations.

### *Likelihood kernels*

Log likelihood calculations in the current implementation of the CASA model use log likelihood “kernels” or “concentrated likelihoods” that omit constants. The constants can be omitted because they do not affect slope of the NLL surface, final point estimates for parameters or asymptotic variance estimates.<sup>10</sup>

For data with normally distributed measurement errors, the complete NLL for one observation is:

$$L = \ln(\sigma) + \ln(\sqrt{2\pi}) + 0.5 \left( \frac{x - u}{\sigma} \right)^2$$

The constant  $\ln(\sqrt{2\pi})$  can always be omitted. If the standard deviation is known or assumed known, then  $\ln(\sigma)$  can be omitted as well because it is a constant that does not affect derivatives. In such cases, the concentrated NLL is:

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<sup>10</sup> Likelihood kernels in the present implementation prevent use of AD-Model Builder’s MCMC algorithms for Bayesian statistical approaches.

$$L = 0.5 \left( \frac{x - \mu}{\sigma} \right)^2$$

If there are  $N$  observations with possible different variances (known or assumed known) and possibly different expected values:

$$L = 0.5 \sum_{i=1}^N \left( \frac{x_i - \mu_i}{\sigma_i} \right)^2$$

If the standard deviation for a normally distributed quantity is not known and is estimated (implicitly or explicitly) by the model, then one of two equivalent calculations is used. Both approaches assume that all observations have the same variance and standard deviation. The first approach is used when all observations have the same weight in the NLL:

$$L = 0.5N \ln \left[ \sum_{i=1}^N (x_i - u)^2 \right]$$

The second approach is equivalent but used when the weights for each observation ( $w_i$ ) may differ:

$$L = \sum_{i=1}^N w_i \left[ \ln(\sigma) + 0.5 \left( \frac{x_i - u}{\sigma} \right)^2 \right]$$

In the latter case, the maximum likelihood estimator:

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^N (x_i - \hat{x})^2}{N}}$$

(where  $\hat{x}$  is the average or predicted value from the model) is used explicitly for  $\sigma$ . The maximum likelihood estimator is biased by  $N/(N-d_f)$  where  $d_f$  is degrees of freedom for the model. The bias may be significant for small sample sizes, which are common in stock assessment modeling, but  $d_f$  is usually unknown.

If data  $x$  have lognormal measurement errors, then  $\ln(x)$  is normal and  $L$  is calculated as above. In some cases it is necessary to correct for bias in converting arithmetic scale means to log scale means (and *vice-versa*) because  $\bar{x} = e^{\bar{\chi} + \sigma^2/2}$  where  $\chi = \ln(x)$ . It is often convenient to convert arithmetic scale CVs for lognormal variables to log scale standard deviations using  $\sigma = \sqrt{\ln(1 + CV^2)}$ .

For data with multinomial measurement errors, the likelihood kernel is:

$$L = n \sum_{i=1}^n p_i \ln(\theta_i) - K$$

where  $n$  is the known or assumed number of observations (the “effective” sample size),  $p_i$  is the proportion of observations in bin  $i$ , and  $\theta_i$  is the model’s estimate of the probability of an observation in the bin. The constant  $K$  is used for convenience to keep  $L$  to a manageable number of digits. It measures the lowest value of  $L$  that could be achieved if the data fit matched the model’s expectations exactly:

$$K = n \sum_{i=1}^n p_i \ln(p_i)$$

For data  $x$  that have measurement errors with expected values of zero from a gamma distribution:

$$L = (\gamma - 1) \ln\left(\frac{x}{\beta}\right) - \frac{x}{\beta} - \ln(\beta)$$

where  $\beta > 0$  and  $\gamma > 0$  are gamma distribution parameters in the model. For data that lie between zero and one with measurement errors from a beta distribution:

$$L = (p - 1) \ln(x) + (q - 1) \ln(1 - x)$$

where  $p > 0$  and  $q > 0$  are parameters in the model.

In CASA model calculations, distributions are usually described in terms of the mean and CV. Normal, gamma and beta distribution parameters can be calculated mean and CV by the method of moments. Means, CV’s and distributional parameters may, depending on the situation, be estimated in the model or specified by the user.

