Northeast Fisheries Science Center Reference Document 95-18

Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

Report of the 20th SAW

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, MA 02543-1026

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This report is a product of the 20th Northeast Regional Stock Assessment Workshop (20th SAW). Proceedings and products of the 20th SAW are scheduled to be documented and released in the following CRD's:

CRD 95-13	Assessment of the Georges Bank haddock stock for 1994. By L. O'Brien and R.W. Brown.
CRD 95-14	An examination of the influence of environmental conditions on spring survey catches of Atlantic mackerel. By J.K.T. Brodziak and S.-W. Ling.
CRD 95-15	A comparison of some biological reference points for fisheries management By J.K.T. Brodziak and W.J. Overholtz.
CRD 95-16	Assessment for sea scallop in Mid-Atlantic and Georges Bank. By H-L. Lai, P. Rago, S. Wigley, L.C. Hendrickson, and J. Idoine.
CRD 95-17	Assessment of black sea bass north of Cape Hatteras, North Carolina. By G.R. Shepherd and M.C. Lambert.
CRD 95-18	Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments.
CRD 95-19	Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW): SAW Public Review Workshop.

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MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) Meeting of the 20th Northeast Regional Stock Assessment Workshop (20th SAW) was held at the Northeast Fisheries Science Center (NEFSC), Woods Hole, Massachusetts during 19 - 23 June 1995. SARC Chairman was Dr. Terrence P. Smith (NEFSC). Members of the SARC were from the NEFSC and other NMFS Centers, from the NMFS Northeast Regional Office, New England and Mid-Atlantic Fishery Management Councils, Atlantic States Marine Fisheries Commission (ASMFC) and two States, from Canada and academia (Table 1). In addition, more than 30 other persons attended all or part of the meeting (Table 2). The meeting agenda is presented in Table 3.

Table 1. Composition of the SARC.

Chair:
Terry Smith, NEFSC
(SAW Chairman)

Four ad hoc experts chosen by the Chair:
Marinelle Basson, NEFSC
Ray Conser, NMFS, Hatfield Marine Science Center
Kevin Friedland, NEFSC
Josef Idoine, NEFSC

One person from NMFS, Northeast Regional Office:
Peter Colosi, NERO

One person from each Regional Management Council:
Andy Applegate, NEFMC
Chris Moore, MAFMC

Atlantic States Marine Fisheries Commission/State personnel:
Steve Correia, MA DMF
Robert O'Reilly, VA MRC
Harry Upton, ASMFC

One scientist from:
Canada - **Stratis Gavaris, DFO**
Academia - **Diane Brousseau, Fairfield University**
Other Region - **Douglas Vaughan, NMFS/SEFSC**

Industry Representative:
Karl English, LGL Limited

Table 2. List of participants.

National Marine Fisheries Service
<u>Northeast Fisheries Science Center</u>
Frank Almeida
Jon Brodziak
Russ Brown
David Dow
Wendy Gabriel
Tom Helser
Lisa Hendrickson
Wei Ling
Marjorie Lambert
Ralph Mayo
Steve Murawski
Helen Mustafa
Loretta O'Brien
Bill Overholtz
Paul Rago
Fred Serchuk
Gary Shepherd
Katherine Sosebee
Mark Terceiro
Jim Weinberg
Susan Wigley

Atlantic States Marine Fisheries Commission
John Carmichael
Barbara Dorf
Najih Lazar
Connecticut DEP Marine Fisheries
Dave Simpson
Massachusetts Div. of Marine Fisheries
Steve Cadrin
Paul Caruso
Dan McKiernan
David Pierce
Karen Rypka
New York DEC
Sherri Aicher
Rhode Island DF&W
Mark Gibson
Conservation and Law Foundation
Ellie Dorsey
Manomet Bird Observatory
Steve Kennelly

Table 3. Agenda of the 20th Northeast Regional Sock Assessment Workshop (SAW-20) Stock Assessment Review Committee (SARC) Meeting.

NEFSC Aquarium Conference Room
166 Water Street
Woods Hole , Massachusetts
Telephone: 508-548-5123
19 - 23 June 1995

AGENDA

SPECIES/STOCK	SUBCOMMITTEE & PRESENTER	SARC LEADER	RAPPORTEUR
MONDAY, June 19 (1:00 PM - 7:30 PM)................			
Opening Welcome Agenda Conduct of Meeting		T.P. Smith, Chairman	H. Mustafa
Ad Hoc Working Group on Sea- Port-Sampling Report (G)			
Haddock (A)	No. Demersal R. Mayo	S. Gavaris	R. Brown
Approve "points" for Advisory Report			
TUESDAY, June 20 (9:00 AM - 6:00 PM)................			
Summer Flounder (B)	So. Demersal W. Gabriel	M. Basson	M. Terceiro
Approve "points" for Advisory Report			
Black Sea Bass (E)	Pelagic/Coastal G. Shepherd	D. Vaughan	D. Simpson
Approve "points" for Advisory Report			
Review available draft sections for the SARC report			
WEDNESDAY, June 21 (9:00 AM - 6:00 PM)................			
Mackerel (C)	Pelagic Coastal J. Brodziak	K. Friedland	T. Helser
Approve "points" for Advisory Report			
Sea Scallop (D)	Invertebrate P. Rago	D. Brousseau	H.-L. Lai
Approve "points" for Advisory Report			
Review available draft sections for the SARC report			

Table 3. (Continued)

THURSDAY, June 22 (9:00 AM - 6:00 PM)			
Sea Scallop (D) -- Continued			
Tautog (F)	Pelagic/Coastal N. Lazar	S. Correia	M. Gibson
Approve "points" for Advisory Report			
Review available documentation			
FRIDAY, June 23 (9:00 AM - 6:00 PM)			
Review all Research Recommendations			
Complete SARC Report sections			H. Mustafa (Coordinator)
Complete Advisory Report and review final draft			
Other Business			H. Mustafa

Opening

The Chairman welcomed the meeting participants and introduced the members of the SARC. In addition to the organizations regularly represented on the SARC, the 20th SAW SARC included a representative from the summer flounder industry. The inclusion of an industry representative is in response to a court order resulting from the summer flounder law suit.

Dr. Smith reviewed the SAW process (Figure 1), a cycle of activities which begin and end with a meeting of the SAW steering group, the responsibilities of those who participate in the process, and the resulting documentation. He outlined the steps for the development of the two reports that would come out of the SARC meeting.

The Chairman indicated that at the last Steering Committee Meeting a change had been introduced to the delivery of the advice developed at the SARC meeting. The advice, usually presented during two half days of a Plenary Meeting, will henceforth be summarized by the SAW Chair as part of the

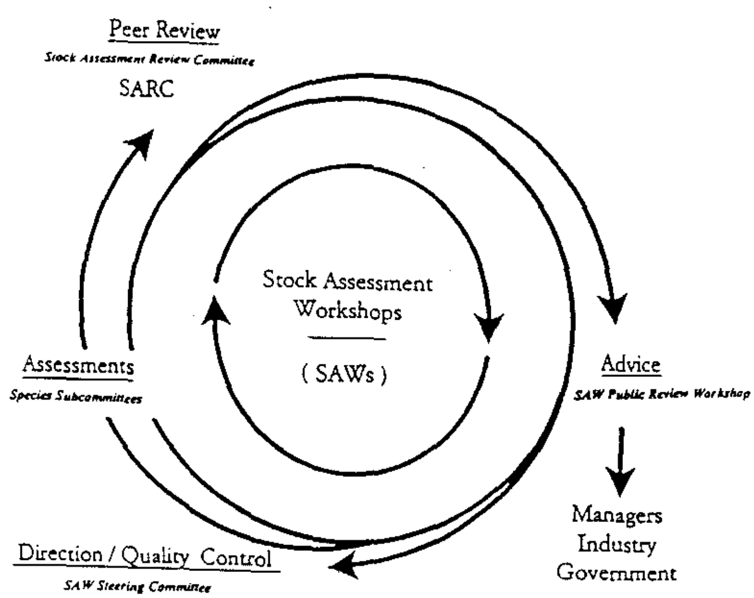

Figure 1. Northeast Regional Stock Assessment Workshop (SAW) process.

meeting agendas of the two Regional Fishery Management Councils (New England and Mid-Atlantic). These presentation sessions have been named Public Review Workshop, North and South.

Dr. Smith welcomed the new Chair of the Invertebrate Subcommittee, Dr. Paul Rago (NEFSC) and reviewed the species assigned to each Subcommittee (Table 4).

Agenda and Reports

The SARC meeting agenda included six species/stocks and a report on an Ad Hoc Working Group on Sea- Port- Sampling. The SARC reviewed analyses on Georges Bank haddock, summer flounder, Atlantic mackerel, sea scallop, black sea bass, and tautog. A Chart of U.S. commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 2.

Table4. Subcommittee species assignments.

o Northern Demersal Subcommittee

Atlantic Cod	Witch Flounder
Haddock	Silver Hake
Pollock	Cusk
American Plaice	Wolffish
Redfish	White Hake

o Southern Demersal Subcommittee

Summer Flounder	Skate
Yellowtail Flounder	Winter Flounder
Goosefish	Windowpane Flounder
Red Hake	Ocean Pout
Tilefish	

o Pelagic/Coastal Subcommittee

Mackerel	River Herring
Herring	Striped Bass
Atlantic Salmon	Black Sea Bass
Butterfish	Bluefish
American Shad	Scup
Dogfish	Tautog

o Invertebrate Subcommittee

Scallop	Northern Shrimp
Lobster	Surfclam
Short-finned Squid	Ocean Quahog
Long-finned Squid	

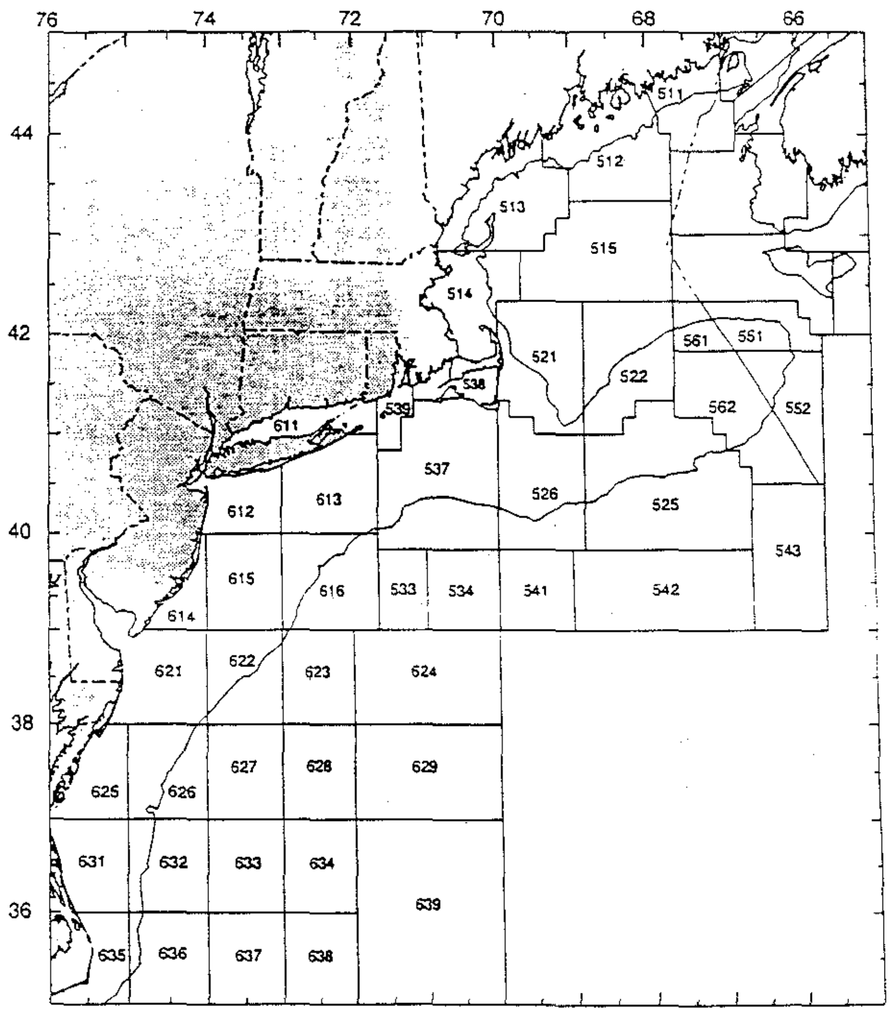

Figure 2. Statistical areas used for catch monitoring in offshore fisheries in the northeast United States.

Table 5. SAW-20 Subcommittee meetings.

Subcommittee - Species Analysis Attendance		Meeting Date and Place
Northern Demersal Subcommittee - GEORGES BANK HADDOCK		
A. Applegate, NMFS/NEFMC	L. Hendrickson, NMFS/NEFSC	30 May - 2 June 1995
R. Brown, NMFS/NEFSC	R. Mayo, NMFS/NEFSC (Chair)	Woods Hole, MA
S. Cadrin, MA DMF	L. O'Brien, NMFS/NEFSC	
L. VanEeckhaute, DFO, Canada	K. Sosebee, NMFS/NEFSC	
S. Gavaris, DFO, Canada	M. Terceiro, NMFS/NEFSC	
T. Helser, NMFS/NEFSC	S. Wigley, NMFS/NEFSC	
Southern Demersal Subcommittee - SUMMER FLOUNDER		
S. Aicher, NYS DEC	J. Mason, NYS DEC	15 - 19 May 1995
W. Gabriel, NMFS/NEFSC (Chair)	S. Michels, DEDFW	Woods Hole, MA
M. Gibson, RI DEM	R. Monaghan, NC DMF	
H. Goodale, NMFS/NERO	C. Moore, MAFMC	
G. Gray, NMFS/MRFSS	D. Simpson, CT DEP	
F. Gregoire, DFO, Canada	K. Sosebee, NMFS/NEFSC	
M. Lambert NMFS/NEFSC	M. Terceiro, NMFS/NEFSC	
N. Lazar, ASMFC		
The following persons did not attend the meeting but provided data used in the assessment:		
S. Correia, MA DMF		
S. Doctor, MD DNR		
J. Musick, VIMS		
Pelagic/Coastal Subcommittee - ATLANTIC MACKEREL BLACK SEA BASS TAUTOG		15 - 19 May 1995 Woods Hole, MA
S. Aicher, NY DEC	S. Michels, DE DFW	
E. Anderson, NMFS/NEFSC, (Chair)	R. Monaghan, NC DMF	
J. Brodziak, NMFS/NEFSC	C. Moore, MAFMC	
K. Friedland, NMFS/NEFSC	W. Overholtz, NMFS/NEFSC	
W. Gabriel, NMFS/NEFSC	P. Rago, NMFS/NEFSC	
M. Gibson, RI DFW	R. Seagraves, MAFMC	
H. Goodale, NMFS/NERO	F. Serchuk, NMFS/NEFSC	
G. Gray, NMFS/MRFSS	G. Shepherd, NMFS/NEFSC	
F. Gregoire, DFO Canada	D. Simpson, NMFS/NEFSC	
M. Lambert, NMFS/NEFSC	K. Sosebee, NMFS/NEFSC	
N. Lazar, ASMFC	M. Terceiro, NMFS, NEFSC	
J. Mason, NY DEC		
Invertebrate Subcommittee - SEA SCALLOP		
A. Applegate, NEFMC	J. Idoine, NMFS/NEFSC	22 - 26 May 1995
J. Brodziak, NMFS/NEFSC	H.-L. Lai, NMFS/NEFSC	Woods Hole, MA
J. Brust, VIMS	P. Rago, NMFS/NEFSC, (Chair)	
R. Conser, NMFS/NWFSC	A. Richards NMFS/NEFSC	
W. DuPaul, VIMS	P. Spalt. Cape Oceanic Coop. (part-time)	
W. Gabriel, NMFS/NEFSC	J. Weinberg, NMFS/NEFSC	
L. Hendrickson, NMFS/NEFSC	S. Wigley, NMFS/NEFSC	

The SARC reviewed a total of 13 working papers (some with extensive appendixes of the analyses) on the above species/stocks, including Subcommittee reports, detailed assessment papers, and other accompanying papers of a technical/methods nature. The Subcommittee reports were developed in a series of formal meetings (Table 5) and form the basis of this report. The SARC determined that eight of the working papers should be published in the NEFSC Center Reference Document series (Table 6).

Table 6. 20th SAW NEFSC Reference Documents

CRD 95-13	Assessment of the Georges Bank haddock stock for 1994 by L. O'Brien and R. Brown
CRD 95-14	An examination of the influence of environmental conditions on spring survey catches of Atlantic mackerel by J. Brodziak and W. Ling
CRD 95-15	A comparison of some biological reference points for fisheries management by J. Brodziak and W. Overholtz
CRD 95-16	Status of the sea scallop fisheries off the northeastern United States, 1993 by H.-L. Lai, L. Hendrickson, and S. Wigley
CRD 95-17	Selectivities of lined and unlined dredges used in sea scallop research surveys by H.-L. Lai
CRD 95-18	Assessment of black sea bass (*Centropristis striata*), 1995 report of the Coastal/Pelagic Subcommittee
CRD 95-19	Assessment of tautog (*Tautoga onitis*), 1995 report of the Coastal/Pelagic Subcommittee
CRD 95-20	Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW), Stock Assessment Review Committee (SARC Consensus Summary of Assessments
CRD 95-21	Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW), SAW Public Review Workshop

Major SARC products are the SARC Consensus Summary of Assessments, a comprehensive technical report containing SARC comments and research recommendations and the "Advisory Report on Stock Status," a stylized report whose format was set by the Steering Committee. Both reports will be published in the NEFSC Center Reference Document series.

Presentations and Discussion

Ad Hoc Sea- Port-Sampling Working Group

The SAW-19 SARC panel suggested the establishment of a working group for the purpose of addressing the issue of port- and sea-sampling as it relates to resource assessments. The Steering Committee approved the general terms of reference presented in Table 7a at its February meeting. Working group members, at the time of the time of the SARC meeting, are presented in Table 7b. The group will initially meet on 27 June 1995.

Table 7a. General terms of reference for the port sea-sampling working group.

a) Summarize sea sampling activity, by fishery, season, and year for the period 1989-1993 (1994 if possible), including estimates of the fraction of fishery trips and catch sampled;

b) Provide a framework for the statistical design of sea sampling programs, evaluating the effects of sample size on precision of discard estimates, and appropriate protocol for biological sampling;

c) Evaluate the effects of precision and bias of discard estimates on stock assessment calculations and estimates of biological reference points; and,

d) Prioritize and strategize the allocation of sampling (days-at-sea) with recognition of ad hoc needs, mandated requirements (e.g., marine mammal bycatch), management needs, and assessment needs and the dynamics of those needs.

Table 7b. Members of the port- sea-sampling working group.

K. Bisak, NEFSC	D. McKiernan, MA DMF
J. Brodziak, NEFSC	M. Pennington, NEFSC
D. Christensen, NEFSC	M. Terceiro, NEFSC
S. Kennelly, Monomet Obs.	S. Wigley, NEFSC

Species/Stock Presentations and Discussion Overview

The species/stock presentations are summarized in detail in the sections that follow. Each section includes the terms of reference, comments, sources of uncertainty, and research recommendations.

The unavailability of 1994 fishery-dependent data due to the changeover in data collection and data management systems complicated the development of analyses for a number of species/stocks, as well as the work of the SARC itself. For example, in the case of Georges Bank haddock, while the SAW Steering Committee required an assessment only through 1993, development of projections, as stated in the terms of reference required an estimate of U.S. landings in 1994.

Obtaining sufficient sea sampling data for the development of reliable estimates of commercial fishery discards was a prevailing issue of discussion of several species, as was the importance of state data in the analyses of at least three species/stocks (summer flounder, black sea bass, and tautog). Additional state data sets could have facilitated the analyses of at least two species/stocks, but were not available at the time of their development. The availability of state data in a standard format is addressed among the SARC's comments and recommendations. Noted was the growing importance of sea sampling in light of the need to monitor the effects of recent regulatory measures.

The need to refer issues to the Assessment Methods Subcommittee was discussed and or recommended in connection with several species, specifically:

- o Investigation of the utility of bias corrections to VPA and bootstrap realization;
- o Further testing of the sensitivity of the VPA analysis to potential sources of bias (e.g., misreporting of landings, systematic error in surveys, incorrect assumptions about discard rates and discard mortality, mis-specification of the objective function in the VPA); and,
- o General evaluation of methods for the calculation of long-term potential yield based on VPA stock-recruitment data.

Closing and Follow-Up

The meeting adjourned at approximately 6:00 PM on Friday. The revised documentation, advisory reports and comment and recommendation sections of the SARC report, not available at the time of the SARC members' departure were mailed for review within a week. The edited advisory report sections were later reviewed by the SARC Leaders.

Copies of the draft 20th SAW SARC Consensus Summary of Assessments and the draft Advisory Report will be available at the SAW Public Review Workshop (Session- South, Mid-Atlantic Fishery Management Council Meeting, 2 August 1995 and Session-North, New England Fishery Management Council Meeting, 10 August 1995). This documentation will be finalized and available for general distribution after the SAW Steering Committee meeting of 15 August 1995.

A. GEORGES BANK HADDOCK

Terms of Reference

The following terms of reference were addressed for Georges Bank haddock:

a. Assess the status of Georges Bank haddock through 1993 and characterize variability of estimates of abundance and fishing mortality rates.

b. Provide updated estimates of maximum sustainable yield for the Georges Bank haddock stock.

c. Provide projected estimates of catch and SSB through 1996 at various levels of fishing mortality.

The Fishery

Commercial Landings

Total commercial landings in 1993 were estimated at 4,400 mt, 27% lower than 1992 (Table A1, Figure A1). The USA fleet landed 16% (687 mt), and the Canadian fleet landed 84% (3,700 mt) of the total landings. The 1993 USA landings were 66% lower than the 1992 landings, and the Canadian landings were 8% lower than in 1992. The Canadian fleet landed 2,411 mt in 1994. USA landings in 1994 were estimated by assuming a slight reduction from the 1993 reported level of approximately 700 t due to the extension of closed Area 2 and the imposition of a 500 lb trip limit in mid-year. The assumed USA landings used in the assessment was 500 mt. When combined with the reported Canadian total landings of 2,411 mt, the resulting estimate of total 1994 landings was 2,911 mt.

In 1993, haddock were landed primarily by otter trawl (96%) in the USA fishery and by both the otter trawl (67%) and the longline fleet (31%) in the Canadian fishery. Otter trawl gear has historically been the primary gear for haddock by the USA and Canadian fleet; however, the proportion of haddock taken by the Canadian longline fleet has increased from about 17% in the mid-1980s to about 30% in the early 1990s (Table A2).

Discards

Estimates of discards were not derived for this analysis. The most recent year class of any historic significance occurred in 1987, and that has now passed through the fishery. Except for the 1992 year class, most recent year classes have been very weak, and discarding would have been minimal.

Sampling Intensity

Quarterly samples are aggregated by market category within Eastern Georges (area 523-524, 561-562) and Western Georges (area 521-522,525-526, 537-539 and area 6). The annual sampling intensity ranged from 9 to 338 mt landed per sample from 1982-1993. In 1993 the sampling intensity was relatively high, due to lower landings rather than increased sampling coverage.

Catch at Age

The age composition of the 1963-1994 Canadian landings was estimated by Gavaris and Van Eeckhaute (1995). Age composition for the 1963-1990 USA landings was estimated by Hayes and Buxton (1992). The age composition of the 1991-1993 landings from Georges Bank was estimated by applying commercial and research vessel age-length keys to semi-annual commercial numbers at length, by market category. Due to the lack of quarterly samples, the Eastern and Western Georges areas were combined as one unit area and both age and length samples were aggregated to six month periods. Mean weights at age were estimated by applying the length-weight (landed weight) equations to the semi-annual length frequency samples, by market category. Total numbers landed per half-year were estimated by applying the mean weights to the semi-annual landings, by market category and prorating according to the sample length frequency.

Age keys were applied over market category on a half-year basis using combined commercial and survey age-length keys after testing using Fisher's Exact tests (Hayes 1993) revealed few significant differences between length classes. Numbers at age were summed over market category within each half-year and annual estimates of catch at age were obtained by summing values over the semi-annual periods. The numbers of fish landed at age by USA in 1994 were estimated to be 21% of the Canadian landings at age, based on the ratio of derived USA landings/reported Canadian landings (500/2411 mt). The total 1994 catch at age was derived by raising the Canadian catch at age by 1.21.

Mean Weights at Age

Mean weights at age are summarized for combined USA and Canadian landings in Table A3. ince 1991, n the USA fishery, there has been a declining trend in mean weight for fish age 6 and older . The 1993 mean weight at age for fish age 6-8 and older are the lowest in the time series. Since similar trends are not apparent in the Canadian mean weights at age, the apparent trends may be due more to timing of the fishery than to a real change in growth rates. The 1989 year class, however, does show increased growth compared to previous year classes. Subsequent year classes show the same trend, but not as strongly as the 1989 year class. This phenomenon is present in both USA and Canadian mean weight at age estimates.

Stock Abundance and Biomass Indices

Commercial Catch Rates

The LPUE series was not used as an index of abundance, due to the history of management measures imposed on this fishery. The haddock fishery has traditionally been subjected to total allowable catches (TAC) constraints, trip limits and seasonal closures. Under these management restrictions the haddock fishery has effectively become a by-catch fishery and the effort series will not be representative.

Research Vessel Survey Indices

Research survey indices of abundance (stratified mean number per tow) and biomass (stratified mean weight (kg) per tow) were estimated from both the NEFSC spring (1968-1994) and autumn (1963-1994) bottom trawl surveys (Table A4, Figure A2). The indices were adjusted for differences in fishing power due to use of different research vessels and catchability due to changes in trawl doors (NEFSC 1991). Both the spring and autumn abundance and biomass indices exhibit similar trends throughout the time period (Table A4, Figure A2). The indices declined from the mid-1960s to the mid -1970s then fluctuated, reaching a peak in the early 1980s, and have subsequently declined to very low levels. The spring and autumn time series indicate the strongest year class occurred in 1963, followed by the relatively strong 1975, 1978, 1980, and 1985 year classes (Figures A3, A4). The 1966, 1972, 1976, and 1983 year classes were near or slightly above the long term average of 5.9 mean number per tow. Since 1987 the year classes have been relatively weak; however, the 1991, and particularly the 1992 year class have higher abundance as age 1 and 2 fish than the adjacent year classes, although they are indicated to be well below the long-term average (9.5, age 1; 6.5, age 2).

Indices of abundance for Canadian surveys (S. Gavaris, pers. comm.) are summarized as stratified mean number per tow from 1986 -1995 (Table A6).

In 1993 and 1994, the Canadian research survey did not sample the western part of Georges Bank (Canadian strata 5-7). The indices were therefore re-estimated by first raising the total number per strata by a factor of 1.068, derived by using a ratio estimator (Mendenhall et al. 1971) The Canadian research survey indices indicate a relatively strong 1992 year class (Table A6).

The quotient of the raised total number to the total area resulted in a lower stratified mean number per tow, which was then prorated among ages 1-9. Bias could be introduced into the estimate if the distribution of juveniles and adults are different in western part of the Bank. However, a review of haddock distribution did not reveal any differential distributions of juvenile and adults.

Mortality and Maturation

Natural Mortality

Instantaneous natural mortality (M) of Georges Bank haddock is assumed to be 0.2. This value has been used in previous assessments (Hayes and Buxton 1991, Gavaris and Van Eeckhaute 1995).

Maturity

The percentage of mature female haddock at age was derived from 1990-1994 NEFSC maturity data using logistic regression (Table A7). Annual maturity ogives were estimated and pooled ogives (1990-1992, 1993-1994) were then derived by aggregating data across years that exhibited similar maturity at age. Annual maturity estimates derived for 1977-1983 (Overholtz 1987) were averaged to reduce the annual variability of the estimates (Table A7).

Estimates of Stock Size and Fishing Mortality

Virtual Population Analysis Calibration

The ADAPT calibration method (Parrack 1986, Gavaris 1988, Conser and Powers 1990) was used to derive estimates of fishing mortality in 1994. The total catch used in the VPA consisted of both US and Canadian commercial landings for ages 1-8, with a 9+ age group for 1963-1994. The indices used to calibrate the VPA were the US and Canadian spring research vessel survey catch at age (ages 1-8) in numbers and the US autumn survey catch at age (0-7), lagged forward one age and one year. A preliminary ADAPT calibration indicated a high coefficient of variation (CV) on stock size at age 7 in 1995 and a very high F estimate for the corresponding age 6 in 1994.

The final ADAPT calibration provided stock size estimates for age 1-6, and 8 in 1995 and corresponding F estimates for ages 1-5, and 7 in 1994. The stock size estimate for age 7 in 1995 and the corresponding age 6 F estimate in 1994 were estimated from the smoothed partial recruitment vector, assuming full recruitment at age 4. The F on ages 8 and 9+ in the terminal year were estimated as the average of the F on ages 4, 5, and 7. The F on age 8 in all years prior to the terminal year was derived from weighted estimates of Z for ages 4 through 8. For all years, the F on age 8 was applied to the 9+ age group. Spawning stock estimates were derived for applying maturity ogives (Table A8).

The final ADAPT calibration results are presented in Table A8. The CV's on age 2-6, and 8 were low ranging from .31 (age3) to .39 (age 8). The CV on age 1, however, was high (.60) most likely due to having fewer observations for this year class. The residual patterns for most indices did not show any strong trends except age 2 in the spring Canadian indices which showed a strong positive trend in the residuals.

Average fishing mortality (ages 4-5,7) in 1994 was estimated as 0.29, a decline of 54 % from 1993 (Table A8, Figure A5). The 1994 estimate of SSB was 14,600 mt, a 46% increase from the 1993 estimate (10,000 mt) which was the lowest in the time series (Table A8, Figure A6). Recruitment of the 1988-1990 year classes (1.2-2.5 million fish) was poor, whereas the 1991, 1993 and 1994 year classes (7.5-8.4 million fish) were about equal to the long-term (1963-1993) geometric mean (7.9 million fish). The 1992 year class (14 million fish) was estimated to be slightly less than twice the long term mean (Table A8, Figure A6).

Precision estimates of F and SSB

A bootstrap procedure (Efron 1982) was used to evaluate the uncertainty associated with the estimates of fishing mortality and spawning stock biomass from the final VPA. Five hundred bootstrap iterations were performed to obtain standard errors, coefficients of variation (CVs) and bias estimates for ages 1-9 stock size estimates at the start of 1995 and for the age 1-7 Fs in 1994. Results indicate an 80% probability that the 1994 F was between 0.24 and 0.39 (Figure A7) and the 1994 SSB is between 12,500 mt and 18,500 mt (Figure A8).

Yield and Spawning Stock Biomass per Recruit

Yield per recruit and spawning stock biomass per recruit were estimated using methodology of Thompson and Bell (1934). Data used to derive the estimates were based on partial recruitment calculated as the geometric mean of 1993-1994 F estimates from the final VPA (Table A8), arithmetic means of the 1984-1993 catch and stock weight at age, and the 1968-1994 mean maturity at age (Table A7). Results of the analysis are provided in Figure A9. The resulting biological reference points were $F_{0.1}$=.24, and $F_{30\%}$=.35.

Projections

Short-term Projections

Total catch and SSB for 1995, 1996, and 1997 was projected. An initial deterministic projection was performed to obtain a starting F value for 1995, based on total landings of 3,000 mt. The assumption was made that the Canadian fishery would land the 2,500 mt and the US fishery would land 500 mt. The projection was based on a partial recruitment derived from the geometric mean of the 1993-1994 Fs from the final VPA, an arithmetic mean from 1990-1993 for catch and stock mean weights at age, and the median maturity estimates for 1993-1994. Recruitment in 1995 was obtained from the VPA calibration based on NEFSC autumn 1994 and Canadian 1995 spring research vessel survey indices.

The projection indicated that F = 0.18 would result in landings of 3,000 mt.

Short-term stochastic projections (Brodziak and Rago 1994) were then carried out from 1995 to 1997 under four scenarios of F = 0.0 (closure); F_{95} =0.18; $F_{0.1}$ = 0.24; and $F_{30\%}$=0.35. Data inputs were the same as the deterministic projection except that recruitment in 1996 and 1997 was estimated from the median outcome of resampling of the distribution of the 1979-1992 year classes at age 1.

In 1995, spawning stock biomass and landings are projected to be 21,200 mt and 3,100 mt, respectively under all four scenarios (Figure A10). Under the F_{95} = 0.18 scenario, landings increase to 4,100 mt in 1996 and SSB increases to 25,800 mt in 1996 and to 28,200 mt in 1997 (Table A9, Figure A10).

Medium-term Projections

Medium-term projections (10 years) were performed under the same F scenarios as in the short-term projections. The stochastic projection model incorporating the bootstrapped estimates of abundance at age was used with recruitment being determined by random sampling of the 1969-1995 recruitment values from the final ADAPT calibration. Additional data provided to the model included partial recruitment estimated from the geometric mean of the 1993-1994 F values from the final ADAPT calibration, catch and stock weights at age estimated as the mean of the 1984-1993 values, and maturity at age estimated as the mean of the 1968-1994 values.

Under the constant F scenarios of 0.0, 0.18, 0.24 and 0.35, the probability of SSB exceeding 80,000 mt in 10 years is 50%, 23%, 16%, and 8%, respectively. Under F_{95} =0.18, SSB increases to 44,000 mt and landings increase to 7,000 mt by 2004 (Figure A11).

Equilibrium Yield Calculations

Average yield calculations were performed under several assumptions of equilibrium recruitment and growth. Current equilibrium conditions were those applied in the yield per recruit analysis with the added assumption of mean recruitment realized over the 1965-1993 period (arithmetic mean = 14.2 million). This incorporates all recruiting year classes subsequent to the very large 1963 year class. The resulting yield was computed as the product of yield per recruit and average realized recruitment. A second set of equilibrium conditions corresponding to the period of stable yield and recruitment between 1935 and 1960 was also approximated using mean catch weights and mean recruitment obtained from Clark et al. (1982).

Equilibrium yield obtained under 1935-1960 average conditions of growth and maturation was approximately 44,000 mt at $F_{0.1}$ and 48,500 mt at $F_{30\%}$ (Table A10). Under the more recent 1965-1993 conditions of lower recruitment and faster growth, equilibrium yield was approximately 10,900 mt at $F_{0.1}$ and 11,800 mt at $F_{30\%}$. If one assumes that future yields will be predicated on the continuation of recent levels of average recruitment combined with the lower growth associated with earlier higher stock sizes, equilibrium yield declines to 8,800 mt at $F_{0.1}$ and 9,600 mt at $F_{30\%}$.

If recruitment continues at levels realized since 1965, yields in the range of 9,000-12,000 mt are to be expected in the future. In order to achieve yields in the range of 40,000-50,000 mt, recruitment would have to average about 70 million fish or about 5 times the recent average.

Conclusions

The stock is at a low biomass level and, with respect to the 1994 and projected 1995 F levels, is considered to be fully exploited. Although current F is below the overfishing definition ($F_{30\%}$ = 0.35, 27% exploitation rate), the stock remains in an overfished and a collapsed condition. Spawning stock biomass in 1993 was the lowest on record, increased in 1994 and 1995, and is expected to continue to increase in 1996 and 1997. Except for the 1992 year class, recruitment has been average or below average since 1987. F increased in 1992 and 1993, but has since declined to below the overfishing level due to the combined effects of increased stock size and restrictive management measures initially imposed in 1994. Current bottom trawl survey indices have increased slightly since 1991 but continue to remain among the lowest on record.

This stock remains in a collapsed condition; therefore, fishing mortality should be held as low as possible. Reductions in F will increase the prospect of further rebuilding of SSB in the long term. The 1992 year class will contribute 49% of the spawning stock biomass in 1995. More rapid rebuilding of spawning stock biomass will occur if this year class is protected. Rebuilding of spawning stock biomass over the long term is necessary to reduce the risk of recruitment failure.

Sources of Uncertainty

1. Lack of U.S. commercial catch at age data for 1994.

2. Lack of bias corrections for bootstrap realizations.

3. Trend toward increasing mean weights at age in recent years.

4. Recent shifts in the maturity ogives.

SARC Cmments

Future assessments should investigate using commercial age data, as well as recent patterns in the survey weights at age. Several peculiar patterns were noted in the average weight at age, but it could not be determined if these were related to changes in fishery practices.

LPUE was not considered to reflect stock abundance due to historically changing management regulations and actions. The SARC suggested that the LPUE analysis could be conducted at a finer spatial resolution (10' squares) to account for changes in fishing patterns associated with the introduction of the Hague Line. It was uncertain though, if an LPUE series that covers a small portion of the principal area of concentration in latter years would be representative of stock abundance. Because of variable, empirical maturinty ogives, the SARC discussed using a constant age component (e.g., 3+, 4+, 5+) as a more stable index of spawning potential.

The SARC voiced concern regarding adherence to the terms of reference which stated that the assessment should be updated through 1993. After viewing results of VPA output for the assessment updated through 1993, SARC members noted that termination of the assessment with 1993 resulted in the exclusion of the 1994-1995 survey index values needed to assess the strength of the 1992 year class. The SARC commented that a high survey index value for age 2 fish in the 1994 Canadian spring index unduly influenced the terminal year results of the 1993 assessment.

The SARC discussed the validity of using estimated 1994 USA landings and applying the Canadian age composition data to produce the catch at age for 1994. It was noted, however, that some assumption about the USA landings in 1994 was needed to compare stock projections through 1996. The SARC concluded that making these assumptions at the VPA stage was preferable to making them at the projection stage. It was noted that Canadian landings represent the majority of landings (84% in 1993) and were known for 1994.

Discussion then focused on the estimate of U.S. 1994 catch and management actions that would influence the level of USA landings in 1994 relative to recent years. Based on anecdotal evidence, most SARC members believed that the 1994 USA catches would be less than the 1993 landings of approximately 700 mt, and agreed that the subcommittee's assumption that a catch of approximately 500 mt in 1994 was reasonable. However, the SARC requested an investigation of the sensitivity of the model results to this assumption by commissioning additional ADAPT runs based on USA catch of 250 and 750 mt. Results from the three VPA runs based on USA catches of 250, 500, and 750 mt were virtually indistinguishable and well within the levels of precision for estimates of stock numbers, SSB and F. No unusual diagnostic patterns were observed among the three runs. Based on these results, the SARC agreed to use a 1994 USA landings value of 500 mt to advance the VPA through 1994. Given that the USA landings in 1994 were assumed to be about 15% of the total, the SARC considered that applying the age composition from the Canadian catch to the USA landings would not introduce significant bias. Based on these observations, the SARC accepted the assessment run through 1994 and noted that the report including tables and figures should clearly reflect that the 1994 USA landings were assumed.

The SARC discussed issues surrounding bias correction related to ADAPT runs and bootstrap realizations. SARC members noted that bias levels exceeded 14% for age 1, but were at lower levels for older age classes. Members noted that bias correction issues are a relatively new problem related to stochastic projections, and that if bias corrections are made, corrections should be made to both the VPA and the bootstrap realizations. It was noted that bias corrections are routinely used for groundfish species in Canadian assessments, often resulting in improvements to the retrospective analysis. It was noted that bias correction would only affect the last few years of the assessment and the projection. Based on these observations, the consensus of the SARC was that bias corrections should not be performed for the current assessment, but that the general issue of bias correction should be investigated by the Assessment Methods Subcommittee.

SARC members commented that it would be desirable to have short-term projections completed using the stochastic model, which would give probability distributions for projection statistics. It was noted that the presented 20-year projections may not be useful given changing stock density and environmental conditions. The SARC recommended that medium-term projections be terminated after 10 years and that the report should include specific probabilities for reaching the management threshold stock level (80,000 mt) at various levels of fishing mortality.

The SARC was presented with calculations of equilibrium yield. It was noted that it is difficult to explicitly define MSY under the current rebuilding strategy, and that equilibrium yields represent an appropriate surrogate for estimating yields.

Research Recommendations

- o Consider including Canadian DFO commercial and survey age data to augment age keys for future assessments.
- o Consider using commercial age data to augment survey ages for older haddock in years when survey ageing samples are not collected for all sampled haddock.
- o Investigate trends in the maturity ogives from previous studies and consider the inclusion of Canadian maturity data in future assessments.
- o Investigate methods to estimate discards, based on available sea sampling data.
- o The utility of bias corrections to VPA and bootstrap realizations should be investigated by the Assessment Methods Subcommittee. If bias corrections are recommended in cases where bias is directional and significant, the subcommittee should distribute the necessary software and documentation.

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Table A1. Commercial landings (metric tons, live) of haddock from Georges Bank and South (NAFO Division 5Z and Statistical Area 6), 1960-1994.[1]

Year	USA	Canada	USSR	Spain	Other	Total
1960	40800	77	0	0	0	40877
1961	46384	266	0	0	0	46650
1962	49409	3461	1134	0	0	54004
1963	44150	8379	2317	0	0	54846
1964	46512	11625	5483	2	464	64086
1965	52823	14889	81882	10	758	150362
1966	52918	18292	48409	1111	544	121274
1967	34728	13040	2316	1355	30	51469
1968	25469	9323	1397	3014	1720	40923
1969	16456	3990	65	1201	540	22252
1970	8415	1978	103	782	22	11300
1971	7306	1630	374	1310	242	10862
1972	3869	609	137	1098	20	5733
1973	2777	1563	602	386	3	5331
1974	2396	462	109	764	559	4290
1975	3989	1358	8	61	4	5420
1976	2904	1361	4	46	9	4324
1977	7934	2909	0	0	0	10843
1978	12160	10179	0	0	0	22339
1979	14279	5182	0	0	0	19461
1980	17470	10017	0	0	0	27487
1981	19176	5658	0	0	0	24834
1982	12625	4872	0	0	0	17497
1983	8682	3208	0	0	0	11890
1984	8807	1463	0	0	0	10270
1985	4273	3484	0	0	0	7757
1986	3339	3415	0	0	0	6754
1987	2156	4703	0	0	0	6859
1988	2492	4046[2]	0	0	0	6538
1989	1430	3059	0	0	0	4489
1990	2001	3340	0	0	0	5284
1991	1395	5446	0	0	0	6841
1992	2005	4058	0	0	0	6063
1993	687	3727	0	0	0	4414
1994	N/A[3]	2411	0	0	0	-

[1]All landings 1960-1979 are from Clark et al. (1982); USA landings 1980-1981 are from Overholtz et al. (1983); USA landings 1982-1993 are from NMFS, NEFC Detailed Weighout Files and Canvass data; Canadian landings 1980-1994 from Gavaris and Van Eeckhaute (1995).
[2] Landings of 1895 tons were excluded because of suspected misreporting (Gavaris and Van Eeckhaute 1995).
[3]USA assumed to have landed 500 tons in 1994.

Table A2. USA and Canadian commercial landings (Metric tons, live) of haddock from Georges Bank and South (NAFO Division 5Z and Statistical Area 6) by major gear type, 1965-1994

	United States				Canada			
	Otter Trawl	Long line	Other	Total	Otter Trawl	Long line	Other	Total
1964	45617	742	153	46512	11624	1	0	11625
1965	52034	716	73	52823	14862	22	5	14889
1966	51686	1127	105	52918	17905	63	324	18292
1967	33825	814	89	34728	12923	96	21	13040
1968	24930	495	44	25469	9201	111	11	9323
1969	15494	950	12	16456	3955	22	13	3990
1970	7979	430	6	8415	1900	76	2	1978
1971	7004	300	2	7306	1475	154	1	1630
1972	3674	190	5	3869	411	198	0	609
1973	2675	100	2	2777	1461	102	0	1358
1974	2308	80	8	2396	374	87	1	462
1975	3839	143	7	3989	1247	111	0	1358
1976	2840	51	13	2904	1192	154	15	1361
1977	7842	36	56	7934	2814	94	1	2909
1978	11962	63	135	12160	9716	171	292	10179
1979	14138	30	111	14279	4907	274	1	5182
1980	17170	30	270	17470	9510	590	1	10101
1981	19031	3	142	19176	4644	1015	0	5659
1982	12484	2	139	12625	4222	709	0	4931
1983	8588	35	59	8682	2396	813	3	3212
1984	8661	79	67	8807	624	838	1	1463
1985	4194	43	36	4273	2745	626	41	3484
1986	3298	24	17	3339	2734	594	35	3415
1987	2124	21	11	2156	3521	1046	89	4703
1988	2408	32	52	2492	3183	695	97	4046
1989	1356	24	50	1430	1976	977	106	3059
1990	1949	15	37	2001	2411	853	76	3340
1991	1340	28	27	1395	4018	1309	119	5446
1992	1974	17	14	2005	2583	1384	90	4058
1993	659	16	12	687	2490	1144	94	3727
1994	n/a	n/a	n/a	n/a[1]	1597	714	100	2411

Other includes: scallop dredge, handline, gillnet, midwater trawl
[1]USA assumed to have landed 500 tons in 1994

Table A3. Total landings at age (000's) and mean weight (kg) and mean length (cm) at age of USA commerical landings of haddock from Georges Bank and South (NAFO Division 5Z and Statistical Area 6), 1982-1994.

Year	1	2	3	4	5	6	7	8	9+	TOTAL
					Total Commercial Landings in Numbers (000's) at Age					
1963	2910	4047	7418	11152	8198	2205	1405	721	1096	39152
1964	10101	15935	4554	4776	8722	5794	2082	1028	1332	54324
1965	9601	125818	44496	5356	4391	6690	3772	1094	1366	202584
1966	114	6843	100810	19167	2768	2591	2332	1268	867	136760
1967	1150	168	2891	20667	10338	1209	993	917	698	39031
1968	8	2994	709	1921	14519	3499	667	453	842	25612
1969	2	11	1698	448	654	5954	1574	225	570	11136
1970	46	158	16	570	186	214	2308	746	464	4708
1971	1	1375	223	40	289	246	285	1469	928	4856
1972	156	2	450	81	32	120	78	66	1236	2221
1973	2560	2075	3	386	53	30	77	15	447	5646
1974	46	4320[2]	657	2	70	2	2	53	249	5401
1975	192	1034	1864	375	4	42	4	4	88	3607
1976	144	473	550	880	216	0	23	4	112	2402
1977	1	19585[3]	187	680	515	357	4	39	111	21479
1978	1	761	14395[4]	305	567	517	139	14	67	16766
1979	1	26	1726	7169	525	410	315	96	46	10314
1980	8	31000[5]	347	975	6054	594	546	153	81	39758
1981	1	1743	10998	831	937	2572	331	158	94	17665
1982	1	1165	1633	3733	391	569	1119	106	110	8827
1983	0	214	813	690	2239	272	186	800	76	5290
1984	0	93	297	727	397	1482	234	267	543	4041
1985	0	2406	550	194	461	228	526	78	152	4596
1986	6	54	2810	223	146	173	150	266	60	3888
1987	0	1995	129	1613	122	73	89	106	135	4262
1988	4	52	2384	134	931	149	55	64	106	3879
1989	0	1263	86	877	143	358	46	28	45	2846
1990	2	11	1445	172	868	98	177	46	44	2863
1991	6	448	91	2149	102	410	73	154	72	3505
1992	7	247	320	132	1527	111	323	27	94	2788
1993	7	290	350	299	104	659	38	159	76	1980
1994	0	254	851	166	59	40	129	16	45	1560[1]

Includes 500 tons assumed to have been landed by USA in 1994 prorated by Canadian age compostion.
[1]Data 1963-1979 from Clark et al. (1982); Data 1980-1981 from Overholtz et al. (1983); Data 1982-1990 current assessment and Gavaris and Van Eekhaute (1991)
[2]Of this total, approximately 1000000 fish were added to the catch at age to account for high discards that occurred during 1974 (W. Overholtz, personal communication).
[3]Of this total, approximately 12800000 fish were added to the catch at age to account for high discards that occurred during 1977 (W. Overholtz, personal communication).
[4]Of this total, approximately 5000000 fish were added to the catch at age to account for high discards that occurred during 1978 (W. Overholtz, personal communication).
[5]Of this total, approximately 20000000 fish were added to the catch at age to account for high discards that occurred during 1980 (W. Overholtz, personal communication).

Table A3. (continued).

Year	1	2	3	4	5	6	7	8	9+	TOTAL
			Total Commercial Landings Mean Weight[6](kg) at Age							
1963	0.57	0.87	1.18	1.47	1.68	2.15	2.35	3.04	3.10	
1964	0.50	0.83	1.12	1.43	1.64	2.01	2.40	2.64	2.97	
1965	0.58	0.69	1.03	1.35	1.67	1.99	2.26	2.66	3.11	
1966	0.58	0.73	0.89	1.26	1.70	2.07	2.28	2.87	3.18	
1967	0.66	0.70	0.95	1.18	1.42	2.05	2.31	2.66	3.10	
1968	0.59	0.81	1.05	1.32	1.57	2.10	2.32	2.62	2.86	
1969	0.52	0.78	1.10	1.69	1.75	1.99	2.52	2.99	3.63	
1970	0.71	1.27	1.22	1.93	2.19	2.39	2.58	3.23	3.75	
1971	(0.67)	1.03	1.31	1.74	2.39	2.81	2.92	3.10	3.72	
1972	0.62	1.03	1.74	2.04	2.42	2.92	3.06	3.44	3.66	
1973	0.60	1.03	1.58	2.13	2.41	3.29	3.42	3.86	3.94	
1974	0.72	1.06	1.82	2.32	2.83	3.76	4.05	3.92	4.26	
1975	0.62	0.98	1.63	2.21	2.20	2.94	4.00	4.05	4.33	
1976	0.50	0.99	1.39	1.99	2.66	(3.08)	3.69	4.67	4.94	
1977	(0.53)	1.07	1.44	2.17	2.73	3.21	4.15	4.00	4.99	
1978	(0.53)	0.94	1.50	2.04	2.79	3.19	3.37	3.61	5.11	
1979	(0.53)	1.00	1.28	2.02	2.51	3.14	3.78	3.79	4.87	
1980	0.55	0.94	1.21	1.73	2.17	2.82	3.60	3.56	3.87	
1981	0.39	0.87	1.24	1.83	2.30	2.72	3.71	4.04	4.44	
1982	0.22	0.97	1.45	1.88	2.37	2.76	3.24	3.96	4.09	
1983	(0.33)	1.02	1.37	1.83	2.21	2.65	3.25	3.36	4.27	
1984	(0.33)	0.92	1.32	1.83	2.20	2.67	2.96	3.41	3.72	
1985	(0.33)	0.99	1.39	1.98	2.46	2.72	3.06	3.72	3.80	
1986	0.45	0.94	1.36	1.83	2.56	2.83	2.96	3.46	3.78	
1987	(0.43)	0.83	1.43	2.00	2.25	2.63	3.02	3.77	4.29	
1988	0.42	0.98	1.34	1.68	2.06	2.45	2.97	3.49	3.96	
1989	(0.53)	0.89	1.48	1.79	2.21	2.57	3.24	3.56	3.82	
1990	0.64	0.97	1.48	1.78	2.12	2.55	2.81	2.99	4.16	
1991	0.58	1.20	1.31	1.82	2.18	2.65	2.85	3.05	4.34	
1992	0.54	1.18	1.64	1.77	2.19	2.52	2.97	3.37	4.27	
1993	0.66	1.17	1.73	2.17	2.12	2.63	2.65	3.12	4.01	
1994	0.41	1.14	1.67	2.25	2.66	2.44	2.84	3.24	4.01	

[6]Canadian mean weight only (Gavaris and Van Eekhaute 1995)

Table A4. Mean number and mean weight (kg) per tow of haddock caught in NEFSC Spring and Autumn bottom trawl surveys from 1963-1994.

	Spring Survey		Autumn Survey	
Year	Number/Tow	Weight (kg)/tow	Number/tow	Weight (kg)/tow
1963	-----	-----	145.01	79.77
1964	-----	-----	193.24	96.75
1965	-----	-----	101.69	72.78
1966	-----	-----	33.26	29.87
1967	-----	-----	17.70	25.47
1968	13.84	20.55	7.51	15.40
1969	7.33	16.93	3.38	8.44
1970	6.00	17.12	7.70	13.50
1971	2.79	5.00	4.20	5.59
1972	6.38	7.37	11.35	8.47
1973	37.62	15.37	14.89	9.78
1974	19.01	17.70	4.05	3.99
1975	6.24	8.21	30.95	15.10
1976	83.19	15.72	71.07	35.76
1977	36.86	26.58	23.25	27.52
1978	19.41	31.27	25.29	18.06
1979	45.50	19.77	52.24	31.98
1980	60.06	53.92	30.54	21.98
1981	31.21	38.02	13.45	14.01
1982	8.60	13.11	4.96	7.34
1983	5.60	13.21	7.99	5.75
1984	6.24	7.45	5.38	4.48
1985	8.85	11.14	14.19	3.86
1986	5.85	5.86	6.81	5.10
1987	4.95	5.60	3.62	2.56
1988	3.38	3.43	4.39	4.40
1989	5.35	4.70	4.34	4.70
1990	7.68	7.57	2.92	2.62
1991	3.97	4.38	2.92	0.94
1992	1.18	1.41	6.06	3.17
1993	2.79	2.48	8.09	4.33
1994	4.91	3.63	3.58	2.93

Table A5. Stratified adjusted mean catch per tow (numbers) for haddock in NEFSC spring research vessel bottom trawl surveys on Georges Bank (Strata 13-25, 29-30), 1968-1994.

Adjusted Spring

Year	0	1	2	3	4	5	6	7	8	9+	Total	Total 1+
1968	0.00	0.40	2.83	0.46	0.70	6.72	1.68	0.25	0.45	0.34	13.84	13.84
1969	0.00	0.00	0.07	0.58	0.25	0.42	4.23	1.03	0.28	0.46	7.33	7.33
1970	0.00	0.67	0.25	0.00	0.33	0.46	0.46	2.00	0.98	0.85	6.00	6.00
1971	0.00	0.00	1.16	0.25	0.00	0.12	0.12	0.09	0.82	0.22	2.79	2.79
1972	0.00	4.02	0.09	0.61	0.12	0.03	0.04	0.13	0.03	1.30	6.38	6.38
1973	0.00	30.68	4.84	0.00	0.54	0.09	0.00	0.18	0.01	1.28	37.62	37.62
1974	0.00	2.13	13.29	2.86	0.00	0.24	0.00	0.01	0.10	0.37	19.01	19.01
1975	0.00	0.94	0.97	3.32	0.63	0.00	0.13	0.09	0.01	0.15	6.24	6.24
1976	0.00	80.79	0.30	0.60	0.92	0.43	0.00	0.04	0.00	0.10	83.19	83.19
1977	0.00	0.61	33.41	0.42	1.22	0.60	0.45	0.00	0.04	0.12	36.86	36.86
1978	0.00	0.07	0.97	15.93	0.36	0.94	0.82	0.16	0.06	0.10	19.41	19.41
1979	0.00	36.12	1.58	1.13	5.71	0.33	0.16	0.37	0.06	0.04	45.50	45.50
1980	0.00	5.20	46.70	0.51	1.04	4.87	0.67	0.37	0.46	0.24	60.06	60.06
1981	0.00	3.30	3.29	19.49	2.19	0.76	1.78	0.24	0.11	0.05	31.21	31.21
1982	0.00	0.76	1.53	0.94	4.07	0.42	0.28	0.61	0.00	0.00	8.60	8.60
1983	0.00	0.43	0.55	0.58	0.22	2.41	0.01	0.04	1.16	0.18	5.60	5.60
1984	0.00	2.09	1.18	0.64	0.63	0.58	0.72	0.07	0.04	0.30	6.24	6.24
1985	0.00	0.00	4.96	0.76	0.40	0.87	0.34	1.17	0.10	0.25	8.85	8.85
1986	0.00	2.49	0.18	2.06	0.24	0.11	0.21	0.12	0.33	0.11	5.85	5.85
1987	0.00	0.00	3.62	0.06	0.81	0.08	0.10	0.05	0.22	0.01	4.95	4.95
1988	0.00	1.55	0.04	0.99	0.13	0.32	0.12	0.11	0.12	0.00	3.38	3.38
1989	0.00	0.02	3.49	0.45	0.71	0.14	0.41	0.06	0.05	0.01	5.35	5.35
1990	0.00	0.86	0.00	5.72	0.33	0.58	0.06	0.13	0.00	0.01	7.68	7.68
1991	0.00	0.54	1.07	0.24	1.85	0.09	0.10	0.02	0.04	0.02	3.97	3.97
1992	0.00	0.40	0.18	0.11	0.07	0.33	0.03	0.03	0.03	0.00	1.18	1.18
1993	0.00	1.17	0.65	0.18	0.14	0.12	0.37	0.06	0.02	0.02	2.73	2.73
1994	0.08	0.70	2.68	1.00	0.15	0.10	0.07	0.16	0.02	0.05	4.99	4.99

Adjusted Autumn

Year	0	1	2	3	4	5	6	7	8	9+	Total	Total 1+
1963	83.93	25.39	9.22	6.81	8.34	5.95	2.04	1.68	1.18	0.46	145.01	61.08
1964	2.37	112.87	63.74	5.83	1.79	3.81	1.56	0.69	0.25	0.33	193.24	190.87
1965	0.33	10.16	77.39	9.70	1.07	0.80	0.91	0.80	0.25	0.27	101.69	101.36
1966	6.14	0.95	2.89	18.39	3.35	0.52	0.49	0.33	0.12	0.07	33.26	27.12
1967	0.03	6.72	0.36	0.99	6.76	1.62	0.49	0.21	0.33	0.18	17.70	17.67
1968	0.09	0.06	0.95	0.13	0.33	3.86	1.27	0.27	0.16	0.39	7.51	7.42
1969	0.39	0.03	0	0.28	0.13	0.16	1.52	0.51	0.09	0.27	3.38	2.99
1970	0.04	4.13	0.21	0.01	0.28	0.27	0.51	1.37	0.48	0.40	7.70	7.66
1971	2.43	0	0.31	0.07	0.01	0.22	0.03	0.09	0.75	0.28	4.20	1.77
1972	6.75	2.52	0	0.52	0.09	0	0.09	0.06	0.03	1.30	11.35	4.60
1973	3.23	9.00	1.61	0	0.19	0.04	0	0.07	0.01	0.72	14.89	11.65
1974	0.75	1.77	0.98	0.31	0	0.01	0	0	0	0.22	4.05	3.31
1975	23.48	0.63	0.72	4.86	0.92	0	0.03	0	0.01	0.30	30.95	7.46
1976	4.32	64.17	0.52	0.54	0.82	0.30	0	0.04	0.10	0.25	71.07	66.75
1977	0.13	2.14	18.73	0.56	0.57	0.64	0.34	0.04	0.01	0.09	23.25	23.12
1978	13.22	0.84	1.04	9.27	0.18	0.26	0.45	0.01	0	0.01	25.30	12.07
1979	1.32	45.57	0.04	0.90	3.81	0.26	0.28	0.05	0.01	0	52.24	50.92
1980	11.68	2.71	12.72	0.45	0.18	1.70	0.48	0.46	0.09	0.06	30.54	18.86
1981	0.38	6.13	2.08	3.70	0.21	0.42	0.53	0	0	0.01	13.45	13.07
1982	1.37	0	1.33	0.34	1.40	0.13	0.07	0.21	0.01	0.10	4.96	3.61
1983	5.80	0.24	0.21	0.27	0.30	0.94	0.12	0	0.10	0.02	7.99	2.19
1984	0.03	3.32	0.88	0.24	0.28	0.06	0.45	0	0	0.12	5.38	5.35
1985	11.35	0.65	1.53	0.22	0.05	0.1	0.07	0.17	0	0.05	14.19	2.84
1986	0	5.11	0.09	1.21	0.06	0.13	0.13	0.02	0.03	0.03	6.81	6.81
1987	1.8	0	0.79	0.1	0.77	0.06	0.06	0.02	0.02	0	3.62	1.82
1988	0.06	2.48	0.15	1.07	0.10	0.33	0.10	0.09	0	0.03	4.39	4.33
1989	0.47	0.05	2.71	0.20	0.66	0.09	0.13	0.02	0.02	0	4.33	3.87
1990	0.78	0.67	0.03	1.19	0.05	0.17	0.04	0	0	0	2.92	2.15
1991	2.16	0.21	0.24	0.05	0.22	0.02	0.02	0	0	0.02	2.92	0.76
1992	2.85	2.08	0.23	0.24	0	0.47	0.02	0.08	0.03	0.06	6.06	3.21
1993	1.52	4.04	2.01	0.30	0	0.06	0.15	0.02	0	0	8.09	6.58
1994	0.91	0.77	0.81	0.67	0.12	0.05	0.02	0.17	0.06	0	3.58	2.67

Table A5. (Continued)

	Spring Survey						Autumn Survey					
Year	1+	2+	3+	4+	5+	6+	1+	2+	3+	4+	5+	6+
1963	----	----	----	----	----		53.64	52.15	49.17	44.70	38.74	31.29
1964	----	----	----	----	----		61.07	35.68	26.46	19.65	11.31	5.36
1965	----	----	----	----	----		190.87	78.00	14.26	8.43	6.64	2.83
1966	----	----	----	----	----		101.35	91.19	13.80	4.10	3.03	2.23
1967	----	----	----	----	----		27.11	26.16	23.27	4.88	1.53	1.01
1968	13.83	13.43	10.60	10.14	9.44	2.72	17.67	10.95	10.59	9.59	2.83	1.21
1969	7.32	7.32	7.25	6.67	6.42	6.00	7.42	7.36	6.41	6.28	5.95	2.09
1970	6.00	5.33	5.08	5.08	4.75	4.29	2.99	2.96	2.96	2.68	2.55	2.39
1971	2.78	2.78	1.62	1.37	1.37	1.25	7.66	3.53	3.32	3.31	3.03	2.76
1972	6.37	2.35	2.26	1.65	1.53	1.50	1.76	1.76	1.45	1.38	1.37	1.15
1973	37.62	6.94	2.10	2.10	1.56	1.47	4.61	2.09	2.09	1.57	1.48	1.48
1974	19.00	16.87	3.58	0.72	0.72	0.48	11.64	2.64	1.03	1.03	0.84	0.80
1975	6.24	5.30	4.33	1.01	0.38	0.38	3.29	1.52	0.54	0.23	0.23	0.22
1976	83.18	2.39	2.09	1.49	0.57	0.14	7.47	6.84	6.12	1.26	0.34	0.34
1977	36.87	36.26	2.85	2.43	1.21	0.61	54.75	2.12	1.69	1.25	0.58	0.34
1978	19.41	19.34	18.37	2.44	2.08	1.14	23.12	20.98	2.25	1.69	1.12	0.48
1979	45.50	9.38	7.80	6.67	0.96	0.63	12.06	11.22	10.18	0.91	0.73	0.47
1980	60.06	54.86	8.16	7.65	6.61	1.74	50.92	5.35	5.31	4.41	0.60	0.34
1981	31.21	27.91	24.62	5.13	2.94	2.18	18.85	16.14	3.42	2.97	2.79	1.09
1982	8.61	7.85	6.32	5.38	1.31	0.89	15.93	8.45	5.92	1.41	1.16	0.65
1983	5.58	5.15	4.60	4.02	3.80	1.39	3.59	3.59	2.26	1.92	0.52	0.39
1984	6.25	4.16	2.98	2.34	1.71	1.13	2.19	1.95	1.74	1.47	1.17	0.23
1985	8.85	8.85	3.89	3.13	2.73	1.86	3.59	1.36	0.77	0.61	0.42	0.38
1986	5.85	3.36	3.18	1.12	0.88	0.77	2.84	2.19	0.66	0.44	0.39	0.29
1987	4.95	4.95	1.33	1.27	0.46	0.38	6.81	1.70	1.61	0.40	0.34	0.21
1988	3.38	1.83	1.79	0.80	0.67	0.35	1.50	1.50	0.85	0.77	0.14	0.09
1989	5.34	5.32	1.83	1.38	0.67	0.53	4.34	1.86	1.71	0.64	0.54	0.21
1990	7.69	6.83	6.83	1.11	0.78	0.20	3.88	3.83	1.12	0.92	0.26	0.17
1991	3.97	3.43	2.36	2.12	0.27	0.18	2.14	1.47	1.45	0.26	0.21	0.04
1992	1.18	0.78	0.60	0.49	0.42	0.09	0.93	0.68	0.39	0.33	0.06	0.04
1993	2.73	1.56	0.91	0.73	0.59	0.47	2.65	0.94	0.75	0.55	0.55	0.16
1994	4.93	4.23	1.55	0.55	0.40	0.30	8.02	3.09	0.64	0.27	0.27	0.20

Table A6. Stratified mean catch per tow (numbers) for haddock in Canadian offshore research vessel bottom trawl surveys on Georges Bank, 1986-1990.[1]

	Age group										
Year	0	1	2	3	4	5	6	7	8	9+	Total
1986	0.00	4.06	0.22	6.05	1.07	0.19	0.29	0.34	0.37	0.42	13.01
1987	0.00	0.03	3.04	0.69	2.51	0.67	0.08	0.30	0.10	0.86	8.28
1988	0.00	1.47	0.05	8.53	0.17	2.85	0.18	0.17	0.11	0.50	14.03
1989	0.00	0.03	5.34	0.72	2.12	0.19	0.42	0.03	0.03	0.23	9.11
1990	0.00	0.93	0.11	9.87	0.13	3.36	0.23	1.09	0.13	0.34	16.19
1991	0.00	0.75	1.67	0.14	8.99	0.11	1.60	0.09	0.44	0.21	14.00
1992	0.00	3.30	2.95	1.13	0.17	3.82	0.03	1.06	0.04	0.58	13.08
1993	0.00	3.96	2.16	0.55	0.45	0.04	1.28	0.02	0.32	0.16	8.94
1994	0.00	3.32	11.52	4.08	0.42	0.24	0.02	0.70	0.01	0.27	20.59
1995	0.00	1.94	2.62	4.30	2.22	0.56	0.28	0.00	0.48	0.66	13.06

[1] S. Gavaris, personal communication

Table A7. Percentage mature of female Georges Bank haddock, 1963-1994.

	Age				
Year	1	2	3	4+	Source
1963	0	0	78	100	Clark (1959)
1964	0	0	78	100	Clark (1959)
1965	0	0	78	100	Clark (1959)
1966	0	0	78	100	Clark (1959)
1967	0	0	78	100	Clark (1959)
1968	0	28	76	100	Clark et al. (1982)
1969	0	28	76	100	Clark et al. (1982)
1970	0	28	76	100	Clark et al. (1982)
1971	0	28	76	100	Clark et al. (1982)
1972	0	28	76	100	Clark et al. (1982)
1973	0	34	92	100	Clark et al. (1982)
1974	0	34	92	100	Clark et al. (1982)
1975	0	34	92	100	Clark et al. (1982)
1976	0	34	92	100	Clark et al. (1982)
1977	0	61	100	100	Overholtz (1987)
1978	0	26	99	100	Overholtz (1987)
1979	0	8	71	100	Overholtz (1987)
1980	0	41	100	100	Overholtz (1987)
1981	0	52	94	100	Overholtz (1987)
1982	0	31	67	100	Overholtz (1987)
1983	0	11	39	100	Overholtz (1987)
1984	12	33	94	100	O'Brien (pers. comm.)
1985	26	77	97	100	O'Brien et al. (1993)
1986	26	77	97	100	O'Brien et al. (1993)
1987	26	77	97	100	O'Brien et al. (1993)
1988	26	77	97	100	O'Brien et al. (1993)
1989	26	77	97	100	O'Brien et al. (1993)
1990	16	75	98	100	Current assessment
1991	16	75	98	100	Current assessment
1992	16	75	98	100	Current assessment
1993	06	43	90	100	Current assessment
1994	06	43	90	100	Current assessment

Table A8. Stock size, fishing mortality, and SSB output from ADAPT.

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1	190704	471879	33154	4137	12952	422	988	4660	369	8515
2	32266	153502	377202	18457	3284	9564	338	807	3774	301
3	32743	22755	111258	194982	8919	2536	5121	267	518	1845
4	45820	20095	14510	50829	68421	4687	1435	2656	204	222
5	29031	27424	12131	7033	24272	37318	2099	770	1659	131
6	9186	16350	14561	5959	3254	10518	17416	1127	462	1097
7	5595	5526	8144	5868	2534	1570	5445	8872	729	155
8	2794	3309	2640	3255	2694	1177	682	3034	5175	339
9	4217	4251	3258	2201	2031	2163	1712	1874	3244	6308
1+	352356	725092	576859	292720	128362	69955	35237	24067	16133	18913

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	19414	10540	7654	103233	13783	6058	83883	10105	7200	2460
2	6830	13579	8588	6093	84389	11284	4959	68676	8266	5894
3	245	3714	7208	6096	4560	51371	8550	4037	28178	5191
4	1104	198	2447	4215	4493	3564	29034	5438	2991	13118
5	109	554	160	1664	2655	3063	2642	17284	3570	1697
6	78	41	391	127	1167	1708	1995	1688	8673	2075
7	789	37	32	282	104	632	930	1262	845	4774
8	57	577	28	22	210	82	392	477	540	392
9	1678	2700	622	623	594	389	186	250	318	404
1+	30304	31940	27129	122354	111956	78152	132572	109218	60581	36005

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	3039	17096	1731	14467	1565	16049	1160	2489	1983	8350
2	2013	2488	13997	1418	11840	1281	13136	950	2036	1618
3	3772	1454	1953	9283	1112	7888	1002	9612	768	1262
4	2772	2352	922	1101	5057	793	4301	742	6562	546
5	7363	1645	1268	579	700	2681	528	2728	452	3428
6	1036	4002	988	621	342	463	1353	303	1448	278
7	1184	602	1936	603	352	214	244	784	160	815
8	2896	801	281	1109	358	208	126	158	481	65
9	273	1614	543	248	452	341	201	150	223	222
1+	24347	32056	23619	29429	21777	29918	22051	17916	14113	16584

	1993	1994	1995
1	14438	7509	7877
2	6830	11815	6148
3	1101	5330	9443
4	743	585	3594
5	328	338	329
6	1425	174	223
7	127	571	106
8	375	70	350
9	177	195	162
1+	25545	26585	28232

Table A8. (Continued)

FISHING MORTALITY - GBHADD5

■	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1 ■	0.02	0.02	0.39	0.03	0.10	0.02	0.00	0.01	0.00	0.02	0.16	0.00	0.03	0.00	0.00	0.00
2 ■	0.15	0.12	0.46	0.53	0.06	0.42	0.04	0.24	0.52	0.01	0.41	0.43	0.14	0.09	0.30	0.08
3 ■	0.29	0.25	0.58	0.85	0.44	0.37	0.46	0.07	0.65	0.31	0.01	0.22	0.34	0.11	0.05	0.37
4 ■	0.31	0.30	0.52	0.54	0.41	0.60	0.42	0.27	0.24	0.52	0.49	0.01	0.19	0.26	0.18	0.10
5 ■	0.37	0.43	0.51	0.57	0.64	0.56	0.42	0.31	0.21	0.32	0.78	0.15	0.03	0.15	0.24	0.23
6 ■	0.31	0.50	0.71	0.65	0.53	0.46	0.47	0.24	0.89	0.13	0.55	0.06	0.13	0.00	0.41	0.41
7 ■	0.33	0.54	0.72	0.58	0.57	0.63	0.38	0.34	0.57	0.81	0.11	0.06	0.15	0.09	0.04	0.28
8 ■	0.34	0.42	0.61	0.56	0.47	0.55	0.45	0.32	0.38	0.24	0.35	0.11	0.17	0.22	0.23	0.21
9 ■	0.34	0.42	0.61	0.56	0.47	0.55	0.45	0.32	0.38	0.24	0.35	0.11	0.17	0.22	0.23	0.21
4-7■	0.33	0.44	0.62	0.59	0.54	0.56	0.42	0.29	0.48	0.45	0.48	0.07	0.13	0.13	0.22	0.26

■	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1 ■	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 ■	0.01	0.69	0.27	0.25	0.12	0.04	0.21	0.04	0.21	0.05	0.11	0.01	0.28	0.18	0.05	0.02
3 ■	0.25	0.10	0.56	0.43	0.27	0.26	0.37	0.41	0.14	0.41	0.10	0.18	0.14	0.33	0.43	0.19
4 ■	0.32	0.22	0.37	0.38	0.32	0.42	0.26	0.25	0.43	0.21	0.26	0.30	0.45	0.31	0.59	0.38
5 ■	0.25	0.49	0.34	0.29	0.41	0.31	0.51	0.33	0.21	0.48	0.36	0.43	0.29	0.68	0.43	0.21
6 ■	0.26	0.49	0.40	0.36	0.34	0.53	0.29	0.37	0.27	0.44	0.35	0.44	0.38	0.58	0.72	0.29
7 ■	0.47	0.65	0.57	0.30	0.19	0.56	0.36	0.32	0.33	0.33	0.23	0.29	0.70	0.58	0.40	0.29
8 ■	0.32	0.44	0.39	0.35	0.36	0.46	0.37	0.31	0.40	0.42	0.28	0.39	0.44	0.62	0.63	0.29
9 ■	0.32	0.44	0.39	0.35	0.36	0.46	0.37	0.31	0.40	0.42	0.28	0.39	0.44	0.62	0.63	0.29
4-7■	0.33	0.46	0.42	0.33	0.32	0.46	0.36	0.32	0.31	0.37	0.30	0.36	0.45	0.54	0.53	0.29

SSB AT THE START OF THE SPAWNING SEASON - males & females (MT)

■	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1 ■	0	0	0	0	0	0	0	0	0	0
2 ■	0	0	0	0	0	1675	61	164	756	66
3 ■	24230	15656	65967	91729	4933	1433	3118	185	411	1651
4 ■	56089	23010	14887	48135	60257	4293	1636	3441	266	304
5 ■	38627	36347	15695	8787	26342	41983	2730	1303	3213	236
6 ■	16463	25241	20958	8947	5063	15407	26008	2066	873	2669
7 ■	10878	10436	13801	10289	4575	2780	10823	17569	1590	354
8 ■	6533	7058	5445	6849	5609	2397	1525	7607	12672	961
9 ■	11435	10811	8271	5784	5324	5124	5277	6176	10447	20670
1+■	164256	128559	145025	180521	112102	75092	51178	38511	30227	26912

■	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
1 ■	0	0	0	0	0	0	0	0	0	0	0
2 ■	1594	3143	2251	1510	17992	2452	1132	12803	1680	1070	290
3 ■	272	4215	7623	6065	4147	45707	6784	3337	20354	4037	3130
4 ■	1789	359	4456	6763	7091	5669	44393	7285	3863	17336	3964
5 ■	189	1247	341	3692	5542	6771	5346	30457	6218	3124	12886
6 ■	183	116	1038	315	2925	4329	5267	3778	18149	4544	2266
7 ■	2306	126	113	862	351	1845	2733	3432	2256	12507	3217
8 ■	170	1955	105	87	724	286	1231	1491	1775	1308	8298
9 ■	5768	10652	2454	2769	2662	1795	798	825	1219	1438	1012
1+■	12271	21813	18381	22063	41434	68854	67683	63406	55515	45365	35062

■	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1 ■	372	84	1185	110	1145	112	177	123	464	413	81
2 ■	426	5559	572	5034	602	5720	484	1188	911	2189	4165
3 ■	1416	1856	8976	1149	6934	1086	9827	779	1520	1206	6071
4 ■	3191	1327	1568	7117	1111	5945	1064	9149	732	1152	998
5 ■	2906	2251	1144	1281	4587	886	4533	789	5486	542	733
6 ■	8107	2136	1422	790	926	2715	613	2968	536	2717	350
7 ■	1393	4814	1500	902	524	617	1863	343	1879	283	1379
8 ■	2262	809	3178	1029	578	362	425	1201	163	926	180
9 ■	5093	1792	827	1669	1157	679	539	825	773	577	691
1+■	25166	20627	20373	19080	17563	18122	19525	17365	12463	10003	14649

Table A9. Results of short-term (1995-1997) forecasts of SSB and landings for Georges Bank haddock under several fishing mortality scenarios.

			Median Landings and SSB				
Option	Basis	F	SSB (95)	Landings (95)	SSB (96)	Landings (96)	SSB (97)
A	Close	0.00	21.2	3.1	26.8	0.0	33.0
B	$F_{(95)}$	0.18	21.2	3.1	25.8	4.1	28.2
C	$F_{0.1}$	0.24	21.2	3.1	25.5	5.4	26.7
D	$F_{30\%}$	0.35	21.2	3.1	24.9	7.4	24.3

Table A10. Equilibrium yield calculations for Georges Bank haddock under three sets of recruitment assumptions.

- GM Recruitment 1963-1993 = 7.8 milllion

F level	Y/R (kg)	Yield (tongs)	SSB/R (kg)	SSB (tons)
0.10	0.5296	4,100	5.6716	44,200
0.24	0.7661	6,000	3.5938	28,000
0.35	0.8335	6,500	2.7922	21,800
1935-1960 Average Weights				
0.10	0.4427	3,500		
0.18	0.6207	4,800		
0.24	0.6792	5,300		

- GM Recruitment 1935-1960 = 71.4 million

F level	Y/R (kg)	Yield (tons)	SSB/R (kg)	SSB (tons)
0.10	0.5296	37,800	5.6716	404,950
0.24	0.7661	54,700	3.5938	256,600
0.35	0.8335	59,500	2.7922	199,400
1935-1960 Average Weights				
0.10	0.4427	31,600		
0.24	0.6207	44,300		
0.35	06792	48,500		

- AM Recruitment 1965-1993 = 14.2 million

F level	Y/R (kg)	Yield (tons)	SSB/R (kg)	SSB(tons)
0.10	0.5296	7,500	5.6716	80,500
0.24	0.7761	10,900	3.5938	51,000
0.35	0.8335	11,800	2.7922	39,600
1935-1960 Average Weights				
0.10	0.4427	6,300		
0.24	0.6207	8,800		
0.35	0.6792	9,600		

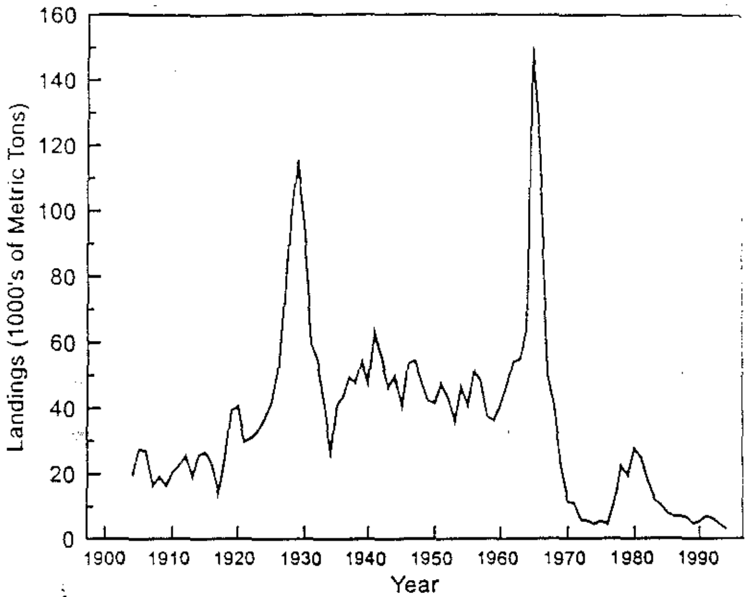

Figure A1. Total commercial landings of haddock from Georges Bank and South, 1904-1994.

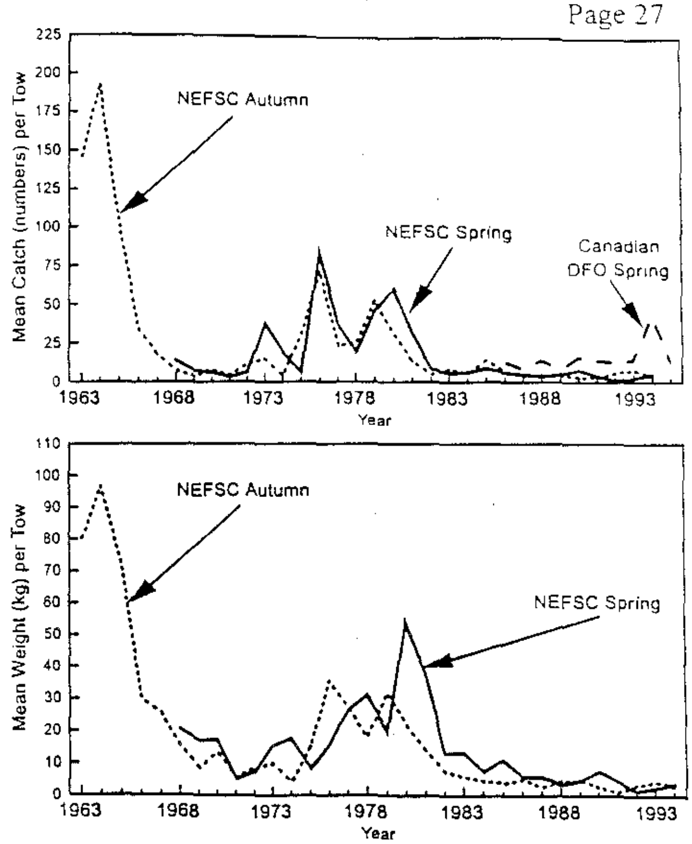

Figure A2. NEFSC and Canadian DFO bottom trawl survey abundance, number • tow $^{-1}$, (top) and biomass, kg • tow $^{-1}$, (bottom) for Georges Bank haddock.

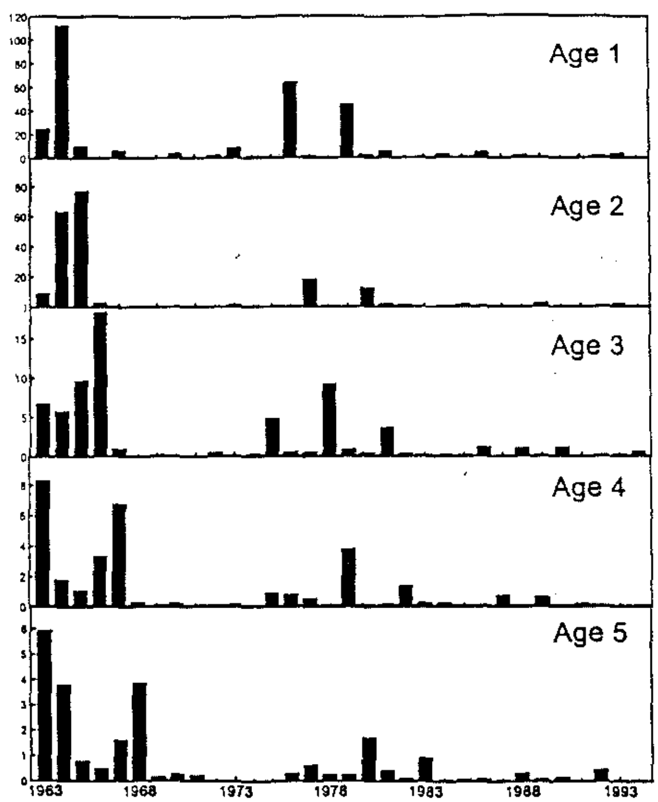

Figure A3. Abundance by year class (number • tow $^{-1}$) of haddock sampled in NEFSC Spring Research Vessel bottom trawl surveys on Georges Bank from 1968-1994.

