Northeast Fisheries Science Center Reference Document 01-18

33rd Northeast Regional Stock Assessment Workshop (33rd SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

December 2001

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01-12 **Northeast Fisheries Science Center Publications, Reports, and Abstracts for Calendar Year 2000.** By L. Garner and J.A. Gibson. August 2001.

01-13 **Elemental Composition of Fish Otoliths: Results of a Laboratory Intercomparison Exercise.** By V.S. Zdanowicz. September 2001.

01-14 **Identification of Seasonal Area Management Zones for North Atlantic Right Whale Conservation.** By R.L. Merrick, P.J. Clapham, T.V.N. Cole, P. Gerrior, and R.M. Pace, III. October 2001.

01-15 **Bycatch Estimates of Coastal Bottlenose Dolphin (*Tursiops truncatus*) in U.S. Mid-Atlantic Gillnet Fisheries for 1996 to 2000.** By D.L. Palka and M.C. Rossman. November 2001.

01-16 **Causes of Reproductive Failure in North Atlantic Right Whales: New Avenues for Research -- Report of a Workshop Held 26-28 April 2000, Falmouth, Massachusetts.** By R.R. Reeves, R. Roland, and P.J. Clapham, editors. November 2001.

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A Report of the 33rd Northeast Regional Stock Assessment Workshop

33rd Northeast Regional Stock Assessment Workshop (33rd SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

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

December 2001

Northeast Fisheries Science Center Reference Documents

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The Stock Assessment Review Committee (SARC) meeting of the 33rd Northeast Regional Stock Assessment Workshop (33^{rd} SAW) was held in the Aquarium Conference Room of the Northeast Fisheries Science Center's Woods Hole Laboratory, Woods Hole, MA during June 25-29, 2001. The SARC Chairman was Dr. Pat Sullivan, Cornell University, Ithaca NY. Members of the SARC included scientists from the NEFSC, the Northeast Regional Office (NERO), the New England Fishery Management Council (NEFMC), Atlantic States Marine Fisheries Commission (ASMFC), and the Canadian Department of Fisheries and Oceans (Table 1). Support for Drs. Sullivan and Hall was provided by the Center for Independent Experts, University of Miami. In addition, 31 other persons attended some or all of the meeting (Table 2). The meeting agenda is presented in Table 3.

Table 1. SAW-32 SARC Composition.

Pat Sullivan (Cornell University -CIE)

NEFSC experts chosen by the Chair:
Steve Cadrin
Michael Fogarty
Josef Idoine
Bill Overholtz

NMFS Northeast Regional Office:
John Witzig, NMFS/NERO

Regional Fishery Management Councils:
Andrew Applegate, NEFMC

Atlantic States Marine Fisheries Commission/States:
Jim Armstrong, NC
Kevin Kelly, ME

Other experts:
Norm Hall (Murdoch University, Australia - CIE)
Bob Mohn (DFO/BIO, Halifax)
Donald Power (DFO, St. Johns, Newfoundland)
Michael Prager (NOAA/NMFS/SEFSC, Beaufort)
Peter Shelton (DFO, St. Johns, Newfoundland)

Advisors:
Carl Bouchard - NEFMC (Groundfish)

Opening

Dr. John Boreman, NEFSC Deputy Science and Research Director welcomed the meeting participants and Dr. Terrence Smith, Stock Assessment Workshop (SAW) Chairman, briefly reviewed the overall SAW process. Dr. Sullivan reviewed the agenda and discussed the conduct of the meeting.

Table 2. List of Participants

NMFS, Northeast Fisheries Science Center

Frank Almeida	Pamela Mace
John Boreman	Lisa Morrison
Jon Brodziak	Paul Nitschke
Jay Burnett	Paul Rago
Steve Clark	Gina Repucci
David Curelli	Anne Richards
David Dow	Gary Shepherd
Dvora Hart	Pie Smith
Lisa Hendrickson	Katherine Sosebee
Chris Legault	Mark Terceiro
George Liles	Susan Wigley
Jason Link	

NOAA/NMFS, Headquarters
Dan D'Entremont, NERO

NEFMC/ASMFC/States/Industry
Arnie Howe, MA
Jeremy King, MA
Laura Lee, ASMFC
Leslie-Anne McGee, NEFMC
Tom Nies, NEFMC
Barbara Taormina, Gloucester Times

Table 3. Agenda of the 33rd Northeast regional Stock Assessment Workshop (SAW-33) Stock Assessment Review Committee (SARC) meeting.

Aquarium Conference Room
NEFSC Woods Hole Laboratory
Woods Hole, Massachusetts
25 June (1:00 PM) - 29 June (6:00 PM) 2001

AGENDA

TOPIC	WORKING GROUP & PRESENTER(S)	SARC LEADER	RAPPORTEUR(S)
MONDAY, 25 June (1:00 - 5:30 PM)			
Opening			
Welcome	**Terry Smith, SAW Chairman**		**P. Smith**
Introduction	**Pat Sullivan, SARC Chairman**		
Agenda			
Conduct of meeting			
Gulf of Maine Cod (A)	**R. Mayo**	**P. Shelton**	**J. Weinberg**
Informal social (6:00 PM)) - Meigs Room of MBL's SWOPE Bldg.			
TUESDAY, 26 June (8:30 AM - 5:00 PM)			
Production Modeling (D) - Overview	**P. Rago**		
White Hake (B)	**K. Sosebee**	**D. Power**	**S. Wigley**
WEDNESDAY, 27 June (8:30 AM - 5:00 PM)			
Redfish (C)	**R. Mayo** **S. Cadrin** **J. Brodziak**	**N. Hall**	**P. Nitchske**
Production Modeling (D) **Examples and synthesis**	**P. Rago**		
THURSDAY, 28 June (8:30 AM - 5:00PM)			
Review Advisory Reports and Sections for the SARC Report			
FRIDAY, 29 June (8:30 AM - 5:00 PM)			
SARC comments, research recommendations, and 2nd drafts of Advisory Reports			
Other business			**P. Smith**

The Process

The SAW Steering Committee, which guides the SAW process, is composed of the executives of the five partner organizations responsible for fisheries management in the Northeast Region (NMFS/Northeast Fisheries Science Center, New England Fishery Management Council, Mid-Atlantic Fishery Management Council, and the Atlantic States Marine Fisheries Commission). Working groups assemble the data for assessments, decide on methodology, and prepare documents for SARC review. The SARC members have a dual role; panelists are both reviewers of assessments and drafters of management advice. More specifically, although the SARC's primary role is peer review of the assessments tabled at the meeting, the Committee also prepares a report with advice for fishery managers contained in the *33rd SAW Public Review Workshop Report*, *NEFSC Ref. Doc. 01-19.*

Assessments for SARC review were prepared at meetings listed in Table 4.

Table 4. SAW-33 Working Group meetings and participants.

Working Group and Participants	Meeting Date	Stock/Species
Northern Demersal Working Group	14-18, May, 2001	Gulf of Maine cod, white hake, and redfish
J. Brodziak, NEFSC		
S. Cadrin, NEFSC		
S. Correia,, MA DMF		
R. Mayo, NEFSC (Chair)		
T. Nies, NEFMC		
L. O'Brien, NEFSC		
P. Rago, NEFSC		
K. Sosebee, NEFSC		
M. Terceiro, NEFSC (Chair, part time)		
M. Thompson, NEFSC		
E. Thunberg,, NEFSC		
S. Wigley, NEFSC		
Methods Working Group	23 April and 2, 3, 9, 24, May, 2001	
J. Brodziak, NEFSC		
L. Jacobson, NEFSC		
H. Lai, NEFSC		
C. Legault, NEFSC		
P. Rago, NEFSC (Chair)		

Agenda and Reports

The SAW-33 SARC agenda (Table 3) included presentations on assessments for Gulf of Maine cod, white hake, and redfish.

A chart of US commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 1. A chart showing the sampling strata used in NEFSC bottom trawls surveys is presented in Figure 2.

SARC documentation includes two reports, one containing the assessments, SARC comments, and research recommendations (this report, the SARC Consensus Summary), and another produced in a standard format which includes the status of stocks and management advice (SARC Advisory Report). The draft reports were made available at two sessions of the SAW-33 Public Review Workshop that were held during regularly scheduled NEFMC and MAFMC meetings (25 July and 9 August, 2001 respectively). The documents will be published in the NEFSC Reference Document series as the *33rd SARC Consensus Summary of Assessments* and the 33re *SAW Public Review Workshop* Report (the latter document includes the Advisory Report), after the Public Review Workshop sessions.

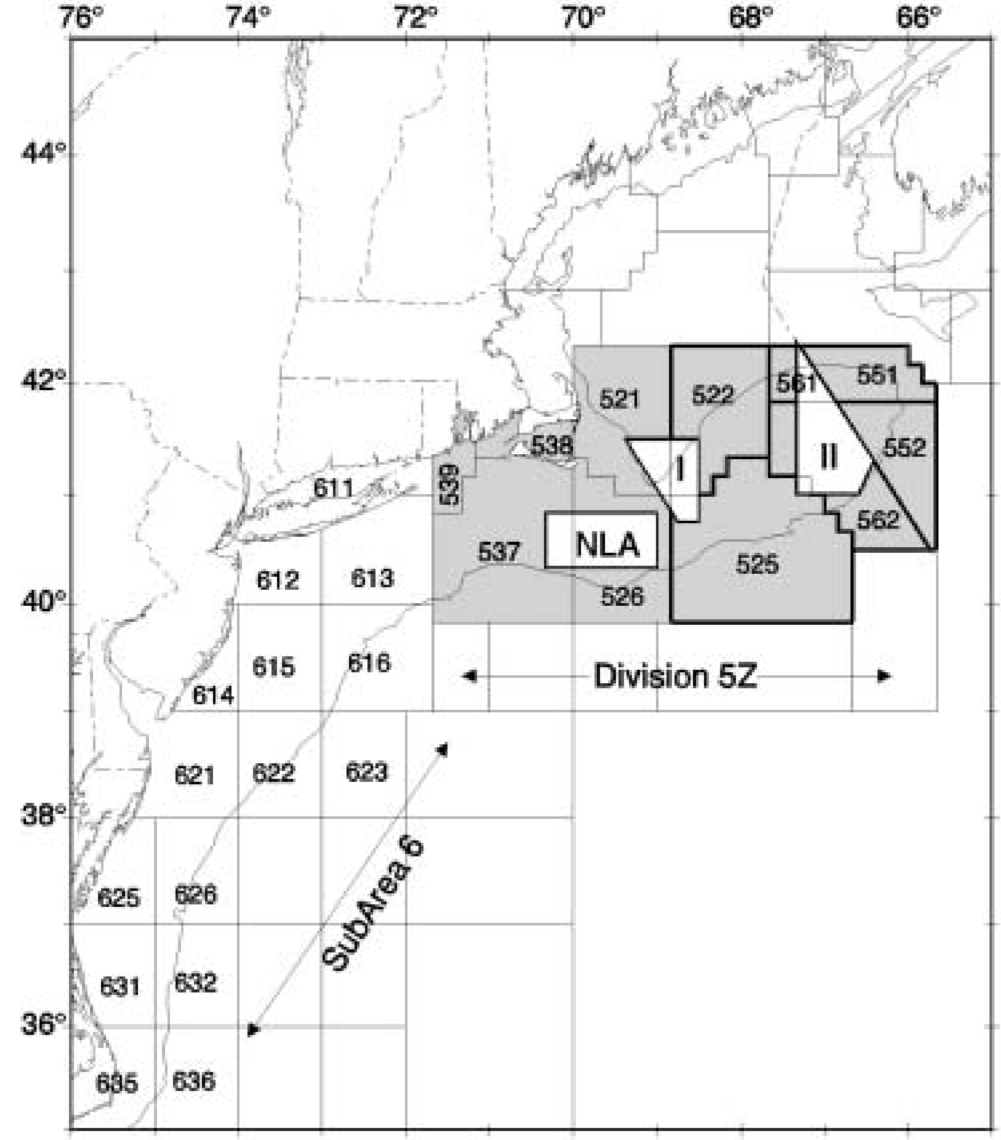

Figure 1. Statistical areas used for catch monitoring in offshore fisheries in the Northeast United States.

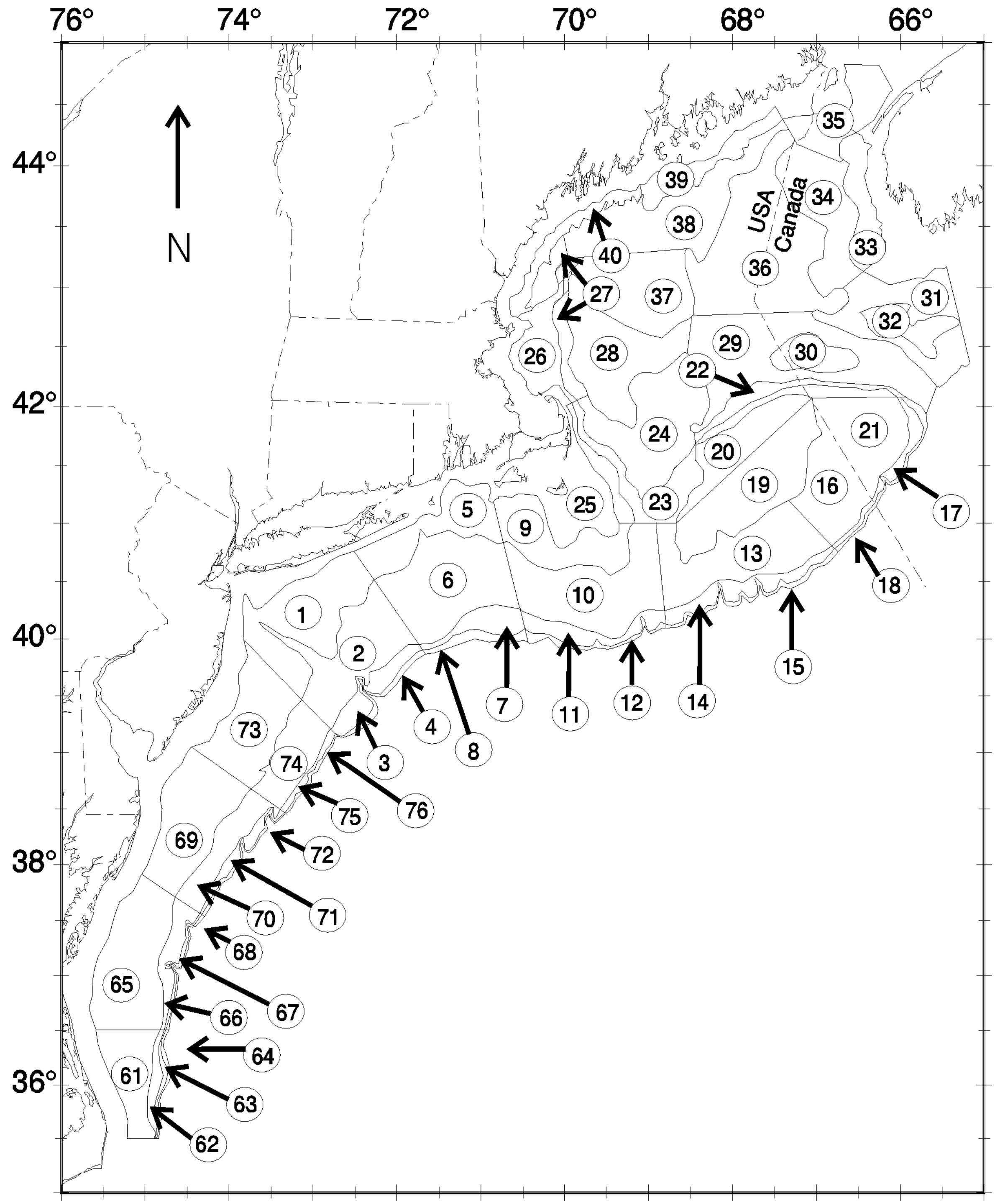

Figure 2. Offshore sampling strata used in NEFSC bottom trawl surveys.

A. GULF OF MAINE COD

EXECUTIVE SUMMARY

The status of the Gulf of Maine cod (*Gadus morhua*) stock is reviewed, and terminal year VPA estimates of 2000 fishing mortality and spawning stock biomass and the survivors in 2001 are presented. Precision estimates of the 2000 fishing mortality and spawning stock biomass estimates for Gulf of Maine cod are also provided. Short-term projections of 2002 catches and resulting 2003 spawning stock biomass at various levels of 2002 fishing mortality are also given. Long-term (25-yr) projections were conducted to evaluate relative trajectories of stock biomass and catch under various fishing mortality scenarios, and an age-structured production model was applied to estimate MSY-based reference points.

The 2001 assessment is based on several sources of information including: the age composition of USA commercial and recreational landings, commercial fishing vessel trip reports (VTR), NEFSC sea sample data, MRFSS estimates of recreational harvest, Northeast Fisheries Science Center (NEFSC) and Massachusetts Division of Marine Fisheries (DMF) spring and autumn research vessel survey data, and standardized USA commercial fishing effort data. This assessment updates the analyses presented in the 1998 assessment of the Gulf of Maine cod stock (Mayo *et al.* 1998) as well as those prepared in 1999 and 2000 by the Northern Demersal Working Group (NEFSC 2000, 2001).

Total landings of Gulf of Maine cod equaled 4,156 metric tons (mt) in 1998, declined to 1,636 mt in 1999, and increased to 3,730 mt in 2000. The sharp decline in landings between 1998 and 1999 and the subsequent increase in 2000 likely reflects the imposition of very low trip limits during 1999 and the subsequent relaxation of these limits in early 2000. It is probable that the extent of discarding increased sharply in 1999 in response to these reduced trip limits.

Commercial landings per unit of standardized effort declined steadily between 1982 and 1987, increased during 1988-1990 but declined sharply in 1992 and remained low in 1993. Fishery-independent spring and autumn bottom trawl surveys conducted by the NEFSC have documented a steady decline in total stock biomass since the 1960s; the largest decreases occurred during the 1980s. Although the most recent indices suggest a slight increase, overall, the Gulf of Maine cod stock biomass remains low relative to the 1960s and 1970s. Except for the 1998 year class, recent recruitment has been well below average.

Fully recruited fishing mortality appears to have declined slightly during 1998 - 2000 compared to pre-1998 fishing mortality rates although F in 2000 (0.73) remained very high relative to fully recruited F reference points ($F_{0.1}$ = 0.15; F_{max} = 0.27). Spawning stock biomass (SSB) declined from over 24,200 mt in 1990 to a low of 9,900 mt in 1998, but increased to 13,100 mt in 2000.

Total stock biomass (ages 1+) declined from a maximum of 41,900 mt in 1990 to 14,800 mt in 1998, but has since increased to 20,400 mt in 2000. Mean biomass for ages 1+ declined from a maximum of 42,700 mt in 1989 to 14,800 mt in 1997 and 1998, but increased sharply between 1999 and 2000 to 25,900 mt, due, in part, to the impact of the 1998 year class. B_{msy} is now estimated to be 90,300 mt (total stock biomass, ages 1+) with a corresponding F_{msy} of 0.23, (fully recruited, ages 4+). With respect to the age-structured MSY-based reference points, total stock biomass is slightly above 1/4 B_{msy} and F is over 3 times F_{msy}.

TERMS OF REFERENCE

The following Terms of Reference were provided by the Stock Assessment Workshop (SAW) Steering Committee as the context for this assessment of Gulf of Maine Cod reviewed by the Stock Assessment Review Committee (SARC) 33 in June, 2001.

(A) Update the status of the Gulf of Maine cod stock, providing, to the extent practicable, estimates of fishing mortality and stock size. Characterize uncertainty in estimates.

(B) Provide updated estimates of biological reference points (biomass and fishing mortality targets/thresholds), or appropriate proxies, based on available population data.

(C) Provide projections of biomass in 2002 and 2003 and catch in 2002 under various fishing mortality rate options.

INTRODUCTION

Atlantic cod (*Gadus morhua*) in the Gulf of Maine region have been commercially exploited since the 17th century, and reliable landings statistics are available since 1893. Historically, the Gulf of Maine fishery can be separated into four periods (Figure 1): (1) an early era from 1893-1915 in which record-high landings (> 17,000 mt) in 1895 and 1906 were followed by about 10 years of sharply-reduced catches; (2) a later period from 1916-1940 in which annual landings were relatively stable, fluctuating between 5,000 and 11,500 mt, and averaging 8,300 mt per year; (3) a period from 1941-1963 when landings sharply increased (1945: 14,500 mt) and then rapidly decreased, reaching a record-low of 2,600 mt in 1957; and (4) the most recent period from 1964 onward during which Gulf of Maine landings have generally increased but have declined steadily since the early 1990s. Total landings doubled between 1964 and 1968, doubled again between 1968 and 1977, and averaged 12,200 mt per year during 1976-1985. Gulf of Maine cod landings subsequently increased, reaching 17,800 mt in 1991, the highest level since the early 1900s. Total landings declined sharply in 1992 to 10,891 mt, and have since decreased steadily to 1,636 mt in 1999 before increasing to 3,730 mt in 2000.

This report presents an updated and revised analytical assessment of the Gulf of Maine cod stock (NAFO Division 5Y) for the period 1982-2000 based on analyses of commercial, recreational and and research vessel survey data through 2000. From the early 1960s through 1993, information on the catch quantity by market category was derived from reports of landings transactions submitted voluntarily by processors and dealers. More detailed data on fishing effort and location of fishing activity were obtained for a subset of trips from personal interviews of fishing captains conducted by port agents in the major ports of the Northeast. Information acquired during the course of these interviews was used to augment the total catch information obtained from the dealer. Procedures for collecting and processing commercial fishery data in the Northeast were revised after 1993.

Beginning in 1994, data on number of hauls, average haul time, and catch locale were obtained from logbooks submitted to National Marine Fisheries Service (NMFS) by operators fishing for groundfish in the Northeast under a mandatory reporting program. Estimates of total catch by species and market category were derived from mandatory dealer reports submitted on a trip basis to NMFS. Catches (landed and discarded portions) by market category were allocated to stock based on a matched subset of trips between the dealer and logbook databases. Data in both databases were stratified by calendar quarter, port group, and gear group to form a pool of observations from which proportions of catch by stock could be allocated to market category within the matched subset. The cross-products of the market category by stock proportions derived from the matched subset were employed to compute the total catch by stock, market category, calendar quarter, port group, and gear group in the full dealer database. A full description of the proration methodology and an evaluation of the 1994-1996 logbook data is given in Wigley *et al.* (1998) and DeLong *et al.* (MS 1997).

An initial analytical assessment of this stock was presented at the Seventh NEFSC Stock Assessment Workshop in November 1988 (NEFSC 1989) and subsequent revisions were presented at the 12th, 15th, 19th, 24th and 27th Northeast Regional Stock Assessment Workshops in June 1991, December 1992, December 1994, June 1997 and December 1998 (NEFSC 1991, 1993, 1995, 1997, 1998; Mayo 1995, 1998; Mayo *et al.* 1993, 1998). Interim assessments were reviewed by the Northern Demersal Working Group in 1999 (NEFSC 2000) and 2000 (NEFSC 2001).

THE FISHERY

Management History

Fishing for Gulf of Maine cod had been managed under international treaty prior to 1977 and by domestic management authority since 1977 (Table A1). Annual Total Allowable Catches (TACs) were first established under the International Commission for the Northwest Atlantic Fisheries (ICNAF) for Division 5Y (i.e., the Gulf of Maine) cod in 1973. The TAC remained at 10,000 mt from 1973-1975; the 1976 TAC was reduced to 8,000 mt and the TAC proposed for 1977 was reduced further to 5,000 mt.

Following implementation of the Magnuson Fishery Conservation and Management Act (FCMA) in 1977, management of this stock fell under the auspices of the New England Fishery Management Council. TACs were carried forward for the first few years under the Fishery Management Plan for Atlantic Groundfish, and were distributed among vessel tonnage classes and quarters of the years until 1982 when the “Interim” Plan for Atlantic groundfish was implemented. This plan eliminated all direct catch controls (quotas) and established mesh size and minimum landing size regulations as the primary regulatory measures for cod, haddock and yellowtail flounder.

Management of the Gulf of Maine cod fishery has been carried out since 1985 under the Northeast Multi-species Fishery Management Plan (FMP). This plan and its Amendments 1 through 4 essentially carried forward the regulatory measures originally implemented in 1982 under the "Interim" Plan. Beginning in 1994, with the implementation of Amendment 5, the primary goal of the FMP became a reduction in fishing mortality for 5 key monitoring stocks. This was to be achieved through a combination of reductions in days at sea (DAS) usage and, under Amendment 7, an additional series of seasonal and year-round area closures oriented primarily towards Gulf of Maine stocks.

Commercial Fishery Landings

Annual commercial landings data for Gulf of Maine cod in years prior to 1994 were obtained from trip-level detailed landings records contained in master data files maintained by the Northeast Fisheries Science Center, Woods Hole, Massachusetts (1963-1993) and from summary reports of the Bureau of Commercial Fisheries and its predecessor the U.S. Fish Commission (1895-1962). Beginning in 1994, landings estimates were derived from dealer reports prorated to stock based on the distribution of reported landed catch contained in fishing vessel logbooks as described above.

Total commercial landings in 2000 were 3,730 mt, approximately 130% greater than in 1999 but 10% less than in 1998 (Table A2, Figure A1). Since 1977, the USA fishery has accounted for all of the commercial catch. Canadian landings reported as Gulf of Maine catch during 1977-1990 are believed by Canadian scientists to be misreported catches from the Scotian Shelf stock (Campana and Simon 1985; Campana and Hamel 1990). Although otter trawl catches account for most of the landings (54% by weight in 2000), the otter trawl percentage has declined considerably compared to the period prior to 1993. Most of this change can be attributed to an increase in the percentage of cod taken by sink gillnets since 1993, although the percentage from combined handline and line trawls also increased substantially during the 1990s (Table A3).

Commercial Fishery Discards

Discard rates have been routinely calculated for Gulf of Maine cod by quarter and gear from NEFSC sea sampling data collected since 1989 (Table A4). Discard and kept components of the catch were summed for all observed tows, within each gear type, occurring in Division 5Y, and the ratio of the discarded- to-kept quantity was applied to landings for the corresponding quarter and gear type within each year. Data were available for otter trawls, shrimp trawls, and sink gillnets.

For otter trawl gear, discard-to-kept ratios (D/K) and absolute quantities of discarded cod declined from relatively high values in 1989 and 1990 to relatively low levels from 1991 through1998 as D/K ratios generally fluctuated between 0.002 and 0.155.. In the shrimp trawl fishery, D/K ratios remained high throughout 1989-1991, but declined substantially in 1992 and remained negligible in 1993. Sea sampling data for 1994-2000 were minimal; therefore, landings by this gear component were not distinguished from all other otter trawls in the proration scheme employed to derive the landings by stock for the present assessment. Consequently, discard estimates from both otter trawl and shrimp trawl gear were combined for the 1994-2000 period. D/K ratios from the sink gill net fishery remained relatively low between 1989 and 1998, generally in the range of 0.05 or so. In 1999, discard ratios increased sharply for otter trawl and sink gill nets during the second and third quarters, declined from these peak levels in the fourth quarter, but continued to remain relatively high through all of 2000 compared to pre-1999 rates.

Discards of Gulf of Maine cod ranged from 139 mt in 1998 to 3,598 mt in 1990 (Table A4). Discards exceeded 1,000 mt in each year between 1989 and 1991 before declining steadily since 1992. The relatively high discard rates calculated for otter trawl and shrimp trawl gear during 1989-1991 coincide with recruitment of the strong 1987 year class to the small mesh shrimp trawl gear and then the large mesh general otter trawl gear. Available length composition data for these gear types suggest that most of the discarded cod were about 30-50 cm with a mode around 40 cm. Discards emanating from these two gears are the likely result of minimum size regulations. In contrast, the relatively low, but persistent, discards of cod in the gillnet fishery comprised fish of all lengths, up to 125 cm. The larger size range reflects discarding resulting from minimum size regulations as well as poor fish quality (in the case of the larger, marketable cod). Discards in 1999 were estimated to be 2,630 mt, one of the highest in the data series, due to the imposition of low trip limits. Estimated discards declined to 1,170 mt in 2000 as trip limits were relaxed to 400 lbs/day in early 2000.

To further evaluate discarding in 1999 and 2000 when low trip limits were imposed, all available vessel trip report (VTR) records were examined from trips fishing in the Gulf of Maine and reporting some catch of cod. In addition, all trips from vessels which never reported any discard were excluded from the discard analysis. The VTR data were treated in the same manner as the sea sample data except that the discard-to-kept ratios and subsequent estimates of absolute discard were derived on a monthly basis instead of a quarterly basis. This increased temporal resolution, available due to the greater quantity of VTR records, afforded a means of comparing the seasonal progression of discarding with the evolution of trip limits in 1999 and 2000. Analysis of the VTR data (Figure A2) generally confirms the seasonal patterns as well as the magnitude of the discard estimates derived from the sea sample data in 1999 and 2000 (Appendix 1: Figures 1-3). The estimated total discards of Gulf of Maine cod derived from the monthly VTR discard-to-kept ratios equaled 2,822 mt in 1999 (Table A5a) and 2,246 mt in 2000 (Table A5b).

A third approach to estimating the magnitude of 1999 and 2000 discards of Gulf of Maine cod was based on a predictive model by imposing 1999 and 2000 trip limits on 1996 and 1997 VTR data at the appropriate times of the year. Given the manner in which fishery conditions change from year to year (number of trips taken and catch rates) as well as regulatory changes over time, the primary objective was to estimate a discard-to-keep ratio rather than a direct estimate of discards. The resulting discard-to-kept ratios were then applied to observed 1999 and 2000 calendar year Gulf of Maine cod landings to provide an estimate of total discards in those years.

The predictive model incorporated information about total trip income and fishing costs including operating costs and payments to labor to determine which trips may no longer be profitable as a result of the trip limit (a detailed description of the model, data, and assumptions is included in an appendix). Trips that were no longer profitable were assumed to be abandoned while the remaining trips were assumed to occur while incurring discards of all cod in excess of the trip limit. That is, if the cod value (P_{cod}*Q_{cod}) plus income earned from all component catch (ΣPiQi) exceeds the cost of paying crew (C_{crew}) plus operating the vessel ($C_{operating}$):

$$(1)\,(P_{cod} * Q_{cod} + \sum_i P_i Q_i) - (C_{crew} + C_{operating}) > 0$$

then the trip was assumed to be taken as observed. Otherwise the trip was assumed to be abandoned. Given that prices and landings are generally known, the economic relationship described in (1) will be sensitive to assumptions about crew and operating costs. Estimated operating costs for principal gear types (otter trawl, gillnet, and hook) were based on cost surveys (Georgianna and Cass, 1998; Lallemand et. al., 1998; Lallemand et. al., 1999). Since payments to crew are based on a share system, crew income will be affected by trip limits. Thus, some minimum return to crew was assumed to be required to enable a vessel to make a trip.

The minimum crew payment was estimated using two different methods; a minimum share and a minimum payment. The minimum share methods is consistent with the manner in which crew are remunerated which reflects some risk sharing between the crew and owner but could result in unrealistically low residual payments to labor. By contrast, the minimum payment approach provides an income floor below which the vessel owner may be assumed to be unable to recruit crew because they could earn more income by taking a job elsewhere. This income floor was assumed to be equal to the average wage rate for blue-collar occupations in New England ($13 per hour). Three sensitivity trials were used for the minimum share (50%, 25%, and 10%) and one minimum payment trial ($13 per hour x 8 hours or $104 per crew per day) was conducted to test the sensitivity of the discard-to-kept ratios to crew payment assumptions.

The predictive model was applied to VTR records for calendar years 1996 and 1997 to infer what landings and discards would have been had the trip limits been implemented in those calendar years. Since these data come from observed trips the trip limit model provides an estimate of landings and total discards (discards due to the trip limit plus recorded VTR discards for other reasons). The 1996 and 1997 calendar years were selected for analysis because they represent a time period over which the Gulf of Maine cod fishery was least affected by trip limits (there were no trip limits in 1996 and the trip limits for 1997 were not binding on most occasions). By contrast, the 1998 trip limits, as well as the rolling closures, make use of data from that calendar year problematic.

The trip limit model was run separately for each of the 1996 and 1997 calendar year data and the four different sensitivity runs yielding 8 estimates for each of the 1999 and 2000 discard-to-keep ratios (Table A6a). Note that as the assumed payment necessary to attract labor to the fishery declines, formerly marginal trips become profitable resulting in higher estimated landings and discarding hence the increasing discard-to-keep ratios. Overall, the minimum payment trial results in an intermediate discard-to-kept estimate. The estimated Gulf of Maine cod discard-to-kept ratios ranged from 1.80 to 2.47 with a median value of 2.15 for calendar year 1999. Due to higher trip limits, the discard-to-kept ratios ranged between 0.72 and 0.99 with a median value of 0.83 for calendar year 2000. Applying the estimated discard-to-kept ratios to the observed landings results in a median estimate of 3,524 metric tons of discards of

Gulf of Maine cod in 1999. Similarly, the median estimate of calendar year 2000 Gulf of Maine cod discards was 3,081 metric tons (Table A6b).

The estimates of discard of Gulf of Maine cod derived by each of the 3 methods are reasonably close to each other, within the range of 2,600-3,500 mt for 1999 and 1,200-3,100 mt for 2000. Each method has advantages and limitations. The sea sample data are less subjective since they are based on consistent interpretation by a small group of individuals. But these data are rather sparse, leading to considerable imprecision. The 1999 VTR data provide considerably more observations, which may increase precision, but these data may have been influenced by possible reporting bias in response to severe management actions in 1999. The third method uses VTR data from years prior to the imposition of severe trip limits, and presumably is less affected by reporting bias. However, this method relies on several assumptions regarding constancy of effort and catch rates.

While there is, at present, no objective basis to select one method over any other, all 3 suggest that total discards were in the range of approximately 2,500 mt in 1999 and 1,000 mt in 2000. When these discards are added to the reported landings, the resulting total commercial catch is estimated to be 4,136 mt in 1999 (1,636 mt + 2,500 mt) and 4,730 mt in 2000 (3,730 mt + 1,000 mt). These results provide expansion factors of 2.53 in 1999 (4,136 mt/1,636 mt) and 1.27 in 2000 (4,730 mt/3,730 mt). To convert commercial landings to commercial catch.

Commercial Fishery Sampling Intensity

A summary of USA length frequency and age sampling of Gulf of Maine cod landings during 1982-2000 is presented in Table A7. USA length frequency sampling averaged one sample per 155-200 mt landed during 1983-1987 but the sampling intensity was reduced in 1990 (1 sample per 387 mt) and 1993 (1 sample per 360 mt), and the absolute level of sampling was extremely low in 1993. Overall sampling improved slightly in 1994 and 1995, but the seasonal distribution was uneven and poorly matched to the landings. Sampling improved substantially in 1996 and remained equally high in 1997, reaching all-time highs in terms of both absolute number of samples and samples per ton landed in both years.

Most of the USA samples have been taken from otter trawl landings, but sampling and the estimation of length composition is stratified by market category (scrod, market, and large). Although the length composition of cod differs among gear types (primarily between otter trawl and gillnet), the length composition of cod landings within each market category is virtually identical among gear types.

Beginning in 1998, the quality of commercial port sampling for Gulf of Maine cod has declined considerably. The total number of samples taken declined sharply in 1998 and again in 1999, a possible outcome of the very low trip limits imposed in 1999. Although the number samples collected increased in 2000, the distribution by market category has been out of phase with actual landings. In particular, the number of 'Large' market category cod samples has diminished to the point that the representation of the older age groups may be somewhat compromised in recent years.

Of the 61 samples collected in 2000, 24 were scrod samples (39%), 36 were market (59%), and 1 was large (2%). Compared with the 2000 market category landings distribution by weight (scrod: 9%; market: 59%; large: 30%) (Table A8), sampling in 2000 over-represented the scrod category and severely under-represented the large category.

As well, the seasonal distribution of samples has become skewed such that, although there appears to have been sufficient numbers of samples taken, there has been insufficient sampling in some quarters and half-years, requiring pooling of samples on an annual basis. This approach was necessary in 1999 and 2000.

Commercial Landings Age Composition

The age composition of landings during 1982-1993 was estimated, by market category, from monthly length frequency and age samples, pooled by calendar quarter. Quarterly mean weights, by market category, were obtained by applying the NEFSC research vessel survey length-weight equation for cod:

$$\ln Weight_{(kg,live)} = -11.7231 + 3.0521 \ln Length_{(cm)}$$

to the quarterly market category sample length frequencies. Computed mean weights were then divided into quarterly market category landed weight to derive estimated numbers landed by quarter, by market category. Quarterly age/length keys were applied to the quarterly market category numbers at length distributions to provide numbers at age. These results were summed over market categories and quarters to derive the annual landings-at-age matrix (Table A9a).

Age composition of landings from 1994 through 2000 was estimated in a manner similar to that employed for the 1982-1993 estimates except that samples and landings were, at times, pooled to semi-annual or annual resolution because of the uneven distribution of length and age samples by quarter (Table A7). Semi-annual pooling was required for the 1st and 2nd quarters of 1994 because of incomplete sampling coverage of scrod and large cod landings; in 1995, samples were pooled in both semi-annual periods due to the absence of large cod samples and the sparse coverage of market cod in quarters 1 and 3. Quarterly allocation of samples to landings was achieved for all market categories in 1996 and 1997, but semi-annual and annual pooling was required in 1998 and annual pooling was required in 1999 and 2000.

Biological sampling in 2000 was especially problematic for 'Large' category cod. As only one sample was taken throughout the year, the entire representation of older age groups depended on this sample with a maximum length at just over 100 cm. To achieve greater representation of larger fish, the 'Large' category commercial port sample was augmented with length measurements of > 100 cm cod obtained from Gulf of Maine sea sample trips. The resulting 2000 age compositions obtained from the original and the augmented length data are presented in Tables A9 and A10. It was the consensus of the SARC that the 2000 age composition based on the original port sample data be used for further analyses.

Gulf of Maine cod landings have been generally dominated by age 3 and 4 fish in numbers and by ages 3, 4, and 5 in weight. Cod from the strong 1987 year class predominated from 1990 through 1992 but, by 1993, fish from the 1990 year class accounted for the greatest proportion of the total number landed. In terms of weight, the 1993 landings were equally distributed between the 1987 and

1990 year classes. In 1993, these two year classes accounted for approximately 70% of the total number and weight landed. From 1994 through 1996, landings were dominated by age 4 cod in both number and weight. In 1997, age 5 fish were dominant in terms of both number and weight, reflecting the higher abundance of the 1992 year class. Although traditionally low in terms of their contribution to the total landings, age 10 and 11+ fish were completely absent in 1993 and 1996, and numbers of age 8 and 9 fish have also been unusually low (Table A9a). Although this pattern may be partly a result of the poor sampling of 'Large' category cod, especially in recent years, a trend towards fewer older fish in the landings has been apparent since 1991. As well, the contribution of age 2 fish to the landings has decreased in recent years.

Adjustment of the 1999 and 2000 Commercial Landings at Age

The fishery for Gulf of Maine cod was affected in many ways by management actions which occurred in 1999 and have continued into 2000. Primarily, the imposition of extremely low trip limits in 1999 are likely to have precipitated a substantial increase in the amount of cod discarded compared to previous years, as noted above. Consequently, the 1999 and 2000 estimated commercial landings at age presented in Tables A9 and A10 do not reflect the full extent of removals from the stock by the fishery. Therefore, prior to inclusion in the VPA, the 1999 and 2000 landings estimates must be adjusted upwards at each age by the ratio of total estimated catch biomass (landings+discard) to the landed catch biomass.

This approach assumes that the age composition of the discarded component of the catch is the same as the landed component. In most discarding cases, where discards generally occur in response to mesh selectivity which is out of phase with minimum landing size regulations, it is necessary to estimate the size and age composition of the discarded component separate from the landed component. In general, the discards comprise the smaller, younger fish compared to those that are landed. However, in this case , where regulatory discards were generated as a result of extremely low trip limits, it is presumed that cod of all sizes and ages were discarded without prejudice. An examination of the 1998, 1999 and 2000 kept and discarded length composition samples from the NEFSC Sea Sample database supports this assumption. The sizes of discarded cod in 1998, when trip limits were considerably higher, were primarily below the 48 cm minimum landing size and the sizes of retained cod were approximately the same as those observed in the commercial port samples. In 1999 and 2000, however, the sizes of discarded and retained cod were generally the same, well above the minimum landing size and similar to those observed in the 1999 commercial port samples. Therefore the 1999 and 2000 commercial landings at age estimates from Table A10 were multiplied by discard adjustment factors of 2.53 and 1.27, respectively, before inclusion in the VPA catch at age matrix (see page 13).

Commercial Landings Mean Weights at Age

Mean weights at age in the catch for ages 1-11+ during 1982-2000 are given in Table A9b and, based on landings patterns, are considered mid-year values. Mean weights of age 2 and 3 cod have risen since about 1992, reflecting decreased partial recruitment of younger fish to the fishery, while those for intermediate aged fish have fluctuated without any particular trend. Mean weights for ages 9 and older fluctuate considerably and are particularly sensitive to sampling variability.

Thus, it is unlikely that the apparent increases in mean weight at age for ages 10 and 11+ since the late 1980s would indicate a shift in growth or an increase in older fish in the plus group.

In 1990, mean weights at age for ages 2 and 4 were the lowest in the 9-year time series, while mean weights for ages 6, 7, and 9 were among the highest. These changes, however, may be artifacts of low sampling levels in 1990. Mean weights at ages 8 and 9 in 1993 and at ages 5 and 6 in 1995 were the highest in the series, but these anomalies are also the likely result of poor sampling. However, the generally higher mean weights at ages 2 through 4 since 1996 may be related to the required use of 152 mm (6 in.) mesh in the otter trawl fishery. Catch at age and recalculated mean weights at age for the 7+ group which are used in the VPA are given in Tables A10a and A10b.

Recreational Fishery Catches

Estimates of the recreational cod catch were derived from the Marine Recreational Fishery Statistics Survey (MRFSS) conducted annually since 1979. The Gulf of Maine cod catch was estimated assuming that catches of cod recorded by that portion of the intercept survey were removed from the ocean in statistical areas adjacent to the state or county of landing. The MRFSS database has been recently revised, resulting in adjusted catch estimates for the years 1981 through 1997. Estimates of the total Gulf of Maine cod recreational catch as well as the portion of the catch excluding those caught and released through 2000 are provided in Table A11. Information on the catch prior to 1981, which has not been revised, is included in Table A11 to provide a longer-term perspective. Further information on the details of the allocation scheme and sampling intensity are given in NEFSC (1992).

The quantity of cod retained generally exceeded 75% of the total recreational catch from 1979 through 1991, but has averaged less than 50% since 1993. The estimated total cod catch (including those caught and released) declined from over 5,000 mt in 1980 and 1981 to less than 2,000 mt between 1983 and 1986, increased to over 3,500 mt in 1990 and 1991, then fluctuated between 1,100 and 2,600 mt between 1992 and 1996 before declining sharply to 671 mt in 1997. The total catch has since increased to 2,853 mt in 2000 of which 1,147 mt was retained. The proportion of the total landings (commercial and recreational) taken by the recreational sector increased to 34 and 24 percent in 1999 and 2000, respectively. The reported total catch and retained cod from party/charter vessel VTR reports is also provided in Table A11 since 1995.

Recreational Fishery Sampling Intensity

Information on the length frequency sampling levels of Gulf of Maine cod taken in the recreational fishery is provided in Table A11. An examination of the available length frequency sampling coverage was conducted to evaluate the potential utility of these data in estimating the overall length composition of the removals from the stock which could be attributed to this gear type. Overall, sampling for cod taken by recreational gear is poor, averaging less than 1 sample per 1,000 mt removed (Table A11). Sampling of the recreational fishery improved in 1994-1996, but has been relatively low in recent years. The age composition of the 1982-1996 recreational landings was derived for the 1997 assessment (Mayo 1998) but, given the highly variable sampling, these data were not formally included in the VPA conducted in 1997 (NEFSC 1997; Mayo 1998). However, given the recent increase in the proportion of the total landings accounted by the retained recreational catch, the 1997-2000 age composition of the recreational landings was estimated for the current assessment and the 1982-2000 estimates were incorporated into the total catch at age.

Recreational Fishery Landings Age Composition

Given the limited sampling coverage in this sector of the fishery, estimation of numbers caught by length and age required samples to be pooled on an annual basis. The low inter-seasonal variability displayed by the sample length composition data supports this approach. Differences between fishing modes 6 and 7 are also minimal. Therefore, estimates of the age composition of cod retained by the recreational sector were derived from the length composition data applied to the retained numbers of cod based on pooled annual length frequency samples from Gulf of Maine trips. Only the retained numbers of cod were included because the intercept sampling may not accurately reflect the size composition of the released cod. Age-length keys obtained from sampling the commercial landings, augmented by age samples from NEFSC bottom trawl surveys for cod less than 40 cm, were applied to the numbers retained at length on an annual basis to derive the numbers retained at age (Table A12a).

During the 1980s, Gulf of Maine cod recreational landings in numbers were dominated by age 3 fish with age 2 fish next in importance. Following the increases in minimum retention size in 1989 and again in 1996, the proportion of age 2 cod declined, and the age composition of the landings from this sector now resembles that from the commercial fishery with ages 3, 4 and 5 predominant (Tables A10a and A12a). The strong 1987 year class dominated the recreational catch in 1990, 1991 and 1992, and the 1992 year class can also be tracked in the estimated catch at age between 1995 and 1999. Ages 3 and 4 cod generally predominate in terms of weight caught, although the 1987 and 1992 year classes predominated at age 5 in 1992 and 1997, respectively.

Recreational Landings Mean Weights at Age

Mean weights at age were obtained by applying the NEFSC research vessel survey length-weight equation for cod to the numbers retained at age on an annual basis:

$$\ln Weight_{(kg,live)} = -11.7231 + 3.0521 \ln Length_{(cm)}$$

Mean lengths and weights at age of cod landed by the recreational sector (Table A12b) are consistently lower than those taken in the commercial fishery. This pattern persists through age 5, but for ages 6 and older, mean weights are highly variable due to the relatively poor sampling of fish at the larger sizes combined with the lack of market category stratification. Despite this variability, patterns present in the commercial landings mean weights are also evident in the recreational landings, ie,. low mean weights in 1990 and higher mean weights at age 2 in 1995 and 1996.

Total Landings Age Composition

Estimates of the age composition of total cod landings (Table A13a) were derived by combining the separate age composition estimates obtained for the commercial (Table A10a) and recreational sectors (Table A12a). Given the general similarities between the age compositions estimated for the commercial and recreational sectors, the total age composition reflects the same dominant year classes and age structure over time. In general, ages 3, 4 and 5 have predominated; the 1987 year class dominated the total landings in 1990, 1991 and 1992, and the 1992 year class can also be tracked between 1995 and 1999.

Total Landings Mean Weights at Age

Mean lengths and weights at age of cod landed by the combined commercial and recreational sectors (Table A13b) are intermediate to those obtained from the individual sectors. Mean weights at age are highly variable for the older ages due to the relatively poor sampling of fish at the larger sizes. Mean weights at age for calculating stock biomass at the beginning of the year are provided in Table A14. These values were derived from the landings mean weight at age data (Tables A9b and A13b) using procedures described by Rivard (1980).

STOCK ABUNDANCE and BIOMASS INDICES

Commercial Catch Rates

Trends in commercial landings per unit effort (LPUE) and fishing effort for the period 1965-1993 and 1994-1996 have been recently reported by Mayo (1998). Given the uncertainty in reported fishing effort since 1994, the 1994-1997 LPUE data were not formally included in the VPA conducted in 1998 (NEFSC 1998; Mayo *et al.*1998). Recent management actions, including imposition of trip limits and rolling closures also make interpretation of 1997-2000 LPUE inconsistent with previous years. Until effort units are resolved in the commercial fishery database, no further treatment of the LPUE series after 1993 will be performed. Trends in commercial LPUE through 1996 are illustrated in Figure A3.

The 1982-1993 age composition of the landings corresponding to the effort sub-fleet as presented by Mayo *et al.* (1994) was used with the updated standardized effort estimates to calculate a revised LPUE-at-age index. Numbers landed at age were estimated by applying quarterly commercial age-length keys to quarterly commercial numbers landed at length by market category. The LPUE-at-age indices were derived by dividing the estimated numbers landed at age by corresponding 1982 through 1993 standardized fishing effort. Further details regarding data selection, preparation and estimation procedures are provided in Mayo *et al.* (1994).

Research Vessel Survey Indices

Indices of cod abundance (stratified mean catch per tow in numbers) and biomass (stratified mean weight per tow in kilograms), developed from NEFSC and Commonwealth of Massachusetts Division of Marine Fisheries (MADMF) research vessel bottom trawl survey data, have been used to monitor changes and assess trends in population size and recruitment of cod populations off New England. Offshore (> 27 m) stratified random NEFSC surveys have been conducted annually in the Gulf of Maine in autumn since 1963 and in spring since 1968. Inshore areas of the Gulf of Maine (< 27 m) have been sampled during spring and autumn NEFSC and MADMF inshore bottom trawl surveys since 1978. For the NEFSC surveys, a "36 Yankee" trawl has been the standard sampling gear except during spring 1973-1981 when a modified "41 Yankee" trawl was used.

Prior to 1985, BMV oval doors (550 kg) were used in all NEFSC surveys; since 1985, Portuguese polyvalent doors (450 kg) have been used. Details on NEFSC survey sampling design and procedures are provided in Azarovitz (1981) and Clark (1981). The MADMF inshore bottom trawl sampling program is described in Howe *et al*. (1981). No adjustments in the survey catch-per-tow data for cod have been made for any of the trawl differences, but vessel and door coefficients have been applied to adjust the stratified means (number and weight per tow) as described in Table A15. Standardized catch-per-tow-at-age (number) indices are listed in Table A16. Catch-per-tow-at-age (number) indices from DMF spring and autumn surveys are listed in Table A17.

NEFSC spring and autumn offshore catch per tow indices for Gulf of Maine cod have generally exhibited similar trends throughout the survey time series (Table A15, Figure A4). Number-per-tow indices declined during the mid- and late 1960s, but since 1972-73 have fluctuated as a result of a series of recruitment pulses. Sharp increases in the number per tow indices reflect above-average recruitment of the 1971, 1973, 1977-1980, 1983, and 1985-1987 year classes at ages 1 and 2 (Table A16, Figure A5). The sequential dominance of these cohorts at older ages can be discerned from number-per-tow-at-age values in both spring and autumn NEFSC surveys (Table A16). The recent increases in the autumn 1994-1995 and spring 1996-1997 biomass indices may be attributed to somatic growth of fish from the 1992 year class which was the largest within the recent series of poor year classes.

Spring NEFSC number-per-tow indices have remained relatively low since 1985, below the 1981-1984 average (Table A15); spring weight-per-tow indices have also remained relatively low through 1991, but the index increased substantially in 1992, and remained relatively high in 1993, due to a large contribution from the 1987 year class (Table A16). The index declined markedly in 1994, remained low in 1995, increased moderately in 1996 and remained essentially unchanged in 1997. Spring weight-per-tow indices have since declined through 2000 (Figure A4).

Autumn number- and weight-per-tow indices declined sharply in 1991 to unprecedented low abundance; weight-per-tow indices continued to decline to record low levels through 1993 and remained extremely low through 1998 (Figure A4) but increases were evident in 1999 and 2000. The higher abundance in 1988 and 1989, resulting from recruitment of the 1986 and 1987 year classes, became depleted by 1991, resulting in the sharp declines in the overall index. This reduction, combined with a general paucity of large fish in the surveys in recent years (Table A16), resulted in the decline in the weight-per-tow indices after 1991. The recent increase in the autumn abundance and biomass indices in 1994 and 1995 reflected recruitment of the 1992 year class, but these indices had already begun to decline by 1996. Although the autumn biomass indices increased in 1999 and 2000, they still remain relatively low compared to earlier periods (Figure A4).

Overall, the 1987 year class appears to have been one of the strongest ever produced; catch-per-tow indices of this cohort at ages 1-3 in the NEFSC autumn surveys and at ages 0 and 1 in the MADMF autumn inshore surveys were nearly all record-high values (Tables A16 and A17). Based on MADMF and NEFSC survey catch per tow indices, the 1992 and 1998 year classes appear to have been of moderate strength; the intervening year classes of Gulf of Maine cod, particularly the 1993, 1994, 1995, and 1996 year classes have been well below average (Figures A5 and A6).

Inshore/Offshore Biomass Comparisons

To examine changes in the distribution of cod biomass in the Gulf of Maine, the NEFSC autumn survey data were partitioned into an inshore strata set (strata: 26 and 27; area: 1,734 square miles) and an offshore strata set (strata: 28-30, 36-40; area: 16,158 square miles). The inshore strata set approximates the area in the vicinity of Massachusetts Bay up to Jeffreys Ledge which represents the core area where cod presently occur in greatest concentrations. When two or more strata sets of unequal area are compared in this manner, the stratified mean catch per tow indices must be considered to represent the density of fish (index of number per unit area) rather than actual abundance or biomass (index of population size).

To compare trends in actual abundance and biomass between regions, the indices must be weighted by the area of each strata set. This provides an index of population size within each strata set which can be directly compared on the same basis by taking account of the area of the two regions (in this case, the inshore and offshore strata sets). Trends in the autumn NEFSC survey stratified mean weight-per-tow indices are illustrated in Figure A7 for each region and for the combined strata set (as in Figure A4). Stratified mean biomass indices from the inshore Gulf of Maine are considerably higher (generally between 20 and 60 kg/tow) than those for the offshore region (generally less than 20 kg/tow), simply indicating greater densities of cod in the two inshore strata. When area is taken into account, an opposite pattern is evident (Figure A8). When compared in this manner, it is more readily apparent that, while biomass has declined since the 1960s and 1970s in both the inshore and the offshore regions of the Gulf of Maine, the decline has been most severe in the offshore region. This trend is also evident when trends in the proportion of total biomass from each region are compared (Figure A9). During the 1960s and 1970s, between 70 and 80 percent of the cod biomass in the Gulf of Maine was distributed in the offshore region. The offshore proportion began to decline during the early 1980s, culminating in an approximately 50:50 split during the 1990s. Since then, the proportion of cod in the offshore region appears to have increased slightly.

Concentration Indices

The Lorenz curve is an econometrics method developed to study the distribution of income among individuals (Lorenz 1905, Dagum 1985). Thompson (1976) applied the Lorenz curve in a study of the distribution of fish caught by a population of fishermen (i.e., was it true that 90 percent of the fish were caught by 10 percent of the fishermen?). Myers and Cadigan (1995) applied this method to northern cod biomass off Newfoundland using 76 strata from a 12 year research survey time series. When the technique is applied to fish distributions, the Lorenz curve simultaneously takes into account biomass and area and puts them on a comparable basis. The Lorenz curve method used by Myers and Cadigan does not fully account for strata of unequal size. Since the NEFSC survey has a wide range of strata sizes, Wigley (1996) modified the method to account for strata of unequal size.

A Lorenz curve is calculated as follows: for a set of n strata, let x_i be the biomass and a_i be the area of stratum i, i=1,2...n, ranked by mean weight per tow. The Lorenz curve is the polygon joining the points (A_h/A_n, L_h/L_n), h=(0,1,2 ... n) where $L_0 = 0$ and $L_h = \sum^{h}_{i=1} x_i$ is the total biomass in the h strata with the lowest biomass, and $A_0 = 0$ and $A_h = \sum^{h}_{i=1} a_i$ is the total area of the h strata with the lowest biomass. The x-axis of the Lorenz curve represents the cumulative percentage of area, while the y-axis depicts the cumulative percentage of biomass. If fish are evenly distributed among strata the Lorenz curve would be an identity function. If fish are unevenly distributed (i.e., concentrated) the Lorenz curve bows downward and to the right. The concentration index is derived by doubling the area between the identity function and the Lorenz curve (Dagum 1985).

The Lorenz curve method was applied to Northeast Fisheries Science Center (NEFSC) research vessel survey data to examined the distribution of cod biomass as estimated from NEFSC autumn bottom trawl surveys in the Gulf of Maine region over a 38 year period. Lorenz curves were calculated for each NEFSC autumn bottom trawl survey between 1963 and 2000. The strata set used corresponded to that used in the stock assessment, strata 26-30, 36-40. Biomass values used in the analysis were estimates of minimum swept area biomass (kg) calculated for each stratum in each year. Cod biomass values were adjusted for differences in fishing power of the *Albatross IV* and the *Delaware II*, and for differences in the catchability of BMV doors and the polyvalent doors introduced to the survey in 1985.

Annual Lorenz curve plots (Figure A10) indicate that cod distribution in the Gulf of Maine became increasingly more evenly distributed between 1963 and the early 1980's, as indicated by the general declining trend in the concentration indices (Figure A11). However, in the second half of the time series, the concentration indices generally increase, indicating that cod biomass has become more concentrated in recent years. The 1982 concentration index is highly influenced by a one tow of cod in stratum 26.

Overall, patterns in cod distribution and concentration are consistent with the notion that, in recent years, the Gulf of Maine cod population has been primarily distributed in the inner, western regions of the Gulf of Maine. Thus, a higher proportion of the stock is now found within a relatively small area compared to earlier periods. This contraction in the overall distribution of the stock may have implications on catchability in the fishery.

MORTALITY

Total Mortality Estimates

Pooled estimates of instantaneous total mortality (Z) were calculated for 7 time periods encompassed by the NEFSC spring and autumn offshore surveys: 1964-1967, 1968-1976, 1977-1982, 1983-1987, 1988-1992, 1993-1997, and 1998-1999 (Table A18). Total mortality was calculated from NEFSC survey catch per tow at age data (Table A16) for fully recruited age groups (ages 4+) by the $\log_e$ ratio of the pooled age 3+/age 4+ indices in the autumn surveys, and the pooled age 4+/age 5+ indices in the spring surveys. For example, the 1983-1987 values were derived from:

Spring: ln (Σ age 4+ for 1983-87/ Σ age 5+ for 1984-88)

Autumn: ln (Σ age 3+ for 1982-86/ Σ age 4+ for 1983-87)

Different age groups were used in the spring and autumn analyses so that Z could be evaluated over the same year classes within each time period.

Values of Z derived from the spring surveys are generally comparable to those calculated from the autumn data. Rather than selecting one survey series over the other, total mortality was calculated by taking a geometric mean of the spring and autumn estimates in each time period. The pooled estimates indicate that total mortality was relatively low (Z <= 0.50) between 1964 and 1982, but increased significantly thereafter to approximately 1.0 during 1983-1997, with an indication of a slight decline after 1997.

Estimates of total mortality were also derived on an annual basis from the spring and autumn survey data (Figure A12). These values of Z exhibit considerable inter-annual variability due primarily to year effects in the surveys. When smoothed, however, the annual estimates suggest the same pattern of increasing mortality during the1980s as indicated by the pooled analysis presented in Table A18.

Natural Mortality

Instantaneous natural mortality (M) for Gulf of Maine cod is assumed to be 0.20, the conventional value of M used for all Northwest Atlantic cod stocks (Paloheimo and Koehler 1968; Pinhorn 1975; Minet 1978).

ESTIMATION of FISHING MORTALITY RATES and STOCK SIZE

Virtual Population Analysis Calibration

The ADAPT calibration method (Parrack 1986, Gavaris 1988, Conser and Powers 1990) was used to derive estimates of terminal fishing mortality (F) in 2000. As in previous assessments, age-disaggregated analyses were performed. Several comparative ADAPT calibrations were performed, each using the same NEFSC spring and autumn (ages 2-6) and MADMF spring (ages 2-4) and autumn (age 2) survey series. Due to uncertainty in the interpretation of effort units in the 1994-1997 VTR data, USA commercial LPUE abundance indices for ages 2-6 were included only through 1993. This change effectively removed the influence of the LPUE indices on the terminal year outcome of the calibration, while preserving the historic relationship employed in the previous assessment. As in the previous assessments (see Mayo *et al.* 1998), the USA commercial LPUE indices from 1982 through 1993 were derived from the catch at age corresponding to the effort sub-fleet used in the estimation of standardized fishing effort as described by Mayo *et al.* (1994). The NEFSC and MADMF autumn indices were lagged forward by one age and one year whereby age 1-6 indices were related to age 2-7 stock sizes in the subsequent year for corresponding cohorts. All NEFSC and MADMF indices were related to January 1 stock sizes, and USA commercial LPUE indices were related to mid-year stock sizes.

The 1982-2000 commercial landings at age as provided in Table A9a include true ages 2-10 as well as the 11+ group. In recent years, however, fish beyond age 7 have been poorly represented. As reported by Mayo (1995), a calibration run employing an extended age complement (true ages 2-9) produced high coefficients of variation (CV) on the terminal year stock size estimates and variable estimates of F on ages 7-9 in most years prior to the terminal year. Therefore, as in previous assessments of this stock (Mayo *et al.* 1993; Mayo 1995, Mayo 1998, Mayo *et al.* 1998, NEFSC 2000, NEFSC 2001), all VPA formulations employed a reduced age range (ages 2-6 and 7+).

Impact of 1999 and 2000 Discards

The VPA for the current assessment includes commercial landings from1982-2000 (Table A10), commercial discards from 1999 and 2000, and recreational landings from 1982-2000 (Table A12). The final catch at age used in the VPA is listed in Table A13, including the discard adjustment to the 1999 and 2000 commercial landings at age. Comparative ADAPT calibrations were performed to evaluate the impact of a range of discard estimates in 1999 and 2000 on terminal year fishing mortality. A summary of each of three VPA runs (lower, middle, and upper range of discard estimates in 1999 and 2000) is provided in Table A19.

Very little difference in the overall model fit is evident. The total sums of squares and the mean square residuals are almost identical under all scenarios, although there is a slight degradation in the coefficients of variation (CV) of the stock size estimates (2001 Ns) under the upper end discards scenario (Table A19). The major impact of the various discard scenarios occurs in the estimation of terminal year F. The effects on stock size estimates is relatively minor. Differences in fishing mortality between the lower and middle range scenarios are minor, but the estimate of the 2000 fully recruited fishing mortality is substantially greater under the upper end discards scenario.

Impact of Including Recreational Landings

The VPA formulation presented above was employed in an additional analysis to evaluate the specific impact of including (or excluding) recreational landings in the VPA. In general, inclusion of the recreational landings served to marginally increase the estimates of fully recruited F, and to substantially revise upwards the estimates of stock size. The CVs on estimates of stock size in 2001 were almost identical to those obtained from the commercial-only base formulation. The retrospective pattern, evident in the commercial-only run, remains in the commercial/recreational run. Overall, inclusion of recreational landings does not alter our perception of current stock status.

Final VPA Formulation

The ADAPT formulation employed in the final VPA calibration was the same as that used in the previous assessments (Mayo *et al.* 1998, NEFSC 2000, NEFSC 2001) except for the inclusion of 1982-2000 recreational landings at age. This analysis provided direct stock size estimates for ages 2 through 6 in 2001 and corresponding estimates of F on ages 1 through 5 in 2000. Since the age at full recruitment was defined as 4 years in the input partial recruitment vector, the terminal year F on age 6 was estimated as the mean of the age 4 and 5 Fs; age 6 is also the oldest true age in the terminal year. In all years prior to the terminal year, F on the oldest true age (age 6) was determined from weighted estimates of Z for ages 4 through 6. In all years, the age 6 F was applied to the 7+ group. Spawning stock biomass (SSB) was calculated at spawning time (March 1) by applying a series of period-specific maturity ogives. The present analysis used a maturity schedule which reflected earlier maturation beginning in 1994.

Residuals of the observed and predicted indices derived from the final VPA formulation (Figure A13) do not indicate any consistent trends over the period of the VPA, except for the MADMF age 2 autumn index.

Virtual Population Analysis Results

Summary results from the final VPA calibration, including age-specific estimates of instantaneous fishing mortality (F), stock size, mean biomass and spawning stock biomass, are presented in Table A20. All parameter estimates were significant. Coefficients of variation on the stock size estimates ranged from 0.29 (age 4) to 0.53 (age 6), while CVs on the estimates of q were between 0.15 and 0.20. Slopes of the abundance index-stock size relationships increased with age through age 6 for the NEFSC spring and autumn surveys and the USA commercial LPUE indices. The MADMF spring indices exhibited an increasing trend in q between ages 2 and 4.

Average (ages 4-5, unweighted) fishing mortality in 2000 was estimated to be 0.73 (Table A20, Figure A14), a slight decrease from 1999. The spawning stock biomass of age 1 and older cod declined from 23,900 mt in 1982 to 15,300 mt in 1987. Following the recruitment and maturation of the strong 1987 year class, SSB increased to 24,200 mt in 1990 but declined to 11,400 mt in 1993, a 3-year reduction of 53% (Table A20, Figure A15). SSB increased to 14,600 mt in 1995 due to the growth and maturation of the 1992 year class, but declined again in 1996 and reached a record-low of 9,900 mt in 1998. SSB is estimated to have increased gradually between 1998 and 2000 (Table A20). Total stock size (ages 1+) has also declined sharply in recent years from 44.6 million fish in 1988 to an average of 12.4 million fish during 1996-1998 (Table A20), a decrease of 72% but is estimated to have increased to about 18-19 million fish in 1999 and 2000 due in large part to recruitment of the 1998 year class.

Since 1982, recruitment at age 1 has ranged from less than 3.5 million fish (1993, 1994, and 1995 year classes) to 25.2 million fish (1987 year class). Over the 1982-2000 period, geometric mean recruitment for the 1981-1999 year classes was 6.6 million fish. The 1987 year class is the highest in the 1982-2000 series and about twice the size of the next strongest year class. The1992 year class was of moderate strength, and the 1998 year class appears to be comparable (Table A20, Figure A15).

Precision of F and SSB

A bootstrap procedure (Efron 1982) was used to evaluate the precision of terminal year estimates, by generating 600 estimates of the 2000 fully recruited fishing mortality rate and spawning stock biomass. The distributions of the bootstrap estimates and the corresponding cumulative probability curves are shown in Figures A16 and A17. The cumulative probability expresses the likelihood that the fishing mortality rate was greater than a given level (Figure A16) or the likelihood that spawning stock biomass was less than a given level (Figure A17), when measurement error is considered.

Coefficients of variation for the 2001 stock size (numbers) estimates ranged from 0.29 (age 4) to 0.51 (age 2), and CVs for qs among all indices ranged from 0.14 to 0.18. The fully-recruited fishing mortality in 2000 for ages 4+ was reasonably well estimated (CV = 0.30). The mean bootstrap estimate of F (0.76) was slightly higher than the point estimate (0.73) from the VPA, and ranged from 0.41 to 2.36. The 80% probability interval ranges from 0.58 to 0.96 (Figure A16).

Although the abundance estimates for individual ages in 2001 had wide variances (CV = 0.29 to 0.51), the estimates of 2000 spawning stock biomass and mean biomass were robust (CV = 0.17 and 0.13, respectively). The bootstrap means were 2.9 - 4.6% higher than the VPA point estimates. The 80% probability interval for SSB ranges from 11,200 mt to 15,600 mt (Figure A17). Despite this variability, current spawning stock biomass is estimated to have increased substantially from recent record lows. In general, estimates of stock size and fishing mortality in the present assessment are estimated with about the same precision as in the previous assessment of this stock (Mayo *et al.*1998).

Retrospective Analysis

The previous retrospective analysis for this stock was reported by Mayo *et al.* (1998). Although the formulation used in the present assessment is the same as in the previous assessment, changes in management measures for this stock during 1997-2000 may have imposed additional uncertainty in the interpretation of current stock status. Therefore, the retrospective analyses were conducted again. Retrospective patterns with respect to terminal F are evident for Gulf of Maine cod in the most recent years (Figure A18). Mean F (ages 4-5, unweighted) in the terminal year had been generally under-estimated between 1994 and 1997 by the ADAPT calibration. The previous retrospective analysis by Mayo *et al.* (1998) indicated the same pattern, but was able to detect the opposite pattern (slight over-estimate of F) prior to 1994. Convergence of estimates is generally evident within 3 years, and often within 2 years, prior to any given terminal year. The retrospective analysis provides additional evidence that current fishing mortality on this stock, although somewhat lower than in previous years, remains relatively high. The retrospective pattern for age 1 recruits suggests that recruitment has generally been under-estimated over the past 6 years. The estimates of SSB have been relatively stable, although there was a slight tendency to under-estimate spawning biomass.

Spawning Stock and Recruitment

The relationship between spawning stock biomass and recruitment for Gulf of Maine cod was examined from two perspectives. First, a traditional spawning stock-recruitment scatterplot (Figure A19a) was constructed over the period covering the 1982-1999 year classes. In addition, a survival ratio, expressed as recruits per unit of SSB (R/SSB) was also calculated for each year class (Figure A19b). The stock-recruitment trajectory indicates the position of the most recent levels of SSB and recruitment in the lower left corner of the plot. The 1993-1997 year classes are all below average and the 1993-1995 year classes are the lowest in the series.

Survival ratios of pre-recruits up to age 1 are highest for the 1987, 1992 and 1998 year classes, the first two emerging from about average SSB and the 1998 year class from low SSB. Survival ratios were generally higher during the early-to-mid 1980s prior to the emergence of the large 1987 year class. Survival declined after the 1992 year class appeared, but increased in 1997 and 1998.

Hind-cast VPA Total Biomass Estimates

The 1982-2000 total stock biomass estimates derived from the VPA were extended back through time to 1963 utilizing NEFSC autumn research vessel survey biomass (kg/tow) indices. Estimates of the catchability coefficient (q), defined as the ratio between the survey index of total biomass and the VPA estimate of age 1+ stock biomass, were computed annually from 1982-2000. The average of these ratios was then applied to the entire 1963-2000 series of survey biomass indices to derive scaled estimates of total stock biomass. Results suggest that the total biomass of Gulf of Maine cod was likely to have been well over 100,000 mt during the 1960s and 1970s (Figure A20), and that VPA estimates beginning in 1982 may represent the condition of the stock following sharp declines in the late 1970s and early 1980s.

BIOLOGICAL REFERENCE POINTS

Yield and Spawning Stock Biomass per Recruit

Yield, total stock biomass, and spawning stock biomass per recruit analyses were performed using the method of Thompson and Bell (1934). Mean weights at age for application to yield per recruit were computed as a 17-year arithmetic average of total catch mean weights at age (Table A13b) over the 1982-1998 period. Mean weights at age for application to SSB per recruit were computed as a 17-year arithmetic average of stock mean weights at age (Table A14) over the 1982-1998 period. The 1999 and 2000 mean weights at age were excluded due to poor sampling of commercial landings during these years. The maturation ogive was the same as used in computing SSB during the 1994-2000 period in the VPA. To obtain the exploitation pattern for these analyses, a two-year geometric mean F at age was first computed over 1999 and 2000 from the final converged VPA results. These years were chosen specifically to encompass the period since enactment of the most recent increase in the minimum allowable mesh (165 mm). A smoothed exploitation pattern was then obtained by dividing the F at age by the mean unweighted F for ages 4-5, adjusted to the average partial recruitment for ages 4 and 5. The final exploitation pattern is as follows:

Age 1 0.000, Age 2 0.0134,
Age 3 0.2867, Age 4 0.9889,
Ages 5+ 1.000

This pattern is similar to that used in the 1998 assessment (Mayo *et al.*1998) for ages 1 through 3, but indicates increased selection of age 4 fish (from about 80% to 100%) compared to the 1998 assessment, possibly reflecting the inclusion of recreational data in the catch at age employed in the VPA. This partial recruitment pattern was used in yield and SSB per recruit calculations. Input data and results of the yield and SSB per recruit calculations are listed in Table A21 and are illustrated in Figure A21. The yield per recruit analyses indicate that $F_{0.1}$ = 0.15 and F_{max} = 0.27, and SSB per recruit calculations indicate that $F_{20\%}$ = 0.36. The yield per recruit reference points ($F_{0.1}$ and F_{max}), and the SSB per recruit reference point ($F_{20\%}$) are slightly lower than those reported in the 1998 assessment (Mayo *et al.*1998).

MSY-Based Reference Points

The existing estimates of B_{msy} and F_{msy} for Gulf of Maine cod were derived in 1998 from a biomass dynamics model (ASPIC; Prager 1994, 1995) integrating landings and relative biomass indices over the period 1963-1997 (Anon.1998). The biomass dynamics model analysis was conditioned on the relationship between age 1+ mean biomass derived from the 1997 VPA and biomass indices from the NEFSC spring and autumn surveys and the MADMF spring survey. Estimates of q, expressed as the ratio of the survey index to the age 1+ mean biomass, were fixed for each of the 3 surveys used to calibrate the production model. The analysis conditioned on age 1+ VPA mean biomass suggested that B_{msy} for Gulf of Maine cod was in the range of 33,000 mt and that the corresponding age 1+ F_{msy} was 0.31 (Fwb).

Because Gulf of Maine cod do not recruit to the fishery until age 2, the biomass dynamics model was re-run, conditioned on the relationship between age 2+ mean biomass derived from the current VPA and the same survey biomass indices updated through 2000. The revised analysis suggests that age 2+ B_{msy} for Gulf of Maine cod is in the range of 26,000 mt and that the corresponding age 2+ F_{msy} is 0.41 (Fwb). The modeling results indicate that stock biomass was above B_{msy} from the 1960s to the early 1980s but, as F exceeded F_{msy} in the early 1980s, stock biomass declined to low levels in the 1990s. The model further suggests that stock biomass increased sharply in 1999 and 2000, approaching B_{msy} as F declined below F_{msy}.

The rapid increase in biomass estimated by the biomass dynamics model is consistent with the recent increase in mean biomass derived from the VPA. However, the age-structured information provided by the VPA suggests that a considerable portion of the recent increase in mean biomass can be attributable to the recruitment of the 1998 year class. This effect is also reflected in the survey biomass indices which were incorporated into the production model analysis.

Age-Structured Production Model

As an alternative to the ASPIC biomass dynamics model, an age-structured production model (Sissenwine and Shepherd 1987) was developed using stock and recruitment observations from VPA and yield and biomass per recruit results. Age-structured production models are more informative than biomass dynamics models and can determine F_{msy} in the form of fully-recruited F, and can estimate SSB_{msy} as an alternative to B_{msy}. As concluded by the SAW Methods Working Group (Section D of this report), fully-recruited F_{msy} and SSB_{msy} are less sensitive to transient conditions and are directly comparable to VPA estimates of fully-recruited F and SSB. Comparison of current VPA results with reference points derived from the biomass dynamics model in Anon. (1998) is no longer appropriate, because the revised VPA includes recreational catch (1982-2000), and historical recreational catch is not available for a revised ASPIC analysis.

Age-Structured Production Model Results

A Beverton-Holt (1957) stock- recruit function was fit to the VPA estimates of SSB (in thousand mt) and age-1 recruitment (in millions) assuming lognormal error structure as:

(1) $R=(9.87 \cdot SSB)/(7.55+SSB)$

Estimates of yield, total biomass, and spawning biomass per recruit (YPR, BPR, and SPR) were derived from the Thompson-Bell (1934) dynamic pool model over a range of fully-recruited fishing mortality rates (Table A21, Figure A21). Equilibrium SSB (SSB*) was then calculated at various levels of fully-recruited fishing mortality to scale the dynamic pool estimates of SSB per recruit to absolute values as:

(2) $SSB^*=(9.87 \cdot SSB \text{ per recruit})-7.55$

Equilibrium recruitment (R*) was calculated as a function of SSB*, using equation 1, and equilibrium yield was calculated as the product of yield per recruit and R*.

F_{msy} was determined as the F that produced the maximum equilibrium yield (MSY), SSB_{msy} was the SSB* at F_{msy}, and B_{msy} was calculated as the product of yield per recruit and R* at F_{msy}. F on total biomass was also approximated as YPR/BPR for comparison to biomass dynamics results. Estimates of yield, F, SSB, and B from VPA were plotted with equilibrium calculations for comparison (Figure A22**).**

Results indicate that MSY=16,100 mt, fully-recruited F_{msy}=0.23, B_{msy}=90,300 mt, and that SSB_{msy}=78,000 mt (Figure A22). Alternative stock recruit decisions were considered for sensitivity analyses, including the use of hindcasted SSB and R observations (Brodziak et al. 2001) and assuming geometric mean recruitment. Estimates of F_{MSY} appeared to be robust to stock-recruit decisions, ranging from 0.23-0.27. However, MSY and B_{msy} were more sensitive to alternative stock recruit assumptions and were proportional to the estimate of maximum R. For comparison, F_{msy} on biomass (0.18) is substantially less than the estimate from the ASPIC biomass dynamics model, and B_{msy} is substantially greater than that from ASPIC. However, fully-recruited F_{msy} is only slightly less than F_{max}, which was the previous overfishing definition.

Differences between the existing F_{msy} and B_{msy} reference points derived from the biomass dynamics model and those derived from the present analysis based on the age-structured production model are due to many factors. First, the age structured approach better accounts for the productivity of the stock by specifically incorporating past and present information on the relationship between spawning stock and recruitment. In addition, the age structured approach is predicated on the yield and biomass per recruit analyses which incorporate age-specific growth and maturity information and the most appropriate exploitation pattern from the fishery. The age-aggregated approach employed in the biomass dynamics model subsumes all of the age-specific information into an estimate of a single parameter (r), the intrinsic rate of growth of the stock. This rate of increase may not always reflect the current growth potential of the stock. As noted above, the age-structured model is consistent with the assessment model because it is based on the SSB and recruitment from the current VPA, which includes recreational catch and recent discards. It is not currently possible to develop a long time series of recreational catch for a revised ASPIC analysis that could be comparable to the VPA.

The ASPIC approach was adopted by the Overfishing Definition Review Panel (Anon. 1998) as a means of applying a consistent method across as many stocks as possible, including those for which information on age structure was not yet available. In the case of the Gulf of Maine cod analysis, it was necessary to condition the biomass dynamics model (i.e., fix the estimates of q) based on the relationship between the NEFSC survey biomass indices and the corresponding VPA estimates of mean biomass in order to obtain a significant fit. This may have imposed constraints on the subsequent estimates of B_{msy} and F_{msy}.

Long-term projections, reported below, confirmed the results from the age-structured production model. The projection results indicate that long-term yield at the revised estimate of F_{MSY} (0.23) is significantly greater than the previous estimate of MSY (10,000 mt, Anon.1998) and is near the revised estimate of MSY (16,100 mt). Similarly, projected total stock biomass is significantly greater than the previous estimate of B_{msy} (33,000 mt) and close to the revised estimate of B_{msy} (90,300 mt). Furthermore, historical survey observations indicate that stock biomass exceeded the revised estimate of B_{MSY} during most of the 1960s and 1970s (Figure A20). Therefore, it appears that the previous estimates of MSY and B_{msy} were greatly underestimated (conversely it appears that F_{msy} was over-estimated), and revised reference point estimates are more consistent with long-term projections and historical observations.

CATCH and STOCK BIOMASS PROJECTIONS

Stochastic age-based projections (Brodziak and Rago MS1994) were performed over a 25-year time horizon to evaluate relative trajectories of stock biomass and catch under various fishing mortality scenarios. Recruitment was derived from the Beverton-Holt spawning stock-recruitment relationship employed in the age structured production model. Stock and catch mean weights at age, the maturity at age schedule, and the partial recruitment at age vector are the same as those employed in the yield and SSB per recruit analyses presented above. The 2001 survivors derived from 600 bootstrap iterations of the final VPA formulation were employed as the initial population vector. The projection was performed at four fishing mortality rates: $F_{0.1}$ (0.15), F_{msy} (0.23), F_{max} (0.27) and F_{sq} (0.73). Fully recruited fishing mortality in 2001 was assumed equal to that in 2000 (0.73) under all F scenarios. Short-term forecasts of 2002 catch and corresponding 2003 SSB were derived from the first two years of the long-term projections. All input data are provided in Table A22.

Short-Term Projection Results

The forecast for 2002 and 2003 is summarized in Table A22 and Figure A23. The results suggest that if the current fishing mortality rate is reduced to F_{max} or less in 2002, SSB will continue to increase in 2003. However, if F in 2002 remains at or near the 2000 F, SSB in 2003 will not increase beyond that projected for 2002.

Long-Term Projection Results

The long-term projections (Table A23; Figures A24 and A25) suggest that fishing at F_{msy} (0.23) will result in the total stock biomass stabilizing at about 92,000 mt providing total catches of about 15,000 mt per year. If F is not reduced from the current level (0.73), neither total stock biomass nor spawning stock biomass are likely to increase appreciably above the existing level. Because the spawning stock-recruit relationship for this stock is relatively flat across most observed levels of SSB (Figure A22), recruitment is estimated to be only slightly impaired at this high fishing mortality rate. Given the recent trends in observed recruitment at low SSB, this is an unlikely optimistic outcome of these projections.

CONCLUSIONS

The Gulf of Maine cod stock remains at a low biomass level, although there are indications of a recent increase in total biomass and spawning stock biomass in 1999 and 2000.

Fully recruited fishing mortality appears to have declined only slightly in 2000 (0.73), indicating that F continues to remain very high relative to fully recruited F reference points ($F_{0.1}$ = 0.15; F_{msy} = 0.23; F_{max} = 0.27). Spawning stock biomass (SSB) declined from over 24,000 mt in 1990 to a low of 9,900 mt in 1998, but increased to 13,100 mt in 2000.

Biomass weighted F on ages 1+ generally fluctuated between 0.4 and 0.6 during 1982-1997, except for the period 1988-1989 when the strong 1987 year class influenced the calculation significantly. Biomass weighted F on ages 1+ declined to 0.30 in 1999 and to 0.23 in 2000, but these estimates are influenced to a large extent by the entry of the 1998 year class. Mean biomass (ages 1+) declined from a maximum of 42,700 mt in 1989 to 14,800 mt in 1997 and 1998, but has since increased to 26,000 mt in 2000, primarily on the strength of the 1998 year class.

Total (age 1+) stock biomass in 2001 is slightly above 1/4 of the revised B_{msy} reference point (90,300 mt) and fully recruited F in 2000 is about 3 times greater than the revised F_{msy} reference point (0.23).

A substantial retrospective pattern has existed in the VPA results for this stock whereby fully recruited F has generally been underestimated in the terminal year since 1994. In the retrospective analysis of the present assessment, F_{1998} and F_{1999} appear to have been slightly overestimated, while terminal Fs from 1994-1997 were underestimated.

SARC COMMENTS

Discards

Three methods for calculating discards were presented. The first method computes discards on a quarterly basis using sea sample data. The SARC agreed that this method does not have enough resolution to track discards accurately when trip limits are changing on a monthly basis. Further, the sampling level is low and the rate of discarding is likely to be very different depending on whether or not an observer is on board. The second method uses VTR data. These data allow discarding to be computed on a monthly basis, thus providing the resolution required to track trip limit changes. However, serious questions were raised with regard to the quantity and quality of the data and the approach of using the discard-to-kept ratio when it was revealed that the data are highly skewed. Coding problems, which did not distinguish between zero discards and null data, were an added concern. The SARC concluded the calculation of discards from the VTR data could not be accepted in the present form. The third method provided a calculation of discards for 1999 and 2000 based on a model of trip level economics applied to the 1996 and 1997 VTR data. This approach has the advantage of being independent of the suspect 1999 and 2000 VTR data. While considered to be very promising, sensitivity to assumptions needs to be evaluated and predictions need to be compared with data.

The SARC agreed that it was not appropriate to use discards calculated from any of the three approaches or to derive a value from some combination of these data. Instead, the decision was made to carry out three VPA runs with zero discard values for the period prior to 1999 and "ballpark" values for 1999 and 2000 which bracketed the possible range as well as a "middle" run. The terminal F's were fairly robust to changes in assumed discards and survivors in the final year changed only slightly. In addition to the problem of the magnitude of the discards, it was noted that "high-grading" was likely to be occurring when severe trip limits were imposed, and consequently the sizes and ages of discarded fish are also uncertain**.**

The SARC noted that the sampling of the large cod category in recent years, particularly in 2000, was poor, making it difficult to derive a catch at age matrix, even when quarterly estimates were pooled. Evidence of the problem can be seen by the low weights of the 7+ age group in 1999 and 2000. An approach of augmenting the port sample data for 2000 with length frequencies from sea sampling until the mean weight in the 7+ category appeared reasonable was considered; however, the approach is subjective and masks the problem of inadequate sampling. The SARC decided to proceed based on the port sampling data.

Recreational catches

Recreational catches have not previously been included in the VPA for this stock; however, the magnitude has been increasing and it now represents between 24% and 34% of the catches and cannot be ignored. Although the sampling of these catches is less than adequate, the SARC felt that the data should be included in the analysis because it represents a significant part of the catch and its inclusion will result in a more accurately estimated q for scaling population size in the unconverged portion of the time series. It was noted that the total number of cod caught in 2000 is nearly double the 1999 value and it was thought that this apparent change may in part be a consequence of inadequate sampling.

Geographical changes in distribution

It was noted that there is a geographical component to the abundance of cod over time. In recent years the Gulf of Maine cod population has been concentrated in the inner, western regions of the Gulf of Maine It is not apparent what factors have caused the increased concentration, and it was suggested by SARC that the weighted cumulative probability distribution approach of Smith and Page (1996) might be useful for examining the possible role of physical factors. While the size of the stock had declined considerably overall, this will be less apparent to those only looking at the inner Gulf of Maine. These changes may also influence the CPUE index. The SARC felt that it would be very useful to include the stock abundance trends in the different areas as part of the public presentations to clear up misconceptions that might exist.

Model calibration

The SARC evaluated the low, middle and high discarding VPA runs and noted that while the estimates of survivors are very similar there is some difference in the estimates of F. The diagnostics provided no support for favoring one discarding scenario over another. The middle run was accepted as the final model for projection purposes. It was noted that zeros for any survey at age index values are treated as missing in the minimization. Although there are not many instances in the age ranges used, this could potentially bias the VPA estimates. It was also noted that the VPA estimates are scaled by the assumed value for M and consequently caution should be applied in interpreting these estimates in absolute terms.

Biological reference points

It was necessary to recompute the biological reference points in the current assessment because of the inclusion of the recreational catch. The SARC felt that as a general principle, reference points should be recomputed in each assessment based on the updated information.

In contrast to previous assessments, the SARC decided that it was more appropriate to compute reference points from the age structured model rather than from the age-aggregated biomass dynamics model. The age structured model uses more of the available information related to the stock and there was no reason to think that reference points derived from the biomass dynamics model would be more robust with respect to uncertainties. It was agreed that the results from the age structured model would be compared qualitatively with those from the biomass dynamics model.

The SARC agreed that reference points should be computed using the Sissenwine and Shepherd (1987) approach. The SARC evaluated the sensitivity of reference point estimates to decisions regarding recruitment models. It was determined that F_{msy} estimates are relatively robust to alternative recruitment decisions but that MSY and B_{msy} were more sensitive. The SARC concluded that long term projections should be based on the same Beverton-Holt stock-recruitment model used in the age-structured production model which was fitted to the values estimated by the VPA with no hind-casting.

The SARC debated the relative merits of using total biomass vs spawning stock biomass as the basis for computing reference points. The former includes information about recruits, but is more likely to vary through time. Spawning biomass is more stable over time, but does not contain information about recruitment. Focusing on spawning biomass may be preferable if the primary management goal is to monitor and maintain the spawning stock.

Projections

The SARC emphasized that long term projections using age structured models provided a valuable tool for evaluating rebuilding scenarios. Current limitations of the software are for a 25 year time horizon which may not be long enough for the stock to reach equilibrium conditions.

Long term projections were done using the status quo F (0.73) as well as lower F's corresponding to biological reference points ($F_{0.1}$, F_{msy}, F_{max}). The annual landings (yield) did not differ very much between these runs, although fishing at the higher F resulted in a much lower stock biomass after 25 years. Fishing at the higher F is risky because the resulting stock biomass is low which makes it vulnerable to stochastic perturbations. The long term yield and spawning stock biomass predicted by the age-based production model and the long term projections were similar.

RESEARCH RECOMMENDATIONS

- Improve information on discards through increased observer coverage, further evaluation of VTR data and statistical analysis appropriate to the data.

  Examine the predicted distribution of trips from the economic trip limit model with actual distribution of trips.

- Conduct a more thorough comparison of party/charter boat catch estimates from VTR and MRFSS sampling.

- Increase the sampling of lengths and ages from both the commercial and the recreational catches, including the Maine DMR party boat survey

- Evaluate the uncertainty associated with the estimates of reference points from age-structured models and further develop methods to compare the uncertainty in projected biomass and fishing mortality with the uncertainty in the reference points.

- Evaluate physical factors that may be associated with increased cod concentration within the stock area using the weighted cumulative probability approach of Smith and Page (1996).

- Evaluate alternative approaches for fitting the Beverton and Holt stock recruitment model. See Myers, R.A. Bridson, J. and Barrownan, N. J. 1995. Summary of worldwide stock and recruit data. Can. Tech. Rept. Fish. Aquat. Sci. No. 2024.

- Develop approaches within the VPA calibration for distinguishing between zero's and null data. Consider adding computer code to track and list additional diagnostics about population state through time during simulation.

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Table A1. A brief chronology of management measures affecting Gulf of Maine cod.

1973
Total Allowable Catch (TAC) limits implemented by the International Commission for the Northwest Atlantic Fisheries (ICNAF) for Division 5Y (Gulf of Maine) cod.
Minimum codend mesh size at 4 ½" (114 mm).

1977
Fishery Conservation and Management Act (FCMA) implemented. Management under the auspices of the New England Fishery Management Council.

1977-1982
Management of groundfish resources under the Fishery Management Plan (FMP) for Atlantic groundfish.
Carried forward TACs; implemented by vessel tonnage class and calendar quarter with trip limits.
Minimum codend mesh size increased to 5 1/8" (130 mm).

1982-1985
Management of groundfish resources under the "Interim" Plan for Atlantic groundfish.
Eliminated direct catch controls; primary tools for fishery management were minimum mesh sizes and minimum landing sizes.

1983
Minimum codend mesh size increased to 5 ½" (140 mm).

1985
Northeast Multi-species FMP implemented. Amendments 1-4 retained indirect controls, including minimum mesh and minimum fish landing sizes.

1989
Minimum fish size = 19" (48 cm) for commercial and recreational sectors.

1994
January 1 Amendment 5
50% reduction in F and effort over 5-7 years.
Days at Sea (DAS) monitoring
Implemented a Mandatory Reporting Scheme

May 1 Amendment 5 (again)
Minimum codend mesh size increased to 6" (152 mm), diamond or square.

1996
May 1 Amendment 7
Established rebuilding program based on Fmax target fishing mortality
Established Target TACs
Accelerated Days at Sea reductions
Established Framework Adjustment Process and the Multi-species Monitoring Committee to permit annual adjustments to management measures
Minimum fish size increased to 20" (51 cm) for recreational sector.

Table A1 (Continued).

1997
May 1 Framework 20
Target TAC: 2,605 mt
Gulf of Maine cod trip limit: 1,000 or 1,500 lbs/day
Minimum fish size increased to 21" (53 cm) for recreational sector.

1998
May 1 Framework 25
Target TAC: 1,800 mt with trigger provision
Gulf of Maine cod trip limit 700 lbs/day
Series of 1-month rolling closures from Massachusetts Bay to Penobscot Bay.
Year-round closure of portions of Jeffreys Ledge and Stellwagen Bank (WGOM Closed Area)

June 25 Framework trigger pulled
Gulf of Maine cod trip limit: 400 lbs/day

1999
February 1 Framework 26
Additional month-block (30x30 minutes) closures implemented for February and April

May 1 Framework 27
Target TAC: 1,300 mt with trigger provision
Gulf of Maine cod trip limit: 200 lbs/day
Minimum square mesh increased to 6.5" (165 mm).

May 28 Framework trigger pulled
Gulf of Maine cod trip limit: 30 lbs/day

August 3 Interim Rule
Gulf of Maine cod trip limit: 100 lbs/day

2000
January 5 Framework 31
Gulf of Maine cod trip limit: 400 lbs/day- 4,000 maximum/trip.
Additional month-block (30x30 minutes) closures implemented for February

May 1 Framework 33
Target TAC: 1,900 mt with trigger provision
Continuation of most Framework 27 and 31 measures
Year-round closure of WGOM area extended until April, 2002.

November 1 Framework trigger pulled
One-month closure of Cashes Ledge

2001
January 1 Framework trigger pulled
Additional month-block (30x30 minutes) closures implemented for January

May 1 Annual Adjustment
Target TAC: 1,118 mt
Continuation of most Framework 27 and 31, and 33 measures.

Table A2. Commercial landings (metric tons, live) of Atlantic cod the Gulf of Maine (NAFO Division 5Y), 1960 - 2000.[1]

	Gulf of Maine				
Year	USA	Canada	USSR	Other	Total
1960	3448	129	-	-	3577
1961	3216	18	-	-	3234
1962	2989	83	-	-	3072
1963	2595	3	133	-	2731
1964	3226	25	-	-	3251
1965	3780	148	-	-	3928
1966	4008	384	-	-	4392
1967	5676	297	-	-	5973
1968	6360	61	-	-	6421
1969	8157	59	-	268	8484
1970	7812	26	-	423	8261
1971	7380	119	-	163	7662
1972	6776	53	11	77	6917
1973	6069	68	-	9	6146
1974	7639	120	-	5	7764
1975	8903	86	-	26	9015
1976	10172	16	-	-	10188
1977	12426	-	-	-	12426
1978	12426	-	-	-	12426
1979	11680	-	-	-	11680
1980	13528	-	-	-	13528
1981	12534	-	-	-	12534
1982	13582	-	-	-	13582
1983	13981	-	-	-	13981
1984	10806	-	-	-	10806
1985	10693	-	-	-	10693
1986	9664	-	-	-	9664
1987	7527	-	-	-	7527
1988	7958	-	-	-	7958
1989	10397	-	-	-	10397
1990	15154	-	-	-	15154
1991	17781	-	-	-	17781
1992	10891	-	-	-	10891
1993	8287	-	-	-	8287
1994*	7877	-	-	-	7877
1995*	6798	-	-	-	6798
1996*	7194	-	-	-	7194
1997*	5421	-	-	-	5421
1998*	4156	-	-	-	4156
1999*	1636	-	-	-	1636
2000*	3730	-	-	-	3730

[*] Provisional

[1] USA 1960-1993 landings from NMFS, NEFSC Detailed Weighout Files and Canvass data.
[2] USA 1994-2000 landings estimated by prorating NMFS, NEFSC Detailed Weighout data by Vessel Trip Reports.

Table A3. Distribution of USA commercial landings (metric tons, live) of Atlantic cod from the Gulf of Maine (Area 5Y), by gear type, 1965 - 2000. The percentage of total USA commercial landings of Atlantic cod from the Gulf of Maine, by gear type, is also presented for each year. Data only reflect Gulf of Maine cod landings that could be identified by gear type.

	Landings (metric tons, live)						Percentage of Annual Landings					
Year	Otter Trawl	Sink Gill Net	Line Trawl	Handline	Other Gear	Total	Otter Trawl	Sink Gill Net	Line Trawl	Handline	Other Gear	Total
1965	2480	501	462	168	1	3612	68.7	13.9	12.8	4.6	-	100.0
1966	2549	830	308	150	4	3841	66.4	21.6	8.0	3.9	0.1	100.0
1967	4312	734	206	274	<1	5526	78.0	13.3	3.7	5.0	-	100.0
1968	4143	1377	213	339	4	6076	68.2	22.7	3.5	5.6	-	100.0
1969	6553	851	258	162	4	7828	83.7	10.9	3.3	2.1	-	100.0
1970	5967	951	407	178	9	7512	79.4	12.7	5.4	2.4	0.1	100.0
1971	5117	1043	927	98	8	7193	71.1	14.5	12.9	1.4	0.1	100.0
1972	4004	1492	1234	54	2	6786	59.0	22.0	18.2	0.8	-	100.0
1973	3542	1182	1305	23	9	6061	58.4	19.5	21.5	0.4	0.2	100.0
1974	5056	1412	904	36	17	7425	68.1	19.0	12.2	0.5	0.2	100.0
1975	6255	1480	920	12	8	8675	72.1	17.1	10.6	0.1	0.1	100.0
1976	6701	2511	621	4	41	9878	67.8	25.4	6.3	0.1	0.4	100.0
1977	8415	2872	534	6	166 [a]	11993	70.2	23.9	4.5	-	1.4	100.0
1978	7958	3438	393	10	91 [b]	11890	66.9	28.9	3.3	0.1	0.8	100.0
1979	7567	2900	334	19	167 [c]	10987	68.9	26.4	3.0	0.2	1.5	100.0
1980	8420	3733	251	48	61	12513	67.3	29.8	2.0	0.4	0.5	100.0
1981	7937	4102	276	23	45	12383	64.1	33.1	2.2	0.2	0.4	100.0
1982	9758	3453	188	46	34	13479	72.4	25.6	1.4	0.3	0.3	100.0
1983	9975	3744	77	4	67	13867	71.9	27.0	0.6	-	0.5	100.0
1984	6646	3985	22	3	69	10725	62.0	37.2	0.2	-	0.6	100.0
1985	7119	3090	55	6	326 [d]	10596	67.2	29.1	0.5	0.1	3.1	100.0
1986	6664	2692	56	12	180 [e]	9604	69.4	28.0	0.6	0.1	1.9	100.0
1987	4356	2994	70	13	68	7501	58.1	39.9	0.9	0.2	0.9	100.0
1988	4513	3308	68	27	22	7938	56.9	41.7	0.8	0.3	0.3	100.0
1989	6152	4000	72	36	119 [f]	10379	59.3	38.5	0.7	0.4	1.1	100.0
1990	10420	4343	126	20	186 [g]	15095	69.0	28.8	0.8	0.1	1.2	100.0
1991	13049	4158	212	59	266 [h]	17744	73.5	23.4	1.2	0.3	1.5	100.0
1992	7344	3081	359	94	14	10891	67.4	28.3	3.3	0.9	0.1	100.0
1993	4876	3130	236	16	29	8287	58.8	37.8	2.8	0.2	0.3	100.0
1994	4205	3317	338	[i]	17	7877	53.4	42.1	4.3	[i]	0.2	100.0
1995	3450	3050	281	[i]	17	6798	50.8	44.9	4.1	[i]	0.3	100.0
1996	4012	2825	335	[i]	22	7194	55.8	39.3	4.7	[i]	0.3	100.0
1997	2798	2175	426	[i]	22	5421	51.6	40.1	7.9	[i]	0.4	100.0
1998	2329	1431	381	[i]	15	4156	56.0	34.4	9.2	[i]	0.4	100.0
1999	838	494	302	[I]	2	1630	51.2	30.2	18.5	[I]	0.1	100.0
2000	2007	1393	309	[I]	20	3730	53.8	37.4	8.3	[I]	0.5	100.0

[a] Of 166 mt landed, 107 mt were by mid-water pair trawl and 42 mt were by drifiting gill nets.
[b] Of 91 mt landed, 56 mt were by Danish seine and 27 mt were by drifting gill nets.
[c] Of 167 mt landed, 199 mt were by drifting gill nets and 38 mt were by Danish seine.
[d] Of 326 mt landed, 268 mt were by longline and 37 mt were by Danish seine.
[e] Of 181 mt landed, 152 mt were by longline and 23 mt were by Danish seine.
[f] Of 199 mt landed, 75 mt were by longline and 27 mt were by Danish seine.
[g] Of 186 mt landed, 159 mt were by longline and 16 mt were by Danish seine.
[h] Of 266 mt landed, 245 mt were by longline and 9 mt were by Danish seine.
[i] Handline and line trawl combined.

Table A4. Discard and total catch estimates (metric tons, live) for Gulf of Maine cod by otter trawl, shrimp trawl, and sink gillnet gear derived from 1989-2000 NEFSC Sea Sample data.

Year	Total Landings	Discard Estimates: Included Landings	Discard Estimates: Discard Estimate	Discard Estimates: Discard to Landings Ratio	Total Discard	Total Catch
1989	10397	10182	1513	0.1486	1545	11942
1990	15154	14827	3521	0.2375	3598	18752
1991	17781	17374	1025	0.0590	1049	18830
1992	10891	10511	582	0.0554	603	11494
1993	8287	8058	320	0.0397	329	8616
1994	7877	7522	228	0.0303	239	8116
1995	6798	6500	408	0.0627	426	7224
1996	7194	6837	189	0.0277	199	7393
1997	5421	4974	164	0.0330	179	5600
1998	4156	3760	139	0.0370	154	4310
1999	1636	1332	2141	1.6074	2630	4266
2000	3730	3401	1067	0.3137	1170	4900

Table A5a. 1999 Discard estimation procedure for Gulf of Maine cod based on 1999 VTR records.

	Month of the Year												
D/K Ratio	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	0.164	0.149	0.149	0.176	0.785	8.403	5.706	0.820	1.153	1.227	2.548	2.157	
100	0.428	0.006	0.041	0.019	1.135	10.731	13.596	3.718	4.393	6.027	7.216	3.136	
Other	0.114	0.052	0.318	0.011	0.042	3.651	4.837	0.014	0.016	0.028	0.208	0.208	
Total													
Landings	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	141.6	68.1	112.5	112.5	185.4	44.9	20.5	22.2	21.1	18.9	30.3	57.8	835.8
100	81.1	36.2	30.3	111.4	109.8	29.2	38.9	36.2	38.9	31.4	24.3	38.4	606.1
Other	38.9	17.3	30.3	26.5	23.2	2.7	3.8	4.9	9.2	9.2	11.4	16.8	194.1
Total	261.7	121.6	173.0	250.3	318.4	76.8	63.3	63.3	69.2	59.5	66.0	113.0	1636.0
Disc	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	23.2	10.2	16.8	19.8	145.5	377.1	117.2	18.2	24.3	23.2	77.1	124.8	977.4
100	34.7	0.2	1.3	2.1	124.6	313.3	529.2	134.7	171.0	189.0	175.6	120.4	1795.9
Other	4.5	0.9	9.6	0.3	1.0	9.9	18.3	0.1	0.1	0.1	0.3	3.5	48.6
Total	62.4	11.3	27.7	22.1	271.0	700.2	664.8	152.9	195.4	212.3	253.0	248.6	2821.9
Catch	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	164.9	78.3	129.3	132.2	330.9	421.9	137.8	40.3	45.4	42.1	107.4	182.6	1813.2
100	115.8	36.4	31.5	113.4	234.3	342.5	568.2	170.9	209.9	220.3	199.9	158.8	2402.0
Other	43.4	18.2	39.9	26.8	24.2	12.6	22.1	4.9	9.3	9.3	11.7	20.3	242.7
Total	324.1	132.9	200.7	272.5	589.5	777.0	728.0	216.2	264.6	271.8	319.0	361.6	4457.9

Table A5b. Discard estimation procedure for Gulf of Maine cod based on 2000 VTR records.

					Month of the Year								
D/K Ratio	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	1.223	0.506	0.555	0.193	0.389	0.346	0.581	0.285	0.414	0.476	0.426	0.345	
100	0.816	0.258	0.282	0.447	0.287	0.876	1.039	0.567	1.764	0.674	1.127	0.694	
Other	0.242	0.056	0.041	0.183	0.164	0.017	0.233	0.556	0.554	0.200	0.088	0.117	
Total													
Landings	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	170.6	92.1	90.2	58.4	398.1	215.9	133.6	77.6	57.0	68.7	170.1	340.2	1872.5
100	58.9	25.7	69.6	55.6	169.6	357.5	253.7	192.5	108.9	116.4	115.0	121.5	1644.9
Other	30.4	15.9	20.1	8.9	30.8	22.0	7.9	4.2	14.0	9.8	4.2	44.4	212.6
Total	259.8	133.6	179.9	122.9	598.6	595.3	395.3	274.3	179.9	194.9	289.3	506.1	3730.0
Disc	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	208.6	46.5	50.1	11.3	155.0	74.6	77.6	22.1	23.6	32.7	72.4	117.4	891.8
100	48.0	6.6	19.6	24.9	48.8	313.2	263.7	109.1	192.1	78.4	129.5	84.3	1318.2
Other	7.4	0.9	0.8	1.6	5.1	0.4	1.8	2.3	7.8	2.0	0.4	5.2	35.6
Total	264.0	54.1	70.5	37.8	208.8	388.2	343.1	133.5	223.4	113.1	202.3	206.8	2245.6
Catch	1	2	3	4	5	6	7	8	9	10	11	12	Total
50	379.2	138.6	140.3	69.7	553.1	290.5	211.2	99.7	80.6	101.4	242.5	457.6	2764.3
100	106.9	32.3	89.3	80.5	218.4	670.6	517.4	301.7	301.0	194.8	244.5	205.8	2963.1
Other	37.7	16.8	20.9	10.5	35.9	22.3	9.8	6.5	21.8	11.8	4.6	49.6	248.2
Total	523.9	187.7	250.4	160.7	807.4	983.5	738.4	407.9	403.3	308.0	491.6	712.9	5975.6

Table A6a. Estimated Discard-to-Kept Ratios (discarded pounds to landed pounds).				
	Calendar Year 1999		Calendar Year 2000	
Sensitivity Trial	1996 Data	1997 Data	1996 Data	1997 Data
Minimum Share = 50%	1.80	1.95	0.73	0.72
Minimum Share = 25%	2.27	2.25	0.92	0.84
Minimum Share = 10%	2.47	2.34	0.99	0.87
Minimum Payment	2.00	2.05	0.81	0.78

Table A6b. Estimated Discards of Gulf of Maine Cod (metric tons).				
	Calendar Year 1999		Calendar Year 2000	
Sensitivity Trial	1996 Data	1997 Data	1996 Data	1997 Data
Minimum Share = 50%	2949	3194	2707	2701
Minimum Share = 25%	3719	3686	3432	3133
Minimum Share = 10%	4038	3832	3682	3253
Minimum Payment	3270	3362	3028	2919

Table A7. USA sampling of commercial Atlantic cod landings from the Gulf of Maine cod stock (NAFO Division 5Y), 1982 - 2000.

	Number of Samples				Number of Samples, by Market Category & Quarter															Annual Sampling Intensity			
	Length Samples		Age Samples		Scrod					Market					Large					No. of Tons Landed/Sample			
Year	No.	No. Fish Measured	No.	No. Fish Aged	Q1	Q2	Q3	Q4	∑	Q1	Q2	Q3	Q4	∑	Q1	Q2	Q3	Q4	∑	Scrod	Market	Large	∑
1982	48	3848	48	866	6	7	6	6	**25**	4	3	7	4	**18**	0	2	1	2	**5**	134	348	792	266
1983	71	5241	67	1348	14	10	10	4	**38**	4	10	6	2	**22**	1	3	5	2	**11**	106	294	318	197
1984	55	3925	55	1224	7	5	6	7	**25**	4	3	5	6	**18**	1	6	3	2	**12**	85	319	245	193
1985	69	5426	66	1546	5	6	7	5	**23**	8	6	7	4	**25**	7	5	3	6	**21**	95	229	132	155
1986	53	3970	51	1160	5	5	6	3	**19**	5	6	8	2	**21**	1	5	4	3	**13**	124	242	170	182
1987	43	3184	42	939	4	4	3	4	**15**	5	5	3	5	**18**	4	2	3	1	**10**	83	224	225	175
1988	34	2669	33	741	4	3	4	4	**15**	1	5	3	5	**14**	1	2	2	0	**5**	147	271	391	234
1989	32	2668	32	714	3	3	3	3	**12**	4	1	5	4	**14**	2	2	1	1	**6**	209	430	311	325
1990	39	2982	38	789	3	7	3	5	**18**	4	7	4	3	**18**	0	2	1	0	**3**	300	378	966	387
1991	56	4519	56	1152	2	10	4	3	**19**	5	11	11	3	**30**	0	3	3	1	**7**	250	313	519	318
1992	51	4086	51	1002	2	8	6	3	**19**	6	7	7	3	**23**	3	1	1	4	**9**	104	232	375	214
1993	23	1753	23	447	3	3	3	1	**10**	1	2	4	1	**8**	1	1	2	1	**5**	177	453	527	360
1994	30	2696	33	665	0	2	2	4	**8**	1	4	4	6	**15**	0	2	3	2	**7**	180	284	272	263
1995	31	2568	32	662	4	2	2	4	**12**	2	7	1	2	**12**	0	5	0	2	**7**	133	300	202	219
1996	77	7027	71	1483	6	5	7	9	**27**	7	9	10	12	**38**	1	3	3	5	**12**	62	116	79	93
1997	78	6657	74	1521	7	10	3	9	**29**	11	9	9	7	**36**	1	8	2	2	**13**	37	91	71	69
1998	46	4205	46	912	4	7	0	3	**14**	8	9	9	3	**29**	0	0	2	1	**3**	53	81	321	90
1999	15	1305	16	350	6	0	1	0	**7**	4	2	0	0	**6**	2	0	0	0	**2**	36	144	245	109
2000	61	4687	57	1300	12	5	3	4	**24**	12	14	4	6	**36**	0	0	0	1	**1**	14	62	1131	61

Source: 1982-1985 from Serchuk and Wigley (Woods Hole Lab. Ref 86-12); 1986-2000 from NEFSC files.

Table A8. Percentage (by weight) of USA commercial Atlantic cod landings from the Gulf of Maine (NAFO Division 5Y), by market category, 1964 - 2000.

	Gulf of Maine			
Year	Large	Market	Scrod	Total [a]
1964	29	59	12	100
1965	39	54	7	100
1966	42	48	10	100
1967	41	41	17	100
1968	47	43	9	100
1969	35	55	9	100
1970	43	52	6	100
1971	52	42	6	100
1972	58	35	7	100
1973	52	36	11	100
1974	39	33	28	100
1975	32	42	26	100
1976	29	45	20	100
1977	33	42	22	100
1978	38	44	17	100
1979	37	49	14	100
1980	36	45	19	100
1981	29	45	22	100
1982	29	45	24	100
1983	25	45	28	100
1984	26	51	19	100
1985	25	51	20	100
1986	22	51	23	100
1987	29	52	16	100
1988	26	45	23	100
1989	17	55	23	100
1990	34	43	19	100
1991	26	51	20	100
1992	31	49	18	100
1993	32	44	21	100
1994	24	54	18	100
1995	21	53	23	100
1996	13	61	23	100
1997	17	60	20	100
1998	23	57	18	100
1999	29	53	16	100
2000	30	59	9	100

[a] Includes landings of 'mixed' cod.

Table A9a. Commercial landings at age (thousands of fish; metric tons) of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000.

Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Total
Commercial Landings at Age in Numbers (000's)												
1982	30	1380	1633	1143	633	69	91	61	41	4	33	5118
1983	-	866	2357	1058	638	422	47	61	23	9	15	5496
1984	4	446	1240	1500	437	194	74	19	15	11	17	3957
1985	-	407	1445	991	630	128	78	32	4	11	11	3737
1986	-	84	2164	813	250	177	39	24	20	4	8	3583
1987	2	216	595	1109	277	66	51	9	8	8	3	2344
1988	-	160	1443	953	406	43	9	17	1	2	1	3035
1989	-	337	1583	1454	449	81	35	6	3	5	7	3960
1990	-	205	3425	2064	430	157	27	30	10	15	17	6380
1991	-	344	934	4161	851	143	41	30	6	1	1	6512
1992	-	313	530	484	2018	202	62	7	12	3	-	3631
1993	-	76	1487	641	129	457	28	6	2	-	-	2825
1994	-	29	1016	1135	288	72	54	17	13	1	1	2626
1995	-	218	880	1153	194	12	8	22	3	1	-	2491
1996	-	65	584	1738	347	45	5	2	3	-	-	2789
1997	-	53	438	435	832	68	4	1	1	1	1	1834
1998	-	94	390	542	165	193	8	1	1	1	-	1395
1999	-	-	178	192	90	27	28	6	2	-	-	523
2000	-	42	239	569	141	64	8	7	3	-	-	1074
2000a	-	42	233	523	112	34	5	32	30	9	1	1020
Commercial Landings at Age in Weight (Tons)												
1982	24	1595	2717	3160	3019	461	813	608	531	41	613	13582
1983	-	1009	3913	2619	2410	2518	271	643	227	102	269	13981
1984	3	516	2071	4080	1607	1145	603	186	193	152	250	10816
1985	-	513	2523	2816	2814	705	615	363	51	141	152	10693
1986	-	110	3976	2375	1153	1072	296	243	253	54	132	9664
1987	2	283	1001	3641	1340	451	455	88	116	110	40	7527
1988	-	203	2715	2311	2097	295	85	191	11	36	14	7958
1989	-	420	2811	4351	1737	325	323	67	43	87	163	10397
1990	-	219	5794	4687	1834	1200	290	354	153	214	350	15095
1991	-	388	1463	10455	3520	1045	399	369	93	32	17	17781
1992	-	480	1019	1313	6175	1011	594	88	161	49	-	10891
1993	-	99	2809	1611	561	2819	281	79	27	-	-	8286
1994	-	43	1975	3576	991	442	451	218	156	20	6	7877
1995	-	361	1689	3200	997	96	92	291	45	27	-	6798
1996	-	110	1247	4131	1267	333	49	18	39	-	-	7194
1997	-	92	977	1308	2658	316	36	15	7	10	2	5421
1998	-	120	816	1614	693	812	67	13	12	13	-	4157
1999	-	-	315	520	361	155	203	54	28	-	-	1636
2000	-	68	578	1962	621	366	45	55	36	-	-	3730
2000a	-	68	541	1690	443	180	25	294	345	125	20	3730

a 2000 Estimates include additional length data from sea sample trips.

Table A9b. Mean weight (kg) and mean length (cm) at age of commercial landings of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000.

	Age											
Year	1	2	3	4	5	6	7	8	9	10	11+	Average
Commercial Landings Mean Weight(kg) at Age												
1982	0.801	1.156	1.664	2.764	4.770	6.739	8.944	9.931	12.922	10.618	18.456	2.654
1983	-	1.164	1.660	2.475	3.778	5.962	5.808	10.522	10.089	10.898	17.813	2.544
1984	0.589	1.159	1.670	2.721	3.677	5.898	8.119	9.595	12.889	13.951	15.028	2.731
1985	-	1.260	1.746	2.840	4.466	5.525	7.901	11.218	11.420	13.386	14.523	2.861
1986	-	1.304	1.837	2.923	4.619	6.067	7.669	10.030	12.463	12.907	16.554	2.698
1987	1.028	1.313	1.684	3.283	4.831	6.824	8.878	10.023	13.752	14.738	14.596	3.212
1988	-	1.268	1.881	2.426	5.166	6.767	9.932	11.126	14.960	15.763	20.356	2.622
1989	-	1.247	1.776	2.993	3.864	4.872	9.267	11.938	14.806	18.196	21.521	2.626
1990	-	1.071	1.692	2.271	4.265	7.645	10.734	11.758	15.015	14.784	20.295	2.366
1991	-	1.130	1.568	2.512	4.136	7.309	9.642	12.322	15.547	24.328	21.885	2.731
1992	-	1.533	1.922	2.714	3.061	5.000	9.566	12.462	13.449	16.631	-	2.999
1993	-	1.293	1.889	2.513	4.356	6.174	9.999	13.869	17.544	-	-	2.933
1994	-	1.450	1.943	3.151	3.444	6.132	8.321	12.628	12.052	21.532	19.369	3.000
1995	-	1.652	1.921	2.775	5.142	8.290	10.755	12.914	16.433	21.504	-	2.728
1996	-	1.687	2.136	2.376	3.648	7.376	10.440	11.928	13.471	-	-	2.580
1997	-	1.733	2.233	3.007	3.193	4.649	8.543	13.439	14.787	16.075	21.356	2.958
1998	-	1.277	2.089	2.979	4.191	4.211	8.538	11.747	19.369	20.847	-	2.980
1999	-	-	1.774	2.704	4.020	5.727	7.254	9.231	12.542	-	-	3.128
2000	-	1.627	2.415	3.447	4.399	5.702	5.551	8.344	10.952	-	-	3.474
2000a	-	1.627	2.323	3.233	3.971	5.298	5.115	9.297	11.340	13.830	17.514	3.657
Commercial Landings Mean Length (cm) at Age												
1982	43.2	48.3	53.8	63.4	76.8	86.1	94.6	97.9	107.4	101.0	120.7	59.9
1983	-	48.6	53.8	61.4	70.8	82.4	80.5	98.8	97.5	100.0	118.7	59.8
1984	39.0	48.4	54.1	63.4	69.7	81.8	91.5	96.7	106.9	109.6	112.0	61.6
1985	-	49.8	55.1	64.6	74.9	80.3	90.8	101.9	103.1	108.2	109.7	62.8
1986	-	50.3	55.9	65.0	75.4	82.6	89.9	98.7	105.8	107.5	116.2	61.6
1987	47.0	50.4	54.4	67.8	76.9	86.5	93.8	98.7	109.5	111.7	111.3	65.4
1988	-	50.1	56.4	61.1	78.7	86.4	98.6	102.3	113.0	114.8	125.0	61.4
1989	-	49.8	55.5	65.7	71.5	76.7	95.8	103.4	112.6	120.4	126.8	61.7
1990	-	47.5	54.8	60.0	73.7	90.0	100.9	104.0	111.8	112.6	124.6	59.2
1991	-	47.7	52.6	61.8	72.6	88.6	97.2	105.0	113.3	132.5	128.0	62.2
1992	-	53.1	56.6	62.9	65.6	77.0	97.3	106.1	109.1	117.0	-	64.3
1993	-	50.5	56.8	61.7	74.2	83.7	98.6	110.0	119.1	-	-	63.5
1994	-	52.4	57.2	66.6	68.1	82.7	92.0	106.4	104.9	127.3	123.0	64.4
1995	-	54.4	56.9	63.4	78.6	92.5	101.1	107.2	116.1	127.2	-	62.3
1996	-	54.6	58.8	60.7	69.3	88.9	99.9	104.8	108.7	-	-	61.8
1997	-	55.0	59.7	65.4	66.4	74.9	93.3	108.7	112.2	115.6	127.0	64.7
1998	-	50.1	58.4	65.1	72.9	72.7	92.9	102.2	123.0	126.0	-	64.4
1999	-	-	55.5	63.4	71.7	80.8	88.3	96.2	106.6	-	-	64.9
2000	-	54.1	60.8	66.2	74.6	82.1	81.3	93.3	102.0	-	-	68.3
2000a	-	54.1	60.2	64.8	72.2	80.0	79.1	96.7	103.2	110.1	119.0	68.6

a 2000 Estimates include additional length data from sea sample trips.