### *Robust methods*

“Robust” maximum likelihood calculations are available for noisy data in the CASA model that might be assumed otherwise to have normally distributed measurement errors. Robust likelihood calculations assume that measurement errors are from a Student’s  $t$  distribution with user-specified degrees of freedom  $d_f$ . Degrees of freedom are specified independently for each observation so that robust calculations can be carried out for as many (or as few) cases as required. The  $t$  distribution is similar to the normal distribution for  $d_f \geq 30$ . As  $d_f$  are reduced, the tails of the  $t$  distribution become fatter so that small observations seem more probable (have higher probability) and have less effect on model estimates. If  $d_f = 0$ , then measurement errors are assumed in the model to be normally distributed.

The first step in robust NLL calculations is to standardize the measurement error residual  $t = (x - \bar{x})/\sigma$  based on the mean and standard deviation. Then:

$$L = \ln\left(1 + \frac{t^2}{d_f}\right) \left(1 - \frac{1-d_f}{2}\right) - \frac{\ln(d_f)}{2}$$

### *Catch weight data*

In the current version of the CASA model, catch data are for a single or “composite” fishery. The terms “catches” and “landings” are used interchangeably in the current version because discard and non-landed fishery induced mortality are not distinguished. In the current version, total catch and must be specified in units of weight. Ideally, catch data should include all fishery-induced mortality and fishery length composition data (if available) should be represent the size distribution of all individuals that suffered fishery-induced mortality.

Catch data are assumed to have normally distributed measurement errors with a user specified CV. The standard deviation for catch weight in a particular year is  $\sigma_Y = \kappa \hat{C}_Y$  where “^” indicates that the variable is a model estimate. The standardized residual used in computing NLL for a single catch observation and in making residual plots is  $r_Y = (C_Y - \hat{C}_Y) / \sigma_Y$ .

### *Fishery length composition data*

Data describing numbers or relative numbers of individuals at length in catch data (fishery catch-at-length) are modeled as multinomial proportions  $c_{y,L}$ :

$$c_{y,L} = \frac{C_{y,L}}{\sum_{j=1}^{n_L} C_{y,j}}$$

The NLL for the observed proportions in each year is computed based on the kernel for the multinomial distribution, the model’s estimate of proportional catch-at-length ( $\hat{c}_Y$ ) and an estimate of effective sample size  ${}^cN_Y$  supplied by the user. Care is required in specifying effective sample sizes, because catch-at-length data typically carry substantially less information than would be expected based on the number of individuals measured (Fournier and Archibald, 1982; Pennington et al., 2002). Typical conventions make  ${}^cN_Y \leq 200$  or set  ${}^cN_Y$  equal to the number of trips or tows sampled. Effective sample sizes are sometimes chosen based on goodness of fits in preliminary model runs (Methot, 2000; Butler et al., 2003).

Standardized residuals are not used in computing NLL fishery length composition data. However, approximate standardized residuals  $r_y = (c_{y,L} - \hat{c}_{y,L}) / \sigma_{y,L}$  with standard deviations  $\sigma_{y,L} = \sqrt{\hat{c}_{y,L}(1 - \hat{c}_{y,L}) / {}^cN_Y}$  based on the theoretical variance for proportions are computed for use in making residual plots.



### Survey index data

In CASA model calculations, “survey indices” are data from any source that reflect relative proportional changes in annual abundance or biomass over time. In the current implementation of the CASA model, survey indices are assumed to be linear indices of abundance or biomass so that changes in the index (apart from measurement error) are assumed due to proportional changes in the population. Nonlinear commercial catch rate data are handled separately (see below).

In general, survey index data give one number that summarizes relative abundance for a wide range of length bins. Catch at length data from surveys are handled separately (see below). For example, a survey index might consist of stratified mean numbers per tow for all size bins in a bottom trawl survey carried out over a series of years, with one observation of the index per year of sampling.

NLL calculations for survey indices use predicted values calculated:

$$\hat{I}_{k,y} = q_k A_{k,y}$$

where  $q_k$  is a scaling factor for survey index  $k$ , and  $A_{k,y}$  is abundance or biomass available to the survey. Scaling factors are calculated  $q_s = e^{\varpi_s}$  where  $\varpi_s$  is estimable and survey-specific. Available abundance is:

$$A_{k,y} = \sum_{L=first_k}^{last_k} s_{k,L} N_{y,L} e^{-Z_{y,L} \tau_{k,y}}$$

where  $s_{k,L}$  is size-specific selectivity of the survey,  $\tau_{k,y} = J_{k,y}/365$  where  $J_{k,y}$  is the mean Julian date of the survey, and  $e^{-Z_{y,L} \tau_{k,y}}$  is a correction for mortality prior to the survey. Options and procedures for estimating survey selectivity patterns are the same as for fishery selectivity patterns, but survey selectivity patterns are not allowed to change over time. Available biomass is calculated in the same way except that body weights  $w_L$  are included in the product on the right hand side.