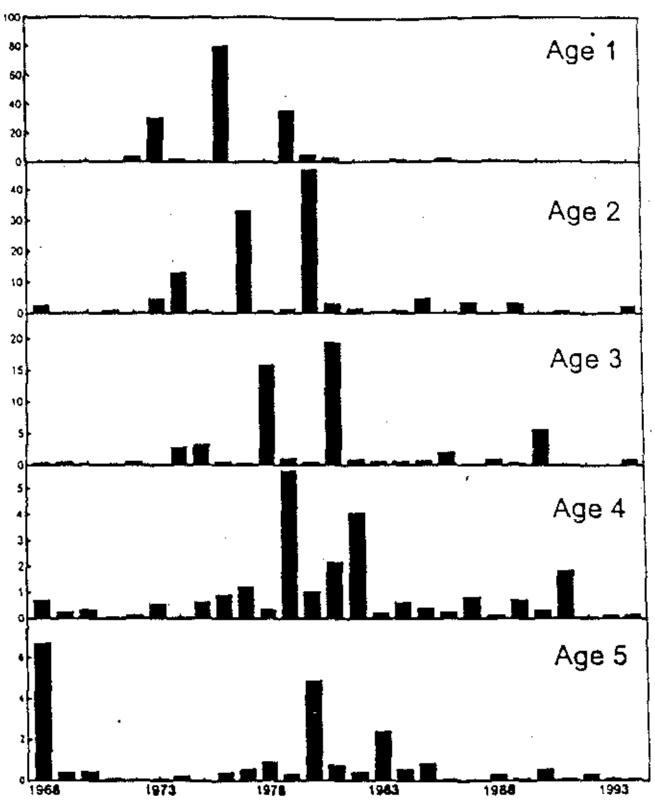

Figure A4. Abundance by year class (number • tow $^{-1}$) of haddock sampled in NEFSC autumn research vessel bottom trawl surveys on Georges Bank from 1963-1994.

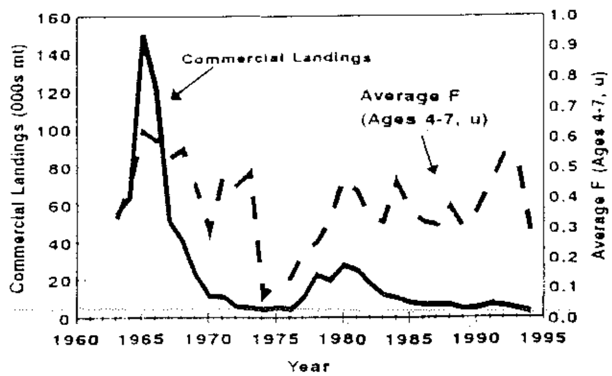

Figure A5. Trends in commercial landings (metric tons, live wt) and fully recruited fishing mortality (mean F, 4-7, u) for Georges Bank haddock, 1963-1994.

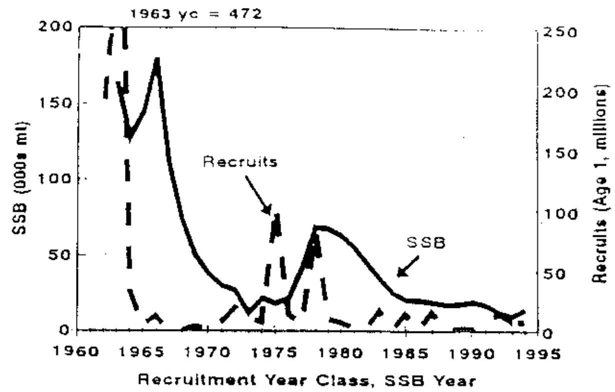

Figure A6. Trends in spawning stock biomass (SSB, 000s metric tons) and recruitment (Age 1, million of fish) for Georges Bank haddock, 1963-1994.

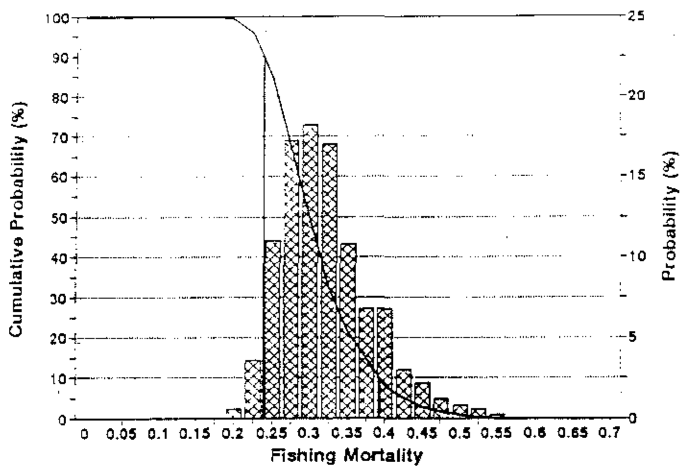

Figure A7. Precision of the estimates of the instantaneous rate of fishing mortality (F) on the fully recruited ages (age 4+) in 1994 for Georges Bank haddock. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that F is greater than any selected value on the X-axis. The precision estimates were derived from 500 bootstrap replications of the final ADAPT VPA formulation.

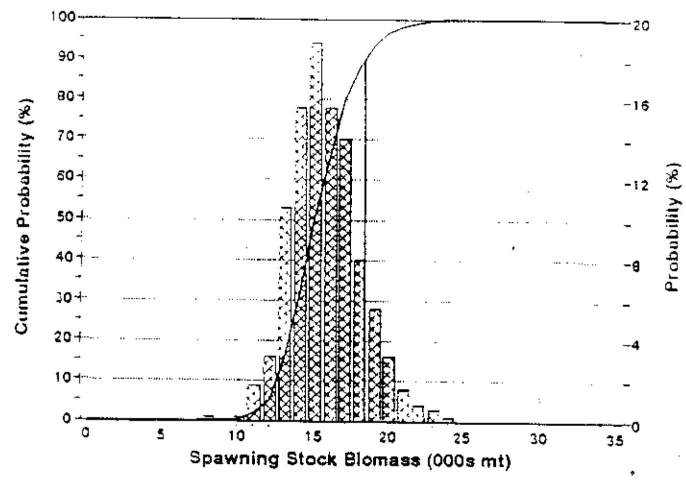

Figure A8. Precision of the estimates of the spawning stock biomass (SSB) at the beginning of the spawning season (April 1) for Georges Bank haddock in 1994. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that SSB is less than any selected value on the X-axis. The precision estimates were derived from 500 bootstrap replications of the final ADAPT VPA formulation.

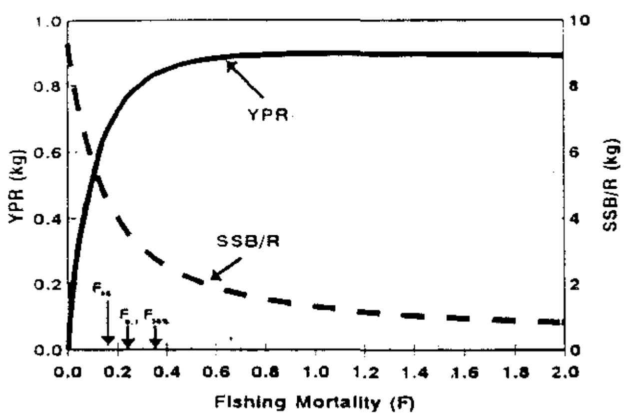

Figure A9. Yield (YPR) and spawning stock biomass (SSB/R per recruit for Georges Bank haddock.

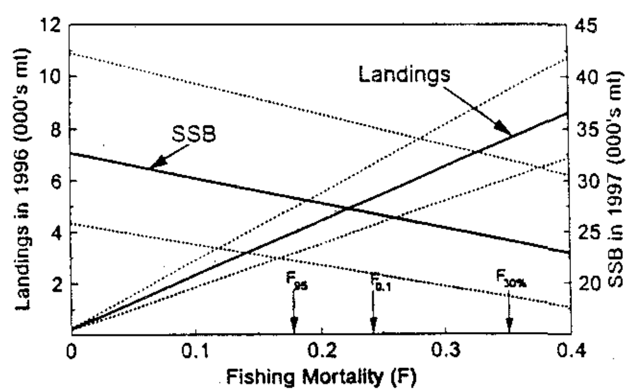

Figure A10. Short term projections of 1996 landings and 1997 SSB for Georges Bank haddock.

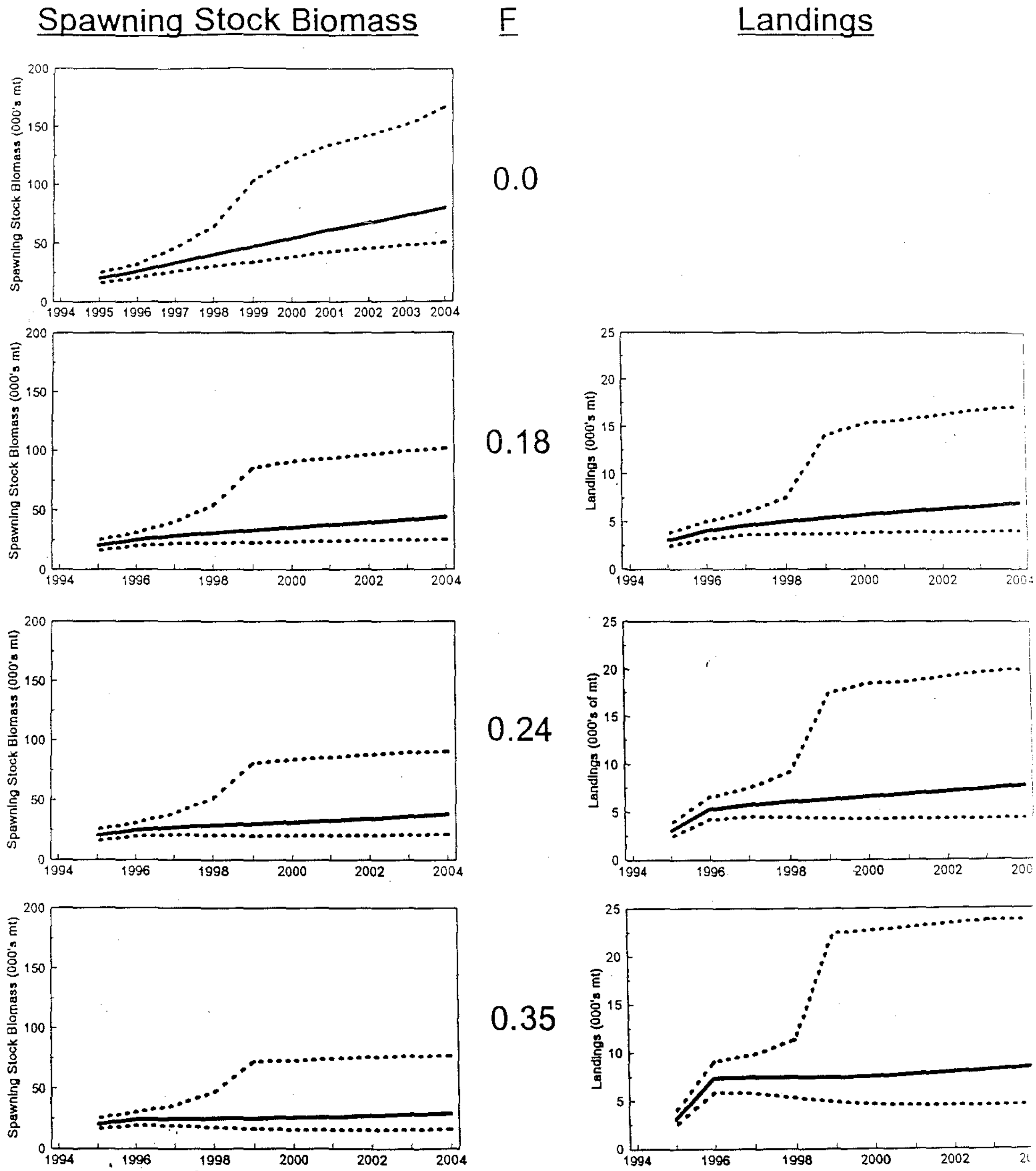

Figure A11. Results of medium-term (10 year) projections for Georges Bank haddock using fishing mortality scenarios of 0.0, 0.18, 0.24, and 0.35. Solid line = 50%, dashed line = 10%, 90%.

B. SUMMER FLOUNDER

Terms of Reference

The following terms of reference were addressed:

a. Provide updated assessment for the coastwide stock of summer flounder and provide catch and SSB options at various levels of fishing mortality;

b. Provide catch and SSB forecasts incorporating uncertainty in recruitment and stock size estimates (stochastic projections).

Introduction

For assessment purposes, the previous definition of Wilk *et al.* (1980) of a unit stock extending from Cape Hatteras north to New England was accepted. The Mid-Atlantic Fishery Management Council (MAFMC) Fishery Management Plan (FMP) for summer flounder has as a management unit all summer flounder from the southern border of North Carolina, northeast to the U.S.-Canadian border. Amendment 2 to the FMP was accepted by the Secretary of Commerce in August, 1992. The FMP has set a target fishing mortality rate (F_{tgt}) of 0.53 for 1993-1995, with a target of F_{max} = 0.23 for 1996 and beyond.

Major regulations enacted under Amendment 2 to meet these fishing mortality rate targets include 1) an annual commercial fishery quota, to be distributed to the states based on their share of commercial landings during 1980-1989, 2) commercial fish size limitation to remain at a 13 in (33 cm) minimum size, which may be changed annually if needed, 3) a minimum mesh size of 5.5 in (140 mm) diamond or 6.0 in (152 mm) square mesh for commercial vessels using otter trawls that possess 100 lb (45 kg) or more of summer flounder, with exemptions for the flynet fishery and vessels fishing in an exempted area off southern New England during 1 November to 30 April, 4) permit requirements for the sale and purchase of summer flounder, and 5) annually adjustable regulations for the recreational fishery. Amendment 3 to the FMP revised the area included in the southern New England exempted fishery to include the Hudson Canyon area, increased the large mesh net threshold to 200 lbs during the winter fishery (1 November to 30 April), and stipulated that otter trawl vessels fishing from 1 May to 31 October could retain only 100 lbs of summer flounder before using the large mesh net. Amendment 4 to the FMP adjusted the state of Connecticut's commercial fishery quota and revised the state-specific shares of the coastwide commercial quota. Amendment 5 to the FMP allowed states to transfer or combine their shares of the commercial fishery quota. Amendment 6 allowed multiple nets (varying mesh) on board. Proposed Amendment 7 would revise the fishing mortality rate reduction schedule established under Amendment 2 (see projections).

The Fishery

Northeast Region (NER: Maine to Virginia) commercial landings for 1980-1994 were derived from the Northeast Fisheries Science Center (NEFSC) commercial landings files and quota reports. North Carolina commercial landings were provided by the North Carolina Division of Marine Fisheries (NCDMF). Total U.S. commercial landings of summer flounder from Maine to North Carolina peaked in 1979 at nearly 18,000 metric tons (mt; 40 million lb). The reported landings in 1994 of about 6,600 mt (about 14.5 million lb) were about 9% under the target quota. Recreational landings were based on revised statistics from the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS), for type A+B1 landings (recreational statistics reported herein reflect changes in estimation procedures implemented by MRFSS for 1981-1994 data). In 1994, recreational landings rose to 4,100 mt, about 15% below the target quota for the fishery. Landings are still well below levels in the early 1980s, when landings ranged between 5,000 and 14,000 mt (Table B1).

Age samples were available to construct the landings-at-age matrix for the NER (Maine to Virginia) commercial landings for the period 1982-1993 (Table B2). A landings-at-age matrix for 1982-1994 was also developed for the North Carolina winter trawl fishery (Table B3), which historically accounts for about 99% of summer flounder commercial landings in North Carolina. The matrix is based on NCDMF fishery length frequency samples and age-length keys from NEFSC commercial and spring survey data (1982 to 1987) or NCDMF commercial fishery data (1988 to 1994).

Information on the length frequency and market classification of the 1994 NER commercial landings was not available to the SARC, and so landings at age could not be directly estimated. Total landed weight was available from the quota monitoring system. Since landings at age data for 1994 from the North Carolina commercial and the coastwide recreational fishery and research survey data through spring of 1995 were available, indirect means were used to estimate the NER 1994 commercial landings at age, in order to include 1994 catch in analytical models for this assessment. A regression model relating the sum of North Carolina commercial and recreational landings to the NER commercial component for years 1989 to 1993 was used to estimate NER landings at age for 1994.

The fishery components at age appeared linearly related, but with a tendency for variability to increase with the independent (North Carolina and recreational) variable. Consequently, a logarithmic transformation was applied to stabilize variance. The fitted regression model (log[NER commercial landings at age and year] = log[NC commercial landings at age and year + recreational landings at age and year]) explained 80% of the variance in log NER landings. The regression slope of 0.92 (SE = 0.07) was highly significant ($P < 0.01$) for 43 degrees of freedom. Examination of regression residuals with respect to age and year indicated small estimation error with no trend, with the exception of age-0 fish in 1990 and 1991 which had large negative residuals. This suggested that the fitted regression might overestimate NER commercial age-0 landings; however, a higher estimate for the NER commercial fishery at age-0 in 1994 was consistent with research survey data indicating an above average strength (relative to 1989-1993) 1994 year class. The regression estimates for the NER commercial landings at age in 1994 were accepted and appear in Table B2. Mean weights at age in 1994 were assumed to be the average of the mean weights of the 1989-1993 NER commericial landings.

Discards from the commercial fishery during 1989-1993 were estimated using observed discards and days fished from NEFSC sea sampling trips to calculate fishery discard rates by two-digit statistical area and calendar quarter. These rates were applied to the total days fished (days fished on trips landing any summer flounder) from the weighout data base in the corresponding area-quarter cell, to provide estimates of fishery discard by cell. Discard estimates were aggregated over all cells. That total was then raised to reflect potential discard associated with general canvas and North Carolina EEZ landings. Because existing sea sampling length-age data are not adequate to characterize discards at this level of resolution, with large amounts of estimated discard represented by one or no length-age samples, length-age samples are applied at a coarser stratum level as needed.

A NER commercial fishery discard-at-age matrix for 1989-1993 was developed using sea sampled length frequency and age-length distribution samples from 1989-1993, assuming a commercial fishery discard mortality rate of 80%, as recommended by SAW 16 (NEFSC 1993) (Table B4). Sampling intensity was at least one sample of 100 lengths per 29 mt. Although data are inadequate to develop a commercial discard-at-age matrix for 1982-1988, it is likely that discard numbers were small relative to landings during that period, because there was no minimum size limit for fish caught in the EEZ. Discards likely increased in 1989-1993 with the initial implementation of minimum size regulations for the EEZ in 1989. Not accounting directly for commercial fishery discards will result in underestimation of fishery mortality and population sizes in 1982-1988.

Sea sample discard rate and length frequency data for 1994 were not available to the SARC. To develop estimates of total discard and discard at age for 1994, arithmetic weighted (by numbers at age and year) mean 1989-1993 discard to landings ratio by weight (mt)(mean 1989-1993 proportion = 0.143), proportions at age by weight, and mean lengths and weights at age were assumed for the 1994 discard (Table B4).

As noted above, the time series of recreational fishery landings (catch type A+B1) as estimated by the NNMFS Marine Recreational Fishery Statistics Survey was revised in 1995 to incorporate improved estimation and data quality control procedures (Tables B5 and B6). Revised estimates of recreational fishery summer flounder catch (catch types A + B1 +25% B2; in numbers) differed from the original estimates by -32 to + 2 percent (Table B7).

Estimates of recreational landings at age (type A+B1) were developed from MRFSS sample length frequencies, and NEFSC commercial and survey age-length data (Table B8). Estimates of recreational discards at age were based on assumptions that the ratio of age 0:age 1 fish in type B2 catches were the same as in A+B1 landings and that 25% of type B2 catches die of hooking mortality. Type B2 catches have become a more significant component of total recreational catches (up to 70% in 1993) as minimum size regulations have been implemented on a state-by-state basis. Because discard lengths and weights are unobserved, mean weight at age in the discard is set equal to mean weight at age in the landings. The SARC noted that discard weight at age consequently would be overestimated (although sub-legal sized fish are observed in landings). The recreational discard at age matrix is displayed in Table B9.

NER total commercial landings and discards at age, North Carolina winter trawl landings and discards at age, and MRFSS recreational landings and discards at age totals were summed to provide a total fishery catch at age matrix for 1982-1994 (Table B10). The numbers and proportions at age of fish age 4 and older are low and quite variable, reflecting the limited numbers of fish available to be sampled. Overall mean lengths and weights at age for the total catch were calculated as weighted means (by number in the catch at age) of the respective mean values at age from the NER commercial (Maine to Virginia), North Carolina commercial winter trawl, and recreational (Maine to North Carolina) fisheries (Table B11, B12).

Research Survey Abundance and Biomass Indices

Age-specific mean catch rates, in numbers, from the NEFSC spring offshore survey (Table B13, 1976-1995 (1995 preliminary)), NEFSC winter offshore survey (Table B14, 1992-1995 (1995 preliminary)), the Massachusetts Department of Marine Fisheries (MADMF) spring and fall inshore surveys (Table B15, 1978-1994), and the Connecticut Department of Environmental Protection (CTDEP) spring and fall trawl surveys (Table B16, 1984-1994) were available as indices of abundance.

Young-of-year (YOY) survey indices were also available from NCDMF Pamlico Sound trawl survey (1987-1994), Virginia Institute of Marine Science (VIMS) juvenile fish trawl survey (1979-1994), Maryland Department of Natural Resources (MDDNR) trawl survey (1972-1994), Delaware

Division of Fish and Wildlife (DEDFW) Delaware Bay trawl survey (1980-1994), Rhode Island Department of Environmental Management (1979-1994), and MADMF beach seine survey (1986-1994)(Table B17). Because values of zero were observed in the Rhode Island and Massachusetts YOY time series, a value of 1 was added to each value in the series when used for VPA tuning to avoid calculating the logarithm of zero.

Since several indices from a broad geographic range are available to estimate the strength of the 1994 year class, the SARC noted that the spatial distribution of recruitment success may not be uniform over the range of the stock, and may be important in recovery dynamics. Considered in aggregate, available research surveys indicate that the 1994 year class was stronger than the 1993 year class.

Estimates of Mortality and Stock Size

Natural Mortality Rate

The SARC reviewed alternative estimates of the instantaneous natural mortality rate (M) for summer flounder developed using the methods of Pauly (1980), Hoenig (1983), and consideration of age structure expected in unexploited populations (5% rule, 3/M rule, e.g., Anthony 1982). The key parameters needed to use these indirect methods to estimate M are the maximum age of the fish (t_{max}), the parameters of the von Bertalanffy growth equation (L_{inf} and K), and the water temperature characteristic of the range of the fish (T). The SARC felt that the current value of M (0.2) was reasonable given the mean (0.23) and range (0.15-0.28) obtained from the various analyses.

Estimates of Mortality from ALS Tagging Data

Tagging data for summer flounder from the American Littoral Society (ALS) angler program were used to make estimates of fishing mortality. Since 1983, a total of 19,101 summer flounder have been tagged by ALS anglers. Through 1994, 1,487 had been recovered. Based on reported length at tagging, most summer flounder tagged by anglers were ages 0 to 2. Tag release and recapture data were compiled from 1983 through the first quarter of 1995 by year of release. Estimates of survival rates were made using the Brownie *et al.* (1985) framework which has an extensive history in waterfowl and upland game bird marking studies. The statistical framework consists of a series of models which consider tag recoveries in sequential years following release to be multinomial random variables. Model structure in terms of recovery rate and survival probability proceeds from most restrictive (no time dependence) to most general (time dependent parameters). Maximum likelihood methods are used to estimate parameters and provide a covariance matrix for the estimates. Goodness of fit and likelihood ratio testing are used to select the most parsimonious model which adequately reflects the data. The models estimate survival rate directly which is transformed into total mortality rate. Total mortality rate was corrected for tag loss on the basis of Sprankle's (1994) study on striped bass which indicated an instantaneous loss of 0.48 per year for the ALS tags. Fishing mortality rate was estimated by subtracting M=0.20 from corrected Z values.

A model which assumed time dependent recovery and survival rate was selected as the best representation of the 1983-1994 tag data. Survival rate (S) ranged from 0.09 in 1985 to 0.32 in 1992 without clear trend. The terminal value in 1993 was 0.20 (SE = 0.03). Coefficients of variation on the survival estimates ranged from 0.15 to 0.45 and in general were proportional to the number of fish tagged. The period of inference for the survival estimate was from July of one year to July in the next. The estimated survival rates correspond to a total instantaneous loss rate ranging from Z = 1.15 to Z = 2.39. Allowing for tag loss as estimated in the retention study and natural mortality losses, fishing mortality rate ranged from F = 0.47 in 1985 to F = 1.72 in 1992. F in the terminal year (July 1993 to July 1994) was 0.95. Assuming no uncertainty in the natural mortality and tag loss adjustments, a 95% confidence interval on F in

1993-1994 estimated from the ALS tag data was 0.65 to 1.25.

Virtual Population Analysis Calibration

ADAPT tuning for the VPA (1982-1994) was used (Parrack 1986, Gavaris 1988, Conser and Powers 1990). All survey indices were included in the tuning procedure. Indices were not weighted: weighting would have lead to estimates strongly influenced by the NEFSC winter trawl survey, which consists of only four observations at age. The instantaneous natural mortality rate was assumed to be 0.2. Fishing mortality rates in 1994 and abundances of ages 1-4 in 1994-1995 were directly estimated, while abundance of age 5+ was estimated from Fs estimated in 1994 and the input partial recruitment pattern. Because no recruitment indices were available for 1995, stock size at age 0 was not estimated. The F on age 4 (oldest true age) was estimated from back-calculated stock sizes for ages 2-4. The F on the age 5+ group was set equal to the rate for age 4.

In order to incorporate available information from 1994 recreational catch at age statistics, 1994 North Carolina commercial fishery landings at age statistics, and age-specific 1994-1995 research survey indices related to 1995 stock abundances, a VPA was undertaken using estimated 1994 NER (Maine to Virginia) commercial fishery landings at age and 1994 commercial fishery discards at age (see Fishery section for details). Results discussed in the following sections relate to the VPA which includes all available 1994-1995 survey data and 1994 estimated catch data. These results should be considered more uncertain than previous VPA results for this stock.

Fishing mortality rates on fully recruited ages have exceeded 1.0 between 1982-1992, varying between 1.0-1.9 (58-79% exploitation rate). The fishing mortality rate showed a decline in 1993 to 0.8 (51% exploitation rate), and in 1994 to 0.7 (46% exploitation rate) (Table B18, Figure B1).

Summer flounder spawn in the late autumn and into early winter (peak spawning on November 1), and age 0 fish recruit to the fishery the autumn after they are spawned. For example, summer flounder spawned in autumn 1987 (from the November 1, 1987 spawning stock biomass) recruit to the fishery in autumn 1988, and appear in VPA tables as age 0 fish in 1988. This assessment indicates that the 1982 and 1983 year classes were the largest of the VPA series, at 76 and 83 million fish, respectively. The 1988 year class was the smallest of the series, at only 13 million fish. The 1994 year class is estimated at about 50 million fish. (Table B18, Figure B2).

Total stock size in 1994 (ages 0 and older) was estimated at about 88 million fish, about 54% of the peak abundance estimated for 1983 (163 million). Spawning stock biomass (SSB) on November 1, 1994 was estimated to be about 14,800 mt, about 78% of the peak estimated for 1983 (18,900 mt). Age 2-5+ SSB, which may be a more realistic estimate of viable spawners given the uncertain spawning potential of age 0 and age 1 summer flounder, was estimated to be about 6,100 mt, about 6% above the SSB estimated for 1983 (5,700 mt)(Table B18, Figure B2). A comparison between catch biomass as calculated in the VPA and reported landings plus estimated discard (Table B19) indicates a slight tendency of the VPA estimate to exceed the reported landings estimate (1 - 3%, 1991 - 1994).

In summary, the VPA results indicate that fishing mortality rates on summer flounder declined substantially in 1993-1994 due to limits on the catch and improved recruitment since 1988, although management target rates were exceeded (F_{tgt} = 0.53 in 1993-1994). Spawning stock biomass has increased since 1989, but this biomass continues to be concentrated in a few age classes, with only about 26% of the total SSB at ages 3 and older in 1995. Under FMP Amendment 7 Option 1 (status quo), about 60% of the spawning stock biomass is expected to be of ages 3 and older in 1998. In contrast, under equilibrium conditions, about 77% of the spawning stock would be expected to be aged 3 and older if the stock were rebuilt and fished over the long-term at $F_{max} = 0.23$ (Figure B3). Spawning stock biomass and corresponding recruitment estimates are summarized in Figure B4.

The distribution of bootstrap (Efron 1982) fishing mortality rates was not strongly skewed, resulting in the bootstrap mean F for 1994 (0.70) being about equal to the point estimate from the VPA (0.69). There is a 80% chance that F in 1994 was between 0.55 and 0.85, given variability in survey observations (Figure B5).

The bootstrap estimate of spawning stock biomass was relatively precise, with a bias corrected CV of 16%. The bootstrap mean (15,500 mt) was slightly higher than the VPA point estimate (14,800 mt). The bootstrap results suggest a high probability (>90%) that spawning stock biomass in 1994 was at least 13,000 mt, again reflecting only variability in survey observations (Figure B6).

Retrospective analyses of the summer flounder VPA were carried out using the final VPA configuration, with the NEFSC winter survey omitted because of the brevity of that time series. Convergence is generally evident within 2-3 years prior to any given terminal year. Some retrospective pattern was evident in the summer flounder VPA, with a tendency for F to be underestimated and stock sizes overestimated (Table B20).

The calculation of biological reference points for summer flounder using the Thompson and Bell (1934) model was detailed in the Report of the Eleventh SAW (NEFC 1990). No revised analysis was performed. The 1990 analysis indicated $F_{0.1} = 0.136$, $F_{max} = 0.232$, and $F_{20\%} = 0.270$ (Figure B7).

Yield and stock size projections were made for 1995-1997 assuming that the 1995 quotas will be landed, but not exceeded (commercial = 6,663 mt, recreational = 3,520 mt, total = 10,183 mt; commercial quota includes 1,361 mt [3 million lbs] added for 1995 by judicial action), and that total discards in 1995 will not exceed 2,300 mt. The projections also assume that recent patterns of discarding will continue over the time span of the projections. Different patterns that could develop during 1995-1997 due to trip and bag limits and fishery closures have not been evaluated. The partial recruitment pattern (including discards) used in the projections was estimated as the geometric mean of F at age for 1993-1994, to reflect conditions in the fisheries resulting from the implementation of FMP Amendment 2 regulations (see Introduction). Mean weights at age were estimated as the arithmetic means of 1993-1994 values. Separate mean weight at age vectors were developed for the spawning stock, landings, and discards (Table B21).

Stochastic projections were made to estimate landings and spawning stock biomass levels under three options (1, 5A, and 5B) of proposed FMP Amendment 7, given uncertainty in 1995 age-1 and older stock size estimates and 1995-1998 age-0 recruitment levels. Two hundred projections were made for each of the 200 bootstrapped realizations of 1995 stock sizes from VPA runs, using algorithms and software described by Brodziak and Rago (MS 1994). Recruitment in 1995-1998 was generated randomly from recruitment levels estimated by VPA for 1990-1994. Uncertainty in partial recruitment patterns, discard rates, or components other than survey variability was not reflected.

Summer flounder FMP Amendment 7 Option 1 proposes retaining the current fishing mortality reduction schedule, with a 1995 target F of 0.53, and with the F target reduced to 0.23 in 1996 and beyond. Under Option 1, total landings would need to be reduced to about 6,600 mt in 1996 to meet the target of F = 0.23, with spawning stock biomass rising to 28,800 mt (Table B21, Figures B8-B10).

Option 5A proposes revised targets of F = 0.41 in 1996, F = 0.30 in 1997, and F = 0.23 in 1998. Under Option 5A, totals landings could increase to about 10,900 mt in 1996 and meet the target of F =

0.41, with spawning stock biomass rising to 25,400 mt (Table B21, Figures B8-B10).

Option 5B adopts the same F targets as Options 5A, but with total landings capped at 8,400 mt in 1996-1997, unless the quota provides a realized F = 0.23. Under Option 5B, totals landings of 8,400 mt in 1996 would provide a realized median F = 0.30, with spawning stock biomass rising to 27,400 mt (Table B21, Figures B8-B10).

Conclusions

The summer flounder stock is at a medium level of historic abundance and is overexploited, with fishing mortality rates exceeding 1.0 as recently as 1992. Fishing mortality rates on summer flounder declined substantially in 1993-1994, due to limits on the catch and improved recruitment since 1988. Stock rebuilding has begun with this improved recruitment and decreased fishing mortality, even though management target fishing mortality rates (F = 0.53) were exceeded in 1993 and 1994.

The 1994 year class is estimated by VPA to be about 50 million fish, the largest year class to recruit to the stock since 1986. The presence of a relatively strong 1994 year class affords the opportunity to rapidly rebuild the summer flounder spawning stock biomass, while allowing moderate catches. Moving to the overfishing level (F_{max} = 0.23) will maximize the yield and improve the spawning potential of the 1994 and subsequent year classes.

Sources of Uncertainty

The following major sources of uncertainty in the current assessment were identified:

1) VPA estimates of stock size in 1995 are not precise because they depend on imprecise, and in some cases preliminary, survey indices. Projected landings should be considered with caution.

2) Samples of the 1994 NER commercial landings and discards by length interval were not available, and so those components of the catch at age matrix (about 48% of total 1994 catch numbers) were estimated by indirect methods (see Fishery section).

3) The landings from the commercial fisheries used in this assessment assume no mis-reporting or non-reporting of summer flounder landings. Therefore, reported landings from the commercial fisheries should be considered minimum estimates. The SARC noted that the fishing mortality rate in the terminal year of the VPA has been underestimated in the previous two assessments (NEFSC 1993, 1994).

4) The current assumptions accepted to allow characterization of the age composition of the recreational live discard (catch type B2) are based on data from a limited geographic area (Long Island, New York).

5) The proportion of the catch at age which is discarded is likely to change under regulation (e.g., recreational fishery bag limits, commercial fishery trip limits and closures), but it is assumed to remain constant in current projections. This will likely lead to underestimation of discards and fishing mortality rates in the projections.

SARC Comments

The SARC assumptions made to characterize the age frequency of the discards in the recreational fishery were discussed. It was noted that the data on which those assumptions are based are from a single, regional fishing mode component (New York party boat) of the coastwide fishery.

The slope of the regression used to characterize the age composition of the 1994 NER commercial landings (expresses NER landings at age as a function of NC commercial plus coastwide recreational landings at age; 1989-1993) is strongly influenced by landings at ages 1 and 2, which account for most of the landings. Results from other methods considered by the Subcommittee were briefly discussed (e.g., assuming the same proportions as the NC commercial plus recreational landings in 1994; assuming the same proportions as the NC commercial and recreational landings in 1993 or 1989-1993). It was noted that the regression method used provided a method of averaging the age compositions of the NC commercial and recreational fisheries over time.

The SARC noted that it was difficult to detect the presence of strong and weak year classes by inspection of the catch-at-age matrix. Discussion about possible reasons for this difficulty included: 1) the total catch at age is comprised of catch estimated for five components (NER commercial landings and discard, NC commercial landings, recreational landings and discards), each with different partial recruitment patterns; 2) the fishing mortality rates have been very high, quickly removing strong year classes from the stock; and 3) regulations have been changing differentially between regions and fisheries.

In discussing the natural mortality rate (M) used in the assessment, the SARC noted that the rate used (0.2) was an approximation of the mean (0.23) of the range of values (0.15-0.28) considered by the Subcommittee.

The SARC discussed the issue of which survey indices to include in the VPA calibration, and whether to weight them. It was noted that some of the indices (especially some of the recruitment indices), exert little influence on the tuning, other than to contribute to increased overall variance. There was a brief discussion of the work done by the Subcommittee on this aspect of the calibration. The Subcommittee found no readily apparent objective method for index elimination, in terms of partial variance associated with indices or tests for reduction in mean squared residuals. The alternatives to index elimination include reweighting by the inverse of partial variances associated with each index, or by *a priori* assumptions about survey performance in terms of survey gear characteristics or geographic coverage. For surveys with common geographic coverage, the SARC noted that some means to standardize among or combine surveys (as was done in the SAW 18 work on coherence among recruitment indices) might improve the utility of some of the recruitment indices. The SARC suggested it might be appropriate in future assessments to eliminate some indices which fit extremely poorly and have limited geographic or temporal scope. The SARC noted that lack of correspondence with VPA estimates might be due to restricted geographical range, inappropriate seasonality of sampling, or inappropriate sampling gear. The SARC encourages communication between the Subcommittee and state agencies on means to improve the utility of surveys for summer flounder.

The calibration of survey biomass and recruitment indices with VPA estimates, with the goal of extending the time series of spawning stock and recruitment estimates (this was a research recommendation from SAW 18) was discussed. It was noted that while progress has been made, the work has not been completed, and is not ready for peer review.

The bootstrap and stochastic projections of landings, fishing mortality, and spawning stock biomass account only for variability in the research survey indices used in the VPA calibration, and do not account for any error in the estimation of catch at age (e.g., errors in assumptions about the age composition of the 1994 NER commercial landings, or in the magnitude and age composition of the 1994 commercial fishery discard), or in the input parameters of the projections (e.g., mean weights or partial recruitment at age).

The retrospective trends in VPA estimates of stock size (overestimated relative to the terminal year) are more pronounced than the trend in VPA estimates of fully recruited fishing mortality (underestimated relative to the terminal year).

The SARC noted the importance of obtaining sufficient sea sample data to develop reliable estimates of commercial fishery discard. This aspect of the assessment is of particular importance because recent changes in regulations (e.g., increases in mesh size, imposition of landings quotas and commercial fishery trips limits) may change the observed pattern of discarding.

Research Recommendations

- If the summer flounder assessment remains on a mid-year review schedule, it is critical that data from surveys and the fisheries be made available to the Subcommittee by the end of April.

- Continue the NEFSC sea sampling program collection of data for summer flounder, with special emphasis on a) improved areal and temporal coverage, b) adequate length and age sampling, and c) continued sampling after commercial fishery areal and seasonal quotas are reached and fisheries are limited or closed. Maintaining adequate sea sampling will be especially important in the next few years, in order to monitor a) the effects of implementation of gear and closed/exempted area regulations, both in terms of the response of the stock and the fishermen, b) potential continuing changes in "directivity" in the summer flounder fishery, as a results of changes in stock levels and regulations, and c) discards of summer flounder in the otter trawl fishery once quota levels have been attained and the summer flounder fishery is closed or restricted by trip limits.

- Continue research to determine length and age frequency and discard mortality rates of commercial and recreational fishery summer flounder discards.

- Continue the NEFSC winter trawl survey, since analyses of winter survey data suggest that this series provides more reliable and precise indices of abundance for use in mortality estimation and VPA tuning than those provided by the NEFSC spring and autumn survey time series.

- Data from the New Jersey DFW trawl survey, which began in 1988, have not been available to the Subcommittee for use in VPA tuning. The NJ DFW may wish to provide these data to the Subcommittee for use in future assessments.

- With the SAW Assessment Methods Subcommittee, conduct further testing of the sensitivity of the analysis to potential sources of bias (e.g., mis-reporting of landings, systematic error in surveys, incorrect assumptions about discard rates and discard mortality, mis-specification of the objective function in the VPA).

- Assess the feasibility of extending the historic SSB/Recruit time series by calibrating VPA results and survey time series.

- The present maturity ogive for summer flounder is based on simple gross examination of ovaries, and may not accurately reflect the spawning potential of summer flounder, especially age 0 and age 1 fish. The SARC encourages completion of ongoing work using histological examination of ovaries to better characterize the spawning contribution of young summer flounder.

- Review available NEFSC egg and larval survey data and determine if they would be useful either as a tuning index or as an exogenous means to judge the likely utility of recruitment indices currently used in VPA calibration.

- Review available research survey indices and eliminate from the VPA tuning those that do not reasonably match corresponding patterns in abundance in the converged part of the VPA.

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Table B1. Commercial and recreational landings (metric tons, A+ B1 recreational type) of summer flounder, Maine to North Carolina (NAFO Statistical Areas 5, 6),1980-1994, as reported by NMFS Fisheries Statistics Division (U.S.) and NEFSC (foreign). Recreational landings are aggregated from wave/state/mode/ area estimates.

	U.S.				U.S.	
Year	Comm.	Rec.	Foreign*	Total	% Comm.	% Rec.
1980	14,159	14,149	75	28,383	50	50.00
1981	9,551	4,852	59	14,462	66	34
1982	10,400	8,267	35	20,056	52	48
1983	13,403	12,687	**	29,760	45	55
1984	17,130	8,512	**	30,277	57	43
1985	14,675	5,665	2	22,235	66	34
1986	12,186	8,102	2	20,685	59	41
1987	12,271	5,519	1	17,930	68	32
1988	14,686	6,733	**	23,173	63	37
1989	8,125	1,435	NA	9,585	85	15
1990	4,199	2,329	NA	6,634	63	37
1991	6,224	3,611	NA	9,757	64	36
1992	7,302	3,242	NA	10,666	68	32
1993	5,715	3,484	NA	9,697	59	41
1994	6,584	4,111	NA	10,695	62	38.00
Mean	10,441	6,180	19	17,600	59	41

NA = not available
* Foreign catch includes both directed foreign fisheries and joint venture fishing.
** Less than 0.5 metric ton.

Table B2. Commercial landings at age of summer flounder ('000), ME-VA. Does not include discards, assumes catch not sampled by NEFSC weighout has same biological characteristics as weighout catch. 1994 ME-VA commercial fishery landings are a preliminary estimate (see text).

	AGE										
YEAR	0	1	2	3	4	5	6	7	8	9	Total
1982	1,441	6,879	5,630	232	61	97	57	22	2	0	14,421
1983	1,956	12,119	4,352	554	30	62	13	17	4	2	19,109
1984	1,403	10,706	6,734	1,618	575	72	3	5	1	4	21,121
1985	840	6,441	10,068	956	263	169	25	4	2	1	18,769
1986	407	7,041	6,374	2,215	158	93	29	7	2	0	16,326
1987	332	8,908	7,456	935	337	23	24	27	11	0	18,053
1988	305	11,116	8,992	1,280	327	79	18	9	5	0	22,131
1989	96	2,491	4,829	841	152	16	3	1	1	0	8,430
1990	0	2,670	861	459	81	18	6	1	1	0	4,096
1991	0	3,755	3,256	142	61	11	1	1	0	0	7,227
1992	114	5,760	3,575	338	19	22	0	1	0	0	9,829
1993	151	4,308	2,340	174	29	43	19	2	1	0	7,067
1994	690	3,200	2,251	610	146	20	12	2	2	0	6,934

Table B3. Number ('000) of summer flounder at age landed in the North Carolina commercial winter trawl fishery. The 1982-1987 NCDMF length samples were aged using NEFSC age-lengths keys for comparable times and areas (i.e., same quarter and statistical areas). The 1988-1994 NCDMFF length samples were aged using NCDMF age-length keys.

	AGE									
Year	0	1	2	3	4	5	6	7	8	Total
1982	981	3,463	1,021	142	52	19	6	4	2	5,691
1983	492	3,778	1,581	287	135	41	3	3	<1	6,321
1984	907	5,658	3,889	550	107	18	<1	0	0	11,130
1985	196	2,974	3,529	338	85	24	5	<1	0	7,152
1986	216	2,478	1,897	479	29	32	1	1	<1	5,134
1987	233	2,420	1,299	265	28	1	0	0	0	4,243
1988	0	2,917	2,225	471	227	39	1	6	<1	5,887
1989	2	49	1,437	716	185	37	1	2	0	2,429
1990	2	142	730	418	117	12	1	<1	0	1,424
1991	0	382	1,641	521	116	20	2	<1	0	2,682
1992	0	36	795	697	131	21	2	<1	0	1,682
1993	0	515	1,101	252	44	1	<1	0	0	1,913
1994	6	258	1,262	503	115	14	3	<1	0	2,161

Table B4. Summary of Northeast Region sea sample data to estimate summer flounder discard at age in the commercial fishery, 1989-1994. Estimates developed using sea sample length samples, age-length data, and estimates of total discard in mt. Because 1994 sea sample data were not available to the SARC, arithmetic weighted (by number at age and year) mean 1989-1993 total discard (mt), proportions at age, and mean lengths and weights at age were assumed for the 1994 discard. An 80% discard mortality rate is assumed.

Year	Lengths	Ages	Sea Sample Discard Estimate (mt)	Sampling Intensity (mt per 100 lengths)	Raised Discard Estimate (mt)	Raised Estimate with 80% mortality rate (mt)
1989	2,337	54	642	26	886	709
1990	3,891	453	1,121	29	1,516	1,213
1991	5,326	190	993	19	1,315	1,052
1992	9,626	331	956	10	1,147	918
1993	3,410	406	597	18	811	650
1994						941

Discard numbers at age (000s)

Year	0	1	2	3	Total
1989	775	1,628	94	0	2,497
1990	1,440	2,753	67	0	4,260
1991	891	3,424	<1	0	4,315
1992	1,966	1,569	57	7	3,636
1993	1,197	914	101	0	2,212
1994	1,302	2,137	66	1	3,506

Discard mean length at age

Year	0	1	2	3	All
1989	25.9	31.5	44.2		30.2
1990	29.0	31.7	38.9		30.9
1991	24.0	30.9	37.0		29.5
1992	29.3	30.0	36.6	51.2	30.0
1993	29.9	32.6	34.8		31.2
1994	28.2	31.2	38.8	51.2	30.2

Discard mean weight at age

Year	0	1	2	3	All
1989	0.182	0.296	0.909		0.284
1990	0.235	0.304	0.559		0.285
1991	0.124	0.275	0.491		0.244
1992	0.238	0.256	0.498	1.450	0.252
1993	0.253	0.332	0.413		0.293
1994	0.217	0.288	0.605	1.450	0.272

Table B5. REVISED estimated total landings in numbers (catch types A + B1, [000s]) of summer flounder by recreational fishermen. SHORE mode includes fish taken from beach/bank and man-made structures. P/C indicates catch taken from party/charter boats, while P/R indicates fish taken from private/rental boats.

Landings (000's of fish)

	YEAR												
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
North													
Shore	167	144	62	10	70	39	42	4	16	9	26	36	49
P/C Boat	138	201	5	3	48	7	1	1	1	8	1	10	24
P/R Boat	1,293	747	568	382	2,562	648	379	137	99	173	211	250	596
TOTAL	1,598	1,092	635	395	2,680	694	422	142	116	190	238	296	669
Mid													
Shore	682	3,296	977	272	478	251	594	84	96	505	200	176	195
P/C Boat	5,745	3,321	2,381	1,068	1,541	1,143	1,164	141	412	589	374	872	773
P/R Boat	5,731	12,345	11,764	8,454	5,924	5,499	7,271	1,141	2,658	4,573	3,983	3,969	4,372
TOTAL	12,158	18,962	15,122	9,794	7,943	6,893	9,029	1,366	3,166	5,667	4,557	5,017	5,340
South													
Shore	272	523	316	504	689	115	306	91	150	51	50	113	180
P/C Boat	53	52	110	81	20	1	1	1	1	1	1	1	2
P/R Boat	1,392	367	1,292	292	289	162	355	117	361	159	156	236	197
TOTAL	1,717	942	1,718	877	998	278	662	209	512	211	207	350	379
All Regions													
Shore	1,121	3,963	1,355	786	1,237	405	942	179	262	565	276	325	424
P/C Boat	5,936	3,574	2,496	1,152	1,609	1,151	1,166	143	414	598	376	883	799
P/R Boat	8,416	13,459	13,624	9,128	8,775	6,309	8,005	1,395	3,118	4,905	4,350	4,455	5,165
TOTAL	15,473	20,996	17,475	11,066	11,621	7,865	10,113	1,717	3,794	6,068	5,002	5,663	6,388

Table B6. REVISED estimated total landings in weight (catch types A + B1, [mt]) of summer flounder by recreational fishermen. SHORE mode includes fish take from beach/bank and man-made structures. P/C indicates catch taken from party/charter boats, while P/R indicates fish taken from private/rental boats.

	Landings (metric tons)												
	YEAR												
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
North													
Shore	87	59	17	7	25	21	32	2	16	6	20	25	30
P/C Boat	85	87	4	2	45	4	<1	<1	<1	6	<1	7	14
P/R Boat	875	454	388	328	2,597	582	289	141	89	150	175	181	424
TOTAL	1,047	600	409	337	2,667	607	322	144	106	162	196	213	468
Mid													
Shore	295	1,254	399	140	293	129	329	52	56	306	126	88	112
P/C Boat	3,112	2,196	1,426	609	1,093	1,098	799	125	264	364	267	534	478
P/R Boat	3,085	8,389	5,686	4,187	3,521	3,596	5,003	985	1,665	2,673	2,536	2,453	2,849
TOTAL	6,492	11,839	7,511	4,936	4,907	4,823	6,131	1,162	1,985	3,343	2,929	3,075	3,439
South													
Shore	87	134	98	230	425	34	113	57	76	25	25	59	100
P/C Boat	12	12	23	20	7	1	<1	<1	<1	<1	<1	<1	1
P/R Boat	629	102	471	142	96	54	166	71	161	80	91	136	103
TOTAL	728	248	592	392	528	89	280	129	238	106	117	196	204
All Regions													
Shore	469	1,447	514	377	743	184	474	111	148	337	171	172	242
P/C Boat	3,209	2,295	1,453	631	1,145	1,103	801	127	266	371	269	542	493
P/R Boat	4,589	8,945	6,545	4,657	6,214	4,232	5,458	1,197	1,915	2,903	2,802	2,770	3,376
TOTAL	8,267	12,687	8,512	5,665	8,102	5,519	6,733	1,435	2,329	3,611	3,242	3,484	4,111.0

Table B7. Comparison of original and revised MRFSS estimates of recreational fishery catch of summer flounder (catch type A + B1 + 25% B2; millions of fish).

Year	Original estimate	Revised estimate	Percent change
1982	17.8	17.5	-2.0
1983	30.0	23.8	-21.0
1984	30.5	20.6	-32.0
1985	15.9	11.7	-26.0
1986	14.9	15.0	1.0
1987	12.0	11.2	-7.0
1988	14.6	11.9	-18.0
1989	2.0	2.0	0.0
1990	5.4	5.1	-6.0
1991	8.4	8.6	2.0
1992	7.1	6.7	-5.0
1993	10.6	9.2	-13.0
1994	n/a	9.0	n/a

Table B8. Estimated recreational landings at age of summer flounder (000s), (catch type A + B1).

					AGE					
YEAR	0	1	2	3	4	5	6	7	8	Total
1982	2,750	8,445	3,498	561	215	<1	4	0	0	15,473
1983	2,302	11,612	4,978	1,340	528	220	0	16	0	20,996
1984	2,282	9,198	4,831	1,012	147	5	<1	0	0	17,475
1985	1,002	5,002	4,382	473	148	59	0	0	0	11,066
1986	1,169	6,404	2,784	1,088	129	15	28	4	0	11,621
1987	466	4,674	2,083	448	182	1	5	6	0	7,865
1988	434	5,855	3,345	386	90	3	0	0	0	10,113
1989	74	539	946	135	16	2	5	0	0	1,717
1990	353	2,770	529	118	23	<1	1	0	0	3,794
1991	86	3,611	2,251	79	40	1	0	0	0	6,068
1992	82	3,183	1,620	90	<1	27	0	0	0	5,002
1993	71	3,470	1,981	139	<1	2	0	0	0	5,663
1994	765	3,872	1,549	171	26	<1	5	0	0	6,388

Table B9. Estimated recreational fishery discard at age of summer flounder (catch type B2). Discards allocated to age groups in same relative proportions as ages 0 and 1 in the subregional catch, the same mean weight at age as in the landings, and assuming 25% hooking mortality.

Year	Numbers at age 0	Numbers at age 1	Total	Metric tons at age 0	Metric tons at age 1	Total
1982	431	1,591	2,022	97	643	740
1983	437	2,329	2,766	77	862	939
1984	526	2,551	3,077	108	929	1,037
1985	101	514	615	24	205	229
1986	375	3,043	3,418	84	1,360	1,444
1987	265	3,024	3,289	61	1,246	1,307
1988	139	1,673	1,812	41	816	857
1989	32	208	240	8	106	114
1990	151	1,176	1,327	46	541	587
1991	59	2,443	2,502	16	1,058	1,074
1992	43	1,684	1,727	10	849	859
1993	55	3,525	3,580	14	1,826	1,840
1994	443	2,143	2,586	193	1,249	1,442

Table B10. Total catch at age of summer flounder (000s), ME-NC.

	AGE										
YEAR	0	1	2	3	4	5	6	7	8	9	Total
1982	5,604	20,378	10,149	935	328	116	67	26	4	0	37,607
1983	5,187	29,838	10,911	2,181	693	323	16	36	5	2	49,193
1984	5,118	28,113	15,454	3,180	829	95	4	5	1	4	52,803
1985	2,139	14,931	17,979	1,767	496	252	30	5	2	1	37,602
1986	2,167	18,966	11,055	3,782	316	140	58	12	3	0	36,498
1987	1,296	19,026	10,838	1,648	544	25	29	33	11	0	33,450
1988	878	21,561	14,562	2,137	644	121	19	15	6	0	39,943
1989	979	4,915	7,306	1,692	353	55	9	3	1	0	15,313
1990	1,946	9,512	2,187	995	221	30	8	2	1	0	14,902
1991	1,036	13,615	7,148	742	217	32	3	1	0	0	22,795
1992	2,205	12,269	6,047	1,125	151	70	2	1	0	0	21,869
1993	1,473	12,732	5,523	565	73	45	20	2	1	0	20,435
1994	3,206	11,610	5,128	1,285	287	34	20	3	2	0	21,575

Table B11. Mean length (cm) at age of summer flounder catch, ME-NC.

YEAR	AGE 0	1	2	3	4	5	6	7	8	9	MEAN LENGTH ALL AGES
1982	29.4	34.5	38.8	50.7	55.3	61.0	60.7	68.0	71.2		35.7
1983	28.7	34.5	40.9	46.5	48.8	51.6	60.7	60.9	69.3	72.0	36.2
1984	29.3	33.8	39.1	45.9	51.3	57.9	66.8	68.4	74.0	70.7	36.0
1985	30.5	34.8	38.8	46.8	53.9	58.6	61.5	74.5	73.3	75.0	37.5
1986	29.6	35.6	39.9	47.5	54.0	56.2	65.8	66.4	72.8		38.1
1987	29.8	35.3	39.7	46.9	55.8	63.3	65.9	63.2	73.5		37.5
1988	32.3	35.8	39.1	46.6	53.1	60.2	69.6	68.5	72.7		37.9
1989	27.1	35.8	40.8	45.5	50.6	58.5	59.1	63.1	59.0		39.1
1990	29.7	35.2	41.9	46.8	51.4	57.4	66.4	71.7	75.2		36.5
1991	25.0	34.6	40.4	47.1	54.3	61.0	61.7	68.1			36.6
1992	29.9	36.1	41.1	46.9	49.7	61.0	58.8	72.2			37.6
1993	30.2	36.9	40.7	50.4	52.9	54.7	62.6	70.6	75.5		38.0
1994											

Table B12. Mean weight (kg) at age of summer flounder catch, ME-NC.

YEAR	AGE 0	1	2	3	4	5	6	7	8	9	MEAN WEIGHT ALL AGES
1982	0.254	0.418	0.616	1.447	1.907	2.795	2.673	3.758	4.408		0.500
1983	0.240	0.417	0.716	1.075	1.257	1.495	2.572	2.594	3.849	4.370	0.516
1984	0.248	0.396	0.632	1.046	1.500	2.163	3.302	3.620	4.640	4.030	0.512
1985	0.289	0.428	0.613	1.109	1.726	2.297	2.671	4.682	4.780	4.800	0.573
1986	0.253	0.453	0.668	1.160	1.739	1.994	3.311	4.000	4.432		0.602
1987	0.259	0.442	0.651	1.140	1.941	2.855	3.326	3.314	4.140		0.570
1988	0.316	0.463	0.624	1.130	1.739	2.485	3.888	3.545	4.316		0.584
1989	0.208	0.460	0.723	1.044	1.479	2.249	2.399	2.861	2.251		0.666
1990	0.251	0.431	0.810	1.169	1.538	2.121	3.461	3.951	5.029		0.536
1991	0.145	0.407	0.702	1.186	1.811	2.527	2.936	3.586			0.530
1992	0.243	0.469	0.748	1.223	1.390	2.696	2.302	4.479			0.576
1993	0.263	0.493	0.703	1.464	1.659	1.859	2.816	4.136	5.199		0.570
1994	0.328	0.506	0.712	1.402	2.080	2.476	3.436	4.023	3.640		0.609

Table B13. NEFSC spring trawl survey (offshore strata 1-12, 61-76) mean number of summer flounder per tow at age (delta values). 1995 values are preliminary.

YEAR	AGE 1	2	3	4	5	6	7	8	9	10	TOTAL
1976	0.03	1.70	0.68	0.28	0.01	0.01	0.01				2.72
1977	0.61	1.30	0.70	0.10	0.09	0.01		0.01			2.82
1978	0.70	0.95	0.66	0.19	0.04	0.03	0.03			0.02	2.62
1979	0.06	0.18	0.08	0.04	0.03			0.01			0.40
1980	0.01	0.71	0.31	0.14	0.02	0.06	0.03	0.01		0.01	1.31
1981	0.59	0.53	0.17	0.08	0.05	0.03	0.02	0.01			1.48
1982	0.69	1.41	0.12	0.03							2.24
1983	0.32	0.39	0.19	0.04	0.01				0.01		0.95
1984	0.17	0.33	0.09	0.05		0.01	0.01				0.66
1985	0.55	1.56	0.21	0.04	0.02						2.38
1986	1.49	0.43	0.20	0.02	0.01						2.15
1987	0.46	0.43	0.02	0.02							0.92
1988	0.59	0.79	0.07	0.03							1.47
1989	0.06	0.23	0.02	0.01							0.32
1990	0.62	0.03	0.06								0.71
1991	0.81	0.28		0.02							1.11
1992	0.75	0.41	0.01		0.01						1.19
1993	0.87	0.34	0.04	0.01							1.27
1994	0.15	0.68	0.08	0.01		<0.01					0.92
1995	0.55	0.48	0.06				0.01				1.09

Table B14. NEFSC Winter trawl survey (offshore strata 1-18,61-76; Southern Georges Bank to Cape Hatteras) mean number, mean weight (kg), and mean number at age per tow, 1992-1995. Data for 1995 are preliminary.

Year	Stratified mean number per tow	Coefficient of variation	Stratified mean weight (kg) per tow	Coefficient of variation
1992	12.295	15.6	4.898	15.4
1993	13.577	15.2	5.486	11.9
1994	11.917	17.3	5.818	14.4
1995	11.244		5.228	

Year	Age 1	2	3	4	5	6	7	8	Total
1992	7.15	4.74	0.33	0.04	0.01	0.03	0.00	0.00	12.29
1993	6.48	6.69	0.31	0.05	0.02	0.02	0.00	0.00	13.58
1994	3.42	6.95	1.22	0.27	0.15	0.03	0.01	0.00	11.92
1995	4.99	4.88	1.23	0.12	<0.01	0.02	<0.01	0.00	11.24

Table B15. MADMF Spring and Fall survey cruises: stratified mean number per tow at age.

Spring	Age									
	0	1	2	3	4	5	6	7	8+	Total
1978		0.097	0.520	0.274	0.221		0.042			1.15
1979			0.084	0.087	0.147	0.048	0.011			0.37
1980		0.055	0.061	0.052	0.075	0.053	0.055	0.011		0.36
1981	0.010	0.395	0.558	0.074	0.031	0.043	0.060		0.031	1.20
1982		0.376	1.424	0.118	0.084	0.020		0.010		2.03
1983		0.241	1.304	0.544	0.021	0.009	0.003			2.12
1984		0.042	0.073	0.063	0.111	0.010				0.30
1985		0.142	1.191	0.034	0.042					1.41
1986		0.966	0.528	0.140	0.008					1.64
1987		0.615	0.583	0.012			0.011			1.22
1988		0.153	0.966	0.109	0.012					1.24
1989			0.338	0.079			0.010			0.43
1990		0.247	0.021	0.079	0.012					0.36
1991		0.029	0.048	0.010						0.09
1992		0.274	0.320	0.080		0.011	0.011			0.70
1993		0.120	0.470	0.060	0.010		0.020			0.68
1994		1.770	1.160	0.050	0.020		0.010			3.01

Fall	Age									
	0	1	2	3	4	5	6	7	8+	Total
1978		0.011	0.124	0.024		0.007				0.17
1979			0.047	0.101		0.019				0.17
1980		0.114	0.326	0.020	0.020	0.010				0.49
1981	0.009	0.362	0.367	0.011						0.75
1982		0.255	1.741	0.016						2.01
1983		0.026	0.583	0.140	0.004					0.75
1984	0.033	0.453	0.249	0.120	0.008					0.86
1985	0.051	0.108	1.662	0.033						1.85
1986	0.128	2.149	0.488	0.128						2.89
1987		1.159	0.598	0.010	0.004					1.77
1988		0.441	0.414	0.018						0.87
1989			0.286	0.024						0.31
1990		0.108		0.012						0.12
1991	0.021	0.493	0.262	0.010						0.79
1992		1.110	0.170							1.28
1993	0.010	0.300	0.430	0.020	0.020					0.79
1994	0.414	1.484	0.338	0.009	0.020					2.27

Table B16. CTDEP spring and fall trawl surveys: summer flounder index of abundance, geometric mean number per tow at age.

Spring				Age					
Year	0	1	2	3	4	5	6	7	Total
1984	0.000	0.314	0.269	0.046	0.000	0.000	0.000	0.000	0.63
1985	0.000	0.015	0.282	0.028	0.052	0.000	0.000	0.000	0.38
1986	0.000	0.751	0.087	0.076	0.009	0.005	0.000	0.000	0.93
1987	0.000	0.951	0.086	0.015	0.004	0.002	0.000	0.000	1.06
1988	0.000	0.232	0.223	0.035	0.009	0.001	0.000	0.000	0.50
1989	0.000	0.013	0.048	0.026	0.016	0.000	0.000	0.000	0.10
1990	0.000	0.302	0.024	0.013	0.006	0.001	0.000	0.000	0.35
1991	0.000	0.391	0.189	0.030	0.028	0.001	0.000	0.000	0.64
1992	0.000	0.319	0.186	0.023	0.004	0.023	0.000	0.000	0.56
1993	0.000	0.319	0.152	0.015	0.019	0.003	0.000	0.000	0.51
1994	0.000	0.496	0.314	0.025	0.019	0.005	0.000	0.000	0.86

Fall				Age					
Year	0	1	2	3	4	5	6	7	Total
1984	0.000	0.558	0.329	0.072	0.014	0.004	0.004	0.003	0.98
1985	0.239	0.351	0.486	0.078	0.000	0.000	0.000	0.000	1.15
1986	0.170	1.168	0.271	0.071	0.003	0.000	0.000	0.000	1.68
1987	0.075	1.058	0.224	0.036	0.003	0.000	0.000	0.000	1.40
1988	0.015	0.879	0.481	0.038	0.002	0.001	0.000	0.000	1.42
1989	0.000	0.025	0.094	0.016	0.001	0.000	0.000	0.000	0.14
1990	0.032	0.671	0.112	0.041	0.007	0.005	0.000	0.000	0.87
1991	0.036	0.814	0.342	0.042	0.013	0.005	0.004	0.000	1.26
1992	0.013	0.569	0.365	0.046	0.017	0.009	0.000	0.000	1.02
1993	0.085	0.825	0.154	0.041	0.003	0.001	0.002	0.001	1.11
1994	0.133	0.301	0.085	0.025	0.009	0.000	0.000	0.000	0.55

Table B17. Summary of summer flounder recruitment indices from state surveys, Massachusetts to North Carolina.

	YEAR CLASS														
Survey	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
MASS Spring (age 1)	0.40	0.38	0.24	0.04	0.14	0.97	0.62	0.15	0.00	0.25	0.03	0.27	0.12	1.77	
MASS[2] Spring (age 2)	1.42	1.30	0.07	1.19	0.53	0.58	0.97	0.34	0.02	0.05	0.32	0.47	1.16		
CT (age 0)					0.01	0.24	0.17	0.08	0.02	0.00	0.03	0.04	0.01	0.09	0.13
CT (age 1)					0.35	1.17	1.06	0.88	0.03	0.67	0.81	0.57	0.83	0.30	
RI (age 1)	2.13	0.36	0.25	0.85	0.33	2.20	0.72	0.40	0.04	0.47	0.07	0.71	0.27	0.12	
RI (age 0)	0.08	0.16	0.00	0.02	0.16	0.33	0.63	0.44	0.02	0.00	0.06	0.04	0.00	0.00	0.00
MASS Seine (age 0)			3	3	1	19	5	5	2	3	11	4	0	2	1
DE: 16 ft (age 0)	0.12	0.06	0.11	0.03	0.08	0.06	0.10	0.14	0.01	0.12	0.23	0.07	0.31	0.03	0.29
DE: 30 ft (age 0)												1.44	0.47	0.04	2.30
MD (age 0)	4.2	3.9	2.0	10.6	5.4	5.6	16.2	4.6	0.5	1.3	2.1	3.1	3.5	1.6	8.2
VIMS Rivers only (age 0)	7.64	5.29	3.23	5.20	1.90	0.93	1.27	0.45	0.54	0.96	2.61	1.42	0.49	0.49	1.10
VIMS Rivers and Bay (age 0)									0.57	1.23	2.61	2.77	0.93	0.54	2.44
NC Pamlico Trawl (age 0)								19.86	2.61	6.63	4.27	5.85	9.41	5.01	8.17

Table B18. Summary resluts from summer flounder SAW 20 VPA.

CATCH AT AGE (thousands) - SAW 20

■	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0 ■	5604	5187	5118	2139	2167	1296	878	979	1946	1036
1 ■	20378	29838	28113	14931	18966	19026	21561	4915	9512	13615
2 ■	10149	10911	15454	17979	11055	10838	14562	7306	2187	7148
3 ■	935	2181	3180	1767	3782	1648	2137	1692	995	742
4 ■	328	693	829	496	316	544	644	353	221	217
5 ■	213	382	109	290	213	96	161	68	41	36
0+■	37607	49192	52803	37602	36499	33448	39943	15313	14902	22794

■	1992	1993	1994
0 ■	2205	1474	3206
1 ■	12269	12732	11610
2 ■	6047	5523	5128
3 ■	1125	565	1285
4 ■	151	73	287
5 ■	73	68	59
0+■	21870	20435	21575

STOCK NUMBERS (Jan 1) in thousands - SAW 20

■	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0 ■	76468	82679	49173	51168	56276	45221	13151	28268	33053	32402
1 ■	43770	57536	62998	35628	39957	44114	35851	9973	22258	25301
2 ■	15736	17397	20108	26141	15660	15553	18902	9843	3718	9616
3 ■	2370	3701	4371	2480	5134	2818	2927	2299	1448	1065
4 ■	525	1094	1056	701	431	781	816	463	352	286
5+■	334	591	134	400	283	134	197	86	64	46
0+■	139204	162998	137841	116518	117741	108623	71846	50933	60893	68716

■	1992	1993	1994	1995
0 ■	35532	30530	49505	0
1 ■	25591	27096	23662	37630
2 ■	8395	9851	10664	8868
3 ■	1405	1402	3068	4091
4 ■	201	133	636	1349
5+■	94	122	129	314
0+■	71219	69133	87665	52253

Summaries for ages 2-5+

■	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
■	18965	22783	25670	29722	21508	19287	22843	12692	5582	11013	10095

■	1993	1994	1995
■	11507	14497	14622

Table B18 (Continued).

FISHING MORTALITY - SAW 20

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	0.08	0.07	0.12	0.05	0.04	0.03	0.08	0.04	0.07	0.04	0.07	0.05	0.07
1	0.72	0.85	0.68	0.62	0.74	0.65	1.09	0.79	0.64	0.90	0.75	0.73	0.78
2	1.25	1.18	1.89	1.43	1.51	1.47	1.91	1.72	1.05	1.72	1.59	0.97	0.76
3	0.57	1.05	1.63	1.55	1.68	1.04	1.64	1.68	1.42	1.47	2.16	0.59	0.62
4	1.17	1.20	2.02	1.52	1.66	1.47	2.06	1.85	1.19	1.83	1.78	0.94	0.69
5+	1.17	1.20	2.02	1.52	1.66	1.47	2.06	1.85	1.19	1.83	1.78	0.94	0.69

Avg F for ages 2-4

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
	1.00	1.14	1.85	1.50	1.62	1.33	1.87	1.75	1.22	1.67	1.84	0.83	0.69

BACKCALCULATED PARTIAL RECRUITMENT

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	0.07	0.06	0.06	0.03	0.03	0.02	0.04	0.02	0.05	0.02	0.03	0.06	0.10
1	0.58	0.71	0.34	0.40	0.44	0.44	0.53	0.43	0.45	0.49	0.35	0.76	1.00
2	1.00	0.98	0.94	0.92	0.90	1.00	0.93	0.93	0.74	0.94	0.74	1.00	0.97
3	0.46	0.88	0.81	1.00	1.00	0.71	0.80	0.91	1.00	0.80	1.00	0.61	0.80
4	0.94	1.00	1.00	0.98	0.99	1.00	1.00	1.00	0.83	1.00	0.82	0.97	0.88
5+	0.94	1.00	1.00	0.98	0.99	1.00	1.00	1.00	0.83	1.00	0.82	0.97	0.88

SSB AT THE START OF THE SPAWNING SEASON - males & females (mt)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	5829	6017	3547	4577	4420	3671	1255	1832	2525	1468	2620
1	6125	7219	8655	5550	5955	6948	4088	1456	3442	2968	3913
2	2624	3562	2013	3735	2268	2278	1847	1305	960	1231	1279
3	1806	1405	1001	644	1248	1149	716	505	440	316	242
4	321	429	251	290	160	380	218	125	171	96	54
5+	311	311	50	230	151	111	86	36	51	22	49
0+	17015	18944	15518	15026	14203	14537	8210	5260	7590	6101	8158
2+	5061	5708	3316	4899	3828	3918	2867	1972	1623	1665	1625

	1993	1994
0	2470	4914
1	4436	3817
2	2367	3085
3	1066	2175
4	86	633
5+	107	180
0+	10530	14804
2+	3624	6073

Table B19. Commercial and recreational fishery landings, estimated discard, and total catch statistics (metric tons) as used in the assessment of summer flounder, Maine to North Carolina, compared with VPA estimates of total catch biomass.

	Commercial			Recreational			Total				
Year	Landings	Discard	Catch	Landings	Discard	Catch	Landings	Discard	Catch	VPA Catch	VPA:Catch ratio
1982	10,400	n/a	10,400	8,267	740	9,007	18,667	740	19,407	19,077	0.983
1983	13,403	n/a	13,403	12,687	939	13,626	26,090	939	27,029	25,788	0.954
1984	17,130	n/a	17,130	8,512	1,037	9,549	25,642	1,037	26,679	27,590	1.034
1985	14,675	n/a	14,675	5,665	229	5,894	20,340	229	20,569	21,970	1.068
1986	12,186	n/a	12,186	8,102	1,444	9,546	20,288	1,444	21,732	22,449	1.033
1987	12,271	n/a	12,271	5,519	1,307	6,826	17,790	1,307	19,097	19,400	1.016
1988	14,686	n/a	14,686	6,733	857	7,590	21,419	857	22,276	23,927	1.074
1989	8,125	709	8,834	1,435	114	1,549	9,560	823	10,383	10,446	1.006
1990	4,199	1,213	5,412	2,329	587	2,916	6,528	1,800	8,328	8,087	0.971
1991	6,224	1,052	7,276	3,611	1,074	4,685	9,835	2,126	11,961	12,349	1.032
1992	7,529	918	8,447	3,242	859	4,101	10,771	1,777	12,548	12,859	1.025
1993	5,715	650	6,365	3,484	1,840	5,324	9,199	2,490	11,689	11,817	1.011
1994	6,584	941	7,525	4,111	1,442	5,553	10,695	2,383	13,078	13,318	1.018

Table B20. SARC 20 VPA retrospective analysis. All runs exclude NEFSC Winter survey (conducted during 1992-1995) to facilitate a consistent retrospective time series.

Fishing Mortality

Terminal Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1989	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.8					
1990	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.6	1.2				
1991	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.7	1.1	1.3			
1992	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.8	1.2	1.5	1.1		
1993	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.8	1.2	1.7	1.8	0.7	
1994	1.0	1.1	1.9	1.5	1.6	1.3	1.9	1.8	1.2	1.7	1.8	0.8	0.8

Age-0 Recruitment (millions)

Terminal Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1989	76.5	82.7	49.2	51.2	56.1	45.5	9.1	40.1					
1990	76.5	82.7	49.2	51.2	56.3	45.8	12.4	31.3	42.1				
1991	76.5	82.7	49.2	51.2	56.3	45.3	13.3	29.6	40.8	45.5			
1992	76.5	82.7	49.2	51.2	56.3	45.3	13.3	29.3	34.8	46.7	36.5		
1993	76.5	82.7	49.2	51.2	56.3	45.3	13.2	28.3	33.0	33.8	43.8	33.2	
1994	76.5	82.7	49.2	51.2	56.3	45.3	13.2	28.3	33.1	33.0	34.9	31.1	52.2

Spawning Stock Biomass ('000 mt)

Terminal Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1989	17.0	18.9	15.5	15.0	14.2	14.5	7.8	5.1					
1990	17.0	18.9	15.5	15.0	14.2	14.6	8.3	5.6	9.0				
1991	17.0	18.9	15.5	15.0	14.2	14.6	8.2	5.4	8.7	9.1			
1992	17.0	18.9	15.5	15.0	14.2	14.6	8.2	5.4	8.1	7.7	13.2		
1993	17.0	18.9	15.5	15.0	14.2	14.6	8.2	5.3	7.6	6.2	9.2	13.4	
1994	17.0	18.9	15.5	15.0	14.2	14.6	8.2	5.3	7.6	6.1	8.3	10.7	15.5

Table B21. Input parameters and stochastic projection results for summer flounder: landings, discard, and spawning stock biomass ('000 mt). Starting stock sizes on 1 January 1995 (age-1 and older) are as estimated by VPA bootstrap procedure (200 iterations). Age-0 Recruitment levels in 1995-1998 are selected at random from VPA estimates of numbes at age 0 during 1990-1994. Fishing mortality was apportioned among landings and discard based on the proportion of F associated with landings and discard at age during 1993-1994. Mean weights at age (spawning stock, landings, and discards) are weighted (by fishery) arithmetic means of 1993-1994 values. F_{95} is the F realized if fishery landings quotas, plus associated discard, are caught in 1995 (commercial landings = 6,663 mt, recreational landings = 3,520 mt). Proportion of F, M before spawning = 0.83 (spawning peak at 1 November).

Age	Fishing Mortality Pattern	Proportion Landed	Proportion Mature	Mean Weights SSB	Mean Weights Landings	Mean Weights Discards
0	0.07	0.36	0.38	0.296	0.357	0.263
1	0.88	0.64	0.72	0.500	0.524	0.458
2	1.00	0.98	0.90	0.708	0.711	0.509
3	1.00	1.00	1.00	1.433	1.433	1.450
4	1.00	1.00	1.00	1.870	1.870	-----
5+	1.00	1.00	1.00	2.591	2.591	-----

Projected Medians (50% Probability Levels)
Landings, Discard, and SSB in '000 mt

	1995				1996				1997				1998			
Amend 7 Option	F95	Land.	Disc.	SSB	F96	Land.	Disc.	SSB	F97	Land.	Disc.	SSB	F98	Land.	Disc.	SSB
1	0.50	10.2	2.3	20.1	0.23	6.6	0.9	28.8	0.23	9.6	0.9	39.8	0.23	12.0	0.9	48.7
5A	0.50	10.2	2.3	20.1	0.41	10.9	1.4	25.4	0.30	10.5	1.1	33.3	0.23	10.2	0.9	41.8
5B	0.50	10.2	2.3	20.1	0.30	8.4	1.1	27.3	0.21	8.4	0.8	38.4	0.23	11.7	0.9	47.6

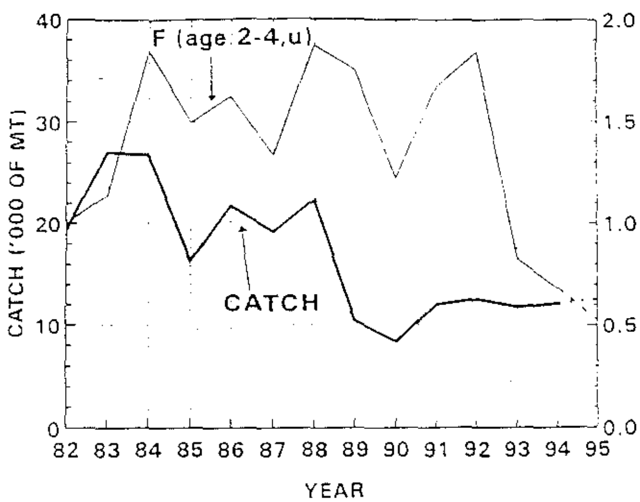

Figure B1. Total catch (landings and discard, thousands of metric tons) and fishing mortality rate (fully recruited F, ages 2-4, unweighted) for summer flounder.

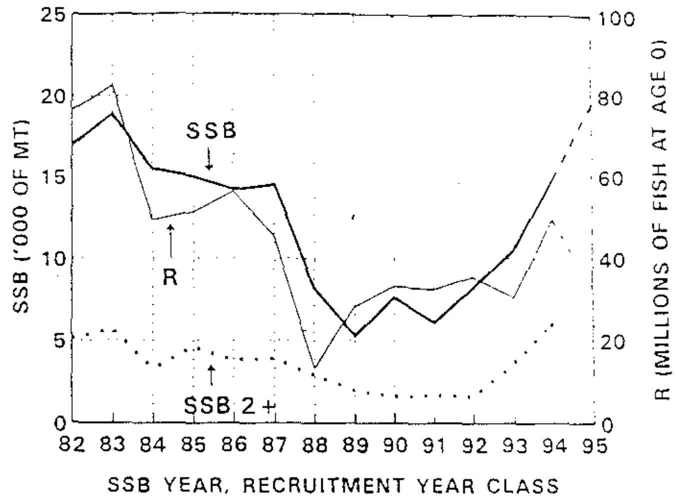

Figure B2. Spawning stock biomass (SSB age 0 to 5+, thousands of metric tons) and recruitment (millions of fish at age-0) for summer flounder. Note that because summer flounder spawn in late autumn, fish recruit to the fishery at age-0 the following autumn.

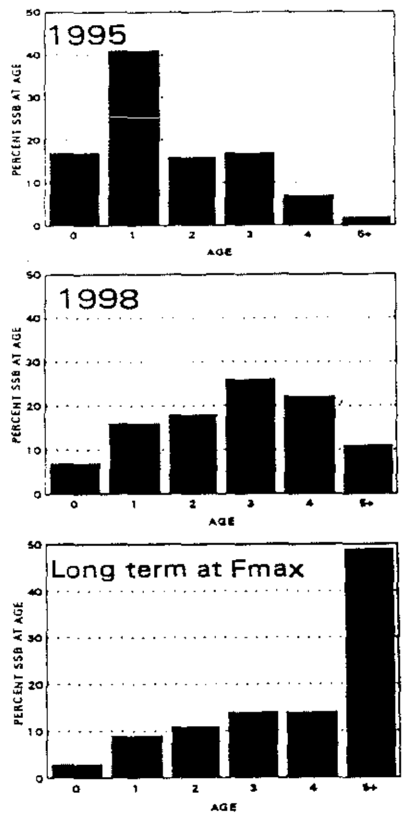

Figure B3. Summer founder spawning stock biomass percentages at age under FMP Amendment 7 Option 1 projected fishing mortality rates: 1995, 1998, and under equilibrium (long-term) conditions at $F_{max} = 0.23$.

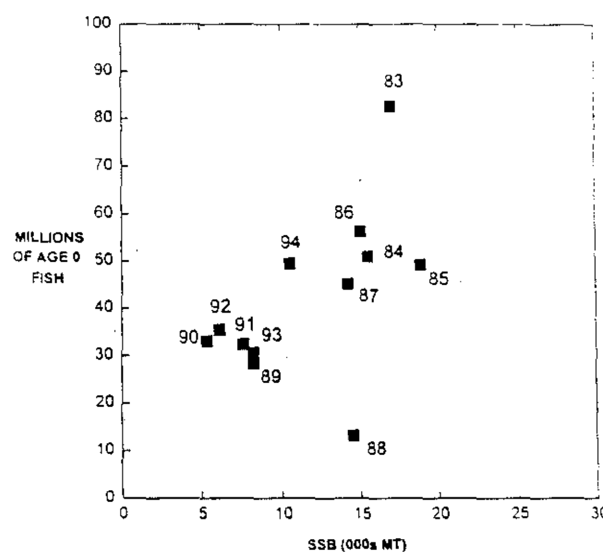

Figure B4. Summer flounder SAW-20 VPA run spawning stock biomass and recruitment estimates.

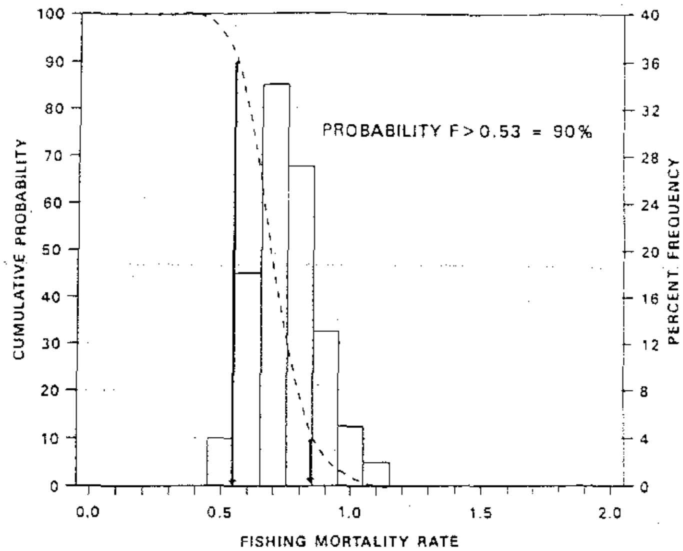

Figure B5. Precision of the estimates of fully recruited F (ages 2-4, u) in 1994 for summer flounder. Vertical bars display the range of the bootstrap estimates and the probability of individual values in the range. The dashed line gives the probability that F is greater than any value along the X axis.