Table A10a. Commercial landings at age (thousands of fish; metric tons)of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Partial Input data for Virtual Population Analysis).

Year	Age 1	2	3	4	5	6	7+	Total
Commercial Landings at Age in Numbers (000's)								
1982	30	1380	1633	1143	633	69	230	5118
1983	-	866	2357	1058	638	422	155	5496
1984	4	446	1240	1500	437	194	136	3957
1985	-	407	1445	991	630	128	136	3737
1986	-	84	2164	813	250	177	95	3583
1987	2	216	595	1109	277	66	79	2344
1988	-	160	1443	953	406	43	30	3035
1989	-	337	1583	1454	449	81	56	3960
1990	-	205	3425	2064	430	157	99	6380
1991	-	344	934	4161	851	143	79	6512
1992	-	313	530	484	2018	202	84	3631
1993	-	76	1487	641	129	457	36	2825
1994	-	29	1016	1135	288	72	86	2626
1995	-	218	880	1153	194	12	34	2491
1996	-	65	584	1738	347	45	10	2789
1997	-	53	438	435	832	68	8	1834
1998	-	94	390	542	165	193	10	1395
1999	-	-	178	192	90	27	36	523
2000	-	42	239	569	141	64	18	1074
2000a	-	42	233	523	112	34	77	1020
Commercial Landings at Age in Weight (Tons)								
1982	24	1595	2717	3160	3019	461	2606	13582
1983	-	1009	3913	2619	2410	2518	1512	13981
1984	3	516	2071	4080	1607	1145	1384	10816
1985	-	513	2523	2816	2814	705	1322	10693
1986	-	110	3976	2375	1153	1072	978	9664
1987	2	283	1001	3641	1340	451	809	7527
1988	-	203	2715	2311	2097	295	337	7958
1989	-	420	2811	4351	1737	325	683	10397
1990	-	219	5794	4687	1834	1200	1361	15095
1991	-	388	1463	10455	3520	1045	910	17781
1992	-	480	1019	1313	6175	1011	892	10891
1993	-	99	2809	1611	561	2819	387	8286
1994	-	43	1975	3576	991	442	851	7877
1995	-	361	1689	3200	997	96	455	6798
1996	-	110	1247	4131	1267	333	106	7194
1997	-	92	977	1308	2658	316	70	5421
1998	-	120	816	1614	693	812	104	4157
1999	-	-	315	520	361	155	285	1636
2000	-	68	578	1962	621	366	136	3730
2000a	-	68	542	1690	443	180	809	3730

a 2000 Estimates include additional length data from sea sample trips.

Table A10b. Mean weight (kg) and mean length (cm) at age of commercial landings of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Partial Input data for Virtual Population Analysis)

	Age							
Year	1	2	3	4	5	6	7+	Average
	Commercial Landings Mean Weight (kg) at Age							
1982	0.801	1.156	1.664	2.764	4.770	6.739	11.330	2.654
1983	-	1.164	1.660	2.475	3.778	5.962	9.755	2.544
1984	0.589	1.159	1.670	2.721	3.677	5.898	10.176	2.731
1985	-	1.260	1.746	2.840	4.466	5.525	9.721	2.861
1986	-	1.304	1.837	2.923	4.619	6.067	10.295	2.698
1987	1.028	1.313	1.684	3.283	4.831	6.824	10.241	3.212
1988	-	1.268	1.881	2.426	5.166	6.767	11.233	2.622
1989	-	1.247	1.776	2.993	3.864	4.872	12.200	2.626
1990	-	1.071	1.692	2.271	4.265	7.645	13.747	2.366
1991	-	1.130	1.568	2.512	4.136	7.309	11.449	2.731
1992	-	1.533	1.922	2.714	3.061	5.000	10.614	2.999
1993	-	1.293	1.889	2.513	4.353	6.174	11.063	2.933
1994	-	1.450	1.943	3.151	3.444	6.132	10.018	3.000
1995	-	1.652	1.921	2.775	5.142	8.290	12.969	2.728
1996	-	1.687	2.136	2.376	3.648	7.376	11.647	2.580
1997	-	1.733	2.233	3.007	3.193	4.649	12.479	2.958
1998	-	1.277	2.089	2.979	4.191	4.211	10.262	2.980
1999	-	-	1.774	2.704	4.020	5.727	7.901	3.128
2000	-	1.627	2.415	3.447	4.399	5.702	7.553	3.474
2000a	-	1.627	2.323	3.233	3.971	5.298	10.491	3.657
	Commercial Landings Mean Length (cm) at Age							
1982	43.2	48.3	53.8	63.4	76.8	86.1	101.6	59.9
1983	-	48.6	53.8	61.4	70.8	82.4	95.1	59.8
1984	39.0	48.4	54.1	63.4	69.7	81.8	98.0	61.6
1985	-	49.8	55.1	64.6	74.9	80.3	96.7	62.8
1986	-	50.3	55.9	65.0	75.4	82.6	98.4	61.6
1987	47.0	50.4	54.4	67.8	76.9	86.5	98.4	65.4
1988	-	50.1	56.4	61.1	78.7	86.4	103.1	61.4
1989	-	49.8	55.5	65.7	71.5	76.7	103.6	61.7
1990	-	47.5	54.8	60.0	73.7	90.0	108.8	59.2
1991	-	47.7	52.6	61.8	72.6	88.6	102.2	62.2
1992	-	53.1	56.6	62.9	65.6	77.0	100.4	64.3
1993	-	50.5	56.8	61.7	74.2	83.7	101.6	63.5
1994	-	52.4	57.2	66.6	68.1	82.7	97.6	64.4
1995	-	54.4	56.9	63.4	78.6	92.5	107.1	62.3
1996	-	54.6	58.8	60.7	69.3	88.9	103.5	61.8
1997	-	55.0	59.7	65.4	66.4	74.9	104.6	64.7
1998	-	50.1	58.4	65.1	72.9	72.7	97.7	64.4
1999	-	-	55.5	63.4	71.7	80.8	90.7	64.9
2000	-	54.1	60.8	66.2	74.6	82.1	89.5	68.3
2000a	-	54.1	60.2	64.8	72.2	80.0	100.0	68.6

a 2000 Estimates include additional length data from sea sample trips.

Table A11. Estimated number (000's) and weight (metric tons, live) of Atlantic cod caught by marine recreational fishermen from the Gulf of Maine stock, 1979 - 2000.[1]

Year		Total Cod Caught			Total Cod Retained (excluding those caught and released)				
		No. of Cod (000's)	Wt. of Cod (mt)		No. of Cod (000's)	Wt. of Cod (mt)	Sample Mean Weight (kg)	Number Measured	Percent of Total Landings
1979		2698	3466		not estimated		| ------- not estimated ------ |		
1980		2254	6860		not estimated		| ------- not estimated ------ |		
1981		2933	5944		2738	5549	1.595	380	30.7
1982		1833	2138		1736	2025	1.121	377	13.0
1983		1455	1388		1237	1180	1.323	882	7.8
1984		1098	1705		905	1405	1.520	596	11.5
1985		1671	1964		1471	1729	1.238	295	13.9
1986		1114	967		993	862	1.942	75	8.2
1987		2625	2317		2054	1813	1.738	320	19.4
1988		1487	2114		1300	1848	2.049	407	18.8
1989		1769	2690		1193	1814	1.736	404	14.9
1990		1725	3882		1247	2806	1.964	206	15.6
1991		1770	3635		1419	2914	2.004	370	14.1
1992		585	1154		332	655	2.001	922	5.7
1993		1564	2378		772	1174	1.831	290	12.4
1994	VTR P/C	1424	2578	VTR P/C	516	934	1.844	750	10.6
1995	393	1206	1799	247	517	771	1.716	1028	10.2
1996	278	812	2112	174	351	913	2.099	1068	11.3
1997	208	434	671	123	161	250	2.692	525	4.4
1998	299	331	1245	119	219	824	2.507	580	16.5
1999	226	539	1680	143	264	823	3.448	212	33.5
2000	241	1211	2853	160	487	1147	2.733	144	23.5

[1] 1981-2000 from Revised Marine Recreational Fishery Statistics Survey database expanded catch estimates.

2 VTR P/C are estimates of the number of cod caught and retained derived from VTR records of Part/Charter vessels.

Table A12a. Recreational landings at age (thousands of fish; metric tons) of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Partial input data for Virtual Population Analysis)

Year	Age 1	2	3	4	5	6	7+	Total
Recreational Landings at Age in Numbers (000's)								
1982	58	615	717	243	84	6	12	1735
1983	14	471	539	126	47	26	14	1237
1984	20	367	332	136	32	11	6	904
1985	49	582	666	131	35	5	1	1469
1986	26	124	586	116	25	20	95	992
1987	39	691	823	416	53	13	18	2053
1988	6	360	697	196	28	8	4	1299
1989	5	193	701	244	36	10	5	1194
1990	7	89	770	309	58	10	6	1249
1991	5	103	415	787	95	8	6	1419
1992	-	37	70	42	166	14	2	331
1993	1	76	511	146	11	24	3	772
1994	1	28	364	93	27	2	2	517
1995	-	61	272	171	10	2	-	516
1996	-	21	104	205	21	1	-	352
1997	-	8	56	31	62	4	-	161
1998	-	16	95	74	15	18	1	219
1999	1	8	113	81	39	10	13	264
2000	-	44	182	212	32	15	2	487
Recreational Landings at Age in Weight (Tons)								
1982	26	556	1018	559	373	33	132	2697
1983	6	412	751	272	158	173	168	1940
1984	9	304	480	332	103	47	78	1353
1985	18	494	899	305	115	20	5	1856
1986	11	103	970	304	99	114	1247	2848
1987	11	634	1184	1111	224	96	189	3449
1988	1	310	1049	425	107	26	26	1944
1989	3	208	1111	628	124	61	43	2178
1990	1	80	1147	727	212	66	63	2296
1991	1	119	582	1749	287	48	34	2820
1992	-	56	130	119	509	69	19	902
1993	1	73	841	292	33	108	41	1389
1994	-	35	593	214	56	7	17	922
1995	-	91	443	331	36	4	-	905
1996	-	32	193	406	54	7	3	695
1997	-	13	111	74	149	12	1	360
1998	-	27	207	195	51	59	5	544
1999	-	10	238	260	178	58	82	827
2000	-	69	371	603	118	96	9	1265

Table A12b. Mean weight (kg) and mean length (cm) at age of recreational landings of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Partial input data for Virtual Population Analysis)

Year	Age 1	2	3	4	5	6	7+	Average
Recreational Landings Mean Weight (kg) at Age								
1982	0.452	0.904	1.420	2.297	4.417	5.542	10.872	1.554
1983	0.410	0.874	1.394	2.159	3.350	6.635	12.136	1.568
1984	0.450	0.827	1.447	2.432	3.236	4.215	11.892	1.497
1985	0.371	0.848	1.349	2.330	3.298	3.780	5.2091	1.263
1986	0.413	0.832	1.655	2.630	3.884	5.600	12.995	2.871
1987	0.269	0.918	1.439	2.672	4.252	7.134	10.283	1.680
1988	0.184	0.860	1.504	2.165	3.816	3.443	6.067	1.497
1989	0.615	1.081	1.586	2.575	3.498	6.285	7.851	1.824
1990	0.148	0.900	1.489	2.354	3.640	6.587	13.783	1.838
1991	0.171	1.156	1.403	2.223	3.013	5.696	5.696	1.987
1992	0.456	1.495	1.858	2.832	3.074	4.820	7.221	2.725
1993	0.582	0.959	1.645	2.001	3.131	4.566	11.797	1.799
1994	0.183	1.240	1.632	2.302	2.046	4.613	8.947	1.783
1995	-	1.501	1.627	1.931	3.404	1.871	6.062	1.754
1996	0.582	1.541	1.853	1.979	2.706	7.829	12.378	1.974
1997	0.327	1.585	1.989	2.376	2.410	3.104	9.111	2.235
1998	0.456	1.724	2.183	2.640	3.376	3.261	3.526	2.482
1999	0.335	1.204	2.105	3.225	4.572	5.698	6.598	3.131
2000	-	1.571	2.036	2.841	3.652	6.543	4.271	2.598
Recreational Landings Mean Length (cm) at Age								
1982	33.9	42.9	50.2	59.0	74.1	79.9	98.4	49.9
1983	33.5	42.9	50.1	57.9	67.1	84.5	101.2	49.9
1984	34.2	42.0	50.5	60.1	66.1	71.0	100.1	49.3
1985	32.0	42.4	49.3	60.0	67.0	70.1	78.9	47.5
1986	33.7	41.6	53.3	62.0	70.8	80.4	113.4	59.1
1987	27.8	43.4	50.5	62.5	72.3	86.0	98.6	51.3
1988	26.2	42.8	51.3	58.2	69.9	66.2	81.3	50.5
1989	38.4	46.2	52.5	61.6	67.8	83.9	97.5	54.2
1990	23.7	43.1	51.1	59.8	69.7	84.4	110.0	53.9
1991	24.9	47.0	50.4	58.5	64.5	80.0	80.9	55.8
1992	35.0	51.3	54.7	63.1	64.9	75.4	86.6	61.6
1993	38.0	44.3	53.2	56.6	64.9	72.8	103.1	53.9
1994	26.3	48.2	53.2	59.1	57.2	71.7	95.1	54.4
1995	-	51.8	53.2	55.9	67.1	55.1	83.0	54.2
1996	38.0	52.3	55.4	56.6	62.0	90.1	106.3	56.4
1997	32.4	52.3	56.9	60.0	64.4	72.8	95.7	60.6
1998	35.0	54.3	58.6	62.2	67.1	65.9	68.6	60.7
1999	33.0	47.4	57.8	66.6	74.4	80.0	84.5	64.9
2000	-	52.6	57.0	63.5	68.8	83.5	72.1	61.1

Table A13a. Total (commercial and recreational)landings at age (thousands of fish; metric tons) of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Input data for Virtual Population Analysis)

Year	Age 1	2	3	4	5	6	7+	Total
Total Landings at Age in Numbers (000's)								
1982	88	1995	2350	1386	717	75	242	6853
1983	14	1337	2896	1184	685	448	169	6733
1984	24	813	1572	1636	469	205	142	4861
1985	49	989	2111	1122	665	133	137	5206
1986	26	208	2750	929	275	197	190	4575
1987	41	907	1418	1525	330	79	97	4397
1988	6	520	2140	1149	434	51	34	4334
1989	5	530	2284	1698	485	91	61	5154
1990	7	294	4195	2373	488	167	105	7629
1991	5	447	1349	4948	946	151	85	7931
1992	-	350	600	526	2184	218	86	3962
1993	1	152	1998	787	140	481	39	3597
1994	1	57	1380	1228	315	74	88	3143
1995	-	279	1152	1324	204	14	34	3007
1996	-	86	688	1943	368	46	10	3141
1997	-	61	494	466	894	72	8	1995
1998	-	110	485	616	180	211	11	1614
1999[1]	1	8	563	566	267	78	104	1586
2000[2]	-	97	485	934	211	96	25	1849
Total Landings at Age in Weight (Tons)								
1982	50	2151	3735	3719	3392	494	2738	16279
1983	6	1421	4664	2891	2568	2691	1680	15921
1984	12	820	2551	4412	1710	1192	1462	12169
1985	18	1007	3442	3121	2929	725	1327	12549
1986	11	213	4946	2679	1252	1186	2225	12512
1987	13	917	2185	4752	1564	547	998	10976
1988	1	513	3764	2736	2204	321	363	9902
1989	3	628	3922	4979	1861	386	726	12575
1990	1	299	6941	5414	2046	1266	1424	17391
1991	1	507	2045	12204	3807	1093	944	20601
1992	-	536	1149	1432	6684	1080	911	11793
1993	1	172	3650	1903	594	2927	428	9675
1994	-	78	2568	3790	1047	449	868	8799
1995	-	452	2132	3531	1033	100	455	7703
1996	-	142	1440	4537	1321	340	109	7889
1997	-	105	1088	1382	2807	328	71	5781
1998	-	147	1023	1809	744	871	109	4701
1999[1]	-	10	1036	1573	1093	449	801	4963
2000[2]	-	156	1103	3090	905	559	181	5996

1. Includes 2,500 mt of estimated discards
2. Includes 1,000 mt of estimated discards.

Table A13b. Mean weight (kg) and mean length (cm) at age of total landings (commercial and recreational) of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2000. (Input data for Virtual Population Analysis)

Year	Age 1	2	3	4	5	6	7+	Average
Total Landings Mean Weight (kg) at Age								
1982	0.568	1.078	1.589	2.683	4.731	6.587	11.314	2.375
1983	0.429	1.063	1.610	2.442	3.749	6.007	9.941	2.365
1984	0.500	1.009	1.623	2.697	3.646	5.815	10.296	2.503
1985	0.367	1.018	1.621	2.782	4.405	5.451	9.686	2.410
1986	0.423	1.024	1.799	2.884	4.553	6.020	11.711	2.735
1987	0.317	1.011	1.541	3.116	4.739	6.924	10.289	2.496
1988	0.167	0.987	1.759	2.381	5.078	6.294	10.676	2.285
1989	0.600	1.185	1.717	2.932	3.837	4.242	11.902	2.440
1990	0.143	1.017	1.655	2.282	4.193	7.581	13.562	2.280
1991	0.171	1.134	1.516	2.466	4.024	7.238	11.106	2.598
1992	0.468	1.531	1.915	2.722	3.060	5.000	10.593	2.977
1993	1.000	1.132	1.627	2.418	4.243	6.085	10.974	2.690
1994	0.468	1.368	1.861	3.086	3.324	6.068	9.864	2.800
1995	0.468	1.620	1.851	2.667	5.064	7.143	13.382	2.562
1996	0.468	1.651	2.093	2.335	3.590	7.391	10.900	2.512
1997	0.468	1.721	2.202	2.966	3.140	4.556	8.875	2.898
1998	0.466	1.336	2.109	2.937	4.133	4.128	9.909	2.913
1999	0.331	1.250	1.841	2.776	4.100	5.736	7.702	3.129
2000	0.468	1.600	2.274	3.310	4.291	5.811	7.307	3.243
Total Landings Mean Length (cm) at Age								
1982	37.1	46.6	52.7	62.6	76.5	85.6	101.4	57.4
1983	33.5	46.6	53.1	61.0	70.5	82.5	95.6	58.0
1984	28.5	45.5	53.3	63.1	69.5	81.2	98.1	59.3
1985	32.0	45.4	53.3	64.1	74.5	79.9	96.6	58.5
1986	33.7	45.1	55.3	64.6	75.0	82.4	105.9	61.1
1987	26.4	45.1	52.1	66.4	76.2	86.4	98.4	58.8
1988	26.2	45.0	54.7	60.6	78.1	83.2	100.5	58.1
1989	38.4	48.5	54.6	65.1	71.2	77.5	103.1	60.0
1990	23.7	46.2	54.1	60.0	73.2	89.7	108.9	58.3
1991	24.9	47.5	51.9	61.3	71.8	88.1	100.7	61.1
1992	31.3	52.9	56.4	62.9	65.5	76.9	100.1	64.1
1993	38.0	47.4	55.9	60.8	73.5	83.2	101.7	61.4
1994	26.3	50.3	56.1	66.0	67.2	82.4	97.5	62.8
1995	31.2	53.8	56.0	62.4	78.0	87.2	107.1	60.9
1996	31.2	54.0	58.3	60.3	68.9	88.9	103.5	61.2
1997	31.2	54.6	59.4	65.0	66.3	74.8	104.6	64.4
1998	35.0	50.7	58.4	64.8	72.4	72.1	95.1	63.9
1999	33.0	47.4	56.0	63.9	72.1	80.7	89.9	64.9
2000	31.2	53.4	59.4	65.6	73.7	82.3	88.1	66.4

Table A14. Mean weight at age (kg) at the beginning of the year (January 1) for Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 2001. Values derived from total landings (commercial and recreational) mean weight-at-age data (mid-year) using procedures described by Rivard (1980).

	Age										
Year	1	2	3	4	5	6	7	8	9	10	11+
1982	0.415	0.882	1.282	2.27	4.199	5.582	8.246	9.853	14.071	11.713	18.456
1983	0.28	0.777	1.317	1.97	3.172	5.331	6.256	9.701	10.01	11.867	17.813
1984	0.35	0.658	1.313	2.084	2.984	4.669	6.957	7.465	11.646	11.864	15.028
1985	0.22	0.713	1.279	2.125	3.447	4.458	6.826	9.544	10.468	13.135	14.523
1986	0.274	0.613	1.353	2.162	3.559	5.15	6.509	8.902	11.824	12.141	16.554
1987	0.18	0.654	1.256	2.368	3.697	5.615	7.339	8.767	11.744	13.553	14.596
1988	0.063	0.559	1.334	1.915	3.978	5.461	8.233	9.939	12.245	14.723	20.356
1989	0.461	0.445	1.302	2.271	3.023	4.641	7.919	10.889	12.835	16.499	21.521
1990	0.051	0.781	1.4	1.979	3.506	5.393	7.232	10.438	13.388	14.795	20.295
1991	0.057	0.403	1.242	2.02	3.03	5.509	8.586	11.501	13.52	19.112	21.885
1992	0.301	0.512	1.474	2.031	2.747	4.486	8.362	10.962	12.873	16.08	18.479
1993	0.855	0.728	1.672	2.152	3.398	4.315	7.071	11.518	14.786	14.856	18.479
1994	0.252	1.17	1.451	2.374	2.835	5.074	7.168	11.237	12.929	19.436	19.369
1995	0.249	0.871	1.591	2.228	3.953	4.873	8.121	10.366	14.405	16.099	18.479
1996	0.244	0.879	1.841	2.079	3.094	6.118	9.303	11.326	13.19	16.422	18.479
1997	0.277	0.897	1.907	2.492	2.708	4.044	7.938	11.845	13.281	14.716	21.356
1998	0.286	0.791	1.905	2.543	3.501	3.6	6.3	10.018	16.134	17.557	18.479
1999	0.151	0.765	1.568	2.42	3.47	4.869	5.527	8.878	12.138	17.829	18.479
2000	0.301	0.728	1.686	2.469	3.451	4.881	5.412	8.212	10.231	13.170	17.514
2001	0.226	0.728	3.518	3.067	4.438	5.335	6.082	4.834	10.525	12.569	17.514
Avg 1982-1998	0.283	0.725	1.466	2.180	3.343	4.960	7.551	10.251	12.903	14.975	18.479
Avg 1996-1998	0.269	0.856	1.884	2.371	3.101	4.587	7.847	11.063	14.202	16.232	19.438

Table A15. Standardized stratified mean catch per tow in numbers and weight (kg) for Atlantic cod from NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine (Strata 26-30 and 36-40), 1963 - 2000 [a,b]

	Gulf of Maine [c]			
	Spring		Autumn	
Year	No/Tow	Wt/Tow	No/Tow	Wt/Tow
1963	-	-	5.92	17.9
1964	-	-	4.00	22.8
1965	-	-	4.49	12.0
1966	-	-	3.78	12.9
1967	-	-	2.56	9.2
1968	5.44	17.9	4.39	19.4
1969	3.25	13.2	2.76	15.4
1970	2.21	11.1	4.90	16.4
1971	1.43	7.0	4.37	16.5
1972	2.06	8.0	9.31	13.0
1973	7.54	18.8	4.46	8.7
1974	2.91	7.4	4.33	9.0
1975	2.51	6.0	6.15	8.6
1976	2.78	7.6	2.15	6.7
1977	3.88	8.5	3.08	10.2
1978	2.06	7.7	5.75	12.9
1979	4.27	9.5	3.49	17.5
1980	2.15	6.2	7.04	14.2
1981	4.86	10.8	2.42	8.1
1982	3.75	8.6	7.77	16.1
1983	3.91	10.5	4.22	8.8
1984	3.40	5.8	2.42	8.8
1985	2.52	7.7	2.92	8.5
1986	1.96	3.6	1.95	5.1
1987	1.68	3.0	2.98	3.4
1988	3.13	3.3	5.90	6.6
1989	2.26	2.5	4.65	4.6
1990	2.36	3.1	2.99	4.9
1991	2.39	2.9	1.25	2.8
1992	2.41	8.7	1.43	2.4
1993	2.50	5.9	1.23	1.0
1994	1.27	2.4	2.14	2.7
1995	1.91	2.4	2.01	3.7
1996	2.46	5.4	1.32	2.4
1997	2.19	5.6	0.87	1.9
1998	1.71	4.2	0.84	1.5
1999	2.30	5.1	1.81	3.5
2000	3.08	3.2	2.60	4.7

[a] During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portugeuse polyvalent doors have been used in both surveys. Adjustments have been made to the 1963-1984 catch per tow data to standardize these data to polyvalent door equivalents. Conversion coefficients of 1.56 (numbers) and 1.62 (weight) were used in this standardization (NEFSC 1991).

[b] Spring surveys during 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. No adjustments have been made to the catch per tow data for these differences.

[c] In the Gulf of Maine, spring surveys during 1980-1982, 1989-1991 and 1994, and autumn surveys during 1977-1978, 1980, 1989-1991 and 1993 were accomplished with the R/V DELAWARE II; in all other years, the surveys were accomplished using the R/V ALBATROSS IV. Adjustments have been made to the R/V DELAWARE II catch per tow data to standardize these to R/V ALBTATROSS IV equivalents. Conversion coefficients 0.79 (number) and 0.67 (weight) were used in this standardization (NEFSC 1991).

Table A16. Standardized [for both door and gear changes] stratified mean number per tow at age and standardized stratified mean weight (kg) per tow of Atlantic cod in NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine, 1963-2000. [**a,b**]

	Age Group											Totals						Standardized
Year	0	1	2	3	4	5	6	7	8	9	10+	0+	1+	2+	3+	4+	5+	Mean Wt (kg)/Tow
Spring [c,d,e]																		
1968	0.128	0.613	1.234	1.407	0.846	0.538	0.207	0.129	0.111	0.059	0.165	5.438	5.310	4.697	3.463	2.056	1.211	17.92
1969	0.000	0.000	0.036	0.307	0.880	0.807	0.633	0.256	0.144	0.089	0.101	3.253	3.253	3.253	3.217	2.909	2.030	13.20
1970	0.000	0.159	0.123	0.055	0.094	0.273	0.466	0.615	0.075	0.059	0.287	2.206	2.206	2.047	1.923	1.869	1.775	11.06
1971	0.000	0.025	0.142	0.109	0.292	0.048	0.083	0.300	0.206	0.154	0.072	1.431	1.431	1.406	1.264	1.154	0.863	6.98
1972	0.000	0.353	0.153	0.519	0.197	0.200	0.036	0.106	0.101	0.229	0.164	2.058	2.058	1.705	1.552	1.033	0.836	8.04
1973	0.000	0.034	4.249	0.906	0.619	0.349	0.195	0.095	0.223	0.251	0.612	7.535	7.535	7.500	3.251	2.345	1.725	18.79
1974	0.000	0.476	0.056	1.359	0.329	0.222	0.114	0.048	0.048	0.020	0.232	2.905	2.905	2.429	2.373	1.014	0.685	7.44
1975	0.006	0.094	0.699	0.106	1.065	0.259	0.111	0.005	0.005	0.019	0.144	2.512	2.505	2.412	1.713	1.607	0.541	6.03
1976	0.000	0.042	0.304	1.048	0.153	0.897	0.086	0.108	0.066	0.000	0.073	2.777	2.777	2.735	2.430	1.382	1.229	7.55
1977	0.000	0.025	0.298	0.521	1.994	0.109	0.791	0.006	0.101	0.000	0.037	3.883	3.883	3.858	3.560	3.039	1.045	8.54
1978	0.000	0.034	0.105	0.285	0.348	0.766	0.075	0.320	0.008	0.106	0.008	2.055	2.055	2.020	1.916	1.630	1.282	7.70
1979	0.044	0.535	1.630	0.212	0.499	0.401	0.685	0.059	0.142	0.012	0.053	4.273	4.229	3.694	2.064	1.852	1.353	9.49
1980	0.070	0.070	0.440	0.343	0.123	0.418	0.239	0.303	0.000	0.129	0.014	2.149	2.079	2.009	1.569	1.226	1.103	6.18
1981	0.000	1.014	0.662	0.986	1.216	0.328	0.287	0.110	0.155	0.106	0.000	4.864	4.864	3.850	3.188	2.202	0.986	10.79
1982	0.015	0.336	1.019	0.516	0.694	0.864	0.117	0.108	0.000	0.042	0.039	3.751	3.737	3.400	2.381	1.865	1.171	8.62
1983	0.012	0.626	0.978	0.833	0.641	0.357	0.181	0.092	0.000	0.090	0.101	3.912	3.900	3.274	2.296	1.463	0.822	10.50
1984	0.000	0.151	1.033	1.147	0.741	0.190	0.053	0.058	0.030	0.000	0.000	3.402	3.402	3.251	2.218	1.072	0.331	5.83
1985	0.000	0.028	0.238	0.622	0.665	0.677	0.095	0.114	0.052	0.000	0.026	2.517	2.517	2.489	2.251	1.629	0.964	7.65
1986	0.000	0.417	0.330	0.647	0.387	0.074	0.046	0.027	0.011	0.000	0.018	1.957	1.957	1.540	1.210	0.563	0.176	3.60
1987	0.000	0.049	0.638	0.486	0.300	0.128	0.011	0.045	0.011	0.000	0.014	1.682	1.682	1.633	0.995	0.509	0.209	3.01
1988	0.029	0.663	1.053	0.633	0.355	0.217	0.087	0.063	0.000	0.027	0.000	3.127	3.098	2.435	1.382	0.749	0.394	3.30
1989	0.000	0.023	0.649	0.790	0.632	0.090	0.077	0.000	0.000	0.000	0.000	2.261	2.261	2.238	1.589	0.799	0.167	2.53
1990	0.000	0.000	0.190	1.327	0.627	0.167	0.032	0.018	0.000	0.000	0.000	2.362	2.362	2.362	2.172	0.845	0.217	3.08
1991	0.000	0.043	0.209	0.355	1.477	0.268	0.024	0.018	0.000	0.000	0.000	2.394	2.394	2.351	2.142	1.787	0.310	2.89
1992	0.000	0.050	0.230	0.240	0.280	1.310	0.220	0.070	0.000	0.010	0.000	2.410	2.410	2.360	2.130	1.890	1.610	8.66
1993	0.000	0.200	0.500	0.800	0.330	0.090	0.480	0.060	0.020	0.000	0.023	2.503	2.503	2.303	1.803	1.003	0.673	5.87
1994	0.000	0.016	0.316	0.387	0.213	0.095	0.047	0.126	0.024	0.024	0.018	1.266	1.266	1.251	0.935	0.547	0.334	2.43
1995	0.000	0.050	0.180	1.120	0.370	0.150	0.030	0.000	0.010	0.000	0.000	1.910	1.910	1.860	1.680	0.560	0.190	2.43
1996	0.000	0.060	0.020	0.590	1.330	0.400	0.060	0.000	0.000	0.000	0.000	2.465	2.465	2.405	2.385	1.795	0.465	5.43
1997	0.000	0.158	0.132	0.399	0.264	0.876	0.242	0.120	0.000	0.000	0.000	2.191	2.191	2.033	1.901	1.502	1.238	5.62
1998	0.000	0.018	0.224	0.330	0.517	0.142	0.421	0.022	0.037	0.000	0.000	1.710	1.710	1.692	1.468	1.138	0.621	4.18
1999	0.000	0.166	0.344	0.713	0.344	0.315	0.134	0.273	0.000	0.000	0.011	2.301	2.301	2.135	1.791	1.078	0.734	5.09
2000	0.026	1.184	0.725	0.438	0.457	0.107	0.101	0.024	0.022	0.000	0.000	3.083	3.057	1.873	1.148	0.710	0.253	3.21

[**a**] Strata 26-30 and 36-40.

[**c**] Spring surveys during 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. No adjustments have been made to the catch per tow data for these differences.

[**d**] During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portugeuse polyvalent doors have been used in both surveys. Adjustments have been made to the 1963-1984 catch per tow data to standardize these data to polyvalent door equivalents. Conversion coefficients of 1.56 (numbers) and 1.62 (weight) were used in this standardization (NESFC 1991).

[**e**] In the Gulf of Maine, spring surveys during 1980-1982, 1989-1991 amd 1994, and autumn surveys during 1977-1978, 1980, 1989-1991 and 1993, were accomplished with the R/V DELAWARE II; in all other years, the surveys were accomplished using the R/V ALBATROSS IV. Adjustments have been made to the R/V DELAWARE II catch per tow data to standardize these to R/V ALBTATROSS IV equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFSC 1991).

Table A16 (Continued). [**a**,**b**]

Year	Age Group 0	1	2	3	4	5	6	7	8	9	10+	Totals 0+	1+	2+	3+	4+	5+	Standardized Mean Wt (kg)/Tow
Autumn [d,e]																		
1963	0.050	0.649	1.349	1.253	0.849	0.579	0.537	0.300	0.183	0.095	0.075	5.917	5.867	5.218	3.869	2.616	1.767	17.95
1964	0.000	0.092	0.122	0.471	0.856	0.853	0.783	0.373	0.237	0.114	0.101	4.003	4.003	3.911	3.789	3.318	2.462	22.79
1965	0.002	0.850	0.880	0.824	0.750	0.496	0.374	0.170	0.080	0.044	0.025	4.494	4.493	3.643	2.763	1.939	1.189	12.00
1966	0.170	0.204	0.640	0.697	0.718	0.558	0.441	0.192	0.078	0.048	0.036	3.783	3.613	3.409	2.769	2.072	1.354	12.91
1967	0.012	0.129	0.215	0.574	0.671	0.384	0.268	0.162	0.070	0.041	0.034	2.562	2.549	2.420	2.204	1.630	0.959	9.23
1968	0.012	0.036	0.179	0.719	1.256	0.973	0.627	0.261	0.156	0.072	0.095	4.387	4.374	4.338	4.159	3.440	2.184	19.44
1969	0.016	0.059	0.123	0.354	0.630	0.552	0.466	0.220	0.145	0.129	0.062	2.758	2.742	2.683	2.560	2.206	1.576	15.37
1970	0.743	0.941	0.265	0.551	0.329	0.488	0.423	0.789	0.131	0.094	0.147	4.900	4.157	3.217	2.952	2.401	2.072	16.43
1971	1.346	0.178	0.239	0.211	0.597	0.460	0.434	0.254	0.318	0.200	0.128	4.365	3.019	2.841	2.602	2.391	1.794	16.52
1972	0.031	5.579	1.217	1.526	0.234	0.094	0.172	0.039	0.159	0.242	0.016	9.307	9.276	3.697	2.480	0.955	0.721	12.96
1973	0.636	0.328	2.173	0.139	0.507	0.212	0.078	0.028	0.051	0.168	0.136	4.457	3.820	3.493	1.320	1.181	0.674	8.73
1974	0.282	1.123	0.189	1.744	0.292	0.359	0.078	0.012	0.012	0.042	0.198	4.332	4.050	2.927	2.738	0.994	0.702	8.97
1975	0.047	0.147	3.067	0.134	2.356	0.254	0.109	0.017	0.003	0.003	0.012	6.150	6.103	5.956	2.889	2.755	0.399	8.62
1976	0.000	0.243	0.209	0.632	0.100	0.768	0.058	0.095	0.000	0.016	0.031	2.151	2.151	1.908	1.699	1.067	0.967	6.74
1977	0.000	0.022	0.359	0.550	1.155	0.152	0.593	0.038	0.097	0.022	0.096	3.083	3.083	3.061	2.703	2.153	0.998	10.22
1978	0.249	1.369	0.371	1.118	0.656	1.430	0.112	0.325	0.009	0.060	0.051	5.749	5.500	4.131	3.760	2.642	1.987	12.89
1979	0.005	0.368	0.594	0.162	0.836	0.392	0.782	0.051	0.215	0.000	0.083	3.488	3.483	3.115	2.521	2.359	1.523	17.54
1980	0.027	1.264	2.602	1.754	0.497	0.232	0.335	0.207	0.030	0.018	0.071	7.037	7.010	5.745	3.144	1.390	0.893	14.21
1981	0.012	0.619	0.382	0.549	0.474	0.089	0.119	0.037	0.108	0.000	0.028	2.418	2.406	1.786	1.404	0.855	0.381	8.05
1982	0.000	0.700	3.142	2.473	1.167	0.248	0.000	0.039	0.000	0.000	0.000	7.769	7.769	7.068	3.927	1.454	0.287	16.07
1983	0.045	1.660	0.977	0.852	0.139	0.264	0.197	0.000	0.000	0.000	0.090	4.223	4.178	2.518	1.541	0.690	0.551	8.81
1984	0.044	0.384	0.421	0.565	0.399	0.220	0.204	0.089	0.000	0.031	0.066	2.423	2.379	1.995	1.574	1.009	0.610	8.81
1985	0.266	0.378	0.910	0.763	0.209	0.218	0.074	0.000	0.034	0.021	0.049	2.922	2.656	2.278	1.368	0.605	0.396	8.49
1986	0.000	0.301	0.490	0.654	0.333	0.086	0.042	0.000	0.000	0.024	0.021	1.951	1.951	1.650	1.160	0.506	0.173	5.10
1987	0.138	0.599	1.324	0.600	0.257	0.061	0.000	0.000	0.000	0.000	0.000	2.979	2.841	2.242	0.918	0.318	0.061	3.41
1988	0.000	1.951	2.245	0.960	0.528	0.110	0.076	0.033	0.000	0.000	0.000	5.903	5.903	3.952	1.707	0.747	0.219	6.61
1989	0.000	0.416	2.391	1.356	0.294	0.174	0.014	0.000	0.000	0.009	0.000	4.653	4.653	4.238	1.847	0.491	0.197	4.58
1990	0.006	0.029	0.367	1.643	0.623	0.278	0.028	0.010	0.000	0.000	0.000	2.985	2.978	2.949	2.583	0.939	0.317	4.91
1991	0.008	0.142	0.142	0.221	0.632	0.079	0.000	0.024	0.000	0.000	0.000	1.248	1.240	1.098	0.956	0.735	0.103	2.78
1992	0.060	0.290	0.450	0.140	0.040	0.330	0.110	0.000	0.010	0.000	0.000	1.430	1.370	1.080	0.630	0.490	0.450	2.45
1993	0.040	0.198	0.569	0.363	0.032	0.000	0.032	0.000	0.000	0.000	0.000	1.232	1.193	0.995	0.427	0.063	0.032	1.00
1994	0.030	0.210	0.880	0.830	0.090	0.050	0.000	0.050	0.000	0.000	0.000	2.140	2.110	1.900	1.020	0.190	0.100	2.74
1995	0.010	0.070	0.280	1.230	0.330	0.080	0.010	0.000	0.000	0.000	0.000	2.010	2.000	1.930	1.650	0.420	0.090	3.67
1996	0.030	0.120	0.380	0.190	0.540	0.060	0.000	0.000	0.000	0.000	0.000	1.320	1.290	1.170	0.790	0.600	0.060	2.35
1997	0.000	0.297	0.086	0.160	0.182	0.149	0.000	0.000	0.000	0.000	0.000	0.872	0.872	0.575	0.490	0.330	0.149	1.87
1998	0.050	0.097	0.320	0.115	0.192	0.039	0.031	0.000	0.000	0.000	0.000	0.843	0.793	0.696	0.376	0.261	0.069	1.50
1999	0.025	0.431	0.363	0.590	0.243	0.132	0.023	0.000	0.000	0.000	0.000	1.807	1.782	1.351	0.998	0.408	0.165	3.50
2000	0.008	0.533	0.984	0.394	0.507	0.134	0.010	0.034	0.000	0.000	0.000	2.804	2.596	2.063	1.079	0.685	0.178	4.65

[**a**] Strata 26-30 and 36-40.

[**b**] Autumn catch per tow at age values for 1963-1969 obtained by applying combined 1970-1981 age-length keys to stratified mean catch per tow at length distributions from each survey.

[**d**] During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portugeuse polyvalent doors have been used in both surveys. Adjustments have been made to the 1963-1984 catch per tow data to standardize these data to polyvalent door equivalents. Conversion coefficients of 1.56 (numbers) and 1.62 (weight) were used in this standardization (NEFSC 1991).

[**e**] In the Gulf of Maine, spring surveys during 1980-1982, 1989-1991 and 1994, and autumn surveys during 1977-1978, 1980, 1989-1991 and 1993 were accomplished with the R/V DELAWARE II; in all other years, the surveys were accomplished using the R/V ALBATROSS IV. Adjustments have been made to the R/V DELAWARE II catch per tow data to standardize these to R/V ALBTATROSS IV equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFSC 1991).

Table A17. Stratified mean catch per tow in numbers and weight (kg) of Atlantic cod in State of Massachusetts inshore spring and autumn bottom trawl surveys in territorial waters adjacent to the Gulf of Maine (Mass. Regions 4-5), 1978 - 2000. **[a]**

	Age Group											Totals				Stratified Mean Weight/tow
Year	0	1	2	3	4	5	6	7	8	9	10+	0+	1+	2+	3+	(kg)
					Gulf of Maine Area (Mass. Regions 4-5)											
Spring																
1978	21.965	12.784	4.162	4.572	0.872	1.028	0.000	0.000	0.023	0.000	0.000	45.406	23.441	10.657	6.495	12.16
1979	56.393	36.630	2.581	1.533	4.659	1.995	0.183	0.000	0.000	0.000	0.069	104.043	47.650	11.020	8.439	20.53
1980	8.156	50.311	12.679	0.971	0.745	0.737	0.080	0.214	0.000	0.025	0.000	73.918	65.762	15.451	2.772	17.71
1981	19.753	24.794	23.884	3.122	1.279	0.041	0.146	0.022	0.022	0.000	0.000	73.063	53.310	28.516	4.632	21.79
1982	1.489	16.235	7.060	3.418	1.147	0.232	0.011	0.057	0.045	0.000	0.000	29.694	28.205	11.970	4.910	13.42
1983	0.453	27.703	18.572	5.331	0.501	1.221	0.142	0.022	0.000	0.000	0.000	53.945	53.492	25.789	7.217	19.77
1984	0.206	2.896	5.408	2.271	0.865	0.138	0.162	0.000	0.000	0.000	0.000	11.946	11.740	8.844	3.436	8.63
1985	0.793	2.711	3.822	2.794	0.692	0.000	0.000	0.000	0.000	0.000	0.000	10.812	10.019	7.308	3.486	6.42
1986	0.957	19.960	3.222	0.887	0.426	0.090	0.019	0.000	0.000	0.000	0.000	25.561	24.604	4.644	1.422	7.77
1987	0.659	8.590	6.997	2.268	0.257	0.147	0.048	0.000	0.000	0.087	0.000	19.053	18.394	9.804	2.807	9.59
1988	1.595	11.841	11.356	2.511	1.370	0.000	0.039	0.000	0.000	0.000	0.000	28.712	27.117	15.276	3.920	9.66
1989	0.157	20.679	25.260	6.580	0.458	0.106	0.124	0.000	0.000	0.000	0.000	53.364	53.207	32.528	7.268	18.26
1990	4.10	6.33	6.89	17.77	2.64	0.18	0.05	0.02	0.000	0.000	0.000	37.980	33.88	27.55	20.66	19.51
1991	0.32	5.88	3.56	2.54	5.03	0.36	0.000	0.000	0.000	0.000	0.000	17.69	17.37	11.49	7.93	11.37
1992	1.36	6.42	6.35	3.58	0.65	1.37	0.12	0.04	0.00	0.00	0.00	19.88	18.53	12.11	5.76	10.10
1993	69.03	3.40	7.76	3.60	1.45	0.05	0.30	0.00	0.00	0.00	0.00	85.59	16.56	13.16	5.40	7.63
1994	3.90	4.45	5.67	2.46	0.52	0.23	0.03	0.06	0.00	0.03	0.00	17.35	13.45	9.00	3.33	4.83
1995	9.84	6.41	1.36	3.89	1.20	0.09	0.00	0.00	0.00	0.00	0.00	22.79	12.95	6.54	5.18	4.49
1996	6.39	1.37	0.65	1.15	2.00	0.38	0.00	0.00	0.00	0.00	0.00	11.96	5.57	4.20	3.55	4.06
1997	10.40	3.66	1.25	1.05	0.22	0.50	0.03	0.00	0.00	0.00	0.00	17.09	6.69	3.03	1.78	2.97
1998	20.72	3.15	1.80	0.99	1.06	0.08	0.46	0.04	0.00	0.00	0.00	28.30	7.58	4.43	2.63	5.76
1999	116.22	14.36	3.57	3.46	1.20	1.08	0.06	0.22	0.04	0.00	0.00	140.08	23.84	9.48	5.91	14.19
2000	1.83	27.99	7.12	2.85	2.60	0.78	0.77	0.06	0.13	0.00	0.00	44.10	42.47	14.48	7.36	22.36
Autumn																
1978	151.533	2.082	0.000	0.120	0.140	0.318	0.000	0.080	0.000	0.000	0.000	154.273	2.740	0.658	0.658	3.02
1979	4.933	3.430	0.042	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	8.431	3.498	0.068	0.026	0.99
1980	5.680	8.834	0.052	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	14.616	8.936	0.102	0.050	1.57
1981	2.018	5.652	7.290	0.729	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.689	13.671	8.019	0.729	6.65
1982	4.667	2.346	1.005	0.060	0.050	0.000	0.000	0.000	0.000	0.000	0.000	8.128	3.461	1.115	0.110	1.35
1983	1.308	0.651	0.100	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.072	0.764	0.113	0.013	0.18
1984	12.296	0.344	0.022	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.675	0.379	0.035	0.013	0.18
1985	2.832	0.419	0.018	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.279	0.447	0.028	0.010	0.09
1986	2.478	1.150	0.833	0.000	0.067	0.000	0.000	0.000	0.000	0.000	0.000	4.528	2.050	0.900	0.067	0.55
1987	389.584	2.386	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	391.990	2.406	0.020	0.000	0.45
1988	4.571	20.490	0.679	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	25.740	21.169	0.679	0.000	1.57
1989	2.971	2.700	0.350	0.210	0.185	0.000	0.000	0.000	0.000	0.000	0.000	6.416	3.445	0.745	0.395	1.27
1990	9.37	9.13	1.74	0.31	0.06	0.03	0.000	0.000	0.000	0.000	0.000	20.638	11.27	2.14	0.40	1.56
1991	4.65	4.20	0.81	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	9.74	5.09	0.89	0.08	0.80
1992	24.30	2.01	0.11	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	26.48	2.18	0.17	0.06	0.42
1993	49.92	3.32	0.61	0.33	0.00	0.00	0.01	0.00	0.00	0.00	0.00	54.21	4.29	0.97	0.36	1.97
1994	33.49	14.13	6.37	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.26	20.77	6.64	0.27	4.47
1995	2.56	0.64	0.54	0.79	0.02	0.00	0.00	0.00	0.00	0.00	0.00	4.55	1.99	1.35	0.81	0.74
1996	7.59	0.15	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	7.78	0.19	0.04	0.03	0.09
1997	2.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	0.02	0.00	0.00	0.02
1998	2.61	1.04	0.62	0.08	0.11	0.00	0.00	0.00	0.00	0.00	0.00	4.46	1.85	0.81	0.19	0.56
1999	6.34	0.98	0.28	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	7.65	1.31	0.33	0.05	0.43
2000	0.04	0.54	0.27	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.87	0.33	0.06	0.34

[a] Massachusetts sampling strata 25-36.

Table A18. Estimates of instantaneous total mortality (Z) and fishing mortality (F)[1] for Gulf of Maine Atlantic cod, 1964 - 2000, derived from NEFSC offshore spring and autumn bottom trawl survey data.[2]

Time Period	Gulf of Maine Spring Z	Spring F	Autumn Z	Autumn F	Geometric Mean Z	Geometric Mean F
1964-1967	-	-	0.39	0.19	0.39	0.19
1968-1976	0.36	0.16	0.44	0.24	0.40	0.20[3]
1977-1982	0.56	0.36	0.44	0.37	0.50	0.30[4]
1983-1987	0.93	0.73	1.12	0.92	1.02	0.82
1988-1992	1.24	1.04	0.86	0.66	1.03	0.83[5]
1993-1997	0.73	0.53	1.05	0.85	0.88	0.68
1998-1999	0.81	0.61	N/a	N/a	0.81	0.61

[1] Instantaneous natural mortality (M) assumed to be 0.20.

[2] Estimates derived from:

Spring: ln (Σ age 4+ for year i to j/ Σ age 5+ for years i+1 to j+1).
Autumn: ln (Σ age 3+ for years i-1 to j-1/ Σ age 4+ for years i to j).

[3] Excludes autumn 1967-1968 data (3+/4+) since these gave large negative Z value.

[4] Excludes autumn 1976-1977 data (3+/4+) since these gave large negative Z value.

[5] Excludes spring 1991-1992 data (4+/5+) since these gave unreasonably low Z value.

Table A19. Comparative VPA Results for Gulf of Maine Cod Assuming 3 Discard scenarios in 1999 and 2000.

Discard Option 1: Lower End of Range

1999 Discards = 2,000 mt
2000 Discards = 1,000 mt

Approximate Statistics Assuming Linearity Near Solution
Sum of Squares: 133.743222421604
Mean Square Residuals: 0.45184

	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
N 2	4.61E+03	2.26E+03	2.04E+00	0.49
N 3	6.28E+03	1.97E+03	3.18E+00	0.31
N 4	2.01E+03	5.86E+02	3.44E+00	0.29
N 5	8.10E+02	3.29E+02	2.46E+00	0.41
N 6	1.85E+02	8.97E+01	2.06E+00	0.49

Discard Option 2: Middle of the Range.

1999 Discards = 2,500 mt
2000 Discards = 1,000 mt

Approximate Statistics Assuming Linearity Near Solution
Sum of Squares: 134.032264575886
Mean Square Residuals: 0.45281

	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
N 2	4.63E+03	2.27E+03	2.04E+00	0.49
N 3	6.31E+03	1.99E+03	3.18E+00	0.31
N 4	2.02E+03	5.89E+02	3.44E+00	0.29
N 5	8.03E+02	3.30E+02	2.43E+00	0.41
N 6	1.76E+02	8.79E+01	2.01E+00	0.50

Discard Option 3: Upper End of Range

1999 Discards = 3,000 mt
2000 Discards = 2,000 mt

Approximate Statistics Assuming Linearity Near Solution
Sum of Squares: 134.72526691389
Mean Square Residuals: 0.45515

	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
N 2	4.67E+03	2.30E+03	2.03E+00	0.49
N 3	6.36E+03	2.01E+03	3.17E+00	0.32
N 4	1.99E+03	5.94E+02	3.36E+00	0.30
N 5	7.32E+02	3.29E+02	2.23E+00	0.45
N 6	1.56E+02	8.42E+01	1.86E+00	0.54

Table A19 (Continued).

STOCK NUMBERS (Jan 1) in thousands - D:\ASSESS\GMcod\gmcod2001\gmcod2001_recr_2.2

Lower End of Range

Ages	1996	1997	1998	1999	2000	2001
1+	12303	11878	12375	18196	19150	14007

Middle of Range

Ages	1996	1997	1998	1999	2000	2001
1+	12480	12095	12571	18399	19200	14048

Upper End of Range

Ages	1996	1997	1998	1999	2000	2001
1+	12766	12566	13007	18842	19464	14004

FISHING MORTALITY - D:\ASSESS\GMcod\gmcod2001\gmcod2001_recr_2.2

Lower End of Range

Ages	1996	1997	1998	1999	2000
4,5	1.01	0.89	0.73	0.70	0.71

Middle of Range

Ages	1996	1997	1998	1999	2000
4,5	1.01	0.88	0.70	0.77	0.73

Upper End of Range

Ages	1996	1997	1998	1999	2000
4,5	1.00	0.85	0.67	0.80	0.87

Table A20. Final VPA Results for Gulf of Maine Cod, 1982-2000

STOCK NUMBERS (Jan 1) in thousands - D:\ASSESS\GMcod\gmcod2001\gmcod2001_recr_2.2

	1982	1983	1984	1985	1986	1987	1988
1	7769	7539	10464	7004	10161	12538	25198
2	10891	6281	6160	8545	5690	8296	10228
3	5359	7112	3933	4307	6101	4471	5971
4	3026	2262	3202	1797	1616	2507	2377
5	1796	1223	780	1142	456	483	673
6	170	822	382	214	333	125	97
7	541	305	260	216	315	150	63
1+	29552	25543	25180	23227	24674	28569	44607

	1989	1990	1991	1992	1993	1994	1995
1	4302	4021	6992	6411	9327	3325	3386
2	20625	3518	3286	5720	5249	7635	2721
3	7903	16406	2614	2286	4367	4160	6200
4	2953	4404	9637	920	1328	1767	2157
5	907	881	1459	3413	277	375	336
6	158	303	280	338	818	100	22
7	104	188	155	132	65	116	53
1+	36951	29721	24421	19219	21430	17478	14876

	1996	1997	1998	1999	2000	2001
1	3020	4745	4498	9549	5656	00
2	2773	2473	3885	3683	7817	4630
3	1975	2192	1969	3081	3008	6312
4	4033	995	1348	1174	2013	2024
5	568	1544	393	546	449	803
6	90	132	455	159	206	176
7	19	14	23	209	53	102
1+	12480	12095	12571	18399	19200	14048

Table A20 (Continued).

FISHING MORTALITY - D:\ASSESS\GMcod\gmcod2001\gmcod2001_recr_2.2

	1982	1983	1984	1985	1986	1987	1988
1	0.01	0.00	0.00	0.01	0.00	0.00	0.00
2	0.23	0.27	0.16	0.14	0.04	0.13	0.06
3	0.66	0.60	0.58	0.78	0.69	0.43	0.50
4	0.71	0.86	0.83	1.17	1.01	1.12	0.76
5	0.58	0.96	1.09	1.03	1.10	1.41	1.25
6	0.67	0.92	0.90	1.16	1.06	1.20	0.87
7	0.67	0.92	0.90	1.16	1.06	1.20	0.87
F(4,5)	0.64	0.91	0.96	1.10	1.05	1.26	1.01
F(wb)	0.47	0.60	0.51	0.59	0.54	0.49	0.38

	1989	1990	1991	1992	1993	1994	1995
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.03	0.10	0.16	0.07	0.03	0.01	0.12
3	0.38	0.33	0.84	0.34	0.70	0.46	0.23
4	1.01	0.91	0.84	1.00	1.06	1.46	1.13
5	0.89	0.95	1.26	1.23	0.82	2.62	1.11
6	1.01	0.94	0.91	1.22	1.05	1.70	1.17
7	1.01	0.94	0.91	1.22	1.05	1.70	1.17
F(4,5)	0.95	0.93	1.05	1.11	0.94	2.04	1.12
F(wb)	0.30	0.49	0.78	0.53	0.40	0.44	0.41

	1996	1997	1998	1999	2000
1	0.00	0.00	0.00	0.00	0.00
2	0.03	0.03	0.03	0.00	0.01
3	0.49	0.29	0.32	0.23	0.20
4	0.76	0.73	0.70	0.76	0.72
5	1.26	1.02	0.71	0.78	0.73
6	0.83	0.92	0.72	0.78	0.73
7	0.83	0.92	0.72	0.78	0.73
F(4,5)	1.01	0.88	0.70	0.77	0.73
F(wb)	0.50	0.40	0.32	0.30	0.23

MEAN BIOMASS (using catch mean weights at age)

	1982	1983	1984	1985	1986	1987	1988
1	3975	2928	4736	2321	3890	3596	3813
2	9560	5331	5225	7385	5177	7148	8899
3	5705	7889	4426	4451	7270	5108	7540
4	5340	3399	5389	2721	2706	4345	3632
5	5895	2709	1597	2891	1164	1138	1804
6	747	2966	1346	640	1139	464	373
7	4089	1821	1624	1148	2097	829	415
1+	35312	27044	24343	21557	23444	22628	26477

	1989	1990	1991	1992	1993	1994	1995
1	2338	521	1083	2719	8453	1410	1436
2	21846	3095	3125	7675	5302	9429	3772
3	10275	21056	2459	3378	5250	5676	9327
4	5022	6083	14785	1457	1824	2660	3177
5	2114	2197	3085	5558	737	416	946
6	389	1374	1224	902	2841	272	87
7	718	1519	1040	745	408	510	387
1+	42702	35845	26800	22434	24814	20372	19133

Table A20 (Continued).

	1996	1997	1998	1999	2000	
1	1281	2013	1908	2864	2399	
2	4080	3806	4632	4167	11260	
3	2992	3822	3242	4619	5647	
4	6054	1922	2606	2093	4358	
5	1074	2800	1068	1429	1252	
6	417	362	1230	580	779	
7	132	77	152	1023	252	
1+	16028	14802	14838	16775	25946	00

SSB AT THE START OF THE SPAWNING SEASON -MALES AND FEMALES (MT) (using SSB mean weights)

	1982	1983	1984	1985	1986	1987	1988
1	218	143	248	60	108	87	61
2	2326	1174	993	2765	1608	2465	2629
3	3630	5002	2764	4445	6762	4801	6729
4	5197	3283	4945	3039	2857	4768	3877
5	6421	3100	1821	3204	1308	1365	2102
6	820	3633	1483	763	1390	554	442
7	5296	2513	2229	1672	2991	1221	567
1+	23908	18848	14484	15947	17024	15262	16406

	1989	1990	1991	1992	1993	1994	1995
1	77	22	42	205	848	32	33
2	4241	732	349	784	1029	3279	854
3	8868	11771	1527	1723	3516	4815	8171
4	5481	5872	13262	1238	1876	3149	3810
5	2284	2372	3221	6871	738	665	1066
6	599	1327	1255	1173	2808	370	87
7	1012	2104	1430	1101	580	831	567
1+	22561	24200	21088	13096	11396	13141	14587

	1996	1997	1998	1999	2000
1	29	51	50	56	66
2	891	812	1123	1035	2087
3	2887	3431	3063	4005	4225
4	7074	2102	2919	2395	4221
5	1379	3411	1182	1610	1325
6	465	444	1407	656	860
7	177	106	199	1364	331
1+	12901	10357	9943	11121	13114

Table A21. Yield and spawning stock biomass per recruit estimates and input data for Gulf of Maine cod.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 28- 6-2001; Time: 10:23:22.61

GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 11
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> yrcodgma.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0000	1.0000	.0400	.441	.283
2	.0134	1.0000	.3800	1.229	.725
3	.2867	1.0000	.8900	1.782	1.466
4	.9889	1.0000	.9900	2.694	2.180
5	1.0000	1.0000	1.0000	4.089	3.343
6	1.0000	1.0000	1.0000	6.031	4.960
7	1.0000	1.0000	1.0000	9.003	7.551
8	1.0000	1.0000	1.0000	11.615	10.251
9	1.0000	1.0000	1.0000	14.175	12.903
10	1.0000	1.0000	1.0000	16.411	14.975
11+	1.0000	1.0000	1.0000	18.479	18.479

Summary of Yield per Recruit Analysis for:
GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

Slope of the Yield/Recruit Curve at F=0.00: --> 27.9322
F level at slope=1/10 of the above slope (F0.1): -----> .153
Yield/Recruit corresponding to F0.1: -----> 1.6797
F level to produce Maximum Yield/Recruit (Fmax): -----> .267
Yield/Recruit corresponding to Fmax: -----> 1.8015
F level at 20 % of Max Spawning Potential (F20): -----> .363
SSB/Recruit corresponding to F20: --------> 5.6681

Listing of Yield per Recruit Results for:
GULF OF MAINE COD (5Y) - 2001 UPDATED AVE WTS, FPAT AND MAT VECTORS

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	5.5167	30.0615	3.8396	28.3409	100.00
	.05	.11706	.97975	4.9338	21.7023	3.2551	20.0950	70.90
	.10	.19534	1.44901	4.5447	16.5838	2.8643	15.0665	53.16
	.15	.25146	1.67194	4.2664	13.2304	2.5843	11.7852	41.58
F0.1	.15	.25406	1.67973	4.2535	13.0825	2.5714	11.6408	41.07
	.20	.29373	1.76902	4.0573	10.9224	2.3736	9.5355	33.65
	.25	.32676	1.79997	3.8943	9.2722	2.2090	7.9325	27.99
Fmax	.27	.33641	1.80149	3.8469	8.8186	2.1610	7.4929	26.44
	.30	.35333	1.79603	3.7637	8.0552	2.0767	6.7541	23.83
	.35	.37519	1.77411	3.6565	7.1343	1.9679	5.8648	20.69
F20%	.36	.38029	1.76668	3.6315	6.9303	1.9426	5.6681	20.00
	.40	.39351	1.74357	3.5669	6.4217	1.8768	5.1784	18.27
	.45	.40912	1.70964	3.4908	5.8596	1.7992	4.6381	16.37
	.50	.42259	1.67520	3.4254	5.4087	1.7323	4.2053	14.84
	.55	.43435	1.64181	3.3686	5.0413	1.6740	3.8532	13.60
	.60	.44472	1.61027	3.3186	4.7380	1.6225	3.5626	12.57
	.65	.45394	1.58092	3.2743	4.4844	1.5768	3.3199	11.71
	.70	.46220	1.55386	3.2348	4.2700	1.5358	3.1147	10.99
	.75	.46966	1.52903	3.1992	4.0868	1.4989	2.9394	10.37
	.80	.47643	1.50633	3.1670	3.9290	1.4653	2.7882	9.84
	.85	.48261	1.48560	3.1378	3.7917	1.4347	2.6567	9.37
	.90	.48828	1.46666	3.1110	3.6714	1.4067	2.5413	8.97
	.95	.49351	1.44936	3.0865	3.5653	1.3808	2.4393	8.61
	1.00	.49835	1.43352	3.0638	3.4710	1.3569	2.3486	8.29

Table A22a. Starting conditions and input data for short-term (2001-2003) and long-term (2001-2025) stochastic stock biomass and catch projections for Gulf of Maine cod.

Input for Projections:

Number of Years: 3; Initial Year: 2001; Final Year: 2003
Number of Ages : 7; Age at Recruitment: 1; Last Age: 7
Natural Mortality is assumed Constant over time at: .200
Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Last age is a PLUS group;

Age-specific Input data for Projection # 1

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0010	1.0000	.0400	0.441	0.283
2	.0134	1.0000	.3800	1.229	0.725
3	.2867	1.0000	.8900	1.782	1.466
4	1.0000	1.0000	.9900	2.694	2.180
5	1.0000	1.0000	1.0000	4.089	3.343
6	1.0000	1.0000	1.0000	6.031	4.960
7+	1.0000	1.0000	1.0000	10.881	10.881

Table A22b. Results of short-term stochastic stock biomass and catch projections for Gulf of Maine cod.

Projections for 2001-2003; F(2001)=0.73, Basis: Status quo 2000 point estimate.
Recruitment (age 1) 2001 and 2002 year classes derived from Beverton-Holts spawning stock-recruitment relationship based on 1981-1999 year classes.

SSB was estimated to be 13,100 t in 2000.

2001			2002			2003
F	Catch	SSB	F	Catch	SSB	SSB
0.73	7540	18210	$F_{0.1}$ =0.15	2619	21339	29819
0.73	7540	18210	F_{msy} =0.23	3884	21122	28153
0.73	7540	18210	F_{max} =0.27	4482	21015	27374
0.73	7540	18210	F_{SQ} =0.73	10107	19862	20401

Table A23. Long-term (25 yr) Projections for Gulf of Maine cod at F0.1 (0.15), Fmsy (0.23) and Fmax (0.27).

A) F0.1 = 0.15

PROJECTION RUN: GM Cod F0.1 25 yr projection
INPUT FILE: gmc2001mod5.in
OUTPUT FILE: gmc2001mod5_F01.out
RECRUITMENT MODEL: 5
NUMBER OF SIMULATIONS: 100

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2001	0.730
2002	0.150
2003	0.150
2004	0.150
2005	0.150
2006	0.150
2007	0.150
2008	0.150
2009	0.150
2010	0.150
2011	0.150
2012	0.150
2013	0.150
2014	0.150
2015	0.150
2016	0.150
2017	0.150
2018	0.150
2019	0.150
2020	0.150
2021	0.150
2022	0.150
2023	0.150
2024	0.150
2025	0.150

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	12.397	13.705	14.578	16.323	18.210	20.442	22.278	23.559	27.247
2002	14.141	16.331	17.389	19.059	21.339	24.107	26.764	28.120	31.894
2003	21.298	23.704	25.015	27.087	29.819	33.068	36.313	38.050	42.339
2004	28.288	31.246	32.752	35.553	39.049	42.958	46.889	49.369	54.707
2005	37.130	40.900	42.899	46.704	51.394	56.591	61.670	65.011	72.334
2006	42.726	47.054	49.427	53.691	58.943	64.873	70.803	74.464	82.868
2007	49.741	54.075	56.505	60.864	66.118	72.062	77.897	81.714	89.707
2008	54.106	58.988	61.735	66.724	72.684	79.418	86.107	90.334	99.409
2009	58.281	63.596	66.501	71.888	78.380	85.547	92.755	97.432	106.650
2010	62.379	67.842	70.975	76.586	83.416	90.955	98.410	103.306	113.095
2011	65.782	71.580	74.800	80.635	87.742	95.516	103.260	108.446	118.213
2012	68.706	74.659	77.968	83.999	91.278	99.290	107.195	112.334	122.463
2013	71.004	77.136	80.524	86.698	94.103	102.236	110.348	115.427	126.060
2014	72.983	79.115	82.648	88.784	96.288	104.609	112.722	117.933	128.586
2015	74.684	80.698	84.263	90.465	98.054	106.421	114.597	119.894	130.496
2016	75.712	81.900	85.502	91.744	99.415	107.781	115.961	121.203	131.929
2017	76.708	82.924	86.460	92.794	100.514	108.842	117.100	122.351	132.953
2018	77.442	83.650	87.220	93.605	101.306	109.682	118.078	123.300	133.940
2019	78.078	84.175	87.783	94.260	101.951	110.303	118.783	124.111	134.857
2020	78.301	84.668	88.256	94.707	102.464	110.815	119.242	124.453	135.459
2021	78.750	85.087	88.614	95.070	102.831	111.231	119.625	124.930	135.835
2022	78.917	85.276	88.961	95.390	103.080	111.512	119.894	125.364	136.318
2023	79.225	85.615	89.163	95.583	103.287	111.723	120.182	125.668	136.640
2024	79.481	85.722	89.296	95.726	103.428	111.909	120.423	125.786	137.046
2025	79.584	85.928	89.436	95.833	103.584	112.097	120.425	125.875	136.951

PERCENTILES OF TOTAL JANUARY 1 STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	16.976	19.063	19.892	21.970	24.424	27.174	29.536	31.219	35.279
2002	19.197	21.392	22.507	24.480	27.054	30.064	32.968	34.695	38.753
2003	26.874	29.583	31.037	33.601	36.812	40.495	44.077	46.357	51.159
2004	35.066	38.422	40.217	43.501	47.532	52.011	56.418	59.285	65.393
2005	45.691	50.077	52.454	56.778	62.088	67.973	73.754	77.477	85.465
2006	52.471	57.414	60.175	65.057	71.017	77.710	84.422	88.624	97.959
2007	60.604	65.699	68.387	73.397	79.372	86.073	92.689	96.979	106.093
2008	65.992	71.506	74.744	80.463	87.322	94.981	102.707	107.591	118.017
2009	70.880	76.841	80.250	86.439	93.849	102.047	110.266	115.564	125.960
2010	75.360	81.629	85.201	91.616	99.401	107.956	116.491	122.036	133.111
2011	79.137	85.670	89.283	95.952	104.020	112.782	121.631	127.450	138.541
2012	82.167	88.909	92.692	99.538	107.772	116.824	125.749	131.457	142.792
2013	84.692	91.534	95.417	102.342	110.687	119.849	128.893	134.657	146.269
2014	86.715	93.614	97.538	104.469	112.948	122.244	131.263	137.211	149.056
2015	88.299	95.234	99.223	106.213	114.774	124.039	133.237	139.043	150.888
2016	89.460	96.497	100.452	107.478	116.120	125.482	134.559	140.496	152.513
2017	90.423	97.471	101.468	108.531	117.183	126.479	135.760	141.710	153.493
2018	91.251	98.131	102.185	109.347	118.019	127.323	136.609	142.522	154.377
2019	91.801	98.672	102.774	109.974	118.606	127.925	137.359	143.204	155.109
2020	91.987	99.110	103.177	110.408	119.086	128.439	137.736	143.568	155.560
2021	92.271	99.550	103.515	110.745	119.419	128.747	138.156	144.001	156.056
2022	92.574	99.761	103.804	111.072	119.641	129.033	138.326	144.435	156.725
2023	92.858	100.093	104.066	111.192	119.849	129.264	138.560	144.662	156.808
2024	93.145	100.252	104.145	111.381	119.977	129.412	138.848	144.740	157.222
2025	93.202	100.354	104.318	111.460	120.146	129.645	138.921	144.856	157.002

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	4.869	5.651	5.970	6.730	7.540	8.371	9.204	9.823	10.962
2002	1.709	1.947	2.070	2.307	2.619	2.939	3.275	3.458	4.087
2003	2.477	2.832	3.027	3.332	3.722	4.207	4.717	4.968	5.549
2004	3.633	4.068	4.259	4.596	5.058	5.580	6.096	6.417	7.106
2005	4.765	5.282	5.550	6.058	6.690	7.402	8.101	8.568	9.551
2006	5.538	6.102	6.425	6.997	7.717	8.519	9.328	9.834	10.996
2007	6.454	7.028	7.368	7.964	8.693	9.525	10.348	10.884	12.058
2008	7.043	7.707	8.089	8.764	9.594	10.540	11.477	12.102	13.371
2009	7.634	8.346	8.763	9.500	10.398	11.407	12.415	13.061	14.384
2010	8.172	8.938	9.376	10.152	11.106	12.160	13.225	13.898	15.301
2011	8.657	9.467	9.904	10.709	11.707	12.799	13.886	14.598	15.977
2012	9.073	9.890	10.348	11.181	12.195	13.323	14.436	15.169	16.604
2013	9.381	10.224	10.694	11.553	12.585	13.727	14.856	15.606	17.091
2014	9.648	10.497	10.986	11.846	12.889	14.053	15.193	15.939	17.447
2015	9.867	10.728	11.212	12.077	13.135	14.296	15.450	16.201	17.705
2016	10.041	10.883	11.381	12.251	13.324	14.501	15.649	16.403	17.900
2017	10.136	11.011	11.514	12.398	13.471	14.638	15.810	16.557	18.038
2018	10.281	11.127	11.623	12.511	13.587	14.758	15.927	16.665	18.168
2019	10.346	11.203	11.692	12.597	13.672	14.852	16.032	16.790	18.288
2020	10.391	11.252	11.769	12.656	13.743	14.913	16.107	16.837	18.385
2021	10.435	11.315	11.817	12.709	13.799	14.971	16.148	16.918	18.425
2022	10.466	11.354	11.849	12.751	13.835	15.019	16.181	16.960	18.504
2023	10.498	11.393	11.897	12.780	13.861	15.036	16.223	17.002	18.556
2024	10.548	11.417	11.909	12.797	13.882	15.063	16.271	17.019	18.611
2025	10.563	11.426	11.924	12.804	13.897	15.078	16.282	17.033	18.616

B) Fmsy = 0.23

PROJECTION RUN: GM Cod Fmsy 25 yr projection
INPUT FILE: gmc2001mod5.in
OUTPUT FILE: gmc2001mod5_Fmsy.out
RECRUITMENT MODEL: 5
NUMBER OF SIMULATIONS: 100

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2001	0.730
2002	0.230
2003	0.230
2004	0.230
2005	0.230
2006	0.230
2007	0.230
2008	0.230
2009	0.230
2010	0.230
2011	0.230
2012	0.230
2013	0.230
2014	0.230
2015	0.230
2016	0.230
2017	0.230
2018	0.230
2019	0.230
2020	0.230
2021	0.230
2022	0.230
2023	0.230
2024	0.230
2025	0.230

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	12.397	13.705	14.578	16.323	18.210	20.442	22.278	23.559	27.247
2002	14.001	16.165	17.214	18.870	21.122	23.859	26.506	27.866	31.562
2003	20.161	22.434	23.655	25.610	28.153	31.195	34.270	35.911	39.813
2004	25.737	28.334	29.699	32.220	35.368	38.889	42.428	44.709	49.617
2005	32.202	35.437	37.195	40.462	44.538	49.033	53.443	56.370	62.517
2006	36.023	39.534	41.589	45.178	49.617	54.622	59.663	62.815	70.053
2007	40.691	44.313	46.319	50.016	54.474	59.497	64.495	67.813	74.554
2008	43.427	47.457	49.743	53.875	58.852	64.446	70.019	73.615	80.985
2009	46.132	50.389	52.771	57.219	62.532	68.430	74.340	78.163	85.661
2010	48.599	53.082	55.588	60.111	65.699	71.811	77.945	81.830	89.800
2011	50.703	55.321	57.898	62.615	68.320	74.591	80.909	84.991	92.817
2012	52.335	57.114	59.743	64.589	70.397	76.817	83.165	87.276	95.551
2013	53.702	58.539	61.226	66.118	72.014	78.514	85.002	89.077	97.665
2014	54.779	59.638	62.422	67.261	73.211	79.853	86.256	90.475	98.825
2015	55.710	60.465	63.258	68.173	74.165	80.800	87.351	91.539	99.930
2016	56.226	61.068	63.882	68.871	74.914	81.509	88.064	92.273	100.642
2017	56.792	61.637	64.406	69.408	75.522	82.052	88.692	92.793	101.151
2018	57.126	61.977	64.766	69.811	75.869	82.530	89.096	93.281	101.737
2019	57.383	62.167	65.069	70.134	76.245	82.832	89.501	93.757	102.336
2020	57.508	62.459	65.261	70.357	76.462	83.095	89.772	94.006	102.591
2021	57.638	62.650	65.462	70.518	76.670	83.310	89.847	94.151	102.624
2022	57.812	62.707	65.644	70.648	76.720	83.418	90.024	94.322	103.158
2023	58.032	62.932	65.700	70.756	76.821	83.430	90.210	94.492	103.164
2024	58.130	62.965	65.735	70.798	76.881	83.593	90.301	94.586	103.420
2025	58.132	63.086	65.791	70.837	76.953	83.678	90.320	94.609	103.336

PERCENTILES OF TOTAL JANUARY 1 STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	16.976	19.063	19.892	21.970	24.424	27.174	29.536	31.219	35.279
2002	19.197	21.392	22.507	24.480	27.054	30.064	32.968	34.695	38.753
2003	25.873	28.449	29.843	32.299	35.382	38.893	42.338	44.528	49.146
2004	32.564	35.584	37.271	40.272	44.003	48.122	52.219	54.878	60.616
2005	40.586	44.471	46.586	50.414	55.095	60.320	65.458	68.775	75.728
2006	45.280	49.516	51.939	56.187	61.312	67.126	72.886	76.571	84.687
2007	50.931	55.251	57.589	61.926	67.105	72.923	78.644	82.420	90.302
2008	54.382	59.142	61.804	66.678	72.538	79.037	85.606	89.693	98.359
2009	57.610	62.631	65.436	70.609	76.804	83.684	90.511	94.981	103.585
2010	60.365	65.589	68.571	73.838	80.328	87.395	94.454	98.977	107.888
2011	62.698	68.046	71.041	76.522	83.149	90.361	97.600	102.203	111.193
2012	64.451	69.991	73.017	78.583	85.325	92.693	99.901	104.606	113.962
2013	65.912	71.469	74.583	80.185	86.941	94.405	101.750	106.482	116.200
2014	66.966	72.549	75.739	81.347	88.205	95.748	103.049	107.813	117.080
2015	67.817	73.399	76.634	82.270	89.171	96.681	104.071	108.795	118.426
2016	68.304	74.046	77.227	82.940	89.861	97.392	104.790	109.637	119.128
2017	68.915	74.558	77.743	83.450	90.460	97.899	105.367	110.151	119.464
2018	69.338	74.857	78.069	83.874	90.794	98.341	105.831	110.598	120.155
2019	69.438	75.050	78.349	84.154	91.108	98.630	106.222	110.970	120.581
2020	69.533	75.297	78.560	84.354	91.337	98.863	106.317	111.121	120.793
2021	69.800	75.527	78.742	84.500	91.494	99.006	106.521	111.303	120.929
2022	69.895	75.599	78.824	84.647	91.508	99.123	106.598	111.530	121.424
2023	69.991	75.772	78.933	84.672	91.603	99.173	106.752	111.602	121.353
2024	70.162	75.827	78.938	84.761	91.643	99.298	106.814	111.616	121.639
2025	70.186	75.857	79.034	84.774	91.723	99.412	106.875	111.683	121.398

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	4.869	5.651	5.970	6.730	7.540	8.371	9.204	9.823	10.962
2002	2.531	2.887	3.066	3.421	3.884	4.357	4.859	5.132	6.054
2003	3.473	3.954	4.256	4.663	5.214	5.891	6.615	6.958	7.773
2004	4.890	5.462	5.710	6.160	6.761	7.447	8.125	8.540	9.432
2005	6.123	6.759	7.107	7.752	8.561	9.467	10.365	10.965	12.248
2006	6.872	7.573	7.974	8.685	9.593	10.594	11.606	12.248	13.749
2007	7.785	8.498	8.915	9.653	10.568	11.613	12.649	13.351	14.819
2008	8.330	9.145	9.609	10.436	11.467	12.635	13.807	14.567	16.145
2009	8.887	9.750	10.258	11.152	12.249	13.475	14.699	15.493	17.089
2010	9.396	10.307	10.820	11.758	12.910	14.180	15.468	16.290	17.972
2011	9.829	10.785	11.303	12.261	13.450	14.771	16.067	16.940	18.606
2012	10.187	11.148	11.696	12.678	13.883	15.225	16.565	17.410	19.177
2013	10.439	11.434	11.980	12.993	14.208	15.574	16.916	17.795	19.587
2014	10.647	11.660	12.230	13.232	14.469	15.850	17.202	18.085	19.850
2015	10.858	11.838	12.416	13.416	14.666	16.038	17.418	18.309	20.079
2016	10.994	11.961	12.542	13.563	14.816	16.205	17.572	18.464	20.234
2017	11.059	12.057	12.642	13.677	14.934	16.314	17.701	18.583	20.349
2018	11.162	12.147	12.724	13.763	15.022	16.405	17.780	18.643	20.469
2019	11.197	12.195	12.769	13.827	15.081	16.476	17.867	18.764	20.586
2020	11.228	12.230	12.824	13.863	15.135	16.513	17.931	18.808	20.637
2021	11.270	12.288	12.854	13.900	15.182	16.572	17.954	18.857	20.631
2022	11.295	12.307	12.884	13.932	15.192	16.597	17.966	18.871	20.718
2023	11.336	12.330	12.920	13.953	15.213	16.603	17.998	18.922	20.782
2024	11.331	12.358	12.921	13.962	15.219	16.624	18.032	18.917	20.807
2025	11.351	12.356	12.931	13.964	15.234	16.637	18.046	18.950	20.813

Table A23 (Continued).

C) Fmax = 0.27

PROJECTION RUN: GM Cod Fmax 25 yr projection
INPUT FILE: gmc2001mod5.in
OUTPUT FILE: gmc2001mod5_Fmax.out
RECRUITMENT MODEL: 5
NUMBER OF SIMULATIONS: 100

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2001	0.730
2002	0.270
2003	0.270
2004	0.270
2005	0.270
2006	0.270
2007	0.270
2008	0.270
2009	0.270
2010	0.270
2011	0.270
2012	0.270
2013	0.270
2014	0.270
2015	0.270
2016	0.270
2017	0.270
2018	0.270
2019	0.270
2020	0.270
2021	0.270
2022	0.270
2023	0.270
2024	0.270
2025	0.270

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	12.397	13.705	14.578	16.323	18.210	20.442	22.278	23.559	27.247
2002	13.930	16.082	17.126	18.774	21.015	23.733	26.374	27.740	31.398
2003	19.630	21.841	23.017	24.917	27.374	30.319	33.307	34.906	38.655
2004	24.591	27.017	28.323	30.737	33.724	37.077	40.459	42.640	47.337
2005	30.100	33.099	34.752	37.808	41.623	45.816	49.939	52.718	58.389
2006	33.134	36.428	38.326	41.661	45.781	50.429	55.119	58.070	64.756
2007	36.975	40.364	42.219	45.625	49.773	54.470	59.129	62.207	68.593
2008	39.185	42.891	44.992	48.794	53.386	58.554	63.712	67.047	73.854
2009	41.355	45.268	47.432	51.511	56.379	61.807	67.206	70.708	77.619
2010	43.352	47.427	49.675	53.802	58.901	64.490	70.099	73.634	80.923
2011	44.991	49.182	51.519	55.772	60.978	66.699	72.455	76.168	83.409
2012	46.256	50.542	52.922	57.321	62.584	68.442	74.183	77.925	85.460
2013	47.264	51.647	54.077	58.480	63.819	69.729	75.625	79.279	87.149
2014	48.075	52.499	54.989	59.372	64.771	70.741	76.582	80.398	88.000
2015	48.771	53.087	55.632	60.043	65.478	71.482	77.406	81.203	88.740
2016	49.222	53.525	56.084	60.574	66.046	72.006	77.940	81.751	89.277
2017	49.571	53.953	56.450	60.971	66.493	72.390	78.366	82.132	89.806
2018	49.912	54.196	56.726	61.266	66.741	72.757	78.700	82.545	90.132
2019	50.041	54.334	56.962	61.494	67.026	73.000	79.061	82.906	90.621
2020	50.100	54.576	57.082	61.652	67.180	73.182	79.211	83.047	90.817
2021	50.256	54.724	57.262	61.792	67.327	73.336	79.251	83.171	90.867
2022	50.355	54.768	57.384	61.887	67.365	73.388	79.372	83.233	91.272
2023	50.548	54.901	57.402	61.948	67.416	73.424	79.552	83.392	91.276
2024	50.561	54.903	57.416	61.983	67.453	73.521	79.613	83.474	91.430
2025	50.585	54.985	57.471	62.004	67.527	73.577	79.600	83.473	91.375

PERCENTILES OF TOTAL JANUARY 1 STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	16.976	19.063	19.892	21.970	24.424	27.174	29.536	31.219	35.279
2002	19.197	21.392	22.507	24.480	27.054	30.064	32.968	34.695	38.753
2003	25.402	27.906	29.278	31.684	34.698	38.138	41.517	43.667	48.197
2004	31.418	34.307	35.922	38.821	42.415	46.386	50.342	52.909	58.528
2005	38.355	42.022	44.038	47.662	52.098	57.037	61.926	65.068	71.726
2006	42.240	46.247	48.495	52.472	57.307	62.775	68.192	71.694	79.282
2007	46.915	50.961	53.208	57.259	62.120	67.619	73.051	76.579	84.026
2008	49.761	54.197	56.679	61.222	66.679	72.723	78.829	82.651	90.602
2009	52.376	57.047	59.660	64.426	70.152	76.551	82.853	87.011	94.925
2010	54.653	59.415	62.128	66.984	72.984	79.484	86.002	90.168	98.450
2011	56.472	61.340	64.109	69.115	75.214	81.863	88.490	92.760	100.917
2012	57.795	62.836	65.630	70.764	76.921	83.657	90.270	94.546	103.323
2013	58.873	64.029	66.842	71.957	78.128	84.980	91.674	96.000	104.978
2014	59.746	64.789	67.678	72.831	79.085	86.000	92.639	97.057	105.399
2015	60.354	65.453	68.387	73.515	79.807	86.691	93.473	97.771	106.474
2016	60.711	65.891	68.800	74.011	80.361	87.165	93.991	98.373	107.075
2017	61.139	66.290	69.181	74.399	80.780	87.598	94.383	98.736	107.314
2018	61.442	66.483	69.441	74.710	81.004	87.874	94.711	99.088	107.942
2019	61.557	66.629	69.604	74.924	81.235	88.114	95.036	99.317	108.163
2020	61.541	66.836	69.780	75.047	81.417	88.280	95.098	99.459	108.340
2021	61.808	66.973	69.899	75.132	81.504	88.389	95.211	99.595	108.346
2022	61.857	67.009	69.959	75.220	81.516	88.437	95.232	99.750	108.890
2023	61.910	67.143	70.059	75.241	81.562	88.462	95.401	99.849	108.737
2024	62.050	67.156	70.030	75.315	81.604	88.591	95.442	99.854	108.976
2025	62.070	67.191	70.077	75.303	81.631	88.644	95.470	99.868	108.720

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2001	4.869	5.651	5.970	6.730	7.540	8.371	9.204	9.823	10.962
2002	2.921	3.333	3.539	3.949	4.482	5.028	5.613	5.928	6.986
2003	3.896	4.436	4.777	5.231	5.857	6.622	7.418	7.815	8.750
2004	5.391	6.009	6.280	6.774	7.426	8.169	8.906	9.358	10.326
2005	6.595	7.271	7.646	8.340	9.213	10.184	11.156	11.807	13.217
2006	7.286	8.035	8.457	9.220	10.191	11.267	12.356	13.045	14.687
2007	8.141	8.910	9.353	10.139	11.117	12.241	13.361	14.112	15.683
2008	8.654	9.516	10.008	10.881	11.977	13.218	14.457	15.272	16.945
2009	9.167	10.072	10.611	11.557	12.712	14.007	15.309	16.153	17.865
2010	9.638	10.586	11.132	12.112	13.322	14.662	16.026	16.891	18.675
2011	10.037	11.027	11.569	12.574	13.817	15.209	16.572	17.478	19.254
2012	10.356	11.343	11.924	12.948	14.212	15.614	17.015	17.913	19.765
2013	10.587	11.601	12.173	13.229	14.495	15.934	17.341	18.250	20.163
2014	10.750	11.805	12.397	13.439	14.730	16.165	17.577	18.525	20.358
2015	10.941	11.953	12.554	13.597	14.900	16.334	17.778	18.720	20.591
2016	11.061	12.062	12.664	13.727	15.027	16.478	17.911	18.851	20.720
2017	11.110	12.140	12.744	13.821	15.135	16.573	18.017	18.949	20.791
2018	11.194	12.222	12.818	13.900	15.207	16.652	18.087	19.006	20.915
2019	11.226	12.261	12.856	13.945	15.258	16.716	18.175	19.107	21.019
2020	11.242	12.287	12.900	13.979	15.301	16.749	18.228	19.154	21.094
2021	11.299	12.338	12.928	14.012	15.344	16.797	18.233	19.186	21.064
2022	11.306	12.353	12.955	14.039	15.356	16.819	18.247	19.206	21.113
2023	11.333	12.375	12.988	14.061	15.365	16.816	18.272	19.243	21.187
2024	11.352	12.399	12.983	14.060	15.368	16.840	18.312	19.244	21.244
2025	11.369	12.398	12.989	14.058	15.383	16.848	18.314	19.286	21.236

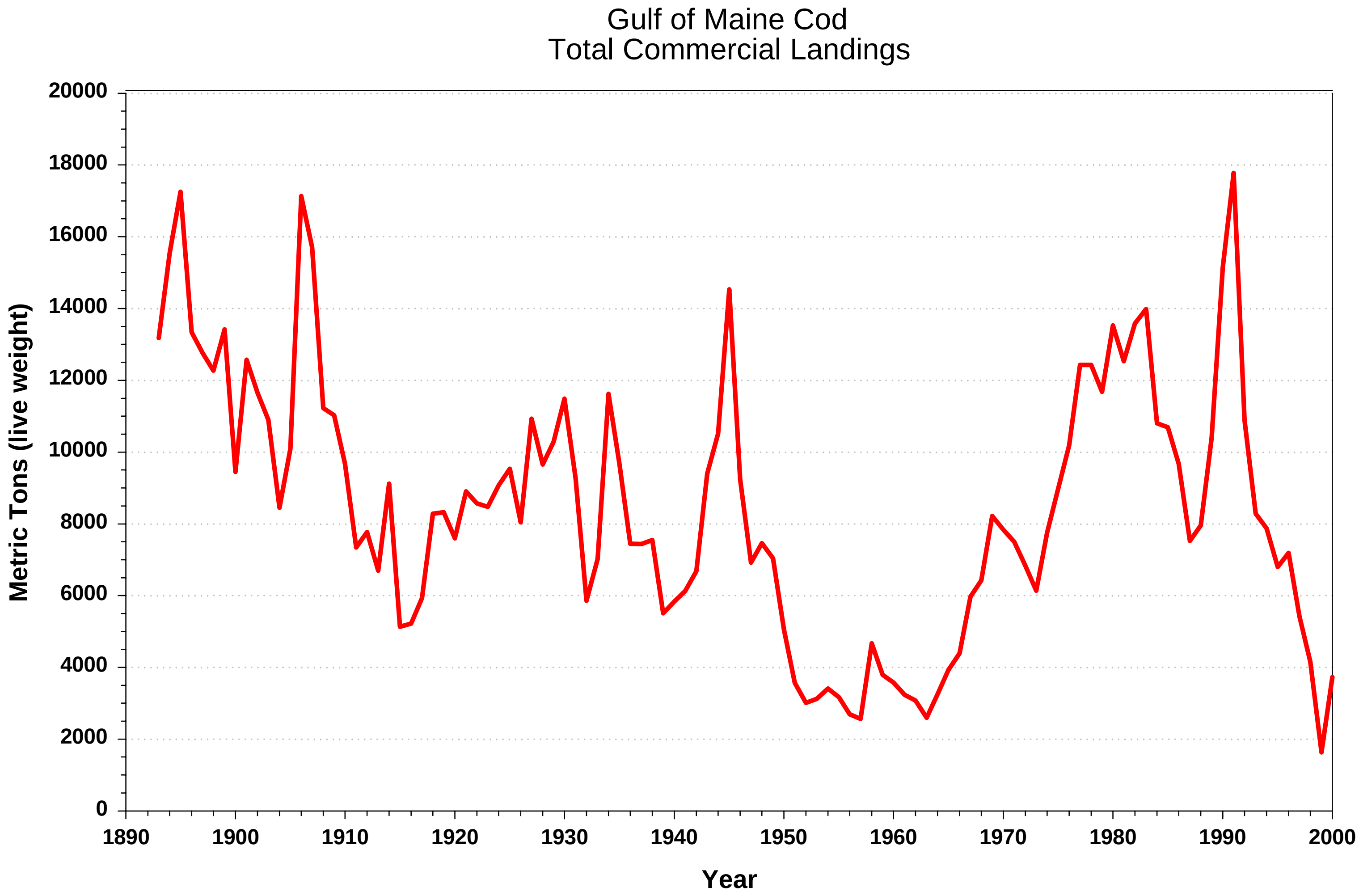
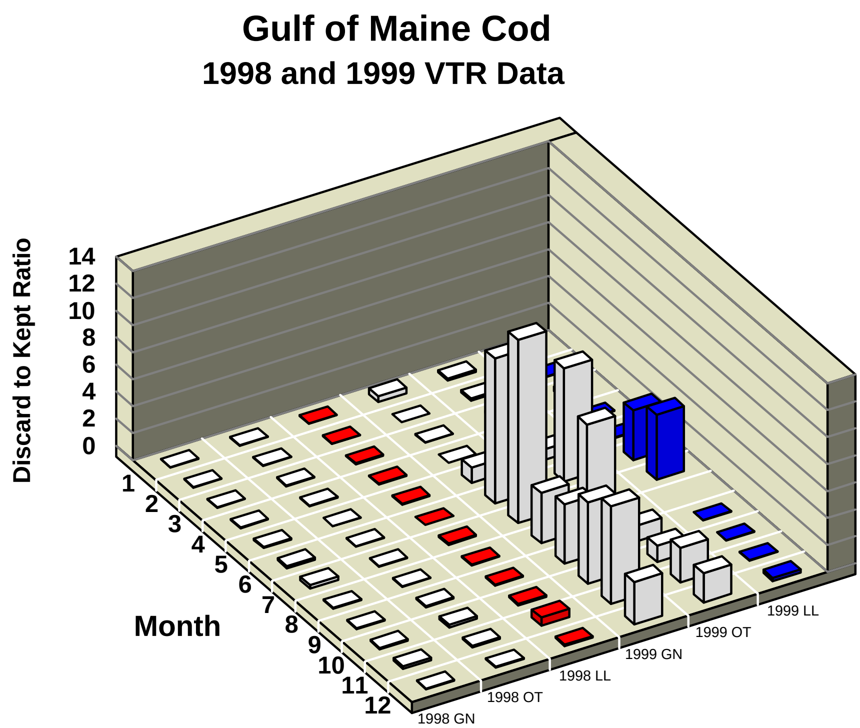


Figure A1. Total commercial landings of Gulf of Maine cod (NAFO Div. 5Y), 1893-2000.



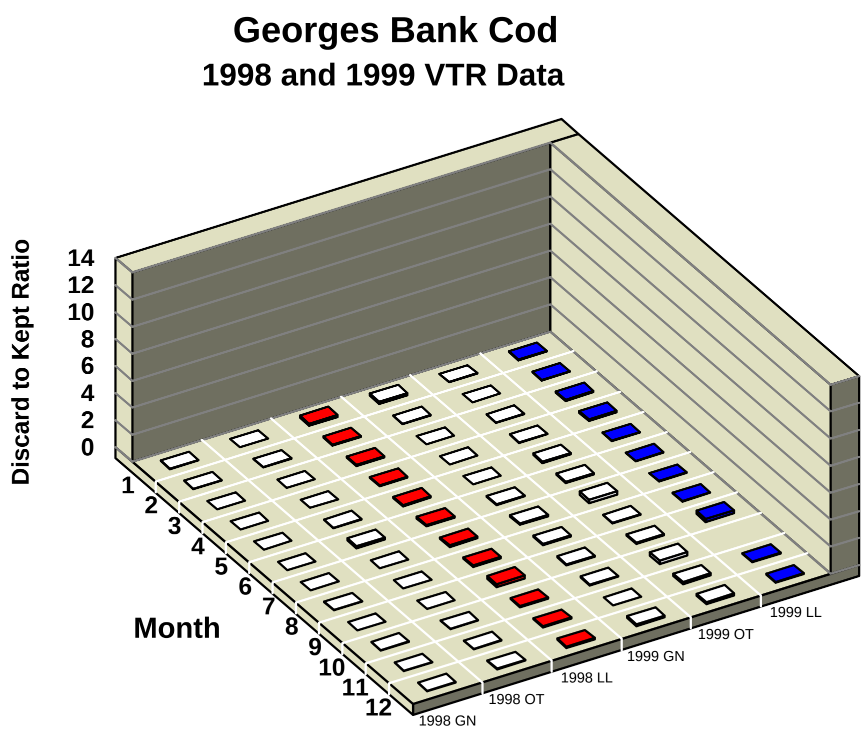
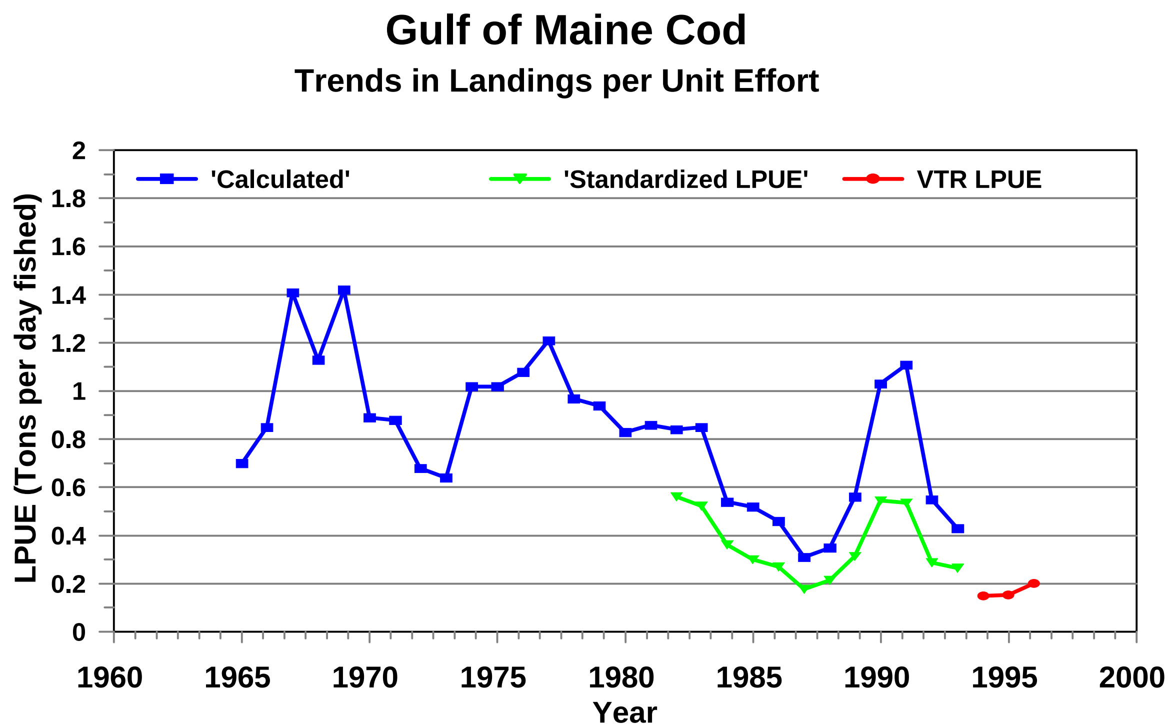


Figure A2. Discard to kept ratios based of 1998 and 1999 VTR data for Gulf of Maine and Georges Bank cod.



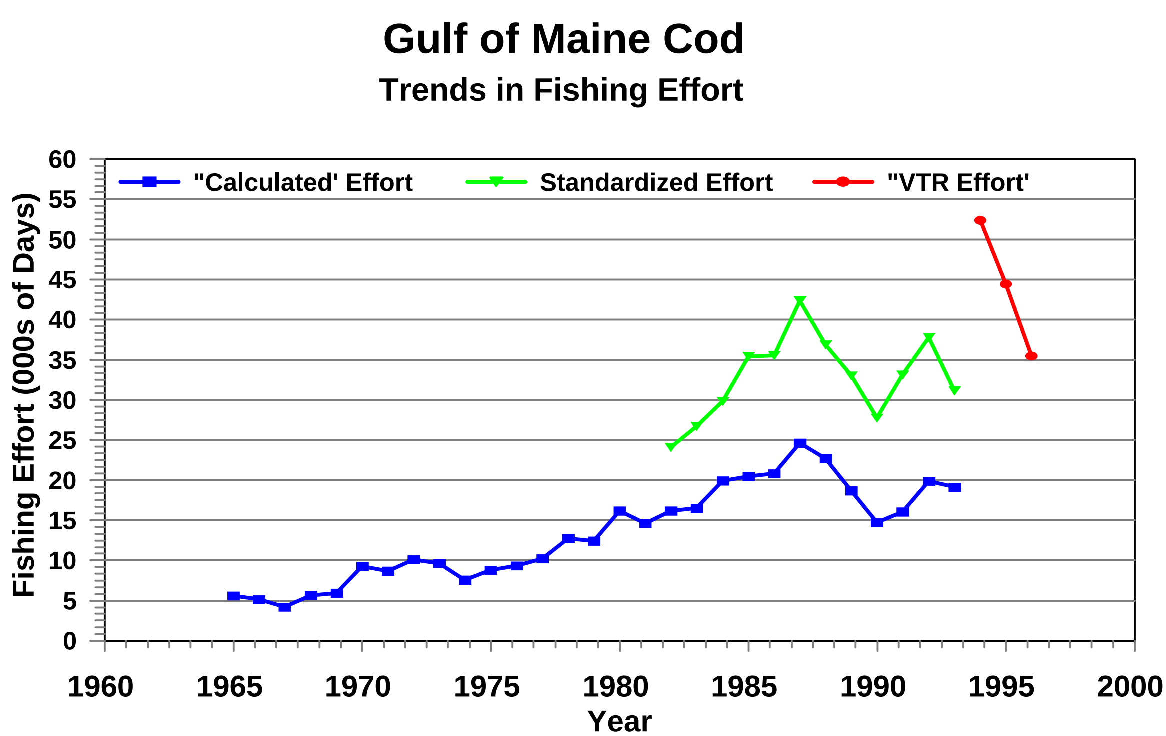


Figure A3. (a) Trends in LPUE for Gulf of Maine cod, 1964-1996.
(b) Trends in fishing effort for Gulf of Maine cod, 1964-1996.

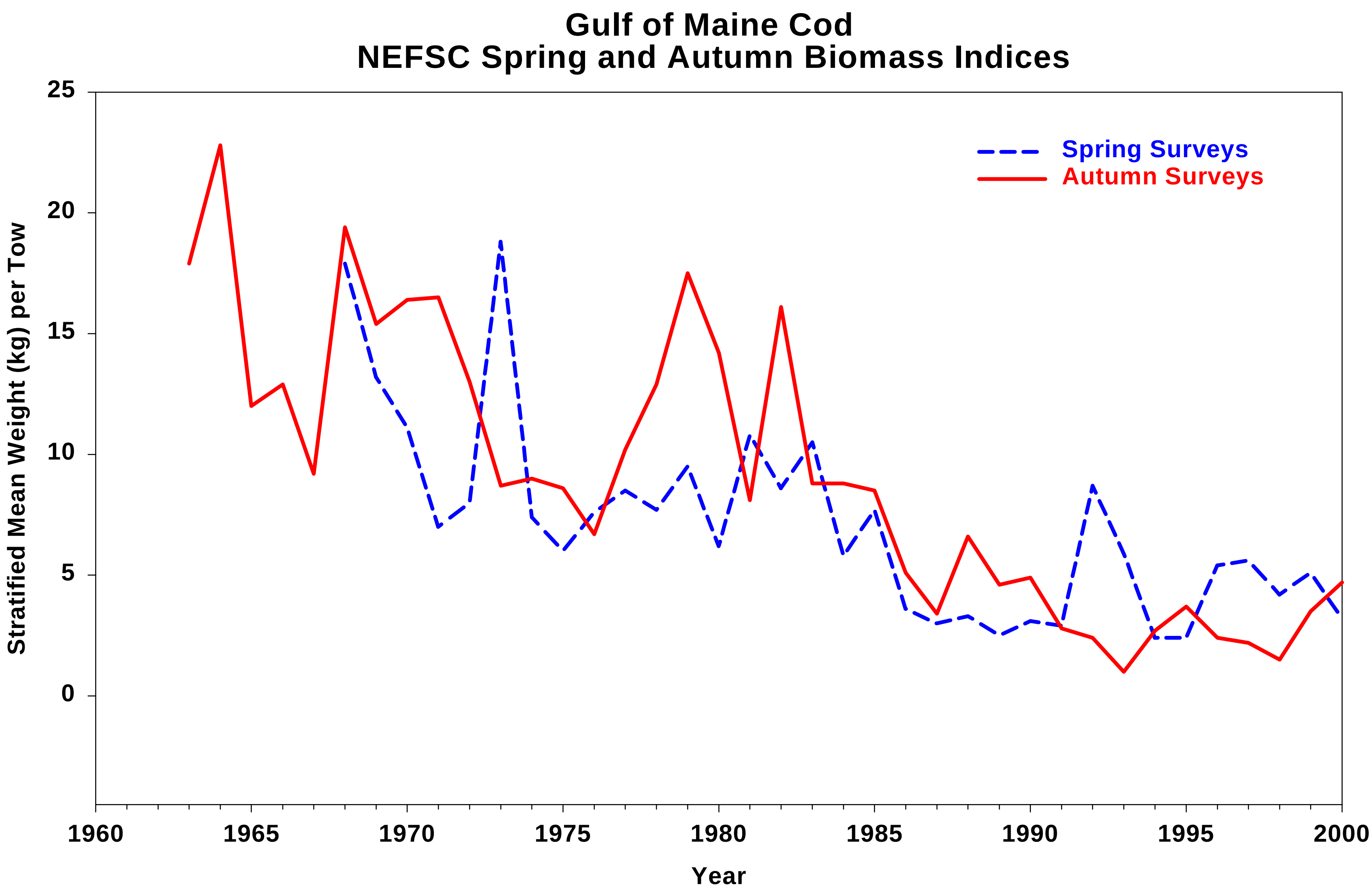
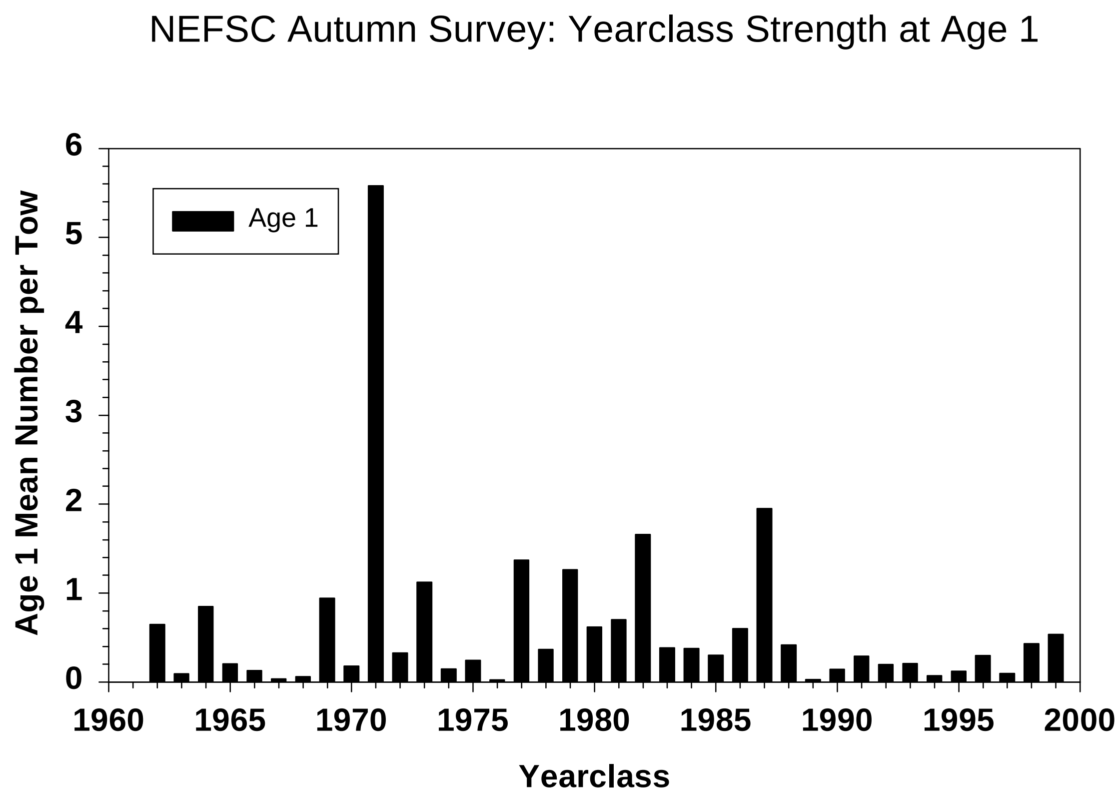


Figure A4. Biomass indices (stratified mean weight per tow) for Gulf of Maine cod from NEFSC autumn bottom trawl surveys.



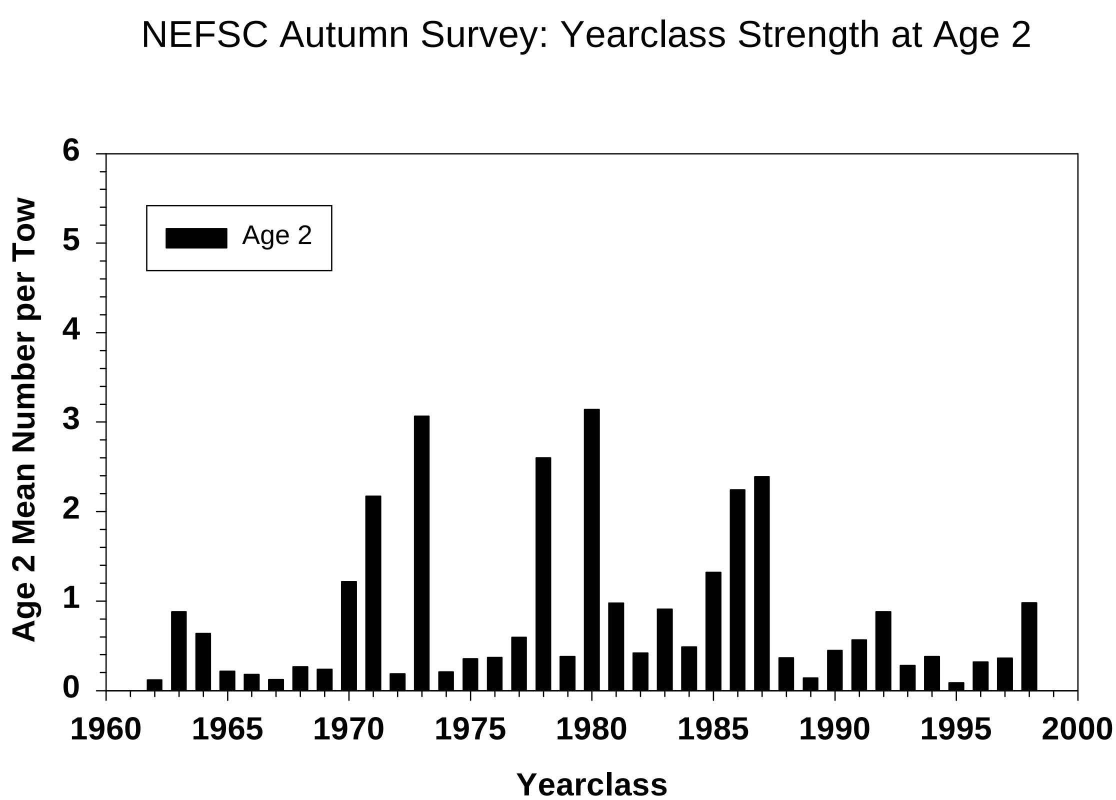
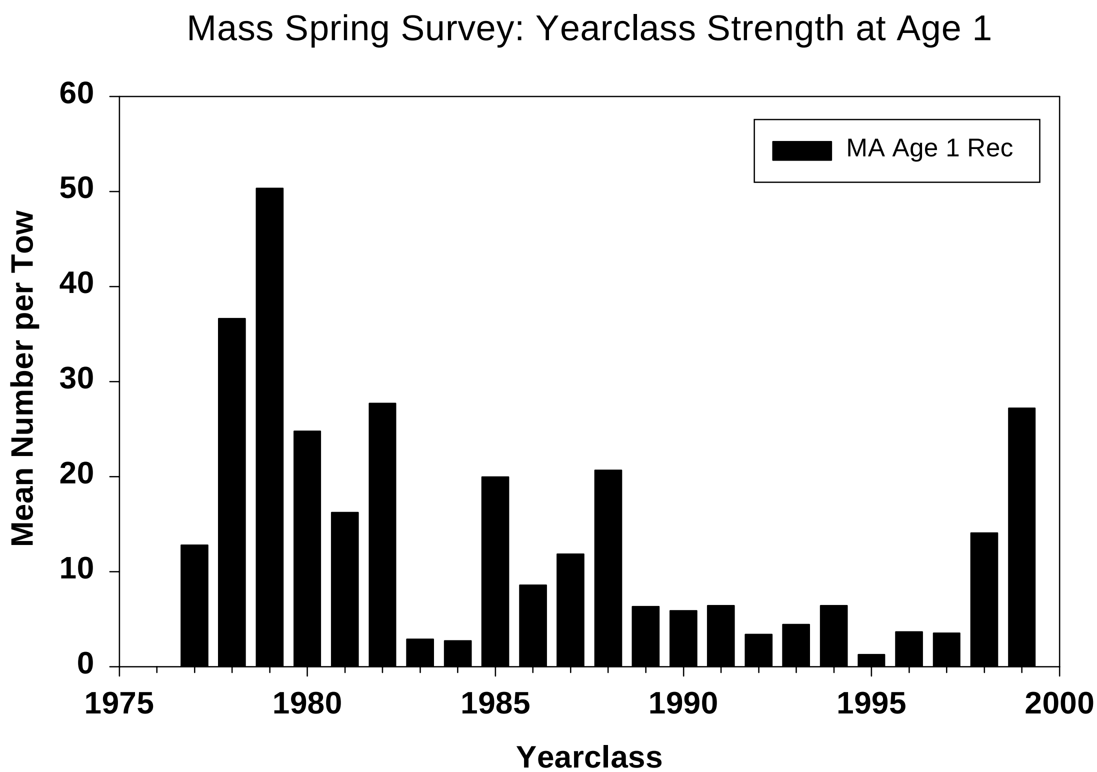


Figure A5. Recruitment indices at age 1 and 2 for Gulf of Maine cod from NEFSC autumn bottom trawl surveys.



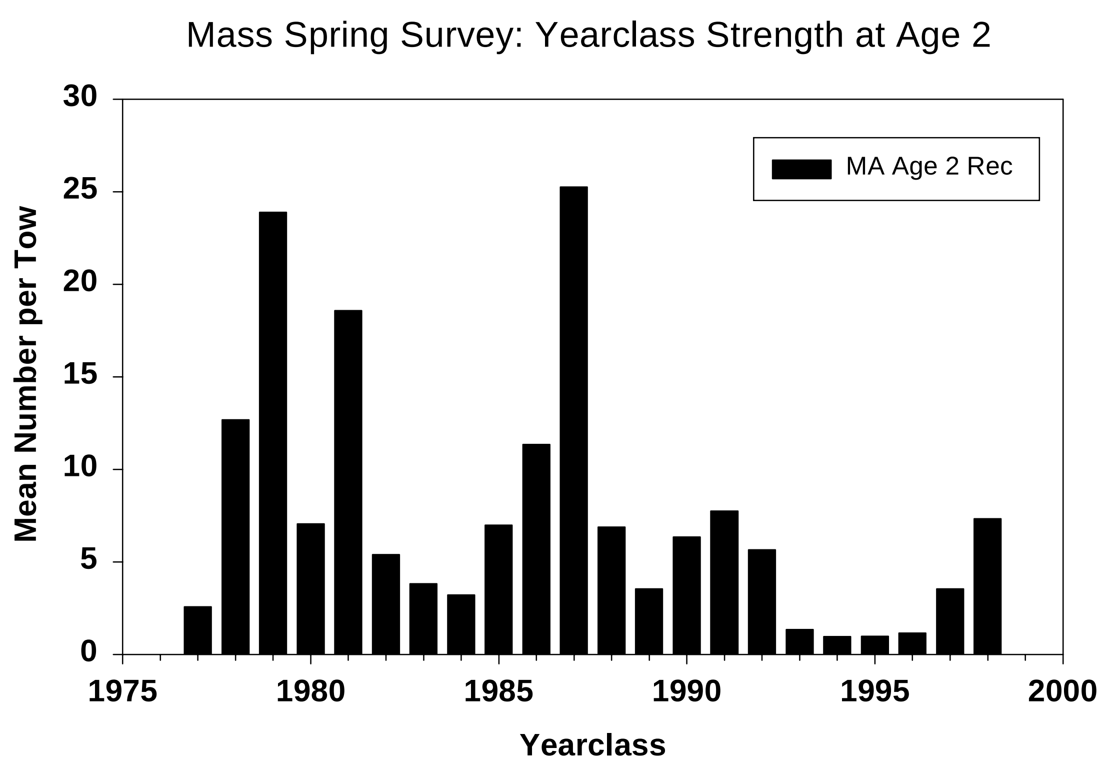


Figure A6. Recruitment indices at age 1 and 2 for Gulf of Maine cod from MA DMF autumn bottom trawl surveys.