The range of lengths ( $first_k \geq 1$  to  $last_k \leq n_L$ ) included in the calculation of  $A_{k,y}$  is specified by the user for each survey. In addition, the user specifies whether  $first_k$  and  $last_k$  are plus-groups meant to contain smaller or larger individuals.

NLL calculations for survey index data assume that log scale measurement errors are either normally distributed (default approach) or from a  $t$  distribution (robust estimation approach). In either case, log scale measurement errors are assumed to have mean zero and log scale standard errors either estimated internally by the model or calculated from the arithmetic CVs supplied with the survey data.

The standardized residual used in computing NLL for one survey index

observation is  $r_{k,y} = \ln(I_{k,y}/\hat{I}_{k,y})/\sigma_{k,y}$  where  $I_{k,y}$  is the observation. The standard deviations  $\sigma_{k,y}$  will vary among surveys and years if CVs are used to specify the variance of measurement errors. Otherwise a single standard deviation is estimated internally for the survey as a whole.

### *Survey length composition data*

NLL calculations for survey length composition data are roughly analogous to calculations for fishery length composition data, except that measurement errors in length data can be modeled explicitly. Survey length composition data represent a sample from the true population length composition which is modified by survey selectivity, sampling errors (due to having a limited number of tows) and, if applicable, errors in recording length data (i.e. errors in observations to size bins). For example, with errors in length measurements, individuals belonging to length bin  $j$ , might be mistakenly assigned to adjacent length bins  $j-2$ ,  $j-1$ ,  $j+1$  or  $j+2$ . Well-tested methods for dealing with errors in length data can be applied if some information about the distribution of the errors is available (e.g. Methot 2000).

Survey length composition data are treated as multinomial proportions calculated:

$$i_{k,y,L} = \frac{n_{k,y,L}}{\sum_{j=first_k}^{last_k} n_{k,y,j}}$$

The model's estimate of length composition for the population available to the survey is:

$$A_{k,y,L} = \frac{s_{k,L} N_{y,L} e^{-Z_{y,j} \tau_{k,y}}}{\sum_{j=first_k}^{last_k} s_{k,j} N_{y,j} e^{-Z_{y,j} \tau_{k,y}}}$$

The expected length composition  $\vec{A}'_{k,y}$  for survey catches, including length measurement errors is:

$$\vec{A}'_{k,y} = \vec{A}_{k,y} \mathbf{E}_k$$

where  $\mathbf{E}_k$  is an error matrix that simulates errors in collecting length data by mapping true length bins in the model to observed length bins in the data.

The error matrix  $\mathbf{E}_k$  has  $n_L$  rows (one for each true length bin) and  $n_L$  columns (one for each possible observed length bin). For example, row  $k$  and column  $j$  of the error matrix gives the conditional probability  $P(k|j)$  of being assigned to bin  $k$ , given that an individual actually belongs to bin  $j$ . More generally, column  $j$  gives the probabilities that an individual actually belonging to length bin  $j$  will be recorded as being in length

bins  $j-2, j-1, j, j+1, j+2$  and so on. The columns of  $E_k$  add to one to account for all possible outcomes in assigning individuals to observed length bins.

In CASA, the probabilities in the error matrix are computed from a normal distribution with mean zero and  $CV = e^{\pi_k}$ , where  $\pi_k$  is an estimable parameter. The normal distribution is truncated to cover a user-specified number of observed bins.

The NLL for observed proportions at length in each survey and year is computed with the kernel for a multinomial distribution, the model's estimate of proportional survey catch-at-length ( $\hat{i}_{k,y,L}$ ) and an estimate of effective sample size  ${}^l N_y$  supplied by the user. Standardized residuals for residual plots are computed as for fishery length composition data.

### LPUE data

Commercial landings per unit of fishing effort (LPUE) data are modeled in the current implementation of the CASA model as a linear function of average biomass available to the fishery, and as a nonlinear function of average available abundance. The nonlinear relationship with abundance is meant to reflect limitations in “shucking” capacity for sea scallops.<sup>11</sup> Briefly, tows with large numbers of scallops require more time to sort and shuck and therefore reduce LPUE from fishing trips when abundance is high. The effect is exaggerated when the catch is composed of relatively small individuals. In other words, at any given level of stock biomass, LPUE is reduced as the number of individuals in the catch increases or, equivalently, as the mean size of individuals in the catch is reduced.