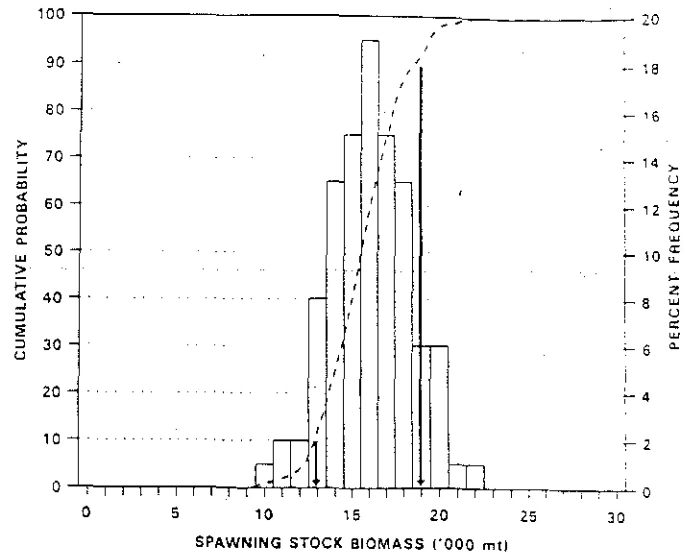

Figure B6. Precision of the estimates of spawning stock biomass on November 1, 1994 for summer flounder. Vertical bars display the range of the bootstrap estimate and the probability of individual values in the range. The dashed line gives the probability that SSB is less than any value along the X axis.

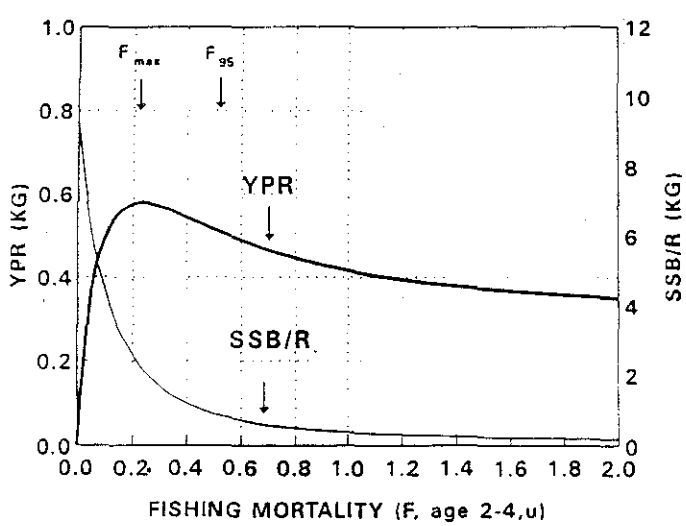

Figure B7. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R).

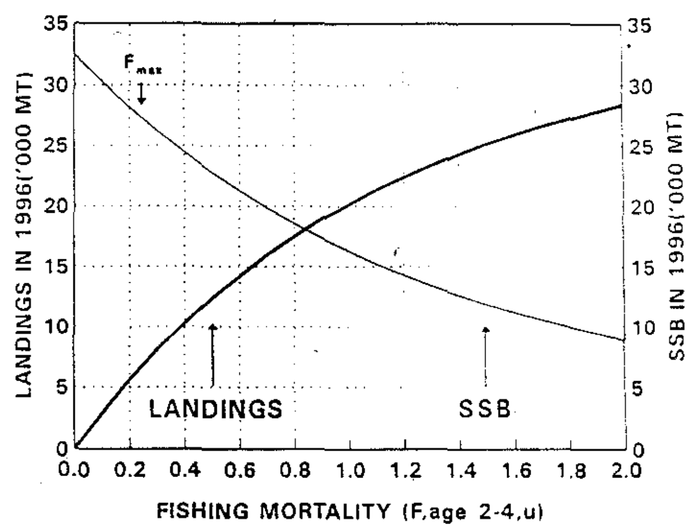

Figure B8. Predicted landings in 1996 and spawning stock biomass (SSB) in 1996 of summer flounder over a range of fishing mortalities in 1996, from F=0 to F=2.0.

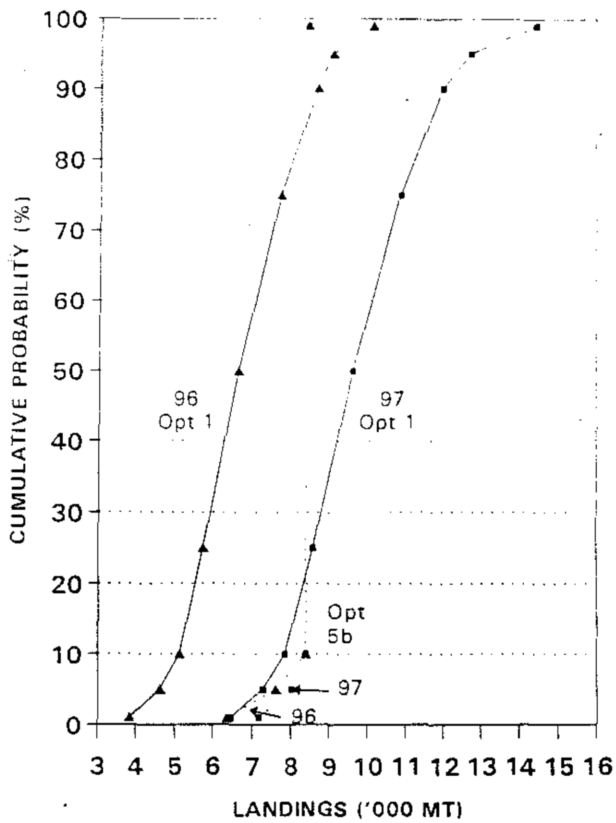

Figure B9. Probability of exceeding landings levels ('000 mt) given 1995 F-0.50 and 1996-1997 F rates proposed under FMP Amendment 7 Option 1 and 5B.

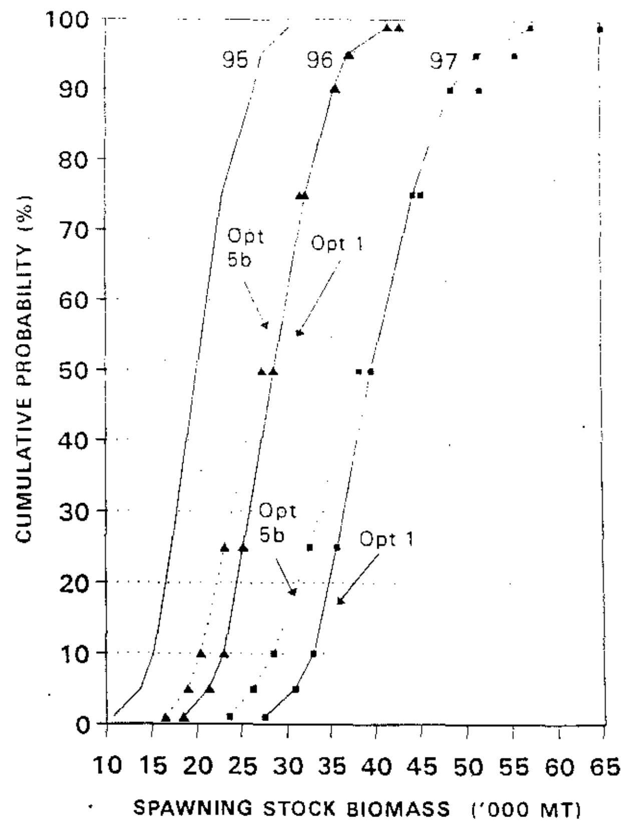

Figure B10. Probability of exceeding spawning stock biomass levels ('000 mt) given 1995 F=0.50 and 1996-1997 F rates proposed under FMP Amendment 7 Options 1 and 5B.

C. ATLANTIC MACKEREL

Terms of Reference

The following terms of reference were addressed for Atlantic mackerel:

a. Provide updated analytical assessment of the Northwest Atlantic mackerel stock (NAFO Subareas 2-6) through 1993 and characterize the variability of the terminal estimates of fishing mortality (F) and spawning stock biomass (SSB).

b. Provide short-term estimates of the catch and SSB at various levels of F.

c. Recalculate the long-term potential yield of this stock.

d. Review and update, as necessary, the biological reference points for this stock.

e. Describe the distribution of the stock in the spring of 1995 based on catches from the 1995 NEFSC spring trawl survey.

f. Evaluate the existing stock structure, i.e., the northern and southern components of the stock. If these components are not two distinct stocks, are there any behavioral or migratory differences between them?

Introduction

The Northwest Atlantic mackerel stock ranges from North Carolina (Sette 1950) to Labrador (Parsons 1970). This transboundary stock is highly migratory. In the spring the stock migrates northward in response to vernal warming, while in the fall it migrates southward and offshore to avoid seasonal cooling of shelf waters. During the winter the stock is associated with the relatively warm waters of the shelf break from Cape Hatteras to Sable Island. Atlantic mackerel spawn in two areas of the Northwest Atlantic: the Gulf of St. Lawrence and U.S. coastal waters from New Jersey to Long Island. The stock was heavily exploited by distant water fleets during the 1970s. Total mackerel landings in NAFO Subareas 2-6 averaged 310,000 mt during 1970-1976, but this level of landings was not sustained. Annual landings decreased to less than 50,000 mt during 1978-1984. In recent years, annual landings have been below 40,000 mt with the majority of landings from Canadian waters. During 1992-1993, U.S. commercial and recreational landings totaled less than 10,000 mt/yr; well below long-term historic yields.

The U.S. assessment of the Atlantic mackerel stock in 1991 indicated that the stock was at a relatively high level of abundance (Overholtz 1991). However, estimates of current stock size in 1991 were relatively imprecise due to low catches in the late 1980s. Similar uncertainties about current stock size were also evident in the most recent Canadian assessment (Gregoire *et al.* 1994). Estimates of fishing mortality rates and stock sizes presented in this assessment update were expected to have similar levels of precision given recent fishery trends.

Stock Structure

For the purpose of discussing stock structure, the definition of a fish stock is "an intraspecific group of randomly mating individuals with temporal or spatial integrity" (Ihssen *et al.* 1981). Sette (1950) proposed dividing the Atlantic mackerel population in the Northwest Atlantic into northern and southern contingents. However, Sette was careful to note that the contingents were not likely to have temporal integrity through successive generations. In particular, he stated that

> *"it is preferable to regard the two components as subdivisions of more or less stable nature enduring through several seasons, but not necessarily from one generation to another."*

Sette observed that the two spawning grounds of the Atlantic mackerel population were widely separated, with the southern ground in the Mid-Atlantic Bight and the northern ground in the Gulf of St. Lawrence. The migratory pattern of the southern contingent coincided with the observance of mackerel eggs during April-June in the Mid-Atlantic Bight. The migratory pattern of the northern contingent into the Gulf of St. Lawrence coincided with the observance of mackerel eggs there in late June and July. Based on these observations, Sette concluded that the two contingents segregated for spawning, but that:

> *"the weight of evidence, if not definitely in favor of the shift of individuals from one contingent to the other, at least is sufficiently suggestive of this as to prevent the adoption of the view that the two contingents maintain their integrity throughout life and from one generation to another, as would be necessary for postulation of genetically separate stocks."*

Analyses of biochemical and meristic characteristics (MacKay 1967, Sette 1950, MacKay and Garside 1969) and parasitological studies (Isakov 1976) have supported Sette's view; significant differences between the two contingents were not found in these studies. More recently, Maguire *et al.* (1987) examined potential biochemical differences between two samples of mackerel taken from waters off New Jersey and New York and two samples taken from the Gulf of St. Lawrence in 1984-1985 during the spawning season. Maguire *et al.* (1987) noted that the Gulf of St. Lawrence samples were more dissimilar genetically than the New York Bight samples, even though the same year class was present at age 2 and age 3 during consecutive years within the Canadian samples. They noted that biochemical changes associated with the onset of sexual maturation for age 2 and age 3 fish might have had an effect on the amount of detectable genetic variation. Nonetheless, their results were consistent with the approach of ICNAF to assess the Atlantic mackerel population as a single stock (ICNAF 1974).

At present, the most credible hypothesis is that the northern and southern contingents are dynamic components of a single stock. This hypothesis is consistent with the review of Smith *et al.* (1990) which found that the majority of genetic variation was within, not between, spawning groups of marine teleosts.

The Fishery

Commercial Landings

Anderson and Paciorkowski (1980) summarized historic records of commercial landings of Atlantic mackerel in U.S. and Canadian waters (Table C1). U.S. landings averaged 24,300 mt during 1804-1961, while Canadian landings averaged 11,000 mt during 1876-1961. Annual U.S. and Canadian landings were significantly positively correlated during 1876-1961 (ρ=0.60, P=0.0001). This significant positive association suggests that the level of landings in U.S. and Canadian waters might have been influenced by similar processes through time. Autocorrelations were also computed for both U.S. and Canadian landings series. Both series had significant positive autocorrelations at lags of 1-6 years. The temporal correlation in U.S. and Canadian mackerel landings might be related to the frequency of strong year classes or, possibly, to natural cycles in environmental conditions that influence stock availability to the commercial fisheries. Crosscorrelations were computed between the series of U.S. and Canadian landings. Significant positive crosscorrelations occurred for Canadian landings lagging U.S. landings by 1-6 years and for Canadian landings leading by 1-10 years. The consistent pattern of positive crosscorrelations between lags and leads of 6 years suggests that levels of U.S. and Canadian landings were synchronous during 1876-1961.

Atlantic mackerel landings during 1960-1994 were obtained from various sources (Table C2). U.S. commercial landings during 1960-1990, Canadian landings during 1960-1980, and foreign landings during 1960-1980 were taken from Overholtz (1991). Joint venture and foreign landings in 1991 were taken from confidential reports. U.S. commercial landings during 1991-1993 were taken from the NEFSC weighout data base. U.S. commercial landings were estimated to be 10,070 mt based on an expansion of preliminary 1994 landings in the state of New Jersey (2,737 mt) and the percentage of landings from New Jersey during 1993 (27.3%). Foreign landings during 1981-1993 were updated to reflect minor changes in reported amounts from Canadian waters. Canadian landings during 1981-1993 and preliminary landings in 1994 (12,430 mt) were also provided by DFO, Canada (F. Gregoire, pers. comm.).

Bottom otter trawl gear accounted for 94%, 96%, and 82% of U.S. commercial landings reported in the NEFSC weighout data base during 1991-1993. Major ports for U.S. commercial mackerel landings were Cape May, NJ, Pt. Judith, RI, and other Rhode Island ports; these ports accounted for 87%, 85%, and 76% of U.S. commercial mackerel landings during 1991-1993. New Jersey and Rhode Island together accounted for 88%, 89%, and 83% of the U.S. commercial mackerel landings during 1991-1993.

Commercial Discards

Discards of Atlantic mackerel are believed to be insignificant in recent years and, as in previous assessments, were not estimated. Discarding of Atlantic mackerel by distant water fleets during the 1960s and 1970s remains unquantified, but likely occurred when catches by large freezer trawlers exceeded processing capacity. Regardless of whether discarding was substantial, overflight and vessel boarding data indicated that some mackerel catches were underreported by distant water fleets (Brennan 1976).

Recreational Catch

U.S. recreational landings during 1960-1980 were taken from Overholtz (1991). U.S. recreational landings during 1981-1993 were obtained from the MRFSS data base. Preliminary recreational landings in 1994 (1,140 mt) were also taken from the Marine Recreational Fisheries Statistics Survey (MRFSS) data base. Recreational landings from 1981-1993 were type A+B1 (landed fish) catches taken from the updated MRFSS data base (Table C2). Recreational catches during 1962-1980 were taken from Overholtz (1991). As in previous assessments, type B2 (discarded alive) catches were relatively low and hooking mortality of type B2 fish was considered to be insignificant. Mean weights of type B1 (landed but not observed) fish were calculated at the subregion/mode/area level as in the most recent status of stocks report. Preliminary recreational landings in 1994 were also gathered.

Revisions to the MRFSS data base led to changes in the estimated recreational catches (Table C3). The revised recreational catch estimates were generally lower than the previous figures, and the largest changes occurred in 1981-1982. The changes in estimated recreational landings were primarily due to the pooling and outlier reduction of the party and charter boat trips within the revised MRFSS data base.

Most U.S. recreational landings occur during the spring when the stock is available to nearshore fishing in the Mid-Atlantic Bight. In particular, the average percentage of the total mackerel recreational catch taken from March to June was 72% during 1981-1994. The mean length of mackerel captured in the recreational fishery during 1981-1994 was 36 cm.

Sampling Intensity

Length frequency samples to characterize the U.S. commercial and foreign landings in 1991 were taken from various sources. U.S. commercial landings that were not from joint venture (JV) operations were characterized by quarterly length frequency distributions from the NEFSC weighout data base. For quarter 1, the commercial length frequency distribution (CLF) consisted of a catch-weighted average of samples from SA[1] 616 (N=101) and from SA 621 (N=203); the weighting factors were the proportion of sampled landings taken from each sampled area. The weighting factor for SA 616, for example, was computed as the total quarter 1 landings in SA 616 divided by the total quarter 1 landings in SA 616 and SA 621. Weighted averages for other quarters were computed in the same way. For quarter 2, the CLF consisted of a catch-weighted average of samples from SA 526 (N=113), SA 537 (N=516), SA 538 (N=91), and SA 616 (N=220). For quarter 3, the CLF was taken from a sample from SA 513 (N=100). For quarter 4, the CLF consisted of a catch-weighted average of samples from SA 514 (N=85) and SA 539 (N=100).

Sampling intensities for U.S. commercial landings during quarters 1-4 were 100 fish lengths per 3,333, 541, 62, and 241 mt, respectively. The CLF for U.S. commercial landings originating from JV operations was characterized with a sample of 8,692 fish (100 fish lengths per 120 mt). The CLF for directed foreign commercial landings was characterized with a sample of 2,554 fish (100 fish lengths per 208 mt).

In 1992, there were no directed foreign or JV landings. The 1992 U.S. commercial landings were characterized by length frequency distributions for quarters 1-4. The CLF for quarter 1 consisted of a catch-weighted average of samples from SA 537 (N=397), SA 614 (N=100), SA 615 (N=100), SA 616 (N=194), and SA 621 (N=300). The CLF for quarter 2 consisted of a catch-weighted average of samples from SA 526 (N=244), SA 537 (N=202), SA 538 (N=193), SA 541 (N=100), SA 616 (N=204), SA 621 (N=100), SA 622 (N=200), and SA 626 (N=100). Since there were no length frequency data collected during quarters 3 and 4, and the CLF from quarter 2 was used to characterize those landings. Sampling intensities for U.S. commercial landings during quarter 1 and quarters 2-4 were 100 fish lengths per 500 and 465 mt, respectively.

In 1993, there were no directed foreign or JV landings. The length frequency data to characterize U.S. commercial landings in 1993 were limited to 2 samples. The CLF of landings in all quarters consisted of a catch-weighted average of samples from SA 626 (N=101, Qtr 1) and SA 513 (N=110, Qtr 3). The sampling intensity for U.S. commercial landings was 100 fish lengths per 2,222 mt.

In 1994, there were no directed foreign or JV landings. The length frequency data to characterize U.S. commercial landings in 1994 were taken from 8 samples (N=798). The CLF of landings in all quarters was computed from the combined numbers at length in all samples because the spatial pattern of 1994 landings was not available. Based on preliminary 1994 landings, the sampling intensity for U.S. commercial landings was 100 lengths per 1,250 mt.

The sampling intensity to characterize the length composition of U.S. commercial landings has been below 100 fish lengths per 400 mt since 1992. The low levels of length frequency sampling in recent years are below the target level of 100 fish lengths per 200 mt, and the sampling intensity for the U.S. commercial fishery needs to be increased.

Age-length keys (ALKs) for 1991 commercial and foreign mackerel landings in U.S. waters were taken from several sources. For U.S. commercial landings that were not part of JV operations, an ALK was determined for quarters 1-3 and for quarter 4. The ALK for quarters 1-3 consisted of com-

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[1]U.S. Statistical Areas used to report landings; see Figure 2, p.4.

mercial age samples from Qtr 1 (N=109) and Qtr 2 (N=300) and NEFSC spring survey age samples (N=182). A statistical method to compare ALKs (Hayes 1993) was applied to test for differences in age-at-length distributions for the 3 samples. The age-at-length data were grouped by 2-cm intervals. There were a total of 16 possible comparisons between the 3 samples and only 1 significant difference was detected. As a result, the 3 samples were combined (N=591) to give the 1991 U.S. commercial ALK for quarters 1-3. The ALK for U.S. commercial landings that were not part of JV operations in quarter 4 consisted of commercial age samples from Qtr 4 (N=45) and NEFSC fall survey samples (N=90). These samples were summed to give the Qtr 4 ALK (N=135). For foreign and U.S. JV landings in 1991, an ALK was determined as the sum of Qtr 1 (N=576) and Qtr 2 (N=89) age samples (N=665). Foreign age-at-length distributions were statistically compared to the U.S. commercial data for Qtr 1 and Qtr 2 of 1991. Test results indicated that 4 out of 12 comparisons were significant and as a result, foreign and U.S. ALKs were not combined.

ALKs for 1992 U.S. commercial landings were derived from NEFSC spring survey and commercial age samples. The ALK for Qtr 1 consisted of U.S. Qtr 1 commercial data (N=209) and NEFSC spring survey data (N=352) based on comparisons between age-at-length distributions (Hayes 1993). Out of 7 comparisons, no significant differences were detected between the U.S. Qtr 1 and spring survey age-at-length distributions. In contrast, 2 out of 7 comparisons were significant between the U.S. Qtr 2 and spring survey age-at-length distributions. As a result, Qtr 1 and NEFSC spring survey data were combined for the Qtr 1, 1992 ALK (N=561), and the U.S. Qtr 2 commercial data were used to characterize the age-length composition of U.S. commercial landings during quarters 2-4 (N=265).

An ALK for 1993 U.S. commercial landings was derived from available NEFSC spring survey and commercial age data. The ALK for all quarters was the sum of U.S. Qtr 1 commercial data (N=31) and NEFSC spring survey data (N=190) based on the limited amount of age-length data (N=221).

An ALK for 1994 U.S. commercial landings was derived from available NEFSC spring survey and commercial age data. The ALK for all quarters was the sum of U.S. Qtr 1 commercial data (N=76) and NEFSC spring survey data (N=269) based on the limited amount of age-length data (N=344).

There were fewer than 100 fish sampled for ageing from U.S. commercial mackerel landings in 1993-1994. This level of sampling would be inadequate if survey age-at-length data were not available. More age-at-length data should be collected each year from U.S. commercial landings. In the absence of increased commercial age sampling, the level of age sampling for mackerel during the spring survey should be increased from 1 fish per 1-cm interval to 2 fish per 1-cm interval.

Age Composition of Landings

Atlantic mackerel catch-at-age data (Table C4) were taken from various sources. U.S. commercial and recreational, Canadian, and foreign catch-at-age data for 1962-1980 were taken from Overholtz (1991). U.S. commercial and foreign catch-at-age data from U.S. waters during 1981-1990 were provided by Overholtz (pers. comm.). U.S. commercial and foreign catch-at-age data during 1991-1994 were determined from available length frequency samples and age length keys collected during this period. In general, the level of biological sampling of U.S. commercial landings was low during 1991-1994. Canadian and foreign catch-at-age data from Canadian waters were provided by DFO, Canada (F. Gregoire, pers. comm.). As in previous assessments, the age composition of recreational landings was assumed to be the same as the age composition of the combined U.S. commercial, Canadian, and foreign landings.

Atlantic mackerel mean weight-at-age data (Table C5) were taken from various sources. Data for 1962-1990 were taken from Overholtz (1991).

U.S. mean weight-at-age data during 1991-1994 were determined from available length frequency samples and age-length keys. The length-weight relationship used to compute mean weight (g) at length (cm) was the same as used in the 1991 assessment: $W = 0.00590 \cdot L^{3.15400}$. Canadian weight-at-age data during 1981-1993 were taken from Gregoire *et al.* (1994) and preliminary Canadian weight-at-age data for 1994 were provided by DFO, Canada (F. Gregoire, pers. comm.). Mean weights at age during 1991-1994 were computed as the weighted average of U.S. and Canadian mean weight-at-age data; for averaging, the weighting factors were the fraction of total annual landings (mt) attributed to each source.

Stock Abundance Indices

Research Survey Indices

As in previous assessments (Overholtz 1991), the NEFSC spring survey from Cape Hatteras to Georges Bank (offshore strata 1-25 and 61-76) provided an index of relative abundance for mackerel near the end of their overwintering period in southerly offshore waters (Table C6). Mackerel catches during the NEFSC autumn survey are more variable than from the spring survey (Anderson 1982) and the autumn index is not considered to be a reliable measure of relative abundance. Trends in the stratified-mean-number-per-tow index during 1968-1994 (Figure C1) were depicted using a locally-weighted regression smoother (Statistical Sciences 1994). There was an apparent downward trend in numbers from 1968 to the late 1970s, and an upward trend from the early 1980s to the present. Trends in the stratified-mean-weight-per-tow index are similar, but more pronounced (Figure C2). Preliminary weight- and number-per-tow indices from the 1995 NEFSC spring survey were consistent with the above average survey indices during 1991-1994.

Age-specific indices of relative Atlantic mackerel abundance were calculated from log-transformed catch per tow at age to stabilize variance, as in previous assessments (cf. Anderson and Paciorkowski 1980; Overholtz 1991), and retransformed values are reported (Table C7). In 1991, the combined NEFSC spring survey and U.S. commercial Qtr 1 and Qtr 2 ALK was used to characterize the age-at-length distribution for this calculation, while during 1992-1994, the combined NEFSC spring survey and U.S. commercial Qtr 1 ALK was used. The number-per-tow-at-age indices show that the 1982 year class was strong in comparison to other year classes and that recruitment (number of age 1 fish per tow) has been well above average in the 1990s.

A preliminary examination of Atlantic mackerel catch per tow during the NEFSC winter survey (offshore strata 1-25, 61-76) suggested substantial annual variation in stock availability to the survey (Table 8). There were substantial differences in the weight- and number-per-tow indices between the 1994 survey and the 1992-1993 and 1995 surveys.

Commercial LPUE

Nominal U.S. commercial landings per unit effort (LPUE) by tonnage class for Atlantic mackerel captured with otter trawl gear during 1982-1993 were taken from the NEFSC weighout data base (Table C9). LPUE for otter trawl trips that landed at least 50% mackerel by weight were also summarized. Commercial LPUE varied substantially, but was relatively high for tonnage class 4 vessels during 1986-1992. Commercial LPUE was not used as a tuning index because it was assumed to be influenced by a number of factors other than stock abundance including, for example, stock distribution, market price and demand, and the number of vessels searching for schools of mackerel. Previous studies (Ulltang 1980; Anderson 1982) have demonstrated that CPUE from mobile fishing gear targeting a pelagic schooling species such as mackerel is an unreliable measure of relative abundance. Accordingly, the nominal LPUE presented here should not be interpreted as an index of relative mackerel abundance.

Recreational LPUE

Nominal recreational catches per angler per trip were calculated as the mean number of mackerel caught during trips that targeted mackerel divided by the total number of trips that captured mackerel from North Carolina to Maine (Table 10). Recreational LPUE was relatively high during 1983-1991, but declined in 1992-1994. Preliminary reports indicated that recreational catches taken in the spring of 1995 off Cape May were "decent" in comparison to the low levels of the previous 3 years. Regardless, recreational LPUE should not be interpreted as an index of relative mackerel abundance because it is influenced by stock availability to nearshore recreational fishing.

Current Stock Distribution

The univariate method of Perry and Smith (1994) was used to examine whether environmental variables influenced Atlantic mackerel catches during the NEFSC spring bottom trawl survey, 1968-1994 (Brodziak and Ling 1995). Four environmental variables (average depth, bottom temperature, surface temperature, and wind speed) were tested for significant association based on the maximum absolute difference between the catch-weighted and unweighted cumulative distribution of the environmental variables. Test results indicated that surface or bottom water temperature had a significant effect on mackerel distribution in 16 out of 27 years (59%). Significant associations were found between mackerel catches and bottom temperatures during NEFSC spring surveys in 1968, 1969, 1971, 1977, 1978, 1980, 1981, 1988, 1993, and 1994, while significant associations between mackerel catches and surface temperatures were found in 1968-1971, 1973, 1976, 1978, 1979, 1981, 1985, 1992, 1993, and 1994. The associations were generally positive (greater catches of mackerel were associated with warmer water temperatures), although the association with surface temperature was not as pronounced in 1976 and 1992. Previous studies have indicated that mackerel avoid water temperatures of less 5°C and greater than 16°C (Olla *et al.* 1976; Overholtz and Anderson 1976) and that wind-forced advections of warm (≥7°C) surface water influences the nearshore mackerel distribution (Castonguay *et al.* 1992). The findings based on the habitat association test were consistent with these studies. In particular, the interquartile ranges of the catch-weighted cumulative distribution of surface temperature were consistently between 5.2°C and 10.0°C when surface temperature was significantly associated with mackerel catches (Brodziak and Ling 1995). Similarly, the interquartile ranges of the catch-weighted cumulative distribution of bottom temperature were consistently between 4.9°C and 11.1°C when bottom temperature was significantly associated with mackerel catches. Overholtz *et al.* (1991A) also showed similar associations stock size, spring surface temperature, and March wind stress with recreational mackerel catches during 1979-1987. Results indicated that there were significant associations of recreational mackerel catches with surface temperature and wind stress. There was a positive association between mackerel catches and surface temperature and a negative association between mackerel catches and wind stress. In contrast, there was no significant association between mackerel stock size and recreational catches.

A geographic information system (GIS) was used to plot the distribution of juvenile (≤30 cm fork length) and adult (>30 cm fork length) mackerel in relation to surface temperature during the 1982, 1988, and 1993 NEFSC spring trawl surveys (Figure 3, bathymetry is 50 f). These years covered the range of available data for the GIS plots. These years also provided some contrast in the level of recreational catches: 666, 3,251, and 540 mt during 1982, 1988, and 1993, respectively. In 1982, juvenile mackerel were found on the continental shelf in the Mid-Atlantic Bight south of Long Island (Figure C4). Adult mackerel were distributed further offshore (Figure C5). Both juvenile and adult mackerel were associated with surface temperatures greater than 4°C in 1982. In 1988, substantial concentrations of juvenile mackerel were found on the continental shelf between Cape May and Long

Island (Figure C6). Adult mackerel were generally distributed further offshore than juveniles, although substantial concentrations were found nearshore from Cape Charles to Cape Henlopen (Figure C7). As in 1982, mackerel catches in 1988 were associated with surface temperatures greater than 4°C. In 1993, juvenile mackerel were found along the edge of the continental shelf primarily between Cape Hatteras and Hudson Canyon (Figure C8). Adult mackerel were also distributed along the edge of the continental shelf in 1993, but their distribution extended further north, with some fish captured in the Gulf of Maine (Figure C9). As in 1982 and 1988, mackerel catches in 1993 were associated with surface temperatures greater than 4°C. The nearshore surface water temperatures from Cape Henlopen to Cape Cod were roughly 4°C in 1993 (Figure C8). It appears that this cool mass of surface water may have shifted the spring distribution of mackerel further offshore in 1993 than in 1982 and 1988. This observation is consistent with the lower recreational catch in 1993 (roughly 500 mt) in comparison to 1988 (roughly 3,300 mt). Overall, these plots suggest that the spring distribution of mackerel is influenced by surface temperature. When the vernal warming of shelf waters is relatively slow and inshore surface water temperatures remain cool, it appears that both juvenile and adult mackerel may be distributed further offshore along the edge of the continental shelf where surface water temperatures exceed 4°C. In such years, the availability of mackerel to spring recreational fisheries may be greatly reduced.

Preliminary results from the 1995 NEFSC spring survey (Figure C10) indicate that large mackerel catches were taken closer inshore than in 1993. This suggests that mackerel were distributed further inshore relative to the last several years, which is supported by observations that recreational catches taken in the spring of 1995 off Cape May, NJ were "decent" in comparison to the low levels of the previous 3 years. Water temperature data collected during the 1995 spring survey were unavailable to confirm whether or not higher temperatures were associated with the larger inshore mackerel catches.

Life History Parameters

Growth

Anderson and Paciorkowski (1980) summarized estimates of von Bertalanffy growth parameters for weight (W_t) in grams and fork length in centimeters at age (t) of Atlantic mackerel in the Northwest Atlantic. The von Bertalanffy equation used for their yield-per-recruit analysis was:

$$W_t = W_\infty \cdot \left(1 - \exp[-K(t-t_0)]\right)^3 \qquad (1)$$

where $W_\infty = 735$, $K = 0.250$, and $t_0 = -1.900$. The length-weight relationship [grams at fork length (cm)] used in this assessment was taken from the most recent mackerel assessment (Overholtz 1991):

$$W_L = a \cdot L^b \qquad (2)$$

where a = 0.00590 and b = 3.15400.

Natural Mortality

The instantaneous natural mortality rate (M) of Atlantic mackerel was assumed to be 0.2, as in the most recent assessment (Overholtz 1991).

Maturity

The proportions of Atlantic mackerel mature at age were taken from O'Brien *et al.* (1993). The estimated proportions of mature females at ages 1, 2, and 3 were 0.02, 0.63, and 0.99, respectively. The estimated proportions of mature males at ages 1, 2, and 3 were 0.05, 0.58, and 0.97, respectively. Fish at ages 4 and older were fully mature, regardless of sex.

Mortality and Stock Size Estimates

The ADAPT model (Gavaris 1988; Conser and Powers 1990) for tuned virtual population analysis (VPA) was applied to estimate fishing mortality (F) rates and stock size at ages 1-11+ during 1962-1994. The partial recruitment (PR) to F at age in 1994 was estimated using the separable analysis option of the SVPA model of Pope and Shepherd (1982) for catch-at-age data from 1980-1994. As in the most recent assessment, a terminal F of 0.05, a terminal S of 1.0, and a reference age for unit selection of 4 years were used for ages 1-10. The estimated partial recruitment at age for 1994 was:

Age	1	2	3	4	5	6	7	8	9	10
PR	0.08	0.53	0.85	1.00	1.21	1.07	1.07	1.02	1.10	1.00

Since this estimated partial recruitment was consistent with a flat-topped selection pattern for ages 4 and older, the partial recruitment in 1994 was assumed to be 1.0 for ages 4 and older and was assumed to be 0.08, 0.53, and 0.85 for ages 1, 2, and 3, respectively. Other input data for the ADAPT VPA model were catch-at-age data (Table C4), mean weights at age (Table C5), the proportion of females mature at age, and the NEFSC spring number of mackerel per tow at age (Table C7). As in the most recent assessment, the spring survey indices of numbers per tow at ages 1-7 from 1970 to the terminal year were used for tuning the VPA.

A total of 11 different runs of the ADAPT model were made: 1) an unweighted run which represented a continuation of the tuned VPA from the previous assessment; 2) an iteratively re-weighted[2] run; 3) an unweighted run with tricubic downweights for 1977-1994; 4) an iteratively re-weighted run with tricubic downweights for 1977-1994; 5) an unweighted run with tricubic downweights for 1983-1994; 6) an iteratively re-weighted run with tricubic downweights for 1983-1994; 7) an unweighted run with tricubic downweights for 1981-1994; 8) an iteratively re-weighted run with tricubic downweights for 1981-1994; 9) an unweighted run with tricubic down-weights for 1976-1994; 10) an unweighted run with tuning indices for 1977-1994; and 11) a weighted run with tuning indices for 1977-1994.

Runs (1) and (2) had reasonable residual patterns, but produced very large stock sizes (>20 billion fish[3]) in the terminal year. Runs (3) and (4) were made to examine the effects of excluding survey data from 1970-1976 in the objective function to account for the apparent mismatch between low survey indices and large foreign catches through 1976. Run (3) was judged to have the better residual pattern of these two runs. Runs (5), (6), (7), (8), and (9) were made to examine the effects of excluding various years of survey data for tuning in the objective function. These runs had poor residual patterns and were rejected. Runs (10) and (11) were made to examine the effects of eliminating the tricubic downweighting of the survey indices during 1977-1994. Both runs produced extremely large stock sizes (>25 billion fish) in 1994, and were rejected.

The Subcommittee discussed the relative merits of runs (1) and (3). The difference between these runs was that run (3) excluded 1970-1976 survey data from the tuning indices, while run (1) was a continuation of the previous tuned VPA formulation. The Subcommittee observed that the 1970-1976 survey indices were relatively low in comparison to those of recent years, but that mackerel catches in those years were very large (>300,000 mt per year). The effects of the intensive foreign fishery on spring survey results were discussed and could not be excluded as a potential mechanism for the low survey indices during 1970-1976. The potential effects of changes in net size and the use of two survey vessels (*Albatross IV* and *Delaware II*) on spring survey catches were also discussed, but it was noted that adjustments for net size and vessel effects would decrease the 1970-1976 indices. Unusual environ-

[2] These are the inverse variance weights calculated by tuning the VPA to each index separately and then normalizing the resulting weights to sum to 1 [see Conser and Powers (1990)].

[3] A stock size of 20 billion mackerel laid nose to tail would circle the earth roughly 150 times.

mental conditions were also discussed as a potential cause for the low indices. It was noted that in 4 out of the 7 years (1970-1976), there were significant associations of mackerel with surface or bottom temperature. The Subcommittee concluded that it would be desirable to reevaluate the time series of spring survey indices. It was also noted that the estimated stock sizes of run (3) were consistent with the most recent Canadian assessment, while those of run (1) were much higher. Overall, the Subcommittee concluded that run (3) was preferable to run (1) even though parameter estimates were not precisely determined (Tables C11 and C12).

Bootstrap resampling (Efron and Tibshirani 1993) of residuals from run (3) of the ADAPT VPA model was used to characterize the variability of estimated parameters (Table C12). Results indicated that parameters were imprecisely determined as expected. Bias-corrected parameter estimates generally had larger coefficients of variation than the uncorrected estimates. Some bias-corrected parameter estimates were infeasible; for example, the bias-corrected estimate of stock numbers at age 3 in 1994 was negative. For these reasons, bias correction was not applied.

Fishing mortality estimates from the tuned VPA (Figure C11) indicate that F (weighted mean for ages 4-11+)[4] was below 0.05 during the 1990s, and was below 0.15 during 1978-1989. During 1970-1976, F ranged from a low of 0.21 in 1970 to a high of 0.46 in 1976. Fishing mortality in 1994 was very low; the point estimate was $F_{94} = 0.016$ and the 80% confidence interval from bootstrapping was 0.004-0.032.

Spawning stock biomass (SSB) estimates from the tuned VPA (Figure C12) increased to above 1 million mt in the early 1970s when the large 1967 year class was fully mature. It decreased rapidly from a peak of 1.268 million mt in 1972 to 498,000 mt in 1976 and remained near 500,000 mt until 1984 when the large 1982 year class began to mature. SSB again increased dramatically during the mid-1980s and exceeded 1 million mt in 1985 when the majority of the 1982 year class was mature. SSB has remained above 1 million mt since 1985, increased through the 1990s, and in 1994 was very high; the point estimate of SSB is 2.121 million mt, and 80% confidence interval of 1.241 to 8.223 million mt.

Estimates from the tuned VPA indicate that recruitment was relatively low during the 1960s until the large 1966-1969 year classes recruited to the stock. In particular, the 1967 year class was exceptional (4.968 billion fish at age 1). Recruitment remained above 1 billion fish during 1967-1975, but declined to low levels during 1976-1982. In 1983, the exceptional 1982 year class (6.381 billion fish) recruited to the stock, but the subsequent 1983-1986 year classes were below average. In contrast, the 1987-1988 and 1990-1993 year classes have all been above average and the 1991 and 1993 year classes appear to be very large (>3 billion fish at age 1).

Stock-recruitment data for the Atlantic mackerel stock were obtained from the results of the tuned VPA (Table C13) to examine the stock-recruitment relationship (SRR). SSB during 1962-1993 averaged about 875,000 mt (CV=58%). The median SSB was about 720,000 mt with an interquartile range of 496,000 - 1,305,000 mt. Recruitment during 1962-1993 averaged 1.391 billion fish at age 1 (CV=105%). Median recruitment was 1.037 billion fish with an interquartile range of 0.332-1.943 billion fish. The ratio of recruitment to spawning stock biomass (R/SSB) averaged 2.198 billion recruits/million mt of SSB (CV=160%) during 1962-1993. Median R/SSB was 1.106 billion recruits/million mt of SSB with an interquartile range of 0.562-1.954 billion recruits/million mt of SSB.

[4] An average F weighted by population size gave appropriate weighting to the high estimates of F for the 1955-1957 year classes in 1964-1966, while for other years, weighted and unweighted Fs were virtually the same.

Substantial variability was evident in the scatterplot of recruitment and SSB (Figure C13), although there was indication that recruitment was greater, on average, when SSB was above 1 million mt. Parameters of a Ricker SRR with a lognormal error term were estimated using a linear regression of the natural log-transformed, as described by Hilborn and Walters (1992).

The form of the Ricker SRR was:

$$R = \alpha \cdot SSB \cdot e^{-\beta \cdot SSB} \cdot e^{w} \qquad \textbf{(3)}$$

where $w \sim N(0,\sigma_w^2)$. The regression had an R^2 of 0.03 and was not significant ($P=0.36$). Parameters of a Beverton-Holt SRR with a lognormal error term were estimated with a nonlinear regression. The form of the Beverton-Holt SRR was:

$$R = \frac{a \cdot SSB}{b + SSB} \cdot e^{w} \qquad \textbf{(4)}$$

where $w \sim N(0,\sigma_w^2)$. The nonlinear regression had an R^2 of 0.97 and was considered to provide an adequate representation of the mackerel SRR. The natural log-transformed residuals of the estimated SRR were tested for normality and found to conform to the assumed error structure. The estimated parameters were: $\hat{a} = 2033.164$, $\hat{b} = 1044.602$, and $\hat{\sigma}_w^2 = 1.32073$. Bootstrap estimates of the standard deviations of the a and b parameters were: $\hat{\sigma}_a = 1274.621$ and $\hat{\sigma}_b = 612.616$. The expected value of maximum recruitment (R_{MAX}) was 3.935 billion fish, while the SSB that would produce 50% of R_{MAX} (SSB_{50}) was 1.044 million mt.

Biological Reference Points

Yield and Spawning Stock Biomass Per Recruit

Biological reference points based on yield and spawning stock biomass per recruit of Atlantic mackerel were calculated. As in the previous assessment, ages 1-11+ were used. Mean catch and stock weights were taken to be the average values of mean weights (Table C5). The fishing mortality pattern was calculated as the average of the back-calculated partial recruitment values for ages 1-4 during 1992-1994; these averages were rescaled so that age 4 fish were fully-recruited. The results (Table C14) were almost identical to those of the previous assessment: $F_{0.1}=0.27$ and $F_{20\%}=0.72$.

Recruitment Overfishing Threshold

Myers *et al.* (1994) considered various methods to estimate recruitment overfishing thresholds. They recommended that methods based on the stock size that produced 50% of the maximum predicted recruitment (50% R_{MAX}) would be likely to produce reliable thresholds, although methods based on survival and recruitment percentiles were recommended when recruitment does not appear to decline over a range of stock sizes.

Two estimates of a recruitment overfishing threshold were calculated for the Atlantic mackerel stock. A 50% R_{MAX} threshold was estimated from the Beverton-Holt SRR. Recall that the 50% R_{MAX} threshold was 1.044 ≈ 1 million mt of SSB. Another threshold (90% R/SSB) based on the SSB corresponding to the intersection of the 90th percentiles of observed recruitment (3.294 billion fish) and observed R/SSB values (3.571 billion fish/million mt of SSB) was calculated as: 90% R/SSB = 3.294/3.571 = 922,000 mt ≈ 900,000 mt of SSB.

The potential utility of these thresholds was examined by comparing mean levels of recruitment and R/SSB above and below these thresholds. A natural logarithmic transform was applied to recruitment to stabilize variance for comparison of means of recruitment.

For the 50% R_{MAX} threshold of 1 million mt of SSB, mean levels of recruitment above and below the threshold were 1.643 and 1.218 billion fish, respectively. Mean levels of R/SSB above and below the threshold were 2.902 and 1.168 billion fish/million mt of SSB. The GT2 test (Hochberg 1974, Sokal and Rohlf 1981) was applied to compare means of log-transformed recruitment and of R/SSB for SSB levels above and below the threshold. Results indicated that the means of log-transformed recruitment and of R/SSB were significantly different at the α=0.20 level of significance.

For the 90% R/SSB threshold of 900,000 mt of SSB, mean levels of recruitment above and below the threshold were 1.653 and 1.187 billion fish, respectively. Mean levels of R/SSB above and below the threshold were 2.957 and 1.223 billion fish/million mt of SSB. The GT2 test was applied to compare means of log-transformed recruitment and of R/SSB for SSB levels above and below the threshold. Results indicated that the means of log-transformed recruitment and of R/SSB were significantly different at the α=0.20 level of significance.

Levels of recruitment and R/SSB above and below both estimated recruitment overfishing thresholds were significantly different. The lower SSB threshold of 900,000 mt led to a slightly greater difference between the mean levels of recruitment above and below the threshold. Overall, these analyses suggested that stock productivity decreases when SSB falls below 900,000 mt.

Long-Term Potential Yield

The long-term potential yield from the Atlantic mackerel stock was estimated to be 134,000 mt with an associated SSB of 1.0-1.2 million mt. This estimate was based on a fishing mortality rate of $F_{0.1}$=0.27 applied to the geometric mean of the 1961-1984 year classes (NEFSC 1993).

Brodziak and Overholtz (1995) recalculated maximum sustainable yield and the associated SSB using the dynamic pool model of Thompson (1992A) and the estimated recruitment and SSB levels from the tuned VPA for 1962-1994. Their results indicated a maximum sustainable yield of 148,000 mt with an associated SSB of 1.029 million mt and an F of 0.17. They also calculated the value of a risk-averse reference point (F_{MELSY}) due to Thompson (1992B) that incorporates uncertainty in the degree of compensation in the stock-recruitment relationship. Their estimate of F_{MELSY} was 0.08; the associated long-term yield was 131,000 mt at an SSB level of 1.823 million mt.

Previous research has indicated that density-dependence in growth, natural mortality, and maturity (Overholtz 1989; Overholtz *et al.* 1991B) of Atlantic mackerel can have a substantial impact on assessment advice for this stock. Overholtz (1993) examined the impacts of density-dependence in growth, natural mortality, and maturity on harvest strategies for Atlantic mackerel and found that constant annual catches on the order of 150,000-160,000 mt could be sustained over a 15-year period without SSB falling below 600,000 mt. This result is consistent with the estimated MSY of 148,000 mt. Overall, the long-term potential yield for the Atlantic mackerel stock appears to be roughly 150,000 mt with an associated SSB of 1.0 million mt.

Summary and Conclusions

- The Northwest Atlantic mackerel stock is currently at a high level of biomass and is underexploited. In 1994, F was estimated to be 0.02 with an 80% confidence interval of 0.00-0.03, while SSB was estimated to be 2.1 million mt with an 80% confidence interval of 1.2-8.2 million mt.

- Recent U.S. commercial mackerel landings (8,300 mt/yr during 1992-1993) are substantially lower than historic yields. At present, the level of foregone yield from the stock exceeds 100,000 mt per year. It is likely that annual landings of 200,000 mt could be sustained for several years.

- The long-term potential yield from the Atlantic mackerel stock is roughly 150,000 mt/yr with an associated SSB of at least 1.0 million mt. Stock productivity appears to decline when the SSB falls below 900,000 mt.

- Stock availability to recreational and commercial fisheries is affected by environmental conditions. In years when the vernal warming of shelf waters is relatively slow and water temperatures on the continental shelf are relatively cool, the availability of mackerel to spring recreational and commercial fisheries may be greatly reduced.

- Atlantic mackerel in the Northwest Atlantic comprise a single biological stock. There is no indication that the northern and southern components constitute genetically discrete stocks with temporal and spatial integrity.

SARC Discussion

The SARC discussed the use of tri-cubic weighting of survey indices used in VPA tuning. The weighting scheme was found to resolve a residual pattern in earlier years (prior to 1977) compared to an unweighted run. The SARC concluded that the use of downweighting techniques should be evaluated on a species-by-species basis, and that it would be appropriate for mackerel given the VPA results.

The SARC expressed concern over the VPA results of estimated stock sizes with highly correlated residuals, imprecisely estimated CVs (65-80%) and large bias (20-100%). The VPA was difficult to tune because of low Fs in recent years (much lower than natural mortality), noisy survey indices and the possibility of non-linear relationship in catchability between abundance indices and stock abundance. The SARC recommended exploration of a non-linear catchability relationship.

Given the imprecision of the VPA results, the SARC concluded that short-term projections would be unreliable, and suggested that characterization of uncertainty in stock sizes and F using bootstrapping would be more useful. The SARC recommended that boostrapping be performed using VPA results with zero weighted survey indices excluded (prior 1977) to properly characterize uncertainty. The SARC concluded that while VPA estimates of stock biomass were uncertain (80% confidence interval ranging from 1 million to 8 million mt) other information such as very low catches since the late 1970s and increasing trends in NEFSC survey indices and commercial CPUE indices support current substantial estimates of low Fs and high stock biomass. The SARC, however, recommended that non-age structured approaches be investigated to estimate stock size.

The SARC reviewed long-term potential yield calculations based on VPA stock-recruitment data and concluded that these were an improvement over previous estimates, and recommended that these methods be more generally evaluated by the Assessment Methods Working Group.

Given the schooling nature of mackerel and patchy distribution of catches in the NEFSC survey, it was suggested that other approaches be explored to derive a more robust index of abundance. Restratification of survey strata sets to correspond to temporal/spatial abundance associations with oceanographic factors (e.g. temperature) within the GLM framework was suggested as one possible approach.

Research Recommendations

- The level of biological sampling of U.S. commercial landings should be increased to maintain the precision of the estimates .

- Given current low levels of F and high stock biomass, annual analytical stock assessments are not warranted unless otherwise indicated by decreasing stock biomass or increasing landings approaching 80,000 mt.

- Alternative assessment approaches should be explored given the uncertain estimates of stock size from VPA.

- The historic time series of relative abundance indices derived from the NEFSC spring survey should be reevaluated, and possibly adjusted, in view of gear and vessel changes during the time period. Other research survey indices should be examined for potential application as measures of mackerel abundance. These may include re-stratification of survey strata sets corresponding to temporal/spatial abundance associations with oceanographic factors (e.g. temperature) within the GLM framework, as well as non-parametric techniques.

- Evaluate the use of a non-linear catchability relationship between survey indices and stock size in VPA formulation.

- To better characterize mackerel stock abundance, pelagic surveys should be conducted using methods such as hydroacoustics, egg and larval surveys and mid-water trawl surveys.

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Table C1. U.S. and Canadian commercial landings (mt) of Atlantic mackerel in the northwest Atlantic during 1804-1961.

YEAR	US	CANADA	YEAR	US	CANADA	YEAR	US	CANADA
1804	1631	-	1857	35014	-	1910	2569	3166
1805	1780		1858	27313	-	1911	5470	4088
1806	1707	-	1859	20695	-	1912	4608	4897
1807	1931	-	1860	48914	-	1913	6130	9771
1808	1583	-	1861	40322	-	1914	9516	6518
1809	1832	-	1862	54141	-	1915	10550	8208
1810	2605	-	1863	63703	-	1916	13450	7078
1811	3611	-	1864	57579	-	1917	16743	7576
1812	1221	-	1865	55200	-	1918	9146	8924
1813	780	-	1866	49072	-	1919	7358	10425
1814	278	-	1867	43400	-	1920	8737	6456
1815	3333	-	1868	37059	-	1921	4551	6601
1816	6428	-	1869	48187	-	1922	5782	11393
1817	7754	-	1870	66464	-	1923	15374	6429
1818	9619	-	1871	55029	-	1924	12292	9777
1819	20777	-	1872	36559	-	1925	22316	8511
1820	24000	-	1873	37327	-	1926	30975	5238
1821	23039	-	1874	54595	-	1927	27365	7202
1822	33267	-	1875	25374	-	1928	20365	5614
1823	33095	-	1876	45026	14223	1929	29079	6928
1824	39775	-	1877	22697	22474	1930	23524	8094
1825	52795	-	1878	33413	25129	1931	21493	8900
1826	32945	-	1879	37517	25994	1932	27598	8093
1827	39496	-	1880	59468	31896	1933	18838	11942
1828	49254	-	1881	66608	14699	1934	23746	8654
1829	46900	-	1882	64433	15552	1935	29517	7279
1830	64019	-	1883	38552	17520	1936	23808	10324
1831	79602	-	1884	81306	24732	1937	12064	10846
1832	46168	-	1885	56112	20281	1938	19632	12951
1833	46268	-	1886	13605	20785	1939	14782	23612
1834	52483	-	1887	15011	16415	1940	18427	16206
1835	40429	-	1888	8938	8595	1941	21024	15924
1836	36197	-	1889	4631	8646	1942	23163	13745
1837	28673	-	1890	4964	13351	1943	26981	16819
1838	22983	-	1891	8781	18393	1944	33644	15543
1839	15413	-	1892	9961	12771	1945	26609	18234
1840	10479	-	1893	11444	10220	1946	23620	13387
1841	11526	-	1894	10223	7859	1947	26668	11911
1842	15678	-	1895	5431	5775	1948	23156	11735
1843	13376	-	1896	16009	6239	1949	19079	15203
1844	17928	-	1897	4808	3783	1950	10020	12349
1845	41986	-	1898	4556	4603	1951	7142	11221
1846	37256	-	1899	6114	4708	1952	8248	9973
1847	52279	-	1900	20785	11433	1953	3875	8371
1848	62289	-	1901	15768	10501	1954	1822	11570
1849	43365	-	1902	10502	5930	1955	1756	11275
1850	50343	-	1903	11592	11352	1956	1829	9584
1851	68332	-	1904	8872	5005	1957	1097	8800
1852	41117	-	1905	10121	6828	1958	2074	7299
1853	27673	-	1906	5328	9309	1959	1835	4286
1854	28090	-	1907	11109	7001	1960	1396	5957
1855	43990	-	1908	9449	10316	1961	1361	5459
1856	44479	-	1909	7691	7446			

Table C2. Atlantic mackerel landings (mt) from NAFO Statistical Areas 2-6 during 1960-1993 with preliminary 1994 landings.

Year	USA Commercial	USA Recreational	Canada	Other Countries	Commercial Total	Grand Total
1960	1396	2478	5957	0	7353	9831
1961	1361	-	5459	11	6831	6831
1962	938	-	6865	175	7878	7978
1963	1320	-	6473	1299	9092	9092
1964	1644	-	10960	801	13405	13405
1965	1998	4292	11590	2945	16533	20825
1966	2724	-	12821	7951	23496	23496
1967	3891	-	11243	19047	34181	34181
1968	3929	-	20819	65747	90495	90495
1969	4364	-	17364	114189	135917	135917
1970	4049	16039	19959	210864	234872	250911
1971	2406	-	24496	355892	382794	382794
1972	2006	-	22360	391464	415830	415830
1973	1336	-	38514	396759	436609	436609
1974	1042	-	44655	321837	367534	367534
1975	1974	5190	36258	271719	309951	315141
1976	2712	-	33065	223275	259052	259052
1977	1377	-	22765	56067	80209	80209
1978	1605	-	25899	841	28345	28345
1979	1990	3588	30612	440	33042	36630
1980	2683	2364	22296	566	25545	27909
1981	2941	3233	19294	5361	27596	30829
1982	3330	666	16379	6647	26356	27022
1983	3805	3022	19797	5955	29557	32579
1984	5954	2457	16995	15045	37994	40451
1985	6632	2986	29855	32409	68896	71882
1986	9637	3856	31097	26507	67241	71097
1987	12310	4025	27559	36564	76433	80458
1988	12309	3251	25016	42858	80183	83434
1989	14556	1862	21142	36823	72521	74383
1990	31261	1908	23044	30678	84983	86891
1991	26961	2439	20870	15714	63545	65894
1992	11775	344	25475	0	37250	37594
1993	4666	540	26873	0	31539	32079
1994[1]	10070	1140	12430	0	22500	23640

[1] Preliminary landings.

Table C3. Comparison of Atlantic mackerel recreational landings (mt) taken from the revised MRFSS database to the recreational landings used in the previous (1991) U.S. assessment.

YEAR	REVISED LANDINGS	PREVIOUS LANDINGS	RELATIVE CHANGE
1981	3233	8505	-62%
1982	666	1162	-43%
1983	3022	3280	-8%
1984	2457	2618	-6%
1985	2986	3287	-9%
1986	3856	3943	-2%
1987	4025	5567	-28%
1988	3251	4204	-23%
1989	1862	2251	-17%
1990	1908	2000	-5%

Table C4. Atlantic mackerel commercial and recreational[1] catch at age (millions of fish) from NAFO SA 2-6 during 1962-1994[2].

YEAR	AGE 0	1	2	3	4	5	6	7	8	9	10	11+	TOTAL	MEAN AGE
1962	-	16.1	2.8	15.2	3.8	1.2	1.6	1.4	0.8	0.4	0.1	0.3	43.7	2.8
1963		1.1	4.2	1.3	26.3	6.0	0.3	0.2	0.2	0.2	0.1	0.1	40.0	4.1
1964	-	12.9	7.0	4.1	4.0	19.4	4.1	3.9	0.7	0.8	0.2	-	57.1	3.8
1965	-	9.0	3.6	2.9	4.0	5.2	19.5	4.2	4.0	0.7	-	-	53.1	4.7
1966	-	24.0	11.5	5.3	2.6	4.7	7.9	21.8	0.5	0.2	-	-	78.5	3.9
1967	1.8	0.8	26.7	19.8	3.5	3.3	5.1	6.1	32.3	0.3	-	-	99.7	4.8
1968	1.1	141.4	61.5	59.3	38.1	14.3	6.6	0.7	1.0	6.1	0.1	-	330.2	2.3
1969	4.0	7.1	262.1	160.7	65.8	5.7	3.0	2.0	3.1	2.2	8.3	-	524.0	2.8
1970	4.8	193.5	54.5	522.1	162.9	27.6	7.0	5.3	9.9	10.0	3.8	2.8	1,004.2	3.0
1971	2.4	74.6	294.2	127.4	558.9	203.5	34.6	8.9	3.6	4.3	8.1	7.2	1,327.7	3.6
1972	3.6	22.1	85.7	256.2	182.6	390.4	87.3	24.0	4.2	8.2	3.8	5.6	1,073.7	4.2
1973	4.0	161.8	283.2	285.1	233.6	192.4	197.2	31.2	11.0	4.1	3.8	1.6	1,409.0	3.6
1974	2.0	95.9	242.2	264.4	101.5	114.3	111.8	108.3	25.7	6.4	2.5	0.8	1,075.8	3.8
1975	3.7	373.7	431.4	113.7	100.8	58.6	67.8	51.9	50.5	12.5	2.3	1.0	1,267.9	2.8
1976	-	12.5	353.5	272.5	85.7	52.4	27.3	40.5	34.6	22.6	13.4	1.4	916.4	3.5
1977	-	2.0	27.0	101.0	54.0	12.0	9.9	5.6	6.3	3.8	3.6	0.6	225.8	3.8
1978	-	0.1	0.2	4.7	17.4	13.3	8.4	4.7	2.2	4.5	1.5	5.8	62.8	5.9
1979	-	0.4	0.6	1.3	7.1	18.6	13.1	6.2	2.6	2.2	2.3	4.2	58.6	6.2
1980	-	1.2	10.9	1.0	1.0	6.9	13.8	4.7	2.0	1.0	1.0	4.2	47.7	5.6
1981	-	16.1	7.1	9.2	1.4	2.0	6.1	11.7	4.9	2.5	0.9	2.6	64.6	4.5
1982	-	3.7	11.8	2.7	9.1	1.2	1.9	3.4	8.4	2.9	1.5	3.6	50.3	5.2
1983	-	2.2	15.3	6.5	1.9	7.0	0.7	1.2	5.5	10.2	4.2	2.3	57.0	5.5
1984	-	0.5	40.4	27.2	3.2	1.2	4.6	0.6	0.7	3.4	7.9	6.1	95.8	4.1
1985	-	3.4	1.9	135.7	33.4	2.7	0.8	3.2	0.3	0.5	2.5	8.9	193.3	3.7
1986	-	1.1	10.4	6.5	91.7	22.1	1.7	0.5	3.1	0.2	0.7	4.9	143.0	4.3
1987	-	9.7	14.2	13.3	7.5	106.9	17.5	2.6	0.4	2.1	0.3	3.5	178.0	4.7
1988	-	1.5	13.0	10.3	10.1	11.5	107.4	22.5	2.6	1.2	0.9	4.8	185.9	5.7
1989	-	1.9	14.0	11.0	7.4	6.8	2.3	85.7	4.3	0.8	0.4	1.3	135.9	5.9
1990	-	1.8	19.4	26.4	7.5	6.3	4.2	0.8	51.8	5.0	0.4	0.8	124.5	5.5
1991	-	1.2	11.7	51.8	23.0	6.1	3.9	3.9	1.5	29.9	0.9	0.3	134.1	4.8
1992	-	1.9	7.9	4.4	18.3	11.0	1.4	1.0	0.7	0.9	10.8	0.6	58.7	5.1
1993	-	1.0	8.9	12.1	7.3	19.1	10.0	1.9	0.9	1.1	0.9	7.8	71.0	5.1
1994[2]	-	3.1	3.8	11.3	13.7	4.2	12.8	4.3	0.8	0.2	0.5	2.4	57.1	4.7

[1] Includes estimated recreational catches for 1961-1964, 1966-1969, 1971-1974, 1976-1978.
[2] Preliminary data.

Table C5. Commercial mean weight-at-age for Atlantic mackerel from 1962 to 1994 landings.

	AGE													
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1962[1]	.130	.208	.289	.365	.433	.491	.541	.581	.614	.641	.662	.000	.000	.000
1963	.120	.192	.264	.334	.395	.448	.492	.529	.559	.583	.602	.000	.000	.000
1964	.116	.188	.262	.332	.395	.450	.495	.533	.564	.588	.000	.000	.000	.000
1965	.123	.200	.278	.352	.419	.477	.525	.565	.598	.000	.000	.000	.000	.000
1966	.128	.209	.294	.374	.447	.509	.562	.605	.641	.000	.000	.000	.000	.000
1967	.123	.202	.283	.360	.428	.489	.540	.581	.615	.000	.000	.000	.000	.000
1968	.148	.241	.335	.425	.506	.576	.634	.683	.722	.753	.000	.000	.000	.000
1969	.131	.214	.300	.382	.456	.520	.574	.618	.654	.683	.000	.000	.000	.000
1970	.107	.179	.253	.324	.389	.444	.491	.530	.562	.587	.608	.000	.000	.000
1971	.110	.181	.256	.327	.391	.446	.494	.532	.564	.589	.610	.000	.000	.000
1972	.123	.210	.300	.386	.464	.533	.590	.638	.677	.708	.733	.000	.000	.000
1973	.113	.189	.269	.345	.414	.473	.524	.565	.600	.628	.650	.000	.000	.000
1974	.111	.190	.273	.352	.425	.487	.541	.585	.621	.649	.673	.000	.000	.000
1975	.104	.176	.252	.326	.393	.451	.500	.540	.573	.600	.621	.000	.000	.000
1976	.097	.168	.244	.316	.382	.440	.489	.530	.563	.590	.611	.000	.000	.000
1977	.114	.198	.288	.375	.454	.524	.582	.631	.671	.703	.729	.749	.000	.000
1978	.192	.285	.425	.463	.509	.582	.625	.659	.673	.697	.717	.797	.705	.000
1979	.190	.272	.531	.567	.579	.603	.652	.714	.752	.769	.822	.809	.842	.830
1980	.146	.376	.548	.609	.617	.635	.672	.705	.781	.743	.785	.773	.775	.778
1981	.114	.315	.523	.577	.643	.660	.674	.707	.723	.756	.772	.812	.780	.801
1982	.152	.340	.541	.606	.666	.743	.737	.722	.719	.740	.790	.811	.798	.829
1983	.098	.257	.479	.593	.628	.659	.712	.709	.705	.727	.735	.752	.744	.805
1984	.098	.162	.338	.525	.625	.657	.696	.715	.705	.709	.726	.755	.775	.770
1985	.111	.260	.277	.416	.558	.644	.677	.665	.737	.717	.715	.739	.731	.782
1986	.079	.234	.349	.366	.452	.581	.640	.729	.777	.750	.738	.717	.776	.781
1987	.107	.210	.316	.404	.411	.505	.502	.706	.747	.680	.750	.736	.781	.775
1988	.100	.222	.343	.408	.453	.484	.584	.694	.755	.815	.762	.775	.790	.761
1989	.100	.231	.375	.414	.474	.509	.529	.631	.753	.803	.816	.825	.801	.893
1990	.104	.206	.332	.450	.477	.528	.625	.572	.659	.718	.828	.806	.808	.853
1991	.145	.257	.362	.432	.506	.551	.572	.636	.640	.702	.830	.888	.818	.924
1992	.148	.261	.380	.430	.494	.549	.601	.678	.674	.686	.730	.753	.000	.957
1993	.229	.249	.340	.432	.475	.533	.602	.622	.679	.691	.698	.768	.000	.000
1994[2]	.177	.286	.345	.413	.489	.510	.560	.615	.704	.646	.714	.710	.843	.884

[1] Data from 1962-1983 are from Anderson (1984).

[2] Preliminary data.

Table C6. Stratified mean weight and number per tow of Atlantic mackerel from the NEFSC spring bottom trawl survey (offshore strata 1-25 and 61-76) during 1968-1994 with preliminary 1995 data.

YEAR	KG PER TOW	NUMBER PER TOW
1968	5.609	70.869
1969	0.055	0.484
1970	2.200	9.356
1971	3.145	12.668
1972	1.542	8.490
1973	6.746	20.973
1974	0.656	2.241
1975	0.242	3.540
1976	0.254	1.800
1977	0.081	0.287
1978	0.345	0.970
1979	0.089	0.172
1980	0.202	0.559
1981	2.470	5.872
1982	0.854	5.167
1983	0.135	0.884
1984	2.611	16.228
1985	2.232	8.242
1986	1.264	4.178
1987	7.492	35.231
1988	4.133	16.792
1989	1.100	12.273
1990	1.548	10.748
1991	5.604	23.265
1992	4.705	24.275
1993	5.583	26.089
1994	5.987	38.638
1995[1]	5.178	25.350

[1] Preliminary data.

Table C7. Number of Atlantic mackerel per tow at age from the NEFSC Spring bottom trawl survey (offshore strata 1-25 and 61-76) during 1968-1994.

	AGE													
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1968	12.9400	0.4150	0.1894	0.0523	0.0164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1969	0.0297	0.1418	0.0167	0.0058	0.0003	0.0007	0.0005	0.0009	0.0004	0.0004	0.0000	0.0000	0.0000	0.0000
1970	0.2795	0.1845	1.3910	0.6115	0.1812	0.0617	0.0549	0.0877	0.0827	0.0447	0.0026	0.0000	0.0000	0.0000
1971	0.3282	0.9409	0.4383	1.1250	0.3929	0.0621	0.0141	0.0073	0.0062	0.0048	0.0035	0.0000	0.0000	0.0000
1972	0.8719	0.3077	0.5929	0.2261	0.3254	0.0583	0.0112	0.0011	0.0018	0.0004	0.0000	0.0000	0.0000	0.0000
1973	0.3514	0.3398	0.1758	0.2338	0.1262	0.2846	0.1821	0.1524	0.0460	0.0367	0.0033	0.0291	0.0181	0.0150
1974	0.3478	0.1796	0.2358	0.0478	0.0985	0.0599	0.2084	0.0912	0.0590	0.0117	0.0115	0.0000	0.0000	0.0000
1975	0.6544	0.2298	0.0409	0.0226	0.0064	0.0073	0.0043	0.0039	0.0034	0.0000	0.0000	0.0000	0.0000	0.0000
1976	0.0959	0.3871	0.0710	0.0135	0.0024	0.0006	0.0028	0.0004	0.0019	0.0003	0.0003	0.0000	0.0000	0.0000
1977	0.0095	0.0472	0.0850	0.0453	0.0154	0.0052	0.0028	0.0070	0.0038	0.0054	0.0010	0.0075	0.0000	0.0000
1978	0.0502	0.1097	0.1032	0.1943	0.0958	0.0284	0.0110	0.0027	0.0148	0.0000	0.0164	0.0000	0.0013	0.0000
1979	0.0105	0.0037	0.0072	0.0126	0.0495	0.0144	0.0103	0.0057	0.0057	0.0190	0.0042	0.0156	0.0030	0.0064
1980	0.0234	0.1877	0.0066	0.0048	0.0233	0.0489	0.0110	0.0107	0.0070	0.0017	0.0096	0.0000	0.0107	0.0064
1981	0.3355	0.1371	0.4294	0.0476	0.0463	0.1613	0.4041	0.2302	0.1385	0.0704	0.0673	0.0844	0.0769	0.1031
1982	0.4323	0.1950	0.0215	0.0979	0.0182	0.0102	0.0245	0.0965	0.0440	0.0266	0.0156	0.0122	0.0200	0.0092
1983	0.2357	0.2873	0.0222	0.0016	0.0036	0.0006	0.0002	0.0014	0.0022	0.0004	0.0008	0.0006	0.0002	0.0000
1984	0.2598	1.8014	0.6055	0.0415	0.0050	0.0432	0.0036	0.0025	0.0161	0.0470	0.0153	0.0075	0.0041	0.0098
1985	0.3382	0.0846	1.8513	0.2348	0.0277	0.0107	0. ,69	0.0032	0.0097	0.0416	0.0666	0.0405	0.0119	0.0258
1986	0.1301	0.4497	0.0778	0.5908	0.1177	0.0080	0.0014	0.0196	0.0004	0.0019	0.0184	0.0101	0.0054	0.0116
1987	1.4842	1.7945	0.8742	0.3719	2.9450	0.4967	0.1427	0.0156	0.1383	0.0058	0.0406	0.0412	0.1202	0.0482
1988	0.6336	0.4577	0.3666	0.3357	0.3748	1.7688	0.4428	0.0513	0.0478	0.0405	0.0426	0.0764	0.0519	0.0118
1989	1.5826	1.6407	0.0707	0.2841	0.0087	0.0108	0.0666	0.0086	0.0050	0.0044	0.0060	0.0020	0.0029	0.0029
1990	1.3003	1.3849	0.5010	0.0157	0.0129	0.0059	0.0004	0.0762	0.0094	0.0043	0.0026	0.0014	0.0045	0.0029
1991	1.6697	0.8891	1.4843	0.5374	0.2400	0.1144	0.0578	0.0000	0.2685	0.0027	0.0000	0.0000	0.0000	0.0000
1992	2.6984	2.3787	0.5585	1.0531	0.6272	0.1155	0.1321	0.0312	0.0449	0.2642	0.0085	0.0256	0.0000	0.0000
1993	0.9331	2.2477	0.9019	0.6031	0.9864	0.4515	0.1389	0.0915	0.2184	0.0981	0.4495	0.0810	0.0000	0.0000
1994	3.5268	1.5597	1.8807	0.6936	0.2594	0.4821	0.1735	0.0615	0.0100	0.0802	0.0380	0.0886	0.0000	0.0000

Table C8. Stratified mean weight (kg) and number per tow of Atlantic mackerel captured during the NEFSC winter bottom trawl survey (Offshore strata 1-25 and 61-76), 1992-1995[1].

KG PER TOW

YEAR	MEAN	CV
1992	12.538	(60%)
1993	4.257	(42%)
1994	0.229	(29%)
1995[1]	23.478	-

[1] Preliminary data.

NUMBER PER TOW

YEAR	MEAN	CV
1992	40.681	(48%)
1993	17.229	(37%)
1994	1.050	(30%)
1995[1]	64.619	-

[1] Preliminary data.

Table C10. Average number of Atlantic mackerel caught per angler trip in the U.S. recreational fishery from North Carolina to Maine, 1981-1994.

YEAR	MACKEREL PER ANGLER PER TRIP
1981	12.5
1982	13.9
1983	33.1
1984	43.1
1985	25.2
1986	36.6
1987	26.9
1988	31.0
1989	29.0
1990	26.8
1991	22.3
1992	15.2
1993	7.0
1994	4.3

Table C9. Nominal U.S. commercial LPUE (mt per day fished) and vessel counts (in parentheses) by tonnage class[1] for trips that landed Atlantic mackerel with otter trawl gear during 1982-1993, and nominal LPUE for the subset of these trips that landed at least 50% mackerel.

	ALL TRIPS TONNAGE CLASS			50% MACKEREL TRIPS TONNAGE CLASS		
YEAR	2	3	4	2	3	4
1982	2.7 (101[2])	15.3 (132)	57.6 (28)	78.0 (8)	183.6 (24)	191.6 (10)
1983	2.6 (120)	4.4 (146)	27.0 (27)	89.4 (12)	232.6 (14)	439.5 (6)
1984	2.4 (112)	6.9 (150)	23.2 (26)	63.6 (11)	176.0 (17)	269.7 (10)
1985	1.0 (113)	5.7 (160)	36.0 (30)	31.0 (5)	223.2 (18)	373.5 (10)
1986	1.8 (105)	7.0 (142)	98.3 (30)	109.0 (6)	353.8 (17)	590.2 (12)
1987	1.7 (95)	8.5 (148)	89.6 (30)	-	268.2 (18)	791.6 (12)
1988	1.6 (95)	10.3 (117)	104.8 (36)	191.0 (3)	175.1 (21)	646.5 (20)
1989	0.5 (71)	14.8 (112)	106.0 (42)	43.0 (2)	305.4 (15)	495.7 (20)
1990	2.2 (70)	27.9 (117)	118.8 (38)	158.5 (5)	646.5 (25)	875.9 (21)
1991	3.1 (79)	90.1 (113)	194.2 (37)	62.8 (7)	913.9 (22)	1040.9 (21)
1992	3.2 (72)	54.4 (128)	123.6 (37)	98.0 (4)	648.8 (34)	661.5 (20)
1993	2.9 (70)	15.0 (127)	44.3 (39)	106.5 (4)	214.8 (24)	257.2 (12)

[1] Vessels in tonnage class 2 are 5-50 GRT, vessels in tonnage class 3 are 51-150 GRT, and vessel in tonnage class 4 are 151-500 GRT.
[2] Vessel count.

Table C11. Summary output from the ADAPT VPA tuning model as applied to Atlantic mackerel.

STOCK NUMBERS (Jan 1) in millions - MACK95

	1962	1963	1964	1965	1966	1967	1968
1	347.997	213.648	229.840	288.323	684.067	1969.820	4968.030
2	179.863	270.348	173.925	176.505	227.915	538.350	1612.029
3	549.067	144.726	217.542	136.064	141.252	176.196	416.605
4	32.014	435.784	117.315	174.398	108.776	110.852	126.341
5	16.708	22.772	332.993	92.430	139.166	86.705	87.591
6	4.602	12.594	13.215	255.078	70.970	109.687	68.002
7	3.136	2.320	10.040	7.110	191.196	50.957	85.189
8	6.733	1.301	1.719	4.691	2.021	136.812	36.201
9	2.646	4.789	0.884	0.774	0.221	1.202	82.786
10	2.514	1.805	3.740	0.000	0.000	0.000	0.713
11+	7.525	1.800	0.001	0.001	0.001	0.000	0.000
1+	1152.806	1111.887	1101.213	1135.373	1565.585	3180.583	7483.488

	1969	1970	1971	1972	1973	1974	1975
1	2060.528	2497.431	1317.329	1355.237	1164.219	1774.134	2038.159
2	3939.535	1680.594	1869.638	1011.037	1089.578	806.780	1365.764
3	1264.170	2988.261	1326.640	1264.527	750.222	635.821	441.384
4	287.430	889.607	1974.165	970.885	803.488	356.261	281.327
5	68.965	175.790	580.951	1110.596	629.670	446.470	199.841
6	58.774	51.306	118.951	291.508	556.031	341.439	262.116
7	49.704	45.406	35.672	66.081	159.674	276.806	178.386
8	69.114	38.884	32.379	21.153	32.387	102.499	128.635
9	28.734	53.780	22.878	23.253	13.518	16.563	60.665
10	62.260	21.535	34.983	14.840	11.618	7.358	7.770
11+	0.000	15.784	30.893	21.713	4.848	2.332	3.350
1+	7889.215	8458.379	7344.480	6150.830	5215.253	4766.463	4967.397

	1976	1977	1978	1979	1980	1981	1982
1	560.122	158.017	54.838	212.269	86.653	159.025	535.631
2	1330.566	447.278	127.564	44.807	173.429	69.860	115.631
3	727.846	769.515	341.770	104.259	36.142	132.129	50.772
4	258.494	349.342	538.637	275.565	84.184	28.686	99.854
5	139.123	134.093	237.156	425.255	219.189	68.019	22.219
6	110.592	66.491	98.928	182.132	331.339	173.213	53.880
7	153.254	65.843	45.480	73.395	137.264	258.791	136.296
8	99.089	88.828	48.841	32.984	54.480	108.130	201.293
9	59.623	49.820	67.026	37.997	24.652	42.795	84.095
10	38.358	28.366	37.351	50.804	29.119	19.279	32.776
11+	3.969	4.708	144.074	92.540	122.016	55.552	78.463
1+	3481.038	2162.302	1741.664	1532.006	1298.467	1115.478	1410.909

	1983	1984	1985	1986	1987	1988	1989
1	6380.537	396.727	376.381	558.490	514.281	1546.277	1916.196
2	435.190	5221.951	324.360	305.078	456.258	412.281	1264.627
3	83.993	342.459	4238.817	263.845	240.366	360.703	325.784
4	39.125	62.886	255.770	3347.663	210.136	184.761	285.999
5	73.519	30.314	48.592	179.185	2657.861	165.259	142.131
6	17.106	53.859	23.733	37.340	126.708	2079.346	124.897
7	42.394	13.372	39.933	18.707	29.033	87.905	1605.245
8	108.513	33.623	10.405	29.799	14.864	21.418	51.612

Table C11 (Continued)

9	157.204	83.866	26.895	8.247	21.593	11.807	15.183
10	66.227	119.479	65.587	21.567	6.571	15.778	8.581
11+	36.164	102.542	232.937	150.630	76.473	83.921	27.819
1+	7439.973	6461.079	5643.410	4920.552	4354.144	4969.455	5768.074

	1990	1991	1992	1993	1994	1995
1	910.739	1441.162	3294.080	1490.705	3355.944	0.000
2	1567.130	744.021	1178.838	2695.246	1219.581	2744.809
3	1022.721	1265.503	598.567	958.003	2198.627	995.070
4	256.776	813.446	989.236	486.084	773.398	1789.859
5	227.460	203.444	645.182	793.359	391.366	620.808
6	110.214	180.528	161.047	518.277	632.265	316.623
7	99.904	86.435	144.275	130.587	415.281	506.073
8	1236.719	81.071	67.238	117.218	105.196	336.112
9	38.365	965.669	65.018	54.417	95.155	85.404
10	11.707	26.887	763.568	52.418	43.557	77.726
11+	23.361	8.943	42.341	453.389	208.685	203.899
1+	5505.097	5817.109	7949.390	7749.701	9439.057	7676.384

FISHING MORTALITY - MACK95

	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	0.0525	0.0057	0.0640	0.0351	0.0395	0.0004	0.0320	0.0038	0.0895	0.0646
2	0.0174	0.0173	0.0455	0.0228	0.0574	0.0564	0.0431	0.0764	0.0365	0.1910
3	0.0311	0.0100	0.0210	0.0238	0.0424	0.1326	0.1712	0.1514	0.2145	0.1122
4	0.1406	0.0690	0.0384	0.0257	0.0268	0.0355	0.4054	0.2917	0.2261	0.3752
5	0.0827	0.3442	0.0666	0.0642	0.0380	0.0430	0.1990	0.0958	0.1906	0.4896
6	0.4849	0.0267	0.4199	0.0883	0.1313	0.0528	0.1135	0.0581	0.1634	0.3878
7	0.6798	0.1001	0.5609	1.0580	0.1347	0.1419	0.0091	0.0455	0.1381	0.3226
8	0.1408	0.1862	0.5980	2.8545	0.3195	0.3023	0.0310	0.0508	0.3304	0.1311
9	0.1828	0.0473	8.3860	8.3381	7.5510	0.3227	0.0849	0.0884	0.2300	0.2328
10	0.0450	0.0632	0.0609	0.0693	0.0757	0.1235	0.1685	0.1594	0.2169	0.2956
11	0.0450	0.0632	0.0609	0.0693	0.0757	0.1235	0.1685	0.1594	0.2169	0.2956
4+[1]	0.1599	0.0811	0.0969	0.1128	0.0890	0.1258	0.1754	0.1794	0.2187	0.3928

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	0.0182	0.1668	0.0616	0.2264	0.0250	0.0141	0.0020	0.0021	0.0154	0.1187
2	0.0984	0.3386	0.4031	0.4294	0.3476	0.0690	0.0017	0.0149	0.0720	0.1191
3	0.2535	0.5447	0.6154	0.3350	0.5340	0.1567	0.0153	0.0139	0.0311	0.0801
4	0.2330	0.3876	0.3781	0.5042	0.4563	0.1873	0.0364	0.0289	0.0132	0.0554
5	0.4918	0.4120	0.3326	0.3917	0.5383	0.1041	0.0640	0.0495	0.0354	0.0330
6	0.4019	0.4975	0.4492	0.3367	0.3186	0.1798	0.0985	0.0828	0.0471	0.0397
7	0.5131	0.2433	0.5663	0.3879	0.3454	0.0987	0.1213	0.0980	0.0386	0.0513
8	0.2477	0.4706	0.3245	0.5689	0.4876	0.0816	0.0511	0.0911	0.0414	0.0514
9	0.4939	0.4083	0.5569	0.2584	0.5428	0.0881	0.0771	0.0661	0.0459	0.0667
10	0.3327	0.4486	0.4708	0.3962	0.4879	0.1511	0.0454	0.0513	0.0387	0.0530
11	0.3327	0.4486	0.4708	0.3962	0.4879	0.1511	0.0454	0.0513	0.0387	0.0530
4+	0.3779	0.4136	0.4132	0.4196	0.4433	0.1454	0.0541	0.0548	0.0389	0.0482

[1]Mean F ages 4-11 weighted by stock numbers at age.