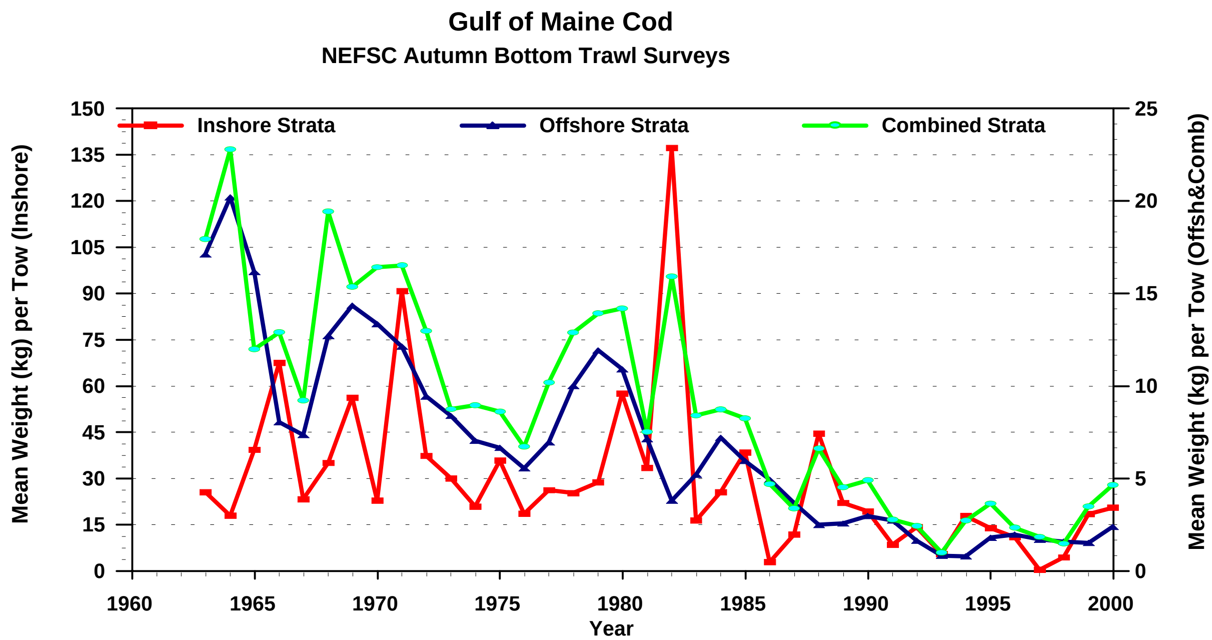


Figure A7. Biomass indices (Stratified mean weight per tow) for Gulf of Maine cod based on inshore (strata 26 and 27), offshore (strata 28-30 and 36-40), and combined regions from NEFSC autumn bottom trawl surveys.

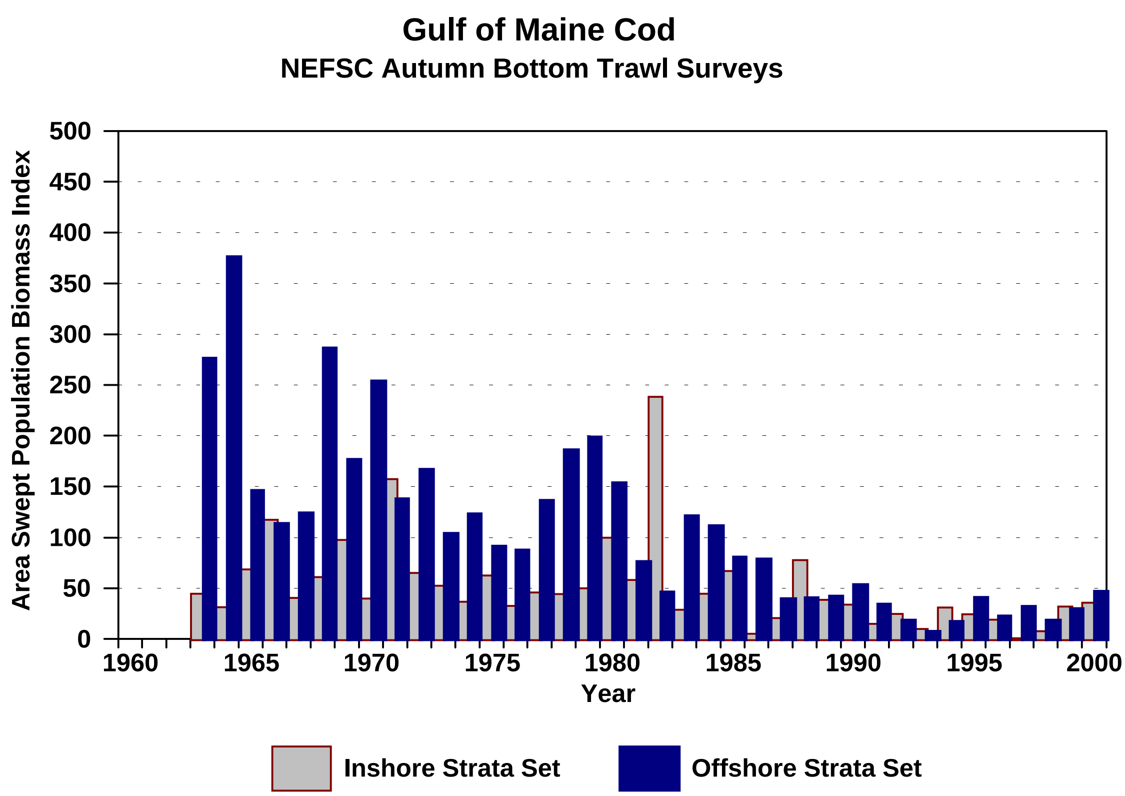


Figure A8. Swept area weighted biomass indices (Stratified mean weight per tow) for Gulf of Maine cod based on inshore (strata 26 and 27) and offshore (strata 28-30 and 36-40) regions from NEFSC autumn bottom trawl surveys.

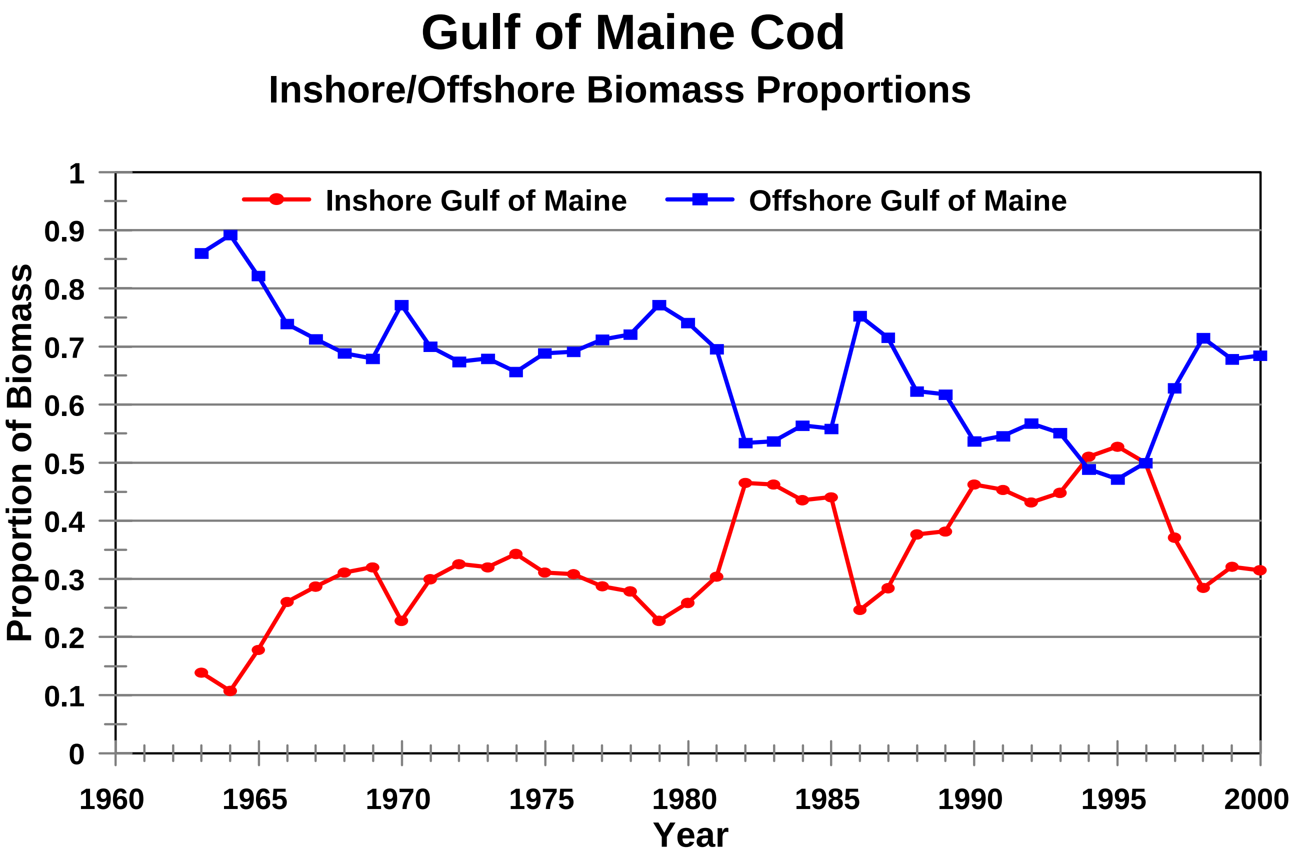


Figure A9. Proportion of biomass of Gulf of Maine cod from inshore (strata 26 and 27) and offshore (strata 28-30, 36-40) regions from NEFSC autumn bottom trawl surveys (4-year running average).

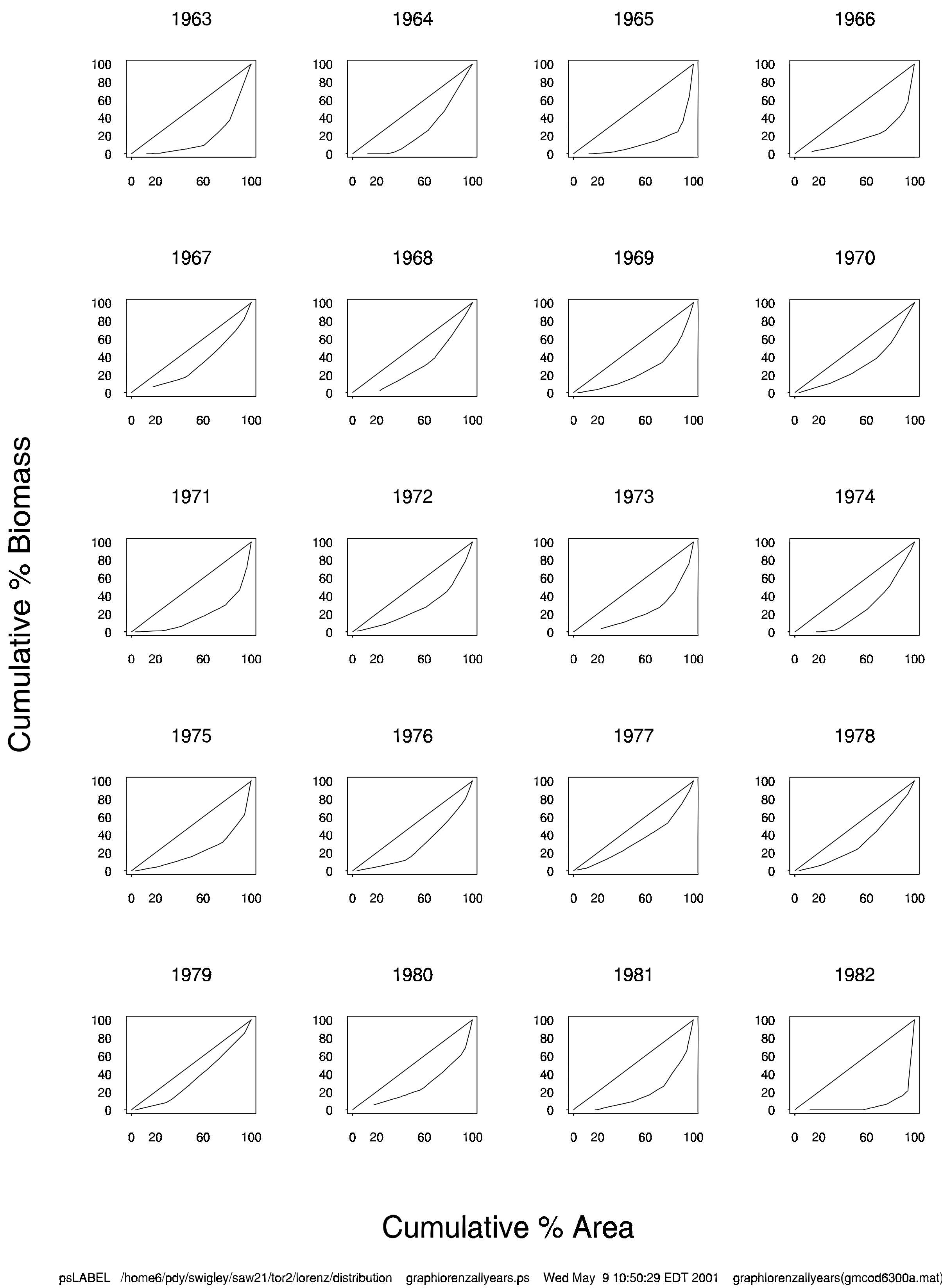
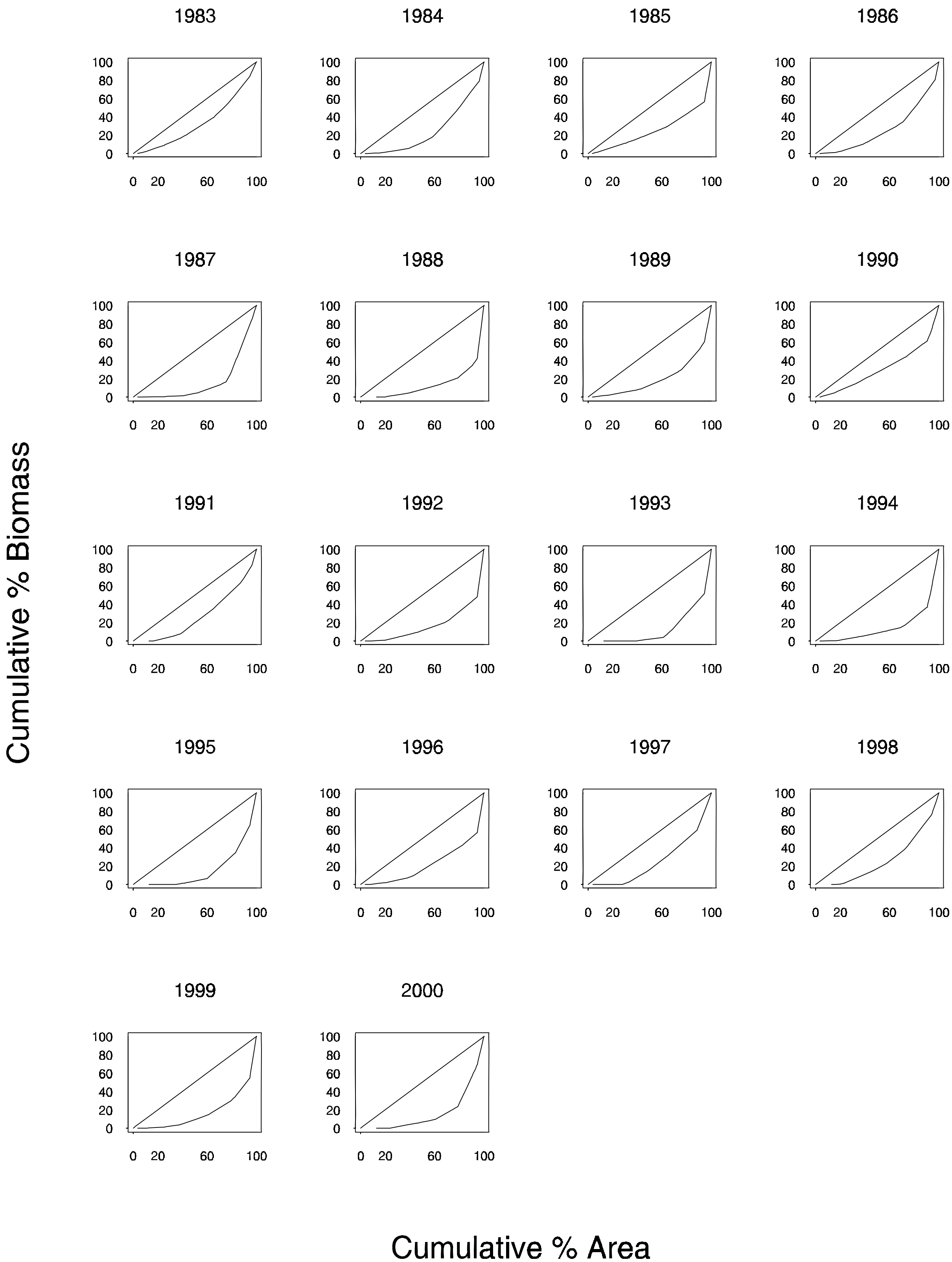


Figure A10. Lorenz curves for Gulf of Maine cod from NEFSC autumn bottom trawl survey biomass indices, strata 26-30 and 36-40.



psLABEL /home6/pdy/swigley/saw21/tor2/lorenz/distribution graphlorenzallyears.ps Wed May 9 10:57:25 EDT 2001 graphlorenzallyears(gmcod6300b.mat)

Figure A10 (Continued).

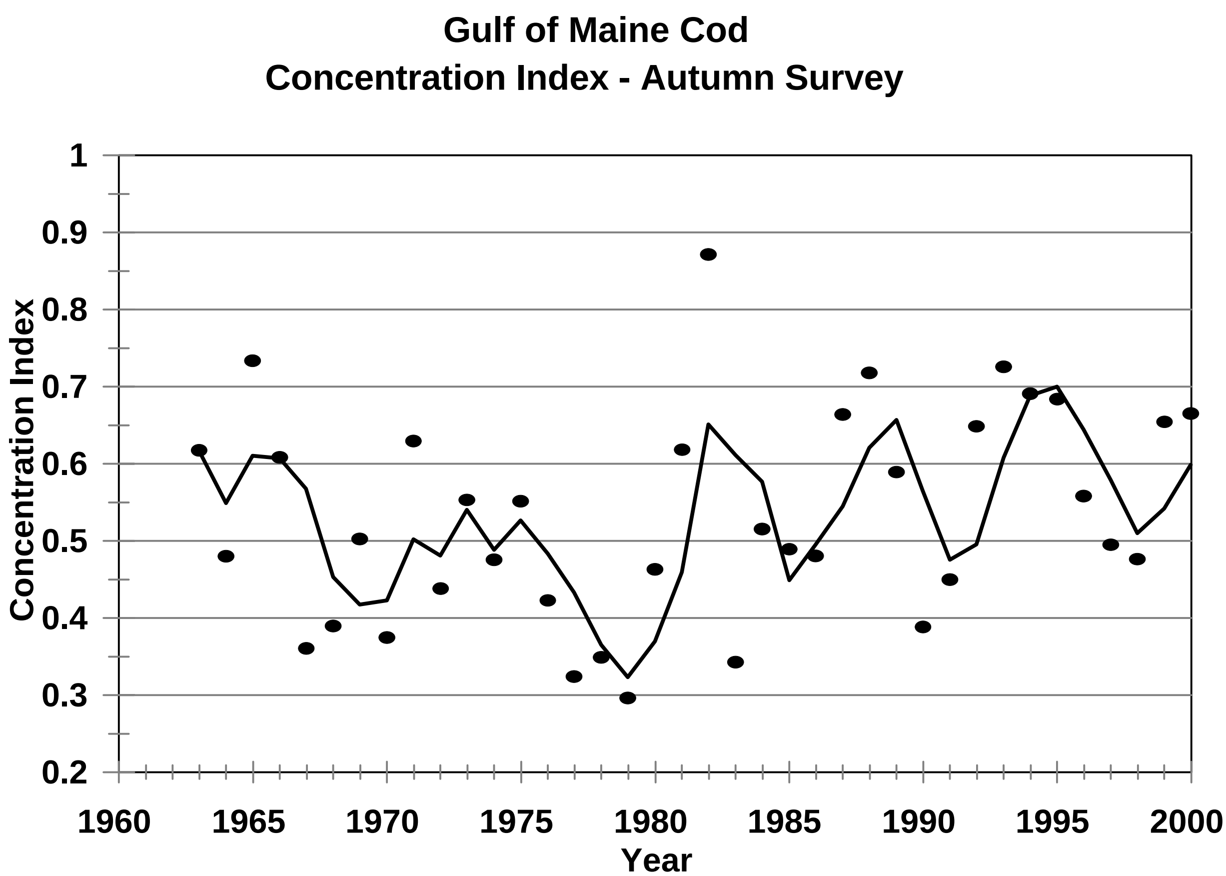
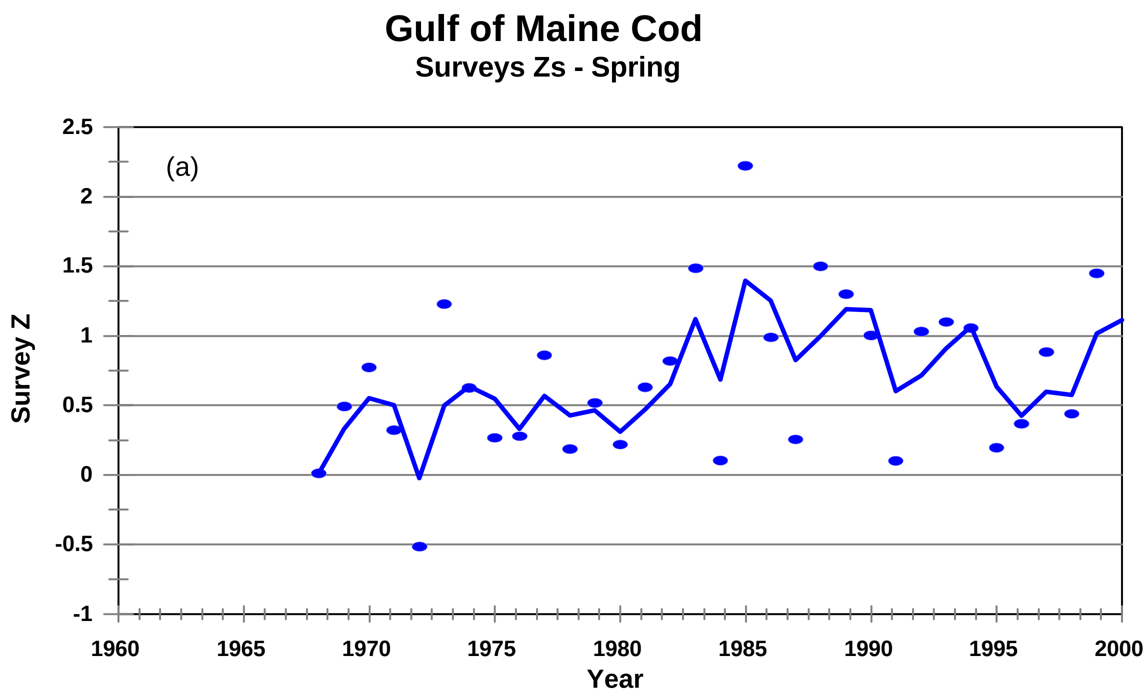


Figure A11. Concentration Index for Gulf of Maine cod derived from Lorenz curves from NEFSC autumn bottom trawl survey biomass indices, strata 26-30 and 36-40.



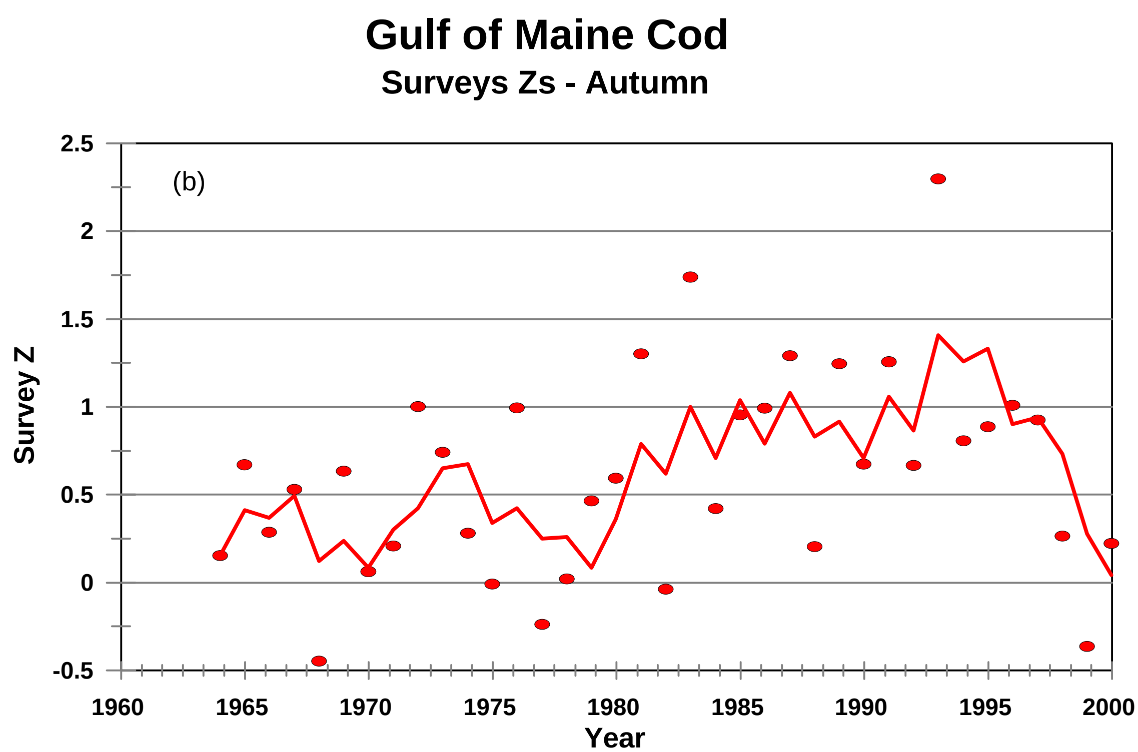
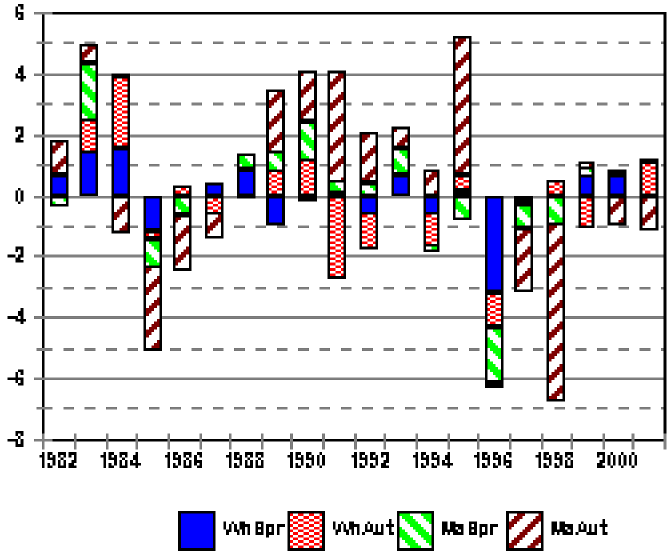
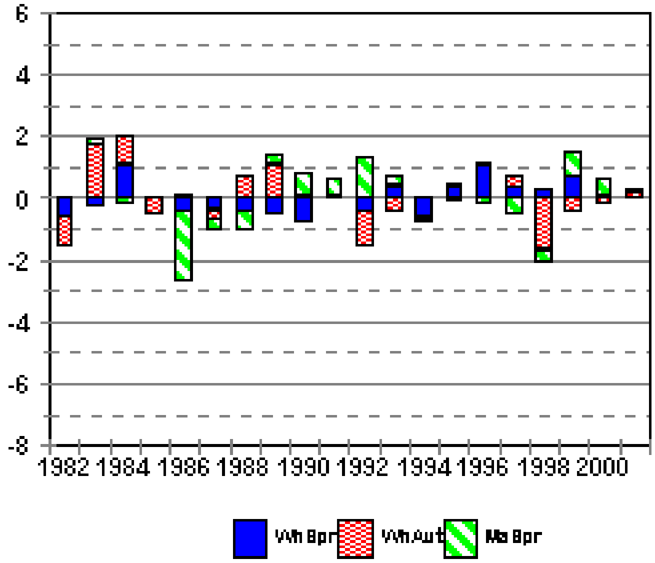


Figure A12. Annual estimates of total instantaneous mortality (Z) for Gulf of Maine cod (points) and 3-year running average (line) from (a) NEFSC spring and (b) NEFSC autumn bottom trawl surveys.

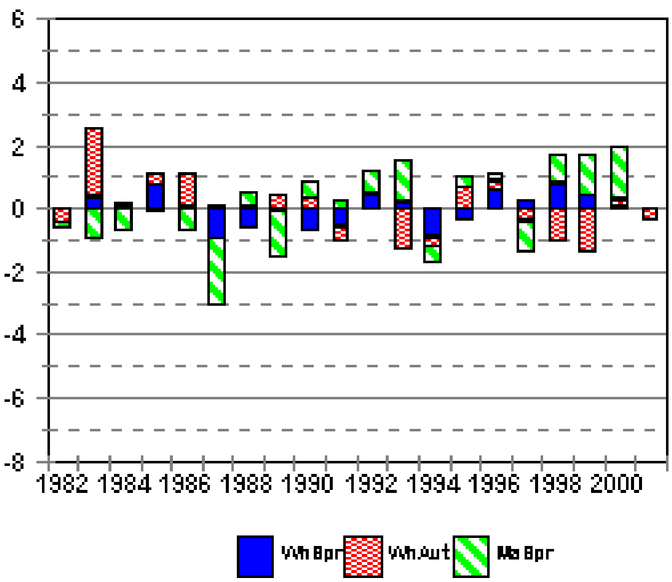
Gulf of Maine Cod
Age 2 Residuals



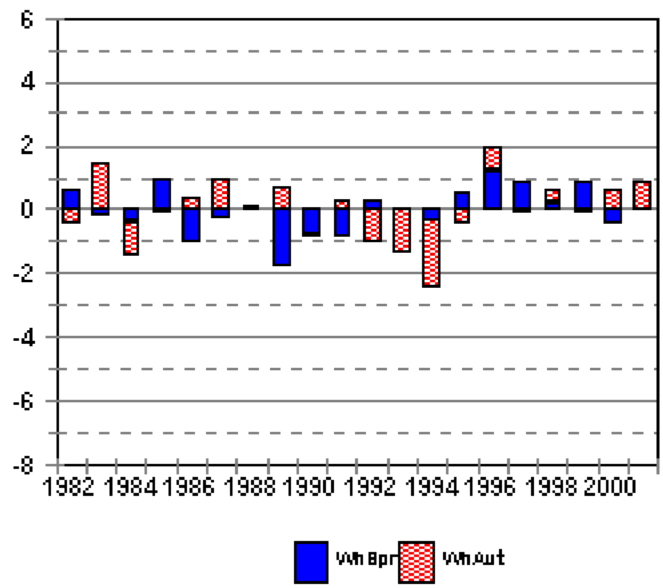
Gulf of Maine Cod
Age 3 Residuals



Gulf of Maine Cod
Age 4 Residuals



Gulf of Maine Cod
Age 5 Residuals



Gulf of Maine Cod
Age 6 Residuals

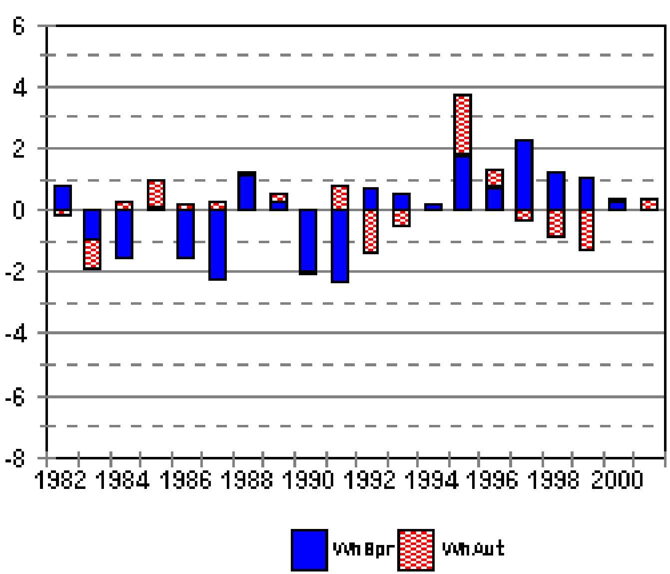


Figure A13. Residual plots from VPA calibration for Gulf of Maine cod.

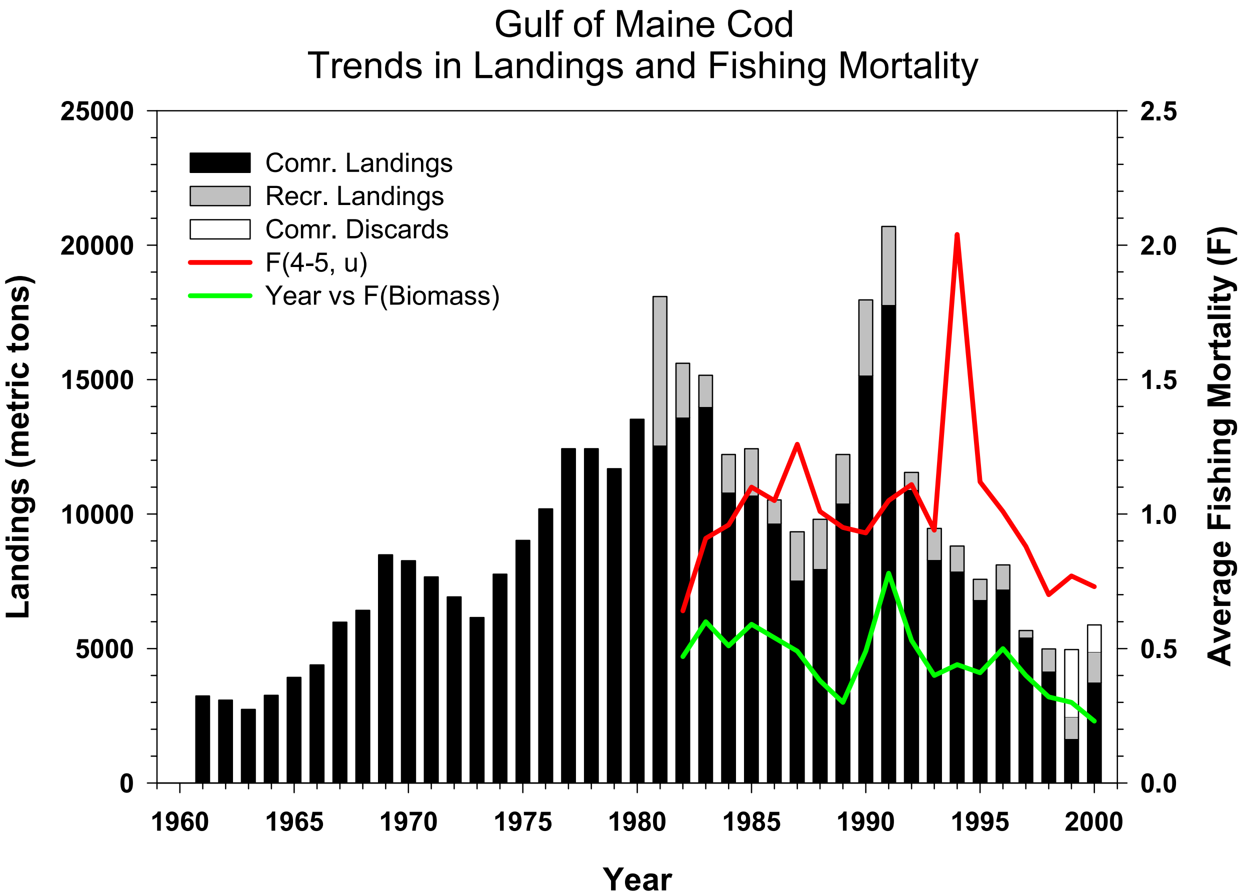


Figure A14. Trends in landings and fishing mortality for Gulf of Maine cod.

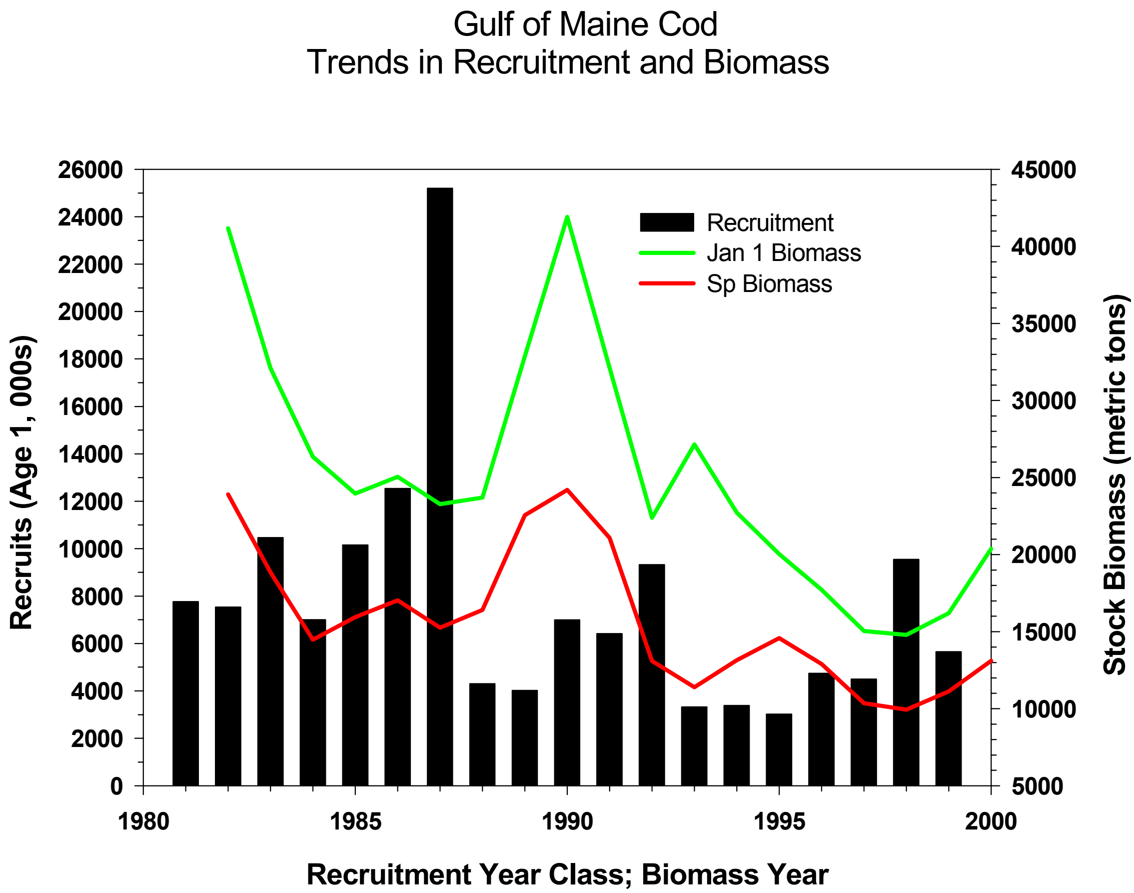


Figure A15. Trends in recruitment (age 1) and biomass for Gulf of Maine cod.

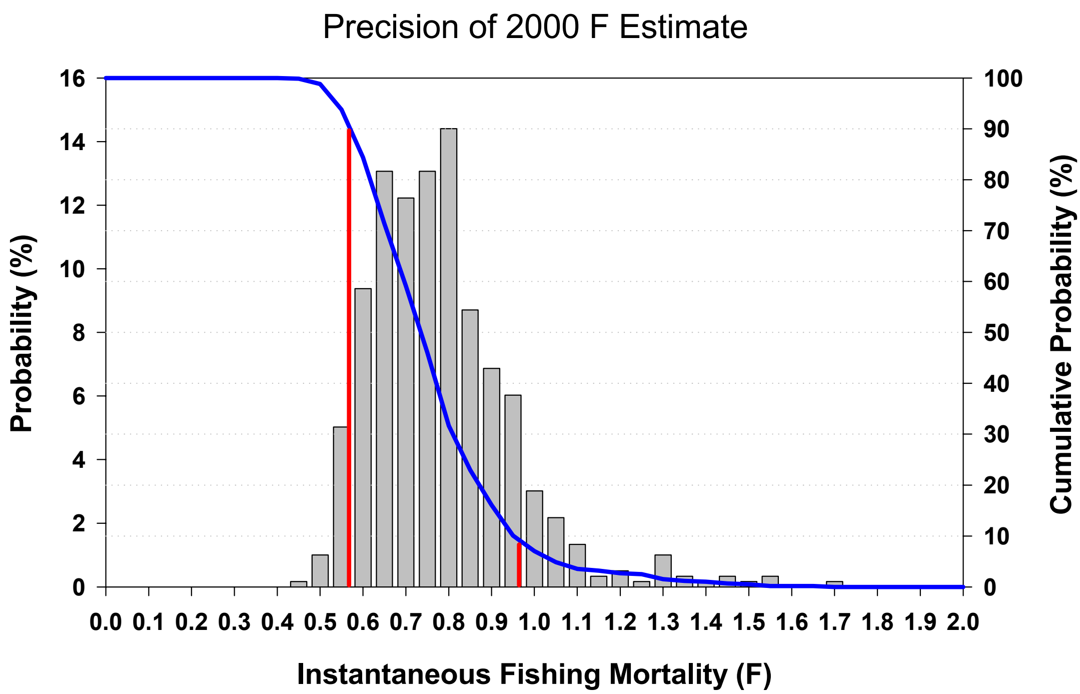


Figure A16. Precision of the estimated fully recruited fishing mortality in 2000 based on 600 bootstrap realizations of the VPA for Gulf of Maine cod.

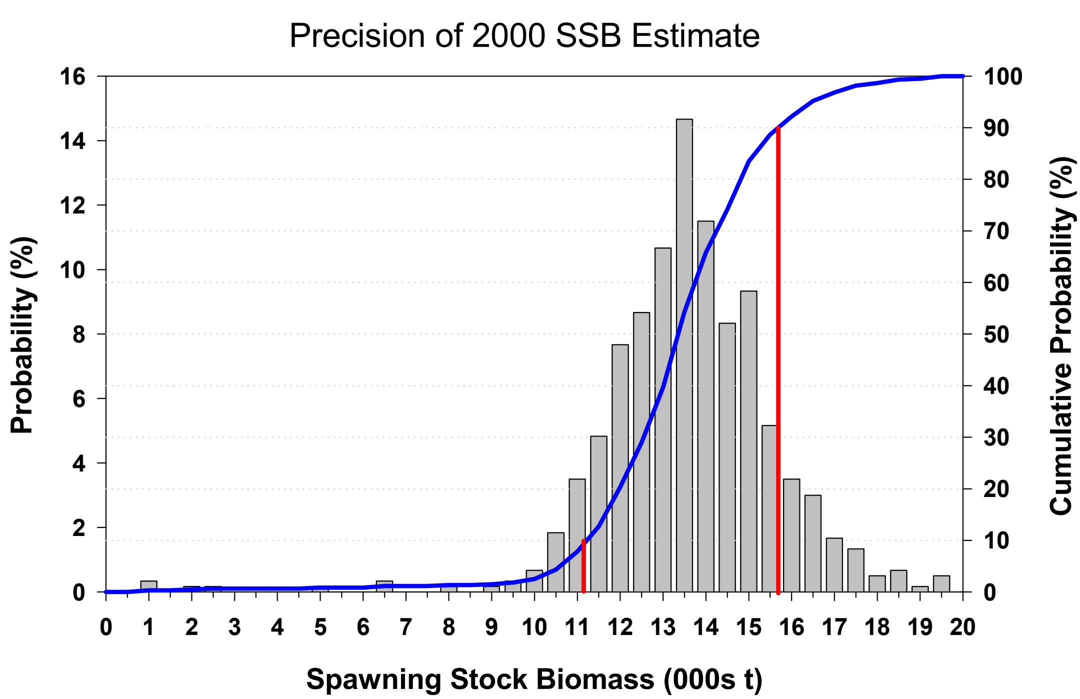
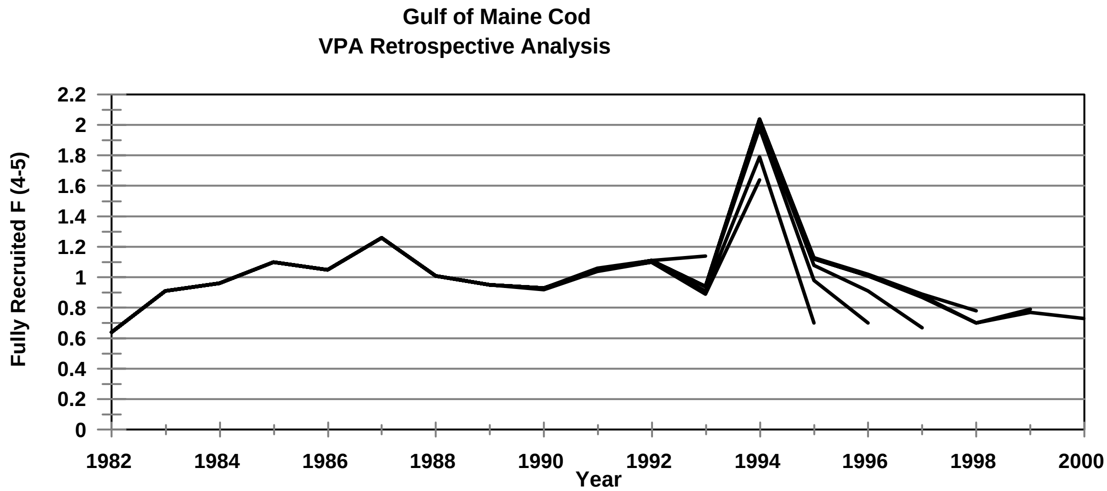
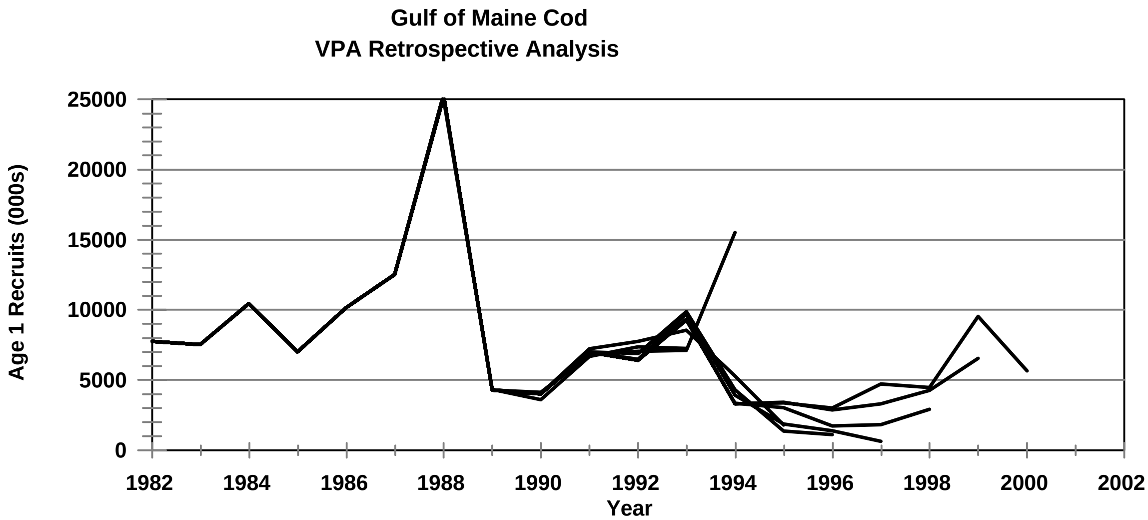


Figure A17. Precision of the estimated spawning stock biomass in 2000 based on 600 bootstrap realizations of the VPA for Gulf of Maine cod.





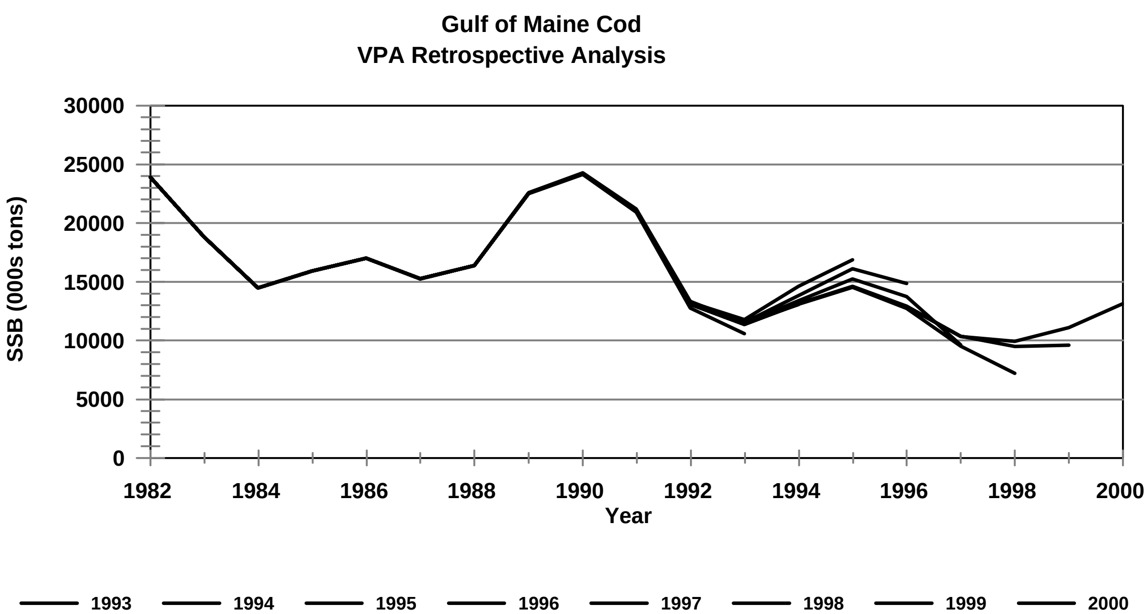


Figure A18. Retrospective analysis of estimates of terminal year F, recruitment and SSB from the VPA for Gulf of Maine cod.

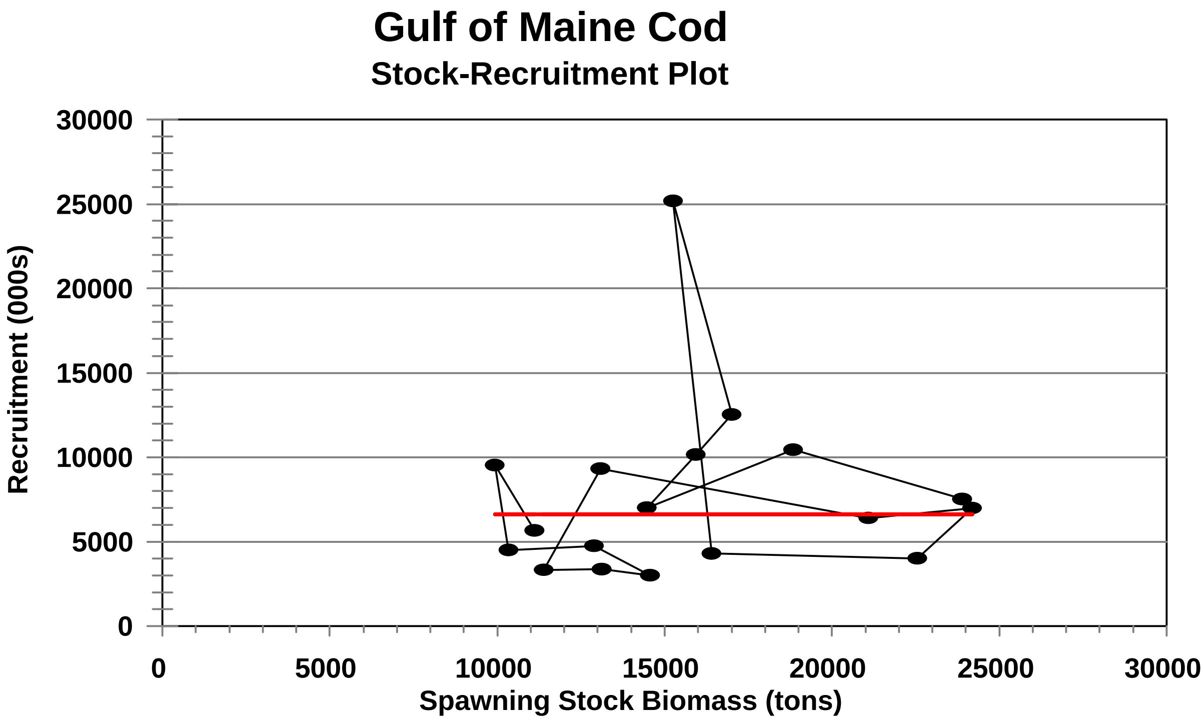


Figure A19a. Spawning stock-recruitment scatterplot for Gulf of Maine cod. The solid horizontal line represents the geometric mean.

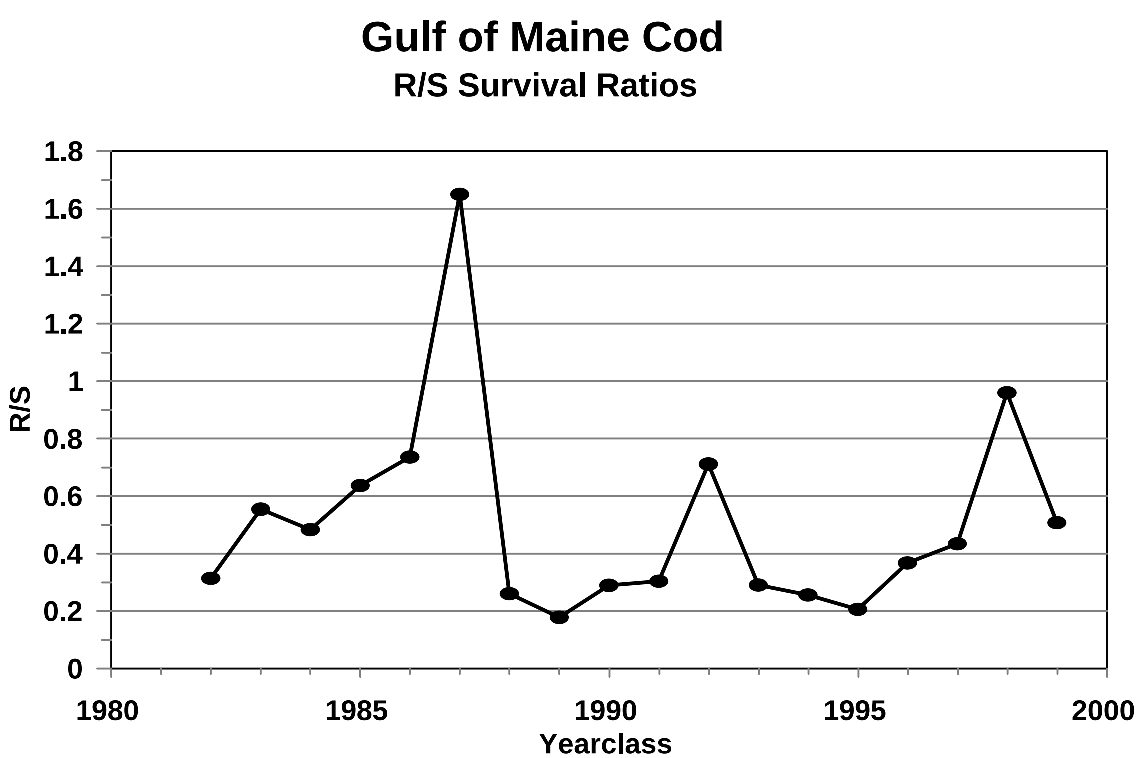
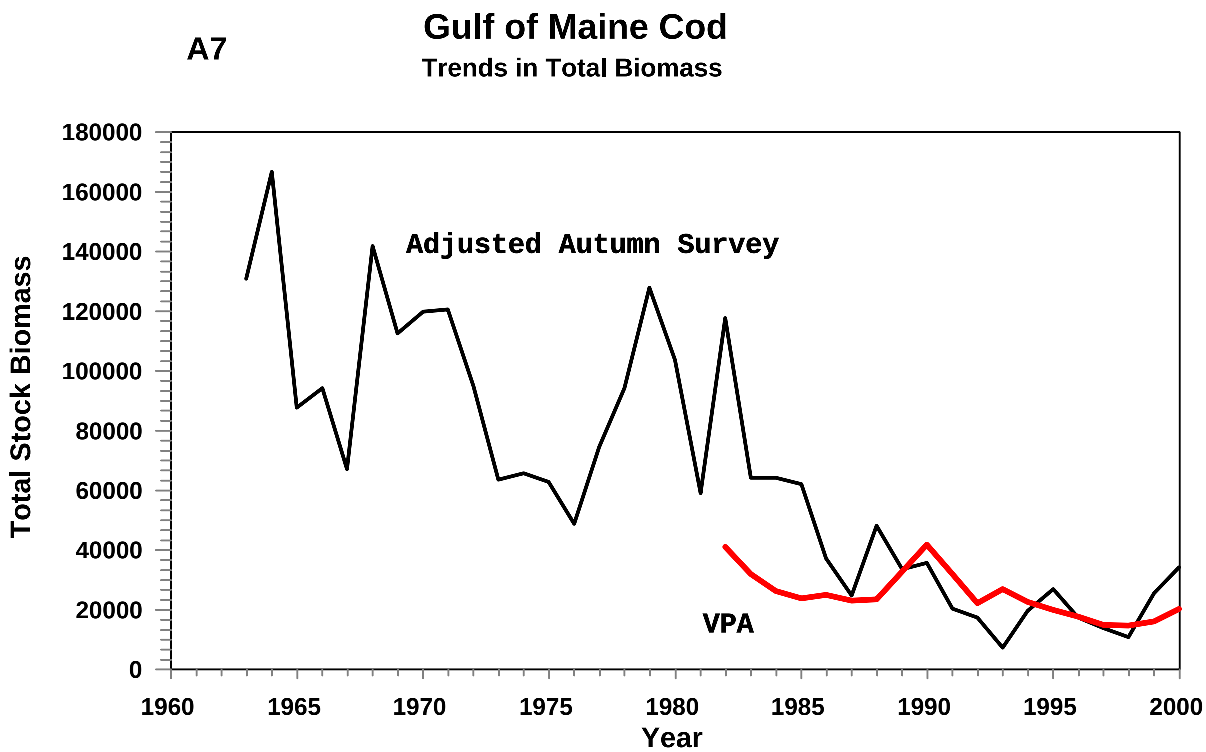


Figure A19b. Trends in survival ratios (R/SSB) for Gulf of Maine cod.



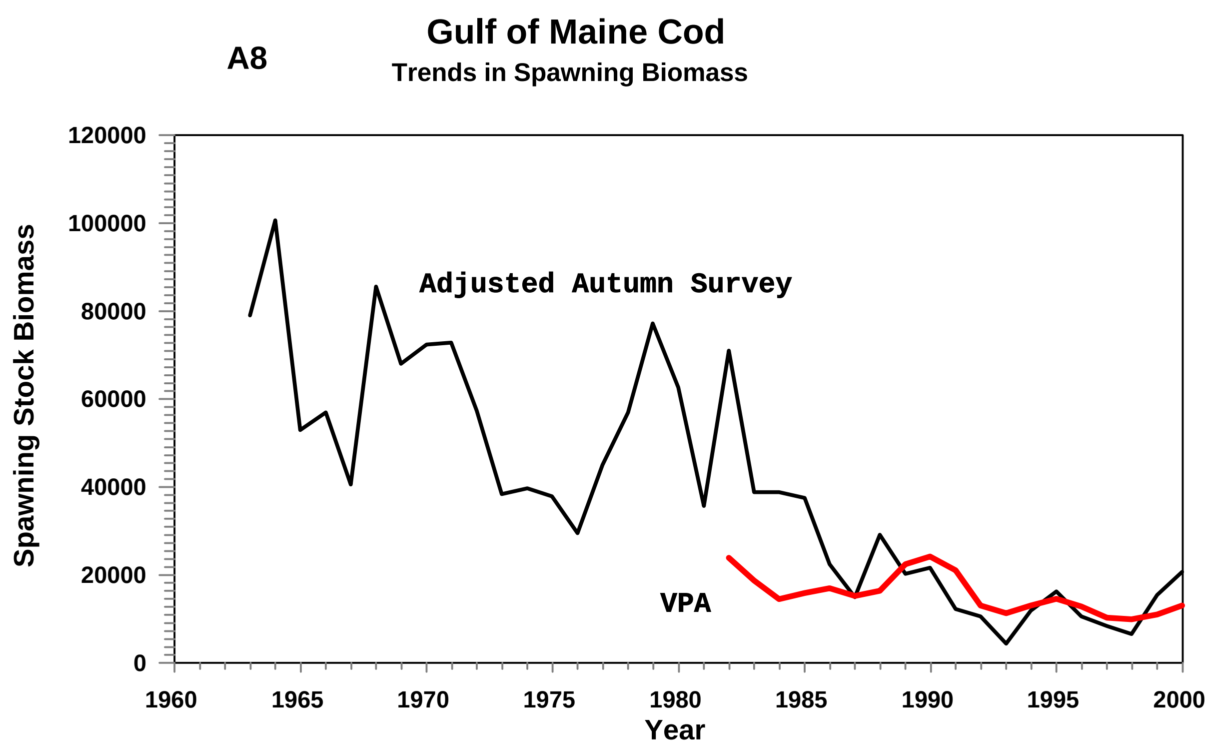


Figure A20. **Hind-cast estimates of total stock biomass (upper panel) and spawning stock biomass (lower panel) for Gulf of Maine cod based on VPA-NEFSC autumn survey biomass relaionships.**

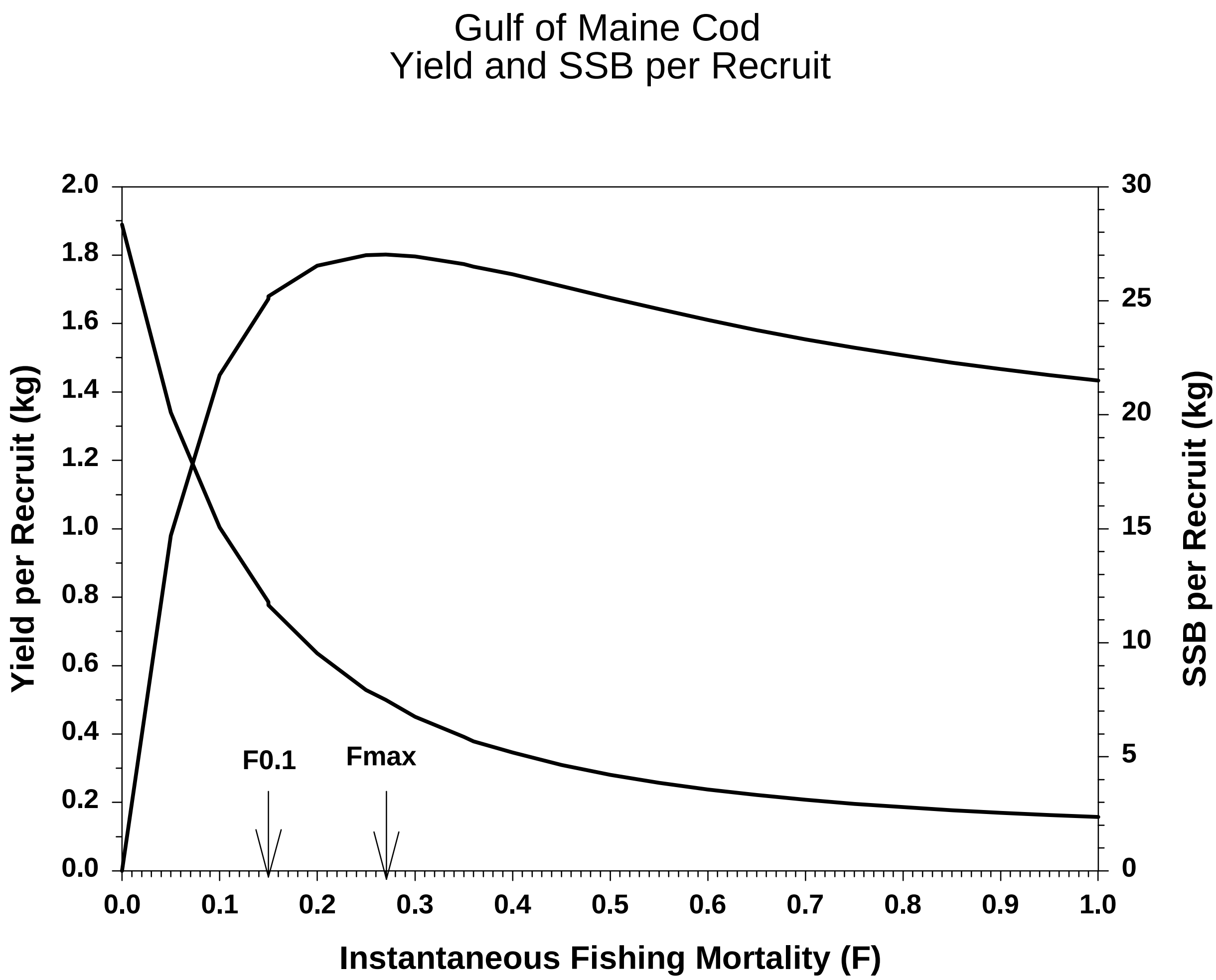


Figure A21. Yield and SSB per recruit results for Gulf of Maine cod.

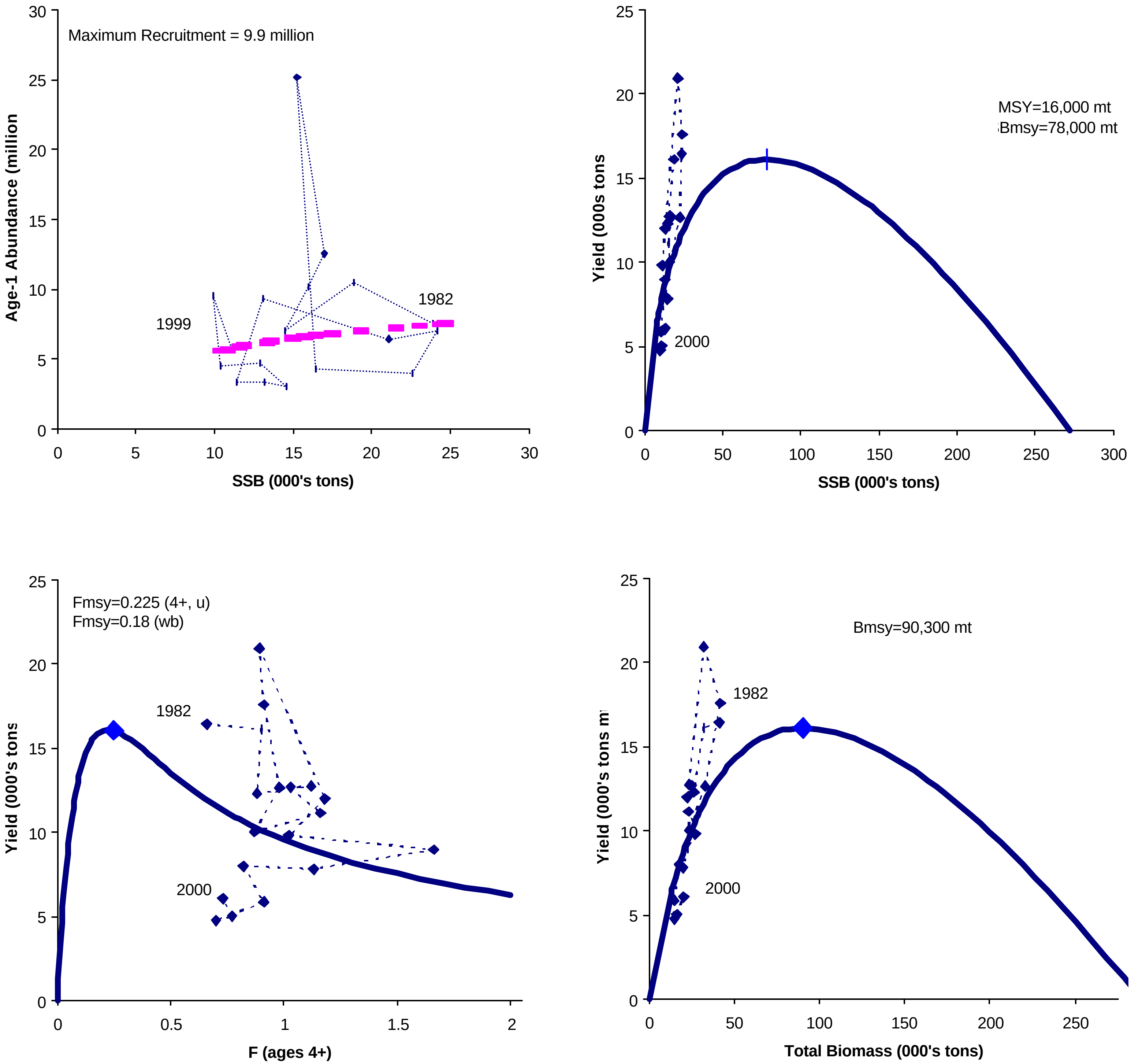


Figure A22. Age structured production model results for Gulf of Maine cod.

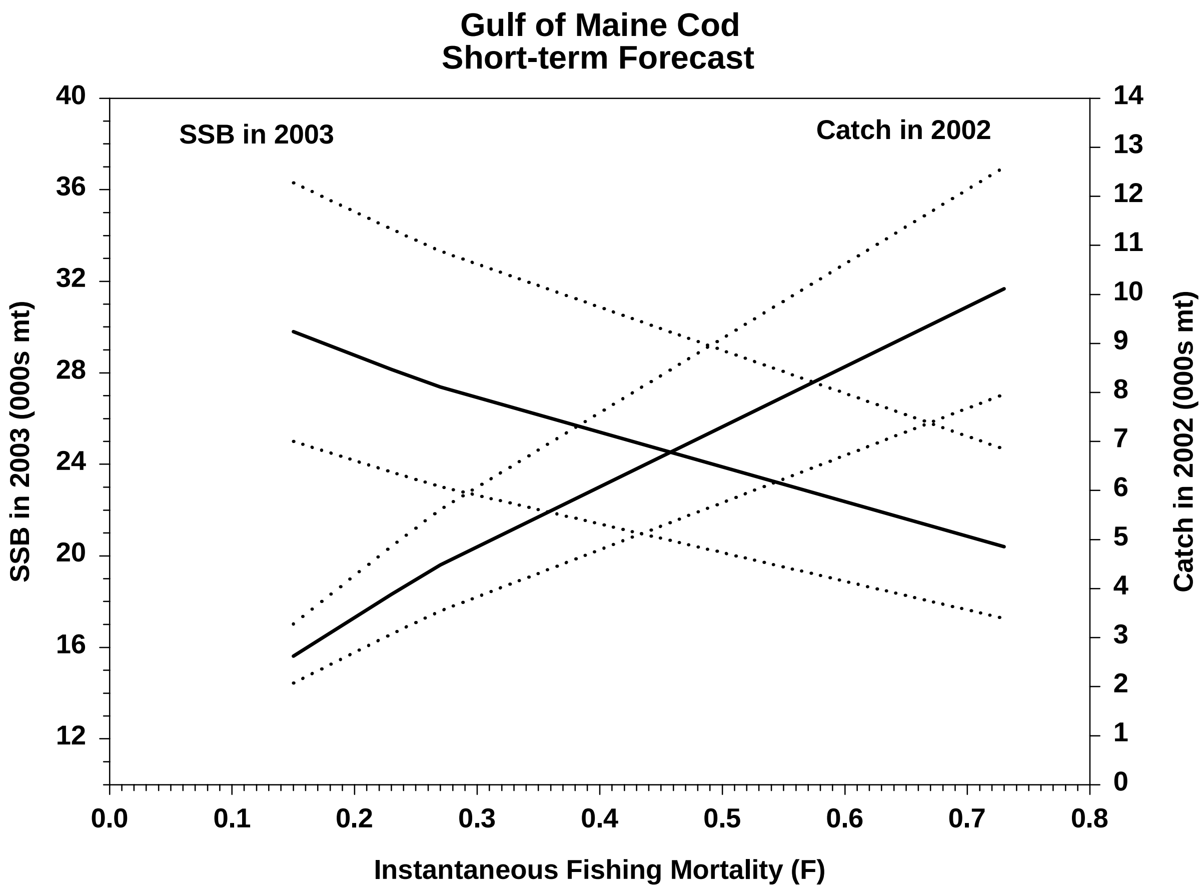


Figure A23. Short-term stochastic catch and stock biomass projection results for Gulf of Maine cod.

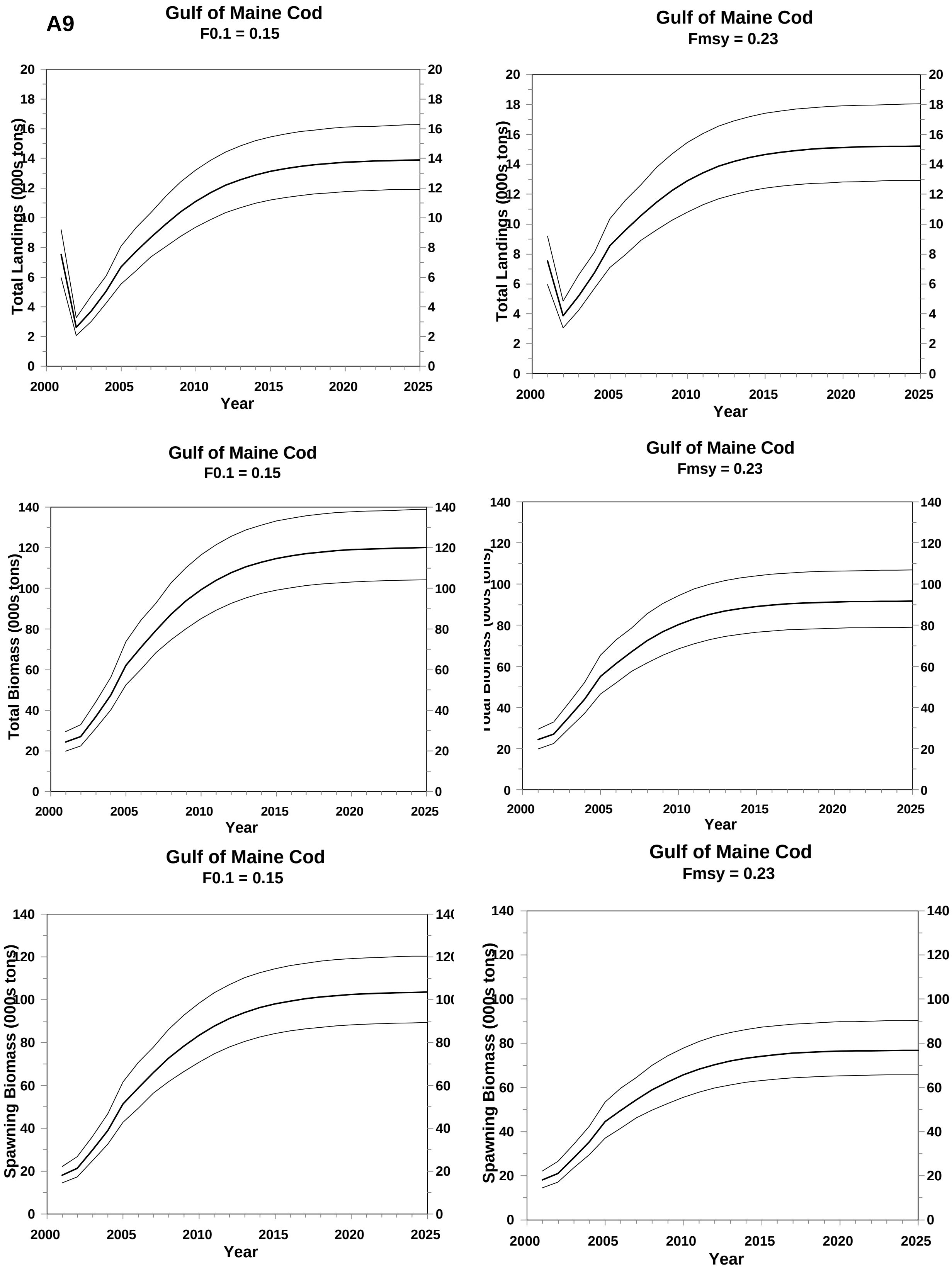


Figure A24. Long-term stochastic catch and stock biomass results for Gulf of Maine cod at F0.1 (0.15) and Fmsy (0.23).

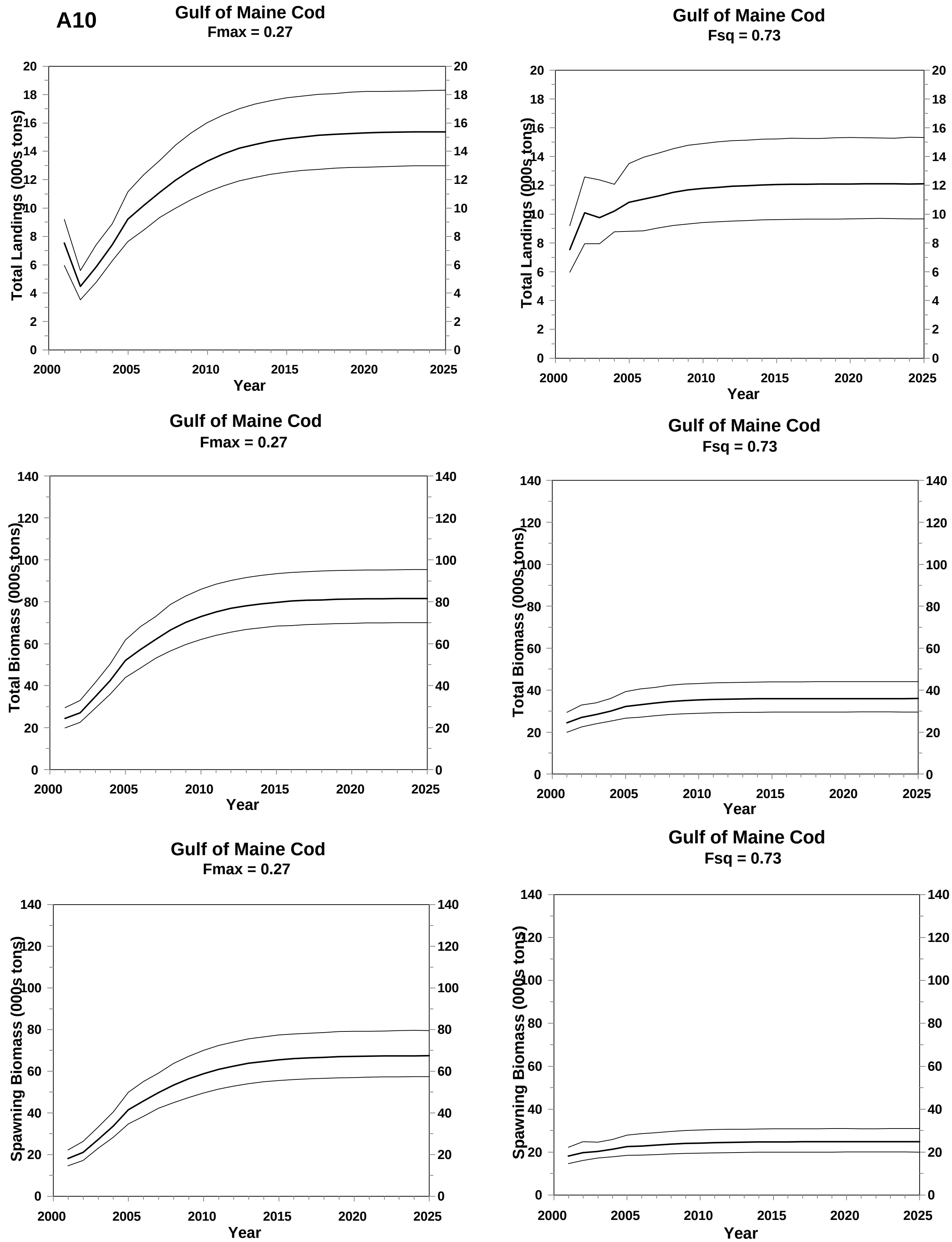


Figure A25. Long-term stochastic catch and stock biomass results for Gulf of Maine cod at Fmax (0.27) and Fsq (0.73).

B. WHITE HAKE

TERMS OF REFERENCE

(A) Update the status of the white hake stock, providing, to the extent practicable, estimates of fishing mortality and stock size. Characterize uncertainty in estimates.

(B) Provide updated estimates of biological reference points (biomass and fishing mortality targets/thresholds), or appropriate proxies, based on available population data.

(C) Provide projections of biomass in 2002 and 2003 and catch in 2002 under various fishing mortality rate options.

INTRODUCTION

White hake (*Urophycis tenuis*) are distributed from the Gulf of St. Lawrence to North Carolina (Figure B1; Bigelow and Schroeder, 1953). Much confusion on the distribution of this species exists because of the close resemblance to its congener, the red hake (*Urophycis chuss*). Both species occupy much of the same habitat (mud bottom) and have often been described together (Bigelow and Schroeder, 1953; Musick, 1974; Markle et al. 1982). White hake tend to be found in deeper water than red hake, but are also found with red hake in shallow bays and estuaries in the Gulf of Maine. This is especially true for juveniles which are the hardest size classes to distinguish from red hake.

Landings of white hake have been viewed as less important than more desirable species of groundfish such as cod and haddock. In 1993, however, white hake landings exceeded those for Gulf of Maine cod (CUD 1995). Concern arose about the sustainability of such high landings. A preliminary assessment of white hake in 1994 showed that fishing mortality rates based on a Modified DeLury model were higher than any biological reference points (NEFSC 1995). Information from a surplus production model also demonstrated that landings were exceeding MSY. In 1998, a new analysis using a virtual population analysis and a surplus production model was conducted (NEFSC 1999). This analysis showed that fishing mortalities had exceeded 0.6 from 1985 to 1997 and were over 1.0 in 1997. Landings and spawning stock biomass were declining. This paper summarizes all current information on the white hake fishery.

STOCK STRUCTURE

There is no new information about the stock structure of white hake. In light of this, all the white hake found in NAFO subareas 5 and 6 were treated as one stock as in the 1994 and 1998 assessments (Sosebee et al. 1998, NEFSC 1999).

THE FISHERY

Commercial Landings

Total landings of white hake decreased from about 3,000 mt in 1964 to a low of 1,100 mt in 1967 (Table B1, Figure B2). Landings then gradually increased and peaked at 8,300 mt in 1985. Landings fluctuated around 5,000 to 6,000 mt until they peaked again in 1992 at 9,600 tons and declined slightly to 9,100 tons in 1993 (Table B1). Landings fell sharply to a 1997 level of 2500 tons but have since increased moderately to 3,200 tons. The US has accounted for the major portion of landings with small amounts landed by Canada. Landings from other countries have been negligible since 1977.

The primary gear type used to catch white hake is the otter trawl (Table B2, Figure B3). Historically, line trawls were also important, but from 1980 to 1991, this gear accounted for less than 5% of the total. Line trawls again increased in importance and, in 1997, represented 18% of the total landings. However, in recent years they averaged less than 10 percent. Sink gill nets have historically (1960s) accounted for less than 10% of total landings but the share enlarged in the 1970s to between 20 and 40% of the total.

The primary season for landing white hake is summer or quarter 3 (Table B3, Figure B4). The highest percentage of landings occurs in August, with the months of July, September and October each accounting for over 10% of the annual landings.

Maine landings have averaged between 40 and 70% of the total US landings since 1964 (Table B4, Figure B5). Massachusetts landings exceeded those of Maine from 1968 to 1974 but have since accounted for 20 to 40% of the total landings. Other states contributing to landings are New Hampshire, Connecticut, Rhode Island, New York, New Jersey, Delaware, and Virginia.

Undertonnage vessels (less than 5 GRT) traditionally accounted for between 20 and 40% of US landings (Table B5), but have since become less important and, in 1997, were not represented in the total landings. Tonnage classes 2 and 3 (5-50 GRT and 51-150 GRT, respectively) have accounted for the majority of the landings with tonnage class 3 dominating landings for the last ten years. Tonnage class 4 vessels (151-500 GRT) increased in importance in the 1980s and 1990s but have since declined.

Recreational Catches

The amount of white hake recreational catches reported in the Marine Recreational Fishery Statistical Survey since 1979 is insignificant (< 0.1 mt per year).

Discards

Estimates of discards were estimated for three gear types and by half year from the Domestic Sea Sampling Program (DSSP). The discard rate was estimated as the total pounds discarded/total pounds kept for each gear/half cell. The rate was then multiplied by the reported landings for that cell.

The estimates range from less than 200 mt in 1995 to more than 4000 mt in 1990 (Table B6). The three years in which discards accounted for more than 30 per cent of the landings occur in years in which there was at least one dominant year class. To estimate otter trawl discards prior to 1989, an average proportion for 1989-2000 was estimated (25%) and applied to the landings from 1964-1988 (Table B7).

Sampling Intensity

Since the majority of white hake are landed in headed and gutted condition, length measurements have not generally been available from port samples. A regression developed to convert dorsal fin-caudal fin length to total length (Creaser and Lyons, 1985), has allowed measurements obtained from landed catch to be used to evaluate overall length composition since 1985. Age samples are still unavailable from port samples since otoliths are the structures used for ageing and are lost when the head is removed.

Table B8 shows the summary of commercial length samples from the ports by market category. Since medium white hake were poorly sampled at the beginning of the sampling period and since there appeared to be no difference in length composition between small and medium market categories, the two size categories were pooled. The sampling intensity overall has been adequate (< 300 mt/sample), except in 1989 and 1995 when only 13 and 12 samples were taken (one sample taken for every 350 mt and 361 mt landed). The sampling intensity in 1997 was very good (32 mt/sample), but the unclassified market category had only one sample for the entire year. In 1999 and 2000, there were no samples for the unclassified. The landings for this group were small so the landings were added at the end.

Length and Age Composition

Commercial length composition during 1985-2000 was estimated by market category (pooling small and medium size categories together) from length frequency samples, pooled on a semiannual basis. Mean weights were obtained by applying the NEFSC survey length-weight equation,

$$\ln \text{Weight (kg, live)} = -12.58 + 3.2196 * \ln \text{Length (cm)}$$

to the semiannual market category length frequencies. Mean weight values were then divided into semiannual market category landings to derive estimated numbers landed by market category. These numbers were then summed over market categories and half-years to produce annual length compositions.

Age-length keys were derived from NEFSC survey data for 1985-1988 and 1991-1994. Survey data for 1989-1990 and 1995-2000 were combined with data collected from sea sampling trips. Age structures have been collected but not aged for 1991-1994. Commercial landings-at-age were derived by applying these age-length keys to the length composition. The number of ages used in each cell varied from a low of 91 in the spring of 1998 to 844 in the fall of 1990 (Table B9). The landings-at-age are shown in Table B10 and Figure B6.

The length composition of the otter trawl portion of the discards was characterized from the DSSP length samples (Table B11). The sampling of discards from sink gill nets has not been adequate for characterizing that fleet sector. Samples for the otter trawl fishery were pooled by half year. Samples were also pooled for 1997-1999 by half year. The lack of samples in these years, particularly 1998, required pooling. The same age-length keys used for commercial landings were used to derive the age composition shown in Table B12 and Figure B7. The combined age composition is shown in Table B13 and Figure B8.

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial LPUE

Commercial LPUE was not examined for this assessment due to the existence of new regulations (i.e. closed areas) that will impact LPUE.

Research Vessel Abundance and Biomass Indices

The NEFSC autumn bottom trawl survey has been in existence since 1963 (Azarovitz, 1981). Offshore areas from the Gulf of Maine to Southern New England are sampled, and, beginning in 1967, offshore areas in the Mid-Atlantic were sampled as well. The NEFSC spring bottom trawl survey began in 1968. The surveys have been conducted with the same gear and vessel as often as possible. The strata set used for white hake is the Gulf of Maine to Northern Georges Bank (offshore strata 21-30 and 33-40). Indices of abundance and biomass were calculated following the methods of Cochran (1977). Vessel, door, and gear effects were not found to be significant for white hake (NEFSC, 1991).

Spring stratified mean number and weight per tow are variable but have been declining since 1990 (Table B14, Figures B9 and B10). The autumn weight per tow index fluctuated around 5 kg/tow in the early 1960s and increased to approximately 12 kg/tow during the 1970s (Table B15, Figure B11). Excluding the 1982 data point, the autumn mean weight per tow index fluctuated around 10 kg/tow from 1983 to 1993. From 1994-1998 the index declined to a low of 4.55 but has since increased slightly. Over the time period, the autumn abundance index increased relative to the biomass index indicating a gradual shift from larger to smaller fish during the 1970s and 1980s (Figure B12).

The State of Massachusetts has also conducted spring and fall surveys since 1978 (Howe et al., 1981). The survey only covers a portion of the white hake stock area but can still be useful. The spring survey shows a decline over the time series until about 1988 when it dropped to a low level and remained until the present (Figure B13). The autumn series is more variable, particularly for abundance but has shown a similar decline (Figure B14).

The ASMFC conducts a summer shrimp survey in the Gulf of Maine. Finfish are also weighed and measured on these surveys and white hake are often caught. This survey also shows a decline over the time series (Figure B15).

STOCK PARAMETERS

Natural Mortality

Natural mortality (M) for most gadid stocks is assumed to be 0.2. Hoenig (1983) developed an empirical relationship between total mortality (Z) and longevity (T_{max}):

$$\ln Z = 1.46 - 1.01 \ln T_{max}$$

Assuming a maximum age of 20 years for white hake (the oldest fish in the age samples was 15 years and the maximum length is larger than this fish) this relationship estimates a Z of 0.2. In the absence of fishing mortality Z = M = 0.2.

Maturity

Maturity ogives are as in the previous assessment (NEFSC 1999).

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Attempts were made to update the previous assessment using virtual population analysis (VPA). Many formulations of the VPA were examined (Table B16). All show a severe retrospective pattern with a tendency to overestimate fishing mortality and to underestimate spawning stock biomass in the terminal year. There were also patterns in the residuals which shifted among ages when indices were removed. The uncertainties associated with the VPA were attributed to mis-identification of species in the catch, poor estimation of discards, low sampling of the commercial landings and low catchability of large fish in the survey. Therefore, the VPA was not accepted at this time.

The possible mis-identification of species is particularly a problem for the discards. The length compositions of both the landings and discards were broken out into fish <= 60 cm and fish > 60 cm (Table B17, Figure B16). This length cutoff ensures that most of the fish > 60 cm are white hake since red hake do not reach this size. For years prior to 1985, an average proportion of fish > 60 cm for 1985-2000 was used to split the landings into two parts (75% > 60 cm). All discards prior to 1989 were assumed to be <= 60 cm. The NEFSC surveys were also split into two parts as in the commercial length compositions (Figure B17, Table B18). The rate of decline for the > 60 cm portion of the stock is apparently greater than that for the stock as a whole. Exploitation (catch/survey biomass) on the 60+ cm component has increased since the 1970s (Figure B18, Table B19). Recruitment estimates from the autumn survey indicate that after some good recruitment in the late 1980s, there were several years of poor recruitment (Figure B19). However, there appears to be an above average year class in 1998.

BIOLOGICAL REFERENCE POINTS

Yield and Spawning Stock Biomass per recruit

Since a VPA was not accepted, updates to the yield-per-recruit and SSB-per-recruit analyses could not be conducted. Estimates of reference points from previous analyses may not be appropriate due to the uncertainties associated with the VPA.

SFA Requirements

A surplus production model incorporating covariates (ASPIC, Prager, 1995) was conducted on the biomass of white hake greater than 60 cm (Table B20). A pattern of residuals from the spring surveys indicated that the gear change in 1973 may have increased the catchability of white hake even though there is currently no significant conversion factor. It was therefore decided that the reference points from this analysis would be considered provisionally acceptable. B_{msy} is estimated to be 14,700 mt and F_{msy} is estimated to be 0.29. The biomass estimates from the model indicate that biomass increased to levels above B_{msy} in the late 1960s through the early 1980s (Figure 20). Biomass has since declined and is estimated to be about 20% of B_{msy}. The estimates of fishing mortality show an increasing trend from a low in 1967 (Figure 21). The current estimate of fishing mortality is at least twice the F_{msy} estimate.

CATCH and STOCK BIOMASS PROJECTIONS

No projections could be completed.

CONCLUSIONS

The Gulf of Maine to Northern Georges Bank stock of white hake is overfished and overfishing is occurring. Fishing mortality should be reduced immediately if the 1998 year class is to be protected.

White Hake SARC Comments

The SARC reviewed the white hake VPA base run and concurred with the Working Group that the VPA was problematic given the persistent retrospective pattern resulting from a catch at age which was not well characterized due to the following issues: possible species mis-identification at small sizes, sparse data to estimate discards, insufficient commercial sampling in recent years, the catchability of older (6+) fish in the survey, and possible mis-identification of stock components. Additionally, the SARC noted that the blending of sea sampling and survey age data may introduce bias if the proportions at age are not similar between the two data sets. The SARC also observed that 1) mean weights at age and mean lengths at age of younger fish, particularly ages 1-3, have a relatively large range within each age group; 2) partial recruitment varied considerably from year to year; and 3) fishing mortality pattern at age varied more than expected.

In an attempt to minimize the species mis-identification and discard issues in the catch at age, the SARC suggested two additional analyses which focused on the older fish in the catch which are believed to be only white hake. Given that red hake, the species often confused with white hake, rarely attain lengths greater than 50 cm, the SARC first suggested that the relative exploitation ratios (catch/survey index) be derived using fish 1) less than or equal to 60 cm (ages 1-3); 2) greater than 60 cm (age 4+ fish); and 3) all fish. The SARC then suggested that a VPA be conducted in which ages 1-3 were removed from the catch at age.

The relative exploitation trend for fish >60 cm indicated that exploitation had increased since the mid-1970's. However, the exploitation pattern for white hake less than or equal to 60 cm revealed a declining trend since 1980. The conflicting trends for the two size groups indicated that the catch may indeed be mis-specified. The exploitation trend for younger fish was consistent with the fishing mortality trend in the base VPA. However, results from the VPA using a catch at age excluding ages 1 to 3 revealed the same persistent retrospective pattern as the VPA base run. The SARC concluded that the VPA formulations were too problematic to accept as the basis for estimating stock size and fishing mortality.

A surplus production model (ASPIC) which utilized catch (> 60 cm) tuned with NEFSC spring (>60 cm) and autumn survey indices (> 60 cm) was reviewed. ASPIC estimates of biomass and fishing mortality were consistent with survey biomass indices and relative exploitation trends. However, there were some problems with residual patterns in the early period; specifically, the SARC noted a cluster of large positive residuals in the spring survey series between 1970 and 1985. These positive residuals may be associated with the gear change which occurred during this time period. The SARC suggested that an intervention analysis may be useful to determine if these years constituted a separate time series or not. The bootstrap analysis which included these large residuals indicated that production parameters have low precision. Resolving the apparent change in the spring survey catchability is likely to reduce uncertainty in the biomass dynamic model. It was the consensus of the SARC that the ASPIC results were illustrative of trends in fishing mortality and biomass but that further investigation would be required to address the diagnostics before the model could be used to provide a definitive update of biological reference points. In the absence of definitive results from either the VPA or the ASPIC, the SARC agreed to use survey biomass indices and relative exploitation ratios as proxies for biomass and fishing mortality estimates.

Sources of Uncertainty

- Catch at age not well characterized due to possible mis-identification of species in the commercial and sea sampling data, low sampling of commercial landings, and sparse discard data.
- Catchability of older ages in the survey.
- Mean weights at age in the catch for ages 5-8 in 1991-1994 may not be well specified due to unaged sea sampling samples.
- Current formulation depends on partially recruited/ younger ages for tuning and estimation of fishing mortality.
- The persistent retrospective pattern indicates the fishing mortality in the terminal year is likely to decrease when the analysis is updated.

RESEARCH RECOMMENDATIONS

- Explore causes of retrospective pattern, if possible.
- Improve species identification in sea sampling.
- Increase sea sampling coverage for improved estimates of discard rates.
- Expand NEFSC survey coverage into deeper water to better define stock distribution.
- Explore the use of 4X landings, 4X samples, and Canadian survey data to define stock area..
- Continue the collection and ageing of samples from the ASMFC Shrimp survey.
- For improved age-based analyses of commercial landings, continue ageing of sea sampling samples from 1991-1994.
- Explore alternative assessment methodology.
- Explore catch curve analysis of survey data.
- Investigate residual patterns observed in ASPIC results, i.e. intervention analysis.

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Table B1. Total landings (mt,live)[1] of white hake by country from the Gulf of Maine to Cape Hatteras (NAFO Subareas 5 and 6), 1964-2000.

	Canada	USA	Other	Total
1964	29	3016	0	3045
1965	0	2615	0	2615
1966	0	1562	0	1562
1967	16	1126	0	1142
1968	85	1209	0	1294
1969	34	1343	6	1383
1970	46	1807	280	2133
1971	100	2583	214	2897
1972	40	2946	159	3145
1973	117	3278	5	3400
1974	232	3773	0	4005
1975	146	3673	0	3819
1976	195	4104	0	4299
1977	170	4976	338	5484
1978	155	4869	29	5053
1979	251	4044	4	4299
1980	305	4746	2	5053
1981	454	5970	0	6424
1982	764	6179	2	6945
1983	810	6408	0	7218
1984	1013	6757	0	7770
1985	953	7353	0	8306
1986	956	6109	0	7065
1987	555	5818	0	6373
1988	534	4783	0	5130
1989	583	4547	0	5130
1990	547	4927	0	5474
1991	552	5607	0	6159
1992	1138	8444	0	9582
1993	1681	7466	0	9147
1994	955	4737	0	5692
1995	481	4333	0	4814
1996	372	3287	0	3659
1997	290	2225	0	2515
1998	228	2367	0	2595
1999	174	2624	0	2728
2000	224	2990	0	3214

[1]Canada and Other as reported to ICNAF/NAFO for1964-1992.
USA Landings derived from NEFSC Weighout files.
[4]Includes Japan, Spain, and USSR.

Table B2. US commercial landings (mt,live) and the annual percentage of total landings of white hake by gear type, 1964-2000.

	Landings (mt,live)					Percentage of Annual Landings				
		Line	Bottom Otter	Sink Gill	Other[1]		Line	Bottom Otter	Sink Gill	Other[1]
Year	Trawl	Trawl	Net	Gear	Total	Trawl	Trawl	Net	Gear	Total
1964	1228	1681	99	8	3016	40.7	55.7	3.3	0.3	100.0
1965	1513	1034	64	4	2615	57.9	39.5	2.4	0.2	100.0
1966	704	755	99	5	1562	45.1	48.3	6.3	0.3	100.0
1967	326	730	67	4	1126	28.9	64.8	5.9	0.4	100.0
1968	265	825	116	3	1209	21.9	68.2	9.6	0.3	100.0
1969	228	1005	108	2	1343	17.0	74.8	8.0	0.2	100.0
1970	201	1474	129	4	1807	11.1	81.5	7.2	0.2	100.0
1971	532	1925	118	9	2583	20.6	74.5	4.6	0.3	100.0
1972	834	1717	384	11	2946	28.3	58.3	13.0	0.4	100.0
1973	840	1941	491	6	3278	25.6	59.2	15.0	0.2	100.0
1974	638	1852	1274	9	3773	16.9	49.1	33.8	0.2	100.0
1975	993	1356	1320	4	3673	27.1	36.9	35.9	0.1	100.0
1976	546	1606	1943	9	4104	13.3	39.2	47.3	0.2	100.0
1977	391	2316	2257	12	4976	7.9	46.5	45.4	0.2	100.0
1978	321	2183	2341	23	4869	6.6	44.8	48.1	0.5	100.0
1979	206	2058	1752	28	4044	5.1	50.9	43.3	0.7	100.0
1980	90	2656	1967	33	4746	1.9	56.0	41.5	0.7	100.0
1981	108	3473	2376	13	5970	1.8	58.2	39.8	0.2	100.0
1982	97	3860	2202	20	6179	1.6	62.5	35.6	0.3	100.0
1983	79	4868	1395	66	6408	1.2	76.0	21.8	1.0	100.0
1984	22	5158	1486	90	6757	0.3	76.3	22.0	1.4	100.0
1985	315	5508	1418	112	7353	4.3	74.9	19.3	1.5	100.0
1986	231	4671	1163	44	6109	3.8	76.5	19.0	0.7	100.0
1987	86	4798	911	24	5818	1.5	82.5	15.6	0.4	100.0
1988	85	3655	1008	35	4783	1.8	76.4	21.1	0.7	100.0
1989	15	2552	1892	88	4547	0.3	56.1	41.6	2.0	100.0
1990	78	3286	1508	54	4927	1.6	66.7	30.6	1.1	100.0
1991	249	3553	1616	189	5607	4.4	63.4	28.8	3.4	100.0
1992	948	5195	2262	40	8444	11.2	61.5	26.8	0.5	100.0
1993	1203	4656	1590	16	7466	16.1	62.4	21.3	0.2	100.0
1994	1186	2479	1065	7	4737	25.0	52.3	22.5	0.2	100.0
1995	764	2407	1123	39	4333	17.6	55.6	25.9	0.9	100.0
1996	307	2036	926	19	3287	9.3	61.9	28.2	0.6	100.0
1997	394	1284	543	5	2225	17.7	57.7	24.4	0.2	100.0
1998	326	1370	662	9	2367	13.8	57.9	28.0	0.4	100.0
1999	140	1535	925	23	2624	5.4	58.5	35.2	0.9	100.0
2000	95	1831	1042	22	2990	3.2	61.2	34.9	0.7	100.0

[1] Includes handline, Scottish seine, drift gill net, scallop dredge, Danish seine, pound net, floating trap net, longline, midwater trawl, lobster pots, fish pots, purse seine, troll line, common seine, diving gear, set gill net, harpoon, rakes, and trammel net.

Table B3. Landings (mt, live) and the annual percentage of landings of white hake by season, 1964-2000.

						Month								
Year	Unk.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1964	111	148	126	125	166	110	221	721	406	364	220	199	99	3016
1965	22	82	105	88	38	26	151	763	551	371	163	134	121	2615
1966	26	37	40	67	47	29	94	91	552	224	168	104	83	1562
1967	17	55	29	50	22	22	33	58	241	234	207	97	61	1126
1968	17	38	52	51	22	28	67	103	302	220	165	79	65	1209
1969	8	55	44	19	24	34	69	81	264	254	216	163	112	1343
1970	12	57	54	50	38	115	160	183	243	259	331	171	134	1807
1971	37	82	39	37	43	99	180	181	453	405	443	400	184	2583
1972	22	123	65	54	45	150	186	379	628	423	495	211	165	2946
1973	252	124	54	65	78	145	191	311	578	415	481	323	261	3278
1974	133	175	51	85	148	164	194	354	529	557	640	417	326	3773
1975	187	105	72	64	98	233	296	464	727	500	312	422	193	3673
1976	184	96	147	152	128	133	316	758	563	667	364	378	218	4104
1977	236	117	91	199	146	191	283	684	852	645	648	612	272	4976
1978	185	105	147	114	131	172	271	370	1084	859	761	480	190	4869
1979	262	102	34	78	106	232	322	642	964	433	379	308	182	4044
1980	380	109	108	106	102	131	442	720	860	636	553	405	195	4746
1981	53	196	86	126	116	129	437	903	1375	798	649	766	336	5970
1982	6	174	180	194	134	190	462	1139	1280	809	693	571	348	6179
1983	4	405	237	284	211	334	630	817	1015	745	744	577	406	6408
1984	13	425	228	221	208	341	537	770	1209	961	934	549	362	6757
1985	4	273	231	292	345	358	705	1097	1030	1115	825	633	445	7353
1986	2	309	276	288	386	392	619	999	851	723	623	370	272	6109
1987	4	135	188	221	163	270	724	1000	936	805	694	411	267	5818
1988	7	183	100	132	165	287	646	682	761	844	503	314	159	4783
1989	5	149	130	130	137	204	596	795	807	603	540	291	161	4547
1990	7	157	112	172	135	269	595	812	916	635	617	319	181	4927
1991	7	163	162	90	114	457	554	846	1126	871	624	345	247	5607
1992	5	277	247	294	283	344	832	1487	1756	1203	802	595	321	8444
1993	4	272	213	274	307	532	1000	1319	1232	790	744	514	266	7466
1994		143	275	198	325	348	617	688	717	447	465	293	221	4737
1995		141	180	190	138	261	504	712	597	504	566	366	175	4333
1996		135	149	152	100	243	382	366	553	448	402	236	122	3287
1997		97	116	73	73	62	209	271	344	343	287	206	143	2225
1998		67	92	116	107	101	257	318	308	322	275	213	191	2367
1999		151	141	156	142	181	346	379	330	288	209	175	125	2624
2000		125	160	195	192	294	298	371	358	257	344	225	170	2990

Table B3. Cont.

Percentage of total													
1964	3.7	4.9	4.2	4.1	5.5	3.6	7.3	23.9	13.5	12.1	7.3	7.0	3.3	100.0
1965	0.8	3.1	4.0	3.4	1.5	1.0	5.8	29.2	21.1	14.2	6.2	5.1	4.6	100.0
1966	1.7	2.4	2.6	4.3	3.0	1.9	6.0	5.8	35.3	14.3	10.7	6.7	5.3	100.0
1967	1.5	4.9	2.6	4.4	2.0	2.0	2.9	5.2	21.4	20.8	18.4	8.6	5.4	100.0
1968	1.4	3.1	4.3	4.2	1.8	2.3	5.5	8.5	25.0	18.2	13.6	6.5	5.4	100.0
1969	0.6	4.1	3.3	1.4	1.8	2.5	5.1	6.0	19.6	18.9	16.1	12.2	8.3	100.0
1970	0.7	3.2	3.0	2.8	2.1	6.4	8.8	10.1	13.4	14.3	18.3	9.5	7.4	100.0
1971	1.4	3.2	1.5	1.5	1.7	3.8	7.0	7.0	17.5	15.7	17.1	15.5	7.1	100.0
1972	0.7	4.2	2.2	1.8	1.5	5.1	6.3	12.9	21.3	14.3	16.8	7.2	5.6	100.0
1973	7.7	3.8	1.6	2.0	2.4	4.4	5.8	9.5	17.6	12.7	14.7	9.9	8.0	100.0
1974	3.5	4.6	1.4	2.3	3.9	4.3	5.1	9.4	14.0	14.8	17.0	11.0	8.6	100.0
1975	5.1	2.9	2.0	1.7	2.7	6.3	8.1	12.7	19.8	13.6	8.5	11.5	5.3	100.0
1976	4.5	2.4	3.6	3.7	3.1	3.2	7.7	18.5	13.7	16.2	8.9	9.2	5.3	100.0
1977	4.7	2.4	1.8	4.0	2.9	3.8	5.7	13.8	17.1	13.0	13.0	12.3	5.5	100.0
1978	3.8	2.2	3.0	2.3	2.7	3.5	5.6	7.6	22.3	17.7	15.6	9.9	3.9	100.0
1979	6.5	2.5	0.8	1.9	2.6	5.7	8.0	15.9	23.8	10.7	9.4	7.6	4.5	100.0
1980	8.0	2.3	2.3	2.2	2.2	2.8	9.3	15.2	18.1	13.4	11.7	8.5	4.1	100.0
1981	0.9	3.3	1.4	2.1	1.9	2.2	7.3	15.1	23.0	13.4	10.9	12.8	5.6	100.0
1982	0.1	2.8	2.9	3.1	2.2	3.1	7.5	18.4	20.7	13.1	11.2	9.2	5.6	100.0
1983	0.1	6.3	3.7	4.4	3.3	5.2	9.8	12.7	15.8	11.6	11.6	9.0	6.3	100.0
1984	0.2	6.3	3.4	3.3	3.1	5.0	7.9	11.4	17.9	14.2	13.8	8.1	5.4	100.0
1985	0.1	3.7	3.1	4.0	4.7	4.9	9.6	14.9	14.0	15.2	11.2	8.6	6.1	100.0
1986	0.0	5.0	4.5	4.7	6.3	6.4	10.1	16.4	13.9	11.8	10.2	6.1	4.5	100.0
1987	0.1	2.3	3.2	3.8	2.8	4.6	12.5	17.2	16.1	13.8	11.9	7.1	4.6	100.0
1988	0.1	3.8	2.1	2.8	3.4	6.0	13.5	14.3	15.9	17.6	10.5	6.6	3.3	100.0
1989	0.1	3.3	2.9	2.9	3.0	4.5	13.1	17.5	17.8	13.3	11.9	6.4	3.5	100.0
1990	0.1	3.2	2.3	3.5	2.7	5.5	12.1	16.5	18.6	12.9	12.5	6.5	3.7	100.0
1991	0.1	2.9	2.9	1.6	2.0	8.2	9.9	15.1	20.1	15.5	11.1	6.1	4.4	100.0
1992	0.1	3.3	2.9	3.5	3.4	4.1	9.8	17.6	20.8	14.2	9.5	7.0	3.8	100.0
1993	0.1	3.6	2.9	3.7	4.1	7.1	13.4	17.7	16.5	10.6	10.0	6.9	3.6	100.0
1994	0.0	3.0	5.8	4.2	6.9	7.3	13.0	14.5	15.1	9.4	9.8	6.2	4.7	100.0
1995	0.0	3.2	4.1	4.4	3.2	6.0	11.6	16.4	13.8	11.6	13.1	8.5	4.0	100.0
1996	0.0	4.1	4.5	4.6	3.0	7.4	11.6	11.1	16.8	13.6	12.2	7.2	3.7	100.0
1997	0.0	4.4	5.2	3.3	3.3	2.8	9.4	12.2	15.5	15.4	12.9	9.3	6.4	100.0
1998	0.0	2.8	3.9	4.9	4.5	4.3	10.9	13.5	13.0	13.6	11.6	9.0	8.1	100.0
1999	0.0	5.8	5.4	6.0	5.4	6.9	13.2	14.5	12.6	11.0	8.0	6.7	4.8	100.0
2000	0.0	4.2	5.4	6.5	6.4	9.8	10.0	12.4	12.0	8.6	11.5	7.5	5.7	100.0

Table B4. Total US Landings (mt,live) and the annual percentage of landings of white hake by state, 1964-2000.

	Landings (mt, live)				Percentage of total			
Year	Maine	Mass.	Others[1]	Total	Maine	Mass.	Others[1]	Total
1964	1603	1362	51	3016	53.1	45.2	1.7	100.0
1965	1743	831	41	2615	66.7	31.8	1.5	100.0
1966	914	598	50	1562	58.5	38.3	3.2	100.0
1967	639	453	34	1126	56.8	40.2	3.0	100.0
1968	569	576	64	1209	47.1	47.6	5.3	100.0
1969	475	818	51	1343	35.3	60.9	3.8	100.0
1970	639	1088	81	1807	35.3	60.2	4.5	100.0
1971	892	1563	128	2583	34.5	60.5	5.0	100.0
1972	1329	1538	79	2946	45.1	52.2	2.7	100.0
1973	1295	1812	171	3278	39.5	55.3	5.2	100.0
1974	1708	1905	160	3773	45.3	50.5	4.2	100.0
1975	2063	1439	170	3673	56.2	39.2	4.6	100.0
1976	2502	1431	171	4104	61.0	34.9	4.1	100.0
1977	2967	1785	223	4976	59.6	35.9	4.5	100.0
1978	3047	1645	178	4869	62.6	33.8	3.6	100.0
1979	2404	1394	246	4044	59.4	34.5	6.1	100.0
1980	2729	1598	419	4746	57.5	33.7	8.8	100.0
1981	3756	2028	186	5970	62.9	34.0	3.1	100.0
1982	4253	1794	133	6179	68.8	29.0	2.2	100.0
1983	4289	1874	245	6408	66.9	29.3	3.8	100.0
1984	3881	2444	431	6757	57.4	36.2	6.4	100.0
1985	3696	3370	287	7353	50.3	45.8	3.9	100.0
1986	2955	2875	280	6109	48.4	47.1	4.5	100.0
1987	3246	2255	317	5818	55.8	38.8	5.4	100.0
1988	2695	1900	188	4783	56.3	39.7	4.0	100.0
1989	3123	1324	100	4547	68.7	29.1	2.2	100.0
1990	2744	2108	74	4927	55.7	42.8	1.5	100.0
1991	3280	2122	205	5607	58.5	37.8	3.7	100.0
1992	5357	2521	566	8444	63.4	29.9	6.7	100.0
1993	5042	2067	357	7466	67.5	27.7	4.8	100.0
1994	2940	1385	412	4737	62.1	29.2	8.7	100.0
1995	2532	1526	275	4333	58.4	35.2	6.3	100.0
1996	1950	1129	208	3287	59.3	34.3	6.3	100.0
1997	1428	623	175	2225	64.1	28.0	7.9	100.0
1998	1357	886	123	2367	57.3	37.4	5.2	100.0
1999	1353	943	328	2624	51.6	35.9	12.5	100.0
2000	1703	910	377	2990	56.9	30.4	12.6	100.0

[1]Others include NH,RI,NY,NJ,VA

Table B5. US Landings (mt,live) and the annual percentage of total landings of white hake by tonnage class[1], 1964-2000.