Average available abundance in LPUE calculations is:

$${}^a \bar{N}_y = \sum_{L=1}^{n_L} s_{y,L} \bar{N}_{y,L}$$

and average available biomass is:

$${}^a \bar{B}_y = \sum_{L=1}^{n_L} s_{y,L} w_L \bar{N}_{y,L}$$

Predicted values for LPUE data are calculated:

$$\hat{L}_y = \frac{{}^a \bar{B}_y \eta}{\sqrt{\phi^2 + {}^a \bar{N}_y^2}}$$

Measurement errors in LPUE data are assumed normally distributed with standard deviations  $\sigma_y = CV_y \hat{L}_y$ . Standardized residuals are  $r_y = (L_y - \hat{L}_y) / \sigma_y$ .

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<sup>11</sup> D. Hart, National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA, pers. comm.

### *Growth data*

Growth data in CASA consist of records giving initial length, length after one year of growth, and number of corresponding observations. Growth data may be used to help estimate growth parameters that determine the growth matrix  $P$ . The first step is to convert the data for each starting length to proportions:

$$P(b,a) = \frac{n(b,a)}{\sum_{j=n_L-b+1}^{n_L} n(j,a)}$$

where  $n(b,a)$  is the number of individuals starting at size *that* grew to size  $b$  after one year. The NLL is computed assuming that observed proportions  $p(a|b)$  at each starting size are a sample from a multinomial distribution with probabilities given by the corresponding column in the models estimated growth matrix  $P$ . The user must specify an effective sample size  $^P N_j$  based, for example, on the number of observations in each bin or the number of individuals contributing data to each bin. Observations outside bin ranges specified by the user are ignored. Standardized residuals for plotting are computed based on the variance for proportions.

### *Survey gear efficiency data*

Survey gear efficiency for towed trawls and dredges is the probability of capture for individuals anywhere in the water column or sediments along the path swept by the trawl. Ideally, the area surveyed and the distribution of the stock coincide so that:

$$\begin{aligned} I_{k,y} &= q_k A_{k,y} \\ q_k &= \frac{A e_k}{a_k} \\ e_k &= \frac{a_k q_k}{A_k} \end{aligned}$$

where  $A$  is the area of the stock,  $a_k$  is the area swept during one tow and  $0 < e_k \leq 1$  is efficiency of the survey gear. Efficiency estimates from studies outside the CASA model may be used as prior information in CASA. The user supplies the mean and CV for the prior estimate of efficiency, along with estimates of  $A_k$  and  $a_k$ . Then, at each iteration of the model, the gear efficiency implied by the current estimate of  $q_k$  is computed. The model then calculates the NLL of the implied efficiency estimate assuming it was sampled from a beta distribution with the user-specified mean and CV. Alternatively, in Bayesian jargon, the prior probability of the implied efficiency estimate is computed and added to the overall objective function.

Care should be taken in using prior information from field studies designed to

estimate survey gear efficiency. Field studies usually estimate efficiency with respect to individuals on the same ground (e.g. by sampling the same grounds exhaustively or with two types of gear). It seems reasonable to use an independent efficiency estimate and the corresponding survey index to estimate abundance in the area surveyed. However, stock assessment models are usually applied to the entire stock, which is probably distributed over a larger area than the area covered by the survey. Thus the simple abundance calculation based on efficiency and the survey index will be biased low for the stock as a whole.

*Maximum fishing mortality rate*

Stock assessment models occasionally estimate absurdly high fishing mortality rates because abundance estimates are too small. The NLL component used to prevent this potential problem is:

$$L = \lambda \sum_{t=0}^N (d_t^2 + q^2)$$

where:

$$d_t = \begin{cases} Ft - \Phi & \text{if } Ft > \Phi \\ 0 & \text{otherwise} \end{cases}$$

and

$$q_t = \begin{cases} \ln(Ft / \Phi) & \text{if } Ft > \Phi \\ 0 & \text{otherwise} \end{cases}$$

with the user-specified threshold value  $\Phi$  set larger than the largest value of  $F_t$  that might possibly be expected (e.g.  $\Phi=3$ ). The weighting factor  $\lambda$  is normally set to a large value (e.g. 1000).



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