Table C11. (Continued)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0.0077	0.0004	0.0014	0.0100	0.0022	0.0211	0.0011	0.0011	0.0022	0.0009
2	0.1197	0.0396	0.0086	0.0065	0.0384	0.0350	0.0355	0.0123	0.0138	0.0175
3	0.0606	0.0894	0.0919	0.0360	0.0276	0.0631	0.0321	0.0380	0.0289	0.0463
4	0.1062	0.0552	0.0579	0.1559	0.0307	0.0402	0.0623	0.0290	0.0328	0.0317
5	0.0615	0.1112	0.0447	0.0634	0.1465	0.0455	0.0800	0.0543	0.0311	0.0337
6	0.0398	0.0463	0.0991	0.0380	0.0516	0.1656	0.0588	0.0233	0.0430	0.0242
7	0.0280	0.0318	0.0509	0.0927	0.0300	0.1042	0.3325	0.0608	0.0089	0.0512
8	0.0472	0.0576	0.0233	0.0324	0.1221	0.0302	0.1441	0.0966	0.0474	0.0207
9	0.0389	0.0744	0.0458	0.0208	0.0272	0.1137	0.1191	0.0600	0.1555	0.0348
10	0.0519	0.0727	0.0759	0.0430	0.0365	0.0518	0.0651	0.0529	0.0385	0.0377
11	0.0519	0.0727	0.0759	0.0430	0.0365	0.0518	0.0651	0.0529	0.0385	0.0377
4+	0.0514	0.0701	0.0650	0.0871	0.0374	0.0511	0.0706	0.0550	0.0434	0.0330

	1992	1993	1994
1	0.0006	0.0007	0.0010
2	0.0074	0.0037	0.0034
3	0.0082	0.0141	0.0057
4	0.0207	0.0167	0.0198
5	0.0190	0.0270	0.0119
6	0.0097	0.0216	0.0226
7	0.0077	0.0162	0.0115
8	0.0116	0.0085	0.0084
9	0.0154	0.0226	0.0023
10	0.0158	0.0192	0.0128
11	0.0158	0.0192	0.0128
4+	0.0173	0.0210	0.0163

BACKCALCULATED PARTIAL RECRUITMENT

	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	0.08	0.02	0.01	0.00	0.01	0.00	0.08	0.01	0.27	0.13	0.04	0.31	0.10	0.40	0.05
2	0.03	0.05	0.01	0.00	0.01	0.17	0.11	0.26	0.11	0.39	0.19	0.62	0.66	0.75	0.64
3	0.05	0.03	0.00	0.00	0.01	0.41	0.42	0.52	0.65	0.23	0.49	1.00	1.00	0.59	0.98
4	0.21	0.20	0.00	0.00	0.00	0.11	1.00	1.00	0.68	0.77	0.45	0.71	0.61	0.89	0.84
5	0.12	1.00	0.01	0.01	0.01	0.13	0.49	0.33	0.58	1.00	0.96	0.76	0.54	0.69	0.99
6	0.71	0.08	0.05	0.01	0.02	0.16	0.28	0.20	0.49	0.79	0.78	0.91	0.73	0.59	0.59
7	1.00	0.29	0.07	0.13	0.02	0.44	0.02	0.16	0.42	0.66	1.00	0.45	0.92	0.68	0.64
8	0.21	0.54	0.07	0.34	0.04	0.94	0.08	0.17	1.00	0.27	0.48	0.86	0.53	1.00	0.90
9	0.27	0.14	1.00	1.00	1.00	1.00	0.21	0.30	0.70	0.48	0.96	0.75	0.91	0.45	1.00
10	0.07	0.18	0.01	0.01	0.01	0.38	0.42	0.55	0.66	0.60	0.65	0.82	0.77	0.70	0.90
11+	0.07	0.18	0.01	0.01	0.01	0.38	0.42	0.55	0.66	0.60	0.65	0.82	0.77	0.70	0.90

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0.08	0.02	0.02	0.21	1.00	0.06	0.00	0.01	0.06	0.01	0.13	0.00	0.01	0.01	0.02
2	0.37	0.01	0.15	1.00	1.00	1.00	0.36	0.09	0.04	0.26	0.21	0.11	0.13	0.09	0.34
3	0.84	0.13	0.14	0.43	0.67	0.51	0.80	0.93	0.23	0.19	0.38	0.10	0.39	0.19	0.90
4	1.00	0.30	0.29	0.18	0.47	0.89	0.50	0.58	1.00	0.21	0.24	0.19	0.30	0.21	0.62
5	0.56	0.53	0.51	0.49	0.28	0.51	1.00	0.45	0.41	1.00	0.27	0.24	0.56	0.20	0.66
6	0.96	0.81	0.85	0.65	0.33	0.33	0.42	1.00	0.24	0.35	1.00	0.18	0.24	0.28	0.47
7	0.53	1.00	1.00	0.54	0.43	0.23	0.29	0.51	0.59	0.20	0.63	1.00	0.63	0.06	1.00
8	0.44	0.42	0.93	0.58	0.43	0.39	0.52	0.23	0.21	0.83	0.18	0.43	1.00	0.30	0.40
9	0.47	0.64	0.67	0.64	0.56	0.32	0.67	0.46	0.13	0.19	0.69	0.36	0.62	1.00	0.68
10	0.81	0.37	0.52	0.54	0.44	0.43	0.65	0.77	0.28	0.25	0.31	0.20	0.55	0.25	0.74
11+	0.81	0.37	0.52	0.54	0.44	0.43	0.65	0.77	0.28	0.25	0.31	0.20	0.55	0.25	0.74

Table C11. (Continued)

	1992	1993	1994
1	0.03	0.03	0.05
2	0.36	0.14	0.15
3	0.39	0.52	0.25
4	1.00	0.62	0.87
5	0.92	1.00	0.53
6	0.47	0.80	1.00
7	0.37	0.60	0.51
8	0.56	0.32	0.37
9	0.75	0.84	0.10
10	0.76	0.71	0.56
11+	0.76	0.71	0.56

SSB AT THE START OF THE SPAWNING SEASON - males & females (1000s MT)

	1962	1963	1964	1965	1966	1967	1968	1969
1	0.797	0.463	0.467	0.631	1.554	4.384	13.095	4.876
2	21.142	29.334	18.220	19.895	26.386	60.268	216.744	462.579
3	139.953	34.056	50.522	33.482	36.421	41.801	114.765	314.962
4	9.855	127.233	34.572	54.838	36.321	35.474	39.671	85.867
5	6.281	6.852	115.120	33.936	55.227	32.865	36.306	27.125
6	1.605	5.037	4.362	105.340	30.610	47.269	33.487	26.863
7	1.093	0.983	3.397	1.990	90.894	23.193	48.648	25.234
8	3.299	0.567	0.615	0.575	0.943	61.833	22.028	37.678
9	1.342	2.366	0.007	0.006	0.003	0.569	51.835	16.268
10	1.426	0.922	1.930	0.000	0.000	0.000	0.446	35.530
11+	4.407	0.950	0.000	0.000	0.000	0.000	0.000	0.000
1+	191.200	208.763	229.212	250.694	278.359	307.656	577.025	1036.982

	1970	1971	1972	1973	1974	1975	1976	1977
1	4.624	2.539	2.989	2.190	3.456	3.425	0.971	0.324
2	168.384	175.332	115.223	99.106	71.430	110.551	107.097	48.771
3	608.355	287.631	299.371	137.679	114.306	84.269	121.806	183.563
4	232.924	484.192	301.806	206.635	93.922	64.495	58.832	107.938
5	56.251	160.906	364.624	191.961	145.389	58.425	36.741	52.290
6	18.995	39.542	114.993	185.566	120.189	90.392	37.547	28.815
7	18.827	13.570	27.295	67.036	102.086	66.476	57.055	33.004
8	15.808	14.598	10.789	13.086	46.130	47.291	37.238	48.688
9	24.377	10.392	11.127	5.984	7.045	27.641	23.154	28.945
10	10.262	16.083	8.050	5.275	3.415	3.460	16.045	16.731
11+	7.791	14.709	12.194	2.278	1.122	1.544	1.719	2.919
1+	1166.597	1219.493	1268.461	916.797	708.490	557.969	498.204	551.988

	1978	1979	1980	1981	1982	1983	1984	1985
1	0.190	0.729	0.227	0.309	1.468	11.314	0.703	0.752
2	20.706	6.896	35.858	11.819	21.110	62.505	480.169	47.918
3	129.123	49.250	17.468	59.473	23.871	34.464	99.033	1033.019
4	221.592	139.349	46.084	14.567	51.922	20.422	29.021	89.057
5	105.786	217.340	120.222	38.926	12.984	39.517	16.764	23.769
6	49.592	95.343	185.945	101.409	35.510	9.967	30.469	13.570
7	24.207	41.229	81.869	153.833	89.629	26.881	8.209	23.354
8	28.389	20.360	34.041	67.418	128.435	67.636	21.501	6.160
9	39.272	25.014	17.026	27.078	53.658	96.620	52.287	17.750
10	23.027	34.455	19.201	12.843	21.384	42.011	73.795	41.645
11+	92.269	66.993	84.373	37.791	54.650	23.193	64.853	147.492
1+	734.155	696.957	642.315	525.465	494.621	434.531	876.807	1444.486

Table C11 (Continued)

■	1986	1987	1988	1989	1990	1991	1992
1 ■	0.798	0.985	2.797	3.466	1.712	3.780	8.820
2 ■	39.921	53.671	51.257	165.505	182.765	108.049	174.740
3 ■	81.355	65.927	109.065	107.376	299.789	400.982	202.923
4 ■	1091.737	75.286	66.116	105.593	102.852	312.960	380.937
5 ■	68.107	966.209	65.081	59.325	96.659	91.590	285.660
6 ■	19.130	53.297	884.259	56.857	51.534	88.924	79.616
7 ■	10.672	12.518	39.336	745.353	56.248	43.606	78.157
8 ■	18.492	9.353	12.515	28.078	625.094	46.175	41.011
9 ■	5.720	13.788	7.600	10.039	21.165	549.564	39.347
10 ■	14.371	3.940	11.263	6.072	7.461	16.759	470.242
11+■	98.765	50.570	56.009	20.004	17.168	6.591	27.748
1+■	1449.069	1305.545	1305.298	1307.670	1462.448	1668.981	1789.200

■	1993	1994
1 ■	6.175	10.744
2 ■	381.869	198.490
3 ■	289.734	677.547
4 ■	188.422	286.174
5 ■	336.417	172.136
6 ■	247.274	288.487
7 ■	70.558	209.219
8 ■	65.691	58.293
9 ■	33.057	60.544
10 ■	32.461	25.298
11+■	283.620	133.964
1+■	1935.279	2120.897

Table C12. Bootstrap results for the mackerel ADAPT run.

BOOTSTRAP RESULTS FOR MACK95 Timestamp 1995 6 22 9 4 38
NORTHWEST ATLANTIC MACKEREL

SEED FOR THE RANDOM NUMBER GENERATOR: 74747
MAIN LOOP LIMIT IN MARQUARDT ALGORITHM: 50
NUMBER OF BOOTSTRAP REPLICATIONS ATTEMPTED: 500
NUMBER FOR WHICH NLLS CONVERGED: 500
Results from the converged replications are used for computing the statistics that follow. Other replications are ignored.

BOOTSTRAP OUTPUT VARIABLE: N_t1
Full vector of age-specific stocksizes on Jan 1, 1995

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
7.687E2	9.118E2	3.740E2	0.49
2.745E3	3.770E3	3.578E3	1.30
9.950E2	2.315E3	4.479E3	4.50
1.790E3	3.495E3	3.975E3	2.22
6.208E2	1.080E3	1.091E3	1.76
3.166E2	5.659E2	6.877E2	2.17
5.061E2	8.964E2	1.039E3	2.05
3.361E2	5.678E2	5.738E2	1.71
8.540E1	1.403E2	1.508E2	1.77
7.772E1	1.400E2	1.767E2	2.27
2.039E2	2.805E2	2.674E2	1.31

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1.431E2	1.673E1	18.61	6.257E2	0.60
1.025E3	1.600E2	37.35	1.720E3	2.08
1.320E3	2.003E2	132.68	-3.251E2	-13.78
1.705E3	1.778E2	95.25	8.493E1	46.81
4.589E2	4.879E1	73.92	1.619E2	6.74
2.493E2	3.075E1	78.73	6.735E1	10.21
3.904E2	4.645E1	77.14	1.157E2	8.98
2.317E2	2.566E1	68.94	1.044E2	5.50
5.489E1	6.742E0	64.27	3.051E1	4.94
6.228E1	7.902E0	80.13	1.544E1	11.44
7.661E1	1.196E1	37.57	1.273E2	2.10

BOOTSTRAP OUTPUT VARIABLE: F_t
Full vector of age-specific terminal F's (in 1994)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1.021E-3	1.328E-3	1.038E-3	1.02
3.450E-3	6.040E-3	1.138E-2	3.30
5.696E-3	7.330E-3	8.063E-3	1.42
1.977E-2	2.423E-2	2.451E-2	1.24
1.193E-2	1.445E-2	1.517E-2	1.27
2.263E-2	3.045E-2	3.458E-2	1.53
1.151E-2	1.488E-2	1.462E-2	1.27
8.440E-3	1.175E-2	1.552E-2	1.84
2.326E-3	3.867E-3	2.243E-2	9.64
1.277E-2	1.660E-2	1.298E-2	1.02
1.277E-2	1.660E-2	1.298E-2	1.02

Table C12. (Continued)

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
3.069E-4	4.643E-5	30.04	7.146E-4	1.45
2.590E-3	5.089E-4	75.10	8.591E-4	13.25
1.634E-3	3.606E-4	28.68	4.063E-3	1.98
4.460E-3	1.096E-3	22.56	1.531E-2	1.60
2.515E-3	6.785E-4	21.08	9.416E-3	1.61
7.824E-3	1.547E-3	34.57	1.481E-2	2.34
3.366E-3	6.539E-4	29.25	8.144E-3	1.80
3.307E-3	6.940E-4	39.18	5.134E-3	3.02
1.541E-3	1.003E-3	66.27	7.844E-4	28.59
3.836E-3	5.804E-4	30.04	8.932E-3	1.45
3.836E-3	5.804E-4	30.04	8.932E-3	1.45

BOOTSTRAP OUTPUT VARIABLE: F_full_t
Fully-recruited F in the terminal year (1994)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1.277E-2	1.660E-2	1.298E-2	1.02

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
3.836E-3	5.804E-4	30.04	8.932E-3	1.45

BOOTSTRAP OUTPUT VARIABLE: B_mean_t
Mean stock biomass during the terminal year (1994)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
2.776E3	4.900E3	4.574E3	1.65

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
2.124E3	2.046E2	76.53	6.515E2	7.02

BOOTSTRAP OUTPUT VARIABLE: SSB_spawn_t
SSB (males & females) at start of spawning season (1994)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
2.121E3	3.884E3	3.566E3	1.68

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1.763E3	1.595E2	83.14	3.576E2	9.97

Table C13. Atlantic mackerel spawning stock biomass (SSB), recruitment(R),and R/SSB, 1962-1993.

YEAR CLASS	SSB (000'S MT)	RECRUITMENT (000,000'S)	R/SSB
1962	191.2	213.6	1.117
1963	208.8	229.8	1.101
1964	229.2	288.3	1.258
1965	250.7	684.1	2.729
1966	278.4	1969.8	7.077
1967	307.7	4968.0	16.148
1968	577.0	2060.5	3.571
1969	1037.0	2497.4	2.408
1970	1166.6	1317.3	1.129
1971	1219.5	1355.2	1.111
1972	1268.5	1164.2	0.918
1973	916.8	1774.1	1.935
1974	708.5	2038.2	2.877
1975	558.0	560.1	1.004
1976	498.2	158.0	0.317
1977	552.0	54.8	0.099
1978	734.2	212.3	0.289
1979	697.0	86.7	0.124
1980	642.3	159.0	0.248
1981	525.5	535.6	1.019
1982	494.6	6380.5	12.900
1983	434.5	396.7	0.913
1984	876.8	376.4	0.429
1985	1444.5	558.5	0.387
1986	1449.1	514.3	0.355
1987	1305.5	1546.3	1.184
1988	1305.3	1916.2	1.468
1989	1307.7	910.7	0.696
1990	1462.4	1441.2	0.985
1991	1669.0	3294.1	1.974
1992	1789.2	1490.7	0.833
1993	1935.3	3355.9	1.734
AVG 62-69	385.0	1614.0	4.426
AVG 70-79	831.9	872.1	0.980
AVG 80-89	978.6	1329.4	1.960
AVG 90-93	1714.0	2395.5	1.382
AVG 62-93	876.3	1390.9	2.198

Table C14. Yield and spawning stock biomass per recruit analysis for Atlantic mackerel.

Yield and Spawning Stock Biomass per Recruit
Atlantic_Mackerel

Proportion of F before spawning: 0.5000
Proportion of M before spawning: 0.5000
Natural mortality is constant at: 0.2000
Initial age is: 1 Last age is: 11
Last age is a PLUS group
Input data from file named: mackerel.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Stock	Average Weights Catch
1	0.0500	1.0000	0.0200	0.1270	0.1270
2	0.2700	1.0000	0.6300	0.2290	0.2290
3	0.4700	1.0000	0.9900	0.3410	0.3410
4	1.0000	1.0000	1.0000	0.4180	0.4180
5	1.0000	1.0000	1.0000	0.4800	0.4800
6	1.0000	1.0000	1.0000	0.5360	0.5360
7	1.0000	1.0000	1.0000	0.5830	0.5830
8	1.0000	1.0000	1.0000	0.6280	0.6280
9	1.0000	1.0000	1.0000	0.6660	0.6660
10	1.0000	1.0000	1.0000	0.6880	0.6880
11+	1.0000	1.0000	1.0000	0.7200	0.7200

Summary of Yield per Recruit Analysis for:
Atlantic_Mackerel

The slope of the yield per recruit curve at F=0: 1.742784
F level at slope=1/10 of the above slope (F0.1): 0.269958
Yield/Recruit corresponding to F0.1: 0.164178
F level to produce Maximum Yield/Recruit (Fmax): 0.977439
Yield/Recruit corresponding to Fmax: 0.192960
F level at 0.20 of max spawning potential: 0.722231
SSB/Recruit corresponding to F=0.722231: 0.381012

Listing of Yield per Recruit Results for:
Atlantic_Mackerel

FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	%MSP
0.000	0.00000	0.00000	5.5167	2.3015	3.8248	1.9051	100.00
0.050	0.13159	0.06642	4.8613	1.8754	3.1693	1.4868	78.04
0.100	0.22028	0.10615	4.4205	1.5981	2.7284	1.2160	63.83
0.150	0.28441	0.13156	4.1023	1.4044	2.4102	1.0278	53.95
0.200	0.33318	0.14860	3.8607	1.2620	2.1689	0.8902	46.73
0.250	0.37170	0.16046	3.6704	1.1531	1.9789	0.7856	41.24
0.300	0.40301	0.16894	3.5160	1.0674	1.8249	0.7035	36.93
0.350	0.42908	0.17513	3.3877	0.9980	1.6972	0.6375	33.46
0.400	0.45119	0.17973	3.2791	0.9409	1.5892	0.5833	30.62
0.450	0.47026	0.18318	3.1857	0.8928	1.4965	0.5380	28.24
0.500	0.48693	0.18580	3.1042	0.8519	1.4159	0.4995	26.22
0.550	0.50166	0.18779	3.0322	0.8165	1.3449	0.4665	24.49
0.600	0.51481	0.18930	2.9682	0.7856	1.2818	0.4377	22.98
0.650	0.52665	0.19045	2.9105	0.7584	1.2252	0.4125	21.65
0.700	0.53740	0.19130	2.8583	0.7341	1.1742	0.3902	20.48
0.750	0.54722	0.19193	2.8107	0.7123	1.1278	0.3702	19.43
0.800	0.55625	0.19238	2.7670	0.6926	1.0853	0.3523	18.49
0.850	0.56459	0.19268	2.7267	0.6747	1.0463	0.3360	17.64
0.900	0.57233	0.19286	2.6893	0.6584	1.0103	0.3213	16.86
0.950	0.57955	0.19295	2.6545	0.6433	0.9769	0.3078	16.16
1.000	0.58630	0.19295	2.6220	0.6294	0.9459	0.2954	15.50

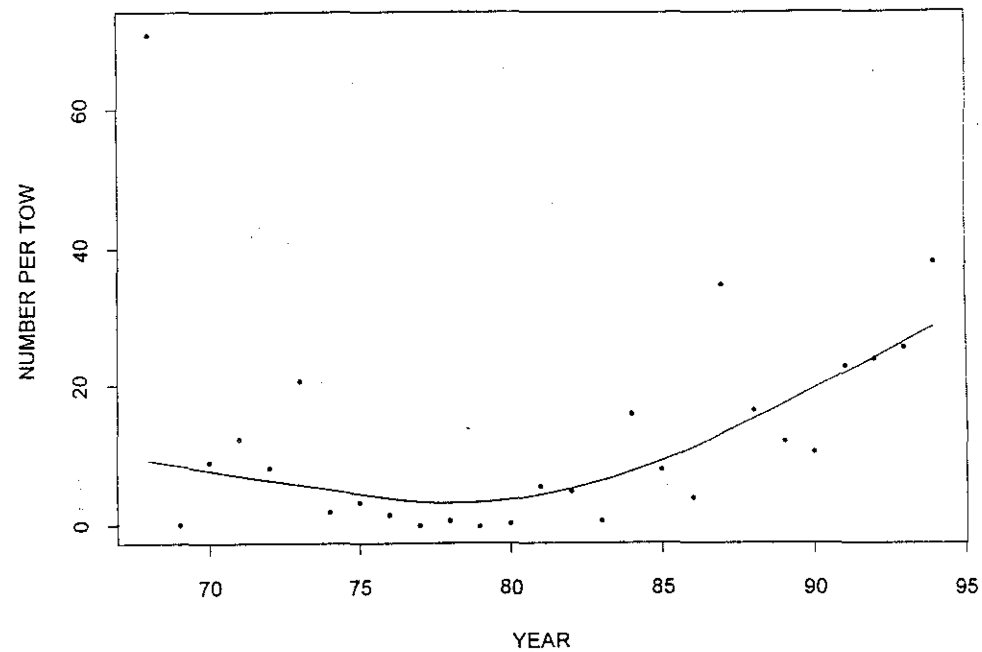

Figure C1. Mackerel number per tow, spring survey.

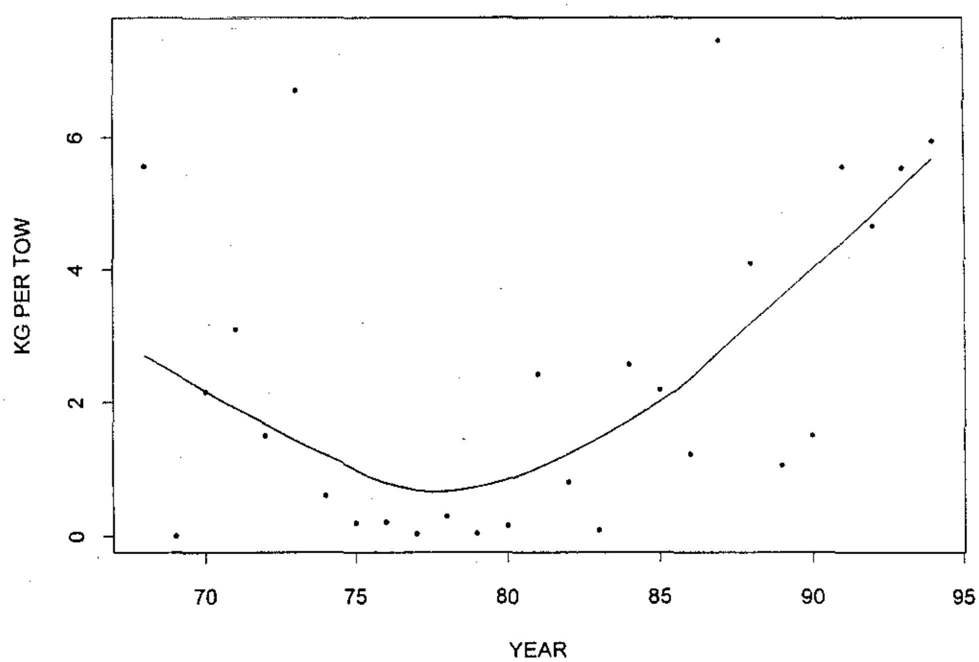

Figure C2. Mackerel weight per tow, spring survey.

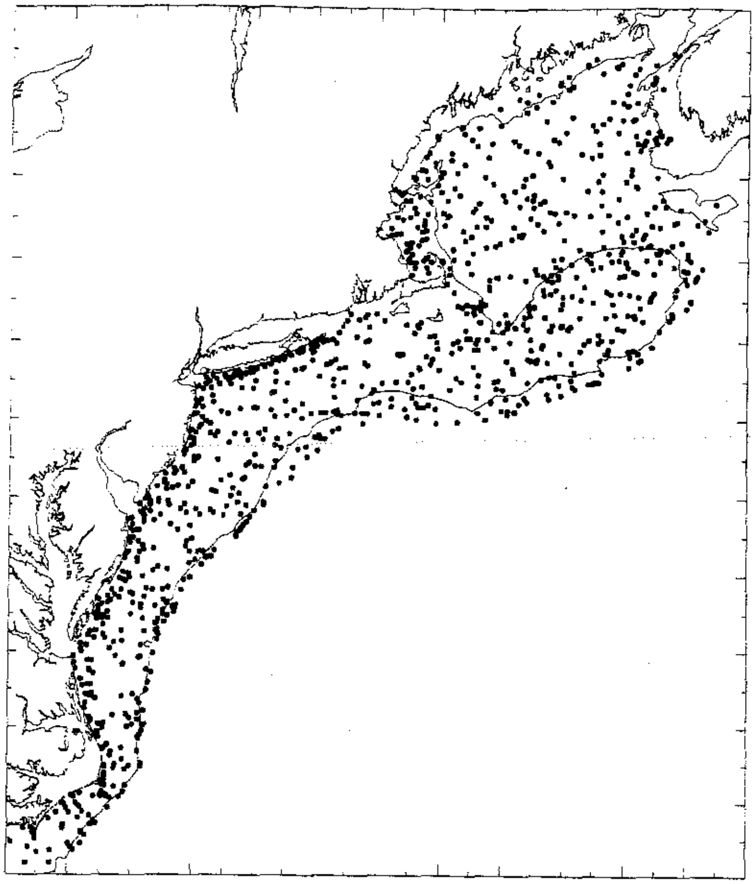

Figure C3. NEFSC spring survey stations in 1992, 1988, and 1993.

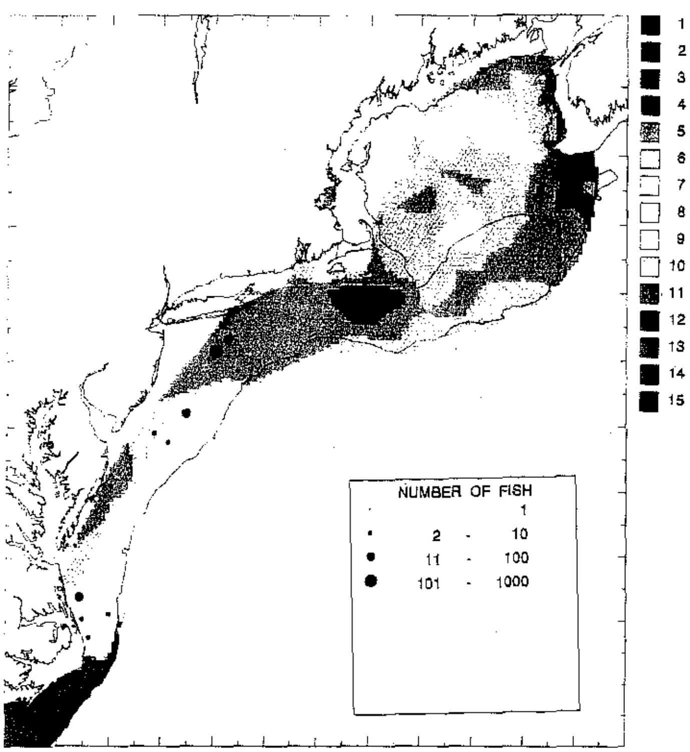

Figure C4. Spring distribution of juvenile Atlantic mackerel, 1982.

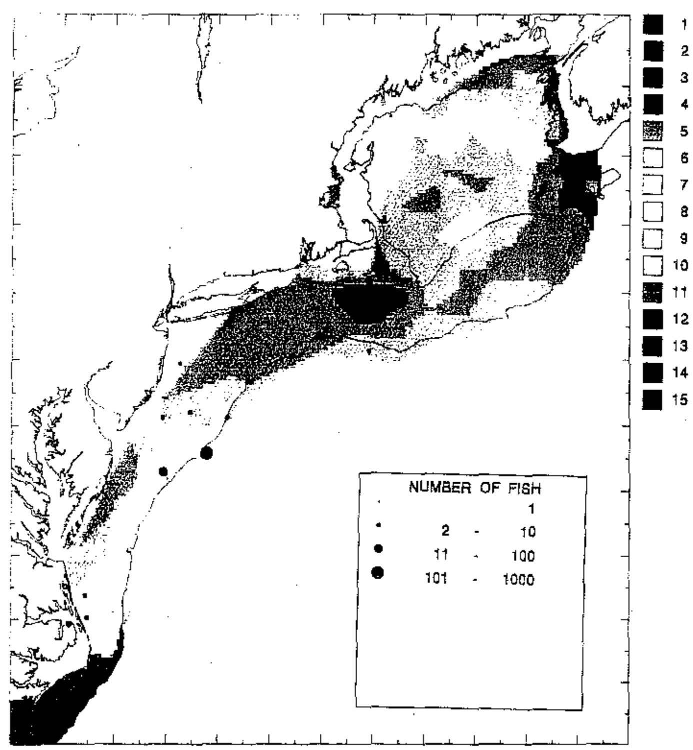

Figure C5. Spring distribution of adult Atlantic Mackerel, 1982.

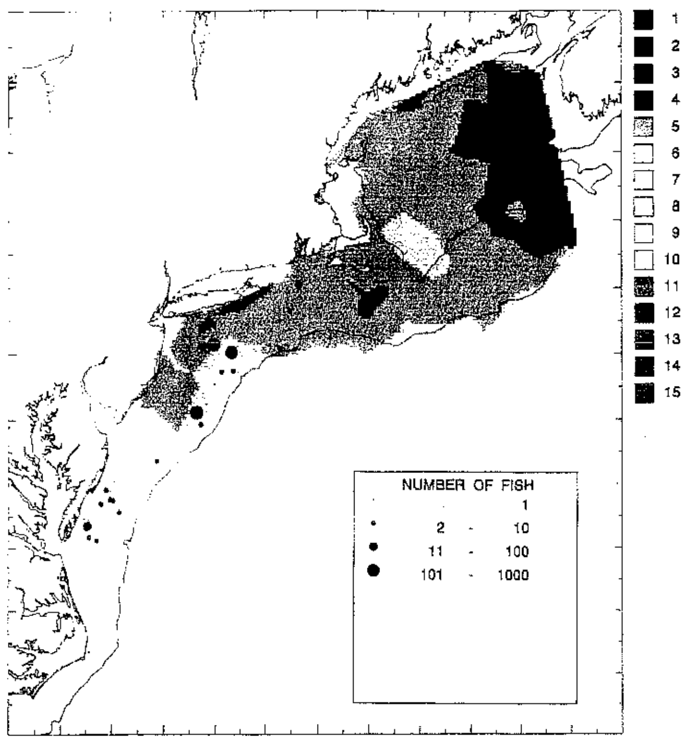

Figure C6. Spring distribution of juvenile Atlantic mackerel, 1988.

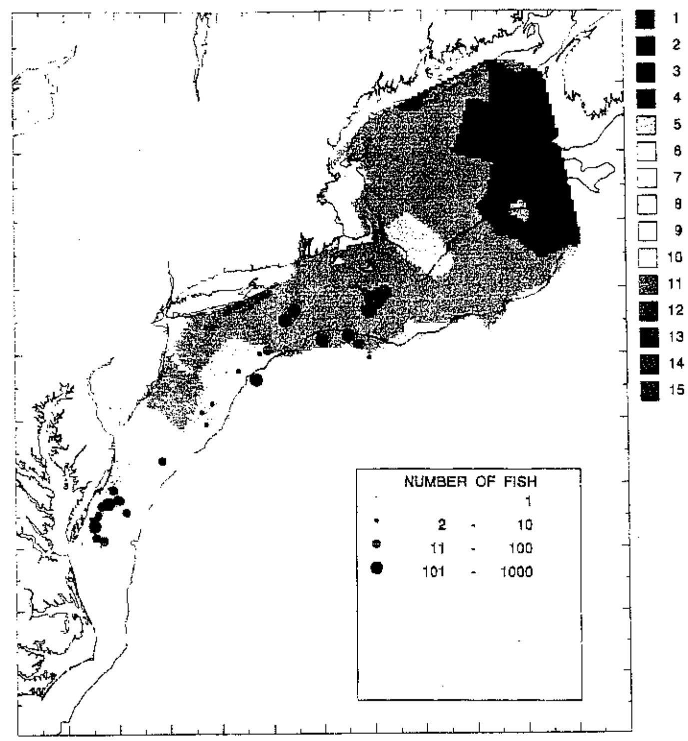

Figure C7. Spring distribution of adult Atlantic mackerel, 1988.

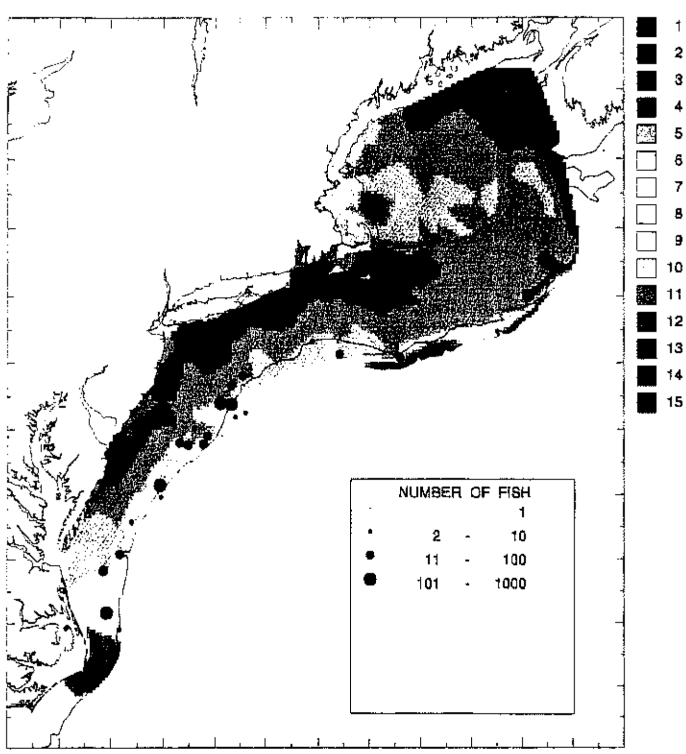

Figure C8. Spring distribution of juvenile Atlantic mackerel, 1993.

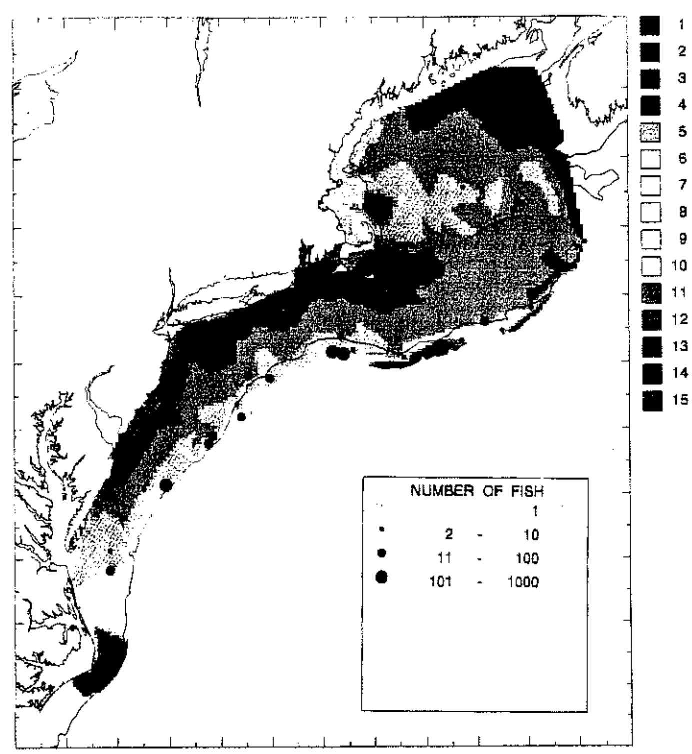

Figure C9. Spring distribution of adult Atlantic mackerel, 1993.

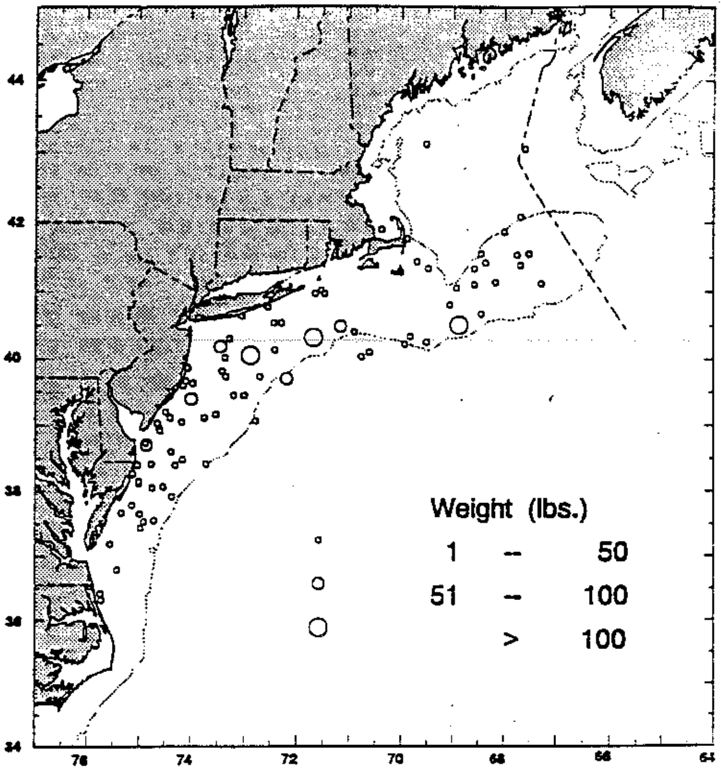

Figure C10. Atlantic mackerel NEFSC Bottom Trawl Survey March 7-April 27, 1995.

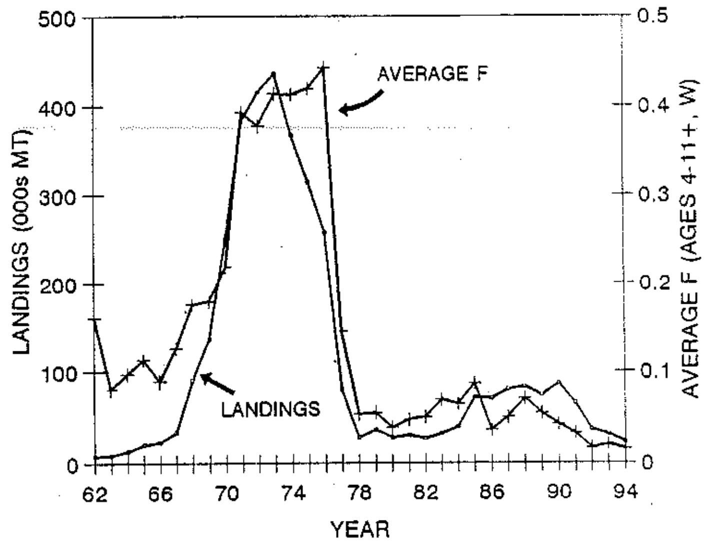

Figure C11. Atlantic mackerel landings and fishing mortality.

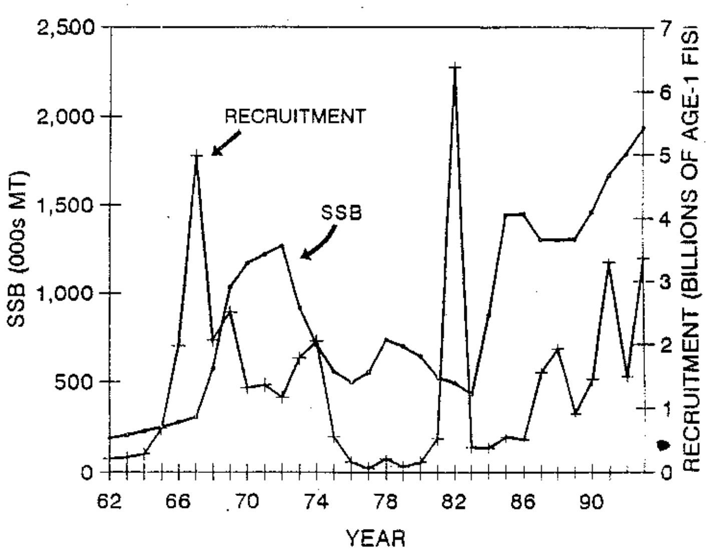

Figure C12. Atlantic mackerel spawning stock biomass (SSB) and recruitment.

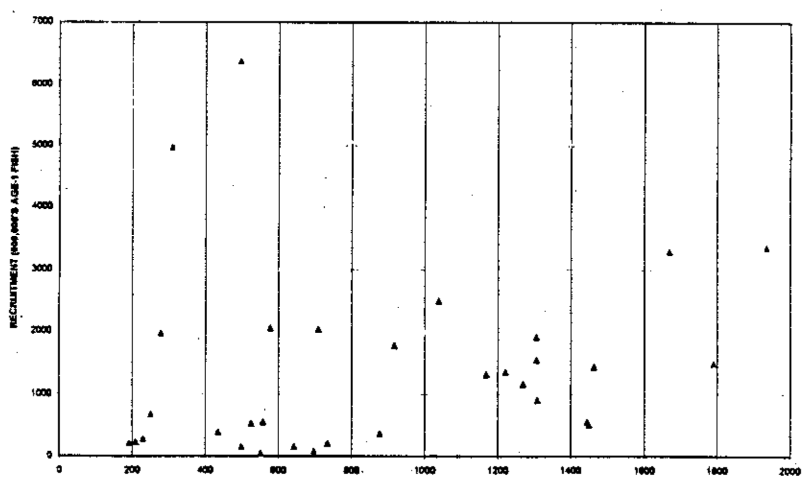

Figure C13. Atlantic mackerel stock-recruitment data.

D. SEA SCALLOP IN MID-ATLANTIC AND GEORGES BANK

The following terms of reference were addressed:

a. Provide updated research vessel survey data summarizing trends in abundance, size composition and recruitment for appropriate fishery units;

b. Summarize trends in the areal distribution, landings, effort, and size composition for commercial catches through 1993;

c. Provide results of sea sampled scallop trips to evaluate the size composition, relative abundance, and other relevant features of the sea scallop fishery;

d. Evaluate relative trends in size composition from NMFS dock-side and sea sampling programs and make recommendations concerning future commercial sampling programs for sea scallop;

e. Evaluate the results of recent ageing studies of sea scallop and their utility in stock assessment. Make further recommendations regarding directions in future ageing studies.

Introduction

Sea scallops, *Placopecten magellanicus*, are found in the northwest Atlantic Ocean from North Carolina to Newfoundland along the continental shelf of North America. Sea scallops grow rapidly during their first several years of life with a 50% to 80% increase in shell height and quadrupling in meat weight between ages 3 and 5. Maximum size is about 23 cm but scallops larger than 17 cm are rare. Sexual maturity commences at age 2 and as small as 25 mm, but scallops less than 4 year old probably contribute little to total egg production (NEFSC 1993). Spawning generally occurs in the late summer and early autumn but a second annual spawning has been observed in the early spring in the Delmarva Region (DuPaul et al. 1989). Spring spawning off Georges Bank may also occur (DiBacco 1993). Eggs are buoyant and the larvae remain in the water column for four to six weeks before settling. During this period considerable transport of larvae can occur depending on prevailing current patterns.

The majority of US commercial landings are from the depth between 40 and 200 m (22 to 110 fm) on Georges Bank and in Mid-Atlantic (NEFSC 1993). The fishing grounds of USA scallop fisheries include the Gulf of Maine, Georges Bank, and Mid-Atlantic. The populations in each of eight resources areas: Gulf of Maine, South Channel, Southeast Part, North Edge and Peak, South New England, New York Bight, Delmarva, and VA-NC, were designated as a unit stock for assessment and management purposes. Survey strata corresponding to these areas are shown in Figure D1; statistical areas for commercial landings are shown in Figure D2. The US landings reached an historical high in 1990 when 17,174 mt of sea scallop meat were landed. Landings have declined markedly since then.

A considerable body of stock assessment and biological research was reviewed and analyzed at a series of previous NEFSC Stock Assessment Workshops (Anon. 1992). Results of these Workshops provided the scientific basis for the evaluation of the sea scallop resources inside the US EEZ and led to the development of Amendment 4 of the Sea Scallop Fishery Management Plan adopted in November 1993. Implementation of the provisions of Amendment 4 began in March 1994. Inasmuch as the landings for 1994 are not yet available, this document provides a summary of the state of the stock prior to the implementation of Amendment 4.

This document summarizes the work of the Invertebrate Subcommittee to address the Terms of Reference for SARC 20. Companion documents provide more detailed information on the NEFSC research survey for scallop (Wigley and Serchuk 1995), a detailed status report on USA commercial fisheries (Lai et al. 1995), a selectivity model for lined and unlined scallop dredges (Lai 1995), and an analysis of discard rates from the sea sampling program (Lai and Hendrickson 1995).

The Fishery

Commercial Landings and Effort

Data on 1994 landings are not available at present. The historical U.S. and Canada landings from NAFO Statistical Areas 5 and 6 (including the Gulf of Maine) are shown in Table D1. Total commercial landings (US and Canada) peaked at 26,671 mt (meats) in 1978. US and Canada landings declined to 9,781 mt in 1984, increased to a near record-high of 22,831 mt in 1991 but fell to 13,456 mt in 1993. Total US sea scallop landings in 1993 were 7,296 mt, the second lowest since 1980 and a decrease of 48% from the US landings in 1992.

Scallop dredges and otter trawls are the primary gear types in the sea scallop fisheries. The vessels using scallop dredges have accounted for more than 98% of landings since 1964 (Table D2). Among the scallop dredge vessels, tonnage classes 3 (51-151 GRT) and 4 (151-500 GRT) have landed more than 95% of scallops since 1980. The percentage of landings by tonnage class 3 decreased generally over the past three decades while the percentage of landings by tonnage class 4 increased (Table D3).

Landings information for the two major assessment regions (Georges Bank and the Mid Atlantic) is summarized below. More detailed information on the commercial fishery may be found in Lai et al. (1995).

Georges Bank

Total international (USA and Canada) landings in 1993 from Georges Bank of 9,815 mt represented a 27% decrease from 1992 (Table D4). The 1993 USA Georges Bank catch (3,655 mt) decreased by 56% from that in 1992 and was the lowest since 1986. Canadian landings on Georges Bank occur mainly from the region east of the International Court of Justice Line, especially after 1979. The 1993 Canadian catch (6,160 mt) was 20% greater than that in 1992, and the highest since 1987. The USA landings comprised 37% of the total Georges Bank scallop catch in 1993, in contrast with an average exceeding 60% in 1990-92. Georges Bank landings accounted for 50% of the 1993 USA total landings: about 56.5% (2,065 mt) was taken from the South Channel area, 13.5% from the Southeast Part area, and 29.8% from the Northern Edge and Peak area.

Mid-Atlantic

Total 1993 Mid-Atlantic sea scallop landings (exclusively USA) were 2,778 mt, 44% and 60% less than that in 1992 and 1991, respectively (Table D5). Among the 1993 Mid-Atlantic catch, 63% was taken from the New York Bight. In the Delmarva area (off Delaware, Maryland and Virginia), scallop catches decreased to 775 mt in 1993 from 1,588 mt in 1992. The landings from Virginia - North Carolina (VA-NC) area also declined by 55% from 1992 (565 mt) to 1993 (257 mt). Landings by vessels using scallop dredges accounted for about 95% of the total catch in 1964-93, however, landings by otter trawls increased substantially in the Mid-Atlantic in the recent years (Table D2).

Spatial Analysis of Landings and Effort

The Subcommittee noted an apparent coherence in the overall pattern of landings by region. To test this hypothesis, landings were compared using scatterplot matrices (Figure D3) with 75% bivariate normal confidence ellipses and LOWESS smoothing lines superimposed on the data points. Results suggest stronger coherence of landings within regions than between regions. For example, the confidence ellipses for the South Channel (SC), Southeast Part (SEP), and the Northern Edge and Peak (NEP) indicated highly correlated catch patterns among areas. Similarly, the confidence ellipse for the New York Bight and Delmarva regions indicated a strong association. In contrast, historical comparison of catches between Georges Bank and Mid-Atlantic resource areas had weaker associations (i.e., confidence ellipses had lower slopes and were more circular). These results suggest some independence of the dynamic behavior of landings between Georges Bank and the Mid-Atlantic regions.

The spatial pattern of landings and effort can be assessed further by examining reports from interviewed trips. Interviewed trips represent a high fraction of total effort and landings and should be representative of the entire fishery. The spatial distribution of total interviewed landings by 10 minute square for 1991-1993 (Figure D4) was consistent with earlier patterns for 1982-1984, 1985-1987, and 1988-1990 (not shown). The clustering of catches within the major resource areas is evident. Within the Mid-Atlantic region the area of highest landings (>110,000 pounds) is concentrated in a region bounded roughly by the Hudson Canyon and the mouth of Delaware Bay.

Examination of the distribution of interviewed effort (days fished) reported by state for 1992-1993 suggested highly mobile fleets with major variations among states. The variation in the spatial dynamics of the fleet could become increasingly important as the provisions of Amendment 4 take effect and could be an important explanatory variable in statistical models for effort standardization.

Discards

The NEFSC scallop sea sampling program was established in 1992 (NEFSC. 1992, 1993, 1994, Lai and Hendrickson 1995). Lai and Hendrickson (1995) applied a tow-based ratio estimator (Cochran 1977) to estimate the discard-to-keep ratios of scallop catch. The discarded scallops from 1992-1993 were about 2.2% of the kept scallops by weight. The discard-to-keep ratio decreased from 1992 to 1993 in the North Edge and Peak and New York Bight areas and increased in the South Channel area (Tables D6, D7). The discarded scallops in Southeast Part and South New England were likely minimal in both years. The discard-to-keep ratios were aggregated into 10"-square and plotted with the interviewed landings for 1992 and 1993, respectively (Figures D5, D6). East and west ends of USA Georges Bank had higher discard-to-keep ratios in both years.

Lai and Hendrickson (1995) discussed some disadvantages of the tow-based ratio estimator. Because the fishing trips are the primary sampling units in the protocol of the scallop sea sampling program, a two-stage sampling technique is more appropriate. The number of trips to be sampled to reach 30% coefficient of variation (CV) for the estimated discard-to-keep ratio is 20 to 25 for a specified time-area stratum (Figure D7). The Subcommittee noted the low number of trips in the scallop sea sampling program. Over the six resource areas, only 15 trips in 1992 and 21 trips in 1993 were sampled. Therefore, any estimates of discard rates should be used with caution; results may only reflect a particular pattern of a few vessels.

It was also noted that scallops weights are based on estimated whole weights whereas the NEFSC weighout program records meat weights. Conversions between these measurement types may introduce additional error.

In view of the low sampling frequency, and a need to increase coverage of the fishery to attain acceptable levels of precision, the Invertebrate Subcommittee recommended development of a supplementary sampling program involving selected fishermen. A core of fishermen trained to provide scientific data could provide useful information for assessments and special biological studies (See Lai et al 1995).

Commercial Shell Height Frequency Distributions

Shell height frequency distributions for commercial landings were derived from two sources: dock-side sampling and sea-sampling . The dock-side program has provided the historical basis of the landings data; the sea sampling program began in 1992. Assessment information in this report is based on dock-side samples rather than sea sampling.

Monthly shell height frequency samples from commercial landings were pooled by calendar quarter and resource area (Virginia-North Carolina, Delmarva, and New York Bight for the Mid-Atlantic region; South Channel, Southeast Part, and Northern Edge and Peak for the Georges Bank region). Quarterly mean weights were obtained by applying shell height-meat weight equations (Serchuk and Rak 1983) to the quarterly sample shell height frequencies. Mean weight values were then divided into quarterly landings to derive estimated numbers landed at shell height by quarter and resource area. These values were summed over quarters and resource area to derive the annual catch composition for each resource area. Scallops tend to recruit to the commercial dredge gear at about 70 mm shell height, with small individuals generally discarded if caught. Distinct shell height modes between 82-97 mm were frequently present in the landings from Georges Bank and Mid-Atlantic regions.

Estimates of commercial shell height frequencies are derived from samples collected by commercial vessels. Sampling protocols request a sample of roughly 200 shells obtained from the last tow of the trip. Numbers of samples and total shells used to construct commercial size frequencies are summarized in Table D8. The Subcommittee expressed concerns that this sampling regime could bias the geographical distribution of samples resulting in an aggregation of samples near the vessels' home ports. The Subcommittee reviewed sea scallop commercial samples (dredge gear only) by year, quarter, and ten-minute degree square for 1991-1993. Visual comparison of the sample distributions suggested a spatial pattern comparable to overall landings. No obvious or consistent clustering pattern of samples was evident on Georges Bank or in the New York Bight resource area. Some clustering of samples was apparent near the southern boundary of the Delmarva resource area in the second and third quarters of 1992 but not in other years.

More detailed statistical tests would be required to test for nonrandomness of the samples. For example, the size compositions of the last tows from sea sample trips could be compared to the composite size composition of the trip. The Subcommittee expressed concerns that the the current sea-sampling protocol of randomly selecting 100 shells per tow may not be sufficient to characterize the size distribution when a wide range of shell heights are present.

The Subcommittee noted that changes to the existing protocols could cause operational problems for commercial vessels and possibly compromise the reliability of samples. In view of these concerns and the absence of consistent clustering, the Subcommittee did not recommend changes to existing sampling methodology for scallop dredges. Additional samples will need to be collected from otter trawl landings because they appear to catch higher proportions of small scallops.

In general, the size composition from dock-side sampling consists of more large-sized scallops than that from sea sampling. Hayes and Wigley (1992) pointed out that culling practices may be a major contributor to this difference. The differences of size composition before and after abolishment of the meat count regulation cannot be addressed until the 1993-1994 data are audited.

Differences between the size compositions obtained from dock-side and sea sampling will result into different estimates of meat count and mean meat weight, used to calculate the catch in numbers. Figure D8 shows the quarterly fluctuation of meat count over year calculated from commercial and sea samplings. The trendline in each area and quarter stratum is projected by fitting a polynomial function. There is a general increasing trend in meat count from 1984 to 1992. All regions (except VA-NC) showed declining meat count after 1992. For the South Channel, Northern Edge and Peak, South New England, New York Bight and Delmarva, where sufficient sea samples were collected in 1992, the fluctuation of calculated meat count from sea sampling is similar to that from commercial landings. Among the eighteen quarters in which calculated meat counts from dock-side and sea samplings are available, twelve of them show that the calculated meat count values obtained from sea sampling are larger than dock-side sampling.

This finding could have significant implications for the stock assessment because the catch data input into the modified DeLury model are in number of scallops, calculated from the dock-side sampling. Because year-class strength fluctuates year-to-year, the effect of meat count variations on the estimations of fishing mortality and abundance should be evaluated. However it is difficult, at present, to determine the statistical reliability of the sea-sampling data.

Figure D9 shows the shell height frequency distributions of the discarded scallops. Most of the discarded scallops were less than 82 mm in shell height. Seasonal and areal variabilities in shell height frequency distributions of discarded scallops are substantial. The size of discarded scallops in South Channel increased quarterly. In the absence of meat count regulation since March 1994 and given implementation of new minimum ring sizes and other provisions of Amendment 4, additional fishery-dependent information should be collected to assess management effects.

Synopsis of Sea Scallop Management

The Subcommittee prepared a chronological summary of the major management measures that have been implemented or are currently planned under the provisions of Amendment 4 (Figure D10). Key regulations include minimum meat counts per pound, minimum shell heights, the planned schedule of days at sea reductions, minimum ring sizes, maximum crew sizes, and restrictions on gear configuration. The timeline indicates the starting and stopping points of various regulations and should be useful for future assessments. Given the diversity of measures, variations in their timing, and potential confounding of effects, any changes in fishing mortality effected by Amendment 4 will be difficult to attribute to any single management provision.

Stock Abundance and Biomass Indices

Commercial LPUE

Total USA sea scallop fishing effort (nominal days fished) in 1993 was 43,389 days for the vessels using dredges, the second highest in the time series exceeded only by effort in 1992 (Table D9). Effort in the Georges Bank fishery decreased by 12% in 1993 after the record-high level in 1992. Effort in the Mid-Atlantic fishery decreased by 9% in 1993 from that in 1992. While the effort by Classes 3 and 4 vessels decreased in the Georges Bank and the Mid-Atlantic, the effort by Class 2 vessels increased by 27% in the Mid-Atlantic. Total effort in 1993 in the Gulf of Maine increased by almost 50% over 1992 levels and attained the highest level on record in all vessel tonnage class categories.

The nominal USA commercial landing per unit effort (LPUE) indices declined substantially in 1993 for all vessel classes in the Georges Bank and Mid-Atlantic fisheries (Table D10). For Georges Bank, overall LPUE in 1993 decreased by 50% from the 1992 level. In the Mid-Atlantic, LPUE indices dropped by 37% overall: 36% for Class 3 vessels and 42% for Class 4 vessels. Quarterly fluctuations of effort, and LPUE were consistent until 1992 on Georges Bank and in Mid-Atlantic (Figure D11), but quarterly LPUE declined markedly in 1993.

The geographic distribution of LPUE based on the interviewed landings, aggregated by a period of three years starting in 1982 was examined. The general contraction of the range of high LPUE areas is dramatic, particularly when comparing 1988-1990 (Figure D12) and 1991-1993 (Figure D13) periods . The high level of fishing effort in 1993 and apparent contraction of high density areas has important implications for stock dynamics and could lead to high, localized rates of fishing mortality.

Research Survey Abundance and Biomass Indices

NEFSC sea scallop research surveys began in 1975 and have been conducted annually since 1977 to monitor and assess abundance, population composition and recruitment of the off-shore sea scallop resources. The survey design and estimations are given in Serchuk and Wigley (1989) and Wigley and Serchuk (1995). Survey length frequencies, depicted in Figures D14 to D17, were adjusted for lined dredge selectivity (see Eq. 9)

USA Georges Bank

Overall, the 1994 survey catches per tow (in numbers) were among the lowest since 1985, although larger than the 1993 value (Table D11). In South Channel area, the number of scallops per tow (56.3) was 3% higher than that in 1993 despite an increase in the total weight per tow from 0.39 kg/tow in 1993 to 0.48 kg/tow in 1994. Survey size frequency data show the recent lack of strong year classes (Figure D14). The strong 1987-1989 year classes were fished down during 1992-1993. The abundance levels in the South Channel will continue to be depressed until recruitment improves.

In the Southeast Part area, the 1994 abundance and biomass indices were at the average level (Table D11). The survey size frequency data indicate the population was dominated by the 1991 year class (Figure D15). The strong 1988-1989 year classes provided the major harvestable population in this area. The commercial catches are expected to increase in the next few years as the 1991 year class becomes fully recruited to the fishery.

In the North Edge and Peak area, the survey abundance and biomass indices in 1994 remained relatively unchanged from the record-low levels in 1993 (Table D11). Size frequency data indicates that the population was dominated by the weak 1991 year class, without other recent strong year classes (Figure D16). The commercial catch from this area will be low in the next few years until recruitment improves.

Mid-Atlantic

In Mid-Atlantic region, the number of scallops per tow in the 1994 survey (165.4) was the third highest value in the 19 year time series. Total weight per tow increased 38 % over the 1993 value. In the New York Bight area, the abundance and biomass indices had increased since 1992. The total number of scallops per tow in 1994 (147.9) was more than twice that in 1993 and the weight per tow (0.61 kg/tow) increased by 49% from that in 1993 (Table D12). Survey size frequency data indicates that the strong 1991 year class dominated the population (Figure D17). Wigley and Serchuk (1995) indicated that the increase in the proportion of 80-40 count scallops and a decrease in <30 count scallops, suggesting that the fisheries operating primarily on small scallops in the incoming year classes.

In the Delmarva area, total abundance in 1994 (244.4 scallops/tow) decreased from 404.1 scallops/tow in 1993 but was still the second highest in the survey time series (Table D12). Survey size frequency data indicate that the population is dominated by the 1990 year class (Figure D18). The 1991 year class strength is moderate. In the 1994 survey, 67% of scallops were 80-40 count, suggesting the fishery operated primarily on small scallops. If this fishing pattern continues, the 1991 year class will be fished down soon.

Estimates of Stock Size and Fishing Mortality Rate

In SAW-14 (Anon. 1992) the modified DeLury model (Conser 1991, 1995) was first applied to scallops and several problems were identified, particularly with respect to alternative assumptions about gear selectivity in research surveys. For SARC 20, the Subcommittee applied the modified DeLury model to five separate resource areas for which sufficient data on landings, research surveys, and size compositions were available. The five resource areas are South Channel, Southeast Part and North Edge and Peak on Georges Bank and New York Bight and Delmarva in Mid-Atlantic. In the following sections a new model for estimation of gear selectivity is developed, an alternative methodology for estimation recruits and full recruits is presented, and the modified DeLury model is described. Results of the modified DeLury model follow; additional detail can be found in Tables D16 to D20.

Selectivity of Lined and Unlined Dredges Used in Research Survey

Since 1979, the NEFSC's research surveys used a 2.44 m (8') wide sea scallop dredge, equipped with 5.1 cm (2") rings and a 3.8 cm (1.5") polypropylene mesh liner, towed for 15 minutes at 6.5 km/hr (3.5 knots) with a 3:1 wire scope (Serchuk and Smolowitz 1980). This gear was used as a standard because lined gear was more efficient in retaining pre-recruit scallops (< 70 mm shell height) than the unlined dredge used in 1975-78 (3.05 m or 10' wide). However, Serchuk and Smolowitz (1980), as well as Jamieson and Lundy (1979) and Worms and Lanteigne (1986), found that the presence of a liner resulted in lower catchability of scallops larger than approximately 75 mm shell height.

A statistical model was used to depict the size-dependent selectivity pattern and to estimate the parameters of the model for the lined and unlined dredges used in the NEFSC's research surveys (Lai 1985). The basic assumptions of the model are:

1. The sea scallop population in the survey area is homogeneously distributed, so that catch in number per tow for each size category is an unbiased estimate of the population in the corresponding category.

2. Existing data from Serchuk and Smolowitz (1980) were standardized to density. Subsequently, it is assumed that any differences detected between the two kinds of gear are the result of the liner. This would include direct differences in retention due to ring size, as well as indirect effects caused by the liner such as a change in hydrodynamic properties at the mouth of the dredge.

3. Selectivity is defined as the probability of a scallop at size h retained by lined and unlined dredges. The selectivity pattern of lined dredge follows a reversed logistic curve (z-shaped curve). The logistic model originally derived by Preece and Banes (1978) and Baines (1978) was modified to mimic the z-shaped curve:

$$q_h = \frac{\kappa \exp[\gamma\kappa(x-\theta)] + \exp[\gamma(x-\theta)]}{\exp[\gamma\kappa(x-\theta)] + \exp[\gamma(x-\theta)]} \div \max(q_h) \qquad (1)$$

where $x = x_o - h$ ($x_o = 160$ is selected as an arbitrary value); k is the lower bound of this z-shaped curve; and γ is proportional to the slope of the curve at $x = \theta$, the value about which q_h is centered. This assumption implies that the selectivity of small sized scallops is almost 1. As the size of scallops become larger, selectivity decreases and levels out when scallops reach a certain shell height.

4. The selectivity pattern of the unlined dredge follows a logistic curve given by:

$$q'_h = \frac{1}{1 + \exp(\alpha - \beta h)} \div \max(q'_h) \qquad \textbf{(2)}$$

where the parameter β defines the slope of the logistic equation and α/β defines the shell height corresponding to 50% retention.

5. Selectivity q'_h and q_h are rescaled such that the largest value is set to 1 to ensure that the selectivity curve is well defined (Deriso et al. 1985).

Following the assumptions in Eq. 1 and 2, the population abundance at size h (N_h) can be expressed as

$$N_h q_h = n_h A, \quad \textit{for a lined dredge, and} \qquad \textbf{(3)}$$

$$N_h q'_h = n'_h A, \quad \textit{for an unlined dredge} \qquad \textbf{(4)}$$

where n_h and n'_h are the densities in number of scallops at size h measured by lined and unlined dredges, respectively. The retention ratio (R_h) for the unlined and lined dredges is:

$$R_h = \frac{n'_h}{n_h} = \frac{q'_h}{q_h} \qquad \textbf{(5)}$$

Given n_h and n'_h (Table D13), the parameters (κ, γ, θ, α, β) in Eq. 1 and 2 were estimated by the method of maximum likelihood estimation (MLE). A multiplicative random error was assumed such that:

$$R_h = \frac{q'_h}{q_h} \exp(\epsilon_h) \qquad \textbf{(6)}$$

where $\epsilon_h \sim N(0, \sigma^2)$.

The logarithm of the likelihood function for Eq. 6 is

$$\ln L = -\frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln(\sigma^2) - \frac{1}{\sigma^2}\sum_{h=1}^{n}(\ln \tilde{R}_h - \ln R_h)^2 \qquad \textbf{(7)}$$

where R_h is the observed value of the retention ratio at size h and ln is the natural logarithm. The likelihood profile technique (Venzon and Moolgavkor 1988, Polacheck et al. 1993) was used to quantify the uncertainty (i.e., 95% confidence interval) associated with the five estimated parameters.

Using the data of Serchuk and Smolowitz (1980) Table D13, the maximum likelihood estimates of model parameters were

$$\hat{q}'_h = \frac{1}{1 + \exp(3.7992 - 0.0768\,h)} \div \max(\hat{q}'_h) \qquad \textbf{(8)}$$

for an unlined dredge, and

$$\hat{q}_h = \frac{0.7148 \quad \exp[(0.9180)(0.7148)(x-106.3091)] + \exp[0.9180(x-106.3091)]}{\exp[(0.9180)(0.7148)(x-106.3091)] + \exp[0.9180(x-106.3091)]} \div \max(\hat{q}_h) \qquad \textbf{(9)}$$

for a lined dredge. The model appeared to fit the data well, no large residuals were observed (Figure D19d) and the overall normality assumption appeared to be satisfied.

The 95% confidence intervals for the five estimated parameters were relatively small (Figure D20) and the joint profiles of parameters revealed no significant correlations. While α and β were correlated, other parameters were not substantially correlated with one another. Moreover, the precision of the most important parameters, especially κ, was very high. The high variability in the estimation of γ is relatively unimportant since the effect of this parameter is to increase the slope of the curve at the inflection point and make the selectivity more knife-edged.

The estimated selectivity of the lined dredge (Table D13) was then applied to the shell height frequency distributions from the research vessel surveys (Figures D14 to D18) such that the survey-derived abundance indices by 5-mm size category represent the entire population.

The Invertebrate Subcommittee noted that the raw data for estimating selectivity curves were aggregated across areas but that area-specific selectivity patterns may occur due to differences in substrate characteristics. It was noted that the lined and unlined dredges were alternated between stations along the cruise track. Some of these tows may be sufficiently similar to constitute paired tows, but no generalizations were possible without a review of the original data. Potential area-specific selectivity patterns cannot be evaluated within the present data set. Concern over lumping of the data stems from the fact that the selectivity estimates have been applied to the entire survey region.

Estimation of Abundance Indices of Recruited and Fully Recruited Stock Sizes

The primary input data to the modified DeLury model are survey abundance indices (standardized mean catch in number per tow from the surveys) for recruited and fully recruited stocks and catch in number. Recruited stock is defined as scallops that are recruited to survey gear and will entered the fully exploitable stock in the subsequent year. The fully recruited stock consists of the scallops that are fully vulnerable to commercial fishing gear. In SAW-14, the method of MULTIFAN (Fournier et al. 1990, 1991) was used to estimate the abundance indices for the recruited and fully recruited stocks using the shell height frequency distributions collected from research surveys, unadjusted for gear selectivity.

Some disadvantages of application of MULTIFAN that were discussed included: (1) the size distributions of recruited stock (assumed to be the first age class defined under MULTIFAN) are not identifiable confidently due to the extensive overlap among size distributions of different age classes; (2) there is substantial year-to-year variability in growth so that recruited and fully recruited stocks based on the MULTIFAN may be biased because of size-dependent fishery selectivity, and (3) fishery selectivity is size-dependent.

A new procedure was developed to estimate the recruited and fully recruited stocks based on the fishery selectivity and von Bertalanffy growth model. For the purposes of this assessment, the methodology is termed the "Selectivity Method". A diagrammatic representation of the method is given in Figure D21. Basically the composite size frequency distribution of the survey at time t, can be partitioned into three groups: 1) fully vulnerable to fishery at time t, n_t, 2) invulnerable to the fishery at time t but vulnerable by time t+1, r_t, and 3) invulnerable to the fishery at time t and t+1, b_t.

$$\sum_{L=L_{min}}^{L_{max}} N_L = n_t + r_t + b_t \qquad \textbf{(10)}$$

where: N_L = number of animals in sample at size L at time t

n_t = fully recruited portion of the sample at time t

r_t = recruit portion of the sample at time t

b_t = portion of the sample that are neither fully recruited nor recruits

L_{min}= minimum size in the sample

L_{max}= maximum size in the sample

The number of full recruits is derived by applying a commercial selectivity function s(L), to the composite size distribution. The function developed by consensus at SAW 14 (Anon. 1992), describes the expected probability of landing a scallop of shell height L, given capture, as a time-invariant piecewise-linear function:

$$s(L) = \begin{cases} 0.0, & \text{if } L<L_{minsel} \\ \left(\dfrac{L - L_{minsel}}{L_{fullsel} - L_{minsel}}\right), & \text{if } L_{minsel} < L < L_{fullsel} \\ 1.0, & \text{if } L>L_{fullsel} \end{cases} \qquad \textbf{(11)}$$

where L_{minsel} = smallest animal selected by fishery = 65 mm
$L_{fullsel}$ = 1st size that is fully selected = 88 mm.

Multiplication of Eq.11 by the composite size frequency gives:

$$n_t = \sum_{L=L_{min}}^{L_{max}} N_L \cdot s(L) \qquad \textbf{(12)}$$

Estimation of the number of recruits also involves the joint product of the fraction invulnerable to the fishery at time t, $(1.0\text{-}s(L))$, and the expected fraction vulnerable at time t+1, $s(L+\Delta L)$.

$$r_t = \sum_{L=L_{min}}^{L_{max}} N_L \cdot (1.0 - s(L)) \cdot s(L+\Delta L_L) \qquad \textbf{(13)}$$

The term $s(L+\Delta L)$ depends on the growth increment ΔL_L which is defined as

$$\Delta L_L = (L_\infty - L)(1 - e^{-K})$$

where L_∞ and K are von Bertalanffy growth parameters specific to the Georges Bank and the Mid-Atlantic regions

Region	L_∞	K
Georges Bank	152.46	0.3374
Mid-Atlantic	151.94	0.2297

The group of scallops that are either too small to grow into the vulnerable size group or which fail to become fully vulnerable can be estimated as the sum of two components:

$$\begin{aligned} b_t &= \sum_{L=L_{minsel}}^{L_{fullsel-1}} N_L \cdot (1.0 - s(L)) \cdot [1.0 - s(L+\Delta L_L)] \\ &+ \sum_{L=L_{min}}^{L_{minsel-1}} N_L \cdot [1.0 - (1.0 - s(L)) \cdot s(L+\Delta L_L)] \\ &= \sum_{L=L_{min}}^{L_{max}} N_L \cdot (1.0 - s(L)) \cdot (1 - s(L+\Delta L_L)) \end{aligned} \qquad \textbf{(15)}$$

Table D14 provides detailed comparison of the Selectivity Method with MULTIFAN. The Sub-committee considered the Selectivity Method to have a greater degree of realism than MULTIFAN for estimation of recruits and full-recruits for the modified DeLury model.

The Selectivity Method was applied to the adjusted annual survey size frequency compositions (Figures D14 to D18) to estimate recruited and fully-recruited stocks (Table D15) in each resource area. Annual landings, mean weights and catch in number by half-year intervals are also provided in Table D15 for each resource area.

Application of Modified DeLury Method

Model and parameter estimation

The modified DeLury model was applied for the estimation of stock sizes in number and biomass and fishing mortality rates for the sea scallop population in the five resource areas mentioned above. In summary, the model is based on the assumptions described in the following equations:

$$\begin{aligned} n_t &= q_n N_t \\ r_t &= q_r R_t \end{aligned} \qquad \textbf{(16)}$$

and

$$N_t = (N_{t-1} + R_{t-1}) \exp(-M) - C_{t-1} \exp[(t_c - t_s - 1)M] \qquad \textbf{(17)}$$

where N_t is the fully recruited stock size in number of the population at year t,
R_t is the recruited stock size in number of the population at year t,
C_t is the catch in number at year t,
M is the instantaneous natural mortality rate,
t_c is the point during the calendar year when the catch is taken,
t_s is the point during the calendar year when the research survey is carried out, for which $0 \leq t_s < t_c \leq 1$,
n_t is the survey abundance index of the fully recruited stock at year t,
r_t is the survey abundance index of the recruited stock at year t,
q_n, is the survey catchability for the fully recruited portion of the stock,
q_r is the survey catchability for the recruiting portion of the stock.

Substituting Eq. 16 into 17 and adding random process error (ϵ_t) to obtain the relationship of the abundance indices of the fully recruited and recruited stocks gives:

$$n_t = \{(n_{t-1} + s_r r_{t-1}) \exp(-M) - q_n C_{t-1} \exp[(t_c - t_s - 1)M]\} \exp(\epsilon_t) \quad \textbf{(18)}$$

where $s_r = q_n / q_r$. Let n'_t and r'_t be the observations of population abundance indices n_t and r_t, respectively, then

$$\begin{aligned} n'_t &= n_t \exp(\eta_t) \\ r'_t &= r_t \exp(\delta_t) \end{aligned} \quad \textbf{(19)}$$

where δ_t and η_t are the random measurement errors.

The parameters $\underline{\Theta}' = \{(n_t| t=1,...T), (r_t| t=1,...T-1), q_n\}$ are estimated by a method of weighted least squares:

$$SS(\underline{\Theta}) = \lambda_\epsilon \sum_{t=2}^{T} \epsilon_t^2 + \lambda_\eta \sum_{t=1}^{T} \eta_t^2 + \lambda_\delta \sum_{t=1}^{T-1} \delta_t^2 \quad \textbf{(20)}$$

where λ_ϵ, λ_η and λ_δ are the weighting factors for the process error associated with the system Eq. 18 and the measurement errors associated with the observed values (Eq. 19). The weighting factors are normalized so that $\lambda_\epsilon + \lambda_\eta + \lambda_\delta = 1$ The coefficient s_r is set equal to 1.0. The catches in number for all years are input into the model without the assumed structure of random error.

Estimation of mortality rates

The recruited and fully recruited stock sizes are estimated as

$$\begin{aligned} \hat{N}_t &= \hat{n}/\hat{q}_n \\ \hat{R}_t &= s_r \hat{r}/\hat{q}_n \end{aligned} \quad \textbf{(21)}$$

the total mortality and fishing mortality rates in year t for the entire population are calculated respectively by:

$$\begin{aligned} Z_{R\cdot N,t} &= -\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t + \hat{R}_t}\right) \\ F_{R\cdot N,t} &= Z_{R\cdot N,t} - M \end{aligned} \quad \textbf{(22)}$$

The fishing mortality rates for the recruited ($F_{R,t}$) and fully recruited ($F_{N,t}$) stocks are calculated by applying the average partial recruitment ($\overline{p_{R,t}}$) of the recruited stock into the commercial fishery over the course of year t, i.e.,

$$\begin{aligned} F_{N,t} &= \frac{F_{R\cdot N,t} (\hat{R}_t + \hat{N}_t)}{\overline{p_{R,t}} \hat{R}_t} \\ F_{R,t} &= \overline{p_{R,t}} F_{N,t} \end{aligned} \quad \textbf{(23)}$$

Estimates of Abundance and Fishing Mortality Rates

Fishing mortality rates and recruited and fully recruited stocks for the sea scallops in the five resource areas were estimated from the modified DeLury model using the data in Table D15. The summary outputs from the final runs for the populations in the five resource areas are given in Tables D16 to D20. Figures D22 to D26 show the observed survey indices and their fitted values, catches, and the standardized residuals for the measurement and process errors.

The standardized residual of predicted recruited and calculated fully recruited survey indices have a similar trend with one year lag. This pattern is to be expected in the DeLury model when the level of fishing mortality is high and catch is nearly equal to or exceeds the number of full recruits. None of the standardized residuals exceeded 2.0, suggesting no significant outliers. The smoothing process inherent in the DeLury model revealed substantial discrepancies between observed and fitted abundance indices in the South Channel area (recruited indices in 1989-1992), North Edge and Peak area (fully recruited indices in 1990), and New York Bight area (calculated fully-recruited indices in 1989-1992; recruited indices in 1990).

In general, abundance of sea scallops on Georges Bank continues to decline from peak levels in 1990 and 1991 in each resource area. Catches have also declined in each area (Figures D22 to D24).

The stock status in the Mid-Atlantic region is slightly better owing to an apparent strong year class in 1990. Model results suggest that this year class began to recruit to the Delmarva fishery in 1991 and became part of the fully recruited pool in 1994 (Figure D26). The pattern in the New York Bight area is similar to observed for Georges Bank. Between 1989 and 1993, catches in the New York Bight declined by about 75%, full recruits declined by 64% and recruits varied between 117 and 814 million scallops (Figure D25).

Several different measures of exploitation are summarized in Figures D27 to D31. The first measure is the ratio of catch to the estimated number of fully recruited scallops. Ratio values approaching or exceeding 1.0 imply heavy reliance of the fishery on annual recruitment. Average F, denoted as F_{R-N} (Eq. 22) provides a measure of total fishing mortality on the stock that is independent of the within year partial recruitment pattern. Finally, F on the fully recruited stocks F_N, was estimated for a range of partial recruitment values ($p_{R,t}$= 0.25, 0.5, 0.75). The sampling distributions of C/N and F_{R+N} were estimated from three hundred bootstrap replications of the DeLury estimates for each resource area. The values of F_{R+N} and C/N at 10, 25, 50, 75, 90 percentiles were compared with the maximum likelihood estimates (Figures D27 to D31). In general, the percentiles ranges were tighter in the earlier years than the later years.

A comparison of estimates of F_N estimates from SAW 14 (1982-1990) with SARC 20 (1982-1993) provided in Table D21 for the South Channel and Southeast Part of Georges Bank and the Delmarva region of the Mid-Atlantic. The 80% confidence limits derived from bootstrap methods overlap for all areas and all years. Agreement between median estimates in the South Channel and Southeast Part is good for all years. In Delmarva, the estimates from SARC 20 are generally lower than those estimated from SAW14 but not significantly different (i.e., the confidence intervals overlap for all years).

On Georges Bank, the 1993 fishing mortality rates of the entire population (F_{R+N}) in the South Channel, Southeast Part and North Edge and Peak were 0.89, 0.42, and 1.35, respectively (Figures D27 to D29). Although 1993 estimates of F_{R+N} have decreased from the 1992 levels, the exploitation rates of the fully recruited stock (C/N) in the South Channel and North Edge and Peak areas remained close to or greater than 1.0. Thus, the Georges Bank fishery is highly dependent on new recruits. In fact, the fishing mortality rates of the fully recruited stocks (F_N) in the South Channel and North Edge and Peak areas have exceeded the overfishing definition (OD, F=0.71) over most of the assessment period. The average F_N in the Southeast Part area since 1987 was almost equal to the OD.

In the Mid-Atlantic region, the 1993 average Fs 0.24 and 0.23, in New York Bight and Delmarva areas, respectively (Figures D30 and D31) were lower than 1992 F_{R-N} levels (0.96 and 0.99, respectively) and may be anomalous. Estimated catches (C_t) in numbers appeared to be declining more rapidly than abundance indices. Other evidence suggests low abundance and high exploitation. Survey indices show a general decline in the Mid Atlantic region through 1992. Recruitment of the 1990 year class in the Delmarva resource area resulted in a slight increase in abundance in 1993 recruits and possibly full recruits in 1994. Trends in LPUE (Table D10) suggested 1993 levels less than one third of 1988-1990 average. Moreover, the spatial extent of high LPUE areas was severely diminished in 1991-1993 compared to the previous 3-yr period (Figures D13 vs D12). Overall 1993 effort (days fished) in the Delmarva area declined by only 9% compared to 1992 levels. The estimated exploitation rate of the fully recruited stock was around 0.3 in New York Bight area but was 0.6 in Delmarva. The decrease of 1993 *C/N* from an average of 0.9 in 1990-92 in Delmarva was probably due to the strong 1990 year class that became fully recruited to the fishery in 1993.

Sensitivity analyses of the estimate of F_N, with respect to partial recruitment levels revealed little variation over the range of $\overline{p_{R,t}}$ = 0.25 to 0.75. Thus most of the variation in F_N can probably be attributed to variations in R_t.

Retrospective analysis of the accuracy of the terminal F_N was investigated for two resource areas (South Channel, New York Bight). Estimates of $F_{N,T}^*$ derived from the time series truncated at year T^* were compared to estimates of $F_{N,T}$ where $T^* < T$. For the two resource areas examined, an underestimation of terminal F_N was evident. The magnitude of the underestimation can be severe when a strong year class enters the population. The terminal year population size estimate n_T can be written as a weighted average of the calculated and observed values:

$$n_T = \exp\left(\frac{\lambda_\epsilon \ln(\hat{n}_T) + \lambda_\eta \ln(n'_T)}{\lambda_\epsilon + \lambda_\eta}\right)$$

The dependence of n_T on the weighting factors in the modified DeLury model result in biased estimation of the terminal $F_{N,T}$.

Biological Reference Points

The Subcommittee reviewed the concept of a biological reference point for scallop, particularly in light of biological and oceanographical information. Several lines of reasoning led the Subcommittee to recommend review of the biological reference points and its application to sea scallops. Large differences in growth rates between Georges Bank and the Mid-Atlantic regions were reported by Serchuk et al. (1979). Coupled with potential differences in maturation rates, within year distribution of spawning(s), and interannual variations in growth owing to food availability and temperature, there is a high likelihood that scallops in these areas differ in their intrinsic ability to withstand fishing mortality.