	Tonnage Class (TC)					Percentage of total				
Year	2	3	4	Others[2]	Total	2	3	4	Others[2]	Total
1964	450	991	230	1345	3016	14.9	32.9	7.6	44.6	100.0
1965	312	510	198	1595	2615	11.9	19.5	7.6	61.0	100.0
1966	280	404	125	753	1562	17.9	25.9	8.0	48.2	100.0
1967	206	333	111	476	1126	18.3	29.6	9.9	42.3	100.0
1968	300	414	162	333	1209	24.8	34.2	13.4	27.5	100.0
1969	286	532	227	298	1343	21.3	39.6	16.9	22.2	100.0
1970	520	728	296	263	1807	28.8	40.3	16.4	14.6	100.0
1971	600	1084	341	558	2583	23.2	42.0	13.2	21.6	100.0
1972	738	972	303	934	2946	25.0	33.0	10.3	31.7	100.0
1973	934	913	287	1144	3278	28.5	27.9	8.8	34.9	100.0
1974	1334	884	338	1217	3773	35.4	23.4	9.0	32.3	100.0
1975	1302	603	254	1514	3673	35.5	16.4	6.9	41.2	100.0
1976	1587	837	279	1401	4104	38.7	20.4	6.8	34.1	100.0
1977	2363	1008	485	1119	4976	47.5	20.3	9.7	22.5	100.0
1978	2161	1083	534	1091	4869	44.4	22.2	11.0	22.4	100.0
1979	1687	1055	469	833	4044	41.7	26.1	11.6	20.6	100.0
1980	1809	1143	730	1065	4746	38.1	24.1	15.4	22.4	100.0
1981	2346	1492	1348	784	5970	39.3	25.0	22.6	13.1	100.0
1982	2626	1828	1309	417	6179	42.5	29.6	21.2	6.7	100.0
1983	1964	2402	1798	244	6408	30.6	37.5	28.1	3.8	100.0
1984	1966	2746	1621	424	6757	29.1	40.6	24.0	6.3	100.0
1985	1883	2987	2180	303	7353	25.6	40.6	29.7	4.1	100.0
1986	1189	2257	2195	468	6109	19.5	36.9	35.9	7.7	100.0
1987	1078	2556	1865	319	5818	18.5	43.9	32.1	5.5	100.0
1988	1114	1753	1682	234	4783	23.3	36.7	35.2	4.9	100.0
1989	1535	1495	1220	297	4547	33.8	32.9	26.8	6.5	100.0
1990	1330	1696	1702	199	4927	27.0	34.4	34.5	4.0	100.0
1991	1749	1895	1688	275	5607	31.2	33.8	30.1	4.9	100.0
1992	2665	2925	2362	491	8444	31.6	34.6	28.0	5.8	100.0
1993	1994	2563	2704	204	7466	26.7	34.3	36.2	2.7	100.0
1994	1294	1733	1695	15	4737	27.3	36.6	35.8	0.3	100.0
1995	1381	1564	1366	22	4333	31.9	36.1	31.5	0.5	100.0
1996	1202	1162	909	15	3287	36.6	35.3	27.7	0.4	100.0
1997	850	951	424	0	2225	38.2	42.7	19.0	0.0	100.0
1998	950	1007	376	34	2367	40.1	42.6	15.9	1.5	100.0
1999	1146	1019	430	29	2624	43.7	38.8	16.4	1.1	100.0
2000	1178	1180	625	7	2990	39.4	39.5	20.9	0.2	100.0

[1]TC2 = 5-50 GRT, TC3 = 51-150 GRT, TC4 = 151-500 GRT.
[2]Undertonnage vessels

Table B6. Estimates of discards in the otter trawl, shrimp trawl, and sink gill net fleets from the DSSP from 1989-2000.

Year		Jan-Jun			Jul-Dec			Total				Percent
		trawl	shrimp	SGN	trawl	shrimp	SGN	trawl	shrimp	SGN	Total	of total
1989	tot land (mt)	928	6	378	1620	10	1514	2548	16	1892	4457	
	trips	26	5	0	49	4	62					
	tot kept (mt)	6.20	0.02		7.56	0.06	6.19					
	tot disc (mt)	1.65	0.06		8.41	0.11	0.20					
	discard/kept	0.27	3.89		1.11	1.82	0.03					
	Exp disc (mt)	247	25	0	1804	18	50	2050	42	50	2143	48.1
1990	tot land (mt)	1073	8	300	2207	8	1208	3280	17	1508	4805	
	trips	18	6	16	30	2	37	48	8	53		
	tot kept (mt)	1.80	0.03	1.19	4.74	0.01	14.13	7	0	15		
	tot disc (mt)	3.54	0.04	0.04	4.69	0.02	0.76	8	0	1		
	discard/kept	1.97	1.15	0.04	0.99	3.23	0.05					
	Exp disc (mt)	2114	9	11	2182	27	65	4297	37	76	4409	91.8
1991	tot land (mt)	1019	8	291	2529	6	1323	3548	14	1614	5176	
	trips	16	16	58	56	6	394	72	22	452		
	tot kept (mt)	2.32	0.07	15.70	7.86	0.23	107.06	10	0	123		
	tot disc (mt)	0.25	0.18	0.76	3.85	0.38	3.90	4	1	5		
	disc/kept	0.11	2.66	0.05	0.49	1.71	0.04					
	Exp disc (mt)	111	20	14	1239	11	48	1350	31	62	1443	27.9
1992	tot land (mt)	1274	8	402	3917	0	1859	5191	8	2261	7460	
	trips	33	36	93	22	6	358	55	42	451		
	tot kept (mt)	11.37	0.44	25.08	11.80	0.01	97.89	23	0	123		
	tot disc (mt)	3.13	0.79	1.81	1.10	0.01	4.52	4	1	6		
	discard/kept	0.28	1.83	0.07	0.09	1.14	0.05					
	Exp disc (mt)	350	14	29	364	0	86	715	15	114	844	11.3
1993	tot land (mt)	1445	0	442	3209	0	1146	4653	0	1588	6242	
	trips	21	23	53	16	2	245	37	25	298		
	tot kept (mt)	8.68	0.00	16.20	8.81	0.00	61.47	17	0	78		
	tot disc (mt)	0.25	0.05	1.48	1.54	0.00	3.36	2	0	5		
	discard/kept	0.03	-	0.09	0.18	-	0.06					
	Exp disc (mt)	42	-	41	561	-	63	603		104	707	11.3
1994	tot land (mt)	1011	0	322	1468	1	743	2479	1	1065	3545	
	trips	24	41	9	11	7	31	35	48	40		
	tot kept (mt)	5.38	0.00	0.16	4.29	0.00	4.06	10	0	4		
	tot disc (mt)	0.77	0.07	0.01	0.25	0.05	0.10	1	0	0		
	discard/kept	0.14	-	0.06	0.06	-	0.03					
	Exp disc (mt)	145	-	18	85	-	19	230	-	37	267	7.5

Table B6 (Continued). Estimates of discards in the otter trawl, shrimp trawl, and sink gill net fleets from the DSSP from 1989-2000.

1995	tot land (mt)	743	0	401	1665	0	721	2407	0	1123	353	
	trips	35	49	10	29	2	31	64	51	41		
	tot kept (mt)	12.02	0.00	0.44	9.76	0.00	4.72	22	0	5		
	tot disc (mt)	0.54	0.10	0.01	0.59	0.01	0.29	1	0	0		
	discard/kept	0.05	-	0.02	0.06	-	0.06					
	Exp disc (mt)	33	-	9	101	-	45	134	0	54	188	5.3
1996	tot land (mt)	716	0	313	1320	0	613	2036	0	926	2961	
	trips	15	17	5	26	2	20	41	19	25		
	tot kept (mt)	6.06	0.00	0.83	0.46	0.00	7.74	7	0	9		
	tot disc (mt)	0.48	0.04	0.05	0.16	0.00	0.37	1	0	0		
	discard/kept	0.08	-	0.06	0.35	-	0.05	0	0	0		
	Exp disc (mt)	57	-	18	460	-	29	517	0	47	564	19.0
1997	tot land (mt)	458	2	120	824	0	423	1281	2	543	1826	
	trips	15	6	8	11	0	17	26	6	25		
	tot kept (mt)	2.10	0.00	0.57	1.73	-	2.38	4	0	3		
	tot disc (mt)	0.41	0.00	0.07	0.28	-	0.09	1	0	0		
	discard/kept	0.19	-	0.13	0.16	-	0.04					
	Exp disc (mt)	89	-	15	133	-	15	222	0	31	253	13.8
1998	tot land (mt)	423	1	210	945	0	453	1368	1	662	2032	
	trips	6	0	12	2	-	23	8	0	35		
	tot kept (mt)	0.68	-	0.91	0.15	-	0.36	1	0	1		
	tot disc (mt)	0.13	-	0.03	0.02	-	0.03	0	0	0		
	discard/kept	0.19	-	0.03	0.17	-	0.08	0	0	0		
	Exp disc (mt)	81	-	6	157	-	35	238	0	41	279	13.7
1999	tot land (mt)	717	0	317	818	0	608	1535	0	925	2460	
	trips	10	-	6	44	-	29	54	0	35		
	tot kept (mt)	0.24	-	1.85	1.79	-	16.59	2	0	18		
	tot disc (mt)	0.01	-	0.09	4.50	-	0.10	5	0	0		
	discard/kept	0.03	-	0.05	2.51	-	0.01	3	0	0		
	Exp disc (mt)	24	-	16	2051	-	4	2076	0	19	2095	85.2
2000	tot land (mt)	900	0	342	931	0	701	1831	0	1042	2873	
	trips	20	0	16	31	0	16	51	0	32		
	tot kept (mt)	7.25	-	3.11	11.41	-	1.58	19	0	5		
	tot disc (mt)	1.50	-	0.06	1.14	-	0.07	3	0	0		
	discard/kept	0.21	-	0.02	0.10	-	0.05	0	0	0		
	Exp disc (mt)	187	-	6	93	-	32	280	0	38	318	11.1

Table B7. Estimates of otter trawl discards from 1964-2000. The estimates for 1989-2000 are directly from sea sampling data while the 1964-1988 estimates are 25% of the landings.

Year	Discards
1964	664
1965	408
1966	298
1967	288
1968	325
1969	370
1970	582
1971	760
1972	678
1973	767
1974	731
1975	536
1976	634
1977	914
1978	862
1979	813
1980	1049
1981	1372
1982	1525
1983	1923
1984	2037
1985	2176
1986	1845
1987	1895
1988	1444
1989	2050
1990	4297
1991	1350
1992	715
1993	603
1994	230
1995	134
1996	517
1997	222
1998	238
1999	2076
2000	280

Table B8. Summary of US commercial white hake landings (mt), number of length samples (n), and number of fish measured (len) by market category and quarter from the Gulf of Maine to the Mid-Atlantic (SA 464,465, 511-515, 521-526, 533-539, 611-626) for all gear types, 1985-2000.

		Sampling Intensity																					
		small					medium					large					unclassified					All	mt/
Year		Q1	Q2	Q3	Q4	sum	Q1	Q2	Q3	Q4	sum	Q1	Q2	Q3	Q4	sum	Q1	Q2	Q3	Q4	sum	Total	sample
1985	mt	129	162	235	167	694	63	78	181	124	446	237	433	1135	623	2428	367	737	1690	988	3782	7349	272
	N	-	2	4	3	9	-	-	-	-	-	-	5	5	3	13	-	1	3	1	5	27	
	#fish	-	233	323	317	873	-	-	-	-	-	-	632	519	271	1422	-	101	293	104	498	2793	
1986	mt	59	134	105	100	398	86	89	55	54	284	274	422	835	417	1948	455	752	1578	694	3478	6107	235
	N	1	3	2	1	7	1	1	-	2	4	1	3	2	1	7	2	2	3	1	8	26	
	#fish	102	263	215	101	681	94	122	-	229	445	122	315	248	96	781	215	206	292	106	819	2726	
1987	mt	98	300	641	576	1616	13	49	122	123	306	171	326	943	372	1813	262	482	1035	301	2080	5814	194
	N	-	2	4	5	11	-	2	1	1	4	-	1	6	3	10	2	1	1	1	5	30	
	#fish	-	240	291	507	1038	-	203	91	109	403	-	111	518	236	865	218	140	112	125	595	2901	
1988	mt	181	549	893	397	2020	26	82	262	120	489	136	330	695	325	1486	73	137	437	134	782	4776	165
	N	5	6	3	5	19	1	1	1	-	3	1	1	2	1	5	-	1	-	1	2	29	
	#fish	558	764	240	478	2040	100	92	105	-	297	112	121	214	85	532	-	100	-	41	141	3010	
1989	mt	149	221	404	358	1132	41	54	124	68	287	188	473	904	470	2035	33	190	774	96	1092	4547	350
	N	1	1	2	2	6	-	-	1	-	1	-	-	2	2	4	1	-	1	-	2	13	
	#fish	91	94	213	195	593	-	-	103	-	103	-	-	206	204	410	100	-	106	-	206	1312	
1990	mt	207	411	885	450	1953	43	108	303	171	625	167	300	596	320	1382	24	182	580	176	962	4922	234
	N	3	4	4	2	13	-	-	2	1	3	2	-	1	1	4	-	-	-	1	1	21	
	#fish	309	408	399	151	1267	-	-	302	99	401	214	-	101	103	418	-	-	-	101	101	2087	
1991	mt	150	366	1215	612	2342	88	160	381	129	758	126	241	533	338	1238	52	358	714	138	1262	5601	156
	N	2	5	6	4	17	1	1	3	1	6	4	1	1	4	10	-	2	1	-	3	36	
	#fish	151	471	485	244	1351	103	100	382	100	685	375	99	96	539	1109	-	207	94	-	301	3446	
1992	mt	424	626	1735	848	3633	102	202	766	358	1428	231	351	699	371	1651	60	280	1246	141	1727	8439	211
	N	4	4	8	3	19	1	4	3	3	11	-	2	3	2	7	1	-	2	-	3	40	
	#fish	329	432	655	240	1656	80	388	266	317	1051	-	194	325	297	816	97	-	237	-	334	3857	
1993	mt	331	502	453	214	1500	161	397	1117	461	2136	173	476	795	416	1860	94	463	975	433	1965	7462	191
	N	2	5	4	1	12	2	3	2	1	8	2	3	7	2	14	-	2	2	1	5	39	
	#fish	150	504	275	50	979	184	309	196	95	784	199	262	676	175	1312	-	214	196	97	507	3582	
1994	mt	63	82	116	56	317	154	374	593	265	1386	206	481	687	407	1782	193	352	457	251	1252	4737	144
	N	-	2	4	1	7	-	2	3	3	8	-	3	4	2	9	-	2	4	3	9	33	
	#fish	-	167	386	100	653	-	230	305	272	807	-	303	363	304	970	-	236	431	372	1039	3469	
1995	mt	39	43	98	56	245	140	238	616	399	1393	197	398	595	374	1564	134	225	504	268	1130	4333	361
	N	-	1	1	1	3	-	2	2	1	5	-	2	-	1	3	-	1	-	-	1	12	
	#fish	-	107	97	105	309	-	191	222	111	524	-	221	-	103	324	-	100	-	-	100	1257	
1996	mt	23	34	80	43	181	96	207	531	269	1103	208	331	416	280	1234	110	152	339	169	769	3287	122
	N	-	-	-	-	-	1	-	4	4	9	-	2	4	5	11	1	1	3	2	7	27	
	#fish	-	-	-	-	-	101	-	435	541	1077	-	202	451	759	1412	127	72	326	220	745	3234	
1997	mt	31	58	124	83	295	76	113	369	193	751	146	146	438	335	1065	34	28	26	26	113	2225	32
	N	4	2	4	2	12	3	7	6	13	29	5	7	7	9	28	-	-	-	1	1	70	
	#fish	458	206	430	261	1355	276	694	564	1200	2734	541	720	678	896	2835	-	-	-	58	58	6982	
1998	mt	31	54	128	105	318	55	77	218	152	502	159	311	571	407	1449	28	23	34	14	100	2370	74
	N	1	2	1	1	5	3	-	3	2	8	7	2	8	1	18	-	-	1	-	1	32	
	#fish	53	220	120	59	452	327	-	402	305	1034	684	213	1311	110	2318	-	-	118	-	118	3922	
1999	mt	50	76	103	87	317	85	110	236	149	580	303	468	633	257	1661	11	14	25	16	66	2624	119
	N	-	-	1	-	1	1	1	3	4	9	1	6	2	3	12	-	-	-	-	-	22	
	#fish	-	-	119	-	119	111	102	315	313	841	166	665	202	327	1360	-	-	-	-	-	2320	
2000	mt	55	70	81	81	286	118	202	289	201	811	293	497	596	446	1833	14	15	20	12	60	2990	120
	N	4	-	-	1	5	5	1	5	4	15	1	1	-	3	5	-	-	-	-	-	25	
	#fish	428	-	-	123	551	527	106	573	450	1656	103	126	-	336	565	-	-	-	-	-	2772	

Table B9. Number of ages used to age the commercial length composition from NEFSC survey and DSSP data.

Year	Spring (Half 1)	Autumn (Half 2)	Total
1985	217	338	555
1986	655	653	1308
1987	171	392	563
1988	273	454	727
1989	192	424	616
1990	436	844	1280
1991	492	762	1254
1992	300	674	974
1993	323	556	879
1994	276	525	801
1995	357	636	993
1996	237	500	737
1997	204	366	570
1998	91	436	527
1999	220	331	551
2000	272	369	641

Table B10. Total US commercial landings-at-age of white hake.

Year	1	2	3	4	5	6	7	8	9+	Total
					Age					
		Total Commercial Landings in Numbers (000s) at age								
1985	0	12	617	1847	679	157	55	20	34	3422
1986	0	18	285	371	289	187	146	84	214	1593
1987	0	46	839	697	351	164	66	74	92	2329
1988	15	1077	966	938	431	86	5	10	27	3556
1989	0	11	540	786	523	243	32	25	11	2172
1990	14	569	1061	1083	298	98	53	11	18	3206
1991	9	237	1458	1276	365	101	20	15	22	3502
1992	0	43	2006	2224	432	214	78	24	11	5032
1993	0	39	1557	2380	632	172	14	5	11	4810
1994	45	28	798	1045	513	225	40	25	7	2726
1995	0	270	1544	789	295	149	42	26	15	3130
1996	0	31	317	477	415	231	46	23	9	1550
1997	0	1	72	216	285	165	93	25	11	867
1998	1	17	58	132	151	183	159	41	1	743
1999	0	0	125	176	200	148	98	82	37	868
2000	0	1	26	214	218	142	90	109	80	879
		Total Commercial Landings in Weight (Tons) at age								
1985	0	8	677	3775	2171	706	344	158	466	8306
1986	0	10	289	626	937	926	858	677	2743	7066
1987	0	25	857	1338	1221	901	372	497	1161	6373
1988	3	491	837	1801	1238	365	34	77	472	5317
1989	0	8	593	1474	1551	999	207	165	134	5131
1990	3	263	1203	2053	916	406	289	91	251	5474
1991	2	90	1656	2551	987	353	111	126	283	6159
1992	0	28	2093	4106	1488	1089	441	178	159	9582
1993	0	14	1639	4466	1939	787	96	43	163	9147
1994	6	10	815	1820	1495	983	254	213	97	5692
1995	0	164	1659	1323	730	461	189	160	127	4814
1996	0	19	357	854	1133	842	198	161	94	3659
1997	0	1	75	402	757	592	436	162	90	2515
1998	0	7	67	250	424	718	808	310	10	2595
1999	0	0	99	302	516	544	486	539	311	2798
2000	0	1	27	398	555	481	417	728	608	3214
		Total Commercial Landings Mean Weight (kg) at age								
1985	0.000	0.682	1.096	2.044	3.195	4.505	6.281	8.104	13.525	2.427
1986	0.000	0.562	1.015	1.686	3.242	4.958	5.898	8.095	12.804	4.435
1987	0.000	0.541	1.022	1.920	3.474	5.492	5.681	6.713	12.677	2.736
1988	0.176	0.455	0.867	1.919	2.874	4.245	7.238	7.604	17.504	1.495
1989	0.000	0.678	1.099	1.875	2.963	4.117	6.399	6.515	11.762	2.362
1990	0.217	0.462	1.134	1.895	3.073	4.118	5.432	8.192	13.902	1.707
1991	0.253	0.379	1.136	1.998	2.708	3.512	5.438	8.712	12.865	1.759
1992	0.000	0.645	1.044	1.847	3.443	5.086	5.668	7.376	13.980	1.904
1993	0.000	0.353	1.053	1.877	3.070	4.571	6.912	9.132	14.312	1.902
1994	0.130	0.362	1.021	1.742	2.914	4.361	6.358	8.483	13.627	2.088
1995	0.000	0.608	1.074	1.677	2.478	3.104	4.500	6.190	8.298	1.538
1996	0.000	0.616	1.125	1.793	2.730	3.643	4.273	6.898	10.129	2.361
1997	0.000	0.693	1.035	1.860	2.658	3.597	4.690	6.565	8.510	2.899
1998	0.202	0.433	1.164	1.889	2.809	3.924	5.083	7.605	9.462	2.382
1999	0.000	0.538	0.797	1.715	2.584	3.668	4.938	6.573	8.288	3.225
2000	0.000	0.612	1.066	1.861	2.550	3.390	4.639	6.682	7.560	3.656
		Total Commercial Landings Mean Length (cm) at age								
1985	0.0	43.8	50.8	61.5	71.0	79.3	87.9	95.4	110.2	63.3
1986	0.0	40.8	49.3	58.0	71.2	81.6	86.3	95.2	107.5	72.6
1987	35.0	40.7	49.7	60.3	72.9	84.0	85.2	89.6	108.5	63.2
1988	28.7	37.7	47.0	60.4	68.7	77.5	92.0	93.6	120.3	52.1
1989	0.0	43.9	50.7	60.1	69.5	77.0	88.6	88.9	106.5	62.8
1990	30.1	38.8	51.1	60.4	70.1	77.1	84.0	95.9	111.6	55.6
1991	31.8	35.6	50.7	60.8	67.1	73.2	84.1	97.1	109.7	56.4
1992	0.0	42.9	49.9	59.1	72.4	82.1	85.2	92.5	113.2	58.1
1993	0.0	35.7	50.0	59.9	70.3	79.7	90.7	98.2	113.3	58.8
1994	26.3	34.8	49.6	58.5	69.0	78.5	88.6	96.4	111.2	59.7
1995	0.0	42.3	50.4	58.1	65.8	70.4	79.3	87.3	94.2	55.0
1996	0.0	42.5	51.1	59.2	67.8	74.2	77.7	90.6	101.9	63.0
1997	0.0	43.5	49.6	59.8	67.1	73.9	80.2	89.1	96.4	67.5
1998	30.2	37.8	51.5	60.2	68.4	75.9	82.3	93.4	100.4	71.1
1999	0.0	40.0	45.8	58.0	66.6	74.3	81.6	89.0	95.8	68.2
2000	0.0	42.2	50.1	60.0	66.4	72.5	79.9	89.5	93.1	72.0

Table B11. Summary of Domestic Sea Sampling number of number of trips (trips) and number of age samples taken (age) by gear type, half year, and catch disposition, 1989-2000.

		Sink Gill Net						Otter Trawl						Grand	
		Half 1		Half 2		Total		Half 1		Half 2		Total		Total	
		Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc
1989	trips			14	1	14	1	4	10	3	19	7	29	21	30
	len			512	2	512	2	123	916	154	1734	277	2650	789	2652
	age			8		8	0		7	16	113	16	120	24	120
1990	trips	6		8	1	14	1	3	4	1	5	4	9	18	10
	len	206		1197	32	1403	32	69	53	138	312	207	365	1610	397
	age	30		76		106	0	19	7			19	7	125	7
1991	trips	20	1	89	7	109	8	2	1	3	2	5	3	114	11
	len	2526	135	9973	30	12499	165	53	180	413	45	466	225	12965	390
	age	155	49	334	11	489	60				2	0	2	489	62
1992	trips	34	1	182	4	216	5	7	6	2	4	9	10	225	15
	len	1620	1	8473	4	10093	5	265	17	59	144	324	161	10417	166
	age	61		278	3	339	3	47			13	47	13	386	16
1993	trips	26	1	129	10	155	11	8	20	5	2	13	22	168	33
	len	1276	1	4001	13	5277	14	681	333	658	44	1339	377	6616	391
	age	30	1	169	4	199	5	17	16	3		20	16	219	21
1994	trips	10		81	3	91	3	12	37	8	7	20	44	111	47
	len	44		1835	12	1879	12	247	570	489	294	736	864	2615	876
	age	9		64	1	73	1	22	22	54	2	76	24	149	25
1995	trips	9	1	117	7	126	8	12	49	9	10	21	59	147	67
	len	167	1	2638	30	2805	31	1111	1375	697	372	1808	1747	4613	1778
	age	7	1	57	2	64	3	70	57	137	41	207	98	271	101
1996	trips	11	2	78	2	89	4	8	16	6	13	14	29	103	33
	len	70	13	826	3	896	16	284	526	331	381	615	907	1511	923
	age	22		284		306	0	99	31	15	28	114	59	420	59
1997	trips	8		24	2	32	2	5	9	6	6	11	15	43	17
	len	85		427	4	512	4	117	93	110	64	227	157	739	161
	age	34		118	2	152	2	65	64	93	65	158	129	310	131
1998	trips	8		31	1	39	1	3	2	1	1	4	3	43	4
	len	36		411	1	447	1	39	17	12	2	51	19	498	20
	age	31		113	1	144	1	29	14	12	2	41	16	185	17
1999	trips	6		17	3	23	3	1		7	17	8	17	31	20
	len	79		218	20	297	20	23		113	287	136	287	433	307
	age	38		76	12	114	12	24		104	113	128	113	242	125
2000	trips	7	2	5		12	2	7	5	15	10	22	15	34	17
	len	47	9	143		190	9	421	119	475	76	896	195	1086	204
	age	4	4	15		19	4	160	34	114	6	274	40	293	44

Table B12. Discards at age in the otter trawl fishery, 1989-2000

	Age									
Year	0	1	2	3	4	5	6	7	8	Total
Otter Trawl Discards in Numbers (000s) at age										
1989	0	646	2476	1864	95	1	0	0	0	5082
1990	32	939	10362	2204	267	0	0	0	0	13804
1991	2152	7342	92	514	109	0	0	0	0	10209
1992	268	1754	2372	573	0	0	0	0	0	4967
1993	0	237	1161	443	2	0	0	0	0	1843
1994	37	833	608	41	23	14	1	0	0	1557
1995	0	139	237	77	4	1	<1	0	0	458
1996	0	1317	1013	112	6	0	0	0	0	2448
1997	0	76	214	76	27	13	4	3	<1	414
1998	0	88	237	80	29	12	2	3	0	451
1999	0	1232	2110	615	223	88	5	3	9	4286
2000	0	23	878	192	7	4	1	0	0	1106
Otter Trawl Discards in Weight (tons) at age										
1989	0	90	874	1383	104	3	0	0	0	2454
1990	2	169	2812	1027	286	0	0	0	0	4296
1991	113	537	24	530	146	0	0	0	0	1350
1992	9	111	326	268	0	0	0	0	0	714
1993	0	36	262	304	1	0	0	0	0	603
1994	2	63	68	22	36	36	3	0	0	230
1995	0	11	64	53	5	1	<1	0	0	134
1996	0	169	285	57	6	0	0	0	0	517
1997	0	10	63	46	44	29	13	16	2	222
1998	0	13	70	54	49	30	7	15	0	238
1999	0	224	682	459	421	203	14	20	53	2075
2000	0	4	177	75	11	11	2	0	0	280
Otter Trawl Discards Mean Weight (kg) at age										
1989	0.058	0.140	0.353	0.742	1.090	2.562				0.483
1990		0.180	0.271	0.466	1.071					0.311
1991	0.053	0.073	0.258	1.032	1.337					0.132
1992	0.034	0.063	0.137	0.467						0.144
1993		0.150	0.225	0.688	0.628					0.327
1994	0.040	0.076	0.112	0.543	1.589	2.519	3.746			0.148
1995		0.077	0.269	0.691	1.194	2.411	2.605			0.293
1996		0.128	0.281	0.511	0.997					0.211
1997		0.133	0.292	0.605	1.635	2.234	3.292	4.715	4.519	0.537
1998		0.150	0.293	0.674	1.720	2.539	4.292	4.567		0.528
1999		0.182	0.323	0.746	1.888	2.315	2.804	5.650	5.819	0.484
2000		0.156	0.201	0.392	1.546	2.624	2.677			0.253
Otter Trawl Discards Mean Length (cm) at age										
1989	20.5	26.8	35.4	45.0	50.9	66.2				38.1
1990		28.8	32.7	38.7	49.5					33.7
1991	19.8	22.0	31.4	49.0	53.7					23.3
1992	17.4	20.9	25.9	37.0						24.9
1993		27.0	30.8	44.1	42.7					33.5
1994	18.1	21.5	24.3	40.6	56.9	66.1	75.0			24.0
1995		21.4	30.9	43.7	52.1	65.3	67.0			30.4
1996		25.9	33.0	39.9	49.6					29.5
1997		26.1	33.4	41.8	57.7	63.7	71.9	80.4	79.5	36.9
1998		27.0	33.4	43.2	58.5	66.3	77.8	79.6		36.9
1999		29.0	34.7	44.7	60.4	64.5	68.4	85.2	86.0	36.6
2000		27.6	29.5	36.4	55.6	67.1	67.5			31.0

Table B13. Total catch at age for white hake 1989-2000.

Year	1	2	3	4	5	6	7	8	9+	Total
			Total Catch in Numbers (000s) at age							
1989	646	2488	2403	881	525	243	32	25	11	7255
1990	953	10932	3264	1351	298	98	53	11	18	17010
1991	7350	329	1972	1385	365	101	20	15	22	13710
1992	1754	2415	2579	2224	432	214	78	24	11	9999
1993	237	1201	2000	2382	632	172	14	5	11	6653
1994	878	636	839	1068	527	226	40	25	7	4283
1995	139	508	1620	793	295	149	42	26	15	3587
1996	1317	1045	429	482	415	231	46	23	9	3998
1997	76	216	148	243	298	169	96	25	11	1281
1998	89	255	138	161	163	184	162	41	1	1194
1999	1232	2111	740	399	297	153	102	91	37	5154
2000	23	879	218	221	222	142	90	109	80	1985
			Total Catch in Weight (tons) at age							
1989	90	881	1976	1578	1554	999	207	165	134	7585
1990	172	3074	2230	2339	916	406	289	91	251	9770
1991	539	114	2186	2697	987	353	111	126	283	7509
1992	111	353	2361	4106	1488	1089	441	178	159	10296
1993	36	276	1944	4468	1939	787	96	43	163	9750
1994	69	78	837	1857	1530	986	254	213	97	5922
1995	11	228	1712	1328	731	461	189	160	127	4948
1996	169	304	414	860	1133	842	198	161	94	4176
1997	10	64	121	446	786	605	452	164	90	2737
1998	13	77	121	299	454	725	823	310	10	2833
1999	224	682	558	724	719	558	506	592	311	4873
2000	4	177	103	409	567	482	417	728	608	3494
			Total Catch Mean Weight (kg) at age							
1989	0.140	0.354	0.822	1.790	2.962	4.117	6.399	6.515	11.762	1.046
1990	0.181	0.281	0.683	1.732	3.073	4.118	5.432	8.192	13.902	0.574
1991	0.073	0.345	1.109	1.946	2.708	3.512	5.438	8.712	12.865	0.548
1992	0.063	0.146	0.915	1.847	3.443	5.086	5.668	7.376	13.980	1.030
1993	0.150	0.230	0.972	1.876	3.070	4.571	6.912	9.132	14.312	1.465
1994	0.079	0.123	0.998	1.739	2.903	4.359	6.358	8.483	13.627	1.383
1995	0.078	0.450	1.056	1.674	2.478	3.104	4.500	6.190	8.298	1.379
1996	0.128	0.291	0.965	1.783	2.730	3.643	4.273	6.898	10.129	1.044
1997	0.133	0.295	0.814	1.835	2.640	3.590	4.691	6.535	8.510	2.137
1998	0.150	0.302	0.879	1.859	2.790	3.928	5.072	7.605	9.462	2.373
1999	0.182	0.323	0.754	1.812	2.418	3.640	4.962	6.498	8.288	0.946
2000	0.155	0.202	0.471	1.851	2.552	3.386	4.639	6.682	7.560	1.760
			Total Catch in Mean Length (cm) at age							
1989	26.79	35.45	46.25	59.11	69.45	77.05	88.56	88.87	106.54	45.52
1990	28.86	33.02	42.76	58.22	70.13	77.07	83.99	95.85	111.62	37.82
1991	21.99	34.37	50.30	60.23	67.11	73.20	84.05	97.14	109.73	31.76
1992	20.85	26.20	47.04	59.06	72.43	82.13	85.16	92.45	113.18	41.62
1993	27.01	30.92	48.69	59.92	70.28	79.66	90.67	98.24	113.32	51.81
1994	21.73	24.78	49.19	58.43	68.96	78.48	88.56	96.41	111.17	46.70
1995	21.40	36.95	50.11	58.05	65.76	70.44	79.28	87.30	94.18	51.82
1996	25.85	33.28	48.13	59.11	67.77	74.16	77.69	90.64	101.94	42.49
1997	26.11	33.45	45.62	59.53	67.00	73.86	80.20	88.98	96.43	57.61
1998	27.04	33.73	46.69	59.88	68.23	75.90	82.22	93.44	100.37	58.16
1999	29.04	34.67	44.90	59.35	65.90	74.08	81.68	88.75	95.82	41.95
2000	27.55	29.52	38.05	59.85	66.41	72.48	79.89	89.51	93.06	49.16

Table B14. Stratified mean catch per tow in numbers and weight (kg) for white hake from NEFSC offshore spring research vessel bottom trawl surveys (strata 21-30,33-40), 1968-2000.

	Abundance						Biomass											Number
	Raw Index			Smoothed			Raw Index			Smoothed			Individual	Length			Number	of Nonzero
Year	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean Wt	Min	Mean	Max	of Tows	Tows
1968	1.60	0.99	2.21	2.80			1.74	0.85	2.63	3.63			1.09	10	44.1	118	84	32
1969	3.76	2.14	5.38	3.59			5.09	3.15	7.03	5.02			1.36	11	46.3	127	83	40
1970	5.84	3.48	8.19	4.50			11.86	2.60	21.12	6.92			2.03	21	52.9	114	90	47
1971	3.31	2.16	4.47	5.03	3.25	7.88	5.14	3.03	7.25	7.50	4.43	12.69	1.55	17	51.3	121	94	45
1972	10.18	6.71	13.65	6.78	4.38	10.61	12.66	6.03	19.30	9.60	5.67	16.26	1.24	18	47.3	112	94	59
1973	9.24	4.96	13.52	7.62	4.92	11.93	12.22	7.30	17.15	10.89	6.43	18.43	1.32	18	49.9	120	85	55
1974	8.08	5.61	10.54	7.86	5.08	12.32	13.99	9.06	18.93	11.72	6.92	19.85	1.73	10	55.0	126	81	56
1975	9.32	5.94	12.70	8.02	5.18	12.56	11.22	7.60	14.85	11.67	6.89	19.77	1.21	9	44.7	115	81	48
1976	9.98	6.90	13.06	7.66	4.94	11.99	17.01	9.27	24.74	11.83	6.98	20.03	1.70	10	52.7	122	97	70
1977	6.13	3.82	8.43	6.50	4.19	10.17	11.01	6.79	15.23	10.20	6.02	17.28	1.79	22	55.5	128	105	52
1978	3.22	2.10	4.34	5.66	3.65	8.86	6.14	3.76	8.52	8.51	5.02	14.40	1.91	20	51.8	131	112	49
1979	5.26	3.40	7.11	6.32	4.08	9.90	4.97	2.56	7.38	8.19	4.84	13.88	1.02	16	43.0	113	131	65
1980	10.38	7.26	13.49	7.66	4.95	12.00	13.96	9.51	18.41	9.85	5.82	16.69	1.35	10	49.7	123	83	54
1981	17.09	12.45	21.73	8.12	5.25	12.72	19.92	8.91	30.93	10.15	5.99	17.19	1.17	11	45.9	131	84	66
1982	6.06	3.33	8.78	6.20	4.00	9.70	8.91	4.86	12.95	7.76	4.58	13.14	1.47	16	51.0	122	90	52
1983	3.23	2.26	4.19	4.77	3.08	7.47	3.12	2.13	4.11	5.58	3.29	9.45	0.97	15	43.7	102	87	54
1984	2.75	1.85	3.65	4.37	2.82	6.84	4.17	2.10	6.24	5.19	3.06	8.79	1.52	15	51.4	118	83	38
1985	4.33	2.97	5.68	4.90	3.17	7.68	5.38	3.12	7.64	5.32	3.14	9.00	1.24	20	48.5	117	78	39
1986	8.24	6.39	10.10	5.82	3.76	9.11	5.61	3.97	7.25	5.42	3.20	9.17	0.68	11	40.0	96	87	60
1987	7.15	5.29	9.00	5.92	3.82	9.27	6.44	4.56	8.31	5.44	3.21	9.21	0.90	12	45.3	128	81	49
1988	4.52	3.58	5.45	5.54	3.58	8.67	3.69	2.82	4.57	5.06	2.99	8.57	0.82	13	41.9	95	87	50
1989	3.65	2.06	5.24	5.67	3.66	8.88	3.22	1.22	5.22	5.42	3.20	9.18	0.88	16	43.0	92	79	42
1990	11.11	0.84	21.38	7.05	4.55	11.04	18.37	-8.27	45.00	7.31	4.32	12.38	1.65	22	53.3	119	87	50
1991	8.42	6.30	10.55	7.17	4.63	11.23	6.14	4.05	8.23	6.56	3.87	11.10	0.73	9	41.6	131	83	55
1992	7.59	4.95	10.24	6.79	4.39	10.63	7.11	3.54	10.69	6.06	3.57	10.25	0.94	22	45.1	105	77	48
1993	7.93	5.50	10.35	6.13	3.96	9.58	6.84	4.49	9.19	5.21	3.07	8.82	0.86	17	45.1	85	84	48
1994	4.59	3.29	5.89	4.93	3.18	7.71	3.17	1.69	4.66	3.97	2.34	6.72	0.69	18	40.1	96	85	55
1995	4.38	3.20	5.55	4.09	2.64	6.41	4.02	2.58	5.46	3.34	1.97	5.65	0.92	14	44.1	100	86	48
1996	2.87	2.17	3.58	3.30	2.13	5.25	3.07	2.22	3.92	2.58	1.52	4.38	1.07	12	45.9	104	78	47
1997	1.88	1.27	2.48	2.82	1.82	4.78	0.89	0.58	1.20	1.85	1.09	3.15	0.47	18	38.4	67	87	36
1998	2.25	1.57	2.92	2.90	1.85	4.52	1.09	0.70	1.48	1.84	1.08	3.15	0.49	17	37.7	74	113	53
1999	3.32	1.75	4.90	3.32	2.08	5.30	2.97	0.88	5.05	2.31	1.31	4.05	0.89	10	44.6	89	81	44
2000	5.19	3.85	6.52	3.81	2.22	6.53	3.33	2.32	4.35	2.58	1.35	4.94	0.64	14	40.4	77	86	54

Table B15. Stratified mean catch per tow in numbers and weight (kg) for white hake from NEFSC offshore autumn research vessel bottom trawl surveys (strata 21-30,33-40), 1963-2000.

	Abundance						Biomass											Number
	Raw Index			Smoothed			Raw Index			Smoothed			Individual	Length			Number	of Nonzero
Year	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI	Mean Wt	Min	Mean	Max	of Tows	Tows
1963	5.00	3.85	6.15	3.87			6.31	4.66	7.97	5.75			1.26	9	46.2	121	90	54
1964	1.77	1.22	2.31	3.46			4.14	2.51	5.78	5.52			2.38	24	56.3	123	86	36
1965	4.39	2.75	6.02	4.16			6.86	4.61	9.11	6.02			1.56	15	50.4	125	87	60
1966	6.79	5.06	8.53	4.88	3.34	7.13	7.67	5.75	9.59	6.20	4.30	8.93	1.13	18	45.1	121	85	66
1967	3.92	2.85	5.00	4.94	3.39	7.22	3.64	2.33	4.95	5.80	4.03	8.36	0.93	9	42.6	117	83	53
1968	4.24	2.57	5.91	5.55	3.80	8.11	4.54	2.46	6.62	6.68	4.63	9.62	1.07	11	44.9	120	84	54
1969	9.24	7.08	11.41	7.03	4.82	10.27	13.09	9.00	17.19	9.12	6.33	13.14	1.42	14	46.8	112	85	62
1970	8.05	6.17	9.92	7.89	5.40	11.52	12.82	8.95	16.70	10.60	7.36	15.28	1.59	5	51.3	127	90	68
1971	10.38	6.33	14.43	8.77	6.01	12.81	12.10	9.49	14.71	11.34	7.87	16.34	1.17	5	43.6	130	92	76
1972	12.52	5.80	19.24	9.05	6.20	13.22	13.10	8.54	17.65	11.78	8.17	16.97	1.05	9	45.2	122	92	74
1973	9.05	6.39	11.72	8.09	5.54	11.81	13.46	9.15	17.76	11.67	8.10	16.82	1.49	8	51.7	119	89	72
1974	5.35	4.12	6.59	6.88	4.71	10.04	11.00	7.96	14.04	10.85	7.53	15.64	2.06	7	54.5	130	95	73
1975	5.28	4.03	6.53	6.53	4.47	9.54	7.23	5.43	9.03	10.04	6.97	14.46	1.37	15	48.5	116	105	74
1976	6.04	4.09	7.99	6.82	4.67	9.97	10.56	7.39	13.72	10.73	7.45	15.47	1.75	8	54.7	134	91	68
1977	9.78	7.77	11.78	7.52	5.15	10.99	13.74	10.51	16.96	11.56	8.02	16.66	1.41	10	47.8	123	122	94
1978	7.87	6.25	9.49	7.38	5.05	10.78	12.54	9.73	15.35	11.54	8.01	16.63	1.59	12	50.2	131	191	146
1979	5.62	4.38	6.85	7.04	4.82	10.28	10.31	7.27	13.36	11.10	7.70	15.99	1.84	22	53.1	127	203	146
1980	10.86	7.38	14.33	7.42	5.08	10.84	16.66	8.79	24.54	11.03	7.65	15.89	1.54	4	48.8	118	94	76
1981	8.70	6.87	10.53	6.61	4.53	9.65	12.16	9.69	14.63	9.13	6.33	13.15	1.40	20	49.9	132	88	65
1982	1.96	1.37	2.55	5.21	3.57	7.61	2.11	1.35	2.88	6.65	4.62	9.58	1.08	12	46.7	93	92	49
1983	8.22	6.11	10.32	6.33	4.34	9.25	10.79	8.16	13.42	8.06	5.59	11.62	1.31	22	48.8	117	80	59
1984	5.32	4.38	6.26	6.86	4.70	10.02	8.23	6.60	9.86	8.58	5.96	12.37	1.55	22	51.9	123	86	69
1985	9.37	6.79	11.94	8.31	5.69	12.14	9.74	6.48	12.99	9.32	6.46	13.43	1.04	9	42.9	128	85	68
1986	14.42	11.34	17.50	9.55	6.54	13.95	11.56	9.54	13.58	9.91	6.88	14.28	0.80	10	41.9	108	89	79
1987	7.59	6.16	9.02	9.14	6.26	13.35	9.62	6.79	12.44	9.85	6.84	14.20	1.27	17	49.2	113	85	61
1988	8.12	6.35	9.89	9.51	6.51	13.88	9.88	6.87	12.90	9.89	6.87	14.26	1.22	19	46.1	136	86	69
1989	11.76	7.94	15.58	10.60	7.26	15.47	9.23	7.39	11.07	9.94	6.90	14.33	0.79	9	40.5	91	85	68
1990	13.09	9.76	16.41	11.28	7.72	16.47	10.58	6.87	14.28	10.33	7.17	14.89	0.81	5	41.5	83	87	72
1991	13.22	9.77	16.68	11.24	7.70	16.41	12.20	8.05	16.36	10.62	7.37	15.30	0.92	16	44.6	94	87	76
1992	10.16	8.57	11.76	10.42	7.14	15.22	11.24	9.09	13.39	10.26	7.12	14.79	1.11	16	47.7	115	84	68
1993	11.35	8.64	14.05	9.78	6.69	14.28	11.66	8.89	14.42	9.52	6.61	13.72	1.03	11	45.2	86	84	75
1994	8.44	6.67	10.20	8.58	5.88	12.54	7.02	5.02	9.02	8.08	5.61	11.64	0.83	3	42.3	88	86	73
1995	9.54	7.81	11.28	7.59	5.20	11.09	8.20	6.43	9.96	7.30	5.06	10.52	0.86	3	40.8	126	91	72
1996	4.52	3.66	5.37	6.07	4.15	8.87	6.35	4.74	7.96	6.26	4.34	9.02	1.41	10	51.2	97	83	56
1997	4.69	3.58	5.80	5.53	3.78	8.09	4.55	3.29	5.80	5.33	3.69	7.70	0.97	18	41.5	118	88	65
1998	4.41	3.59	5.23	5.42	3.68	7.97	4.27	3.30	5.25	4.87	3.36	7.07	0.97	12	44.5	97	101	72
1999	5.68	3.55	7.80	5.81	3.88	8.71	3.44	2.48	4.39	4.72	3.19	6.97	0.61	11	36.3	92	104	72
2000	7.57	5.95	9.19	6.30	3.95	10.06	6.72	5.25	8.19	5.26	3.35	8.25	0.89	5	43.8	110	85	62

Table B16. Summary of results from alternative ADAPT calibrations.

run#	1	2	3	4	5	6	7
CAA data	Survey only	With SS	With disc	With SS	With SS	With SS (8+)	With SS
Tuning	2-7	2-7	2-7	2-7	2-6	2-5, 6+	2-7
Estimation	2-7	2-7	2-7	2-6	2-6	2-6	2-7
Ages for est. of Z on oldest age	4-8	4-8	4-8	4-8	4-8	4-7	5-8
Years	85-00	85-00	85-00	85-00	85-00	85-00	
Age PR set to one	4	4	4	4	4	4	5
results							
MSR	0.549	0.542	0.604	0.556	0.447	0.505	0.514
N2	2095	2106	3159	2080	2114	2074	2115
N3	4899	4924	6315	4864	4942	4848	4943
N4	1433	1450	1527	1433	1457	1427	1455
N5	901	986	897	926	944	1015	1061
N6	206	195	204	60	91	32	257
N7	21	32	31	-	-	-	34
CV(N2)	0.77	0.76	0.81	0.77	0.69	0.74	0.74
CV(N3)	0.44	0.44	0.50	0.45	0.40	0.43	0.43
CV(N4)	0.35	0.35	0.47	0.35	0.32	0.34	0.34
CV(N5)	0.37	0.35	0.44	0.36	0.32	0.34	0.34
CV(N6)	0.50	0.51	0.58	0.52	0.50	0.86	0.45
CV(N7)	0.70	0.69	0.74	-	-	-	0.67
F00	0.91	0.83	0.84	0.82	0.67	1.08	1.07
SSB00	6016	6412	5627	6255	6972	5748	6220

Table B16. Continued. (Summary of results from alternative ADAPT calibrations.)

Run #	8	9	10	11	12	13	14	15
CAA	9+	9+ with Disc.	7+	9+	9+ with 4X	9+ with 4X	9+ with disc.	9+ with disc.
Tuning	NEFSC2-7 Shrimp1-5	NEFSC2-7 Shrimp 1-5	NEFSC2-6 Shrimp 1-5	NEFSC2-5 Shrimp 1-5	NEFSC2-5 Shrimp 1-5	NEFSC2-7 Shrimp 1-5	NEFSC2-5 Shrimp1-5	NEFSC2-5 Shrimp1-5
Estimation	2-7	2-7	2-6	2-5	2-5	2-7	2-5	2-5
Ages for Est. of Z on oldest age	5-8	5-8	4-6	4-6	4-6	5-8	4-6	4-6
Years	85-00	89-00	85-00	85-00	85-00	85-00	89-00	85-00
Age PR set to one	5	5	4	4	4	4	4	
MSR	0.502	0.587	0.506	0.398	0.400	0.517	0.464	0.448
CV2	0.53	0.58	0.53	0.47	0.48	0.54	0.51	0.50
CV3	0.34	0.39	0.34	0.30	0.30	0.34	0.35	0.34
CV4	0.27	0.40	0.27	0.24	0.24	0.27	0.36	0.35
CV5	0.28	0.35	0.28	0.21	0.21	0.28	0.28	0.28
CV6	0.34	0.41	0.42	-	-	0.33	-	-
CV7	0.63	0.69	-	-	-	0.64	-	-
N2	6316	11135	6510	6659	10474	9882	11624	10554
N3	6601	9773	6842	6995	11071	10413	10388	9258
N4	969	1164	1014	1034	1642	1537	1260	1119
N5	952	1009	921	470	769	1459	530	412
N6	342	353	127	-	-	574	-	-
N7	36	46	-	-	-	45	-	-
F00	0.99	0.89	0.56	0.35	0.31	0.74	0.32	0.40
SSB00	6315	6378	8003	10306	16416	10416	10697	8884

Table B17. Commercial catch of white hake by size group.

Year	> 60 cm Landings	Discards	Total	<= 60 cm Landings	Discards	Total
1964	2284	0	2284	761	664	1425
1965	1963	0	1963	654	408	1062
1966	1173	0	1173	391	298	689
1967	857	0	857	286	288	574
1968	971	0	971	324	325	649
1969	1037	0	1037	346	370	716
1970	1600	0	1600	533	582	1115
1971	2173	0	2173	724	760	1484
1972	2359	0	2359	786	678	1464
1973	2551	0	2551	850	767	1617
1974	3004	0	3004	1001	731	1732
1975	2864	0	2864	954	536	1490
1976	3224	0	3224	1075	634	1709
1977	4113	0	4113	1371	914	2285
1978	3790	0	3790	1263	862	2125
1979	3224	0	3224	1075	813	1888
1980	3790	0	3790	1263	1049	2312
1981	4817	0	4817	1606	1372	2978
1982	5209	0	5209	1736	1525	3261
1983	5414	0	5414	1805	1923	3728
1984	5828	0	5828	1943	2037	3980
1985	6306	0	6306	1987	2176	4163
1986	6405	0	6405	654	1845	2499
1987	5025	0	5025	1353	1895	3248
1988	3295	0	3295	2041	1444	3485
1989	3944	0	3944	1186	2050	3236
1990	3156	0	3156	2330	4297	6627
1991	3824	0	3824	2347	1350	3697
1992	6147	0	6147	3434	715	4149
1993	5576	0	5576	3583	603	4186
1994	3985	55	4040	1706	177	1883
1995	2185	2	2187	2625	133	2758
1996	2850	0	2850	806	517	1323
1997	2248	75	2323	270	147	417
1998	2421	78	2499	173	160	333
1999	2530	565	3095	269	1509	1778
2000	2999	17	3016	215	263	478

Table B18. NEFSC autumn and spring survey indices by size group.

Year	Autumn > 60	Autumn <= 60	Spring > 60	Spring <= 60
1964	3.25	0.89		
1965	4.60	2.26		
1966	4.00	3.67		
1967	1.77	1.85		
1968	2.20	2.34	0.98	0.76
1969	8.38	4.71	3.58	1.52
1970	7.76	5.07	9.12	2.74
1971	8.00	4.10	3.62	1.52
1972	7.04	6.05	8.95	3.71
1973	8.22	5.23	7.01	5.21
1974	8.19	2.80	10.34	3.65
1975	4.46	2.77	7.48	3.74
1976	6.83	3.73	12.90	4.10
1977	9.07	4.67	7.97	3.04
1978	8.46	4.08	4.97	1.17
1979	6.97	3.34	2.83	2.14
1980	11.60	5.06	8.73	5.23
1981	8.44	3.72	13.47	6.45
1982			6.15	2.76
1983	6.06	4.73	1.54	1.58
1984	5.05	3.18	2.68	1.49
1985	5.49	4.24	3.06	2.32
1986	4.38	7.18	2.29	3.32
1987	4.56	5.06	2.56	3.88
1988	5.41	4.48	1.90	1.80
1989	3.84	5.39	1.80	1.42
1990	3.79	6.79	12.14	6.22
1991	4.83	7.37	2.76	3.38
1992	4.14	7.10	2.30	4.81
1993	4.90	6.76	2.68	4.16
1994	2.46	4.56	1.23	1.94
1995	2.96	5.23	1.96	2.06
1996	3.34	3.01	1.77	1.30
1997	2.60	1.95	0.14	0.75
1998	1.64	2.64	0.26	0.84
1999	1.26	2.17	1.43	1.53
2000	2.91	3.81	1.08	2.26

Table B19. Exploitation ratios (catch/autumn survey).

Year	< 60	<= 60	Total
1964	0.70	1.60	0.90
1965	0.43	0.47	0.44
1966	0.29	0.19	0.24
1967	0.48	0.31	0.39
1968	0.44	0.28	0.36
1969	0.12	0.15	0.13
1970	0.21	0.22	0.21
1971	0.27	0.36	0.30
1972	0.33	0.24	0.29
1973	0.31	0.31	0.31
1974	0.37	0.62	0.43
1975	0.64	0.54	0.60
1976	0.47	0.46	0.47
1977	0.45	0.49	0.47
1978	0.45	0.52	0.47
1979	0.46	0.57	0.50
1980	0.33	0.46	0.37
1981	0.57	0.80	0.64
1982			
1983	0.89	0.79	0.85
1984	1.15	1.25	1.19
1985	1.15	0.98	1.08
1986	1.46	0.35	0.77
1987	1.10	0.64	0.86
1988	0.61	0.78	0.68
1989	1.03	0.60	0.78
1990	0.83	0.98	0.92
1991	0.79	0.50	0.62
1992	1.48	0.58	0.92
1993	1.14	0.62	0.84
1994	1.64	0.41	0.84
1995	0.74	0.53	0.60
1996	0.85	0.44	0.66
1997	0.89	0.21	0.60
1998	1.53	0.13	0.66
1999	2.45	0.82	1.42
2000	1.04	0.13	0.52

Table B20. White Hake -- ASPIC 3.6x -- 60+ Biomass

```
09 Jul 2001 at 14:51.12

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.77)                                  BOT Mode

CONTROL PARAMETERS USED (FROM INPUT FILE)
------------------------------------------------------------------------------------------------------------------------
Number of years analyzed:                        37           Number of bootstrap trials:                        500
Number of data series:                            2           Lower bound on MSY:                          1.000E+00
Objective function computed:              in effort           Upper bound on MSY:                          5.000E+02
Relative conv. criterion (simplex):       1.000E-08           Lower bound on r:                            1.000E-01
Relative conv. criterion (restart):       3.000E-08           Upper bound on r:                            1.000E+01
Relative conv. criterion (effort):        1.000E-04           Random number seed:                            1964285
Maximum F allowed in fitting:                 5.000           Monte Carlo search trials:                       50000


PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS)                                                       code  0
------------------------------------------------------------------------------------------------------------------------
Normal convergence.


CORRELATION AMONG INPUT SERIES EXPRESSED AS CPUE (NUMBER OF PAIRWISE OBSERVATIONS BELOW)
------------------------------------------------------------------------------------------------------------------------
                                       |
 1  Fall Survey                        |   1.000
                                       |      36
                                       |
 2                                     |   0.606   1.000
                                       |      32      33
                                       --------------------------------------------------
                                               1       2


GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS
------------------------------------------------------------------------------------------------------------------------
                                                    Weighted              Weighted      Current    Suggested    R-squared
Loss component number and title                          SSE    N              MSE       weight       weight      in CPUE

Loss(-1)  SSE in yield                             0.000E+00
Loss( 0)  Penalty for B1R > 2                      0.000E+00    1              N/A    1.000E+00          N/A
Loss( 1)  Fall Survey                              4.387E+00   36        1.290E-01    1.000E+00    1.575E+00        0.620
Loss( 2)                                           1.689E+01   33        5.450E-01    1.000E+00    3.729E-01        0.294
TOTAL OBJECTIVE FUNCTION:                     2.12811511E+01

Number of restarts required for convergence:               7
Est. B-ratio coverage index (0 worst, 2 best):        1.2499              < These two measures are defined in Prager
Est. B-ratio nearness index (0 worst, 1 best):        1.0000              <     et al. (1996), Trans. A.F.S. 125:729

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate     Starting guess    Estimated   User guess

B1R       Starting biomass ratio, year 1964        3.465E-01          5.000E-01            1            1
MSY       Maximum sustainable yield                4.234E+00          7.700E+00            1            1
r         Intrinsic rate of increase               5.761E-01          7.000E-01            1            1
......... Catchability coefficients by fishery:
q( 1)     Fall Survey                              4.090E-01          6.000E-01            1            1
q( 2)                                              2.414E-01          4.000E-01            1            1

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate            Formula        Related quantity

MSY       Maximum sustainable yield                4.234E+00               Kr/4
K         Maximum stock biomass                    2.940E+01
Bmsy      Stock biomass at MSY                     1.470E+01                K/2
Fmsy      Fishing mortality at MSY                 2.880E-01                r/2

F(0.1)    Management benchmark                     2.592E-01          0.9*Fmsy
Y(0.1)    Equilibrium yield at F(0.1)              4.192E+00           0.99*MSY

B-ratio   Ratio of B(2001) to Bmsy                 2.053E-01
F-ratio   Ratio of F(2000) to Fmsy                 2.924E+00
F01-mult  Ratio of F(0.1) to F(2000)               3.078E-01
Y-ratio   Proportion of MSY avail in 2001          3.685E-01          2*Br-Br^2    Ye(2001) = 1.560E+00

......... Fishing effort at MSY in units of each fishery:
fmsy( 1)  Fall Survey                              7.043E-01          r/2q( 1)      f(0.1) = 6.339E-01
```

Table B20. Continued (White Hake -- ASPIC 3.6x -- 60+ Biomass)

ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)

Obs	Year or ID	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to Fmsy	Ratio of biomass to Bmsy
1	1964	0.441	5.094E+00	5.183E+00	2.284E+00	2.284E+00	2.459E+00	1.530E+00	3.465E-01
2	1965	0.351	5.269E+00	5.592E+00	1.963E+00	1.963E+00	2.608E+00	1.219E+00	3.585E-01
3	1966	0.172	5.915E+00	6.812E+00	1.172E+00	1.172E+00	3.010E+00	5.974E-01	4.024E-01
4	1967	0.094	7.752E+00	9.099E+00	8.565E-01	8.565E-01	3.607E+00	3.268E-01	5.273E-01
5	1968	0.081	1.050E+01	1.205E+01	9.712E-01	9.712E-01	4.081E+00	2.798E-01	7.145E-01
6	1969	0.068	1.361E+01	1.522E+01	1.037E+00	1.037E+00	4.212E+00	2.366E-01	9.260E-01
7	1970	0.089	1.679E+01	1.803E+01	1.600E+00	1.600E+00	4.007E+00	3.080E-01	1.142E+00
8	1971	0.109	1.919E+01	1.999E+01	2.173E+00	2.173E+00	3.682E+00	3.774E-01	1.306E+00
9	1972	0.111	2.070E+01	2.125E+01	2.359E+00	2.359E+00	3.391E+00	3.854E-01	1.408E+00
10	1973	0.116	2.174E+01	2.207E+01	2.551E+00	2.551E+00	3.170E+00	4.013E-01	1.479E+00
11	1974	0.134	2.235E+01	2.239E+01	3.004E+00	3.004E+00	3.074E+00	4.657E-01	1.521E+00
12	1975	0.127	2.243E+01	2.252E+01	2.864E+00	2.864E+00	3.036E+00	4.415E-01	1.526E+00
13	1976	0.143	2.260E+01	2.250E+01	3.224E+00	3.224E+00	3.042E+00	4.975E-01	1.537E+00
14	1977	0.188	2.242E+01	2.193E+01	4.113E+00	4.113E+00	3.209E+00	6.512E-01	1.525E+00
15	1978	0.178	2.151E+01	2.129E+01	3.790E+00	3.790E+00	3.382E+00	6.179E-01	1.463E+00
16	1979	0.152	2.110E+01	2.120E+01	3.224E+00	3.224E+00	3.406E+00	5.280E-01	1.436E+00
17	1980	0.180	2.128E+01	2.109E+01	3.790E+00	3.790E+00	3.433E+00	6.238E-01	1.448E+00
18	1981	0.237	2.093E+01	2.028E+01	4.817E+00	4.817E+00	3.621E+00	8.245E-01	1.424E+00
19	1982	0.274	1.973E+01	1.901E+01	5.209E+00	5.209E+00	3.867E+00	9.513E-01	1.342E+00
20	1983	0.306	1.839E+01	1.766E+01	5.413E+00	5.413E+00	4.059E+00	1.064E+00	1.251E+00
21	1984	0.361	1.703E+01	1.616E+01	5.827E+00	5.827E+00	4.188E+00	1.252E+00	1.159E+00
22	1985	0.442	1.539E+01	1.428E+01	6.306E+00	6.306E+00	4.224E+00	1.533E+00	1.047E+00
23	1986	0.531	1.331E+01	1.207E+01	6.405E+00	6.405E+00	4.090E+00	1.842E+00	9.056E-01
24	1987	0.484	1.100E+01	1.039E+01	5.025E+00	5.025E+00	3.868E+00	1.679E+00	7.482E-01
25	1988	0.326	9.841E+00	1.011E+01	3.295E+00	3.295E+00	3.821E+00	1.131E+00	6.695E-01
26	1989	0.382	1.037E+01	1.032E+01	3.944E+00	3.944E+00	3.859E+00	1.326E+00	7.053E-01
27	1990	0.296	1.028E+01	1.067E+01	3.156E+00	3.156E+00	3.915E+00	1.027E+00	6.995E-01
28	1991	0.344	1.104E+01	1.112E+01	3.824E+00	3.824E+00	3.984E+00	1.193E+00	7.512E-01
29	1992	0.619	1.120E+01	9.933E+00	6.147E+00	6.147E+00	3.780E+00	2.149E+00	7.620E-01
30	1993	0.736	8.834E+00	7.572E+00	5.576E+00	5.576E+00	3.230E+00	2.556E+00	6.010E-01
31	1994	0.701	6.489E+00	5.761E+00	4.041E+00	4.041E+00	2.665E+00	2.435E+00	4.414E-01
32	1995	0.416	5.113E+00	5.266E+00	2.188E+00	2.188E+00	2.490E+00	1.443E+00	3.479E-01
33	1996	0.546	5.416E+00	5.222E+00	2.850E+00	2.850E+00	2.474E+00	1.895E+00	3.684E-01
34	1997	0.456	5.039E+00	5.091E+00	2.322E+00	2.322E+00	2.425E+00	1.584E+00	3.428E-01
35	1998	0.489	5.141E+00	5.107E+00	2.498E+00	2.498E+00	2.431E+00	1.699E+00	3.497E-01
36	1999	0.669	5.074E+00	4.630E+00	3.095E+00	3.095E+00	2.246E+00	2.321E+00	3.452E-01
37	2000	0.842	4.224E+00	3.581E+00	3.015E+00	3.015E+00	1.809E+00	2.924E+00	2.874E-01
38	2001		3.018E+00						2.053E-01

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) **Fall Survey**

Data type CC: CPUE-catch series Series weight: 1.000

Obs	Year	Observed CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale	Resid in yield
1	1964	3.253E+00	2.119E+00	0.4407	2.284E+00	2.284E+00	-0.42842	0.000E+00
2	1965	4.602E+00	2.287E+00	0.3510	1.963E+00	1.963E+00	-0.69936	0.000E+00
3	1966	4.002E+00	2.786E+00	0.1721	1.172E+00	1.172E+00	-0.36217	0.000E+00
4	1967	1.786E+00	3.721E+00	0.0941	8.565E-01	8.565E-01	0.73388	0.000E+00
5	1968	2.201E+00	4.928E+00	0.0806	9.712E-01	9.712E-01	0.80588	0.000E+00
6	1969	8.382E+00	6.225E+00	0.0681	1.037E+00	1.037E+00	-0.29745	0.000E+00
7	1970	7.757E+00	7.375E+00	0.0887	1.600E+00	1.600E+00	-0.05044	0.000E+00
8	1971	7.999E+00	8.174E+00	0.1087	2.173E+00	2.173E+00	0.02173	0.000E+00
9	1972	7.042E+00	8.691E+00	0.1110	2.359E+00	2.359E+00	0.21036	0.000E+00
10	1973	8.223E+00	9.024E+00	0.1156	2.551E+00	2.551E+00	0.09294	0.000E+00
11	1974	8.195E+00	9.158E+00	0.1341	3.004E+00	3.004E+00	0.11106	0.000E+00
12	1975	4.459E+00	9.209E+00	0.1272	2.864E+00	2.864E+00	0.72524	0.000E+00
13	1976	6.830E+00	9.201E+00	0.1433	3.224E+00	3.224E+00	0.29801	0.000E+00
14	1977	9.066E+00	8.967E+00	0.1876	4.113E+00	4.113E+00	-0.01098	0.000E+00
15	1978	8.462E+00	8.708E+00	0.1780	3.790E+00	3.790E+00	0.02857	0.000E+00
16	1979	6.972E+00	8.670E+00	0.1521	3.224E+00	3.224E+00	0.21789	0.000E+00
17	1980	1.160E+01	8.626E+00	0.1797	3.790E+00	3.790E+00	-0.29590	0.000E+00
18	1981	8.437E+00	8.295E+00	0.2375	4.817E+00	4.817E+00	-0.01694	0.000E+00
19	1982	*	7.774E+00	0.2740	5.209E+00	5.209E+00	0.00000	0.000E+00
20	1983	6.059E+00	7.224E+00	0.3065	5.413E+00	5.413E+00	0.17589	0.000E+00
21	1984	5.054E+00	6.608E+00	0.3607	5.827E+00	5.827E+00	0.26803	0.000E+00
22	1985	5.491E+00	5.840E+00	0.4416	6.306E+00	6.306E+00	0.06160	0.000E+00
23	1986	4.380E+00	4.937E+00	0.5305	6.405E+00	6.405E+00	0.11985	0.000E+00
24	1987	4.556E+00	4.249E+00	0.4837	5.025E+00	5.025E+00	-0.06976	0.000E+00
25	1988	5.405E+00	4.135E+00	0.3259	3.295E+00	3.295E+00	-0.26795	0.000E+00
26	1989	3.845E+00	4.222E+00	0.3820	3.944E+00	3.944E+00	0.09357	0.000E+00
27	1990	3.787E+00	4.364E+00	0.2957	3.156E+00	3.156E+00	0.14168	0.000E+00
28	1991	4.832E+00	4.549E+00	0.3437	3.824E+00	3.824E+00	-0.06033	0.000E+00
29	1992	4.145E+00	4.062E+00	0.6189	6.147E+00	6.147E+00	-0.02011	0.000E+00
30	1993	4.900E+00	3.097E+00	0.7363	5.576E+00	5.576E+00	-0.45897	0.000E+00
31	1994	2.462E+00	2.356E+00	0.7014	4.041E+00	4.041E+00	-0.04427	0.000E+00
32	1995	2.963E+00	2.153E+00	0.4155	2.188E+00	2.188E+00	-0.31907	0.000E+00
33	1996	3.335E+00	2.135E+00	0.5459	2.850E+00	2.850E+00	-0.44596	0.000E+00
34	1997	2.597E+00	2.082E+00	0.4562	2.322E+00	2.322E+00	-0.22126	0.000E+00
35	1998	1.636E+00	2.088E+00	0.4892	2.498E+00	2.498E+00	0.24436	0.000E+00
36	1999	1.263E+00	1.893E+00	0.6686	3.095E+00	3.095E+00	0.40475	0.000E+00
37	2000	2.909E+00	1.464E+00	0.8422	3.015E+00	3.015E+00	-0.68652	0.000E+00

* Asterisk indicates missing value(s).

Table B20. Continued (White Hake -- ASPIC 3.6x -- 60+ Biomass)

UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 1

```
                   -1       -0.75     -0.5      -0.25       0        0.25      0.5      0.75        1
                    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    ------------------------------------------------------------------------------------
1964    -0.4284                            =================|
1965    -0.6994                 ============================|
1966    -0.3622                               ==============|
1967     0.7339                                             |=============================
1968     0.8059                                             |================================
1969    -0.2975                                 ============|
1970    -0.0504                                           ==|
1971     0.0217                                             |=
1972     0.2104                                             |========
1973     0.0929                                             |====
1974     0.1111                                             |====
1975     0.7252                                             |=============================
1976     0.2980                                             |============
1977    -0.0110                                             |
1978     0.0286                                             |=
1979     0.2179                                             |=========
1980    -0.2959                                 ============|
1981    -0.0169                                            =|
1982     0.0000                                             |
1983     0.1759                                             |=======
1984     0.2680                                             |===========
1985     0.0616                                             |==
1986     0.1199                                             |=====
1987    -0.0698                                          ===|
1988    -0.2679                                  ===========|
1989     0.0936                                             |====
1990     0.1417                                             |======
1991    -0.0603                                           ==|
1992    -0.0201                                            =|
1993    -0.4590                           ==================|
1994    -0.0443                                           ==|
1995    -0.3191                                =============|
1996    -0.4460                           ==================|
1997    -0.2213                                    =========|
1998     0.2444                                             |==========
1999     0.4047                                             |================
2000    -0.6865                  ===========================|
                   ------------------------------------------------------------------------------------
```

RESULTS FOR DATA SERIES # 2 (NON-BOOTSTRAPPED)

Data type I2: End-of-year biomass index   Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Resid in index
1	1964	0.000E+00	0.000E+00	0.0	*	1.272E+00	0.00000	0.0
2	1965	0.000E+00	0.000E+00	0.0	*	1.428E+00	0.00000	0.0
3	1966	0.000E+00	0.000E+00	0.0	*	1.872E+00	0.00000	0.0
4	1967	1.000E+00	1.000E+00	0.0	9.829E-01	2.536E+00	-0.94778	-1.553E+00
5	1968	1.000E+00	1.000E+00	0.0	3.577E+00	3.287E+00	0.08455	2.900E-01
6	1969	1.000E+00	1.000E+00	0.0	9.124E+00	4.053E+00	0.81138	5.071E+00
7	1970	1.000E+00	1.000E+00	0.0	3.619E+00	4.634E+00	-0.24718	-1.015E+00
8	1971	1.000E+00	1.000E+00	0.0	8.951E+00	4.999E+00	0.58253	3.952E+00
9	1972	1.000E+00	1.000E+00	0.0	7.010E+00	5.248E+00	0.28951	1.762E+00
10	1973	1.000E+00	1.000E+00	0.0	1.034E+01	5.398E+00	0.64998	4.942E+00
11	1974	1.000E+00	1.000E+00	0.0	7.481E+00	5.415E+00	0.32328	2.066E+00
12	1975	1.000E+00	1.000E+00	0.0	1.290E+01	5.456E+00	0.86065	7.446E+00
13	1976	1.000E+00	1.000E+00	0.0	7.969E+00	5.412E+00	0.38692	2.557E+00
14	1977	1.000E+00	1.000E+00	0.0	4.969E+00	5.194E+00	-0.04430	-2.250E-01
15	1978	1.000E+00	1.000E+00	0.0	2.829E+00	5.095E+00	-0.58833	-2.266E+00
16	1979	1.000E+00	1.000E+00	0.0	8.728E+00	5.139E+00	0.52966	3.589E+00
17	1980	1.000E+00	1.000E+00	0.0	1.347E+01	5.053E+00	0.98079	8.421E+00
18	1981	1.000E+00	1.000E+00	0.0	6.152E+00	4.764E+00	0.25565	1.388E+00
19	1982	1.000E+00	1.000E+00	0.0	1.539E+00	4.440E+00	-1.05936	-2.901E+00
20	1983	1.000E+00	1.000E+00	0.0	2.676E+00	4.113E+00	-0.42969	-1.437E+00
21	1984	1.000E+00	1.000E+00	0.0	3.065E+00	3.717E+00	-0.19301	-6.524E-01
22	1985	1.000E+00	1.000E+00	0.0	2.286E+00	3.214E+00	-0.34075	-9.282E-01
23	1986	1.000E+00	1.000E+00	0.0	2.558E+00	2.656E+00	-0.03735	-9.734E-02
24	1987	1.000E+00	1.000E+00	0.0	1.897E+00	2.376E+00	-0.22502	-4.788E-01
25	1988	1.000E+00	1.000E+00	0.0	1.803E+00	2.503E+00	-0.32817	-7.003E-01
26	1989	1.000E+00	1.000E+00	0.0	1.214E+01	2.483E+00	1.58719	9.658E+00
27	1990	1.000E+00	1.000E+00	0.0	2.763E+00	2.666E+00	0.03585	9.731E-02
28	1991	1.000E+00	1.000E+00	0.0	2.305E+00	2.705E+00	-0.15995	-3.998E-01
29	1992	1.000E+00	1.000E+00	0.0	2.680E+00	2.133E+00	0.22827	5.470E-01
30	1993	1.000E+00	1.000E+00	0.0	1.229E+00	1.567E+00	-0.24244	-3.373E-01
31	1994	1.000E+00	1.000E+00	0.0	1.960E+00	1.235E+00	0.46196	7.249E-01
32	1995	1.000E+00	1.000E+00	0.0	1.773E+00	1.308E+00	0.30478	4.659E-01
33	1996	1.000E+00	1.000E+00	0.0	1.403E-01	1.217E+00	-2.15991	-1.076E+00
34	1997	1.000E+00	1.000E+00	0.0	2.556E-01	1.241E+00	-1.58014	-9.857E-01
35	1998	1.000E+00	1.000E+00	0.0	1.432E+00	1.225E+00	0.15628	2.072E-01
36	1999	1.000E+00	1.000E+00	0.0	1.077E+00	1.020E+00	0.05439	5.701E-02
37	2000	0.000E+00	0.000E+00	0.0	*	7.287E-01	0.00000	0.0

* Asterisk indicates missing value(s).

Table B20. Continued (White Hake -- ASPIC 3.6x -- 60+ Biomass)

```
UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 2
                   -4        -3        -2        -1         0         1         2         3         4
                    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    ------------------------------------------------------------------------------------
1964     0.0000                                             |
1965     0.0000                                             |
1966     0.0000                                             |
1967    -0.9478                                    =========|
1968     0.0845                                             |=
1969     0.8114                                             |========
1970    -0.2472                                           ==|
1971     0.5825                                             |======
1972     0.2895                                             |===
1973     0.6500                                             |======
1974     0.3233                                             |===
1975     0.8606                                             |=========
1976     0.3869                                             |====
1977    -0.0443                                             |
1978    -0.5883                                       ======|
1979     0.5297                                             |=====
1980     0.9808                                             |==========
1981     0.2557                                             |===
1982    -1.0594                                  ===========|
1983    -0.4297                                         ====|
1984    -0.1930                                           ==|
1985    -0.3407                                          ===|
1986    -0.0373                                             |
1987    -0.2250                                           ==|
1988    -0.3282                                          ===|
1989     1.5872                                             |================
1990     0.0358                                             |
1991    -0.1599                                           ==|
1992     0.2283                                             |==
1993    -0.2424                                           ==|
1994     0.4620                                             |=====
1995     0.3048                                             |===
1996    -2.1599                       ======================|
1997    -1.5801                             ================|
1998     0.1563                                             |==
1999     0.0544                                             |=
2000     0.0000                                             |
                   ------------------------------------------------------------------------------------
```

RESULTS OF BOOTSTRAPPED ANALYSIS

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
B1ratio	3.576E-01	3.465E-01	-3.10%	2.835E-01	5.272E-01	3.155E-01	4.329E-01	1.174E-01	0.328
K	2.957E+01	2.940E+01	-0.58%	2.107E+01	4.112E+01	2.441E+01	3.511E+01	1.070E+01	0.362
r	5.725E-01	5.761E-01	0.63%	3.785E-01	8.708E-01	4.633E-01	7.261E-01	2.627E-01	0.459
q(1)	3.964E-01	4.090E-01	3.17%	2.830E-01	5.768E-01	3.324E-01	4.850E-01	1.526E-01	0.385
q(2)	2.374E-01	2.414E-01	1.68%	1.694E-01	3.351E-01	1.995E-01	2.868E-01	8.726E-02	0.367
MSY	4.214E+00	4.234E+00	0.47%	3.952E+00	4.580E+00	4.067E+00	4.419E+00	3.521E-01	0.084
Ye(2001)	1.630E+00	1.560E+00	-4.28%	6.310E-01	3.099E+00	1.108E+00	2.286E+00	1.178E+00	0.723
Bmsy	1.479E+01	1.470E+01	-0.58%	1.054E+01	2.056E+01	1.221E+01	1.756E+01	5.350E+00	0.362
Fmsy	2.862E-01	2.880E-01	0.63%	1.893E-01	4.354E-01	2.317E-01	3.630E-01	1.314E-01	0.459
fmsy(1)	7.116E-01	7.043E-01	-1.02%	5.873E-01	8.466E-01	6.457E-01	7.719E-01	1.262E-01	0.177
fmsy(2)	1.196E+00	1.193E+00	-0.28%	9.763E-01	1.435E+00	1.077E+00	1.310E+00	2.327E-01	0.195
F(0.1)	2.576E-01	2.592E-01	0.56%	1.703E-01	3.919E-01	2.085E-01	3.267E-01	1.182E-01	0.459
Y(0.1)	4.172E+00	4.192E+00	0.46%	3.912E+00	4.534E+00	4.026E+00	4.375E+00	3.486E-01	0.084
B-ratio	2.188E-01	2.053E-01	-6.16%	7.623E-02	4.420E-01	1.375E-01	3.122E-01	1.747E-01	0.798
F-ratio	2.835E+00	2.924E+00	3.15%	1.493E+00	5.046E+00	2.031E+00	3.683E+00	1.652E+00	0.583
Y-ratio	3.901E-01	3.685E-01	-5.53%	1.466E-01	6.886E-01	2.562E-01	5.269E-01	2.708E-01	0.694
f0.1(1)	6.404E-01	6.339E-01	-0.92%	* * * * *	0.177				
f0.1(2)	1.077E+00	1.074E+00	-0.26%	* * * * *	0.195				
q2/q1	5.952E-01	5.904E-01	-0.81%	4.975E-01	7.189E-01	5.435E-01	6.586E-01	1.150E-01	0.193

NOTES ON BOOTSTRAPPED ESTIMATES:

- The bootstrapped results shown were computed from 500 trials.
- These results are conditional on the constraints placed upon MSY and r in the input file (ASPIC.INP).
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
- The bias corrections used here are based on medians. This is an accepted statistical procedure, but may estimate nonzero bias for unbiased, skewed estimators.

```
Trials replaced for lack of convergence:            5
Trials replaced for MSY out-of-bounds:              0
Trials replaced for r out-of-bounds:                1
Residual-adjustment factor:                    1.0383
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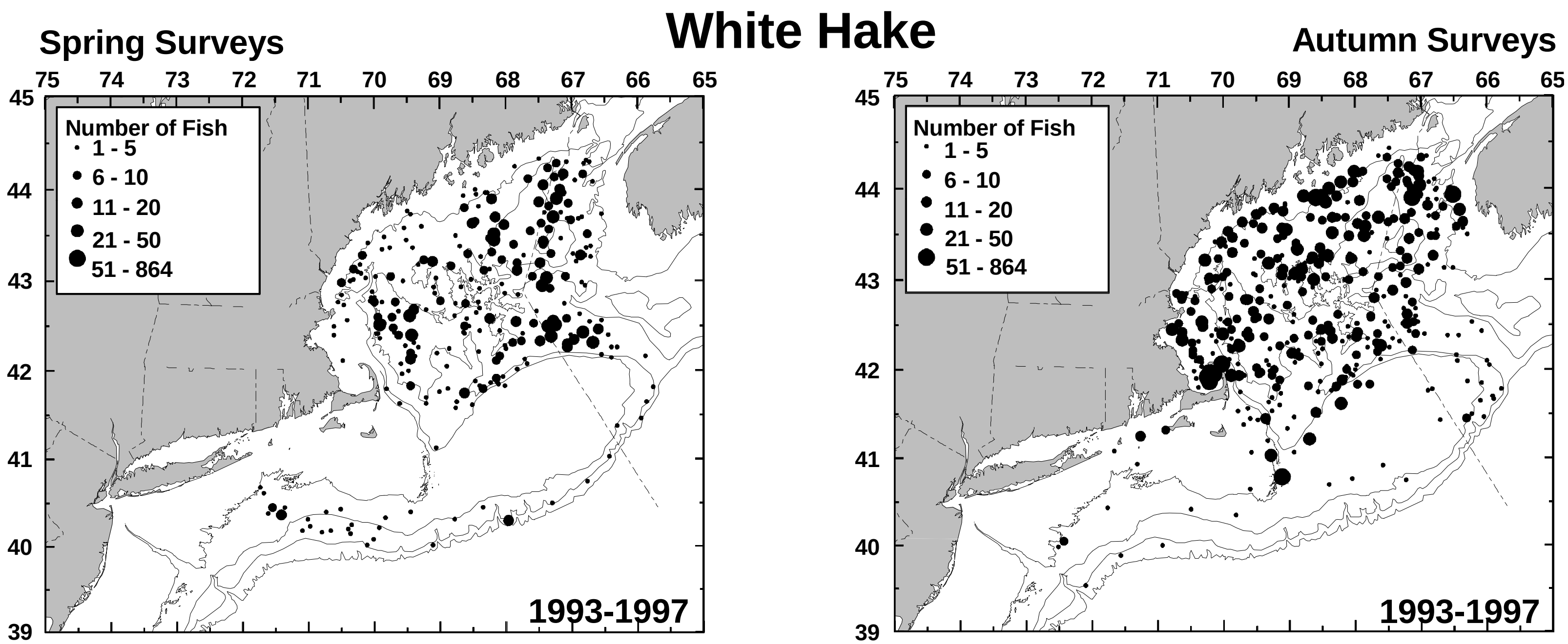


Figure B1. Distribution of white hake in the NEFSC spring and autumn surveys from 1993-1997.

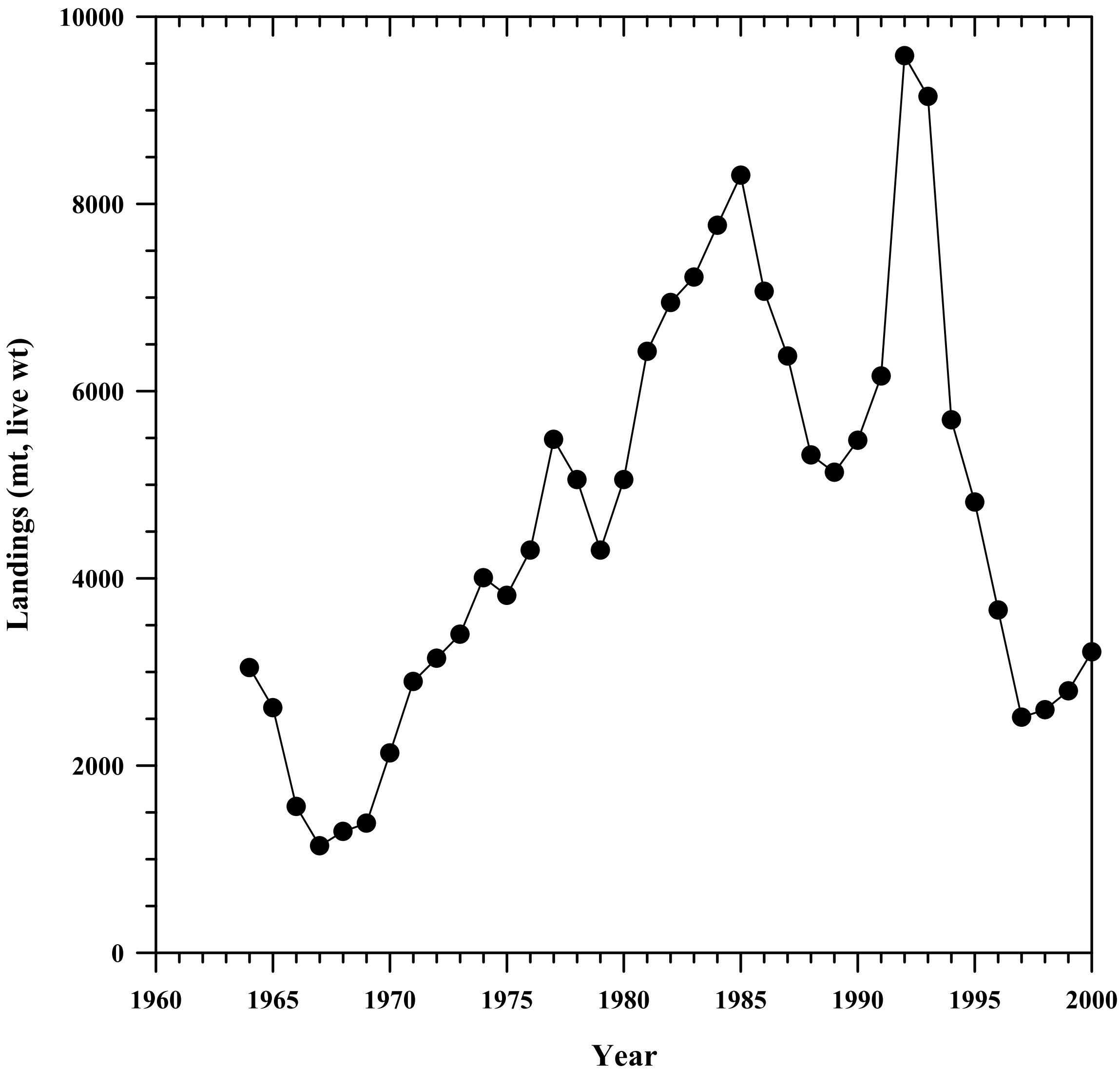


Figure B2. Total landings of white hake from the Gulf of Maine to Mid-Atlantic region, 1964-2000.

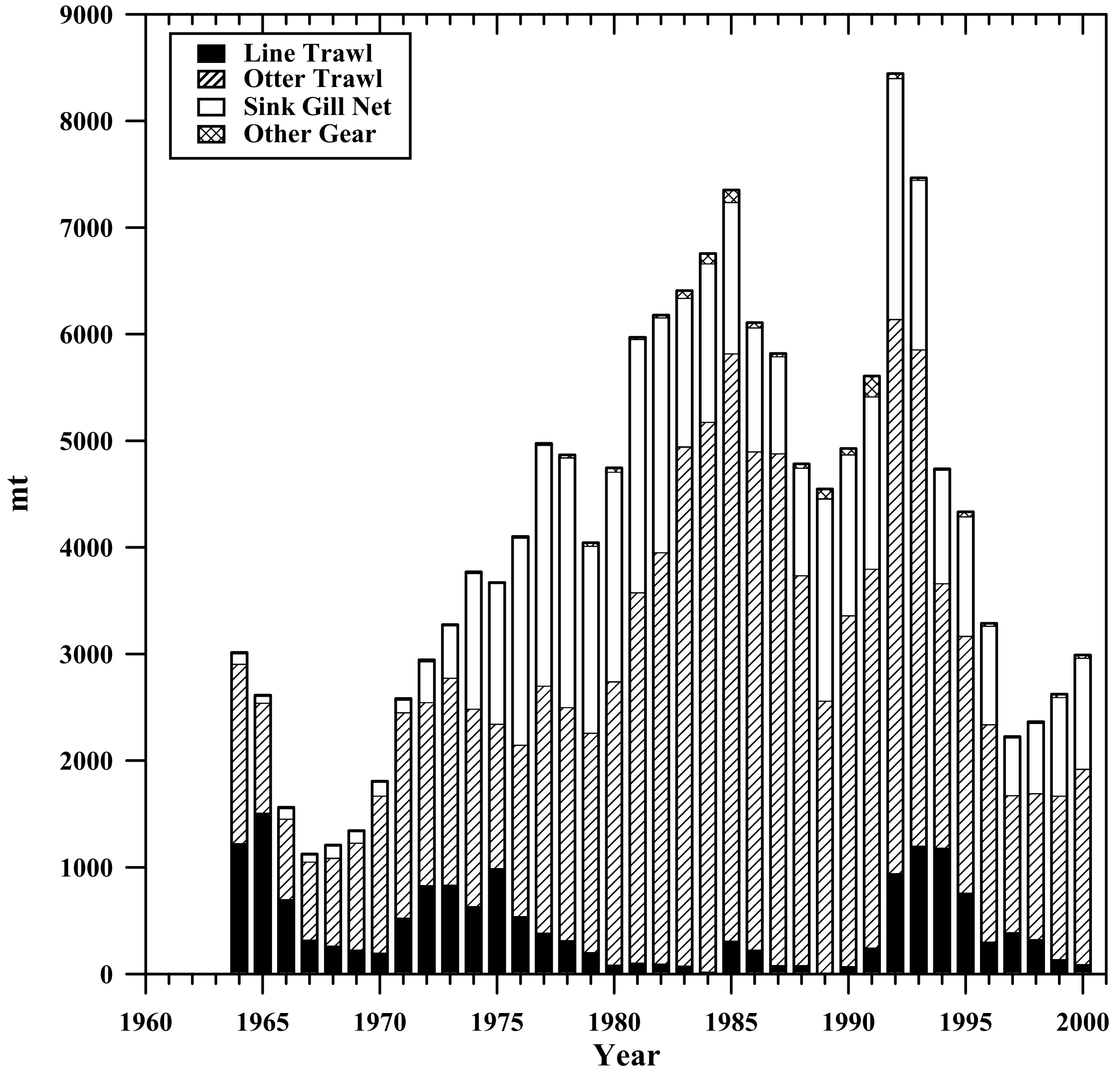


Figure B3. Total US landings of white hake (mt, live weight) by gear, 1964-2000.

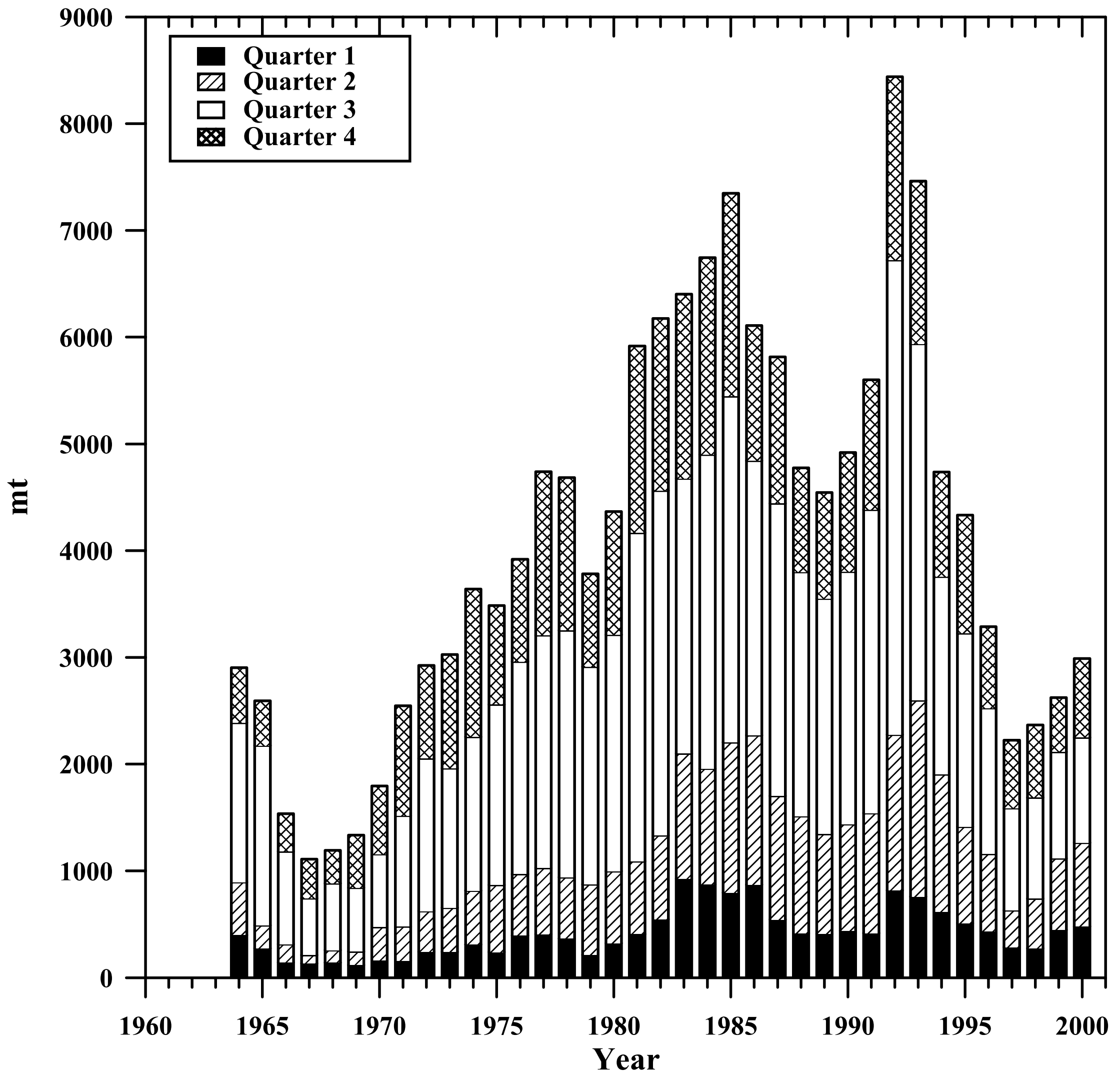


Figure B4. Total US landings of white hake (mt, live weight) by quarter, 1964-2000.

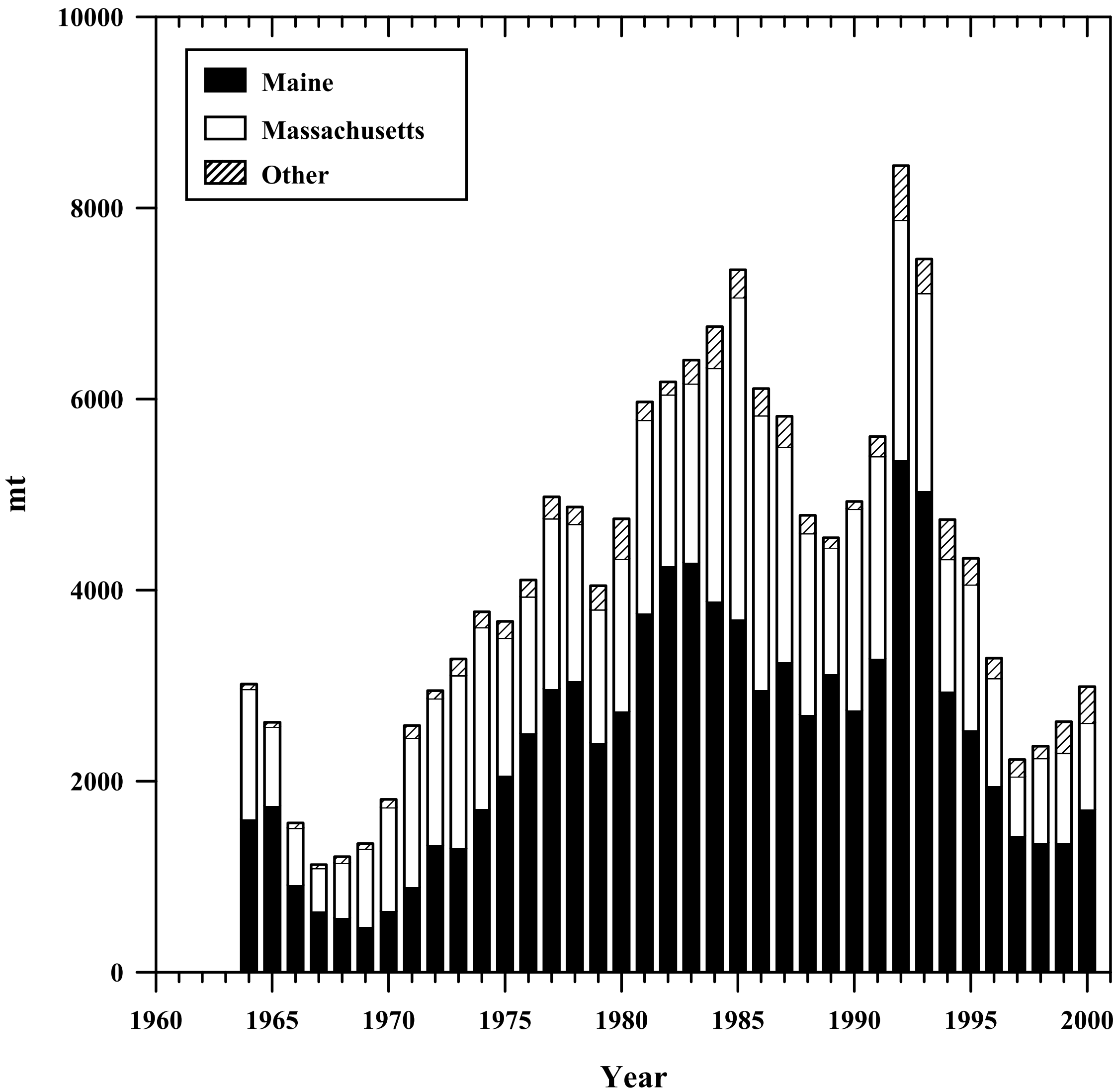


Figure B5. Commercial landings (mt, live weight) of white hake in Maine, Massachusetts, and other states.

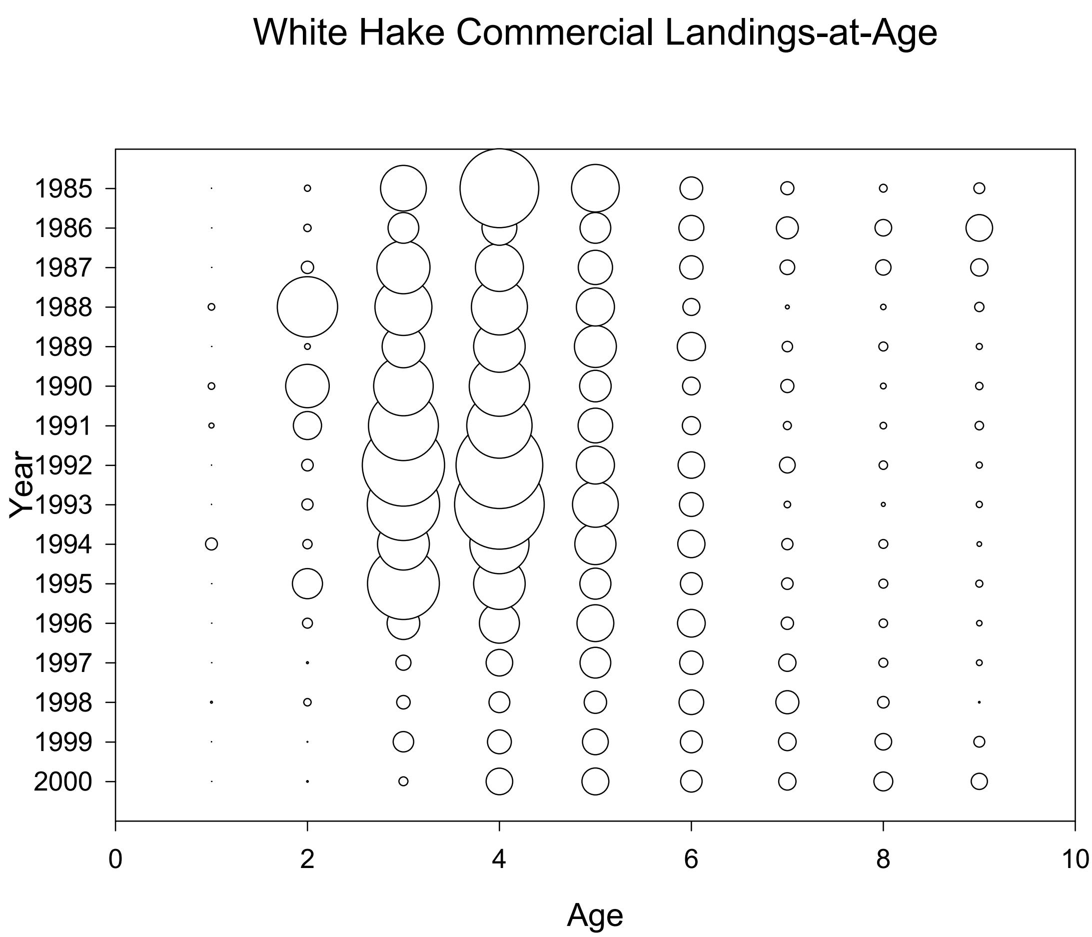


Figure B6. White hake commercial landings-at-age, 1985-2000.

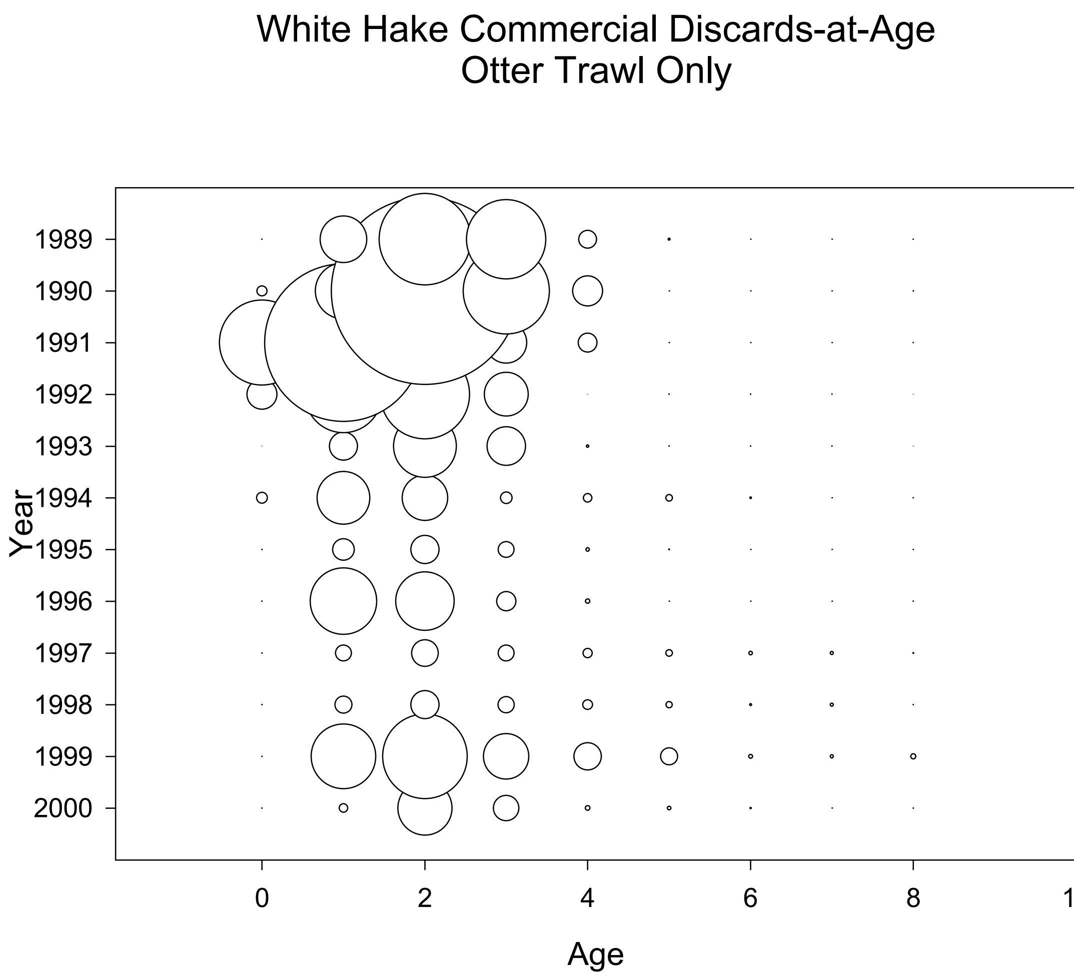


Figure B7. White hake commercial otter trawl discard-at-age, 1989-2000.

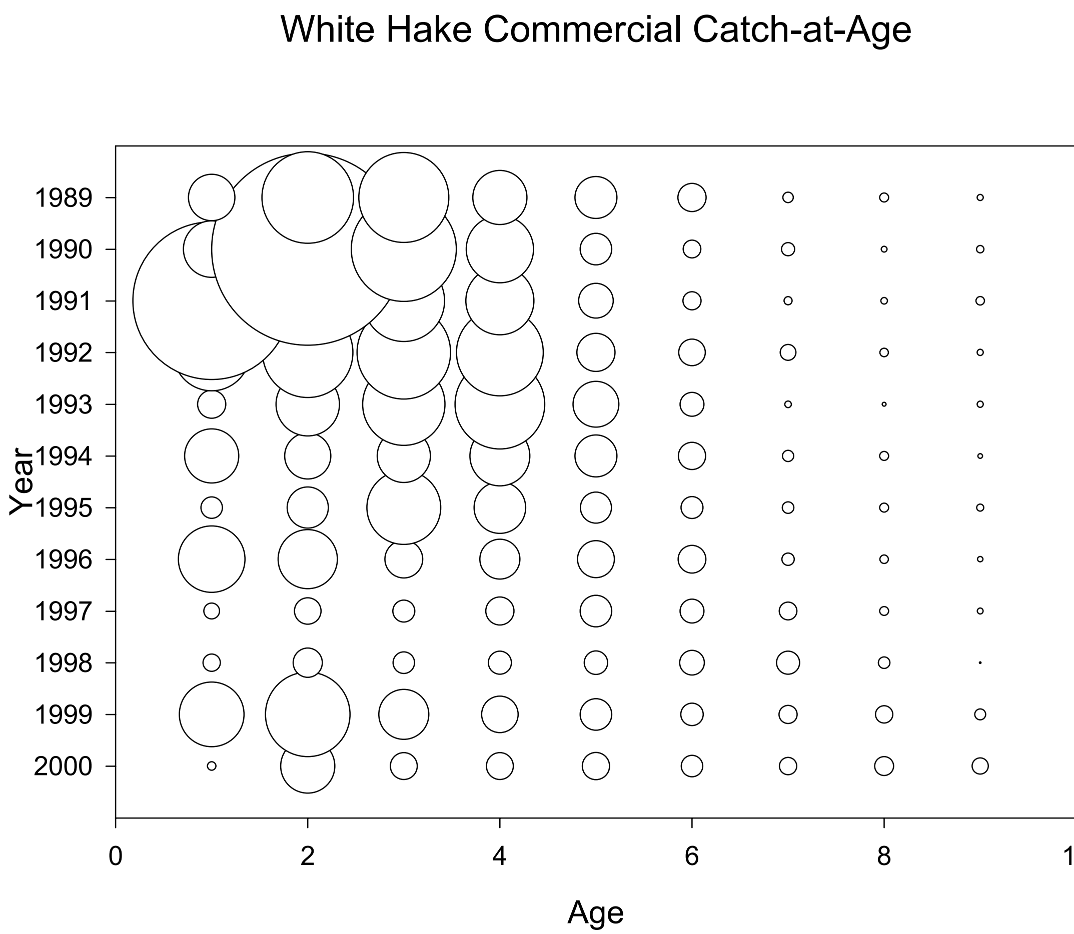
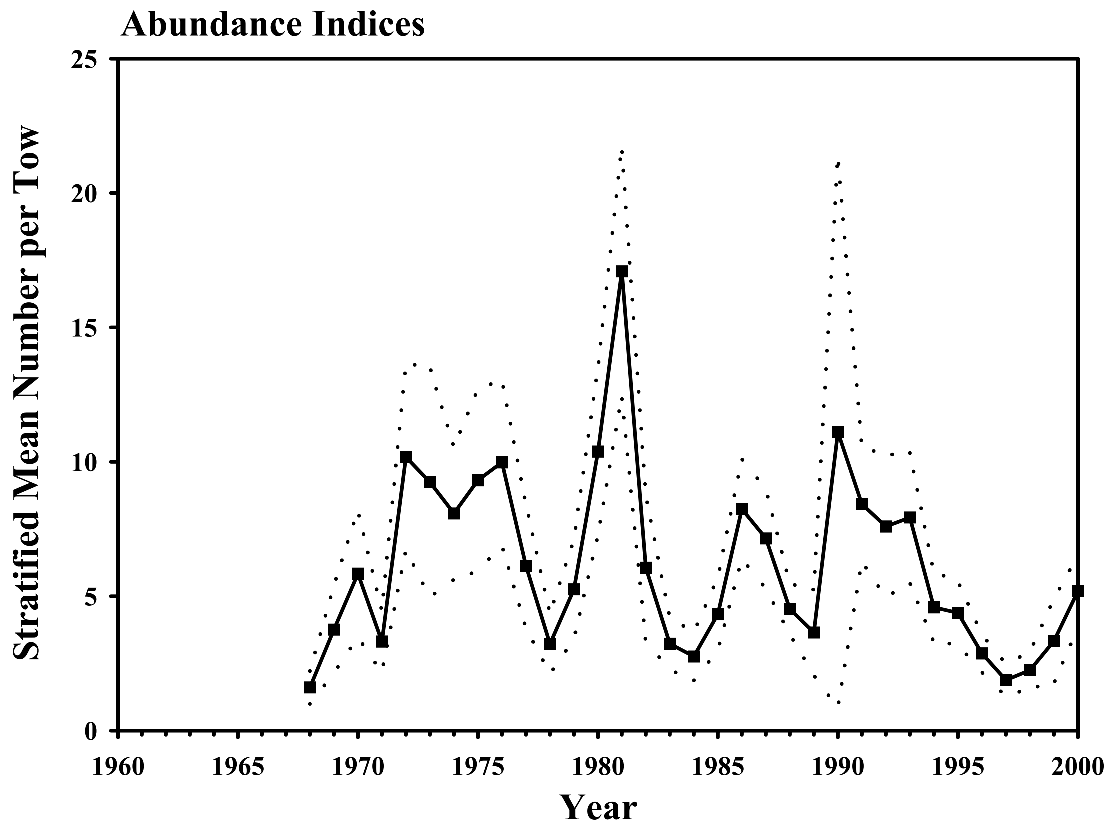


Figure B8. White hake catch-at-age, 1989-2000.



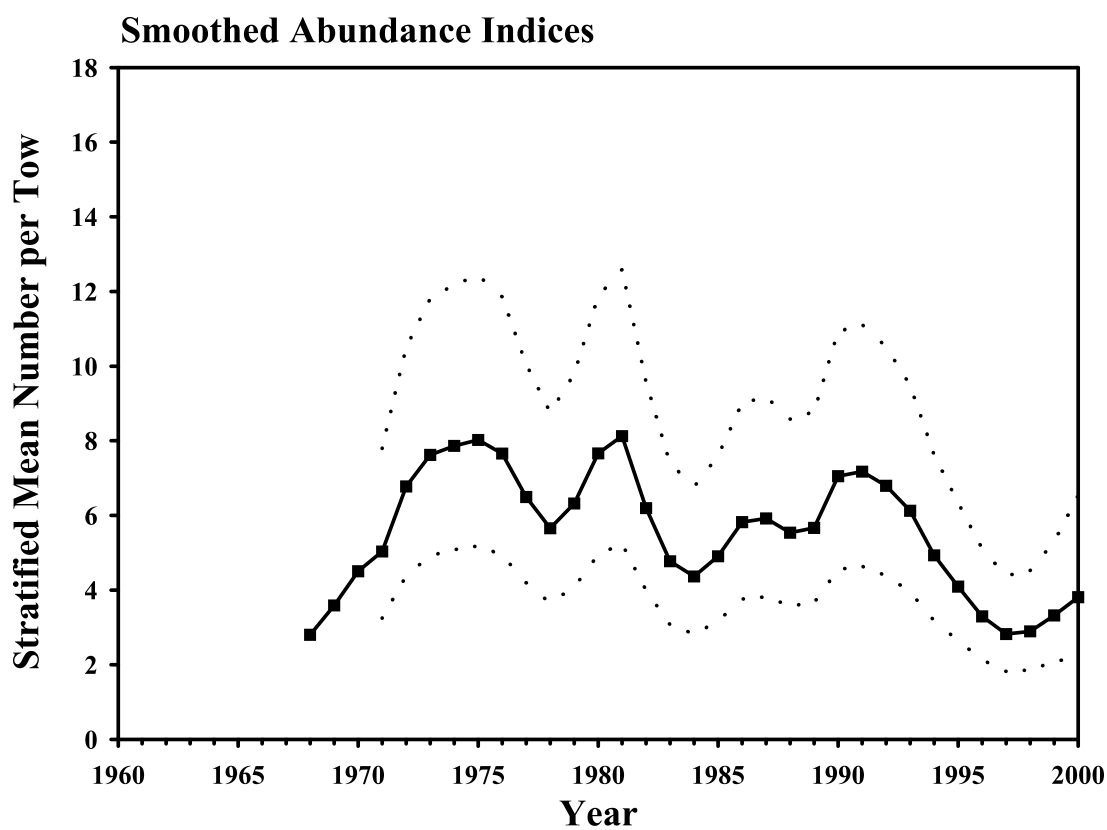


Figure B9. Abundance indices and smoothed indices from the NEFSC spring bottom trawl survey for the for the Gulf of Maine to Northern Georges Bank region from 1968-2000. The 95% confidence limits are shown by the dashed line.

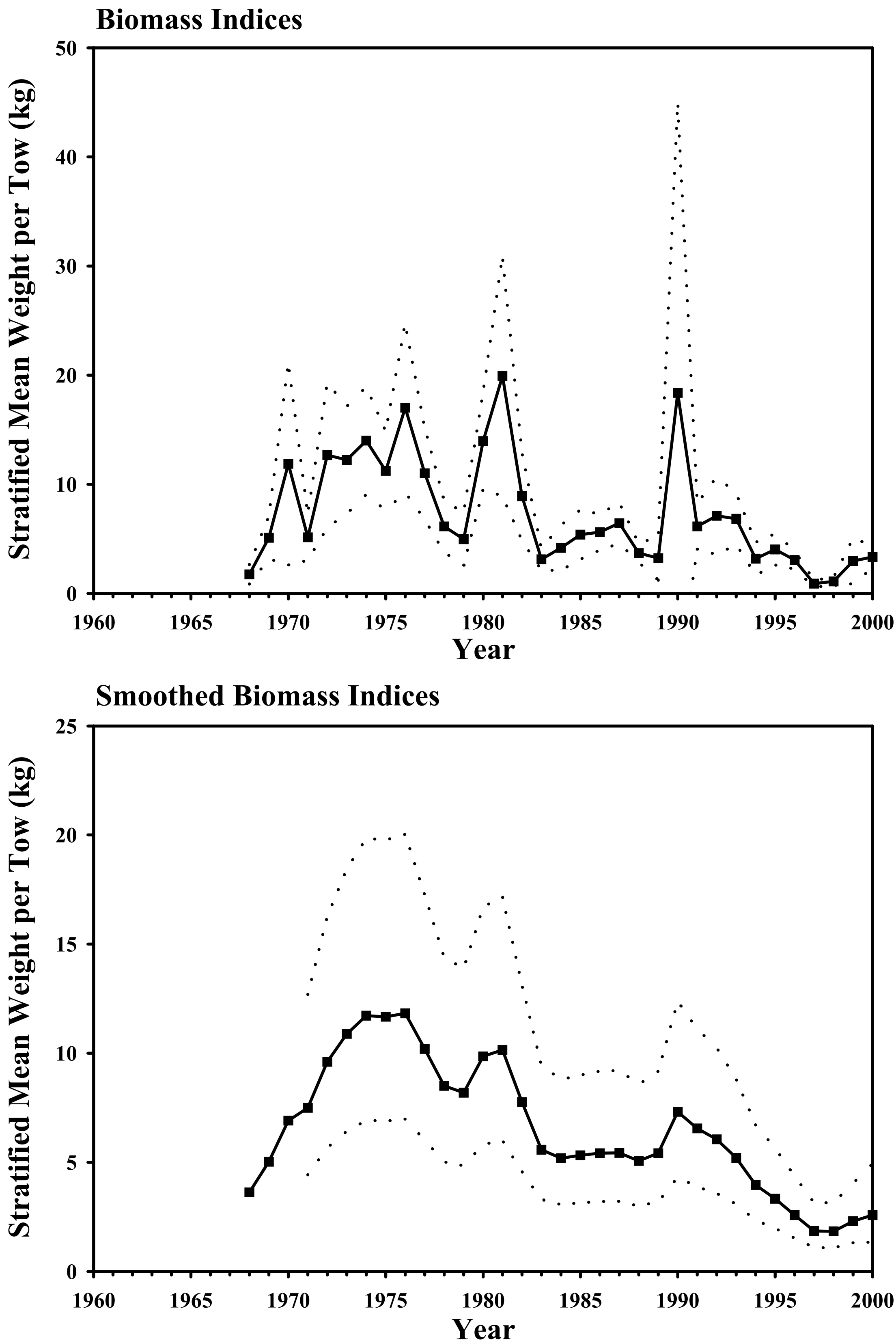
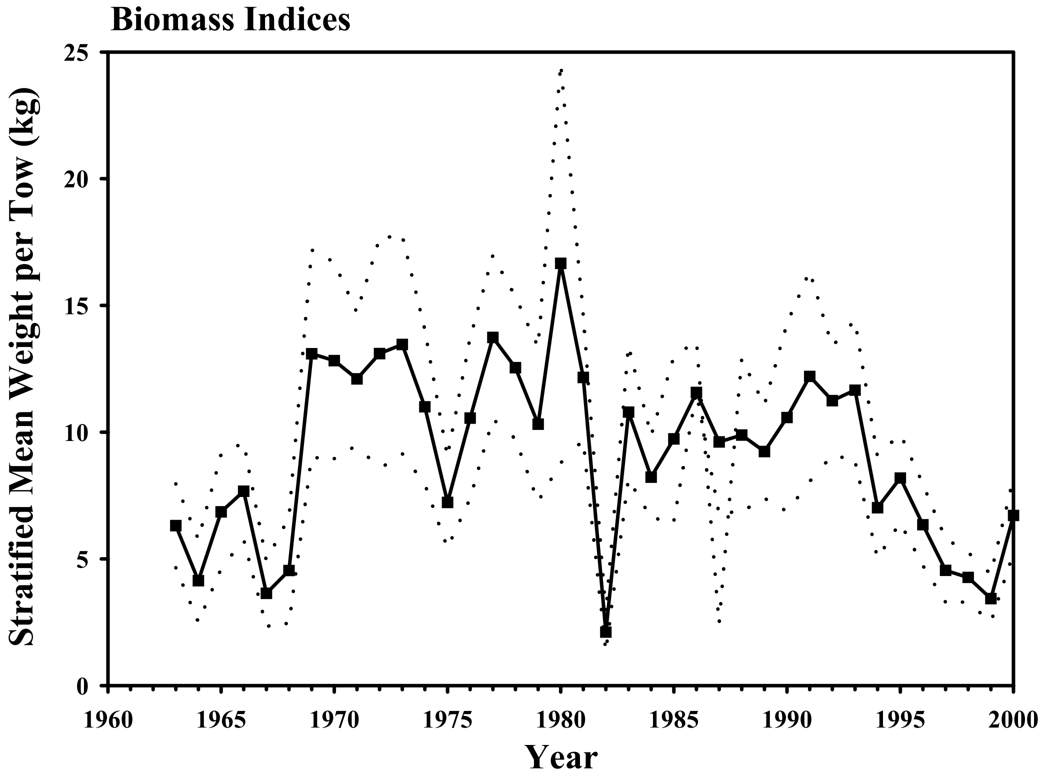


Figure B10. Biomass indices and smoothed indices from the NEFSC spring bottom trawl survey for the Gulf of Maine to Northern Georges Bank region from 1968-2000. The 95% confidence limits are shown by the dashed line.



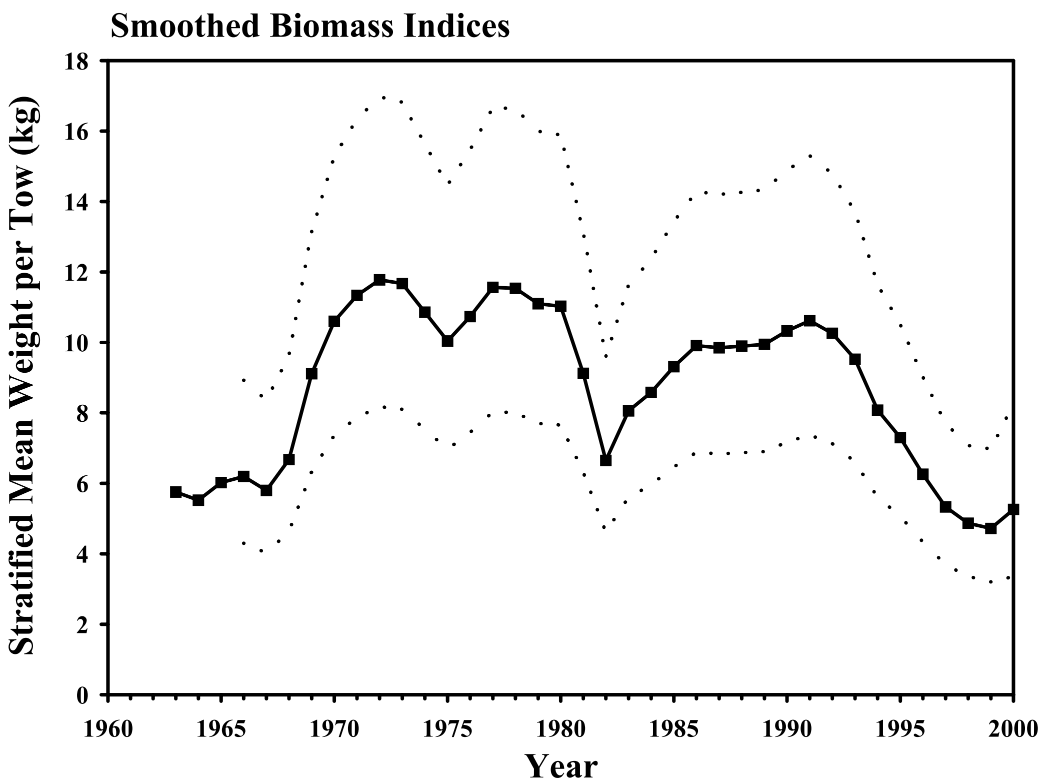


Figure B11. Biomass indices and smoothed indices from the NEFSC autumn bottom trawl survey for the Gulf of Maine to Northern Georges Bank region from 1963-2000. The 95% confidence limits are shown by the dashed line.

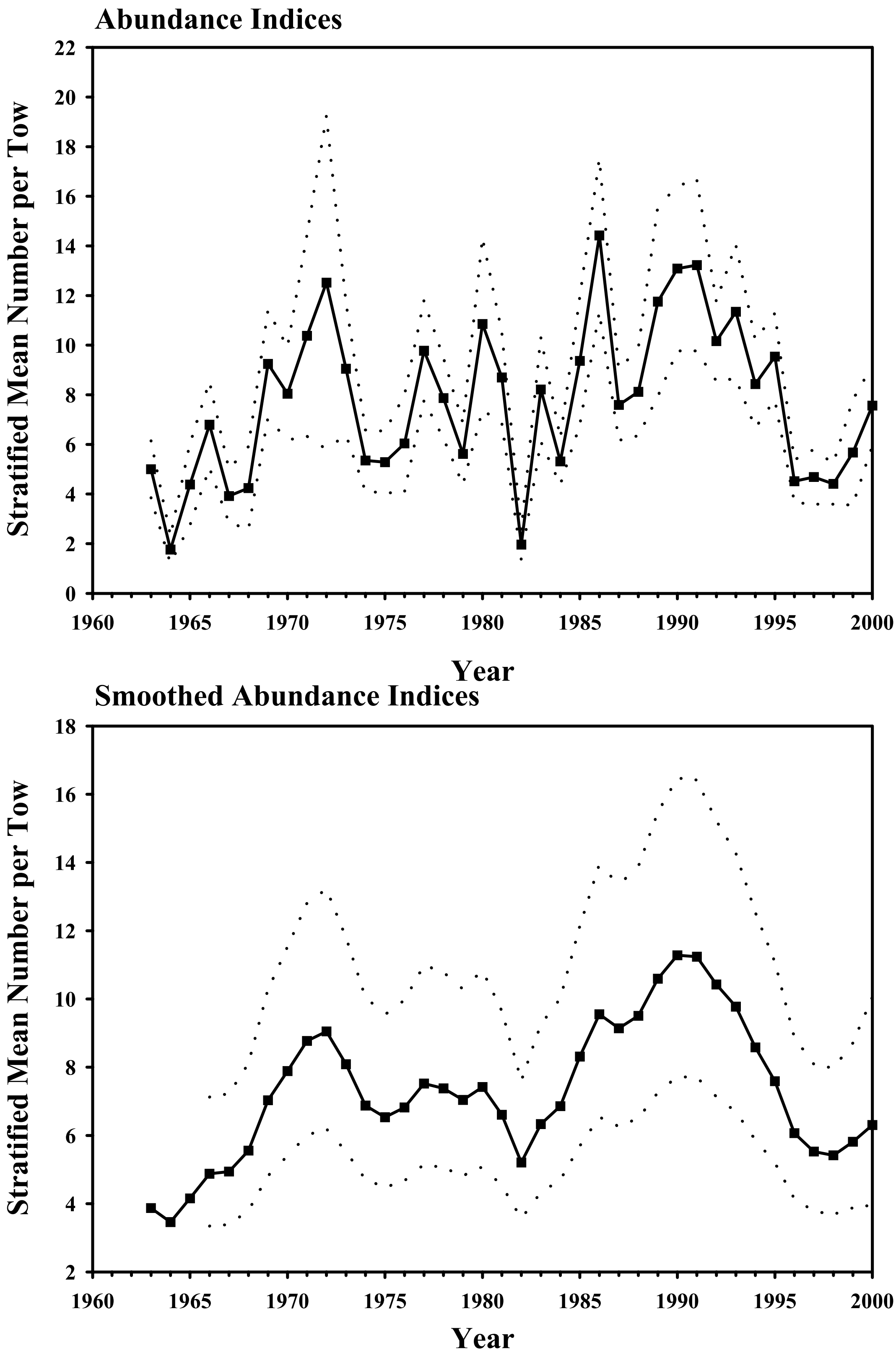
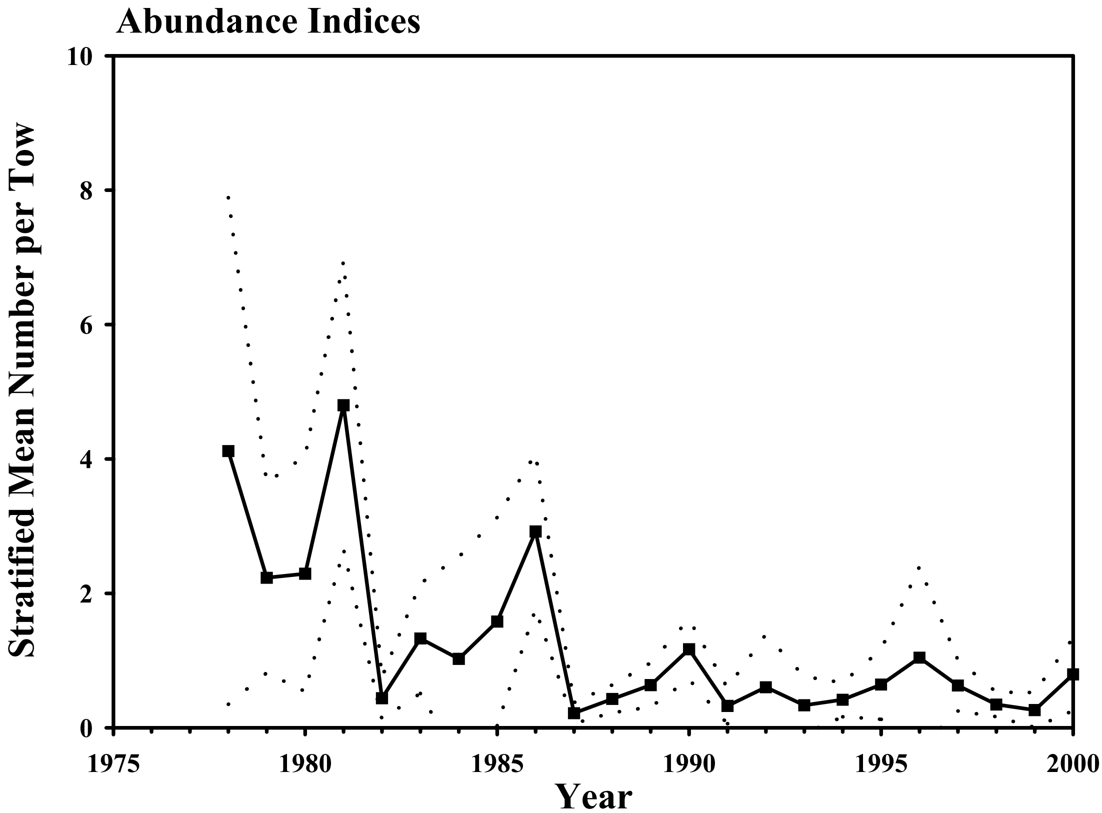


Figure B12. Abundance indices and smoothed indices from the NEFSC autumn bottom trawl survey for the Gulf of Maine to Northern Georges Bank region from 1963-2000. The 95% confidence limits are shown by the dashed line.



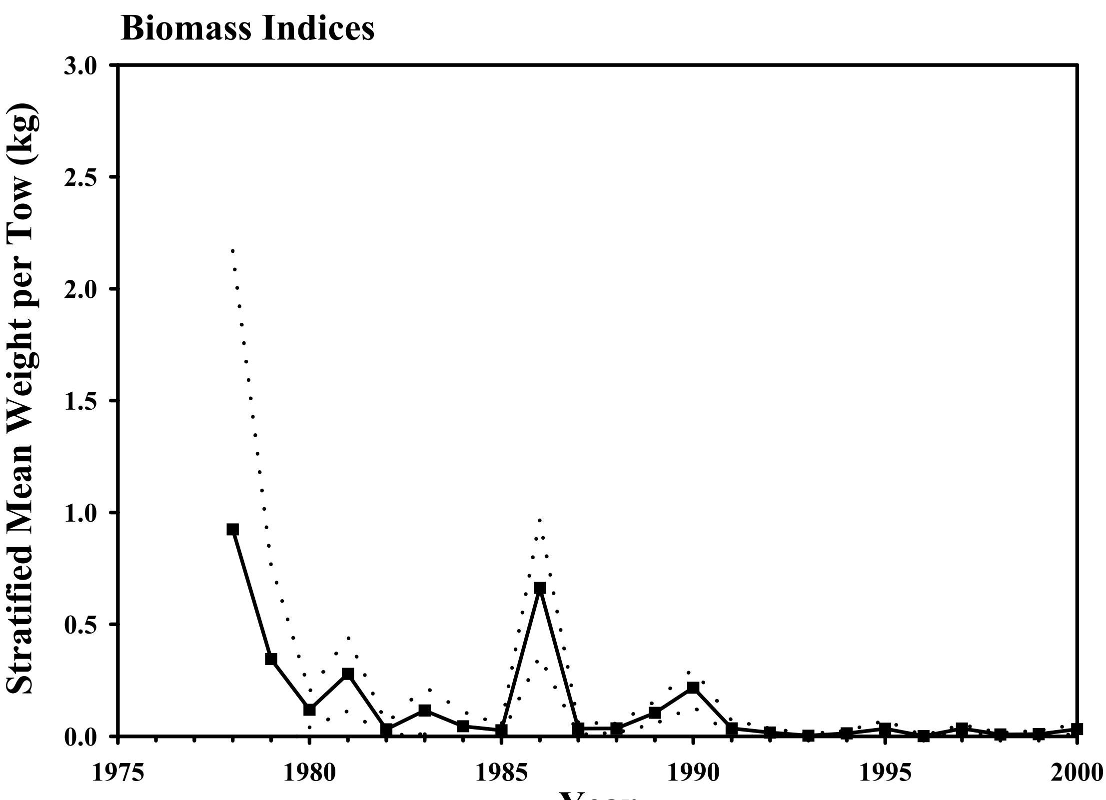
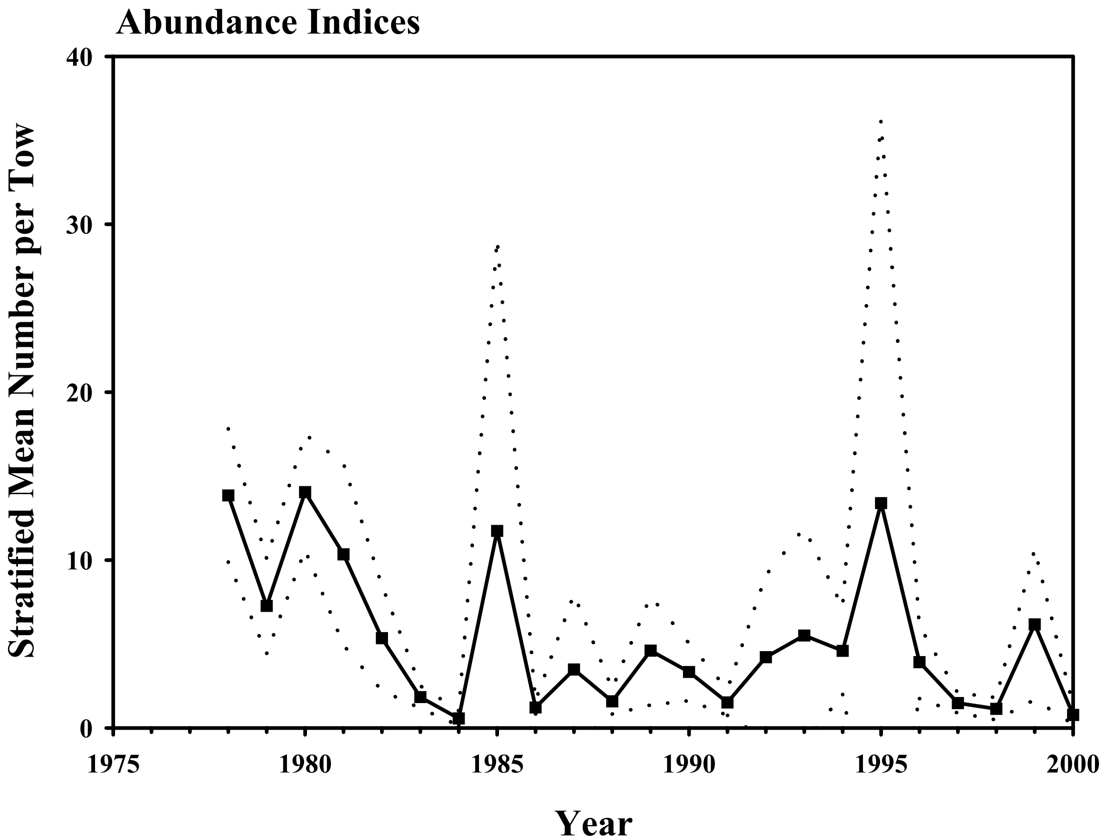


Figure B13. Abundance and biomass indices from the Massachusetts spring bottom trawl survey
The 95% confidence limits are shown by the dashed line.



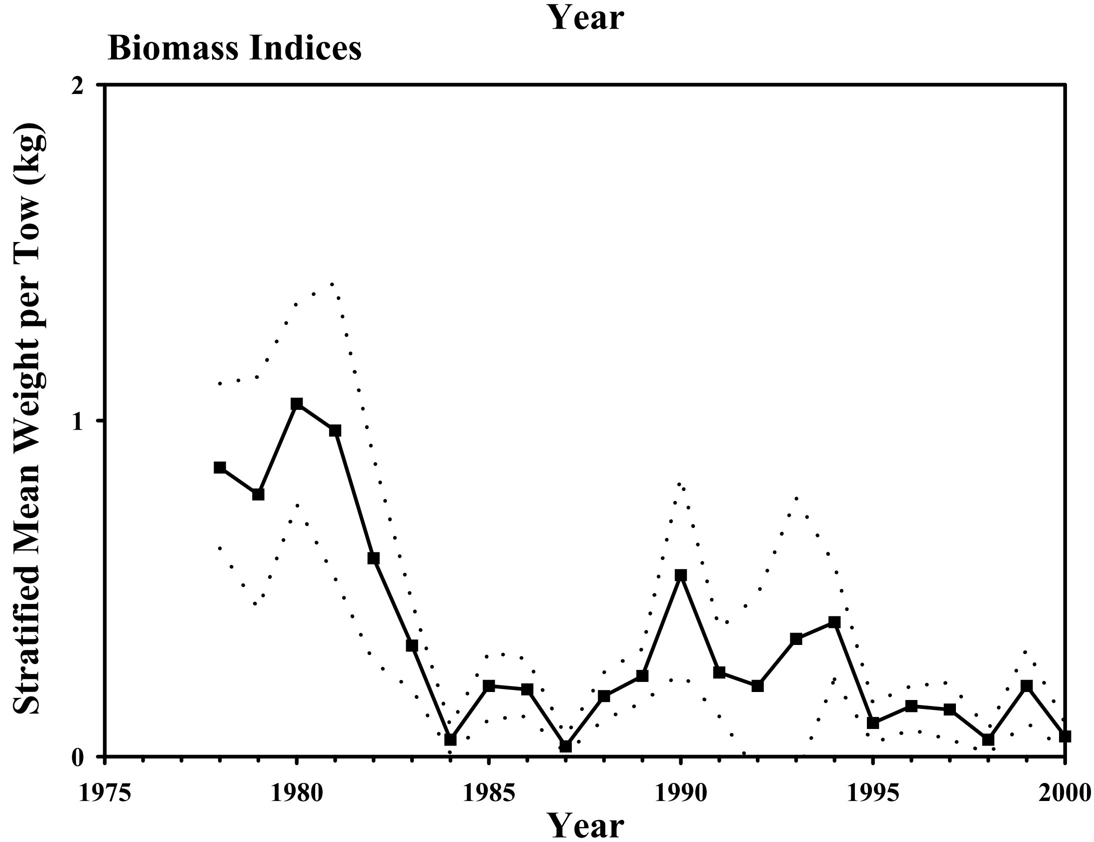


Figure B14. Abundance and biomass indices from the Massachusetts autumn bottom trawl survey The 95% confidence limits are shown by the dashed line.

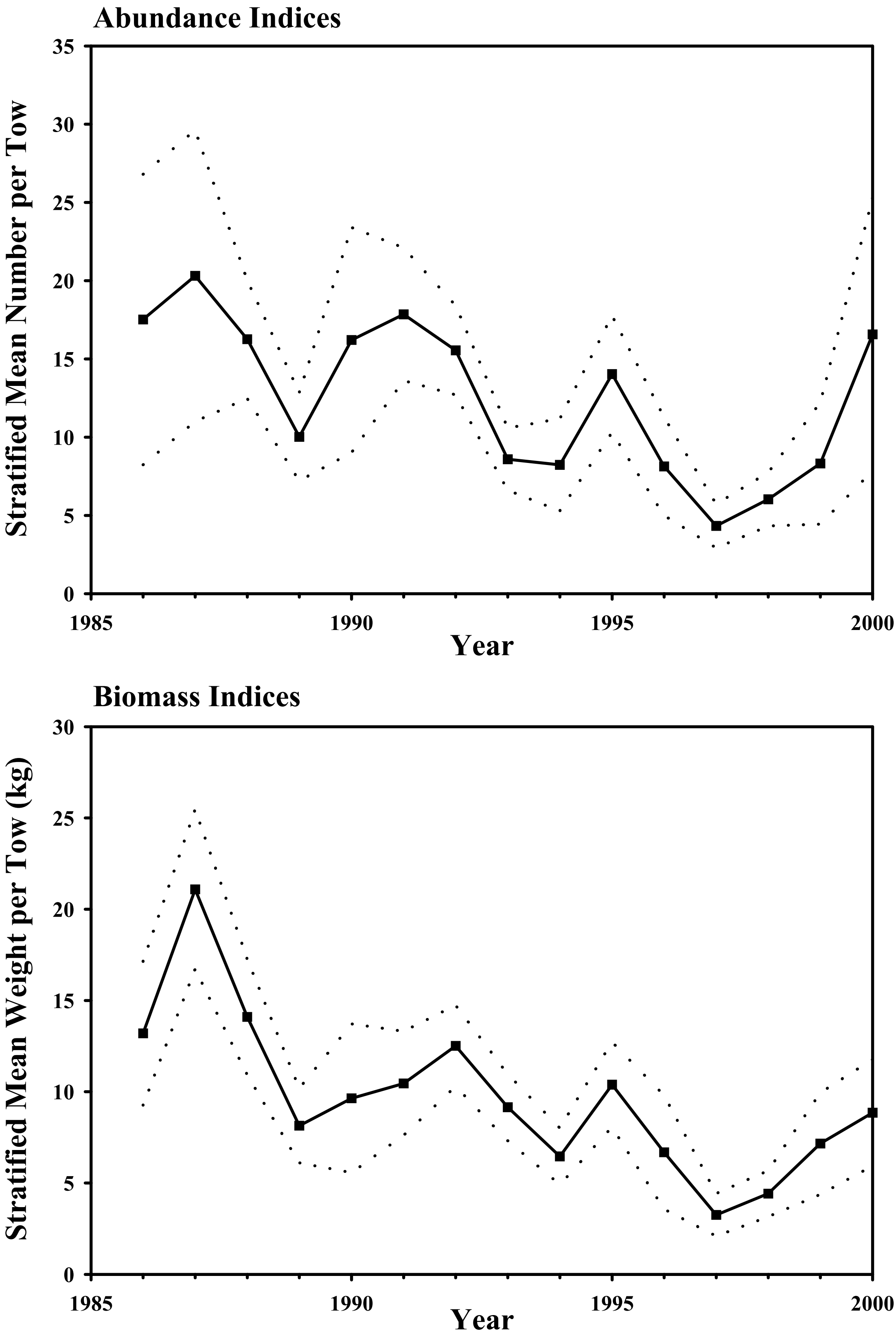


Figure B15. Abundance and biomass indices from the ASMFC shrimp survey. The 95% confidence limits are shown by the dashed line.

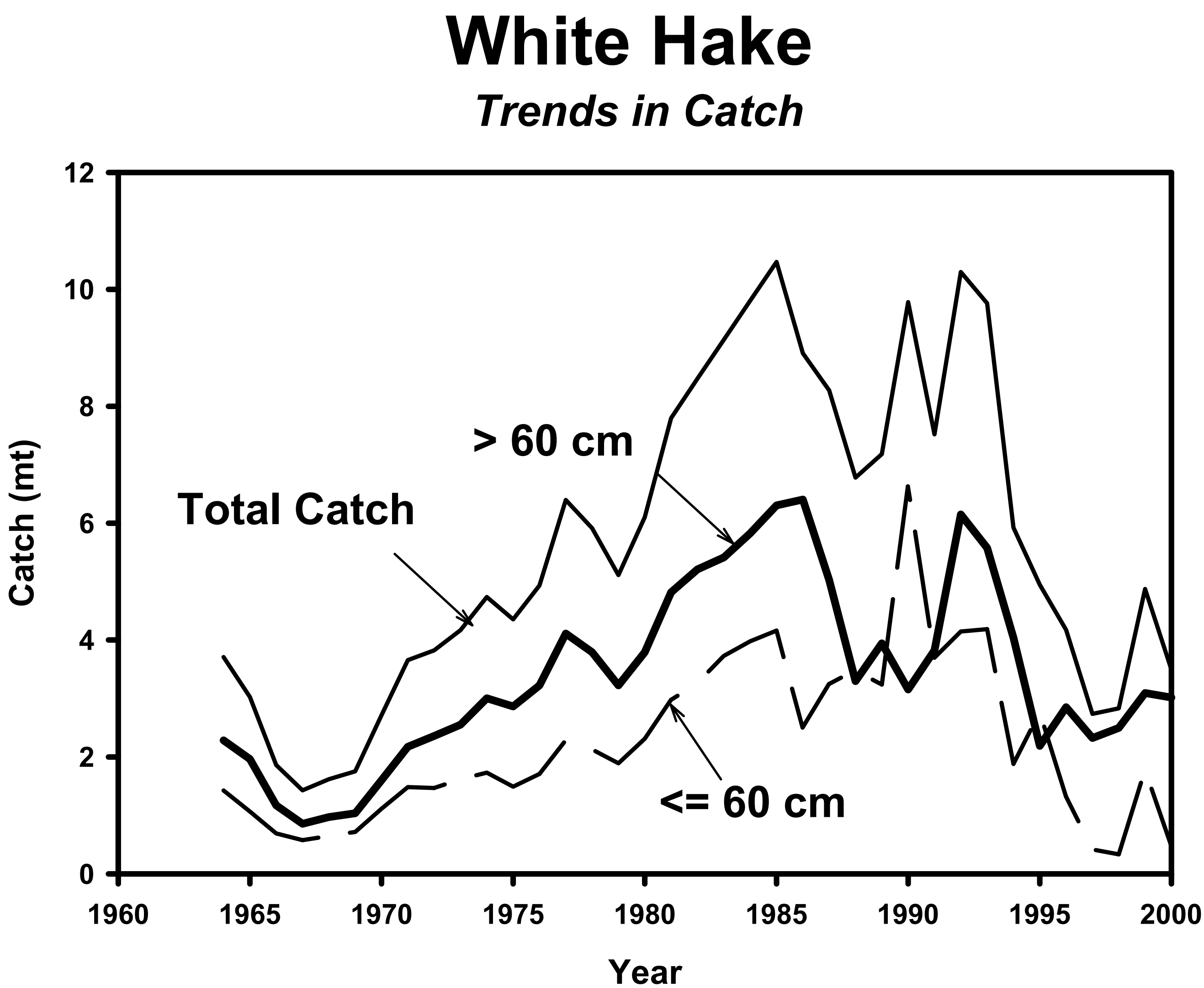


Figure B16. Trends in total catch by size category.

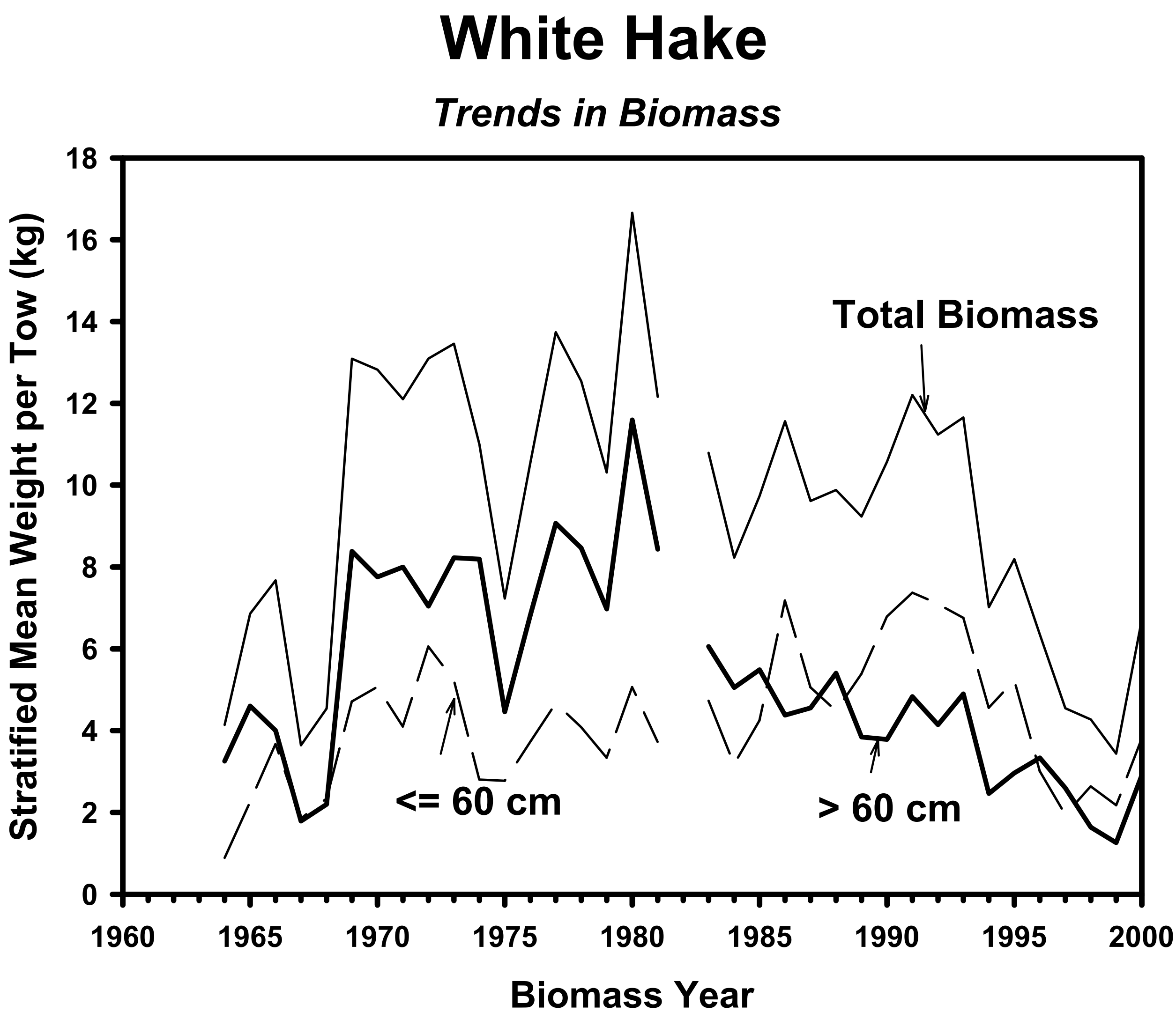


Figure B17. Stratified mean weight per tow from the autumn survey by size class.

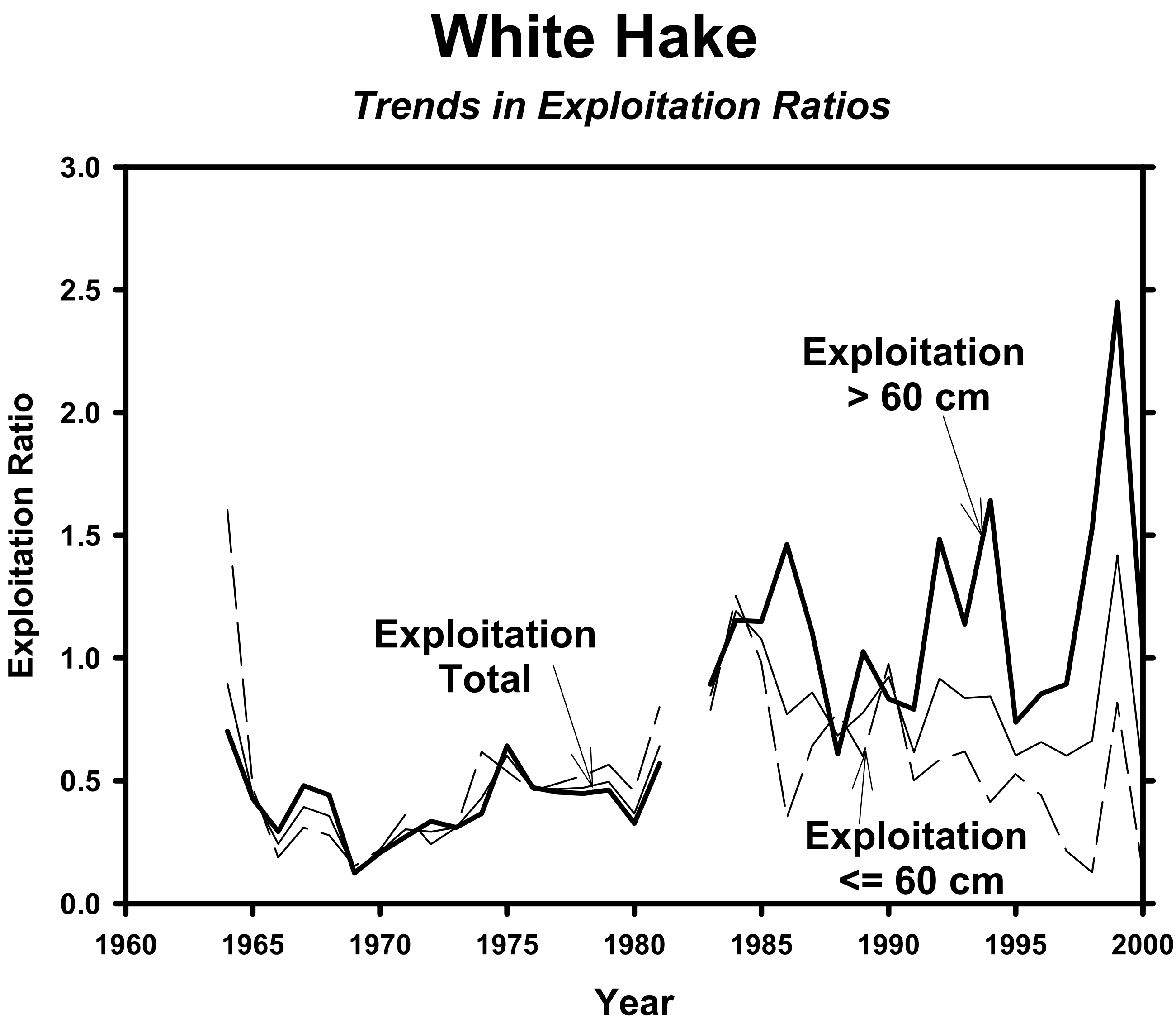


Figure B18. Exploitation ratios (catch/autumn survey) for two size categories and all fish combined.

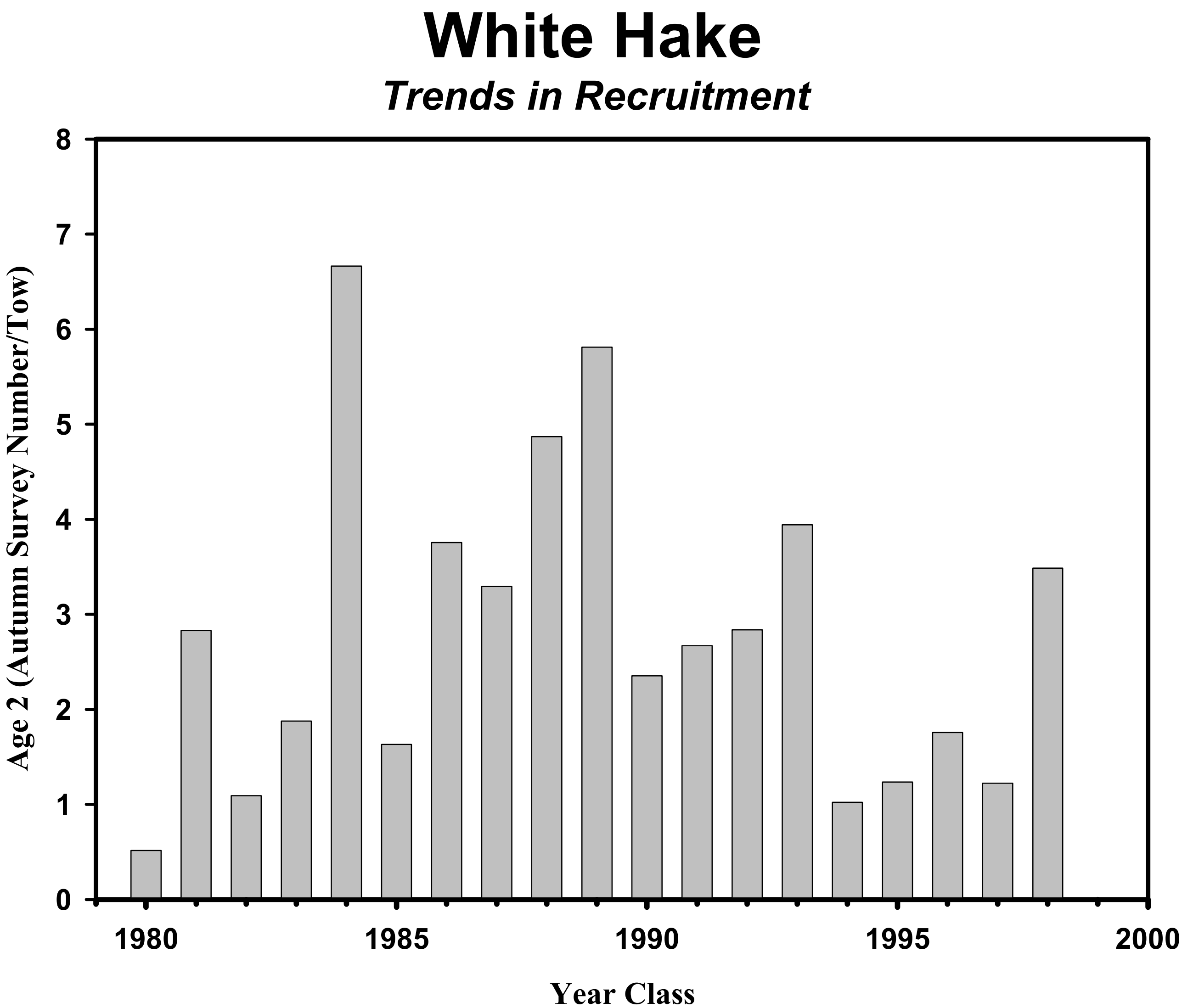


Figure B19. Trends in year class strength (Age 2 from the autumn survey).

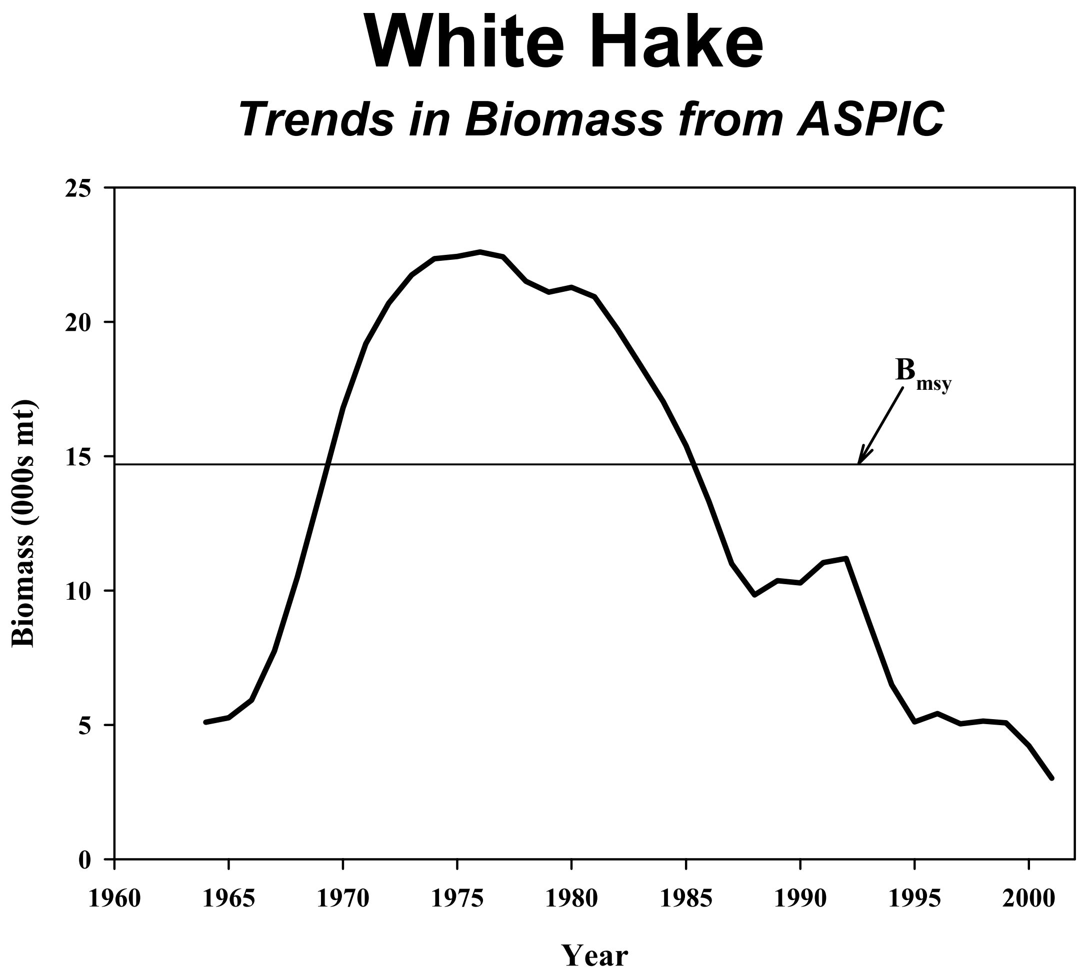


Figure B20. Trends in biomass > 60 cm from the ASPIC model.

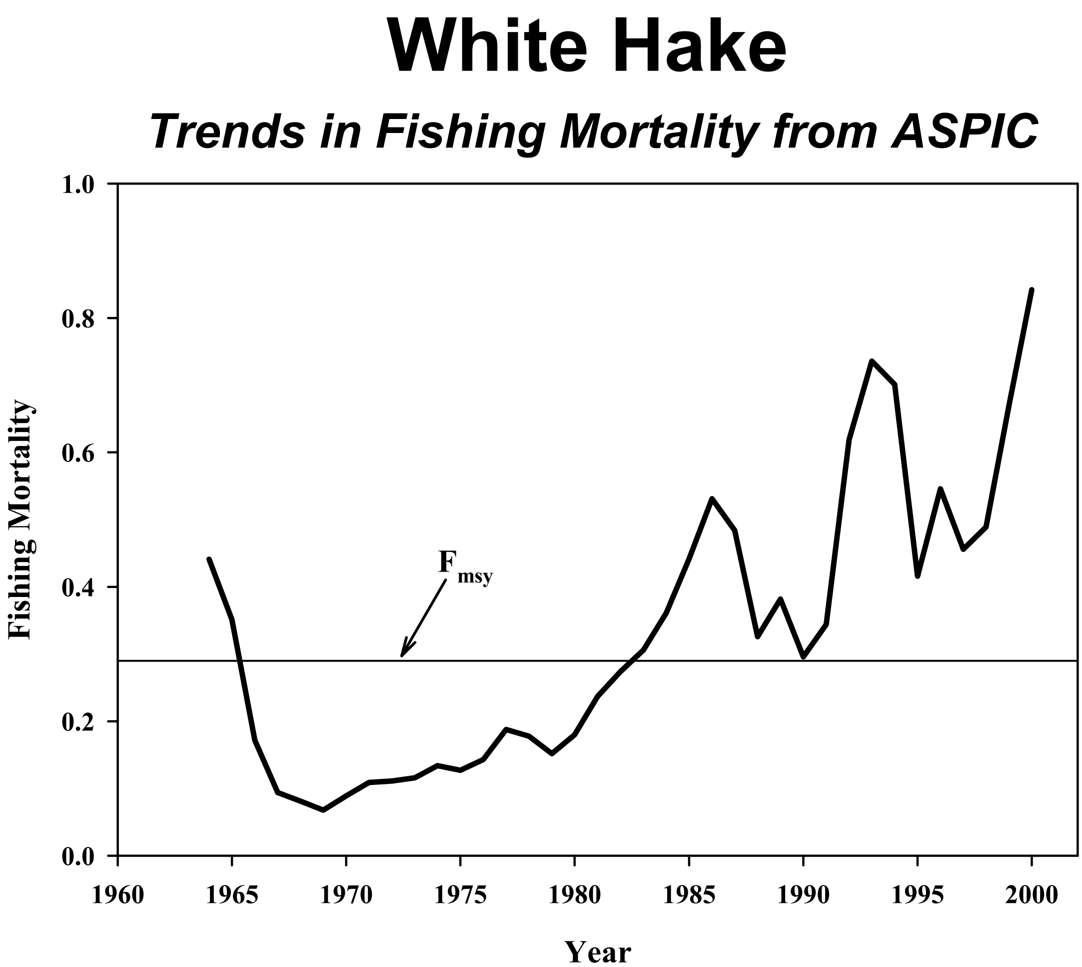


Figure B21. Trends in fishing mortality from the ASPIC model.

C. GULF OF MAINE/GEORGES BANK ACADIAN REDFISH

EXECUTIVE SUMMARY

The status of the Gulf of Maine/Georges Bank redfish (*Sebastes fasciatus*) stock through 2000 is reviewed, and the current status of the stock is compared on a relative basis to revised estimates MSY-based reference points. The 2001 assessment is based on several sources of information including: the age composition of USA commercial landings, Northeast Fisheries Science Center (NEFSC) spring and autumn research vessel survey data, and standardized USA commercial fishing effort data. This assessment updates the analyses presented in the 1993 assessment of the Gulf of Maine/Georges Bank redfish stock (Mayo 1993) as well as that prepared in 2000 by the Northern Demersal Working Group (NEFSC 2001).

Information on the size and age structure of the redfish stock is presented including: age composition of the commercial landings (1969-1985), length composition of inshore and offshore components of the stock based on NEFSC spring (1968-2000) and autumn (1963-2000) research vessel surveys, and age composition of the stock based on NEFSC spring and autumn research vessel surveys (1975-2000). Several aspects of the biology of the redfish stock are also presented including: patterns in diurnal catchability, length-weight relationships, analyses of maturity at length, and inshore/offshore biomass comparisons.

The assessment of current status is based on several analyses including: trends in catch/survey biomass exploitation ratios; a yield and biomass per recruit analysis; an age-structured dynamics model which incorporates information on the age composition of the landings, size and age composition of the population, and trends in relative abundance derived from commercial CPUE and research vessel survey biomass indices; and an age-aggregated biomass dynamics model. Surplus production estimates were derived from the age-structured production model, and information on current status of biomass and fishing mortality relative to MSY-based reference points is also provided by the biomass dynamics model.

The fishery on this stock developed during the 1930s. Landings rose rapidly from less than 100 mt in the early 1930s to over 20,000 mt in 1939, peaking at 56,000 mt in 1942, then declined throughout the 1940s and 1950s. Redfish have been harvested primarily by domestic vessels, although distant water fleets took considerable quantities for a brief period during the early 1970s. The distant water fleet effort, combined with increased domestic fishing effort, resulted in a brief increase in total catch to about 20,000 mt during the early 1970s. Landings declined throughout the 1980s and have averaged less than 500 mt per year during the 1990s.

Exploitation ratios (catch/survey biomass) suggest that fishing mortality has been very low since the mid-1980s compared to previous periods. Estimates of fishing mortality derived from the age-structured dynamics model and the age-aggregated biomass model are similar, both indicating that current fishing mortality is low relative to past decades and with respect to Fmsy (<5%). Stock biomass has increased since the mid-1990s, and is presently estimated to be about 33% of Bmsy due, in large part, to recruitment of one or more strong year classes from the early 1990s.

TERMS OF REFERENCE

(A) Update the status of the redfish stock, providing, to the extent practicable, estimates of fishing mortality and stock size. Characterize uncertainty in estimates.

(B) Provide updated estimates of biological reference points (biomass and fishing mortality targets/thresholds), or appropriate proxies, based on available population data.

(C) Provide updated indices of relative abundance and biomass, based on appropriate research vessel survey series.

INTRODUCTION

Redfish, *Sebastes fasciatus* Storer, have supported a substantial domestic fishery in the Gulf of Maine and the Georges Bank (Great South Channel) regions off the northeast coast of the U.S. (Northwest Atlantic Fisheries Organization [NAFO] Subarea 5) since the late 1930s when the development of freezing techniques enabled a widespread distribution of the frozen product throughout the country. Landings by domestic vessels rose rapidly, peaking at 56,000 t in 1942 in Subarea 5, then declined throughout the 1940s and 1950s (Table C1, Figure C1). As landings declined in local waters, U.S. fishing effort began to expand to the Scotian Shelf and the Gulf of St. Lawrence (NAFO Subarea 4), and finally to the Grand Bank of Newfoundland (NAFO Subarea 3). This expansion continued throughout the 1940s and early 1950s, culminating with a peak U.S catch of 130,000 t in 1952 (Figure C1). By the mid-1950s, redfish stocks throughout the Northwest Atlantic were heavily exploited by U.S and Canadian fleets (Atkinson 1987), and total landings began to decline in all Subareas.

During the 1960s and early to mid-1970s, catches by distant water fleets were substantial, at times accounting for 25-30% of the total Subarea 5 redfish catch (Table C1). With the declaration of exclusive economic zones by the U.S. and Canada in 1977, U.S. vessels were prohibited from fishing in all but a small portion of Subarea 4 off Southwest Nova Scotia. Landings from the Gulf of Maine subsequently increased temporarily during the late 1970s, but have been declining throughout the 1980s, and have remained below 1,000 t per year throughout the 1990s. Recent landings from this stock are at their lowest level since the directed fishery commenced in 1934.

The status of this stock has been assessed since the 1970s with a variety of techniques including production models (Schaefer 1954, 1957; Pella and Tomlinson 1969; Fox 1975), yield per recruit (Thompson and Bell 1934; Beverton and Holt 1957) and virtual population analysis (VPA). A preliminary production model estimate suggested a long-term potential yield of 20,000 t from this stock (Mayo 1975) but this was revised to 14,000 t when non-equilibrium conditions were taken into account (Walter 1976), irrespective of the growth model (exponential or logistic) employed (Mayo 1980). A yield per recruit analysis performed with M=0.05 and partial recruitment of 50% at age 6 and full recruitment at age 9, indicated Fmax at 0.13 and F0.1 at 0.06 (Mayo 1993).

Virtual population analysis, which was first performed on this stock using catch at age data from 1969-1980, indicated that age 9+

fishing mortality rates, in the range of 0.18 to 0.28 throughout most of the 1970s, were accompanied by a 62% decline in exploitable (age 5+) biomass between 1969 and 1980 (Mayo et al. 1983). A subsequent analysis which included additional catch at age data through 1983 indicated that, although F had begun to decline from a maximum value of 0.28 in 1979 to 0.17 in 1983, exploitable biomass had been reduced by 75% from the 1969 level by 1984 (NEFC 1986). The VPA was discontinued after 1986, but further declines in redfish landings since then suggest that F is now likely to be rather low (at or below M), rendering the convergence of VPAs somewhat unlikely.

The potential for this stock to return to conditions observed in the 1960s is limited, in part, by the combination of slow growth and low fecundity of redfish. Even at relatively low levels of F, ranging from 0.03 to 0.05, restoration of the 1969 age structure is not likely to occur except under extremely favorable recruitment conditions over the next 30-40 years (Mayo 1987).

COMMERCIAL FISHERY

Commercial Catch and Effort

Landings of redfish from Subarea 5 from 1934 through 2000 are given in Table C1 and Figure C1. Landings by domestic vessels rose rapidly from less than 100 t in the early 1930s to over 20,000 t in 1939, peaking at 56,000 t in 1942, then declined throughout the 1940s and 1950s. Redfish have been harvested primarily by domestic vessels, although distant water fleets took considerable quantities for a brief period during the early 1970s (Table C1). The distant water fleet effort, combined with increased domestic fishing effort, resulted in a brief increase in total catch to about 20,000 t during the early 1970s. Landings declined throughout the 1980s and have averaged less than 500 t per year during the 1990s. Landings in 2000 (319 t) remain close to an historic low. Redfish have been harvested almost exclusively by otter trawlers fishing out of Maine and Massachusetts ports.

Commercial catch per unit effort (CPUE) indices for directed redfish trips, standardized by vessel tonnage class as described by Mayo et al. (1979), are listed in Table C1 and illustrated in Figure C2a. The resulting calculated fishing effort values were derived by dividing total annual landings by the directed CPUE index. Directed CPUE has declined steadily from over 10 tons per day fished during the late 1960s to less than 2 tons per day fished since 1984 (Table C1, Figure C2a). This 70-80% decline is consistent with the 60-70% decline in exploitable biomass estimated by previous VPAs (Mayo et al. 1983; NEFC 1986). Total fishing effort, after peaking during the late 1970s (coincident with the highest estimates of fishing mortality [NEFC 1986]), appeared to stabilize during the mid-1980s before declining precipitously through 1989.

A depiction of the available effort data is presented in Figure C2b. Historically, 80-90% of the total redfish catch and 20-40% of the total number of trips on which redfish were taken were accounted for in the directed CPUE calculation (50% redfish trips). These percentages declined sharply between 1979 and 1982, and are now at levels which preclude any definitive interpretation of the CPUE and effort trends.

Commercial Length Composition

The available commercial length and age sample data are summarized in Table C2.

Commercial length sampling for redfish has generally been sufficient to allow quarterly pooling until the 1990s. Sampling during most years since 1994 has been insufficient to characterize the length composition of the landings. The apparent improvement in sampling intensity in recent years is an artifact of the rapid decline in landings. Even with very low landings, sampling must be maintained at relatively high levels in order to reflect the age structure of the population. Age samples have been routinely collected since the 1960s but production ageing ceased after 1985 (Table C2).

Estimates of numbers landed at length were derived from 1969 through 2000 when sample data permitted. In most years prior to 1991, sampling was sufficient to allow pooling of length data on a quarterly, and in a few cases, semi-annual basis. However, from 1991 to 2000, pooling of samples was required on a semi-annual, and in several cases, an annual basis. Due to the differences in growth between males and females, sampling for redfish is conducted separately by sex, and estimates of numbers landed are also derived separately for males and females. The overall length composition is then obtained by addition of the estimates by sex.

Changes in the length composition of the landings between 1969 and 2000 are illustrated in Figure C3. In 1978, the landings still reflected a fairly broad age structure in the population of both males and females with the 1971 year class accounting for the mode between 20 and 30 cm. With the decline in subsequent recruitment, modes shifted toward larger sizes until fish from the 1978 year class appeared in 1983 and 1984. As landings continued to decrease throughout the 1980s, modal lengths shifted further until few fish between 20 and 25 cm could be seen recruiting to the fishery.

Shifts in modal lengths are reflected in annual changes in mean length of the landings as illustrated in Figure C4. Increases in mean length occur during periods of poor recruitment (such as 1965-1976) while sharp decreases generally signify the appearance of a strong year class entering the fishery. The declines which began in 1976 and 1983 indicate recruitment of the 1971 and 1978 year classes entering the fishery at age 5. The subsequent overall increasing trend indicates a gradual ageing of the population as recruitment has declined over the past 30 years. Mean lengths of the landings have become extremely variable in recent years as landings have become extremely low and sampling has deteriorated.

Commercial Age Composition

Estimates of numbers landed at age were also derived from the biological sampling data for the period 1969 through 1985. With the sharp decline in landings evident during the 1980s, ageing of commercial samples was discontinued after 1985. For the period 1969-1985, however, estimates of numbers landed at age were derived by applying quarterly age/length keys, separately by sex, to the estimated numbers landed at length by sex. The overall age composition was then obtained by addition of the estimates by sex.

Catch at age and mean weight at age matrices based on all available commercial length and age data from 1969 through 1985 are given in Table C3, and trends in the age composition of the landings are illustrated in Figure C5 . The sharp discontinuity in the age structure of the population created by poor recruitment since the 1960s can be inferred from the age composition of the landings. The most striking feature is the singular presence of the 1971 year class advancing through the fishery since 1976, followed by the entrance of the 1978 year class during 1983-1985. By the early 1980s, the fishery had become dependent on a few relatively strong year classes and recruitment appeared to have collapsed.

RESEARCH VESSEL SURVEYS

Bottom trawl surveys have been conducted by the Northeast Fisheries Science Center in the Gulf of Maine - Georges Bank region since autumn 1963 and spring 1968 (Azarovitz 1981). The NEFSC spring and autumn bottom trawl survey data were analyzed to evaluate trends in total abundance and biomass of redfish, diurnal effects on catchability, differences in density between inshore and offshore regions of the Gulf of Maine, trends in the size and age composition of the population, total mortality, relationships between length and weight, and changes in maturation at length.

Trends in Total Abundance and Biomass

Abundance (stratified mean number per tow) and biomass (stratified mean weight per tow) indices have been calculated from NEFSC spring and autumn surveys based on strata encompassing the Gulf of Maine and the portions of the Great South Channel (strata 24, 26-30, 36-40; Tables C4 and C5; Figures C6a and C6b). Trends in total abundance and biomass are similar in both spring and autumn surveys. Relative abundance of redfish has declined sharply in both survey series, from peak levels over of 100 fish per tow in the late 1960s and early 1970s to generally less than 10 fish per tow during the mid-1980s through mid-1990s. The decline in biomass has been of the same order (Figures C6a and C6b). Both series suggest a slight increase in abundance and biomass between the mid-1980s and 1990s followed by a sharp increase in autumn 1996 and spring 1997.

Day/Night Comparisons

Redfish have been observed to exhibit consistent diurnal patterns in their vertical distribution. Although Kelly and Barker (1961) concluded that there is little evidence of diurnal movement of planktonic larvae, they also noted a significant decrease in catches of larval redfish by an Isaacs-Kidd midwater trawl during daylight. This was attributed to possible gear avoidance by larval redfish. Adult redfish, however, are thought to exhibit very pronounced diurnal movement patterns. Templeman (1959) noted that, off Newfoundland, redfish catches from sets made more than one hour before sunrise or after sunset were negligible compared to those from daytime sets. Catches were also related to the season, with good catches extending over a longer part of the day in the brightest months with the longest period of daylight. This pattern was well known in the commercial redfish fishery as vessels would often lay to during the night.

In an earlier paper on redfish biology, Steele (1957) noted the same overall diurnal pattern in redfish catches. In this study, Steele provided evidence of a 2-3 fold difference in average catch rates over a 24-hour period. This pattern was correlated , in part, with the vertical movement of the euphausiid, *Meganyctiphanes norvegica*, a major prey item of redfish in the North Atlantic. Steele (1957) also observed seasonal departures from the general pattern, and speculated that these differences may be related to the sexual maturation cycle of males and females. The diurnal response of males and females differed among seasons.

The presence of a diurnal pattern in redfish activity in the Gulf of Maine was examined over the period 1992-2000. NEFSC spring and autumn survey catch data were partitioned into six 4-hour time blocks as follows: 0001-0400 hr (night2), 0401-0800 hr (dawn), 0801-1200 hr (day1), 1201-1600 hr (day2), 1601-2000 hr (dusk), and 2001-2400 hr (night1). Catch data for valid survey tows within the total Gulf of Maine strata set as above were selected from the spring, summer, and autumn surveys. Summer surveys were conducted only in 1992, 1993 and 1994 and the number of tows in the Gulf of Maine which contained redfish (n=85) was relatively small.

The catch data were analyzed for seasonal and diurnal effects by ANOVA using PROC GLM (SAS, 1990). Initial analyses indicated that seasonal effects were not significant; however, based on the observations of Steele (1957) regarding different seasonal responses by males and females, further analyses were conducted separately for spring and autumn data, with summer excluded. In the analyses of diurnal effects, the last time block (2001-2400 hr) was elected to represent unity and each of the 5 remaining blocks were related to the last block. The factors for each time block were re-transformed from log scale to linear scale.

In the overall analysis, catch rates from periods 2 (0401-0800 hr), 3 (0801-1200 hr) and 4 (1201-1600 hr) were significantly different ($p < 0.05$) from period 6 (2001-2400 hr). These represent dawn and the 2 daytime periods. Catch rates from the remaining periods (1 and 5), representing dusk (1601-2000 hr) and night (2001-2400 hr) were not significantly different from period 6. Analyses of the spring and autumn data revealed possible seasonal differences (Figure C7). During spring, catch rates from time periods 2, 3, and 4 were significantly different ($p < 0.05$) from those of period 6, but during autumn, none of the time periods exhibited statistically significant differences in catch rates, although the general pattern was similar to spring. These differences between spring and autumn were not due to any pronounced bias in survey station coverage by time period as the number of stations in both spring and autumn were almost evenly distributed (Figures C8a and C8b).

In fact, the seasonal differences obtained for the Gulf of Maine are consistent with the observations of Steele (1957) and Templeman (1959). When the timing of the NEFSC survey in the Gulf of Maine is taken into account, (spring survey in late April, autumn survey in late October), it can be seen that this portion of the spring survey occurs during a period of considerably longer daylight compared to autumn. There is a 2-month absolute difference in the timing of the spring and autumn surveys with respect to the corresponding vernal and autumnal equinoxes. These results are consistent with Templeman's (1959) observation that good catches occur over a longer part of the day in the brightest months. The results also seem to corroborate Steele's (1957) observation that seasonal differences may be related to the reproductive cycle where females may be more pelagic during the larval extrusion stage in spring whereas both sexes may occupy bottom during a greater period of time during the copulation stage in autumn.

Despite the large diurnal differences in catch rates derived from these analyses, abundance and biomass indices are not likely to exhibit any substantial bias given the even distribution of occupied stations over time. It is likely, however, that annual departures from an even distribution among the six time periods may impart a degree of inter-annual variability which may partially explain some of the large year effects exhibited in these data. However, if the redfish survey indices were to form the basis of an estimate of absolute biomass, the diurnal differences noted herein must be taken into account before any estimation is made.

Inshore/Offshore Comparisons

Indices were also computed for inshore (strata 26, 27, 39, and 40; area: 3,042 square miles) and offshore (strata 24, 28-30, 36-38; area: 17,419 square miles) subsets of the data (Figures C9a and C9b). When two or more strata sets of unequal area are compared in this manner, the stratified mean catch per tow indices must be considered to represent the density of fish (index of number or biomass per unit area) rather than actual abundance or biomass (index of population size). The inshore Gulf of Maine area from Massachusetts Bay to the eastern coast of Maine has generally contained higher densities of redfish compared to the offshore regions, particularly in terms of numbers (Figure C9a). These fish are generally smaller than those in the offshore regions, and the index from the inshore area may be used as a measure of recruitment (Mayo 1980). Trends in these indices have been consistent with trends in the overall combined indices (Figures C6a and C6b).

Trends in mean length and weight of redfish from inshore and offshore strata sets during autumn are illustrated in Figures C10a and C10b. As with commercial mean lengths, sharp declines indicate the appearance of a relatively strong year class. This is most evident in the autumn series of inshore data which has provided the most consistent indicator of recruitment patterns over time. The sharp declines which occur immediately after 1971, 1978, and 1984 reflect the initial appearance and subsequent increased influence of these year classes in the inshore bottom trawl survey indices. The 1991 year class is reflected in the offshore mean length and weight patterns.

To compare trends in actual abundance and biomass between regions, the indices must be weighted by the area of each strata set. This approach provides indices of population size within each strata set which can be directly compared on the same basis. When viewed in this manner, it is clear that the greatest fraction of the redfish population has historically been found in the offshore region of the Gulf of Maine (Figures C11a and C11b).

Size Composition

Length composition data from spring, autumn and shrimp surveys (Figures C12 and C12a) simultaneously illustrate the changes in relative abundance and size structure of the population which resulted from the decline in recruitment over time. The redfish population was composed of a relatively broad range of sizes in the 1960s resulting from consistent recruitment of year classes from the 1950s and 1960s. By the mid-1970s, however, abundance of large fish had declined substantially and only the 1971 year class remained a dominant feature in the demographics of the population. The consistency of the survey indices had begun to erode by the beginning of the 1980s and, throughout this decade, only sporadic indications of the 1978 and subsequent year classes were evident.

During the 1990s, however, substantial numbers of redfish, generally between 20 and 25 cm, began to appear, first in spring 1992, then in autumn 1995 and 1996. These data likely reflect the strength of one or more year classes from the mid-1980s and early 1990s. In autumn 1999, a mode at 5 cm could indicate a potentially strong 1999 year class. By 1997, large numbers of redfish up to 30 cm and larger were appearing consistently. However, the size structure of the population remains truncated compared to the 1960s and early 1970s. The same pattern appears in the shrimp survey.

Age Composition

Age composition estimates are available from NEFSC autumn surveys from 1975 through 2000 and from NEFSC spring surveys from 1975 through 1990 with some exceptions. The survey otolith collection is routinely aged to the maximum possible age. For this analysis and the subsequent analysis of mortality rates, all ages greater than 50 years were binned at 50+. As the autumn survey has provided the most consistent set of abundance and biomass indices, priority was given to ageing of the autumn survey otolith collection. Annual trends are illustrated in Figure C13. The age composition data clearly illustrate recruitment patterns and changes in age structure of the population that are suggested by the length composition data. In 1975 the population still appeared to exhibit a relatively broad age structure. The 1971 year class is prominently featured in 1975 followed by the 1978 year class in the early 1980s; these two year classes continued to dominate the demographics of the population through the 1980s. More recently, the 1985 and 1991 year classes appear most prominent. As indicated by the length composition estimates, the age structure of the population during the late 1990s remains truncated compared to the 1975 and earlier period.

Total Mortality Estimates

Estimates of instantaneous total mortality were computed from the age composition data derived from NEFSC autumn surveys from 1975-1996. Annual Z estimates, based on the annual survival rate from ages 6 and older to ages 7 and older, were highly variable, ranging between -1.6 to + 1.6. These estimates reflect the high degree of variability in year class strength evident in the survey abundance indices at age presented in Figure C13. Therefore, an alternate approach was attempted.

The 1975-1996 autumn survey age composition data contain information on cohorts spanning 1925 to as recently as 1995. To minimize the variability induced by variation in year class strength, separate catch curves were constructed for each cohort. Since the time span represented in the age composition data covers the years 1975-1996, cohorts from years prior to the mid-1970s become truncated at the younger ages whereas cohorts from years after 1975 become progressively truncated at the older ages. When combined in a single plot, the mortality on by various ages spanning the period 1925-1995 is visually represented (Figure C14). This provides a general indication of the average mortality sustained by the population over this 70 year period. It is evident that, in most cases, redfish are incompletely recruited until ages 5 or 6. However, mortality rates appear to be relatively consistent for most cohorts after age 6. No attempt was made at this stage to derive mortality estimates for individual cohorts.

Length-Weight Analyses

The relationship between length (cm) and weight (kg) of redfish was examined by season and sex using linear regression (PROC REG; SAS 1990) of the form:

$$\text{Ln Weight} = a + b^{*} \text{ Ln Length}.$$

The analysis is based on 8,567 individual length and weight measurements collected during NEFSC spring and autumn surveys since 1992. There are no significant differences ($p=0.800$) in the length-weight relationship between spring and autumn. However, differences between males and females are highly significant ($P< 0.01$) (Figure C15), with females considerably heavier at a given length.

Maturation Analyses

Redfish are relatively long-lived, slow growing fish with an extremely low natural mortality rate compared to most highly exploited species. Growth studies have indicated maximum ages ranging from 50-60 years at lengths of 45-50 cm (Mayo et al. 1990). Perlmutter and Clark (1949) provided early evidence that immature redfish in the Gulf of Maine exhibited extremely slow growth and that maturation was delayed until about age 9. Kelly and Wolf (1959) further demonstrated the extremely slow growth of adult redfish up to age 20. More recently, Mayo et al. (1981) provided further validation of the slow growth rates for redfish up to age 7 based on length mode progression and otolith edge formation. Consequently, an instantaneous natural mortality rate of 0.05 has been employed in age-structured models, consistent with the longevity of this species. Moreover, growth and maturation appear to be linked. The most recent estimates of redfish maturation suggest a median age of about 5.5 years (Mayo et al. 1990; O'Brien et al. 1993) compared to the 9-10 years indicated by Perlmutter and Clark (1949).

In this analysis, the relationship between maturation and length is examined within 3 time periods using logistic regression (PROC LOGISTIC; SAS 1990) of the form:

$$Pm = e^{(a + b^{*}Len)} / (1 + e^{(a + b^{*}Len)}).$$

The analysis is based on 3,728 individual maturity stage observations from 1975 through 2000 within the following periods: 1975-1981, 1982-1991, and 1992-2000. There are 6 maturation stages for male redfish and 7 stages (including eyed larvae) for females. The development and present basis for the NEFSC maturity stages are described by Burnett et al. (1989).

In general, redfish maturation at length remained relatively constant over the 25 year period analyzed. A slight trend towards decreasing size at maturity is evident in both the spring and autumn results (Figure C16). Estimates of median length at maturation (L50) for females varied between 20.3 cm and 22.6 cm. The slightly higher values occurred in the earliest period. Estimates of L50 for males ranged from 20.2 to 21.3 cm and the higher values also correspond to the 1975-1981 period Figure C17).

ASSESSMENT OF CURRENT STATUS

Yield and SSB per Recruit

Yield and spawning stock biomass (SSB) per recruit were calculated according to the methods described by Thompson and Bell (1934) and Gabriel et al. (1989). Natural mortality was assumed to be 0.05. Mean weights at age for the yield per recruit calculations were taken as the 1969-1984 mean of the commercial mean weights at age (Table C3). Partial recruitment was based on the fishery selectivity pattern derived from the age-structured model presented below. This pattern was similar to that employed in the previously published VPA (Mayo 1993) which was taken from the most recently published VPA (NEFC 1986) which reflects the recruitment of the 1971 year class. Growth and maturation data for SSB/R analysis were taken from the female data presented by Mayo et al. (1990).

Estimates of $F_{0.1}$ (0.06) and F_{max} (0.13) (Table C6, Figure C18) are identical to those derived by Mayo (1993); these estimates were similar to those reported by Mayo (1980) using the Beverton-Holt approach with the same value of M (0.05) for 89mm mesh (males) and 102 mm mesh (females). F at 30% of Maximum Spawning Potential was estimated as 0.07, slightly above the estimate of $F_{0.1}$.

Index of Exploitation

An index of exploitation (Table C7; Figure C19) was derived for the period 1963-2000, expressed as the ratio of the autumn NEFSC biomass index (Table C5) to total fishery removals (Table C1). The index fluctuated considerably during the 1960s and 1970s, but generally increased until the 1982, then declined sharply during the 1980s. Since 1990, the index of exploitation has remained at an extremely low level as landings remained low despite the recent increase in the survey biomass index. However, in contrast to the 1960s and 1970s, where a substantial portion of the stock persisted in the 30-40 cm range (Figure C12), during the 1990s, almost all of the redfish were less than 25 cm, and almost none were larger than 30 cm. This suggests that, given the present demographics of the stock, only a small fraction of the biomass would be considered exploitable. Thus, the exploitation ratio based on the total biomass index, tends to under-estimate current exploitation relative to the earlier period in the series.

Age-structured Dynamics Model

In this section, an age-structured assessment model is developed for redfish. Age-structured population dynamics of redfish are modeled in a standard manner using forward-projection methods for statistical catch-at-age analyses (Fournier and Archibald 1982, Methot 1990, Ianelli and Fournier 1998, Restrepo and Legault 1998). The population dynamics model, statistical estimation approach, model diagnostics, and model results are described in sequence below.

<u>Population dynamics model</u>

The age-structured model is based on forward projection of population numbers at age. This modeling approach is based on the principle that population numbers through time are determined by recruitment and total mortality at age through time. The population numbers at age matrix $N=(N_{y,a})_{YxA}$ has dimensions Y by A, where Y is the number of years in the assessment time horizon and A is the number of age classes modeled. The oldest age (A) comprises a plus-group consisting of all fish age-A and older. The time horizon for redfish is 1934-2000 (Y=67). The number of age classes is 26, representing ages 1 through 26+.

Recruitment (numbers of age-1 fish) in year y (R_y) is modeled as a lognormal deviation from average recruitment (μ_R), where V_y are iid normal random variables with zero mean and constant variance.

$$R_y = \mu_R e^{V_y}$$

For all years y from 1935-2000, $R_y = N_{y1}$ is estimated from the recruitment deviation and average recruitment.

Initial population abundance at age in 1934 is based on recruitment deviations from average recruitment for 1909-1934 and natural mortality. For all ages a < A, the numbers at age in the first year (ystart=1) are estimated as a lognormal deviations from average recruitment as reduced by natural mortality

$$N_{1,a} = \mu_R e^{V_{ystart-a+1}} e^{-(a-1)M}$$

For the plus group, the initial numbers at age is the sum of numbers at ages 26 and older based on an equilibrium recruitment deviation for ages 26 and older and natural mortality.

$$N_{1,A} = \frac{\mu_R e^{V_{ystart-A+1}} e^{-(A-1)M}}{1-e^{-M}}$$

The total instantaneous mortality at age matrix $Z=(Z_{y,a})_{YxA}$ and the instantaneous fishing mortality at age matrix $F=(F_{y,a})_{YxA}$ both have dimensions Y by A. Instantaneous natural mortality at age is assumed to be constant (M) and for all years y and ages a

$$Z_{y,a} = F_{y,a} + M$$

Population numbers at age through time are computed from the initial population numbers at age, recruitment through time, and total mortality at age through time. For all ages a younger than the plus group (a < A), the number at age are sequentially determined using

$$N_{y,a} = N_{y-1,a-1} e^{-Z_{y-1,a-1}}$$

For the plus group, numbers at age are the sum of survivors at age A-1 and plus group survivors

$$N_{y,A} = N_{y-1,A-1} e^{-Z_{y-1,A-1}} + N_{y-1,A} e^{-Z_{y-1,A}}$$

Fishing mortality at age a in year y is modeled as a separable process, where S_a is selectivity at age a and F_y is fully-recruited fishing mortality in year y

$$F_{y,a} = S_a F_y$$

Fully-recruited fishing mortality in each year is modeled as a lognormal deviation from average fishing mortality (μ_F),where U_y are iid normal random variables with zero mean and constant variance

$$F_y = \mu_F e^{U_y}$$

Fishery selectivity at age is modeled as being time-invariant throughout the assessment time horizon. This approach was chosen for parsimony. In particular, redfish catch-at-age data to estimate fishery selectivity are limited to 1969-1985, a period when the fishery practices are believed to have been relatively stable. Fishery selectivity at age is estimated for ages 1 through 9. For ages older than 9 years, fishery selectivity is assumed to be equal to the age-9 selectivity value. This approach was chosen to reflect the asymptotic selectivity pattern from previous VPA-based assessments of redfish, wherein age 9 was the age of full selectivity. Two constraints are applied to the estimated selectivity at age coefficients. First, the selectivities are constrained to average 1 for estimated ages. This forces the scale of each coefficient to be near unity. Second, a constraint is applied to ensure that estimated selectivities change smoothly between adjacent ages. Details of the implementation of both constraints are described in the section on statistical estimation approach. Last, for each year the selectivity at age values are scaled so that the maximum selectivity at age value is unity. This ensures that estimated fully-recruited fishing mortality rates are directly comparable to biological reference points such as $F_{0.1}$.

The fishery catch numbers at age matrix $C=(C_{y,a})_{YxA}$ and the fishery catch biomass at age (yield) matrix $Y=(Y_{y,a})_{YxA}$ both have dimensions Y by A. Fishery catch at age in each year is computed from Baranov's catch equation using population numbers, fishing mortality, and total mortality at age

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

Catch biomass at age in each year is the product of catch numbers at age and mean weight at age, where W_a is the mean weight at age computed as the average of mean redfish weights at age from fishery sampling during 1969-1985

$$Y_{y,a} = C_{y,a} W_a$$

Total fishery catch biomass in year y (Y_y) is the sum of yields by age class

$$Y_y = \sum_{a=1}^{A} Y_{y,a}$$

The total fishery catch biomass time series is compared to observed values using a lognormal probability model.

The proportion of fishery catch at age a in year y ($P_{y,a}$) is computed from estimated catch numbers

$$P_{y,a} = \frac{C_{y,a}}{\sum_a C_{y,a}}$$

The time series of fishery proportions at age are fitted to observed fishery values using a multinomial probability model.

Fishery catch-per-unit effort in year y ($CPUE_y$) is modeled as a catchability coefficient (Q_{CPUE}) times exploitable biomass raised to a power (β_{CPUE}), where exploitable biomass is computed at the midpoint of the year

$$CPUE_y = Q_{CPUE} \left(\sum_a S_a W_a N_{y,a} e^{-Z_{y,a}} \right)^{\beta_{CPUE}}$$

This model for CPUE coincides with the proportionality model when $\beta_{CPUE} = 1$. The estimated CPUE time series is fitted to observed values using a lognormal probability model.

The survey biomass index in year y (I_y) for either the NEFSC autumn or spring survey is modeled as a catchability coefficient (Q_{SURVEY}) times the population biomass that is vulnerable to the survey, where $S_{SURVEY,a}$ is survey selectivity at age a and p_{SURVEY} is the fraction of annual total mortality that occurs prior to the survey

$$I_y = Q_{SURVEY} \sum_a S_{SURVEY,a} W_a N_{y,a} e^{-p_{SURVEY} Z_{y,a}}$$

The survey biomass index time series are fitted to observed values using a lognormal probability model.

Survey selectivity at age is modeled using Thompson's exponential-logistic model (Thompson 1994), where α, β, and γ are parameters and survey selectivity for redfish is assumed to be time invariant.

$$S_{SURVEY,a} = \frac{1}{1-\gamma} \left(\frac{1-\gamma}{\gamma} \right)^{\gamma} \left(\frac{e^{\alpha\gamma(\beta-a)}}{1+e^{\alpha(\beta-a)}} \right)$$

This model has the useful property that the maximum selectivity value is unity. For values of γ>0 survey selectivity is dome-shaped, and survey selectivity is flat-topped when γ=0.

Survey catch proportion at age a in year y ($P_{SURVEY, y, a}$) is computed from survey selectivity, the fraction of mortality occurring prior to the survey, and population numbers at age

$$P_{SURVEY,y,a} = \frac{S_{SURVEY,a} N_{y,a} e^{-p_{SURVEY} Z_{y,a}}}{\sum_a S_{SURVEY,a} N_{y,a} e^{-p_{SURVEY} Z_{y,a}}}$$

The time series of survey proportions at age are fitted to observed fishery values using a multinomial probability model.

Statistical estimation approach
The population dynamics model is fit to observed data using an iterative maximum likelihood estimation approach. The statistical model consists of nine likelihood components (L_j) and two penalty terms (P_k). The model objective function (Λ) is the weighted sum of the likelihood components and penalties where each summand is multiplied by an emphasis coefficient (λ_j) that reflects the relative importance of the data.

$$\Lambda = \sum_j \lambda_j L_j + \sum_k \lambda_k P_k$$

Each likelihood component is written as a negative log-likelihood so that the maximum likelihood estimates of model parameters are obtained by minimizing the objective function. The Automatic Differentiation Model Builder software is used to estimate a total of 179 model parameters. The likelihood components and penalty terms are described below.

1. <u>Recruitment</u>
Recruitment strength is modeled by lognormal deviations from average recruitment for the period 1909-2000. A total of 92 recruitment deviation parameters (V_y) and one average recruitment parameter (μ_R) are estimated based on the objective function minimization.

The recruitment likelihood component (L_1) is $L_1 = \sum_y V_y^2$

where

$$V_y = \ln(R_y) - \ln(\mu_R)$$

2. <u>Fishery CPUE</u>
Fishery CPUE is modeled by lognormal deviations of predicted values from observed values, denoted with a superscript "OBS" for all variables, during 1942-1989, where W_y are iid normal random variables with zero mean and constant variance

$$CPUE_y^{OBS} = CPUE_y e^{W_y}$$

A total of 2 parameters (Q_{CPUE} and β_{CPUE}) are estimated based on the objective function minimization. The fishery CPUE likelihood component (L_2) is

$$L_2 = \sum_y V_y^2$$

3. <u>Fishery age composition</u>
Fishery age composition is modeled as a multinomial distribution for sampling catch numbers at age. The constant $N_{E,FISHERY,y}$ denotes the effective sample size for the multinomial distribution for year

y and is assumed to be constant across time for the years 1969-1985 when redfish catch-at-age data are available. The observed number of fish at age in the fishery samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 200 fish in each year during 1969-1985. The negative log-likelihood of the multinomial sampling model for the fishery ages (L_3) is

$$L_3 = -\sum_y N_{E,FISHERY,y} \sum_a \left(P_{y,a}^{OBS} \ln P_{y,a} - P_{y,a}^{OBS} \ln P_{y,a}^{OBS} \right)$$

The second term in summation over a is a constant that scales L_3 to be zero if observed and predicted proportions were identical. Nine fishery selectivity coefficients (S_1 through S_9) are estimated based on the objective function minimization.

4. Autumn survey age composition

Autumn survey age composition is also modeled as a multinomial distribution for sampling survey catch numbers at age. The constant $N_{E,AUTUMN,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be constant across time for the years 1975-2000 when redfish autumn survey catch-at-age data are available. The observed number of fish at age in the survey samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 100 fish in each year during each year. The negative log-likelihood of the multinomial sampling model for the autumn survey ages (L_4) is

$$L_4 = -\sum_y N_{E,AUTUMN,y} \sum_a \left(P_{AUTUMN,y,a}^{OBS} \ln P_{AUTUMN,y,a} - P_{AUTUMN,y,a}^{OBS} \ln P_{AUTUMN,y,a}^{OBS} \right)$$

As with the fishery age composition, the second term in the summation over a is a constant that scales L_4 to be zero if observed and predicted proportions were identical. Three autumn survey selectivity coefficients (α_{AUTUMN}, β_{AUTUMN}, γ_{AUTUMN}) are estimated based on the objective function minimization.

5. Autumn survey biomass index

The autumn survey biomass index is modeled by lognormal deviations of predicted values from observed values during 1963-2000, where $D_{AUTUMN,y}$ are iid normal random variables with zero mean and constant variance

$$I_{AUTUMN,y}^{OBS} = I_{AUTUMN,y} e^{D_{AUTUMN,y}}$$

The autumn survey biomass likelihood component (L_5) is

$$L_5 = \sum_y D_{AUTUMN,y}^2$$

One autumn survey catchability ($_{AUTUMN}$) coefficient is estimated based on the objective function minimization.

6. Spring survey age composition

Spring survey age composition is also modeled as a multinomial distribution for sampling survey catch numbers at age. The constant $N_{E,SPRING\,y}$ denotes the effective sample size for the multinomial distribution for year y and is assumed to be constant across time for the years 1975-1980 and 1984-1990 when redfish spring survey catch-at-age data are available. The observed number of fish at age in the survey samples is computed as the effective sample size times the observed proportion at age. The effective sample size was assumed to be 100 fish in each year during each year. The negative log-likelihood of the multinomial sampling model for the autumn survey ages (L_6) is