The second principal reason for review of existing reference points relates to the apparent lack of significant transport of larvae from Georges Bank to the Mid Atlantic Region, and an even lower probability of larval transport in the reverse direction. Physical oceanographers have documented clockwise circulation around Georges Bank (Butman et al. 1982). Biological studies have shown that this gyre has a measurable effect on the distribution and abundance of larval and juvenile sea scallops (Thouzeau et al. 1991, Tremblay et al. 1993) as well as on other species (Lough and Trites 1989, Sherman et al. 1984, Smith and Morse 1985). The general conclusion from these studies is that there is little evidence for substantial loss of organisms from the gyre system. It is probable that Georges Bank scallops are largely self-sustaining, with considerable recruitment coming from the northeast peak.

A thorough review of these concepts and relevant literature could not be accomplished at the Subcommittee meeting. Information on the status of sea scallops in the Canadian portion of Georges Bank should be incorporated in any reevaluation of biological reference points (see Robert et al. 1994).

Sources of Uncertainty

Domestic Sea Sampling

1. Inadequate sample size for discard-to-keep ratio
2. Differences in size compositions: dock-side vs. sea sampling programs
3. Absence of reliable historical estimates of discarding rates and survival of undersized dredged scallops thrown back.

Commercial Fishery

1. Estimates of catch in numbers derived from meat weight-shell height regressions.
2. Spatial and year class targeting of scallop dredge fleet.

NEFSC Research Survey

1. Selectivity of dredge for large scallops
2. Interannual variations in scallop availability to dredge.
3. Absence of resource area specific growth curves.
4. No age validation.

Modified DeLury Model

1. Estimates of n_t and r_t based on assumed fishery selection pattern
2. Reliability of population estimates and fishing mortality rates in terminal year.
3. Structural correlation between estimates of recruit (observation error) and process error when fishing mortality rates are high.

SARC Comments

The SARC expressed concern that the input catch data were based on calendar year and did not agree with the survey year (from July 1 to June 30). The modified DeLury model produces the estimates of recruits and full recruits relative to the time of the survey being conducted. The fishing mortalities are calculated for the period between the two consecutive annual surveys. The disadvantages of using catch data based on the survey year are that with the available data and fully recruited fishery mortality, F_N can only be estimated up to 1992 and the precision of the 1992 estimate is low.

Sources of error related to the computation of catch in numbers were also discussed. The catch in number is calculated from annual commercial size compositions and height-weight relationships obtained from the summer survey in 1982. Because the height-weight relationships vary seasonally and yearly, errors may have been introduced to the input catch data. The SARC noted that some seasonal height-weight data from commercial catches are available, but have not been used.

In the Mid-Atlantic, landings by net fisheries have become more significant. The size of scallops caught by nets tend to be smaller than those caught by dredges. The landings from net fisheries were aggregated with those from the dredge fishery. Any differential size effect may be further compounded by the presence of strong recruitment. Currently, no sampling is carried out to determine size composition and discard rate for the net fisheries.

General concern was expressed concerning 1993 terminal year estimates of fully recruited fishing mortality. The SARC commented that the stock assessment results through 1992 be reported and that the 1993 results be updated when 1994 landings and 1995 survey data become available.

The SARC noted that US Atlantic coast scallops are managed as one unit stock (Management Unit), while the stock assessments are conducted for five resource areas (Stock Assessment Units). The Georges Bank region includes South Channel, Southeast Part and North Edge and Peak, and the Mid-Atlantic region includes New York Bight and Delmarva. The F_N's of these two regions were calculated by the estimated total recruits and total full recruits, which are tallied from the corresponding stock assessment units. The terminal F_N's for these two regions were then compared to the biological reference points derived for the management unit. In view of the differences in biological characteristics among the stock assessment units and regions, issues related to the biological reference points should be re-evaluated.

Because of the issues related to the accuracy of terminal year fishing mortality, the SARC discussed the advantages of scheduling the sea scallop stock assessment in the winter.

Research Recommendations

- o The effect of seasonal height-weight relationships on computation of catch in numbers should be investigated.
- o The issues sources of error on the estimates of terminal F_N should be re-evaluated when 1994 catch and 1995 survey data become available. Because of the uncertainties related to the estimates of terminal F_N the application of retrospective analysis should be enhanced.
- o The results of DeLury runs using input catch data based on the survey year should be compared with those based on the calendar year.
- o Currently, only minimal sampling effort is done for scallop landings by net fisheries. Commercial port sampling are needed to collect biological data from net fisheries. Size compositions of landings and discards from the net fisheries should be collected by the sea sampling program.
- o Data from Canadian North Edge and Peak on Georges Bank should be included in the stock assessment.
- o A scholarly review of the concept of a unit stock and advisability of a single biological reference point for sea scallop should be conducted.
- o The potential effects of application of a single reference point to the Georges Bank and Mid Atlantic regions should be evaluated.

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Table D1. United States and Canadian sea scallop landings (metric tons, meats) from the Northwest Atlantic (NAFO Subarea 5 and Statistical area 6), 1887-1993.

YEAR	USA[1]	YEAR	USA	CANADA[2]	TOTAL
1887	112	1951	8,503	91	8,594
1888*	91	1952	8,451	91	8,542
1889	141	1953	10,713	136	10,849
1892	53	1954	7,997	91	8,088
1897	435	1955	10,036	136	10,172
1898	156	1956	9,102	317	9,419
1899*	24	1957	9,523	771	10,294
1900*	79	1958	8,608	1,179	9,787
1901	286	1959	11,178	2,378	13,556
1902	61	1960	12,065	3,470	15,535
1903*	62	1961	12,456	4,565	17,021
1904	216	1962	11,174	5,715	16,889
1905	200	1963	9,038	5,898	14,936
1906*	255	1964	7,704	5,922	13,626
1907*	236	1965	9,105	7,052	16,157
1908	834	1966	7,237	7,669	14,906
1909*	843	1967	4,646	5,025	9,671
1910*	919	1968	5,473	5,243	10,716
1911*	663	1969	3,363	4,320	7,683
1912*	842	1970	2,613	4,097	6,710
1913*	353	1971	2,593	3,908	6,501
1914*	386	1972	2,655	4,177	6,832
1916*	266	1973	2,401	4,223	6,624
1919	89	1974	2,722	6,137	8,859
1921	38	1975	4,422	7,414	11,836
1924	154	1976	8,721	9,780	18,501
1926	506	1977	11,103	13,091	24,194
1928	216	1978	14,482	12,18	26,671
1929	1,130	1979	14,256	9,207	23,463
1930	1,111	1980	12,566	5,239	17,805
1931	1,058	1981	11,742	8,018	19,760
1932	1,517	1982	9,044	4,330	13,374
1933	2,009	1983	8,707	2,895	11,602
1935	1,955	1984	7,739	2,042	9,781
1937	3,989	1985	6,742	3,851	10,593
1938	4,041	1986	8,661	4,705	13,366
1939	4,440	1987	13,227	6,810	20,037
1940	3,467	1988	13,198	4,405	17,603
1941ʼ	3,622	1989	14,776	4,676	19,452
1942	3,258	1990	17,174	5,130	22,304
1943	2,508	1991	16,998	5,833	22,831
1944	2,209	1992	14,038	5,129	19,167
1945	2,590	1993	7,296	6,16	13,456
1946	5,236	1994	n/a	4,98	n/a
1947	6,647				
1948	7,546				
1949	8,299				
1950	9,063				

[1]USA landings: 1887-1960 from Lyles (1969); 1961-1975 from Fishery Statistics of the United States; 1963-1982 from ICNAF and NAFO Statistical Bulletins; 1964-1994 from Detailed Weighout Data, Northeast Fisheries Center, Woods Hole, Mass.

[2]Canadian landings: 1951 1958 from ICNAF Statistical Bulletins and Caddy (1975); 1953-1988 from Mohn et al. (1989) for Georges Bank and from ICNAF/NAFO Bulletins for Gulf of Maine and Mid Atlantic; 1989 from NAFO SCS Doc. 90/21; 1990, 1991 from DFO, Statistics Branch, Halifax.

*Maine landings only from Baird (1956).

ʼUSA landings for 1941 from O'Brien (1961).

Table D2. Percent distribution of USA commercial landings (metric tons, meats) of sea scallops, by gear type within the principal sea scallop fishing areas off the Northeast coast of the United States, 1964-1993. For 1964-1973, data only reflect landings in New England states [Maine, Massachusetts, New Hampshire and Rhode Island]. For 1974-1993, data reflect landings in both New England and Mid-Atlantic states [Maine to North Carolina].

	GULF OF MAINE			GEORGES BANK		SO. NEW ENGLAND		MID-ATLANTIC			ALL AREAS		
Year	Otter Trawl	Scallop Dredge	Other	Otter Trawl	Scallop Dredge	Otter Trawl	Scallop Dredge	Otter Trawl	Scallop Dredge	Other	Otter Trawl	Scallop Dredge	Other
1964	0.1	99.9		0.8	99.2	-	-	0.0	100.0		0.8	99.2	
1965	0.0	100.0		0.3	99.7	-	-	0.0	100.0		0.1	99.9	
1966	0.2	99.8		0.1	99.9	-	-	0.0	100.0		<0.1	99.9	
1967	0.4	99.6		0.3	99.7	-	-	0.0	100.0		0.1	99.9	
1968	0.4	99.6		0.0	100.0	0.0	100.0	0.0	100.0		<0.1	99.9	
1969	0.6	99.4		0.6	99.4	0.0	100.0	0.6	99.4		0.6	99.4	
1970	0.2	99.8		0.4	99.6	<0.1	99.9	3.0	97.0		0.9	99.1	
1971	1.1	98.9		1.3	98.7	3.0	97.0	<0.1	99.9		1.1	98.9	
1972	0.1	99.9		0.6	99.4	0.5	99.5	0.8	99.2		0.6	99.4	
1973	0.1	99.9		1.4	98.6	3.3	96.7	1.4	98.6		1.1	98.9	
1974	0.2	99.8		1.6	98.4	2.3	97.7	1.2	98.8		1.3	98.7	
1975	0.8	99.2		1.6	98.4	15.9	84.1	20.9	79.1		13.7	86.3	
1976	0.8	99.2		2.2	97.8	38.5	61.5	31.8	68.2		24.5	75.5	
1977	1.5	98.5		0.6	99.4	7.5	92.5	12.8	87.2		7.1	92.9	
1978	0.4	99.6		0.7	99.3	11.8	88.2	6.6	93.4		4.2	95.8	
1979	1.1	98.9		0.4	99.6	5.6	94.4	7.2	92.8		3.8	96.2	
1980	7.6	92.4		0.6	99.4	1.4	98.6	0.3	99.7		1.4	98.6	
1981	5.6	94.4		0.7	99.3	2.2	97.8	0.7	99.3		1.2	98.8	
1982	4.3	94.9	0.8	1.9	98.1	0.1	99.9	0.4	99.5	0.1	1.8	98.2	
1983	8.1	91.1	0.8	0.7	99.3	0.3	99.7	0.6	99.2	0.2	1.7	98.4	0.2
1984	2.6	95.9	1.4	0.9	99.1	1.9	98.1	0.7	99.2	0.1	1.0	98.8	0.2
1985	0.7	96.9	2.4	1.2	98.8	5.3	94.7	1.4	98.5	0.1	1.3	98.5	0.2
1986	0.5	97.5	2.0	0.2	99.8	2.7	97.3	3.0	97.0	0.0	1.4	98.5	0.1
1987	0.1	97.8	2.1	0.6	99.4	2.0	98.0	4.0	96.0	0.0	2.6	97.3	0.1
1988	1.3	96.2	2.5	0.3	99.7	5.3	94.7	6.5	93.5	0.0	3.4	96.5	0.1
1989	0.0	93.2	6.8	0.4	99.6	7.9	92.1	5.3	94.7	0.0	3.2	96.5	0.3
1990	0.1	95.0	4.9	0.1	99.9	5.3	94.7	7.4	92.5	0.1	2.9	96.9	0.2
1991	0.5	87.1	12.4	0.8	99.2	21.8	78.2	11.5	88.4	0.1	5.3	94.2	0.5
1992	0.3	93.5	6.2	0.1	99.9	4.0	96.0	11.4	88.5	0.1	4.1	95.5	0.4
1993	0.3	95.7	4.0	0.5	99.5	1.5	98.5	14.1	85.8	0.1	5.7	93.9	0.5
1964-1993	1.3	97.1	3.9	0.7	99.3	6.0	94.2	5.3	94.8	0.1	3.5	96.7	0.2

Note: 1982-1991 revised by S.Wigley 5/92

Table D3. USA commercial sea scallop landings (mt, meats) from Georges Bank (Area 5Ze), the Mid-Atlantic (Statistical Area 6), and the Gulf of Maine (Division 5Y), by vessel tonnage class, 1965 - 1993. Data derived from vessels using scallop dredges and landing in New England and Mid-Atlantic ports.

	GEORGES BANK				MID-ATLANTIC				GULF OF MAINE				TOTALS			
Year	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Grand Total
1965		1,287	194	1,480	21	3,608	346	3,974	100	15	-	115	120	4,910	539	5,569
1966	-	735	149	884	1	3,530	531	4,062	93	-	-	93	93	4,265	680	5,038
1967	-	923	295	1,217	1	1,548	324	1,873	78	2	-	80	78	2,472	619	3,169
1968	2	819	173	993	8	1,575	815	2,398	109	4	-	113	118	2,398	988	3,504
1969	-	917	399	1,316	2	482	363	846	108	14	-	122	109	1,413	762	2,284
1970	-	993	417	1,410	-	190	269	459	115	17	-	132	115	1,200	686	2,000
1971	-	766	545	1,311	-	72	202	274	223	108	27	358	223	947	773	1,943
1972	9	467	339	816	-	289	364	653	487	32	5	524	496	789	707	1,993
1973	-	678	387	1,065	-	43	203	245	394	47	19	460	394	768	608	1,769
1974	-	557	353	911	-	397	540	937	211	12	-	223	211	967	894	2,071
1975	2	491	350	844	1	660	845	1,506	734	7	-	741	737	1,158	1,196	3,090
1976	261	931	530	1,723	19	1,042	1,911	2,972	349	14	-	363	629	1,988	2,441	5,058
1977	892	2,545	1,271	4,709	34	930	1,600	2,564	249	5	-	254	1,175	3,480	2,872	7,526
1978	370	2,973	2,189	5,532	152	1,678	2,346	4,175	238	3	-	242	760	4,654	4,534	9,949
1979	188	2,613	3,458	6,259	104	1,553	1,203	2,859	313	35	54	401	605	4,200	4,714	9,519
1980	73	1,955	3,355	5,383	13	931	1,023	1,968	587	431	454	1,472	674	3,316	4,832	8,822
1981	77	2,343	5,576	7,996	2	398	473	872	748	237	241	1,225	826	2,978	6,290	10,093
1982	26	1,794	4,384	6,204	7	727	867	1,601	371	76	184	631	403	2,597	5,435	8,435
1983	52	1,244	2,951	4,247	19	1,341	1,725	3,085	544	136	136	815	615	2,721	4,812	8,147
1984	3	1,004	2,004	3,011	16	1,673	1,955	3,643	528	66	55	650	547	2,743	4,014	7,304
1985	3	808	2,049	2,859	9	1,223	1,991	3,224	315	51	41	407	327	2,082	4,081	6,490
1986	7	1,023	3,398	4,428	-	1,624	1,633	3,257	247	12	23	282	253	2,660	5,054	7,966
1987	5	1,096	3,720	4,821	-	3,252	4,236	7,488	323	39	2	364	327	4,387	7,958	12,672
1988	21	1,337	4,678	6,036	7	2,625	3,142	5,774	380	75	20	475	408	4,036	7,840	12,285
1989	28	1,033	4,575	5,636	65	2,882	4,602	7,549	533	49	6	588	626	3,964	9,183	13,773
1990	51	2,403	7,518	9,972	61	2,564	3,329	5,954	461	78	7	546	573	5,045	10,854	16,472
1991	44	1668	7523	9,235	50	3124	3021	6,195	441	62	24	527	535	4,854	10,568	15,957
1992	35	1,577	6,625	8,237	29	2,707	2,219	4,955	612	55	52	719	676	4,339	8,896	13,911
1993	9	602	3044	3,655	28	1548	1202	2,778	678	56	63	797	715	2,206	4,309	7,230

Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT.

Source: NEFC Detailed Weighout Data for vessels using scallop dredges. Mid-Atlantic weighout data are only available from 1978 onward; weighout data from Virginia ports are available for part of 1981 and from 1982 onward.

Table D4. Distribution of USA and Canadian sea scallop landings (mt, meats) in the three principal sea scallop fishing regions on Georges Bank, 1957 - 1993.

	USA				CANADA				TOTAL			
Year	South Channel	So. East Part	No. Edge & Peak	Total	South Channel	So. East Part	No. Edge & Peak	Total	South Channel	So. East Part	No. Edge & Peak	Total
1957	1,491	628	5,727	7,846	8	-	763	771	1,499	628	6,490	8,617
1958	1,241	457	4,833	6,531	-	-	1,179	1,179	1,241	457	6,012	7,710
1959	1,951	2,799	3,731	8,481	-	-	2,378	2,378	1,951	2,799	6,109	10,859
1960	1,788	4,469	3,675	9,932	-	-	3,470	3,470	1,788	4,469	7,145	13,402
1961	2,132	1,812	6,716	10,660	-	-	4,565	4,565	2,132	1,812	11,281	15,225
1962	1,744	1,841	6,105	9,690	-	-	5,715	5,715	1,744	1,841	11,820	15,405
1963	2,057	2,215	3,638	7,910	-	472	5,426	5,898	2,057	2,687	9,064	13,808
1964	2,569	1,909	1,763	6,241	-	118	5,804	5,922	2,569	2,027	7,567	12,163
1965	677	390	416	1,483	-	178	4,256	4,434	677	568	4,672	5,917
1966	716	24	144	884	-	-	4,878	4,878	716	24	5,022	5,762
1967	641	311	269	1,221	-	-	5,019	5,019	641	311	5,288	6,240
1968	713	149	163	1,025	-	-	4,820	4,820	713	149	4,983	5,845
1969	576	227	522	1,325	-	-	4,318	4,318	576	227	4,840	5,643
1970	1,069	159	187	1,415	41	-	4,056	4,097	1,110	159	4,243	5,512
1971	1,091	214	24	1,329	547	-	3,361	3,908	1,638	214	3,385	5,237
1972	623	64	134	821	417	-	3,744	4,161	1,040	64	3,878	4,982
1973	890	173	17	1,080	1,140	-	3,083	4,223	2,030	173	3,100	5,303
1974	783	121	21	925	552	307	5,278	6,137	,335	428	5,299	7,062
1975	566	175	116	857	593	74	6,747	7,414	1,159	249	6,863	8,271
1976	1,583	142	45	1,770	781	-	8,980	9,761	2,364	142	9,025	11,531
1977	4,121	277	407	4,805	262	-	12,827	13,089	4,383	277	13,234	17,894
1978	3,918	366	1,285	5,569	-	-	12,189	12,189	3,918	366	13,474	17,758
1979	3,996	758	1,819	6,573	-	-	9,207	9,207	3,996	758	11,026	15,780
1980	2,994	685	1,941	5,620	-	-	5,221	5,221	2,994	685	7,162	10,841
1981	2,940	515	4,966	8,421	-	-	8,013	8,013	2,940	515	12,979	16,434
1982	3,391	575	2,543	6,509	-	-	4,306	4,306	3,391	575	6,849	10,815
1983	2,439	432	1,457	4,328	-	-	2,748	2,748	2,439	432	4,205	7,076
1984	1,633	691	747	3,071	-	-	1,945	1,945	1,633	691	2,692	5,016
1985	1,554	403	992	2,949	-	-	3,812	3,812	1,554	403	4,804	6,761
1986	2,744	654	1,113	4,511	-	-	4,670	4,670	2,744	654	5,783	9,181
1987	2,404	265	2,216	4,885	-	-	6,793	6,793	2,404	265	9,009	11,678
1988	3,124	835	2,124	6,083	-	-	4,336	4,336	3,124	835	6,460	10,419
1989	2,771	589	2,326	5,686	-	-	4,676	4,676	2,771	589	7,002	10,362
1990	3,974	1,009	5,026	10,009	-	-	5,130	5,130	3,974	1,009	10,156	15,139
1991	5,655	904	2,752	9,311	-	-	5,804	5,804	5,655	904	8,556	15,115
1992	4,817	1,123	2,298	8,238	-	-	5,129	5,129	4,817	1,123	7,427	13,367
1993	2,065	501	1,089	3,655	-	-	6,160	6,160	2,065	501	7,249	9,815
1994	n/a	n/a	n/a	n/a	-	-	4,985	4,985	n/a	n/a	n/a	n/a

South Channel: Statistical Areas 521, 522, & 526.
Southeast Part: Statistical Area 525.
Northern Edge & Peak: Statistical Areas 523 & 524.

Table D5. USA commercial sea scallop landings (mt, meats) from the Northwest Atlantic (NAFO Subarea 5 and Statistical Area 6), by NAFO Statistical Area, 1961 - 1993.

	GULF OF MAINE - GEORGES BANK REGION						MID-ATLANTIC REGION					
Year	Gulf of Maine (5Y)	Georges Bank (5Ze)	So. New England (5Zw)	NAFO Area 5Z	NAFO Area 5NK	NAFO Area 5	New York Bight (6A)	Delmarva (6B)	VA - NC (6C)	NAFO Area 6NK	NAFO Area 6	Total USA
1961	120			10,660		10,780					1,676	12,456
1962	103			9,690	3	9,796					1,378	11,174
1963	127			7,910		8,037					1,001	9,038
1964	192	6,241	55	6,296		6,488					1,216	7,704
1965	115	1,483	27	1,510		1,625	3,098	2,123	2,259		7,480	9,105
1966	93	884	8	892		985	3,164	3,019	69		6,252	7,237
1967	80	1,221	8	1,229		1,309	1,548	1,776	13		3,337	4,646
1968	113	1,025	24	1,049		1,162	1,951	486		1,874	4,311	5,473
1969	123	1,325	19	1,344		1,467	544	307		1,045	1,896	3,363
1970	132	1,415	6	1,421		1,553	431	42		587	1,060	2,613
1971	362	1,329	7	1,336		1,698	274			621	895	2,593
1972	525	821	2	823		1,348	265	388	6	648	1,307	2,655
1973	460	1,080	3	1,083		1,543	143	95	11	609	858	2,401
1974	223	925	5	930		1,153	869	628	72		1,569	2,722
1975	746	857	50	907		1,653	1,641	900	228		2,769	4,422
1976	366	1,770	9	1,779		2,145	4,494	1,725	357		6,576	8,721
1977	258	4,805	11	4,816	125	5,199	3,537	2,233	134		5,904	11,103
1978	243	5,569	29	5,598		5,841	2,602	5,567	472		8,641	14,482
1979	434	6,573	93	6,666		7,100	4,656	2,268	232		7,156	14,256
1980	1,637	5,620	219	5,839		7,476	3,198	1,836	56		5,090	12,566
1981	1,305	8,421	126	8,547		9,852	1,507	293	90		1,890	11,742
1982	670	6,509	163	6,672		7,342	1,312	357	33		1,702	9,044
1983	895	4,328	257	4,585		5,480	2,913	298	16		3,227	8,707
1984	678	3,071	165	3,236		3,914	2,792	945	88		3,825	7,739
1985	421	2,949	81	3,030		3,451	2,753	529	9		3,291	6,742
1986	316	4,511	78	4,589		4,905	2,549	813	394		3,756	8,661
1987	382	4,885	68	4,953		5,335	5,019	2,800	73		7,892	13,227
1988	526	6,083	68	6,151		6,677	3,515	2,687	319		6,521	13,198
1989	644	5,686	137	5,823		6,467	5,905	2,098	306		8,309	14,776
1990	574	10,009	116	10,125		10,699	3,424	2,883	168		6,475	17,174
1991	605	9,311	71	9,382		9,987	4,728	2,192	91		7,011	16,998
1992	722	8,237	124	8,361		9,083	2,802	1,588	565		4,955	14,038
1993	797	3,655	66	3,721		4,518	1,746	775	257		2,778	7,296

Table D6. Summary of discard-to-keep ratio in 1992.

Resource Area		Quarter 1	Quarter 2	Quarters 1 + 2	Quarter 3	Quarter 4	Quarters 3 + 4	Total
Gulf of Maine	lb-keep				1070		1070	1070
	lb-disc				34		34	34
	ratio				0.03143		0.03143	0.03143
	var(r)				0.00357		0.00357	0.00357
	# tows				20		20	20
South Chanel	lb-keep	1651	9546	11197	3779	4814	8593	19790
	lb-disc	273	137	410	44	530	574	984
	ratio	0.16539	0.01435	0.03662	0.01163	0.11005	0.06677	0.04971
	var(r)	0.06938	0.01281	0.01486	0.00168	0.03739	0.02256	0.01312
	# tows	27	211	238	90	135	225	463
Southeast Part	lb-keep		878	878	20		20	898
	lb-disc		0	0	0		0	0
	ratio		0	0	0		0	0
	var(r)		0	0	0		0	0
	# tows		33	33	2		2	35
North Edge & Peak	lb-keep		1963	1963	257	3942	4199	6162
	lb-disc		225	225	0	358	358	583
	ratio		0.11473	0.11473	0	0.09087	0.0853	0.09468
	var(r)		0.07051	0.07051	0	0.00636	0.00619	0.02285
	# tows		54	54	12	165	177	231
South New England	lb-keep	286		286	1440		1440	1726
	lb-disc	0		0	0		0	0
	ratio	0		0	0		0	0
	var(r)	0		0	0		0	0
	# tows	14		14	54		54	68
New York Bight	lb-keep	147		147	4820	4608	9428	9575
	lb-disc	0		0	96	238	333	333
	ratio	0		0	0.01988	0.05156	0.03536	0.03482
	var(r)	0		0	0.00425	0.00953	0.00525	0.00517
	# tows	8		8	164	235	399	407
DEMARVA	lb-keep	634	4051	4686				4686
	lb-disc	0	13	13				13
	ratio	0	0.00332	0.00287				0.00287
	var(r)	0	0.00078	0.00068				0.00068
	# tows	33	154	187				187
VA-NC	lb-keep	1336		1336				1336
	lb-disc	84		84				84
	ratio	0.06289		0.06289				0.06289
	var(r)	0.02388		0.02388				0.02388
	# tows	40		40				40

Table D7. Summary of discard-to-keep ratio in 1993.

Resource Area		Quarter		Quarters	Quarter		Quarters	
		1	2	1 + 2	3	4	3 + 4	Total
South	lb-keep	2909	7025	9934	158	2865	3023	12957
Chanel	lb-disc	343	1027	1370	0	295	295	1665
	ratio	0.11808	0.14614	0.13792	0.00152	0.103	0.09769	0.12854
	var(r)	0.01379	0.01317	0.01008	0.00105	0.01438	0.01385	0.00834
	# tows	65	256	321	11	209	220	541
Southeast	lb-keep	60	666	726	2466		2466	3192
Part	lb-disc	0	0	0	0		0	0
	ratio	0	0.00018	0.00017	0		0	0.00004
	var(r)	0	0.00018	0.00017	0		0	
0.00004								
	# tows	5	45	50	144		144	194
North	lb-keep	2548	960	3508	4113	385	4498	8006
Edge &	lb-disc	191	66	257	15	3	18	275
Peak	ratio	0.07478	0.06901	0.0732	0.00359	0.00874	0.00403	0.03434
	var(r)	0.02106	0.00709	0.01545	0.00024	0.00244	0.00032	0.00784
	# tows	69	33	102	205	32	237	339
South	lb-keep	445		445		149	149	594
New	lb-disc	0		0		0	0	0
England	ratio	0		0		0	0	0
	var(r)	0		0		0	0	0
	# tows	24		24		31	31	55
New York	lb-keep	5058	8192	13249	1315	3036	4351	17600
Bight	lb-disc	20	2	22	3	3	6	28
	ratio	0.00392	0.00025	0.00165	0.00256	0.00083	0.00135	0.00158
	var(r)	0.00312	0.00006	0.00119	0.00125	0.00048	0.00051	0.0009
	# tows	331	380	711	89	171	260	971
DEMARVA	lb-keep	2235	2261	4496	979		979	5475
	lb-disc	63	2	65	18		18	82
	ratio	0.02826	0.00074	0.01442	0.01803		0.01803	0.01506
	var(r)	0.00502	0.00053	0.00269	0.00406		0.00406	0.00233
	# tows	125	164	289	71		71	360

Table D8. Summary of Northeast Fisheries Science Center commercial scallop shell samples collected from vessels landings sea scallops using scallop dredges landings in Georges Bank and Mid-Atlantic ports from 1982 to 1991.

	Samples				Shells			
Year/Quarter	1	2	3	4	1	2	3	4
South Channel								
1982	7	12	10	3	984	2459	1450	624
1983	3	12	7	0	684	2718	1422	0
1984	0	5	5	5	0	1043	734	606
1985	3	3	7	1	520	668	1207	360
1986	6	10	18	21	1500	2795	4343	4752
1987	6	5	23	8	1474	1282	6266	1895
1988	3	13	15	7	629	3095	3732	1618
1989	0	10	16	8	0	2369	3304	1968
1990	7	14	9	8	1981	4607	1937	2122
1991	7	12	11	14	2263	3542	2875	3745
1992	7	12	16	24	1436	4119	4528	8284
1993	9	17	22	13	2568	5459	6892	3484
Southeast Part								
1982	2	0	1	0	431	0	262	0
1983	0	1	1	4	0	187	90	708
1984	0	5	1	2	0	812	118	395
1985	2	3	1	0	427	649	382	0
1986	3	5	5	3	994	1136	1284	644
1987	0	0	5	0	0	0	1158	0
1988	2	5	3	2	390	1119	715	630
1989	1	2	9	7	415	528	2132	1125
1990	0	5	3	0	0	1165	627	0
1991	6	5	8	2	1949	1516	1972	605
1992	7	12	8	3	2211	3512	2307	929
1993	7	7	19	7	1908	1792	4812	1263
Northern Edge and Peak								
1982	9	16	8	2	1810	3052	1718	441
1983	1	5	4	0	45	967	896	0
1984	0	1	0	6	0	84	0	1145
1985	2	0	9	4	261	0	1996	836
1986	0	7	6	1	0	1709	1380	206
1987	2	2	7	6	404	572	1604	1764
1988	1	11	16	6	337	2997	4427	1653
1989	1	3	8	6	342	618	2428	1842
1990	1	8	13	9	137	2393	3421	2944
1991	13	10	9	3	3576	2595	3603	828
1992	6	17	13	9	1641	4841	4542	2743
1993	5	12	12	2	2067	3819	2896	625

Table D8.(Continued).

Year/Quarter	Samples 1	2	3	4
New York Bight				
1982	2	2	1	1
1983	5	22	12	7
1984	14	8	4	4
1985	4	16	0	6
1986	5	5	4	5
1987	10	23	10	6
1988	11	9	10	5
1989	19	11	6	1
1990	22	8	1	0
1991	4	11	9	0
1992	14	11	11	9
1993	6	16	14	1
Delmarva				
1982	1	6	5	7
1983	5	10	4	3
1984	2	7	9	8
1985	0	11	15	11
1986	1	8	15	9
1987	6	21	33	14
1988	13	25	23	11
1989	8	27	23	15
1990	12	14	2	5
1991	2	6	4	8
1992	4	21	6	6
1993	5	9	6	3
Virginia-North Carolina				
1982	0	0	6	1
1983	0	0	0	0
1984	0	2	1	0
1985	0	2	2	0
1986	0	0	0	0
1987	1	0	1	1
1988	1	1	1	1
1989	0	2	2	2
1990	4	3	1	2
1991	0	0	3	0
1992	2	8	4	0
1993	3	1	0	1

Table D9. USA commercial sea scallop effort (days fished) from Georges Bank (Area 5Ze), the Mid-Atlantic (Statistical Area 6), and the Gulf of Maine (Division 5Y), by vessel tonnage class, 1965 - 1993. Data are derived from vessels using scallop dredges and landing in New England and Mid-Atlantic ports.

	GEORGES BANK				MID-ATLANTIC				GULF OF MAINE				TOTALS			
Year	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Grand Total
1965	-	1,921	216	2,138	48	3,622	313	3,982	261	20	-	281	309	5,563	529	6,401
1966	-	886	169	1,055	3	3,784	525	4,312	270	-	-	270	273	4,671	694	5,638
1967		1,468	402	1,870	5	2,224	452	2,681	239	3	-	242	244	3,695	854	4,793
1968	6	1,500	304	1,810	39	2,517	1,180	3,737	424	13	-	437	468	4,030	1,484	5,983
1969	-	1,953	760	2,713	4	1,142	701	1,847	511	54	-	565	514	3,149	1,461	5,125
1970	-	1,755	823	2,578	-	477	516	993	584	50	-	634	584	2,282	1,339	4,205
1971	-	1,424	989	2,413	-	240	480	719	1,063	116	37	1,216	1,063	1,780	1,506	4,348
1972	20	965	806	1,791	-	718	689	1,406	1,999	91	10	2,099	2,019	1,773	1,504	5,297
1973	-	1,103	740	1,842	-	128	428	556	2,365	129	31	2,524	2,365	1,360	1,198	4,922
1974	-	812	576	1,388	-	524	701	1,225	1,546	34	-	1,580	1,546	1,369	1,277	4,192
1975	11	594	495	1,100	3	819	924	1,746	2,393	14	-	2,407	2,407	1,428	1,419	5,253
1976	308	914	517	1,739	60	984	1,626	2,670	2,258	32	-	2,290	2,625	1,931	2,143	6,699
1977	1,028	2,314	1,121	4,463	71	818	1,216	2,105	1,371	4	-	1,376	2,471	3,136	2,337	7,943
1978	675	3,177	2,089	5,941	199	1,888	1,833	3,921	1,606	6	-	1,612	2,481	5,071	3,922	11,473
1979	445	4,057	4,405	8,907	150	2,566	1,564	4,280	1,854	79	45	1,977	2,449	6,702	6,014	15,165
1980	301	4,642	6,133	11,076	39	2,358	1,993	4,391	2,827	347	249	3,423	3,167	7,347	8,375	18,889
1981	165	4,619	8,578	13,361	3	1,240	1,194	2,437	2,700	265	233	3,198	2,868	6,124	10,005	18,996
1982	61	3,462	7,572	11,095	33	1,985	1,785	3,802	1,692	161	268	2,121	1,786	5,608	9,625	17,018
1983	215	3,228	7,027	10,470	37	3,791	3,091	6,918	4,063	390	256	4,709	4,314	7,408	10,374	22,097
1984	16	3,276	6,209	9,501	50	5,091	4,997	10,138	2,719	229	145	3,093	2,785	8,597	11,350	22,732
1985	14	2,650	6,610	9,273	32	4,286	5,539	9,856	2,074	220	148	2,442	2,119	7,155	12,298	21,571
1986	35	2,898	8,528	11,461	-	3,890	3,236	7,126	2,147	74	68	2,289	2,182	6,862	11,833	20,876
1987	9	2,412	7,777	10,198	-	5,509	7,129	12,637	3,349	139	8	3,496	3,358	8,059	14,914	26,331
1988	64	3,295	10,627	13,986	9	5,463	6,386	11,858	2,474	355	51	2,880	2,547	9,113	17,065	28,724
1989	150	2,776	11,923	14,849	65	6,114	8,622	14,801	3,266	211	21	3,498	3,481	9,101	20,566	33,148
1990	113	4,724	14,951	19,788	90	5,763	7,547	13,400	3,648	407	20	4,075	3,851	10,894	22,518	37,263
1991	149	4108	17505	21,762	147	9015	8198	17,360	3474	321	97	3,892	3,770	13,444	25,800	43,014
1992	160	4603	16853	21,616	157	12120	8380	20,657	3370	223	168	3,761	3,687	16,946	25,401	46,034
1993	77	3499	15405	18,981	199	10773	7857	18,829	4595	623	361	5,579	4,871	14,895	23,623	43,389

Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT.
Source: NEFC Detailed Weighout Data for vessels using scallop dredges. Mid-Atlantic weighout data are only available from 1978 onward; weighout data from Virginia ports are available for part of 1981 and from 1982 onward.
Note: Gulf of Maine 1982-1990 have been revised by S. Wigley, 5/24/91.

Table D10. USA commercial sea scallop catch rates (mt of meats per day fished) from Georges Bank (Area 5Ze), the Mid-Atlantic (Statistical Area 6) and the Gulf of Maine (Division 5Y), by vessel tonnage class, 1965 - 1993. Data were derived from vessels using scallop dredges and landing in New England and Mid-Atlantic ports.

	GEORGES BANK				MID-ATLANTIC				GULF OF MAINE				TOTALS			
Year	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Total	Class 2	Class 3	Class 4	Grand Total
1965	-	0.67	0.89	0.69	0.43	1.00	1.10	1.00	0.38	0.74	-	0.41	0.39	0.88	1.02	0.87
1966	-	0.83	0.88	0.84	0.23	0.93	1.01	0.94	0.34	-	-	0.34	0.34	0.91	0.98	0.89
1967	-	0.63	0.73	0.65	0.16	0.70	0.72	0.70	0.32	0.78	-	0.33	0.32	0.67	0.72	0.66
1968	0.27	0.55	0.57	0.55	0.20	0.63	0.69	0.64	0.26	0.34	-	0.26	0.25	0.60	0.67	0.59
1969	-	0.47	0.53	0.49	0.43	0.42	0.52	0.46	0.21	0.26	-	0.22	0.21	0.45	0.52	0.45
1970	-	0.57	0.51	0.55	-	0.40	0.52	0.46	0.20	0.34	-	0.21	0.20	0.53	0.51	0.48
1971	-	0.54	0.55	0.54	-	0.30	0.42	0.38	0.21	0.93	0.71	0.29	0.21	0.53	0.51	0.45
1972	0.46	0.48	0.42	0.46	-	0.40	0.53	0.46	0.24	0.36	0.49	0.25	0.25	0.44	0.47	0.38
1973	-	0.61	0.52	0.58	-	0.33	0.47	0.44	0.17	0.37	0.61	0.18	0.17	0.56	0.51	0.36
1974	-	0.69	0.61	0.66	-	0.76	0.77	0.77	0.14	0.36	-	0.14	0.14	0.71	0.70	0.49
1975	0.19	0.83	0.71	0.77	0.27	0.81	0.91	0.86	0.31	0.46	-	0.31	0.31	0.81	0.84	0.59
1976	0.85	1.02	1.03	0.99	0.31	1.06	1.18	1.11	0.15	0.45	-	0.16	0.24	1.03	1.14	0.76
1977	0.87	1.10	1.13	1.06	0.48	1.14	1.32	1.22	0.18	1.12	-	0.18	0.48	1.11	1.23	0.95
1978	0.55	0.94	1.05	0.93	0.76	0.89	1.28	1.06	0.15	0.56	-	0.15	0.31	0.92	1.16	0.87
1979	0.42	0.64	0.78	0.70	0.69	0.61	0.77	0.67	0.17	0.44	1.20	0.20	0.25	0.63	0.78	0.63
1980	0.24	0.42	0.55	0.49	0.34	0.39	0.51	0.45	0.21	1.24	1.82	0.43	0.21	0.45	0.58	0.47
1981	0.47	0.51	0.65	0.60	0.53	0.32	0.40	0.36	0.28	0.89	1.03	0.38	0.29	0.49	0.63	0.53
1982	0.43	0.52	0.58	0.56	0.20	0.37	0.49	0.42	0.22	0.47	0.69	0.30	0.23	0.46	0.56	0.50
1983	0.24	0.39	0.42	0.41	0.52	0.35	0.56	0.45	0.13	0.35	0.53	0.17	0.14	0.37	0.46	0.37
1984	0.18	0.31	0.32	0.32	0.32	0.33	0.39	0.36	0.19	0.29	0.38	0.21	0.20	0.32	0.35	0.32
1985	0.18	0.31	0.31	0.31	0.30	0.29	0.36	0.33	0.15	0.23	0.28	0.17	0.15	0.29	0.33	0.30
1986	0.19	0.35	0.40	0.39	-	0.42	0.50	0.46	0.11	0.17	0.34	0.12	0.12	0.39	0.43	0.38
1987	0.52	0.45	0.48	0.47	-	0.59	0.59	0.59	0.10	0.28	0.25	0.10	0.10	0.54	0.53	0.48
1988	0.33	0.41	0.44	0.43	0.80	0.48	0.49	0.49	0.15	0.21	0.39	0.16	0.16	0.44	0.46	0.43
1989	0.19	0.37	0.38	0.38	0.99	0.47	0.53	0.51	0.16	0.23	0.29	0.17	0.18	0.44	0.45	0.42
1990	0.45	0.51	0.50	0.50	0.68	0.44	0.44	0.44	0.13	0.19	0.35	0.13	0.15	0.46	0.48	0.44
1991	0.30	0.41	0.43	0.42	0.34	0.35	0.37	0.36	0.13	0.19	0.25	0.14	0.14	0.36	0.41	0.37
1992	0.22	0.34	0.39	0.38	0.18	0.22	0.26	0.24	0.18	0.25	0.31	0.19	0.18	0.26	0.35	0.30
1993	0.12	0.17	0.20	0.19	0.14	0.14	0.15	0.15	0.15	0.09	0.17	0.14	0.15	0.15	0.18	0.17

Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT.
Source: NEFC Detailed Weighout Data for vessels using scallop dredges. Mid-Atlantic weighout data are only available from 1978 onward; Weighout data from Virginia ports are available for part of 1981 and from 1982 onward.
Note: Gulf of Maine 1982-1990 revised by S. Wigley, 5/24/91.

Table D11 USA sea scallop research survey relative abundance indices (standardized stratified mean number and mean weight per tow), [meats only, kg], mean shell height (mm), mean meat weight (g) per scallop, and average meat count (number of scallop meats per pound) of sea scallops from NEFSC surveys on Georges Bank, 1975, 1977-1994. Data are presented by principal areas for Georges Bank[1]. Survey indices are presented for pre-recruit (<70 mm shell height), recruit (>_70 mm shell height), and total scallops per tow.

Area Year Count	No. of Tows	Standardized Stratified Mean Number Per Tow			Standardized Stratified Mean Weight (kg) Per Tow[2]			Mean Shell Height	Meat
		Pre-recruit	Recruit	Total	Pre-recruit	Recruit	Total		
South Channel									
1975	58	45.1	29.9	75.0	0.11	0.81	0.92	76.4	37.0
1977	30	6.3	89.1	95.4	0.02	1.94	1.96	101.3	22.1
1978	46	7.7	49.7	57.4	0.02	1.15	1.17	101.2	22.2
1979	47	6.8	88.2	95.0	0.01	1.53	1.54	93.2	28.0
1980	40	79.7	30.2	109.9	0.12	0.55	0.67	58.2	74.6
1981	56	15.5	36.5	52.0	0.03	0.65	0.68	80.5	34.8
1982	61	213.8	53.0	266.8	0.49	0.67	1.16	58.6	103.9
1983	69	19.0	55.8	74.8	0.06	0.77	0.83	81.4	41.0
1984	69	13.6	17.7	31.3	0.03	0.36	0.39	77.3	36.7
1985	77	40.3	47.3	87.6	0.11	0.76	0.87	75.0	45.7
1986	68	115.3	37.0	152.3	0.24	0.58	0.82	59.5	84.2
1987	86	84.6	56.1	140.7	0.17	0.72	0.89	63.6	71.6
1988	91	32.5	36.0	68.5	0.08	0.46	0.54	70.6	57.7
1989	88	21.7	15.1	36.8	0.06	0.27	0.33	72.0	50.5
1990	76	258.8	49.9	308.7	0.54	0.60	1.14	55.9	122.5
1991	86	432.1	64.2	496.3	0.80	0.71	1.51	52.8	149.5
1992	85	222.8	171.8	394.6	0.78	1.38	2.16	67.5	82.8
1993	77	30.6	24.5	55.1	0.11	0.28	0.39	71.7	63.3
1994	88	18.7	37.6	56.3	0.04	0.44	0.48	74.2	53.4
Southeast Part									
1975	21	1.8	38.4	40.2	<0.01	1.02	1.02	110.3	17.8
1977	21	3.2	27.2	30.4	0.01	0.68	0.69	103.6	20.0
1978	18	2.2	27.1	29.3	<0.01	0.93	0.93	117.2	14.2
1979	20	7.7	21.2	28.9	0.01	0.71	0.72	99.4	18.2
1980	20	21.5	41.7	63.2	0.03	0.71	0.74	78.2	38.8
1981	19	1.4	19.4	20.8	<0.01	0.46	0.46	102.5	20.5
1982	22	0.8	9.8	10.6	<0.01	0.32	0.32	113.5	15.2
1983	20	11.3	9.2	20.5	0.02	0.25	0.27	78.1	34.0
1984	20	4.6	12.9	17.5	0.01	0.23	0.24	85.7	33.0
1985	28	9.1	11.8	20.9	0.02	0.22	0.24	75.3	39.9
1986	32	28.9	20.6	49.5	0.05	0.41	0.46	66.2	48.5
1987	32	23.1	39.6	62.7	0.06	0.60	0.66	79.0	42.8
1988	32	1.4	16.1	17.5	<0.01	0.32	0.32	96.9	24.6
1989	31	23.6	11.8	35.4	0.07	0.23	0.30	70.2	54.4
1990	32	1.6	8.4	10.0	<0.01	0.15	0.15	88.7	30.3
1991	32	18.5	14.1	32.6	0.04	0.21	0.25	65.2	60.2
1992	32	10.3	20.5	30.8	0.03	0.34	0.37	83.3	37.7
1993	32	2.4	9.5	11.8	0.01	0.23	0.24	97.5	22.8
1994	32	19.6	8.9	28.5	0.03	0.25	0.28	66.9	46.2

[1]South Channel: Strata 46-47, 49-55; Southeast Part: Strata 58-60; USA No. Edge & Peak: Strata 61, 621, 631, 651, 662, 71, 72, and 74.

[2]Mean meat weight derived by applying the 1978-1982 USA Georges Bank research survey sea scallop shell height meat weight equation, ln Meat Weight (g) = -11.7656 + 3.1693 ln Shell Height (mm) (n = 5863, r = 0.98) to the to the survey shell height frequency distributions.

[3]Combined South Channel and Southeast Part regions only.

[4]Stratum 72 not sampled, excluded from analyses.

[5]Canadian portion of the Bank not sampled.

Table D11. Continued.

Area Year Count	No. of Tows	Standardized Stratified Mean Number Per Tow			Standardized Stratified Mean Weight (kg) Per Tow[2]			Mean Shell Height	Meat
		Pre-recruit	Recruit	Total	Pre-recruit	Recruit	Total		
USA/Northern Edge and Peak									
1985	67	21.8	26.6	48.4	0.06	0.39	0.45	72.2	48.9
1986	70	45.6	28.6	74.2	0.13	0.48	0.61	70.4	55.2
1987	71	62.0	54.6	116.6	0.12	0.73	0.85	67.1	62.1
1988	71	65.8	60.9	126.7	0.15	0.77	0.92	66.4	62.6
1989	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
1990[4]	65	66.9	196.8	263.7	0.22	1.83	2.05	75.8	58.3
1991	71	118.7	66.9	185.6	0.31	0.85	1.16	66.1	72.4
1992	69	26.1	45.0	71.1	0.08	0.60	0.68	77.6	47.3
1993	67	2.7	15.6	18.3	0.01	0.25	0.26	88.6	32.4
1994	70	14.9	10.4	25.3	0.02	0.22	0.24	69.4	47.7
USA/Georges Bank									
1985	172	26.5	31.8	58.3	0.07	0.50	0.57	74.2	46.4
1986	170	61.3	28.9	90.2	0.14	0.49	0.63	64.4	64.9
1987	189	62.6	51.9	114.5	0.12	0.70	0.82	66.8	63.0
1988	194	38.0	40.8	78.8	0.09	0.54	0.63	69.4	56.6
1989[3]	119	22.4	14.0	36.4	0.06	0.26	0.32	71.4	52.3
1990[4]	173	135.2	87.8	223	0.31	0.89	1.20	63.9	84.1
1991	189	224.1	51.4	278.2	0.45	0.65	1.10	56.4	114.8
1992	186	102.7	91.2	193.9	0.36	0.86	1.22	69.4	72.3
1993	176	14.0	17.8	31.8	0.05	0.26	0.31	77.5	46.9
1994	190	17.5	21.1	38.6	0.04	0.31	0.35	71.8	50.6
Canada/Northern Edge and Peak									
1985	41	186.0	460.3	646.3	0.58	4.20	4.78	74.1	61.3
1986	146	379.6	466.0	845.6	0.80	6.01	6.81	72.3	56.3
1987	47	293.0	231.7	524.7	0.59	3.04	3.63	66.9	65.6
1988	48	153.7	227.1	380.8	0.36	2.77	3.13	72.8	55.3
1989	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
1990	41	431.7	287.9	719.6	0.68	3.80	4.48	61.9	72.9
1991	14	206.4	98.3	304.7	0.53	1.62	2.15	66.7	64.3
1992	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
1993	48	19.5	199.2	218.7	0.06	3.25	3.31	92.8	30.0
1994	47	110.6	237.2	347.8	0.19	3.54	3.73	78.5	42.3
Total Georges Bank(All Areas)									
1975	130	51.7	74.6	126.3	0.13	1.34	1.47	79.9	39.0
1977	122	34.3	218.3	252.6	0.12	3.18	3.30	87.6	34.7
1978	140	79.7	184.0	263.7	0.14	3.88	4.02	87.1	29.8
1979	220	36.6	152.3	188.9	0.10	2.70	2.80	88.6	30.6
1980	371	377.4	92.3	469.7	0.52	1.37	1.89	53.4	112.6
1981	176	97.2	152.4	249.6	0.22	1.62	1.84	70.6	61.5
1982	163	91.0	51.2	142.2	0.22	0.74	0.96	66.5	66.9
1983	171	31.9	38.2	70.1	0.06	0.63	0.69	73.4	46.3
1984	171	148.7	34.6	183.3	0.15	0.57	0.72	49.1	114.9
1985	213	56.3	111.6	167.9	0.17	1.19	1.36	74.1	56.2
1986	316	129.9	123.0	252.9	0.28	1.68	1.96	70.1	58.5
1987	236	105.5	85.4	190.9	0.21	1.14	1.35	66.9	64.3
1988	242	59.5	75.6	135.1	0.14	0.96	1.10	71.2	55.9
1989[3]	119	22.4	14.0	36.4	0.06	0.26	0.32	71.4	52.3
1990[4]	214	193.6	127.3	320.9	0.38	1.47	1.85	63.0	78.7
1991	203	220.8	62.3	283.1	0.46	0.83	1.29	58.5	99.2
1992[5]	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
1993	224	15.0	51.6	66.6	0.05	0.82	0.87	86.8	34.9
1994	117	51.4	97.0	148.4	0.08	1.48	1.56	77.6	42.8

Table D12. USA sea scallop research survey relative abundance indices (standardized stratified mean number and mean weight per tow), [meats only, kg], mean shell height (mm), mean meat weight (g) per scallop, and average meat count (number of scallop meats per pound) of sea scallops from NEFSC surveys in the Mid-Atlantic, 1975, 1977-1994. Data are presented by principal scallop areas in the Mid-Atlantic1. Survey indices are presented for pre-recruit (<70 mm shell height), recruit (>_70 mm shell height) and total scallops per tow.

Area Year Count	No. of Tows	Standardized Stratified Mean Number Per Tow			Standardized Stratified Mean Weight (kg) Per Tow[2]			Mean Shell Height	Meat
		Pre-recruit	Recruit	Total	Pre-recruit	Recruit	Total		
Virginia-No. Carolina									
1975	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
1977	1	0.0	10.0	10.0	0.0	0.23	0.23	108	20
1978	3	15.3	50.3	65.6	0.06	1.10	1.16	91.8	25.7
1979	3	23.7	22.7	46.4	0.04	0.37	0.41	71.7	51.3
1980	3	6.6	39.0	45.6	0.02	0.59	0.61	87.6	34.1
1981	3	0.9	7.6	8.5	<0.01	0.20	0.20	107.7	18.8
1982	7	0.4	3.7	4.1	<0.01	0.12	0.12	111.5	15.8
1983	8	25.8	11.7	37.5	0.10	0.36	0.46	78.1	37.2
1984	9	0.2	14.6	14.8	<0.01	0.27	0.27	98.7	25.3
1985	10	1.7	7.3	9.0	<0.01	0.23	0.23	104.8	17.8
1986	10	5.6	1.8	7.4	<0.02	0.04	0.06	69.1	55.9
1987	10	0.1	2.1	2.2	<0.01	0.04	0.04	93.4	28.3
1988	10	3.1	11.0	14.1	0.01	0.21	0.22	89.8	28.9
1989	10	35.7	5.9	41.6	0.07	0.13	0.20	57.9	92.9
1990	6	36.5	93.1	129.6	0.07	0.88	0.95	73.2	61.7
1991	10	37.2	32.0	69.2	0.10	0.45	0.55	71.6	57.5
1992	10	4.1	29.2	33.3	0.01	0.39	0.40	85.9	37.7
1993	10	245.3	59.1	304.4	0.83	0.54	1.37	64.3	100.5
1994	10	13.3	145.5	158.8	0.05	1.30	1.35	79.8	53.5
Delmarva									
1975	15	36.2	24.0	60.2	0.11	0.44	0.55	75.2	49.3
1977	10	10.7	47.5	58.2	0.03	0.91	0.94	92.2	28.1
1978	45	27.3	75.8	103.2	0.09	1.58	1.67	91.6	28.0
1979	43	25.4	64.6	90.0	0.04	0.95	0.99	78.8	41.2
1980	43	81.1	35.9	117.0	0.13	0.68	0.81	63.3	65.7
1981	41	4.7	14.3	19.0	0.01	0.32	0.33	90.3	26.2
1982	44	10.0	18.6	28.6	0.04	0.43	0.47	89.8	27.8
1983	49	25.7	16.5	42.2	0.09	0.37	0.46	77.0	41.7
1984	52	19.8	19.3	39.1	0.03	0.38	0.41	69.8	43.7
1985	54	70.4	35.8	106.2	0.15	0.43	0.58	58.9	82.5
1986	62	123.5	83.5	207.0	0.37	0.93	1.30	68.5	72.3
1987	61	52.9	59.5	112.4	0.16	0.74	0.90	74.1	56.7
1988	62	75.9	39.1	115.0	0.15	0.62	0.77	64.6	67.9
1989	62	113.1	97.2	210.3	0.24	1.09	1.33	67.5	71.6
1990	62	27.7	80.9	108.6	0.06	0.87	0.93	76.9	53.0
1991	61	53.5	29.3	82.8	0.16	0.47	0.63	71.3	59.4
1992	62	20.9	18.8	39.8	0.04	0.33	0.37	71.9	49.0
1993	58	384.1	20.1	404.1	1.00	0.28	1.28	57.3	143.0
1994	62	73.4	171.0	244.4	0.12	1.45	1.57	69.5	70.5

[1]New York Bight: Strata 22-31, 33-35; Delmarva: Strata 10-11, 14-15, 18-19; VA-NC: Strata 6-7.

[2]Mean meat weight derived by applying the 1977-1982 USA Mid-Atlantic research survey sea scallop shell height meat weight equation, ln Meat Weight (g) = -12.1628 + 3.2539 ln Shell Height (mm) (n = 11943, r = 0.98) to the to the survey shell height frequency distributions.

Table D12. Continued.

Area Year Count	No. of Tows	Standardized Stratified Mean Number Per Tow Pre-recruit	Recruit	Total	Standardized Stratified Mean Weight (kg) Per Tow[2] Pre-recruit	Recruit	Total	Mean Shell Height	Meat
New York Bight									
1975	28	39.4	34.7	74.1	0.10	0.62	0.72	75.3	46.9
1977	101	1.4	56.7	58.1	<0.01	1.03	1.03	98.6	25.6
1978	116	3.3	52.7	56.0	0.01	1.15	1.16	102.8	21.9
1979	120	5.3	17.6	22.9	0.01	0.43	0.44	93.6	23.7
1980	121	15.4	15.2	30.6	0.02	0.36	0.38	75.5	35.7
1981	117	18.8	19.0	37.8	0.03	0.29	0.32	67.7	53.5
1982	134	10.9	20.9	31.8	0.02	0.33	0.35	78.4	41.2
1983	136	11.5	14,0	25.5	0.03	0.29	0.32	80.3	36.6
1984	142	17.4	18.4	35.8	0.03	0.29	0.32	69.2	51.0
1985	137	47.4	30.9	78.3	0.10	0.43	0.53	65.6	67.1
1986	152	53.2	49.3	102.5	0.13	0.65	0.78	69.6	59.9
1987	154	94.5	46.0	140.5	0.18	0.58	0.76	61.7	83.7
1988	154	75.9	100.5	176.4	0.11	1.25	1.36	68.6	58.9
1989	157	168.6	81.8	250.4	0.25	0.90	1.15	56.4	99.1
1990	148	121.1	92.8	213.9	0.35	0.88	1.23	67.2	78.7
1991	157	22.2	53.7	75.9	0.06	0.67	0.73	78.3	47.3
1992	157	17.7	25.3	43.0	0.04	0.37	0.41	75.5	47.4
1993	146	46.6	24.0	70.6	0.10	0.31	0.41	64.9	77.9
1994	155	102.1	45.8	147.9	0.12	0.49	0.61	55.6	109.1
Mid-Atlantic/(All Areas)									
1975	43	38.8	32.6	71.4	0.10	0.59	0.69	75.3	47.2
1977	112	2.8	55.1	57.9	0.01	1.00	1.01	97.7	25.9
1978	164	7.8	56.8	64.6	0.02	1.23	1.25	99.4	23.4
1979	166	9.1	26.2	35.3	0.02	0.52	0.54	86.5	29.8
1980	167	27.1	19.2	46.3	0.04	0.42	0.46	70.1	45.8
1981	161	16.1	18.0	34.1	0.02	0.30	0.32	70.1	48.2
1982	185	10.6	20.3	30.9	0.03	0.34	0.37	80.4	38.1
1983	193	14.3	14.4	28.7	0.04	0.30	0.34	79.4	37.8
1984	203	17.6	18.5	36.1	0.02	0.31	0.33	69.5	49.2
1985	201	51.0	31.5	82.5	0.11	0.43	0.54	64.1	69.8
1986	224	65.2	54.8	120.0	0.17	0.69	0.86	69.3	63.3
1987	225	85.7	47.9	133.6	0.17	0.61	0.78	63.6	78.0
1988	226	74.9	88.3	163.2	0.12	1.12	1.24	68.1	59.9
1989	229	156.9	83.6	240.5	0.24	0.93	1.17	58.1	93.5
1990	216	103.2	90.6	193.8	0.29	0.88	1.17	68.2	74.9
1991	228	28.0	49.0	77.0	0.08	0.63	0.71	76.8	49.4
1992	229	18.1	24.2	42.3	0.03	0.37	0.40	75.0	47.5
1993	214	109.9	23.8	133.6	0.28	0.30	0.58	60.7	104.5
1994	227	95.8	69.6	165.4	0.11	0.67	0.80	59.6	94.2

[1]New York Bight: Strata 22-31, 33-35; Delmarva: Strata 10-11, 14-15, 18-19; VA-NC: Strata 6-7.

[2]Mean meat weight derived by applying the 1977-1982 USA Mid-Atlantic research survey sea scallop shell height meat weight equation, ln Meat Weight (g) = -12.1628 + 3.2539 ln Shell Height (mm) (n = 11943, r = 0.98) to the to the survey shell height frequency distributions.

Table D13. Size-frequency distributions, retention ratio and estimated selectivities of lined and unlined dredges used in the NEFSC sea scallop research surveys.

Shell Height (mm)	Number of Shells		Retention Ratio Lined/Unlined	Selectivity	
	Lined	Unlined		Lined	Unlined
10	4	0	0.0000	1.0000	0.0461
15	2	0	0.0000	1.0000	0.0662
20	5	3	0.6000	1.0000	0.0943
25	59	7	0.1186	0.9998	0.1326
30	179	38	0.2123	0.9994	0.1833
35	459	122	0.2658	0.9979	0.2479
40	900	276	0.3067	0.9923	0.3262
45	1234	494	0.4003	0.9734	0.4155
50	635	360	0.5669	0.9214	0.5108
55	224	166	0.7411	0.8332	0.6052
60	127	116	0.9134	0.7606	0.6925
65	102	101	0.9902	0.7288	0.7679
70	111	120	1.0811	0.7187	0.8294
75	115	166	1.4435	0.7158	0.8772
80	133	140	1.0526	0.7150	0.9131
85	144	211	1.4653	0.7148	0.9392
90	120	179	1.4917	0.7148	0.9579
95	127	207	1.6299	0.7148	0.9711
100	190	274	1.4421	0.7148	0.9803
105	224	264	1.1786	0.7148	0.9866
110	221	293	1.3258	0.7148	0.9910
115	210	231	1.1000	0.7148	0.9940
120	171	231	1.3509	0.7148	0.9960
125	116	180	1.5517	0.7148	0.9974
130	76	103	1.3553	0.7148	0.9984
135	45	52	1.1556	0.7148	0.9990
140	25	35	1.4000	0.7148	0.9995
145	7	12	1.7143	0.7148	0.9998
150	2	3	1.5000	0.7148	1.0000

Table D14. Comparison of alternative methods for estimation of recruits and full recruits in the modified Delury model.

Feature	Multifan	Selectivity Method
Estimation of Recruits	All individuals in the first component normal distribution of the truncated composite survey size composition.	Based on assumed size selectivity pattern of fishery, expected annual growth increment of scallops by 5mm length class, and truncated composite survey size composition.
Ageing	All individuals in the first component normal distribution of the truncated composite survey size composition are assumed to be the same age and will transfer to the fully recruited stage in the next time step.	No explicit ageing although the magnitude of the growth increment for each size class is based on a one year time step.
Growth	Growth varies from year to year but results potentially contaminated by contribution of younger aged scallops not distinguished in the lower mode of the survey size frequency.	Deterministic growth increment, invariant with respect to year, based on fitted von Bertalanffy growth model derived from tagging study described in Serchuk et al. (1979). Growth increment is based on a Ford-Walford type function (Gulland 1969).
Minimum size of recruits	Equal to the minimum size group of the truncated composite survey size frequency.	Depends on the minimum sized scallop that could grow into the size range vulnerable to the fishery.
Estimation of full recruits	Estimated as difference between the truncated composite survey size composition and the derived number of recruits.	Estimated as the number of scallops in the composite size frequency of the survey that are vulnerable to the fishery. Obtained by applying the fishery selectivity function to the composite size frequency.
Estimated total recruits and full recruits in year t	All scallops in the truncated survey size composition are assigned to either recruits or full recruits.	Total will be less than or equal to total number in truncated survey size frequency and depend on growth rates of smallest scallops.
Within year pattern of transition from recruits to fully recruited stage (mean time of transition)	Computed as fraction of recruits vulnerable to fishery at time of survey and estimated by applying the commercial fishery selection pattern to size composition of the recruits.	Dependent on seasonal growth pattern. Unknown for most stock areas, but assumed to range between 0.25 and 0.75.

Table D15. Summary of commercial landings and survey indices input into the modified DeLury model. Survey indices have been adjusted by selectivity of survey lined gear.

	Commercial Landings						Survey Indices (Number/tow)		
	Meat Weight (mt)		Mean Weight (g)		Catch Number ($x10^6$)				
Year	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Recruited	Fully-Recruited	Total
South Channel									
1982	1536	1790	22.76359	20.96474	67.47617	85.38147	195.587	49.129	244.716
1983	1110	1306	24.43944	25.11369	45.41839	52.00351	35.043	61.776	96.819
1984	734	884	25.86715	27.55352	28.37576	32.08302	12.078	21.729	33.807
1985	515	1025	19.13735	25.76958	26.91073	39.77558	46.389	55.896	102.285
1986	1122	1577	17.70376	20.28881	63.37638	77.72757	95.579	40.088	135.667
1987	826	1561	15.83406	20.27522	52.16604	76.99054	74.479	59.744	134.222
1988	1475	1635	20.3632	20.19621	72.43458	80.95579	40.924	36.707	77.631
1989	803	1957	23.28304	21.91101	34.48863	89.31581	24.401	17.377	41.779
1990	1392	2573	15.88573	19.35243	87.62579	132.9549	202.791	53.119	255.910
1991	2748	2907	15.37627	22.22477	178.7169	130.8	307.416	57.881	365.297
1992	2848	1968	17.16323	15.82093	165.9362	124.3922	378.417	127.379	505.796
1993	1247	817	19.6793	21.02421	63.36608	38.85995	49.713	23.170	72.882
1994	n/a	n/a	n/a	n/a	n/a	n/a	24.753	41.436	66.188
North Edge and Peak									
1982	1275	1178	20.22346	22.07952	63.04558	53.35262	55.204	76.604	131.808
1983	890	545	21.73205	27.84994	40.95335	19.56916	31.250	46.776	78.026
1984	206	534	22.43593	25.48935	9.181702	20.94992	106.104	59.899	166.003
1985	218	738	44.94234	25.69632	4.85066	28.72006	28.459	27.689	56.148
1986	684	411	20.47975	21.1695	33.39885	19.41473	50.971	33.224	84.195
1987	985	1216	15.72273	21.18434	62.64814	57.40088	56.705	59.519	116.223
1988	887	1227	20.09406	22.50573	44.14239	54.51944	67.991	66.514	134.505
1989	1387	929	24.30913	23.59833	57.05674	39.36719		NO SURVEY	
1990	1663	3351	16.40028	16.24379	101.4007	206.2942	159.693	189.512	349.205
1991	2082	669	18.05798	15.01882	115.2953	44.5441	129.023	72.122	201.145
1992	864	1434	15.97027	14.62175	54.10052	98.07307	38.855	50.359	89.214
1993	762	328	15.55645	26.56662	48.98291	12.34632	4.941	18.931	23.871
1994	n/a	n/a	n/a	n/a	n/a	n/a	9.175	13.375	22.550
Southeast Part									
1982	201	341	35.57203	22.44122	5.650506	15.19525	0.613	13.585	14.198
1983	119	313	37.68487	40.13157	3.157766	7.799345	9.275	12.304	21.579
1984	368	316	37.76672	29.39831	9.744029	10.74892	5.464	16.574	22.039
1985	92	307	21.7425	26.19851	4.231343	11.71822	8.729	14.220	22.950
1986	189	452	19.85432	24.43338	9.519338	18.49928	23.248	24.521	47.769
1987	105	157	24.19653	24.24813	4.339466	6.474725	26.461	49.557	76.018
1988	381	450	25.71972	20.6367	14.81354	21.80581	3.497	20.388	23.885
1989	198	390	22.29626	29.30445	8.880412	13.30856	23.304	15.182	38.486
1990	578	428	23.59912	17.20452	24.49243	24.87719	2.882	10.172	13.053
1991	518	387	19.74402	26.19007	26.23579	14.77659	17.657	13.644	31.301
1992	676	447	16.37953	24.48566	41.27101	18.25558	14.801	25.296	40.097
1993	266	235	24.18454	27.91695	10.99876	8.417824	3.020	12.405	15.425
1994	n/a	n/a	n/a	n/a	n/a	n/a	11.238	12.059	23.297

Table D15. Continued.

	Commercial Landings						Survey Indices (Number/tow)		
	Meat Weight (mt)		Mean Weight (g)		Catch Number ($x10^6$)			Fully-	
Year	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Recruited	Recruited	Total
New York Bight									
1982	634	589	22.23352	29.236	28.5155	20.1464	12.131	22.582	34.714
1983	1579	1220	24.37336	26.87605	64.78384	45.39358	25.145	19.049	44.194
1984	1908	775	22.06368	24.72407	86.47695	31.34597	8.823	24.844	33.668
1985	1871	866	22.37197	27.2857	83.63145	31.73824	54.245	32.409	86.653
1986	1377	1167	21.14292	20.69132	65.12819	56.40047	119.840	84.272	204.112
1987	3288	1671	18.54746	19.71431	177.2749	84.76079	49.787	70.855	120.642
1988	2075	1389	18.69425	28.15504	110.9967	49.33398	32.400	49.657	82.057
1989	4484	1344	21.53451	19.52107	208.2239	68.84869	76.802	105.427	182.229
1990	2777	607	19.71989	12.69464	140.8223	47.81544	39.092	86.432	125.524
1991	3457	1270	23.09167	28.6927	149.7077	44.26213	42.435	36.537	78.972
1992	1455	1347	19.88908	22.93774	73.15573	58.72418	11.847	22.870	34.717
1993	944	802	26.10057	25.82298	36.1678	31.05761	220.477	23.540	244.018
1994	n/a	n/a	n/a	n/a	n/a	n/a	113.185	146.390	259.575
Delmarva									
1982	135	221	29.36317	32.57581	4.597595	6.784175	9.904	23.929	33.833
1983	114	185	29.88458	33.24843	3.814676	5.564172	7.393	17.795	25.188
1984	365	579	28.00709	23.33965	13.03241	24.80757	7.180	22.420	29.599
1985	281	249	26.89085	26.89652	10.44965	9.257704	30.401	34.304	64.705
1986	430	384	21.8184	22.60358	19.70814	16.98846	39.325	56.135	95.460
1987	1080	1722	18.07713	20.17286	59.74401	85.36223	43.979	53.562	97.541
1988	1566	1121	23.07811	24.22239	67.85651	46.27949	48.599	110.130	158.729
1989	1323	775	19.92837	23.27532	66.38776	33.29707	75.928	81.019	156.947
1990	1910	973	14.84772	18.9549	128.6393	51.33238	126.004	82.973	208.977
1991	1124	1068	23.31765	27.97978	48.20383	38.17043	28.897	57.791	86.688
1992	856	732	20.96633	20.08672	40.82736	36.44199	13.067	29.443	42.510
1993	349	426	22.39168	25.06997	15.58614	16.99244	29.121	25.320	54.441
1994	n/a	n/a	n/a	n/a	n/a	n/a	32.479	45.577	78.056

Table D16. Results from the modified DeLury model for the South Channel on Georges Bank.

DELURY v2.0 Oct94 Run Number 2 1995 5 29 9 5 55
Sea Scallop, SOUTH CHANNEL, 1982-1994

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: SCH1.DAT
Data used in fitting the model:

1. The survey provides indices of abundance for recruit and fully-recruited numbers at a point 50% into the calendar year.

2. The catch is taken a at point 50% into the calendar year.

3. Natural mortality is 0.1

4. Input data for Model: Recruits, Full Recruits, and Catch are summarized in Table 4.3

5. Number per tow is the true value multiplied by 1000

6. C_number in millions. 1994 commercial landing is not available at this time, April 20, 1995

7. Discard has not been included

8. Estimates of biomass were not utilized in this assessment.

9. Note that the recruit abundance index for the last year is NOT used in the least squares estimation. It is, however, used in conjunction with the least squares estimate of q_n and the selectivity of the recruits to calculate recruit population size in 1994

10. Selectivity of the recruits (relative to the fully-recruited animals)to the survey gear is set at 1.0 for all years 1982 to 1994. The SELECTIVITY method (see text, Table D14) was used to separate recruits and fully-recruited age groups

11. Partial recuitment of recruits to the commercial fishery. A survey year (SY) is the period between successive annual surveys. Partial recruitment (PR) of the recruits to the commercial fishery is a function of month during the survey year. As animals grow in size, partial recruitment increases, eventually reaching 1.0 at the end of each survey year. The PR function may vary over SYs due to changes in regulations and/or unusually small (or large) mean size of the recruits. The following table gives the input PR functions for each survey year. The rows of the table represent the percent of the SY completed, e.g. 0 represents the beginning of the SY and 100 (**) represents the end of the SY. The annual average partial recruitment (shown after this table) results from integrating the annual PR functions with respect to time during the SY. The average partial recruitment of recruits to the commercial fishery was set at 0.5 for all years.

12. Measurement error in the abundance indices for both the recruits and the fully-recruited is assumed to be lognormally distributed. Process error is assumed to follow a lognormal distribution.

13. For Tables D16 to D20 note that RECRUITS = SIZECLASS 1 and FULLY-RECRUITED = SIZECLASS 2+. Also note that the recruit population estimate for the last year (1994) is NOT a least squares estimate. It is calculated from the observed survey index, the least squares estimate of q, and the s_r.

14. The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT"). The original input weights for measurement error on the full recruits and recruits and process error were set to {1, 1, 1}, respectively. The normalized weights for these error terms were {0.027, 0.027, 0.027} respectively. Process error weights were set so that percent of total variation contributed by process error was less than 25%.

15. Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates. Initial estimates are the observed values plus a small random error.

Table D16. (Continued).

RESULTS

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

SUM OF SQUARES	0.127411
ORTHOGONALITY OFFSET.........	0.006076
MEAN SQUARE RESIDUALS	0.011583

	PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
1	n 2+ 1982	4.39049E1	2.81608E1	1.55908E0	0.64
2	n 2+ 1983	7.11105E1	3.14438E1	2.26151E0	0.44
3	n 2+ 1984	4.42442E1	1.83085E1	2.41660E0	0.41
4	n 2+ 1985	3.69273E1	1.96582E1	1.87846E0	0.53
5	n 2+ 1986	4.12900E1	2.20013E1	1.87671E0	0.53
6	n 2+ 1987	5.64219E1	2.94802E1	1.91389E0	0.52
7	n 2+ 1988	4.93764E1	2.34585E1	2.10485E0	0.48
8	n 2+ 1989	2.19177E1	1.33121E1	1.64645E0	0.61
9	n 2+ 1990	3.40612E1	2.09595E1	1.62510E0	0.62
10	n 2+ 1991	5.96279E1	3.53493E1	1.68682E0	0.59
11	n 2+ 1992	8.60444E1	4.70953E1	1.82703E0	0.55
12	n 2+ 1993	4.14576E1	2.25564E1	1.83795E0	0.54
13	n 2+ 1994	3.93607E1	2.31018E1	1.70379E0	0.59
14	r 1 1982	1.37668E2	6.51327E1	2.11365E0	0.47
15	r 1 1983	3.31349E1	2.05999E1	1.60850E0	0.62
16	r 1 1984	1.49050E1	9.48464E0	1.57149E0	0.64
17	r 1 1985	4.49566E1	2.54757E1	1.76468E0	0.57
18	r 1 1986	9.48592E1	4.54874E1	2.08539E0	0.48
19	r 1 1987	6.90225E1	3.76644E1	1.83257E0	0.55
20	r 1 1988	5.23430E1	2.74793E1	1.90482E0	0.52
21	r 1 1989	6.81334E1	2.71545E1	2.50910E0	0.40
22	r 1 1990	1.55673E2	6.32542E1	2.46107E0	0.41
23	r 1 1991	2.16197E2	9.26636E1	2.33313E0	0.43
24	r 1 1992	1.42998E2	6.86429E1	2.08321E0	0.48
25	r 1 1993	5.30990E1	2.84631E1	1.86554E0	0.54
26	Surv q_n	5.20762E-1	1.25438E-1	4.15155E0	0.24

CALENDAR YEAR	STOCK SIZE ESTIMATES (millions at time of survey)		MORTALITY RATES (between surveys)		
	RECRUITS	FULLY-RECRUITED	Z on sizes 1+	F on size 1	F on sizes 2+
1982	264.358	84.309	0.94	0.67	1.35
1983	63.628	136.551	0.86	0.45	0.90
1984	28.622	84.961	0.47	0.21	0.42
1985	86.328	70.910	0.68	0.40	0.81
1986	182.155	79.288	0.88	0.60	1.20
1987	132.541	108.345	0.93	0.57	1.15
1988	100.512	94.816	1.53	0.97	1.93
1989	130.834	42.088	0.97	0.70	1.40
1990	298.933	65.406	1.16	0.90	1.79
1991	415.154	114.501	1.16	0.88	1.75
1992	274.593	165.228	1.71	1.17	2.34
1993	101.964	79.609	0.88	0.54	1.08
1994	47.532	75.583			

Table D17. Results from the modified DeLury model for the Southeast Part on Georges Bank.

DELURY v2.0 Oct94 Run Number 3 1995 5 29 9 9 37
Sea Scallop, SOUTHEAST PART, 1982-1994

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: SEP1.DAT
Data used in fitting the model:

REFER TO ITEMS 1 TO 13 IN Table D16.

14. The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT"). The original input weights for measurement error on the full recruits and recruits and process error were set to {1, 1, 2}, respectively. The normalized weights for these error terms were {0.0204, 0.0204, 0.0408} respectively. Process error weights were set so that percent of total variation contributed by process error was less than 25%.

15. Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates. Initial estimates are the observed values plus a small random error.

RESULTS

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

SUM OF SQUARES	0.037815
ORTHOGONALITY OFFSET.........	0.007943
MEAN SQUARE RESIDUALS	0.003438

	PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
1	n 2+ 1982	1.63764E1	4.37347E0	3.74448E0	0.27
2	n 2+ 1983	1.11235E1	3.53508E0	3.14660E0	0.32
3	n 2+ 1984	1.64743E1	4.16634E0	3.95413E0	0.25
4	n 2+ 1985	1.53767E1	4.24833E0	3.61946E0	0.28
5	n 2+ 1986	2.02059E1	5.65374E0	3.57390E0	0.28
6	n 2+ 1987	3.10975E1	8.41901E0	3.69373E0	0.27
7	n 2+ 1988	2.88220E1	6.57538E0	4.38333E0	0.23
8	n 2+ 1989	1.70895E1	4.91266E0	3.47867E0	0.29
9	n 2+ 1990	2.18335E1	4.79023E0	4.55793E0	0.22
10	n 2+ 1991	1.18773E1	3.92620E0	3.02513E0	0.33
11	n 2+ 1992	1.96429E1	5.26925E0	3.72784E0	0.27
12	n 2+ 1993	1.47171E1	3.96824E0	3.70872E0	0.27
13	n 2+ 1994	1.16498E1	3.88388E0	2.99952E0	0.33
14	r 1 1982	6.17176E-1	2.54461E-1	2.42542E0	0.41
15	r 1 1983	9.52349E0	3.58745E0	2.65467E0	0.38
16	r 1 1984	5.54440E0	2.22221E0	2.49500E0	0.40
17	r 1 1985	9.40454E0	3.66372E0	2.56694E0	0.39
18	r 1 1986	2.24668E1	8.21470E0	2.73495E0	0.37
19	r 1 1987	1.91339E1	7.42848E0	2.57576E0	0.39
20	r 1 1988	3.32036E0	1.36333E0	2.43547E0	0.41
21	r 1 1989	1.82100E1	6.66698E0	2.73137E0	0.37
22	r 1 1990	3.03295E0	1.24302E0	2.43998E0	0.41
23	r 1 1991	1.95063E1	6.78540E0	2.87475E0	0.35
24	r 1 1992	1.33807E1	5.07563E0	2.63627E0	0.38
25	r 1 1993	3.04518E0	1.24328E0	2.44931E0	0.41
26	Surv q_n	2.63053E-1	7.33056E-2	3.58845E0	0.28

Table D17. (Continued).

CALENDAR YEAR	STOCK SIZE ESTIMATES (millions at time of survey) RECRUITS	FULLY-RECRUITED	MORTALITY RATES (between surveys) Z on sizes 1+	F on size 1	F on sizes 2+
1982	2.346	62.255	0.42	0.16	0.33
1983	36.204	42.286	0.23	0.08	0.16
1984	21.077	62.627	0.36	0.15	0.30
1985	35.751	58.455	0.20	0.06	0.13
1986	85.408	76.813	0.32	0.15	0.29
1987	72.738	118.217	0.56	0.28	0.56
1988	12.622	109.567	0.63	0.28	0.56
1989	69.225	64.966	0.48	0.26	0.51
1990	11.530	83.000	0.74	0.34	0.68
1991	74.153	45.152	0.47	0.27	0.53
1992	50.867	74.673	0.81	0.44	0.89
1993	11.576	55.947	0.42	0.18	0.35
1994	42.722	44.287			

Table D18. Results from the modified DeLury model for the Northern Edge and Peak on Georges Bank.

DELURY v2.0 Oct94 Run Number 4 1995 5 29 9 12 5
Sea Scallop, NORTH EDGE & PEAK, 1982-1994

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: NEP1.DAT
Data used in fitting the model:

REFER TO ITEMS 1 TO 13 IN Table D16.

14. The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT"). The original input weights for measurement error on the full recruits and recruits and process error were set to (1, 1, 4), respectively. The normalized weights for these error terms were (0.0149, 0.0149, 0.0597) respectively. Process error weights were set so that percent of total variation contributed by process error was less than 25%. Survey data for 1989 wereincomplete for 1989. Therefore the survey indices for this year were set to missing values.

15. Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates. Initial estimates are the observed values plus a small random error.

Table D18. (Continued).

RESULTS

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

SUM OF SQUARES	0.045582
ORTHOGONALITY OFFSET.........	0.008594
MEAN SQUARE RESIDUALS	0.004558

	PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
1	n 2+ 1982	6.32683E1	2.68050E1	2.36032E0	0.42
2	n 2+ 1983	4.72307E1	1.80010E1	2.62378E0	0.38
3	n 2+ 1984	4.03227E1	1.62700E1	2.47834E0	0.40
4	n 2+ 1985	5.46529E1	1.80759E1	3.02353E0	0.33
5	n 2+ 1986	5.08577E1	1.74011E1	2.92267E0	0.34
6	n 2+ 1987	6.91564E1	2.39445E1	2.88819E0	0.35
7	n 2+ 1988	7.19228E1	2.84743E1	2.52588E0	0.40
8	n 2+ 1990	1.04207E2	3.77970E1	2.75701E0	0.36
9	n 2+ 1991	6.80830E1	2.97906E1	2.28539E0	0.44
10	n 2+ 1992	7.24714E1	2.30588E1	3.14289E0	0.32
11	n 2+ 1993	3.58410E1	8.38801E0	4.27289E0	0.23
12	n 2+ 1994	1.07507E1	5.73740E0	1.87378E0	0.53
13	r 1 1982	4.84105E1	2.34053E1	2.06836E0	0.48
14	r 1 1983	2.88521E1	1.46632E1	1.96765E0	0.51
15	r 1 1984	5.31110E1	2.46668E1	2.15314E0	0.46
16	r 1 1985	2.44229E1	1.28937E1	1.89417E0	0.53
17	r 1 1986	5.16290E1	2.45245E1	2.10520E0	0.48
18	r 1 1987	6.62579E1	3.07058E1	2.15783E0	0.46
19	r 1 1988	9.46071E1	4.35654E1	2.17161E0	0.46
20	r 1 1990	1.25542E2	5.36875E1	2.33838E0	0.43
21	r 1 1991	9.63495E1	4.22962E1	2.27797E0	0.44
22	r 1 1992	4.15486E1	2.10309E1	1.97560E0	0.51
23	r 1 1993	5.59177E0	3.07805E0	1.81666E0	0.55
24	Surv q_n	4.92130E-1	9.81412E-2	5.01451E0	0.20

CALENDAR YEAR	STOCK SIZE ESTIMATES (millions at time of survey) RECRUITS	FULLY-RECRUITED	MORTALITY RATES (between surveys) Z on sizes 1+	F on size 1	F on sizes 2+
1982	98.369	128.560	0.86	0.49	0.97
1983	58.627	95.972	0.63	0.33	0.66
1984	107.921	81.935	0.54	0.30	0.61
1985	49.627	111.054	0.44	0.20	0.40
1986	104.909	103.342	0.39	0.20	0.39
1987	134.635	140.525	0.63	0.35	0.71
1988	192.240	146.146	0.44	0.24	0.48
1989	92.045	216.911	0.38	0.16	0.33
1990	255.099	211.746	1.22	0.77	1.54
1991	195.780	138.343	0.82	0.51	1.02
1992	84.426	147.260	1.16	0.65	1.29
1993	11.362	72.828	1.35	0.67	1.34
1994	18.643	21.845			

Note: Index of abundance for recruits is missing in 1989. For these years, the recruit stock size estimates are based on the geometric mean of recruitment in years when indices were available. Index of abundance for fully-recruited is missing in 1989. For these years, the fully-recruited stock size estimates are based on forward calculations from the DeLury difference equation.

Table D19. Results from the modified DeLury model for the New York Bight in Mid-Atlantic.

DELURY v2.0 Oct94 Run Number 2 1995 5 25 9 20 23
Sea Scallop, NEW YORK BIGHT, 1982-1994

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: NYB1.DAT
Data used in fitting the model:

REFER TO ITEMS 1 TO 13 IN Table D16.

14. The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT"). The original input weights for measurement error on the full recruits and recruits and process error were set to (1, 1, 1), respectively. The normalized weights for these error terms were (0.0270, 0.0270, 0.0270) respectively. Process error weights were set so that percent of total variation contributed by process error was less than 25%.

15. Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates. Initial estimates are the observed values plus a small random error.

RESULTS

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

SUM OF SQUARES	0.047368
ORTHOGONALITY OFFSET.........	0.002583
MEAN SQUARE RESIDUALS	0.004306

	PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
1	n 2+ 1982	2.34653E1	8.11714E0	2.89084E0	0.35
2	n 2+ 1983	2.48823E1	6.85526E0	3.62966E0	0.28
3	n 2+ 1984	2.53825E1	6.86655E0	3.69654E0	0.27
4	n 2+ 1985	2.64352E1	8.69028E0	3.04193E0	0.33
5	n 2+ 1986	4.80089E1	1.44792E1	3.31572E0	0.30
6	n 2+ 1987	6.23667E1	1.80424E1	3.45667E0	0.29
7	n 2+ 1988	8.34079E1	2.46285E1	3.38663E0	0.30
8	n 2+ 1989	8.14095E1	2.38431E1	3.41438E0	0.29
9	n 2+ 1990	7.85836E1	2.38251E1	3.29836E0	0.30
10	n 2+ 1991	6.89431E1	1.88696E1	3.65367E0	0.27
11	n 2+ 1992	4.04028E1	1.10515E1	3.65587E0	0.27
12	n 2+ 1993	2.97382E1	9.33871E0	3.18441E0	0.31
13	n 2+ 1994	4.61170E1	1.45262E1	3.17476E0	0.31
14	r 1 1982	9.82284E0	3.85047E0	2.55108E0	0.39
15	r 1 1983	8.19583E0	3.22770E0	2.53922E0	0.39
16	r 1 1984	8.14806E0	3.21567E0	2.53386E0	0.39
17	r 1 1985	3.29794E1	1.20538E1	2.73602E0	0.37
18	r 1 1986	3.80908E1	1.44413E1	2.63763E0	0.38
19	r 1 1987	4.71164E1	1.77509E1	2.65431E0	0.38
20	r 1 1988	4.46331E1	1.73157E1	2.57762E0	0.39
21	r 1 1989	6.44705E1	2.43435E1	2.64837E0	0.38
22	r 1 1990	8.59869E1	3.18140E1	2.70280E0	0.37
23	r 1 1991	2.44888E1	9.61218E0	2.54769E0	0.39
24	r 1 1992	1.23838E1	4.88439E0	2.53538E0	0.39
25	r 1 1993	2.89291E1	1.08790E1	2.65917E0	0.38
26	Surv q_n	1.05569E-1	4.80303E-2	2.19798E0	0.45

Table D19. (Continued).

CALENDAR YEAR	STOCK SIZE ESTIMATES (millions at time of survey) RECRUITS	FULLY-RECRUITED	MORTALITY RATES (between surveys) Z on sizes 1+	F on size 1	F on sizes 2+
1982	93.046	222.274	0.29	0.11	0.22
1983	77.635	235.696	0.26	0.09	0.19
1984	77.182	240.434	0.24	0.08	0.16
1985	312.396	250.406	0.21	0.08	0.16
1986	360.813	454.762	0.32	0.14	0.29
1987	446.307	590.765	0.27	0.11	0.22
1988	422.785	790.077	0.45	0.21	0.43
1989	610.693	771.147	0.62	0.33	0.67
1990	814.506	744.379	0.87	0.52	1.04
1991	231.969	653.060	0.84	0.42	0.85
1992	117.305	382.714	0.57	0.27	0.54
1993	274.030	281.694	0.24	0.09	0.19
1994	307.654	436.841			

Table D20. Results from the modified DeLury model for the Delmarva in Mid-Atlantic.

DELURY v2.0 Oct94   Run Number 2   1995 5 24 16 27 59
Sea Scallop, <u>DELMARVA</u>, 1982-1994

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: DMV1.DAT
Data used in fitting the model:

REFER TO ITEMS 1 TO 13 IN Table D16.

14. The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT"). The original input weights for measurement error on the full recruits and recruits and process error were set to (1, 1, 2), respectively. The normalized weights for these error terms were (0.0204, 0.0204, 0.0408) respectively. Process error weights were set so that percent of total variation contributed by process error was less than 25%.

15. Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates. Initial estimates are the observed values plus a small random error.

RESULTS

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION
SUM OF SQUARES 0.029127
ORTHOGONALITY OFFSET......... 0.002375
MEAN SQUARE RESIDUALS 0.002648

	PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
1	n 2+ 1982	1.95094E1	6.04574E0	3.22696E0	0.31
2	n 2+ 1983	2.14539E1	5.47453E0	3.91886E0	0.26
3	n 2+ 1984	3.43781E1	7.25902E0	4.73591E0	0.21
4	n 2+ 1985	2.78991E1	7.53598E0	3.70212E0	0.27
5	n 2+ 1986	6.70598E1	1.69178E1	3.96385E0	0.25
6	n 2+ 1987	1.00076E2	2.16730E1	4.61752E0	0.22
7	n 2+ 1988	7.58244E1	1.73637E1	4.36684E0	0.23
8	n 2+ 1989	7.05492E1	1.78806E1	3.94558E0	0.25
9	n 2+ 1990	8.13533E1	1.67691E1	4.85137E0	0.21
10	n 2+ 1991	3.80984E1	1.02209E1	3.72750E0	0.27

Table D20. (Continued).

11	n 2+ 1992	3.63850E1	7.44627E0	4.88634E0	0.20
12	n 2+ 1993	1.91910E1	6.37416E0	3.01076E0	0.33
13	n 2+ 1994	1.68105E2	4.68097E1	3.59125E0	0.28
14	r 1 1982	1.11561E1	3.85749E0	2.89205E0	0.35
15	r 1 1983	2.31429E1	7.44042E0	3.11043E0	0.32
16	r 1 1984	9.26000E0	3.27631E0	2.82635E0	0.35
17	r 1 1985	5.41357E1	1.67950E1	3.22333E0	0.31
18	r 1 1986	8.84012E1	2.78502E1	3.17416E0	0.32
19	r 1 1987	4.66545E1	1.58761E1	2.93867E0	0.34
20	r 1 1988	3.76137E1	1.28789E1	2.92056E0	0.34
21	r 1 1989	6.76300E1	2.18820E1	3.09067E0	0.32
22	r 1 1990	3.51424E1	1.21272E1	2.89782E0	0.35
23	r 1 1991	3.85601E1	1.22328E1	3.15220E0	0.32
24	r 1 1992	1.35550E1	4.71486E0	2.87496E0	0.35
25	r 1 1993	1.92825E2	5.48232E1	3.51722E0	0.28
26	Surv q_n	3.96814E-1	7.00639E-2	5.66359E0	0.18

CALENDAR YEAR	STOCK SIZE ESTIMATES (millions at time of survey) RECRUITS	FULLY-RECRUITED	MORTALITY RATES (between surveys) Z on sizes 1+	F on size 1	F on sizes 2+
1982	28.114	49.165	0.36	0.16	0.31
1983	58.322	54.066	0.26	0.11	0.22
1984	23.336	86.635	0.45	0.19	0.39
1985	136.426	70.308	0.20	0.08	0.15
1986	222.778	168.996	0.44	0.24	0.48
1987	117.573	252.198	0.66	0.33	0.67
1988	94.789	191.083	0.47	0.22	0.45
1989	170.433	177.789	0.53	0.28	0.57
1990	88.562	205.016	1.12	0.60	1.20
1991	97.174	96.011	0.75	0.43	0.86
1992	34.160	91.693	0.96	0.50	0.99
1993	485.935	48.363	0.23	0.12	0.24
1994	285.234	423.638			

Table D21. Estimated fishing mortality rates of fully recruited scallops from SAW14 and SAW20.

	SARC 14			SARC 20		
Year	Estimate	10%	90%	Estimate	10%	90%
South Channel						
1982	1.1349	0.7976	1.5159	1.35	0.99	1.67
1983	0.6135	0.4160	0.8613	0.90	0.64	1.19
1984	0.5240	0.2731	0.8164	0.42	0.07	0.79
1985	1.2464	0.6590	1.9302	0.81	0.41	1.21
1986	1.0171	0.6490	1.4349	1.20	0.78	1.64
1987	0.9475	0.5761	1.3816	1.15	0.79	1.54
1988	1.1383	0.6588	1.7319	1.93	1.30	2.63
1989	1.7741	1.0146	2.5945	1.40	0.78	2.04
1990	2.0935	1.1205	3.1501	1.79	1.17	2.46
1991				1.75	1.26	2.28
1992				2.34	1.79	2.98
1993				1.08	0.64	1.60
Southeast Part						
1982	0.5045	0.2763	0.8078	0.33	0.20	0.48
1983	0.5350	0.2876	0.8538	0.16	0.02	0.31
1984	0.3305	0.1577	0.5308	0.30	0.14	0.46
1985	0.3876	0.1674	0.6478	0.13	0.00	0.27
1986	0.3537	0.2120	0.5193	0.29	0.15	0.44
1987	0.3576	0.2642	0.4711	0.56	0.43	0.70
1988	0.4173	0.2437	0.6444	0.56	0.43	0.70
1989	0.4567	0.3122	0.6069	0.51	0.39	0.63
1990	0.6474	0.2702	1.0856	0.68	0.45	0.94
1991				0.53	0.37	0.71
1992				0.89	0.66	1.15
1993				0.35	0.16	0.55

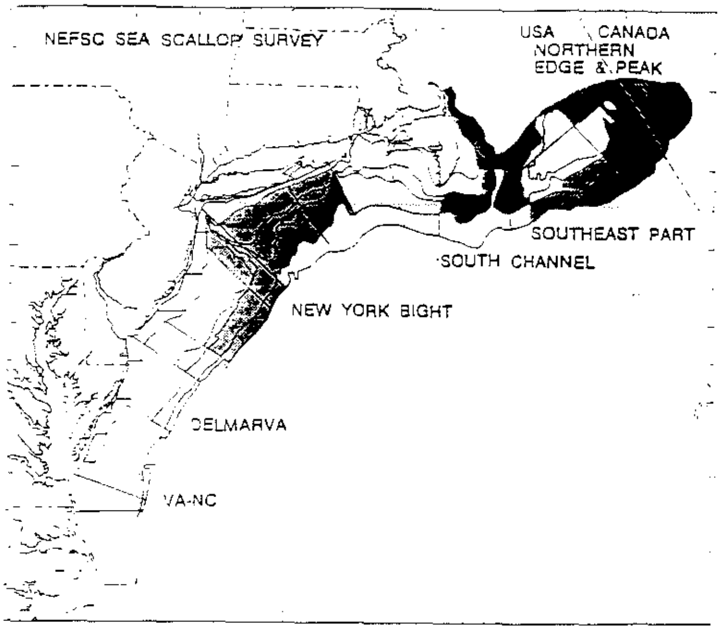


Figure D1. NEFSC scallop dredge survey strata that define the major resource areas for sea scallop.

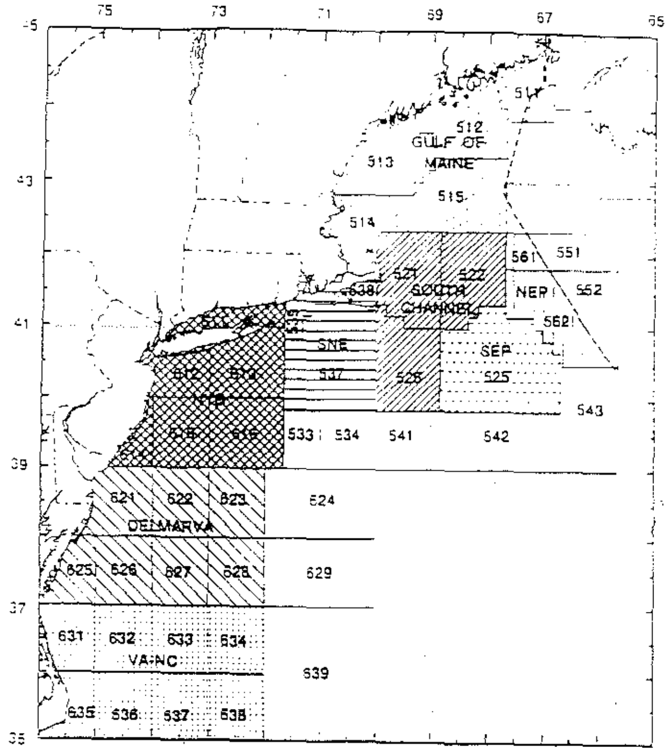


Figure D2. NEFSC statistical reporting areas and stock areas for sea scallop. Gulf of Maine: 511-515; South Channel; 521, 522, 526; Northern Edge and Peak: 561, 562; Southeast Part 525; Southern New England 537-539; New York Bight: 611-616; Delmarva 621-623,625-628; Virginia-North Carolina: 631-638.

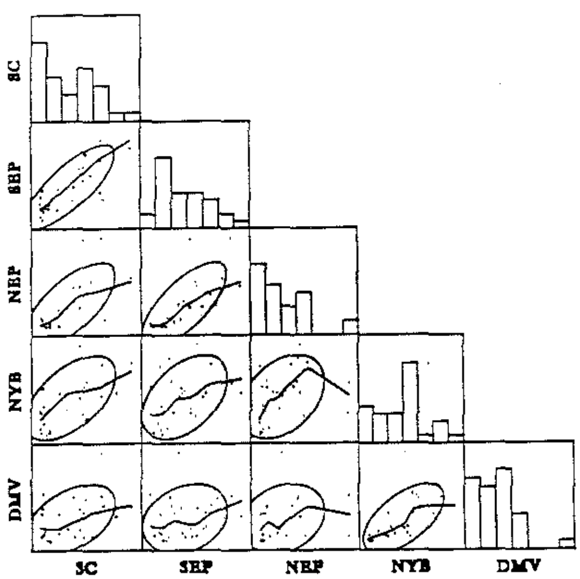


Figure D3. Comparison of sea scallop total landings by resource area (SC=South Channel, SEP=Southeast Part, NEP=Northern Edge and Peak, NYB=New York Bight, DMV=Delmarva) for 1965-1993. Symbols correspond to individual years, ellipses represent 75% confidence assuming a bivariate normal distribution, lines represent LOWESS smoothing with tension factor=0.6 . Bars represent frequency distribution of observed values.

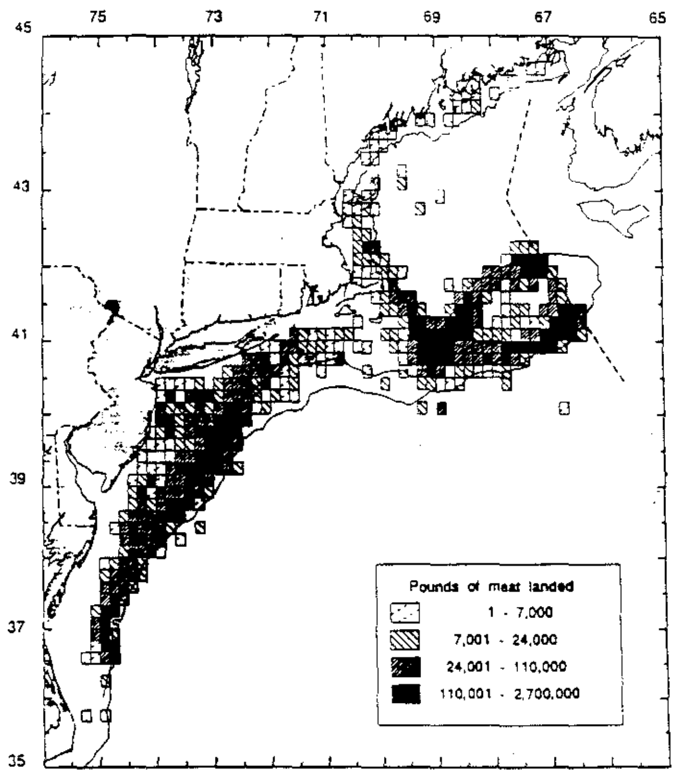


Figure D4. Distribution of pounds of meat landed by ten-minute squares, and reported as interviewed sea scallop trips during 1991-1993.

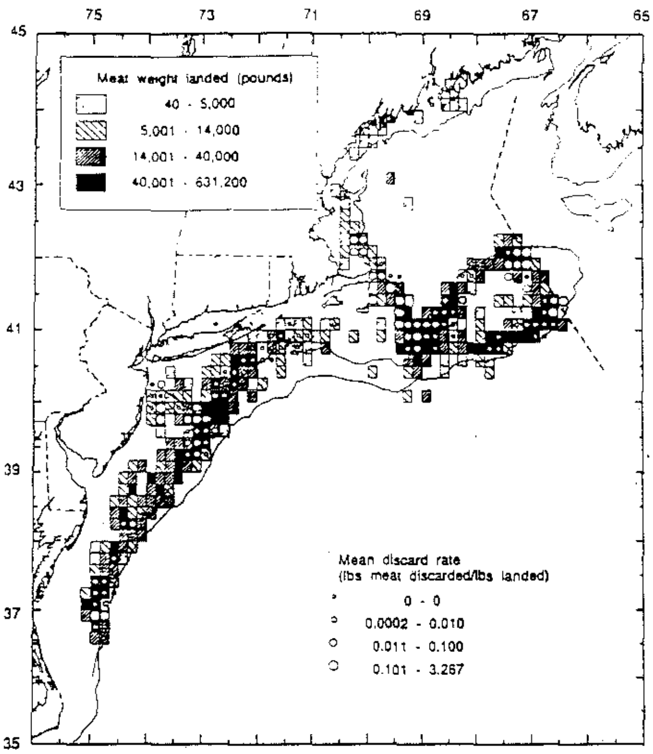


Figure D5. Sea scallop landings (pound of meat) reported as interviewed trips and mean discard rate per tow, by ten-minute square, at sea sampling program stations during 1992.

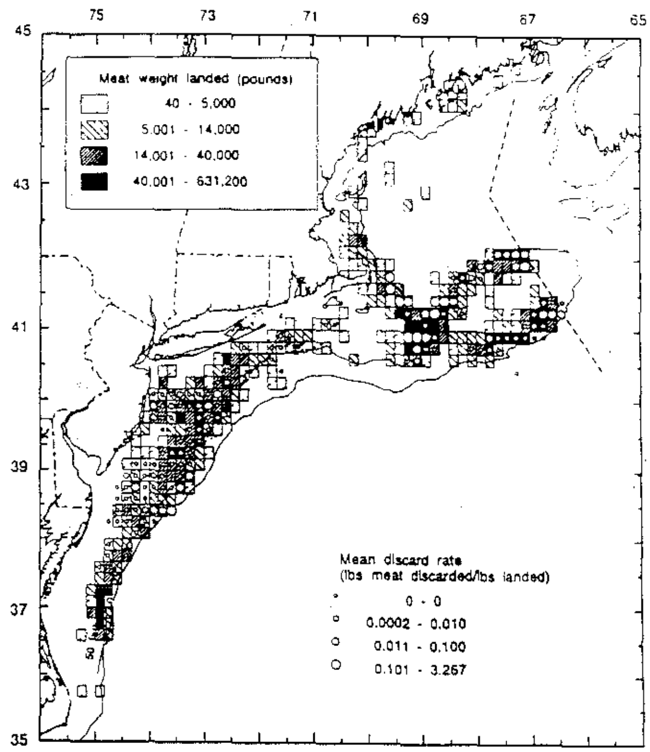


Figure D6. Sea scallop landings (pounds of meat) reported as interviewed trips and mean discard rate per tow, by ten-minute square, at sea sampling program stations during 1993

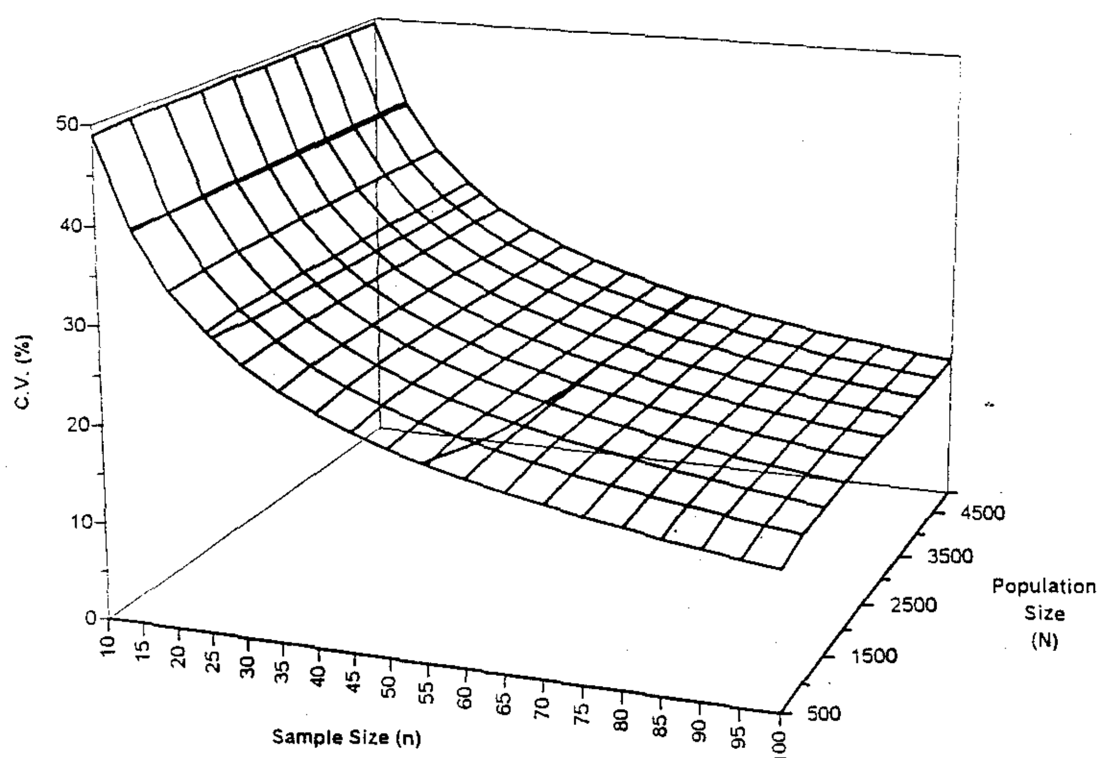


Figure D7. Relationship of coefficient of variation (C.V.) of the estimated discard-to-keep ratio as a function of sample size and population size (number of trips).

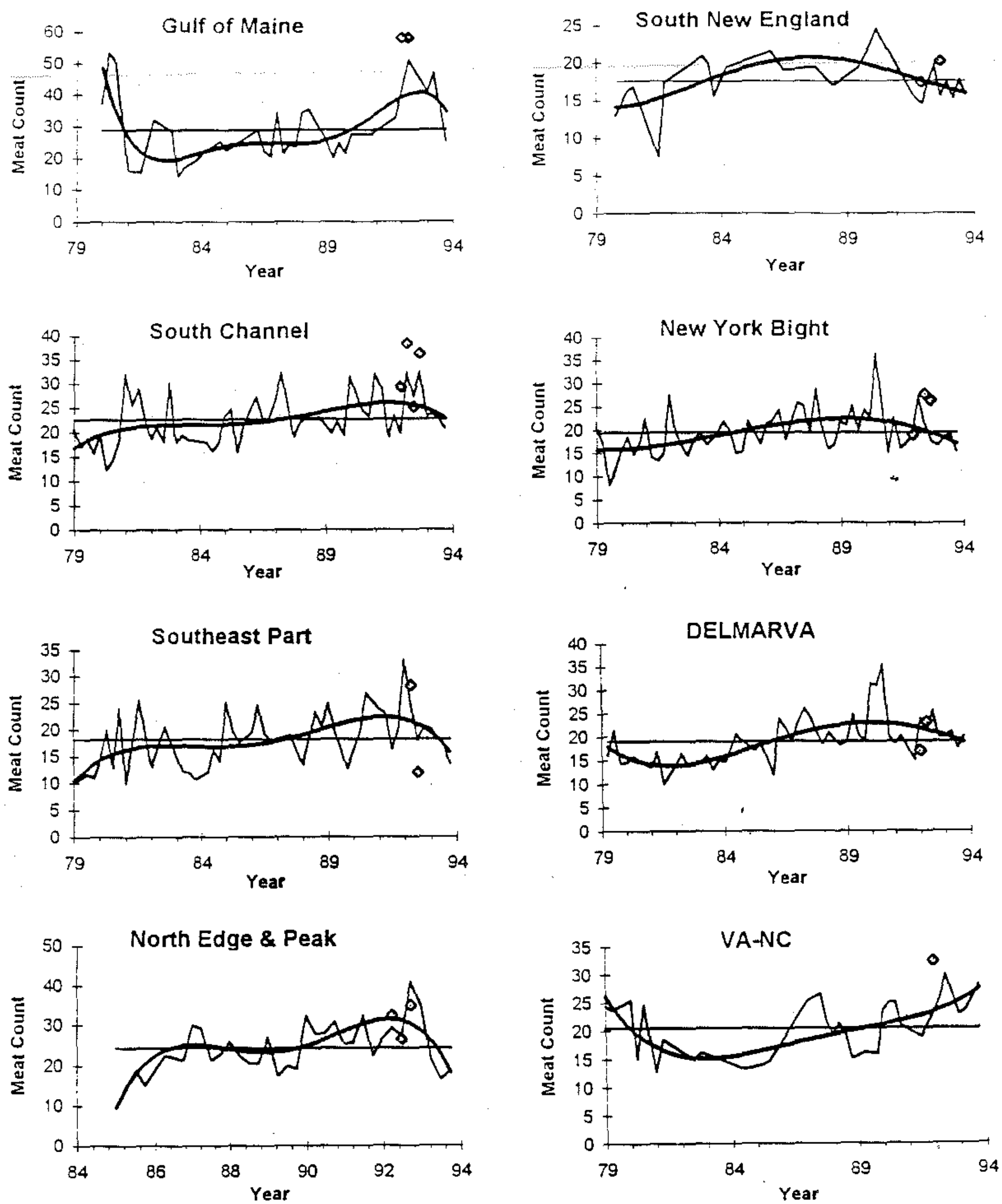


Figure D8. Quarterly fluctuation of sea scallop meat count per pound from the landings of vessels using dredge gear fishing in eight resources areas, 1979-1993. Data are from port sampling (lines, horizontal line indicates average value of all quarters in the corresponding resources area) and from sea sampling data (diamonds).

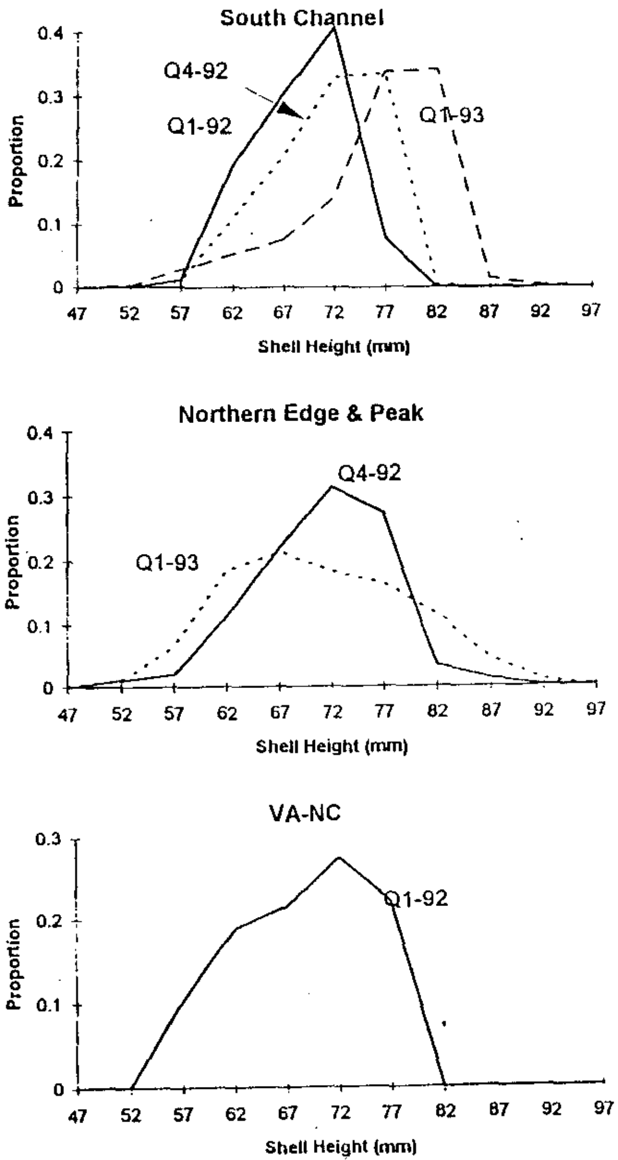


Figure D9. Shell height frequency distribution of discarded sea scallops.

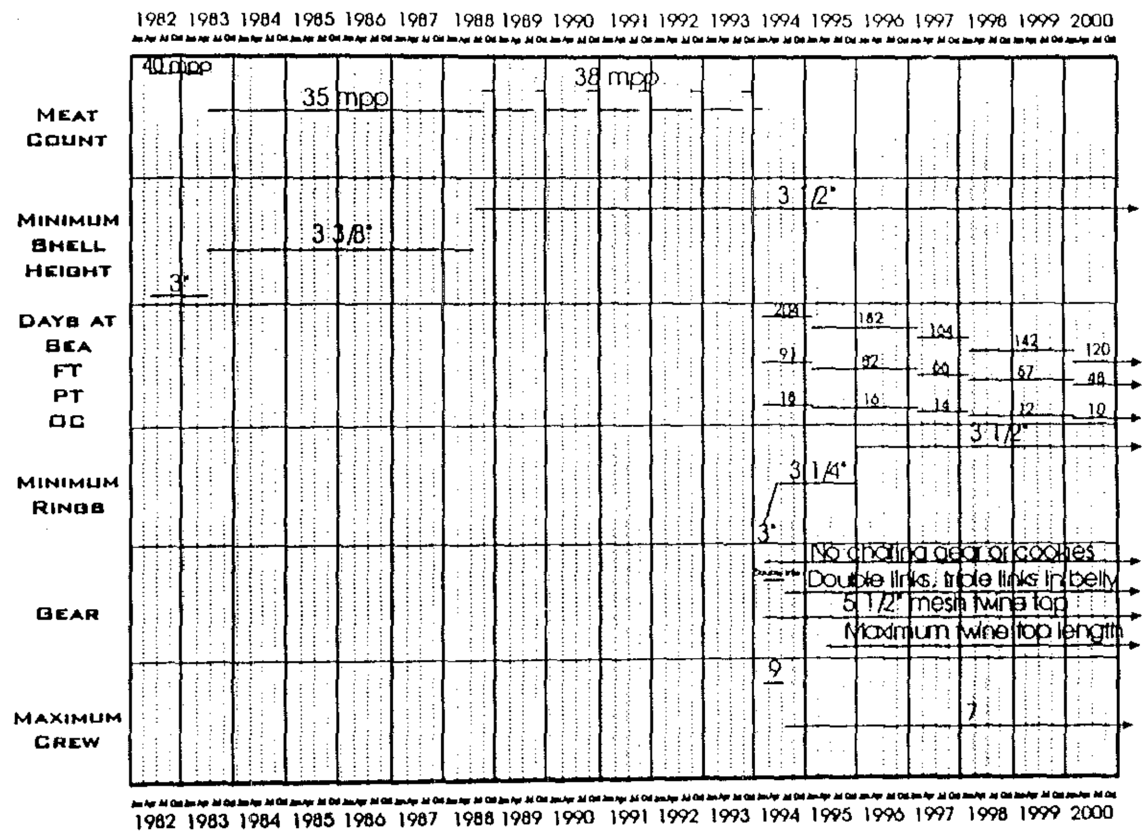


Figure D10. Scallop management chronology of major regulations implemented since 1982 and planned through 2000. Abbreviations: mpp=meats per pound, FT full time vessels, PT=part time vessels, OC=occasional vessels.

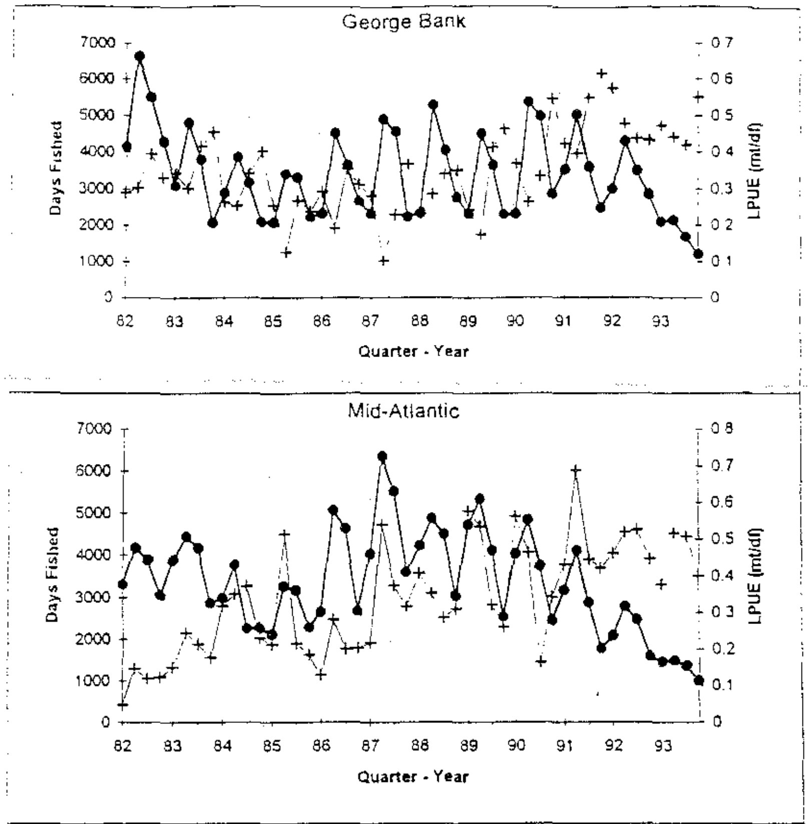


Figure D11. Effort (Days Fished, df) and landing per unit effort (LPUE) in the Georges Bank and the Mid-Atlantic regions, 1982-1993. (Solid circles: LPUE, +:Days Fished).

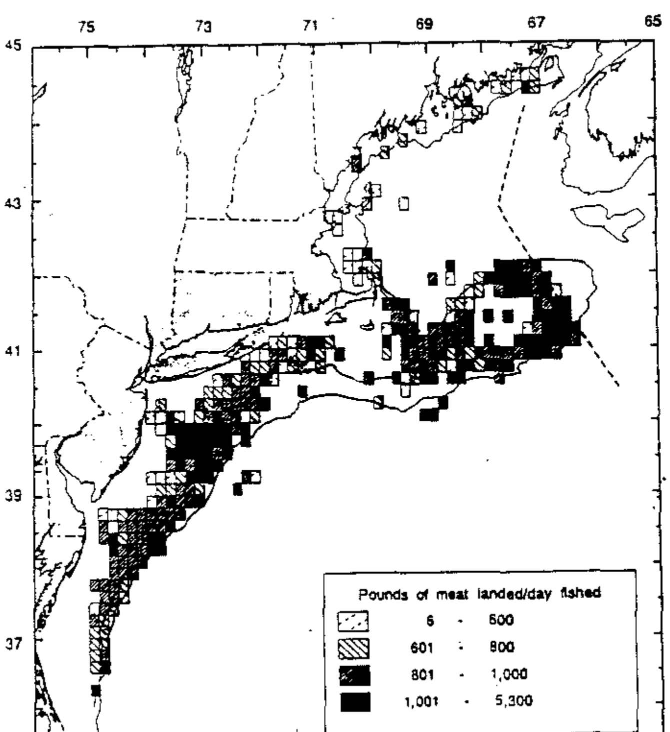


Figure D12. Distribution of pounds of meat landed per day fished, by ten-minute square, for interviewed sea scallop trips during 1988-1990.

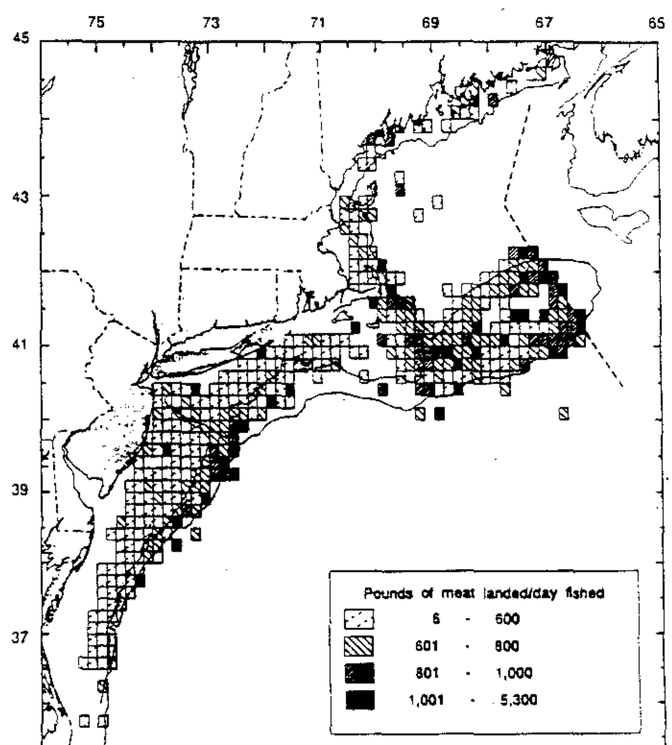
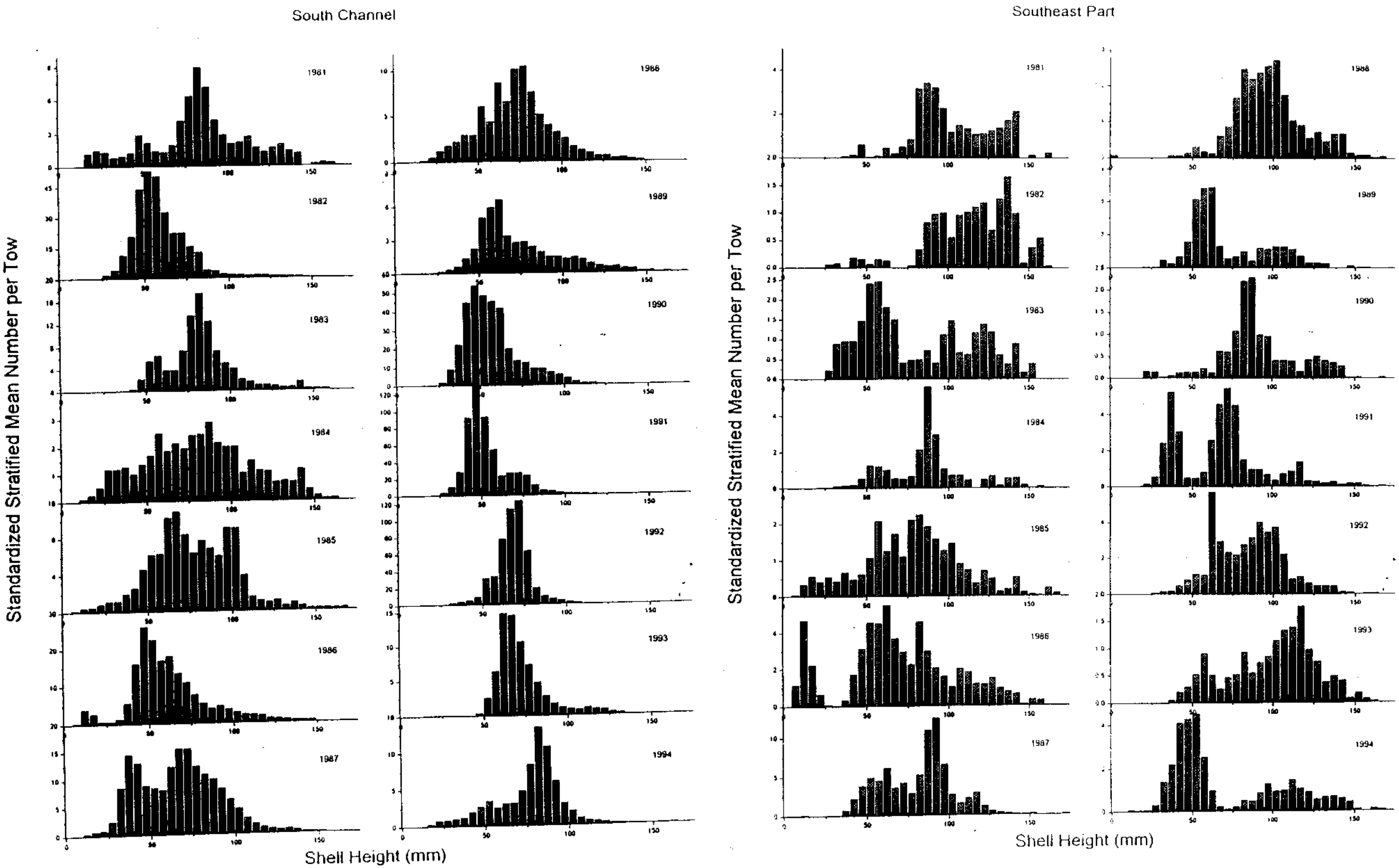
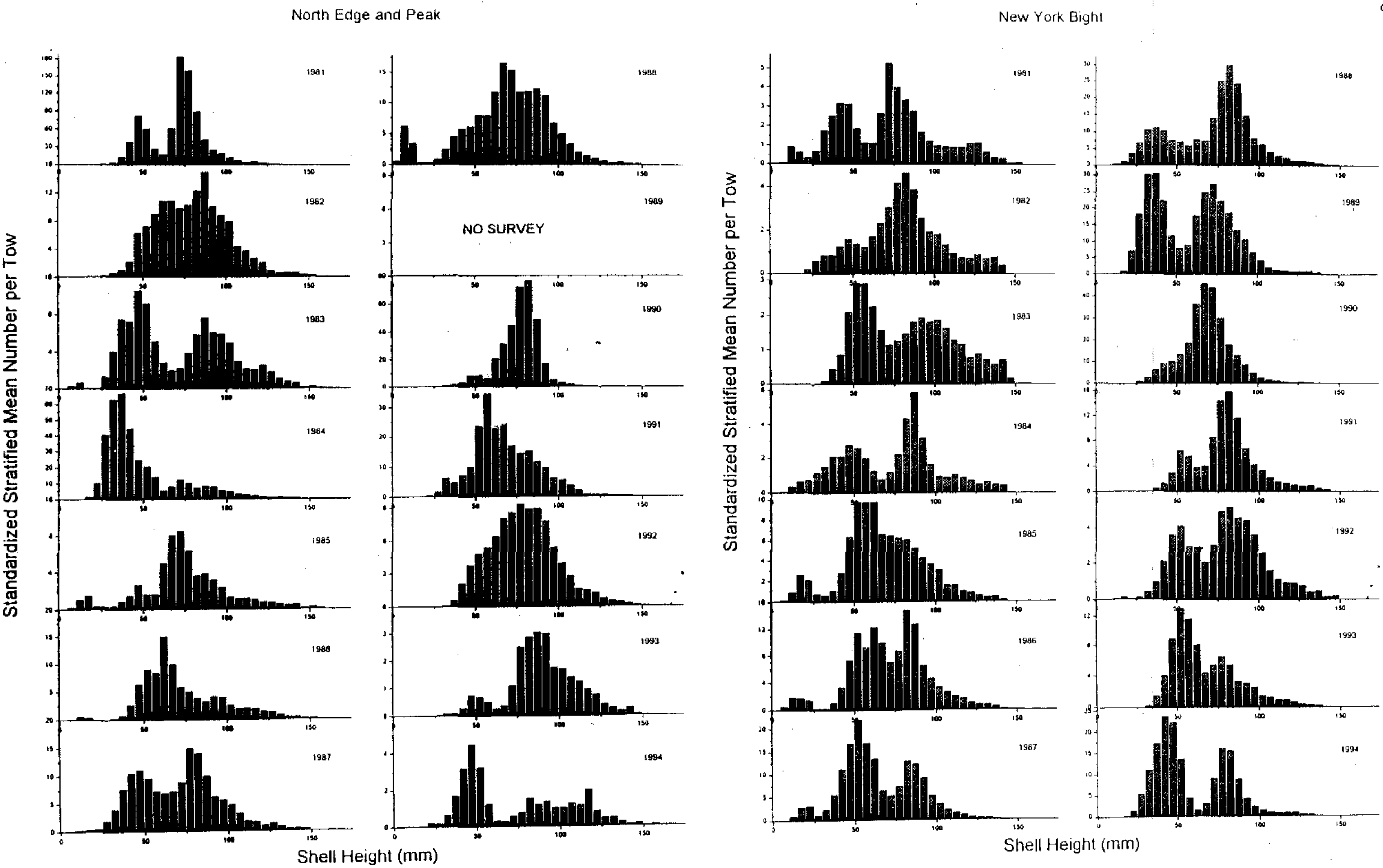


Figure D13. Distribution of pounds of meat landed per day fished, by ten-minute square, for interviewed sea scallop trips during 1991-1993.



Figures D14 and D15. Shell height frequency distributions (adjusted for lined dredge selectivity) collected from sea scallop surveys in South Channel area and Southeast area, 1981-1994.



Figures D16 and D17. Shell height frequency distributions (adjusted for lined dredge selectivity) collected from sea scallop surveys in North Edge and Peak area and New York Bight area, 1981-1994.

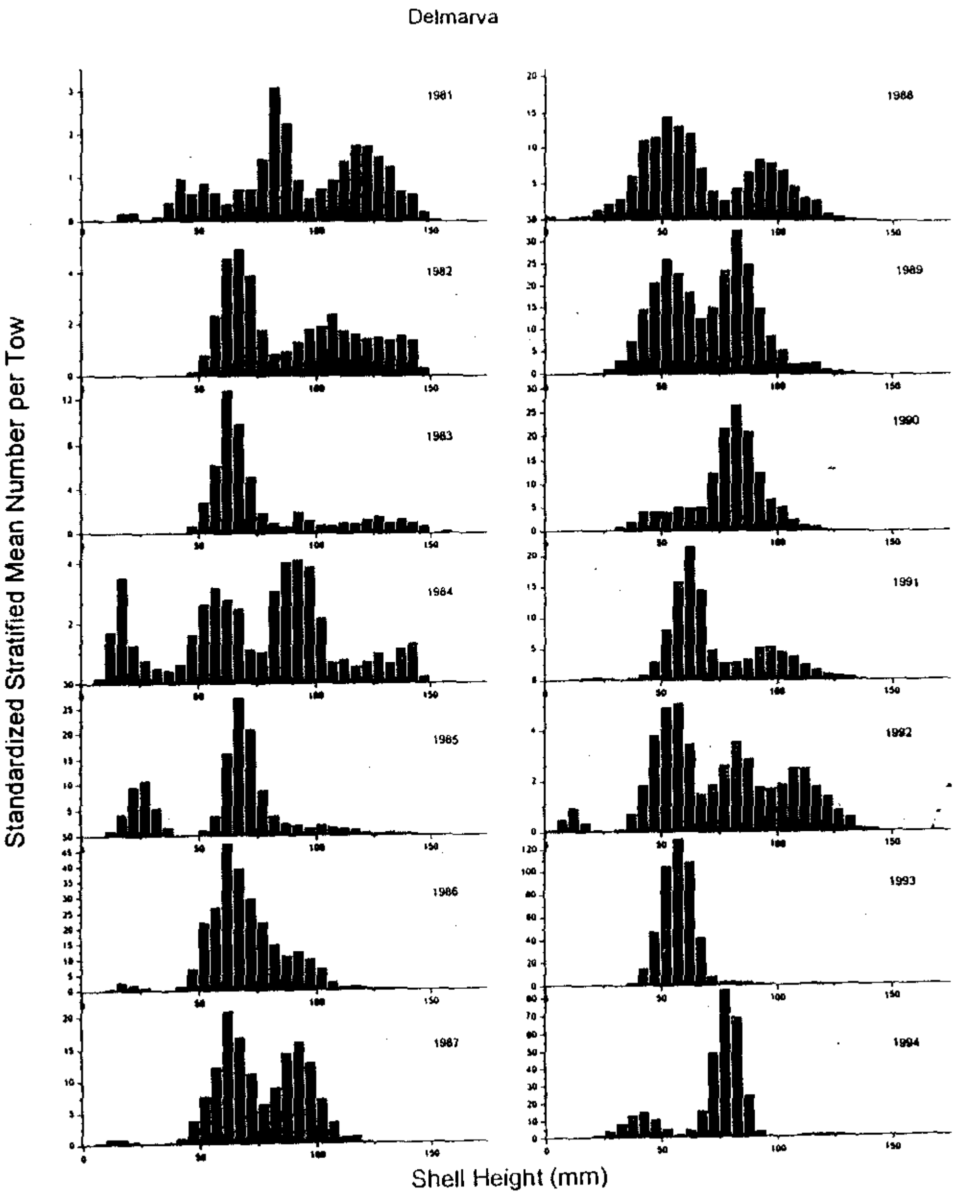


Figure D18. Shell height frequency distributions (adjusted for lined dredge selectivity) collected from sea scallop surveys in Delmarva area, 1981-1994.

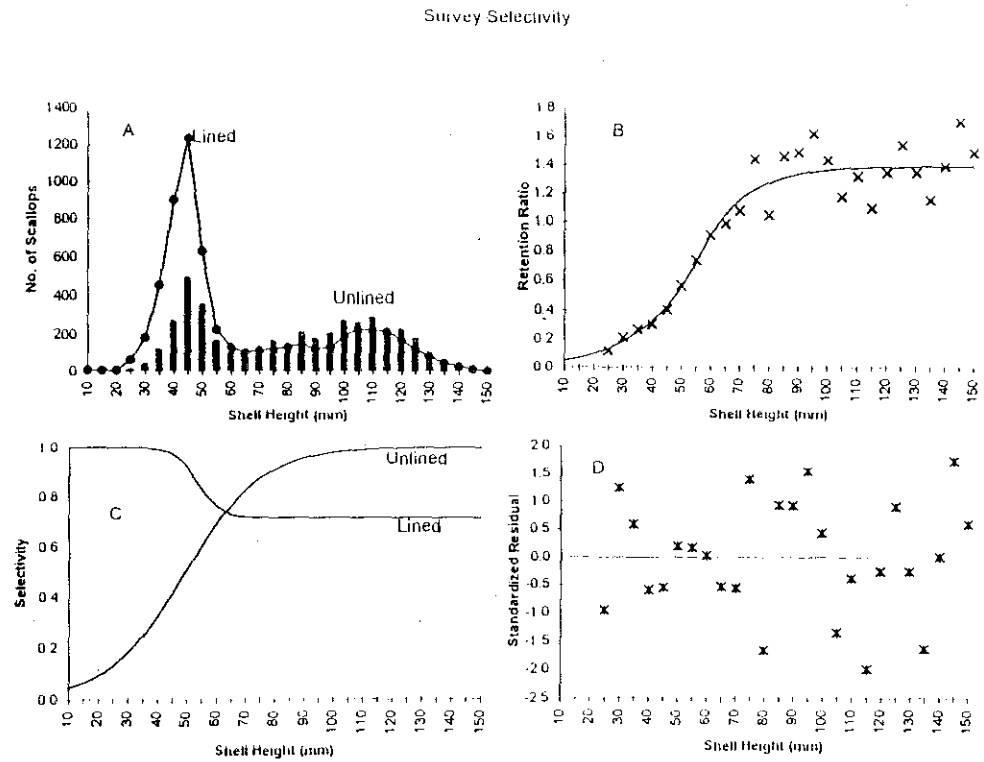


Figure D19. A: Size-frequency distributions of lined and unlined dredges. B: Observed (x) and estimated (curve) retention ratio between the lined and unlined dredges. C: The estimated selectivity curve for lined and unlined dredges. D: Plot of standardized long-transformed residuals between observed and estimated retention ratios.

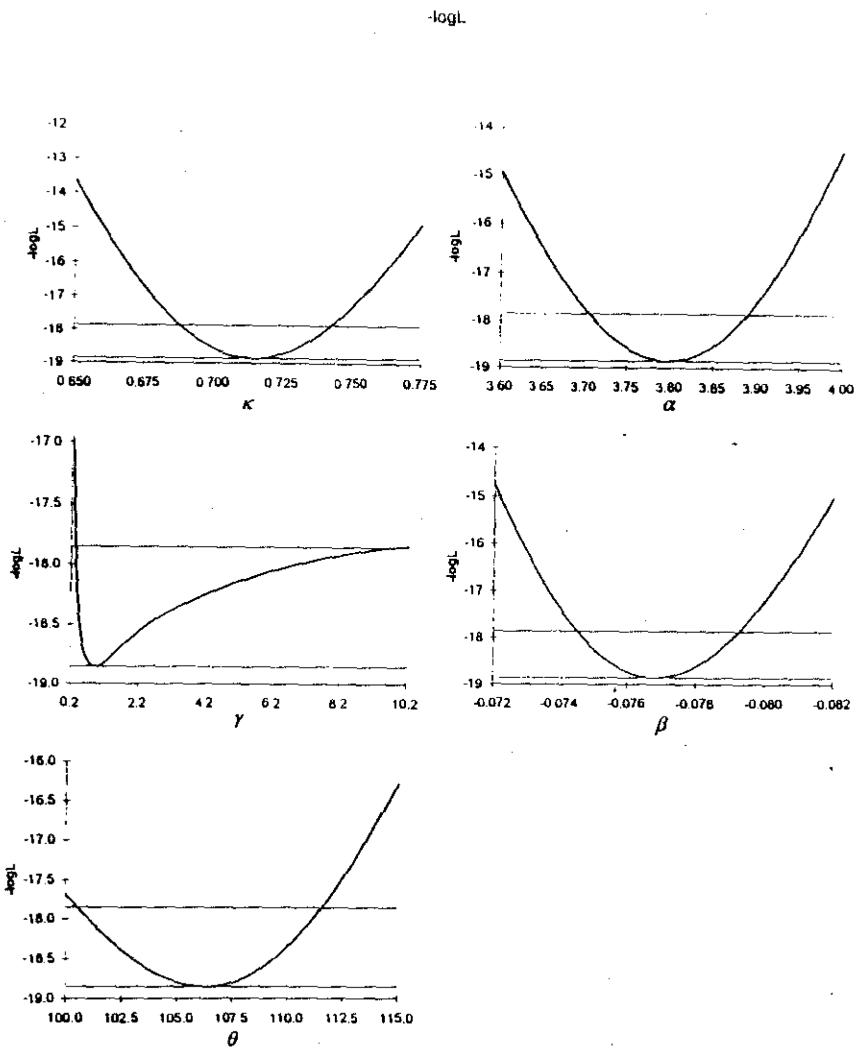


Figure D20. Plot of -logL values for the parameters in Equations (4) and (5). The lower horizontal line indicates one unit change from the lower horizontal line. The 95% CI of the parameter is encompassed between the intersects of the curve and the upper horizontal line.

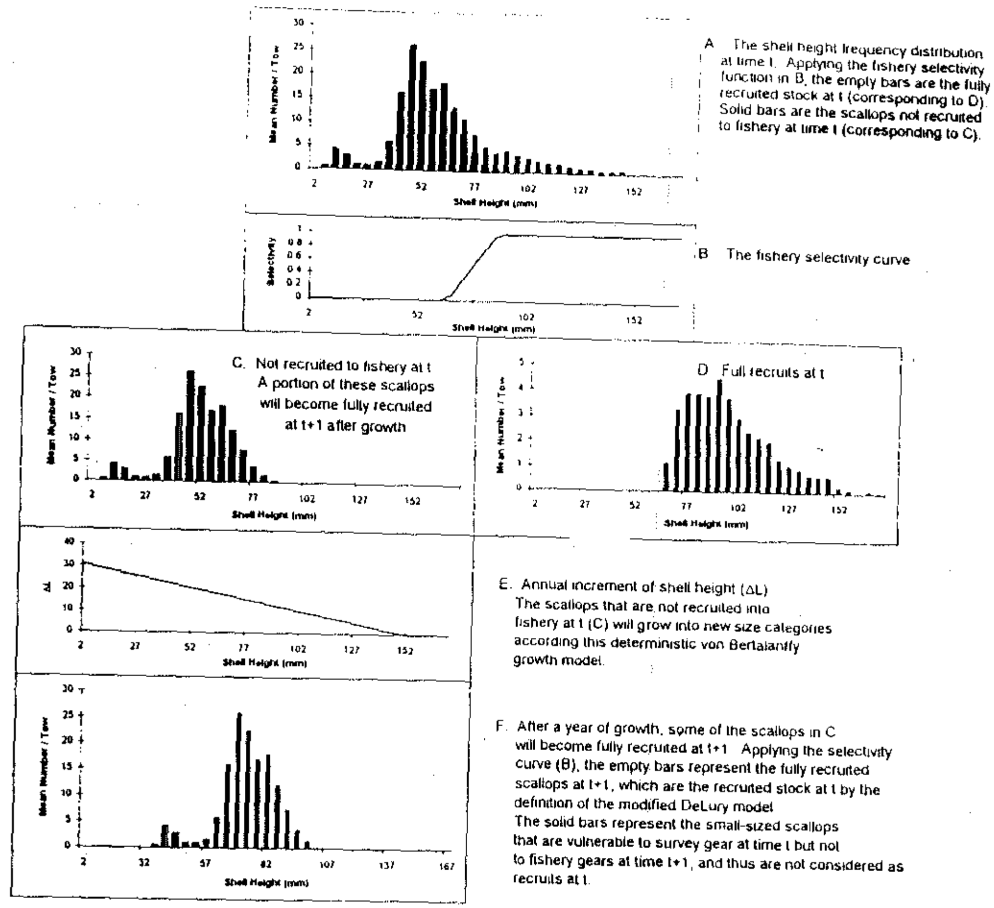


Figure D21. Schematic depiction of selectivity method used to estimate survey indices of recruited and fully recruited stocks from the survey shell height frequency distribution.

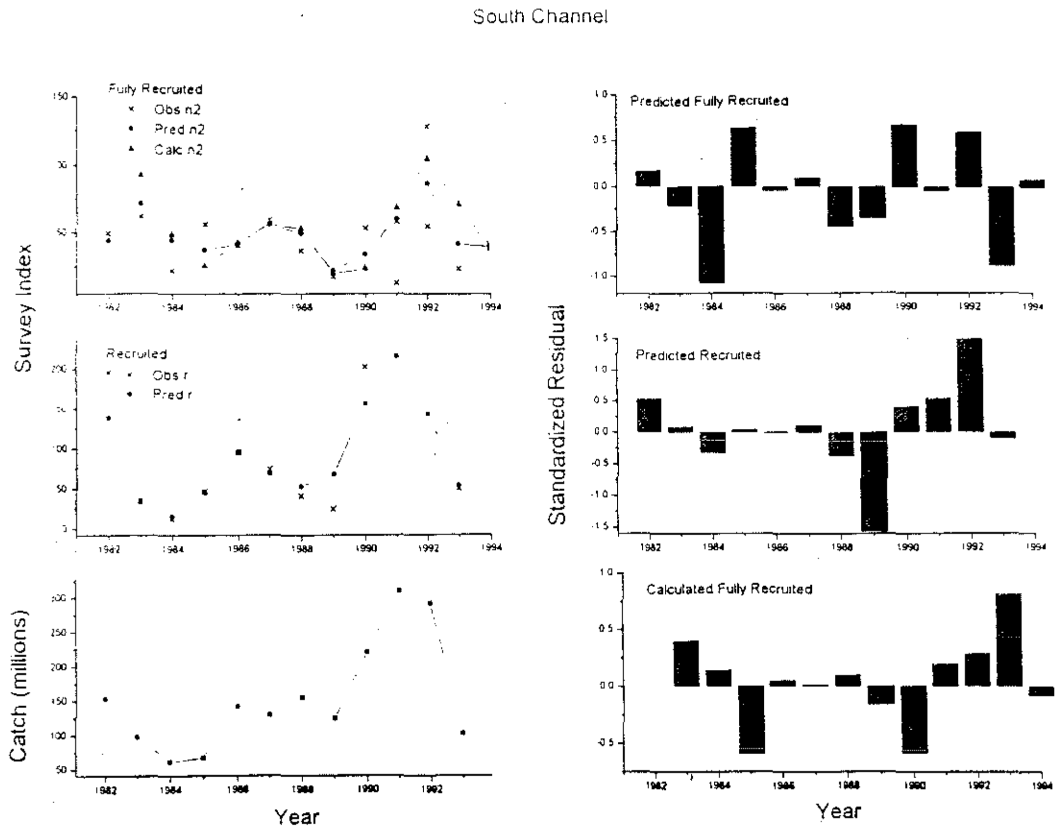


Figure D22. Fits of the modified DeLury model for sea scallops in South Channel area.

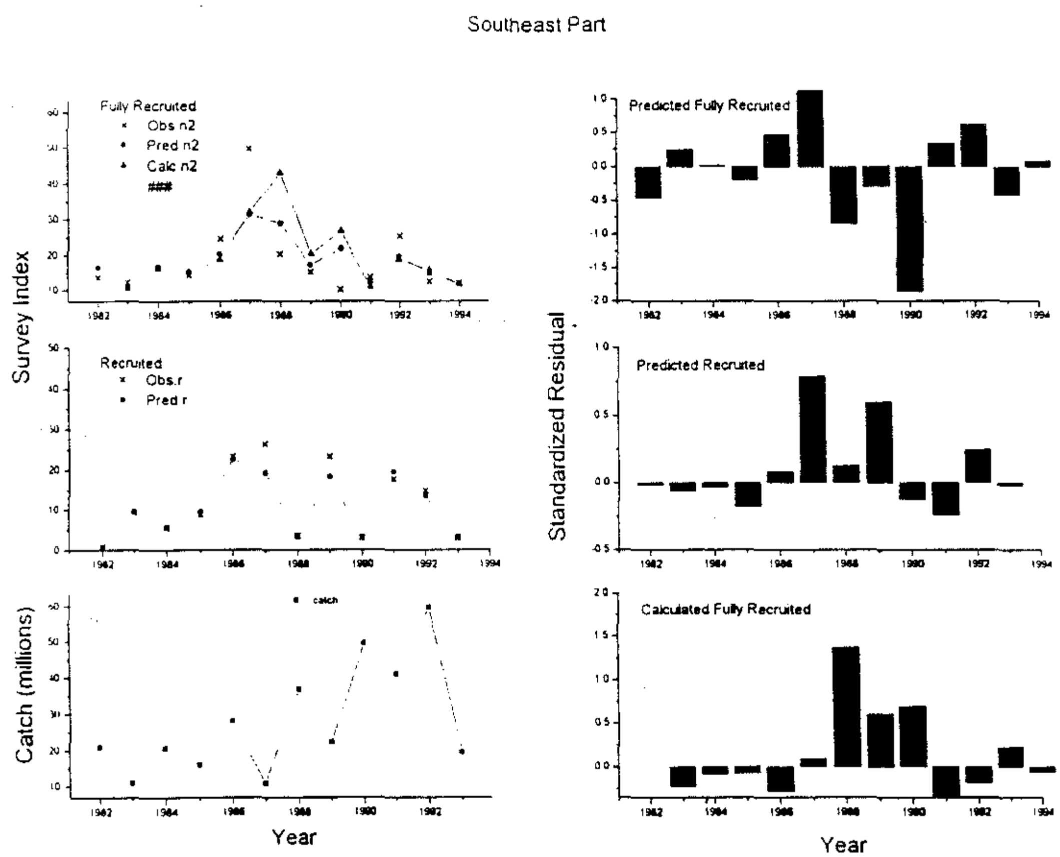


Figure D23. Fits of the modified DeLury model for sea scallops in Southeast Part area.

North Edge and Peak

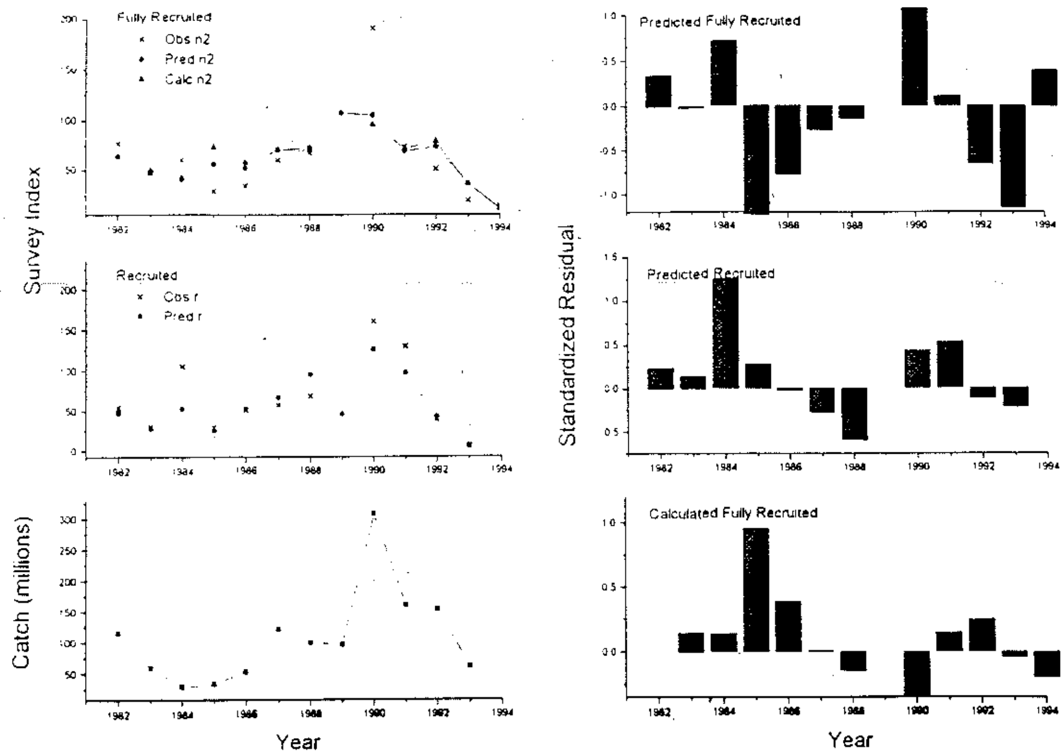


Figure D24. Fits of the modified DeLury model for sea scallops in North Edge and Peak area.

New York Bight

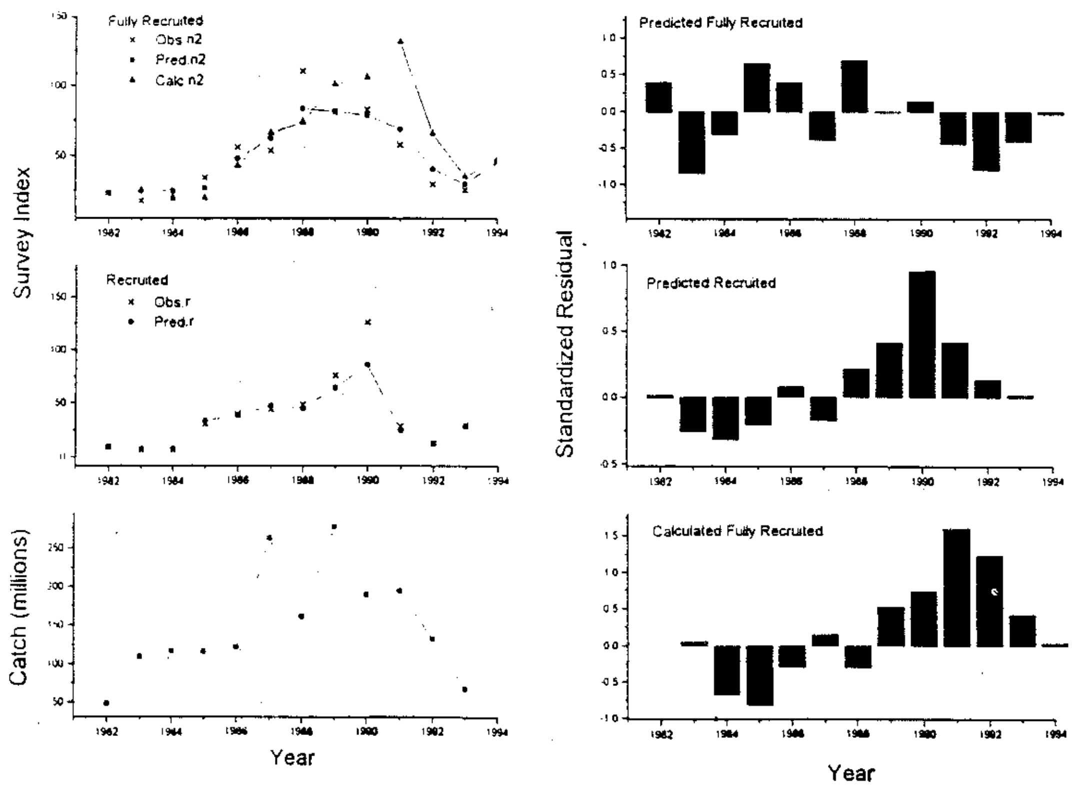


Figure D25. Fits of the modified DeLury model for sea scallops in New York bight area.

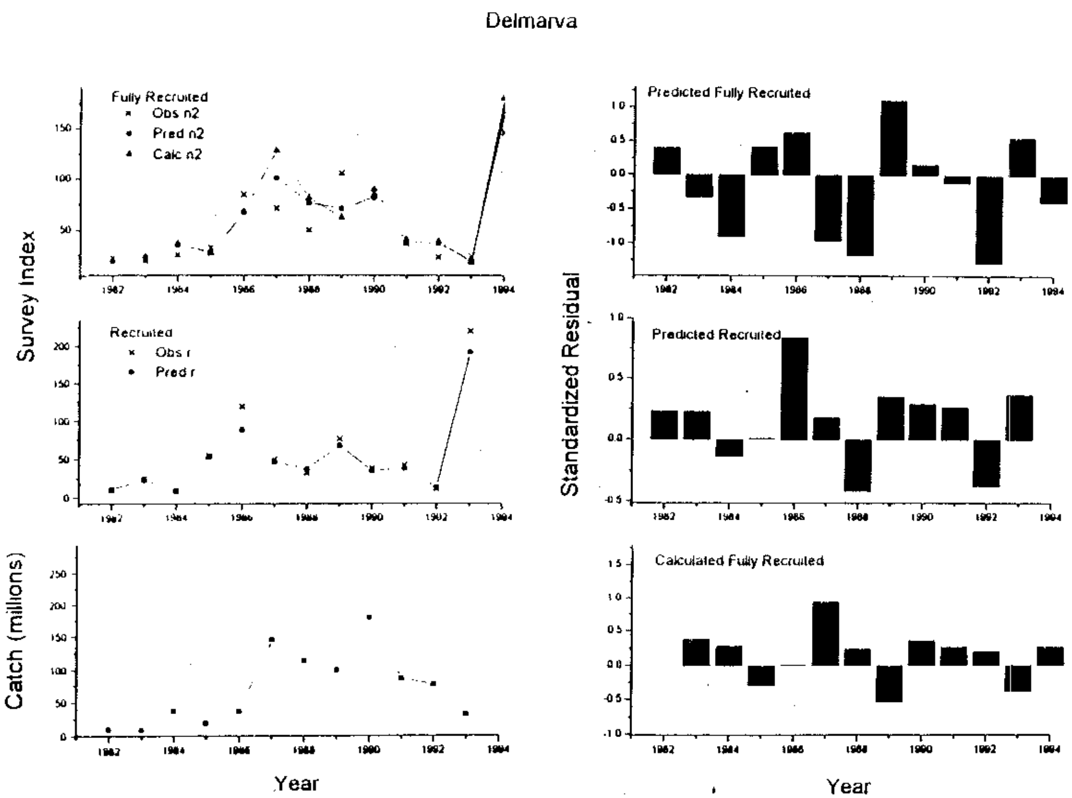


Figure D26. Fits of the modified DeLury Model for sea scallops in Delmarva area.

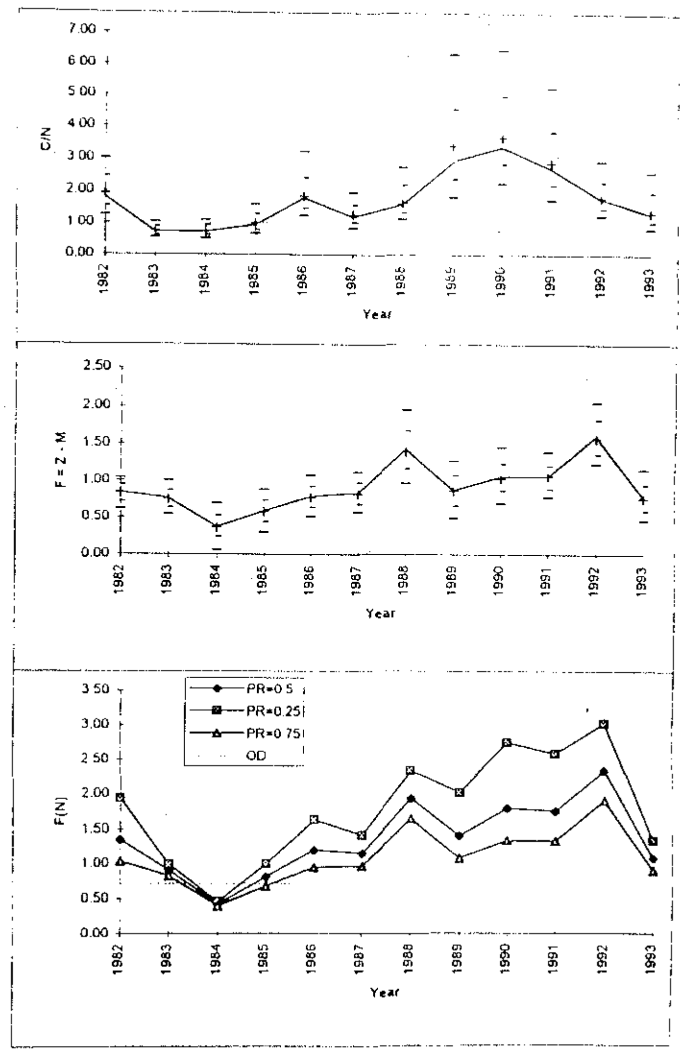


Figure D27. The estimated ratio of catch number and estimated fully recruited stock (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), the estimated overall fishing mortality rate (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), and the estimated fishing mortality rate of fully recruited stock estimated by applying various partial recruitment ratios, for scallops in South Channel area.

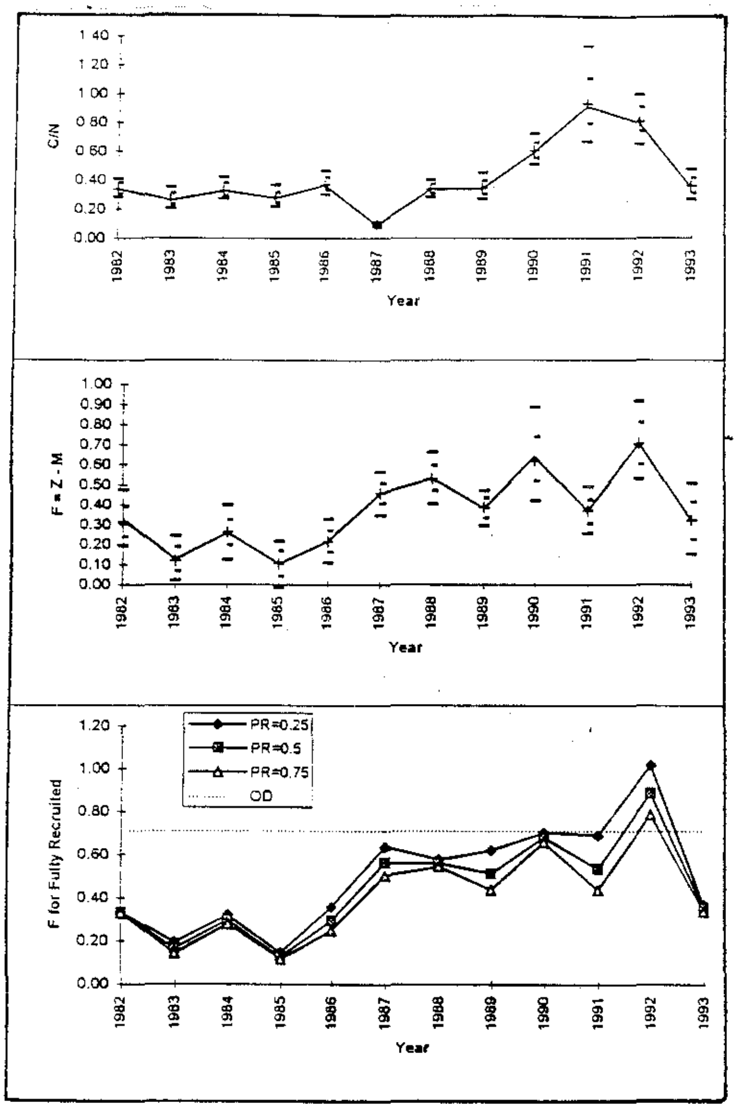


Figure D28. The estimated ratio of catch number and estimated fully recruited stock (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), the estimated overall fishing mortality rate (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), and the estimated fishing mortality rate of fully recruited stock estimated by applying various partial recruitment ratios, for scallops in Southeast Part area.

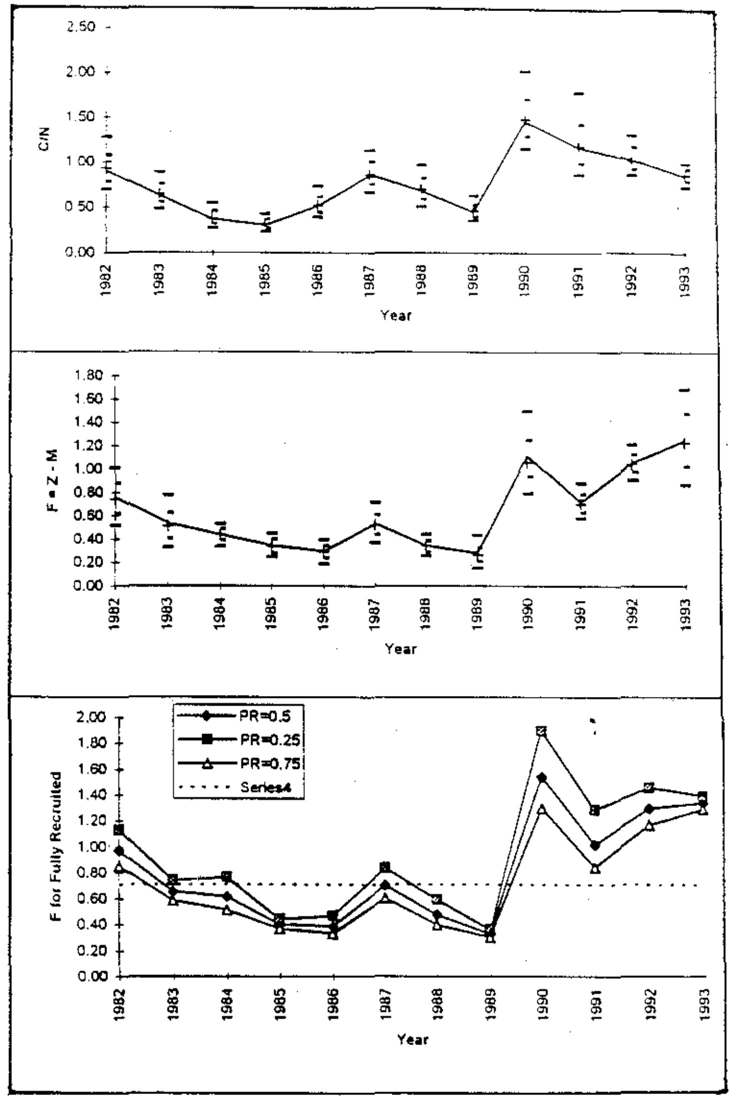


Figure D29. The estimated ratio of catch number and estimated fully recruited stock (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), the estimated overall fishing mortality rate (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), and the estimated fishing mortality rate of fully recruited stock estimated by applying various partial recruitment ratios, for scallops in North Edge and Peak area.