$$L_6 = -\sum_y N_{E,SPRING,y} \sum_a \left(P_{SPRING,y,a}^{OBS} \ln P_{SPRING,y,a} - P_{SPRING,y,a}^{OBS} \ln P_{SPRING,y,a}^{OBS} \right)$$

Three spring survey selectivity coefficients (α_{SPRING}, β_{SPRING}, γ_{SPRING}) are estimated based on the objective function minimization.

7. Spring survey biomass index

The spring survey biomass index is also modeled by lognormal deviations of predicted values from observed values during 1968-2000, where $D_{SPRING,\,y}$ are iid normal random variables with zero mean and constant variance

$$I_{SPRING,y}^{OBS} = I_{SPRING,y} e^{D_{SPRING,y}}$$

The spring survey biomass likelihood component (L_7) is

$$L_7 = \sum_y D_{SPRING,y}^2$$

One spring survey catchability (Q_{SPRING}) coefficient is estimated based on the objective function minimization.

8. Catch biomass

Catch biomass is modeled by lognormal deviations of predicted values from observed values during 1934-1999, where T_y are iid normal random variables with zero mean and constant variance

$$Y_y^{OBS} = Y_y e^{T_y}$$

The catch biomass likelihood component (L_8) is

$$L_8 = \sum_y T_y^2$$

9. Fishing mortality

Fishing mortality on fully-selected ages is modeled by lognormal deviations from average fishing mortality for the period 1934-1999. A total of 66 recruitment deviation parameters (U_y) and one average fishing mortality parameter (μ_F) are estimated based on the objective function minimization. The fishing mortality likelihood component (L_9) is

$$L_9 = \sum_y U_y^2$$

where

$$U_y = \ln(F_y) - \ln(\mu_F)$$

10. Fishery selectivity

Two constraints on fishery selectivity are included in a penalty function. The fishery selectivity penalty function (P_1) is

$$P_1 = \left(\tfrac{1}{9} \sum_{a=1}^{9} S_a - 1 \right)^2 + \sum_{a=1}^{7} \left(S_a - 2S_{a+1} + S_{a+2} \right)^2$$

The first term constrains the fishery selectivity coefficients to scale to an average of 1. The second term constrains the fishery selectivity coefficient of age a+1 to be near to the linear prediction of this value interpolated from age a and age a+2 selectivities over the range of estimated selectivity coefficients.

11. Fishing mortality penalty

One constraint on fishing mortality is imposed to ensure that during the early phases of the iterative estimation process that the observed catch is not generated by an extremely small F on an extremely large population size. The fishing mortality penalty function (P_2) is

$$P_2 = 10 \sum_y \left(F_y - 0.1 \right)^2 \Leftrightarrow \; phase < 3$$

$$P_2 = \tfrac{1}{1000} \sum_y \left(F_y - 0.1 \right)^2 \Leftrightarrow \; phase \geq 3$$

The constraint is weighted with a value of 10 for the initial estimation phases and is weighted with a value of 0.001 for the latter and final estimation phases. The value of 0.1 was used because this is near the maximum computed in previous VPA-based analyses of the redfish stock. Sensitivity analyses that changed 0.1 to either 0.05 or 0.2 showed virtually no difference in parameter estimates.

Initial values are input for all parameters before the estimation phases are conducted. A total of seven estimation phases were used for the iterative minimization of the objective function. The first phase estimates average recruitment. The second phase estimates average fishing mortality and fishing mortality deviations. The third phase estimates recruitment deviations. The fourth phase estimates fishery and survey selectivity coefficients. The fifth and sixth phases are placeholders left open for additional parameters, if needed, while the seventh phase estimates the fishery CPUE catchability and beta parameters.

The eleven emphasis values used for the baseline analysis were: 10 (recruitment), 10 (fishery CPUE), 1 (fishery age composition), 1 (autumn survey age composition), 1000 (autumn survey biomass index), 1 (spring survey age composition), 1000 (spring survey biomass index), 1000 (catch biomass), 1 (fishing mortality), 100 (fishery selectivity penalty), 1 (fishing mortality penalty).

Model diagnostics

Model diagnostics were the discrepancies between observed data and predicted values for the catch biomass series (Figure C20), the autumn survey biomass series (Figure C21), the spring survey biomass series (Figure C22), the fishery CPUE series (Figure C23), fishery age composition series (Figure C24), autumn survey age composition series (Figure C25), and spring survey age composition series (Figure C26).

Model results

Key model results of spawning biomass, fishing mortality, recruitment, and population biomass for the period 1963-2000 are listed in Table C8.

Fishery and survey selectivity estimates at age are shown in Figure C27. Fishery selectivity was flat-topped with full selectivity at age 9. While it was assumed that selectivity for ages 10 and older was equal to age-9 selectivity, this did not mean that the age-9 fish had to be fully-selected. The autumn survey selectivity pattern was moderately dome-shaped with full selection at age 5. In contrast, spring survey selectivity was dome-shaped with full selection at age 9. The NDWG noted that the spring survey selectivity pattern was robust but the autumn survey selectivity pattern was sensitive to the inclusion of recent autumn survey age composition data. In particular, autumn survey selectivity was flat-topped in an initial model run that included the 1996-1998 and 1981-1983 autumn survey age composition data but did not include the 1999-2000 data.

Recruitment estimates are shown in Figure C28 (see also Table C8). Strong year classes have been sporadic in recent years with the 1971 and 1992 year classes being very large. Recruitment was higher, on average, in the 1950s-1960s than in recent years. Overall, the model's ability to resolve which year class(es) in the early 1990s were strong was dependent on the recent autumn survey age composition data, in part due to the lack of commercial fishery age composition data since 1985. The NDWG noted that the earliest recruitment values in the time series (1934-1962) were not reliable as absolute measures of recruitment strength by year because these values were sensitive to assumptions about how to estimate the initial population size at age in 1934. This sensitivity was a natural consequence of having little information on annual recruitment variation at the beginning of the time series. In particular, the extremely large recruitment estimate in 1942 was sensitive to model assumptions about initial population size.

Population biomass estimates are shown in Figure C29 (see also Table C8). Population biomass declined from the 1950s to the late-1980s and has increased since then. The NDWG noted that the early portion of the population biomass time series (1934-1951) was less reliable because there was no relative abundance information during that time period, i.e., the model was only tuned to catch biomass in the 1930s-1940s. The NDWG also noted that population biomass estimates in the 1970s-1980s were very similar to those obtained with an untuned VPA conducted for SAW 2.

Spawning biomass estimates (at start of the spawning season) are shown in Figure C30 (see also Table C8). Spawning biomass declined from the 1950s to the late-1980s and has increased throughout the 1990s. The NDWG noted that the current population biomass estimate was sensitive to the size of the strong year class(es) of the early-1990s which could start to appear in fishery catches, if a directed redfish fishery was started again.

Fishing mortality estimates are shown in Figure C31 (see also Table C8). Annual estimates of fishing mortality early in the time series (1934-62) were not considered to be reliable because they were sensitive to assumptions about initial population size. Instead, the early estimates of F provide information on the average fishing mortality that was experienced by the redfish population as the fishery began. Fishing mortality increased from 0.05-0.1 in the early 1960s to over 0.20 in the late-1970s to early-1980s. Since then, fishing mortality has declined and is currently below 0.01 in 2000.

Stock-recruitment data are shown in Figure C32. Recruitment was below-average throughout 1963-2000, with the exception of a few strong year classes, for example, the 1971 and 1992 year classes.

Surplus production implied by the age-structured estimates of exploitable biomass and observed catches are shown in Figure C33. Surplus production was above 10 kt per year during the 1960s and then declined to very low levels in the 1980s because recruitment was very low. The recent increase in surplus production is due to strong recruitment in the early 1990s. The trajectory of surplus production shows the decline from 1963 to 1990 followed by a sharp increase in recent years.

Model sensitivity to the assumption that natural mortality is 0.05 is shown in Figure C34. The likelihood profile for natural mortality shows that there are values of M from 0.025 to 0.045 that produce a higher value of the total model likelihood than M=0.05. The biomass time series shows the consequence of higher or lower values of M on estimated population biomasses.

Model sensitivity to the assumption that each of the relative abundance indices (autumn and spring survey biomass indices and CPUE) provides useful information on population trend is shown in Figure C35. The delete one index sensitivity analysis shows that the model is robust to the exclusion of one index. The delete two indices sensitivity analysis shows that the model is robust to the use of only the autumn or the spring survey series. However, use of only the CPUE series would produce a substantially different population biomass trajectory.

Biomass Dynamics Model

MSY-based reference points

The current overfishing definition and targets for redfish are based on an MSY estimate from surplus production analysis (MSY=14,000 mt, Mayo 1980), supplemented with an F_{MSY} proxy from a dynamic pool model ($F_{20\%}$=0.12), to derive a proxy B_{MSY} (14,000/0.12=60,500 mt, Applegate et al. 1998). As calculated, the current B_{MSY} proxy is in units of exploitable biomass.

The age-structured model provides some information on the likely range of MSY based on average recruitment and yield-per-recruit values. If $F_{0.1}$=0.06 is assumed to be a suitable proxy for F_{MSY}, then the average recruitment of 27,954 thousand age-1 recruits would produce an MSY of roughly 4,562 mt. Based on the 95% confidence interval for the point estimate of average recruitment and a fixed yield-per-recruit value of 0.1632 at $F_{0.1}$=0.06, the 95% confidence interval for MSY would be (4,401 mt, 4,729 mt). In contrast, if one assumed that F_{MAX}=0.13 was a suitable proxy for F_{MSY}, the point estimate of MSY would be 5,048 mt with a 95% confidence interval of (4,870 mt, 5,234 mt). Thus, the age-structured model suggests that MSY may be on the order of 4,400-5,200 mt, a much lower value than that suggested by surplus production analyses. However, these estimates of recruitment depend considerably on the average recruitment applied to the yield per recruit estimates. Since the mid-1960s, recruitment has been extremely low in most years with the exception of a few very large year classes. Thus, an average value which captures the observed recruitment pattern is difficult to calculate for this stock. For similar reasons, these data provide little evidence of a stock-recruitment relationship. Therefore, an age-disaggregated approach, in which natural mortality, growth and recruitment are subsumed into a single parameter, the intrinsic rate of growth (r), may provide additional insight into the past trajectory of biomass and fishing mortality for this stock.

A biomass dynamics model (ASPIC, Prager 1994) was developed to revise the MSY estimate and replace proxies with direct estimates of MSY reference points that include all available information on trends in biomass and catch. The analysis includes the entire time series of catch since the beginning of the fishery (1934-2000), NEFSC spring and fall survey biomass indices (1968-2000 and 1963-2000, respectively), and the standardized CPUE series (1952-1990; Figure C36). The three biomass indices are moderately correlated (correlation ranged from 0.42-0.63). Initial attempts to fit ASPIC had problems with convergence and sensitivity to starting values and random number seeds. In order to reduce the number of estimated parameters, biomass in 1934 was set equal to K and therefore removed from estimation. Initial trials that estimated B1R indicated that biomass in 1934 was near K. The assumption that the stock was at virgin biomass in 1934 is justified, because there was no fishery prior to 1934 and incidental catch of redfish in other fisheries was negligible. Furthermore, life history characteristics of redfish such as long lifespan, slow growth, slow maturity, and internal fertilization suggest that the population is "K-selected" and will maintain a relatively stable stock size near its carrying capacity in the absence of fishing.

Model results

The model fit the biomass indices well (R^2=0.71 for CPUE, 0.59 for fall, and 0.37 for spring; Figures C37-C39). Although the observed data represents a large dynamic range (Figure C40), biomass dynamics parameters (r: intrinsic rate of increase and K: carrying capacity) are largely influenced by a few observations. For example, r is largely influenced by the large rate of increase in recent years from strong recruitment, and K is largely determined by estimates from the early years in the time series, which are not calibrated with biomass indices (Figure C40).

The estimate of MSY is 20,000 mt (Figure C41) with an 80% confidence limit of 19,000-22,000 mt, which is similar to a previous estimate from production modeling (Mayo 1975). The estimate of F_{MSY} (0.09 on total biomass, with an 80% CI of 0.08-0.10) is consistent with life history and relatively low productivity of redfish. The estimate of B_{MSY} is 226,000 with an 80% CI of 211,000-244,000 mt. However, estimates of absolute biomass from ASPIC are commonly misleading, and ratios of biomass or F to MSY conditions are more reliable (Prager 1994). Comparisons of biomass estimates from ASPIC, the historical VPA (NEFSC 1986) and the present age-based dynamics model suggest that ASPIC underestimates redfish biomass (Figure C42). Therefore, only relative biomass and F estimates from ASPIC (Figures C43 and C44) should be considered to be reliable. The estimate of biomass in 2001 is 33% of B_{MSY} with an 80% CI of 27-40%, and the estimate of F on biomass in 2000 is estimated as 5% of Fmsy with an 80% CI of 4-7% (Table C9, "REDFISH3" in Table C10).

Sensitivity of ASPIC results to excluding the CPUE series and estimating biomass in 1934 was assessed with alternative analyses. Results from sensitivity analyses suggest that estimates are relatively robust to both decisions (Table C10). Estimates of MSY, F_{MSY}, and B_{MSY} and B_{2001}/B_{MSY} had less than 3% difference in estimates among alternative runs, but estimates of F_{2000}/F_{MSY} had slightly greater sensitivity (9% difference). However, alternative runs that estimated B1R had problems converging on a solution. No solution could be found when CPUE was included and B1R was estimated. Many bootstrap trials could not converge when B1R was estimated without including CPUE ("REDFISH2"), and results were sensitive to random number seeds. Including CPUE in the analysis appears to reduce variance of parameter estimates, and therefore "REDFISH3" was chosen as the best run.

An additional analysis was performed to assess sensitivity of model parameter estimates to the recently observed strong recruitment by truncating the analysis to 1934-1995 ("REDFISHT" in Table C10). Results indicate that the stock is less productive (i.e., a 34% decrease in Fmsy) when recent observations are excluded from the model. Therefore, when the entire time series is included in the model, there is an explicit assumption that the recently observed high recruitment is consistent with the long-term reproductive capacity of the stock.

The capacity of the redfish stock to rebuild to B_{MSY} was assessed using ten-year stochastic projections from "REDFISH3" assuming F=0 from 2001 to 2010. Results indicate that the stock can rebuild to B_{MSY} in 2010 in the absence of fishing (Figure C45). However, the projection implicitly assumes the higher productivity indicated by analysis of the entire time series (i.e., including the recently observed strong recruitment). As demonstrated in the sensitivity analyses, the estimate of intrinsic growth rate (r) is sensitive to recent recruitment observations.

SUMMARY

- Landings have remained at historic low levels (< 1,000 t) since 1989 after declining from an average 14,000 t during 1977-1979.

- Commercial CPUE had declined by the late 1980s by over 80% from levels observed during the 1960s.

- Exploitable (age 5+) biomass estimates derived by VPA declined by 75% between 1969 and 1984.

- Fully recruited (age 9+) instantaneous fishing mortality (F) ranged from 0.18 to 0.26 between 1969 and 1983, but has declined in recent years as landings have declined sharply from mid-1980s levels.

- Relative abundance and biomass indices from NEFSC bottom trawl surveys declined by over 90% between the mid-to-late 1960s and late 1980s. Recent indices have increased to levels observed during the early 1970s.

- As a consequence of extremely poor recruitment between the mid-1960s and the mid-1980s, the age structure of the population has narrowed considerably and is now represented by one or two significant year classes. The population is now dominated by relatively young (less than 15 yrs) fish compared to the 1970s.

SARC COMMENTS

The SARC noted that the NEFSC spring and autumn survey indices of abundance, after falling to their lowest recorded levels in the mid-1980s, had gradually increased until the mid-1990s, then increased rapidly in 1996 and 1997 to levels similar to those observed in the late 1960s. The age compositions of the NEFSC survey data revealed relatively strong 1991 and 1992 year classes, supported by recruitment of reasonable magnitude in the surrounding years. The strong 1991-1992 year classes that emerged as age 4 and 5 fish in 1995-1996 were not detected in any numbers at younger ages in either the shrimp or the bottom trawl surveys. It was suggested that these year classes may not have been available to the gear at the younger ages or that the year class may possibly have immigrated from the Scotian shelf. There is an indication from examination of otoliths that size at age of these recent cohorts appears to be slowing down in contrast to previous cohorts.

Currently, the stock is comprised primarily of young fish with few older mature fish. The SARC also noted that the average total mortality (Z) determined from the combined autumn survey age composition data for all cohorts over the period from 1925 to 1995 was in the range of 0.15-0.20.

The SARC considered that the large pulse of recruitment of the 1942 year class in the age-structured dynamics model may be a mathematical artifact of 26 year old fish caught in the first year of catch-at-age data (1969) in the model. The SARC concluded that the age-structured results prior to 1963, when the autumn survey data became available as a relative abundance index, are less reliable and should not be used as they lie beyond the range of the tuning data. In particular, the estimated biomass in 1934 should not be used as an estimate of virgin biomass. Absolute biomass from the age-structured model prior to 1963 is important for a historical perspective of the stock; however, uncertainty exists in the proportion of biomass by age before the survey was conducted.

The SARC expressed concern that F may be higher in recent years than that estimated by the age-structured model due to an unknown and possibly significant discard mortality, from both discarded catch and through encounter of uncaught redfish with the fishing gear, noting that the large mesh trawl fishery effort has recently shifted to the Gulf of Maine from Georges Bank. It was noted that size classes currently present in the population are not yet fully recruited to the 6 inch mesh regulation in the large mesh trawl fishery. The SARC concluded that research is needed to quantify the significance of this non-landed fishing mortality.

The SARC noted that, in the analysis based on the biomass dynamics model (ASPIC), the estimation of 'r', the intrinsic rate of increase, may be unduly influenced by the most recent estimates of recruitment and therefore affect estimation of biological reference points. An alternative ASPIC analysis was requested with the most recent years (1996-2000) of survey indices deleted from the input data. The results indicated that the estimate of 'r' was sensitive to the more recent strong year classes. Reliable information on relative biomass prior to 1952 is not available, since the CPUE was not standardized prior to 1952. As a result the SARC agreed that the early CPUE data be excluded as a relative abundance measure and only the 1952- present data be applied in the analyses.

The SARC discussed the appropriateness of the surplus production model for estimating biological reference points for a slow growing, long lived species such as redfish. Although biomass dynamics models assume an instantaneous response to change in population size, they have been used by the International Whaling Commission in studies of marine mammals, and for other long-lived species such as swordfish, where similar lags might be expected.

The SARC noted that estimates of model parameters will change as the models are improved and as new data are added. The absolute magnitude of selected reference points will change, sometimes considerably, as they must be updated when new parameter estimates become available. Estimates of B_{msy} and F_{msy} from the ASPIC results are not reliable as absolute estimates; however, the ratios of B_{2001}/B_{msy} and F_{2000}/F_{msy} are informative. Rather than specifying absolute values for the threshold and target reference points, it is equally effective and more consistent to express the current status as a ratio of the reference point. The statement that the current biomass is estimated to be 33% of B_{Target} where $B_{Target} = B_{MSY}$ clearly identifies the current status with respect to the reference point.

The values of existing reference points were considered to be inappropriate and the SARC advised that they be replaced with values determined from the curent assessment. Using the ratio derived from the biomass dynamics model, $B_{2001}/B_{MSY} = 0.33$ and the current fishing mortality status is estimated as $F_{2000}/ F_{MSY} = 0.05$. The absolute estimate of F_{MSY} from the surplus production model exceeds the assumed M used in the age-based model, highlighting the difficulty of expressing estimates from two types of models in comparable terms. For long-lived species, it is considered inappropriate to use a value such as $F_{20\%}$ as a limit or threshold reference point, and a value such as $F_{40\%}$ or $F_{50\%}$ is required to ensure sustainability. For rockfish, $F_{50\%}$ is considered necessary (Ralston et al. 1998, Dorn 2001).

The SARC concluded that the stock is being rebuilt from the collapsed state it reached in the 1970s. It is unlikely to recover quickly. The current stock is comprised primarily of young fish, and its growth and reproductive potential may differ from that of a similar sized population with a greater representation of older, mature fish.

Sources of Uncertainty

The source of recent large year classes is not as certain as previous large year classes, and the possibility exists that these year classes immigrated into the Gulf of Maine region.

Characterization of the length composition of the landings is uncertain due to insufficient sampling since 1994.

The difference between the spring and autumn selectivity pattern in the age-structured model can not be explained by differences in the time series and may be due to other causes such as differences in the spatial distribution of the stock during the two seasons.

Reliable information on relative biomass prior to 1952 is not available, since the CPUE was not standardized prior to 1952.

Estimates of B_{msy} and F_{msy} from the ASPIC results are not reliable as absolute estimates, however, the ratios of B_{2001}/B_{msy} and F_{2000}/F_{msy} are informative.

RESEARCH RECOMMENDATIONS

- Further examination of the mortality estimates from catch curve for the individual cohorts should be undertaken. Maturation, growth, yield per recruit, etc., should be calculated for each cohort to examine density dependence of parameters.

- Investigate the growth rate of recent year classes and the implications on the rate of maturation.

- Investigate the option of starting the age-structured model in 1963, and applying the resulting parameters to hindcast the population in 1934.

- Further investigation of the magnitudes of the biomass and fishing mortality estimated by the age-structured dynamic model is required.

- Determine the discard mortality and undertake research to assess the mortality resulting from encounter with fishing gear.

- Examine Canadian surveys to determine if strong year classes were also produced in Division 4X or other regions of the Scotian Shelf area in the early 1990's.

- Investigate whether the increase in the redfish stock might be due to immigration rather than recruitment.

- Explore the possible use of alternative reference points, such as $F_{50\%}$ or F=M, as status determination criteria for redfish.

- Ensure that the intensity of sea sampling is adequate to provide details of the age composition of commercial catches and quantities of discards.

- Incorporate length frequency data into the age-structured model.

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Table C1. Nominal redfish catches (metric tons), actual and standardized catch per unit effort, and calculated standardized USA and total effort for the Gulf of Maine-Georges Bank redfish fishery.

	Nominal Catch (Metric tons)			USA Catch per Unit Effort (tons/day)		Calculated Standard Effort (days fished)	
Year	USA	Others	Total	Actual	Standard	USA	Total
1934	519		519				
1935	7549		7549				
1936	23162		23162				
1937	14823		14823				
1938	20640		20640				
1939	25406		25406				
1940	26762		26762				
1941	50796		50796				
1942	55892		55892	6.9	6.9	8100	8100
1943	48348		48348	6.7	6.7	7216	7216
1944	50439		50439	5.4	5.4	9341	9341
1945	37912		37912	4.5	4.5	8425	8425
1946	42423		42423	4.7	4.7	9026	9026
1947	40160		40160	4.9	4.9	8196	8196
1948	43631		43631	5.4	5.4	8080	8080
1949	30743		30743	3.3	3.3	9316	9316
1950	34307		34307	4.1	4.1	8368	8368
1951	30077		30077	4.1	4.1	7336	7336
1952	21377		21377	3.5	3.4	6287	6287
1953	16791		16791	3.8	3.6	4664	4664
1954	12988		12988	3.4	3.1	4190	4190
1955	13914		13914	4.5	4.0	3479	3479
1956	14388		14388	4.4	3.8	3786	3786
1957	18490		18490	4.3	3.6	5136	5136
1958	16043	4	16047	4.4	3.6	4456	4458
1959	15521		15521	4.3	3.5	4435	4435
1960	11373	2	11375	3.8	3.0	3791	3792
1961	14040	61	14101	4.6	3.5	4011	4029
1962	12541	1593	14134	5.4	4.0	3135	3534
1963	8871	1175	10046	4.1	3.0	2957	3349
1964	7812	501	8313	4.3	2.9	2694	2867
1965	6986	1071	8057	7.0	4.4	1588	1831
1966	7204	1365	8569	11.7	6.4	1126	1339
1967	10442	422	10864	12.4	5.6	1865	1940
1968	6578	199	6777	14.7	6.1	1078	1111
1969	12041	414	12455	11.4	4.9	2457	2542
1970	15534	1207	16741	9.0	4.0	3884	4185
1971	16267	3767	20034	7.0	3.2	5083	6261
1972	13157	5938	19095	5.7	2.9	4537	6584
1973	11954	5406	17360	5.3	2.9	4122	5986
1974	8677	1794	10471	5.0	2.6	3337	4027
1975	9075	1497	10572	4.0	2.2	4125	4805
1976	10131	565	10696	4.6	2.3	4405	4650
1977	13012	211	13223	4.9	2.5	5205	5289
1978	13991	92	14083	4.8	2.4	5830	5868
1979	14722	33	14755	3.6	1.9	7748	7766
1980	10085	98	10183	3.2	1.6	6303	6364
1981	7896	19	7915	2.7	1.4	5640	5654
1982	6735	168	6903	2.7	1.5	4490	4602
1983	5215	113	5328	2.1	1.2	4346	4440
1984	4722	71	4793	1.9	1.1	4293	4357
1985	4164	118	4282	1.4	0.9	4627	4758
1986	2790	139	2929	1.0	0.6	4650	4882
1987	1859	35	1894	1.1	0.7	2656	2706
1988	1076	101	1177	0.9	0.5	2152	2354
1989	628	9	637	1.1	0.6	1047	1062
1990	588	13	601	**	**		
1991	525		525	**	**		
1992	849		849		**		
1993	800		800		**		
1994*	440		440		**		
1995*	440		440		**		
1996*	322		322		**		
1997*	251		251		**		
1998*	320		320		**		
1999*	353		353	**	**		
2000*	319		319	**	**		

* Preliminary
CPUE and effort not calculated due to sharp reduction in directed redfish trips

Table C2. Commercial length and age sampling summary for Gulf of Maine - Georges Bank Redfish, 1969-2000.

Year	Landings (tons)	Number of Samples	Number of tons/sample	Number of Length Measurements	Number of Ages Collected	Number of Ages Available
1969	12455	14	890	3,200	?	616
1970	16741	18	930	2,300	600	461
1971	20034	34	589	7,796	963	963
1972	19095	16	1193	5,085	?	1,066
1973	17360	23	755	6,246	1,120	1,027
1974	10471	34	308	7,945	2,170	1,011
1975	10572	27	392	6,761	2,912	1,147
1976	10696	24	446	8,094	3,700	1,028
1977	13223	31	427	8,495	3,688	863
1978	14083	30	469	5,493	2,352	1,012
1979	14755	35	422	8,975	3,866	1,122
1980	10183	21	485	4,858	2,210	1,110
1981	7915	21	377	3,718	1,718	851
1982	6903	27	256	4,216	1,734	849
1983	5328	31	172	5,100	2,416	995
1984	4793	26	184	4,603	2,275	1,018
1985	4282	37	116	5,775	2,962	1,464
1986	2929	38	77	6,063	3,102	N/A
1987	1894	29	65	4,633	2,290	N/A
1988	1177	21	56	2,487	1,258	N/A
1989	637	17	37	1,921	958	N/A
1990	601	12	51	1,338	692	N/A
1991	525	10	52	1,136	?225	N/A
1992	849	11	77	1,354	?	N/A
1993	800	5	160	528	?	N/A
1994	440	2	220	226	?	N/A
1995	440	3	147	303	?	N/A
1996	322	1	322	113	?	N/A
1997	251	3	84	343	?	N/A
1998	320	0	–	0	?	N/A
1999	353	1	353	111	?	N/A
2000	319	1	319	110	?	N/A

Table C3. Total catch at age and mean weights at age for Gulf of Maine - Georges Bank redfish, 1969-1985.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26+
													Number landed (000s)													
1969	-	-	-	22	421	439	1008	6065	2513	6717	2660	3975	3287	2221	2820	1348	751	526	606	426	451	345	469	38	100	847
1970	-	-	-	-	146	4055	4048	1060	9692	3221	8351	2734	4702	2672	2302	3489	1778	1640	393	662	368	529	572	488	64	1743
1971	-	-	-	-	-	72	1941	4430	1536	7907	2767	6504	3088	4267	3680	2895	2206	2765	1347	1163	560	1048	559	282	138	2439
1972	-	-	-	-	-	-	933	3296	7401	1712	7580	2782	2884	1994	3531	2449	1205	1276	2245	734	1011	1172	718	538	1280	2874
1973	-	-	-	-	-	-	235	2463	7938	8391	2201	7337	2078	3100	2376	2024	1799	1380	864	933	411	590	426	295	289	1977
1974	-	-	308	105	-	17	8	174	1886	4724	2945	2435	1709	1115	1302	935	1454	910	640	661	589	730	271	285	250	1755
1975	-	-	4	695	72	11	-	30	124	1944	4360	2154	1932	1442	1009	1344	1360	1235	945	1116	608	887	492	294	298	1282
1976	-	-	-	196	8961	439	-	-	21	48	467	2706	3375	1702	1725	1388	1233	1166	1424	608	769	681	323	672	94	2011
1977	-	-	-	-	234	16747	311	-	-	-	81	2127	1262	4012	1823	2747	1466	1190	1064	461	706	541	117	571	1013	2157
1978	-	-	-	-	-	271	24569	215	-	34	33	182	1689	1484	2948	1748	1310	866	899	1283	895	734	500	192	530	2220
1979	-	-	-	-	25	205	849	23729	152	117	48	168	541	1228	1972	1299	1580	983	845	1008	798	594	532	538	427	2506
1980	-	-	-	-	-	132	175	1110	16900	208	44	46	217	491	830	1221	860	664	564	452	473	370	349	294	265	1308
1981	-	-	23	-	77	40	57	47	223	12380	84	22	-	44	317	364	1274	506	534	396	318	381	306	326	350	1540
1982	-	-	3	271	123	60	92	30	-	15	7268	56	32	21	128	185	582	452	840	324	501	484	301	134	104	2270
1983	-	-	-	11	1687	159	46	43	86	49	141	4959	58	106	64	42	85	319	270	551	169	224	314	195	131	1817
1984	-	-	46	11	51	6674	-	20	40	-	35	15	3571	-	44	49	34	92	210	166	324	215	144	157	162	1807
1985	-	-	27	146	33	31	3818	-	28	11	13	40	12	3202	-	25	11	101	116	260	230	187	197	142	107	1489
													Mean weight (kg)													
1969	.010	.020	.052	.113	.115	.142	.169	.195	.219	.260	.320	.339	.366	.404	.425	.473	.495	.457	.589	.497	.515	.594	.589	.705	.708	.591
1970	.010	.020	.052	.092	.172	.168	.170	.189	.221	.236	.290	.339	.356	.367	.340	.418	.427	.438	.523	.579	.505	.450	.464	.476	.345	.541
1971	.010	.020	.052	.092	.135	.172	.242	.244	.265	.304	.333	.369	.399	.437	.445	.468	.435	.449	.541	.553	.514	.544	.581	.481	.473	.540
1972	.010	.020	.052	.092	.135	.171	.197	.240	.257	.289	.334	.367	.399	.427	.451	.472	.490	.515	.509	.562	.581	.565	.604	.489	.560	.668
1973	.010	.020	.052	.092	.135	.171	.162	.213	.257	.281	.343	.341	.384	.402	.482	.454	.500	.492	.523	.525	.529	.641	.633	.568	.653	.620
1974	.010	.020	.064	.080	.135	.195	.150	.233	.270	.326	.331	.378	.399	.427	.449	.442	.503	.527	.540	.565	.525	.578	.585	.641	.633	.642
1975	.010	.020	.039	.098	.161	.221	.195	.383	.349	.317	.342	.394	.399	.420	.460	.469	.533	.527	.522	.550	.600	.547	.595	.607	.663	.662
1976	.010	.020	.052	.076	.135	.199	.195	.245	.345	.278	.296	.347	.395	.389	.405	.427	.511	.469	.542	.517	.518	.552	.645	.577	.628	.630
1977	.010	.020	.052	.092	.090	.173	.288	.245	.277	.297	.350	.413	.412	.408	.433	.454	.462	.534	.537	.610	.466	.595	.611	.544	.552	.605
1978	.010	.020	.052	.092	.135	.135	.209	.300	.277	.311	.383	.468	.402	.433	.423	.458	.551	.504	.526	.547	.523	.537	.633	.551	.606	.641
1979	.010	.020	.052	.092	.135	.200	.191	.251	.304	.295	.248	.402	.508	.472	.474	.564	.526	.543	.551	.617	.664	.597	.567	.605	.567	.647
1980	.010	.020	.052	.092	.135	.108	.175	.188	.283	.371	.421	.362	.424	.454	.506	.478	.499	.518	.554	.595	.647	.664	.629	.599	.681	.695
1981	.010	.020	.080	.092	.117	.150	.143	.195	.247	.318	.374	.466	.404	.532	.592	.543	.528	.499	.537	.550	.594	.617	.560	.633	.552	.650
1982	.010	.020	.052	.142	.203	.256	.242	.252	.277	.383	.395	.491	.563	.383	.544	.475	.540	.504	.564	.583	.592	.563	.621	.499	.535	.699
1983	.010	.020	.052	.107	.172	.198	.249	.329	.252	.368	.396	.425	.381	.471	.504	.595	.494	.579	.639	.580	.614	.647	.622	.630	.589	.682
1984	.010	.020	.110	.092	.206	.197	.195	.311	.252	.297	.333	.377	.403	.420	.497	.630	.569	.529	.519	.499	.610	.547	.568	.600	.517	.619
1985	.010	.020	.092	.146	.154	.177	.239	.245	.279	.345	.421	.362	.595	.443	.441	.591	.494	.545	.599	.552	.603	.635	.605	.699	.624	.692

Table C4. Spring NEFSC bottom trawl survey stratified mean catch per tow indices, average weights and average lengths of redfish in the Gulf of Maine - Georges Bank region.

	INSHORE 1				OFFSHORE 2				COMBINED 3	
	Stratified Mean Catch per Tow		Avg. Wt.	Avg. Length	Stratified Mean Catch per Tow		Avg. Wt.	Avg. Length	Stratified Mean Catch per Tow	
Year	Number	kg	kg	cm	Number	kg	kg	cm	Number	kg
1968	7.9	1.2	0.152	17.9	51.7	19.8	0.383	26.4	45.2	17.0
1969	59.0	8.3	0.141	20.3	44.2	21.7	0.491	30.6	46.4	19.7
1970	29.7	9.3	0.313	24.4	59.1	20.6	0.349	26.4	54.7	18.9
1971	49.9	13.3	0.267	24.9	176.0	81.7	0.464	29.8	157.2	71.6
1972	23.8	4.6	0.193	18.6	114.7	51.3	0.447	28.9	101.2	44.4
1973	14.4	4.6	0.319	22.0	49.6	28.9	0.583	31.4	44.4	25.3
1974	25.7	6.1	0.237	19.7	35.8	21.0	0.587	31.5	34.3	18.8
1975	50.9	18.9	0.371	25.5	37.4	17.4	0.465	28.5	38.9	17.6
1976	45.9	6.4	0.139	19.8	65.1	29.6	0.455	29.2	62.2	26.2
1977	79.1	24.0	0.303	25.3	15.6	9.4	0.603	32.1	25.1	11.6
1978	33.7	10.4	0.309	25.0	22.3	12.5	0.561	30.2	24.0	12.2
1979	27.5	8.5	0.309	25.4	67.5	36.4	0.539	30.0	61.6	32.3
1980	8.5	2.2	0.259	25.3	33.5	23.5	0.701	32.4	29.8	20.3
1981	3.0	1.0	0.333	22.5	38.9	21.7	0.558	30.5	33.6	18.6
1982	5.0	1.4	0.280	24.7	19.0	10.8	0.568	30.1	16.9	9.4
1983	4.8	0.9	0.188	21.6	10.7	7.0	0.654	31.0	9.9	6.1
1984	5.4	1.6	0.296	25.1	4.9	2.9	0.592	30.2	5.0	2.7
1985	1.2	0.4	0.333	24.8	13.6	7.7	0.566	30.1	11.7	6.6
1986	9.5	5.4	0.568	29.9	4.5	2.8	0.622	31.4	5.3	3.2
1987	5.5	1.4	0.255	23.9	27.8	14.9	0.536	30.5	24.5	12.9
1988	11.7	2.6	0.222	23.0	7.5	3.4	0.453	28.4	8.1	3.3
1989	17.6	2.7	0.153	17.6	6.5	3.0	0.462	27.8	7.6	2.9
1990	0.8	0.2	0.250	23.1	14.4	8.0	0.556	30.2	12.3	6.8
1991	5.5	0.8	0.145	19.4	10.2	4.9	0.480	28.0	9.5	4.3
1992	77.0	15.8	0.205	23.4	31.0	9.8	0.316	26.1	37.9	10.7
1993	12.4	2.2	0.182	22.6	39.5	20.2	0.510	29.7	35.5	7.5
1994	16.6	2.5	0.152	19.6	16.1	4.2	0.259	24.2	16.1	3.9
1995	11.8	2.1	0.176	20.7	6.4	1.9	0.293	23.6	7.2	1.9
1996	16.4	2.2	0.137	20.0	30.9	13.6	0.439	27.8	28.7	11.9
1997	1235.2	175.8	0.142	20.7	33.3	9.3	0.278	24.6	212.0	34.0
1998	13.6	2.0	0.145	20.4	38.4	8.9	0.231	23.6	4.7	7.8
1999	50.8	6.3	0.125	19.9	80.5	21.2	0.264	24.4	76.0	19.0
2000	12.0	2.9	0.238	23.8	209.4	65.3	0.312	25.9	180.1	56.0

Table C5. Autumn NEFSC bottom trawl survey stratified mean catch per tow indices, average weights and average lengths of redfish in the Gulf of Maine - Georges Bank region.

	INSHORE 1				OFFSHORE 2				COMBINED 3	
	Stratified Mean Catch per Tow		Avg. Wt.	Avg. Length	Stratified Mean Catch per Tow		Avg. Wt.	Avg. Length	Stratified Mean Catch per Tow	
Year	Number	kg	kg	cm	Number	kg	kg	cm	Number	kg
1963	86.3	7.6	0.088	17.4	87.5	27.0	0.309	26.4	87.3	24.1
1964	81.3	13.5	0.166	20.2	122.3	61.8	0.505	30.8	116.3	54.6
1965	189.5	22.3	0.118	17.7	33.9	11.5	0.339	25.3	57.0	13.1
1966	172.8	17.0	0.098	16.2	77.8	31.2	0.401	27.4	91.9	29.1
1967	62.9	5.3	0.084	17.7	107.1	27.6	0.258	23.6	100.5	24.3
1968	41.1	4.7	0.114	18.3	161.3	46.6	0.289	25.1	143.4	40.4
1969	105.9	16.0	0.151	20.7	65.2	24.8	0.380	27.4	71.2	23.5
1970	18.2	2.8	0.154	20.3	107.2	38.2	0.356	26.3	94.0	32.9
1971	20.7	4.7	0.227	21.8	52.8	26.7	0.506	29.7	48.0	23.4
1972	36.4	6.6	0.181	20.8	58.9	27.8	0.472	29.2	55.6	24.6
1973	26.2	2.1	0.080	15.6	41.4	19.7	0.476	29.7	39.2	17.0
1974	44.4	4.7	0.106	18.0	49.0	27.6	0.563	30.1	48.3	24.2
1975	45.7	6.0	0.131	19.6	79.9	45.9	0.574	30.6	74.8	39.9
1976	11.6	2.5	0.216	22.6	31.9	17.5	0.549	30.2	28.9	15.3
1977	54.6	12.3	0.225	23.4	37.9	18.1	0.478	28.5	40.4	17.3
1978	20.4	5.5	0.270	24.6	49.5	23.4	0.473	29.0	45.2	20.7
1979	6.2	2.1	0.339	26.5	32.8	18.4	0.561	30.5	28.9	16.0
1980	20.6	6.2	0.301	24.6	20.6	13.8	0.670	31.8	20.6	12.6
1981	6.8	1.9	0.279	24.9	22.7	14.0	0.617	31.8	20.4	12.2
1982	28.2	4.6	0.163	21.2	5.6	3.2	0.571	31.5	9.0	3.4
1983	30.2	8.7	0.288	24.8	6.5	3.3	0.508	29.1	10.0	4.1
1984	7.7	3.2	0.416	27.9	7.8	4.1	0.526	29.0	7.8	3.9
1985	7.2	2.1	0.292	24.8	14.0	6.3	0.450	28.0	13.0	5.7
1986	67.6	15.3	0.226	23.3	18.8	6.7	0.356	26.1	26.1	8.0
1987	26.5	4.8	0.181	21.9	11.5	5.6	0.487	29.2	13.7	5.5
1988	18.5	5.1	0.276	21.9	11.4	6.5	0.570	29.1	12.4	6.3
1989	14.0	2.9	0.207	22.6	21.3	7.5	0.352	25.9	20.3	6.8
1990	57.6	14.5	0.252	23.8	31.7	11.7	0.369	26.7	35.5	12.2
1991	7.2	1.1	0.153	20.4	21.1	9.6	0.455	28.5	19.1	8.4
1992	7.8	1.2	0.147	20.0	24.9	9.3	0.374	27.3	22.4	8.1
1993	53.7	7.4	0.137	20.0	32.5	11.9	0.366	26.3	35.6	11.2
1994	31.5	5.4	0.171	21.7	19.0	6.0	0.317	25.0	20.9	5.9
1995	109.7	11.1	0.102	18.5	19.9	3.5	0.177	21.3	33.2	4.7
1996	53.8	9.1	0.169	21.5	189.9	34.4	0.181	21.8	169.6	30.6
1997	105.6	15.7	0.149	20.3	57.9	19.5	0.337	26.0	65.0	18.9
1998	48.7	10.7	0.219	20.4	128.9	35.4	0.275	23.6	117.0	31.7
1999	164.2	35.1	0.214	23.2	68.2	20.7	0.304	25.6	82.5	22.9
2000	133.3	22.0	0.165	21.6	99.4	26.9	0.271	24.8	104.4	26.2

Table C6. Yield and spawning stock biomass pre recruit analysis for Gulf of Maine - Georges Bank redfish.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 10- 5-2001; Time: 10:04:15.27
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

Proportion of F before spawning: .4000
Proportion of M before spawning: .4000
Natural Mortality is Constant at: .050
Initial age is: 1; Last age is: 26
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> d:\assess\redf\yrred.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0138	1.0000	.0100	.010	.002
2	.0312	1.0000	.0200	.020	.012
3	.0697	1.0000	.0500	.059	.033
4	.1507	1.0000	.1500	.099	.064
5	.2999	1.0000	.3600	.145	.103
6	.5084	1.0000	.6400	.178	.148
7	.7291	1.0000	.8500	.201	.196
8	.9289	1.0000	.9500	.250	.246
9	1.0000	1.0000	.9800	.272	.295
10	1.0000	1.0000	.9900	.310	.343
11	1.0000	1.0000	1.0000	.348	.388
12	1.0000	1.0000	1.0000	.391	.430
13	1.0000	1.0000	1.0000	.423	.469
14	1.0000	1.0000	1.0000	.429	.505
15	1.0000	1.0000	1.0000	.463	.537
16	1.0000	1.0000	1.0000	.495	.566
17	1.0000	1.0000	1.0000	.503	.592
18	1.0000	1.0000	1.0000	.508	.615
19	1.0000	1.0000	1.0000	.548	.636
20	1.0000	1.0000	1.0000	.558	.654
21	1.0000	1.0000	1.0000	.565	.669
22	1.0000	1.0000	1.0000	.581	.683
23	1.0000	1.0000	1.0000	.595	.696
24	1.0000	1.0000	1.0000	.583	.706
25	1.0000	1.0000	1.0000	.581	.716
26+	1.0000	1.0000	1.0000	.637	.750

Summary of Yield per Recruit Analysis for:
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

Slope of the Yield/Recruit Curve at F=0.00: --> 7.5310
F level at slope=1/10 of the above slope (F0.1): -----> .059
Yield/Recruit corresponding to F0.1: -----> .1632
F level to produce Maximum Yield/Recruit (Fmax): -----> .127
Yield/Recruit corresponding to Fmax: -----> .1806
F level at 30 % of Max Spawning Potential (F30): -----> .075
SSB/Recruit corresponding to F30: --------> 2.6312

Listing of Yield per Recruit Results for:
REDFISH UPDATED AVE WTS & FPAT, MAT VECTOR (MAYO ET AL. 1990)

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	20.5042	9.1737	15.7030	8.7760	100.00
	.05	.38712	.15522	12.7649	3.9263	8.0041	3.5674	40.65
F0.1	.06	.41925	.16317	12.1227	3.5252	7.3690	3.1719	36.14
F30%	.07	.46461	.17220	11.2165	2.9757	6.4750	2.6312	29.98
	.10	.51797	.17890	10.1507	2.3604	5.4286	2.0284	23.11
Fmax	.13	.55860	.18057	9.3395	1.9207	4.6377	1.6001	18.23
	.15	.58466	.17981	8.8194	1.6549	4.1345	1.3428	15.30
	.20	.62564	.17533	8.0023	1.2684	3.3532	.9718	11.07
	.25	.65370	.16973	7.4432	1.0297	2.8287	.7459	8.50
	.30	.67435	.16423	7.0323	.8698	2.4512	.5967	6.80
	.35	.69033	.15916	6.7145	.7561	2.1657	.4923	5.61
	.40	.70318	.15459	6.4593	.6714	1.9418	.4158	4.74
	.45	.71381	.15049	6.2483	.6060	1.7611	.3578	4.08
	.50	.72281	.14681	6.0696	.5540	1.6119	.3124	3.56
	.55	.73058	.14349	5.9156	.5117	1.4864	.2762	3.15
	.60	.73739	.14047	5.7808	.4765	1.3793	.2467	2.81
	.65	.74343	.13772	5.6612	.4467	1.2868	.2222	2.53
	.70	.74885	.13520	5.5540	.4212	1.2058	.2016	2.30
	.75	.75376	.13288	5.4570	.3991	1.1345	.1841	2.10
	.80	.75823	.13072	5.3685	.3797	1.0710	.1690	1.93
	.85	.76234	.12871	5.2872	.3625	1.0141	.1559	1.78
	.90	.76614	.12683	5.2122	.3471	.9628	.1444	1.65
	.95	.76967	.12506	5.1425	.3333	.9163	.1343	1.53
	1.00	.77296	.12340	5.0775	.3208	.8740	.1253	1.43

Table C7. Commercial landings (mt), NEFSC autumn survey biomass index (kg/tow), and index of exploitation for Gulf of Maine redfish.

Year	Commercial landings (mt)	Biomass Index	Exploitation Ratio
1963	10046	24.1	0.4168
1964	8313	54.6	0.1523
1965	8057	13.1	0.6150
1966	8569	29.1	0.2945
1967	10864	24.3	0.4471
1968	6777	40.4	0.1677
1969	12455	23.5	0.5300
1970	16741	32.9	0.5088
1971	20034	23.4	0.8562
1972	19095	24.6	0.7762
1973	17360	17.0	1.0212
1974	10471	24.2	0.4327
1975	10572	39.9	0.2650
1976	10696	15.3	0.6991
1977	13223	17.3	0.7643
1978	14083	20.7	0.6803
1979	14755	16.0	0.9222
1980	10183	12.6	0.8082
1981	7915	12.2	0.6488
1982	6903	3.4	2.0303
1983	5328	4.1	1.2995
1984	4793	3.9	1.2290
1985	4282	5.7	0.7512
1986	2929	8.0	0.3661
1987	1894	5.5	0.3444
1988	1177	6.3	0.1868
1989	637	6.8	0.0937
1990	601	12.2	0.0493
1991	525	8.4	0.0625
1992	849	8.1	0.1049
1993	800	11.2	0.0714
1994	440	5.9	0.0741
1995	440	4.7	0.0946
1996	322	30.6	0.0105
1997	251	18.9	0.0133
1998	320	31.7	0.0101
1999	353	22.9	0.0154
2000	319	26.2	0.0122

Table C8. Spawning biomass (thousand mt), fully-recruited fishing mortality, recruitment (millions of age-1 fish), and population biomass (thousand mt) estimates for Gulf of Maine redfish during the period 1963-2000 from the age-structured dynamics model.

Year	Spawning biomass	Fishing mortality	Recruitment	Population biomass
1963	111.7	0.09	48.3	136.5
1964	112.9	0.08	98.1	137.7
1965	115.7	0.08	76.9	141.1
1966	120.2	0.07	33.8	147.0
1967	122.8	0.09	7.8	150.8
1968	126.0	0.05	4.3	150.8
1969	131.0	0.09	2.6	153.7
1970	130.2	0.11	2.8	148.3
1971	124.7	0.14	4.2	139.6
1972	114.0	0.15	249.2	128.6
1973	101.3	0.16	6.5	116.2
1974	91.0	0.11	2.5	110.6
1975	85.1	0.12	1.9	109.9
1976	82.9	0.14	1.7	108.8
1977	81.9	0.18	1.6	101.9
1978	76.4	0.21	2.2	89.7
1979	68.1	0.29	52.8	79.9
1980	54.4	0.24	2.5	63.1
1981	44.3	0.25	2.8	53.3
1982	35.8	0.28	10.2	45.1
1983	30.4	0.20	21.2	38.2
1984	27.9	0.17	8.7	34.2
1985	25.3	0.17	20.0	31.0
1986	24.3	0.12	11.2	29.7
1987	23.7	0.08	5.1	29.2
1988	24.1	0.05	4.4	29.2
1989	25.5	0.03	29.0	30.2
1990	27.9	0.02	51.4	32.6
1991	29.4	0.02	8.7	34.5
1992	30.6	0.03	35.7	37.8
1993	32.5	0.03	327.5	44.3
1994	35.9	0.01	73.3	51.6
1995	40.3	0.01	35.0	66.1
1996	47.7	0.01	22.4	81.6
1997	62.7	<0.01	24.9	99.2
1998	81.9	<0.01	32.2	111.2
1999	100.5	<0.01	34.5	120.5
2000	119.6	<0.01	29.2	134.6

Table C9. Estimates of relative biomass and fishing mortality for redfish from ASPIC with 80% confidence intervals (CI).

		Lower	Upper		Lower	Upper
Year	Bt/Bmsy	80% CI	80% CI	Ft/Fmsy	80% CI	80% CI
1963	31%	29%	34%	157%	157%	158%
1964	32%	29%	34%	127%	127%	129%
1965	33%	30%	35%	119%	118%	120%
1966	34%	32%	37%	121%	120%	124%
1967	36%	34%	38%	150%	147%	155%
1968	36%	34%	38%	90%	87%	94%
1969	39%	37%	40%	160%	153%	169%
1970	39%	38%	40%	221%	210%	235%
1971	37%	36%	37%	286%	271%	304%
1972	33%	32%	34%	305%	290%	324%
1973	29%	28%	30%	314%	299%	332%
1974	26%	25%	27%	204%	195%	216%
1975	25%	24%	26%	212%	201%	226%
1976	24%	24%	25%	223%	210%	239%
1977	23%	23%	24%	296%	278%	319%
1978	21%	21%	21%	360%	337%	388%
1979	18%	18%	18%	463%	435%	496%
1980	14%	14%	14%	397%	378%	423%
1981	12%	11%	12%	367%	351%	388%
1982	10%	10%	10%	376%	361%	394%
1983	8%	8%	9%	335%	321%	351%
1984	7%	7%	8%	342%	324%	359%
1985	6%	6%	7%	349%	323%	375%
1986	6%	5%	7%	264%	238%	291%
1987	5%	5%	6%	175%	154%	198%
1988	5%	5%	7%	103%	90%	118%
1989	6%	5%	7%	50%	44%	58%
1990	7%	6%	8%	42%	36%	48%
1991	8%	6%	9%	32%	27%	36%
1992	9%	7%	10%	45%	38%	52%
1993	10%	9%	12%	37%	31%	43%
1994	11%	10%	13%	18%	15%	21%
1995	13%	11%	16%	15%	13%	18%
1996	15%	13%	18%	10%	8%	12%
1997	18%	15%	21%	6%	5%	8%
1998	21%	18%	25%	7%	6%	9%
1999	24%	21%	29%	7%	5%	8%
2000	28%	24%	34%	5%	4%	7%
2001	33%	27%	40%			

Table C10. Results from alternative ASPIC analyses as compared to the accepted run, "REDFISH3" (B1R: B_{1934}/B_{MSY}; IQR: interquartile range; Q: catchability).

run options	REDFISH3	REDFISHX	REDFISH2		REDFISHT	
CPUE	included	excluded	excluded		included	
B1R	fixed	fixed	estimated	sensitivity	fixed	
time series	1934-2000	1934-2000	1934-2000	to B1R	1934-1999	sensitivity
results				and CPUE		to time series
B1R	2	2	1.647	17.7%	2	0.0%
IQR	0%	0%	25%			
MSY	20.18	20.19	20.77	2.9%	16.12	20.1%
IQR	8%	12%	13%			
r	0.1776	0.1779	0.1766	0.7%	0.118	33.6%
IQR	16%	23%	25%			
qCPUE	0.0489				0.03623	25.9%
IQR	17%					
qFall	0.3811	0.3772	0.3776	1.0%	0.2942	22.8%
IQR	15%	22%	23%			
qSpring	0.3577	0.3569	0.3569	0.2%	0.2758	22.9%
IQR	17%	24%	24%			
Bmsy	227.2	227.1	227.1	0.0%	273.3	20.3%
IQR	8%	11%	11%			
Fmsy	0.0888	0.08893	0.08893	0.1%	0.05898	33.6%
IQR	16%	23%	23%			
B2001/Bmsy	0.3289	0.3363	0.3363	2.2%		
IQR	21%	25%	25%			
F2000/Fmsy	0.05496	0.05011	0.05011	8.8%		
IQR	16%	33%	33%			
B1996/Bmsy	0.1539				0.1193	22.5%
IQR	17%					
F1995/Fmsy	0.152				0.24	57.9%
IQR	19%					
% bootstrap convergence	100	100	0.79			
random seed sensitivity	<0.01%	<0.01%	25%			

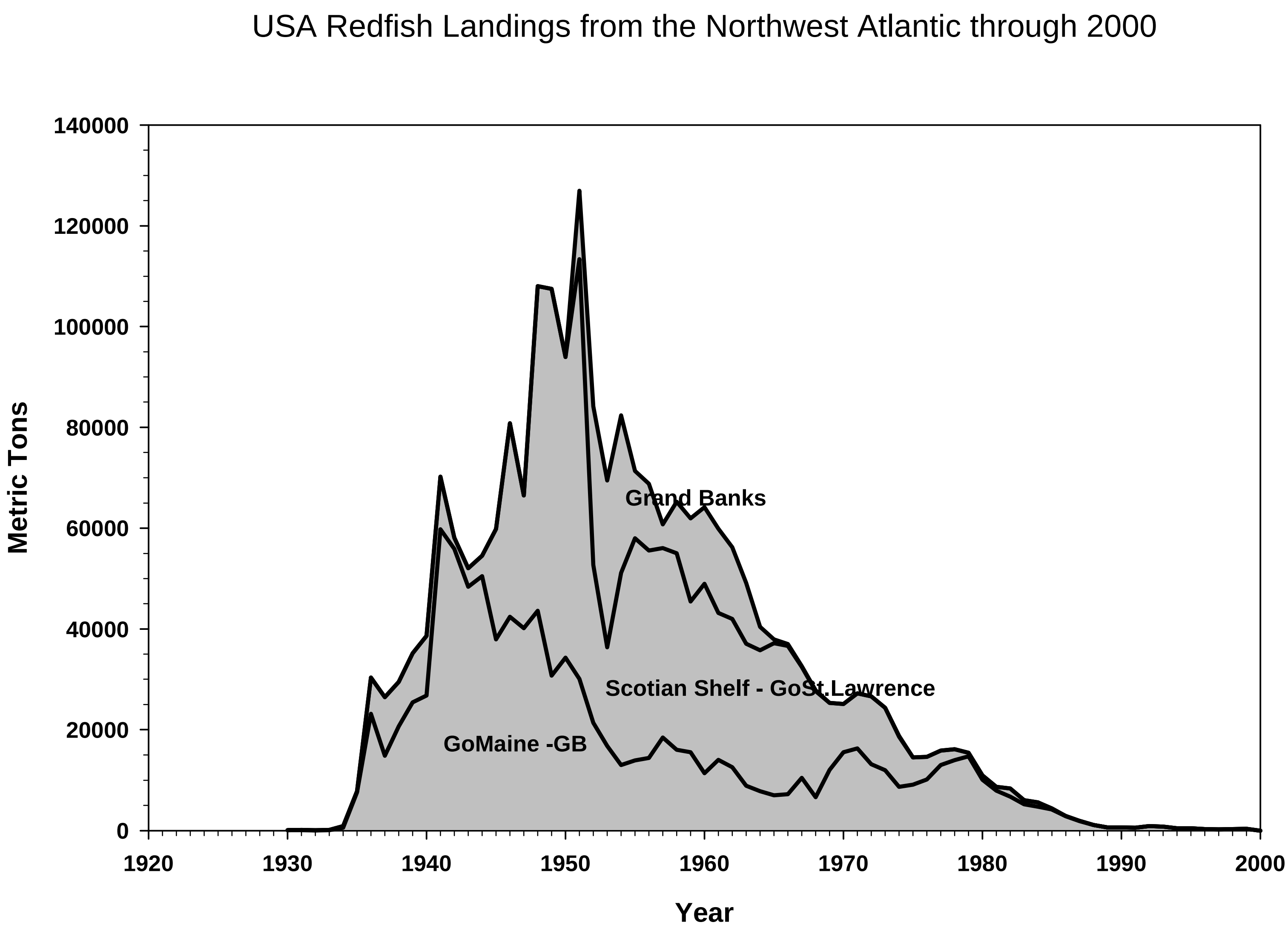
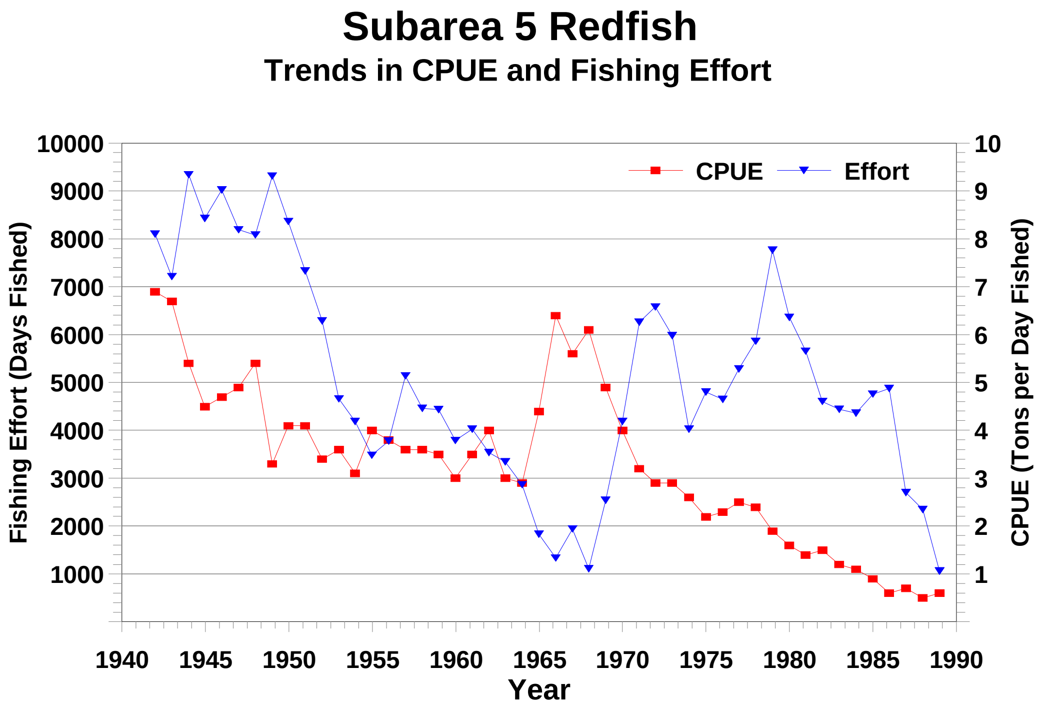


Figure C1. USA landings (metric tons, live weight) of redfish from NAFO Subarea 3 (Grand Banks and Flemish Cap), Subarea 4 (Gulf of St. Lawrence and Scotian Shelf), and Subarea 5 (Gulf of Maine and Georges Bank).



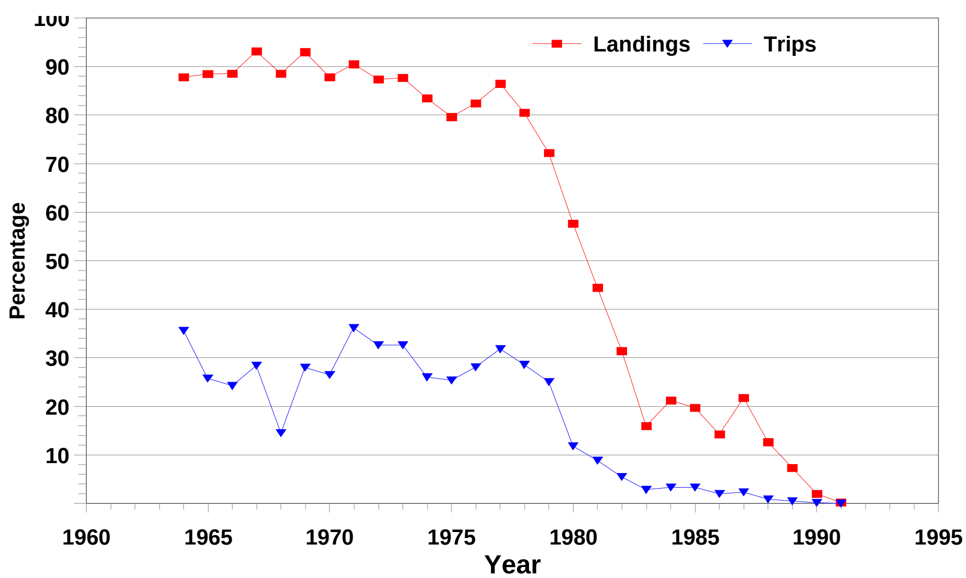


Figure C2. (a) Trends in CPUE and Effort and
(b) Percentage of directed Redfish Trips

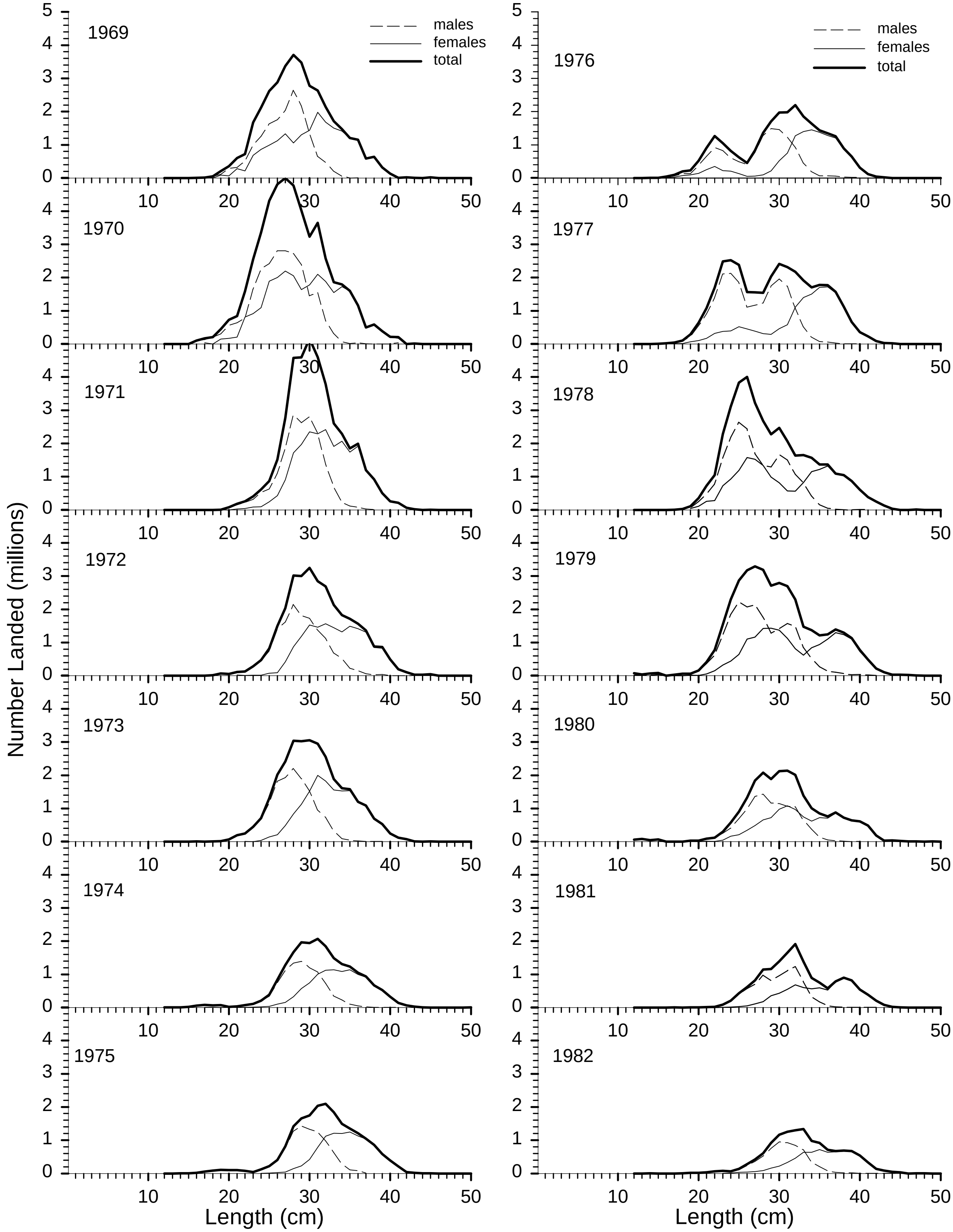


Figure C3. Length composition of redfish in the commercial landings.

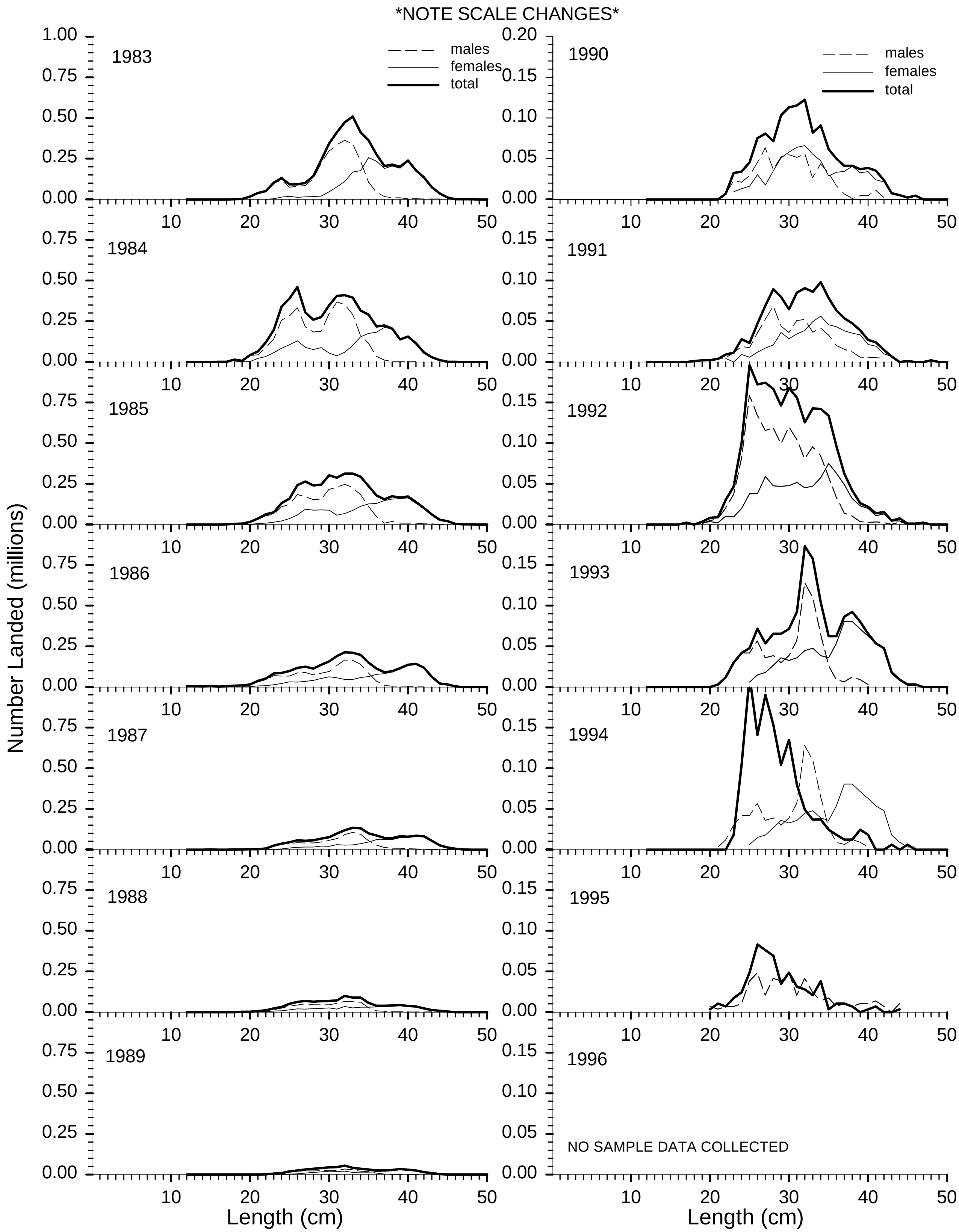


Figure C3 (Continued).

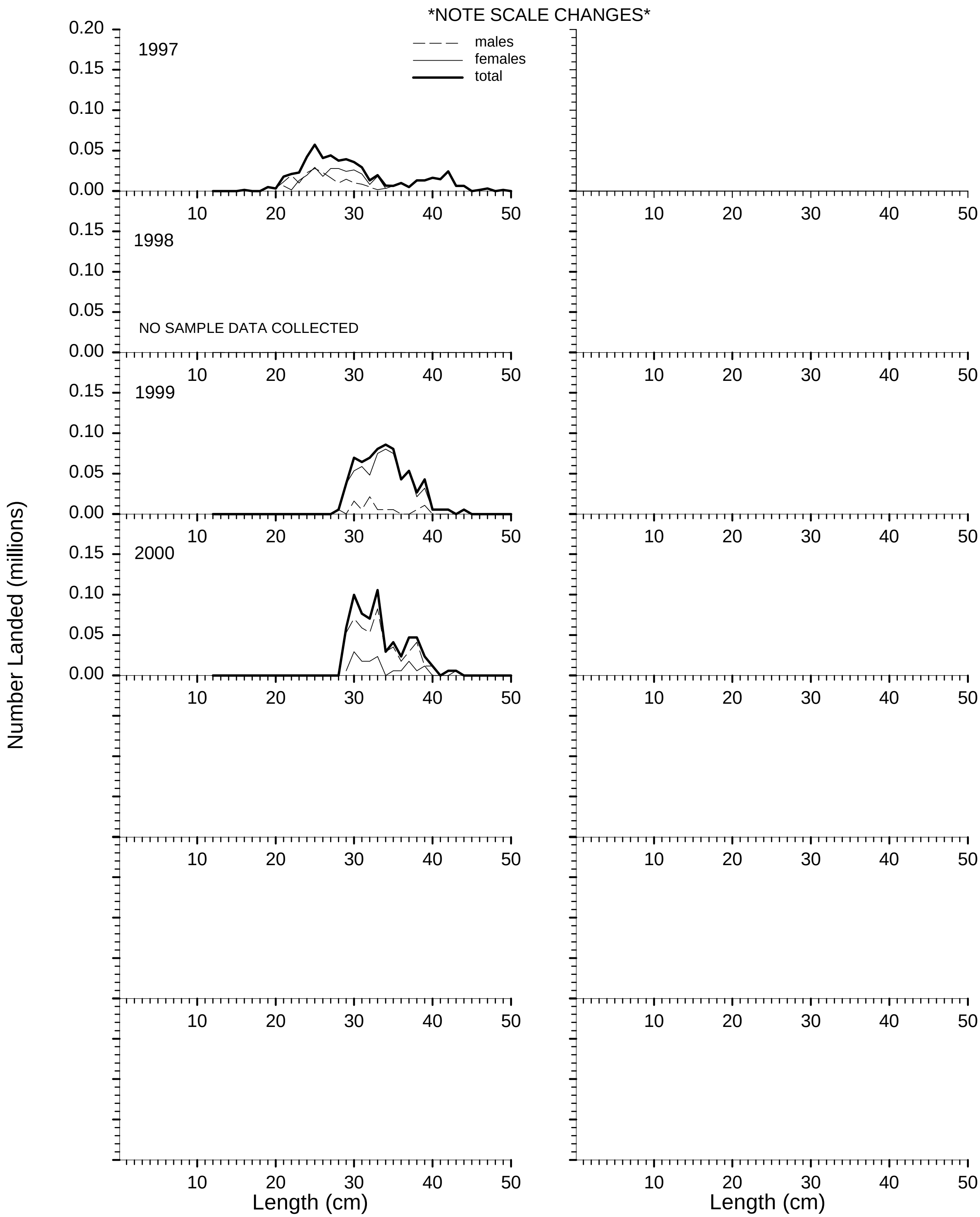


Figure C3 (Continued).

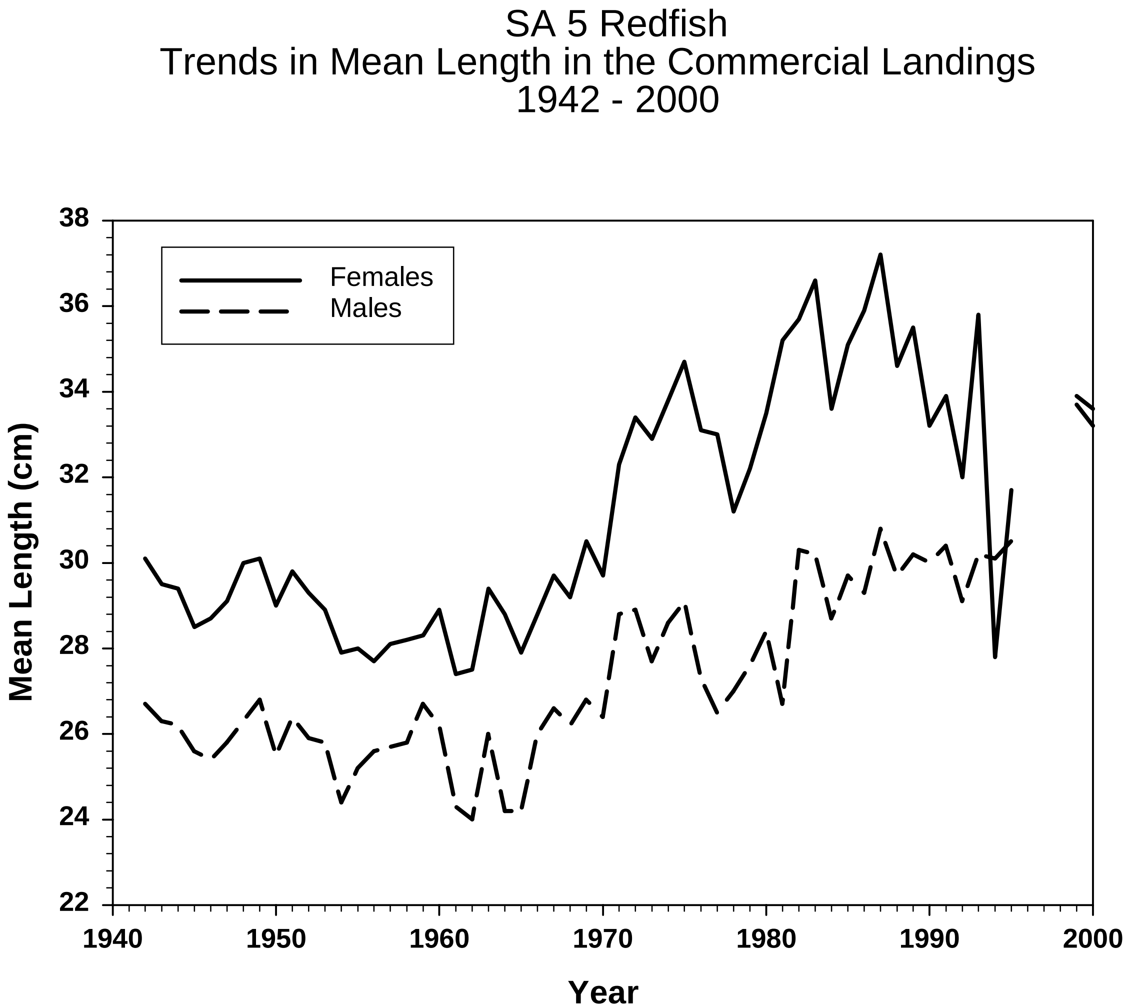


Figure C4. Trends in mean length (cm) of redfish in the commercial landings.

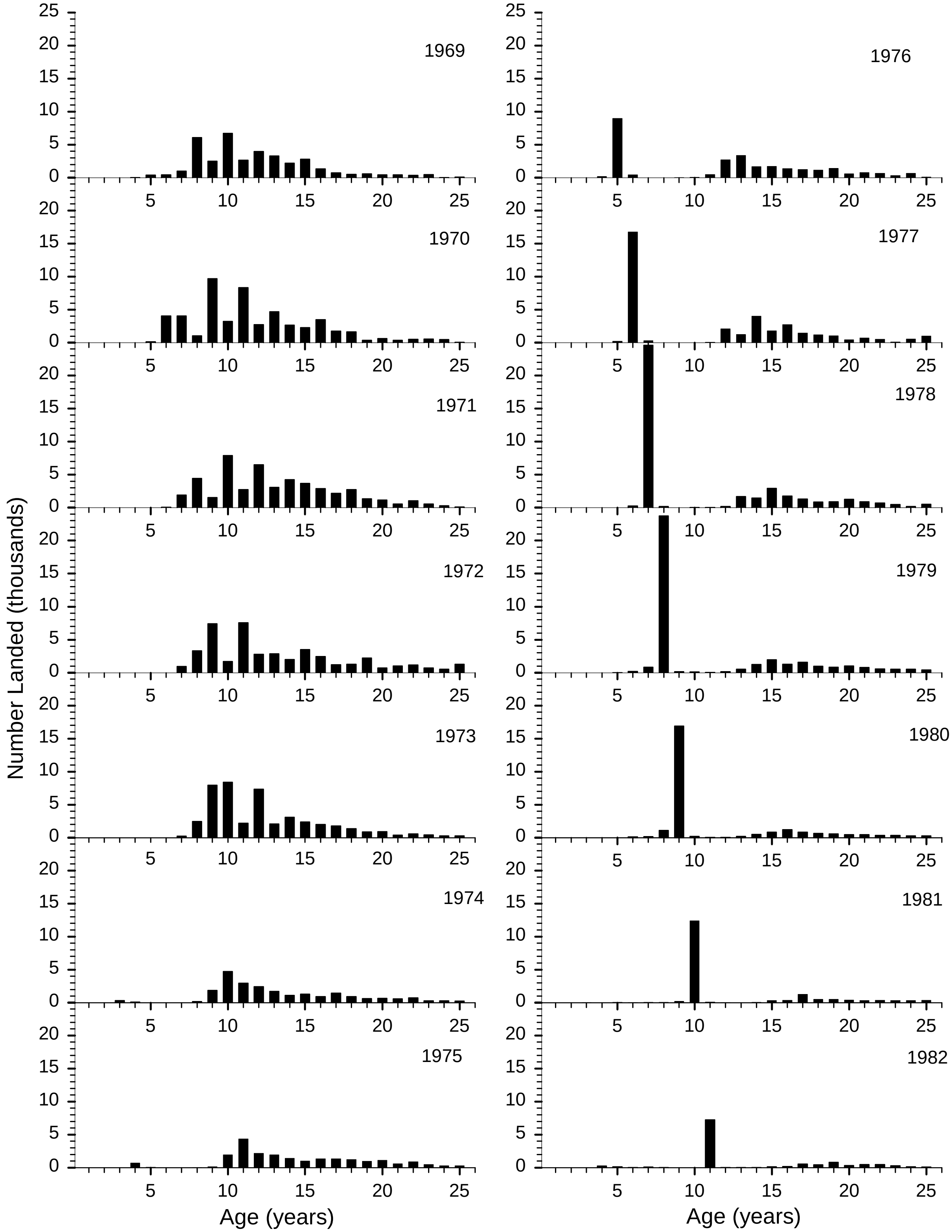


Figure C5. Age composition of redfish in commercial landings.

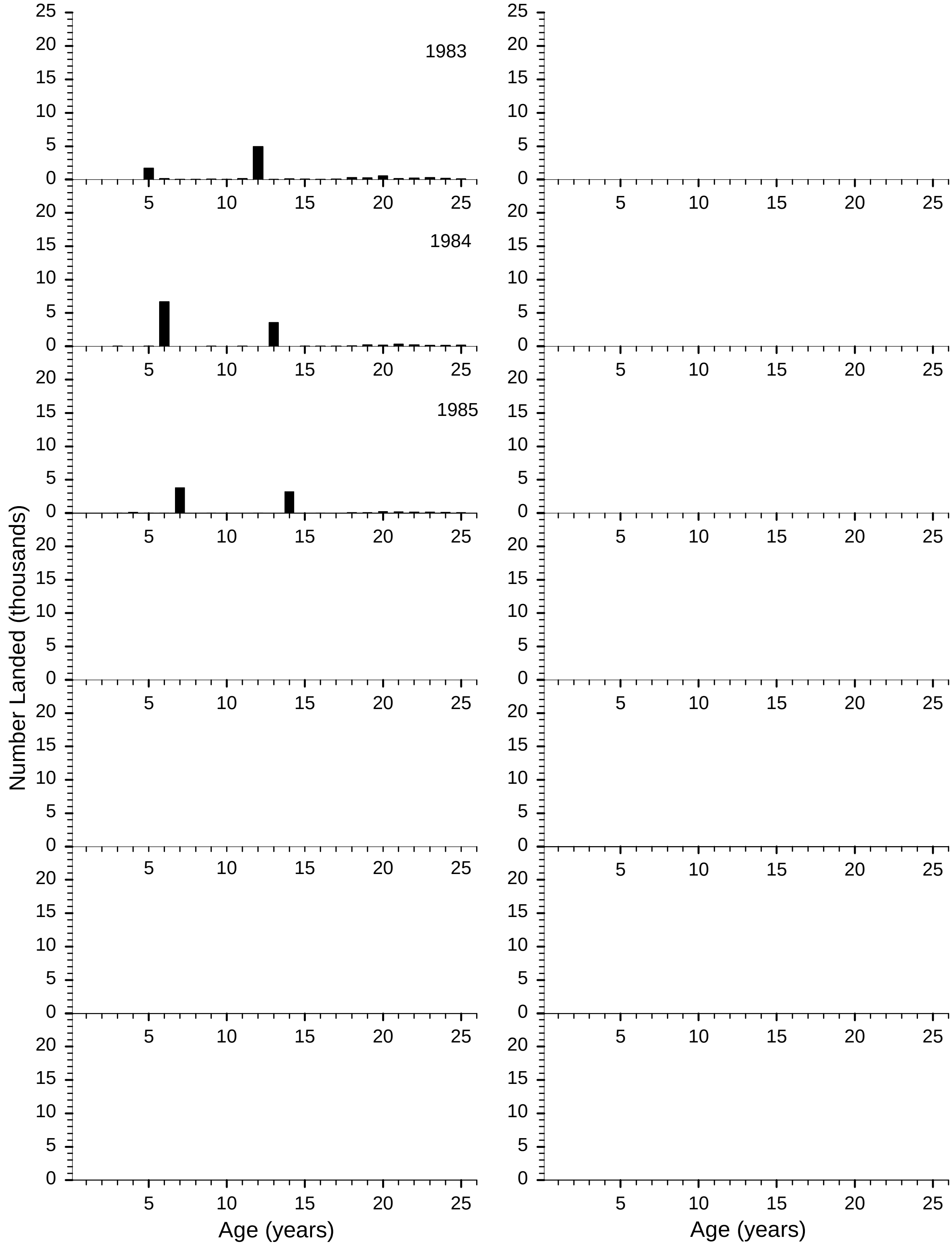
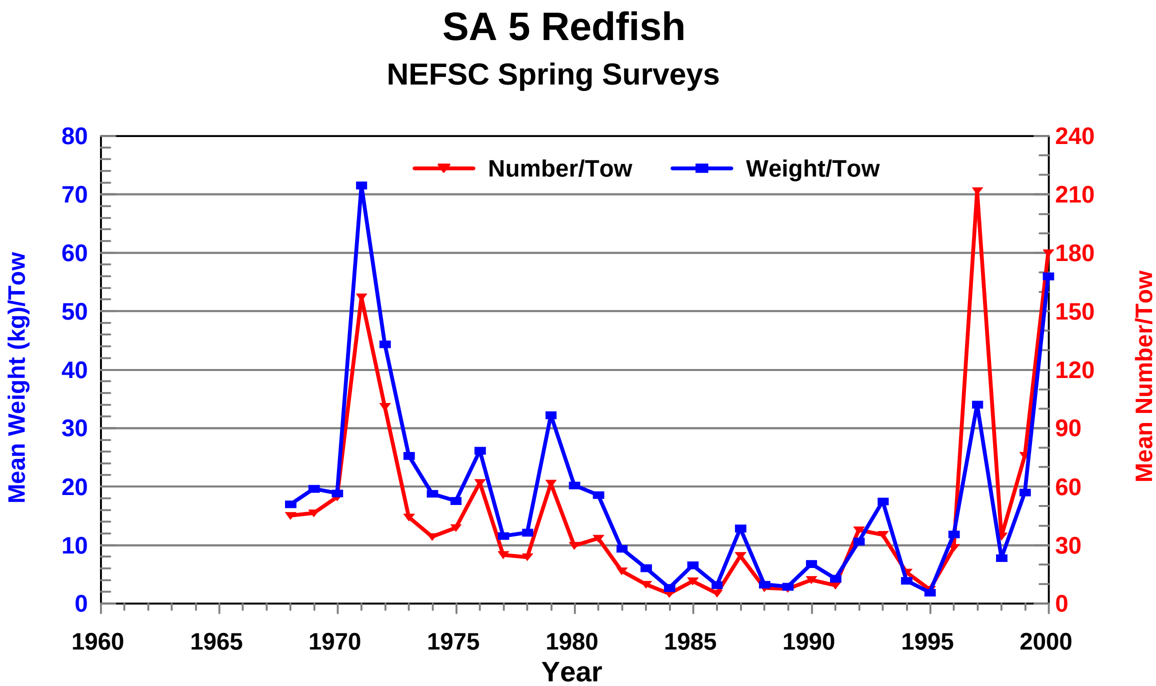


Figure C5 (Continued).



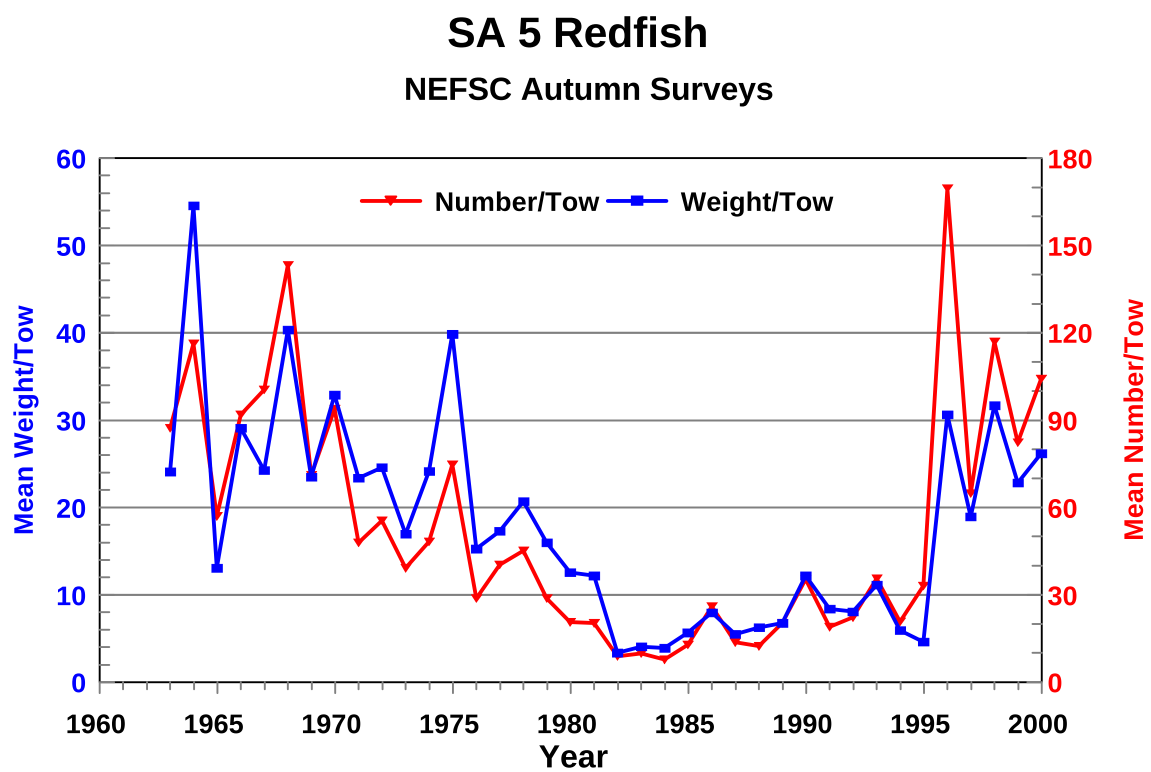
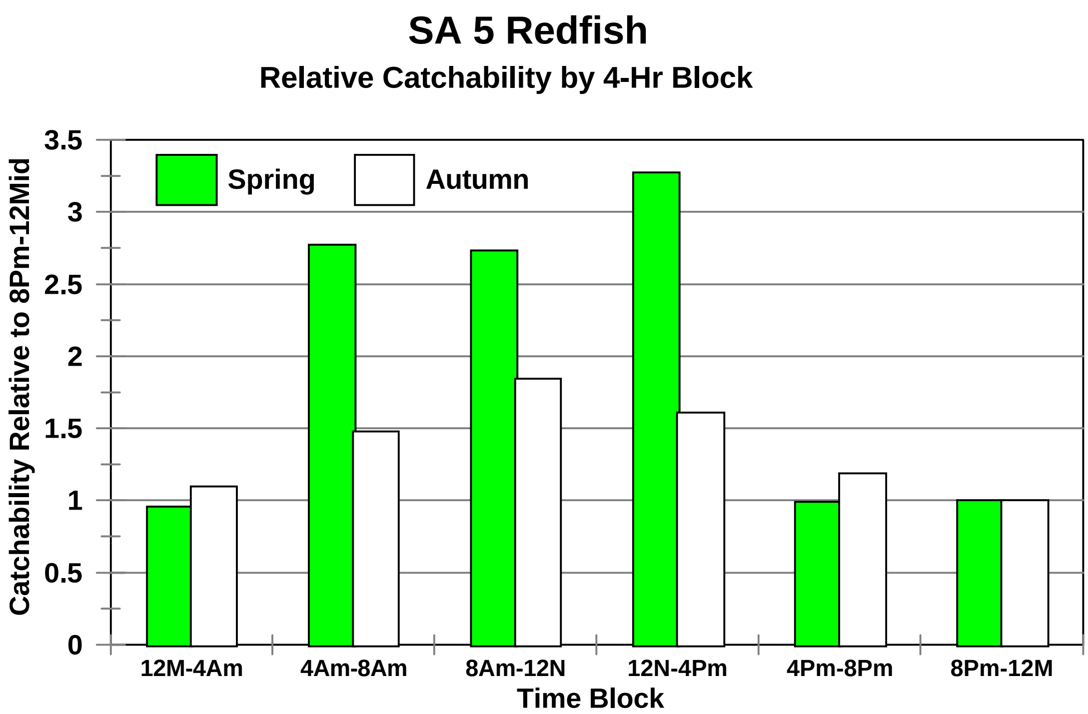


Figure C6 (a) Stratified mean number and weight (kg) per tow of redfish in NEFSC spring surveys, (b) Stratifeid mean number and weight (kg) per tow of redfish in NEFSC autumn surveys.



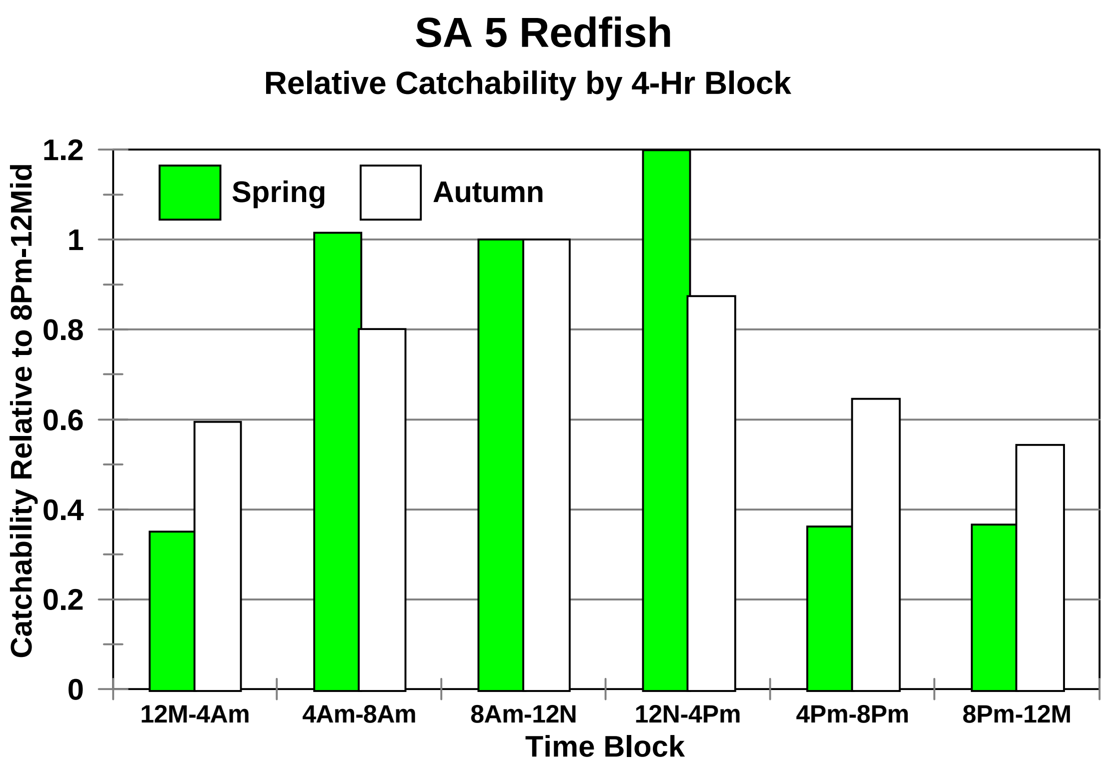
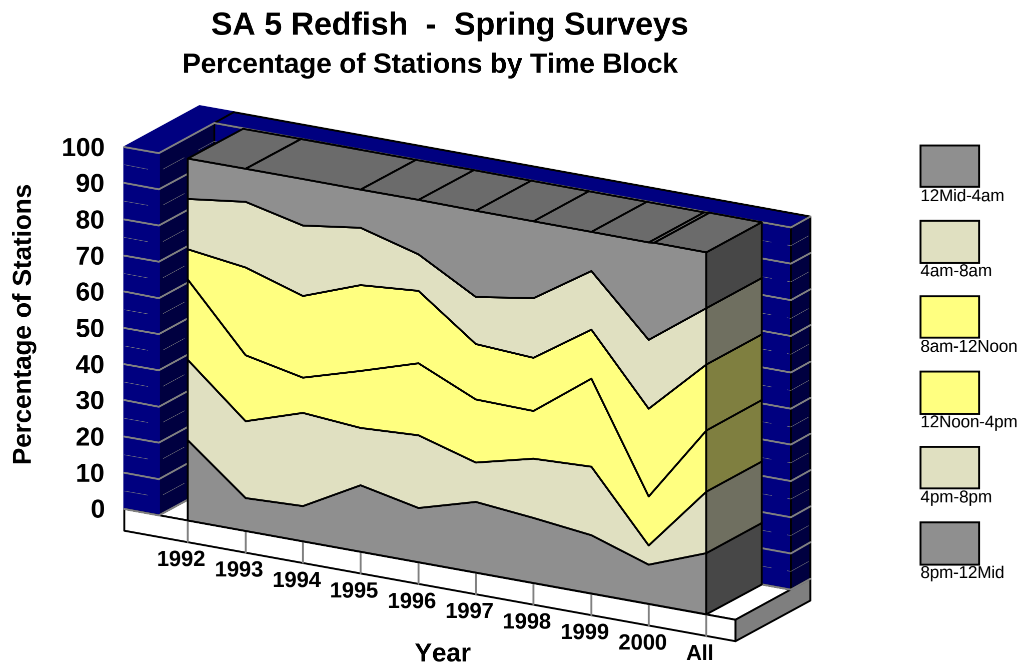


Figure C7. Relative catchability of redfish in NEFSC spring and autumn bottom trawl surveys.



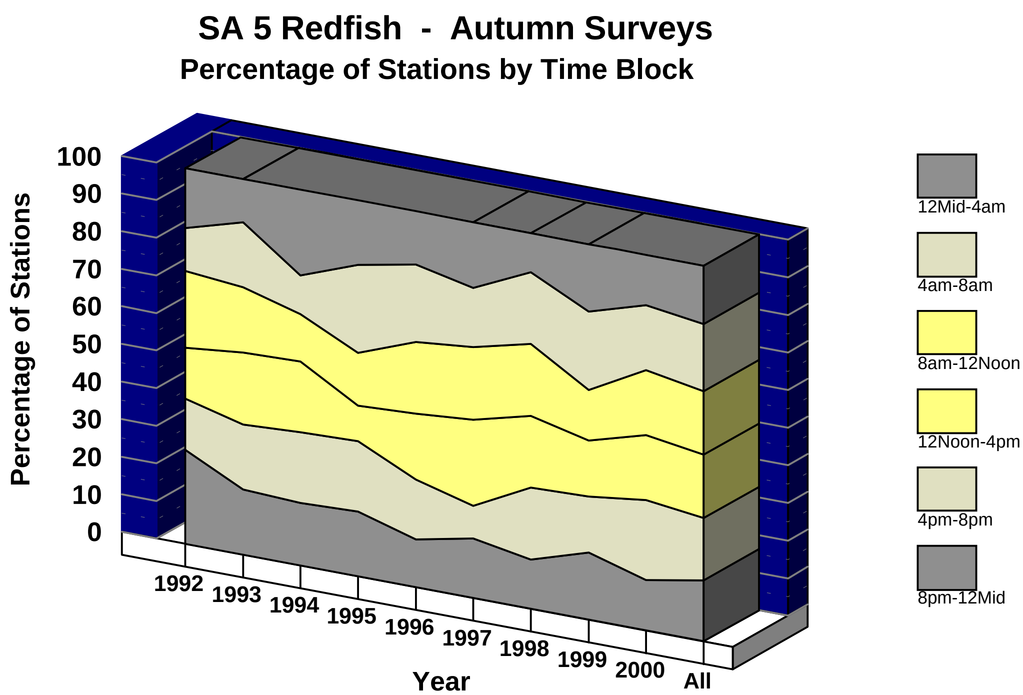


Figure C8 (a) Station coverage percentages by 4-hour time block, NEFSC spring surveys.
(b) Station coverage percentages by 4-hour time block; NEFSC autumn surveys.