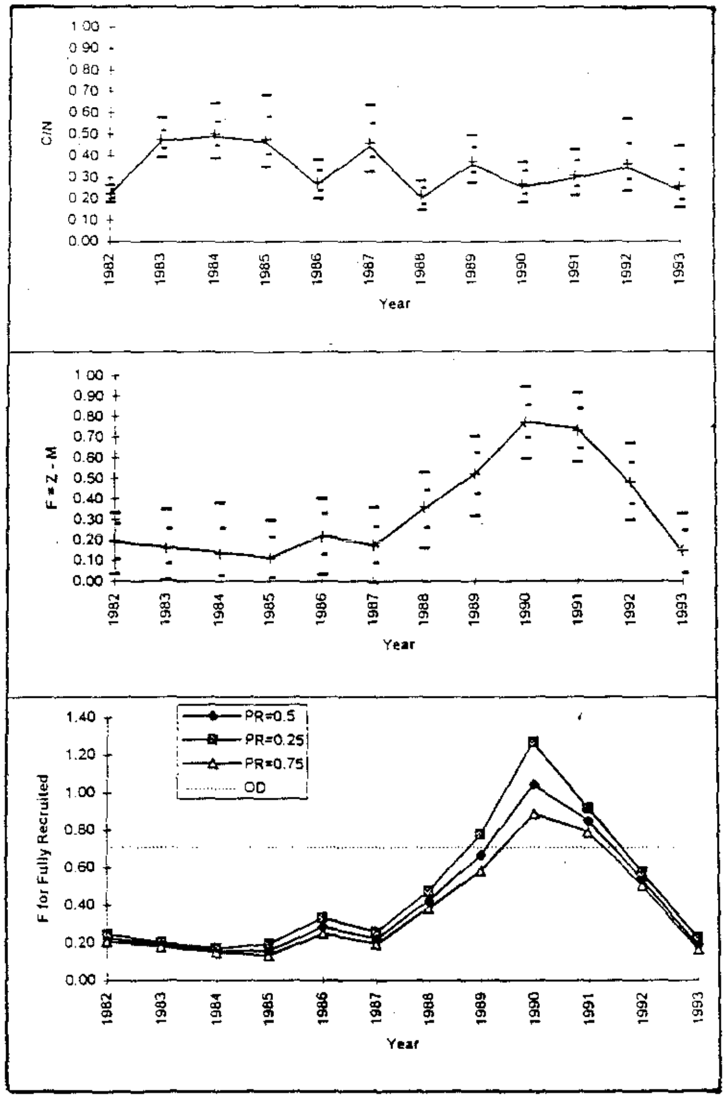


Figure D30. The estimated ratio of catch number and estimated fully recruited stock (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), the estimated overall fishing mortality rate (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), and the estimated fishing mortality rate of fully recruited stock estimated by applying various partial recruitment ratios, for scallops in New York Bight area.

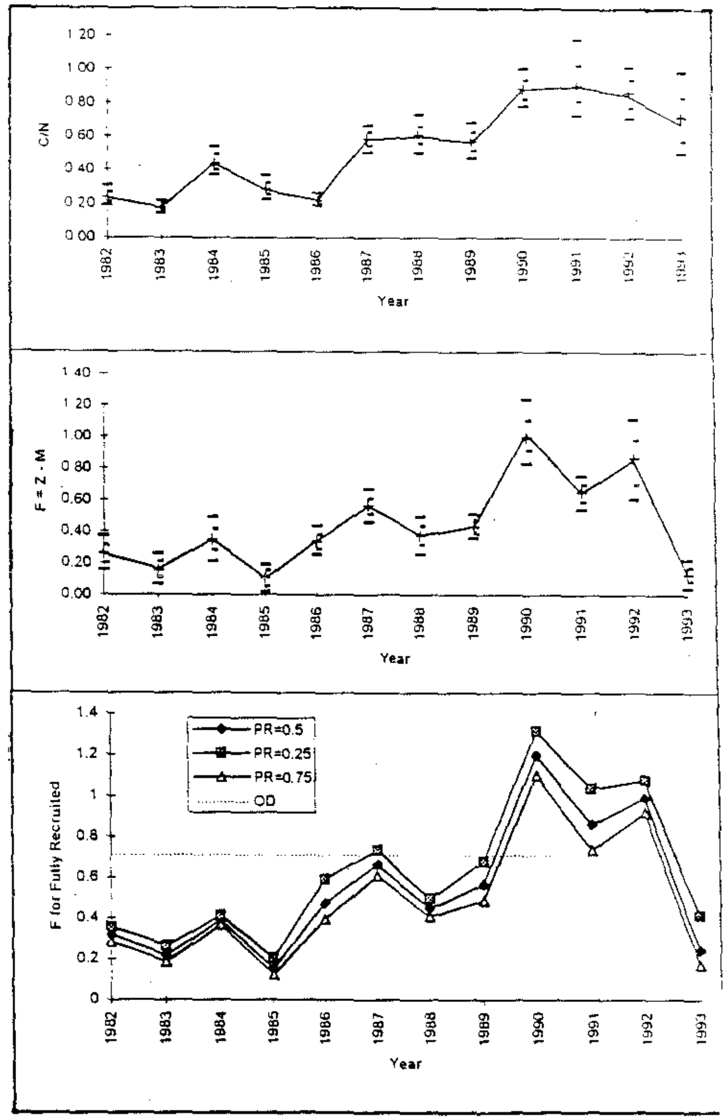


Figure D31. The estimated ratio of catch number and estimated fully recruited stock (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), the estimated overall fishing mortality rate (line) with bootstraping percentiles (10, 25, 50, 75, and 90%), and the estimated fishing mortality rate of fully recruited stock estimated by applying various partial recruitment ratios, for scallops in Delmarva area.

E. BLACK SEA BASS

Terms of Reference

The following terms of reference were addressed for black sea bass:

a. Summarize catches (landings and discards) and available length and age compositions for the northern (Cape Cod - Cape Hatteras) stock of black sea bass.

b. Summarize all available indices of stock abundance/biomass from commercial and recreational LPUE and research survey catch per tow.

c. Review all basic life history parameters for this stock.

d. Evaluate the possibility of upgrading the assessment from the yield-per-recruit to the analytical level (e.g., virtual population analysis if sufficient catch-at-age data exist, and non-age-based methods if not).

e. If possible, provide short-term estimates of the catch and SSB at various levels of F.

f. Update yield-per-recruit and spawning-stock-biomass-per-recruit analyses.

Introduction

Black sea bass (*Centropristis striata*) is a demersal species inhabiting the continental shelf from Cape Cod, MA to southern Florida (Kendall and Mercer 1982). The species has been divided into two stock units, north and south of Cape Hatteras, NC (Mercer 1978), although there is some evidence of heterogeneity among the areas comprising the northern stock (Shepherd 1991). The northern stock undergoes seasonal migratory movements, moving northward and inshore to coastal waters during spring, and moving offshore and south to the edge of the continental shelf during the late autumn. Spawning occurs from May to August, with the season varying latitudinally. Juveniles inhabit coastal and estuarine areas and most are believed to participate in the seasonal offshore migration during the fall (Able *et al.* 1995).

Sea bass are protogynous hermaphrodites, transforming from females to males between the ages of 2 to 5 (Lavenda 1949, Mercer 1978). Sexual maturity occurs at age 2 for males and females. Male sea bass reach a maximum length of 60 cm and a maximum age of 15 years.

Black sea bass fisheries in the EEZ were originally to be managed under a summer flounder-scup-black sea bass plan implemented by the Mid-Atlantic Fishery Management Council. However, summer flounder management was initiated first and a black sea bass plan was not begun until 1993. The proposed plan would implement a number of management measures in the first year of the management program including a minimum fish size, gear restrictions for otter trawl and pot fishermen, and a moratorium on commercial entrants. The plan calls for further restrictions beginning in year 3 of the management program, which could include commercial quotas and recreational possession limits. In addition, several states (MA, RI, NY, CT, NJ) have historically had size limits on black sea bass. Minimum sizes range from 8" in most states and 12" in Massachusetts.

The Fishery

Commercial Landings

Commercial landings north of Cape Hatteras fluctuated around 2,600 mt prior to 1948, at which point landings increased to 6,900 mt (NEFSC 1993). Landings peaked at 9,900 mt in 1952, declined steadily to 600 mt in 1971, then increased to 2,400 mt in 1977 (Figure E1). Between 1983 and 1993, commercial landings ranged from 1,272 to 1,965 mt. Distant water fleet landings were 1,500 mt in 1964, but only ranged from 4 to 33 mt between 1983 and 1987 and have been non-existent since 1988. Commercial landings for 1994 are currently not available.

The predominate gear types in the commercial fishery are otter trawls which have accounted for 25 to 76% of the landings since 1983 (an average of 56%) and fish pots which accounted for 17 to 62% (average of 33%) (Table E2). Hand lines account for 3 to 11% of the commercial landings (average 5%), with minor contributions from lobster pots, floating trap nets, and pound nets.

The majority of landings are from fisheries in the EEZ, with an 1983-1993 average of 84%. The states of New Jersey and Virginia account for the majority of the landings with an average of 26% and 24% of the commercial landings, respectively. Among the remaining states, Massachusetts, Rhode Island, Maryland, and North Carolina account for 9 to 11% each.

The otter trawl landings are primarily the result of bycatch in the summer flounder and squid fisheries (Shepherd and Terceiro 1994). The bulk of these fisheries occur during the winter months along the edge of the continental shelf. The pot fishery, which occurs in coastal waters from April to November, is directed towards black sea bass (Eklund and Targett 1991, Shepherd and Terceiro 1994).

Commercial Discards

The NEFSC sea sampling program has collected information on landings and discards in the commercial fishery on a regular basis from 1989 to 1993. Between 31 and 63 otter trawl trips per year in which sea bass were landed or discarded were sampled. The reason for discarding was generally because of fish undersized according to state regulations or marketability concerns.

Based on analysis of variance, an initial examination of sea sampling data was made to evaluate the effects of year, quarter, and area on the discard rate in the otter trawl fishery . Quarter and area were significant, although there was not a significant year effect. The first quarter in the southern areas (Divisions 62 and 63) had the highest discard rate, consistent with existing knowledge.

Despite the statistical differences between area and quarter, there were not adequate data from which to calculate discards on a quarterly, area basis. Therefore, the data were pooled into half-year periods (January - June, July - December) across all areas for the purpose of discard estimations. Ratios of discards to landings for the period 1989-1993 were multiplied by otter trawl landings in the weighout data base on a half-year basis (Table E2). The discard rate for the second half of 1992 (47.7%) was anomalously large, and was replaced by an average of the rates for the second half of 1991 and 1993. To reflect discards in components of the fishery not included in the weighout data base (general canvas and North Carolina), the estimate of discard (by half year) was raised by the ratio of otter trawl commercial landings (by half year) to weighout landings. For 1984-1988, the average ratio of discard to landings from the period 1989-1991 was applied on a half-year basis. A discard mortality of 100% in the trawl fishery was assumed (Rogers *et al.* 1986).

Estimates of discards in the pot fishery were developed in a similar fashion. Although the slat spacing in fish pots allows the escapement of most small black sea bass, individuals states have minimum size regulations which impose further requirements for discarding undersized fish. Sea sampling data were available from 9 trips in 1989 in New Jersey (5) and Maryland (4). In the samples from Maryland, which were not constrained by a state size limit, the discarding of sea bass from pots was 0 in 3 of 4 trips. Samples from the New Jersey pot fishery, which had an 8" size limit, had an average discard-to-landings ratio of 12%. Sea sampling trips from inshore sea bass fisheries in Massachusetts indicate that survival approaches 100% (P. Caruso, MADMF, pers. comm.). Since most of the sea bass fisheries in southern New England are pursued in shallow water, a negligible discard mortality from pot fisheries in this region was assumed and no estimation of losses was provided. States south of New Jersey have not had a size limit on black sea bass and were assumed to have a limited discard such as that sampled from Maryland. The remaining fishery in New Jersey accounts for the majority of total landings from pots. Therefore, the 12% discard-to-landings ratio was applied to the New Jersey pot fishery landings data on a half-year basis in the same manner as described for trawl fisheries. Since mortality in shallow water fish pots approached 0%, a discard mortality of 50% was assumed to approximately account for the mix of shallow, intermediate and deeper water fisheries.

The Subcommittee concluded that discards from the commercial hook and line gear would likely be negligible due to the nature of the fishery (targeting larger fish, gear selectivity, etc).

Estimates of total commercial discards are shown in Table E3.

Recreational Landings

Black sea bass is an important recreational species, with the greatest proportion of catches taken in the Middle Atlantic states (New Jersey to Virginia). Estimates of catch in numbers were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) for 1979 to 1994. NMFS recently revised the catch estimates for the time series. Estimates were available for three categories: type A - fish landed and available for sampling, type B1 - fish landed but not available for sampling, and type B2 - fish caught and released. Catch estimates for North Carolina north of Cape Hatteras were determined based on the total number for North Carolina minus the North Carolina estimates used by Vaughn *et al.* (1995) for an assessment of the black sea bass stock south of Cape Hatteras. Catch estimates in number for 1984-1994, the period covered by this assessment, are presented in Table E4. Landings ranged from 1.8 million fish in 1984 to 21.7 million fish in 1986.

The estimated recreational landings (types A and B1) in weight during 1984-1994 ranged from 667 mt to 5,622 mt (Table E5) and averaged 1,721 mt per year. Since 1983, the recreational landings average 44% of total landings.

Recreational Discard

The estimated recreational discard (type B2), in number, during 1984-1993 ranged from 1.59 million fish in 1984 to 7.11 million fish in 1986 (Table E4). Mortality of black sea bass recreational discards has been reported in the literature as 5% (Bugley and Shepherd 1991) in a shallow water fishery and 27% (Rogers *et al.* 1986) in deeper water. Since most of the recreational catch occurs in the EEZ, the Subcommittee assumed 25% mortality applies. Based on that rate, discard mortality in number ranged from 318,000 fish in 1984 to 1,422,800 fish in 1986. Total discards by weight are presented in Table E5 (see section on age composition for information concerning calculation of the mean weight of discards).

Total Catch

Estimates of total catch of black sea bass are given in Table E5. These estimates include commercial and recreational landings and discards. The total catch during this period varied from a high of greater than 7,500 mt in 1986 (driven primarily by a high recreational component) to a low of 2,863 mt in 1992. Except for 1986, the total catch has been relatively stable for the last ten years.

Sampling Intensity

Length samples of black sea bass were available from both commercial and recreational landings. In the commercial fishery, annual sampling intensity varied from 100 lengths per 40 mt to 100 lengths per 412 mt. In all years except 1993, sampling exceeded the informal criterion of 100 lengths per 200 mt.

In the recreational fishery, sampling intensity varied from 100 lengths per 37 mt to 100 lengths per 165 mt. In all years, sampling exceeded the minimum requirements.

Commercial Age Composition

Numbers and mean weights at age were estimated for 1984-1993 for the commercial landings and discards. Numbers at length for the commercial landings were determined from the length frequencies collected by market categories applied to total landings per market category (Figure E2). The length frequency samples were assumed to be representative of the total landings, and were expanded to unsampled landings (general canvas data and unclassified landings). The summarized length frequencies by half-year periods were partitioned into age categories using age-length keys derived from NEFSC survey catches of black sea bass. Age-length keys from spring surveys were applied to numbers from the first half of the year, while age-length keys from autumn surveys were applied to numbers at length from the second half of the year. To provide ages in the age-length keys for fish greater than 42 cm, age data from all surveys were pooled into the annual keys. This pooling applied to most fish greater than age 7.

Discard length frequency information from sea sampling in the trawl fishery was collected from a limited number of tows per year since 1989 (i.e., 1 tow in 1990, 1 tow 1991, 3 tows in 1992). The first quarter of 1989 provided the only period with a sample size large enough to characterize the length frequency of discards versus landings in the otter trawl fishery (Figure E3). Additional discard length data were collected from the pot fishery in the Mid-Atlantic Bight in 1989 and 1994 and in coastal Massachusetts in 1993 (Figure E4).

Discards at age were estimated from the available length frequency data and NEFSC survey age data. The available discard length samples, although not adequate to describe total discard length frequencies, indicated the range of sizes present in the discards. The application of NEFSC spring 1989 age length keys to the 1989 first quarter discard lengths indicated that discards ranged in age from 1 to 4, with 92.2% ages 1 and 2 by weight.

The discard numbers at age were calculated for ages 1 and 2 in the first half of the year and ages 0 and 1 in the second half, assuming the first quarter discards also reflected the length distribution of the previous quarter. The ratio of ages 1 to 2 by weight was calculated from the annual spring NEFSC survey data and the ratio of ages 0 to 1 from the annual autumn survey data (Table E6). These ratios were applied to the discard estimates for each half-year period. Discard weights at age were converted to numbers using the mean weight at age from the survey data. Survey weights at age were calculated from the lengths at age and a length-weight equation developed from the corresponding survey period (Table E12).

Discards at age in the pot fishery were estimated in a similar fashion. Survey age-length keys applied to available length frequency samples in 1989 and 1994 as well as aged samples from the Massachusetts pot fishery (Table E7, Caruso 1995) indicated that the age composition of discards in the pot catches was primarily ages 2 in the spring fishery and age 1 in the autumn fishery. NEFSC survey weights at age (converted from grams to pounds) were used to convert the pounds of age 1 discards in the autumn and age 2 discards in the spring to numbers.

The results indicate periodic pulses of high juvenile discards, but no discernable trends. Although the available sea sampling data are probably adequate to indicate the general composition of the discards, the method chosen relies heavily on the NEFSC survey data. The resulting estimates of discards at age are tenuous at best.

Recreational Age Composition

NEFSC age-length keys for spring and autumn were applied to the recreational length frequencies (Figure E5) for the corresponding half-year periods. The weights at age were determined using the annual length frequencies by age and the NEFSC length-weight equations. Recreational landings were dominated by ages 1-3. Young-of-the-year fish were generally absent from the landings. The large landings in 1986 were dominated by the 1985 year class.

Recreational discard length data were derived from sea bass discards in the New York party boat fishery from 1992-1994 (Figure E6). The maximum size was 25 cm while the minimum size was truncated at 15 cm. Fish less than 15 cm accounted for 8% of the total number sampled. NEFSC autumn survey data for fish between 15 and 25 cm were used to determine the age composition of the discards. Since the autumn survey data are occasionally dominated by fish 7-14 cm (age 0), the Subcommittee decided that inclusion of this size range in the discard estimates would be biased toward age 0 fish, which have a higher selection by survey trawl gear than hook and line gear. Therefore, the discard size range was limited to 15-25 cm. The proportion at age for 15-25 cm fish in the NEFSC age length keys was estimated for spring and autumn. The proportions at age were applied to the seasonal (January - June, July - December) estimates of the B2 catch. Mean weights at age from the NEFSC data were used to calculate total weight of the recreational discards. The discards as calculated were ages 1-3 and were dominated by age 2 fish.

Total Age Composition

The age composition of the catch has been dominated by ages 1-3 (Table E8). Age 1 fish in the catch-at-age matrix account for 14.3% of the total, while age 2 fish account for 42.1%. Fish greater than age 4 comprise only 2.5% of the total catch.

Stock Abundance and Biomass Indices

Commercial LPUE

A general linear model (GLM, SAS 1985) of commercial otter trawl landings per unit effort (LPUE) was used to develop a standardized index of black sea bass. The general methods for the GLM were presented in SAW 9 (NEFC 1989). Landings per day fished were calculated for trips in which black sea bass comprised >25% of the landed weight. Due to the bycatch nature of the fishery, higher % per trip as a measure of directedness results in a significant loss of data. The indices covered the period 1978-1993. The GLM included the effects of year, tonnage class, two-digit statistical area, and quarter, with 1993, tonnage class 3, area 63, and quarter 1 as the standard cell. The model explained 26% of the variance. The year coefficients were retransformed adjusting for bias using 1/2 of the model mean square error term. The retransformed year values provided the index of abundance.

The LPUE indices for 1978-1993 are presented in Figure E7 and indicate a reduced level of LPUE since the 1980s. The levels since 1991 are the lowest in the time series (Figure E7).

Recreational LPUE

A general linear model was also used to analyze the variation in MRFSS intercept LPUE for all intercepts coastwide and produce a standardized index of abundance based on year category regression coefficients. Effort was considered as all trips which landed black sea bass or in which sea bass were the primary or secondary species sought.. The coefficients in the model included year, sub-region, mode, and area, with the standard cell being the 1993 party-charter boat mode LPUE from the offshore Mid-Atlantic area. The model explained 12% of the total variance. The year coefficients were retransformed as described for commercial LPUE and provided an index of abundance. In addition, a subset of the data for the Mid-Atlantic offshore party-charter boats was evaluated.

The LPUE indices show a relatively steady pattern since 1984 (Figure E7). In comparison, the subset of indices from the Mid-Atlantic has actually risen over the last several years. The Subcommittee felt that this increase may be a function of changes in recreational fishing practices in the last decade. There has been a substantial increase in the number of artificial reefs deployed along the Mid-Atlantic coast which are well known to the party boat fleets. It is conceivable that since these reefs provide good habitat for sea bass they aggregate the population. This aggregating effect would tend to increase the relative efficiency of the party boat fleet's ability to target black sea bass and consequently increase the catch per angler per trip.

Research Vessel Indices

Indices of black sea bass abundance and biomass were calculated from catch-per-tow data from fishery-independent surveys conducted by the NEFSC, Massachusetts Division of Marine Fisheries (MADMF), Rhode Island Division of Fish, Wildlife, and Estuarine Resources (RIDFW), and the Virginia Institute of Marine Science (VIMS).

Long-term trends in black sea bass abundance were derived from the NEFSC stratified random bottom trawl survey conducted each spring since 1963 between Cape Hatteras and Nova Scotia (Clark 1978). Prior to 1972, the survey was not conducted in inshore strata. The strata area defined for black sea bass extends from Cape Cod to Cape Hatteras and includes inshore and offshore strata. During the spring, black sea bass tend to be congregated offshore along the edge of the continental shelf (Shepherd and Terceiro 1994). Total indices show a overall reduction since the mid-1970s (Figure E8). Indices dropped from 7.151 fish/tow in 1977 to 0.253 fish/tow in 1994. The index in 1994 is the lowest since 1984. Age composition data were only available since 1984. The spring survey catches age 1-10 fish, with age 1 fish averaging 6 cm in length (Table E10). The high value for age 2 in 1986 corresponds to the high recreational landings in the same year. That year class (1984) did not exhibit a high index at age 3 in 1987. There is no indication of any large pulses of juvenile recruitment during this period. There is, however, an indication of poor recruitment in 1992 and 1993. The overall age composition has remained relatively stable.

The NEFSC autumn survey covers the period 1972 to the present. The strata used for this survey are the same as for the NEFSC spring survey. The indices peaked in 1977, but have since shown considerable annual variation (Figure E8). During the autumn survey period, sea bass are distributed inshore in coastal and estuarine waters. The affinity of sea bass to habitat generally unsuitable for otter trawls may influence their availability to the survey gear, and subsequently cause significant annual variation in survey indices.

Age data from 1984-1993 includes fish ages 0-7 (Table E10). Indices suggest above-average recruitment during 1985 and 1986. Fish greater than age 3 are generally absent from the survey. The index for age 0 in 1993 indicates a poor 1993 year class, as suggested by the spring survey. The juvenile abundance for 1994 appears above average.

The MADMF bottom trawl survey has been conducted within state waters from the New Hampshire to Rhode Island state borders since 1978. The strata used in the analysis of black sea bass comprised the area south of Cape Cod and Buzzards Bay. The overall index has declined steadily to a recent low value of 0.09 in 1992 (Figure E9). Since the areas covered by this survey include black sea bass spawning grounds, immature fish (primarily age 1) are under-represented in the spring survey. Sea bass up to age 9 have been collected in this survey, although ages 2, 3, and 4 tend to be the most dominant (Table E11). The survey indicated an above-average index for age 2 fish in 1986. There was a conspicuous absence of age 2 sea bass in 1993 and 1994.

The MADMF autumn index dropped steadily until 1989 and has remained at a low level (Figure E9). The autumn index is dominated by young-of-the-year sea bass (Table E11). Recruitment in 1993 was nearly absent, although the 1994 cohort appeared to be above average. The strong 1984 year class was evident in 1985 and 1986.

A standardized bottom trawl survey has been conducted in Narragansett Bay and state waters of Rhode Island Sound since 1979. The RIDFW index of abundance for young-of-the-year black sea bass was developed from the survey based on fish less than 11 cm. The index showed a large year class in 1981 and a smaller recruitment pulse in 1984-1986. Recruitment indices have been low since 1987, with a particularly bad year class in 1993. The overall index in number peaked in 1981 and 1986 and has remained low since.

VIMS has conducted a bottom trawl survey in the lower James River and Chesapeake Bay since 1978 which captures young-of-the-year black sea bass. Beginning in 1987, the survey expanded into higher salinity nursery areas of the Chesapeake Bay which increased the catch of juvenile sea bass. The results since 1987 suggest poor recruitment in 1992, but improved recruitment levels in 1993.

Life History Parameters

Few studies have been conducted on the population dynamics of the northern stock of black sea bass. Mercer (1978) carried out the first extensive study describing the life history of sea bass, including growth, mortality, and maturity. Growth information in the form of age-length and length-weight models from available sources has been summarized in Table E12. For the purposes of this assessment, a von Bertalanffy growth curve was developed from NEFSC survey mean-length-at-age data. Since 1993, NEFSC bottom trawl surveys have collected weights of individual fish. The length-weight information from spring and autumn surveys was used to develop seasonal coastwide length-weight equations as well as a combined season equation. Natural mortality (M) in these analyses was assumed to be 0.2.

Reproduction in black sea bass was first analyzed by Lavanda (1949), who documented the presence of protogynous hermaphrodites, and then by Mercer (1978). Recently, O'Brien *et al.* (1994) developed maturity ogives for black sea bass from NEFSC survey data between 1985 and 1990. Information provided by Alexander (1981) and Caruso (1995) on maturity from coastal samples is likely biased by the presence of predominately mature fish in coastal waters for the purpose of spawning. The general lack of age 1 fish in spring coastal surveys suggests that not all immature fish make the return migration to spawning areas. The available information for length and age at maturity for the northern stock of black sea bass is summarized in Table E12.

Mortality and Stock Size Estimates

Virtual Population Analysis (VPA) and Tuning

A nonlinear least squares sequential population analysis available in the software ADAPT (Conser and Powers 1990, Gavaris 1988) was used to determine fishing mortality (F) and stock size estimates.

The initial step in running the ADAPT software was determination of the exploitation pattern in the terminal year. The selection-at-age data were provided by a separable analysis using the SVPA model of Pope and Shepherd (1982). A terminal F of 0.5 and a terminal S of 1.0 provided the lowest final sum of squared residuals. The resulting selection pattern with full recruitment at age 4 was:

Age	1	2	3	4	5	6+
S	0.100	0.430	0.889	1.000	0.811	1.000

The assumption of a flat topped selection pattern was made. Since selection at age 3 was higher than at age 5, which was assumed equal to 1.0, age 3 was assumed to have reached full recruitment. Therefore, the model was re-run using full recruitment at age 3. The results were:

Age	1	2	3	4	5	6+
S	0.115	0.490	1.000	1.000	0.811	1.000

The catch was dominated by fish less than age 5. Therefore, the initial VPA was run for ages 0-5, with older ages grouped into a 6+ group.

The SARC felt that all available indices were not appropriate as tuning indices, since they all did not reflect the full population abundance. The indices used in the tuning process were the NEFSC spring survey indices for ages 1-6. Spring survey indices were compared to stock size numbers at the beginning of the same year.

Stock sizes in 1994 were directly estimated for ages 1-5, while the age 6+ group was calculated from Fs estimated in 1993 and the input partial recruitment pattern. Tuning indices were weighted using an iterative re-weighting scheme. For all years prior to 1993, backcalculated stock sizes for ages 3, 4, and 5 were used to estimate fishing mortality at the oldest age (5). The F at the age 6+ group was assumed equal to the F for age 5. The coefficient of variations for the stock size estimates ranged from 1.4 for age 1 to 0.69 for age 4 (Table E13). Although the estimates were imprecise, particularly at age 1, the SARC felt the trend of the estimates corresponded with other indices of abundance.

<u>Stock Size, Fishing Mortality, Recruitment, and Spawning Stock Biomass</u>

The final run provided estimates of stock size for ages 1+, which remained relatively stable between 1984 and 1992 (average of 41.8 million fish). An above-average 1984 year class appeared as a pulse through 1986, but the high abundance did not appear at age 3 in 1987. Stock numbers dropped dramatically to an estimated 10.9 million fish at the beginning of 1994.

Average fishing mortality rates for fully recruited ages (3-6) were above 1.0 throughout the time period (1984-1993) and exceeded 1.9 in 1991-1992 (Figure E10). Relative to 1992, the estimated F declined during 1993 to 1.05.

Estimates of recruitment at age 1 averaged 20 million fish between 1984 and 1992 (Figure E11). Recruitment in 1993 (the 1992 year class) dropped to 2.5 million fish and again in 1994 (the 1993 year class) to 1.6 million fish. This resulted in a sharp decline in stock numbers in 1993 and 1994. The presence of an above-average year class in 1991 maintained the catch biomass at a relatively steady level through 1993. Due to the dominance of age 2 and 3 fish in the catch, good annual recruitment is necessary to maintain recent catch levels.

The spawning stock biomass (SSB) estimates included spawning biomass of males and females and has remained relatively stable from 1984 to 1993, ranging from 2,150 mt to 4,554 mt. The SSB in 1993 (3,115 mt) was the second highest in the ten year time series. The poor recruitment in 1992 and 1993 is not yet fully reflected in spawning stock biomass but would be expected to lead to a sharp decline in future SSB.

Precision of F and SSB Estimates

To evaluate the precision of the final VPA estimates, a bootstrap procedure with 500 iterations was used to generate distributions of the estimated 1993 fishing mortality rate and spawning stock biomass. The results in Figures E12 and E13 depict the frequency of the F and SSB values and the probability that F is greater than a target value or that SSB is less than the targeted estimate.

The bias-corrected estimates of the coefficient of variation (CV) for stock number (Table E14) ranged from 58% at age 5 to 154% at age 1. The bootstrap estimate of fully-recruited F in the terminal year was 0.98. The bootstrap estimates indicate that there is a 90% probability that F in 1993 was greater than or 0.67 (Figure E12).

The bias-corrected estimate of SSB for 1993 was 2,773 mt, lower than the point estimate of 3,116 mt, with a CV of 34%. Bootstrap estimates indicated that there was an 80% probability that the 1993 spawning stock biomass was between 2,400 mt and 4,700 mt (Figure E13).

Projections of Catch and Stock Biomass

Given the imprecision of the VPA results, the SARC suggested that no projections of catch and stock biomass be made.

Catch Curve Analysis

NEFSC spring survey data and the total catch at age data were subjected to catch curve analysis. The ratios of age 3+ to 4+ fish were used in annual estimates for the period 1984 to 1993. Although some estimates from the survey data were not useful due to data limitations, the Fs generated from this analysis ranged from 0.63 to 2.0 and were generally greater than 1.0.

Biological Reference Points

Yield per Recruit

Estimates of biological reference points were derived from the Thompson and Bell (1934) model. Recent work by Shepherd and Idoine (1993) indicated that the protogynous life history of black sea bass does not impact the calculation of yield-per-recruit reference points, because both males and females are included in the yield estimates. The spawning stock biomass estimates for females can be profoundly different with inappropriate model specification. However, in this analysis, spawning stock biomass was considered to include both mature male and female fish which avoids the problem of accounting for sexual transformations. The input parameters and results of the Thompson and Bell model are presented in Table E15. The fishing mortality pattern was determined using the geometric mean of the 1989-1992 backcalculated partial recruitment coefficients estimated from the final ADAPT run. The 1993 estimates were not included due to the imprecision in the terminal year. The proportion of F and M prior to spawning was based on the seasonal pattern of catch, with the mid-point in the spawning season assumed to be mid-June. A maximum age of 15 was assumed, given a natural mortality of 0.2 and the relationship of the oldest age equal to 3/M. The proportion mature was based on the maturity information developed by O'Brien *et al.* (1993). Average stock weights were obtained from NEFSC survey data, while the catch weights were based on the total catch mean weights at age. The weights for older ages were from projections based on a growth curve developed from the NEFSC survey data.

The input parameters described resulted in an estimate of F_{MAX} of 0.29 and an estimate of $F_{0.1}$ of 0.18. These estimates differ from previously reported values due to changes in the growth data and the refinement of the exploitation pattern. The SARC felt that there not enough information available concerning the impact of fishing mortality on reproductive potential in an hermaphroditic species. Consequently no estimates were made of maximum spawning potential.

Summary and Conclusion

"It is regretted that this gamy fish is decreasing so rapidly in numbers. In a short time it will probably become a rare species in this locality. Handlining, even on the spawning-grounds off Hyannis, was remarkably poor this season, and the abundance of the young does not give promise for the coming year." Notes on the migration, spawning, abundance, etc., of certain fishes in 1900. G.H. Sherwood and V.N. Edwards. Biological Notes, Contributions from the Biological Laboratory of the U.S. Fish Commission, Woods Hole, Massachusetts.

Results of indicate that the northern stock of black sea bass is overfished. Despite the imprecision of the estimates, fishing mortality is much greater than the level required for maximum yield per recruit. Spawning stock biomass has remained steady over the last decade but will likely be reduced due to very poor recruitment in 1992 and 1993.

The VPA results suggest that the population biomass has remained relatively stable over the past decade. This corresponds to the relatively stable commercial and recreational LPUE during the same time period. Survey indices have been relatively stable during the 1980's but shown an overall decline since the 1970's. Although there appears to be a reduction of F in 1993, the decade of elevated F levels may be associated with the poor recruitment apparent in 1992 an 1993.

The level of F indicated by the VPA is somewhat contradictory to the relatively stable landings and recreational LPUE indices. The behavior of black sea bass is very structure-oriented; thus it may be possible to maintain catch levels even with a declining stock if fishermen know the location of appropriate structure around which sea bass would congregate. On the other hand, this habitat preference may provide a refuge effect from mobile fishing gear, particularly for larger fish.

The Subcommittee discussed the implications and the possibility that this habitat preference may result in a dome-shaped partial recruitment pattern rather than the assumed flat-topped pattern. This could produce a bias toward a higher estimate of fishing mortality rate. Given the relatively short time series of age data (10 years), it is currently not possible to develop historic estimates of F and stock size to improve the understanding of how the stock has withstood high levels of fishing mortalities.

The Subcommittee felt that overall, there are several pieces of evidence that the stock is being overfished. The survey indices and landings are much reduced from historic levels. The VPA, despite the high degree of imprecision, suggests the level of F exceeds the biological reference point, and the level of F is substantiated by the elevated mortalities determined from catch curve analyses.

SARC Comments

The SARC discussed the characterization of discards in the recreational and commercial fisheries. The presence of black seabass as small as 3 cm in the trawl fishery was noted. These small seabass were attributed to the small mesh squid fishery. Assumptions made concerning discard mortality rates were also discussed. In the assessment, a 50% discard mortality was assumed for the pot fishery. The potential for a higher mortality rate in a deep water pot fishery was raised. However, the SARC concluded that for the depth range the pot fishery is prosecuted, a 50% rate was reasonable. The SARC discussed the 25% discard mortality rate assumed for the recreational fishery and concluded that the 25% rate was reasonable. Finally, the estimates of numbers and weights of discards at age from the commercial fishery were questioned. Commercial discard data are sparse and had to be estimated from first quarter trips only. Interannual variability in discarding rates was large and could not be explained adequately by patterns in recruitment or other factors. The SARC recommended a review of the discard-at-age matrix input to the VPA, prior to another assessment.

The SARC discussed the choice of tuning indices used in the VPA. The need for a qualitative evaluation of indices prior to inclusion in the VPA was emphasized. It was noted that a qualitative review to exclude poor indices - those containing little information or not indicative of overall stock abundance - is assumed in the design of VPA. In particular, the gear used must adequately sample the species and should reflect stock-wide conditions rather than local fluctuations in availability. A general concern about the use of any index with frequently missing values and specific concern about using the NMFS Fall Age 5 index and the Massachusetts spring age 1 index was expressed. The SARC also discussed the need to examine index CV's, partial variances and other diagnostics including trends in survey catchability (q) when deciding which surveys should be retained in the VPA.

Additional indices considered by the SARC were the NMFS winter trawl survey and standardized commercial LPUE. The SARC agreed that the NMFS winter survey should not be included because of the short time series (1992-95) and small sample size associated with the 1994 index. The SARC suggested that commercial LPUE may help to stabilize the VPA and recommended that additional VPA runs be made, including runs using the NMFS Spring survey indices with and without the commercial LPUE. The SARC subsequently reviewed these alternative runs, adopting the version excluding the commercial LPUE index, and including the iteratively reweighted NMFS Spring survey indices. The SARC concluded that the assessment did not have adequate precision to project future stock or catch levels. However, the SARC felt that the assessment was useful for identifying current fishing rates (generally in excess of F=1.0) relative to the overfishing definition F_{MAX} (0.29).

The SARC also recommended that fishing mortality rates be calculated from catch curves of survey indices and the catch-at-age matrix. These estimates were subsequently computed and, although more variable, were similar to VPA derived F's (i.e. generally >1.0).

The SARC discussed the significance of sequential hermaphroditism in the calculation of yield and spawning stock biomass per recruit. It was noted that transition rates most likely vary in response to fishing rate and that equilibrium conditions are assumed in SSB/R calculations. The need for more information on transition rate was forwarded as a research recommendation of the SARC. However, until more is known concerning the effect of transition rate on SSB/R, the SSB/R results are not reliable.

Research Recommendations

- The present analysis relies heavily on the NEFSC survey results. Auxilary data, particularly New Jersey survey data should be considered for incorporation into future assessments.
- Commercial length sampling from landings should be increased to the level experienced prior to 1993.
- Sampling of length frequency data from sea sampling is inadequate for reliably estimating the age composition of discards. In addition, sampling in the Mid-Atlantic area should be increased to better quantify the discard rate of black seabass.
- The VPA models have been fit with the assumption of a linear relationship between fishery catch and survey indices. Alternative models should be explored which allow the incorporation of a non-linear relationship.
- Non-age based assessment alternatives should be considered as a means of potentially extending the time-series and improving the assessment.
- The effect of sex transition rates, sex ratio and potentially differential natural mortality by sex on the calculation of spawning stock biomass per recruit and eggs per recruit should be investigated.

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Table E1. Black sea bass % of commercial landings by year and gear type.

YEAR	Gear Type: Otter Trawl	Pot	Hand-line	Other
1983	67.7	22.8	4.7	4.8
1984	75.6	16.7	3.0	4.7
1985	66.9	17.0	7.0	9.1
1986	60.7	28.5	6.3	4.5
1987	61.5	32.6	3.5	2.4
1988	59.1	33.5	5.2	2.2
1989	51.9	39.4	6.6	2.1
1990	48.7	43.2	6.2	1.9
1991	24.6	61.9	10.7	2.8
1992	37.0	50.8	8.5	3.7
1993	61.8	33.3	2.3	2.6

Table E3. Commercial by-catch and discard estimates (mt) for trawl and pot fisheries, 1983 to 1993.

	Bycatch		Discards		
Year	Trawl	Pot	Trawl	Pot	Total
1984	168.3	12.5	168.3	6.2	174.5
1985	119.8	12.5	119.8	6.2	126.0
1986	131.8	22.0	131.8	11.0	142.9
1987	131.8	18.0	131.8	9.0	140.9
1988	125.2	21.0	125.2	10.5	135.7
1989	93.6	24.0	93.6	12.0	105.6
1990	83.4	30.4	83.4	15.2	98.6
1991	32.0	46.3	32.0	23.1	55.1
1992	124.4	45.0	124.4	22.5	146.9
1993	55.6	26.1	55.6	13.1	68.7

Table E2. Ratios of discards to landings, by half year period, from sea sampled otter trawl trips, 1989-1993.

Year	Discard lbs	Kept lbs	Ratio
1989			
1	824	4648	0.177
2	167	4575	0.037
1990			
1	547	5477	0.100
2	71	564	0.126
1991			
1	64	3055	0.021
2	227	1397	0.179
1992			
1	1059	11651	0.091
2	average 1991 and 1993		0.094
1993			
1	247	2834	0.087
2	4	518	0.008

Table E4. MRFSS black sea bass harvest (A + B1) and release (B2) estimates in number (000's adjusted to include North Carolina catch from north of Cape Hatteras).

Year	A + B1	B2	% B2
1984	1880.6	1588.7	45.7
1985	3770.6	2701.3	41.7
1986	21747.2	7114.4	24.6
1987	2935.7	2134.2	42.1
1988	2949.3	4965.7	62.7
1989	4285.5	2174.7	33.6
1990	3919.9	5196.4	57.0
1991	5237.4	5529.0	51.3
1992	3556.6	4112.8	53.6
1993	5539.9	2753.6	33.2
1994	3334.4	3631.7	52.0

Table E5. Catch (mt) of black sea bass from Maine to North Carolina

YEAR	Landings Commercial	Landings Recreational	Foreign	Discards Recreational	Discards Commercial	Total Catch
1984	1,965	667	18	34	175	2,859
1985	1,551	1,052	33	66	126	2,828
1986	1,901	5,622	10	147	143	7,823
1987	1,890	901	4	66	141	3,002
1988	1,879	1,241		137	136	3,393
1989	1,324	1,509		69	106	3.008
1990	1,588	1,268		135	99	3,090
1991	1,272	1,887		143	55	3,357
1992	1,364	1,199		153	147	2,863
1993	1,412	2,031		96	69	3,608

Assumes pot discards mortality of 50%, trawl discards mortality of 100% and recreational mortality of 25%.

Table E6. Ratio of ages by weight from NEFSC survey applied to commercial discards.

Year	Spring age 1	Spring age 2	Autumn age 0	Autumn age 1
1984	0.007	0.993	0.007	0.993
1985	0.082	0.918	0.180	0.820
1986	0.003	0.997	0.102	0.898
1987	0.003	0.997	0.038	0.962
1988	0.013	0.987	0.087	0.913
1989	0.010	0.990	0.083	0.917
1990	0.055	0.945	0.017	0.983
1991	0.082	0.918	0.074	0.926
1992	0.016	0.984	0.114	0.886
1993	0.000	1.000	0.000	1.000

Table E7. Catch at age from the sampled catch of the Massachusetts pot fishery during spring/summer 1993. (Source: Massachusetts Division of Marine Fisheries.)

LENGTH (cm) — Discarded

AGE	20	21	22	23	24	25	26	27	28	29	30
2		7	18	28	37	45	57	36	28	10	3
3					4	4	7	9	25	26	30
4											
5											
6											

LENGTH (cm) — Landed

AGE	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
2																					
3	42	55	44	50	49	39	25	24	9	5	1		1								
4	2	3	2	2		4	8	7	4	5	4	5	5	2	1	1	1				
5										1	1	1	1	2	2	4	4	3	2	1	1
6																3	1	2	1	2	1

Table E8. Total catch at age (00's) Black Sea Bass from Cape Cod to North Carolina 1984-1993.

		Age										
Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	725	19453	29102	36083	16565	1395	539	232	13	15	0	104121
1985	17050	22674	38399	25612	16327	2760	1617	437	211	45	24	125154
1986	11803	58809	198439	45955	9513	2333	2367	194	763	226	377	330778
1987	1950	16508	45682	43344	5860	1614	1130	98	15	0	147	116349
1988	2831	29448	55702	39865	9735	2694	250	15	121	1	7	140670
1989	3001	8900	45764	25933	7926	1526	772	60	55	58	15	94008
1990	1154	24393	35143	51066	6075	1624	186	5	21	0	41	119707
1991	1419	19866	70209	21441	10963	5706	324	24	69	81	35	130139
1992	5319	11259	58791	34044	5791	360	218	22	28	26	0	115857
1993	0	9447	85694	26986	5382	351	161	12	41	7	0	128081
%>0		96.78										
%>1			81.07									
%>2				33.88								
%>3					8.94							
%>4						2.24						

Table E9. Mean weight at age (kg) of black sea bass catch between Cape Hatteras, NC and Cape Cod, MA.

				Age							
Year	0	1	2	3	4	5	6	7	8	9	10
1984	0.006	0.077	0.166	0.293	0.470	0.852	1.214	0.853	1.290	1.722	
1985	0.003	0.049	0.154	0.264	0.519	0.849	1.256	0.864	1.549	1.949	2.377
1986	0.003	0.073	0.185	0.394	0.663	0.997	1.333	1.199	1.536	1.830	2.369
1987	0.007	0.073	0.176	0.334	0.534	0.782	1.329	1.113	1.370		2.444
1988	0.006	0.062	0.192	0.320	0.413	0.518	1.164	1.184	1.265	1.878	2.223
1989	0.003	0.042	0.184	0.342	0.474	0.741	1.055	1.334	1.500	1.906	2.127
1990	0.004	0.052	0.176	0.323	0.527	0.692	1.179	1.128	1.529		2.460
1991	0.014	0.049	0.161	0.308	0.508	0.631	1.347	1.213	1.571	2.337	2.237
1992	0.004	0.067	0.190	0.308	0.545	0.994	1.284	1.176	1.290	1.898	
1993		0.095	0.201	0.321	0.584	0.927	1.383	1.253	1.469		

Table E10. Mean catch per tow (numbers) at age for NEFSC spring and autumn research vessel surveys, 1983-1993.

Spring					Age							
Year	0	1	2	3	4	5	6	7	8	9	10	TOTAL
1984	0.00	0.01	0.05	0.07	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.23
1985	0.00	0.08	0.08	0.13	0.11	0.02	0.01	0.00	0.00	0.00	0.00	0.45
1986	0.00	0.11	1.18	0.50	0.06	0.00	0.00	0.00	0.00	0.00	0.00	1.91
1987	0.00	0.02	0.67	0.34	0.06	0.03	0.03	0.00	0.00	0.00	0.00	1.17
1988	0.00	0.38	0.69	0.62	0.13	0.04	0.02	0.00	0.01	0.00	0.00	1.96
1989	0.00	0.18	0.41	0.10	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.76
1990	0.00	0.26	0.20	0.23	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.84
1991	0.00	0.63	0.21	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.94
1992	0.00	0.32	0.56	0.64	0.10	0.01	0.00	0.00	0.00	0.00	0.01	1.64
1993	0.00	0.00	0.80	0.56	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.40
1994	0.00	0.01	0.03	0.14	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.25

Table E10. (Continued).

Autumn

Year	0	1	2	3	4	Age 5	6	7	8	9	10	TOTAL
1983	0.53	0.06	0.14	0.05	0.02							0.80
1984	0.21	2.06	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38
1985	1.86	0.49	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	2.64
1986	1.46	0.96	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63
1987	0.13	0.30	0.28	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.81
1988	0.16	0.37	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.68
1989	0.42	0.14	0.22	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86
1990	0.33	1.16	0.61	0.06	0.01	0.00	0.00	0.01	0.00	0.00	0.00	2.27
1991	0.28	1.19	0.41	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89
1992	0.59	0.29	0.41	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
1993	0.00	0.14	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
1994	0.63	0.58	0.04	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.86

Table E11. Mean catch per tow (numbers) at age for Massachusetts spring and autumn research vessel surveys 1984-1993 Strata set 11-21.

Spring

Year	0	1	2	3	4	Age 5	6	7	8	9	10	TOTAL
1984	0.00	0.00	0.40	0.64	0.41	0.12	0.02	0.02	0.00	0.00	0.00	1.61
1985	0.00	0.04	0.15	0.41	0.51	0.02	0.08	0.00	0.00	0.00	0.00	1.21
1986	0.00	0.04	0.69	0.60	0.12	0.04	0.02	0.01	0.03	0.00	0.00	1.55
1987	0.00	0.00	0.34	0.32	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.71
1988	0.00	0.00	0.07	0.23	0.07	0.03	0.00	0.00	0.02	0.00	0.00	0.42
1989	0.00	0.00	0.52	0.35	0.12	0.07	0.02	0.00	0.00	0.00	0.00	1.08
1990	0.00	0.01	0.04	0.37	0.09	0.12	0.04	0.00	0.00	0.02	0.00	0.69
1991	0.00	0.00	0.02	0.01	0.07	0.21	0.02	0.02	0.00	0.02	0.00	0.37
1992	0.00	0.00	0.04	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.09
1993	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.02	0.00	0.00	0.00	0.12
1994	0.00	0.00	0.00	0.05	0.05	0.07	0.05	0.00	0.00	0.00	0.00	0.22

Autumn

Year	0	1	2	3	4	Age 5	6	7	8	9	10	TOTAL
1984	201.29	0.34	0.06	0.32	0.18	0.02	0.00	0.00	0.00	0.00	0.00	202.21
1985	196.58	0.75	0.05	0.28	0.28	0.04	0.00	0.00	0.00	0.00	0.00	197.98
1986	78.69	0.04	0.18	0.61	0.04	0.00	0.00	0.00	0.00	0.00	0.00	79.56
1987	34.17	0.32	0.15	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.85
1988	58.10	2.34	0.16	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	60.70
1989	6.52	0.00	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	4.15	0.06	0.00	0.02	0.02	0.00	0.00	0.04	0.00	0.00	0.00	4.29
1991	9.30	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.46
1992	10.82	0.00	0.00	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.00	11.00
1993	0.98	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06
1994	45.03	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	45.07

Table E12. Growth and maturity parameters for black sea bass.

Length-weight equations:

NEFSC spring	$WT_{gr} = 0.0246 * LEN_{cm}^{2.796}$
NEFSC autumn	$WT_{gr} = 0.0190 * LEN_{cm}^{2.912}$
NEFSC combined	$WT_{gr} = 0.0218 * LEN_{cm}^{2.854}$
Mercer (1978)	$WT_{gr} = 0.00001 * \text{Std. } LEN_{mm}^{3.1798}$
	$TL_{mm} = -11.2 + 1.340 * \text{Std } LEN_{mm}$
	$WT_{gr} = 0.0212 * \text{Std. } LEN_{cm}^{3.0991}$
	$TL_{cm} = 1.78 + 1.24 * \text{Std } LEN_{cm}$

Growth equations

NEFSC	$Len_{cm} = 66.27 * (1-e^{-0.168(t-0.715)})$
Mercer (1978)	$\text{Std } Len_{mm} = 469 * (1-e^{-0.182(t+0.1056)})$
Alexander (1981)	$\text{Std } Len_{mm} = 441.03 * (1-e^{-0.201(t-0.1262)})$

Maturity at Age

% mature

	O'Brien *et al.*			Alexander (1981)			Caruso (1995)		
Age	F	M	n	F	M	n	F	M	n
0	0	0	-	-	-	0	-	-	0
1	0.13	0.08	-	1.0	0	2	-	-	0
2	0.60	0.72	-	1.0	0.995	124	0.99	1.0	200
3	0.87	0.93	-	1.0	1.0	227	1.0	1.0	567
4	0.93	0.98	-	1.0	1.0	180	1.0	1.0	133
5	1.0	1.0	-	1.0	1.0	182	1.0	1.0	71
6+	1.0	1.0	-	1.0	1.0	67	1.0	1.0	52
n =	561	348							

Table E13. Summary VPA results for black sea bass using ADAPT.

STOCK NUMBERS (Jan 1) in thousands

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	16942	38993	21380	16583	20165	10560	19201	19449	20706	2489
2	8685	12111	29873	12183	12083	13845	7841	13513	14126	15934
3	6667	4478	6441	6502	5841	4853	7195	3240	4711	6246
4	2356	2194	1349	1116	1402	1175	1627	1269	713	777
5	234	430	319	244	383	268	244	774	48	60
6	132	357	523	206	54	165	38	70	39	37
1+	35017	58563	59885	36833	39928	30865	36147	38315	40343	25543

	1994
1	1579
2	1183
3	5292
4	2671
5	149
6	28
1+	10902

Table E13. (Continued).

Summaries for ages 3 6

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
	9390	7459	8632	8068	7680	7680	9104	5353	5511	7120	8140

FISHING MORTALITY

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.14	0.07	0.36	0.12	0.18	0.10	0.15	0.12	0.06	0.54
2	0.46	0.43	1.32	0.54	0.71	0.45	0.68	0.85	0.62	0.90
3	0.91	1.00	1.55	1.33	1.40	0.89	1.53	1.31	1.60	0.65
4	1.50	1.73	1.51	0.87	1.46	1.37	0.54	3.08	2.28	1.45
5	1.07	1.24	1.65	1.31	1.49	1.00	1.32	1.69	1.80	1.05
6	1.07	1.24	1.65	1.31	1.49	1.00	1.32	1.69	1.80	1.05

Avg F for ages 3 5

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	1.16	1.32	1.57	1.17	1.45	1.09	1.13	2.03	1.89	1.05

BACKCALCULATED PARTIAL RECRUITMENT

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.09	0.04	0.22	0.09	0.12	0.07	0.10	0.04	0.03	0.38
2	0.31	0.25	0.80	0.40	0.48	0.33	0.45	0.28	0.27	0.62
3	0.61	0.58	0.94	1.00	0.94	0.65	1.00	0.43	0.70	0.45
4	1.00	1.00	0.92	0.65	0.98	1.00	0.35	1.00	1.00	1.00
5	0.71	0.71	1.00	0.98	1.00	0.73	0.86	0.55	0.79	0.72
6	0.71	0.71	1.00	0.98	1.00	0.73	0.86	0.55	0.79	0.72

MEAN BIOMASS (mt)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	1108	1677	1194	1038	1042	384	842	816	1220	167
2	1054	1383	2836	1518	1522	1869	916	1345	1835	1941
3	1179	688	1197	1110	931	1009	1107	512	672	1351
4	532	505	428	366	283	281	605	189	143	222
5	113	194	145	99	96	116	87	219	20	31
6	91	238	318	141	30	114	23	37	21	29
1+	4078	4685	6117	4272	3904	3773	3576	3118	3911	3741

Summaries for ages 3 6

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	1915	1625	2088	1716	1340	1520	1822	957	856	1633

CATCH BIOMASS (mt)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	150	111	433	121	183	38	127	98	76	91
2	488	597	3756	812	1084	850	627	1148	1130	1751
3	1075	688	1859	1481	1307	901	1698	673	1077	877
4	799	872	647	318	412	385	329	584	327	322
5	121	239	239	129	143	115	115	371	37	33
6	97	294	524	185	45	114	31	63	39	30
1+	2730	2802	7458	3046	3175	2403	2926	2937	2685	3103

Table E13. (Continued).

Summaries for ages 3 6

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	1941	1983	2836	1992	1724	1478	2045	1594	1404	1171

SSB AT THE START OF THE SPAWNING SEASON - males & females (mt)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	113	168	126	105	107	39	86	83	122	18
2	734	958	2171	1068	1095	1299	657	985	1304	1428
3	1203	709	1289	1178	993	1028	1191	543	726	1336
4	635	610	511	413	337	332	655	231	176	264
5	130	227	174	116	114	132	102	264	25	36
6	105	278	382	166	36	131	27	45	26	33
1+	2919	2950	4654	3046	2682	2961	2718	2150	2380	3115

The above SSBs by age (a) and year (y) are calculated following the algorithm used in the NEFSC projection program, i.e.

SSB(a,y) = W(a,y) x P(a,y) x N(a,y) x exp[-Z(a,y)]

where Z(a,y) = 0.53 x M(a,y) + 0.3 x F(a,y)
N(a,y) - Jan 1 stock size estimates (males & females)
P(a,y) - proportion mature (generally females)
W(a,y) - weight at age at the beginning of the spawning season

The W(a,y) are assumed to be the same as the mid-year weight at age estimates (see "WT AT AGE" table in input section).

MEAN STOCK NUMBERS (thousands)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	14392	34231	16352	14214	16807	9133	16191	16646	18216	1756
2	6351	8980	15327	8627	7926	10160	5206	8353	9656	9654
3	4025	2608	3038	3325	2909	2952	3416	1669	2183	4209
4	1132	972	646	686	685	592	1148	372	263	380
5	132	228	145	126	185	156	125	347	21	34
6	75	189	238	106	26	96	20	31	17	21
1+	26107	47208	35747	27083	28538	23090	26106	27418	30356	16054

Table E14. Black sea bass bootstrap summary results.

SEED FOR THE RANDOM NUMBER GENERATOR: 74747
MAIN LOOP LIMIT IN MARQUARDT ALGORITHM: 50
NUMBER OF BOOTSTRAP REPLICATIONS ATTEMPTED: 500
NUMBER FOR WHICH NLLS CONVERGED: 500
Results from the converged replications are used for computing the statistics that follow. Other replications are ignored.

BOOTSTRAP OUTPUT VARIABLE: Full vector of age-specific stocksizes on Jan 1, 1994

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1.579E3	3.354E3	4.419E3	2.80
1.183E3	1.590E3	1.196E3	1.01
5.292E3	6.476E3	4.425E3	0.84
2.671E3	3.195E3	1.935E3	0.72
1.492E2	1.786E2	1.305E2	0.87
2.758E1	2.910E1	1.500E1	0.54

Table E14. (Continued).

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1.775E3	1.976E2	112.39	-1.957E2	-22.58
4.072E2	5.350E1	34.43	7.756E2	1.54
1.184E3	1.979E2	22.37	4.108E3	1.08
5.235E2	8.654E1	19.60	2.148E3	0.90
2.940E1	5.837E0	19.70	1.198E2	1.09
1.517E0	6.708E-1	5.50	2.607E1	0.58

BOOTSTRAP OUTPUT VARIABLE: Full vector of age-specific terminal F's (in 1993)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
5.440E-1	6.178E-1	3.634E-1	0.67
9.023E-1	9.868E-1	4.557E-1	0.51
6.493E-1	6.901E-1	2.970E-1	0.46
1.450E0	1.550E0	5.608E-1	0.39
1.050E0	1.120E0	3.233E-1	0.31
1.050E0	1.120E0	3.233E-1	0.31

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
7.373E-2	1.625E-2	13.55	4.703E-1	0.77
8.447E-2	2.038E-2	9.36	8.178E-1	0.56
4.084E-2	1.328E-2	6.29	6.085E-1	0.49
9.997E-2	2.508E-2	6.89	1.350E0	0.42
7.040E-2	1.446E-2	6.71	9.792E-1	0.33
7.040E-2	1.446E-2	6.71	9.792E-1	0.33

BOOTSTRAP OUTPUT VARIABLE: F_full_t
Fully-recruited F in the terminal year (1993)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1.050E0	1.120E0	3.233E-1	0.31

BOOTSTRAP OUTPUT VARIABLE: Mean stock biomass during the terminal year (1993)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
3.748E3	4.253E3	1.274E3	0.34

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
5.053E2	5.698E1	13.48	3.243E3	0.39

BOOTSTRAP OUTPUT VARIABLE: SSB (males & females) at start of spawning season (1993)

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
3.116E3	3.459E3	9.551E2	0.31

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
3.429E2	4.271E1	11.00	2.773E3	0.34

Table E15. Yield per recruit results for black sea bass.

Natural Mortality is Constant at 0.2, Last age is a True Age;

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Average Weights Stock	Average Weights Catch
1	.0540	1.0000	.059	.064
2	.3160	1.0000	.162	.177
3	.6670	1.0000	.370	.321
4	1.0000	1.0000	.654	.524
5	1.0000	1.0000	.803	.798
6	1.0000	1.0000	1.196	1.254
7	1.0000	1.0000	1.031	1.132
8	1.0000	1.0000	1.656	1.437
9	1.0000	1.0000	1.836	1.931
10	1.0000	1.0000	1.997	1.997
11	1.0000	1.0000	2.163	2.163
12	1.0000	1.0000	2.380	2.380
13	1.0000	1.0000	2.575	2.575
14	1.0000	1.0000	2.747	2.747
15	1.0000	1.0000	2.898	2.898

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: --------> 3.522
F level at slope=1/10 of the above slope (F0.1): ---> .176
Yield/Recruit corresponding to F0.1: ---> .2508
F level to produce maximum Yield/Recruit (Fmax): ---> .292
Yield/Recruit corresponding to Fmax: ---> .2668

RESULTS:

	Fishing Mortality	Total Catch Number	Total Catch Weight	Total Stock Number	Total Stock Weight
	.000	.00000	.00000	5.2420	4.1893
	.100	.22608	.20266	4.3170	2.6368
F0.1	.176	.32333	.25084	3.8816	1.9910
	.200	.34653	.25776	3.7742	1.8429
Fmax	.292	.41549	.26676	3.4479	1.4253
	.300	.42029	.26673	3.4248	1.3978
	.400	.47050	.26132	3.1821	1.1262
	.500	.50734	.25182	3.0030	.9476
	.600	.53585	.24169	2.8644	.8228
	.700	.55879	.23207	2.7532	.7311
	.800	.57780	.22329	2.6614	.6610
	.900	.59392	.21541	2.5839	.6057
	1.000	.60783	.20837	2.5171	.5608
	1.100	.62003	.20208	2.4588	.5237
	1.200	.63085	.19647	2.4072	.4924
	1.300	.64056	.19142	2.3611	.4656
	1.400	.64934	.18688	2.3194	.4424
	1.500	.65735	.18276	2.2816	.4221
	1.600	.66470	.17902	2.2469	.4041
	1.700	.67148	.17560	2.2150	.3880
	1.800	.67777	.17246	2.1854	.3736
	1.900	.68363	.16957	2.1580	.3606
	2.000	.68911	.16689	2.1323	.3488

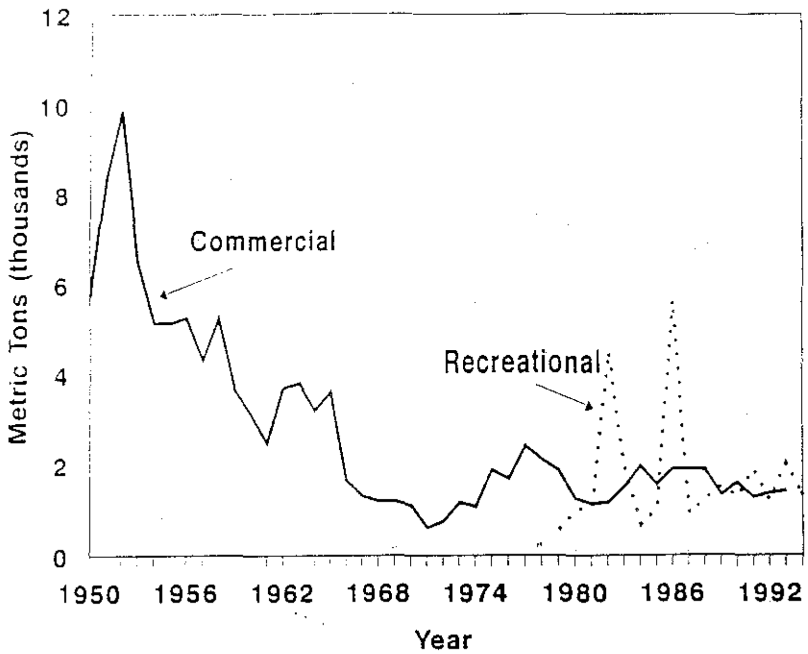

Figure E1. Total U. S. commercial and recreational landings of black sea bass, 1950 to 1994.

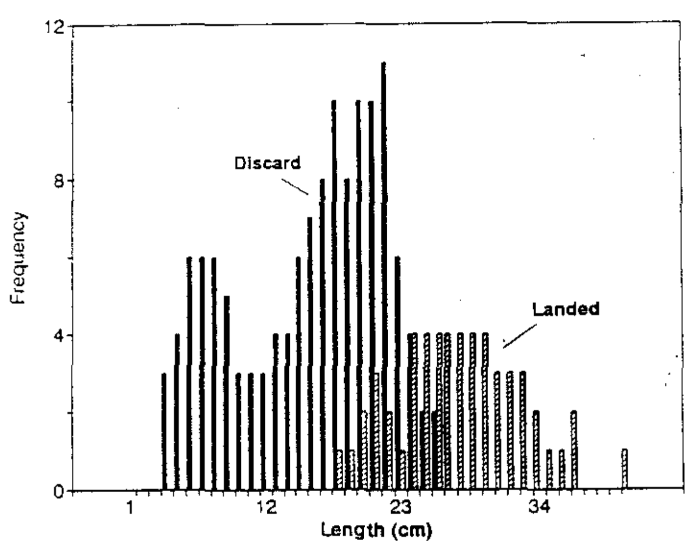

Figure E3. Length frequency of black sea bass otter trawl discards during quarter 1 of 1989.

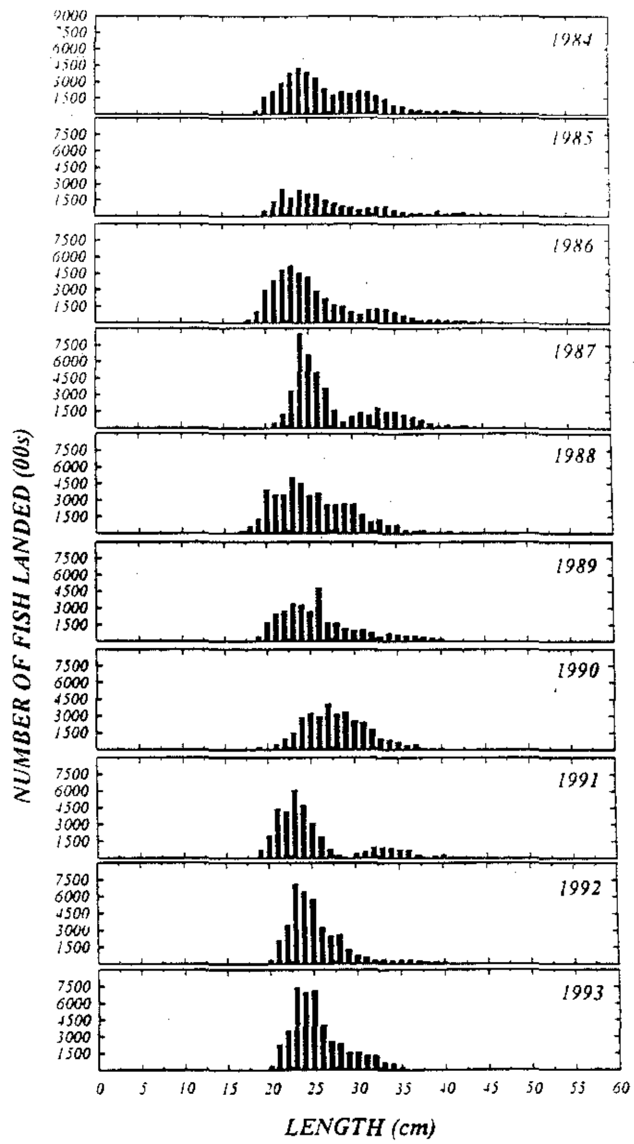

Figure E2. Commercial length frequencies for black sea bass, 1984-1993.

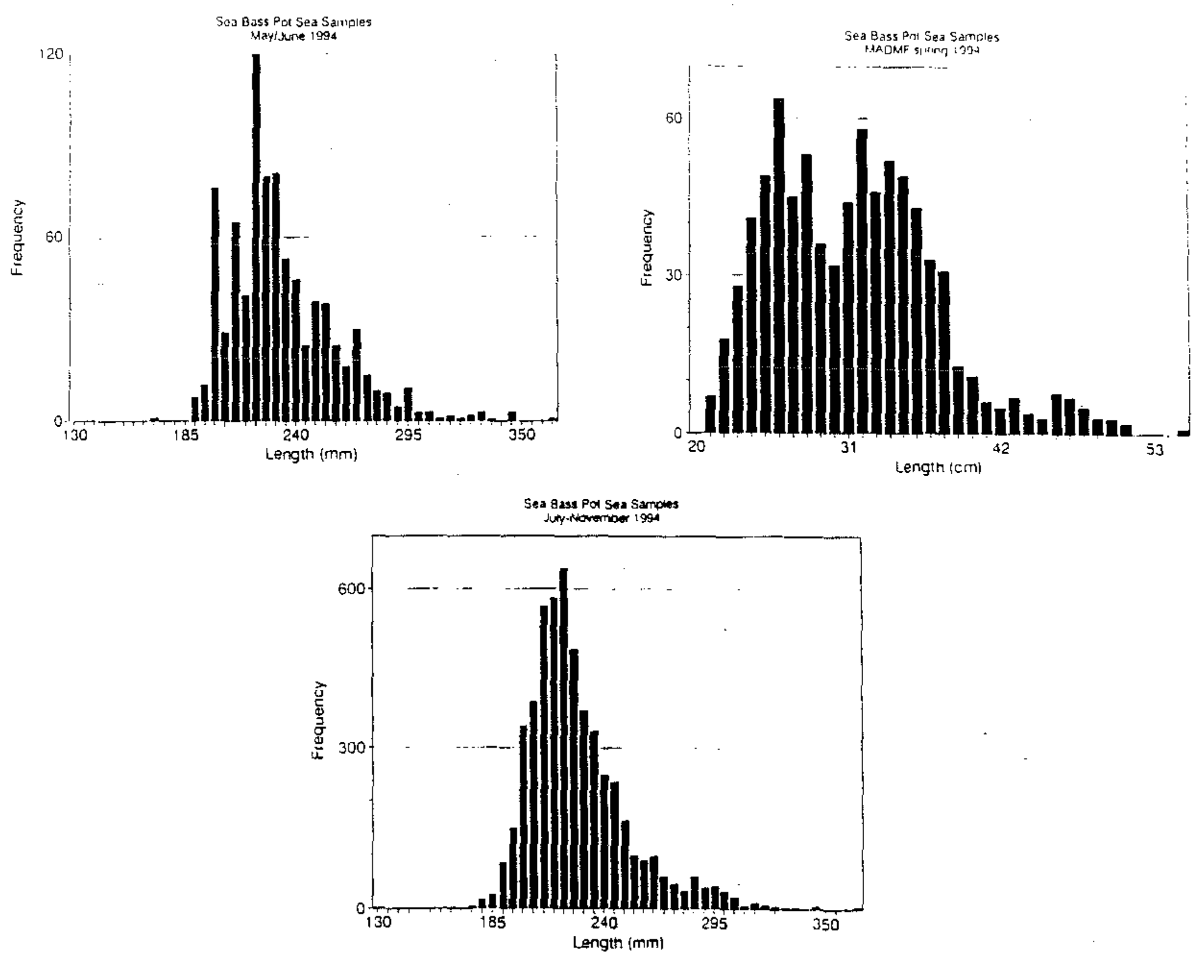

Figure E4. Length frequency of black sea bass discards in the pot fishery, Massachusetts 1993 and Mid-Atlantic 1994.

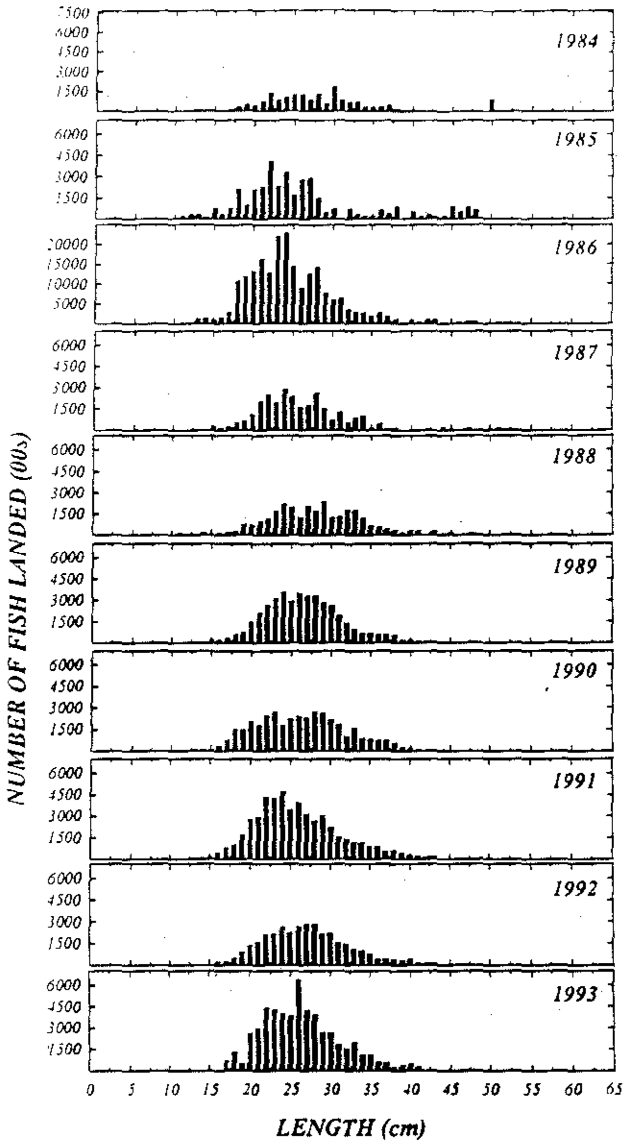

Figure E5. Recreational length frequencies for black sea bass. 1984-1993.

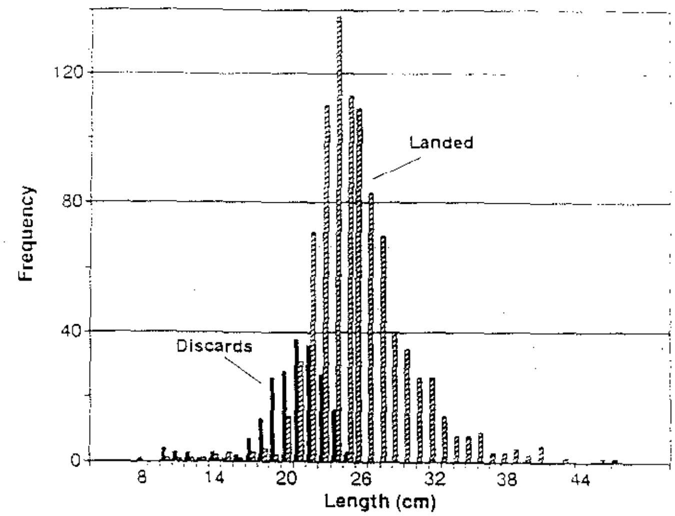

Figure E6. Length frequency of New York party boat landings and discards of black sea bass, 1992-1994.

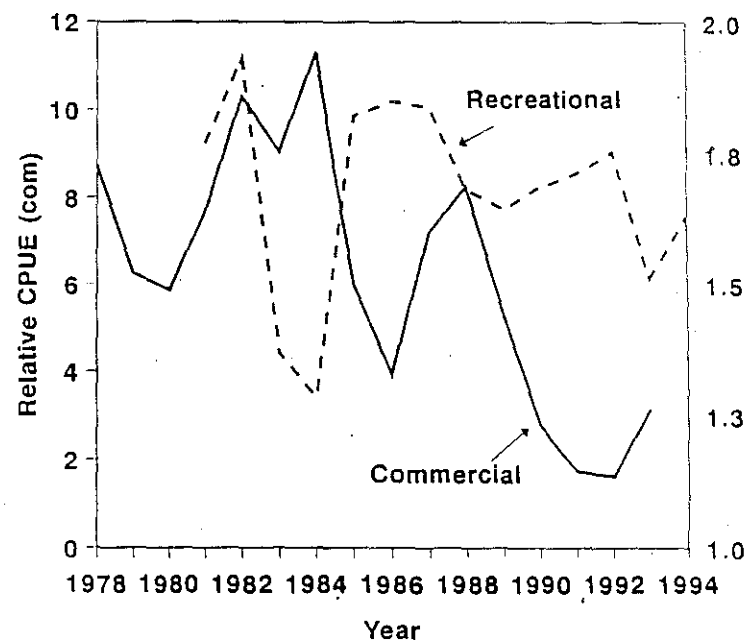

Figure E7. Relative landings per unit effort from commercial black sea bass otter trawl landings (1978-1993) and recreational catch per angler trip (1981-1994).

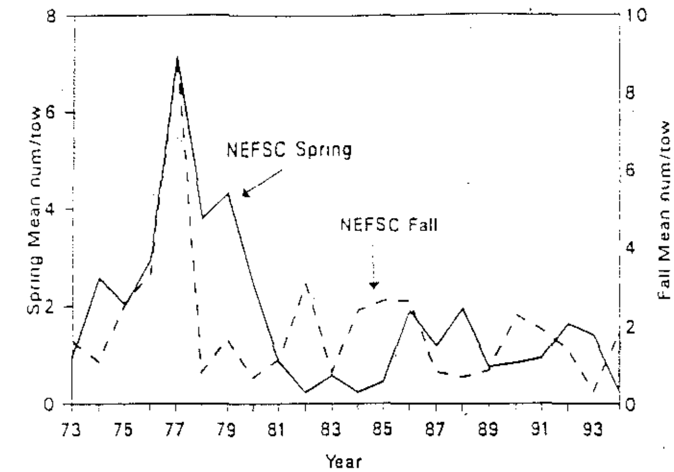

Figure E8. Mean number per tow from NEFSC spring and autumn bottom trawl surveys, 1972-1994.

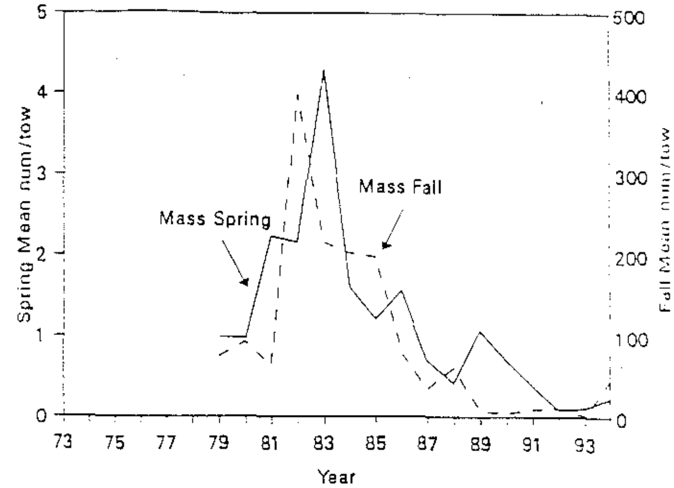

Figure E9. Mean number per tow from Massachusetts Division of Marine Fisheries spring and autumn bottom trawl surveys, 1978-1994.

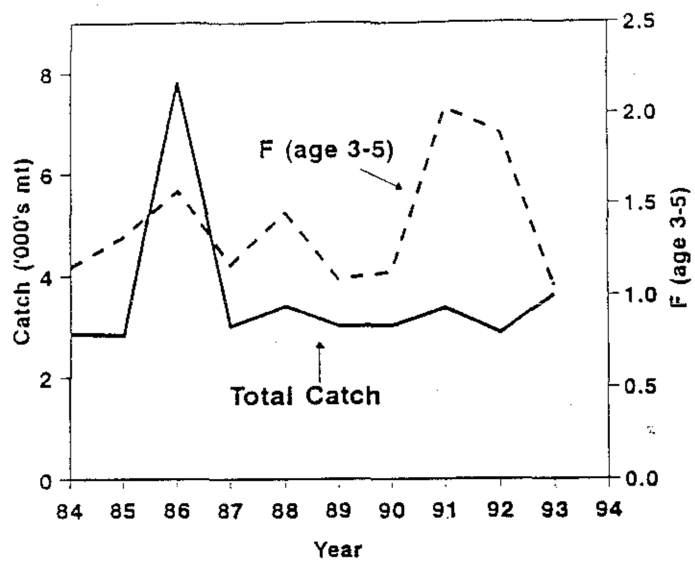

Figure E10. Total catch of black sea bass (mt) and the average fishing mortality rates from VPA, 1984-1993.

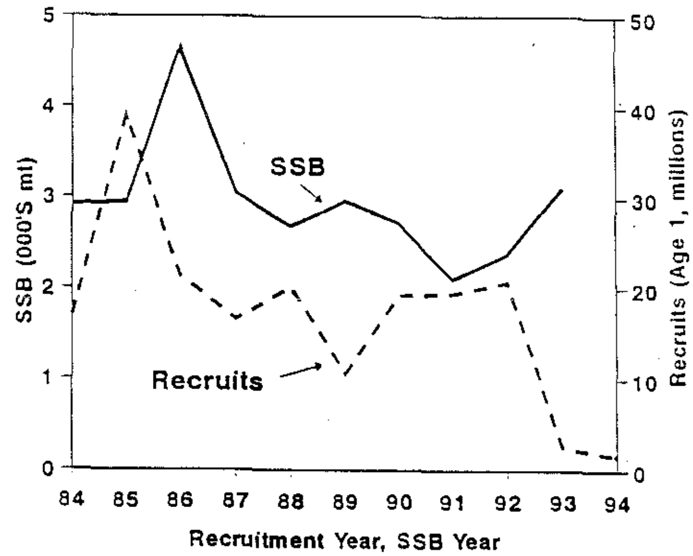

Figure E11. Estimates of annual recruitment of age 1 black sea bass and associated spawning stock biomass from VPA.

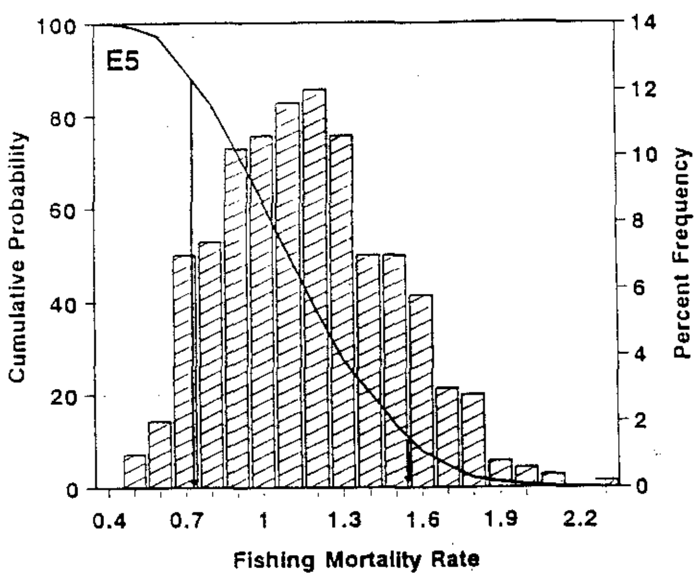

Figure E12. Bootstrap estimates of F and cumulative frequency from VPA.

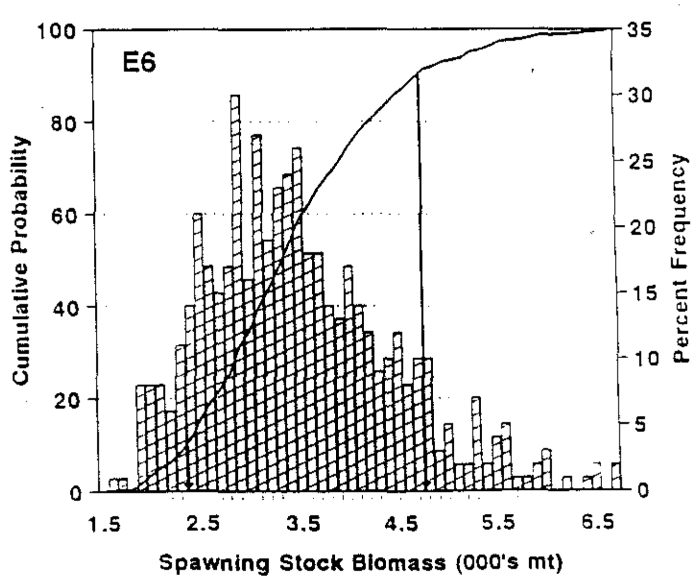

Figure E13. Bootstrap estimates of spawning stock biomass and cumulative frequency from VPA.

F. TAUTOG

Terms of Reference

The following terms of reference were addressed for tautog:

a. Summarize recreational and commercial landings, length composition, and available age-length data by state, Massachusetts to Virginia.

b. Summarize available indices of stock abundance by state based on state bottom trawl and juvenile surveys.

c. Estimate age composition of recreational and commercial landings using Connecticut age/ length key.

d. Provide estimates of fishing mortality for the "entire stock" and, if possible, by region (state).

e. Conduct, if possible, a full age-based VPA and yield-per-recruit and spawning-stock-biomass-per-recruit analyses.

f. Review all data for developing overfishing definitions.

Introduction

The Atlantic States Marine Fisheries Commission (ASMFC) has identified the immediate need for a coastwide Fishery Management Plan (FMP) for tautog (*Tautoga onitis*), and has recommended that the Plan be developed as part of its Interstate Fisheries Management Program. The states of Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, and Virginia have declared an interest in jointly managing this species through the ASMFC. The primary rationale for the development of a tautog FMP is the vulnerability of this species to overfishing. Additional concerns center around localized overfishing and a shift towards increased commercial fishing pressure beginning in the early 1990s. The goal of the tautog FMP is to conserve the resource along the Atlantic coast and to maximize long-term ecological benefits while maintaining the social and economic benefits of commercial and recreational utilization.

Tautog fisheries are not presently under any interstate or Federal management plan. Several states have, over the last few years, adopted minimum size and/or recreational bag limits as a conservation measure. Minimum size limits range from no minimum in Maryland and Virginia to 40.6 cm (16 inches) in Massachusetts and Rhode Island. Connecticut and New York have 35.5 cm (14 inches) and New Jersey and Delaware have 30.5 cm (12 inches) minimum size limits. Delaware is the only state with seasonal minimums 38 cm (15 inches) from April through June; 30.5 cm (12 inches) during the remainder of the year. Massachusetts and Delaware have possession limits for commercial and recreational fisheries and Rhode Island implemented a rectreational possession limit.

This assessment outlines the fishery and biological characteristics of tautog from Massachusetts to Virginia, and provides estimates of fishing mortality and stock size on a regional basis. Because spawning populations of tautog do not exhibit distant migrations and are confined to small areas, it would be preferable to conduct assessments of tautog at the state level. This was not possible because of a lack of biological information and fisheries data on tautog for most states.

Life History

Tautog (*Tautoga onitis*) is one of about 500 species comprising the wrasse or labrid family. In the northeastern U.S., it is often known by the common name "blackfish". Most labrids are inhabitants of tropical waters, making tautog an exception to the rule, since it ranges from Nova Scotia to South Carolina (Bigelow and Schroeder 1953). However, it is most abundant between south of Cape Cod and Chesapeake Bay.

Tautog shares this preference for temperate waters with one other labrid, cunner (*Tautogolabrus adspersus*), whose range extends even further north to Labrador. Tautog is distinguished from the cunner in that the former is stouter, has a higher head profile, and lacks scales on its gill covers (Migdlaski *et al.* 1979). Tautog also grow to a much larger size than cunner (10-12 kg) and reach ages in excess of 30 years.

Tautog are found in association with specific structured habitats throughout their life, and these habitats are important for survival. Structured locations provide shelter during nightly dormant periods. Juveniles require places to feed and hide from predators and are often found in shallow, nearshore submerged vegetation such as beds of seaweed. Larger fish require much more complex structures for shelter and locations where they find food.

Tautog normally reach sexual maturity at age 3-4 (Chenoweth 1963). Mature large tautog can be sexed from external characteristics attributable to sexual dimorphism. Male tautog are distinguished from females according to the more pronounced mandibular structure of the former (Cooper 1967). The spawning process is described under laboratory conditions by Olla and Samet (1977).

Adult tautog reside in offshore wintering sites and migrate inshore in the spring to spawn. Spawning occurs primarily at or near the mouth of estuaries and nearshore marine waters. Inside Narragansett Bay, mature tautog returned to the same spawning site each year, but dispersed throughout the bay after spawning (Cooper 1967). Tagging studies by Olla and Samet (1977) suggested, however, that adult tautog do not always return to the same spawning site in the spring, and mixing of populations from different localities occurs. Some of the adult population remains offshore throughout the year, especially in the southern region, and are found there in spawning condition (Olla and Samet 1977, Eklund and Targett 1990, Hostetter and Munroe 1993).

Studies on age and growth indicate a relatively slow-growing, long-lived fish, with individuals over 30 years of age having been reported in Rhode Island, Connecticut, and Virginia. Males seem to grow faster and longer than females (Cooper 1967). Available evidence suggests that females reach senescence earlier than males. Growth rates for tautog from Virginia are similar to those reported by Cooper (1967) for tautog in Rhode Island until about 15 years, after which growth rates decrease more rapidly in northern waters (Hostetter and Munroe 1993). However, discrepancies in ageing methodologies have been reported by the ASMFC Tautog Stock Assessment Group. These differences were caused by the difference in a birth date assignment and placement of the first annulus, particularly in older tautog.

Stock Structure

Tautog is a coastal species found primarily between Cape Cod and Virginia. The offshore distance and depth range of tautog appears to gradually increase towards the south and near Cape Hatteras. Tautog do not appear to have an extensive along-shore migration, although Briggs (1977) reported that fish from Long Island bays winter in deeper coastal waters off northern New Jersey. Tagging studies conducted by Cooper (1967) and Lynch (1993) in Rhode Island indicate that the Narragansett Bay spawning population of tautog is local to Rhode Island's coastal waters. Tautog exhibit a high degree of fidelity to discrete spawning groups within Narragansett Bay, suggesting multiple stocks/sub-populations within the Bay. However, the mixing of these groups after spawning makes treatment of these fish as a unit stock reasonable for fishery management purposes (Cooper 1966).

Related fishing observations suggest that discrete spawning groups exist in the waters of Narragansett Bay, Long Island Sound, Delaware Bay, and Chesapeake Bay.

For management purposes, the ASMFC Tautog Management Board has assumed a northern unit stock for tautog in the waters between Massachusetts and New York and a southern unit stock between New Jersey and Virginia.

The Fishery

Northern Region (MA, RI, CT, and NY)

Recreational landings:

Annual recreational landings of tautog fluctuated without trend from 1981 to 1985, ranging from 2,830 mt in 19821 to 411 mt in 1985. Landings peaked in 1986 at 6,158 mt and steadily declined after 1990, reaching the lowest level (1981-1993) in 1993 at 1,375 mt (Table F1). The majority of the landings occurred in the private boat mode (70%), followed by the charter/party boat (22%) and shore modes (8%). In all years except 1982, the majority (86%) of landings occurred in waters within 3 miles of shore.

Recreational landings in the northern region have traditionally been dominated by New York which accounted for 35-65% of the total in most years. Massachusetts, Rhode Island, and Connecticut share the remainder with similar percentages for most years. The estimated numbers of fish landed in the northern region declined by 75% from 1991 to 1994 (Table F2).

Massachusetts recreational landings of tautog have fluctuated over the years, reaching the highest level in 1986 at 3,566 mt. The lowest occurred in 1985 at 136 mt (Table F1). The recreational fishery in Massachusetts is most active south of Plymouth. Landings are highest in the spring and early autumn. Tautog ranks 7th among target species sought by recreational anglers in Massachusetts.

In Rhode Island, recreational landings of tautog peaked in 1986 at a little over 927 mt and declined to 172 mt in 1993 (Table F1). The fishery is heaviest during spring and autumn in Narragansett Bay.

Recreational landings of tautog in Connecticut increased from 110 mt in 1981 to a record high in 1987 of 502 mt. Between 1987 and 1993, recreational landings ranged from 91 mt in 1990 to 470 mt in 1989 and 1992 (Table F1). The fishery is also active in the spring and autumn, mostly in Long Island Sound.

Recreational landings of tautog in New York accounted for between 31% and 70% of the total of the major targeted sport fish. Landings have fluctuated from 462 mt to 1,285 mt, with the lowest catch in 1984 at 246 mt (Table F1).

Recreational discards:

Estimates of the recreational tautog discard or fish released (type B2 in numbers of fish) during 1981 to 1993 ranged from 200,000 fish (8% of the total catch) in 1982 to 1.4 million fish (47% of the total catch) in 1991 (Table F3). An increase in the proportion of total fish discarded has been observed in the northern region since 1987, ranging from a low of 30% in 1987-1990 to 52% in 1993 and 61% in 1994. The recent increase in minimum size was the main cause of high discards.

Discard mortality of tautog in the recreational fishery has not been evaluated. There are many conflicting opinions relative to estimating discard mortality for tautog, with estimates ranging from 0 to 50%. Tautog are commonly hooked in the mouth (jaws) when fished by hook and line and are known to swim away when released. Field observations show that tautog tend to remain longer on the surface when fished from shallow waters which makes them vulnerable to predators. Since most of the recreational catch occurs in coastal waters, the Subcommittee agreed to adopt an intermediate 25% discard mortality.

Commercial landings:

Nearly all of the coastwide commercial landings of tautog occurred in states from Massachusetts to New Jersey. The northern region's commercial landings represent 80-85% of the total commercial U.S. landings of tautog. These landings gradually increased from 125 mt in 1981 to 478 mt in 1987 and then remained relatively steady for four consecutive years after 1987 before reaching 224 mt in 1993, the lowest level since 1983 (Table F4).

Since 1984, commercial tautog landings have been dominated by Massachusetts and Rhode Island. Otter trawls were consistently the predominant gear from 1983 to 1991, accounting for 26-54% of the landings. However, in 1982 the predominant gear was inshore lobster pots. In recent years, the proportion of landings attributed to hand lines has increased; in 1991, this gear accounted for 24% of the total, just slightly less than that attributed to otter trawls (26%).

Coastwide, from 1982 to 1993, an average of 72% of the tautog caught commercially came from state waters, taken mostly in the spring and autumn when fish are migrating inshore or offshore. In the Exclusive Economic Zone (EEZ), the average monthly landings peaked in May, with greater amounts of tautog caught in two periods; April-June and November-January.

Commercial discards:

The NEFSC Sea Sampling Program has collected information on landings and discards in the commercial fisheries from 1989 to 1993 from Maine to North Carolina. Tautog discard rates were calculated using a simple arithmetic mean of ratios and total discard/total catch by tow for otter trawls and by string for gillnets (Table F5). These estimates indicate low discard rates (1.6-3.9%), mostly juvenile fish caught by gillnets (Figure F1). For the purpose of this assessment, zero discard mortality was assumed for the commercial fishery because of the near-zero discard estimates and the small portion of the total commercial catch taken by these gears.

Dockside sampling of tautog has not been part of the NMFS/Port Sampling program; therefore, length frequencies of commercial landings are not currently available.

Total catch:

Estimates of total catch of tautog are presented in Table F6. These estimates include only commercial and recreational landings (no discards). The total catch for 1981-1993 was dominated by recreational landings which averaged 87% of the total landings. The proportion of commercial to recreational landings increased from as low as 4% in 1982 to 21% in 1989 and gradually declined to 11% in 1993.

Sampling intensity and length frequencies:

Length frequencies of tautog were available only from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) data base. Plots of length histograms by year are presented in Figures F2 and F3. There is no evidence of size truncation during 1981-1993. The size composition ranged from 200-650 mm and the distribution was primarily unimodal. The sampling intensity was poor from 1981 to 1988, ranging from 100 lengths per 347 mt in 1988 to 100 lengths per 554 mt in 1985, compared to the acceptable criterion of 100 lengths per 200 mt. Sampling intensified after 1988 and fluctuated from 100 lengths per 82 mt to 100 lengths per 170 mt (Table F7).

Southern Region (NJ, DE, MD, and VA)

Recreational landings:

Annual recreational landings of tautog in the southern region fluctuated between 417 to 921mt from 1981 to 1985, increased to about 1,508 mt in 1986, and remained at this level until 1992, with the exception of 1990 (Table F8). A sharp decline was observed in 1993 and 1994, reducing recreational landings from the 1991 value by 34% and 46%, respectively. Landings in numbers of fish (types A and B1) peaked in 1986 at 2.8 million fish and stabilized at about 1 million fish in subsequent years (Table F9). Similarly, the majority of landings occurred by private boat, followed by charter/party boat and shore mode.

Recreational landings in the southern region were traditionally dominated by New Jersey, which took between 65 and 80% of the total in most years. Virginia is the second highest producer of tautog in the region, taking 30% in 1993 and 64% in 1994. The remainder is shared in almost equal proportions between Delaware and Maryland.

New Jersey recreational landings of tautog have fluctuated over the years, reaching a high in 1992 of 1,127 mt and then sharply declining to a 1982-1994 low in 1994. The primary fishing grounds extend from the beach out to about the 12-fathom contour line. Recreational fishing modes include bottom fishing, particularly the directed trips of party and charter boats, jetty fishing, and spear fishing. The fishing seasons are April-June and September-December.

In Delaware, recreational landings of tautog peaked in 1987 at 176 mt and declined to 87 mt and 68 mt in 1993 and 1994. However, the highest catch in numbers of types A and B1 was recorded in 1986 (Table F9). The fishery is primarily restricted to jetties, breakwaters, wrecks, and artificial reefs in the lower Delaware Bay.

The portion of the recreational tautog landings taken in Maryland has been relatively small in most years, with the exception of 1988 and 1994. Landings in Maryland increased from 5 mt in 1981 to a record high in 1988 of 203 mt. The fishery is active in the spring and autumn in Chesapeake Bay.

Recreational landings of tautog in Virginia have fluctuated from 123 mt in 1982 and 1992 to 640 in 1988. Catch in weight increased considerably in recent years (60% increase in 1993 and 42% increase in 1994 from the previous year). However, there was very little change in the estimated numbers of fish landed in 1994, which indicates that higher mean weight per fish occurs as the fishery moves offshore. There is some indication that the MRFSS tautog estimates in Virginia are underestimated because data are not collected during the first wave (January and February) when tautog is one of the few species available to recreational fishermen.

Recreational discards:

Estimates of the recreational tautog discard or fish released (type B2) gradually increased from 4,521 fish (1% of the total catch) in 1981 to 0.9 million fish (44% of the total catch) in 1993 (Table F10). Because of the lack of a minimum size for tautog in Virginia, and a small minimum size in New Jersey, the proportion of discarded fish was relatively low in recent years. However, between 50 and 79% of the tautog caught in Delaware and Maryland were discarded in 1993 and 1994.

Commercial landings:

Only a small portion of the commercial fleet in the southern region appears to target tautog during its spring and autumn migrations, with the exception of vessels in New Jersey. The region's commercial landings represent 4-6% of the total coastwide commercial landings of tautog. Most landings occurred in New Jersey, ranging from a low of 25 mt in 1981 to a high of 70 mt in 1993. This represents between 80% and 97% of the total region commercial landings (Table F11). Most tautog commercial landings in New Jersey and Maryland were from inshore pots and traps, while the majority of the catch in Delaware and Virginia occurred in the commercial hand-line fishery.

Seasonally, from 1981-1989, the majority of catch occurred in state waters at an average rate of about 70%. The inshore dominance of commercial landing declined from 95% of the total in 1983 to 56% in 1989, and reached a low of only 21% in 1993.

Commercial discards:

The NEFSC Sea Sampling Program conducted from 1989 to 1993 did not cover trips of the commercial fleet targeting tautog in the southern region. Therefore, discard rates for the commercial fisheries in this region are not currently available.

Total catch:

Estimates of the total catch of tautog are presented in Table F12. The total catch for 1981-1993 has been dominated by recreational landings, which averaged 85% of the total landings. Despite the small contribution of the commercial industry to the total landings of tautog in the southern region, total tautog landings in the southern region accounted for 30% of the coastwide landings in 1981, gradually increasing to 50% in 1993.

Sampling intensity and length frequencies:

Length frequencies of tautog were available only from the MRFSS data base and are presented in Figure F2. There is no evidence of size truncation during 1981-1993. The average range of size compositions was relatively wider than those in the northern region, ranging from 150 mm to 700 mm. Sampling intensity was very poor from 1981 to 1988, ranging from 100 lengths per 355 mt in 1986 to 100 lengths per 1,128 mt in 1983. Sampling intensified after 1988 and ranged from 100 lengths per 91 mt in 1990 to 100 lengths per 175 mt in 1991 (Table F14).

Recreational and Commercial Age Composition for the Northern Region

Year-specific age-length keys were available from the Connecticut trawl survey for 1984-1993, and from the Rhode Island trawl survey for 1987-1993. A significant discrepancy, due to the difference in the birth date convention, was observed between the Connecticut and Rhode Island keys. The two keys were subsequently adjusted according to the recommendations of a ASMFC tautog ageing workshop held in Connecticut on January 18, 1995.

The age-length keys used in this assessment were constructed using the following pooling approach:

1981-1983	Pooled Connecticut key (1984-1986)
1984-1987	Connecticut year specific key
1988-1993	Pooled Connecticut and Rhode Island keys by year

Because tautog is a slow-growing fish, seasonal age-length keys were not deemed necessary.

The recreational landings-at-age matrix was constructed for the northern region using the MRFSS estimates of total landings, "unweighted" MRFSS length frequencies, and the above pooled age-length keys. A 25% recreational discard mortality was assumed. Because length frequencies of the released fish were not available, a sample drawn from the New York recreational survey was used to partition discards into ages with the above year-specific pooled age-length keys.

Mean weights-at-age for the recreational landings were derived using the MRFSS length frequency data, the length-weight relationship developed with Rhode Island data, and the year-specific pooled age-length keys. Recreational landings in 1986 were more than twice as large as landings in adjacent years. Most of this increase occurred in Massachusetts and Rhode Island. The sudden increase seemed unreasonable for a long-lived species like tautog.

A commercial landings-at-age matrix was constructed using the NEFSC weighout landings partitioned into age categories using the year-specific pooled age-length keys from 1981 to 1993. Because of a lack of commercial length frequencies and the sparseness of sea sampling data, the MRFSS length frequencies were also applied to the commercial landings. Limited length frequencies collected by the NMFS Sea Sampling Program (1989-1993) showed that all landed fish were greater that 13 inches in length. However, the sample size was small and sampling consisted mostly of gillnet trips. An estimate of 13 inches minimum commercial size, based on market forces and/or regulatory minimum sizes, was assumed to follow the MRFSS length frequency for lengths ≥13 inches. Evidence of a 13-inch commercial cull point was also based on testimony received in public hearings in Rhode Island and Massachusetts prior to the development of a live market for tautog.

The total catch consisted of ages 2-15+ and was composed primarily of ages 3-7 . Fish at age 1 were insignificant and were not included in the final catch-at-age matrix. In 1990 and 1991, ages 3 and 4 accounted for more than 40% of the total catch. Mean weights were calculated using the following length-weight relationship:

$$W = 5.056 \cdot 10^{-8} \cdot L^{2.85}$$

Recreational and Commercial Age Composition for the Southern Region

The poor sampling intensity for MRFSS length frequencies coupled with a lack of age-length keys made it impossible to produce an age composition of the recreational and commercial landings of tautog for the southern region. As a result it was not possible to conduct an analytical assessment for that region.

Stock Abundance and Biomass Indices

Commercial LPUE

A general linear model (SAS 1993) of commercial otter trawl landings per unit effort (LPUE) was used to develop a standardized index for tautog in the northern region. Landings per day fished were calculated for all trips that landed tautog. The indices covered the period 1982-1993 for Southern New England. It was difficult to define a unit of effort in the otter trawl fishery since the catch proportions of tautog were very small and there was never a trip targeting tautog either as a primary or secondary species. The GLM included the effects of year, quarter, and area. The program default for standard cells was chosen. The effect of vessel class was not significant and was removed from the model. This was mainly due to the similarity in fishing power of the offshore vessels with the inshore vessels that caught tautog. The overall model explained 20% of the variance, with a high significance of the year, area, and quarter effects. Standardized commercial LPUEs for tautog for 1982-1993 exhibited a significant downward trend after 1984 (Figure F4).

Recreational LPUE

A general linear model was also applied to recreational landings and effort data in both the northern and southern regions. Two definitions of effort were examined: 1) all trips that landed tautog and 2) trips that only targeted tautog. Variables included were year, mode, state, and wave.

The model using the first trip definition explained about 31% of the variance for the northern region and about 51% in the southern region. Log-scaled indices of the recreational LPUEs are presented in Figure F5 for the two regions. There was no apparent trend in any of the standardized LPUEs from 1981 to 1993.

Using the second trip definition, LPUE trends for the two regions seem to follow similar trends from 1986 to 1994 (Figure F6). Data for 1982 and 1992 were not available and were.

Survey Indices

Abundance indices of tautog were calculated from several fishery-independent surveys conducted in the area from Massachusetts to Virginia and were examined for their utility in tuning the VPA conducted for the northern region. A linear regression was fit to abundance data for 6 surveys to calculate the rate of change in abundance over the period of 1984-1994. Regression slopes were all negative but highly variable ranging from -0.01 to -3.21. The rates of change for the three state surveys (MA, RI, and CT) were significantly high ranging from -86% for Connecticut to -118% in Massachusetts. Overall the abundance of tautog in the MA, RI, and CT area declined by as much as 99% over the period of 1984-1994 (Table F14).

NEFSC spring and autumn survey:

Catches of tautog in the NEFSC surveys from 1963 to 1994 were sparse and were insufficient to calculate indices of abundance.

Massachusetts Division of Marine Fisheries (MADMF) spring trawl survey:

The MADMF bottom trawl survey has been conducted within state waters since 1978. The strata used for developing an index of abundance for tautog were from portions of Buzzards Bay. Indices were high in 1984 and 1986 and then gradually decreased to low levels in the 1990s (Figure F7).

Rhode Island Division of Fish and Wildlife (RIDFW) trawl survey:

The RIDFW bottom trawl survey has been conducted in the spring and autumn in Narragansett Bay, Rhode Island Sound, and Block Island Sound since 1979. An annual stratified mean per tow was calculated from all areas to form an index of abundance for tautog. Despite the high variance in this index, a significant negative slope is evident from 1986 to 1994. The 1994 value was the lowest observed since 1979 (Figure F8).

University of Rhode Island (URI) trawl survey:

URI has conducted a weekly bottom trawl survey, year-around, at two fixed stations in Narragansett Bay since 1959. The index of abundance for tautog was calculated as an annual mean number per tow from 1959 to 1994. The index fluctuated between 20 and 60 fish per tow from 1959 to 1976, dropped to low levels in the 1980s, and declined further to the lowest level observed in the entire series in 1994 (Figure F9).

Rhode Island Power plant monitoring program:

A monthly trawl survey in remote areas of Mount Hope Bay has been conducted since 1972, generally catching juvenile tautog. A mean catch per tow was calculated showing high variation in the 1970s and 1980s and then dropping to low levels in the 1990s. The 1994 value was the lowest observed in this time series (Figure F10).

Connecticut Nuclear power plant monitoring program:

Information on tautog abundance was available from the Millstone Nuclear Power Station (MNPS) from 1977 to 1994. Triplicate bottom tows were conducted biweekly throughout the year using a 9.1-m otter trawl with a 0.6-cm codend liner. A delta mean of the catch per tow for tautog indicates a significant negative slope over the entire time series (Figure F11). The 1993-1994 catches were among the lowest recorded in the 18-year data series. In addition, the MNPS monitoring program also collected tautog eggs in the plankton samples since 1979. Egg densities dropped from 6.4 eggs/m^3

in 1986 and 1987, to 3.2 eggs/m^3 in 1993, and to 2.8 eggs/m^3 in 1994 (Anon. 1995).

Connecticut Department of Environmental Protection (CTDEP) trawl survey

The CTDEP trawl survey program began in 1984 and is based on a stratified random design covering all Long Island Sound waters. A spring index calculated for tautog shows a continuous decline since 1984. The three highest values in the series were observed in the beginning of the survey (1984-1986) and all subsequent values have fallen below the time-series mean (Figure F12).

New York Department of Environmental Conservation (NYDEC) small-mesh spring survey:

In 1985, the NYDEC began a small-mesh trawl survey in Peconic Bay to develop a recruitment index for weakfish. In 1987, the data collections were expanded to include all finfish species. Because of the short time series and high variance of the index for tautog, no apparent trend was observed (Figure F13).

New Jersey Division Fish, Game and Wildlife trawl survey:

The New Jersey trawl survey program has been collecting data continuously since August 1988. From 1988 through 1990, sampling cruises were performed once every two months starting in February. Beginning in December 1990, that survey and the one in February 1991 were discontinued and replaced with a single winter survey. This pattern has continued unchanged to the present using a stratified sampling design. The stratified mean catch per tow of tautog was calculated on an annual basis. During this relatively short time series, the index has remained fairly stable, with a high value in 1992 and low values in 1993 and 1994 (Figure F14).

Virginia Institute of Marine Science (VIMS) trawl survey:

The VIMS trawl survey began in 1955 aboard the R/V *Virginia Lee* with a simple fixed station transect from the mouth of Chesapeake Bay up the New York River to the freshwater interface. The monthly survey design was initiated in April 1956 to monitor blue crabs and the commercial finfish species in Virginia waters. Indices of abundance for tautog could not be calculated due to the limited number caught in this trawl survey (206 fish in 18,000 tows).

Life History Parameters

Natural mortality (M) was assumed to be 0.15 based on Hoenig (1983) who provided a table of estimated M values for 134 stocks of mollusks and crustacea using the following relationship:

$$\ln(z)=1.46 - 1.01 \cdot \ln(t_{max})$$

M was estimated by analogy to species like dusky shark and goosefish, reported to have a similar longevity to that of male tautog. Simpson (1989) estimated natural mortality for males to be 0.152 and for females to be 0.142 using the method of Pauly (1980), with L_∞=605 mm, K=0.159, and water temperature=12°C:

$$Log(M)=-0.0066-0.279 \cdot \log(L_\infty) + 0.6543 \cdot \log(K) + 0.4634 \cdot \log(T)$$

Tilefish is similar to tautog in longevity. A maximum life span of 35 years is cited along with M=0.15 for that species (Turner 1986). Redfish longevity is greater than 50 years, corresponding to M=0.05 (Mayo 1993). A natural mortality rate of 0.2 is used for Atlantic cod (Paloheimo and Koehler 1968), which has a lifespan of more than 20 years.

Another commonly used method to develop estimates of natural mortality is the 3/M rule, which generates an M=0.1 for a maximum age of 31 years. The commonly observed maximum age for tautog, aside from the catch records, is less than 30 years. Therefore, a higher M seems reasonable and, in fact, the above methods, approximating M=0.15, appear appropriate for this species. The Subcommittee agreed to use M=0.15 for tautog, both sexes combined.

A maturity ogive indicating 80% maturity at age 3 and 100% maturity at age 4+ was based on Chenoweth (1963). Spawning was assumed to occur on June 1. The proportion of natural mortality occurring prior to spawning was estimated to be 0.42 (153/365 days). The proportion of F occurring before spawning was estimated as the proportion of landings occurring during January-May to the total landings of the entire year (0.15).

Mortality and Stock Size Estimates

Separable VPA

A separable VPA was run for the northern region using ages 2-14 with a reference age of 8, selection at the terminal age 14 of 0.5, and a terminal fishing mortality rate of 0.7. The results were not affected measurably when changing the terminal F. Partial recruitment appeared to be dome-shaped with full recruitment at age 8. This pattern was evident even when the terminal selection was set to 1, forcing the selectivity to increase after age 11. Large residuals occurred between ages 2/3 and 3/4 in 1981/1982, 1986/1987, and 1987/1988. A terminal selection of 0.5 was chosen because it provided low final sum of squared residuals and a smooth dome-shaped selectivity pattern. The dome-shaped partial recruitment pattern was accepted (Table F15), with ages 4-12 (the top part of the dome) used for calculating an annual arithmetic mean F.

Estimates of Fishing Mortality from RI Tagging Data

Estimates of fishing mortality for tautog tagged in northern Narragansett Bay 9 in May and June of 1987-1992 by the Rhode Island Division of Fish and Wildlife were presented by Gibson (1995). The analysis was confined to releases from 1990 to 1992 which used internal anchor tags, recovered during 1990-1994. Tag loss rate from a captive retention study was used to correct apparent total mortality estimates. The instantaneous tag loss rate was 0.31 per year. A natural mortality rate of 0.15 was assumed. Tag returns were compiled from 1990-1994 by year of release. Estimates of survival rates were made using the framework of Brownie , et al, (1985) consisting of a hierarchal class of models which consider tag recoveries in sequential years following release to be multinomial random variables of numbers released, recovery rates, and survival probabilities. Model structure in terms of recovery rate and probability proceeds from most restrictive (no time dependence) to most general (time dependent parameters). Maximum likelihood methods are used to estimate parameters and provide a covariance matrix for the estimates. Goodness of fit and likelihood ratio testing are used to select the most parsimonious model which adequately reflects the data. The models estimate survival rates directly which transform into total mortality rate as Z=-ln(S).

In addition to fish tagged by the RIDFW, companion samples were retained for aging. Mortality rates from age structure data collected from 1987-1992 and in the 1960s were estimated by catch curve methods for comparative purposes. The slope of a regression of log (abundance) on time was taken as an estimate of the total mortality rate (Z) experienced by cohorts in the sample. Fishing mortality rate was estimated by subtracting M=0.15 from Z. The regression was constrained to ages on the descending limb of the catch curve exhibiting linearity.

A model which assumed time-dependent recovery, but constant survival, was selected as the best representation of the 1990-1994 tag data. The constant survival rate (S) was estimated at 0.31 per year with a standard error of 0.04. The period of inference for the survival estimate is from June 1990 to June 1992. Recovery rate (f) increased from 0.07 in 1990 to 0.12 in 1992. Precision on the recovery rate estimates was good, with CVs ranging from 0.12 to 0.15. The estimated survival rate corresponds to a total instantaneous mortality rate

(Z) of 1.17 (SE=0.12). Allowing for tag loss as estimated in the retention study and natural mortality losses, the fishing mortality rate was F=0.71. Assuming no uncertainty in the natural mortality and tag loss adjustments, a 95% confidence interval on F was 0.48-0.95.

Catch curves for the 1961-1963 and 1987-1992 tautog age-structure data indicated lower fishing mortality rates. For the early period, F was estimated to be 0.05. In the later data set, F was higher at 0.3. The period of inference for the catch curves was 1950-1960 and 1981-1986, respectively. The tag and catch curve methods indicate a rise in F from about 0.05 to 0.71 over three decades.

Estimates of Fishing Mortality Rates from Survey Catch Curves

Estimates of total mortality rates (Z) from survey catch curves were made for Massachusetts, Rhode Island, and Connecticut for three time series 1981-1983, 1984-1987, and 1988-1992 (Table F16). Total mortality rates were computed as the log ratio of pooled age 9+ to 8+ for each time series. Estimates ranged from 0.2 in 1981-1983 in MA to 0.95 in 1988-1992 in RI. Although the estimate of Z in Connecticut for 1988-1992 was low (0.3), the regional average of Z increased by about 93% from 1981-1983 to 1988-1992.

VPA Estimates of Fishing Mortality Rates

Three algorithms of the family of VPA tuning procedures were explored in the assessment of tautog in the northern region: 1) *ad hoc* VPA method, 2) Extended Survivors Analysis (XSA), and 3) ADAPT VPA tuning method.

The SARC decided not to include VPA results because of high uncertainty around estimates of stock size, spawning stock biomass, and recruitment. However, estimates of fishing mortality in the terminal year (1993) were retained by the SARC as a useful reference point in concert with estimates of F from tagging and catch curves. The estimator was 0.71 with a CV of 55%.

Precision of SSB and F Estimates

The precision of the 1993 F and SSB estimates from the VPA was evaluated using bootstrap techniques (Efron 1982). Two hundred bootstrap iterations were produced, in which errors (differences between predicted and observed survey values) were resampled. The bootstrap estimates of standard error associated with fishing mortality rates indicate relatively low precision. The CVs for the F estimates ranged from 21% at ages 13 and 14 to 59% at age 11. The bootstrapped estimate of the mean fishing mortality rate in 1993 was 0.71, with a bootstrapped standard error of 0.30 and CV of 55%. This analysis indicated no likelihood of the F in 1993 being below 0.5 (Figure F15).

Bootstrapped estimates of spawning stock biomass are not presented in this document because of high uncertainty of SSB estimates from the VPA.

Biological Reference Points

To examine the relationship between long-term yield and fishing mortality, yield per recruit for a range of fishing mortalities was calculated using the Thompson-Bell model (1934). An maximum age of 15+ years was used in the model. The partial recruitment vector used was that derived from the separable VPA output. Mean weights at age in the spawning stock and catch were taken from catch data and averaged over the last 5 years. The proportions mature at age were obtained from Chenoweth (1963). Natural mortality was assumed to be 0.15.

The analysis indicated $F_{0.1}$=0.13, $F_{30\%}$=0.24, and F_{MAX}=0.28 (Table 17). At F_{MAX}, about 27% of the maximum spawning potential (%MSP) is obtained, while at $F_{0.1}$, 44% of %MSP is obtained (Figure 16).

Overfishing definitions have not yet been developed for tautog, although the $F_{0.1}$ and $F_{30\%}$ and reference points have been proposed to the ASMFC Tautog Technical Committee.

Projections of Catch and Stock Biomass

A quantitative forecast of catch and SSB for tautog in the northern region for 1994 and 1995 was not done because of the high degree of uncertainty in the current estimates of fishing mortality and stock size. However, the results of the VPA indicate that, in the absence of greatly improved recruitment, stock size and catch will continue to decline.

Summary and Conclusion

Although there is evidence suggesting the existence of numerous small discrete stocks of tautog along the coast between Cape Cod and Virginia, it was impossible to assemble data and perform assessments for individual stocks. Consequently, it was decided to group these stocks into northern (Massachusetts - New York) and southern (New Jersey - Virginia) units for the purposes of assessment and management.

Lack of age-length data for the southern region made it impossible to conduct an age-based assessment for that area. When age-length keys from Virginia are completed, an age-based analytical assessment, as performed for the northern region, may be possible for tautog in the southern region.

The tautog resource in the Massachusetts - New York area has declined steadily in abundance to current record low levels. This decline is documented by virtually every state trawl survey as well as by commercial otter trawl LPUE. VPA results also indicate a sharp decline in abundance. Fishing mortality has increased steadily since 1981 to a record high in 1993. Tag return data from Rhode Island indicate an order of magnitude increase in fishing mortality over three decades. The estimate of F in 1993 from the VPA was well above any of the biological reference points determined from yield-per-recruit analysis.

Although there is considerable uncertainty associated with the estimates of fishing mortality presented in this assessment, there is sufficient evidence to conclude that the tautog resource in the northern region is at a very reduced level of abundance and is in an overfished condition. Continued exploitation at current rates will, in light of the low stock level and recent decline in recruitment, lead to a further decrease in SSB and the eventual collapse of the resource.

SARC Comments

In the discussion of catch data sources, the SARC noted that the 1986 recreational catch estimate from the MRFSS seems high relative to other years and that other species have similarly anomalous estimates of recreational catch in 1986. There is currently no adequate explanation for this phenomenon.

The LPUE standardization exercise was determined to be lacking in that there were to many factor levels relative to the available degree of freedom. This led to biased year effect estimates. The SARC recommended aggregation of data prior to standardization.

Large differences in terminal stock size estimates between the Extended Survivors Analysis (ESA) and the ADAPT formulation were noted. Given the lack of diagnostics, no further consideration was given to the ESA output.

Problems with the catch-at-age data used in the tautog assessment were raised. The SARC noted that sampling of recreational length frequencies was poor in early years. Concern was expressed over the application of a single survey-based age-length key (CT) to both fishery catch and survey data. There was extended discussion on the problems associated with mixing and pooling of keys particularly with regard to the problem of age smearing. Also, sampling of small fish in Connecticut was limited to recent years and data were sparse for older ages. Pooling of age groups and use of iterated age-length key methods were suggested as ways to improve the catch-at-age estimation.

The SARC wondered if the ADAPT run showing falling SSB and rising F after 1986 was an artifact of the high 1986 MRFSS estimate of recreational catch. The SARC also discussed the impact of an assumed flat-topped PR pattern in the ADAPT run if in fact the PR pattern was domed-shaped. It was determined that the separable VPA analysis was limited in its ability to verify a domed pattern and assumption of this condition should be made on the basis of external information. The SARC noted that a domed shaped pattern could be an artifact due to smearing in the catch-at-age matrix. Anecdotal information from divers may support a domed-shaped PR as do behavioral traits of the labrids.

Given the problems identified with the ADAPT analysis, it was suggested that the survey indices and tagging study be emphasized in support of the ADAPT analysis. Also, more detail on the survey indices was requested, particularly timing of the survey relative to tautog migratory movements. Constructing a correlation analysis to judge coherency in the various indices would be useful. Shrinking the plus group from 15+ to 10+ was also suggested.

An extended discussion occurred over whether to go forward with the ADAPT results given the identified problems. One opinion was that the VPA results could go forward with appropriate caveats to provide estimates of current F and biological reference points.

Rejecting the VPA analysis was favored by a second group. Uncertainty, particularly that not accounted for by bootstrapping, was considered too high.

No suggestions were made for alternative assessment methods including length based analyses and catch curve approaches. The SARC decided that insufficient time remained for new analyses and rejected the tautog VPA. The SARC requested further analysis of survey indices and revisions to the YPR and SSB/R runs using assumed PR patterns and corrections to catch weights.

With regard to the survey based catch curve estimates of Z, the SARC requested that the indices be pooled over several time periods to provide larger sample size for the analysis.

While reviewing the YPR and SSB/R analyses, questions were raised about the source of mean weights-at-age and the effect of changing from a domed PR to a flat-topped PR pattern. There was concern about rejecting a VPA but using the estimated PR pattern for reference point estimation.

The SARC decided to use the terminal year mortality estimates with bootstrapping from the VPA along with catch curve analyses from fishery independent survey indices, tagging data, and reference points. Given the rejection of the VPA results, conclusions about stock size, recruitment, spawning stock biomass and projections were not made.

The SARC concluded that the preponderance of evidence from various sources including declining trends in fishery independent indices of biomass, catch curve analyses, tagging analysis, and VPA analysis indicates that the stock abundance in the Massachusetts to New York area has declined drastically and is at an extremely low level. There has been an apparent increase in fishing mortality, and fishing appears to be well above any reasonable biological reference point (F_{MAX}, $F_{0.1}$) for this long lived and slow growing species. Fishing mortality rates need to be reduced immediately.

Research Recommendations

- Sample hard parts for ageing from the catches of the recreational fishery and fishery independent surveys throughout the range of the stock.
- Initiate biological sampling of the commercial catch over the entire range of the stock.

- o Investigate the underlying causes of the high 1986 catch estimate from MRFSS.
- o Conduct stock discrimination studies.
- o Study the hooking mortality on discarded tautog taken in the recreational fishery.
- o Investigate the reasons for the apparent dome-shaped partial recruitment pattern.
- o Consider timing the geographic coverage/extent of surveys to assist in deciding which indices to include in tuning.
- o Try non-age-based assessment techniques (e.g., DeLury method), or a stage-based method where ranges of age classes are grouped together. Other possibilities include length-based analyses and catch-curve approaches.
- o In ADAPT VPA, try using iterated age-length keys and shrinking the plus-group to age 10+ rather than 15+.

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Table F1: Recreational landings (in metric tons) by year and state for the northern region 1981-1994.

Years	Massachusetts	Rhode Island	Connecticut	New York	Total Northern Region
1981	359	301	110	679	1449
198	1464	329	277	760	2830
1983	833	279	208	510	1830
1984	333	821	333	246	1733
1985	149	126	214	923	1412
1986	3566	927	380	1285	6158
1987	795	230	502	1038	2565
1988	1023	278	277	1080	2658
1989	488	135	471	462	1556
1990	406	177	91	898	1572
1991	362	457	294	1067	2180
1992	757	298	476	544	2075
1993	286	172	200	715	1373
1994	160	143	181	120	604

Table F2: Estimated numbers of tautog landed in the recreational fisheries by year and state for the northern region 1981-1994 (**A+B1**).

Years	Massachusetts	Rhode Island	Connecticut	New York	Total Northern Region
1981	228736	233508	100308	721062	1283614
1982	1051022	214938	231187	646693	2143840
1983	670508	245796	200676	612163	1729143
1984	258256	490128	287470	286077	1321931
1985	100941	115404	182318	1105234	1503897
1986	1980719	671592	333396	1183114	4168821
1987	617068	130729	312430	929887	1990114
1988	621679	207799	234198	828183	1891859
1989	250077	116506	303782	562549	1232914
1990	233444	153433	75871	953622	1416370
1991	176905	291946	191137	871221	1531209
1992	357949	193786	319221	413236	1284192
1993	182145	115616	149879	457272	904912
1994	78451	82412	146402	187937	495202

Table F3: Estimated numbers of tautog caught and released (MRFSS type **B2** fish) by year and state for the northern region 1981-1994.

	Massachusetts	Rhode Island	Connecticut	New York	Total Northern Region
1981	1153	26806	3780	341706	373445
1982	16583	19764	11952	148454	196753
1983	113536	46703	80802	276104	517145
1984	99633	165325	69881	253821	588660
1985	28387	19917	46011	545460	639775
1986	425840	10853	34026	402949	873668
1987	167396	37570	46981	746021	997968
1988	178903	82792	159775	445264	866734
1989	45042	31818	121778	436938	635576
1990	54935	62433	44805	568868	731041
1991	73892	105955	135700	1083037	1398584
1992	28954	72471	268382	519743	889550
1993	57784	48633	72324	793361	972102
1994	219589	62687	134166	352518	768960

Table F4: Commercial landings of tautog in metric tons by year and state in the northern region 1981-1993. (Massachusetts-New York)

Year	Massahusetts	Rhode Island	Connecticut	New York	Total Northern Region
1981	46.7	31.7	9.3	36.9	124.6
1982	31.4	39.1	9.6	41	121.1
1983	26.1	64.7	15.2	40.1	146.1
1984	30.9	151.8	14.8	46.5	244
1985	28.7	182.9	22.6	38.3	272.5
1986	75.2	164.7	47.1	91.3	378.3
1987	113.4	190.7	72.2	102.2	478.5
1988	125.7	149.2	50.8	115.7	441.4
1989	159.9	97.5	45.2	129.5	432.1
1990	131.1	95.7	37.2	82.3	346.3
1991	160.7	168.6	24.5	102.7	456.5
1992	132.6	163.2	29.8	76.7	402.3
1993	72.7	91.4	20	40.6	224.7

Table F5: Commercial discard estimates for trawl and gillnet fisheries from Massachusetts to New York (1989-1993)

	Otter trawl		Gillnet	
	% Discard	% Kept	% Discard	% Kept
1989	5.77%	94.23%	0%	100%
1990	3.04%	96.96%	0.63%	99.37%
1991	2.12%	97.88%	1.89%	98.11%
1992	2.34%	97.66%	0.65%	99.35%
1993	0	100%	3.58%	96.42%
ALL	**3.90%**	**96.10%**	**1.63%**	**98.37%**

Table F6: Total landings (recreational and commercial) of tautog in the northern region (Massachusetts-New York) 1981-1994

Years	Recreational landings (mt)	Commercial landings (mt)	% Commercial	Total landings Metric-tons
1981	1449	124.6	0.086	1573.6
1982	2830	121.1	0.0409	2951.1
1983	1830	146.1	0.0735	1976.1
1984	1733	244	0.1231	1977
1985	1412	272.2	0.1617	1684.2
1986	6158	378.3	0.0578	6536.3
1987	2565	478.5	0.1571	3043.5
1988	2658	441.4	0.1423	3099.4
1989	1556	432.1	0.2169	1988.1
1990	1572	346.3	0.1801	1918.3
1991	2180	456.5	0.1729	2636.5
1992	2075	402.3	0.1624	2477.3
1993	1373	224.7	0.108	1597.7
1994	604	125		729

Table F7: Summary of sampling intensity (SI) in the northern region by the MRFSS (1981-1993).

SI < 100 = significant sample size
100 < SI < 200 = good sample size
SI > 200 = poor sample size

Years	Number of lengths	Recreational landings (A+B1 in mt)	Sampling intensity (mt/100 lgths)
1981	331	1452	438
1982	539	2836	526
1983	528	1835	347
1984	433	1736	400
1985	255	1414	554
1986	1484	6171	416
1987	547	2570	470
1988	766	2663	347
1989	1890	1559	82
1990	1775	1575	89
1991	1445	2185	151
1992	1225	2079	170
1993	1170	1378	118

Table F8: Recreational landings (in metric tons) of tautog by year and state for the southern region 1981-1994.

Years	New Jersey	Delaware	Maryland	Virginia	Total Southern Region
1981	73	3	5	337	418
1982	563	194	41	123	921
1983	188	2	3	575	768
1984	325	43	36	304	708
1985	336	66	0.5	136	538.5
1986	967	120	5	416	1508
1987	967	176	121	201	1465
1988	604	113	203	640	1560
1989	585	337	36	366	1324
1990	570	65	27	104	766
1991	993	161	48	281	1483
1992	1128	83	73	116	1400
1993	547	87	50	291	975
1994	124	68	95	502	789

Table F9: Estimated numbers of tautog landed in the Recreational fisheries by year and state for the southern region 1981-1994 (**A+B1**).

Years	New Jersey	Delaware	Maryland	Virginia	Total Southern Region
1981	132271	3457	4670	236768	377166
1982	583550	137328	35105	71599	827582
1983	344580	4350	2126	579795	930851
1984	516086	28389	42835	207192	794502
1985	840627	62001	486	91957	995071
1986	2369852	141290	5476	322905	2839523
1987	1015123	99706	90523	126783	1332135
1988	564286	94491	107570	368320	1134667
1989	710958	249928	34709	284477	1280072
1990	841770	61526	45467	111998	1060761
1991	1067284	128985	26770	168068	1391107
1992	1018205	68769	106255	100952	1294181
1993	695025	74492	65017	255390	1089924
1994	695025	65798	158424	255345	1174592

Table F10: Estimated numbers of tautog caught and released (MRFSS type B2 fish) by year and state for the southern region 1981-1994.

Years	New Jersey	Delaware	Maryland	Virginia	Total Southern Region
1981	1748	751	0	2022	4521
1982	76125	19720	0	290	96135
1983	92183	2015	0	64989	159187
1984	25011	486	24126	9680	59303
1985	39947	342	408	36266	76963
1986	120395	64739	3849	39971	228954
1987	314804	3216	46556	43231	407807
1988	263062	7484	18347	85069	373962
1989	268629	92705	33562	34241	429137
1990	371216	24064	35933	75297	506510
1991	656928	70830	17536	112752	858046
1992	513908	59624	86638	57707	717877
1993	399182	214840	171888	86348	872258
1994	215347	255295	163468	57033	691143

Table F11: Commercial landings of tautog in metric tons by year and state in the southern region 1981-1993. (New Jersey-Virginia)

Years	New Jersey	Delaware	Maryland	Virginia	Total Southern Region
1981	24.7	0.5	0.5	0.3	26
1982	67.2	0.4	0	1.2	68.8
1983	45.6	0.4	0	0.8	46.8
1984	58.8	0.6	1.2	0.5	61.1
1985	56.9	1.5	1.1	0.7	60.2
1986	45.7	0.1	1.2	0.8	47.8
1987	43.2	0.2	1.7	1.2	46.3
1988	39.9	0.3	2.8	1.3	44.3
1989	23.5	0.01	1.8	3.4	28.71
1990	45.1	0.2	2.1	2.3	49.7
1991	42.2	0.6	1.4	2.3	46.5
1992	52.8	0.1	1.8	2.01	56.71
1993	69.6	0.1	0.6	1.2	71.5

Table F12: Total landings (recreational and commercial) of tautog in the southern region (New Jersey-Virginia) 1981-1994

Years	Recreational landings (mt)	Commercial landings (mt)	% Commercial	Total landings Metric-tons
1981	418	26	0.0631	444
1982	922	68.8	0.0743	992
1983	768	46.8	0.0609	816
1984	708	61.1	0.0864	771
1985	538	60.2	0.1116	599
1986	1508	47.8	0.0317	1560
1987	1465	46.3	0.0633	1513
1988	1560	44.3	0.0284	1607
1989	1323	28.7	0.0217	1355
1990	766	49.7	0.0648	817
1991	1483	46.5	0.0314	1533
1992	1400	56.7	0.0405	1459
1993	975	71.5	0.0734	1049
1994	789	79.4	0.1006	868

Table F13: Summary of sampling intensity (SI) in the southern region by the MRFSS (1981-1993).

SI < 100 = significant sample size
100 < SI < 200 = good sample size
SI > 200 = poor sample size

Years	Number of lengths	Recreational landings (A+B1 in mt)	Sampling intensity (mt/100 lgths)
1981	68	418	616
1982	225	930	413
1983	69	778	1128
1984	90	709	788
1985	93	542	583
1986	426	1513	355
1987	256	1470	574
1988	293	1565	534
1989	764	1340	175
1990	844	768	91
1991	861	1497	173
1992	981	1408	143
1993	665	981	147

Table F14: Rates of change in tautog abundance from trawl surveys of Massachusetts, Rhode Island, and Connecticut for the period of time 1984-1994.

Survey	Intercept	Slope	R_square	Pred_84	Pred_94	% change
Massachusetts	30.33	-3.21	0.69	27.12	-4.98	-118.36
Rhode Island	1.57	-0.13	0.67	1.44	0.10	-92.86
Connecticut	2.03	-0.16	0.60	1.87	0.27	-85.56
Mean all...>						-98.92%

Table F15: Separable VPA for the northern region's tautog (Massachusetts-New York)from 1981 to 1993 on ages 2 to 14 with Terminal F of 0.7 on age 8 and Terminal S of 0.5 Initial sum of squared residuals was 205.425 and final sum of squared residuals is 40.749 after 60 iterations

Matrix of Residuals

Years, Ages	1981/82,	1982/83,
2/ 3,	2.833,	-.441,
3/ 4,	1.420,	-.411,
4/ 5,	.751,	-.126,
5/ 6,	.253,	-.197,
6/ 7,	.075,	-.085,
7/ 8,	.059,	.161,
8/ 9,	-.332,	.079,
9/10,	-.734,	.028,
10/11,	-.760,	.275,
11/12,	-1.179,	.170,
12/13,	-1.034,	.400,
13/14,	-1.351,	.149,
TOT ,	.000,	.000,
WTS ,	.001,	.001,

Years,	1983/84,	1984/85,	1985/86,	1986/87,	1987/88,	1988/89,	1989/90,	1990/91,	1991/92,	1992/93,	TOT,	WTS,
2/ 3,	.387,	.398,	.249,	1.126,	1.622,	-.089,	-.392,	-.078,	.207,	.345,	.000,	1.000,
3/ 4,	.359,	-.024,	.334,	1.437,	.924,	-1.084,	-.160,	.220,	.695,	.324,	-.001,	1.000,
4/ 5,	.043,	.019,	.172,	-.409,	-.022,	-.689,	-.146,	.271,	.441,	.123,	.000,	1.000,
5/ 6,	-.056,	.216,	-.374,	-.297,	.206,	-.001,	-.229,	.304,	.176,	-.249,	.001,	1.000,
6/ 7,	-.036,	-.031,	-.666,	-.220,	-.261,	-.365,	.009,	.551,	.129,	-.322,	.001,	1.000,
7/ 8,	.338,	.037,	-.057,	-.032,	.040,	.532,	-.163,	-.073,	-.183,	-.113,	.001,	1.000,
8/ 9,	-.087,	-.316,	-.330,	-.648,	-.464,	.372,	-.135,	.199,	.005,	-.439,	.000,	1.000,
9/10,	-.604,	-.338,	-.079,	-.107,	-.503,	.571,	.472,	-.617,	-.045,	-.379,	.000,	1.000,
10/11,	.566,	.140,	-.122,	-.127,	-.248,	.820,	-.205,	-1.073,	.287,	.171,	.000,	1.000,
11/12,	-.462,	-.849,	.426,	.040,	-.693,	-.070,	-.131,	.634,	-.247,	-.184,	.000,	1.000,
12/13,	-.094,	.624,	.589,	-.334,	-.201,	.088,	.345,	-.059,	-.743,	.369,	.001,	1.000,
13/14,	-.355,	.125,	-.141,	-.429,	-.398,	-.083,	.736,	-.281,	-.722,	.354,	.001,	1.000,
TOT ,	.001,	.001,	.001,	.001,	.001,	.001,	.000,	.000,	.000,	.000,	.006,	
WTS ,	.001,	.001,	.001,	.001,	.001,	1.000,	1.000,	1.000,	1.000,	1.000,		

Fishing Mortalities (F)

Years ,	1981,	1982,	1983,	1984,	1985,	1986,	1987,	1988,	1989,	1990,	1991,	1992,	1993,
F-values,	.16	,.34	,.30	,.26	,.30	,.63	,.47	,.51	,.40	,.38	,.57	,.74	,.70 ,

Selection-at-age (S)

Ages ,	2,	3,	4,	5,	6,	7,	8,	9,	10,	11,	12,	13,	14,
S-values,	.018	,.140	,.391	,.607	,.754	,.796	,1.00	,.966	,.711	,.618	,.535	,.540	,.500 ,

Table 16: Tautog mortality estimates from trawl survey indices computed as the log of ratio of pooled age 9+ to age 8+ for three time series.
(example: for 1981-1983= $\log(9+_{1982\text{-}84}/8+_{1981\text{-}83})$)

Year/State	Massachusetts	Rhode Island	Connecticut	Mean
1981-1983	0.2	0.4	n/a	0.3
1984-1987	0.35	0.45	0.57	0.46
1988-1992	0.50	0.95	0.3	0.58

Table F17: Yield and stock size per recruit analysis for the northern region's tautog (MA-NY).

Proportion of F before spawning: .1500
Proportion of M before spawning: .4200
Natural Mortality is Constant at: .150
Initial age is: 1; Last age is: 15
Last age is a PLUS group;

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Stock	Average Weights Catch
1	.0000	1.0000	.0000	.070	.070
2	.0180	1.0000	.0000	.210	.210
3	.1400	1.0000	.8000	.348	.348
4	.3910	1.0000	1.0000	.547	.547
5	.6070	1.0000	1.0000	.708	.708
6	.7540	1.0000	1.0000	.832	.832
7	.7960	1.0000	1.0000	1.080	1.080
8	1.0000	1.0000	1.0000	1.261	1.261
9	1.0000	1.0000	1.0000	1.617	1.617
10	1.0000	1.0000	1.0000	2.190	2.190
11	1.0000	1.0000	1.0000	2.355	2.355
12	1.0000	1.0000	1.0000	2.524	2.524
13	1.0000	1.0000	1.0000	2.568	2.568
14	1.0000	1.0000	1.0000	2.846	2.846
15+	1.0000	1.0000	1.0000	3.519	3.519

Summary of Yield per Recruit Analysis for:
TAUTOG YIELD PER RECRUIT

Slope of the Yield/Recruit Curve at F=0.00: --> 6.9507
F level at slope=1/10 of the above slope (F0.1): -----> .134
Yield/Recruit corresponding to F0.1: -----> .3541
F level to produce Maximum Yield/Recruit (Fmax): -----> .279
Yield/Recruit corresponding to Fmax: -----> .3885
F level at 30 % of Max Spawning Potential (F30): -----> .243
SSB/Recruit corresponding to F30: --------> 2.3106

Listing of Yield per Recruit Results for:
TAUTOG - FPAT AND MAT VECTORS

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	7.1792	8.4746	4.8546	7.7040	100.00
	.100	.22086	.32217	5.7109	4.5757	3.4422	3.9927	51.83
F0.1	.134	.26196	.35415	5.4383	3.9541	3.1796	3.4035	44.18
	.200	.32049	.38165	5.0505	3.1490	2.8058	2.6419	34.29
Fmax	.279	.36892	.38848	4.7303	2.5650	2.4968	2.0913	27.15
F30%	.243	.34880	.38732	4.8632	2.7979	2.6251	2.3107	29.99
	.300	.37908	.38822	4.6631	2.4527	2.4320	1.9856	25.77
	.400	.41862	.38233	4.4025	2.0516	2.1801	1.6085	20.88
	.500	.44763	.37404	4.2118	1.7935	1.9955	1.3664	17.74
	.600	.47012	.36601	4.0644	1.6138	1.8526	1.1981	15.55
	.700	.48825	.35891	3.9458	1.4814	1.7375	1.0740	13.94
	.800	.50331	.35276	3.8476	1.3793	1.6421	.9785	12.70
	.900	.51609	.34744	3.7645	1.2980	1.5612	.9024	11.71
	1.000	.52714	.34280	3.6928	1.2314	1.4914	.8400	10.90
	1.100	.53682	.33871	3.6301	1.1756	1.4304	.7878	10.23
	1.200	.54540	.33505	3.5746	1.1281	1.3763	.7432	9.65
	1.300	.55309	.33175	3.5251	1.0870	1.3279	.7047	9.15
	1.400	.56004	.32874	3.4804	1.0511	1.2843	.6710	8.71
	1.500	.56636	.32596	3.4398	1.0192	1.2446	.6412	8.32
	1.600	.57215	.32338	3.4027	.9908	1.2084	.6145	7.98
	1.700	.57747	.32096	3.3686	.9652	1.1750	.5905	7.66
	1.800	.58240	.31869	3.3372	.9420	1.1442	.5688	7.38
	1.900	.58699	.31653	3.3079	.9209	1.1156	.5489	7.13
	2.000	.59126	.31449	3.2807	.9015	1.0890	.5308	6.89

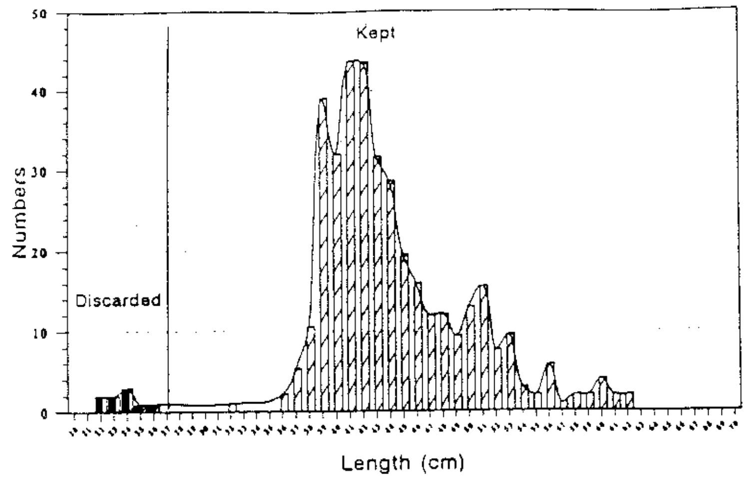

Figure F1. Length frequency distribution of discarded and kept tautog NMFS-Sea Sampling Data (1989-1993), gears and areas combined.

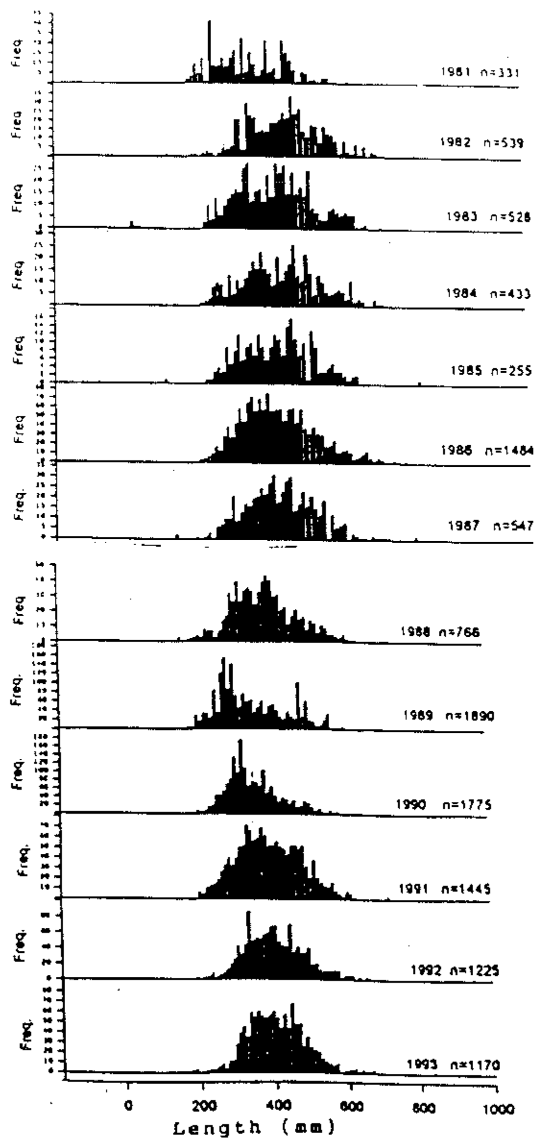

Figure F2. MRFSS/Length Frequency of tautog/region 1 (MA-RI-CT-NY).

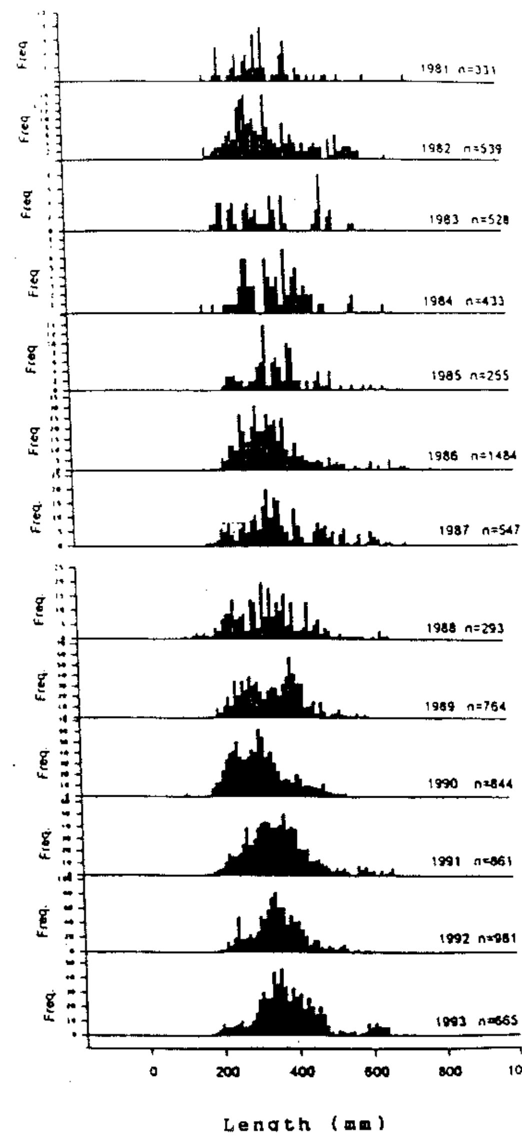

Figure F3. MRFSS/Length Frequency of Tautog/Region 2 (NJ-DE-MD-VA).

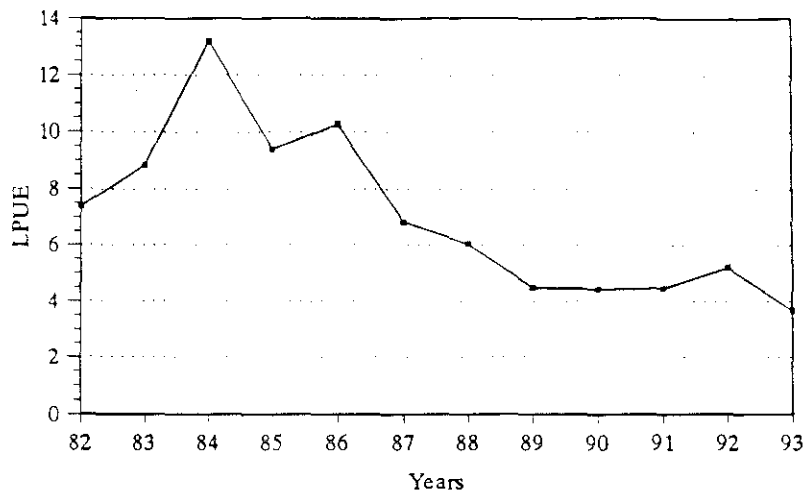

Figure F4. Commercial standardized LPUE for the northern regions tautog (MA-NY), 1982-1993.

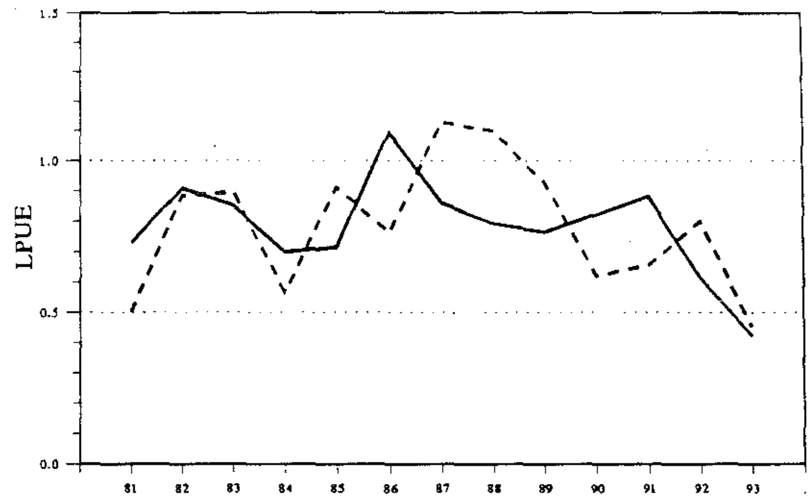

Figure F5. Recreational standardized LPUE for northern and southern regions tautog. All trips that landed tautog.

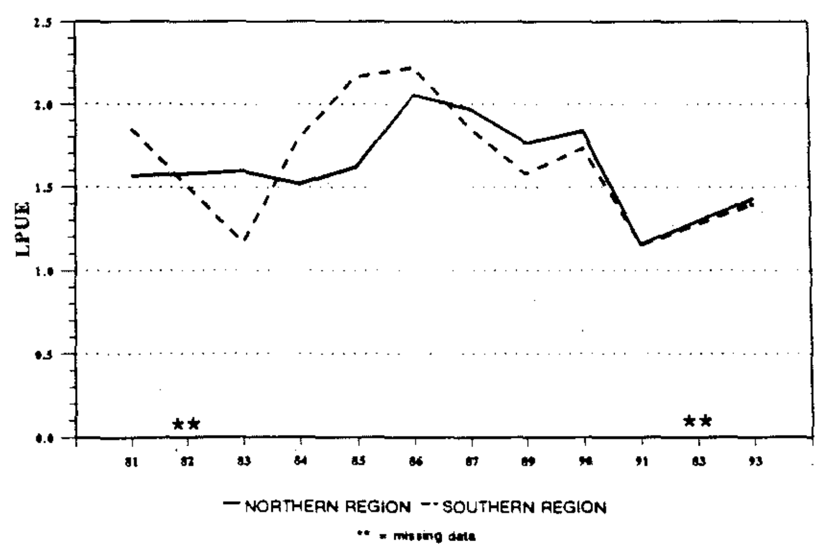

Figure F6. Recreational standardized LPUE for northern and southern regions tautog.

Figure F7. Mean catch per tow of tautog, MA bottom trawl survey (1979-1993).

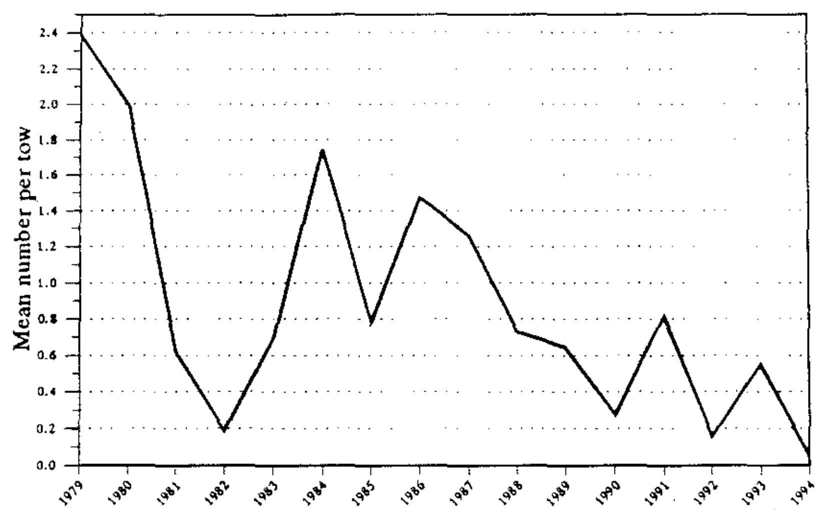

Figure F8. Mean catch per tow of tautog, RI trawl survey (1978-1994).

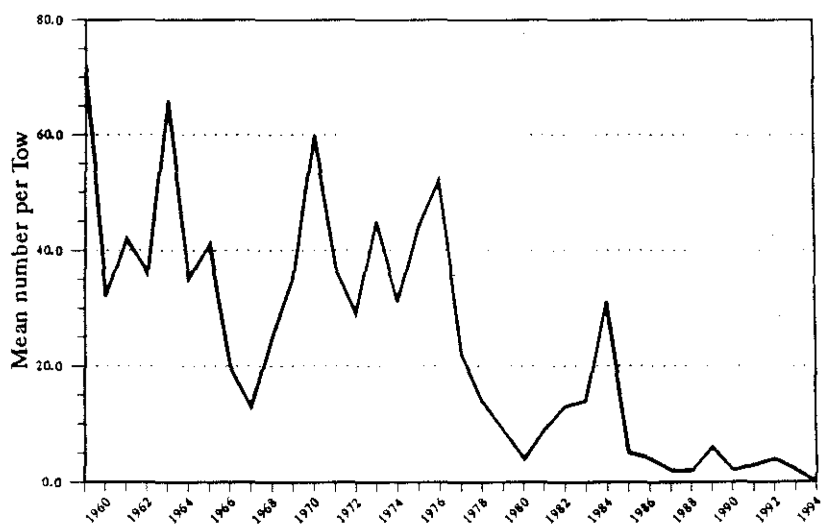

Figure F9. Mean catch per tow of tautog, URI bottom trawl survey (1959-1994).

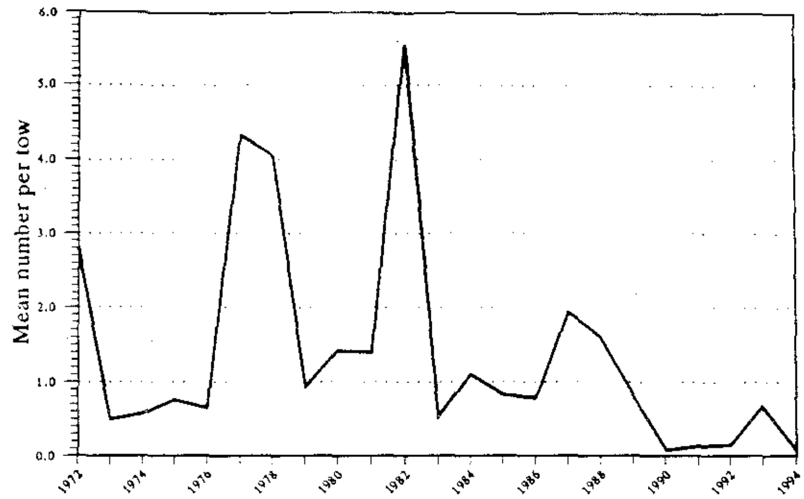

Figure F10. Mean catch per tow , Mount Hope Bay (RI) monitoring program (1972-1994).

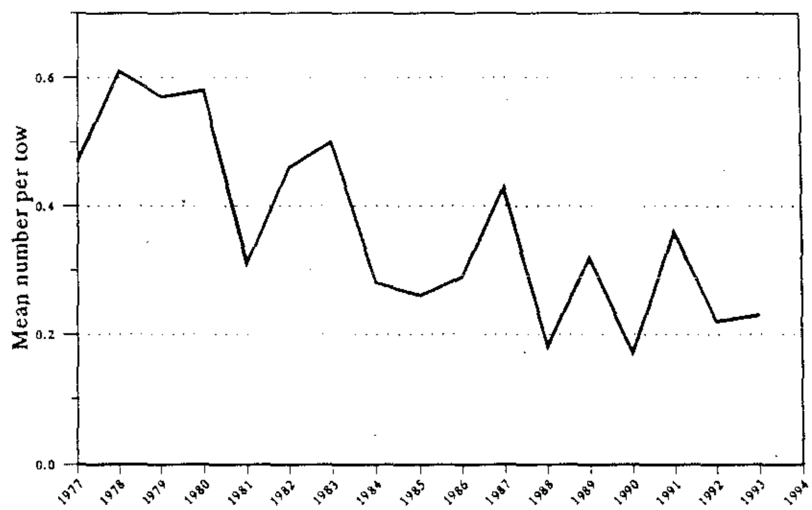

Figure F11. Mean catch per tow of tautog, Millstone Power Plant (CT) monitoring program (1977-1993).

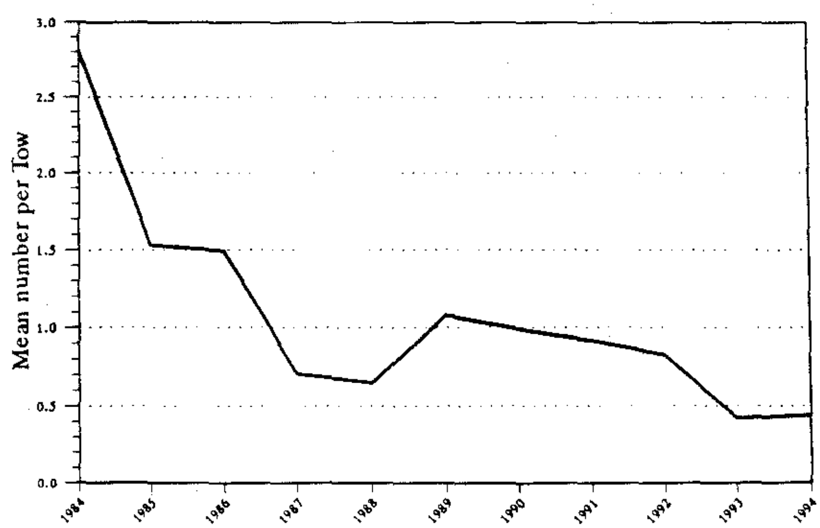

Figure F12. Mean catch per tow of tautog, CT bottom trawl survey (1984-1993).

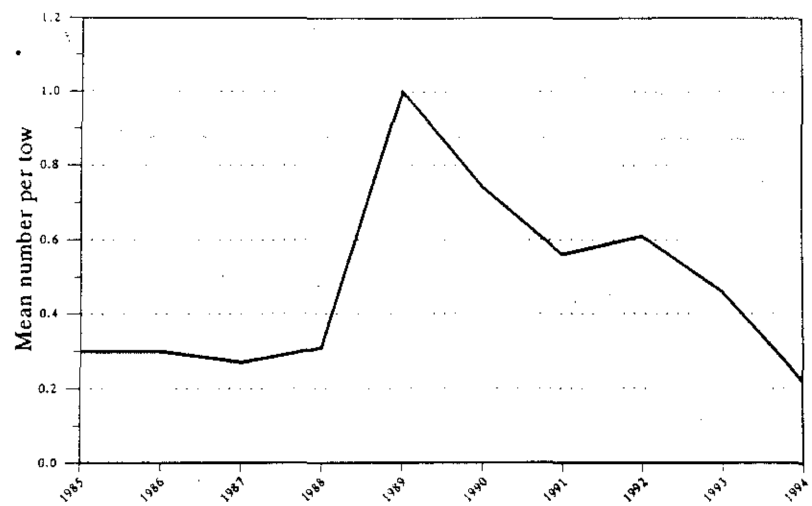

Figure F13. Mean catch per tow of tautog, NY bottom trawl survey (1985-1993).

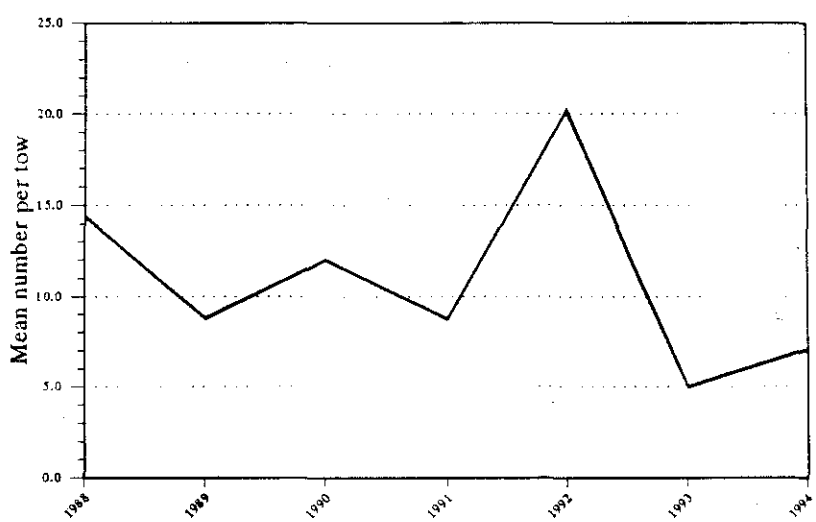

Figure F14. Mean catch per tow of tautog NJ bottom trawl survey (1988-1993).

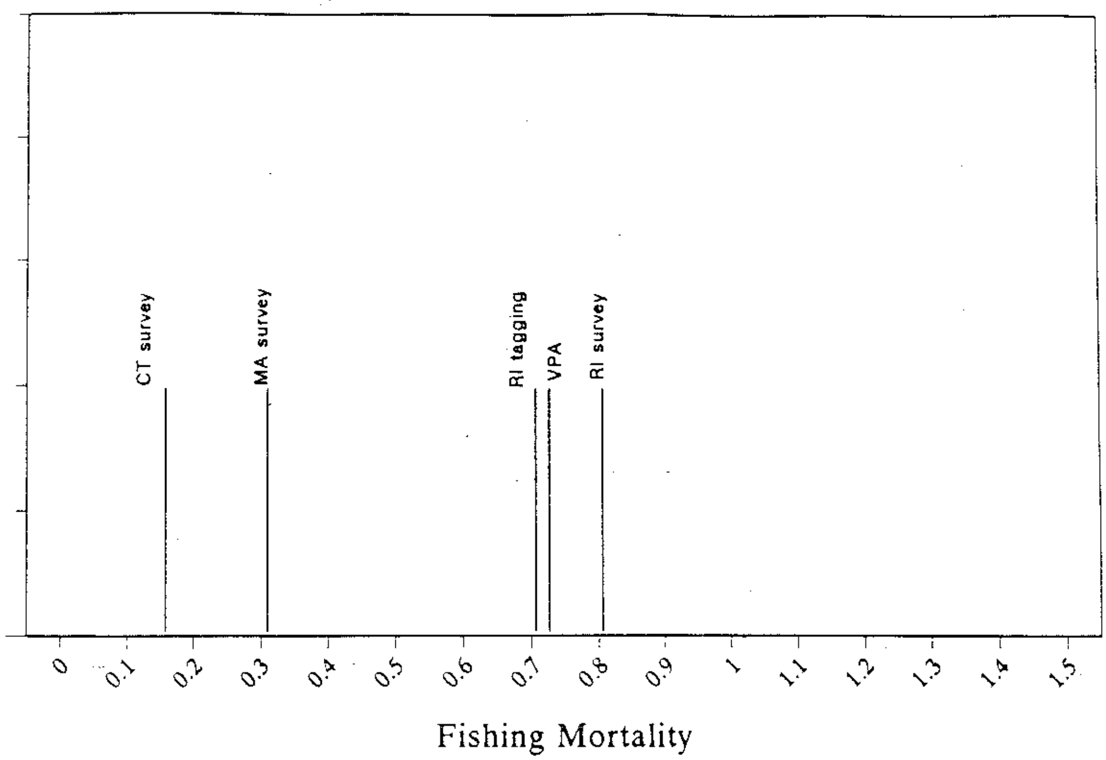

Figure F15. Point estimates of tautog fishing mortality rates from VPA, RI tagging data and MA, RI, and CT trawl surveys.

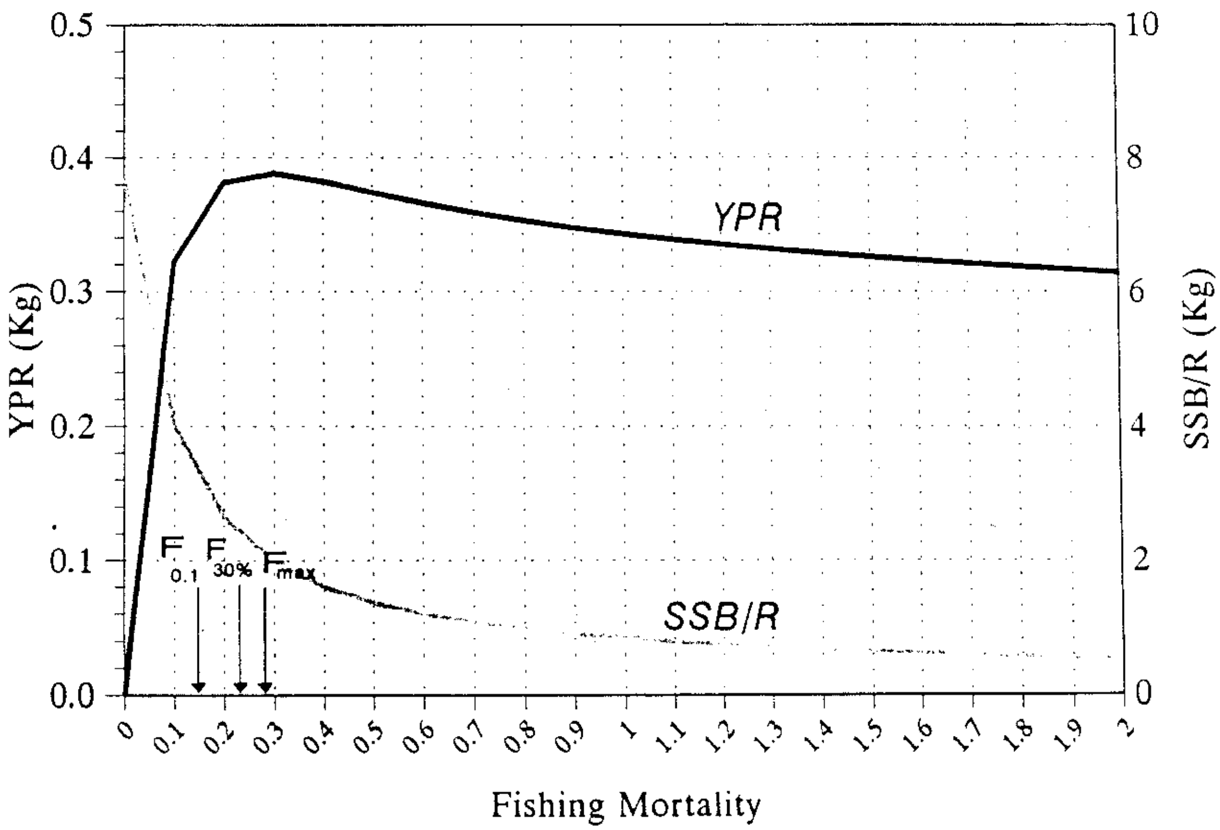

Figure F16. Tautog yield and spawning stock biomass per recruit (M=0.15).