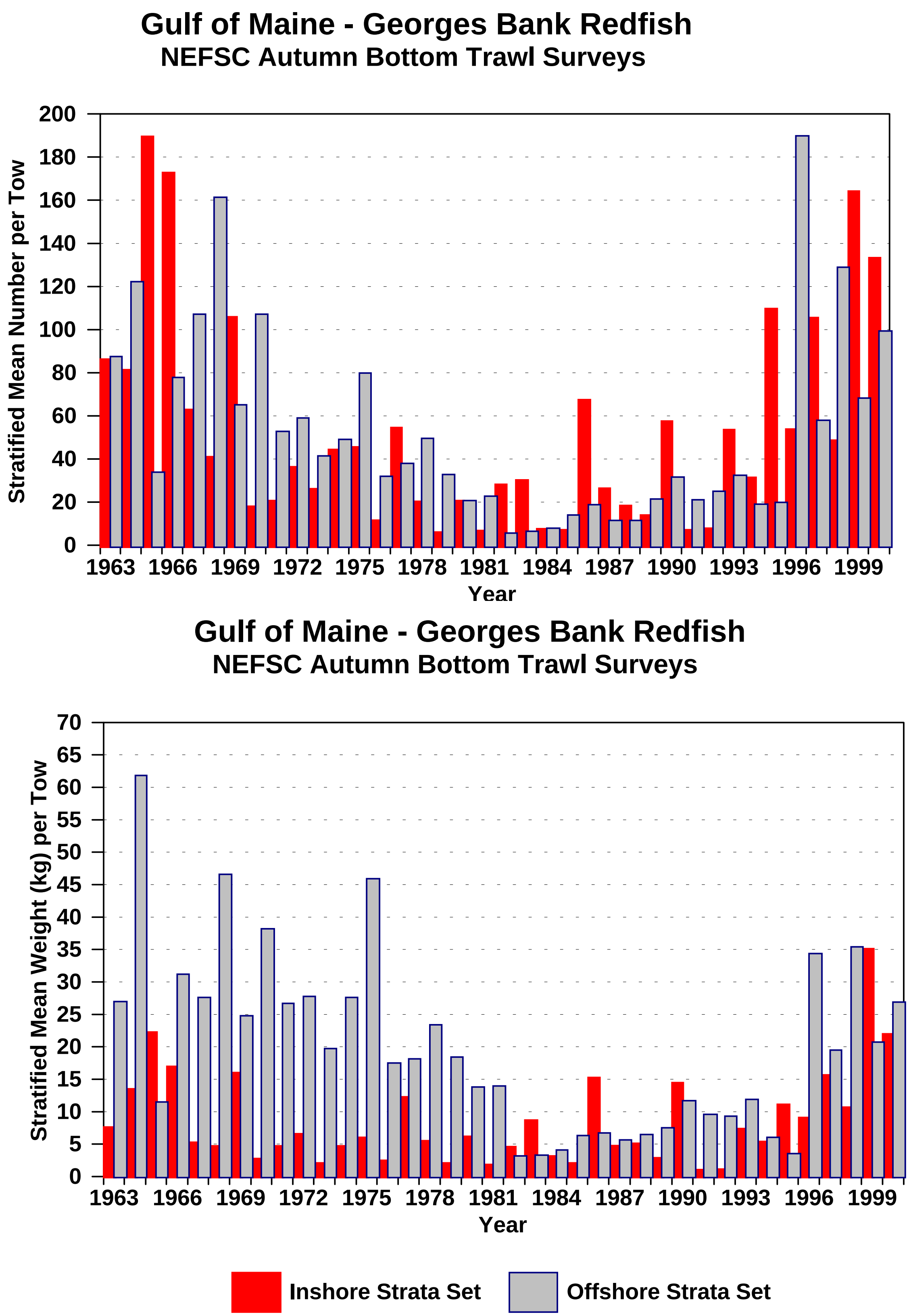
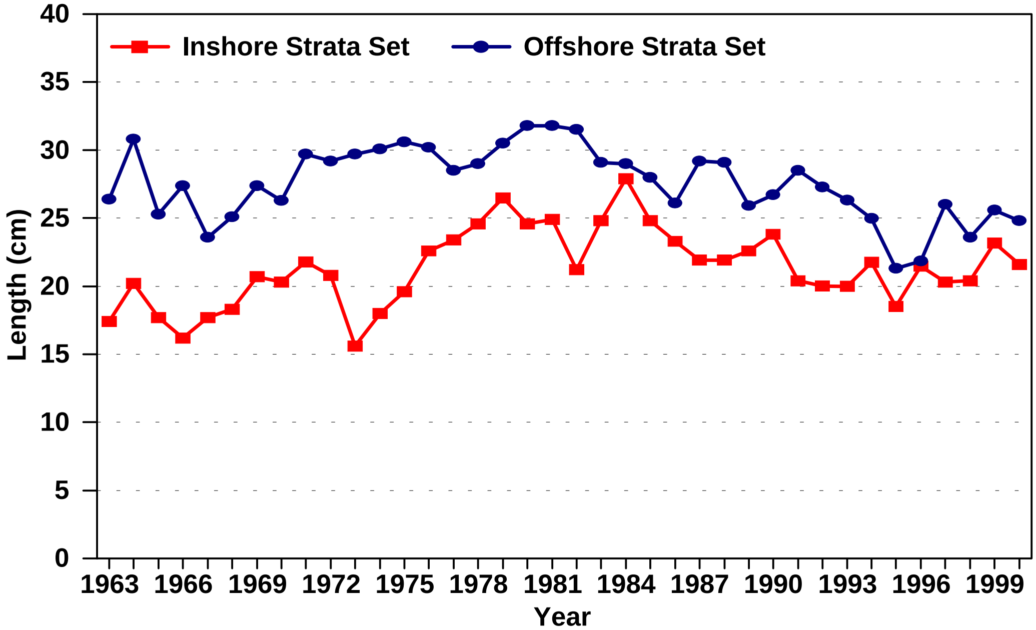


Figure C9 (a) Density indices (number per tow) for redfish in NEFSC autumn inshore and offshore strata sets. (b) Density indices (weight per tow) for redfish in NEFSC autumn inshore and offshore strata sets.

Gulf of Maine - Georges Bank Redfish
NEFSC Autumn Bottom Trawl Surveys



NEFSC Autumn Bottom Trawl Surveys

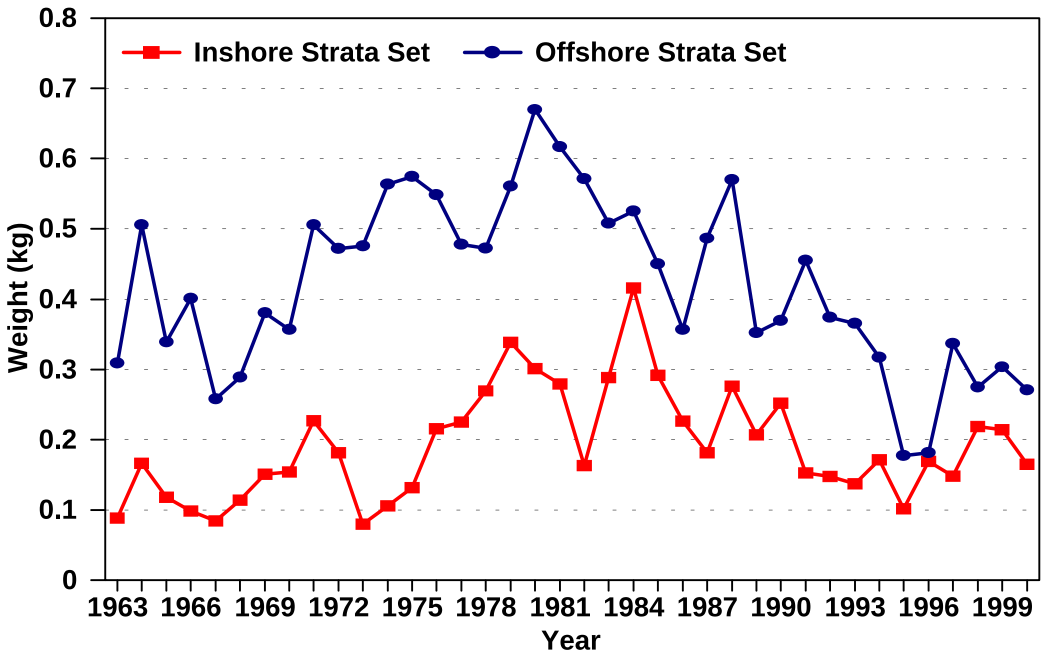
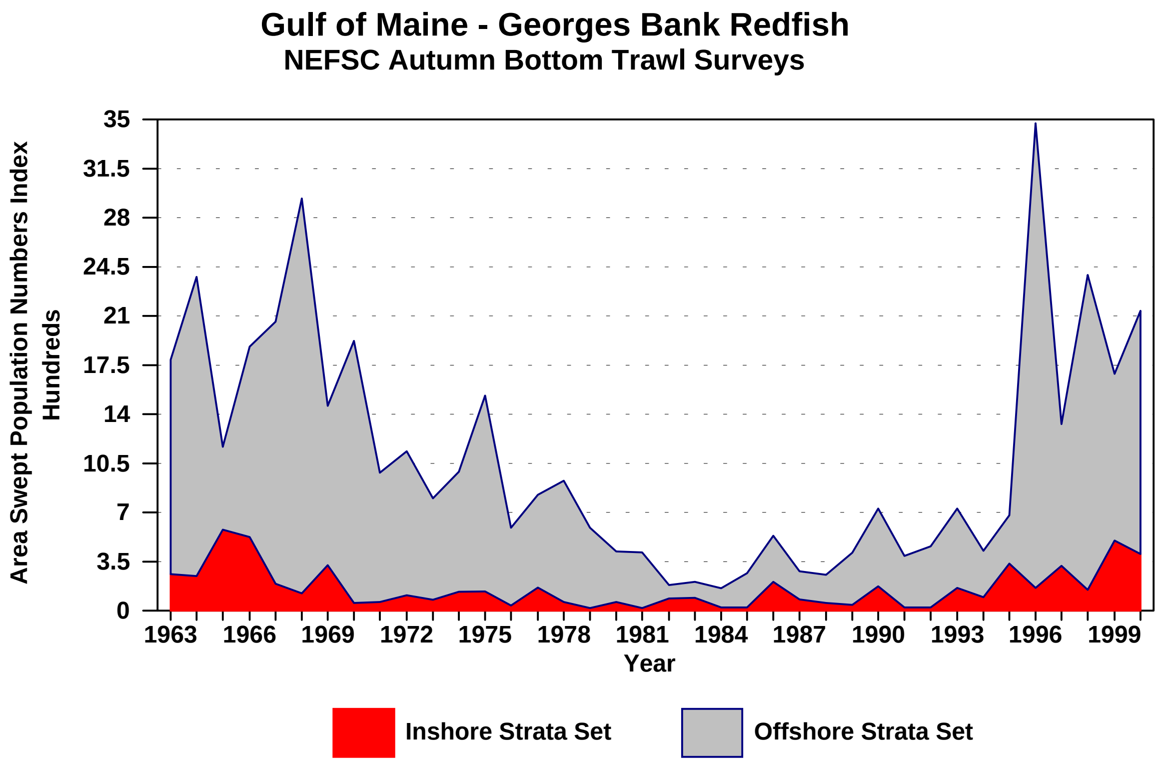


Figure C10 (a) Mean length (cm) of redfish in NEFSC autumn survey inshore and offshore strata sets.
(b) Mean weight (kg) of redfish in NEFSC autumn survey inshore and offshore strata sets.



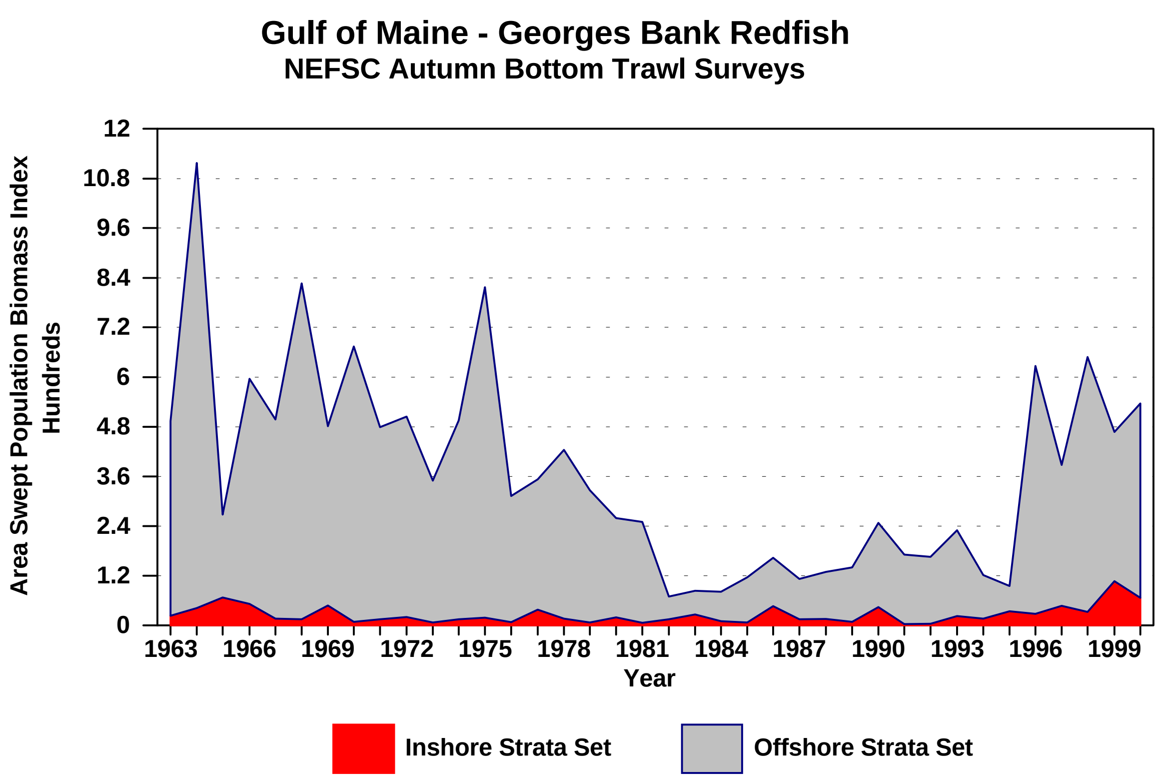


Figure C11 (a) Index of area swept abundance of redfish in NEFSC autumn inshore and offshore strata sets. (b) Index of swept area biomass of redfish in NEFSC autumn inshore and offshore strata sets.

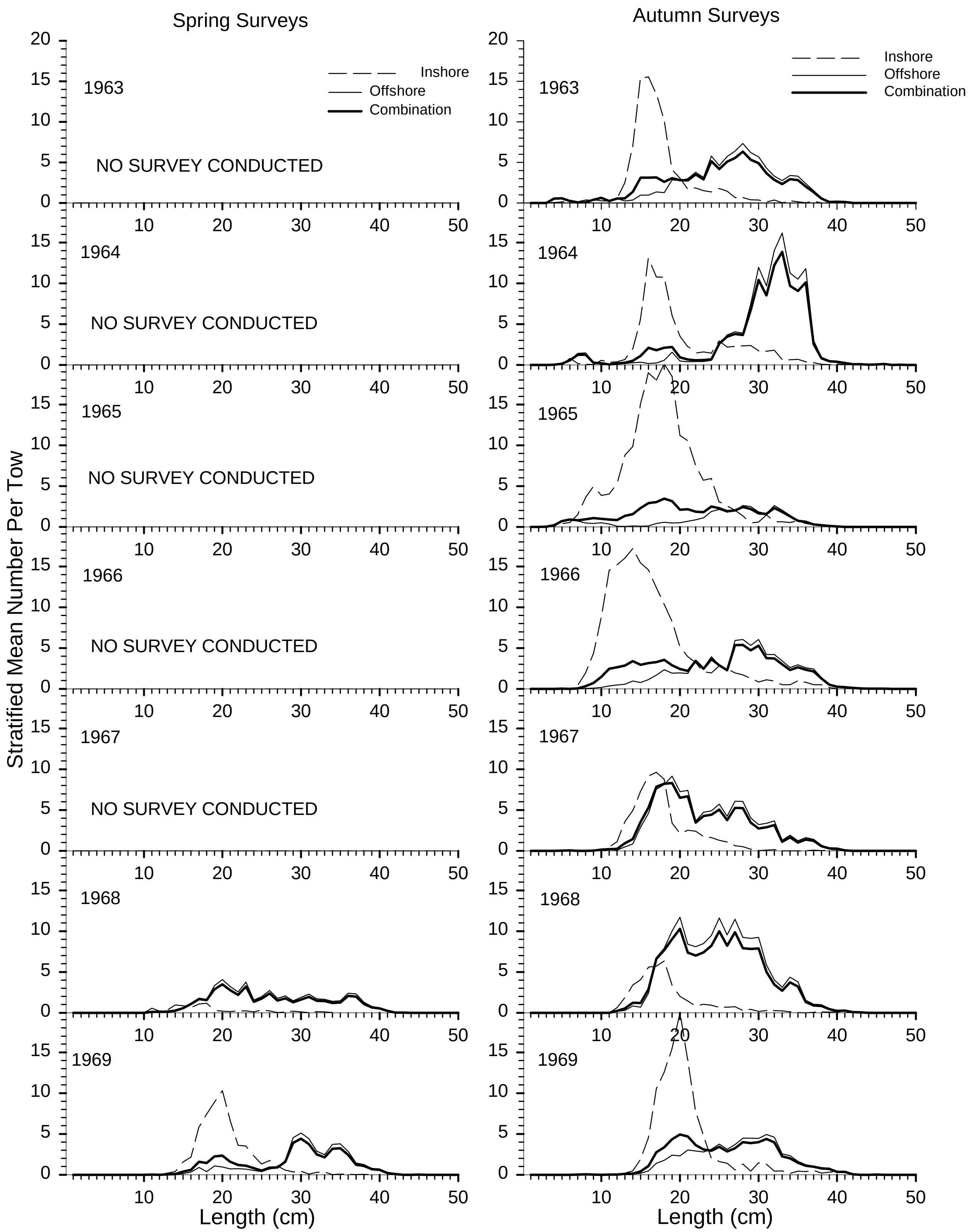


Figure C12. Length composition of redfish in NEFSC spring and autumn surveys.

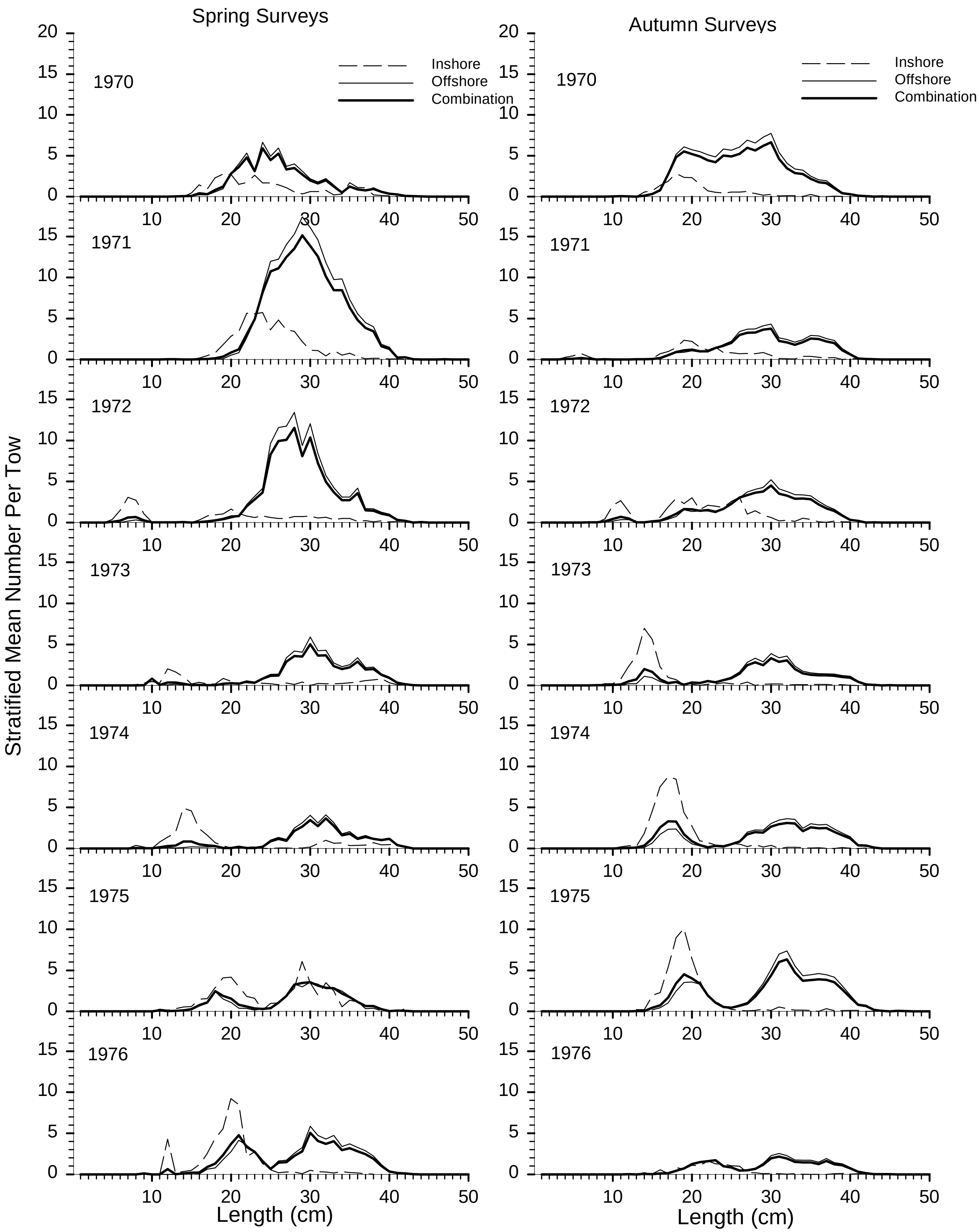
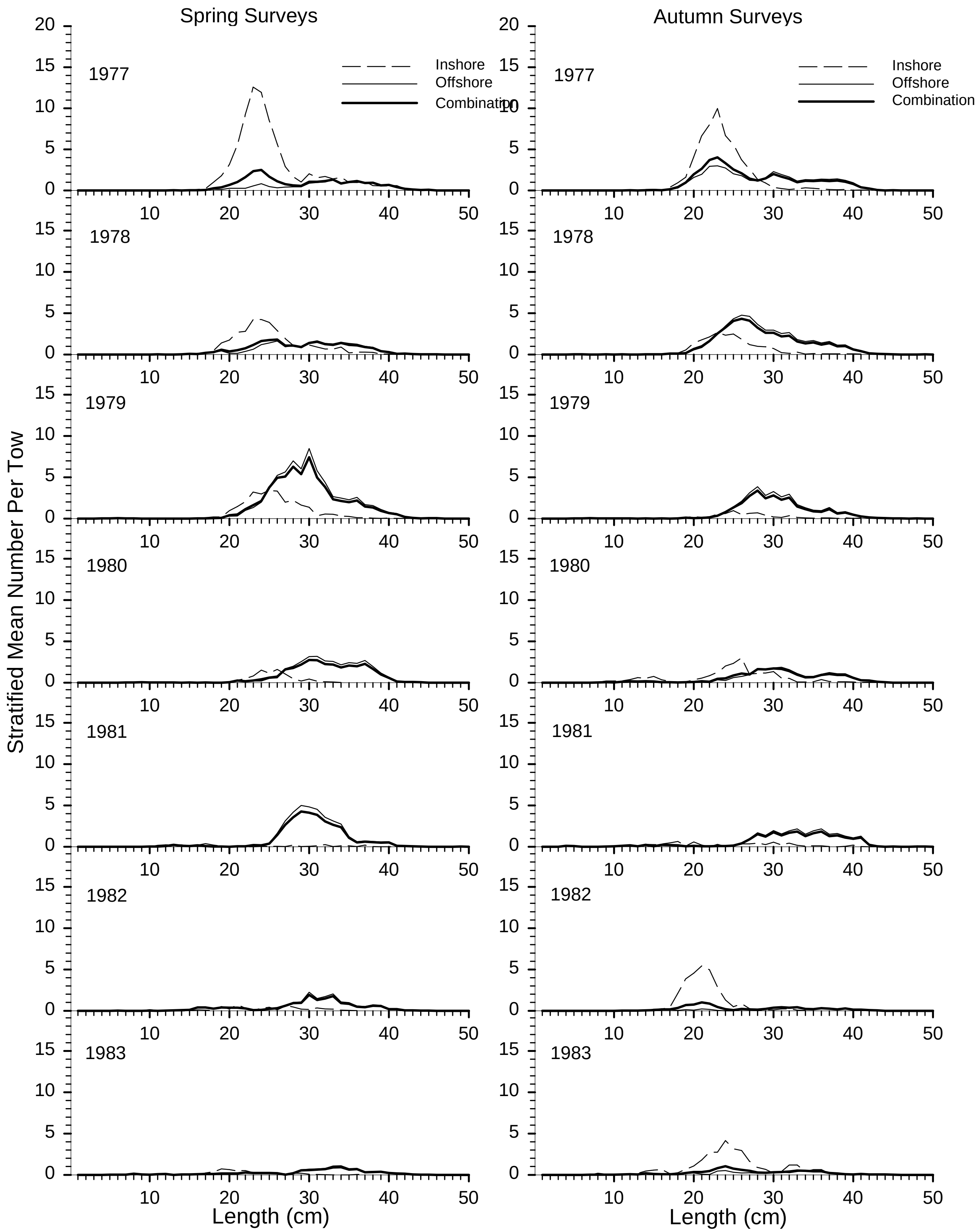


Figure C12 (Continued).



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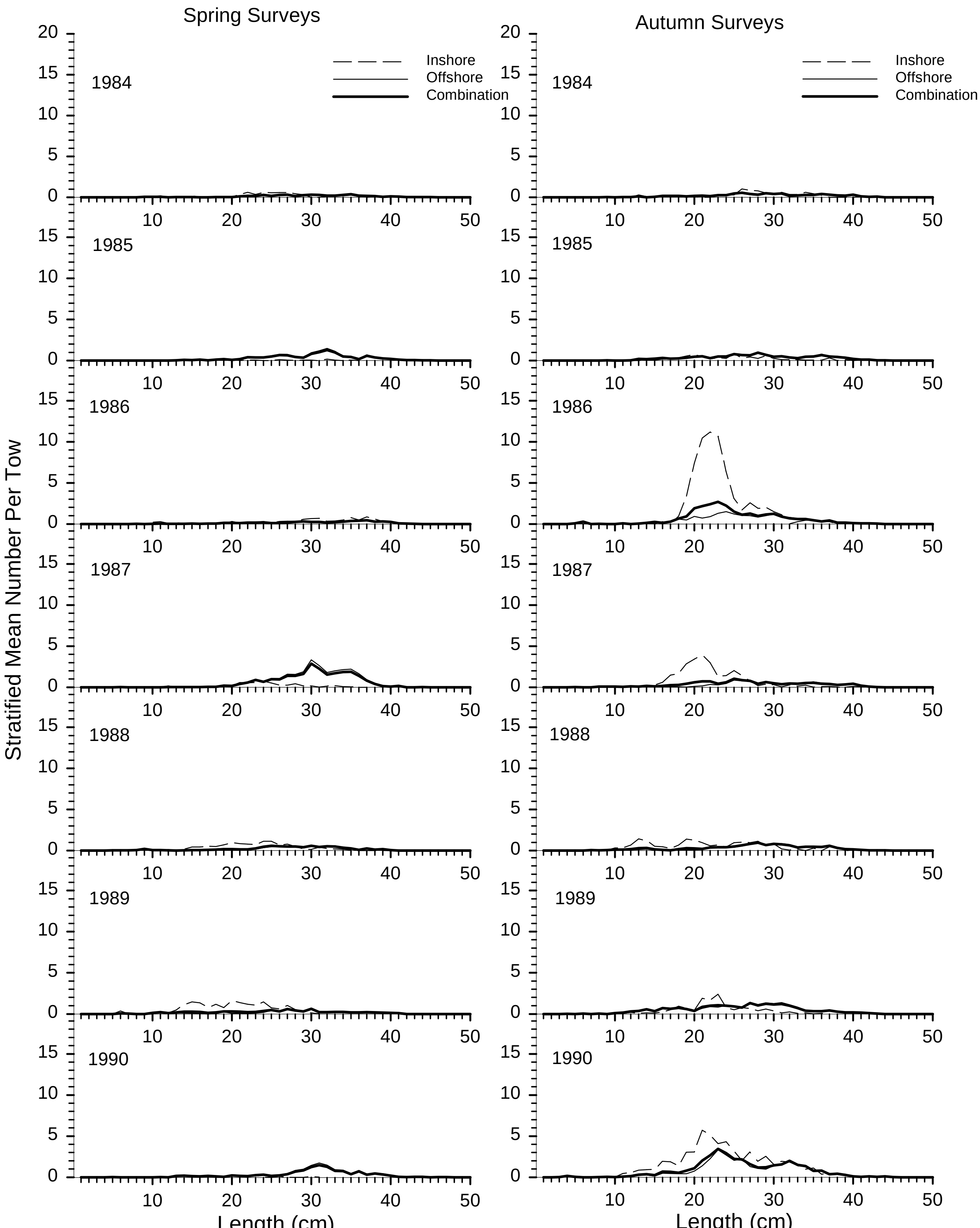

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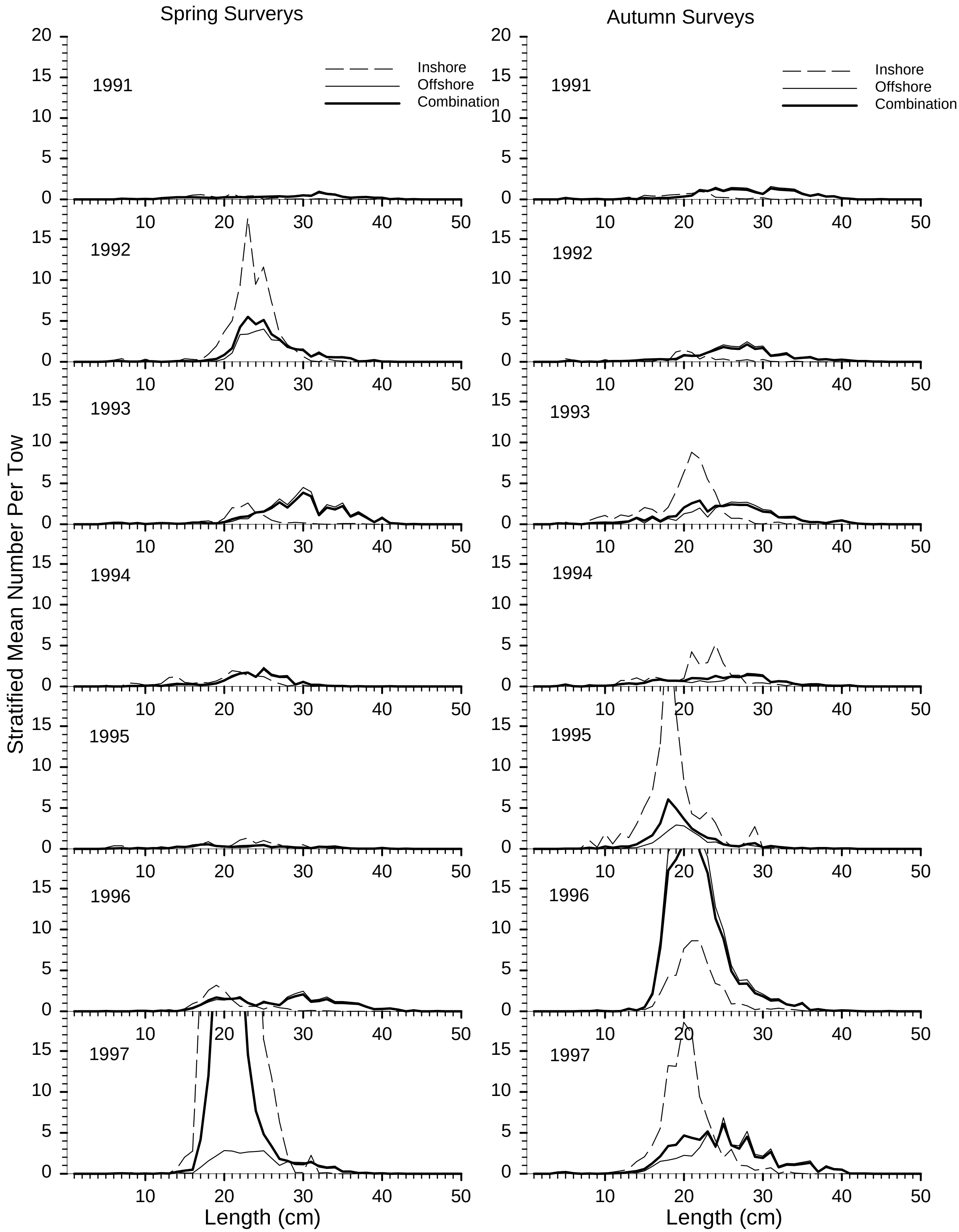

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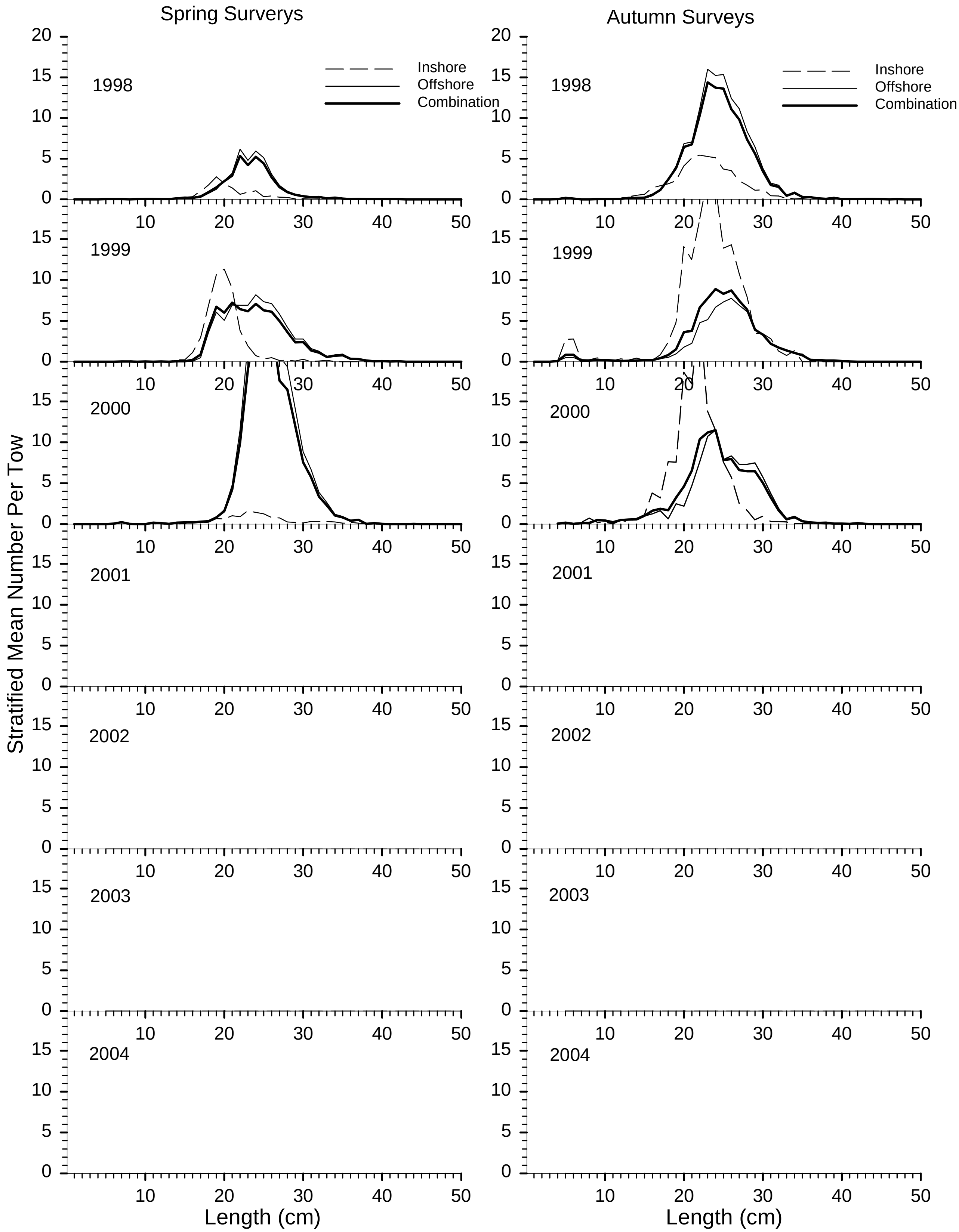


Figure C12 (Continued).

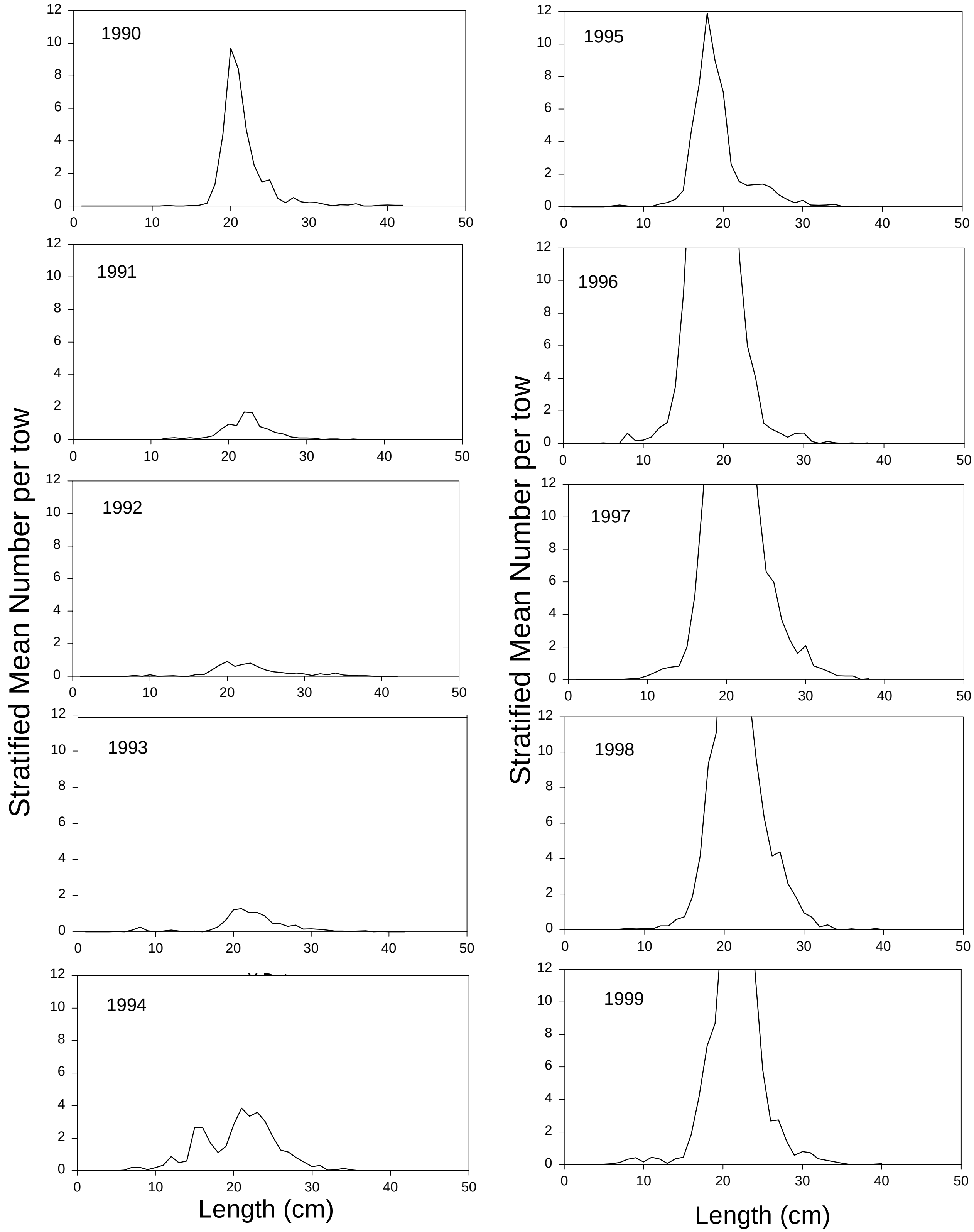


Figure C12a. Length composition of redfish from NEFSC shrimp surveys.

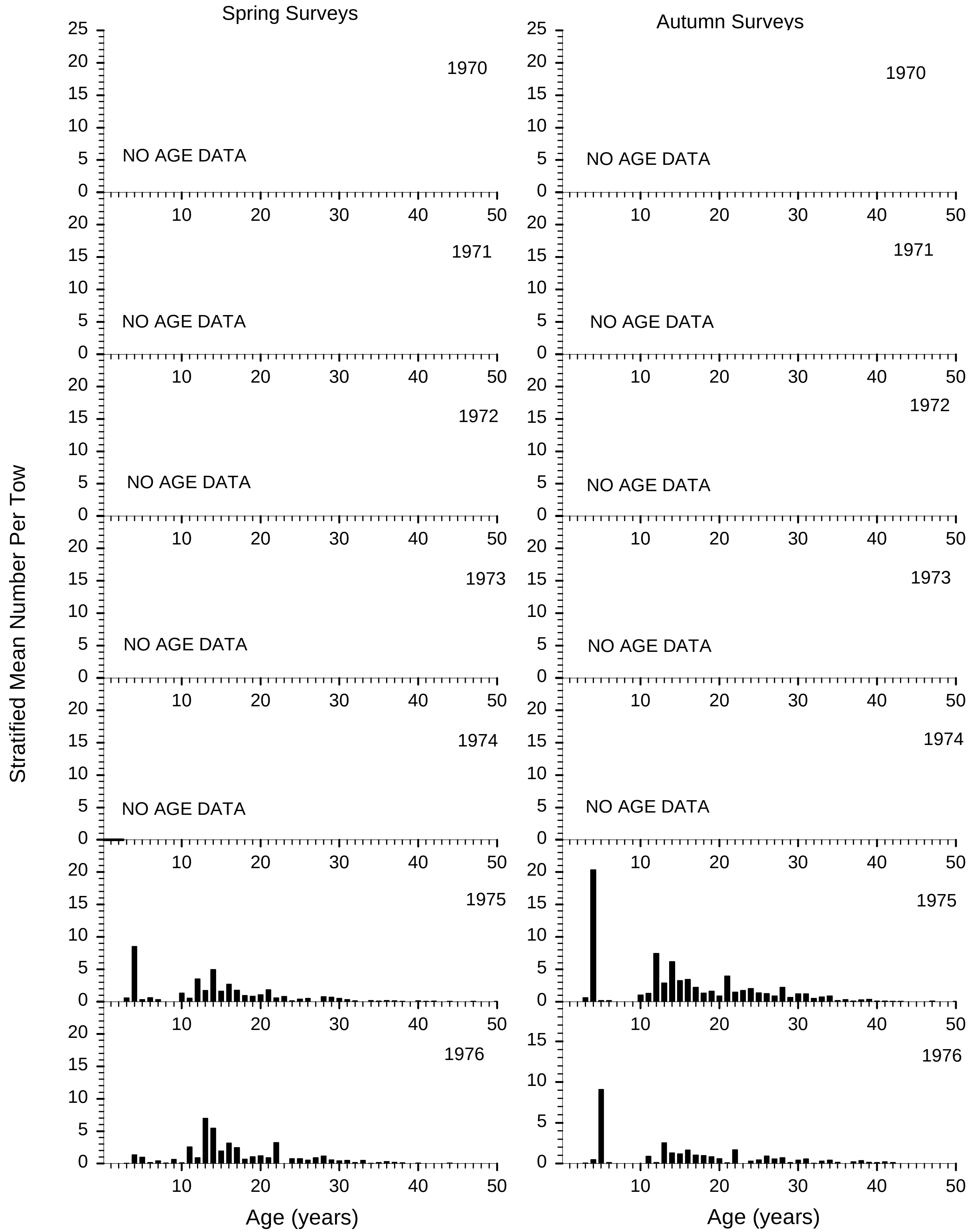


Figure C13. Age composition of redfish in NEFSC spring and autumn surveys.

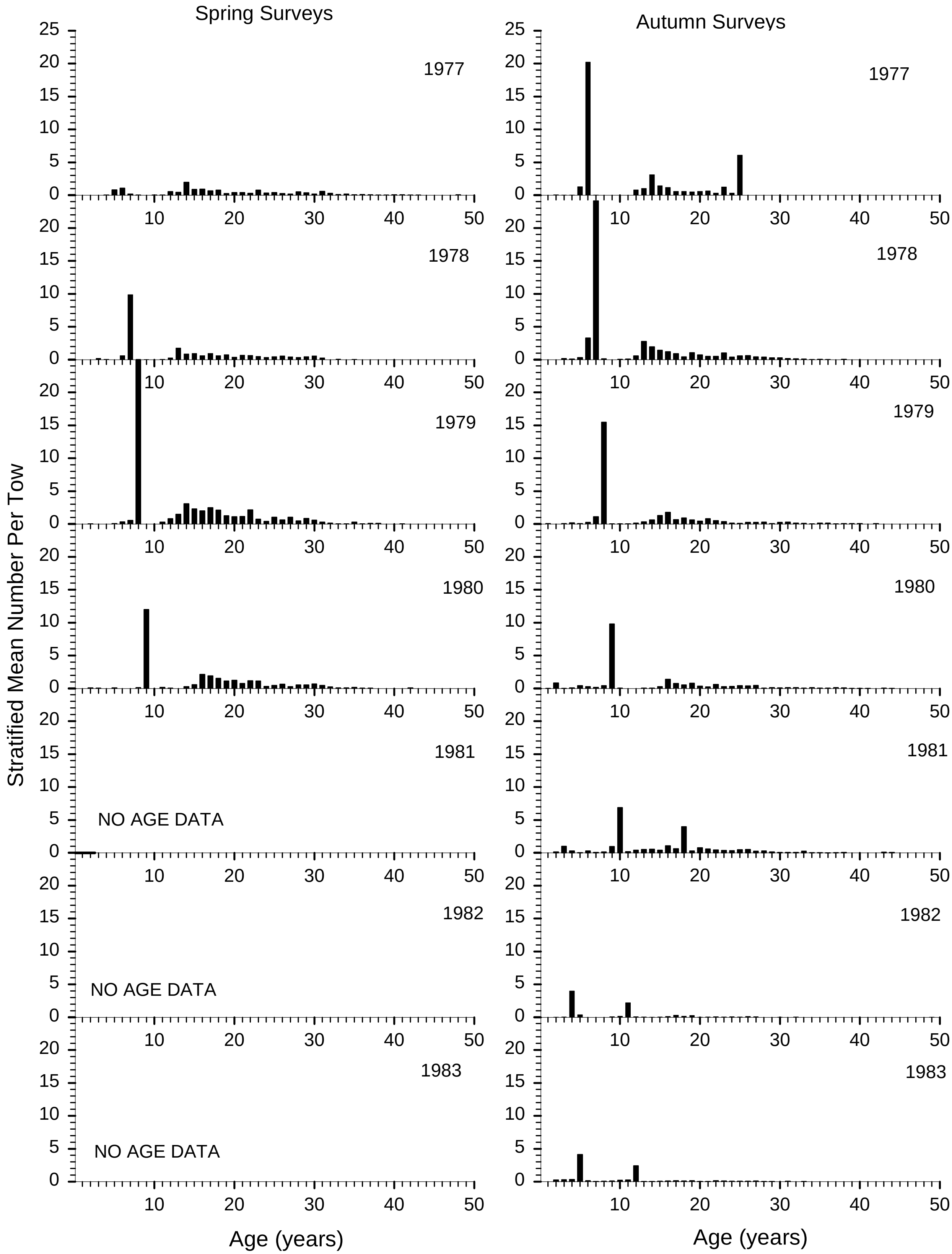
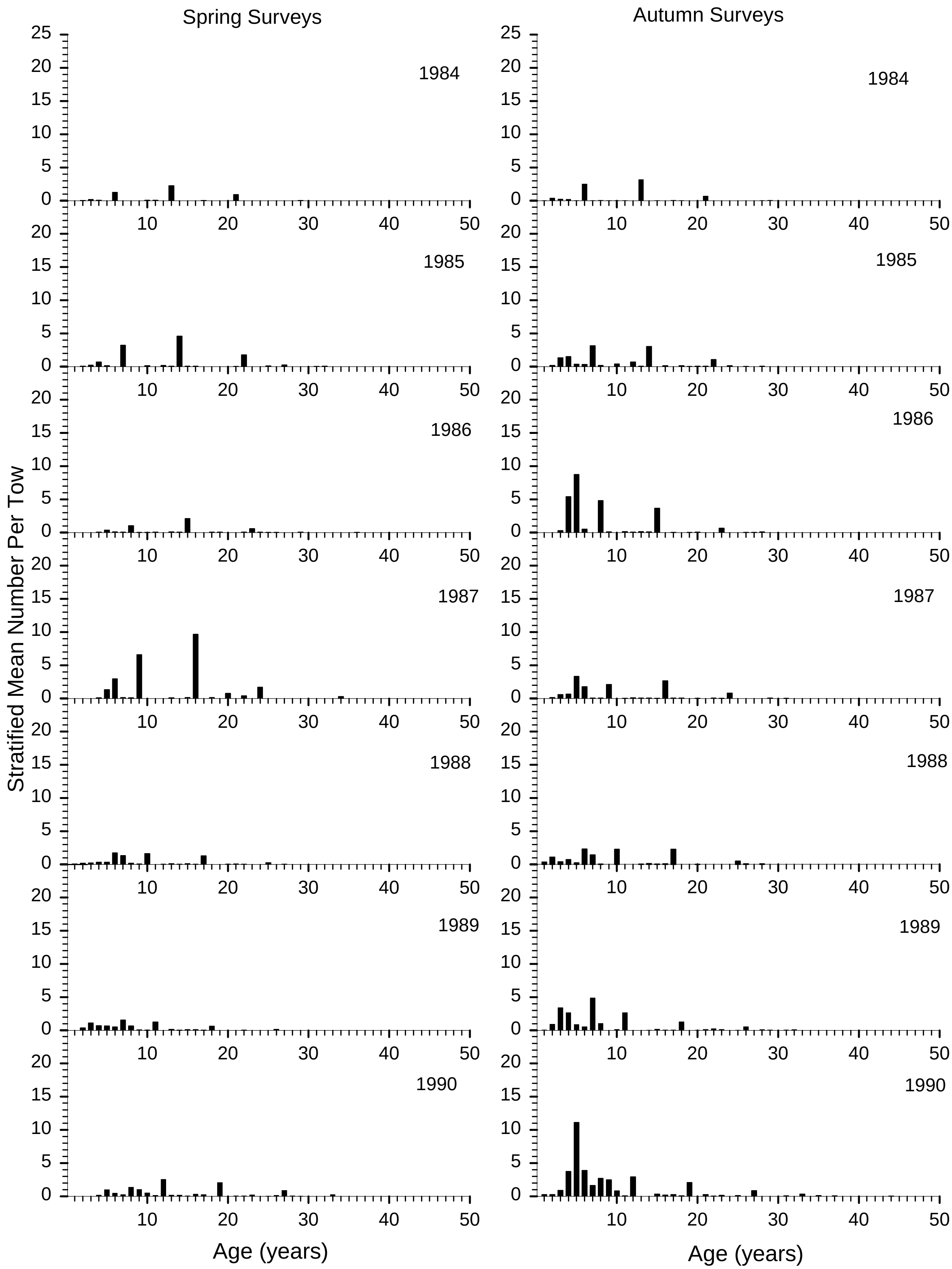


Figure C13 (Continued).



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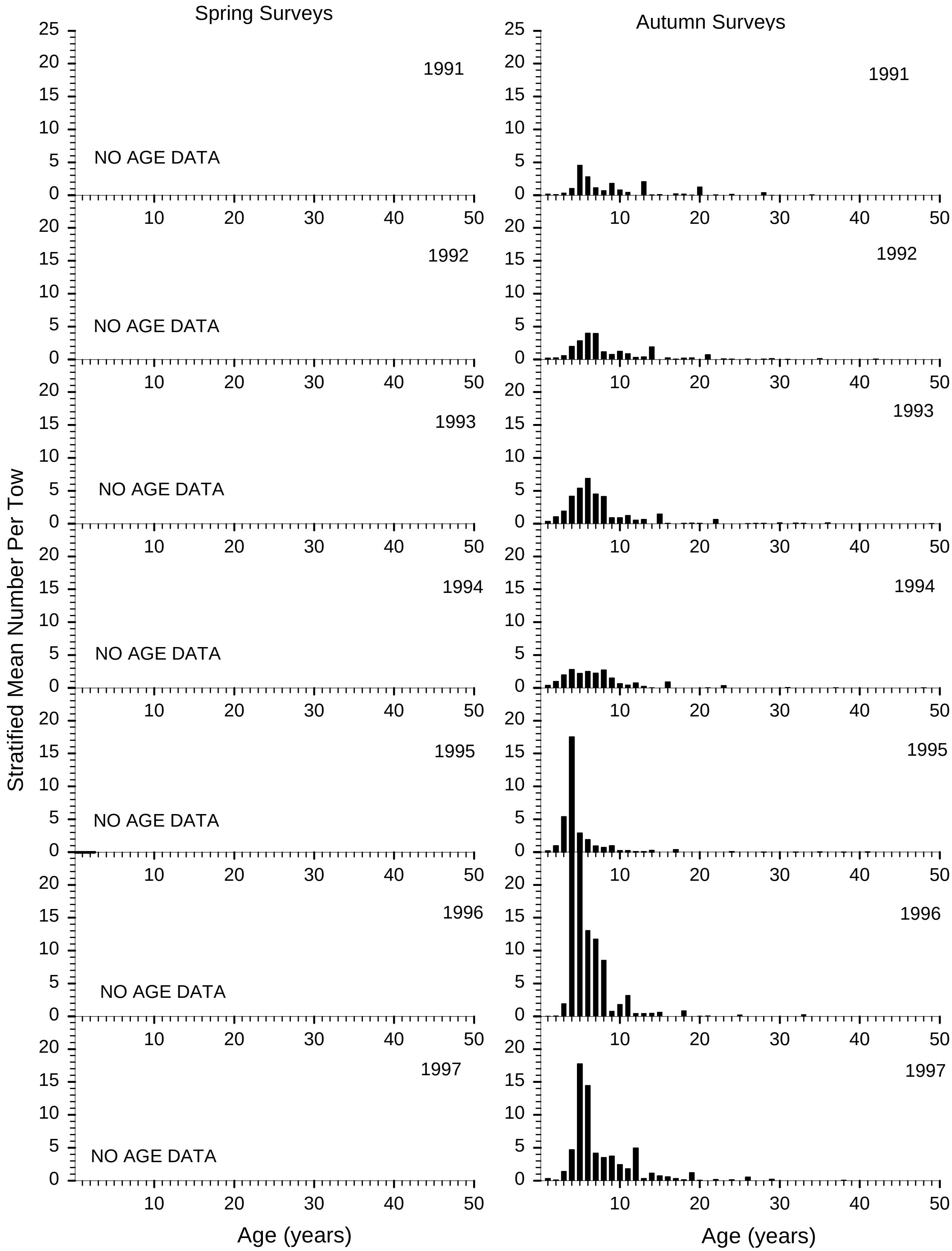

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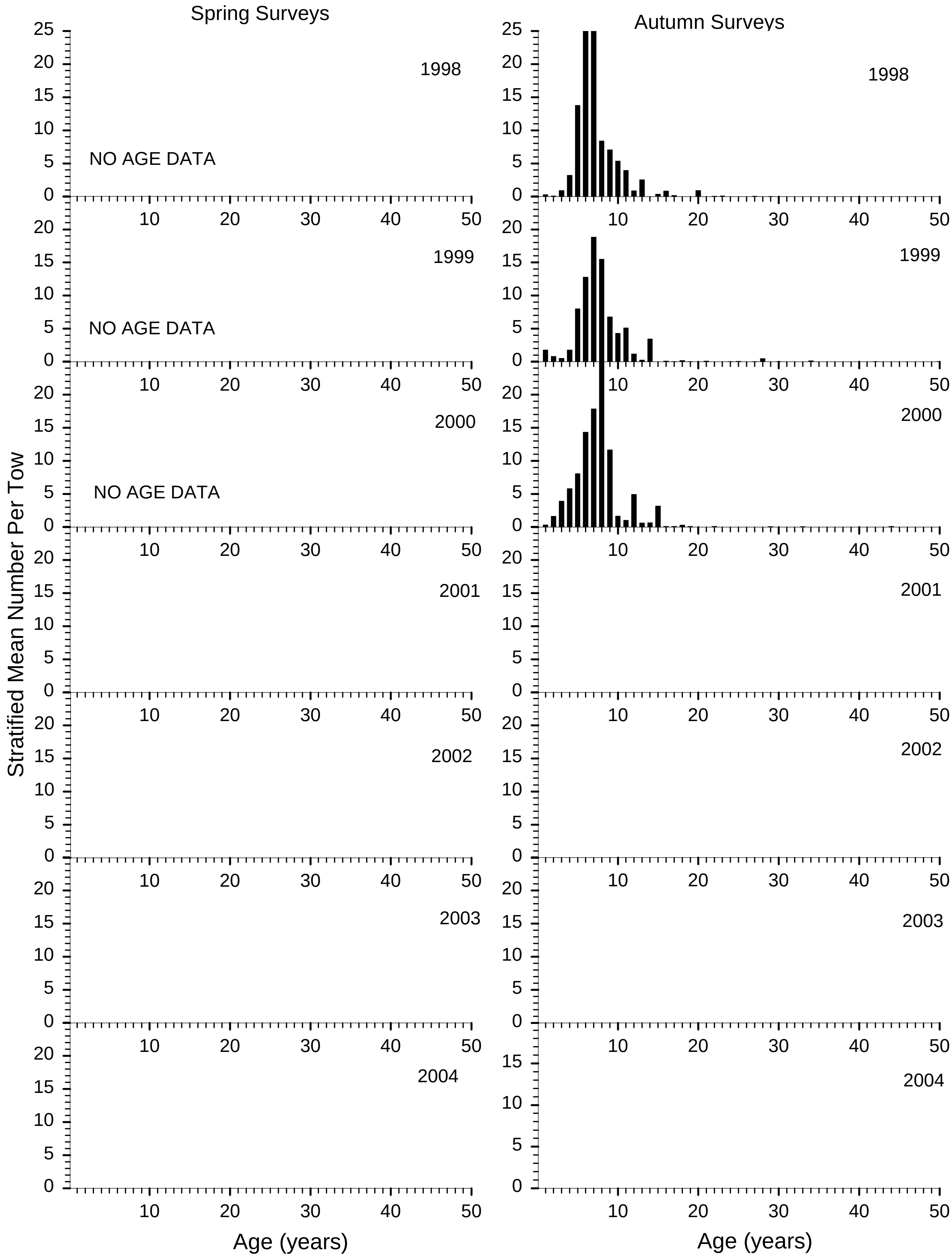


Figure C13 (Continued).

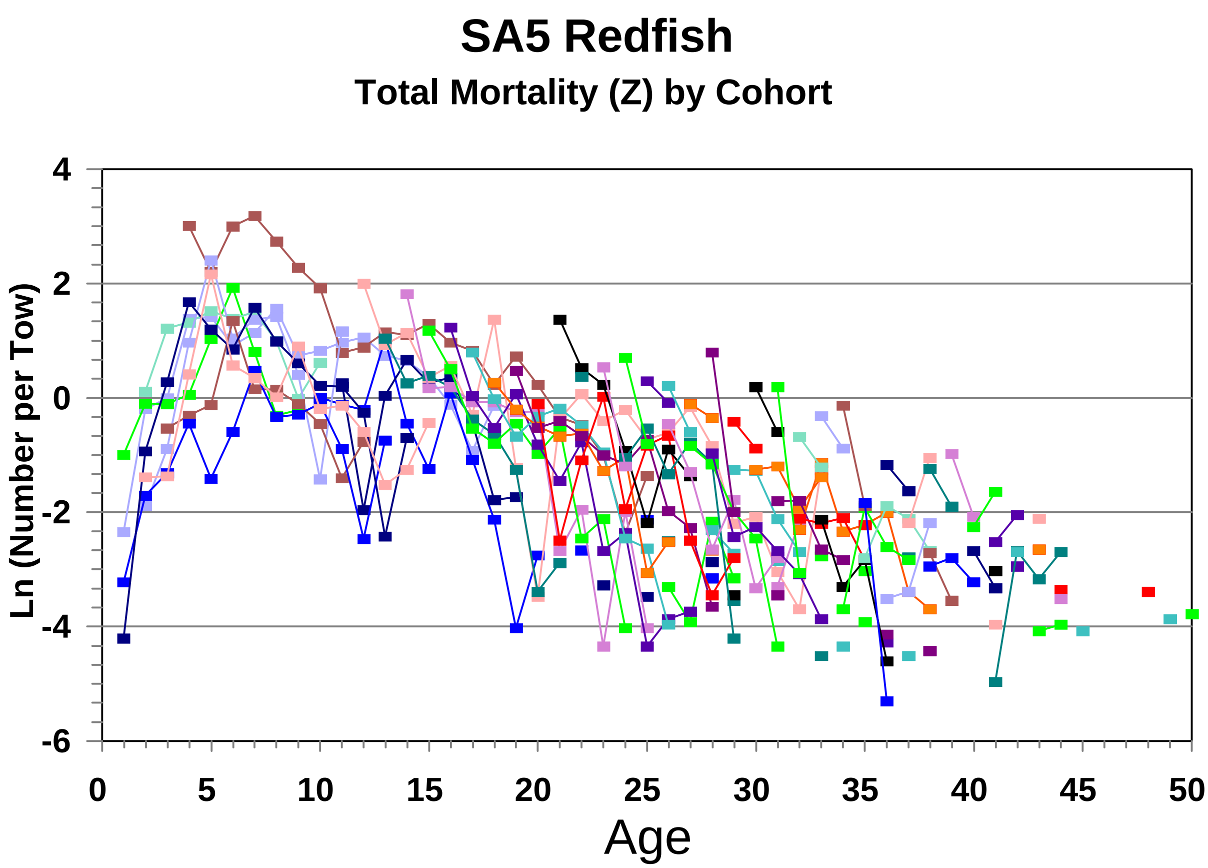
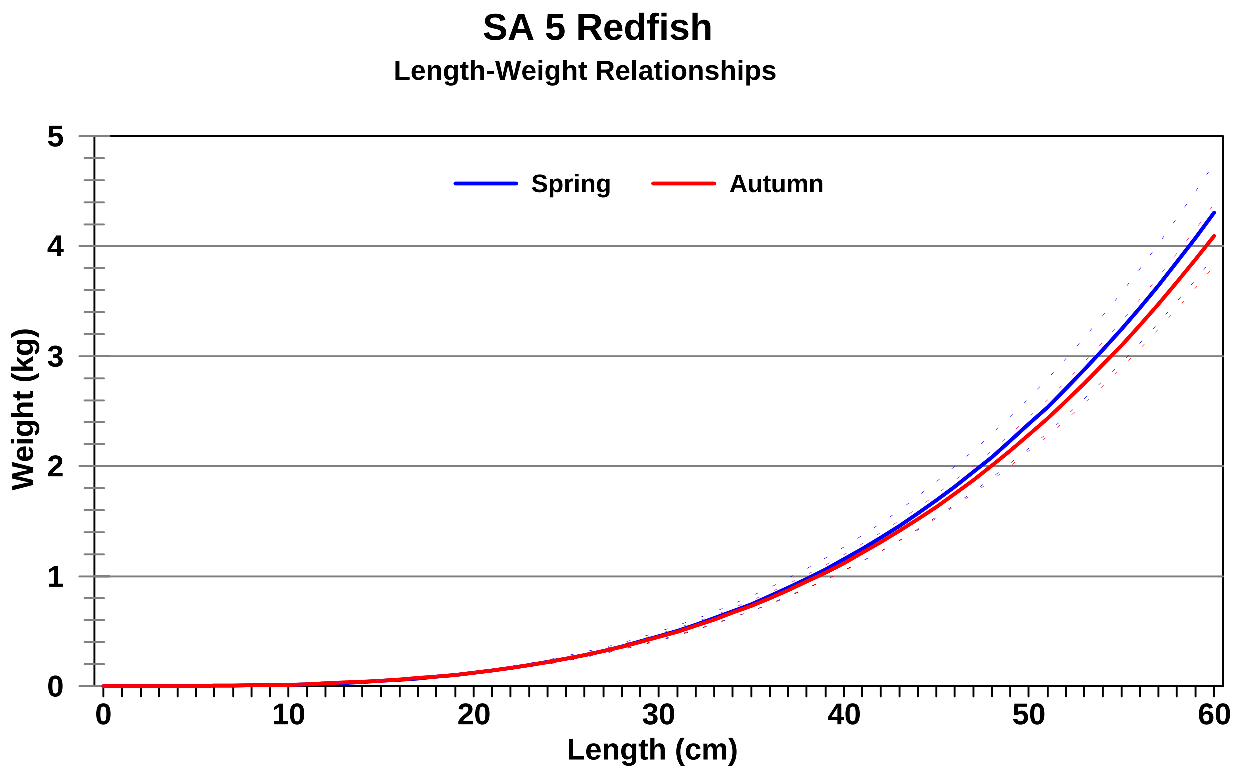


Figure C14. Catch curves based on redfish cohorts from 1925-1995.



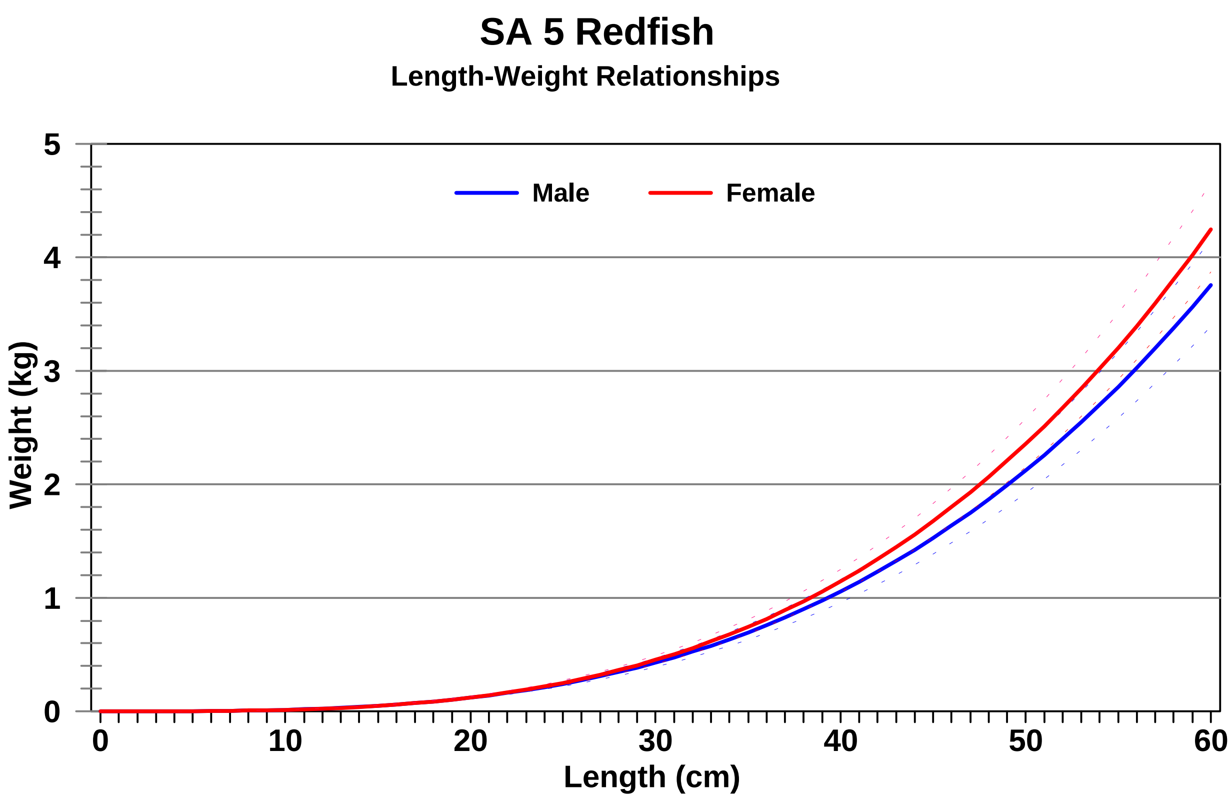
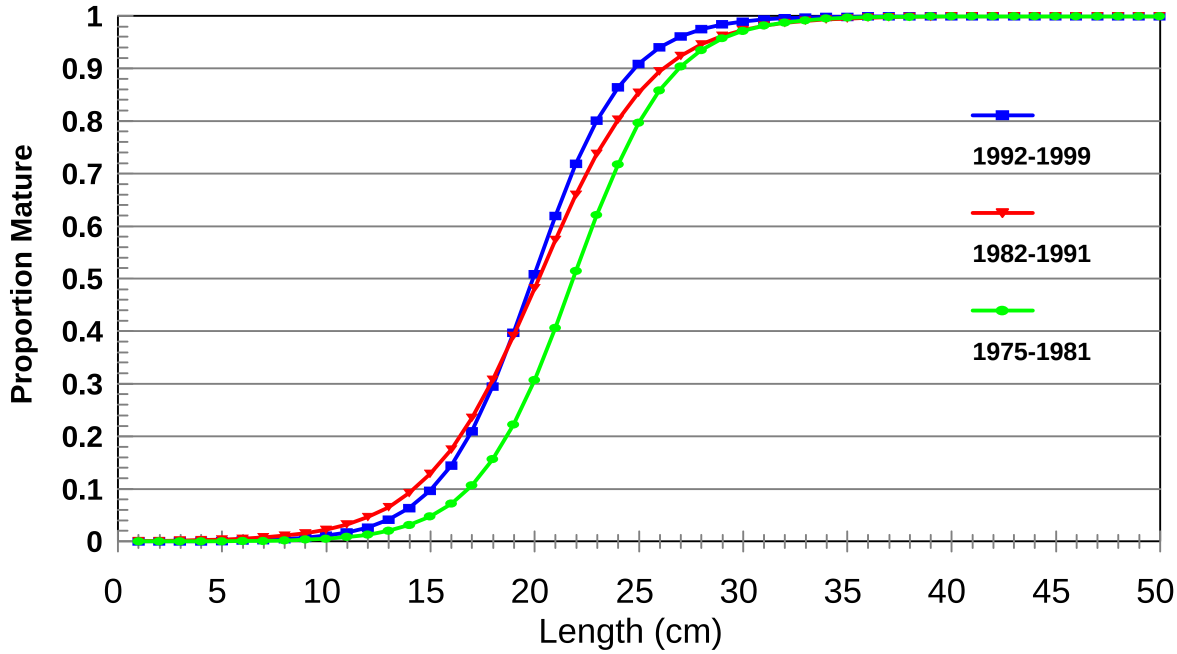


Figure C15. Length-weight relationships for redfish (a) by season and (by) by sex from NEFSC spring and autumn bottom trawl surveys, 1992-2000.

SA 5 Redfish

Maturity Schedules - Spring Data



Maturity Schedules - Autumn Data

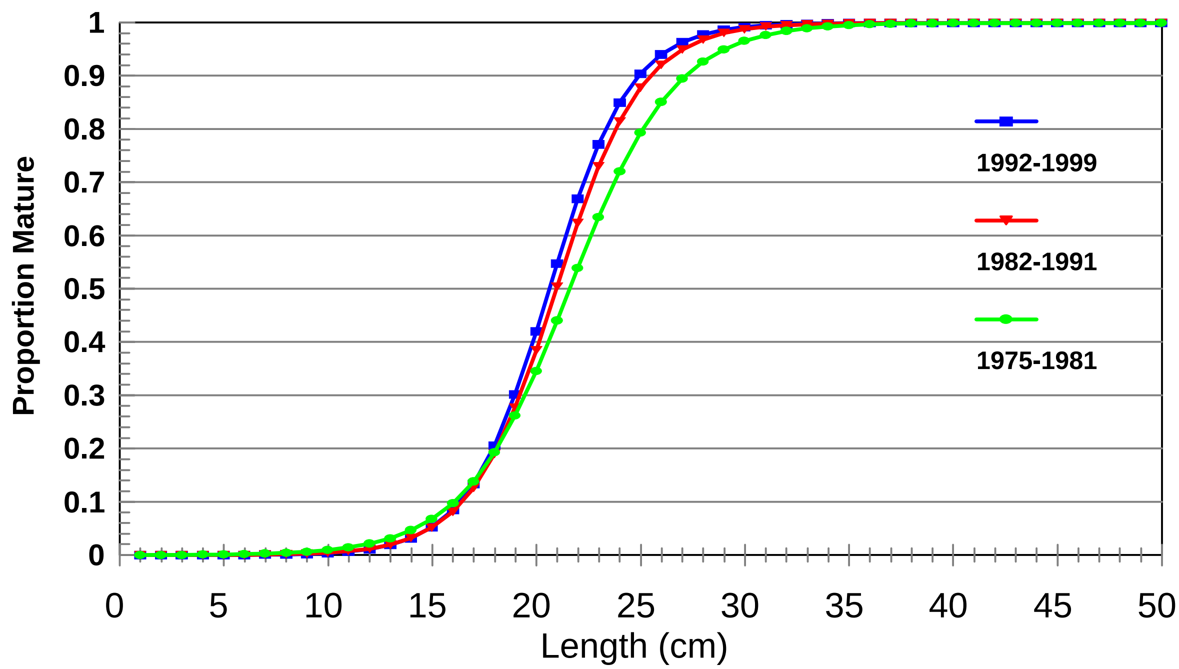


Figure C16. Maturity at length results for redfish (sexes combined) for three time periods from NEFSC (a) spring and (b) autumn bottom trawl surveys, 1975-1999.

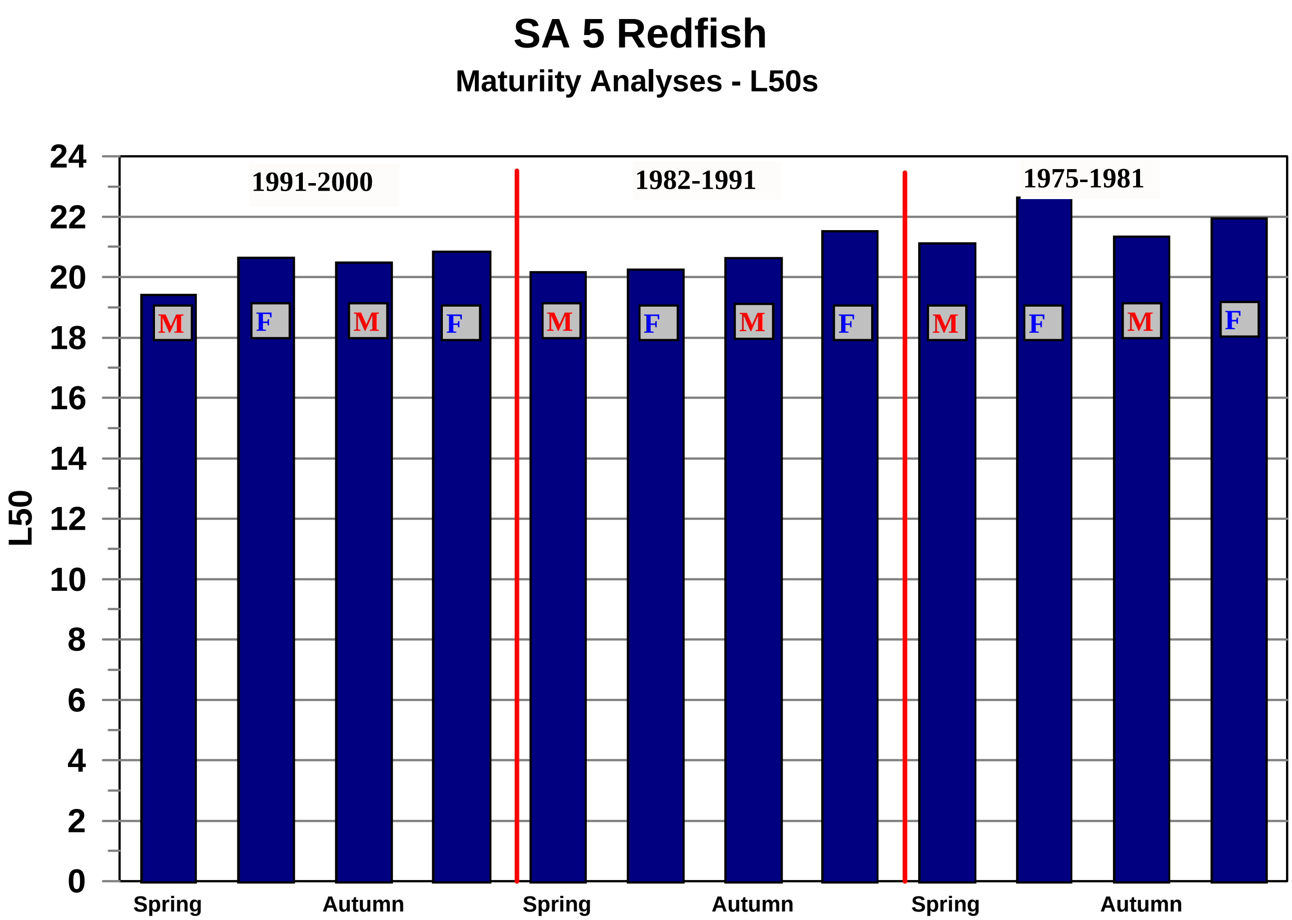


Figure C17. Median length at maturity (L50) by sex for redfish for three time periods from NEFSC spring and autumn bottom trawl surveys.

SA 5 Redfish

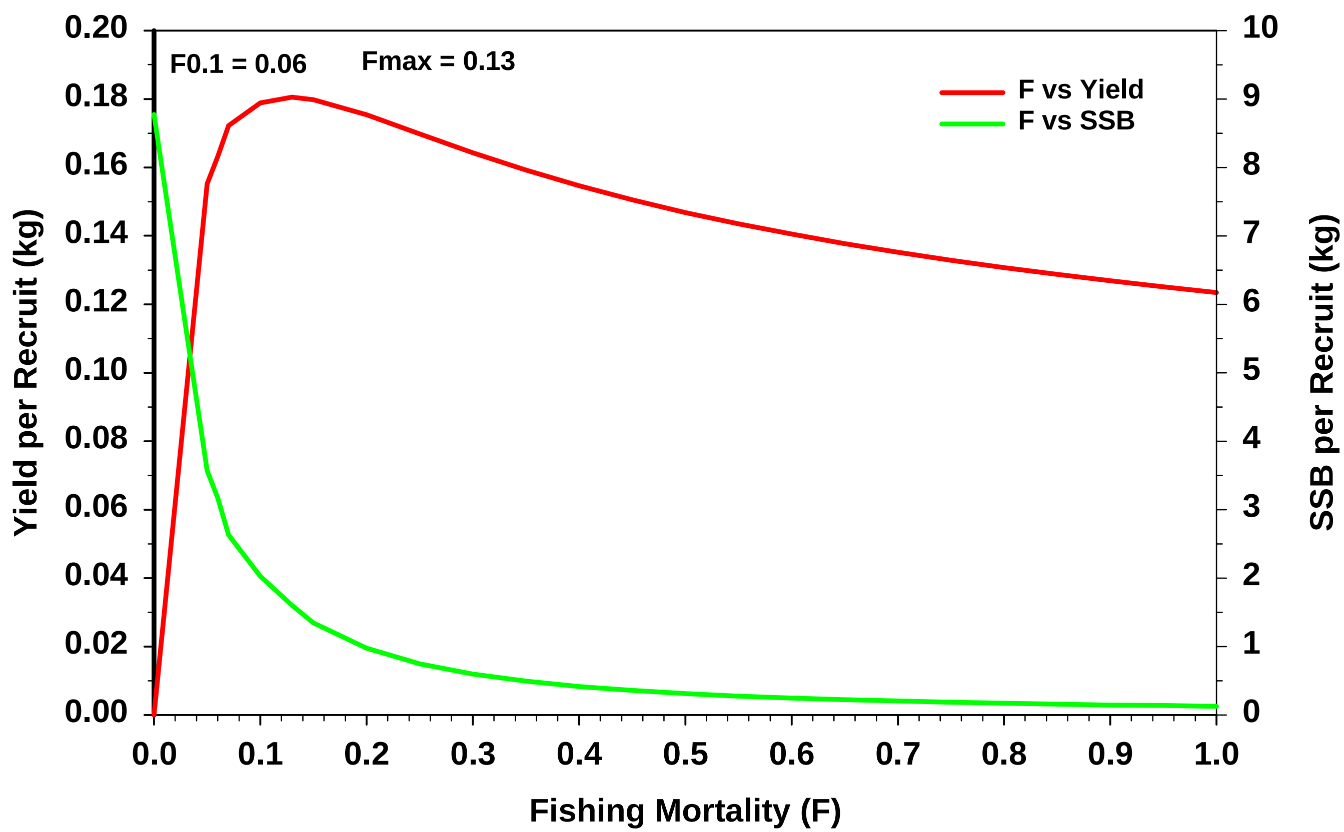
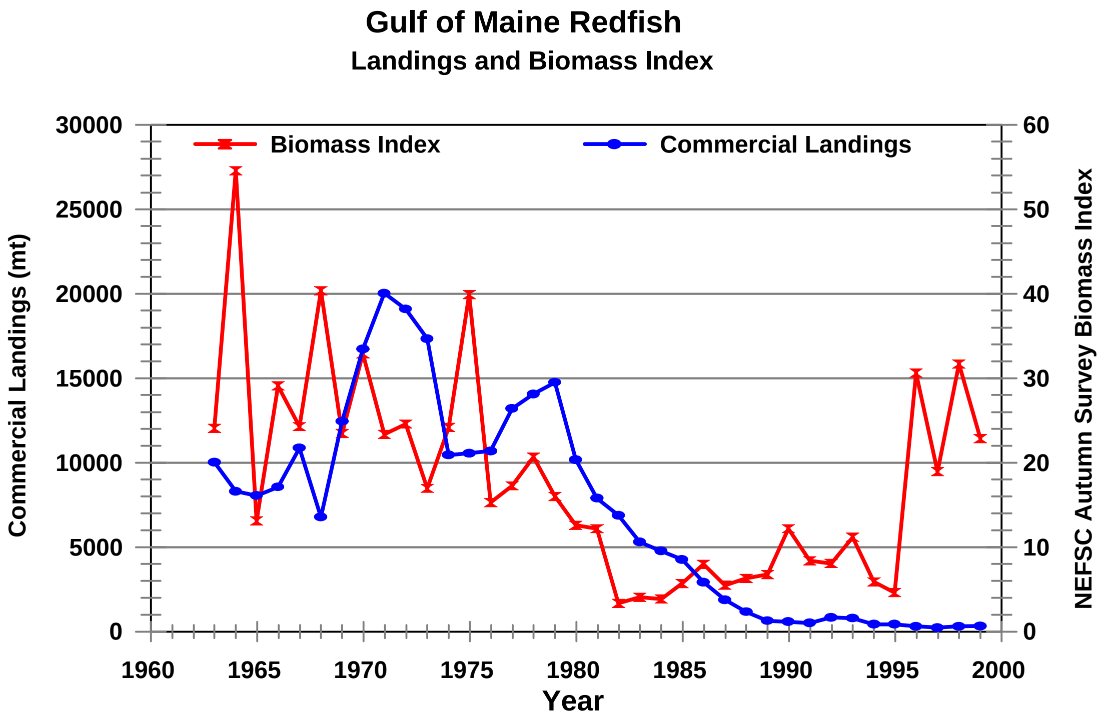


Figure C18 Yield and spawning stock biomass per recruit (kg) for redfish in the Gulf of Maine - Georges Bank region.



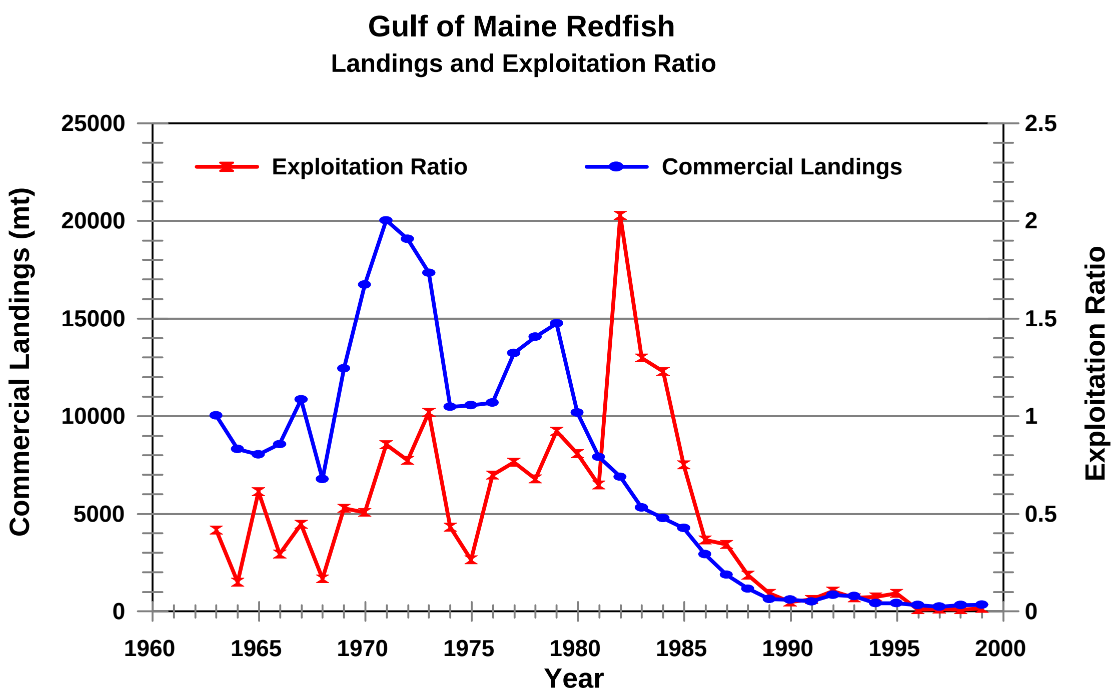
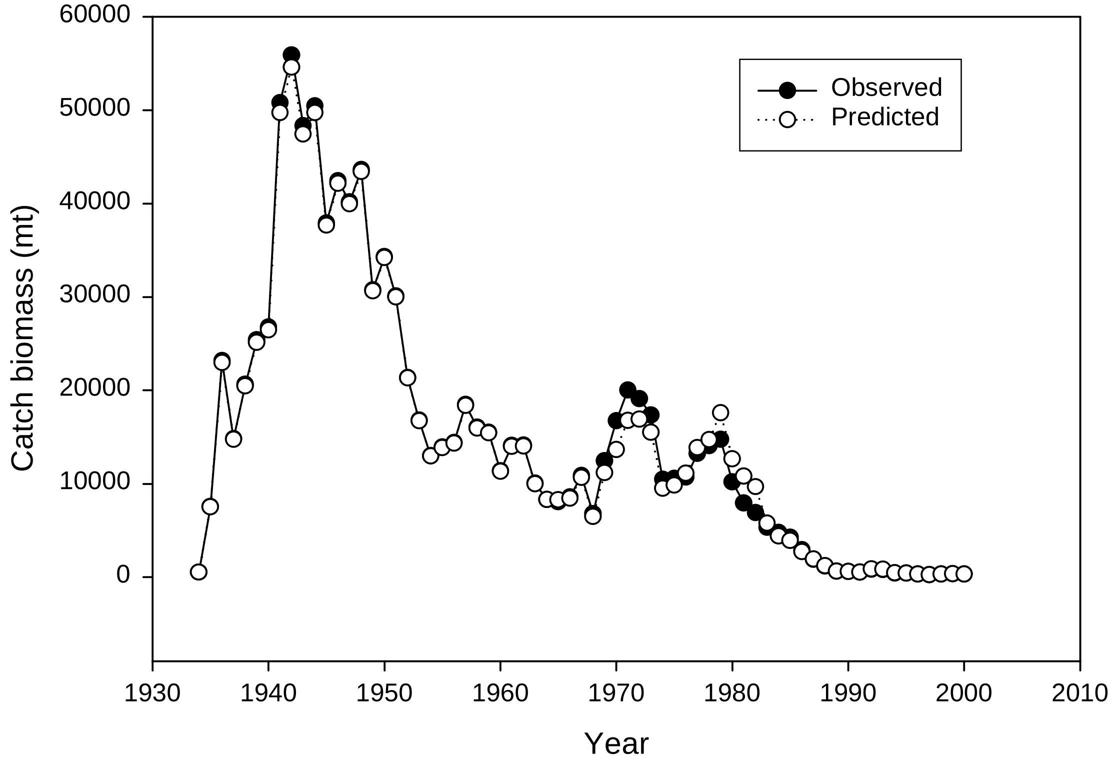


Figure C19 Exploitation index for Gulf of Maine-Georges Bank Redfish expressed as the ratio of NEFSC autumn biomass index to total fisheey removals, 1963-2000.

Figure C20. Redfish catch biomass residuals (mt), 1934-2000 including 1999-2000 autumnm survey age data.



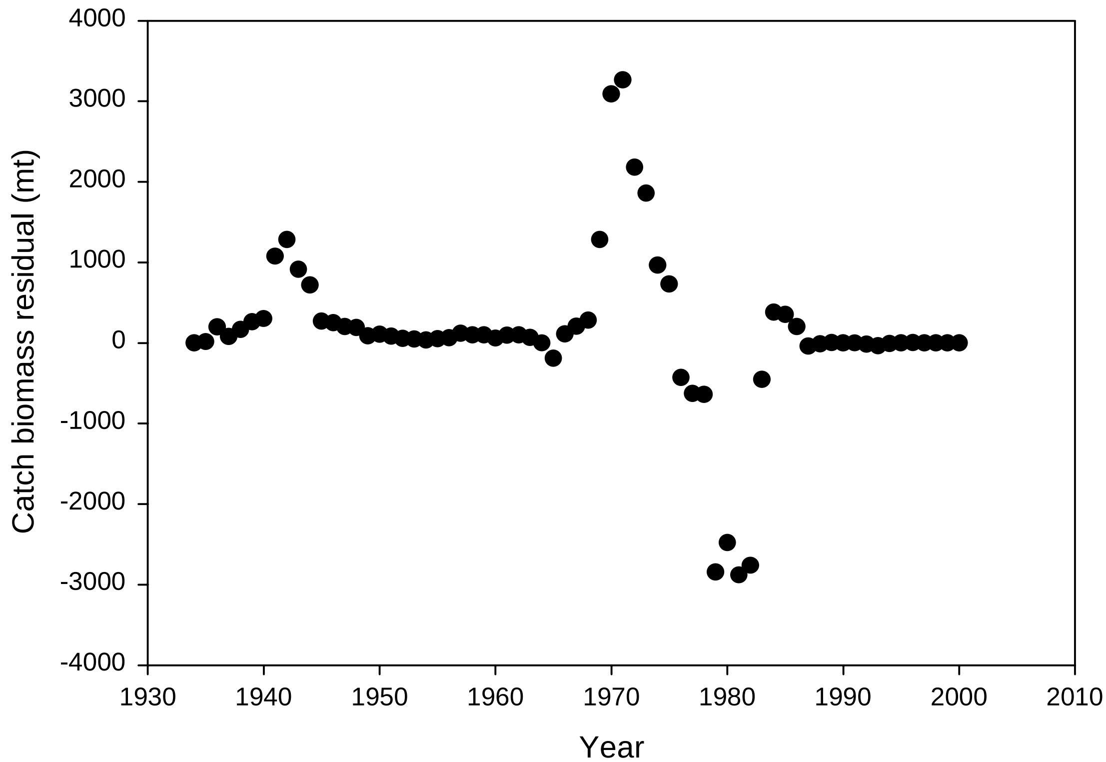
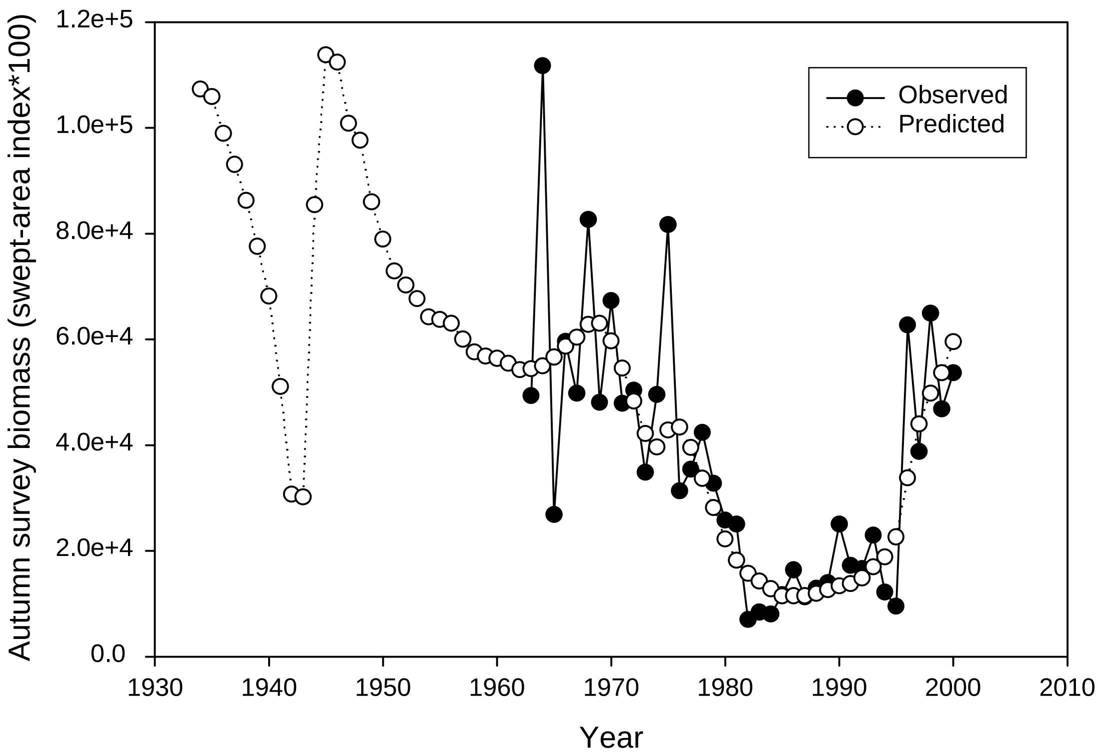


Figure C21. NEFSC autumn survey redfish biomass index residuals, 1963-2000 including 1999-2000 autumn survey age data



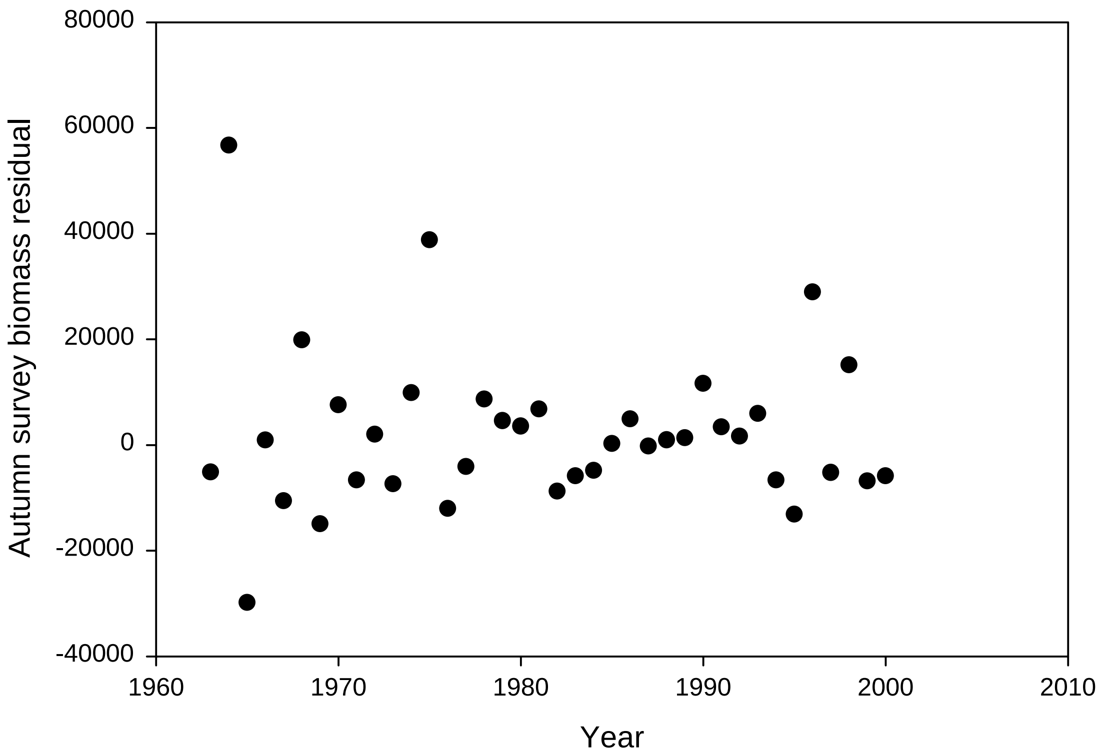
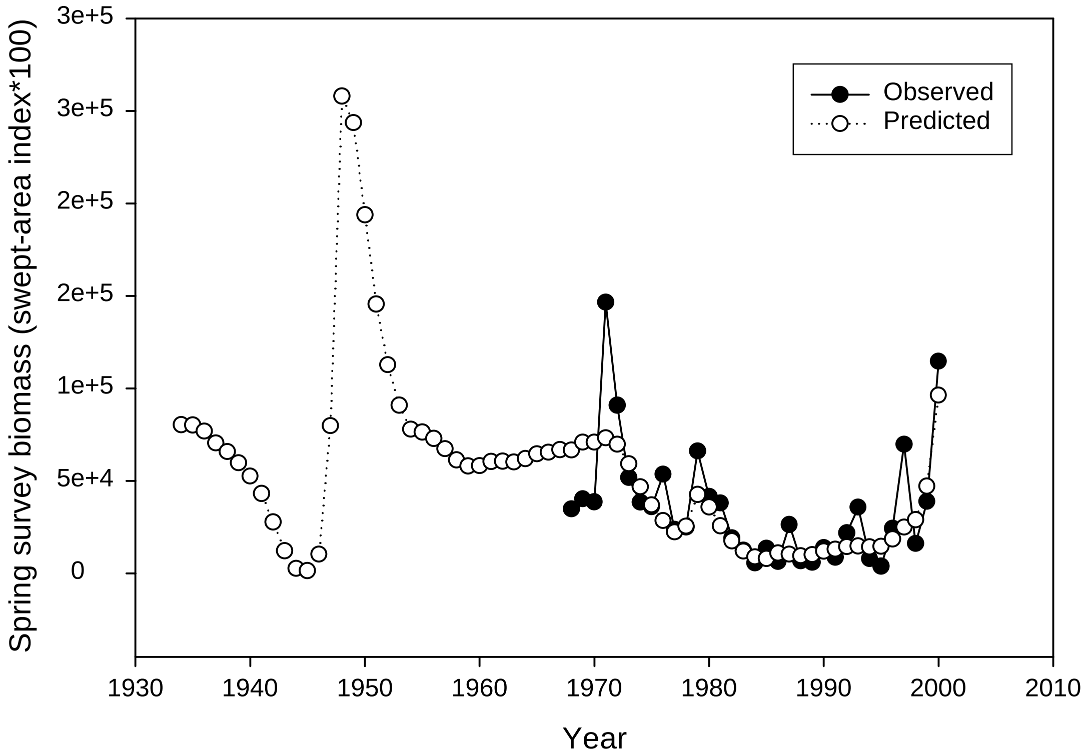


Figure C22. NEFSC spring survey redfish biomass index residuals, 1968-2000 including 1999-2000 autumn survey age data



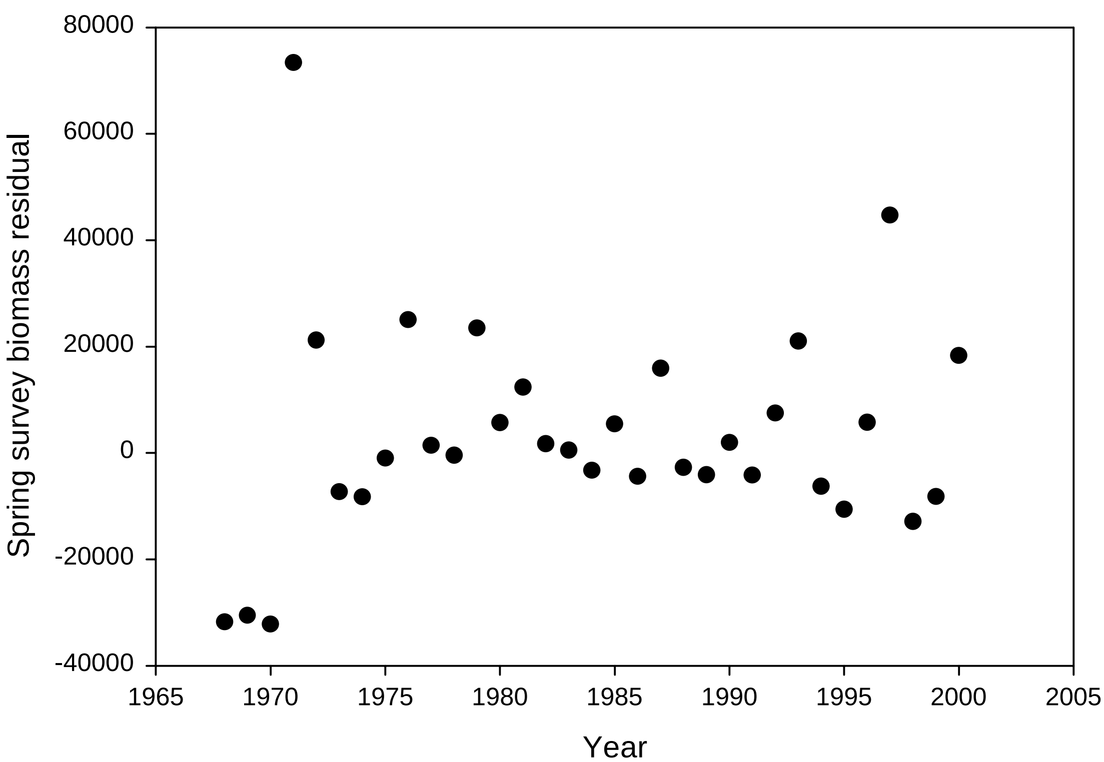
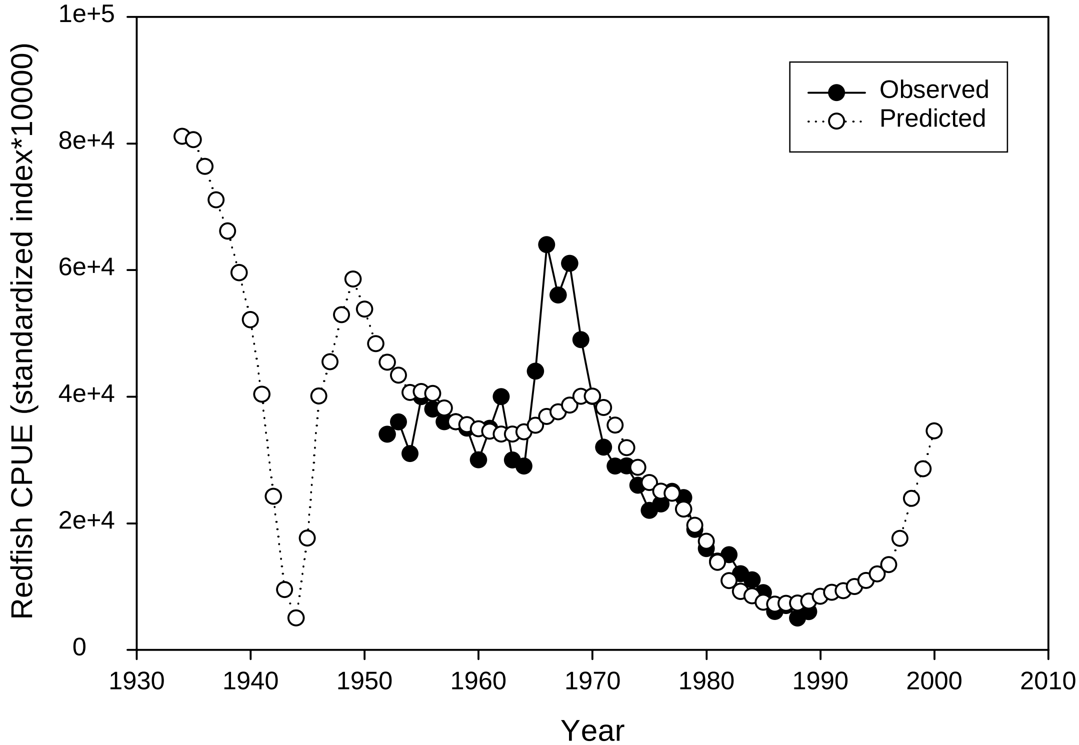


Figure C23. Standardized redfish CPUE index residuals, 1952-1989
including 1999-2000 autumn survey age data



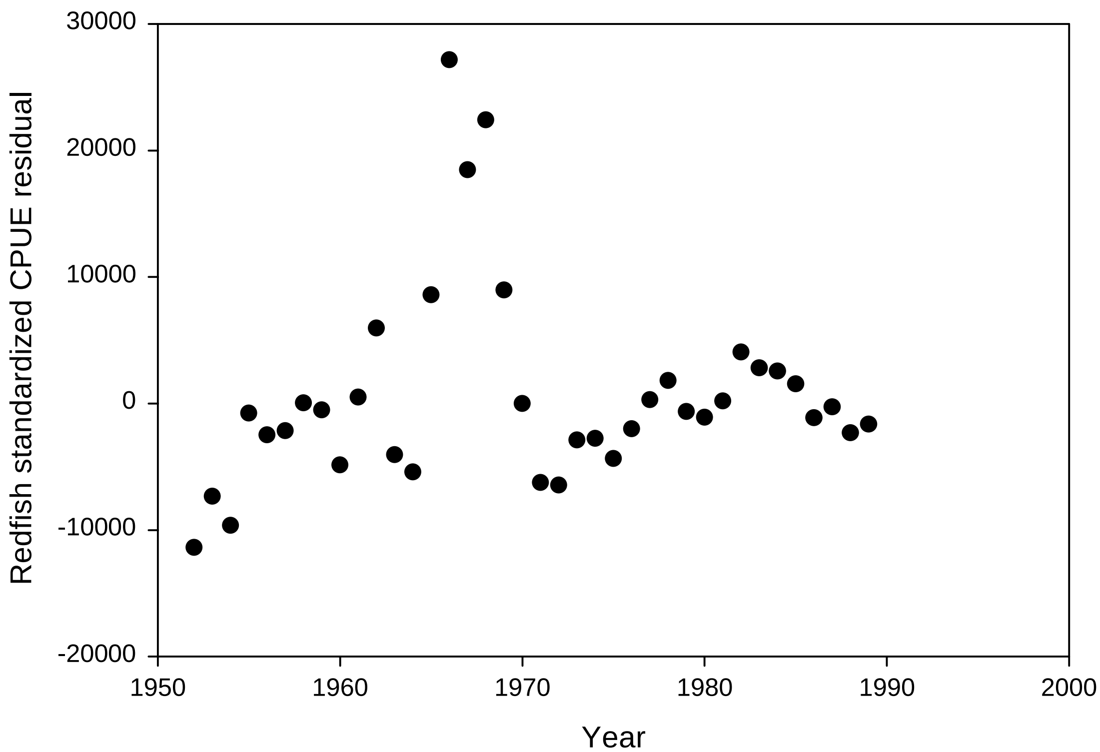


Figure C24. Redfish fishery age composition residuals, 1969-1985
including 1999-2000 autumn survey age data

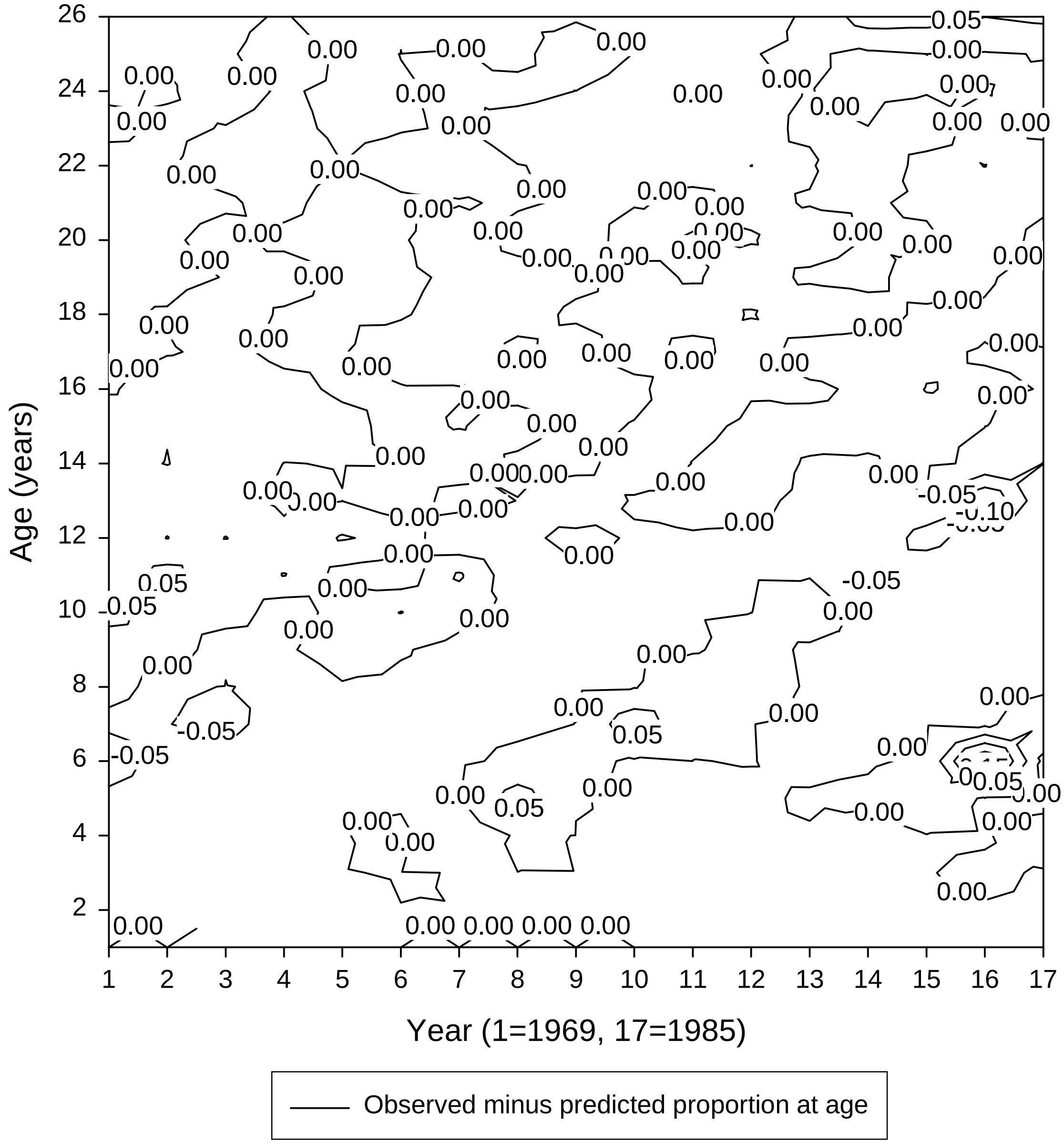


Figure C25. Redfish autumn survey age composition residuals, 1975-2000 including 1999-2000 autumn survey age data

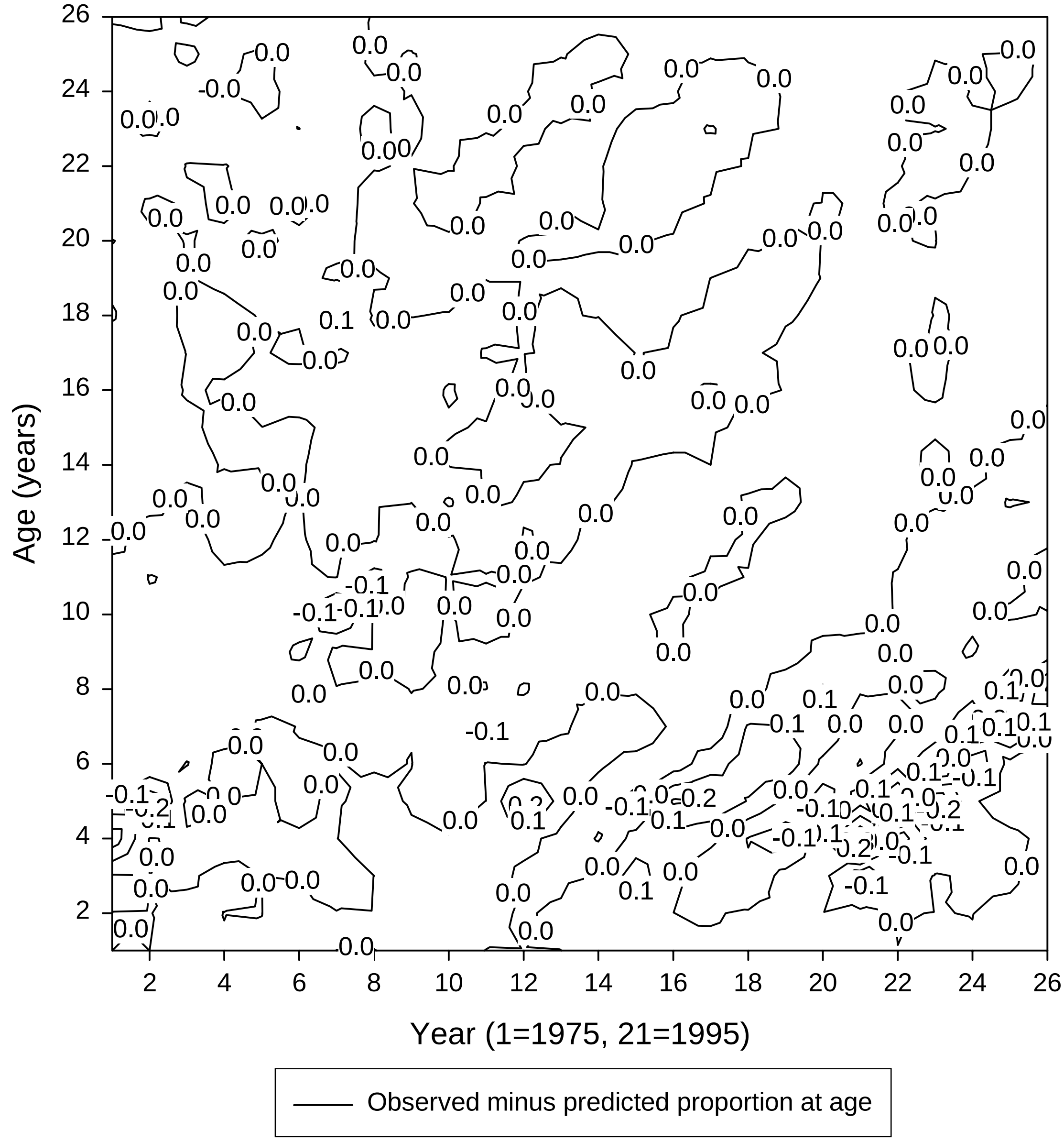


Figure C26. Redfish spring survey age composition residuals, 1975-1990 including 1999-2000 autumn survey age data

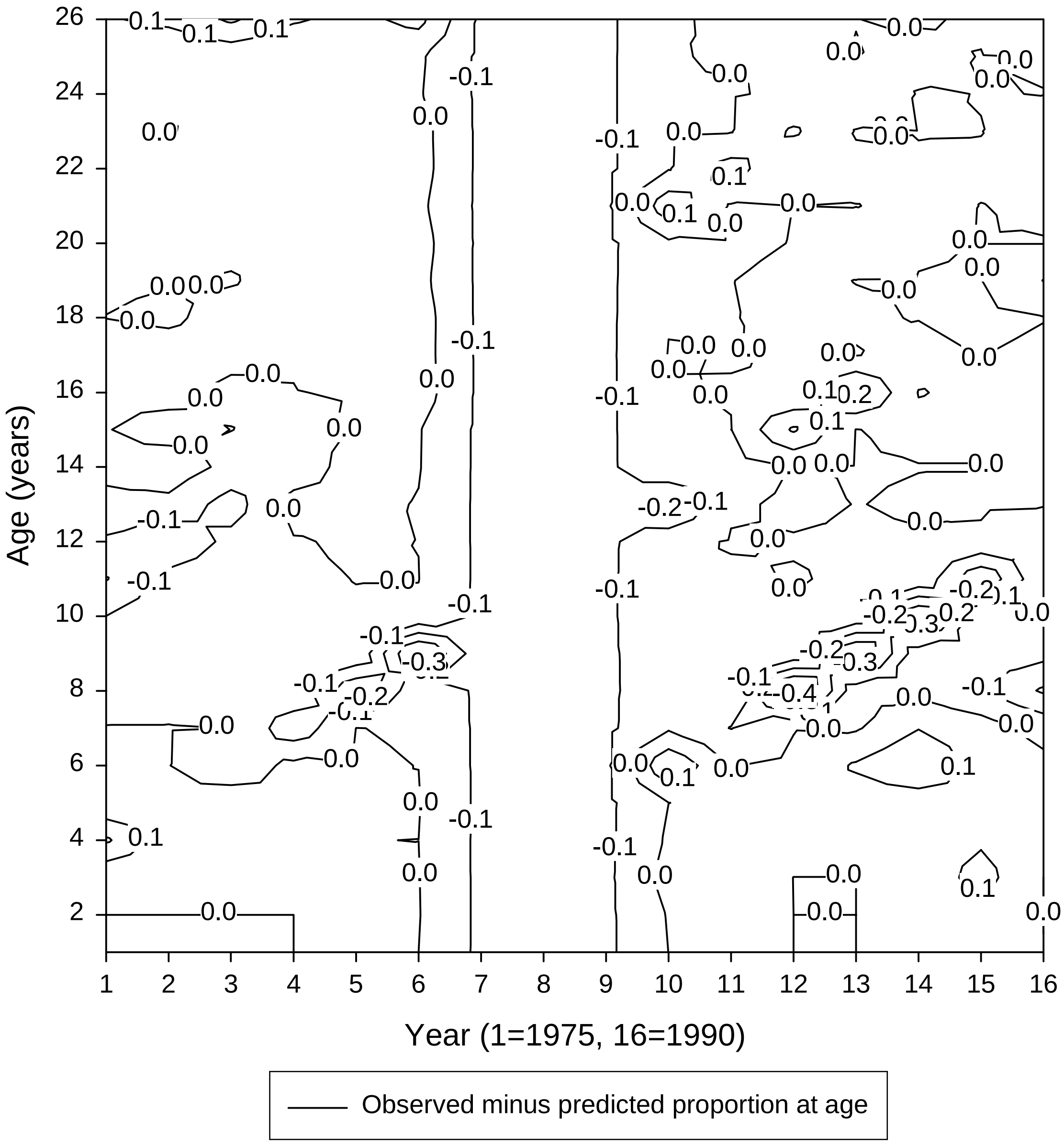
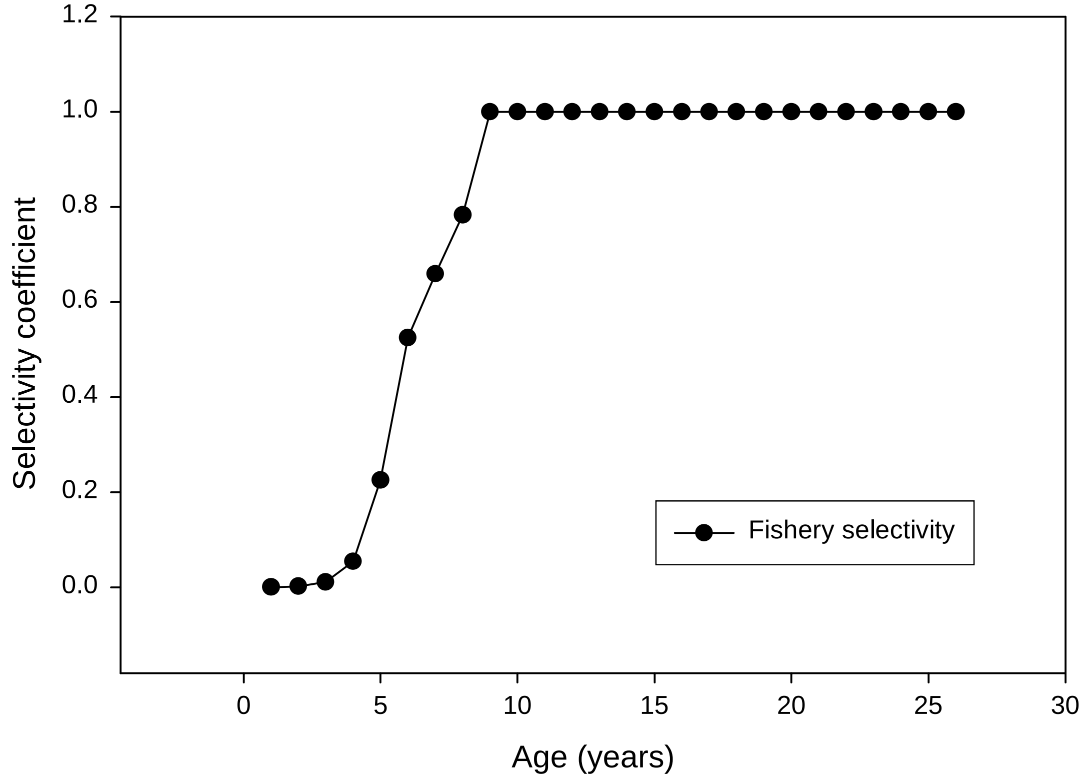


Figure C27. Redfish fishery and survey selectivity at age including 1999-2000 autumn survey age data



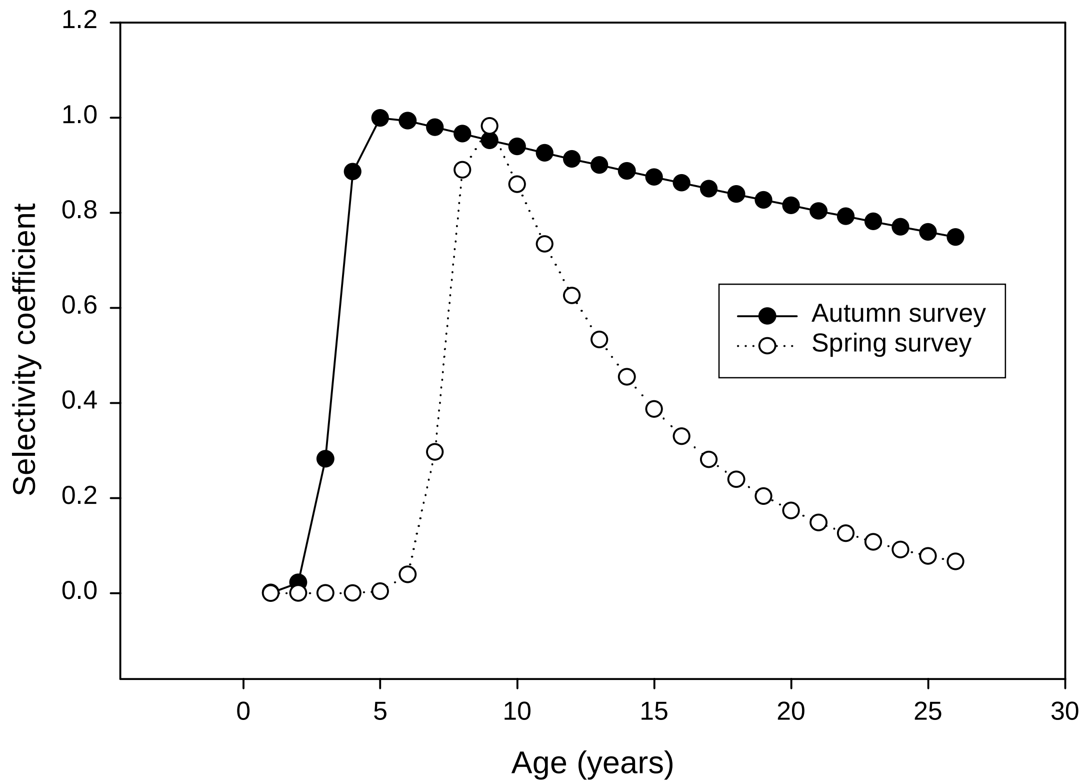
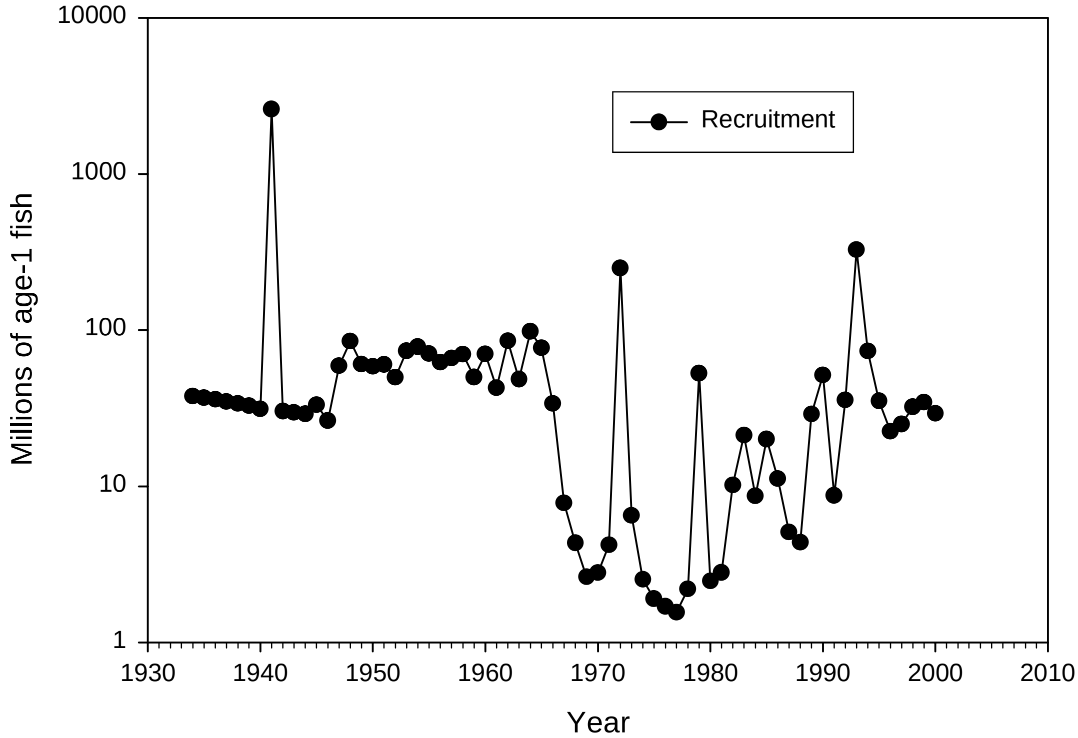


Figure C28. Redfish recruitment, 1934-2000 including 1999-2000 autumn survey age data



Redfish recruitment, 1963-2000
including 1999-2000 autumn survey age data

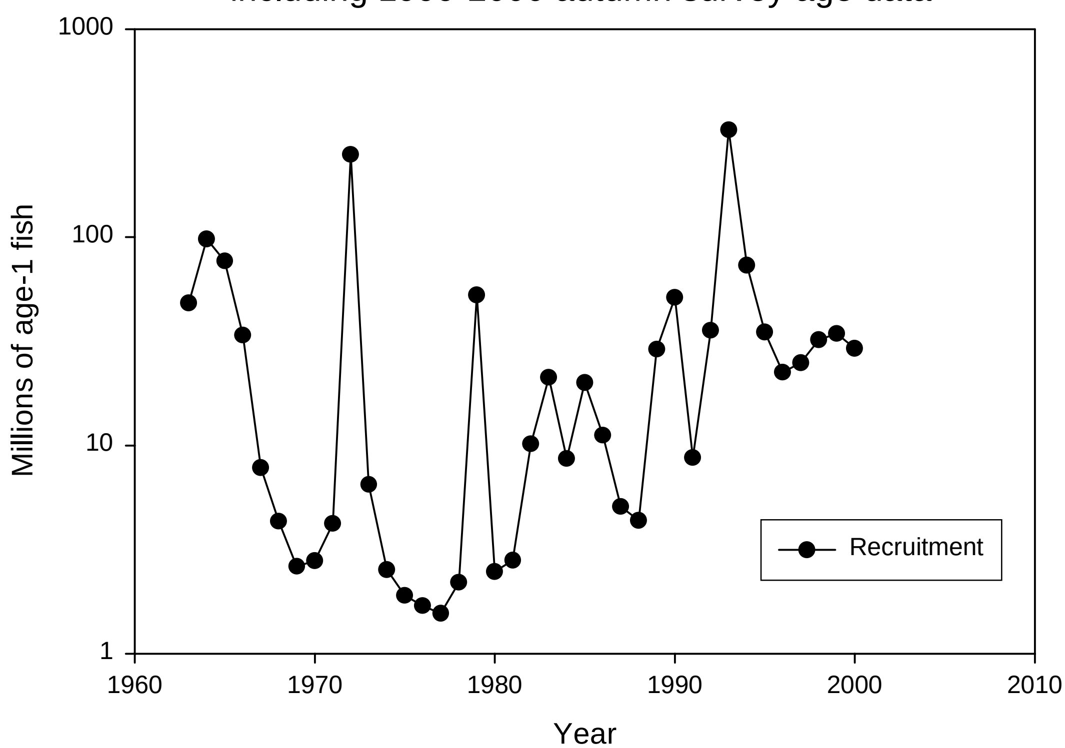
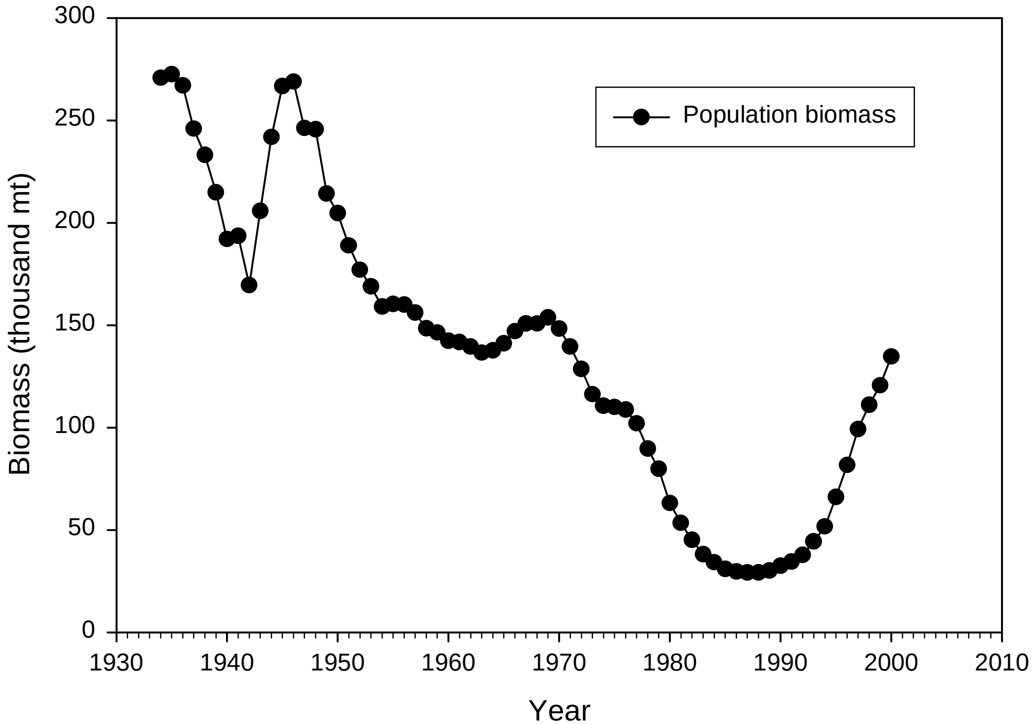


Figure C29. Redfish population biomass (thousand mt), 1934-2000
including 1999-2000 autumn survey age data



Redfish population biomass (thousand mt), 1963-2000
including 1999-2000 autumn survey age data

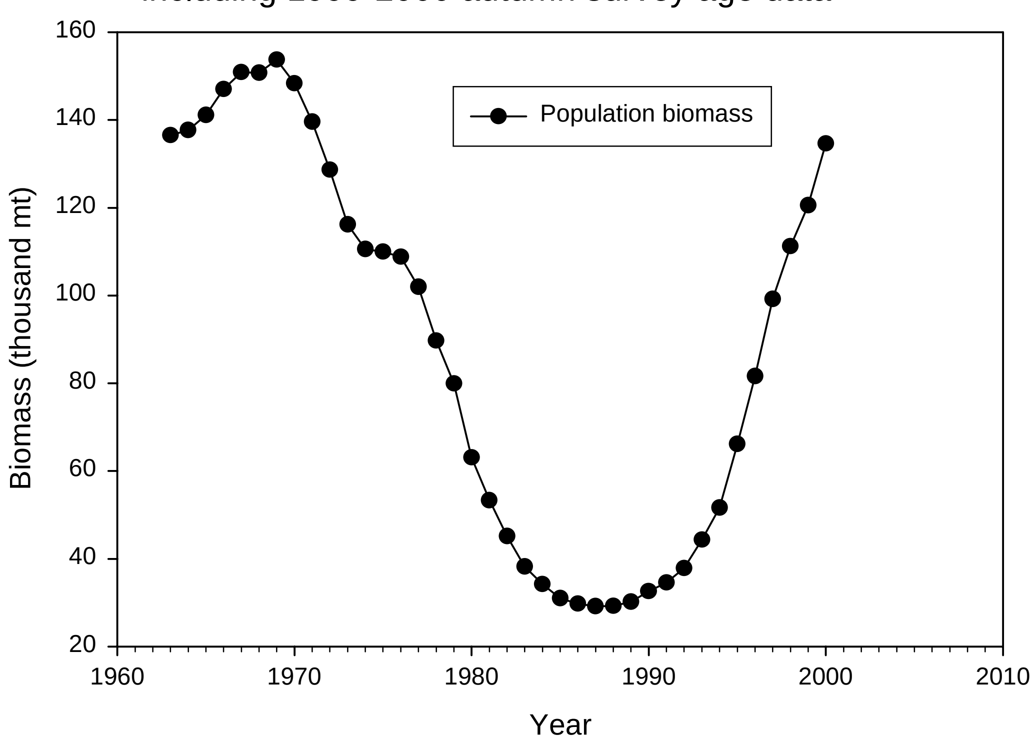
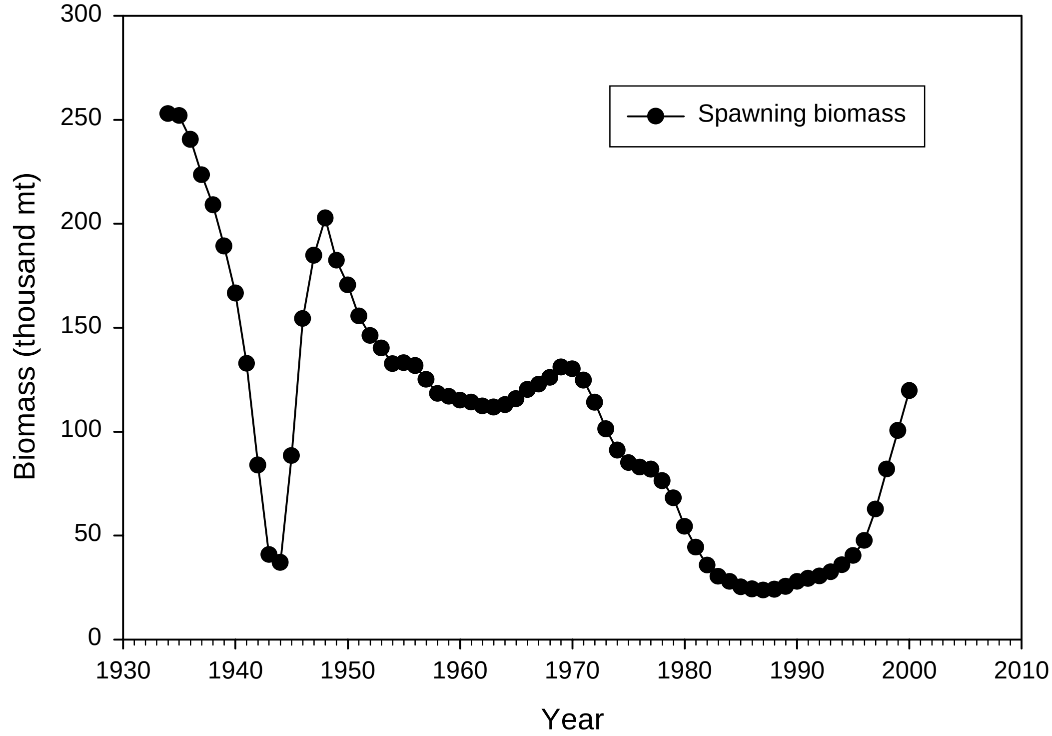


Figure C30. Redfish spawning biomass (thousand mt), 1934-2000
including 1999-2000 autumn survey age data



Redfish spawning biomass (thousand mt), 1963-2000
including 1999-2000 autumn survey age data

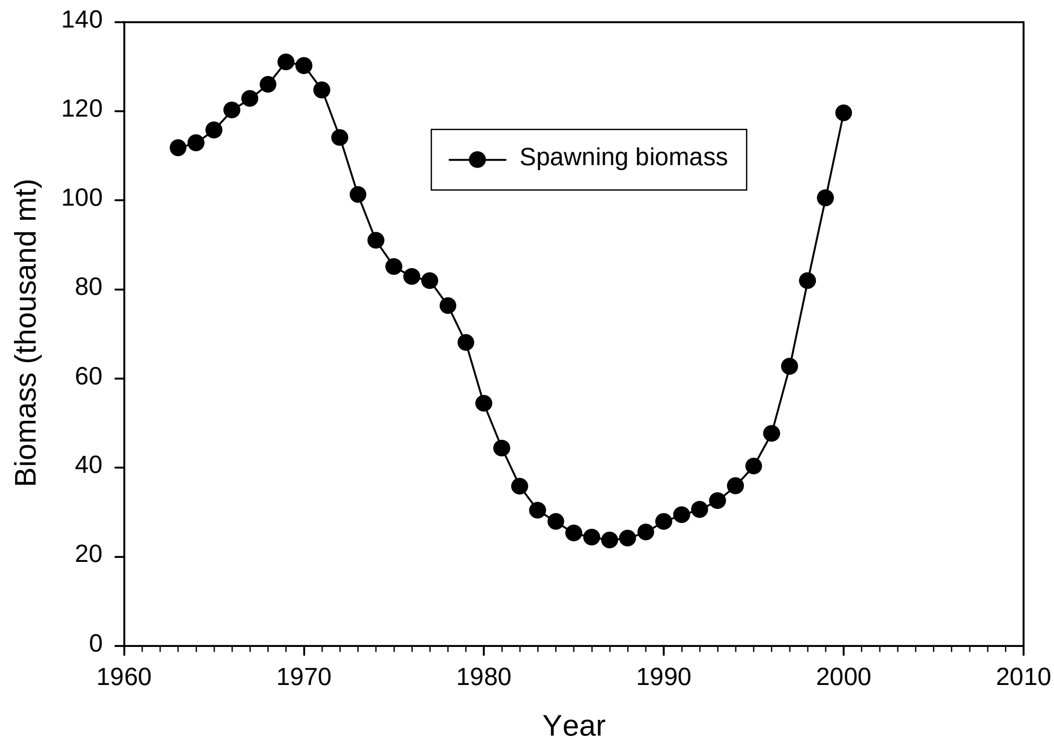
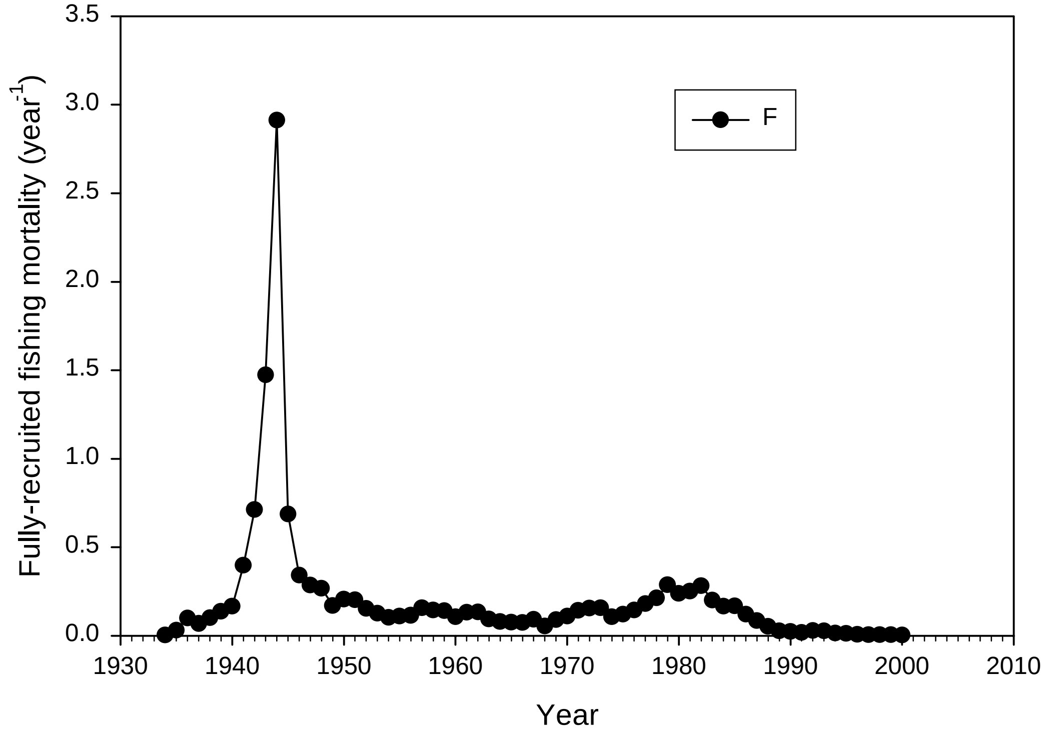


Figure C31. Redfish fishing mortality (F), 1934-2000
including 1999-2000 autumn survey age data



Redfish fishing mortality (F), 1963-2000
including 1999-2000 autumn survey age data

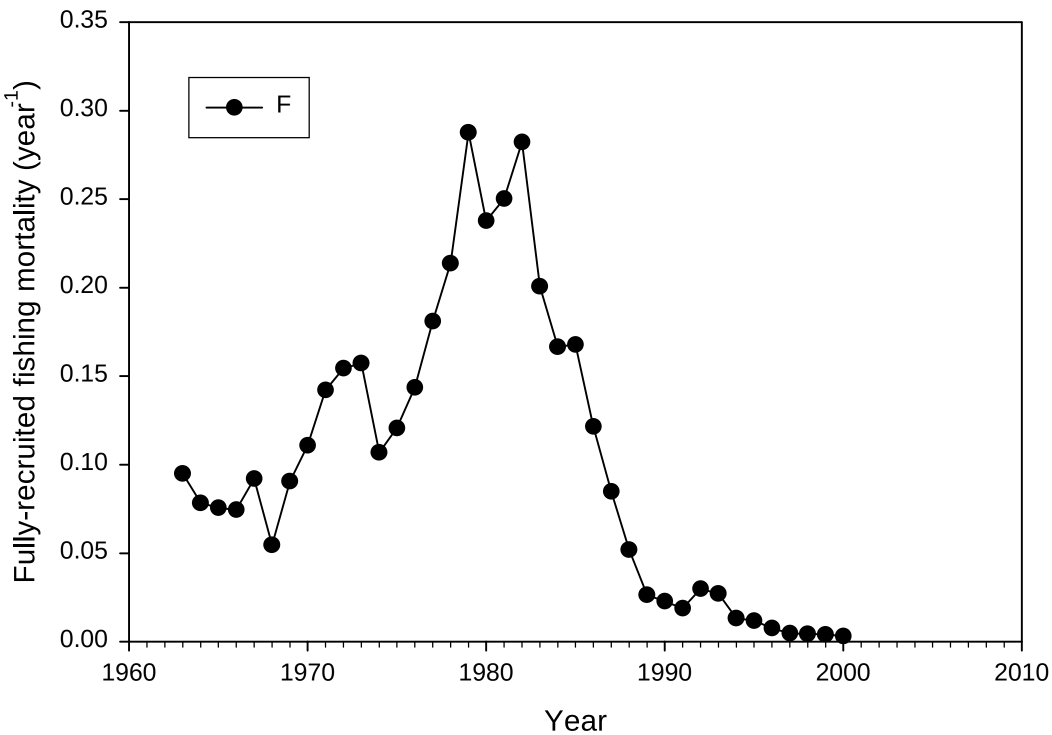


Figure C32. Redfish stock-recruitment data, 1963-2000 including 1999-2000 autumn survey age data

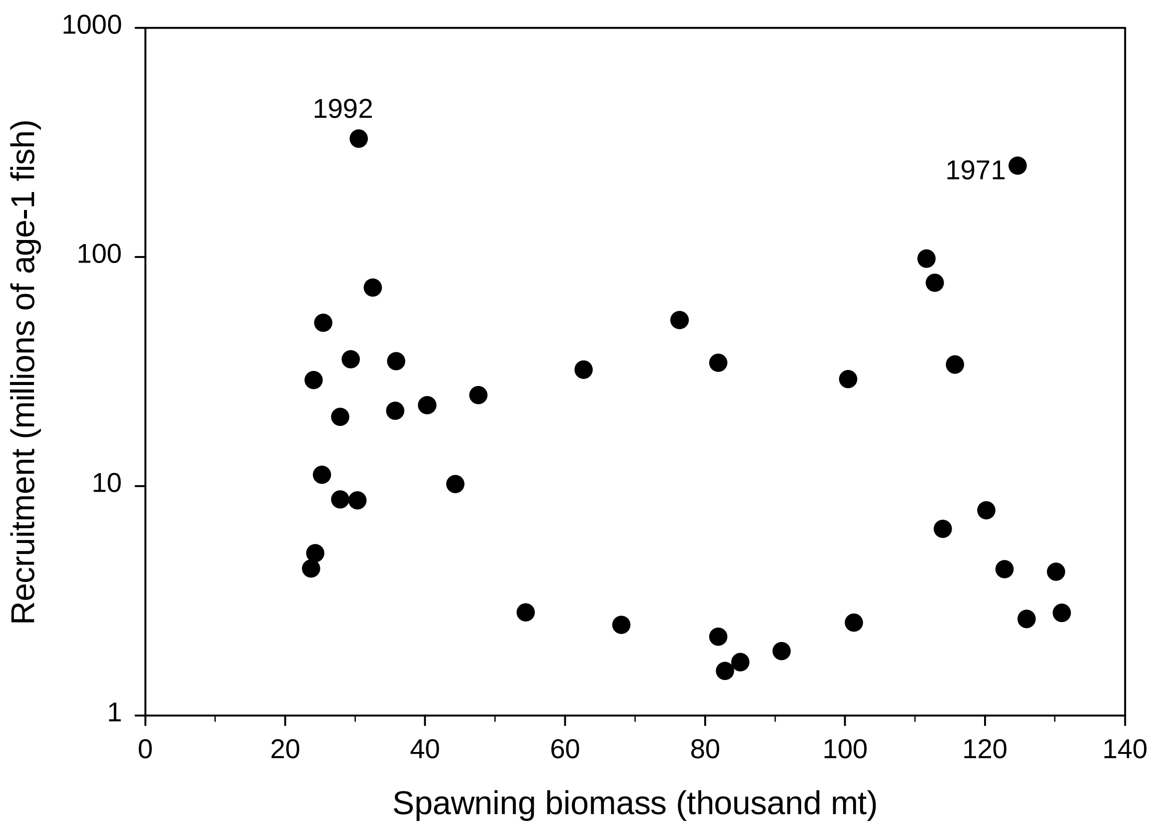
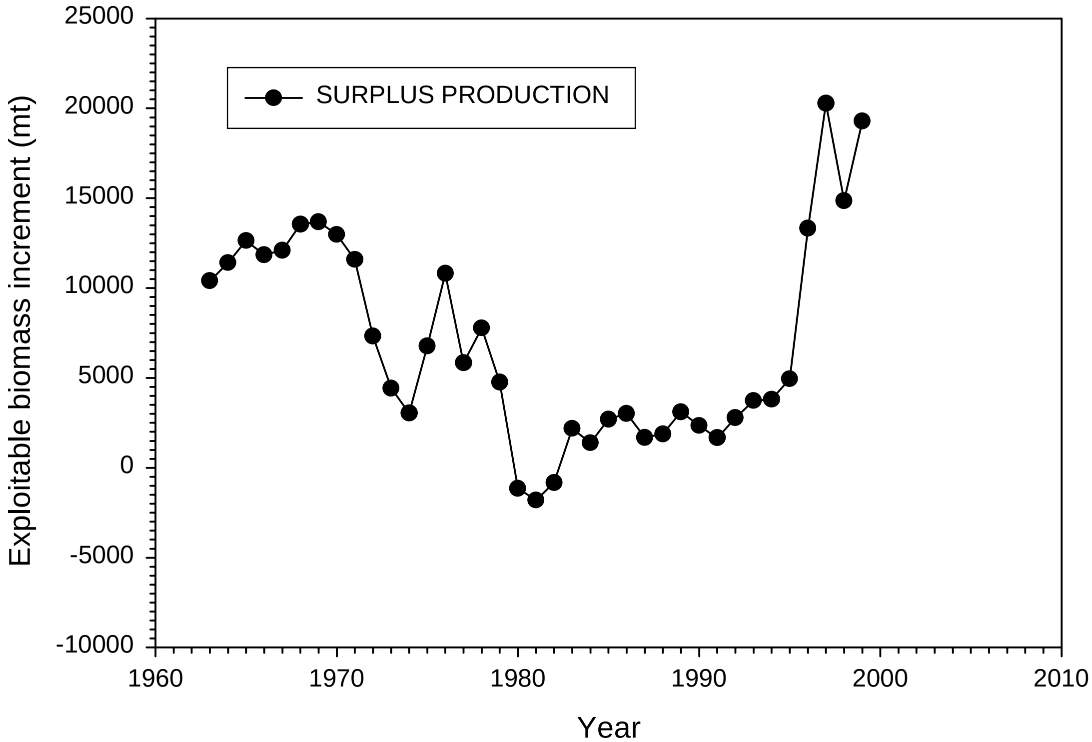


Figure C33. Redfish surplus production, 1963-1999
including 1999-2000 autumn survey age data



Redfish surplus production trajectory, 1934-1999
including 1999-2000 autumn survey age data

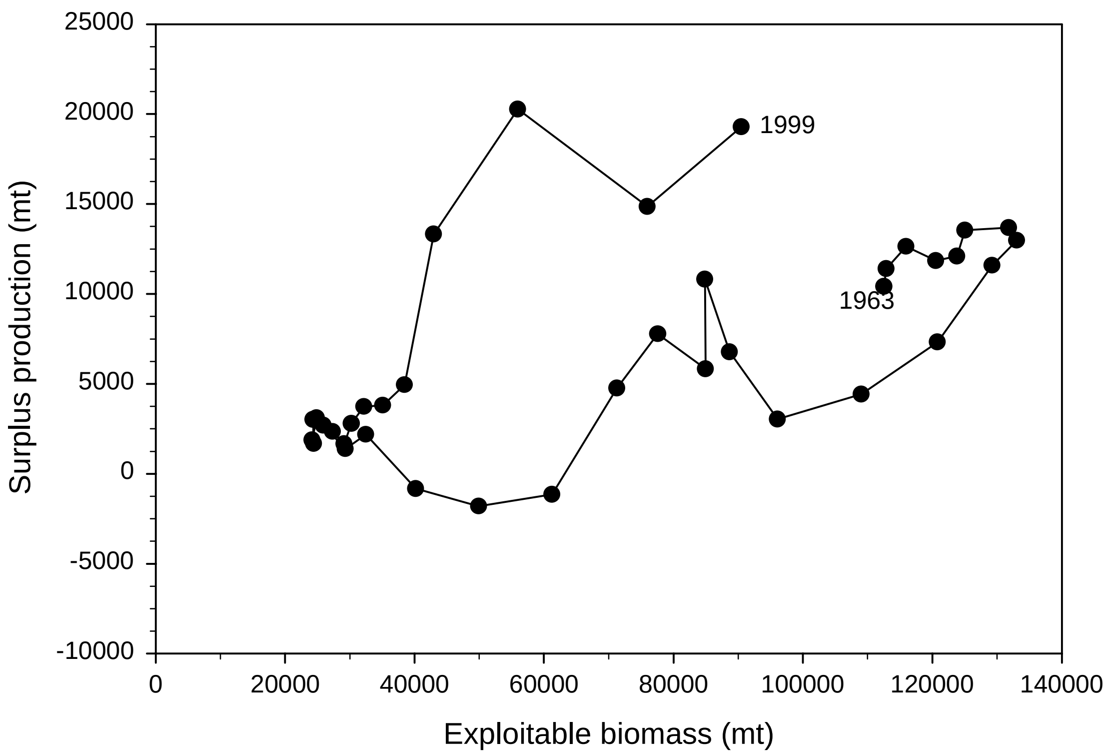
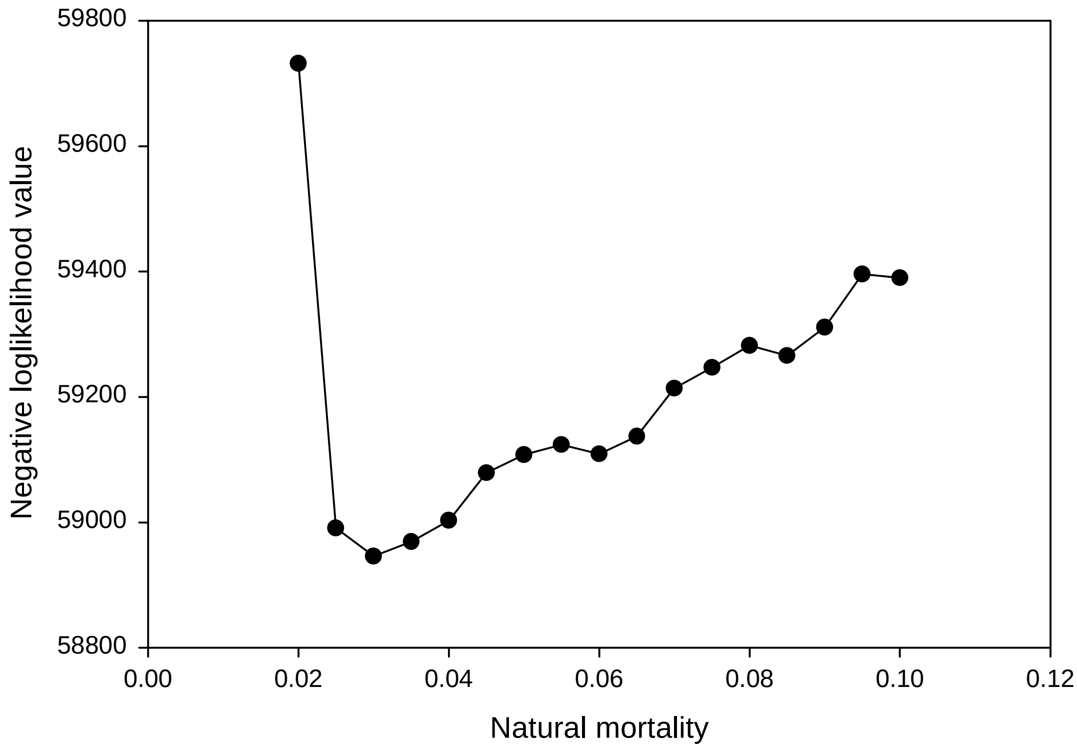


Figure C34. Redfish likelihood profile for natural mortality



Redfish population biomass as a function of natural mortality, 1934-2000

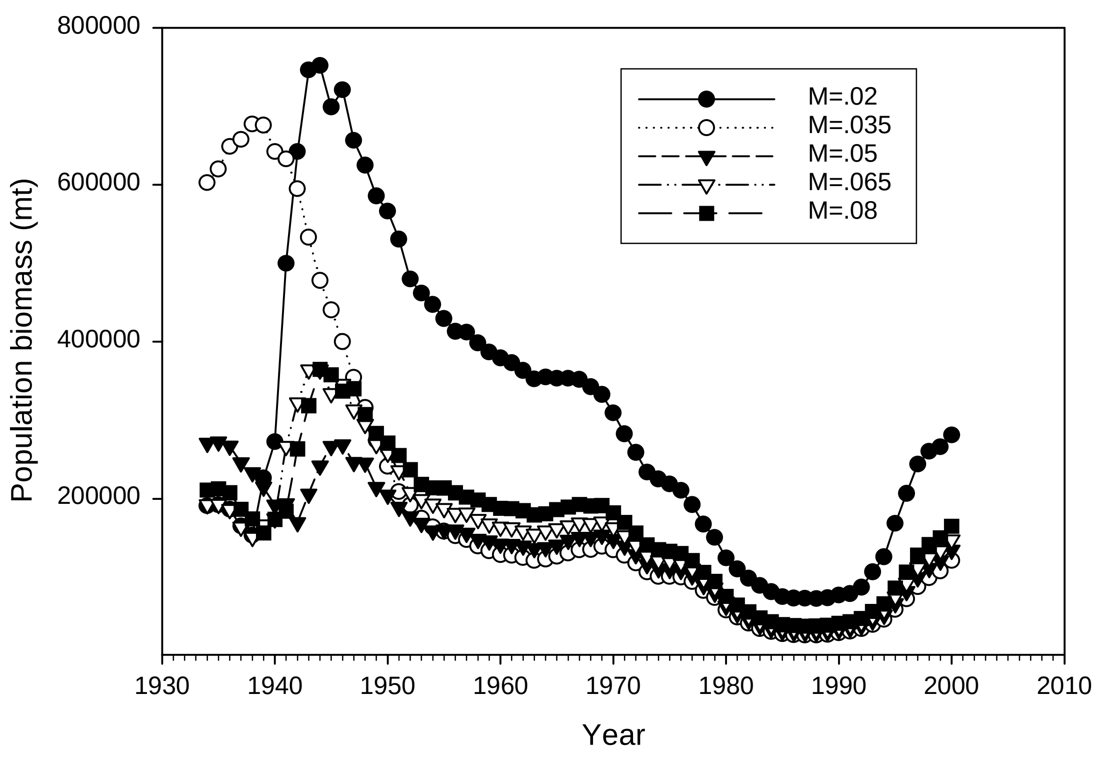
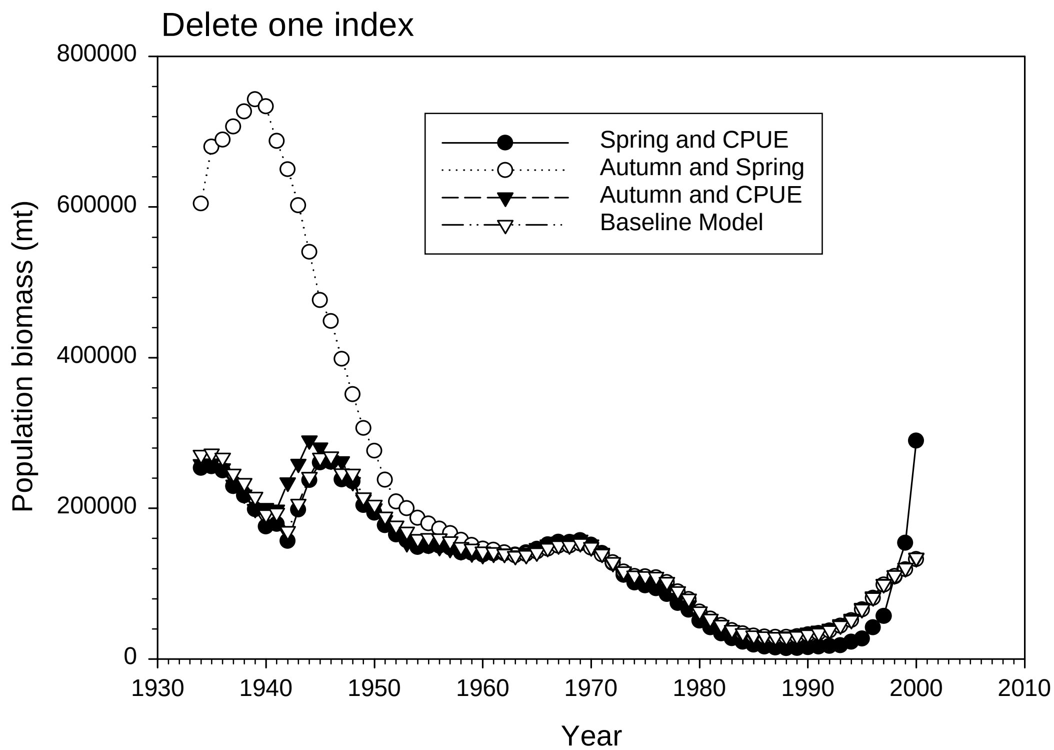
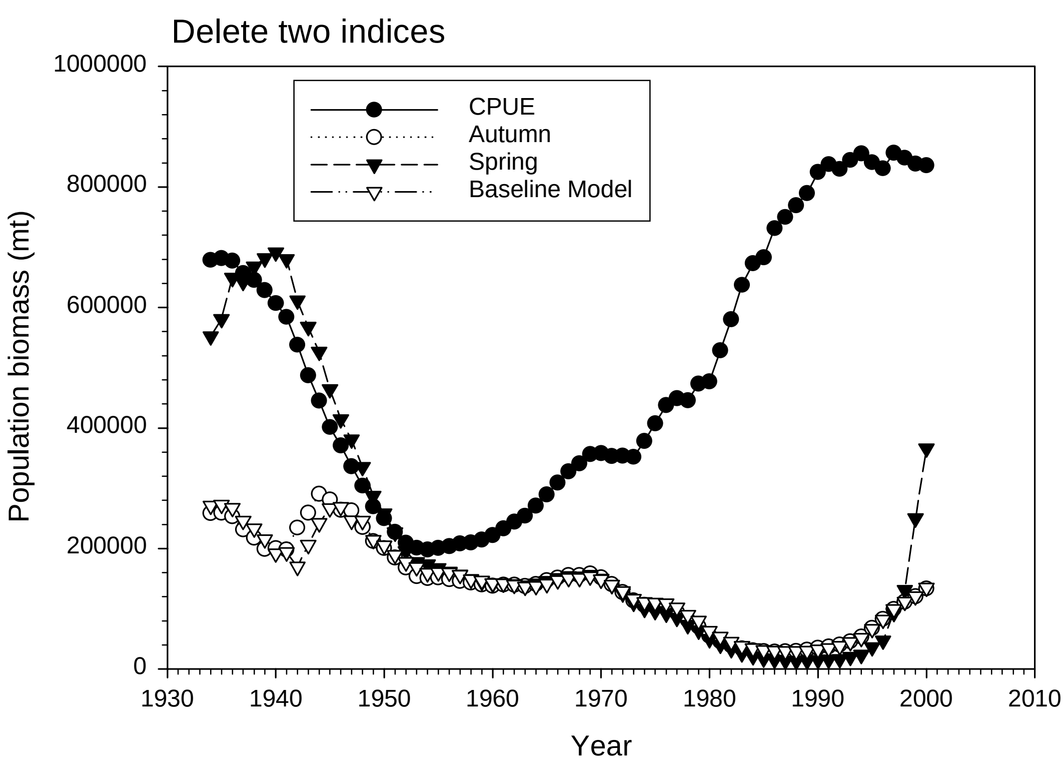


Figure C35. Redfish abundance index sensitivity analyses





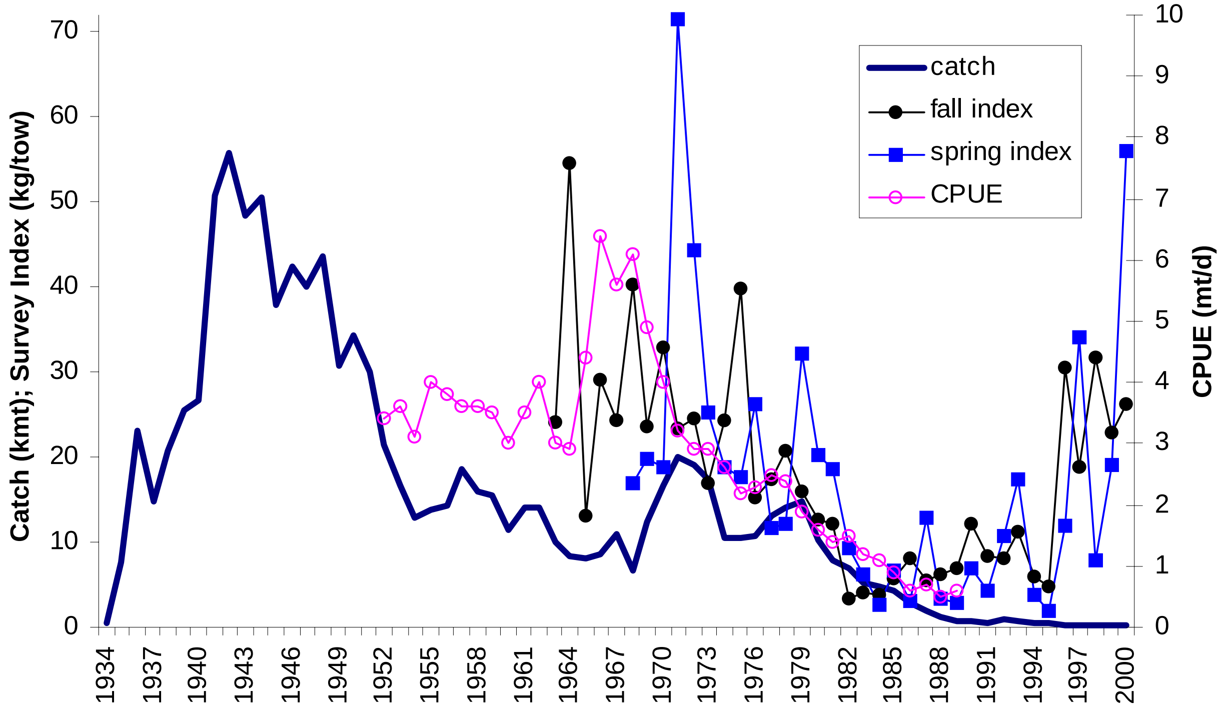


Figure C36. Input data for biomass dynamics analysis.

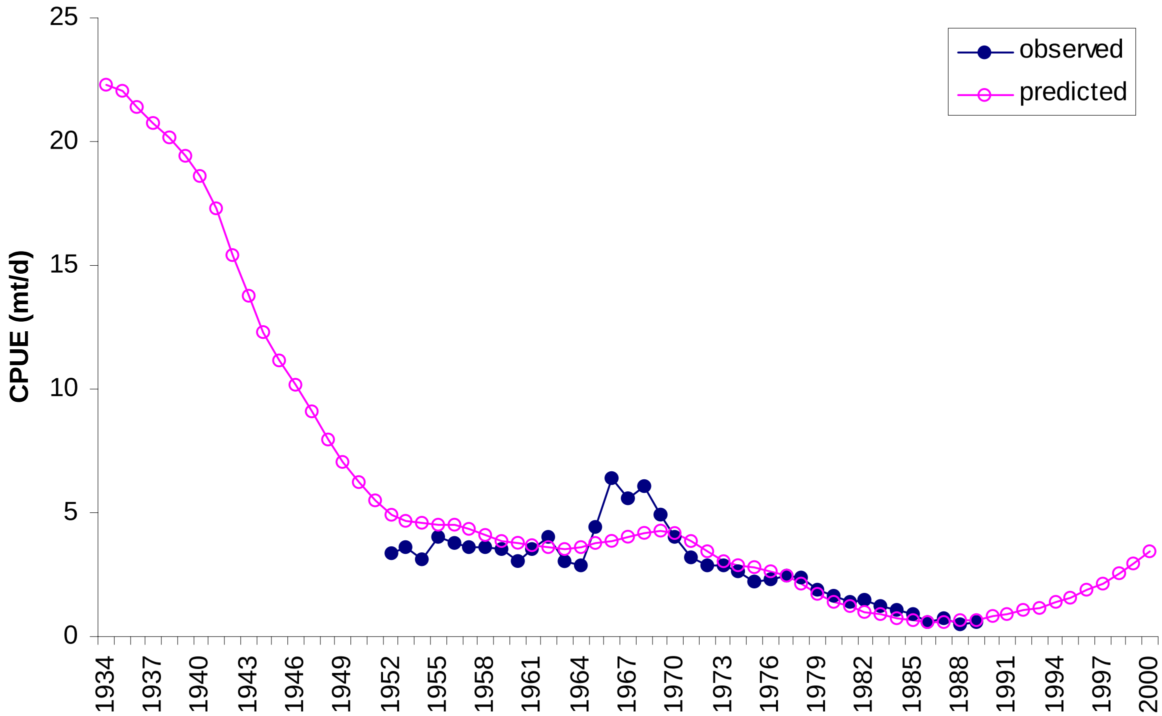


Figure C37. Observed and predicted CPUE from ASPIC.

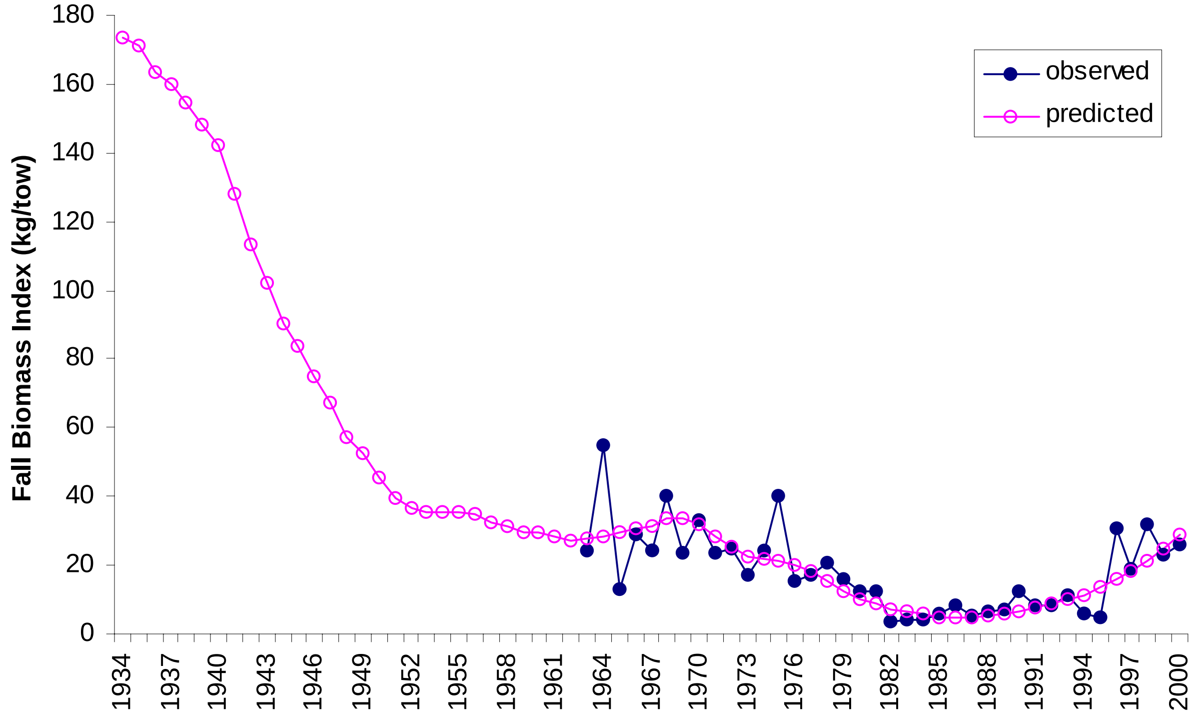


Figure C38. Observerd and predicted autumn survey biomass index from ASPIC.

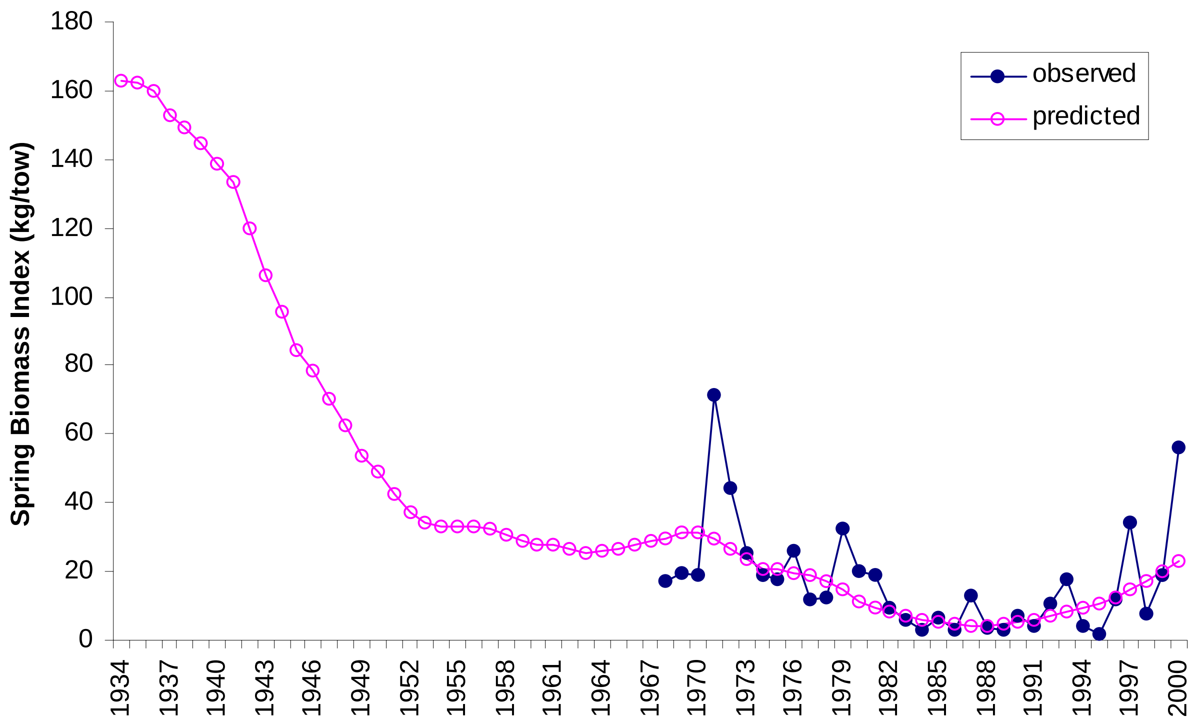


Figure C39. Observed and predicted spring survey biomass index from ASPIC.

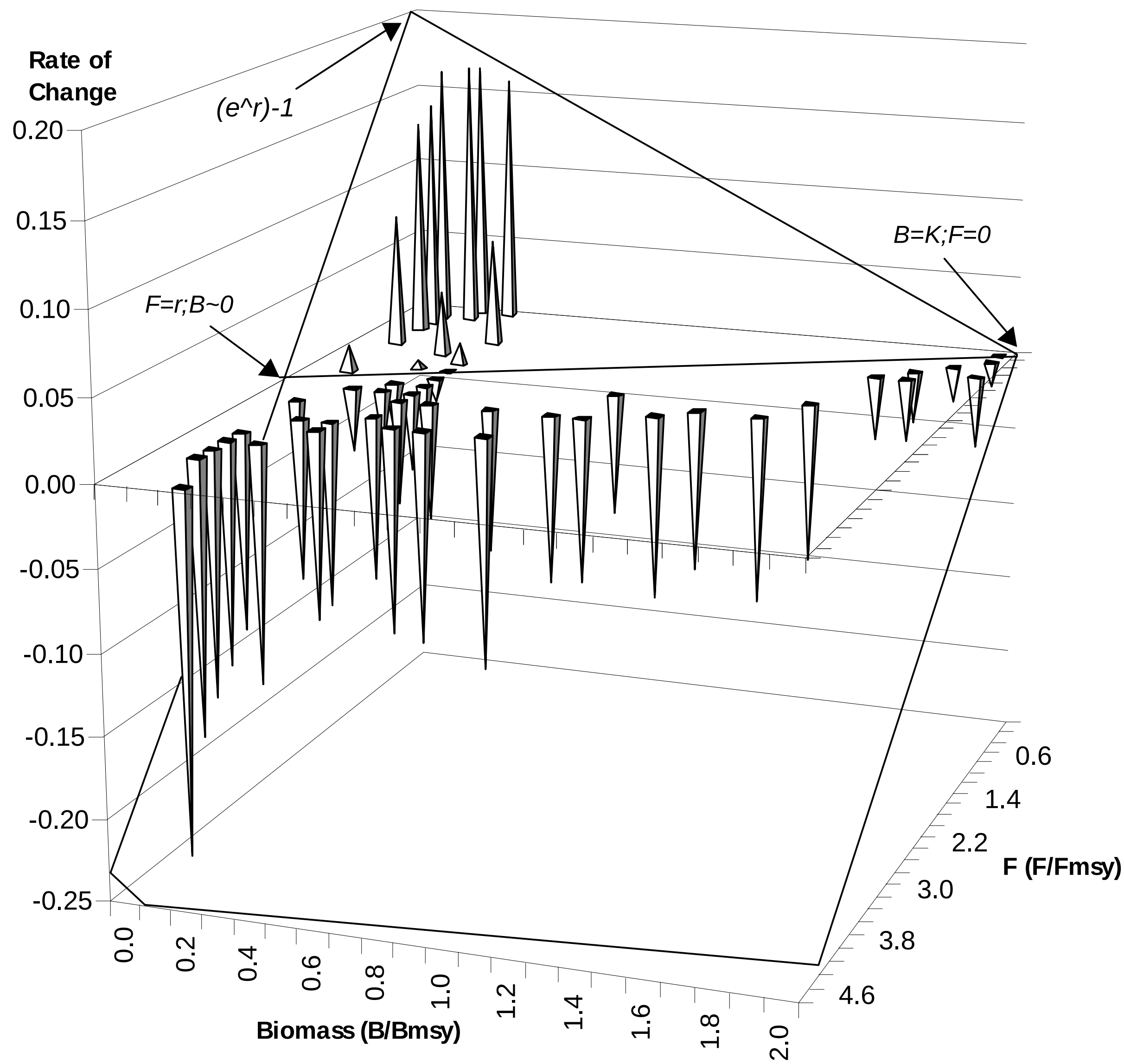


Figure C40. Observed rate of change, expressed as a planar function of biomass and fishing mortality, for estimation of biomass dynamics parameters (dashed line indicates equilibrium conditions.

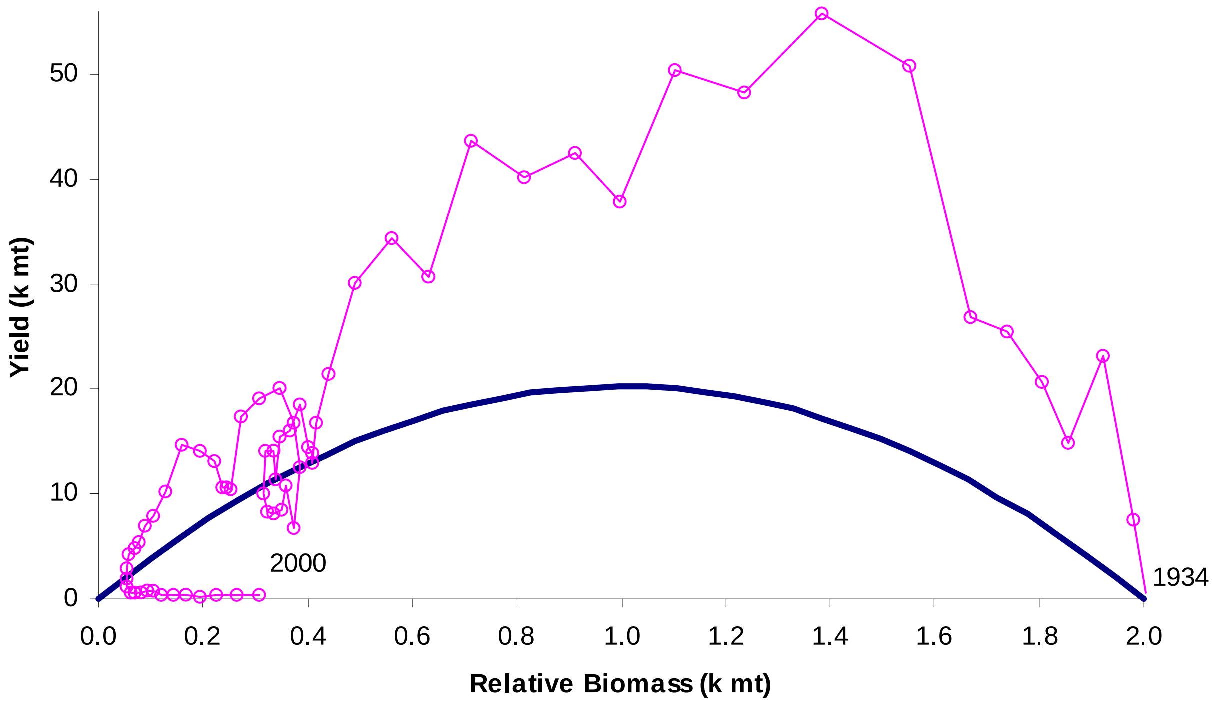


Figure C41. Biomass dynamics of Subarea 5 Redfish from ASPIC.

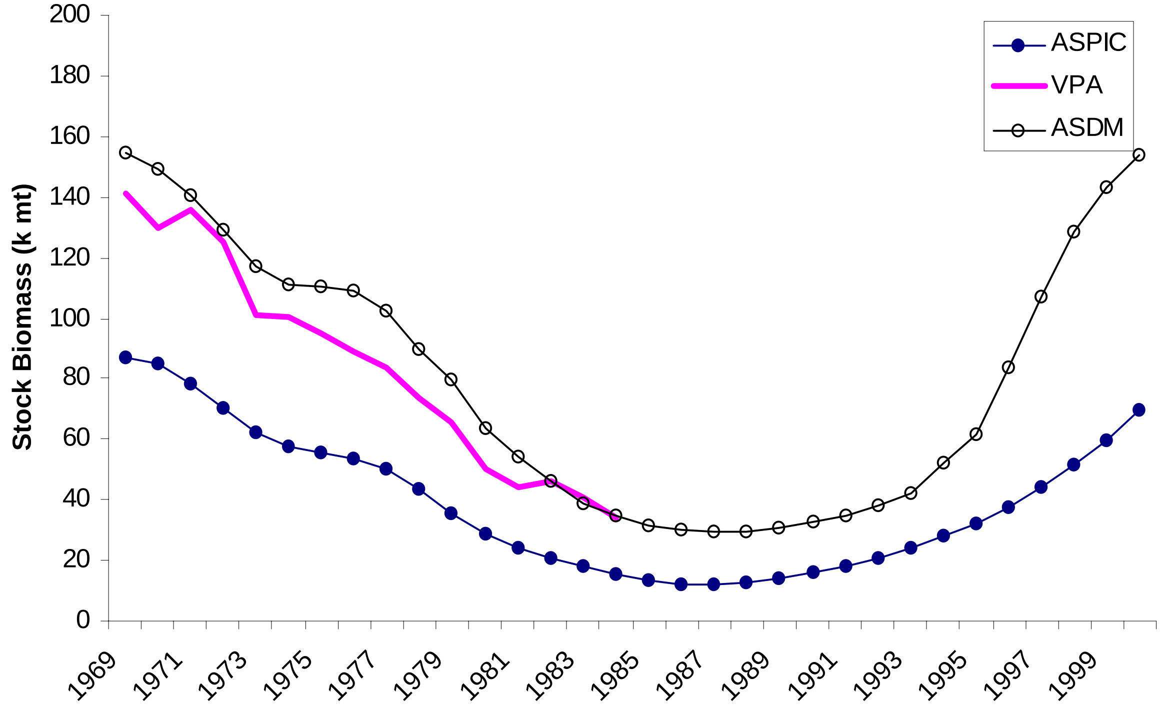


Figure C42. Comparison of biomass estimates from ASPIC, VPA (NEFSC 1986), and the age-structured dynamic model.

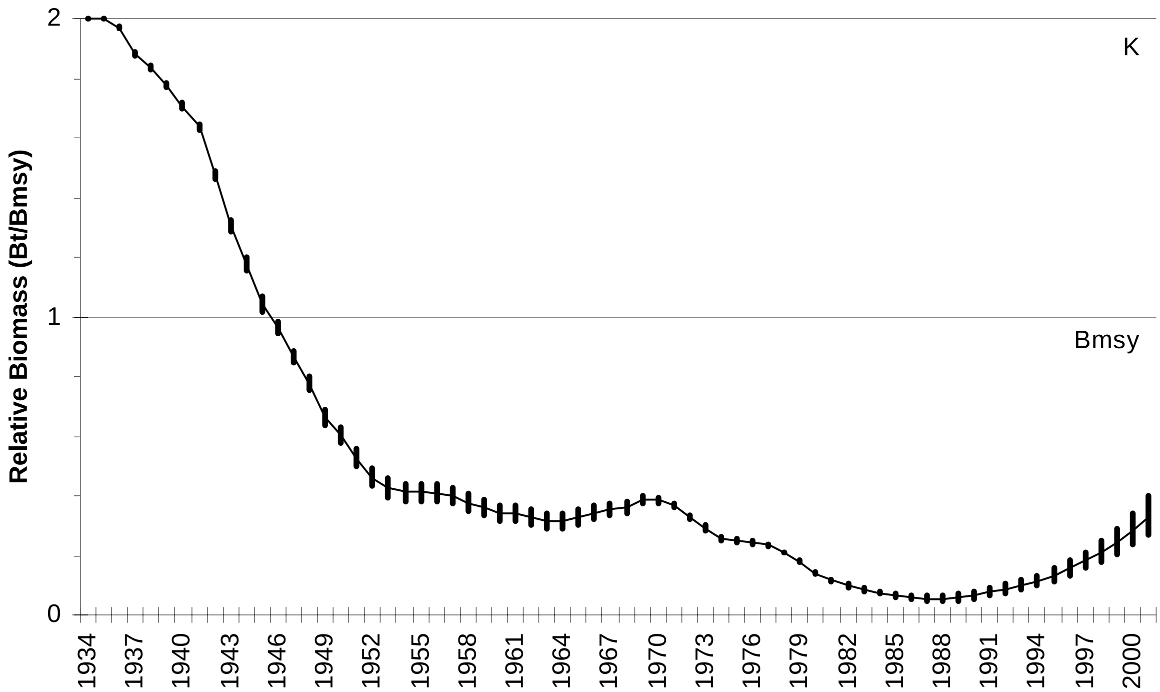


Figure C43. Estimates of relative biomass and 80% confidence limits from ASPIC.

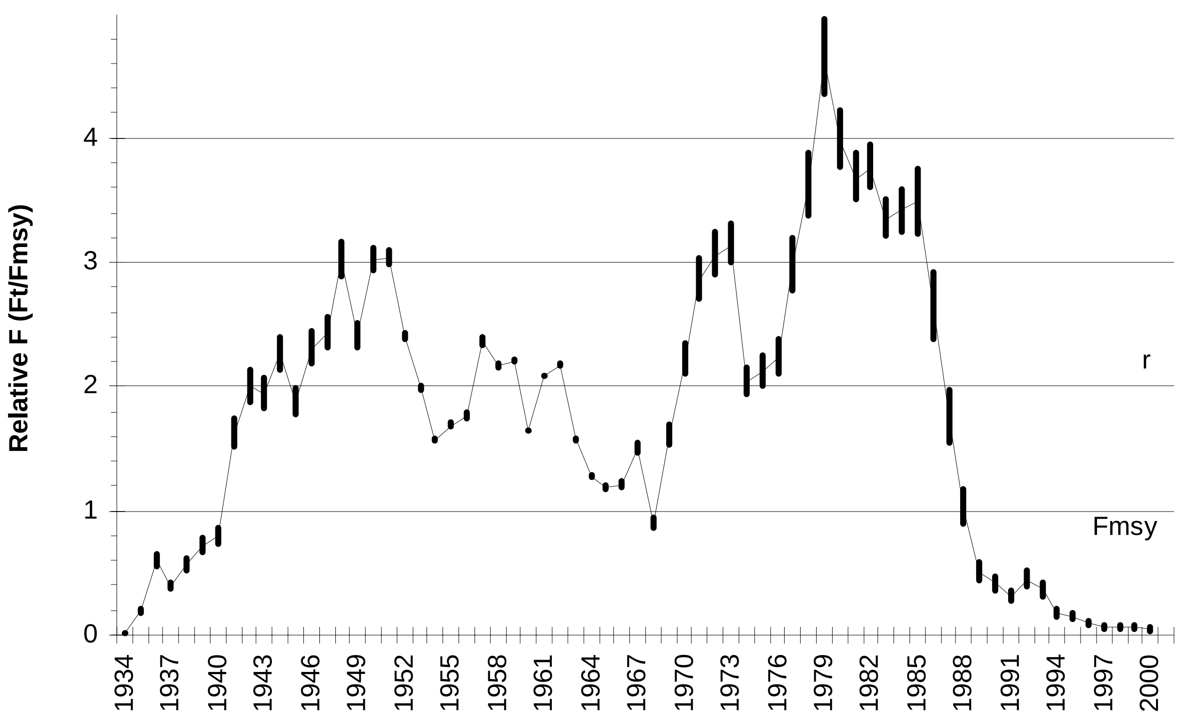


Figure C44. Estimates of relative fishing mortality and 80% confidence limits from ASPIC.

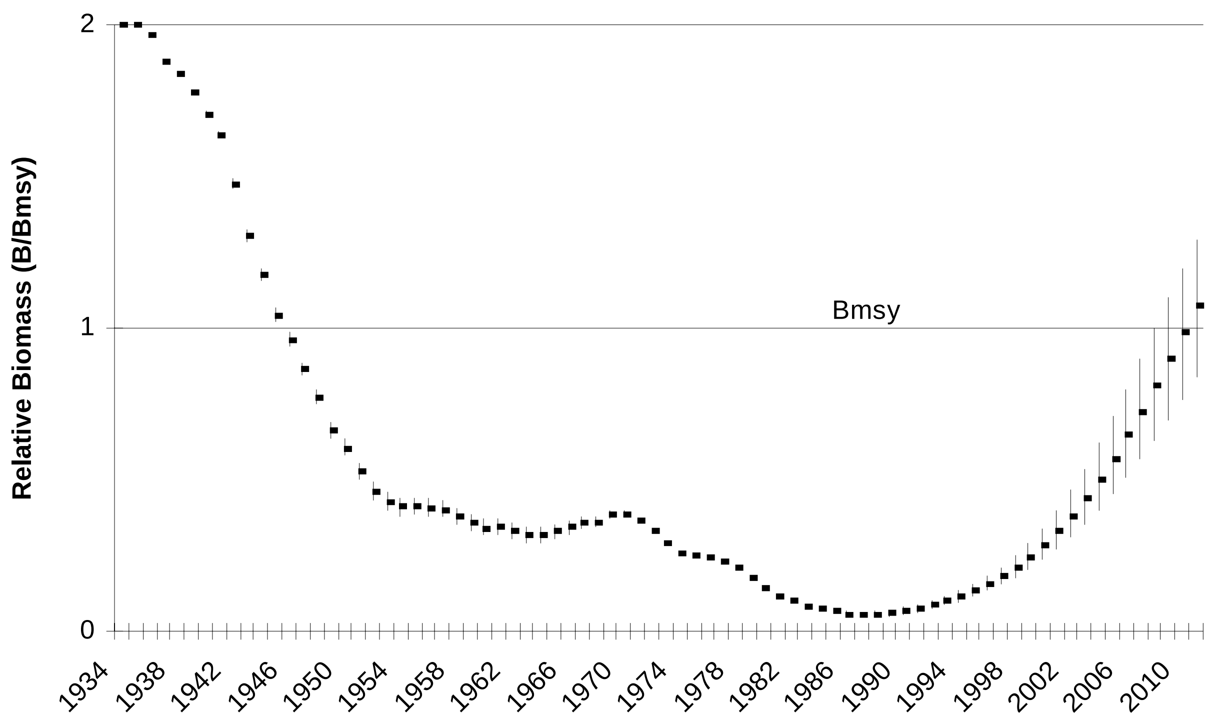


Figure C45. Ten-year projections of redfish biomass assuming no fishing mortality from 2001-2010.

D. PRODUCTION MODELING

PURPOSE

The purpose of this report is to summarize the working papers and discussions of the Methods Working Group concerning the terms of reference related to surplus production models. Each major topic is introduced and accompanied by a brief description of the methodology and one or more example applications. The various approaches are intended to be illustrative, rather than definitive, and should not be construed as revisions to existing assessments or biological reference points. The comments of the SARC on the various approaches are summarized at the end of this section.

INTRODUCTION

Surplus production models play a central role in the management of fisheries under the Sustainable Fisheries Act (SFA) of 1996 (USDC 1997). The SFA provides explicit guidance on the definition of maximum sustainable yield, fishing mortality and biomass targets and thresholds, and time frames for rebuilding of overfished stocks. This guidance has challenged stock assessment scientists to develop estimates of such parameters for a broad range of species. In this report we focus on the challenges relevant to assessments of fishery resources in the northeast region of the United States. Fishery resources in the northeast benefit from a long time series of synoptic survey data. For over 30 years the Northeast Fisheries Science Center has conducted two annual surveys of finfish populations. Since 1992 surveys have been conducted in the winter, and specialized surveys for shellfish are also conducted.

In spite of this wealth of data, estimation of parameters in surplus production models is difficult for many stocks. The difficulties stem from several sources. First, many of the stocks have been heavily fished for almost 100 years. Thus any simplifying assumptions about the state of resource when the surveys began are tenuous. Second, the fisheries are prosecuted by a wide range of fleets and gear types with varying levels of selectivity. Many of these fisheries generate substantial quantities of discards, which in many instances are poorly estimated. Third, many stocks have been subject to intense fishing mortality, first by foreign fleets before 200 mile coastal limits were imposed, and then by overcapitalized domestic fleets. Rebuilding of fish stocks, to the extent it has occurred, has been limited to the past 5-10 years. In terms of surplus production models, these conditions imply that one cannot assume that the initial population size in near the carrying capacity. Heterogeneous fisheries imply that not all removals are known. Many stocks have experienced consistent declines in abundance (the “one-way trip”) such that information about density dependent processes is difficult to discern. In aggregate, these conditions create an ironic circumstance in which a wealth of age-specific survey and catch data contains little information about density-dependent processes.

Nonetheless, models of surplus production have been developed for several species in the Northeast and the resulting parameters have been codified into control rules for fisheries management. Most of the major fish stocks are assessed using age-structured models, especially Virtual Population Analyses “tuned” to survey data. The tuned-VPAs create a further difficulty, in that the vector of derived fishing mortality rate (F) must be translated into an average F comparable to estimates derived from surplus production models. This melding of two model constructs is likely to be a transient condition as more synthetic models are developed. However in the short run it is important that current assessment results be compared to existing definitions of overfishing, however they have been defined.

The Methods Subcommittee of the SARC was asked to provide guidance on the use of surplus production models. The specific terms of reference are listed below:

TERMS OF REFERENCE

(A) Evaluate the use of production models in providing estimates of biomass and yield targets and thresholds consistent with provisions of SFA

(B) Provide guidance on the use and limitations of production model results for establishing management goals

(C) Evaluate various types of production models (age/stage structured, non-equilibrium, etc.) and provide guidance on the use of model types in differing circumstances of data availability, exploitation history and length of time series.

(D) Compare estimates of MSY, Fmsy and Bmsy from production models with those based on catch-at-age model results as a basis for understanding biases, stability and precision of such estimated parameters.

The Methods Subcommittee attempted to address these topics by examining a number of case studies. The approaches taken by the group can be classified into the following:

1) Diagnostic measures–is there evidence to support the underlying processes of density dependence?

2) Commensurate quantities–can we develop internally consistent measures of biomass and fishing mortality from age-structured and production models?

3) Advanced estimation procedures–are there more advanced estimation procedures which improve the accuracy and precision of biological reference points?

4) Identification of promising research areas–especially those related to integrated assessment approaches.

GRAPHICAL AND DIAGNOSTIC METHODS

Design Sufficiency

One of the major difficulties for Northeast fisheries is the determination of biomass targets under SFA. As noted above, high exploitation for many species occurred prior to the primary time series of fishery independent data. This can mean that the biomass that supports MSY has not been observed in the extant data. Restricting inferences of Bmsy to what has been observed may be myopic; extending estimates beyond the range of the data can be tenuous. The realized time series of catches and survey values can be considered as an outcome of an unplanned experiment. The same properties that constrain inferences in experimental design are also important for model based estimation. In particular, the number of observations that occur at each level of treatment factors is a critical factor in experimental design. In fisheries the relative proportion of observations at high and low levels of population level are important. Let population density be proportional to relative survey biomass and exploitation be proportional to catch divided by survey biomass. The relative frequency of observation in each cell provides an indication of the ability to estimate population parameters. A hypothetical example:

	Population Size	
Relative Harvest Rate	Low	High
Low	0.1	0.2
High	0.5	0.2

Note that most of the observations are at high harvest rates and low population size. An even more disturbing pattern will be evident for a heavily exploited stock.

	Population Size		
Relative Harvest Rate	Low	Medium	High
Low	0.05 (5)	0	0
Medium	0.25 (4)	0.1 (1)	0
High	0.4 (3)	0.2 (2)	0

The first number indicates the fraction of observations at each population state. The second number in parentheses indicates the order of observation. Hence the population may never have been monitored at high levels of abundance and the sequence of "treatments" has clearly not been randomized. In an experimental design, such conditions would merit at least a split plot design. In fisheries the analytical solution is not clear, but the warning message is the same. Analytical sophistication may not be sufficient to overcome fundamental problems of inference.

The Envelope Plot

To gain some insight into possible biomass targets it is useful to compute historical measures of abundance under a range of assumptions. For example, a catch series C_t can be used to create a range of possible population biomasses B_t by noting that $B_t = C_t / U$ where U is exploitation rate. If we assume that the catches are the realization of a consistently low exploitation rate then $B_{t(high)} = C_t / U_{low}$. Conversely, if exploitation rates have been consistently high then an ultimate lower bound on exploitable biomass is simply the catch series, i.e., $B_{t(low)} = C_t$. If a time series of survey data are available, swept area biomass estimates can be computed for varying levels of catchability or gear efficiency. Other model-based estimates of abundance, say from a VPA, can be superimposed on the same graph. Finally, estimates of biomass per recruit from standard YPR analyses can be multiplied by average recruitment to generate an estimate of expected population biomass. The resulting series of population estimates can be considered an envelope of feasible population sizes in which surplus production-based estimates of Bmsy should at least have some consistency. An example plot for summer flounder is depicted in Fig. 1 in which the high estimates of population size are based on an exploitation rate ~0.15.

Model Behavior Plots

The standard surplus production model can be written as a difference equation

$$B_{t+1} = B_t + rB_t - \frac{r}{K} B_t^2 - C_t \qquad (1)$$

If survey index I_t is proportional to B_t such that $I_t = q\, B_t$, then Eq. 1 can be written as

$$I_{t+1} = I_t + rI_t - \frac{r}{qK} I_t^2 \quad - qC_t \quad (2)$$

Rearranging terms and dividing though by I_t

$$\frac{I_{t+1} - I_t}{I_t} \quad = +rI_t - \frac{r}{qK} I_t \quad - q\frac{C_t}{I_t} \quad (3)$$

If density dependence is evident in a population, then the rate of increase in relative population size should increase at low population levels and decrease at high population densities. A simple test of this concept is depicted in Fig. 2 in which relative population abundance at time t+1 is plotted against relative harvest rate for summer flounder. The size of the circle is proportional to the magnitude of the quantity $(I_{t+1} - I_t) / I_t$; open circles indicate negative values, filled circles represent positive values. Each point is labeled with the year of observation and time trend is denoted by the line. Figure 2 demonstrates the ongoing recovery of summer flounder as relative harvest rates appear to be decreasing. More importantly, however, the plot suggests that the rate of increase (i.e., circle diameter) at high density and low harvest rate is comparable to those values observed at low densities and high harvest rates. From this plot at least, there does not appear to be any evidence of density dependent reduction in biomass increase. The observed trajectory of summer flounder may in fact reflect the transient effects of several yearclasses surviving for more than a few years in the fishery. Such evidence suggests a priori that the K parameter (and hence B_{msy}) may be difficult to estimate for summer flounder.

When Are Multiple Indices Useful?

It is often assumed that multiple indices will improve model fits by using more information. This is true however, only if the indices are measuring the same attribute of the population in a given spatial domain. If so, information on population abundance will be improved by having multiple measures. In most assessment models, conflicting data trends are accommodated by "splitting the difference". "Splitting the difference" may not be useful if the conflicting observations signal changes in the underlying process (e.g. shifts among spatial units), temporal changes in availability, or changes in the underlying harvest process. As an example of the latter process, consider a management measure that changes the seasonality of harvesting. The relationship between catch and index values will then change over time but the model will accommodate this change as an error term to be minimized.

A simple plot of the spring and fall indices for summer flounder (Fig. 3) suggests that the fall index has been increasing more rapidly than the spring survey since about 1990. A plot of the spring survey in the subsequent spring (t+1) against the fall index in year t suggests that the slope is decreasing. This figure is consistent with the hypothesis that an increasing fraction of the landings are occurring in the winter between the fall and spring surveys. The simple surplus production model with multiple indices cannot accommodate this change since each index is assumed to be representative of the population biomass. Moreover, catch is incorporated as total annual catch rather than temporally disaggregated values.

Response Surface Plots: Graphical Measures of Uncertainty

The sampling covariance between r and K (and hence F_{msy} and B_{msy}) in surplus production has been well studied in the literature. The nonlinear negative association can be particularly severe if the model does not fit particularly well. In these circumstances, both of the primary estimates of interest to management may be useless. Regardless of the degree of fit, it is clear that traditional measures of precision, based on asymptotic properties, are likely to underestimate the true variation. Bootstrap procedures address this issue in part and should be a component of any serious attempt to estimate population parameters. Additional insights can be gained by examining the loss function in the vicinity of the solution and by applying confidence intervals procedures more appropriate for nonlinear models.

To begin this examination, it is necessary to reparameterize the surplus production model in terms of F_{msy} and B_{msy}. This is accomplished by substituting the functional relationships r=2 F_{msy} and K=2 B_{msy} into Equation 2.

$$I_{t+1} = (1+2F_{MSY})I_t - \frac{F_{MSY}}{qB_{MSY}} I_t - qC_t \quad (4)$$

Eq. 4 permits one to immediately compute the primary parameters of interest, an advantage in some statistical packages. Comparisons of parameter estimates obtained by Eq. 2 and 4 were identical (thereby providing empirical evidence of the invariance principle of maximum likelihood estimators!).

In contrast to standard Wald-type estimators of confidence intervals , Cook-Weisberg (C-W) method (Cook and Weisberg 1990) is specifically designed for nonlinear models. The C-W method is conceptually similar to profile likelihood methods since the model is re-estimated for each alternative fixed value of the variable of interest. For example, in Eq. 4, the confidence interval for Fmsy is estimated by recomputing the best estimates of Bmsy and q for each fixed value of Fmsy in the vicinity of the solution. The residual sum of squares is asymptotically distributed as a t-statistic; in a profile likelihood approach the likelihood function would have a χ^2 distribution.

Approximate confidence regions for each parameter can be simply examined by evaluating the RSS in the vicinity of the solution. The C-W method was not applied to the confidence region; instead, the "significance level" was approximated with an F statistic, following the methods in Draper and Smith (1966) (See Fig 4a).

Results of the modified surplus production model fit are summarized in Table 2. The spring and fall survey indices were simply averaged for this heuristic example. For this model configuration, the estimated value of F_{msy} = 0.4 and the B_{msy} level is 59,268 mt. It is worth repeating –these values are used for illustration only.

Contour plots of the loss function for all possible pairings of F_{msy}, B_{msy} and q (not shown) demonstrated a wide range of values for even the nominal significance levels. One example (Fig. 4b) of the B_{msy} vs F_{msy} contour plot may be of general utility for development of uncertainty in control rules.

Funnel Plots—Evaluating the Value of Additional Data

As many authors have noted, long time series of catch data are not necessarily informative about underlying population dynamics in surplus production models. The surplus production model does not exhibit the convergence properties of VPAs and additional data may not improve the precision of estimates. On the contrary, additional data, especially if it is informative, may markedly alter one's perception of the population's dynamics. In principle, a data set derived from a population following a logistic growth model and subject to variations in harvest rates at different stock levels, should be sufficient to recover the underlying parameters. As the length of the time series increases, the estimates should converge to stable estimates of these parameters. Moreover, these parameters should be recoverable from series of any length and any starting point.

These concepts were merged to estimate a set of parameter estimates corresponding the enumeration of all possible series of length s from an initial series of length n. In more mathematical terms, let Θ_{sj} represent a vector of parameters corresponding to the j-th series on length s. For example the series can be enumerated as {j=1; t=1,2, ...s}, {j=2; t=2, 3, ...s+1}, ... {j=k; t=k, k+1, ...n}. This can be done for all series of length s up to n. The corresponding estimates can be displayed as a function of the number of contiguous points in the data set. These can be called funnel plots based on an expected shape. Series with fewer elements might be expected to exhibit greater variation, with a narrower range of estimates at the number of elements approaches the original number of observations. An example set of funnel plots for summer flounder is depicted in Fig. 5. The left column shows the set of estimates circumscribed by a convex hull. The right column shows a box plot of the estimates with a Lowess smooth through the data points. The plots suggest that the surplus production model parameters are not stable since removal of a small number of data points induces wide variations in estimates. The apparent trend in increasing values of F_{msy} and q is also undesirable. Similar concerns were noted by Terceiro (2001) who conducted a retrospective analysis. The funnel plot simply enumerates all possible retrospective patterns and reinforces Terceiro's concerns. As the number of data points in the series decreased, the number of estimation failures (i.e., no convergence) increased. For the shortest length series (m=13), over 35% of the runs failed to converge. Failure rates did not fall below 30% until at least 19 points were included in the time series.

Collectively, the graphical methods proposed herein should be viewed as complementary to existing approaches to derivation of suitable surplus production models. Traditional residual analyses are useful, but many features may not be discernible if the model fitting process masks changes in the underlying process. While it may not be possible to develop a formal proof, it seems logical to assert that the problems of model mis-specification are likely to be more pronounced in simple models. Therefore, considerable caution should be applied when attempting to derive biological reference points from surplus production models.

Use of Smoothed Indices in Surplus Production Models

Modern smoothing methods are an important tool for stock assessment but in the context of modeling methods that include catch, considerable caution is necessary. A simple example will suffice to illustrate the difficulties of interpretation. As before, let B_t represent the population biomass at time t and B'_t represent a simple moving average of B_t centered on time t. For a simple 3 point moving average $B'_t = (B_{t+1} + B_t + B_{t-1})/3$. If P_t denotes the surplus production at time t then

$$P_t = B_{t+1} - B_t + \delta C_t . \quad (5)$$

If B_t is replaced by its moving average then

$$P'_t = (B_{t+2} + B_{t+1} + B_t)/3 - (B_{t+1} + B_t + B_{t-1})/3 + \delta C_t$$

or

$$P'_t = (B_{t+2} - B_{t-1})/3 + \delta C_t \quad (6)$$

Thus the production in year t is written as function of catch in the current year, biomass in the previous year and biomass two years in the future. As the duration of the moving average period increases, the e discounting of the terminal points would become even smaller such that $_{Prt}$–>C_t.

Without additional smoothing of the catch series, the mechanisms that might make the above equation meaningful are unclear. If a more complicated n-point smoothing algorithm was applied, then the smoothed estimate of production in year t would be represented as a linear combination of n+1 biomass levels. Once again, it may be difficult to interpret such equations.

RELATION BETWEEN MSY AND AVERAGE CATCH

The subcommittee also addressed the issue of the expected relationship between estimates of MSY and average catch. Many have noted that MSY is often close to estimates of average catch. It can be shown that a lower bound on MSY can be written as

$$MSY \geq (K\overline{P} + \overline{C})\left(\frac{r}{1+r}\right)^2$$

where $\overline{P}$ is the average fraction of the population present and $\overline{C}$ is the average catch. Unfortunately, it is not possible to develop an upper bound on MSY from the catch series. Thus, the potential for huge MSY values persists as long as there is no direct evidence of density dependence in the time series.

BIOMASS WEIGHTED F-EFFECTS OF TRANSIENT CONDITIONS

Theory

Surplus production models (SPM) treat biomass as an undifferentiated pool in which each unit of biomass has an equal capacity for reproduction, growth and mortality. In contrast, age-structured models (ASM) admit differences in the properties with respect to age. Stochastic variations in recruitment and their subsequent effects on biomass production are subsumed into estimates of r in SPM. The transient effects of recruitment complicate the translation of vector-based Fs in ASM to scalar-based Fs in SPM.

One simplification that identifies the nature of the problem is to note that prediction of yield from an undifferentiated biomass pool is equivalent to that in the age-structured model.

Under the surplus production model $Y = F_{SPM}\overline{B}_{TOT}$. Under the age-structured model $Y = \sum_{i=1}^{A} F_i \overline{B}_i$. Combining these equations for yield and noting that $B_{TOT} = \Sigma B_i$ leads to

$$F_{SPM} = \frac{\sum_{i=1}^{A} F_i \overline{B}_i}{\sum_{i=1}^{A} \overline{B}_i}$$

This implies that the biomass weighted F from an ASM is equivalent to the pooled F from a surplus production model (SPM).

It is important to note however, that the variations in age-specific biomass are induced by variations in the numbers of recruits associated with each cohort and their fishing history. Both factors will cause deviations from the weighting factors associated with constant recruitment and fishing history. A hypothetical age structure, based on the contemporary set of age specific Fs and a constant recruitment can be used to compare the magnitude of deviations in the current age structure.

Let the vector $\underline{F}_{ASM}(t)$ represent the estimated age-specific Fs in year t from an ASM. The expected number at age that would obtain under $\underline{F}_{ASM}(t)$ and constant recruitment R can be estimated as

$$N_{EQ,i} = \mathrm{Re}^{-\sum_{j=0}^{i-1} F_{ASM,j} + M}$$

The expected equilibrium biomass at age can be estimated as $B_{EQi} = N_i \overline{W}_i$ where $\overline{W}_i$ is the average weight at age i. The corresponding biomass-weighted F associated with equilibrium recruitment and F_{ASM} is

$$F_{EQ} = \frac{\sum_{i=1}^{A} F_{ASM,i} \overline{B}_{EQ,i}}{\sum_{i=1}^{A} \overline{B}_{EQ,i}}$$

If we denote the observed age-specific biomass estimates a as the difference between the biomass-weighted F and the equilibrium F i.e., F_{BW} - F_{EQ} can now be examined in terms of its departure from equilibrium conditions. Not that the differences in F are independent of the absolute magnitude of recruitment R and depend only on the vector F and average weights. The differences between F_{BW} and F_{EQ} can be decomposed into deviations associated with non- equilibrium conditions. For the vector difference B_{OBS} - B_{EQ} , positive values are indicative of either lower historical F or higher recruitment; negative values reflect the opposite.

Application

To illustrate the technique, the above equations were applied to an earlier ADAPT version of the Gulf of Maine cod. Ages 1 to 7+ were used in the VPA. The equilibrium estimate of population biomass in the plus group was estimated by extending the population age vector out to 25 years, and retaining the same age weight as employed in the VPA. The observed biomass weighted F from the VPA (i.e., F_{ASM}) = 0.2113 whereas the biomass weighted F under equilibrium conditions was 0.2296. Comparison of the observed and expected biomasses at age suggest that the largest disparity for age 2 (1998 year class) accounts for about 80% of the total deviation.

Discussion

The vector-based approach may be useful for characterizing the transient effects of non-equilibrium age structure on the derived biomass-weighted F. The prediction of an equilibrium biomass structure that would obtain under the observed F vector in the terminal year permits an analysis of how far the current age structure is from equilibrium. The total difference in average F can be computed and the age-specific contributions to the difference can be estimated.

As a discussion point, it could be argued that F_{EQ} is a better "point of entry " for fishery control rules based on surplus production models. By extension, it may also be argued that a total biomass estimate, derived as B^{T}_{EQ} .1, might be appropriate for the biomass axis of the control rule. In either case, the need to translate F's derived from age structured models into their surplus production equivalents (e.g., see Applegate et al. 1998), is a short-term problem that should be resolved as better estimates of biological reference points become available.

EXTERNAL SURPLUS PRODUCTION MODELS

Methodology

Annual surplus production in an unfished stock is defined as $P_t = B_{t+1} - B_t$ (Ricker 1975). When fishing mortality is considered, surplus production is defined as

$$P_t = B_{t+1} - B_t + \delta C_t \quad (7)$$

where δ is a correction factor that adjusts biomass at the beginning of year t+1 for catch during year t. The factor δ accounts for surplus-production by fish taken in the fishery during year t so that the sum $B_{t+1} + \delta C_t$ is the hypothetical biomass that would have existed in year t+1 if there had been no fishing during year t (MacCall 1978). We assumed δ = 1 for all stocks in this analysis. This assumption is valid when the instantaneous rate of natural mortality (M) and average instantaneous somatic growth rate ($\overline{G}$) balance (i.e. where M-$\overline{G}$ is approximately zero for ages taken in the fishery).

Surplus production as defined in Eq. 7 can be estimated for any model that generates a time series of biomass estimates. Such estimates of production are useful in characterizing the response of populations to exploitation and investigating temporal trends. It is also possible to examine the degree to which productivity estimates agree with predictions of surplus productions models. This is accomplished by fitting a quadratic function (Schaefer 1957) to the estimated production estimates such that substituting biomass estimates ($\hat{B}_t$) from the "best available" stock assessment model for biomass (B_t) into Eq. (7), gives:

$$\hat{P}_t = \hat{B}_{t+1} - \hat{B}_t + \delta C_t = a\hat{B}_t + b\hat{B}_t^2 \quad (8)$$

where $\hat{P}_t$ is an "observed" estimate of P_t used as the best available "data" in externally estimated surplus production models. The fitted model of estimate surplus production can be written as

$$\tilde{P}_t = \tilde{a}\hat{B}_t + \tilde{b}\hat{B}_t^2 \quad (9)$$

Thus $\tilde{P}_t$ is the estimate of surplus production based on the zero intercept quadratic model that relies on biomass estimates derived from another model. Estimates of the $\tilde{a}$ and $\tilde{b}$ parameters can be used to derive estimates of the intrinsic rate of increase ($\hat{r} = \tilde{a}$) and carrying capacity ($\hat{K} = -\tilde{a}/\tilde{b}$). Other standard alegebraic deductions of Schaefer's model also follow such at $B_{MSY} = K/2$ (where B_{MSY} is the equilibrium biomass for MSY), MSY = $aK/4$ and $F_{MSY} = a/2$.

The use of the expression "external" reflects the fact that estimates of a and b are not incorporated into the original estimates of B_t. The external approach is a special case in a general family of internally estimated "composite" non-equilibrium surplus production models (Fournier and Warburton 1989), that also includes conventional all measurement error such as ASPIC (Prager 1994) as another special case. Additional details on the estimation and application of external estimates of surplus production parameters may be found in Jacobson et al. (in press). The following examples rely heavily on the methodology presented in Jacobson et al.

As noted earlier, F_{MSY} and B_{MSY} are often correlated and the b parameter in Eq. 9 may be difficult to estimate for heavily fished stocks with few data at high biomass levels. This circumstance implies that F_{MSY} is estimable but B_{MSY} is not. To test for this circumstance we fit the model with and without the quadratic term, and used t-tests (p=0.05) to determine which model was "better" for the available data. One-sided t-tests were used because the expected values of b is less than zero in Schaefer's model (Eq. 4).

The statistical model we used to fit external production models with independent errors was:

$$\hat{P}_t = \tilde{P}_t + \varepsilon_t \quad (5)$$

where ε_t is an independent statistical error term that includes both measurement and process errors. When statistical errors were assumed to be autocorrelated, we used:

$$\hat{P}_t = \tilde{P}_t + \gamma_t = \tilde{P}_t + \varepsilon_t + \sum_{j=1}^{MaxLag} \lambda_{t-j}\varepsilon_{t-j} \quad (6)$$

where the moving average parameters l_{t-j} Î (-1, 1) were for lags of 1-3 years, the simple residual $\gamma = \hat{P}_t - \tilde{P}_t$ was autocorrelated, and the time series residuals ε_t were independent. The moving average approach is easy to use and effective but it requires estimation of additional moving average parameters l_{t-i} (Schnute 1985). In theory, the independent errors prior to the first year (ε_{1-t}) should be estimated as well. For simplicity, we assumed that all independent errors prior to the first year were zero, and we restricted our models to lags £ 3 years.

We used t-tests for parameter estimates to help us determine how many moving average parameters were required in the best model for a particular data set (Schnute 1985). Residual patterns were another factor that considered in making these decisions.

Objective functions used in external surplus production model parameter estimation were weighted sum of squares proportional to one-half the negative log likelihood $L(\hat{P}|\hat{\theta})$ of the observed annual surplus production data ($\hat{P}_t$), given the surplus-production model parameter estimates $\hat{\theta}=(\hat{a},\hat{b},\hat{\lambda}_{t-1},...)$. We assumed that independent errors (ε_t) in modeling surplus production were normally distributed to accommodate the potential for years with zero and negative surplus production. Models with independent statistical errors can be fit by quadratic linear regression (forced through the origin) with $\hat{P}_t$ as the dependent variable, $\hat{B}_t$ as the independent variable and weights, if required. However, we used non-linear regression (AD Model Builder software, Otter Research Ltd.) to fit external surplus production models with both uncorrelated and correlated errors.

The objective function with uncorrelated errors was:

$$L(\hat{P}|\hat{\theta})=0.5\sum_{t=1}^{N}\left(\frac{\hat{P}_t-\tilde{P}_t}{\sigma_t}\right)^2 \qquad (7)$$

where the standard errors s_t were from inverse variance weighting factors ($w_t=1/s_t^2$) supplied as input data. In the simple case of constant variance, the objective function is the same as an unweighted sum of squares. Following Schnute (1985), the objective function with correlated errors was:

$$L(\hat{P}|\hat{\theta})=0.5\sum_{t=1}^{N}\left(\frac{\varepsilon_t}{\sigma_t}\right)^2 \qquad (8)$$

We used a wide range of methods to characterize uncertainty and correlation in estimates of F_{MSY} and B_{MSY} and other model estimates. In particular, we used the delta method based on asymptotic variances for parameters (i.e. from the Hessian matrix in non-linear regression), empirical bootstrap (i.e. original weighted residuals e_y/s_y sampled with replacement, with appropriate calculations for autocorrelated errors), likelihood profiles, and numerical Markov Chain Monte Carlo (MCMC) techniques. Preliminary runs for some stocks indicated that the product $R_{MSY}=F_{MSY}B_{MSY}$ might be estimated robustly because of negative correlation between the individual terms (higher estimates of F_{MSY} tend to be offset in the product by lower estimates of B_{MSY}) so we estimated the variance of the product using all methods.

In interpreting bootstrap results, it is important to remember that the simulation analyses assume a true underlying model with all of the parameters at their estimated value. Bootstrap calculations give confidence intervals and variance estimates that can be compared to results using other techniques. Bivariate distributions for F_{MSY} and B_{MSY} estimates from bootstrap runs were plotted in three dimensions to illustrate the correlation between estimates of F_{MSY} and B_{MSY}.

Summary and Discussion

Externally estimated surplus production models are useful because they summarize assessment model results in terms of surplus production, use all of the information in the original stock assessment model, are simple enough to be carried out in a spreadsheet, depict surplus production-biomass relationships in a way that is easy to understand, and often provide useable estimates of MSY parameters. Moreover, they help assessment scientists avoid problems relating fishing mortality estimates from one model (e.g. VPA) to MSY reference point calculations from a second model (e.g. ASPIC). Hilborn (2001) and Jacobson et al. (in press) recommend carrying out external surplus production calculations routinely, even if results are not used to estimate MSY reference points.

In this paper, we fit a family of nested surplus production models with a linear term only, linear and quadratic terms, and with uncorrelated and correlated statistical errors to accommodate serial correlation in residuals, a common problem in surplus production modeling. The linear model is appropriate and useful when the dynamic range of the data is limited to low biomass levels. The nested model approach could be easily extended to asymmetric surplus production models with an additional parameter (e.g. Pella and Tomlinson 1969). However, data were not sufficient to estimate asymmetric surplus production curves for the stocks in this analysis.

Long time series are most useful in fitting surplus production models so biomass estimates from stock assessment models were supplemented in several cases by rescaling and smoothing bottom trawl survey data for early years. Sensitivity analyses were used to assess affects of combing data from different sources.

Surplus production was negative in 0% to 12% of years, depending on the stock. The best external surplus production models and MSY parameter estimates are summarized below. Models with moving average error terms and weighting were required for most stocks. All stocks showed P/B ratios declining with biomass suggesting density dependent production relationships. However, linear surplus production (rather than Schaefer surplus production) models were used for sea scallop in the Mid-Atlantic Bight and white hake due to lack of dynamic range in biomass levels.

Stock	F_{MSY}	B_{MSY}	Data/Model	Comment
Striped Bass	0.18	69,437	1982-2000 from VPA; 1965-1981 from scaled survey, catch and other data; Schaefer model; No weights; Independent errors	
Summer flounder	0.40	42,398	1982-2000 from VPA; 1974-1981 from scaled survey data; Schaefer model; Downweight data for 1978-1981; MA-1 errors	Implausible, F_{MSY} probably too high, B_{MSY} probably too low due to apparent low production in mid-1970's, possibly stemming from lack of recreational catch data
Redfish	0.087	135,241	1934-1999 from preliminary stock assessment; Schaefer model; Downweight data for 1934-1962; MA-3 errors	
White hake	0.23	Not estimate d	1989-1999 from a preliminary (and problematic!) VPA; Linear production model; No weights; Independent errors	B_{MSY} not estimable due to limited data and linear production model; F_{MSY} possibly biased low; Data from problematic VPA biomass estimates
Gulf of Maine Cod	0.44	22,988	1982-1999 from VPA (1963-1981 excluded due to lack of fit); Scaefer model; No weights; MA-2 errors	Implausible, F_{MSY} probably too high, B_{MSY} probably too low, possibly due to limited dynamic range and imprecise estimates

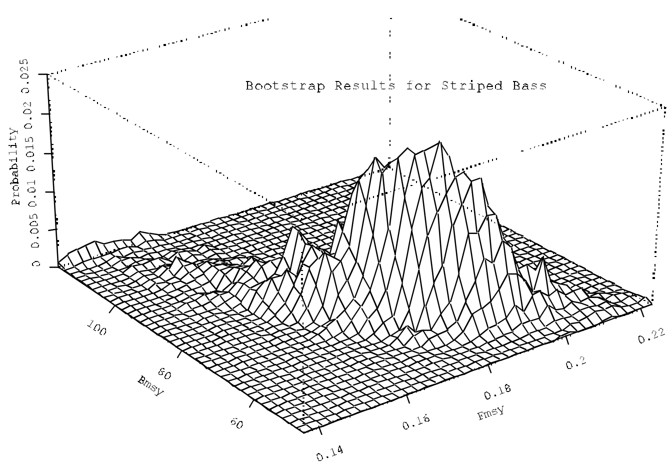
The F_{MSY} estimate (0.23 y^{-1}) from the external linear surplus production model for white hake was based on a problematic VPA. However, the estimate seems plausible (i.e. approximately the same as the assumed natural mortality M=0.2 y^{-1} and an estimate F_{MSY} =0.25 y^{-1} from Applegate et al. 1998). The external estimate may be robust if average surplus production and average biomass were measured accurately by the VPA.

External MSY parameter estimates were implausible for summer flounder with estimates of B_{MSY} probably too low and estimates of F_{MSY} probably. Problems with summer flounder stem from apparently low surplus production during the mid-1970's. Low surplus production, in the context of a surplus production model, indicates that the stock is at carrying capacity. However, summer flounder supported substantial catches for many years prior to the beginning of the mid-1970's. For example, survey age composition and survey abundance data (not included in the stock assessment or external surplus production model) indicate that summer flounder fishing mortality was high prior to the outset of the time series used in production modeling. We hypothesize that apparent low surplus production in early years for summer flounder may have been due to missing recreational catch data.

The best external estimate of F_{MSY} for striped bass was lower and the estimate of B_{MSY} was higher than proxy values used in managing the striped bass fishery. Results for summer flounder were implausible but the best external estimate of F_{MSY} was higher and the estimate of B_{MSY} was lower than proxy values used in managing the fishery. The best external estimate of F_{MSY} for redfish was similar to a preliminary estimate from ASPIC, but estimates of B_{MSY} were different. The best external estimate of F_{MSY} for white hake was similar to an estimate in Applegate et al. (1998) from ASPIC, but there was no external estimate of B_{MSY}. The external estimate of F_{MSY} and B_{MSY} for Georges Bank sea scallop, and the estimate of F_{MSY} for the Mid-Atlantic stock, were similar to proxies used in managing the fishery. External results for Gulf of Maine cod were similar to estimates from a preliminary ASPIC run.

B_{MSY} is more difficult to estimate than F_{MSY} for most of the stocks in this analysis. In practical terms, B_{MSY} may be inestimable currently for some stocks (e.g. white hake) regardless of the modeling approach due to lack of contrast in the available data.

We estimated uncertainty in estimates by bootstrapping, likelihood profiles, the delta method and Markov Chain Monte Carlo techniques. Bootstrapping usually gave the widest confidence intervals with confidence intervals from other methods that were similar. For most stocks, F_{MSY} was estimated more precisely than B_{MSY} because of the relatively large number of data points for low biomass levels and relatively small or lack of data points at high biomass levels. Statistical distributions measuring uncertainty were more symmetrical for F_{MSY} than for B_{MSY}. There was usually a strong negative correlation between F_{MSY} and B_{MSY} estimates. The distribution of bootstrap F_{MSY} and B_{MSY} estimates for striped bass (see below) is typical and shows the relative uncertainty in both parameters as well as their correlation.



Estimates of product MSY = F_{MSY} B_{MSY} were more usually more precise than estimates of B_{MSY}. Thus, the product may be useful in choosing a proxy value for B_{MSY} that corresponds to a particular proxy for F_{MSY}. For example, in striped bass, the product

$$F_{MSY} B_{MSY} \approx 17{,}000 \text{ mt y}^{-1},$$

and F30% (one of many potential proxies for F_{MSY})=0.3 y^{-1}. A corresponding B_{MSY} proxy value might be approximated as 17,000/0.3=57,000 mt.

Uncertainty about F_{MSY} and B_{MSY} is greater than estimated by statistical means in this analysis. Uncertainty is higher because estimation of B_{MSY} involves extrapolation beyond the available biomass data for most stocks and because there is increased uncertainty about model structure at high biomass levels. In particular, the symmetric Schaefer surplus production model may not fit at higher biomass levels. A plausible looking quadratic Schaefer surplus production curve could probably be fit to data from any stock, even if the underlying production curve was asymmetric. This would hold as long as the range of biomass levels did not extend beyond B_{MSY}, because quadratic models are generally good approximations to any monotonic trend over a short interval. This apparent robustness of quadratic models does not imply that F_{MSY} and B_{MSY} parameters are robust, however, because the real F_{MSY} and B_{MSY} values depend on the surplus production relationship in nature, not on the curve fit to the data.

Uncertainty in the biomass estimates, natural mortality, catches and many other factors were not considered in estimation of confidence intervals for this paper. To evaluate the effects of these factors on uncertainty, it will be necessary to incorporate external or internal surplus production model calculations into the original stock assessment model (Jacobson et al. in press). If all calculations are carried out in the same computer program, bootstrap variance calculations for estimates of F_{MSY} would, for example, include uncertainty about biomass and production estimates.

If sufficient data are available, external fits provide useable estimates of MSY parameters and help avoid problems relating fishing mortality estimates from one model (e.g. VPA) to MSY reference point calculations from a second model. Biomass estimates and externally estimated MSY parameters are from the same data and imply the same levels and trends in fishing mortality, biomass and recruitment. However, potential problems due differences in units (e.g. reference points as biomass weighted F's and assessment model estimates of fully recruited F's) remain.

The biomass data B_t used in fitting external surplus production models may, in practice, be fishable biomass, total biomass, fishable abundance, total abundance, or calculated in the original assessment model according to any other convention that is reasonable under the circumstances. However, the interpretation of B_{MSY} and F_{MSY} may be affected. For example, if B_t measures fishable biomass and fishery selectivity is reasonably constant over time, then F_{MSY} estimates are equivalent to F_{MSY} for fully recruited individuals.

The calculations in this paper are based on most recent or preliminary assessment results and meant only to demonstrate the potential utility of using external surplus production models for a wide range of stocks off the northeastern US. Estimates of *MSY* reference points are not for use by managers unless reviewed, and possibly revised.

SENSITIVITY OF MSY REFERENCE POINTS TO RECRUITMENT MODEL

The Sissenwine-Shepherd (1987) age-based approach provides another alternative to surplus production models for estimating MSY. The Sissenwine-Shepherd approach incorporates more biological detail into the model but as noted by Mohn and Black (1998), such estimates are highly sensitive to the assumed relationship between spawning stock and recruits. To assess the implication of the S-R function on biological reference points, the working group considered the effects of five different recruitment models for Georges Bank yellowtail flounder stocks. At present the overfishing definition for this stock is based on a surplus production model but the estimates of B_{MSY} have been unstable. Thus it seemed appropriate to determine if model with more biological realism could improve the estimation of biological reference points.

Application to Georges Bank Yellowtail Flounder

Dynamic pool estimates of yield, mean biomass, and SSB per recruit were estimated for Georges Bank yellowtail flounder using 1994-2000 data (Stone et al. 2001). Five different stock-recruitment models for SSB (mt) and R (recruitment in millions) were assumed. Results of the model fits and comparisons with other alternatives are summarized below.

Model	Error	Years	MSY (mt)	SSB_{msy} (mt)	B_{msy}	F_{msy} (ages 4+)	Fmsy (wb)	Baseline
YPR		94-00						F_{max}=0.82 $F_{0.1}$=0.25 $F_{20\%}$=0.67
B-H: R=(50.3 S) /8.37+S)	lognormal	73-99	10,230	36,772	58,290	0.35	0.18	
B-H: R=(82.8 S)/(13.7+S)	Normal	73-99	16,860	60,620	96,080	0.35	0.18	
B-H: R=(105.8 S)/(24.69+S)	lognormal	60-99	19,620	80,620	123,530	0.30	0.16	
B-H: R=(83 S)/(10.39+S)	Normal	60-99	17,890	57,460	94,060	0.40	0.19	
Constant: R = 20.8	lognormal	73-99	5,530	10,080	20,480	0.82	0.27	
ASPIC-surplus production			14,140		43,470		0.33	

Estimates of MSY and Bmsy were sensitive to the assumed recruitment model. MSY estimates varied by a factor of three among all models and SSBmsy estimates varied by a factor of four. Although these results are deterministic, they suggest that stochasticity should include S-R specification error. Age-based estimates of Fmsy were consistently less than those from ASPIC but MSY and Bmsy were sensitive to the assumed model for the stock-recruitment relationship. While integrated estimates of biological reference points may be more appropriate when based on age-structured models, the choice of a stock-recruitment relationship is likely to become the predominant factor in the estimation. Hence the justification of an appropriate S-R model or set of S-R models should be rigorous. Formal methods of model selection (eg. AIC) may be useful in these instances.

BAYESIAN SURPLUS PRODUCTION MODELS FOR GULF OF MAINE-GEORGES BANK REDFISH

A Bayesian surplus production (BSP) model was applied to catch data and relative abundance indices for redfish to address: (1) whether initial population biomass (B_1) was an estimable parameter when it was not assumed to be equal to carrying capacity (K); (2) whether nonlinear models for survey catchability could be reliably estimated; (3) whether BSP models results were robust to the choice of the prior distribution for carrying capacity; and (4) how BSP model results compare with age-structured and ASPIC-based results (Mayo et al. 2001). The BSP model, the prior distributions, the input data, and selected alternative models are described in the following sections. We then address the four questions and discuss some implications of our findings.

Bayesian Surplus Production Model

We use a Bayesian state-space formulation of the Schaefer surplus production model (Meyer and Millar 1999, NEFSC 2000, Brodziak et al. 2001). This model uses a reparameterized form of the Schaefer surplus production model which relates the fraction of carrying capacity ($P_t = B_t/K$) to intrinsic growth rate, carrying capacity, and the catch time series as

$$P_t = P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}$$

This relationship is the basis of the state equations for the state-space model. Stock biomass changes through time due to harvest and biomass production. Under the assumption that B_1=K, the state equations determine changes in relative stock biomass through time (t=1,...,N) via:

$$P_1 = \exp(u_1)$$

$$P_t = \left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}\right)\exp(u_t) \; for\; t \geq 2$$

where the independent lognormal process errors for relative biomass are $\exp(u_t)$ with

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

Relative abundance in year t is measured by either standardized fishery CPUE or the swept-area index (I_t) from the NEFSC autumn and spring bottom trawl surveys. In the simplest form, the CPUE or survey index is assumed to be proportional to stock biomass with constant catchability (Q) throughout the assessment time horizon. This is the *linear catchability model*

$$I_t = QB_t$$

Alternatively the CPUE or survey index is assumed to be proportional to stock biomass raised to a power (β) with constant catchability throughout the assessment time horizon. This is the *nonlinear catchability model*

$$I_t = QB_t^{\beta}$$

Either the linear or nonlinear relationship forms the basis of the observation equations for the state-space model. Stock biomass is measured by the time series of survey indices. For linear catchability, the observation equations relate the observed survey indices to parameters

$$I_t = QKP_t \cdot \exp(v_t) \ \textit{for} \ t = 1, \ldots, N$$

where the independent lognormal observation errors are $\exp(v_t)$ with $v_t \sim N(0,\tau^2)$. Similarly, the observations equations for nonlinear catchability are

$$I_t = Q(KP_t)^{\beta} \cdot \exp(v_t) \ \textit{for} \ t = 1, \ldots, N$$

Using fishery CPUE and two surveys as tuning indices, all with nonlinear catchability, the BSP model has fifteen parameters (r, K, σ^2, Q_{CPUE}, CPUE_σ^2, CPUE_τ^2, CPUE_β, Q_{FALL}, fall_σ^2, fall_τ^2, fall_β, Q_{SPR}, spr_σ^2, spr_τ^2, spr_β) and N unknown relative biomasses (P_t) for a total of N+15 unknowns. To describe the Bayesian estimation procedure, let the joint prior of the parameters and unobservables be p(Θ). Further, let the joint likelihood of the survey indices given the parameters and unobserved states be p(Data | Θ) and the joint posterior distribution of the unobservables be p(Θ | Data).

Bayes' theorem determines the posterior as a function of the prior and likelihood as

$$p(\Theta|Data) = \frac{p(Data|\Theta)\,p(\Theta)}{\int_{\Theta} p(Data|\Theta)\,p(\Theta)\,d\Theta}$$

Direct calculation of the posterior distribution is not possible for the BSP model because the integral in the denominator of the right hand side is not tractable. As a result, Markov chain Monte Carlo (MCMC) methods were used to obtain samples from the posterior distribution of a Bayesian model (Gilks et al. 1996, Brooks 1998). Gibbs sampling is one type of MCMC algorithm that can be readily applied using the BUGS software (Gilks et al. 1994; Meyer and Millar 1999). Computer code to fit the BSP model was implemented using the WINBUGS1.3 software.

Prior distributions

The prior distribution for carrying capacity was chosen to be either informative or uninformative. The *informative prior* distribution for K was a lognormal distribution with parameters chosen to set the 10^{th} and 90^{th} percentiles of the distribution. These percentiles were 100 kmt and 1,000 kmt, respectively. The *uninformative prior* for K was a broad uniform distribution where K~Uniform[1 kmt, 10000 kmt]. Similarly, the prior distribution for intrinsic growth rate was a broad uniform distribution with r~Uniform[0.01, 1.99].

The prior distribution for the inverse of CPUE or survey catchability was chosen to be a high-variance gamma distribution. In particular, the inverse of Q was assumed to be distributed as Gamma(0.001,0.001). This choice gives a relatively flat prior for Q, p(Q), that is approximately proportional to 1/Q, that is,

$p(Q) \propto 1/Q$. In addition, the range of possible values of Q was bounded to fall within the interval [0.01, 10000] to ensure that model predictions of survey biomass indices (QKP_t) were also bounded. The prior for process error variance parameter (σ^2) was also chosen to be an inverse gamma distribution. The inverse of σ^2 was distributed as Gamma(4.00, 0.01). This choice led to a 10% and 90% quantiles for σ of 0.04 and 0.08, respectively. Similarly, the prior for observation error variance (τ^2) was chosen to be an inverse gamma distribution for each tuning index. The inverse of τ^2 was distributed as Gamma(2.00, 0.01). This choice led to a 10% and 90% quantiles for τ of 0.05 and 0.14, respectively. This implied that observation error was somewhat larger than process error, although these parameters were freely estimated using the MCMC algorithm.

The prior distributions for the relative biomasses (P_t) were lognormal distributions for each year, with the possible exception of the initial year. The prior distribution for relative biomass in the initial year of the assessment time horizon was either lognormal with a mean set to B_1=K or an uniform prior. The assumption that B_1=K was relaxed by choosing a broad uninformative prior for P_1 to examine the consequences of not assuming that initial population abundance was at carrying capacity. This prior was

$$P_1 = Uniform[0.01, 1000]$$

For subsequent years, the conditional prior distribution of P_t (conditioned on values of P_{t-1}, K, r, and σ^2) was

$$P_t \sim Lognormal\left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_t}{K}, \sigma^2 \right)$$

Thus, the prior distribution for relative biomass in year t was dependent upon the previous year's relative biomass, intrinsic growth rate, carrying capacity, and the process error parameter.

Input Data and Alternative BSP Models

Input data were taken from Mayo et al. (2001). These consisted of time series of catch biomass for 1934-2000, standardized fishery CPUE for 1952-1989, and NEFSC autumn and spring survey biomass indices. These input data were the same as the data used for the age-structured model and ASPIC model presented in Mayo et al. (2001).

We fit six alternative BSP models to address (1) whether initial population biomass (B_1) was an estimable parameter when it was not assumed to be equal to carrying capacity (K); (2) whether nonlinear models for survey catchability could be reliably estimated; (3) whether BSP models results were robust to the choice of the prior distribution for carrying capacity; and (4) how BSP model results compare with age-structured and ASPIC-based results. Each model used the same input data. The six models differed in the initial population biomass assumption (B_1=K or $B_1 \neq$K), the tuning index catchability assumption (linear or nonlinear), and the prior assumed for K (informative or uninformative). The six models were:

1. Informative prior on K, B_1=K, and nonlinear catchability
2. Uninformative prior on K, B_1=K, and nonlinear catchability
3. Uninformative prior on K, $B_1 \neq$K, and nonlinear catchability
4. Informative prior on K, $B_1 \neq$K, and nonlinear catchability

5. Informative prior on K, B_1=K, and linear catchability
6. Uninformative prior on K, B_1=K, and linear catchability

Results

Figures D7 through D7 show the results of fitting the six BSP models to redfish input data. In these figures, estimates of exploitable biomass and their 80% CI are depicted as well as median estimates of r, K, maximum surplus production (MSP), the ratio of exploitation rate in year 2000 to the MSP exploitation rate (HRATIO), initial biomass in 1934 (B_{1934} also denoted as B_1), terminal biomass in 2001 (B_{2001}), along with their estimated coefficients of variation (CVs) in parentheses. In addition, the range of CVs for the tuning index catchability coefficients (Qs) are listed in parentheses. Note that the coefficients of variation are provided to give an indication of the precision of the parameter estimates and are not intended for hypothesis testing. Each of the six models shows a long-term decline in redfish biomass from the 1930s to the 1950s, a moderate increase in biomass in the late 1960s, followed by a further decline in biomass through the late 1980s, and an increase in biomass during the 1990s. Overall, the primary difference between the model results is the scale of the biomass trajectory.

Is initial population biomass estimable if it is not assumed to be equal to carrying capacity?

The answer appears to be "No". The redfish BSP models where $B_1 \neq K$ (Figures D8 and D9) have extremely large CVs on initial biomass (92% and 136%) which indicates that this parameter is imprecisely determined. Although we did not have time to complete analyses with linear catchability and $B_1 \neq K$, it is likely that this imprecision is an inherent feature that would not be affected by the choice of catchability submodel, based on our experience with this BSP model. Overall, the two BSP models (3 and 4) with $B_1 \neq K$ are less credible than the others due to this imprecision in B_1.

Are parameters of the nonlinear catchability models reliably estimated?

The answer is probably not, unless they are interpreted as nuisance parameters that can be expected to have high correlation due to nonlinear model structure, as, for example, one might expect in the estimation of L_∞ and K in the von Bertalanffy growth model. The range of CVs for the catchability coefficients (Qs) of the BSP models where B_1 = K with nonlinear catchability is large (Figures D6 and D7), on the order of 100% and these parameters are imprecisely determined. In contrast, the power coefficients (βs) of the nonlinear catchability submodel had lower Cvs, on the order of 20-40%. This suggests that there was probably insufficient information to estimate two parameters for each catchability submodel. We note that this behavior was also apparent for the models where $B_1 \neq K$.

Are the BSP model results robust to the choice of prior distribution for carrying capacity?

The answer appears to be "Yes". For each of the pairs of BSP models using informative and uninformative priors for K, e.g., models 1 & 2 (Figures D6 and D7), models 3 & 4 (Figures D8 and D9), and models 5 & 6 (Figures D10 and D11), the results are generally consistent, with similar estimates of r, K, MSP, HRATIO, B_{1934} , and B_{2001} obtained using informative and uninformative priors for K.

How do the BSP model results compare with age-structured and ASPIC-based results?

The results for the two BSP models with $B_1 \neq K$ are consistent with an initial version of the age-structured dynamics model for redfish (not shown) where the size of the plus-group in the initial year was estimated as a free parameter. In this case, the plus-group size was estimated to be very large in comparison to subsequent recruitment estimates, similar to the large initial population biomasses in Figures D8 and D9. This initial age-structured model was discounted by the NDWG because there was no information to discern recruitment strengths of year classes in the plus-group during the initial year and because it implied that the redfish population was far from an equilibrium state in 1934. Overall, this suggests that estimates of initial biomass different from carrying capacity are not likely to be well determined for redfish. However, since no directed fishery for redfish existed prior to 1934, we believe it is reasonable to assume that B_{1934} was near carrying capacity.

The results for the two BSP models with nonlinear catchability (Fig. D12) are very similar to the results of the age-structured dynamics model for redfish. With the exception of an increase in biomass in the late 1960s, the age-structured and BSP biomass trajectories are quite similar after 1952 when the earliest tuning index (CPUE) begins. This similarity in biomass trajectories over the range of years where there was tuning information (1952-2000) is probably the result of similar modeling assumptions. In particular, the age-structured dynamics model includes a nonlinear catchability submodel for fishery CPUE, to account for non-random behavior of fishing fleets in relation to redfish density, and also includes a nonlinear catchability submodel for the NEFSC spring survey, to account for differences in redfish schooling behavior and availability to survey trawl gear during this season. In contrast, the BSP model results with nonlinear catchability submodels are less consistent with the ASPIC model results, most likely because ASPIC assumes a linear catchability submodel.

Similarly, the results for the two BSP models with linear catchability (Figure D13) are similar to the results of the ASPIC model for redfish, with the exception of the late 1960s. Presumably this is a consequence of both BSP and ASPIC models using the same catchability submodel for the tuning indices.

Discussion

The result that it is not probably not possible to estimate an initial population biomass for redfish that differs from carrying capacity is not surprising given the available data. In particular, the tuning indices for redfish extend from 1952-2000 and so the only information on population dynamics at the beginning of the modeling time horizon (1934-2001) is the catch. Regardless of this indeterminacy, it seems satisfactory to assume that initial redfish biomass was probably near carrying capacity because it is a long-lived species with low natural mortality (e.g., analogous to a K-selected species) that was not subject to a directed fishery prior to 1934. Moreover, it is encouraging to observe that the BSP results for a particular model configuration were robust to the choice of either an informative or uninformative prior for carrying capacity.

The higher precision of the estimates of Qs for BSPs with linear versus nonlinear catchability submodels is consistent with our observation that the marginal posterior densities of the linear models were much smoother. This visual diagnostic shows that the mixing rate for the MCMC chains was much better with the linear versus the nonlinear catchability assumption. Note, however, this does not imply that catchability is in fact linear. Instead, it merely shows that there is insufficient information input to the BSP model to give precise estimates of the particular nonlinear model that we examined. Nonlinear catchability submodels may be more appropriate for modeling the catchability of redfish, but there is no way to discern this using only a biomass dynamics model.

The inclusion of process error in the BSP models allowed for deviations from the simple Schaeffer model dynamics to fit observed tuning indices. This increased flexibility is the reason that biomass estimates from the BSP models and the ASPIC model differed in the late 1960s. In general, allowing for process error is more realistic but comes at the expense of reduced precision, due to the need to estimate the unknown biomass in each year (N=67). We believe that this trade-off worth it because the Bayesian model provides a more realistic depiction of the error processes, and hence a better quantification of the underlying uncertainty in the management parameters of interest for decision analyses. Or as Tukey once put it, *"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise."*

RESEARCH RECOMMENDATIONS

The Methods Subcommittee considered a wide range of topics. The resulting spectrum of research recommendation is similarly broad. It was noted that many of the problems of estimation arise from the lack of integration of reference points in current assessment models. Models that allow direct estimation of biological reference points within the context of biomass and mortality estimation should be useful. However, it should be noted that lack of contrast in the data cannot be overcome by more sophisticated estimation procedures. In that regard, the apparent recovery of many stocks in the Northeast will afford considerable insights into population dynamics. It is important that managers, scientists and industry conduct specific studies and experiments during this period.

The existing software for age-structured projections (e.g., AGEPRO) might be modified to allow for direct search of MSY and biological reference points. There was insufficient time to explore this option for the present SARC. Similarly, age-structured production models and delay difference approaches may provide additional realism in the estimation of biological reference points.

It will be useful to apply the diagnostic measures proposed herein to other species. Improbable changes in reference points over short time periods are probably indicative of poor fits. Similarly, variations in estimates among models are unlikely to occur if the underlying data support the model. Simulation tests of this principle would be helpful.

The subcommittee reviewed a number of species with widely varying life histories, fisheries, and data quality. It is unlikely that a single model or approach will sufficient to capture the underlying dynamics and biological reference points. Bayesian and state-space approaches may also prove to be adequate to incorporate the necessary realism for such species.

SARC COMMENTS

The SARC reviewed working documents and presentations covering several aspects of production modeling. Production models are of special importance in resource assessment because of their role in the development of biological reference points such as those used by the Council.

Many of the biological reference points now in use, however, were developed from age-aggregated production models that pool information across age groups, whereas many of the stocks now managed are fully assessed using age-disaggregated models (e.g. age-structured, cohort-analysis or VPA models). As pointed out in the November 2000 Report of the Groundfish Overfishing Definition Committee, many of the biological reference points developed using production modeling now need to be updated using more comprehensive approaches, which may include production modeling as one component.

Inconsistencies between age-aggregated and age-disaggregated assessments often result from differences in the information content of the data, as well as how biomass and fishing mortality have been defined. These differences have led to attempts by scientists and others to convert the output from one approach so that it corresponds to the recommendations from another. For example, a biomass weighted F from an age-disaggregated model is needed to evaluate the attainment of certain targets such as Fmsy, which are derived from age-aggregated production modeling exercises.

The difficulty here is not production modeling as such, rather it is the development of a better understanding of the association between age-aggregated and age-disaggregated modeling results and how to incorporate new and better information into the management process when that information becomes available. In reviewing this issue, the SARC broadly interpreted the terms of reference and examined not only production-model-based biological reference points, but also considered alternative formats for presenting information important to management, and in particular discussed how information resulting from age structured modeling approaches could be utilized.

SARCs have not formally reviewed such fundamental methodological issues in recent years. And although the current SARC had sufficient expertise to evaluate the production modeling approaches presented at this session, time constraints and the priority given to current stock assessment evaluations limited the discussion on production models and on the specification of biological references points in general.

In addition, although the presentations and discussions provided by Center scientists on these topics were enlightening and useful, the standard Advisory Report format for reporting scientific stock status and stock specific management advice to the Council is not well suited to reviews of technical issues that are more methodological in nature. Therefore we provide only a brief summary of our findings and indicate areas requiring further consideration, perhaps in a workshop setting supported by considerable analysis.

Purpose

The Terms of Reference for this review address a number of issues that may be classified broadly as:

Technical Issues:

1) How can we make better use of, and develop further, production modeling approaches?

2) What are the alternatives to production modeling and how do results from alternative approaches compare to proxy biological reference points? In particular, what should we do in circumstances where additional information, such as age-disaggregated information, becomes available?

Non-technical Issues:

1) What are the implications for management of characterizing a fishery using a broader information base? In particular, how can we best use age-disaggregated information and model results in forming management objectives that have been based historically upon outputs from production models (including outputs, such as Fmsy and Bmsy)?

2) What are the directions for future research in these areas?

3) Is this the appropriate forum for developing, reviewing and presenting results from that methodological research?

Results and Discussion

Center scientists presented information and analyses covering:

D1) Graphical and diagnostic evaluation of production models

D2) External surplus production models

D3) Methods for estimating production and Fmsy in any stock model

D4) Bayesian surplus production models

The SARC listened to these presentations, discussed the implications and potential implementation of each subject presented, then moved into the broader questions of whether management objectives should be constrained to production model type outputs, how more comprehensive information, such as that available from age-disaggregated data and modeling, could be used, and what the appropriate format might be for such discussions in the future.

What follows is a brief summary discussion of these presentations, a discussion of production modeling in the context of other approaches to fisheries management, and a brief statement about the usefulness to scientists and the Council of having methods such as these discussed by the SARC.

NEFSC Presentations

Graphical approaches to the presentation of information and its use in facilitating diagnosis in model estimation have evolved rapidly in the last two decades. Part of this is the availability of easy to use graphical and statistical presentation techniques that make use of the powerful way humans can interpret information visually. Center scientists developed a number of these techniques to demonstrate how they might be used to analyze and interpret production modeling results. The methods presented included exploratory data analysis (EDA) applied to survey catch-rate comparisons to evaluate the adequacy of the data for answering certain questions, envelope plots for presenting the bounds on uncertainty in biomass estimates, model behavior plots to assess density dependence as exhibited by a stock, smoothed time dependent and regression plots to explore correlations between survey indices, response surface plots to describe the uncertainty of parameters of interest, such as biological reference points (which should also be useful in assessing risk associated with decision making), and funnel plots, a newly proposed concept to assess the information content of correlated data. The funnel plots that were discussed are a powerful extension to the widely used retrospective analysis approach and will be useful for other assessment models as well as production models.

It is encouraging to see such novel visual approaches being used and developed. In fact, the use of these approaches is not limited to examining surplus production modeling and can of course be used to examine data (such as survey data) directly as well as be applied to more comprehensive approaches, for example age-structured modeling. The routine use and review of these methods will enhance the use of production modeling and other modeling approaches, increase the likelihood that application of such models is appropriate to the available data, and will allow Council members and their support committees to readily visualize the strengths and weaknesses of the data available.

External production models were investigated as a means to link age-structured models to the more familiar age-aggregated surplus production model. External refers to where in the process a production model is applied. In contrast, internal approaches estimate model parameters simultaneously while other estimates, for example age-structured estimates, are derived. The results, while not encouraging for the data examined, point to important efforts at trying to compare and reconcile production modeling with other modeling and estimation techniques. The National Research Council reports (dates) on stock assessment and improving the collection and use of data encourage applying alternative approaches to data to better understand the information it contains. One consequence, pointed out by the SARC, of comparing age-structured analyses with, for example, production model outputs may be the recognition that earlier production modeling results may need to be reevaluated and updated. These comparisons also force us to clearly define the population biomass in the context of fishing selectivity, fishing effort (possibly from multiple sources), other sources of mortality or population change (such as through discarding, migration, or environmental change), and in the context of management objectives and constraints. Debate still exists on preferred approaches for estimating biological reference points, but efforts such as those discussed are encouraged and should continue to be evaluated through the SAW and SARC processes, as well as through peer review from the broader scientific community.

A presentation was made specifically on estimating biological reference points, such as Fmsy, from any stock assessment model. This, of course can be done, as was pointed out in this work, but it begs the larger question of whether results from more comprehensive models should necessarily be winnowed down to the classical production model outputs.

Fishery models, in general, tend to assume that the fundamental dynamics of a population are in some form of approximate equilibrium. The crude equilibrium assumptions of the past have been abandoned, but by definition models are simplifications of nature and may not capture all population responses to changing abundance (e.g., changes in fecundity patterns, growth, or age structure) or responses to habitat changes over time (e.g., from contaminants or development). This issue may be particularly important in areas, like New England, where most fish stocks are quite far from equilibrium, and is certainly important when planning recovery of depressed stocks. Thus, we consider it especially valuable to explore population dynamics with a variety of models of differing underlying assumptions.

This presumes that the information to conduct an age or size structured assessment is available, but even if it is not, alternatives exist. Several were raised during the SARC discussion on this issue including delay-difference analyses and analyses simply involving catch-rate or survey indices. And looking more towards the future, there exists the possibility of expanding these approaches to the problem of multispecies and trans-boundary stocks.

The final presentation, on a Bayesian surplus production model applied to redfish, showed that the initial population size (if not assumed to be at carrying capacity) was difficult to estimate and that non-linear catchability was also relatively difficult to capture. The Bayesian results, however, were consistent with those of other age structured models and ASPIC (an age-aggregated production model). Again, this is evidence that Center scientists are engaging in research approaches that will broaden the level of information available to stock assessment and decision making. Analogous to discussions made earlier on graphical methods and model comparisons, Bayesian approaches can also be applied more generally, such as to age-structured population analyses, or even to estimating more elementary statistics such as estimates of catch-rate or survey abundance. The Center should be encouraged to continue to explore methods for making the best use of the information they gather through surveys and fishing records.

For each of these topics, stock specific recommendations have been incorporated into the advice for the respective species.

<u>Production Modeling in the Context of Other Approaches to Fisheries Management</u>

Production modeling is a valuable tool in the stock assessment toolbox. It provides a reasonable method of synthesizing information, especially in those situations where very little information is available. (It relies simply upon recorded total catch and an index of abundance or fishing effort.) And, as demonstrated in the presentations discussed, there exist a variety of means of determining the quality of the information available from these methods and for presenting the information they contain.

And yet, there are many instances where there is more information available to the scientist and manager than that provided by total catch or a survey index alone, where the stock may be far from equilibrium, or where the more immediate consequences of the biological response to management actions may be as important as the longer-term consequences of these actions. In these instances, a more comprehensive approach may be required, and scientists and managers should not feel constrained to fitting the results from these more encompassing approaches into the statistics provided from a simple production model analysis.

Unfortunately, many of the biological reference points currently used as management proxies may fit into this category. Stock management will benefit from making use of this broader information base, but scientists will have to respond to that need by providing updated measures that characterize populations more broadly and indicate where additional information is needed and how the population, as defined, should be interpreted.

The utility of production and age-structured modeling is often improved if their interpretation is linked with simpler analyses, that may include simple exploratory data analyses, as well as to more complex analyses, such as age-structured or multispecies models.

All models benefit from longer data series that demonstrate a higher contrast in biomass levels in response to harvest rates. And it goes without saying that if the data in general is poor then no model will suffice. At the other extreme, good information may be poorly utilized, and consideration should be given to which summary statistics are the most informative and robust to uncertainties in the data.

One recommendation is the use of ratios with regard to biological reference points. For example, in representing current F to Fmsy it may be more reliable to consider the ratio of one to the other than considering either estimate in absolute terms. In many instances the absolute levels will change, while their relationship to one another remains stable. Possibilities for deriving more informative and robust measures should be explored.

The SARC notes there has been progress made on a number of fronts on production modeling and data analysis in general. Additional work is needed on utilizing information from production models, age-structured models and more generalized approaches in order to facilitate means for managers and stakeholders to interpret this information in the context of management decisions. This may indicate that we will need to step beyond a few simple biological reference points to viewing alternative means (alternative pathways) towards achieving our goal of sustainable fisheries. This also indicates that vehicles for development, review and implementation of these methods are needed and should be established.

The work reported was useful in generating advice for the stocks under consideration and for assessments in general.

In age-structured models the focus of the uncertainty in the estimation of biological reference points shifts to the specification of a stock-recruit relationship and depends more heavily upon the dynamics observed in recent recruitments. In some instances, age structured approaches may improve upon the estimation of biological reference points or even provide a broader base of reference upon which to make decisions.

<u>SARC Input into Methodological Review and Development</u>

The SARC recognized the benefit of having a discussion related to methodological development and implementation and thought that such discussions should continue. However, it was not clear if this was the most appropriate forum or structure for these discussions. (These discussions certainly will influence and would be influenced by other stock assessment discussions outside the ones currently being considered, namely cod, white hake, and redfish.) Nor was it clear to whom the discussions were to be directed. (Are the discussions aimed at directing fisheries scientists alone, or Council advisors, or the Council itself?) As a consequence, the SARC broke this report into components dealing with the specific presentations, as given above, and into a general discussion-debate. The notes to follow represent a list of ideas based on that general discussion-debate, and should form a good starting point for designing future explorations.

<u>Evaluation of Production Models and Modeling Approaches in General</u>

- Model exploration illustrates the consequences of model choice and provides guidance on uncertainty.

- Model exploration demonstrates the limitation of both models and data.

- Multiple models may provide a needed perspective on uncertainty.

- Exploration of alternative methods demonstrates the limitations and consequences of lack of information.

- Graphical methods, diagnostic approaches, and model comparisons provide a good way of understanding the behavior of models to different pieces of information.

- A single number or statistic may give false sense of security (certainty) about the question being addressed.

- Both real data and simulated data are useful in understanding and characterizing model performance.

RECOMMENDATIONS

! Complex systems may require alternative perspectives and approaches.

! The methods working group should consider a decision theoretic framework under certain management conditions.

! Evolving methods and expanding an information base available for fishery management implies that managers will perceive Amoving goal posts@. This does not mean the rules are changing, but rather that new information has been brought to bear on the problem. This suggests that input controls, such as effort control, may be more a more effective and stable management tool than output controls, such as catch limits. Consideration should be given to such approaches.

! Scientists and managers should be encouraged to use modeling exercises to explore the effectiveness of control rules in achieving production and standing stock objectives and to explore the consequences and risks of alternate management actions.

! Adaptive approaches are encouraged in order to find limits of productivity.

! As information changes it will continue to be important to chronological changes in the fishery, the stock, and the catch so that information from new scientific and management approaches can be linked to what has happened in the past. In other words, preserve history.

BIOLOGICAL REFERENCE POINTS

An evaluation of how biological reference points such as MSY, Fmsy and Bmsy compare between models is a useful exercise, but it is better done on a stock-by-stock basis where the units of comparison and models of choice are clearly defined.

In many instances, it may be difficult to compare Bmsy, for example, from one model to another in absolute terms as the definition of biomass implicit in the model may vary from one model to the next. In one instance biomass may be best defined as the exploitable stock biomass, in another instance it may be best defined as the reproductive stock biomass, or even stock numbers.

This is all very difficult, of course, when the biological and legal settings have been framed in terms of these numbers. This suggests some alternative methods for using this information. First, how stock biomass has been defined should be made explicit for analysis, goal setting, and deliberations. Second, comparisons should be viewed in a relative rather than an absolute sense. For example, one might ask instead what is the ratio of current biomass to Bmsy, what is the current fishing mortality rate is relative to Fmsy, or what the current yield is relative to MSY. These comparisons are less likely to change as models and model estimates are updated than are the absolute values themselves. Finally, recognize that if two or more analytical approaches exist, one can always ask for short-term and long-term predictions under, for example, a statis quo scenario or an Fmsy scenario for each approach to see what consequences, if any, exist under each perspective.

One major difference between production models and age-structured models is in how new biomass enters the standing stock. In production models the influx of new biomass comes in, usually instantaneously, as a proportion of the current biomass. In age-structured models new biomass comes in through recruitment, usually with a time lag and many times based upon a stock-recruitment relationship. Both representations are subject to assumptions and simplifications. It is the robustness of inferences to these assumptions that should form the basis of debate.

These suggestions will not solve all problems encountered in reference point comparisons, but consideration of these issues should move the process towards uses of these measures that have greater stability under uncertainty.

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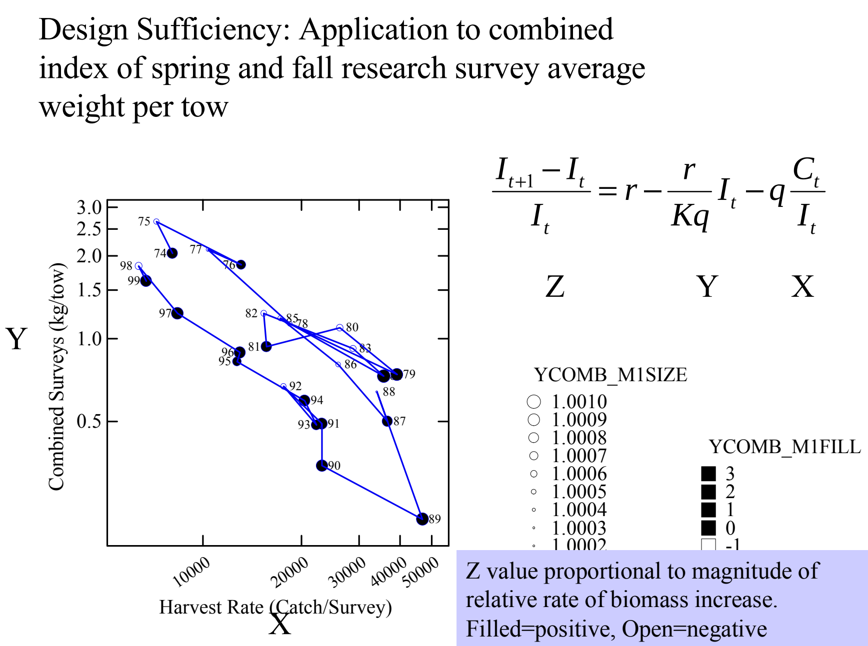


Fig D1. Example plot to illustrate the notion of "design sufficiency for summer flounder stock.

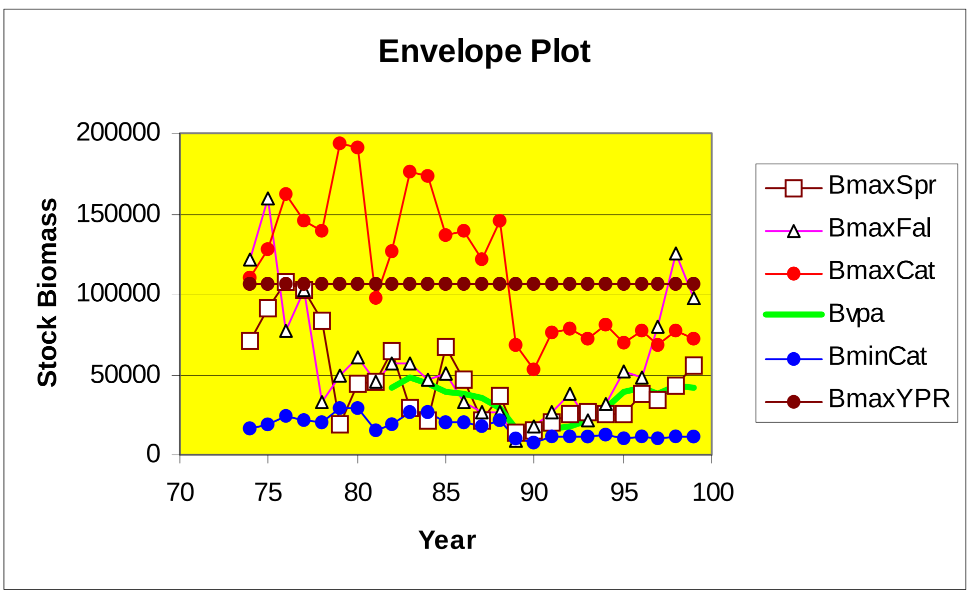
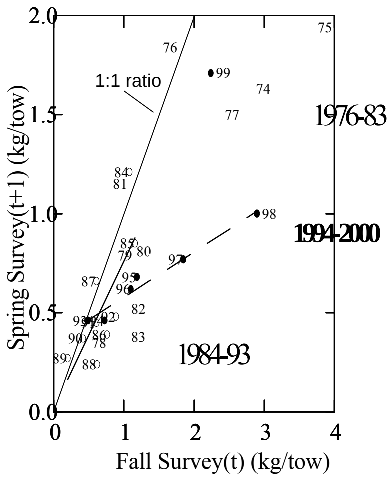


Fig. D2. Construction of an envelope plot for summer flounder. BminCat and BmaxCat are lower and upper bounds respectively, of biomass estimates based on assumed upper and lower bounds of fishing mortality rates. Bvpa is the derived estimate from the ADAPT VPA model. The BmaxSpr and BmaxFal represent biomass levels for swept area estimates from spring and fall survey estimates. BmaxYPR represents the proxy biomass target constructed as the product of B/R at Fmax and the average recruitment estimated from the VPA. See text for additional details.

Potential changes in the relationship between spring and fall surveys over time



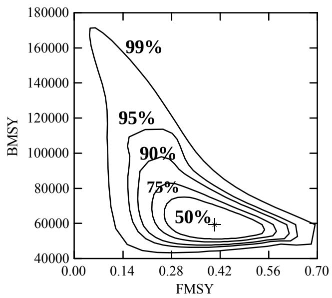
Linear regression lines plotted with bisquare function to downweight residuals.

Take home message: Multiple indices should consistently measure the same set of population attributes over time

Fig. D3. Evaluation of apparent changing relationship between spring and fall survey indices for summer flounder for three stanzas: 1976-1983, 1984-1993, and 1994-2000.

4A

Response surface for NLLS with approximate
50, 75, 90,95,99 % probability levels. Based on F stat.



Approximate Confidence Region:
Find the set of points satisfying
the following equation

$$S(\Theta) = S(\hat{\Theta})\left(1 + \frac{p}{n-p} F_{p,n-p,1-\alpha}\right)$$

Where S(Θ) =residual sum of
squares in model as a function of

$$\Theta = \begin{Bmatrix} F_{MSY} \\ B_{MSY} \\ q \end{Bmatrix}$$

4B

Apply a typical control rule to the confidence region
for reference points

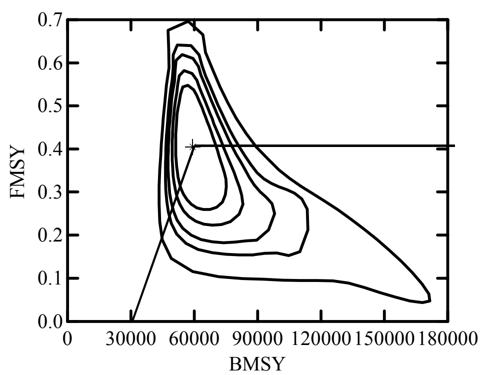


Fig. D4. Approximate confidence regions for F_{MSY} and B_{MSY} for example application to summer flounder. Panel A illustrates the computation methodology. Panel B llustrates the application of the uncertainty in point estimation to development of hypothetical control rule.

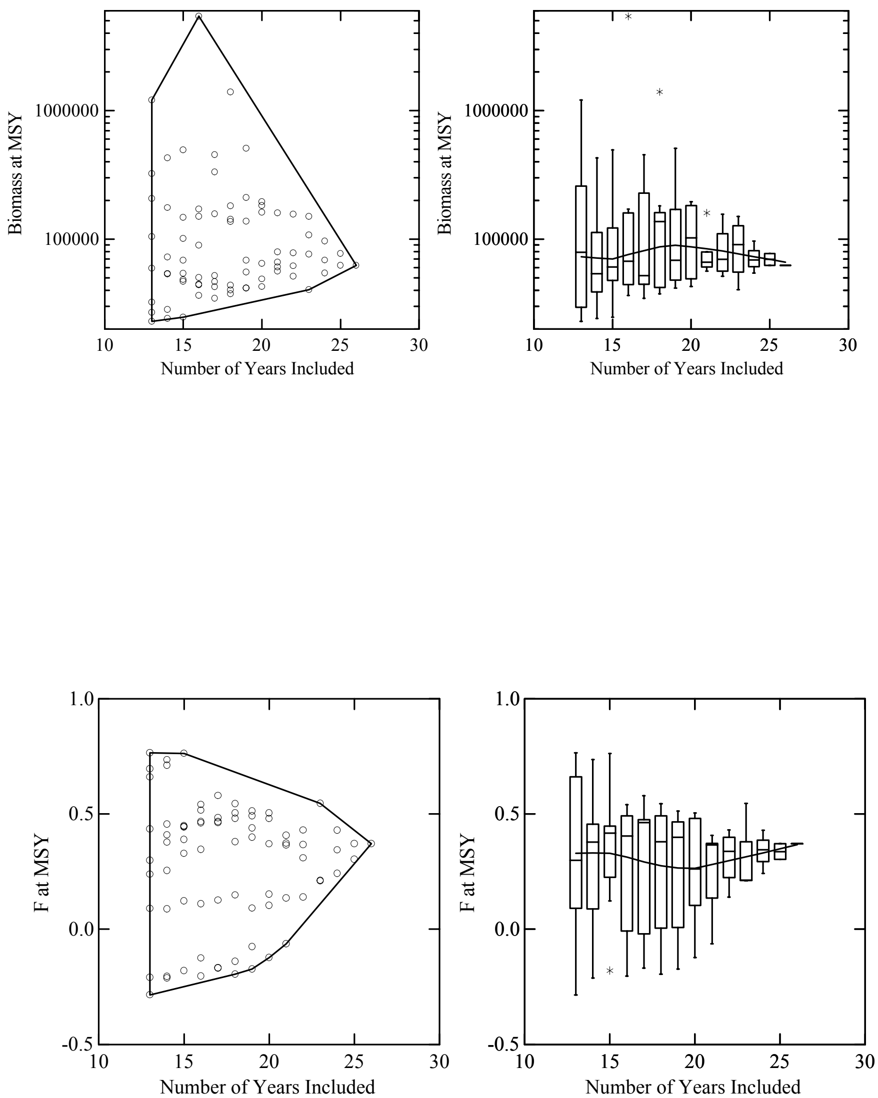


Fig D5. Example “funnel plots” for estimation of parameters of surplus production model for summer flounder. The top two panels show the convergence of estimates of F_{MSY} as additional years of data are incorporated. The lower two panels illustrate the convergence of estimates of B_{MSY}. See text for additional details.

Fig. D6 Results for redfish BSP model 1.

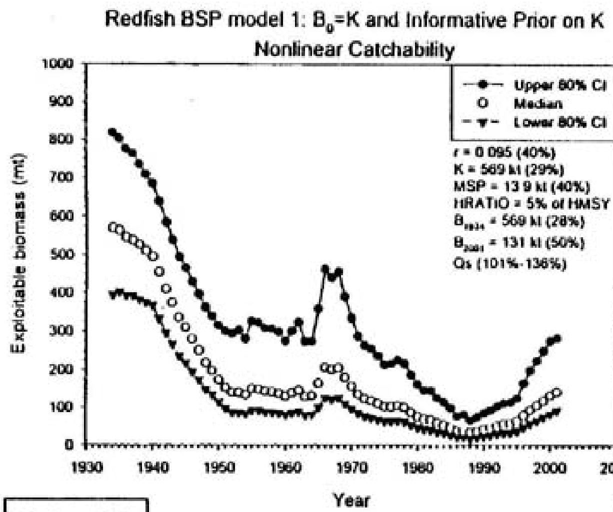


Fig. D7 Results for redfish BSP model 2.

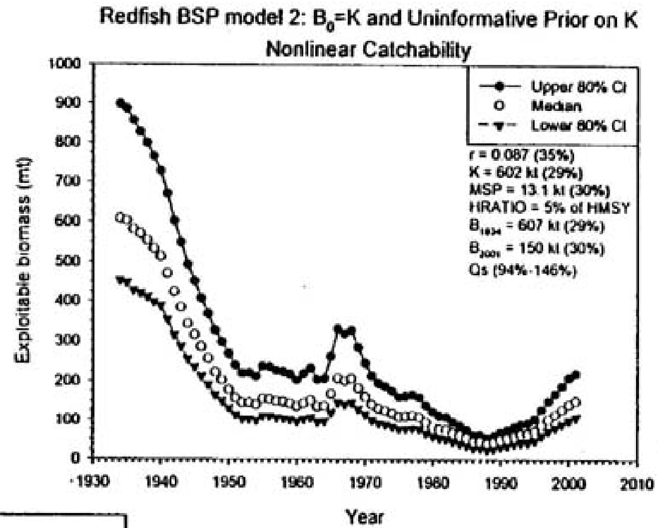


Fig. D8 Results for redfish BSP model 3.

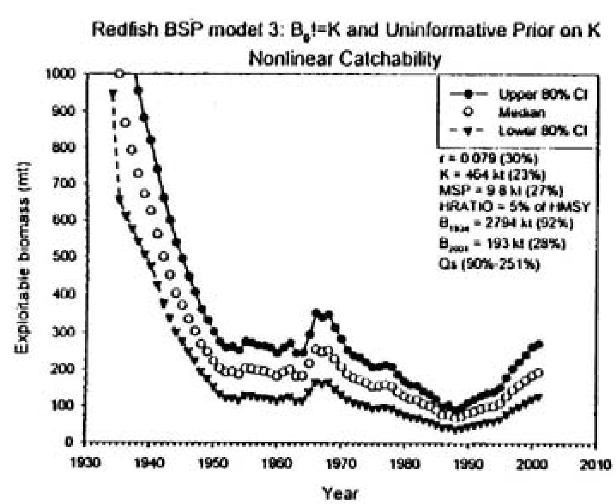


Fig. D9 Results for redfish BSP model 4.

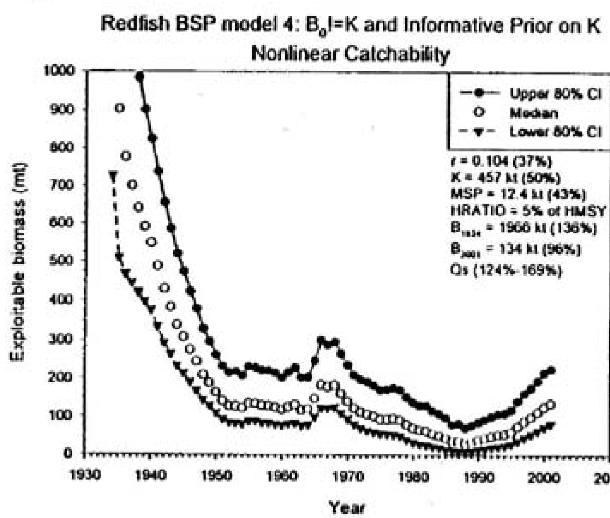


Fig. D10 Results for redfish BSP model 5.

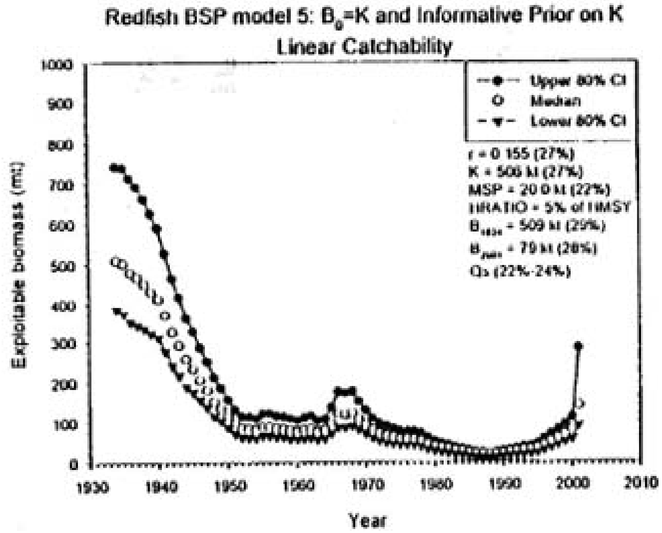


Fig. D11 Results for redfish BSP model 6.

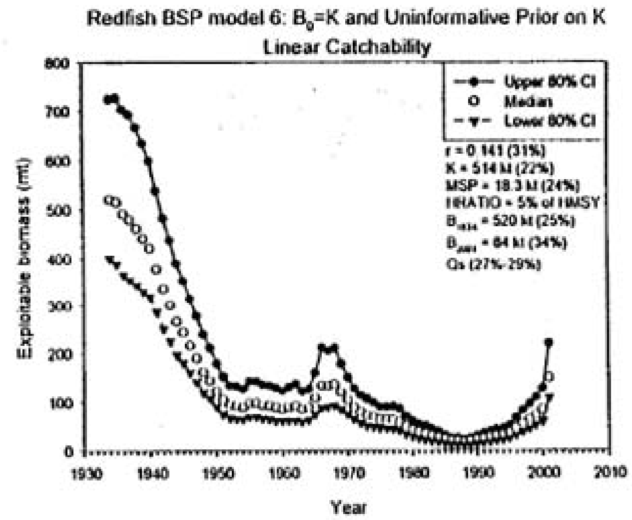


Fig. D12 Comparison of BSP results using nonlinear catchability with assessment results.

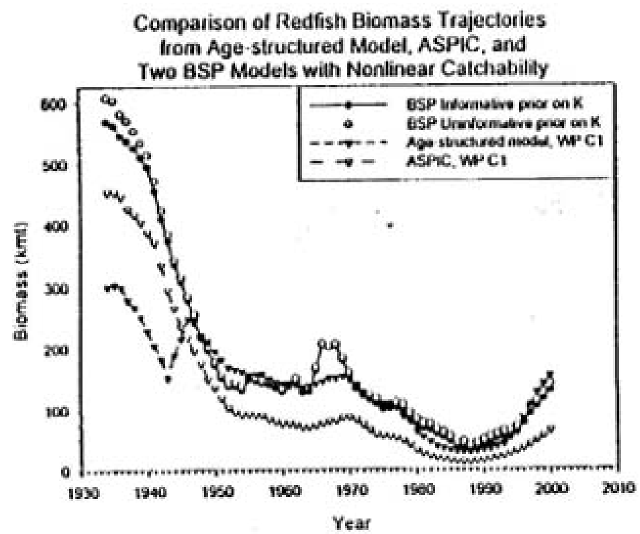
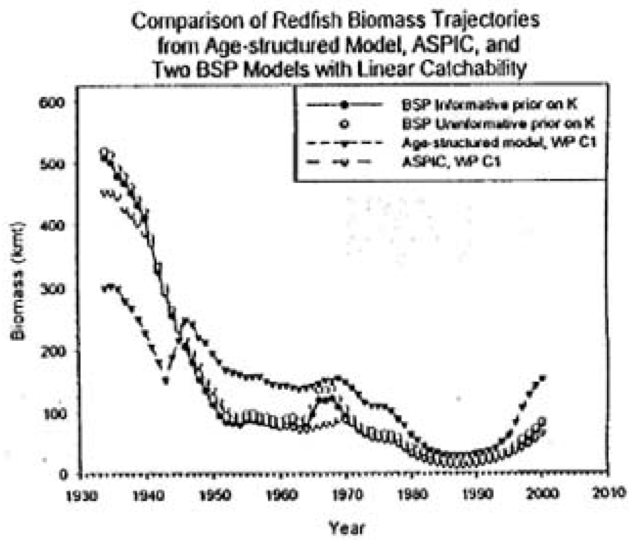


Fig. D13 Comparison of BSP results using linear catchability with assessment results.



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